Light Rail Transit

DESIGN CRITERIA MANUAL

March 2016

METROLINX

An agency of the Government of Ontario

Metrolinx Light Rail Transit

Design Criteria Manual

Public Version 1.0

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PREFACE

This is the first public edition of the, Metrolinx Light Rail Transit (LRT) Design Criteria Manual. It is adapted from the third edition of the, Metrolinx LRT Design Criteria Manual, issued in December 2015 that was not available to the public. The 2015 edition of the DCM replaced earlier versions that were issued in January 2014 and September 2012. The technical content in the Metrolinx DCM had its origins in a predecessor publication, The Design Criteria Manual developed jointly by Metrolinx and the Toronto Transit Commission (TTC) Transit Expansion Department (TED).

The purpose of the Metrolinx LRT DCM is to inform the designs developed by proponents who are involved in an LRT project that is procured using Infrastructure Ontario (IO) Alternative Financing and Procurement (AFP) methodology. It also informs the development of Project Specific Outline Specifications (PSOS), which is a key element in the AFP procurement process. In so far as possible, Metrolinx LRT DCM technical requirements are performance-based rather than prescriptive.

This Metrolinx LRT DCM Public Version includes all of the December 2015 DCM technical requirements. The 2015 DCM incorporated revisions to most chapters, eliminating redundant text and unnecessary narrative.

This Metrolinx LRT DCM Public Version is organized into three broad, functional categories:

Part A – General, including Light Rail Vehicles and Policy;
Part B – Facilities; and
Part C – Systems.

Specialized subject matter experts from a wide range of specialized technical disciplines working under the auspices of Metrolinx developed the technical content of the Metrolinx LRT DCM, Public Version 2016.

Note

The Metrolinx LRT DCM, Public Version 2016, is intended for use by suitably qualified professionals. It is not a substitute for coordination and compliance with all applicable local codes and approvals for fire protection, life safety, or security measures that are part of the planning, design, and implementation of an LRT system.

Suggestions for Revisions and Improvement

Suggestions for revision or improvement can be sent to Metrolinx, Attention: Director, Engineering and Design Standards, Capital Projects Group. Be sure to include a description of the proposed change, background of the application for revision or improvement, and any other useful rationale or justification for the application. Be sure to include your name, company affiliation (if applicable), e-mail address, and phone number.

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A1. General

A1.1 Objectives and Scope

The Metrolinx (MX) Light Rail Transit (LRT) Design Criteria Manual (DCM) establishes guiding principles consistent with the MX Mission Statement, Vision, and Values that follow.

The MX LRT DCM provides information for design development, capital, operating, and maintenance cost estimates, as well as evaluation of potential construction and operations effect on adjacent properties.

The MX LRT DCM was produced by Subject Matter Experts from the MX LRT Technical Advisor teams and collated by the MX LRT Owners Engineering team under the direction of the MX Engineering and Design Standards, Capital Project Group.

When implementing MX LRT design criteria:

- Strive to exceed minimum requirements;
- Identify and notify MX LRT of any necessary or desirable design criteria revisions or variations;
- Submit applications for criteria modifications, changes, or additions in writing to MX LRT for review and acceptance prior to use in design;
- Specific values cited as limits are not targets to achieve but limits to avoid wherever practical;
- Limit values apply only where no other relevant design constraints apply.

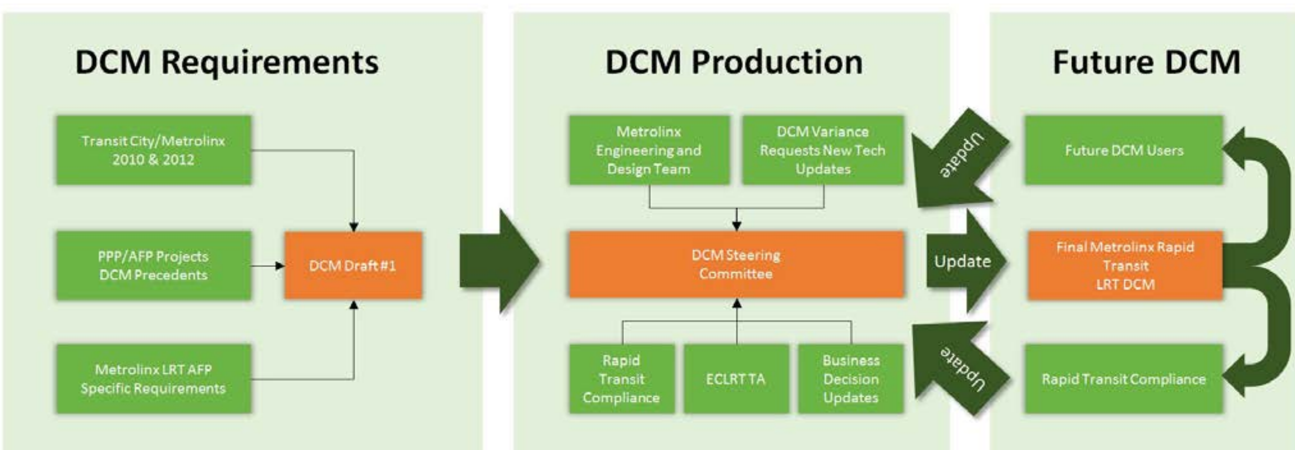
The MX LRT DCM is a resource document providing minimum requirements for MX LRT project disciplines.

The MX LRT DCM is not a substitute for good judgment or sound engineering/architecture practice, nor is it intended to be a barrier to the pursuit of full-value Design Excellence.

A1.2 Design Criteria Manual Development Process

This DCM will be updated periodically either in part or in whole as deemed appropriate by Metrolinx. At the time of approval of DCM updated material or sections, any updates or modifications will take precedence over any previous versions or criteria.

FIGURE A1-1 MX LRT DESIGN CRITERIA MANUAL DEVELOPMENT PROCESS



A1.3 Mission Statement

The MX LRT DCM Mission is to support the MX Corporate Mission in line with the *Big Move Regional Transportation Plan*, Province of Ontario, *Places to Grow Act*.

The MX LRT Program goal is to provide safe, reliable, and accessible rapid public transit to enhance mobility and regional connectivity, respond to growing Ontario Province transportation needs, sustain a vibrant economy, accommodate population growth in the Greater Toronto Hamilton Area (GTHA), and create a legacy for current and future generations.

A1.3.1 Vision

The MX LRT Vision is to transform the way Ontario moves to provide and encourage:

- A livable, competitive, and high quality of life;
- Ontario communities to support healthy, active, and engaged lifestyles, with many options for safe, accessible, reliable, and convenient public transit providing richness of experience and seamless integration with surrounding communities;
- A strong, prosperous, and thriving world class economy competitive with other regions;
- Rapid transit to move people quickly and efficiently in support of enterprise and resources;
- Active transportation in the form of walking and cycling; and
- A sustainable and protected atmosphere.

Low carbon footprint transport systems conserve resources and contribute to the legacy of a healthy and clean environment for generations to come.

A1.3.2 Values

MX LRT Program will accomplish its Mission and Vision applying the following values:

Serve with Passion

- Customer First: MX LRT users and stakeholders are the prime planning and design considerations;
- Accountability: Responsibly complete MX LRT projects on time and within budget.

Think Forward

- Progress: MX LRT considers new ideas and embraces change;
- Excellence: MX Design Excellence principles and requirements incorporate existing MX LRT best practices and evolving state-of-the-art systems;
- Innovation: Seek out and open new paradigms and solutions.

Team Play

- Collaboration: Work with governments, agencies, and the private sector to achieve mutual goals;
- Communication: Provide timely, accurate, clear, and consistent information to the public, communities, businesses, and stakeholders fully informing and engaging them in MX LRT projects.

A1.4 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT DCM.

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

OBC governs where conflicts arise unless otherwise stated.

A1.5 Limitations of Use

MX LRT provides the DCM as minimum requirements.

Reference to materials and methods in the DCM does not necessarily preclude the use of other materials or methods suitable for the intended purpose.

Carefully examine the DCM as resource tools, and modify requirements to suit design intent while providing full-value design excellence.

MX LRT may, from time to time, update or revise the DCM.

Refer to the DCM latest version, including interim updates and revisions, in developing specific design and contract documents.

Submit proposed technical requirement changes to MX LRT for review and acceptance.

Report DCM errors, omissions, and contradictions to MX LRT for review and response. Proceed with affected work only upon MX LRT authorization.

Coordinate design with other interfacing design or work that may affect design.

A1.6 Performance Criteria

These design criteria intend to be performance requirements and are only meant to be prescriptive in so far as necessary and appropriate to meet LRT system operation needs with confidence.

In any phase of MX LRT projects, it is ProjectCo that is responsible for prescriptive design elements to meet design criteria performance requirements subject to MX LRT review and acceptance.

A1.7 Safety and Security

LRT system safety and security is a major focus of MX LRT design criteria.

High visibility and adequate operation sight-lines help maintain public safety.

Incorporate Crime Prevention through Environmental Design (CPTED) principles from the initial design stages to reduce or remove identifiable safety and security risks.

See Chapter A3 – Safety, Chapter A4 – Security, and Chapter B5 – Stations, Stops, Facilities

Provide standard design of systems and facilities such as track work, fare collection equipment, communications, signals, emergency ventilation, elevators, escalators, traction power, overhead contact systems, LRVs, Stations, Stops, and Facilities.

Provide standard materials, equipment, and spare parts to minimize replacement costs as much as possible.

A1.7.1 APTA Safety Management Audit Program

The American Public Transportation Association (APTA) Safety Management Audit Program provides:

- Public transit agencies such as MX LRT with industry-wide LRT System Safety Program Plan formats;
- Formal evaluation of System Safety Program implementation.

The APTA Safety Management Audit Program goal is to guide the relevant parties through a series of safety management processes to strengthen and validate the quality of transit agency safety practices and produce a safe environment for those in direct or indirect contact with LRT systems.

A1.8 Access

Barrier-free access is an MX LRT prerequisite requiring stakeholder involvement.

Provide LRT Stations, Stops, Facilities and Light Rail Vehicles (LRVs) fully accessible to persons with disabilities per *MX Accessible Design Guidelines* as well as AHJ codes and regulations.

Address Rights-of-Way (ROW) access depending on location per provincial, municipal, and AHJ guidelines.

A1.8.1 Integrated Transport Services

Provide LRT to bus and subway, personal vehicles to LRT and buses, LRT to LRT, park-and-ride, and bus terminal transfer facilities for effective interfaces with various transport modes based on use and ridership.

Provide LRT systems and facilities as an integral part of overall regional transport systems specifically designed for efficient passenger transfer to and from private and other public transport modes.

Locate LRT Stations and Stops to provide the travelling public the best and most convenient access.

See Chapter B5 – Stations, Stops, Facilities.

A1.9 Design Excellence

Design Excellence is a key development policy at Metrolinx, shaping capital projects all the way through from planning and design to implementation, operation, and maintenance.

Design Excellence successfully integrates functionality, economy, and beauty to forge true value for money.

Design Excellence aims to achieve lasting value, richness of experience, and quality of life through good design with emphasis on areas of architecture, landscape architecture, and urban design.

Design Excellence criteria are identified in various project-specific references, all based on *Eglinton Crosstown LRT Design Excellence Principles and Requirements* (MX, December 2013).

See also: *Design Excellence Principles and Requirements for Transit-Oriented Development Integrated with Rapid Transit Facilities* (MX, December 2014).

A1.9.1 Public Art

The Metrolinx Integrated Art Policy of July 2014 states:

> "Metrolinx should take an integrated approach to design and public art wherever possible.
>
> Design and public art should be incorporated in the functional design of stations, station areas, vehicles, landscapes, infrastructure elements, billboards, etc., enhancing their attractiveness and becoming visual and tactile identifiers of place.
>
> Integrated public art should retain an interpretative, creative and innovative aspect and authorship, as determined by the commissioned artist, and not be a mere extension of the design of the architecture, landscape architecture, interior design, etc. of the basic building.
>
> Integration of art should be incorporated as early as possible and in a collaborative team approach to reduce delays and encourage creative problem-solving.
>
> Integration is intended to ensure that there is no comprise of or interference with customer service, little or no premium for operational costs, and no safety issues."

MX LRT encourages public art initiatives on AHJ property and their agencies, boards, and commissions.

MX LRT intends to integrate artwork with architecture and finishes as opposed to installing freestanding art in or adjacent to Stations, Stops, and Facilities.

A1.10 Design Integration

A1.10.1 Base Maps

MX LRT anticipates various types of LRT contracts, including civil facilities, system facilities, facility improvements, design, procurement, and installation.

Use a set of systemwide Project Base Maps of different facilities and systems for design compatibility, consistency, uniformity, and coordination in locating proposed facilities.

Include a single Project Control Line defined by a stationing system for each Project Base Map.

A1.10.2 Control Lines

Use common Project Control Lines for project subsystem design and construction activity such as utility relocation, civil improvements, track work, overhead contact systems, signals, and system duct banks.

Develop a Project Control Line base stationing system for MX LRT review and acceptance prior to use.

Design civil and subsystem improvements with stationing and offset references from Project Control Lines.

A1.10.3 CADD and BIM Standards

Comply with Computer Aided Design and Drafting (CADD) standards and directives per *Metrolinx LRT CADD Standards and Procedures Manual* available online.

Metrolinx LRT CADD/BIM Standards define LRT program CADD as well as Building Information Modelling (BIM) specific requirements.

Use MX LRT Standard Drawing title blocks.

A1.10.4 Standard and Directive Drawings

Standard and Directive Drawings define major systems and communicate design requirements taking advantage of lessons learned and best available practices and technologies from other LRT projects to maximize economies of scale and optimize design efficiencies.

Standard Drawings provide mandatory design of LRT project systemwide standard elements.

Directive Drawings provide general design direction and guidance for systemwide design implementation.

Use the most recent versions of ProjectCo Standard and Directive Drawings.

Revise Standard and Directive Drawing files per the MX LRT *CADD Standards and Procedures Manual*.

These revisions are generally internal to SDD.dgn files.

Provide Standard and Directive Drawings in Adobe Portable Document File (PDF) format.

MX LRT takes no responsibility for the amount of work that may be required to convert drawings to comply with MX LRT *CADD Standards and Procedures Manual* requirements.

A1.11 Design Climate Conditions

Provide transit components, materials, equipment, and systems of suitable quality and design to perform safely and reliably over the range of operating environments, climate factors, and other conditions intended for use, operation, and maintenance in the specific region of Ontario where a project is located.

Note that climate data may not be the only factor in defining operating environment.

Also consider local environmental effects of factors such as nearby heat sources, enclosures, and vibration when specifying components, materials, equipment, and systems operating limits.

Use temperatures for design purposes per current ASHRAE and OBC standards.

Provide facilities to accommodate safe removal and/or storage of snow, melting snow, and ice.

Verify climate conditions per the Environment Canada website: http://climate.weather.gc.ca/index_e.html

See Chapter A6 – Sustainability.

A1.11.1 Proven Hardware

Incorporate proven subsystem hardware and design concepts in LRT system design.

Wherever possible procure off-the-shelf major subsystems and spare parts, including LRVs, track work, train control, communications, fare collection, and traction power equipment from established manufacturers with documented current and previous operating history in the project region or other regions with similar climate conditions.

Waiver of these requirements may be considered only where an alternative subsystem offers substantial technical and cost advantages, is in an advanced stage of development, and has accumulated substantial test data in revenue service conditions, subject to MX LRT review and acceptance.

A1.12 Design Life

The target system design life is its intended useful lifespan with respect to lifecycle cost.

Individual subsystems or components may be renewed, replaced, or upgraded during the system design life.

Provide verification methods as to how to meet design life targets for elements with a design life of over 30 years and submit to MX LRT for review and acceptance.

Unless specified elsewhere, the following system component minimum target design life ranges apply:

- Structures and tunnels 100 years
- Major structural components 100 years
- Buildings (per CSA 478-95 guideline) 50–80 years
- Elevated structures and bridges 75 years (Note 1)
- Retaining walls and earth structures 75 years (Note 1)
- Track work slab structures 50 years
- Track work 30 years
- Underground services (pipelines, etc.) 40–50 years
- Minor structural components 30–50 years
- Electric / electronic equipment / cabling 30 years (Note 2)
- Train control signal equipment 30 years (Note 2)
- Communications equipment 30 years (Note 2)
- Traffic signals 30 years (Note 2)
- Mechanical equipment 30 years
- Rolling stock frames and chassis 30 years
- Rolling stock mounted equipment 30 years

- Elevators and escalators 30 years
- Ventilation 30 years
- Traction power and distribution 30 years

Note 1: Compatible with Canadian Highway Bridge Design Code.

Note 2: Upgrade hardware/software at end of useful product life-cycle or when declared obsolete by the manufacture, whichever occurs first.

Fatigue resulting from repeated loading is a safety consideration.

See Canadian Highway Bridge Design Code for Fatigue Limit State loads and occurrence frequencies.

See Chapter A6 – Sustainability.

A1.13 Stakeholders

LRT project implementation introduces new environmental and social influences to surrounding areas.

MX LRT recognizes stakeholder involvement as a major component of new LRT projects.

MX LRT leads stakeholder involvement during Environmental Assessments, planning, design, and construction for information exchange.

The stakeholder involvement process supports LRT project teams in effectively integrating community concerns in LRT project frameworks and in responding to these major challenges:

- Appropriate parties involved in appropriate ways at appropriate times;
- Broad-based, sustained, and balanced community commitment to long-term LRT project goals;
- Stakeholder involvement responsive to emerging situations and issues so that new voices are heard.

LRT project teams and affected residential, institutional, commercial, and corporate communities facilitate appropriate and ongoing dialogue among the many diverse internal and external parties involved.

A1.13.1 Land Use

Implementing LRT projects in residential and commercial areas requires initiative to mitigate stakeholder concerns while maintaining pre-established urban design concept integrity, vehicle and pedestrian traffic movement, land-use bylaws, as well as Design Excellence principles and requirements.

Stakeholder concerns typically include safety, noise, vibration, visual impacts, aesthetics, access for everyone, social and business impacts, electro-magnetic interference, construction, disruption of vehicle and pedestrian traffic, and temporary, as well as future traffic patterns and physical design.

Throughout LRT project planning and design it is important to:

- Provide and maintain general public safety of passengers, operators, pedestrians, and vehicle traffic;
- Provide low-maintenance elements to reduce long-term costs using enduring materials;
- Provide systems, structures, and landscaping to mitigate noise and enhance appearance;
- Provide community integration for LRT projects that are functional, attractive, and cost-effective;
- Identify, reflect and reinforce the character of communities that LRT projects serve;
- Minimize need to replace or relocate existing buildings and structures;
- Maintain, facilitate, and enhance pedestrian and vehicle movement;
- Maintain fiscally responsible development to minimize impact and maximize value;
- Incorporate unique community land use issues through stakeholder involvement;
- Minimize cost and effect of existing and future utility relocations;

- Integrate LRT Stations, Stops, and Facilities with proposed development where appropriate.

LRT project elements involved in land use include Station entrance buildings, guideway portals, track work, retaining walls, catenary systems, signals, traction power substations, other ancillary structures, etc.

A1.13.2 Disruption Management

Disruption Management defines design, construction, project management, community liaison outreach, and visualization principles to minimize community disruption by LRT project implementation.

MX LRT establishes a Disruption Management Strategy for the MX LRT Program as a whole and each individual LRT project to minimize adverse construction effects on local communities to the maximum extent practical.

Incorporating lessons learned in design and construction of previous LRT projects is a key element of Disruption Management Strategy.

A1.14 Value Engineering

MX LRT is committed to using Value Engineering consistently to achieve optimum value for money in keeping with Design Excellence principles and requirements.

Develop and evaluate Value Engineering design alternatives considering the following:

- Performance-proven materials and devices;
- Design Excellence;
- Construction and lifecycle cost savings;
- Operating efficiencies;
- System safety;
- Ease of maintenance;
- Low maintenance and operations costs;
- Effects on other facilities, systems, and local communities;
- Transit Oriented Development opportunities.

The MX LRT goal is to develop design alternatives for improved LRT system and facility safety, construction, operation, and maintenance while integrating opportunities for Transit Oriented Development.

A1.15 Operations and Maintenance

LRT systems and facilities represent a major investment difficult to change or modify once built.

Minimize service disruption and inconvenience to LRT passengers during maintenance.

Consider the following during design development:

- Maintenance access;
- Personnel and equipment access;
- Ability to withstand abuse and vandalism;
- Flexibility and adaptability for alteration and expansion;
- Resistance to combustibility.

Operations and Maintenance (O&M) Manuals are an integral part of design and construction and a priority item in commissioning and final acceptance of the works.

A1.16 Defined Terms

A

Absolute Stop: Irreversible emergency braking initiated by LRV-borne automatic train protection (ATP) equipment when passing a boundary commanding such an absolute stop.

Advance of Signal: Area relative to a signal but located beyond the signal as viewed from an approaching train governed by the signal.

Alarm: Any abnormal condition requiring the attention of an attendant or operator.

Alignment: Three-dimensional geometry of track work used in both horizontal and vertical layouts to describe the line uniformity (straightness) of the rails.

Alignment, Exclusive: Operating environment in which LRV operations are conducted independent of adjacent vehicle traffic except at controlled grade crossings where priority is generally yielded to LRV movements. May be at-grade, elevated, or below grade. Access to the operating environment by other vehicles or people is prohibited except at defined and controlled grade crossings. Maximum authorized speeds are limited by LRV performance capabilities and site-specific civil or operating conditions that may warrant further reduction in speed, for example, grade crossings, curves, signals, and Interlockings.

Alignment, Non-Exclusive: At-grade operating environment where LRVs occupy travel lanes mixed with other traffic and LRV operations are fully integrated with adjacent vehicle or pedestrian traffic. The maximum authorized LRV speed in non-exclusive alignments is not to exceed the speed limit of the street the alignment occupies subject to civil limitations.

Alignment, Semi-Exclusive: At-grade operating environment in which some LRV operations are influenced by adjacent vehicle and pedestrian traffic. Semi-exclusive alignments typically are separated from other traffic by physical barriers such as curbs or fences. Access to semi-exclusive alignments by other vehicles or people is prohibited except at defined controlled grade crossings. The maximum authorized LRV speed in a semi-exclusive alignments is not to exceed the speed limit of the street the alignment occupies except as otherwise authorized.

Ancillary Areas: Non-public areas housing LRT operating, maintenance, or support equipment and functions.

Ambient Noise Monitor: Part of the Public Address (PA) system that monitors and feeds back ambient noise levels to the PA amplifier to automatically adjust voice levels.

Anchor Bolts: Bolts used in combination with plinths or grout pads to anchor track fasteners or other equipment to a slab, invert, or tie. Designed to provide adequate resistance to LRV or other equipment lateral and vertical forces and movement. May also secure elements such as column base plates, street lights, and traffic signals to a pedestal or base.

Assembly: Parts, subassemblies, or any combination thereof that together perform a specific function and are replaceable as a whole unit.

Authorities Having Jurisdiction (AHJ): Organization(s), office(s), or individual(s) responsible for reviewing and accepting equipment, installations, or procedures. Note: Organizations include relevant building and fire officials and other official departments.

Automatic Train Control (ATC): Wayside and LRV systems that provide Automatic Train Operation (ATO), Automatic Train Protection (ATP), Automatic Train Supervision (ATS), and ATC subsystem operations.

Automatic Train Operation (ATO): ATC subsystem performing any speed functions otherwise assigned to LRV Operators.

Automatic Train Protection (ATP): ATC subsystem that maintains fail-safe protection against collision, excessive speed, and other hazardous conditions through a combination of train detection, train separation, and Interlocking.

Automatic Train Supervision (ATS): ATC subsystem that monitors LRVs and adjusts performance to minimize LRV delay effects on operating schedules.

Automatic Voice Announcement System: System built in to the Train Operator Control Panel (TOCP) that stores and plays back pre-recorded audio-visual messages via the LRV PA system and Light-Emitting Diode (LED) display units located on Station and Stop platforms.

Auxiliary Track: Any track other than a Main Track.

Auxiliary Wayside System: Backup or secondary train control system providing full or partial ATP for LRVs not equipped with Communication Based Train Control (CBTC) equipment or LRVs with partially or totally inoperative CBTC equipment. The auxiliary wayside system may include LRV-borne equipment and may also provide broken rail detection.

Availability: Probability that a system or element is ready to perform its intended function on demand subject to acceptable delay as defined by system operating standards.

B

Backlayering: Reversal of smoke and hot gas movement counter to ventilation airflow direction.

Ballast Factor (BF): Measured ability of a particular ballast to produce light from the lamp(s) it powers, derived by dividing lumen output of a particular lamp and ballast combination by lumen output of the same lamp(s) on a reference ballast.

Bill Vault: Locked fare collection equipment box where paper currency is stacked and held upon completion of a transaction.

Block: Defined limit track length where block signals, block limit signs, or cab signals govern train movement.

Block Signal: Fixed wayside signal operated automatically or manually at the entrance to a block governing use of that block.

Blue Light Station (BLS): Location along the trainway, indicated by a blue light, where a person can communicate with the Operations Control Centre (OCC) and disconnect traction power.

Boggie: See Truck.

Bond: Electric continuity wire installed on tracks at standard joints, at special track work locations, or at other specified locations for track signals or negative return path electric continuity.

Brake, (Maximum) Service: Non-emergency brake application that obtains (maximum) brake rate consistent with brake system design retrievable under master control.

Brake, Emergency: Fail-safe, open-loop braking to a complete stop within maximum stopping distance considering all relevant factors. Once emergency braking is initiated, it is irretrievable, i.e., it cannot be released until the train has stopped or a predefined time has elapsed.

Braking Distance: Maximum distance to bring a train to a stop from normal speed under full service braking measured from the point braking is initiated to the point the train is stopped.

Bridge Guard Rail: Rail placed 200 to 280 mm inside the running rail to contain and guide a derailed truck and keep an LRV upright and on the track structure. Installed where the consequences of a derailment could be particularly catastrophic, including on bridges, embankments, approaches to tunnel portals, overhead structure abutments, and where track is immediately alongside critical non-transit facilities such as high-tension power line poles. Also called **Safety Guard Rail**.

Broken Back Alignment: Two curves turning in the same direction separated by a short tangent.

Bumping Post: Braced post or block placed at end-of-track to safely stop a rail vehicle and prevent it from going beyond the ends of the rails; effective for low speeds only.

C

Cab Signal: Signal located in the LRV operator cab indicating a condition affecting train movement used with Interlocking signals, switch indications with or in lieu of **Block Signals**.

Cad Weld: Exothermic chemical reaction weld producing molten metal used to attach bond wires to rails.

Car, LRV: Individual LRV passenger carrying segment that, coupled with other LRV cars, forms an LRV consist.

Car, Elevator: Elevator compartment carrying people in a building from floor to floor via a vertical shaft.

Cash-Only Mode: Fare collection equipment operating mode where only valid paper currency or coins may be used to complete fare purchases.

Certification: Action of determining, verifying, and attesting to personnel and material qualifications.

Checks: Tests, measurements, verifications, or controls placed on an activity by investigation and examination to determine that safety and/or performance criteria are satisfactory and are met.

Civil Speed Limit: For a given section of track, the maximum speed allowed as determined by track structure physical characteristics and limits for passenger comfort on LRVs and passenger platforms. Civil Speed Limit is always less than **Safe Speed Limit**.

Coin Acceptor: Component that authenticates the validity of coins inserted for fare purchase.

Coin Vault: Ticket Vending Machine (TVM) locked box holding coins upon completion of fare purchases.

Command Post: Where the command person controls and coordinates emergency operations.

Communications Based Train Control (CBTC): Continuous ATC system using high-resolution train location determination, independent of track circuits, for continuous, high-capacity, bidirectional train-to-wayside data communications and train-borne and wayside processors for implementing vital functions.

Component: Any device with distinct electrical or mechanical characteristics and connection points to other components to form a subassembly; or a self-contained element of a complete operating unit that performs a function necessary to operate that unit and may comprise a combination of assemblies, attachments, and parts; or a piece or part of an assembly or equipment, such as a mechanical or electric part, valve, or support structure, combined with other components to form a system, subsystem, assembly, subassembly, or part.

Compromise Joint: Bolted or welded connection between two dissimilar rail sections.

Computational Fluid Dynamics (CFD): Solution of fundamental equations for fluid flow using computer techniques to determine velocity, pressure, temperature, and air flow characteristics for underground ventilation systems design.

Computer Information System (CIS): Real-time, mission-critical, computer-based polling system using multichannel, two-way, radio-enabling automatic LRV location tracking and route management as well as LRV dispatch functions. CIS components also provide LRV voice and data communications.

Concourse: Intermediate level(s) or area(s) connecting station platform(s) to public ways via escalators, stairs, elevators, and/or corridors.

Consist: Makeup or composition in number and specific identity of individual cars of an LRV.

Continuously Welded Rail: Track using only welded connections between individual rails with no standard bolted rail joints.

Cover: Dimension from top of underground structure to surface finish grade.

Crest Curve: Vertical curve that appears convex when viewed from above. Also called **Summit Curve**.

Critical Component: Component that, if degraded or lost, has a major effect on system performance, for example, loss of LRV movement or control.

Critical Function: Function that, if degraded or lost, has a major effect on system performance, for example, loss of LRV movement or control.

Critical Velocity: Minimum steady-state ventilation air flow velocity in a tunnel or passageway required to prevent backlayering at the fire site.

Cross-bond: Electric connection from one track to another distributing traction power return current.

Crossover: Pair of track turnouts arranged to connect two nearby and generally parallel tracks. Like the turnouts themselves, crossovers can be described as either facing or trailing.

Crossover, Double: Facing-point single crossover and a trailing-point single crossover superimposed on one another in an X-shaped configuration. Also referred to as a **Diamond Crossover**.

Crossover, Three-track: Track arrangements allowing transfer between mainline tracks and a third, parallel, centre storage track.

D

Defect: Non-fulfillment of intended use or reasonable expectation requirement.

Derailer: Track safety device to guide rolling stock and other on-track equipment off the rails at a designated spot to protect against collision or other accidents.

Design Speed Limit: LRV speed that will subject passengers to 0.1 gravitational-force (g-force) maximum lateral acceleration for a given section of track. May be less than **Civil Speed Limit**.

Diamond Crossover: See Crossover, Double.

Diffuser or **Lens**: Translucent element providing physical protection for a luminaire lamp, either concentrating or spreading light more evenly.

Direction: Assigned orientation of LRV movement. According to convention, LRV direction is assigned as either north-south or east-west, regardless of actual geographic orientation.

Direct Fixation: Track work rigidly connected directly to a concrete foundation or floating slab with rail fasteners open to the air and readily accessible for inspection and maintenance.

Double Tie: Floating track work used to mitigate noise and vibration consisting of individual precast concrete tie units on elastomeric supports, each with two pairs of rail fasteners.

Downtime: Total time equipment is not in acceptable operating condition. Downtime starts with a failure event and ends at successful completion of inspection, repair, and functional checks.

Dwell Time: Time during which an LRV is stopped at a Station or Stop, starting with LRV Doors Open command and ending with LRV Doors Closed and Locked status.

Dynamic Envelope: LRV required clearance area represented as an outline of the space that an LRV may occupy developed from cumulative effects of dynamic car body movement, static car profile, car characteristics, and car and track wear conditions. Also called **Dynamic Profile**.

Dynamic Profile: See Dynamic Envelope.

E

Elastomer: Polymer with elastic properties. Used in track work to lessen noise and vibration.

Element, Subsystems: Discrete system parts that, when combined, constitute a complete system element.

Embedded Direct Fixation Track: Hybrid between embedded track and direct fixation track. Used in areas where embedded track is required but with limited available vertical space. Often used for track work on bridges in semi-exclusive and non-exclusive ROW.

Embedded Track: Track work not readily accessible for inspection or maintenance with concrete paving placed up to top-of-rail level and completely buried track support structures comprising steel ties, elastic track fasteners, extruded rubber rail boots, and foundation slabs.

Emergency Management Panel (EMP): Functions as a command post for emergency response personnel or firefighters to use for onsite control and communication, comprising a fire alarm control panel (FACP), fire ventilation control panel, voice communication, and security subsystem status indicators.

Emergency Procedures Plan: Plan developed by MX LRT and the AHJ in cooperation with participating agencies detailing specific actions required of those responding to an emergency.

Emergency Vehicle Pre-emption: Traffic control system transferring ROW to emergency vehicles, including fire, law enforcement, ambulances, and other official emergency response vehicles, that promptly displays a green signal at locations equipped with emergency receivers ahead of emergency vehicles equipped with detection emitter devices. Takes precedence over and overrides Priority LRV Operation.

Enterprise Security Management System (ESMS): Electronic system for physical facility security comprising access control readers, cardholder databases, and alarm points networked with Closed Circuit Television (CCTV) to allow intrusion event monitoring and reporting as well as entry and exit control for a centralized monitoring and control facility to identify and authenticate users.

Escape Route: Path or paths taken by passengers to reach a point of safety.

Ethernet: Family of frame-based computer networking technologies for Local Area Networks (LANs) defining a number of wiring and signalling standards for network access using a common address format standardized per Institute of Electrical and Electronics Engineers (IEEE) Standard 802.3.

Event: Any action resulting in a data record, hardware, or software condition indication, for example part failure or completion of internal activity indication.

Exact Change Mode: Fare collection equipment operation mode where the TVM cannot dispense change to complete ticket transactions, that is, passengers must use exact change to complete fare purchases.

F

Failed Component: Component that has ceased performing its intended function.

Fail-Safe: Design philosophy applied to safety-critical systems so that hardware failure or software error either prohibits the system from assuming or maintaining an unsafe state or causes the system to assume a known safe state.

Failure: Malfunction of a component, assembly, or system resulting from a cause other than misuse, mishandling, or vandalism, requiring replacement to restore the intended function.

Failure Rate: Frequency of failure expressed as failure per unit of time/miles/cycles/transactions; in case of a constant failure rate, it becomes the reciprocal of **Mean Time between Failure (MTBF)**.

Failure, Independent: Incident, malfunction, failure of equipment, or intermittent condition not the result of another failure, misuse, or error in maintenance of any other equipment, directly or indirectly, that precludes a system from performing its required function.

Failure, Secondary: Failure that occurs as a consequence of another failure, e.g., a dependent failure.

Fare: Required payment for transportation by a passenger on a transit system.

Fare Collection Area: Discrete group of fare collection equipment on or adjacent to a passenger platform. A single Station or Stop may have multiple fare collection areas.

Fare Collection Equipment: Secure, passenger-operated, off-board, and computer controlled assemblies that print and issue evidence of Proof of Payment, account for sales, and temporarily store money paid.

Fare Collection Strategy: Defines the fare collection Proof of Payment Concept of Operations in the interim phase between existing fare media and full Smart Card implementation.

Fare Collection System: Procedures and devices used to collect, accumulate, and account for fares paid.

Fare Structure: Determines what fare passengers pay to use a transit system under specified conditions.

Fare Paid Area: Designated Station and Stop areas where passengers must be able to furnish Proof of Payment upon request.

Fault Condition: Component, assembly, or system malfunction by causes other than vandalism.

Fire Alarm Control Panel (FACP): Displays status of a fire and controls responses to fire in the facility. Activation of a fire detector causes an audible alarm to sound, activates strobe lights in the facility, and displays an alarm indication at the FACP indicating the zone and device where the alarm condition exists. Provides outputs to HVAC/environmental control systems and other equipment required to activate fire situation operation including HVAC equipment shutdown, elevator recall, fire door closing, and designated fan and damper operation.

Fire Emergency: Existence or threat of fire and/or the development of smoke or fumes or any combination thereof that demands immediate action to correct or alleviate the condition or situation.

Firefighter Access (FFA): Dedicated firefighter route from grade to track level in underground facilities.

Fire Heat Release Rate: Rate of energy release for ventilation calculations in a given fire scenario expressed as a function of time (Unit = W or BTU/second). Same as "Heat Release Rate."

Fixed Signal: Signal at a fixed location governing LRV movement including LRT signal aspects under the control of a highway traffic signal.

Flash-Butt Weld: Rail welding technique used to connect two rails end-to-end. A welding plant generates high electric potential between the ends of two rails. When the rail ends reach an appropriate temperature producing a flash the plant rams the two rail ends together and they fuse to form a continuous connection.

Frequency: Number of train departures or arrivals per unit time, usually expressed as number of trains per hour.

Friction Buffer: Track device used at an end-of-track location that safely stops a rail vehicle and prevents it from going beyond the ends of the rails; capable of safely stopping rail vehicles travelling at somewhat higher speeds than can be stopped using a bumping post.

Frog: Device used where two running rails intersect with flangeways allowing wheels and wheel flanges on either rail to cross the other.

Full Service Brake Application: Brake application developing maximum brake force.

G

Girder Guard Rail: Steel rail used in embedded track with an asymmetrical cross section providing a pre-formed flangeway incorporating a “guard” or “check” to bear rail vehicle weight. Also resists lateral forces in curves and protects against derailment by guiding wheels through curves at an appropriate angle.

Grade: Longitudinal track alignment inclination expressed as a percentage of vertical distance over horizontal distance (e.g., 5% grade = 5 m rise in 100 m length).

Grade Crossing: Rail crossing or intersection of a highway or other Right-of Way at the same level.

Grade Separation: Rail crossing or intersection of a highway or other Right-of-Way vertically separated to allow unimpeded crossings at the intersection.

Grand Union: Rail track junction layout where two perpendicular double-track lines cross at grade with 16 turnouts linking all tracks together allowing rail vehicles coming from any direction to take any of the other three directions.

Grout Pads: Poured-in-place structural grout pedestals used to establish and maintain vertical track profile. A grout pad usually supports only one rail fastener, is unreinforced, and is fairly thin (i.e., approximately 25 to 65 mm). Grout pads are not considered structural and cannot be relied upon to provide lateral resistance to train movement forces, but are suitable to resist vertical forces. Grout pads can also be used for columns, poles, equipment, etc.

Guideway: Portion of the fixed guideway transit or rail passenger system included within Right-of-Way fences, outside lines of curbs or shoulders, underground tunnels and Stations, cut or fill slopes, ditches, channels, and waterways and including all appertaining structures.

H

Headway: Interval of time between the arrivals of consecutive trains at a Station. Usually expressed in minutes and/or seconds.

Heat Release Rate: See Fire Heat Release Rate.

Home Signal: Fixed signal or indication governing trains entering an Interlocking.

Horizontal: In lighting design, luminance measured on a horizontal plane such as a floor or passenger platform with a light meter pointed toward the zenith.

I

Illuminance: In lighting design, the photometric measure of total luminous flux incident on a surface per unit area. The SI unit for luminance is lux (lx).

Incident Command Post: Where the person in command during an emergency controls and coordinates emergency operations.

Initial Output: When referring to lumens of a lamp, the output before applying light loss factors.

In Service Mode: Mode where a TVM is operating and available for ticket purchases.

Inside Plant: Equipment racks, cabinets, cable trays, power supplies, batteries, and communications systems hardware installed in a designated enclosed space.

Instrument Housing: Walk-in type house or case used to house signal equipment or terminate cable located along the Right-of-Way.

Insulated Joint: Rail joint with electric insulation between adjoining rails.

Inswing: Effective widening of a vehicle envelope through a curve due to perpendicular movement of an LRV body between wheels on the low side (i.e., the inside) of a curve.

Interface: Point at which two or more systems, subsystems or structures meet, transfer energy, or transfer information or data.

Interior Zone: In tunnel illumination, the area in a tunnel after the end of a portal transition zone where eye adaptation to tunnel ambient light is complete.

Interlocking: Arrangement of signals and signal appliances so interconnected that their movements must succeed each other in proper sequence. An Interlocking prevents conflicting movements through an arrangement of tracks such as junctions or crossings and is designed so that it is impossible to display a signal to proceed unless the route to be used is proven safe. Interlocking Rules apply at Interlockings.

Interlocking Appliances: Includes switches, derails, locks, control mechanisms, and/or moveable point frogs.

Interlocking Limits: Tracks between the opposing home signals or indicators of an Interlocking.

Interlocking Rules: See Canadian Rail Operating Rules (CROR) 601-620.

Interlocking Signals: Fixed signals of an Interlocking.

Intersection Signal: Fixed signal, usually associated with grade crossings in semi-exclusive and non-exclusive alignments, governing rail, and vehicle traffic.

Invert: Solid base of a tunnel upon which track work may be built.

J

Jacking Clearance: Vertical clearance from top of vehicle clearance envelope to ceiling providing sufficient space to allow emergency vehicle jacking.

K

Kirk-Key: System where a key is physically removed from one position and inserted and captured in another lock, either to enable a system or provide personnel access to controlled areas, allowing only one access at any one time. Typically used to control active energy sources or personnel access.

L

Label: Equipment or materials with a label, symbol, or other identifying mark of an organization concerned with product evaluation that maintains periodic inspection of equipment or materials and by whose label the manufacturer indicates compliance with appropriate standards or performance in a specified manner acceptable to the AHJ.

Ladder Track: Series of single turnouts in sequence allowing a rail vehicle travelling along a line to diverge to one of several branch tracks, usually found in yards at the entrance to storage tracks.

Lamp: Replaceable luminaire element that converts electric energy to light (e.g., incandescent light bulb, fluorescent tube, metal-halide bulb, Light Emitting Diode (LED) lamp).

Lamp Lumen Depreciation (LLD): In lighting design, the decrease over time of lamp lumen output caused by bulb wall blackening, phosphor exhaustion, filament depreciation, and other factors.

Lateral Restraint Curb: Integrated tunnel structure that deflects derailed vehicles to prevent an LRV body from contacting the tunnel wall. Tunnel service walkways often act as lateral restraint curbs.

Level of Service: Qualitative measurement describing traffic stream operating conditions based on service measures such as speed and travel time, vehicle delay, freedom to maneuver, traffic interruptions, comfort, and convenience.

Light Loss Factor (LLF): In lighting design, light loss over luminaire maintenance cycle as a product of BF, LLD, and LDD.

Light Rail Transit (LRT): Rail transit mode characterized by LRVs operating on exclusive alignments, semi-exclusive alignments, street running, or grade crossings, allowing passengers to board and alight at track, platform, or LRV floor level.

Light Rail Vehicle (LRV): Self-propelled unit operating in passenger revenue service on an LRT system. One or more LRVs may be coupled together and operated from a single LRV Operator compartment

LRV Clearance Envelope: Space occupied by the dynamic profile, or maximum movement, of an LRV traveling along the track plus an additional running space of 50 mm. Maintain structures, permanent equipment, and construction tolerances clear of the LRV Clearance Envelope.

LRV Detection Equipment: Track circuits, devices, and associated equipment detecting presence of LRVs.

LRV Operator: Person in direct control of an LRV.

LRV Shunt Impedance: Electrical impedance between running rails when spanned by LRV wheels and axles.

LRV Side Display Unit (LSDU): Sign used to display LRV destination.

Limited Use Card (LUC): Single trip fare card generally made of paper with limited use life.

Line: Alignment and facilities over which an LRT route operates.

Line Capacity: Maximum number of passengers LRVs can transport past a fixed point in one direction on a line per unit of time. Typically equals Station/Stop Capacity or Way Capacity, whichever is less.

Line of Sight: Range of unobstructed vision.

Listed: Equipment or materials included in a list published by an organization concerned with product evaluation that maintains periodic inspection of listed equipment or materials production and whose listing states either that the equipment or materials meet appropriate standards or has been tested and found suitable for use in a specified manner acceptable to the AHJ.

Load Factor: Ratio of passengers carried to available passenger spaces.

Local Control: LRT movement under highway traffic signal control. Also emergency ventilation system or ventilation plant under control remote from OCC.

Local Control Unit (LCU): Disseminates messages and media clippings to various visual displays. Each LRV car includes one LCU unit.

Locking: Electrical, mechanical, or software formation of a switch condition, interlocked route, speed limit, or automatic function that cannot be altered except by a prescribed and inviolate unlocking sequence.

Lowest Replaceable Unit (LRU): Lowest unit of a subsystem/system removable and replaceable from an installed position by standard attachments.

Lubricator: Wayside device that lubricates running rails and/or restraining rails to reduce rail squeal, curve resistance, and rail climb.

Lumen (Lm): SI derived unit of luminous flux measuring total amount of visible light a source emits.

Luminaire Dirt Depreciation (LDD): In lighting design calculations, the multiplier used to account for reduction in luminance produced due to accumulation of dirt on a luminaire.

Luminaire: Light fixture complete with lamp, reflector for directing light, aperture with or without a lens or diffuser, housing assembly, ballast, and power source connection, but not including pole or mastarm.

Luminance: In lighting design, the photometric measure of luminous intensity per unit area of light travelling in a given direction. Luminance describes the amount of light that passes through or is emitted from a particular area and falls within a given solid angle. The SI unit for luminance is candela per square metre (cd/m^2).

Lux (Lx): Photometric measure of light intensity hitting or passing through a surface as perceived by the human eye. The SI unit of illumination equal to one lumen per square metre.

M

Main Line Track: Track used for LRV revenue operation carrying passengers. Also called Revenue Track.

Main Track: Track designated by timetable upon which train movement is authorized by timetable, cab signals, or interlocking signals.

Maintainability: Probability that failed systems, facilities and/or equipment can be restored to operable condition within a specified downtime when maintenance is performed under stated conditions, usually expressed in Mean Time To Repair (MTTR).

Maintainability Allocation: Process by which the time allowed for scheduled or unscheduled maintenance of an item is subdivided and equitably apportioned among the item components.

Maintainability Demonstration: Demonstration test using statistical sampling techniques to prove that a unit meets quantitative maintainability requirements.

Maintained: In lighting design, the luminance (i.e., lumen output) after applying light loss factors.

Maintained Minimum: In lighting design, the lowest illumination value of a given set of calculated points after applying light loss factors.

Maintenance: Actions required to restore a failed item to its required level of operability and retain an item in its preferred operable condition(s) using systematic failure inspection, detection, and prevention.

Maintenance Analysis: Analysis of required tasks at each maintenance level, task frequency, and time, crew size, and skill level, as well as necessary support equipment.

Maintenance, Corrective: Actions taken to restore a failed item of equipment to operable condition.

Maintenance, Preventive: Actions performed to attempt to retain an item in a specified condition by providing systematic incipient failure inspection, detection, and prevention.

Malfunction: Anomaly wherein a system, subsystem or component fails to function as intended.

Maximum (MAX): In lighting design, the highest illumination value of a given set of calculated points.

Maximum Authorized Speed (MAS): Highest speed at which LRVs are permitted to operate, subject to safety, civil, operating environment, and other operational considerations that may warrant a further reduction in speed, e.g., grade crossings, curves, signal, and Interlockings. In track work, the speed at which track is designed using maximum allowable actual superelevation and superelevation unbalance. Also known as **Design Speed.**

Mean Cycles Between Failures (MCBF): Mean number of operating cycles between successive independent failures.

Mean Distance Between Component Failure (MDBCF): Arithmetic mean of the component revenue operating distance between successive independent component failures.

Mean Time Between Failure (MTBF): Arithmetic mean of the time between successive independent failures.

Mean Time To Repair (MTTR): Mean active repair time required, after arrival of the maintenance team, to locate and isolate a fault, make repairs, and perform a functional checkout to verify that the equipment has been restored to operating status. The MTTR is the ratio of the total active corrective maintenance repair time expended on an article during a specific period of time to the total number of failure events requiring corrective maintenance actions during that same time period.

Minimum (MIN): In lighting design, the lowest illumination value of a given set of calculated points.

Minimum Maintained Average: In lightning design, the lowest allowable calculated average of luminance, or luminance after applying light loss factors.

Modular: Composed of standard, interchangeable units designed to facilitate maintenance and repair.

Module: Standard, interchangeable unit designed to facilitate maintenance and repair

Movement Authority: Authority for a train to enter and travel through a specific section of track in a given travel direction.

N

Noise, Electrical: Conducted or radiated interference brought about by undesirable random voltage or currents.

Non-Combustible: Not capable of igniting and burning when subjected to fire.

Non-Conformance: Any part, procedure, specification, or drawing that does not conform to contractual or specified requirements.

Non-Vital System: Systems that perform functions of control, indication, communications and related tasks that do not directly perform any logic or function affecting the safety of train movement and protection of life and/or property. Non-Vital Systems may or may not interface with Vital Systems.

Non-Revenue Track: Tracks not normally traversed by LRVs carrying revenue passengers. Includes Yard Tracks and Shop Tracks.

Normal Speed: Maximum authorized speed.

O

Operating Cycle: Complete transaction. For TVMs, the purchase of one or more tickets by a patron in a single operation, e.g., the purchase of two round-trip tickets, is one operating cycle.

Operating Environment: Alignment category applied to a particular Main Track.

Operating Speed: Speed of travel on a line that passengers experience.

Operations Control Centre (OCC): Central operations centre where the operating authority controls and coordinates the system-wide movement of passengers and train operations and from which communications is maintained with supervisory and operating personnel as well as with other participating agencies as and when required.

Out-Of-Service Mode: Mode of TVM operation in which the machine is not operating and available for ticket purchases due to mechanical or electronic error or failure.

Outside Plant: Infrastructure consisting of ductbanks, manholes, copper/fibre cables, pull boxes, splice enclosures, cabinets, and other communications equipment installed at-grade or underground.

Outswing: Effective widening of an LRV envelope through a curved alignment due to perpendicular movement of LRV overhang extremities beyond the wheels outside the curve.

Overturning Speed: Speed at which an LRV will derail or overturn when centrifugal force overcomes gravity.

P

Paired-Single Crossover: Two identical single crossovers positioned close together.

Pass: Media for unlimited rides within a designated time period (e.g., a specified day).

Passenger: Member of the general public using transit services.

Passenger Assistance Intercom (PAI): Hands-free voice intercom to communicate with LRV Operators and/or OCC in case of emergency or life safety situations.

Passenger Demand: Number of passenger trips forecast to use transit network LRT services per unit of time.

Passenger Information System (PIS): On-board LRV system with programmable Global Positioning Satellite or signal system interface-based automatic Station and Stop information announcements and visible display in each LRV module.

Passenger Loading Standard, Comfort Load: Number of passenger spaces in an LRV represented by the sum of the seats plus the remaining effective standee passenger spaces. The basic LRT operations loading standard acceptable under most circumstances is calculated at two passengers per square metre.

Passenger Loading Standard, Design Load: Number of passenger spaces in an LRV represented by the sum of the seats plus the remaining effective standee passenger spaces. The LRT operations loading standard under normal circumstances is calculated at four passengers per square metre.

Passenger Loading Standard, Crush Load: Number of passenger spaces in an LRV represented by the sum of the seats plus the remaining effective standee passenger spaces. The LRT operations loading standard acceptable for limited durations not expected to exceed 10 minutes following special events is calculated at six passengers per square metre.

Passenger Platform: Area in a Stations and Stops for passengers to board and alight LRVs.

Passenger Space: Area occupied by a passenger.

Penalty Stop: Irretrievable full service braking initiated by car-borne ATP equipment in the case of either overspeed due to an ATP decrease of speed command or overspeed on an existing ATP speed command that the LRV operator or ATP system failed to acknowledge.

Place of Safety/Place of Safe Passage: Areas through which occupants pass in case of fire where safe conditions are maintained, primarily by smoke control, for 30 minutes minimum. These areas are normally above, below, or adjacent to where the fire occurs.

Place of Ultimate Safety: Open-air, at-grade, or street-level location offering adequate space for occupants to safely disperse.

Platform, Centre: Platform between two operating tracks where both edges are used for passenger boarding and alighting.

Platform, Side: Platform beside an operating track where only one edge is used for passenger boarding and alighting.

Plinths: Concrete poured-in-place pedestals installed to establish and maintain track vertical profile. Plinths may support two or more consecutive rail fasteners, may be reinforced, and are thicker than grout pads. They may be designed to provide adequate structural resistance to LRV lateral forces.

Pocket Track: Track adjacent to a Main Track used for meeting or passing of trains.

Point of Safety: See NFPA 130.

Point of Compound Curvature: Common tangent point where two circular curves turning in the same direction abut.

Point of Reverse Curvature: Common tangent point where two simple circular curves turning in opposite directions abut.

Priority LRV Operation: Traffic signal system operation providing preferential treatment for LRVs over motor vehicles at a signalized intersections. Priority LRV Operation maintains signal coordination for roadway motor vehicle traffic but also includes measures that will attempt to facilitate LRV progress along the segment. Priority LRV Operation traffic signal systems include features such as early recall of the LRV phase or green extension of the LRV phase giving preference to LRVs without disrupting traffic signal coordination.

Probability: Relative frequency of occurrence of an event that can be expected to be observed in a large number of trials in a population.

ProjectCo: MX LRT **d**esignated entity responsible for financing, design, construction, and maintenance of an LRT project.

Proof (Used as a Suffix): Apparatus is designated as dustproof, waterproof, etc., when so constructed, protected, or treated that its successful operation is not interfered with when subjected to a specified material or condition.

Proof-of-Payment (POP): Barrier-free method of fare collection relying upon passengers furnishing a proof of fare payment, e.g., validated ticket, prepaid pass, valid transfer, upon request while on-board transit vehicles or within designated fare-paid zones. Compliance is monitored through random checking by designated transit employees.

Protected Route: Route leading from a Point of Safety to a Safe Discharge Point and providing one hour minimum Fire Protection Rating physical separation.

Public Address Control Unit (PACU): Part of the LRV PA system with each LRV car including one unit and each car speaker connected to the unit. Automatically adjusts gain control and sound level of speakers.

Pull-Through Terminal: Terminal configured so that LRVs reversing direction must do so by changing control cabs at tail tracks located beyond passenger platforms.

Q

Quality Assurance: Planned and systematic actions necessary to provide a product or service with confidence that it will adequately satisfy given requirements for quality.

Quality Control: Operating techniques and activities used to fulfill quality requirements Also refers to the process of documenting these techniques and activities.

Quality Management Plan (QMP): Written description of actions intended to control quality defining relevant and appropriate quality control procedures.

R

Rail: Rolled steel shape designed to be laid end-to-end in parallel lines as part of track work.

Rail Boot: Extruded shape made of rubber or other elastomer wrapped over a running rail used as an electric and mechanical barrier between rail and infill paving material.

Rear of Signal: Position relative to a wayside signal from which the aspect is in normal view.

Redundancy: Existence in a system of more than one means of accomplishing a given function.

Redundancy, Active: Continuously operating parallel redundant components.

Redundancy, Passive (Standby): Parallel elements that are not activated until their operation is required as a result of prior element failure.

Reference Line: Centre-line of construction, structure, or other element.

Reflector: Reflective luminaire element behind the lamp designed to focus and direct light from the lamp.

Reliability: Probability of performing a specified function without failure and within design parameters for the period of time or the number of cycles specified under actual service conditions.

Reliability Allocation: Process by which the specified failure allowance for an item is subdivided and equitably apportioned among components.

Reliability Analysis: Statistical analysis to determine the degree to which an item meets or fails to meet specified reliability goal(s).

Reliability Demonstration: Test process to assess and demonstrate achievement of certain predetermined reliability requirements during actual or simulated in-service operations.

Reliability Goal: Predetermined reliability objective based upon consideration of operating needs, state-of-the-art capability, cost, time, etc. A Reliability Goal can be a minimum acceptable level, an expected program accomplishment, or an idealistic objective.

Repair: Maintenance activity which restores a failed item to an operable condition.

Replacement-In-Kind (RIK): Replacement that matches existing service capacity such as relocation of existing public utilities (e.g., storm, sanitary, water main, etc.) or private utilities.

Restraining Rail: Additional rail installed on the gauge side of the lower (i.e., inner) rail of a curve, with contact surface oriented vertically and parallel to the running rails. The back of a wheel flange contacts a restraining rail holding the wheel in correct alignment through a curve. Restraining Rail provides LRV truck guidance, divides lateral wheel forces between two rails, reduces forces on rail fasteners, and divides rail wear over two rail surfaces thus increasing time between rail replacements.

Reverse Curve: Two simple circular curves turning in opposite directions and joined at a common tangent, known as the Point of Reverse Curve (PRC)

Right(s) of Way: Strip(s) of land upon which a railroad builds roadbeds and conducts operations.

Route: Specified succession of one or more continuous blocks over which a signal or indicator governs movement of LRVs between two controlled interlocked signals.

Running rails: Rails carrying total LRV vertical loads.

S

Safe: Free from danger or risk; Secure from liability to harm, injury, danger, or risk.

Safe Braking Model: Analytical representation of LRV performance while decelerating to a complete stop, allowing for a combination of worst-case influencing factors and failure scenarios. A CBTC equipped LRV will stop in a distance equal to or less than that indicated by the Safe Braking Model.

Safe Critical: Term applied to a system or function whose correct performance is critical to personnel and/or equipment safety or whose incorrect performance may result in a hazard.

Safe Speed: Speed limit above which an LRV becomes unstable and in danger of derailment with any anomaly in the roadway.

Safe Speed Limit: Maximum speed at which an LRV may safely negotiate a given section of track. Safe Speed Limits are set to minimize potential LRV derailment or tip-over.

Safety: Condition in which persons are free from threat or danger, harm, or loss arising from improper design, manufacture, assembly, malfunction, or failure of a system or any of its components.

Safety Guard Rail: See Bridge Guard Rail.

Safety Walkway: Structure in a tunnel providing a place to walk clear of an LRV dynamic envelope.

Sag Curve: Vertical curve appearing concave when viewed from above

Schedule: Part of a timetable prescribing LRV number, frequency, times, and direction of movement.

Scheduled LRV: LRV designated by timetable schedule.

Self-Revealing Failure: Failures whose effects on system operations are immediately and clearly apparent.

Service, Revenue: Passenger transit service including any service involving passenger trips.

Service-Proven: Identical or near identical equipment with demonstrated successful operation in a transit industry environment.

Serviceway: Structure in a tunnel providing a location for wayside equipment clear of an LRV dynamic envelope. Unlike a Safety Walkway, a Serviceway is not considered a safe place for a person to walk or stand while LRVs pass.

Shop: LRV maintenance and repair facility.

Shop Track: Tracks located in Shops including tracks embedded in the floor or built over maintenance pits. The latter may include several configurations with rails supported on sidewalls or elevated on pedestals allowing shop crews to maintain LRV undercarriages.

Signal: Appliance conveying information governing LRV movements at a stationary wayside location responsive to dynamic information based on conditions affecting safe LRV movement in advance of that location.

Signal Aspect: Signal appearance conveying an indication as viewed either from the direction of an approaching LRV or on a signal display unit in the LRV operator compartment.

Signal Indication: Information conveyed by the aspect/indication of a signal or switch or signal display unit in the operator control compartment.

Signal Speed: Speed for which the signal speed control system is designed. Ideally, signal speed should be just a little faster than the speed at which an experienced operator would normally operate an LRV so that the automatic over speed braking system is not deployed unnecessarily. Also known as **Posted Speed.**

Smart Card: Contact-less card conveying e-purse information, passenger category in the form of passes, and other information required. The Smart card used on Toronto's LRT will be the PRESTO card.

Special Track Work: Track layout deviating from simple tangents or curves. Commonly refers to turnouts and crossovers.

Staff Phone: End-user desktop phone provided for transit employees to allow inter-office or inter- facility voice communications for day-to-day operations and administrative functions.

Stagger: Lateral displacement of contact wire left or right of track centre line at OCS supports.

Stand-Alone Validator (SAV): Tamper-proof assembly to time-stamp pre-purchased tickets at time of use.

Standard Active Control Devices: Standard Active Control Devices give advance notice of the approach of a train. They are activated by the passage of a train over detection circuitry in the trackway, except in those few situations where manual control or manual operation is used. Standard Active Control Devices include flashing light signals (both mast-mounted and cantilevered), bells, automatic gates, active advance warning devices, and highway traffic signals. These devices are supplemented with signs and pavement markings, which are referred to as passive control devices.

Standard Joint: Bolted connection between two rails with the same cross-section.

Static Car Profile: 360-degree outline of the extreme edges of an LRV.

Station Areas: Station areas include platforms, concourses, paid areas, un-paid areas, station concessions, staff accommodation and equipment rooms.

Station: Building where passengers board and alight LRVs, including entrances, concourses, platforms, walkways, and surrounding environments. Does not include open air street level shelters (see Stops below). Refer to OBC.

Station or Stop Capacity: Maximum number of passengers LRVs can transport to or from a Station or Stop in one direction on a line per unit of time.

Stops: At-grade passenger boarding and alighting facilities including platform(s) serving one, two or three car LRV consists with platform access via a ramp and sheltered weather protection for waiting passengers.

Stub Terminal: Terminal so configured that trains reversing direction must do so by changing control cabs at the passenger platform.

Sub-Assembly: Two or more components combined into a unit for convenience in assembling or servicing equipment.

Sub-Grade: Material below the track foundation slab, usually in situ material graded and compacted to the required configuration, which supports the loads transmitted through the track structure.

Subsystem: Combination of equipment groups that perform an operational function within a system.

Summit Curve: See Crest Curve.

Supervisory Control and Data Acquisition (SCADA): Client-server supervisory computer system with human / machine interface enabling automation, control, and monitoring of remotely located equipment.

Supplemental Active Control Devices: Supplemental Active Control Devices provide advanced notification of an approaching train and are activated by the passage of a train over detection circuitry in the trackway, except in those few situations where manual control or manual operation is used. Supplemental Active Control Devices include advanced warning signs with flashers, active second train coming sign (blank-out sign with internal illumination) displaying "Look Both Ways" with a double arrow or Flashing LRV Symbol with a double headed arrow, active turn restriction sign (blank out sign with internal illumination) displaying “No Right Turn” or “No Left Turn” (or appropriate international symbol), active “Do Not Stop On Tracks” sign (blank-out sign with internal illumination), automated pedestrian gates, pedestrian signals, and variable message signs.

Superelevation: Difference in height between top of high (outer) rail and top of low (inner) rail.

Superelevation, Actual: Actual superelevation to be constructed.

Superelevation, Equilibrium: Total amount of superelevation applied to the outer rail that is required for equilibrium.

Superelevation, Unbalanced: Difference between the equilibrium superelevation and the actual superelevation

Surplus Payment: Deposit of an amount for a selected fare greater than required.

Switch (Electric): Device by means of which an electric circuit may be opened or closed.

Switch (Track): Pair of switch points with their fasteners and operating rods providing the means for establishing a route from one track to another.

Switch: Pair of moveable rails with their fasteners and operating rods, providing a connection over which to divert the movement of rolling stock and other on-track equipment.

Switch-And-Lock Movement: Device which performs the sequential functions of unlocking, operating, and locking a track switch.

System: Combination of subsystems that constitute an operating system.

System Accuracy: Measurement of the fare vending system’s precision in accounting for monies deposited and dispensed.

System Element: Combination of subsystems or equipment, generally physically separated when in operation, and other assemblies, sub-assemblies, or parts necessary to perform an operation.

System Operating Concept: Document that defines the guiding principles for the operation of Transit Expansion LRT services as a new form of rapid transit in Toronto.

System Safety Program: Combined tasks and activities of system safety management and system safety engineering that enhance operational effectiveness by satisfying the system safety requirements in a timely, cost-effective manner throughout the system lifecycle.

System Safety: Application of engineering and management principles, criteria, and techniques to optimize all aspects of safety within the constraints of operational effectiveness, time, and cost, throughout all phases of the system lifecycle.

T

Tail Track: Auxiliary track beyond a terminal station/stop platform.

Tamperproof: Items that cannot be easily loosened, opened, or penetrated with commonly available tools such as a screwdriver or pliers.

Tee Rail: Steel rail used to bear the weight of rail vehicles that has a symmetrical cross-section and has a shape somewhat like the letter "T."

Thermite Weld: Rail welding technique used to connect two rails end-to-end. This technique uses an exothermic chemical reaction to produce a molten material which fuses to the rail ends together.

Ticket Vending Machine (TVM): Automated machine device where passengers may pay required fares to purchase Proof of Payment tickets.

Train Door Display Unit (TDDU): LED Display used to display "Next stop" messages.

Train End Display Unit (TEDU): LED Display used to display Train number and/or Destination.

Track Centre Line: Path of LRV.

Track Fastener: Assembly of components that hold the running rail in position on the track.

Track Gauge: Distance between the inner faces of two running rails measured at the gauge point at a fixed distance below top of rail. MX LRT uses international standard gauge of 1435 mm.

Track Sub-Tangent System: Subdivision of the Track Centre Line into manageable sub-tangents having accessible points of intersection within the trainway, especially on curves.

Terminal: Passenger Station/Stop at the end of a route.

Threshold Zone: In tunnel lighting, the area inside the tunnel between the portal and the beginning of the transition zone. It is the first stage of eye adaptation from high natural lighting level outside the tunnel to lower levels inside the tunnel. The length of the transition zone is the safe stopping sight distance. The assumed emergency stopping rate of an LRT vehicle is 7.2 km per hour per second.

Ticket: Printed fare instrument that is used to verify payment of transportation aboard transit vehicles.

Tight (Used as a Suffix): Apparatus is designated as watertight, dust tight, etc., when so constructed that the enclosing case excludes the specified material.

Time Down: Total time during which the equipment is not in acceptable operating condition; it starts with a failure event and ends at the completion of repair.

Time Up: Time during which equipment is either operating satisfactorily or is in operating condition and ready to be placed in service; initiated by completion of a repair and terminated by a failure event.

Time-Out: Prescribed amount of time elapsed during which a specified action has not occurred.

Timetable: Printed, controlled document defining Operating Schedule and Special Instructions governing LRV movements.

Time-To-Repair: Time required to repair a failed item to an operable state.

Train Operator Control Panel (TOCP): On-board LRV computer with touch screen human interface for LRV Operator communications. TOCPs interface with various communication sub-systems such as Train Audio Driver-PAs, PAIs, LRV Radios, CCTV-DVRs, WLAN Antennas, GPS Receivers, ATC/ATP, odometers, etc.

Track Circuit: Arrangement of electrical and/or electronic equipment including a length of the running rails allowing detection of trains.

Track: Rail, ties, rail fasteners, hardware and roadbed between points four feet outside of a parallel pair of rails so configured as to support and allow the movement of rolling stock and other on-track equipment.

Traction Power Systems: Electrical system which supplies and distributes propulsion power.

Traffic Adaptive System: Traffic systems that have the ability to monitor traffic conditions and implement appropriate timing plans that best serve the current traffic needs.

Traffic Control System (TCS): Block or moving block signal system under which train movements are authorized by block signals or zones whose indications supersede the superiority of trains for both opposing and following movements on the same track.

Transit Network: Collective services provided by LRT and interrelated transport modes.

Transit Services: Transit network aspects seen and experienced by actual and potential passengers.

Transition Zone: In tunnel lighting, the area between the portal threshold zone and interior zone allowing LRV Operators to achieve appropriate eye adaptation by incrementally reducing threshold zone illumination levels to interior zone illumination levels in the tunnel. Transition zone length is 10 seconds of LRV travel at posted speed.

Truck: LRV assembly containing wheels, axles, springs, etc. Also known as a **Bogie**.

Tunnel Centre Line: Path of a Tunnel Boring Machine.

Turnout: Special track work consisting of a switch, frog, and connecting rails allowing LRVs to diverge to or merge with another track.

Turnout, Facing: Turnout where oncoming LRV traffic is split from one to two tracks and LRVs traverse the switch point before other parts of the turnout.

Turnout, Trailing: Turnout where oncoming LRV traffic merges from two tracks into one and LRVs traverse the switch point after other parts of the turnout.

U

Uniformity Ratio: In lighting design, the numeric ratio of the maximum calculated point divided by the minimum calculated point (max/min); or the calculated mean value of a given set of calculated points divided by the minimum calculated point (average/min).

Universal Crossover: Universal Crossovers are similar to double crossovers except that facing-point and trailing-point single crossovers are laid out in sequence instead of being superimposed.

Unsafe Condition: Any condition endangering human life or property.

V

Verification: Act of reviewing, inspecting, testing, checking, auditing, or otherwise establishing and documenting whether items, processes, services, or documents conform to specified requirements.

Vertical: In lighting design, luminance in lux measured with a light meter pointed toward the horizon on a vertical plane such as a wall.

Vital Function: Function directly affecting LRV safe operations as a portion of a Vital System needing to be implemented in a fail-safe manner.

Vital System: Signal circuits, software, apparatus, etc., that directly perform a function protecting safe LRV movement and that actively protect life and/or property.

Voice over IP (VoIP): Analog voice signals encoded and encapsulated in an Internet Protocol (IP) data packet and transmitted over a Wide Area Network (WAN) using standard protocol (SIP, H323) services and OSI service layers. Received packets are assembled in sequence and decoded to re-generate the original voice.

W

Way Capacity: Maximum number of passenger that LRVs can transport past a particular point on a line in one direction per unit of time without stopping.

Wheel Gauge: Distance from one wheel outer face of wheel flange to the opposite wheel outer face of wheel flange, measured at the gauge point (i.e., a fixed distance below the wheel tread).

Y

Yard: System of tracks used for making up LRV consists and storing LRVs and other rolling stock.

Yard Track: Maintenance & Storage Facility (MSF) track for switching, storing, and/or maintaining non-revenue service LRVs.

Z

Zenith: Point directly over and above an observer.

Zone Control Room (ZCR): Intermediate hub housing CCTV workstations, recording servers, switches, and fibre patch panels aggregating, recording and distributing CCTV signal feeds from several passenger platform or wayside locations to an OCC.

Zone of Influence: Geotechnic zone of soil significantly influenced by an applied surface load, i.e., the load applied to the soil by the foundation of a structure. For all practical purposes, the Zone of Influence is the stressed zone below a foundation responsible for settlement of a structure.

A1.17 Acronyms

The following acronyms appear throughout the DCM:

AC	Alternating Current
ACAT	Advisory Committee on Accessible Transit
AFP	Alternative Financing Procurement
AHJ	Authorities Having Jurisdiction
AIC	Asymmetrical Interrupting Current
AMSL	Above Mean Sea Level
ANSI	American National Standards Institute
AODA	Accessibility for Ontarians with Disabilities Act
APTA	American Public Transportation Association
ASTM	American Society for Testing & Materials
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
AWWA	American Water Works Association
BACS	Building Automation & Control System
BF	Ballast Factor
BLS	Blue Light Station
CADD	Computer Aided Design and Drafting
CBTC	Communication Based Train Control
CCTV	Closed Circuit Television
CDL	Configuration Data List
CEAA	*Canadian Environmental Assessment Act*
CFD	Computational Fluid Dynamics
CIS	Computer Information System
CLEC	Competitive Local Exchange Carrier
CPM	Critical Path Method
CSA	Canadian Standard Association
DB	Design Build
DBB	Design Bid Build
DBFM	Design Build Finance Maintain
DBFO	Design Build Finance Operate

DBM	Design Basis Memorandum
DC	Direct Current
DCM	Design Criteria Manual
DFO	Department of Fisheries & Oceans
DVR	Digital Video Recorder
DWA	Designated Waiting Area
EA	Environmental Assessment
EEB	Emergency Exit Building
EIA	Energy Information Administration
EMI	Electro-Magnetic Interference
EMP	Emergency Management Panel
EOIS	Electrically Operated Isolating Switch
EPB	Earth Pressure Balance (Tunnel Boring Machine)
EPP	Emergency Power Panel
ESD	Electro-Static Discharge
ESMS	Enterprise Security Management System
ETEL	Emergency Telephone
ETS	Emergency Trip Switch
FACP	Fire Alarm Control Panel
FC	Fare Collection
FFA	Firefighter Access
FFH	Firefighter Handset
FRE	Fibre Reinforced Epoxy
FS	Fire Services
FVC	Fire Ventilation Consultant
GBR	Geotechnical Baseline Report
GEC	Geotechnical Engineering Consultant
GECMS	Geo-Engineering Content Management System
GIDS	Guideway Intrusion Detection System
GTHA	Greater Toronto Hamilton Area
HCoMS	Highway Contribution Management System
HVAC	Heating Ventilating Air Conditioning
IEC	International Electro-technical Commission
IEEE	Institute of Electrical & Electronics Engineers
IESNA	Illuminating Engineering Society of North America

IETA	International Electrical Testing Association
IO	Infrastructure Ontario
IP	Internet Protocol
ISO	International Standards Organization
LAN	Local Area Network
LDD	Luminaire Dirt Depreciation
LIS	Load Interrupter Switch
LLD	Lamp Lumen Depreciation
LLF	Light Loss Factor
LRT	Light Rail Transit
LRV	Light Rail Vehicle
MCC	Motor Control Centre
MCR	Municipal Consent Requirements
MMS	Maintenance Management System
MNR	Ministry of Natural Resources
MOE	Ministry of the Environment
MOU	Memorandum of Understanding
MSF	Maintenance and Storage Facility
MTBF	Mean Time Between Failure
NECA	National Electrical Contractors Association
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NIC	Not in Contract
OAA	Ontario Association of Architects
OBC	Ontario Building Code
OCC	Operations Control Centre
OCS	Overhead Contact System
ODA	*Ontarians with Disabilities Act*
OE	Owners Engineer
OESC	Ontario Electrical Safety Code
OHSA	Occupational Health & Safety Association
O&M	Operating and Maintenance
OPS	Ontario Provincial Standard
PA	Public Address
PAI	Passenger Assistance Intercom

PAT	Passenger Assistance Telephone
PDE	Planning Design Engineering
PEC	Project Engineering Coordinator
PED	Platform Edge Doors
PEng	Registered Professional Engineer
PEO	Professional Engineers Ontario
PGEC	Principal Geo-Engineering Consultant
PIP	Project Implementation Plan
PLC	Programmable Logic Controller
PM	Project Manager
PMO	Project Management Office
PMP	Program Management Plan
PO	Purchase Order
POP	Proof of Payment
PPE	Personal Protection Equipment
PPP / P3	Public Private Partnership
PPUDO	Passenger Pick-Up & Drop-Off
PVIS	Passenger Visual Information System
QA	Quality Assurance
QC	Quality Control
QMP	Quality Management Plan
RAMP	Rail Activation Management Plan
RAMS	Reliability, Availability, Maintainability, Safety
ROW	Right(s)-of-Way
RUL	Remaining Useful Life
SCADA	Supervisory Control and Data Acquisition
SDD	Standard & Directive Drawings
SDWA	*Safe Drinking Water Act*
SES	Subway Environment Simulation
SPE	Senior Project Engineer
TBM	Tunnel Boring Machine
TOCP	Train Operator Control Panel
TOD	Transit Oriented Development
TOR	Top of Rail
TPSS	Traction Power Substation

TRA	Threat & Risk Assessment
TVA	Threat & Vulnerability Assessment
TVM	Ticket Vending Machine
TVS	Tunnel Ventilation System
TWC	Train to Wayside Communication
UFA	Utility Free Area
ULC	Underwriters Laboratories Canada
UPS	Uninterruptible Power Supply
URA	Utility Restriction Area
VE	Value Engineering
VoIP	Voice over Internet Protocol
WAN	Wide Area Network
WBS	Work Breakdown Structure
WHMIS	Workplace Hazardous Material Information System
WWF	Wet Weather Flow

A2 Light Rail Vehicles

A2.1 Introduction

Chapter A2 addresses Metrolinx (MX) Light Rail Transit (LRT) Light Rail Vehicles (LRVs).

The document "Technical Specification for Light Rail Vehicles" governs LRV design.

Chapter A2 information derives from the references below, most from LRV Technical Specifications establishing MX LRT LRV contract requirements.

LRV Detailed Design is to be determined as LRV Design Review completes actual LRV design parameters.

While efforts to see that Chapter A2 MX LRT criteria are complete and accurate, validate design information needed with LRV Technical Specifications.

A2.1.1 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT DCM.

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

LRV specific references include but are not limited to:

- LRV Technical Specifications;
- SAP-Nr-590012150 – Technical Description – Flexity Wide body Stainless Steel Dynamic Clearance;
- Bombardier Technical Description – Performance Curves.

OBC governs where conflicts arise unless otherwise stated.

A2.1.2 Design Approach

Performance and functional specifications rather than design specification define LRV requirements, allowing the LRV contractor significant LRV design freedom to implement required performance and functionality while conforming to generally accepted industry standards and practices.

A2.2 LRV General Description

LRVs are to be specific to the line that they are designed for, however, in general they are to be 100% low floor, bi-directional, multi-articulated vehicles capable of normal operating singly or in consists of two or three cars with doors on both sides.

There are two LRV configurations: Single Cab Configuration (SCC) and Dual Cab Configuration (DCC).

A2.3 General Requirements

Provide fully accessible LRVs, 100 percent stepless[1] low floor, and level boarding from passenger platforms.

[1] Please note that the SCC vehicles will have a step up leading into the passenger area at the hostler cab

LRV design life is 30 years; minimize life-cycle costs.

Provide LRVs designed for easy replacement of equipment, accident damage repair, and interior refurbishment.

Provide LRVs with service proven designs and subsystems to the maximum extent possible.

Provide LRVs per NFPA 130 or DIN 5510 (Class 3) for normal operation in tunnels.

Consider electromagnetic compatibility-radiated, induced, conducted, Electro-Static Discharge (ESD) for both susceptibility of LRVs and Electro-Magnetic Interference (EMI) generated by LRVs.

A2.4 System Interfaces

Numerous other system elements interface with LRVs.

Critical interfaces follow.

See the Interface Control Matrix, Appendix 6-A for full details.

A2.4.1 Track and Alignment

See Chapter B1 – Alignment, Clearances, Rights-of-Way.

A2.4.2 Clearances and Major Dimensions

See Reference[1] for dynamic clearances on level tangent track including track conditions.

See Reference[2] for dynamic clearances on level tangent track.

A2.4.3 Current Collection

Method – pantograph.

A2.5 Operation Requirements

A single LRV Operator will normally operate LRVs in consists of from one to three cars with consists of up to six cars possible for emergency recovery scenarios with defined constraints.

LRVs typically stop with doors released at every Station.

LRVs typically stop with doors released at Stops with waiting passengers and upon LRV on-board passenger Stop request.

Provide LRVs with high reliability allowing most failures to be managed by operating in degraded mode.

A2.6 Performance Requirements

A2.6.1 Operation Speed

Provide LRVs capable of operating at up to 80 km/h plus a maximum permitted speed of 88 km/h for overspeed considerations.

A2.7 Design Requirements

A2.7.1 LRV Car Body Exterior

LRV car appearance is to be sleek and modern in keeping with the MX LRT corporate image.

Conceal LRV roof equipment, except pantographs, when viewed from ground level.

Provide LRV car body structural strength crashworthiness per EN12663 (Category P-V) and EN 15227 (Category P-IV) requirements.

Provide LRV car bodies of welded stainless steel construction for at least the lower half.

Conceal couplers behind covers when not in use for both pedestrian/automobile safety and aesthetics.

Provide sand and washer refilling only from outside the LRVs.

Provide DCC LRVs with destination signs on each end and both sides.

Provide SCC LRVs with destination signs at the cab end and both sides.

A2.7.2 Carbody Interior

Provide spacious LRV carbody interior appearance, maximizing seating, circulation, and passenger flow.

Provide easy to clean and graffiti resistant LRV finishes.

Provide LRV ceiling heights 2000 mm minimum in any location except SCC LRV hostler panel areas.

Provide LRV capacity for 56 minimum fixed seats (DCC) or 60 minimum fixed seats (SCC), plus four wheelchair spaces equipped with flip-down seating.

Provide LRV stainless steel spring-return flip-grip handles, stanchions, and grab rails.

Provide LRV antimicrobial coatings.

Provide LRV windscreens adjacent to doors.

Provide LRV passenger Stop request buttons or strips.

Provide LRV passenger alarm strips to alert LRV Operators in case of emergency.

A2.7.3 Operator Cabs

Provide LRV Operator cabs fully enclosed but allowing Operators to interact with passengers.

Provide LRV operation via manual control with Automatic Train Supervision and Control.

Provide LRVs with good visibility in front and to each side for safety at cross streets and walkways.

A2.7.4 SCC LRV Hostler Cabs

Provide SCC LRVs equipped with hostler cabs.

Hostler cab areas consist of a handhold bar for stability and a keyed access Shunting Control Panel in which the LRV Operator stands to operate the LRV.

LRV Shunting Control Panel operation is not considered normal operation and in most cases is limited to yards when moving LRVs and/or building LRV consists (coupling moves).

LRV Operators are able to operate LRVs from Shunting Control Panels within imposed speed limits.

Shunting Control Panels include coupling/uncoupling capability, intercom communications, and local door controls.

A2.7.5 Coupler and Draft Gear Systems

LRVs are capable of automatic coupling to one another for mechanical, electrical, and data connections.

Each end of each LRV includes a coupler with automatic mechanical, electrical, centering, and energy absorption functions.

Conceal couplers behind covers when not in use for both pedestrian/automobile safety and aesthetics as well as to protect couplers from snow and ice.

Coupler cover operation may be manual with hydraulic damper assist.

Coupler operation may be manual for retraction and deployment.

Coupler and draft gear assemblies allow normal operation of multiple LRV train consists and recovery of failed multiple LRV consists with other multiple LRV consists.

Provide LRV manual uncoupling capability from a location near either mating coupler.

Coupler controls in adjacent LRV Operator or hostler cabs automatically control coupler electric isolation.

A2.7.6 Lighting

Interior Lighting

Provide sufficient interior LRV lighting levels for reading.

Provide LED type LRV exterior lighting for marker lights, brake/stop lights, track lights, door indicators, and turn signals/four-way flashers.

Provide as uniform as practical lighting levels throughout the LRVs.

Exterior Lighting

Provide LRV headlight(s) per the Province of Ontario *Highway Traffic Act* that will not produce objectionable intensity or glare to automobile traffic in street service at distances up to 60 m.

Provide two blue and two red end marker lights above, on the sides of, or incorporated into the LRV destination sign.

When any LRV direction is selected, blue marker lights illuminate on the front, red marker lights on the rear.

Red marker lights illuminate on each end when an LRV is in the “Off” mode.

Provide two upper rear red LRV end marker lights enabled on the LRV rear end when a direction is selected.

Provide a clear white light installed and positioned to illuminate each running rail with a minimum intensity of 5 lux at a distance 4 m ahead of LRVs.

Provide forward and rear facing automotive type turn signal lights.

Provide one minimum side-facing turn signal per LRV car body module on both LRV sides at approximately equal spacing longitudinally.

Provide amber lenses all around.

Brake/Stop Lights – Provide two red stop lights, one in each LRV end cluster, integrated with the lower tail lights to give higher intensity light when braking and lighting automatically on the LRV rear end when braking with a direction selected.

“Door Open” Warning Lights – Provide both sides of LRVs with high level red “door open” warning lights directing light horizontally forward and rearward.

Doorway Flood Lights – Provide each LRV doorway with an external flood light for the area outside the doorway when the door is open.

Shield doorway flood lights from the eyes of boarding and alighting passengers.

Door Indicator Lights – Incorporate flashing lights centred above each doorway and visible from both inside and outside LRVs to indicate that doors are opening or closing.

A2.7.7 Propulsion and Current Collection

LRVs collect propulsion current using a spring-raised, power-lowered, single-arm pantograph with spring-supported contact shoe assembly.

Propulsion equipment is rated for full performance.

Full dynamic braking includes capability to regenerate energy into a receptive line in a preferential scheme or dissipate energy as heat through fully rated on-board LRV braking resistors.

A2.7.8 LRV Onboard Communications Systems

LRV to Wayside Communications

Voice and Data Radio – Included.

Track Switch Control – Include interface with appropriate antenna.

Wireless Local Area Network (WLAN) – Include IEEE 802.11g compatible WLAN with on-board LRV Ethernet network device interfaces to transmit diagnostic data when LRVs are in range of authorized WLAN access points. Used to enhance adhesion when needed with integrated spin/slide control.

LRV Level Communications

The LRV communications network facilitates communication of control signals and Monitoring and Diagnostic System (MDS) data within LRVs.

Provide redundancy for safety critical systems.

Provide LRVs with the following functions:

- Audio inputs and outputs connected via a dedicated analog or digital audio bus;
- Video inputs and outputs connected via specified camera signals recorded digitally;
- Audio and video devices controlled by a dedicated Passenger Information Ethernet Network connected to the LRV control network through a gateway.

Coupled LRV interfaces are realized through analog audio/video lines.

Monitoring and Diagnostic System

A Monitoring and Diagnostic System (MDS) on each LRV monitors each LRV subsystem and specified signals from an LRV consist.

Public Address System

LRV Operators use the Public Address (PA) System to make clear, audible, pleasing announcements to passengers of a single LRV module or simultaneously to multiple LRVs in a consist.

LRV Operators are able to suppress exterior speakers for late night operations.

Interior volume is adjusted automatically (via Automatic Gain Control [AGC]) to maintain clear, audible, and pleasing announcements in LRVs with interior ambient noise present.

Provide interior and exterior LRV PA speakers.

Include PA System cab-to-cab intercom mode.

Passenger Emergency Intercom

A Passenger Assistance Intercom (PAI) system allows passengers to communicate with LRV Operators and OCC in case of emergency or life safety situations.

Locate LRV PAI stations at each door and each designated wheel chair area.

Distress and Covert Alarms

Provide LRVs with a distress alarm system that when activated by the LRV Operator provides an indication on the Dedicated Diagnostic Display causing audio/visual warnings.

Provide a covert alarm function that when activated by the LRV Operator via a hidden switch protected from inadvertent operation communicates to OCC using the data radio and displays the words “Call Police” on the LRV exterior destination displays.

Passenger Information System (PIS)

On-board LRV system with programmable Global Positioning Satellite or signal system interface-based automatic Station and Stop information announcements and visible display in each LRV module.

CCTV System

Provide a CCTV system with on-board video and image recording for MX LRT and police use.

Provide four rear view CCTV cameras per LRV, one on each side of each end, facing back from the cab.

Automatic Train Supervision/Automatic Train Protection/Automatic Train Operation

LRVs include space provisions only for MX LRT issued equipment including but not limited to:

- LRV Operator interface equipment;
- Automatic mode selection on the console;
- Transmission and reception antennae coils;
- Electronic control racks and interface wiring;
- Independent speed sensors and wiring;
- Two accelerometers.

A2.8 Coordination

A2.8.1 Other Design Criteria Chapters

Coordinate LRV design with the following Design Criteria Manual Chapters.

Chapter	Title	Degree of Coordination Needed
A5	Operations	High
A3	Safety	Low
B1	Alignment, Clearances, Rights-of-Way	High
B2	Track Work	High
B6	Maintenance & Storage Facilities	High
B5	Stations, Stops, Facilities	Medium
C1	Traction Power	Medium
B4	Structures	Low
C2	Communications & Control	High

A4	Security	Medium

A2.8.2 Existing Conditions/Systems

MX LRT LRVs will not operate nor interface with existing transit systems.

A2.8.3 Future Expansion

Extending LRVs to increase passenger capacity by adding LRV modules is not a current MX LRT LRV design requirement due to major resulting effects on infrastructure and maintenance facilities.

A2.8.4 Testing Requirements

Main Track and MSF space is needed to test two prototype LRVs, one DCC, and one SCC.

Sufficient track is needed to test full LRV performance capability up to 88 km/h.

A3 Safety

A3.1 General

Chapter A3 addresses Metrolinx (MX) Light Rail Transit (LRT) criteria to promote safety related design uniformity and concepts required for system operation and control of the following:

- Light Rail Vehicles (LRVs);
- Stations, Stops, and Facilities;
- Guideways;
- Operations Control Centres (OCCs);
- Maintenance and Storage Facilities (MSFs);
- Signals;
- Communications;
- Mechanical Systems;
- Electric Systems;
- Fare Collection;
- Operations; and
- Training.

A3.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT DCM.

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Safety specific references include but are not limited to:

- Ontario Building Code (OBC);
- Ontario Fire Code (OFC);
- Ontario Electrical Safety Code (OESC);
- National Building Code (NBC);
- National Fire Code (NFC);
- Canadian Electrical Code (CEC);
- Canadian Standard Association (CSA);
- CAN/ULC-S524: Standard for the Installation of Fire Alarm Systems;
- CAN/ULC-S531: Standard for Smoke Alarms;
- CAN/ULC-S537: Verification of Fire Alarm Systems;
- CAN/ULC-S553: Standard for Installation of Smoke Alarms;

- CAN/ULC-S561: Installation and Services for Fire Signal Receiving Centers and Systems;
- Occupational Health and Safety Act – Regulation 851: Industrial Establishments;
- Municipal by-laws of Authorities Having Jurisdiction (AHJ);
- National Fire Protection Association (NFPA) 10: Standard for Portable Fire Extinguishers;
- NFPA 13: Standard for Installation of Sprinkler Systems;
- NFPA 14: Standard for Installation of Standpipe and Hose Systems;
- NFPA 20: Standard for the Installation of Stationary Pumps for Fire Protection;
- NFPA 24: Standard for the Installation of Private Fire Service Mains and their Appurtenances;
- NFPA 70: National Electrical Code;
- NFPA 72: National Fire Alarm & Signaling Code;
- NFPA 75: Protection of Information Technology Equipment;
- NFPA 90A: Installation of Air-Conditioning and Ventilating Systems;
- NFPA 91: Exhaust Systems for Vapors, Gases, Mists, and Non-combustible Particulate Solids;
- NFPA 101: Life Safety Code;
- NFPA 130: Fixed Guideway Transit and Passenger Rail Systems;
- NFPA 220: Types of Building Construction;
- NFPA 251: Methods of Tests of Fire Resistance of Building Construction and Materials;
- NFPA 255: Method of Test of Surface Burning Characteristics of Building Materials;
- NFPA 256: Methods of Fire Tests of Roof Coverings;
- NFPA 1221: Installation, Maintenance and Use of Emergency Services Communication Systems;
- International Standards Organization (ISO) 8201, Acoustic – Audible Emergency Evacuation Signals;
- Underwriters Laboratories (UL) & Underwriters Laboratories of Canada (ULC);
- Institute of Electrical and Electronic Engineers (IEEE);
- American Society for Testing and Material (ASTM);
- American Public Transportation Association (APTA);
- American Railway Engineering & Maintenance-of-Way Association (AREMA).

OBC governs where conflicts arise unless otherwise stated.

A3.3 Safety Strategy

A3.3.1 Basic Safety Goals

The primary MX LRT system safety goal is to achieve the highest practicable level of safety while maintaining cost effective LRT system operations.

Provide and maintain LRVs and LRT equipment and facilities for safe operation per relevant codes and standards.

In case of emergency as a result of guideway derailment, collision, or fire, basic safety goals include:

- Preserve human life;

- Provide emergency evacuation;
- Provide safe access for emergency services, police, medical and other first response personnel;
- Facilitate safe evacuation controlling spread of smoke and hot gas, maintaining visibility, keeping evacuation routes open and smoke-free;
- Minimize property damage to structures, equipment and ancillary facilities; and
- Purge smoke to allow LRT systems to restore normal operations as safely and quickly as possible.

Provide LRT guideway infrastructure, equipment, fire protection, mechanical, electrical, plumbing and drainage systems to achieve MX LRT safety goals.

A3.3.2 Passenger Safety

Provide for passenger safety and efficient conduct of normal, congested, and emergency LRT operations.

A3.3.3 Physical Segregation

Physically separate tunnels from each other for safety except at crossovers.

Provide tunnels with 2-hour minimum fire rated walls.

A3.4 Light Rail Vehicles

A3.4.1 General

Locate equipment outside LRV passenger compartments wherever practical.

Isolate potential ignition sources from combustible materials.

Configure LRV end cabs, roofs, and floors to prevent fire propagation to LRV interiors.

Separate LRV passenger areas from electrical, mechanical and air conditioning equipment with 1/2-hour minimum fire rated compartments.

Provide fire stops at LRV floor and roof penetrations.

Consider arc penetration and materials ignition from LRV roof or roof-mounted equipment.

Locate critical control and other enclosed equipment for moisture, mechanical, and vandalism protection.

A3.4.2 Combustible Content

Minimize LRV total combustible content.

Specifically identify each combustible material by LRV use, supplier name and type, total weight, heating value in kg/kJ and Btu/lb, and soot yield in grams of soot/grams of fuel burnt.

See Chapter A2 – Light Rail Vehicles.

Determine ventilation system capacity and evacuation time per NFPA 130.

Not more than 55 percent of total LRV combustible value allowed within passenger compartments.

Provide LRV floor panels radiant penetration/structural tested 30 minutes minimum per ASTM 119E.

Conduct further fire spread and heat output fire tests, particularly on aspects such as heat release rate, interior furnishing smoke emissions, and toxicity.

Establish design fire size accurately per NFPA 130 and ASTM standards.

A3.4.3 LRV Materials Flammability and Smoke Emission

Test LRV materials to demonstrate compliance with NFPA 130 requirements.

Provide LRV materials information as follows:

- Test;
- Testing Facility;
- Test Results;
- Pass or Fail Status.

Submit previous certified tests performed and validated on the same LRV type used in similar LRT systems for MX LRT review and acceptance.

A3.4.4 Toxicity

Do not use materials and products generally recognized to generate toxic products of combustion.

A3.4.5 Fire Extinguishers

Provide every LRV with multi-purpose portable 3A:40B:C approved fire extinguishers, one in each LRV Operator cab.

Securely fasten fire extinguishers to LRVs to prevent movement during operation.

A3.4.6 Electric

Provide fixed guideway LRV motors, motor controls, current collectors, and auxiliary equipment.

Conduct fire/heat load tests on roof mounted equipment to verify structural integrity.

Mount self-ventilated resistors with air space between resistor elements and combustible materials.

Protect conductors.

Separate high and low voltage wiring.

Provide power cable per IEEE Standard 383 with the additional requirement that circuit integrity continues for 5 minutes after start of test.

Provide motor leads with insulation suitable for intended operating environment, supported and protected to offer least possible chance of mechanical damage.

Provide electrical circuits and associated cabling with gap / creep distance between voltage potentials and LRV body ground per circuit and cable environment conditions and NFPA 130 requirements.

Provide power circuit protection automatic main line circuit breakers or line switches and overload relays.

Provide non-combustible ground potential protection between line voltage current collector assemblies and any other parts or portions.

Provide emergency lighting throughout each LRV.

A3.4.7 Communications

Provide Public Address (PA) systems in each LRV for OCC and LRV Operator communications with on-board passengers.

Provide Passenger Assistance Intercoms (PAIs) in each LRV.

Provide LRV Operator and OCC radio voice communications.

A3.4.8 Doors and Emergency Exiting

Provide LRV side doors that passengers can open in case of emergency or power loss.

Provide at least two means of emergency evacuation as remotely as possible on sides or ends of each LRV.

Provide at least one LRV door each side emergency response personnel are able to open from outside.

Provide emergency evacuation steps, ramps, etc., with on-board LRV safety instructions to assist passengers, including those with disabilities, in guideway emergency exiting.

A3.4.9 Emergency Uncoupling

Provide LRV uncoupling capability from within LRV cars.

A3.4.10 Heating, Ventilating, Air Conditioning

Provide LRV Operator controlled LRV HVAC systems.

Provide LRV Operator shut-off of HVAC intake dampers to prevent smoke from entering LRVs.

Provide protection for heater element device failures.

A3.5 Stations, Stops, Facilities

A3.5.1 Criteria and Approach

Provide Stations and Stops per NFPA, OBC, and AHJ.

Allow fire engineering as an alternative to standard requirements per NFPA 130 Paragraph 1.4:

> *"**Equivalency.** Nothing in this standard is intended to prevent or discourage the use of new methods, materials, or devices, provided that sufficient technical data are submitted to the authority having jurisdiction to demonstrate that the new method, material, or device is equivalent to or superior to the requirements of this standard with respect to fire performance and life safety."*

Fire engineering offers a flexible alternative especially when applied to special or complex buildings as is the case for some LRT Stations that connect with other Stations or buildings.

The fire engineering approach to safety relies on fire engineering principles, calculations and/or software modeling tools to provide alternative means of meeting NFPA requirements.

This gives added flexibility in the application of safety principles by using a performance-based approach, the NFPA standard requirements, or a combination of both.

A fundamental aspect of the fire engineering approach is an assessment of actual hazards and adoption of realistic design fires to form the basis of design principles for appropriate safety support systems.

The fire engineering approach still needs to substantiate that proposed solutions fully meet the intent of NFPA requirements using established safety engineering methodology.

See Chapter B4 – Structures and Chapter B5 – Stations, Stops, Facilities.

A3.5.2 Fire Separation

Separate public areas from non-public areas with two 2-hour minimum fire rated construction.

Separate public areas from Traction Power Substations (TPS) and vaults in the same structure with 3-hour minimum fire rated construction.

Provide enclosed motor vehicle terminals per OBC.

A3.5.3 Station Safety

Provide Stations with the following:

- Fire prevention measures;
- Fire control measures;
- Fire detection systems;

- Means of egress;
- Fire department access; and
- Means of fighting fire.

Provide fire fighter access routes per Section A3.5.4.

Submit proposed fire prevention and control measures for MX LRT and AHJ review and acceptance.

Provide electric insulated platform edge paving with no grounded metal adjacent to trains within 1500 mm of platform edges.

Size electric protection and conductors per NFPA 70.

Effectively grounded electric current carrying enclosures.

A3.5.4 Station Emergency Access

Provide Fire Service automatic sprinkler and standpipe inlet connections within 7.6 m of emergency vehicle access.

Provide hydrant spacing and locations per NFPA 130 and AHJ.

Provide an emergency key box for timely access to Station and Stop locked ancillary areas and/or facilities in MX LRT Supervisor vehicles.

The primary Fire Fighter Access (FFA) route to an LRT Station is through the public areas.

Provide Station FFA routes and shafts, emergency exit stairs, and/or other approved means of access.

Fire Fighter Access Routes

Provide Station FFA routes based on Interchange, End-of-Line, or In-Line Station requirements.

Interchange Station: Two FFA routes minimum.

End-of-line Station: One FFA route minimum.

In-line Station: One FFA route minimum unless the following conditions are met:

- There are three public entrances minimum;
- One FFA route affords direct access to platform;
- Indirect platform access through an alternative FFA route is available via non-public areas or commercial leased areas provided that these areas and the corridors serving them meet the following conditions:
    - Protected by automatic sprinklers;
    - Equipped with fire detectors;
    - Furnished with smoke control/smoke purging system(s).
- One FFA route does not rely solely on an escalator or elevator.

Notwithstanding the above, MX LRT and AHJ reserve the right to examine and comment on FFA routes on a Station-by-Station basis.

Fire Fighter Access Shafts

FFA Shaft requirements are as follows:

- For dedicated Fire Service use from ground level to underground guideway;
- Vertical access ladders without cages and with rest platforms per Ontario Occupational Health and Safety Act, R.R.O. 1990, Regulation 851, Industrial Establishments;
- Track level access doors between horizontal shaft sections and guideways;
- Two hour minimum fire separation;
- Door openings 915 mm wide x 2150 mm high protected by 1.5 hour fire rated door assemblies with FFA shaft-side self-closing exit devices and track-side key-access.

A3.5.5 Means of Egress

Use Station occupant loads to meet two different means of egress capacity criteria:

- Method One: Use NFPA 130 egress capacity calculation method; and
- Method Two: Use OBC occupant load and egress capacity calculation method.

Evaluate worst case emergency conditions and design criteria in fulfilling Station emergency evacuation time and egress capacity criteria.

Perform both calculations separately.

Do not perform calculations by combining the most restrictive elements of each code, e.g., do not “mix and match” calculation methods from different codes.

A3.5.6 Emergency Evacuation Principles

Station emergency evacuation principles derive from hypothetical emergency scenarios considered to be the realistic worst case scenario that may occur.

The MX LRT worst case scenario assumes that a delayed train on fire enters a Station in the peak hour.

Provide sufficient emergency evacuation routes for passengers waiting to board as well as passengers alighting from LRVs to evacuate to a Point of Safety within evacuation time criteria.

A3.5.7 Evacuation Routes

Plan emergency evacuation routes so that any passenger confronted by an outbreak of fire can turn away and make a safe escape per NFPA 130 and/or OBC.

Provide Station platforms with two means of egress minimum, remote from each other and sized to meet passenger capacity and egress time calculations.

A common path of travel from platform ends is not to exceed 25 m or one car length, whichever is greater.

Platform egress elements may include stairs, escalators stopped or moving in the direction of egress, emergency stairs, doorways, corridors and/or walkways to a Point of Safety per NFPA 130 and OBC.

Clearly sign each equipment room exit with an illuminated EXIT sign per NFPA 70, OSHA, and AHJ.

A3.5.8 Evacuation Time

Configure evacuation routes per NFPA 130 and/or OBC so that in case of emergency passengers can:

- Evacuate the Station platform in four (4) minutes or less; and
- Reach a Point of Safety in six (6) minutes or less.

Establish performance-based emergency evacuation times per NFPA and OBC for MX LRT and AHJ review and acceptance.

A3.5.9 Station Evacuation

Provide for normal, congested and emergency operating conditions including Station and LRV evacuation.

Provide Station public areas with two means of egress 50 m maximum to a Point of Safety, an exit stair, or open air.

Station public occupancy limits comprise any areas passengers may enter including the full length of platforms, concourses, corridors, stairways, ramps, and emergency evacuation passageways.

Public access to underground and elevated Station platforms is by means of vertical circulation elements.

Track-level crossings are not allowed at underground and elevated Stations except for emergency evacuation when potential hazards can be mitigated.

In occupied Station non-public areas the same evacuation criteria apply as in Station public areas.

A3.5.10 Stop Evacuation

Provide open access areas around Stops for emergency response and Fire Service equipment per AHJ.

Since Stops are open to the ambient environment with unimpeded means of egress either to an adjacent street or LRT guideway, no further emergency evacuation means of egress are required.

A3.5.11 Non-Public Areas

Station Non-Public areas are not accessible to the general public and are used to support daily LRT operations including offices, staff areas, plant/equipment rooms, etc.

Non-public area occupant loads are added to platform/concourse occupant loads as applicable.

Provide Station non-public area means of egress per NFPA 130 or OBC, whichever is more restrictive.

As with Station public areas, non-public area corridors may guide occupants directly to an Exit or Point of Safety or to a means of egress via any combination the two.

For non-public areas, a Point of Safety may be in an area outside the compartment where a fire is located.

Non-public areas may be further divided into occupied and unoccupied areas and may include rooms housing equipment only.

A3.5.12 Equipment Rooms

Provide unoccupied equipment rooms with 1120 mm minimum clear width evacuation routes within fire compartments.

Clearly mark evacuation routes on the floor and provide 30 lux minimum average lighting levels backed up with 10 lux minimum emergency lighting measured at the floor for 30 minutes minimum after power failure.

Provide audible and visible fire alarm systems.

Keep evacuation routes clear of any obstruction.

A3.5.13 Fire Prevention Measures

Reduce potential sources of Station fire by providing:

- Non-combustible or smoke retardant materials wherever possible;
- Layouts that permit ease of equipment maintenance and Station cleaning;

- Special storage space for combustible materials such as paint, lubricants or oil; and
- Litter bins.

Prohibit smoking in MX LRT facilities.

A3.5.14 Fire Control Measures

Control the spread of fire and smoke by compartmenting fire risk areas as well as with fire suppression, smoke extraction, and smoke containment systems and methods.

A3.5.15 Fire Protection

General

Provide Underwriters Laboratories of Canada (ULC) rated and labelled fire protection systems and equipment.

Protect fire protection systems and equipment from freezing.

Provide approved dry type systems with sufficient drainage and accessories to completely drain the entire system after charging with water.

Consider alternative dry type systems subject to MX LRT and AHJ review and acceptance.

Water Supply and Fire Hydrants

Provide water supply and fire hydrants for Stations per NFPA 130 and AHJ.

Provide an appropriate street corner fire hydrant adjacent to each LRT Stop.

Standpipe & Hose Systems

Provide each Station with a standpipe system per NFPA 14, NFPA 130, OBC, and AHJ.

Hoses – as required by NFPA 14 – are not required for MX LRT as indicated by OBC.

Protect standpipes in unheated areas from freezing.

Arrange standpipe and dry standpipe (DSP) systems per AHJ.

Cross-connect Station and tunnel DSP systems to supply water to tunnels from either end of two adjacent Station DSP systems.

Annunciate standpipe system water flow at OCC, Fire Alarm Control Panels (FACP), and EMP.

Provide tamper switches on main control valves; annunciate at OCC, FACP and EMP.

Fire Suppression Systems

Protect traction power substation, signal, and communications rooms with environmentally safe and clean fixed fire extinguishing systems per OBC subject to MX LRT AHJ review and acceptance.

Provide both automatic and manual activation inside rooms.

Provide manual activation complete with cover to prevent vandalism outside rooms.

Provide interlocks to shut down room ventilation systems and dampers where applicable.

Provide automatic activation through a cross-zoned detection system.

Provide automatic sprinkler protection per NFPA 13, OBC, and AHJ.

Annunciate water flow, supervisory / tamper switches, and trouble alarms at OCC, FACP and EMP.

Portable Fire Extinguishers

Provide multipurpose fire extinguishers in Stations and ancillary areas per NFPA 10 and OBC.

Automatic Fire Detection System

Except for sprinklered areas, provide automatic fire detection, alarm, and control systems in every service room, ancillary space, leased space, booth and kiosk per OBC.

Provide a central supervising station to monitor each Station with audible and visible indication and information per CAN/ULC-S5611, "Installation and Services for Fire Signal Receiving Centers and Systems."

Provide detection systems for equipment rooms, offices, and ancillary areas.

Provide fire alarms suitable for the vision impaired.

Audible/visible advisory system arrangements and installation details subject to AHJ review and acceptance.

See Chapter A4 - Security

Telephone Systems

Provide Station telephone communication systems with emergency telephone capability and 911 access to OCC or emergency service bureaus for employee and emergency responder use in case of emergency.

See Section A3.7.3 LRT Telephone Systems.

Locate emergency reporting devices throughout Stations so that the distance of travel from any point in public areas to such a device is not more than 90 m per OBC.

Public Address Systems

Provide Station, Stop, and LRV PA systems.

Emergency Management Panels

Provide EMPs for Stations with elevators, escalators, tunnel ventilation systems, and/or emergency ventilation systems per Section A3.7.5.

Locate EMPs in the immediate vicinity of main entrance public areas or as determined by AHJ.

A3.5.16 Station Mechanical Systems

Arrange ventilation systems so that air does not exhaust into Station public areas in any ventilation mode.

Provide Station ventilation systems per NFPA 130, NFPA 90A, OBC Part 6, and reference standards.

Ventilate Battery Rooms or similar ancillary rooms where hydrogen or other hazardous gases are released per NFPA 91 and IEEE 484 as follows:

- Provide interlocks to prevent battery charger operation when there is no power to the ventilation fan or when exhaust air velocity is less than design velocity;
- Provide a no-air-flow signal that activates an alarm at OCC;
- Do not connect Battery Room exhaust ducts with ducts used for other purposes;
- Provide Battery Rooms with spark/explosion proof mechanical, electrical, and plumbing equipment.

A3.5.17 Emergency Ventilation

Provide emergency ventilation per NFPA 130 for:

- Control of heat and smoke in case of fire; and/or
- Removal of flammable or toxic gas in case of release in Stations or in tunnels longer than 305 m.

Mechanical emergency ventilation is not required in an open system or where the length of an underground guideway is 61 m or less.

Provide emergency ventilation system fans, dampers, and accessories as follows.

Tunnel ventilation fans, motors, and related components including cables exposed to hot tunnel airflow in case of emergency designed to operate in 250°C ambient conditions for one hour minimum but not less than the required time-of-tenability.

Non-combustible fire-resistant wiring only.

Power and wiring including conduit, raceways, ducts, boxes, cabinets, and equipment enclosures per NFPA 130 and ASTM E136.

Fans of required supply and exhaust capacity able to reach full operating mode within 180 seconds.

Do not protect fans with thermally activated overload devices.

Reversible dampers able to withstand normal, congested, and emergency condition pressure transients.

Ventilation Controls

Provide fans controlled from the following locations in descending order of precedence:

- Motor Control Centers (MCCs);
- Emergency Management Panels (EMPs);
- Operation Control Centres (OCCs).

Display fan status/operating mode, including damper positions when relevant, at MCCs, EMPs, and OCCs.

Protect local MCC control with two hour separation from fans and protected means of access to MCC.

Verify fan operation by means of positive air flow sensing devices.

Annunciate trouble alarms at MCCs, EMPs, and OCCs.

Tunnels Emergency Ventilation

Provide emergency ventilation in typical tunnel sections.

Locate tunnel emergency ventilation fans at the ends of connecting Stations.

Passengers evacuate upstream of smoke as emergency ventilation systems push the smoke downstream and achieve critical velocity to prevent smoke backlayering.

Consider operating procedures for scenarios with LRV passengers downstream of an emergency incident.

Provide a tenable environment along the evacuation route in case of emergency per NFPA 130 by local smoke extraction at Station/guideway and at large ventilated areas, e.g., track transitions at Station ends.

Adopt a smoke clear height of 2.5 m minimum based on a tenable environment per NFPA 130.

Determine through computer simulations the spread of smoke, maintenance of a tenable environment, and maximum exposure time to untenable tunnel air conditions during evacuation.

Use the signal system to allow only one LRV per ventilation zone, i.e., between vent shafts on a single track per NFPA 130 Paragraph 7.2.5 as follows:

> *"The design and operation of the signal system, traction power blocks, and ventilation system shall be coordinated to match the total number of trains that could be between ventilation shafts during an emergency."*

Provide tunnel emergency ventilation to achieve critical air velocity with two LRVs in one ventilation zone.

Provide an analysis to achieve critical air velocity with two LRVs in one ventilation zone.

Stations Emergency Ventilation

See NFPA 130 Chapter 7 for Station or guideway mechanical and/or non-mechanical emergency ventilation system requirements to achieve a tenable environment along the evacuation route.

Provide Station and tunnel ventilation analyses to determine emergency ventilation requirements.

See *Station Fire Computational Fluid Dynamics (CFD) Criteria Report.*

Provide local smoke extraction at platforms, concourses and/or guideways.

Adopt a smoke clear height of 2.5 m minimum based on a tenable environment per NFPA 130.

Provide Station entrance doors to be held open when emergency ventilation systems are active.

A3.5.18 Station and Stop Electric Systems

Provide Station and Stop electric equipment, wiring materials, and installations per Chapter C3 – Facilities Electric Systems.

Provide wire and cable used in operating vital train signal circuits and power circuits to emergency lights meeting flame-propagation criteria with flame test minimum short-circuit time of five minutes per IEEE 383.

Provide an approved back-up power supply for underground guideway safety critical systems including but not limited to:

- Fire detection, alarm and suppression systems;
- Emergency lighting;
- Emergency telephones;
- Elevators required for emergency access/egress;
- Emergency signage including automated emergency messages;
- Emergency ventilation;
- Fire pumps;
- CCTV.

Protect conductors for emergency lighting, communications, and other emergency operating systems from fire and/or physical damage by LRV or other normal LRT operations and maintenance activities.

Do not depend on thermal properties for operating over-current elements to protect emergency lighting and communications equipment located in spaces other than main distribution system equipment rooms.

Provide electric grounding wherever required.

A3.5.19 Emergency Lighting and Signage

Provide emergency lighting in case of normal lighting failure maintaining illumination levels of 2.7 lux minimum measured at guideway and walkway walking surfaces along evacuation routes for not less than 1½ hours per NFPA 70 Emergency Systems and NFPA 101 Paragraph 7.9.

Mark Station exits with readily visible illuminated EXIT signs.

Provide signs at each enclosed emergency exit stair landing to identify floor level and exit direction, visible from within the stairwell with exit stair doors open or closed.

Provide emergency exit signage per NFPA 101 and governing local code.

A3.6 Guideways

A3.6.1 General

Exclude motor vehicle and pedestrian traffic from LRT guideways.

Prohibit public crossing of LRT guideways other than at marked, controlled crossings.

Provide landscaping, fencing, and other elements to direct the public to appropriate LRT guideway crossings.

The Clearance Envelope is the space occupied by the LRV Dynamic Profile plus 50 mm added running space.

Consider the following factors in developing the Clearance Envelope:

- The LRV Dynamic Profile develops from cumulative effects of dynamic LRV body movement, LRV Static Profile, specific LRV characteristics, and LRV / track wear conditions;
- LRV Out-swing and In-swing occur as an LRV travels along horizontal curves with net effect of increasing as curve radii decrease resulting in an enlarged LRV Dynamic Profile; and
- Super-elevation applied along horizontal curves to obtain maximum operating velocity while maintaining LRV stability and passenger comfort also results in an enlarged LRV Dynamic Profile.

Allowances for chord construction, construction tolerances, acoustic treatment, and equipment and safety walkway clearances are factors used in sizing structures but are not included in the Clearance Envelope.

Provide structures or equipment adjacent to running rails with grounding so that touch potential differences between LRV or running rail and structure/equipment does not expose persons to electric shock hazard.

Provide warning devices where pedestrian or motor vehicle traffic crosses guideways.

Provide lane markings, curbs, fencing and other appropriate means to identify LRT Rights-of-Way and warn of potential danger.

Provide speed limit signs clearly visible from LRV Operator cabs and posted in advance of speed zone changes as well as at intermediate points for speed zones longer than 305 m.

Run LRVs through Stations and Stops at reduced speed designated by operating rules.

Provide warning signs on guideways where sight lines do not allow easy visual identification of Stations.

A3.6.2 Flammable and Combustible Liquids

Protect the LRT system from accidental spills of flammable or combustible liquids per NFPA 130.

A3.6.3 Construction

Provide guideway construction per NFPA 130.

A3.6.4 Emergency Access

Emergency response personnel gain access to guideways through Stations, Stops, or directly from crossing or parallel public streets.

Emergency response personnel may use emergency exit stairs where available for access.

Make special provisions where conditions such as landscaping, other structures, or contiguous private property hinders emergency response access.

Provide roadways or special access roads at intervals of 762 m maximum where normal guideway access cannot readily be met.

Provide maintenance access areas suitable for emergency vehicles in Rights-of-Way more than 45 m from a public roadway.

Provide gates for access to Rights-of-Way.

Provide direct access to public fire hydrants.

Provide guideway emergency access gates as close as possible to portals for access to tunnels.

Provide warning signs identifying appropriate hazards at guideway access points, fences, and barriers.

A3.6.5 Means of Egress

See Section A3.6.11 Emergency Exit Buildings (EEBs).

Provide means of egress along guideways for LRV emergency evacuation.

Provide distance between exits for underground or enclosed guideways per NFPA 130.

Provide guideway means of egress with unobstructed clear width graduated in the following sequence:

- 610 mm minimum at the walking surface;
- 760 mm minimum at 1420 mm above the walking surface; and
- 610 mm minimum at 2025 mm above the walking surface.

Provide emergency evacuation walkways of non-combustible materials.

Provide uniform, slip-resistant walkway surfaces, free of obstructions and sufficiently lit.

Provide continuous guards and/or handrails for walkways raised 600 mm minimum -- rather than 760 mm per NFPA 130 -- above floor or grade below.

Provide smooth walkway transitions where at-grade and elevated guideways meet.

Provide 1120 mm minimum width crosswalks adjacent to crossovers.

Provide guideway lighting.

Provide emergency evacuation tunnel crosspassages per NFPA 130 except as modified herein.

Crosspassages are not to be used in lieu of emergency exit stairs except per the following provision:

> *Where egress to surface level is not practical, e.g., under a body of water, restricted area, or conservation zone, provide crosspassages to the adjacent tunnel at 244 m maximum spacing.*

Provide fire door assemblies with two (2) hour minimum fire rating and self-closing fire doors at crosspassage openings.

Suspend LRV operations on adjacent guideways where passengers evacuating from an LRV may gain access to other guideways not involved in an emergency incident.

A3.6.6 Communications

Provide Emergency Telephones (ETELs) at Blue Light Stations (BLSs) per Section A3.9.8 and NFPA 130.

See Chapter C2 – Communications and Control for Fire Fighter Handset requirements.

A3.6.7 Fire Protection

Provide signal rooms, incoming electric service equipment rooms, and TPS with either an automatic fire detection system or an automatic fire suppression system.

Monitor and display detection and suppression systems status at OCCs.

Provide portable fire extinguishers per Sections A3.4.5, A3.5.15, A3.10.3, and A3.11.5.

Certain guideways sections, such as areas with restricted Fire Service access, short lengths of enclosed or open cut guideways, or between at-grade and elevated guideway sections, may be subject to special fire protection requirements to provide a level of safety equivalent to other guideway sections per AHJ.

Tunnel Standpipe and Hose System

Provide a Class I standpipe system throughout underground guideways per NFPA 130 & NFPA 14.

Supply standpipe systems through public water connections at Stations, portals, and other access points.

For wet standpipe systems provide backflow preventers at each municipal water feed to keep contaminated water from entering the municipal system.

Station and guideway standpipe water supplies may be combined.

Provide a normally closed by-pass where required for standpipe system reliability.

Provide Fire Service inlet connections at each point of connection to public water supplies.

Provide air release valves to accelerate standpipe line charging.

Provide outlets in crosspassages and emergency exit at-grade enclosures.

Provide identifying graphics at each hose outlet valve on tunnel walls or painted directly on the standpipe.

Provide DSP with valves capable of being opened remotely from OCCs, FACPs, and EMPs.

Provide unobstructed Fire Service connections located no more than 45 m maximum from a hydrant.

A3.6.8 Mechanical Systems

Independently ventilate TPS per NFPA 90A.

A3.6.9 Electric Systems

See Chapter C1 – Traction Power for TPS fire protection.

See Chapter C3 – Facilities Electric Systems for TPS electric equipment and wiring.

A3.6.10 LRV Storage and Tail Tracks

Provide LRV storage and tail tracks, other than at MSFs, spaced 3660 mm minimum between centrelines of adjacent tracks.

A3.6.11 Emergency Exit Buildings

Provide EEBs throughout underground guideways located so that the distance from any underground location to an EEB is not be greater than 381 m, i.e., the spacing between EEBs or between an EEB and the closest Station platform or portal entrance is 762 m maximum.

Provide EEBs with track level exit doors and exit stairs up to an at-grade exit.

Where an EEB is not feasible, an alternative to an enclosed at-grade exit may be considered.

Provide emergency evacuation routes from each adjacent underground guideway to a common exit stair between guideways.

Separate each adjacent guideway means of egress from the common exit stair vestibule with fire doors.

Provide EEBs to accommodate portable emergency evacuation carts stored in a box at track level of 400 mm x 700 mm x 1800 mm maximum external dimensions.

EEB doors open in the direction of exit travel.

Suitably identify emergency exits at track level with illuminated exit signs, non-illuminated site identification signs, and enhanced lighting.

Provide emergency exit stairs with two hour minimum fire separation from guideways.

Provide track level exit door assemblies with 1½ hour fire rating and self-closing fire doors.

Provide exit doors with a locking post assembly allowing doors to be held open.

Provide track level door assemblies able to withstand LRV pressure transients of 1,000 Pa maximum incident pressure.

Provide ETELs inside EEBs at grade level.

Provide track level Blue Light Stations per NFPA 130.

A3.7 Communications Systems

A3.7.1 General

Provide telephone, radio, PA systems, etc., performing in normal, congested, and emergency operations to support safety communications requirements.

These systems provide emergency voice communication capability and data to operating and emergency response personnel in case of emergency.

Provide emergency voice communications via the same subsystems used for normal operations.

Provide OCC communications, data, signals, and advanced traffic management through transmission systems suitable to support safety communication requirements.

See Table A3-1 for parties connected with emergency voice communications capability.

A3.7.2 LRT Radio Systems

Provide LRT radio systems with at least one dedicated two-way voice communications group for use in case of emergency.

Provide LRT radio system emergency channel communications capability with LRT personnel on LRVs, in motor vehicles, and throughout the LRT system.

Provide two-way radio voice communication capability for non-LRT emergency response personnel to communicate using their own equipment.

Provide communications in tunnels by integrating a non-LRT system channel with antenna.

Provide detailed data locally from automatic fire detection, alarm, control, and intrusion detection systems to allow emergency response personnel to formulate appropriate emergency responses.

Provide the same data in sufficient detail for responsible LRT system personnel to formulate appropriate emergency responses for the rest of the LRT system.

A3.7.3 LRT Telephone Systems

Provide an internal LRT telephone system for use by LRT personnel and emergency response personnel.

See Chapter C2 – Communications and Control.

Locate LRT telephones to provide communication capability between OCC and Stations, TPS, MSF, emergency exit routes, guideway access points, and Blue Light Stations.

Provide a Fire Fighter Handset telephone system to fulfill “911” system guidelines for manual fire alarms and request for emergency response functions per NFPA 1221.

TABLE A3-1 EMERGENCY VOICE COMMUNICATIONS MATRIX

To: / From:	LRV Passengers	Station/Stop Passengers	LRV Operators	OCC	LRT Personnel	Emergency Responders
LRV Passengers			X	X		X
Station/Stop Passengers				X	X	At Stations Only
LRV Operators	X			X		
OCC	X	X	X		X	X
LRT Personnel		X		X		
Emergency Responders	X	Stations Only		X		

Note: Passengers report emergencies to OCC and Station LRT personnel with Passenger Assistance Intercoms, Emergency Telephones, and Public Telephones.

A3.7.4 Public Address Systems

Provide PA Systems to communicate with LRT passengers, employees, and emergency response personnel in normal, congested, and emergency conditions as well as during service interruptions.

Small separated buildings may be included in nearby principal building zones.

Provide OCC capability to make announcements using the PA system.

Provide override access to Station or MSF PA systems at EMPs associated with the specific facility.

Provide visual displays to communicate necessary emergency information to the hearing impaired in locations approved by AHJ.

Provide automatically adjusted volume control to compensate for ambient noise for both internal and external PA announcements.

See Chapter C2 – Communications and Control.

A3.7.5 Emergency Management Panels

Provide EMPs at Stations with escalators, elevators, fire protection systems, tunnel ventilation and/or emergency ventilation systems, located at grade near the primary entrance or per AHJ.

Provide EMPs with distinctive identification signage and lighting.

Provide EMPs with the following on a site specific basis:

- FACP system status indication;
- Escalator, elevator, and ventilation controls;
- Indication of where fans are controlled: OCC, EMP or MCC; and
- Station layout graphics showing alarm zones and types.

A3.7.6 Fire Alarm Control Panels

Provide FACP for the following functions per NFPA 72, UL, and ULC:

- Automatic fire detection, alarm, and supervision;
- Automatic fire suppression system activation and supervision; and
- Mechanical / electrical systems control and supervision for appropriate emergency response.

OCC supervises and controls FACPs.

See A3.8.3 below.

See Chapter C2 – Communications and Control.

A3.8 Fire Alarm Systems

Provide each MX LRT facility with LRT system-wide standard fire alarm systems including devices, controls, panels, cable, conduit, equipment, materials, and locations for detecting and reporting fire incidents to OCC per OBC and NFPA.

A3.8.1 General

Provide fire alarm systems for locations including but not limited to:

- OCC;
- MSF;
- TPS;
- Underground line sections;
- LRT Stations, Stops, and Facilities;
- Signal relay rooms and facilities;
- Miscellaneous Wayside Structures.

See Chapters A4 - Security, A5 - Operations, and C2 - Communications and Control for further information on fire alarm system remote control and monitoring.

Coordinate fire alarm systems with fire protection, HVAC, communications, signals, elevators, escalators, security, electric and other interfacing systems.

A3.8.2 Functions

Provide addressable, electrically supervised, closed circuit and continuously self-monitoring fire alarm systems per ULC, OBC, NFPA and AHJ.

Provide automatic activation of local alarm devices, HVAC systems shutdown, fire door closing, and other required functions in incident alarm areas.

Provide fire alarm systems to detect and warn of smoke, high heat, rapid temperature rise, or water flow in sprinkler, standpipe, and clean agent protection systems for enclosed areas including but not limited to:

- Station concourse, platform, and ancillary areas;
- Equipment rooms;
- Storage rooms;
- Control rooms;

- Wash rooms;
- Facility power supply rooms;
- Communications rooms;
- Signal instrument facilities, cabinets and equipment rooms;
- Station fire management facilities;
- Fire suppression system rooms;
- Electric equipment rooms where sprinklers are prohibited; and
- Other buildings and facilities per OBC and NFPA.

Provide remote monitoring of fire alarm systems at EMPs, OCCs and/or security offices.

Provide summary indication of each fire alarm system zone or other system malfunctions to OCC.

Underground Stations

Break down and limit Station fire alarm systems to several zones comprising multiple sub-zones as required.

Stops and Elevated Stations

Provide Stop and Elevated Station enclosed areas with fire alarm systems the same as Station fire alarm systems described above.

Elevated Station and Stop areas open to ambient air do not require fire alarm systems.

Interchange Stations

Submit Interchange Station fire alarm systems on a case by case basis for MX LRT and AHJ review.

At a minimum, comply with LRT Station fire alarm system requirements to the limits of LRT physical boundaries so that the fire alarm system of each AHJ is able to operate independently on its own.

Provide appropriate fire alarm system interface and alarm points to and from adjoining Stations and guideways similar to where a means of egress from a Station leads through an adjoining building per OBC.

Provide ample warning signs such as “In Case of Fire – Do Not Enter” at demarcation points.

Maintenance and Storage Facilities

Provide MSF fire alarm systems per OBC.

Operations and Control Centers

Provide OCC fire alarm systems per OBC.

Fire Protection Systems

Provide special fire protection sub-systems, e.g., pre-action sprinkler systems, gas detection, flooding detection for communications and signal equipment rooms, TPS, etc., and corresponding interfaces with Station/OCC/MSF fire alarm systems.

Provide special fire protection sub-systems reporting to OCC with condition alarms as follows:

- Fire detector activation;
- Fire suppression sub-system activation; and
- Fire alarm sub-system trouble.

A3.8.3 Equipment

Fire Alarm Control Panels

FACPs support external monitoring and control circuits.

FACPs summarize alarms for each zone and actuate dry contacts in designated interface terminal cabinets.

Provide each facility with FACPs housing necessary supervisory and monitoring circuits.

Provide fire alarm system zoning as follows:

Alarm:

- Fire detector activation causes audible / visible alarms throughout the facility;
- Station or building FACPs display the zone and device where an alarm condition occurs; and
- HVAC, environmental control, and other systems activate as required in case of fire including equipment shutdown, elevators recall, fire doors closing, and designated fan/damper modes.

Supervision:

- Tamper switch or other supervised component activation causes FACPs to display alarm;
- System status transmits to OCC; and
- Audible / visible malfunction alarms initiate.

Trouble:

- Fire detector circuit malfunction or input power failure causes FACPs to display zones where malfunction or power failure occurs;
- Audible alarm sounds at EMPs until acknowledged at FACPs;
- Visible alarms remain until malfunctions are corrected;
- Audible alarm restarts by subsequent malfunction prior to correction of initial malfunction.

Emergency Management Panels

Provide EMPs at LRT facilities and buildings per OBC.

Locate EMPs next to primary entrances unless otherwise approved by AHJ.

Provide EMP power supply from two independent sources, one normal facility power source and one backup source.

Provide EMPs with the following:

- LRT Telephone Systems;
- Emergency Telephones (ETELs);
- Public Address (PA) system pre-amplified microphone and pre-emption capability;
- Distinctive signage and/or lighting for fire alarm system identification and annunciation;
- FACP system status indicators;
- Elevator and escalator status indicators;
- Station and tunnel ventilation system status and control indicators;
- Emergency ventilation system status and control indicators;
- Indicators where fans are located and controlled: OCC, EMP, or MCC;

- Entrance mounted CCTV EMP coverage but no camera/display inside EMP cabinets; and
- Graphic display of fire alarm zones, circulation elements, and FFA routes to areas indicating fire.

Fire Alarm Control Panels

Provide FACPs that communicate with EMPs at each Station and other facilities.

Provide FACP power supply from two independent sources, one normal facility power source and one internal battery backup source.

Coordinate FACP locations with Fire Service and AHJ.

Manual Fire Alarm Pull Stations

Provide OBC approved manual fire alarm pull stations in Station non-public areas, OCCs, and MSFs.

Public telephones and PAIs also function as fire alarm stations in Station public areas.

Fire Detectors

Except for sprinklered areas, provide 24V DC fire detectors in ancillary areas, locker rooms, janitor rooms, enclosed exit stairs, communications and signal equipment rooms, TPS, and retail areas per OBC.

Coordinate with other fire detector types and ceiling/beam configurations per architectural and structural drawings and industry best practices.

Provide ionization fire detectors in HVAC supply and return air ducts designated by the letter "D" inside a diamond per OBC.

See Chapter C4 - Heating, Ventilating, Air Conditioning.

Smoke Detectors

Provide ULC listed twist/lock plug-in type photoelectric smoke detectors in communications and signal equipment rooms, facility electric power rooms, TPS, and elevator shafts.

Conduit, Wire, Cable

Provide fire alarm system conduit, wire, and cable per Canadian Electrical Code (CEC) and Ontario Electrical Safety Code (OESC).

See Chapter C4 – Facilities Electric Systems.

A3.8.4 Equipment Interfaces

Communications System Interfaces

Provide fire alarm system open circuit and malfunction alarms connected at communications cabinets to Remote Terminal Units interfacing with OCC central alarm facility.

Facility Equipment Interfaces

Provide facility equipment automatic shutdown or other operating mode interfaces in case of fire to be determined by Station and tunnel ventilation and emergency ventilation operating requirements.

Coordinate interface locations with Station and facility design.

A3.9 Electric Power Systems

A3.9.1 General

Provide OCC remote control of LRT lines, MSF, and TPS.

Comply with special procedures for MSF traction power restoration.

Provide TPS electric grounding and lightning protection per OESC, ANSI/IEEE, NFPA 70 and NFPA 780.

Provide OCC control and turnoff capability for essential AC and DC switchgear functions including Overhead Contact System sectioning, alarms, status change visual indications, faults, and other abnormal traction power conditions.

Provide Overhead Contact Systems with minimum overhead clearances per AREMA Chapter 33 unless an enclosed feed with portable cords and insulated plug connections or similar safety features are used.

Provide facilities electric power and light wiring and devices per NFPA 70, NFPA 72, and AHJ.

Provide Blue Light Stations with emergency power shut-off devices per Section A3.9.5.

Provide electric power substations with dry-type transformers.

Provide liquid fuel storage, e.g., gasoline and diesel, liquefied petroleum gas, per OBC and OFC.

Provide for collection and removal of flammable, combustible, and/or toxic liquid and grease to disposal areas approved by AHJ.

A3.9.2 Construction

Provide construction types per governing building codes and AHJ.

Provide floor and walking surfaces of slip-resistant non-combustible materials.

Provide ULC listed roof deck coverings per NFPA 256 Class A or B.

Provide occupancy separation per NFPA 130.

A3.9.3 Egress

Provide emergency evacuation per NFPA 130 and OBC.

A3.9.4 Emergency Lighting

Provide emergency lighting per OBC.

A3.9.5 Blue Light Stations

Per NPFA 130 Paragraph 3.3.5:

> ***Blue Light Station.*** *A location along the guideway, indicated by a blue light, where a person can communicate with the operations control center and disconnect traction power.*

Provide BLS with a power-off push-button device with mechanical lockout capability for tripping traction power feeder breakers to remove power from the OCS in the specific power zone.

Activation of the BLS power-off push-button automatically invokes mechanical lockout to preclude traction power restoration in the BLS controlled power zone until the BLS power-off push-button is deactivated and mechanical lockout released.

Provide OCC capability to restore traction power in the affected power zone.

Provide each BLS with an Emergency Telephone (ETEL) to communicate with OCC.

Provide a blue light for identification at every BLS.

See Chapter C4 – Communication and Control.

A3.10 Maintenance and Storage Facilities

A3.10.1 General

Provide MSF per NFPA 130, NFPA 220, and OBC.

Provide MSF road access and fire suppression.

Provide railroad grade crossings and MSF access roads protected by crossing gates and/or warning lights.

Protect MSF access roads that intersect highways or major thoroughfares with stop signs or traffic lights.

Provide overhead AC and DC power bus systems with audible and visible alarm indications to avoid contact with movable maintenance platforms, ladders, mobile crane control switch cables, or maintenance workers.

Provide warning signs, devices and/or barriers at LRV maintenance pit areas; do not obscure visibility of pit areas with installed fixtures.

Provide MSF with slip resistant walking surfaces.

Provide grounding for pit area electrical equipment including running rail.

A3.10.2 Communications

Principal MSF facilities may use PA systems as fire alarms and for emergency messages per Section A3.8.

Provide MSF with LRT Telephone Systems throughout per Section A3.7.3.

Provide every MSF structure with one or more ETEL within 60 m maximum from any point except for small structures with at least one ETEL within 30 m maximum from any point.

A3.10.3 Emergency Access

Provide MSF emergency access through public streets or LRT access roads.

Provide MSF security fencing and access gates to protect against vandalism, theft, and graffiti.

Provide MSF tracks with 915 mm minimum clearance between sides of adjacent LRVs.

Provide clear emergency evacuation routes for LRT personnel.

Provide clear emergency access routes for emergency response personnel.

A3.10.4 Fire Protection

Water Supply and Distribution

Provide MSFs with sufficient reliable water supply for fire protection including the appropriate number of properly located hydrants per OBC.

Provide fire pumps per NFPA 20.

Portable Fire Extinguishers

Provide portable fire extinguishers of sufficient size and rating per NFPA 10 and OBC.

Provide portable fire extinguishers throughout MSFs, TPS and at each ETEL.

Standpipes and Hose Reels

Provide a Class III wet standpipe system including fire hoses in major repair, service, and inspection shops per NFPA 14, OBC, and OFC Division B.

Provide standpipe spacing in MSF large open areas for hose stream access around, under, and within LRVs.

Automatic Sprinklers

Provide approved automatic hydraulically activated sprinkler systems in MSF structures and areas except electric power distribution rooms, signal rooms, and TPS per NFPA 13 and AHJ.

Provide heat traced wet sprinkler system piping for areas with possible temperatures below 0°C.

Other Fire Suppression Systems

Provide an approved fire suppression system for electronic equipment rooms containing essential communications equipment associated with Stations, OCCs, and MSFs.

Fire Detection Systems

Provide MSFs with automatic fire detection, alarm, and control systems per CAN/ULC S524.

Provide automatic sprinkler systems with water flow alarm and control valve supervision.

Provide FACPs near primary access points to each MSF building or group of buildings.

Blue Light Stations

Provide MSF emergency power trip stations throughout LRV yard and storage areas per Section A3.9.5.

Emergency Telephones

Provide MSF ETELs per Chapter C2 – Communications and Control.

Mount ETELs in enclosures adjacent to Blue Light Stations.

Terminate ETELs at MSF yard towers or at OCC if there is no yard tower.

Mechanical Systems

Provide maintenance pit areas per NFPA 130 with mechanical ventilation systems per NFPA 90A.

Provide positive mechanical exhaust ventilation systems in pit areas where under-car maintenance may generate combustible fumes, e.g., LRV blow-down areas.

Provide pit area exhaust systems capable of 10 air changes per hour or 5 L/s per m^2 of pit floor area, whichever is greater.

Discharge pit area exhaust to atmosphere.

Provide vapor removal blower and exhaust systems per NFPA 91.

Provide sprinklered buildings over 7.5 m high to top of roof trusses with permanent draft stops of rigidly supported, non-combustible material per NFPA 130.

Provide battery charging areas with mechanical ventilation to atmosphere so that hydrogen/air mixtures remain below explosive limits.

Provide mechanical ventilation systems where required per NFPA 91.

Provide electric power and air-flow interlocks per NFPA 130.

Provide ventilation for locations where painting or cleaning occurs and locations where flammable or combustible materials are stored or used per NFPA 130 and AHJ.

Provide MSF overhead cranes per NFPA 70, Article 610, Cranes and Hoists.

A3.11 Operations Control Centres

LRT Operations Control Centres provide:

- Primary control of LRT operations during normal operations;
- Central supervision of the entire LRT system per NFPA 72;
- The central point of coordination for LRT, LRV, Station, Stop, Facility and systems operations;
- Communications with LRV Operators, LRT passengers, maintenance, supervisory, and emergency response personnel;

- Control of facilities housing LRT personnel, equipment, and support systems;
- Supervision of LRT operations, signals, communications, safety, and security management functions;
- Equipment used for data processing, status reporting, and LRT system supervision;
- Support of LRT operations 24-hours per day 7-days per week.

Provide OCCs per NFPA 75 Chapters 4, 5, 6, and 7.

Emergency response personnel control, supervise and coordinate LRT activities in case of emergency.

OCC personnel retain responsibility for operating unaffected parts of an LRT system and coordinating LRT system response with emergency response personnel in case of emergency.

OCCs are equipped to:

- Receive, log, printout, and annunciate fire, security, and supervisory alarms;
- Receive, record, and log ETEL messages, including designation of call origin;
- Communicate with LRV Operators and other LRT personnel;
- Use PA systems as needed;
- Prepare Stations and Stops for evacuation if necessary;
- Selectively remove and restore traction power;
- Monitor and control signals, track work switches, Station and tunnel ventilation fans and pumps;
- Monitor elevators and escalators;
- Remotely stop escalators (MX LRT to seek acceptance of this modification to CSA B44-10).

Provide Fire Fighter Handset telephones at Stations and tunnel portals for communication between emergency response personnel and group leaders at Station EMPs in case of emergency.

Provide an OCC area for coordinating Fire Service operations with access to the following:

- PA systems;
- PA zones displayed at OCC workstations;
- PAIs;
- ETELs;
- Fire detection, sprinkler valve, and water flow detector displays;
- Standby power status indicators;
- Ventilation and air handling equipment status indicators.

Provide dedicated channels allocated for Fire Service and emergency response personnel.

A3.11.1 Construction

Provide Type I or Type II OCC facilities construction per NFPA 220.

Provide non-combustible OCC structural assemblies and building materials.

Provide and maintain OCC occupancy separation per OBC and as follows:

- OCC ancillary areas separated from public areas or any other occupancy by 2-hour minimum fire rated construction and 1 1/2-hour minimum fire rated Class B labeled door assemblies;

- OCC data processing and control areas separated from ancillary rooms by 1-hour minimum fire rated construction and 1-hour minimum fire rated Class B labeled door assemblies;
- Automatic self-closing fire rated door assemblies for fire rated separation openings per NFPA 80;
- OCC cabling to LRT system operating areas and other LRT essential services routed separately from other OCC building services.

A3.11.2 Interior Finishes

Provide OCC interiors with Class I or Class II finishes per NFPA 130.

Provide OCC interior means of egress and evacuation routes with Class I finishes per NFPA 130.

Provide other OCC interior areas with Class II finishes per NFPA 130.

A3.11.3 Access and Egress

Provide emergency access to and means of egress from OCC buildings and facilities per OBC.

Provide OCC evacuation routes with 2-hour minimum fire rated enclosures.

A3.11.4 Emergency Lighting

Provide emergency lighting for OCC evacuation routes and throughout the OCC per OBC.

A3.11.5 Fire Protection

Provide OCC water supply and hydrants per AHJ.

Provide OCC standpipe and automatic sprinkler water supply per NFPA 14 and 13 in addition to OBC.

Provide OCC standpipes and hydraulically activated automatic sprinkler systems per OBC and NFPA 13.

Provide OCC clean agent fire suppression systems for critical communications and signal equipment areas as well as for tape storage and inverter rooms.

Provide fire protected workstation consoles and associated rooms with under floor spaces.

Provide portable fire extinguishers throughout OCC per NFPA 10 and OFC.

A3.11.6 Protective Signaling System

Provide automatic fire detection, alarm, and control systems throughout OCCs per CAN/ULC-S524 and CAN/ULC-S561.

Provide OCC PA systems with fire alarm function.

The fire alarm is a tone followed by a pre-recorded message to differentiate the fire alarm from routine PA announcements.

Provide smoke detectors throughout OCC areas protected by clean agent fire suppression systems, i.e., normally unoccupied areas such as electric equipment rooms, elevator machine rooms, mechanical rooms, and HVAC return air plenums serving more than one area.

Provide OCC automatic sprinkler systems with water flow alarm and control valve supervision for annunciation at the OCC.

For OCCs in buildings with other occupancies, provide the OCC with at least one summary alarm for fire or evacuation notification initiated from any part of the building.

A3.11.7 Mechanical Systems

Provide OCC HVAC systems physically separated and operationally independent from HVAC systems serving any other occupancy.

Provide redundant fan and/or air conditioning units sized and arranged so that any unit is capable of serving the entire OCC facility.

Provide OCC emergency smoke removal systems capable of using 100% outside make-up air and six air changes minimum per hour.

Provide mechanically ventilated battery storage, charging, or similar ancillary rooms where hydrogen or other hazardous gases may be released.

A3.11.8 Electric Requirements

Provide electric equipment and wiring materials per NFPA 70, 72, 75, 130, OBC and AHJ.

Provide separate OCC on-site emergency power systems so that loss of utility electric power does not impair any OCC function per CSA–C282.

A3.11.9 Communications Transmission

Transmission of fire and security alarm and supervision signals from LRT facilities to the appropriate central supervising station may be through direct-line cables or cable transmission subsystems.

Operations signals are allowed to share transmission media with fire and security signals.

Provide Transmission media per CAN/ULC-S524, CAN/ULC-S561, and OBC.

Whatever means is used for fire and security signal transmissions, common use of transmission media must not impair fire alarm functions.

A3.12 Operations

A3.12.1 General

It is essential to accomplish careful operations planning for LRT passenger, personnel, and public safety.

This section addresses operations planning safety requirements.

A3.12.2 Operations Procedures

Objectives

Establish normal operating procedures, including inspection and maintenance programs, so that safety related equipment is in proper working condition and personnel are familiar with the use and care of that equipment as well as with Emergency Preparedness Procedures.

Establish fire plans and emergency operating procedures to govern tunnel ventilation fan and damper operating modes as well as the actions of LRT and emergency response personnel in case of fire or other emergency.

Upon report of any fire or emergency, emergency operating procedures require that the LRV Operator does not stop the LRV in a tunnel or underground section but instead proceeds to the nearest Station whenever and wherever possible.

When the fire or emergency incident is in an at-grade section, emergency operating procedures require that the LRV Operator does not allow the LRV to enter a tunnel or underground section.

Emergency operating procedures allow non-incident LRVs to move out of the way to allow an incident LRV to enter a Station or leave an underground section.

Provide LRT staff regular communications and training in normal and emergency operating procedures.

A4. Security

A4.1 General

Chapter A4 addresses Metrolinx (MX) Light Rail Transit (LRT) system elements to minimize security threats in transit operations and enhance the ability to detect, mitigate, and prevent potential consequences of various security breaches such as vandalism, theft, assault, homicide, and other criminal or terrorist acts.

Provide a Threat and Vulnerability Assessment (TVA) to assess security risks associated with each LRT Station, Stop, Facility and Light Rail Vehicle (LRV).

Determine potential LRT system security threats and issues, then identify, control, minimize, or eliminate them to appropriate levels throughout the intended LRT system service life.

Provide equitable trade-offs between LRT system security and total effects on cost and schedule.

A4.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT DCM.

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Security specific references include but are not limited to:

- Ontario Building Code (OBC);
- Ontario Fire Code (OFC);
- Ontario Electrical Safety Code (OESC);
- National Building Code (NBC);
- National Fire Code (NFC);
- Canadian Electrical Code (CEC);
- Canadian Standard Association (CSA);
- CAN/ULC-S524: Standard for the Installation of Fire Alarm Systems;
- CAN/ULC-S531: Standard for Smoke Alarms;
- CAN/ULC-S537: Verification of Fire Alarm Systems;
- CAN/ULC-S553: Standard for Installation of Smoke Alarms;
- CAN/ULC-S561: Installation and Services for Fire Signal Receiving Centers and Systems;
- Occupational Health and Safety Act – Regulation 851: Industrial Establishments;
- Municipal by-laws of Authorities Having Jurisdiction (AHJ);
- National Fire Protection Association (NFPA) 10: Standard for Portable Fire Extinguishers;
- NFPA 13: Standard for Installation of Sprinkler Systems;
- NFPA 14: Standard for Installation of Standpipe and Hose Systems;
- NFPA 20: Standard for the Installation of Stationary Pumps for Fire Protection;

- NFPA 24: Standard for the Installation of Private Fire Service Mains and their Appurtenances;
- NFPA 70: National Electrical Code;
- NFPA 72: National Fire Alarm & Signaling Code;
- NFPA 75: Standard for the Protection of Information Technology Equipment;
- NFPA 90A: Standard for the Installation of Air-Conditioning and Ventilating Systems;
- NFPA 91: Standard for Exhaust Systems for Air Conveying Vapors, Gases, Mists, and Noncombustible Particulate Solids;
- NFPA 101: Life Safety Code;
- NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems;
- NFPA 220: Standard on Types of Building Construction;
- NFPA 251: Standard Methods of Tests of Fire Resistance of Building Construction and Materials;
- NFPA 255: Standard Method of Test of Surface Burning Characteristics of Building Materials;
- NFPA 256: Standard Methods of Fire Tests of Roof Coverings;
- NFPA 1221: Installation, Maintenance and Use of Emergency Services Communication Systems;
- International Standards Organization (ISO) 8201: Acoustic / Audible Emergency Evacuation Signals;
- International Society for Automation (ISA);
- Underwriters Laboratories (UL);
- UL Automotive Burglary Protection Mechanical Equipment Directory;
- UL Electrical Construction Materials Directory;
- Underwriters Laboratories of Canada (ULC);
- Institute of Electrical and Electronic Engineers (IEEE);
- American Public Transportation Association (APTA);
- American Railway Engineering & Maintenance-of-Way Association (AREMA);
- American Society for Testing and Material (ASTM);
- United States Department of Transportation (DOT);
- Federal Transit Administration (FTA);
- Volpe National Transportation Systems Center (VNTC);
- Department of Homeland Security (DHS);
- Federal Emergency Management Agency (FEMA).

OBC governs where conflicts arise unless otherwise stated.

A4.3 Security Guidelines

Security Guidelines, latest revision, take precedence in case of conflict with MX LRT design criteria as follows:

- Transit Security Design Considerations, Final Report, FTA-TRI-MA-26-7085-05, DOT-VNTSC-FTA;

- Public Transportation System Security and Emergency Preparedness Planning Guide, Final Report, DOT-FTA-MA-26-510903-01, DOT-VNTSC-FTA;
- Facilities Physical Security Measures Guideline, ASIS GDL-FPSM-2009, ASIS International;
- Sensitive Security Information: Designation, Markings, and Control; Resource Document for Transit Agencies, FTA DOT;
- Standard Test Method for LRV Crash Testing of Perimeter Barrier, F2656-07, American Society for Testing and Materials (ASTM);
- Guideline for security lighting for People, Property, and Public Spaces, IESNA G-1-03, Illumination Engineers Society of North America (IESNA);
- Selection and Application of LRV Barriers, US Department of Defense, Unified Facilities Criteria;
- Guide to Industrial Control Systems (ICS), National Institute of Standards and Technology (NIST);
- Security Guidelines for Electricity Sector: Vulnerability and Risk Assessment, North American Electric Reliability Council (NERC);
- Primer for Design of Commercial Buildings to Mitigate Terrorist Attacks, Risk Management Series No. 427, DHS FEMA;
- Catalog of Control Systems Security: Recommendations for Standards, DHS;
- Control Systems Cyber Security: Defense in Depth Strategies, DHS;
- Cyber Security Procurement Language for Control Systems, DHS;
- Security Guidelines and User Resources for Industrial Automation and Control Systems, ISA;
- Crime Prevention through Environmental Design (CPTED) – Applications of Architectural Design and Space Management Concepts, Timothy D. Crowe, Butterworth-Heinemann, Stoneham MA.

A4.4 Systems Approach

A4.4.1 General

Base security related design decisions on a systems approach encompassing every aspect of LRT project planning and implementation including staff, processes, equipment, and technology.

Chapter A4 addresses major elements of LRT system security in the context of interdependence where each individual element is one piece of a larger whole.

An inclusive view also recognizes that systems are linked to other transportation network elements.

Protecting an individual LRV, Station, Stop, Facility, Maintenance and Storage Facility (MSF), Operations and Control Centre (OCC), or computer system is not enough -- any security hazard affects the entire system.

More effective security levels are possible with every aspect of an organization working together to make information critical to deterring, preventing, and responding to security breaches available system-wide.

LRT staff who understand the need for connectivity at all levels among the many physical, technical, legal, and institutional elements are better able to deliver safe and accessible public service.

The systems approach also contributes to LRT security bringing together various parties in security strategy, planning, implementation, and response to a security attack or threat.

A4.4.2 Layered Approach

Provide security measures at several different redundant layers throughout LRT systems.

The layered approach places most critical or vulnerable assets in the center of concentric rings of increasingly stringent security protection measures.

See Figure A4-1.

Do not locate OCC control rooms immediately adjacent to OCC reception areas, for example, but instead locate OCC control rooms deeper inside OCC buildings.

Intruders must then penetrate rings of protection to reach OCC control rooms, e.g., property line fences, locked exterior doors, alert receptionists, key-controlled elevators, and/or locked OCC control room doors.

A4.4.3 Security Consistency

Security is a concept consistently encompassing built-in and integrated design throughout in coordination with safety, operations, maintenance, and other criteria.

Crime Prevention through Environmental Design (CPTED) concepts relate intricately and inextricably to architectural and urban design criteria.

MX LRT security criteria comply with other design criteria unless explicitly noted or stated otherwise.

See MX LRT Safety, Stations, Stops, Facilities, HVAC, Facilities Electric Systems, Communications & Control, OCC, MSF, and other security related design criteria.

A4.4.4 Safety and Security

Whereas safety criteria primarily address prevention of harm resulting from accidents, security criteria primarily address protection from harm and/or fear induced by deliberate acts of others.

Security and safety criteria are meant to be consistent and complementary.

Provide security elements consistent with the System Safety Program Plan (SSPP) that interface with project safety components as follows:

- Emergency Services Advisory Committee (ESAC);
- Safety and Security Certification Review Committee;
- Hazard Identification and Risk Analysis (HIRA) Process; and
- Safety and Security Certification Program.

MX LRT assembles and convenes Emergency Services Advisory Committee (ESAC) members and participants from Emergency Medical Services, Police Service, Fire Service, Safety and Environment, LRT Enforcement and Security Services, Operations, Engineering and other departments as needed to discuss safety and security design issues.

A4.4.5 Light Rail Vehicles

Provide security elements consistent with Chapter A2 – Light Rail Vehicles and LRV technical specifications.

Examples of LRV design security components include:

- Protecting LRV Operators from threats;
- Less flammable LRV materials;
- Less toxic LRV material emissions if burned;
- On-board LRV video monitoring;
- LRV communications equipment and procedures;
- LRV passenger assistance;

- LRV passenger emergency evacuation;
- LRV emergency access by first responders;
- LRV use as weapons by terrorists; and
- Other similar LRV issues with security implications.

A4.4.6 Security Policies and Procedures

A critical aspect of any LRT security system is the need for an effective set of policies and procedures establishing various system elements and security functions.

Security criteria intend to be consistent with AHJ, transit enforcement, security services, police services, and first responder policies, procedures, standards and actions as they relate to:

- Access Management Plans and system functional requirements;
- Standard Operating Procedures addressing security issue response contingencies and first responder actions that may arise;
- Policies and procedures as may be required resulting from new systems or technologies.

More robust security programs proposed for MX LRT projects may have implications for AHJ policy and procedures to be identified through the Safety and Security Committee.

A4.4.7 Other Agencies and General Public

Security issues cut across many disciplines and entities that RT MX and AHJ may represent.

Provide security elements consistent and coordinated with the requirements of MX LRT and AHJ involved at project and/or program level.

Legal, public information, and public safety issues may also arise including but not limited to:

- Public relations issues regarding design and construction security information;
- Which documents to release at what project and/or program stages;
- How to respond to requests for information that may compromise security;
- Requests for information resulting from Freedom of Information Act or competitive bidding process;
- Legal issues related to monitoring, recording, and managing CCTV images per Canada Privacy Act and an effective video recording policy;
- Anti-ram LRV barriers that risk automobile damage or personal injury;
- Design policies coordinated with security incident policies to avoid related legal action.

A4.5 Strategy and Approach

A4.5.1 Supplement Other Criteria Basic Security Levels

The MX LRT Program security strategy and approach assumes that other related design criteria already provide basic security levels of protection.

MX LRT security criteria intend to provide a quantified approach to security that will not impose undue design and implementation costs but will complement the other criteria to create additional layers of protection and fill gaps that may affect security.

For example, a fire deliberately set requires the same safety and security response to address and mitigate as a fire that occurs accidentally.

Fire alarm, communications, and CCTV systems alert OCC to initiate a response.

Structural elements designed per structural criteria and code requirements will survive the event.

In the end, the fire cause may be inconsequential to the fire response, but hazardous materials a fire may produce need to be dealt with by safety and security design elements as well as the response to the fire.

See Figure A4-2.

A4.5.2 Sequential Criteria Layering

With this approach, the US DOT FTA *Transit Security Design Considerations* provide a primary basis for further layers of protection.

The American Society for Information Science (ASIS) *International Guidelines* provide a secondary basis following the US DOT FTA *Transit Security Design Considerations* express intent.

MX LRT adopts both US DOT FTA and ASIS security concepts for LRT projects as described below.

A4.5.3 Existing Transit Systems

Transit design and construction projects with security design elements developed independently or in collaboration with Toronto Transit Commission (TTC) Special Constables include:

- Toronto York Spadina Subway Extension (TYSSE);
- Various Station upgrade/modernization projects.

Meet or exceed TTC Design Manual Section DM-0104-00 - Security Design Criteria for the above projects wherever they apply or interface with new MX LRT projects.

A4.5.4 US DOT FTA/ASIS Guidelines

A4.5.5 Security Design

MX LRT security criteria intend to be consistent with US DOT FTA *Transit Security Design Considerations*.

ASIS Guidelines security criteria apply more to buildings and facilities.

Use them to supplement MX LRT criteria that US DOT FTA design considerations may not include.

A4.5.6 Crime Prevention through Environmental Design

CPTED is a crime prevention method based on the premise that the built environment, properly designed and effectively used, can help reduce crime and improve the quality of life.

Major CPTED elements include defensible space, territoriality, surveillance, lighting, landscaping, and physical security planning.

CPTED has evolved as a means to reduce the opportunity for crime by using physical design features to discourage crime while at the same time encouraging legitimate use of the built environment.

Security measures to protect day-to-day transit systems from crime in many cases can result in improved security against larger threats such as terrorist attacks.

Apply CPTED principles to transit system design including Stations and Stops, OCCs, MSFs, administration buildings, and other facilities.

Importantly, CPTED also applies to LRV design, both from LRV interior space considerations to when, where, and how an LRV interacts with a Station, Stop, or MSF.

CPTED concepts can reduce the need for security staff, CCTV monitoring, detection, deterrence and other security measures.

Natural Surveillance

Provide LRT Stations, Stops, buildings, public spaces and LRVs with ample opportunities to facilitate natural surveillance where legitimate users engaged in normal activities observe the space around them.

In most cases natural surveillance is consistent with good architectural practice and does not incur additional cost if planned and integrated with design from the start.

Specific examples of natural surveillance design basics include:

- Spaces with large fields of vision, long sight lines, and no blind spots or hiding spaces;
- Architectural layouts for effective pedestrian flow;
- Landscape and urban design to enhance fields of vision;
- Strategic sight lines for emergency evacuation and access allowing the public to observe those approaching, trouble, or crime in progress and alert first responders;
- Sufficient lighting to illuminate and eliminate dark spaces;
- Lighting with appropriate color spectra to enhance natural surveillance and CCTV monitoring;
- Lighting levels for greater comfort.

Defensible Space and Access Management

CPTED concepts of defensible space and access management for physical security are consistent with the concept of concentric rings or layers of security.

See Section A4.4.2 for layers of security and Section A4.6 for basic concepts of access management.

Boundary Definition

The CPTED concept of boundary definition is also described as “territoriality” or “natural territorial reinforcement,” i.e., establishing a sense of ownership by legitimate occupants of a building or space relating primarily to secure or access control areas.

Implement restricted area or secure space boundaries with appropriate signage or symbolic markers such as landscaping, different flooring, or other architectural treatment.

A4.5.7 Threat and Vulnerability Analysis

TVA determines the appropriate Security Level Design (Levels A through E), Room Critically (Red, Yellow, Green), and Level of Access for each LRT system area, room, or location with project specific facility or location design recommendations.

See US DOT FTA Public Transportation System Security and Emergency Preparedness Planning Guide for TVA Guidelines.

While the US DOT FTA guide is meant specifically for system wide evaluation and not specific areas, rooms and locations, its principles may be adapted for LRT project specific areas, rooms, and locations.

Review and evaluate specific areas, rooms, and locations with MX LRT Transit Enforcement and Security Services.

A4.5.8 Security Levels of Design

Five Security Levels of Design (SLD) A through E with corresponding facility or asset benchmark references establish a quantified approach in determining appropriate design risk and cost tradeoffs.

The examples below are typical of design threat and vulnerability levels.

The highest Security Level of Design is designated as SLD A and the lowest as SLD E.

Security Level of Design A

SLD A: The highest Security Level of Design.

SLD A includes infrastructure, assets, areas, or locations critical to the continuity of LRT operations, service, and mission.

SLD A requires a very high degree of access control and require the most robust and comprehensive security measures in place.

OCCs may be classified SLD A per TVA because of their importance in operating entire LRT systems.

Security Level of Design B

SLD B: The second highest Security Level of Design.

SLD B areas require a degree of access control, may encompass spatially or geographically restricted SLD A areas, and require comprehensive security measures in place.

SLD B areas have high population density and daily ridership, with high numbers of fatalities and extremely high potential infrastructure damage, cost, and local / regional economic consequences of a security event.

An example of an SLD B area might be an Interchange Station.

Security Level of Design C

SLD C: The third highest Security Level of Design.

SLD C areas require a degree of access control, may encompass spatially or geographically SLD A and/or SLD B areas, and require security measures in place.

SLD C areas have high population density, potentially high to moderate ridership, with potentially high to moderate numbers of fatalities, moderate infrastructure damage costs, and high local but moderate regional economic consequences of a security event.

An example of an SLD C area might be a Station that is not an Interchange Station.

LRT tunnels and bridges may also be classified as SLD C or higher.

Security Level of Design D

SLD D: The fourth highest Security Level of Design.

SLD D areas require security measures in place.

SLD D areas have potentially variable low to high population density, moderate ridership, with potentially low to high numbers of fatalities, but relatively lower infrastructure damage costs and lower local and regional economic consequences of a security event.

An example of an SLD D area might be an at-grade Stop.

Security Level of Design E

SLD E: The lowest Security Level of Design.

SLD E areas require security measures in place.

SLD E areas have potentially very low population density, with potentially low numbers of fatalities, relatively low infrastructure damage costs, and very low local and regional economic consequences of a security event.

Examples of SLD E areas might include an MSF, a remote unmanned electric power substation, track work, signals, and Rights-of-Way between at-grade Stops.

A4.5.9 Security Critical Rooms

TVA also defines building and facility rooms per two criteria, asset value and loss of service, as follows:

Green Room (Low Security Critical) - Asset value $1 million or less and LRT service restoration within 4 hours if room contents are damaged or destroyed.

Examples of Green Rooms include Electric Power Substations.

Yellow Rooms (Medium Security Critical) - Asset Value $1 million to $5 million and/or LRT service restoration requiring between 4 and 24 hours if room contents are damaged or destroyed.

Examples of Yellow Rooms include Communications Equipment Rooms.

Red Rooms (High Security Critical) - Asset Value $5 million or more and/or LRT service restoration requiring 24 hours or more if room contents are damaged or destroyed.

Examples of Red Rooms include Signal Equipment Rooms.

A4.5.10 Access Control Areas

TVA defines Station, Stop, and Facility access control areas as follows:

Restricted Areas

Station, Stop, MSF, facility, equipment, asset, or other infrastructure areas requiring very high security levels and access control, credential authentication, positive identification validation and/or escort for persons not normally allowed access, coupled with multiple higher level security measures.

Restricted Areas are not accessible to general MX LRT staff or the public.

Secure Areas

Station, Stop, MSF, facility, equipment, asset, or other infrastructure areas requiring high levels of security.

Secure Areas are not accessible to general MX LRT staff or the public.

Non-Revenue Areas

Station, Stop, MSF, facility, equipment, asset, or other infrastructure areas not used by the public to board or alight LRVs or for other purposes but primarily staffed by MX LRT employees, consultants, or contractors.

Non-Revenue Areas require LRT system security access control.

Revenue Paid Areas

LRT Station and Stop areas used to board or alight LRVs, but also other facilities, assets, infrastructure, or LRV passenger areas one occupies or travels through after paying a fare.

Public Unpaid Areas

LRT Station and Stop areas one occupies or travels through without paying a fare.

A4.5.11 Automated Access Control

Automated Access Control to non-public secure areas includes mechanically or electronically operated control barriers such as swing doors, revolving doors, slam gates, turnstiles, and portals.

Provide Automated Access Control along with one or more technologies for electromagnetic door locks, keyboards / memorized codes, encoded cards / card readers, video comparators, and biometric identifiers.

See Chapter C2 - Communications and Control.

A4.5.12 Access Management

Access Management is a set of policies, plans, procedures, physical components, and personnel that control and provide awareness of activity and assets in and around facility access control areas.

Access Management controls:

- Who is allowed into facility access control areas;
- Where access is allowed, e.g., MSFs, LRVs, Stations or ancillary areas; and
- When access is allowed, e.g., certain shifts or days of the week.

In addition to determining who has and who does not have access to facility areas, Access Management includes the ability to observe and track movement in and out of access control areas.

A4.5.13 Motor Vehicle Access Control

Provide traffic flow, parking, inspection, waiting areas and related access control to deter unauthorized or illegal motor vehicle access to non-public area facilities such as administration offices, MSFs, and OCCs.

Consider the following for motor vehicle access control per TVA:

- Motor vehicle inspection for bombs and other threats;
- Facility parking/traffic control;
- Adjacent parking facilities and other potential threats;
- Towing of unauthorized vehicles;
- Motor vehicle access points, including separate control points for passenger and delivery vehicles;
- High-speed motor vehicle approaches;
- Drive-up/drop off locations;
- Parking registration/motor vehicle identification systems;
- Automated motor vehicle access control systems.

Provide MSF parking lots and garages as follows:

- MSF parking restrictions for effective control and identification of unauthorized vehicles;
- Separate employee personal motor vehicle parking lots fenced off from MSF work areas, except as regulated for special vehicles, as a loss prevention measure to preclude employee parking adjacent to areas with access to LRT assets;
- Employee parking lots with Automated Access Control, e.g., use of employee ID cards.

Motor Vehicle Barriers

Provide motor vehicle barriers as follows:

Standoff Distance

Motor vehicle barriers provide standoff distance, a measurable blast-effect mitigation or buffer zone between a bomb threat and a facility or asset to keep unauthorized motor vehicles far enough away to limit potential explosion damage.

Asset Protection

Motor vehicle barriers provide equipment and asset protection from unintentional or intentional vehicle ramming, e.g., bollards at fueling stations, entrance gate houses, and LRT Station entrances.

Vehicle Speed

Motor vehicle barriers may control or limit vehicle speed on facility approaches.

Vehicle Stops / Vehicle Incursion

Motor vehicle barriers may stop unauthorized vehicles from entering facility checkpoints, entrances, and other restricted LRT facilities such as tunnel portals.

Vehicle Restriction

Motor vehicle barriers may restrict entry and limit access to authorized vehicles only.

Traffic Direction

Motor vehicle barriers may channel traffic at facility approaches or sites.

Theft Deterrence

Motor vehicle barriers may deter vehicle theft at parking lots and garages.

Motor vehicle barriers may be passive, i.e., static or non-moveable, or active, i.e., operator or automatic controlled.

Provide motor vehicle barriers tested and rated to resist different levels of kinetic energy (K-rating) at the moment of impact and penetration beyond the front line (L-rating).

Determine recommended motor vehicle barrier K-ratings and L-ratings per TVA.

A4.5.14 Fences and Gates

A fencing system is a component of safety and access control. It defines boundaries and limits, and channels access and egress, provides visual barriers, supports security and safety, and can deter and delay intrusion and trespassing.

To the maximum extent possible, design fencing systems to meet the specific needs of MX facilities users.

Employ security and aesthetic considerations in the planning, design, selection, material specification, installation and maintenance of fencing systems.

Comply with AHJ by-laws and complement the Crime Prevention Through Environmental Design (CPTED) principle of natural surveillance in the appropriate fencing system environment.

Provide fences as barriers with heights, dimensions, and other requirements per TVA including but not limited to:

- Perimeters of LRT parking lots and structures;
- MSFs;
- Critical facilities and infrastructure, e.g., OCCs, signal rooms, etc.;
- Along LRT Rights-of-Way and power stations as needed and appropriate; and
- Pedestrian bridges.

Fencing Systems

Fencing systems:

- Give notice of legal boundary of the outermost limits of a facility;
- Assist in controlling and channeling people into or along specific areas and deterring entry elsewhere along the boundary;

- Support surveillance, detection, assessment and other security functions by providing a zone for installing intrusion detection equipment and closed-circuit television CCTV);
- Create a psychological deterrent;
- Deter casual intruders from penetrating a secured area;
- Cause a delay in access to a facility, thereby increasing the possibility of detection;
- Provide a cost-effective method of protecting facilities.

Site Considerations

Include thoughtful assessment of hazards as well as threats in site considerations including:

- Identify high water tables, retaining ponds and site grading plan drainage above and below ground, which may affect the material condition of fencing components or footings, or can affect drainage or result in debris build up;
- Identify topography and analyze surface and subsurface soil components and other conditions to determine suitability and stability for fencing;
- Identify surface and subsurface utilities and other installations;
- Check local ordinances, covenants or agreements for restrictions or requirements that may affect fencing system type, style, color, height, etc.;
- Determine impact to pedestrian/vehicle circulation, users of the community and the transit service;
- Identify frequency, location and targets of vandalism, which may influence the type, style or manufactured components of the fencing design;
- Identify load, wind or other ratings associated with area weather patterns, conditions or other hazardous conditions, such as wind and snow, seismic, wildfire, etc., that may damage or destroy fencing components or structure; weaken its strength or stability; or allow climbing, jumping or stepping over to penetrate the perimeter's boundary;
- Complete a survey of the property identifying pre-existing conditions (such as adjacent property clear zones, stand-off distance, property encroachment, etc.), natural access and surveillance, territorial reinforcement, crime prevention, and security exposures;
- Investigate to identify the locations of fencing systems located within close proximity to power lines, catenary wires, and any future infrastructure to determine the proper grounding of power systems;
- Keeping areas adjacent to fences and barriers clear of vegetation, objects, and debris that could be used to breach the barrier or conceal adversaries and intruders;
- No Storing or stacking of anything against or in close proximity to perimeter barriers;
- Inspecting fences and barriers regularly for integrity;
- Repairing fence and barrier damage promptly;
- Additional security measures for bodies of water forming any part of a perimeter barrier.

Fence Clear Zones

Provide unobstructed Clear Zones on both sides of fences or barriers to make it more difficult to conceal a potential threat or intruder from observation as follows:

- Interior and exterior clear zones 3 m minimum wide wherever practical;
- Clear zones free of objects or features offering concealment, e.g., physical structures or parking areas, or facilitating unauthorized access, e.g., overhanging tree limbs;

- Provide other measures for access control to restricted or secured areas, e.g., increased fence height, increased lighting, remotely monitored CCTV, intrusion detection systems and/or security patrols where Clear Zones are not practical.

Consider a control area and room for sensors or a patrol road with additional security fence lines 3 m to 6 m minimum inside perimeter fences.

Fencing Systems and Materials

Some fencing systems are designed and installed for temporary use, while others are installed for short-term to long-term or even permanent use. Carefully evaluate a combination of the types of fencing installations that may best suit a facility or the specific security requirements of an area as part of the security risk assessment.

Provide corrosion resistant fence materials for permanent fence installations.

Also consider new technologies such as vinyl, plastics, composites and combined wood-metal-plastic-composite products that are being introduced to fencing system industry standards.

Each fencing material has specific maintenance issues and concerns that may affect the use and life expectancy of a fencing system.

Consider materials with demonstrated use in reducing maintenance, upkeep and repair, as well as in increased life-cycle in final fencing system selection.

Fences 1.25 m minimum high may be used to guide pedestrian movement.

Fencing Features

Include fencing with characteristics and features listed below:

- Secure;
- Climb proof;
- Cut and vandal proof;
- Highly Transparent;
- Aesthetically attractive, with simple, lean lines, fitting into a system-wide design vocabulary.

Fence Openings and Integrity

Terminate fence openings well within restricted or secured areas defined by perimeter fences or barriers.

Protect perimeter fence or barrier openings crossing drainage culverts, troughs, ditches, or other openings greater than 620 sq. cm in area or larger than 1.8 m in any one dimension with construction extensions to prevent unauthorized access.

Do not allow such extensions to impede drainage.

Provide hinged security grills with high security hasp, shackle, and padlock that can be opened as necessary as a workable solution to securing drainage structures.

Fence location and selection

Install fences at the following MX facilities/locations and according to the risk profiles indicated.

Consider alternatives, however, including whether a fence is needed at all and, if in fact needed, of what type and height, with supporting justification for MX LRT review and acceptance.

High Risk Facilities:

Provide high risk security fencing 2.4 m high for facilities including but not limited to:

- Layover Yards/Sites;

- Fuel Yards and Tanks;
- Maintenance Facilities.

Medium Risk Facilities:

Provide medium risk security fencing 1.8 m high for facilities including but not limited to:

- Storage/Warehouse Facilities;
- Signal Bungalows.

Low Risk Facilities/Site Components:

Provide low risk fencing no higher than 1.2 m with "knuckles down" terminations and no vertical protrusions, especially around public facilities serving transit passengers, including but not limited to:

- Fencing dividing multiple tracks;
- Significant grade and elevation changes;
- Access control flow, as necessary;
- Ponds, ditches, swales and high embankments.

Overpass Fencing:

Pedestrian overpasses may require vertical fences on both sides with partial or full overhead mesh closure.

See Chapter B3 – Civil Works for additional fencing criteria.

A4.5.15 Security Lighting

Provide access points, perimeters, restricted areas, secured areas, and designated parking areas with security lighting from sunset to sunrise at a minimum as well as during periods of low visibility.

Address circumstances where security lighting may not be required per TVA showing no adverse risk effect and identifying alternative security measures.

Provide facilities with security lighting to acceptable best industry practices such as the Illuminating Engineering Society of North America (IESNA) and other recognized standards.

Consider security lighting appropriate for and compatible with CCTV requirements.

Perimeter Lighting

Provide perimeter lighting units at sufficient distance within the protected area and above perimeter fences so that the light pattern on the ground includes an area both inside and outside the fence.

Provide continuous perimeter lighting and on both sides of fences sufficient to support CCTV and other surveillance equipment.

Entrance and Gate House Lighting

Provide sufficient lighting at designated access control points and gate house entrances to identify persons, examine credentials, inspect entering or departing motor vehicles, and prevent anyone from slipping unobserved into or out of the premises.

Parking Lot Lighting

Provide parking lot areas with uniform illumination sufficient for personnel identification at night and during extreme weather darkness to deter criminal activity.

Emergency Power

Provide facility access control point and entrance lighting connected to emergency power systems to remain in operation during commercial power interruptions.

Types of Lighting

Determine and select from among four general security lighting types per TVA: Continuous, Standby, Moveable, and Emergency Lighting.

Lighting Levels

Provide security lighting illumination levels as follows.

TABLE A4-1 SECURITY LIGHTING ILLUMINATION LEVELS

Illumination Level On The Ground	Light Level (Lux)
Perimeter Fence	5
Guard/Gate House (Interior Dimmable)	300
Entrances/Active Motor Vehicle Gates/Search Areas	100
Inactive Gates	50
Parking Lots	See Chapter C3

See Chapter C3.12 - Facilities Electric Systems, Lighting.

A4.5.16 Infrastructure Assets

LRT system infrastructure includes but is not limited to:

- Stations and Stops;
- Administration Facilities;
- OCCs;
- MSFs;
- Tunnels;
- Portals;
- Elevated Structures;
- Rights-of-Way, Track Work, and Signals;
- Remote and Unguarded Structures.

A4.6 General Design Requirements

Consider the following general design requirements to protect against potential threats:

- Site Layout;
- Architecture and Structures;
- Systems and Services.

A4.6.1 Site Layout

Site Selection

When evaluating a property consider security impact of site elements as follows:

- Natural features such as a stream or swamp;
- Manmade features such as a pipeline or neighboring building;
- Existing easements;
- General characteristics of abutting properties and access control;
- Access to public roads;
- Proximity to private roads;
- Fire truck/apparatus access in placement of structures;
- Possible high-value terrorist targets nearby;
- Local crime rates.

Building/Facility Placement

Appropriate placement and orientation of buildings, facilities and other structures on site is a major component of an effective security strategy to protect against threats.

Building/Facility Orientation

Building/facility orientation may be useful in protecting or shielding vulnerable external building/facility features from attack.

Vulnerable features include entrances, windows, lobby and drop-off areas, loading docks, and other miscellaneous openings.

Site Access Points

Consider the control of how and where vehicles and pedestrians approach and enter a property.

Access Point Numbers and Locations

Provide the minimum number of entrances needed to satisfy daily site operations.

Locate entrances to serve facility users while facilitating security.

Provide facilities with heavy public use such as Stations and Stops with access points that maximize convenience and capacity.

Facilities with less frequent public use less may have less convenient access points without significant negative impact on facility operations.

Dedicated Entrances or Areas

Provide specific entrances and areas within a site dedicated to particular users at facilities with different types of user access.

This strategy is to separate users that present different security threats thus requiring different degrees of access management.

For example, LRT staff pose less threat than LRT users or delivery vehicles, so allow LRT staff easier access to sites and to park their vehicles closer to sensitive assets.

Speed-Control Approaches

Align roadways to prevent high-speed vehicle approaches to site access points and assets such as buildings and impede attacks using fast moving vehicles to ram perimeter security or destroy assets in a collision.

On-Site Vehicle Circulation

Control how vehicles and pedestrians move in and about a site as a useful security measure.

Parking Areas

Provide access control systems for general parking in open lots or dedicated garages.

Drop-Off Areas

Provide passenger drop-off areas where vehicles pose minimal threats outside required standoff distances and without clear lines of sight to windows, lobbies, air intake/exhaust, or other vulnerable external building features and openings wherever possible.

Where impractical to provide a drop-off area outside the required standoff distance, consider additional drop-off area surveillance and monitoring for suspicious activity or devices.

A4.6.2 Architecture and Structures

LRT Stations

MX LRT Stations are defined as designated passenger boarding/alighting locations on exclusive alignment Rights-of-Way.

The Concept of Operations indicates that Stations generally are unattended and thus do not include Attendant Booths.

Station Layout

Plan Stations wherever possible to:

- Minimize length of movement predictors that reduce ability to escape threats, i.e., tunnels, stairways, walkways and corridors allowing potential attackers to predict passenger movement;
- Avoid blind corners and entrapment areas, e.g., alcoves and dead ends;
- Maximize natural surveillance, sight lines, and CCTV coverage;
- Provide safe and unobstructed emergency responder access;
- Provide safe passenger paths from Station entrances to associated surface facilities;
- Provide sufficient and effective lighting inside and outside Stations and associated surface facilities.

Provide Station landscaping and area lighting to avoid concealment and maximize passenger sight lines.

Provide Station entrances capable of being locked during non-operating hours.

Provide doors required as means of egress during non-operating hours per OBC and AHJ requirements.

Provide equipment that does not impede passenger sight lines, Station signage, PAI, or CCTV.

Provide properly designed, located, self-illuminated or artificially illuminated Station signage.

Provide appropriate signage indicating that CCTV operates if PAI is activated or CCTV records an area.

Interior/Platform Layout

Provide Station layouts with unobstructed sight lines, minimizing columns, blind corners, hidden areas and remote passageways.

Locate retail kiosks, outlets, ads, and information conveniently but without disrupting sight lines.

LRT Stops

MX LRT Stops are defined as designated patron boarding/alighting locations on semi-exclusive and non-exclusive alignment Rights-of-Way.

Each Stop will have an automated fare collection/proof of payment machine that also serves as the focal point of communications at Stops.

Stops are not attended.

Site Layout

Provide unobstructed sight lines surrounding Stops.

Provide physical barriers such as bollards and fences for ramming protection.

Platform Layout

Position platform amenities to avoid disrupting sight lines.

Signage

Provide signage and curb marking to direct motor vehicles around and away from Stop areas.

Provide emergency call boxes to report incidents.

Provide adequate lighting for surveillance.

Elevated Stations and Structures

Site Layout

Restrict access to areas below elevated structures wherever possible.

Set back elevated structure from roads, parking areas, and other buildings.

Provide physical barriers, e.g., fences, bollards, fenders, to enforce setbacks and prevent ramming.

Align and separate adjacent roadways to inhibit high-speed column ramming.

Provide clear sight lines under and around elevated structures.

Interior Layout

Limit number of emergency and maintenance access points to elevated structures.

Provide safe areas for occupants with limited mobility to wait for evacuation by emergency responders.

Tunnels

Access Points

Isolate tunnel access points from public roadways and parking areas.

Provide tunnel access points with physical barriers, e.g., ditches, bollards, road spikes, and fences.

Provide unobstructed sight lines around tunnel access points.

Provide tunnel vent ducts and shafts in secures, self-contained buildings, locked, elevated, and hidden.

Interior Layout

Avoid unnecessary tunnel niches that may conceal people or explosives.

Provide physical barriers shielding tunnel walkways from platform or portal access points.

Provide emergency exit doors lockable from outside but allowing unimpeded emergency evacuation.

Provide accessibility compliant emergency evacuation routes and safe areas.

Operations Control Centres and Administration Facilities

For consistency and optimum security response, transmit alarms throughout LRT systems to OCCs.

Provide OCCs with capability to monitor PAI activated CCTV and initiate appropriate response.

Site Layout

Provide inconspicuous or non-descript OCC facilities and/or locations.

Group together OCC facilities with similar security requirements.

Maintenance and Storage Facilities

Site Layout

Provide MSFs with secure perimeters.

Set back MSF structures and LRV storage areas from roads and public parking areas.

Provide physical barriers such as bollards, fences, and grade changes to enforce setbacks and secure MSF perimeters.

Provide minimum number of MSF access points required per TVA.

Provide MSF motor vehicle main entrances with small, basic gate houses for use in case of emergency if other motor vehicle/pedestrian gates are locked with only one staffed access point remains.

Provide unobstructed sight lines throughout MSFs.

Isolate MSF fuel storage sites with appropriate standoff distances.

Segregate MSF parking areas from LRV and fuel storage areas.

A4.6.3 Systems and Services

Light Rail Vehicles

General

See Chapter A2 – Light Rail Vehicles.

The following criteria address additional layers of LRV security.

Consider LRV security planning and design from the following perspectives:

- LRVs are highly visible and carry large numbers of passengers, thus presenting likely targets;
- LRVs operate in non-revenue or secure areas where vandalism, theft, and assault can occur;
- LRV CPTED concepts appropriate to prevent such incidents apply in those areas;
- LRVs provide attackers and security threats with convenient transport because of their public nature and areas typically traveled;
- LRVs must remain functional to the maximum extent possible during and after security incidents.

Potential LRV Threats

Consider LRV potential threats per TVA including:

- On board LRV vandalism, theft, robbery, or assault;
- Hazards or threats such as explosives or improvised explosive devices placed on or under LRVs;
- Hazardous materials released on LRVs;

- Incidents caused by other LRVs or motor vehicles;
- Intentional LRV derailment.

Communications, CCTV, Intrusion Detection

LRT systems use communications extensively on an everyday basis as well as in case of emergency to manage LRV movement, keep staff and passengers informed of real-time changes or events, and coordinate with other agencies and AHJ.

LRT communications infrastructure is a critical asset that must be protected from any potential attack.

LRT communications include transmission of CCTV and intrusion detection information to OCCs.

LRT communications are also an important tool to detect intrusion and transmit voice, video, and other information for effective response in case of emergency or attack on any part of the LRT system or region.

Cyber Security

General

Protect systems subject to cyber security threats, whether connected via wireless or wired domains, implementing current industry standard practices, protocols, and encryption algorithms to enable, enhance, and retain integrity of voice, data, and video content against intrusion and viruses.

MX LRT cyber security criteria, standards, and procedures apply to data transmission, storage, retrieval, encryption/de-encryption, and device authentication/user log-in authorization.

When interconnecting the MX LRT network to external or other networks, comply with MX LRT enterprise network corporate security policies and guidelines.

Also consider MX LRT Industrial Computing policies and guidelines for system administration.

Develop and submit cyber security processes for MX LRT review and acceptance.

Protocols and Procedures

Enabling and enhancing cyber security applies to communications and control systems, signal control, train control systems including ATC, and fare collection systems, whether fixed or portable, which may be provided by a combination of suppliers.

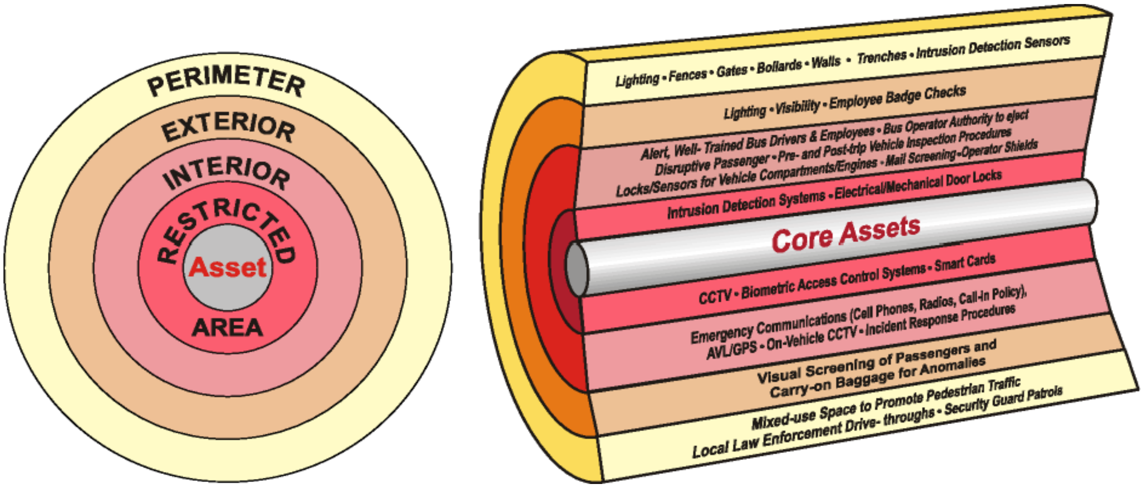
Thoroughly analyze cyber security and communications and control systems to implement security strategies including individual, fully integrated, and existing MX LRT system interfaces.

Develop comprehensive Cyber Security Plans outlining ongoing operations and practices needed to maintain desired levels of cyber security and systems performance.

Address issues such as password administration, update/patch, anti-virus, system monitoring, and configuration management, etc.

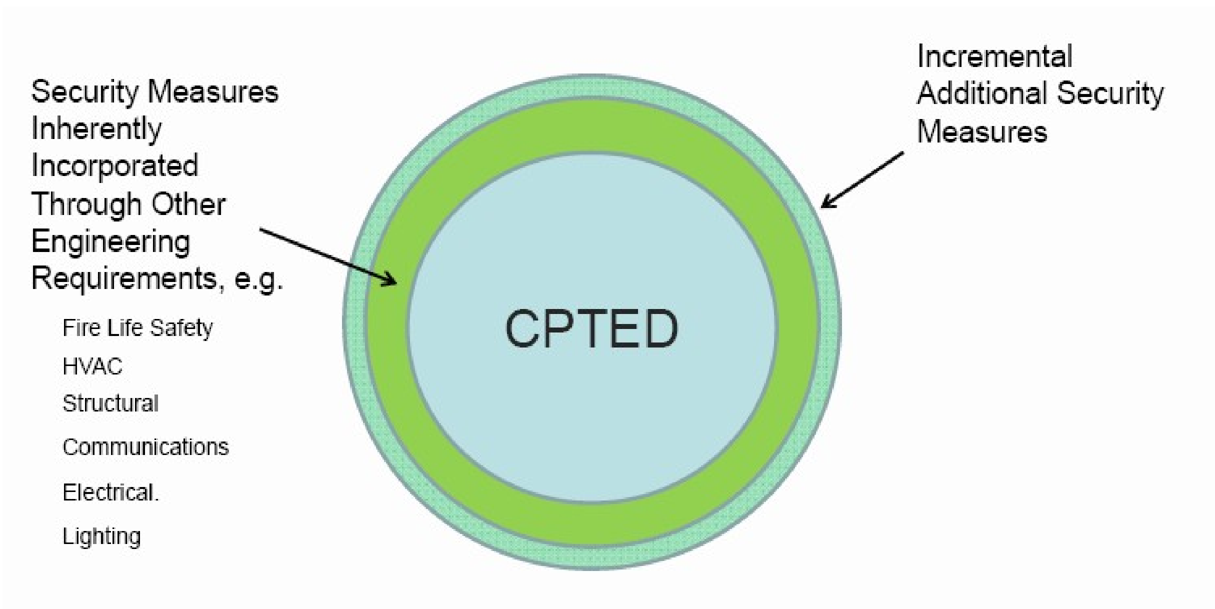
Include Cyber Security Plans in the System Security Program Plan.

FIGURE A4-1 LAYERS OR RINGS OF SECURITY



From US DOT FTA: Transit Security Design Considerations.

FIGURE A4-2 CONCEPT OF SECURITY DESIGN SUPPLEMENTING AND LAYERED ON CPTED CONCEPTS



A5 Operations

Chapter A5 addresses basic Metrolinx (MX) Light Rail Transit (LRT) operations, maintenance, planning, design, principles, standards and related LRT functions and objectives.

Consider Chapter A5 as a companion to the MX LRT System Operating Concept.

A5.1 Objectives

LRT provides safe, reliable, rapid, comfortable, convenient, efficient, cost effective, and fully accessible public transportation services operating in exclusive and/or semi-exclusive Rights-of-Way (ROW).

Implement these guiding principles through a consistent approach to manual and automated Light Rail Vehicle (LRV) operation, accessible Stations and Stops, fare collection, passenger information and security, line operations, and maintenance facilities including:

- Access for everyone including those with various levels of mobility, sight, and hearing through purposeful design of both LRVs and facilities, including level LRV floors and boarding platforms;
- High levels of safety, security, and reliability;
- Effective and efficient service with shorter travel times and close schedule adherence;
- Relatively short walking distances and convenient access for users of bus and other transport modes, bicyclists, and those arriving on foot, by automobile, or taxi;
- Flexible and convenient payment using the benefits of smartcard Proof of Payment technology;
- High levels of customer service, comfort, and convenience including waiting area seating and weather protection;
- Timely and accurate customer service information;
- Support of land use intensification and public realm/streetscape goals;
- Emergency response personnel access and passenger evacuation.

LRT operations are based on industry best practices and procedures including Automatic Train Protection (ATP) and in specific areas Automatic Train Operations (ATO) for enhanced efficiency and cost effectiveness.

A number of other important objectives underlying service/delivery/operations may not be perceived by passengers as directly affecting them but are nonetheless important, including the following:

Safety and Security

- Safe operations;
- Protection from vandalism and other external threats;
- Protection against illegal or unauthorized use of LRT assets and ROW;
- Accident and emergency response.

Cost Effective

- Capital investment;
- Operating and maintenance costs with efficient use of labour;
- Ease of facility and equipment repair and maintenance;

- Expeditious vandalism repair and prompt graffiti removal;
- LRT facilities of durable, easily maintained materials minimizing routine maintenance and operating costs as well as frequent major rehabilitation and/or repair and future capital costs.

Fare Collection

- Security with minimal fare evasion;
- Compatibility with emerging fare technology such as Smart Cards;
- Improved access to facilitate passenger boarding/alighting contributing to higher operating speeds;
- Roving fare inspectors performing random Proof of Payment checks.

Transit Operations

- Maintaining effective and reliable scheduled headways;
- Operating facilities and procedures to mitigate delay;
- Balancing short turn capability with demand allowing service recovery in case of disruption;
- Operating multiple LRVs for cost effective higher capacity when and where required;
- Access to Maintenance and Storage Facility (MSF) services;
- Accident and emergency response.

Effects on Other Agencies

- LRT service complementing other agency operations;
- Emergency service personnel/vehicle response times;
- Maintenance and repair;
- LRT service fully integrated with existing and planned regional/inter-regional transport systems.

Operations Contingency Plans

Develop Operations Contingency Plans in consultation with MX LRT to support continuity during abnormal operations taking into account a cross section of disrupted LRT service scenarios including but not limited to:

- Special events;
- Track blockage;
- Weather disruption;
- Equipment failure;
- Derailment;
- Power failure;
- Collision with motor vehicles and pedestrians;
- Terrorism and other criminal activity.

Provide redundancy for continuous revenue service operations or degraded operating modes.

Base Operations Contingency Plans scenarios on the premise of immediate, pre-programmed response to disrupted services with full field deployment capability in specified time periods.

Operations Contingency Plans may include LRT services supplemented by other services such as bus bridges operating in mixed-traffic, not the LRT ROW, due to safety and operating concerns.

A5.2 Service Criteria

Support MX LRT service levels as follows:

- Normal LRT service span is approximately 6:00 am to 2:00 am the following day;
- LRT service span may be reduced on Saturdays, Sundays, and holidays;
- LRT system is not to preclude special event 24-hour-per-day LRV operation service for short periods.

Minimum operating headways subject to detailed performance and capacity analysis.

A5.3 Safety and Security

LRT operations first priority is for the safety and well-being of passengers, personnel, and the public.

Section A5.3 provides criteria related to promoting safety through good operations practice.

Other MX LRT Design Criteria Manual chapters and the LRT System Safety and Security Program Plan provide additional safety and security criteria.

A5.3.1 LRT Transportation

Control and Supervision

Operations Control Centres (OCCs) control, coordinate, and monitor LRV, Station, and Stop operations.

OCC staff regulate and supervise LRT main line operations and associated electric, mechanical, traction power, tunnel ventilation, intrusion detection, alarm, signals, and communications systems.

OCCs are capable of direct verbal communication at any time with LRV Operators and LRT supervisors.

OCCs control, coordinate, and monitor security, passenger information, and fare collection activity.

In normal operating conditions OCCs monitor LRV operations, control LRT systems, power, passenger activity, and other facility status such as intrusion and fire alarms without direct OCC staff intervention.

OCCs respond to service failures and anomalies including automatic or manual changes in system configuration, modifications to system operating strategies, and LRT system recovery operations.

OCC staff may take manual control to override or modify automatically initiated system responses.

Provide full OCC Interlocking protection in normal operating conditions with local Interlocking control only when handed over by OCC staff for maintenance, testing and/or failure management.

Local Interlocking control allows service to continue as appropriate in failure management mode.

LRT systems include appropriate means for informing passengers of both usual and unusual conditions.

Yard Controllers in Yard Control Rooms regulate and supervise MSF LRV operations.

Yard Controllers route LRVs automatically or by line-of-sight based on procedures governing direction of travel, routing, and switch control, augmented as required by verbal communications.

Yard Control Rooms normally control yard switches with provisions for other appropriate arrangements during failure management or quiet periods including yard control panels and LRV-based switch controls.

Equip LRV systems with vital fail-safe ATP providing various levels of LRV protection depending on LRV/ROW location, i.e., yard vs. main line.

Full ATP functionality including ATO for exclusive ROW allows higher speeds while increasing safe and efficient LRV operations per industry standards and best practices.

Line-of-sight operation with some reduced ATP functionality to adhere to specific restrictions for semi-exclusive ROW continues to monitor LRV Operators.

Main line operations also involve Automatic Train Supervision (ATS) including schedule monitoring.

Employee Considerations

Implement LRT operations based on industry best practices and operating procedures.

Protect against human error to the maximum extent with intuitive and ergonomically correct design.

Assume that LRT operating personnel when confronted with potentially unsafe conditions are trained to pursue the safest course as the first priority over service reliability, passenger convenience, or cost concerns.

Personnel Considerations

The LRT System Operating Concept includes the MX LRT approach to operations and maintenance personnel development including the following considerations:

- LRT personnel are trained, certified, and regularly recertified regarding system safety, security, operating practices, and procedures directly related to their work;
- LRT personnel are subject to drug and alcohol testing programs per Authorities Having Jurisdiction (AHJ) requirements.

A5.3.2 Light Rail Vehicles

Maximum length LRVs in revenue service at rest during normal operating conditions on semi-exclusive ROW must not interfere with cross street motor vehicle traffic.

LRVs include normal service operation braking capability with passenger safety and comfort in mind.

LRVs include maximum emergency/security braking capability for emergency conditions response.

CCTV video is not displayed on board LRVs but is retrievable per MX LRT safety and security criteria.

See Chapter A2 – Light Rail Vehicles.

LRV Movement/Speeds

Tangent Track Maximum Operating Speeds

- 80 km/h on exclusive ROW;
- 70 km/h on semi-exclusive and non-exclusive ROW;
- LRV speeds are not to exceed posted speed limits.

Special Track Work

Sustain as high as possible speeds through special track work while maintaining safe operations.

Provide special track work subject to analysis to achieve performance targets as follows:

- Terminus Station Crossovers consistent with AREMA #8 switches;
- Failure Management/Intermediate special track work consistent with AREMA #6 switches.

Review any differences in special track work with MX LRT prior to implementation.

Other Locations

- Yard Track: 10 km/h except for test tracks;
- Yard ATO Test Track: 30 km/h minimum planned sustainable speed or greater if space available;

- Station Pass Through: 50 km/h maximum through full length of Station platforms under any condition;
- Stop Pass Through Semi-Exclusive ROW: 50 km/h maximum but may require further reduction based on ROW operation restrictions;
- Coupling Speed: 5 km/h or as limited by LRV design considerations.

Listed speeds subject to confirmation of design constraints and performance analysis.

Minimize underground special track work space requirements especially where performance requirements are not severe.

Submit proposed track work that may affect achievable performance for MX LRT review and acceptance.

ATP restrictions displayed to LRV Operators in operating schedules, rules, posted signs, and signal indications govern LRV movements in exclusive ROW.

ATO controls LRV movement, acceleration, coasting, and braking although manual operation may be available under ATP protection.

Schedules, rules, posted signs, and intersection signals supplemented by other fixed signal indications required in response to special circumstances, such as switches and ATP system restrictions, govern LRV movements in semi-exclusive or non-exclusive ROW.

ATO does not apply on semi-exclusive ROW.

Provide perimeter fencing of at-grade non-public area track wherever trespassing is a concern.

Provide OCC supervised intrusion detection at unprotected, semi-exclusive, or non-exclusive ROW transition points with protected exclusive ROW such as tunnel portals.

A5.3.3 Stations and Stops

Stations are exclusive ROW designated passenger boarding/alighting areas.

Stops are semi-exclusive ROW designated passenger boarding/alighting areas.

Provide Stations and Stops giving LRV Operators unobstructed views of guideways and adjacent platforms and walkways.

Provide Stations and Stops with sufficient area to accommodate peak hour demand and emergency egress capacity for the ultimate design year.

Consider specific peak demand data and minimum allowable space allocation per passenger in sizing Stations and Stops.

Provide Stations and Stops that fully comply with MX LRT and AHJ accessibility policies and regulations, whichever deliver the greatest degree of access.

Provide Stations, Stops, and Park-N-Ride lots for optimum CCTV surveillance.

Provide Stations and Stops with Passenger Assistance Intercoms (PAIs) for direct passenger to OCC communications.

Provide local control of communications, security, ventilation, and other systems as appropriate.

Protect for potential future Station Platform Edge Door (PED) implementation.

A5.3.4 Road Intersections

Traffic Signal/LRT System interfaces depend on a number of factors including available technology and LRT system design.

Provide road/walkway/guideway intersections with traffic signals governing LRV and other motor vehicle and pedestrian movement.

While LRT systems may request traffic priority at road intersections, safe operation through intersections remains with LRV Operators.

A5.4 Reliability

A5.4.1 General

Reliable LRT service is high priority.

Provide reliable LRT operations sustained through industry best practices.

A5.4.2 Operating Considerations

Intermodal Connections

Account and protect for intermodal connections, such as rail to bus transfers, to the maximum extent possible in case of abnormal operating conditions per Operations Contingency Plans.

Light Rail Vehicles

Provide Station and Stop platforms level with LRV floors to facilitate passenger boarding and alighting.

Provide LRV interiors that promote good passenger circulation and foster balanced passenger loading.

Fare Collection

Base fare collection on Proof-of-Payment (POP) systems to expedite passenger boarding and alighting.

LRV Operators are not involved in fare sales, distribution, checking, or collection.

No LRV on-board fare collection equipment allowed.

See *POP Concept of Operations*.

Station and Stop Ticket Vending Machines in designated unpaid areas are primary LRT fare collection means.

Roving LRT inspectors perform random fare checks on-board LRVs and in designated paid areas to verify passenger Proof of Payment.

Main Line Tracks

Provide one track minimum per direction of travel LRT main line tracks.

No permanent bi-directional single main line track sections allowed.

LRVs are capable, however, of running in either direction on any main line track.

Provide main line tracks for normal LRV speeds to the maximum extent possible.

Normal direction of LRV traffic is on the “Right-Hand Running” convention.

Systems

Provide signals, communications, and traction power systems with sufficient redundancy and reserve capacity for abnormal operating conditions per Operations Contingency Plans.

A5.4.3 Preventive Maintenance Measures

Light Rail Vehicle Maintenance

LRV manufacturers develop LRV Maintenance Plans based on programs of predictive, preventive, and corrective maintenance to satisfy manufacturer warranty requirements.

Based primarily on LRV mileage or age, LRV Maintenance Plans provide for scheduled light and heavy maintenance as well as component and total LRV overhaul.

Facilities and System Maintenance

Systems Integrators produce LRT Maintenance of Way Plans comprising coordinated sub-system plans prepared by contractors responsible for delivering various systems and maintenance of way components in formats for MX LRT review and acceptance.

Base sub-system Maintenance of Way Plans on programs of periodic preventive maintenance that proactively address systems and fixed facility requirements.

Sub-system Maintenance of Way Plans provide scheduled service and inspection intervals for LRT elements such as signals, communications, fare collection, track work, power substations, overhead contact systems, fixed facilities, and structures such as Stations, Stops, tunnels, portals, and viaducts.

Maintenance of Way Plans also include special service and inspection requirements for extreme weather such as ice and/or heavy snow storms.

A5.4.4 Preparatory Measures

Light Rail Vehicles

LRV fleet requirements over time include minimum spare factors 15 percent above peak scheduled LRV service requirements and any LRV held in ready reserve for maintenance spares.

LRV are to be equipped with high visibility variable signs at front, rear, sides, and interior clearly indicating MX LRT specified information including but not limited to route, destination, and service patterns.

Information may be presented by a combination of text and colour-coding.

Communicate messages to passengers visually via these signs, as well as audibly via automated or operator generated on-board announcements.

Stations and Stops

Provide Stations and Stops with Passenger Visual Information Systems to provide service and emergency information to passengers formatted per MX LRT policy.

Communicate messages to passengers visually via these signs as well as audibly via automated or operator generated on-board announcements.

Provide Stations and Stops with Passenger Assistance Intercoms, CCTV, Public Address, and public telephones.

Provide Terminal Stations with double crossovers, normally before each centre platform.

Alternative Terminal Station configurations may be considered subject to MX LRT review and acceptance.

Provide Terminal Stations with two tail tracks, both long enough to hold one maximum-length LRV, while allowing arriving LRV safe braking distance.

Tail track occupancy must not interfere with normal Terminal Station operations.

Where vertical grade or other constraints limit tail track feasibility, MX LRT may waive tail track requirements subject to review and acceptance.

Main Line Storage Tracks

Mid-route storage tracks comprise a centre track long enough to hold one maximum-length LRV consist accessible in both directions from both main line tracks.

Provide mid-route main line storage tracks based on failure management and operations analyses.

Where vertical grade or other constraints limit access from both main line tracks in both directions, submit proposed waiver of LRV main line mid-route storage tail tracks subject to MX LRT review and acceptance.

Crossovers

Provide double crossover turnouts sized to support maximum operating speeds.

Provide intermediate crossovers based on performance and failure management analyses to support maximum operating speeds.

Yards and Auxiliary Tracks

LRV yard movements must not conflict with LRV normal condition revenue or storage track movements.

Configure LRT yard access so that LRVs pulling into and out of revenue service have at least two movement paths to and from the yard.

Provide yard entrance buffer areas to main line tracks where maximum length LRVs may dwell and LRVs may be added or cut without interfering with main line operations.

Provide LRV daily yard storage located to minimize revenue service LRV deadhead time.

Provide the least number of yard sites to minimize operating costs when more than one yard is required.

Determine the best number of yard sites with an LRT movement operations analysis balancing desire to minimize deadhead mileage against cost to build, operate, and maintain additional support facilities.

Distribute yard storage tracks to store normally scheduled revenue service LRVs without uncoupling.

Several shorter yard storage tracks are preferred over fewer very long yard storage tracks.

Provide individual storage track capacity in multiples of maximum length LRVs.

Accommodate LRV fleets based on ultimate design year total LRT system yard storage capacity estimates.

Avoid curved storage tracks.

Provide storage tracks accessible from either end to the maximum extent possible.

Provide LRV Operator reporting facilities as close as possible to storage yards.

Provide walkways between storage tracks to facilitate personnel access and material movement.

Maintenance Tracks

Provide MSF diagnostic and maintenance shop facilities for safe and reliable LRV service.

Locate MSF shop facilities for easy access to yard storage and main line connections wherever possible.

Provide MSF direct access from storage yards without crossing main line tracks.

Traction Power

Provide traction power systems with sufficient capacity, redundancy, and reliability to support peak period operations under normal, contingency, and emergency conditions.

A5.5 Passenger Convenience

A5.5.1 Operations Planning

Operating Speeds

LRVs normally stop at every Station.

At Stops LRVs normally stop based on LRV on-board passenger demand or LRV Operators observing passengers waiting at Stops.

Levels of Service

Provide LRT service sufficient to meet passenger demand with appropriate LRV headways and lengths.

Provide LRT service capacity to accommodate peak demand consistent with LRV loading standards.

Light Rail Vehicles

Provide LRV performance optimized to combine acceleration, deceleration, and maximum operating speeds sufficient for high degrees of passenger comfort and fastest possible travel times.

A5.5.2 Passenger Facilities

Stations and Stops include passenger information and security systems.

Stations include additional systems including various alarm and ventilation systems, normally monitored and controlled from OCC but also locally.

Stations and Stops are generally unattended but served by roving attendants.

Provide each Station with a Service Room for use by Station LRT staff.

Provide Stop seating and waiting areas with canopies for weather protection and shading.

Provide Stops with controlled walkways at platform ends to adjacent intersection crosswalks across tracks.

Provide pedestrian crossing traffic control signals.

Coordinate pedestrian crossing traffic control signals with roadway traffic signals and LRV operating rules.

Consider additional pedestrian crossing traffic control measures for unique or other circumstances.

Provide Stations and Stops per MX LRT and AHJ accessibility regulations.

Retain current side or centre platform configuration for existing Stations to remain for LRT service.

A5.6 Cost-Effectiveness

Base design decisions on life-cycle cost analyses, including proper balance of operating and capital costs and good operating practices and procedures.

A5.6.1 Planning Considerations

Service Effectiveness

Adjust LRV lengths as needed to minimize operating expense consistent with LRV loading standards and passenger demand.

Optimize location and number of LRV storage areas and LRV Operator reporting locations to minimize operating expenses within reasonable capital cost parameters.

Provide operating requirements, including service planning, equipment, and facilities, to accommodate maximum passenger trip volumes.

Capital Expense

Provide LRT service to minimize current and future capital costs where appropriate.

Operating Expense

Provide LRT service to minimize operating costs while maximizing service effectiveness.

A5.6.2 Maintenance Considerations

Maintenance Effectiveness

Provide LRT facilities to minimize routine maintenance requirements.

Provide LRT facilities constructed of durable, easily maintained materials.

Pay particular consideration to prevention of vandalism and easy rapid repair of vandalism that may occur.

Operating Expense

Provide LRT maintenance plans and facilities to minimize operating costs within reasonable capital cost parameters.

Capital Expense

Provide LRT maintenance plans and facilities to minimize future capital costs and frequency of major rehabilitation and/or repair.

A5.7 Operations Control Centres

A5.7.1 Introduction

This Section addresses LRT Operations Control Centres (OCCs) and Backup Operations Control Centres (BOCCs) focusing on OCC/BOCC functions and hardware.

Specific subsystems, mainly Train Control, Signals, and Communications Systems significantly affect OCC/BOCC development and available functions.

OCCs are generally located in the main MSF.

BOCCs are located in secondary MSFs or other suitable sites.

Both OCCs and BOCCs function as fully-centralized control facilities.

Normal OCC and BOCC functions do not include yard control, which is located in separate rooms in the main MSF and is not considered part of OCC or BOCC configuration.

OCC and BOCC systems include:

- LRV location displays on both large mimic screens and console monitors;
- ATS systems;
- Traction Power Systems control;
- Integrated Communications and Control systems including radio, telephone, CCTV, Public Address, Variable Message Signs, and Passenger Assistance Intercoms;
- Tunnel Ventilation Systems;
- Safety and Security Systems including Fire and Intrusion Detection and Alarm;
- Fare Collection Systems;

- Systems Control and Data Acquisition (SCADA);
- Wide Area Networks.

References to OCCs apply equally to BOCCs unless otherwise noted.

A5.7.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT DCM.

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

OCC specific references include but are not limited to:

- Ontario Building Code (OBC);
- Nation Fire Protection Association (NFPA) 101: Life Safety Code;
- NFPA 130: Standard for Fixed Guideway Transportation Systems;
- IEEE 1474.2 – User Interface Requirements in Communication Based Train Control (CBTC) Systems.

OBC governs where conflicts arise unless otherwise stated.

A5.7.3 Design Standards and Systems Integration

OCCs need to operate LRT systems successfully as standalone facilities given their mission-critical nature.

OCCs and BOCCs may appear to be identical from facilities and systems perspectives.

Consider potential BOCC design efficiencies accordingly.

OCC functions include:

- Public Information;
- Escalator/Elevator Monitoring;
- Fare Collection System Monitoring;
- CCTV/PAI Monitoring and Response.

Allocate these functions to OCC consoles to facilitate effective monitoring and response.

Use existing OCC consoles as a guide for new OCC consoles, systems, and related functions.

Console efficiencies may be proposed subject to the following requirements:

- Power control functions fully separate from other functions;
- Yard control consoles in separate MSF rooms at each yard;
- Expected workload/responsibility levels appropriate for each position;
- Console position functions/duties to support safe normal and emergency operations.

This requires workload projections including expected frequency of CCTV and PAI incidents together with consideration of related human factors such as analysis of how much CCTV monitoring each console can effectively conduct.

Address and document considerations such as these during preliminary design for MX LRT review and acceptance before proceeding with design.

See Chapter A4 – Security.

A5.7.4 Configuration

OCCs include main control room theatres, equipment rooms, and ancillary rooms including restrooms, offices, kitchens, locker facilities, training facilities, command centres, conference rooms, and related systems support rooms as well as parking for personal and service motor vehicles.

Establish BOCC efficiencies wherever appropriate based on BOCCs not normally being in operation subject to MX LRT review and acceptance.

OCC and BOCC functional requirements do not differ regardless of final locations.

OCCs function 24/7/365.

BOCCs must also be capable of functioning 24/7/365 whenever necessary.

Provide OCC functions and networks to achieve high availability and reliability.

Provide OCC facilities to meet applicable MX LRT and AHJ accessibility and other requirements.

Make certain that the introduction of LRT OCC functions to existing transit system facilities and operations, such as annunciation of tunnel ventilation status at interchange stations, does not adversely effect in any way existing transit system levels of safety, security, accessibility, reliability, availability, or redundancy.

OCC equipment includes:

- Control consoles with console-based colour-graph terminals;
- Keyboard and mouse input devices;
- Printers;
- CCTV system monitors;
- Voice radio equipment;
- Telephones;
- SCADA servers/consoles;
- PA audio communications equipment;
- Variable message systems;
- Passenger Assistance Intercoms;
- Overview display boards/mimic screens.

OCC equipment rooms include:

- Data communications equipment;
- System servers and database management systems;
- Audio playback systems to store and access pre-recorded PA messages;
- System manager console equipment;
- Digital access and cross connect systems;
- Channel banks;
- Interconnect equipment.

Make certain that any new OCC systems or equipment installed for LRT in future is compatible with systems or equipment in use at that time, especially at Interchange Stations.

Provide OCCs with secure access facilities and systems.

See Chapter A4 – Security.

A5.7.5 Scope

OCCs do not control yard operations.

A yard control room at each particular MSF controls each respective yard integrating as appropriate equipment rooms and other support room functions.

Also carefully consider cyber-security issues.

See Chapter A4 – Security.

A5.7.6 LRT Functionality

LRT subsystems to be monitored and controlled are similar to existing rail transit systems including:

- Signaling and train control;
- SCADA:
  - Traction power;
  - Tunnel ventilation;
  - Alarm handling;
  - Security including intrusion detection and access control.
- Fire Alarm Monitoring;
- Communications subsystems:
  - PA;
  - Radio;
  - Telephone;
  - Passenger Assistance Intercoms;
  - CCTV.
- Passenger Visual Information Systems;
- Fare Collection Systems (monitoring only);
- Electric power systems;
- Mechanical systems;
- Delay Log Reporting.

Any one of several OCC positions may control and monitor multiple LRT subsystems.

Accommodate various staffing levels according operating modes.

Provide the required flexibility incorporating user control authority, log-on, passwords, and manual management of work assignments to consoles.

OCCs have access to fare collection system monitoring screens if there is a need to see status.

OCCs are not responsible for monitoring or providing notification of fare collection system faults/incidents.

A5.7.7 Signals and Train Control

LRT systems include dedicated program-wide signal systems including ATS used to monitor and control LRV movements according to running requirements of specific line sections.

As the primary interface between OCCs and LRVs, ATS monitors and displays every LRT section providing LRT Controllers identification, location, and status of each LRV on desktop monitors and overview display systems (mimic boards) per industry standards.

Train control varies based on LRVs running in either semi-exclusive or exclusive ROW.

Implement full ATP and ATO in exclusive ROW providing LRT Controllers flexibility to control and modify operations as required.

This includes ability to regulate LRV speed, adjust Station dwell times, skip Stations, adjust stopping positions, override ATS commands, and modify speed profiles to accommodate workers at track level as well as other operating issues.

LRT Controllers are also able to modify LRV routing information and re-route LRVs around problem areas.

Signal system design governs full development of ATS functionality and determines additional ATS control functions available to LRT Controllers for semi-exclusive ROW.

A5.7.8 Alarm Handling

OCCs display subsystem alarms to the appropriate LRT Controller based on area of responsibility.

Alarms areas include:

- Train Operations;
- Signal Systems;
- Stations;
- LRVs;
- Traction power through SCADA;
- Tunnel Ventilation Systems through SCADA;
- Security and Intrusion linked to CCTV;
- Passenger Assistance Intercoms.

Alarms are handled as follows — See Table A5-1:

- LRV Operations by LRT Controllers and Dispatchers;
- Signals by LRT Controllers;
- Stations and Stops by Dispatchers;
- LRVs by Equipment Control Desk and LRT Controllers;
- Traction Power and Tunnel Ventilation by Power Controllers;
- Security and Intrusion by Dispatchers and Power Controllers.

TABLE A5-1 ALARM HANDLING

Alarm Type	Rail Controller	Dispatcher	IMC	Assistant Supt	Power Control	ECD
Train Operations Alarms	X	X		X		X
Signal Alarms	X			X		
Station Alarms	X	X				
LRV Alarms	X			X		X
Traction Power Alarms	X view only				X	
Tunnel Ventilation Alarms	X view only				X	
Automatic fire detection, alarm, and supervision.		X			X	
Intrusion detection, alarm, and supervision at substations and signal rooms		X			X	
Fire Alarm Control Panel indications (Fire alarm, Collector booth/burglar, Hold-up alarm (911), Exits)		X	X			

Provide an OCC Study including development of an Alarm Strategy to address operations as well as human/machine interface issues consistent with the Concept of Operations.

A5.7.9 Timetable Generation and Processing

LRT operating personnel generate timetables for various scenarios including weekday, weekend/holiday, and special event schedules compatible with ATS using standalone Timetable Generation Systems allowing off-line creation of schedules as well as assessment of resulting schedules.

Timetable Generation Systems allow operators to adjust critical performance elements including but not limited to:

- Station dwell;
- Turnback locations;
- Service level increases and decreases; and
- Run times between Stations and Stops.

A5.7.10 Communications Systems

LRT operating personnel use Communications Systems as follows:

- Telephones;
- Blue Light Station Emergency Telephones;
- Station, Stop and LRV Passenger Assistance Intercoms;

- Public Address broadcasts to Stations/Stops/LRVs with pre-recorded and live audio as well as emergency announcements;
- Public Address to one or more LRV;
- CCTV Surveillance:
    - Stations, Stops, Facilities;
    - Fare collection equipment;
    - Onboard LRVs only when triggered by an alarm;
    - Wayside infrastructure subject to MX LRT review and acceptance.
- Radio communications with:
    - Operators;
    - Transit enforcement personnel;
    - Rail supervisors;
    - Wayside maintenance personnel;
    - LRV car houses;
    - Appropriate fire and emergency response radio channels.

See Chapter C2 – Communications and Control.

Additional communications at Interchange Stations or between new and existing transit systems may be routed back to existing OCCs for required joint emergency response.

Review in detail to verify that new LRT systems can be integrated with existing transit operations.

Develop Emergency Response Plans with existing transit operations and AHJ emergency services to demonstrate integration of joint systems and communications in case of emergency.

Model LRT communications on existing communications subject to detailed functional analysis.

Table A5-2 defines various forms of audio communications.

Some OCC positions noted in Table A5-2 may be combined for efficiency where practical.

Final OCC personnel, consoles, positions, and responsibilities subject to MX LRT review and acceptance.

TABLE A5-2 AUDIO COMMUNICATIONS

Audio System	**Rail Controller**	**Wayside Controller**	**Dispatch**	**Industrial Maint. Control**	**Media**	**Asst. Supt.**	**CIS Supervisor****	**Equipment Control Desk**	**Radio Booth**	**Surface Collector**	**Power Control**
Initiate Calls to 911			X	X		X					
Telephones at Blue Light Stations	X	X	X	X		X		X	X		X
Telephone Communications with LRV Car Houses		X	X	X		X		X			X
Passenger Assistance Intercoms										X*	
Public Address Systems			X	X	X						
Response to Handheld Radios									X		
Radio Communication with LRV Operators	X	X	X	X		X	X				
Radio Communication with Supervisors & Maintainers		X	X	X		X				X	X
Radio Communication with Fire and Emergency Responders			X	X		X					

* NOTE – LRT Stations do not include attendant booths; included for information only.

** NOTE – CIS functions are not involved in LRT operations; included for information only.

A5.7.11 SCADA

SCADA monitors and controls:

- LRT Facilities;
- Traction Power;
- Uninterruptable Power Supply;
- Signals;
- Mechanical Equipment;
- Tunnel Ventilation;
- Building Access;

- Intrusion Control;
- Fare Collection and Ticket Vending Machines;
- Escalators and Elevators;
- Electronic Equipment Systemwide.

SCADA displays status, stores and retrieves event information, processes alarms, and generates incident reports at OCCs.

See Chapter C2 – Communications and Control.

SCADA transmits alarms, indications, and status from remote sites through the fibre optic backbone to appropriate OCC personnel for response.

OCCs monitor and control traction power system functions including:

- Essential AC and DC switchgear functions;
- Overhead Contact Systems;
- Traction power equipment and emergency trip switches;
- Removal and restoration of traction power.

OCCs monitor and control tunnel ventilation system functions including:

- Fan and damper operating modes;
- Ventilation mode activation;
- Drainage sumps.

OCCs monitor and control SCADA functions including:

- Elevators and Escalators;
- Major HVAC Alarms at Signals and Communications Rooms;
- Tunnel Ventilation;
- Parking Access Gate Control;
- Fire and Intrusion Detection Alarm Secondary Monitoring.

LRT System Operators configure SCADA to determine and modify as needed which alarms and/or indications to route to appropriate operating positions.

A5.7.12 System Operating Displays

OCC System Operating Displays provide graphic visual depictions of real-time LRT system conditions including LRV locations, switch status, schedule adherence, SCADA information, CCTV of passengers boarding/alighting, and LRV dispatch.

OCC staff select CCTV images “on-demand” based on real-time conditions.

OCC allocates the number of screens to display subsystem information, e.g., CCTV, SCADA, track displays, subject to human-machine interaction and ergonomic assessment.

A5.7.13 Incident Management

LRV Operators, field supervisors, and others report incidents to OCC Incident Management, which then records and time-stamps them and makes appropriate notifications per preset system parameters.

OCC Incident Management includes Delay Log Reporting for significant operating incidents.

A5.7.14 Emergency Response

As part of Emergency Response Plans, evaluate each OCC system to determine its function during emergencies vis-à-vis various OCC console position roles and functions.

Provide a report of proposed LRT systems and operating procedures to verify NFPA 72 compliance including:

- Public Address System Displays;
- Radio communications with LRT Operators and field personnel;
- Radio communications with other LRT system personnel and OCC staff;
- 911 access;
- Passenger Assistance Intercoms;
- Passenger Visual Information Systems;
- Emergency Telephones;
- Fire detection, sprinkler valve, and water flow annunciator displays;
- Standby power status indicators;
- Tunnel ventilation control and monitoring;
- Ventilation equipment status indicators;
- Fire Department radio channel monitoring;
- Fire, security, and supervisory alarms;
- Alarm receipt, logging, annunciation, and printout;
- LRV and Station Evacuation;
- CCTV.

A5.7.15 Facilities and Functions

Workstations

Every OCC includes workstations and each OCC workstation has access to every function needed to operate an LRT system including but not limited to:

- Signal Systems Control and Indications;
- Integrated Communication and Control Systems;
- ATO/ATP on Exclusive ROW;
- LRV Tracking;
- Signal System and ATS Alarm Management;
- Timetable Processing;
- Schedule Adherence Monitoring;
- Log On/Log Off Functions;
- Reporting Functions;
- Graph Display Management;
- System Holds;
- Work Zone Setup.

Operating Positions

Base OCC operating positions, insofar as practical, on existing transit system operating positions.

Propose efficiencies for new OCC operating positions required for monitoring functions that existing operating positions may not include, e.g., CCTV/PAI, escalator/elevator, fare collection equipment, and public information monitoring.

Hardware Systems

Provide each operating position with a console workstation including desktop monitor, keyboard, pointing device, telephone, and appropriate power and switches connecting each system operated at that position.

Legacy Systems

Provide support systems with functions similar to existing legacy systems as well as additional support system applications for other LRT operations as needed.

A5.7.16 Shared Area Emergencies

Shared Area Emergencies (SAEs) are Interchange Station emergencies, including ventilation zones adjacent to Interchange Stations, affecting LRT and other transit agencies.

Key SAE services are handled as follows:

- The designated operating position monitors and takes over command, control, and operation responsibility for every transit mode in the SAE including coordination and communications with emergency response agencies;
- LRT OCC monitors and operates SAE LRT subsystems, including traction power and tunnel ventilation, under the ultimate monitoring, responsibility, and direction of the designated operating position;
- LRT OCC makes PA announcements to SAE LRV passengers under the ultimate direction, monitoring and responsibility of the designated operating position;
- The designated operating position makes PA announcements to SAE Station passengers.

Provide Emergency Response Plans for integrating SAE systems and communications including operating positions with AHJ input for MX LRT review and acceptance.

Emergency Response Plans determine emergency response coordination based on SAE location as well as the locations of LRT, AHJ, and other SAE agency operating and support personnel.

For example, during a tunnel fire SAE, provide close coordination of tunnel ventilation systems with:

- Incident LRV locations;
- Other nearby LRV locations;
- Passenger Evacuation Routes;
- Firefighter/Rescue Access Routes;
- Other SAE Agencies.

Emergency Response Plans document the benefits of the above capabilities.

A6 Sustainability

A6.1 General

Chapter A6 addresses Metrolinx (MX) Light Rail Transit (LRT) sustainability issues.

Comply with by-laws, regulations, specifications, and standards of Authorities Having Jurisdiction (AHJ).

A6.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT DCM.

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Sustainability specific references include but are not limited to:

- Urban Forestry Standards – AHJ;
- Trees By-laws – AHJ;
- Ravine and Natural Features Protection By-law – AHJ:
- Green Development Standards – AHJ;
- Green Roof Standards – AHJ;
- Green Parking Lot Standards – AHJ;
- Wet Weather Flow (WWF) Management Guidelines – AHJ;
- Water Supply By-laws – AHJ;
- Bird Protection By-laws – AHJ;
- Ontario Building Code (OBC);
- Province of Ontario Ministry of Energy (MOE), Green Energy Act;
- MOE, Management of Excess Soil: A Guide for Best Management Practices;
- Province of Ontario Ministry of Municipal Affairs and Housing, Places to Grow Act;
- Leadership in Energy and Environmental Design (LEED);
- Canadian Green Building Council (CAGBC);
- Model National Energy Code for Buildings (MNECB);
- American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE);
- Building Owners and Managers Association (BOMA) of Canada BEST (Building Environmental Standards) Program Energy and Environment Report: National Green Building Report;
- American Public Transportation Association (APTA) Transit Sustainability Guidelines;
- International Association of Public Transport (UITP) Sustainable Development Charter;
- Metrolinx: *The Big Move* Regional Transportation Plan.

OBC governs where conflicts arise unless otherwise stated.

A6.3 Sustainable Development

Provide safe, reliable, accessible, comfortable, and seamlessly integrated rapid transit to significantly reduce carbon footprint, conserve resources, and contribute to a healthy and clean urban environment.

Design, construct, operate, and maintain rapid transit infrastructure per sustainable development principles.

At the heart of one MX key value, “Thinking Forward,” *The Big Move* identifies three key interconnected mission and vision objectives: A *thriving, protected, sustainable* environment.

The Big Move further elaborates:

> *“Our transportation system will have a low carbon footprint, conserve resources, and contribute to a healthy and clean environment for future generations.”*

The MX commitment to sustainable development aligns with those of the American Public Transportation Association (APTA) and the International Association of Public Transport (UITP).

As an APTA and UITP Charter signatory, MX is committed to the three principles of sustainable development, *social*, *economic*, and *environmental*, embedded in its activities and transit infrastructure development.

Provide sustainable transit infrastructure and facilities in the context of the principles that follow.

A6.4 Sustainability Goals

A6.4.1 General

Fully comply with environmental laws and regulations of AHJ.

Meet or exceed minimum sustainability compliance by continuous improvement of environmental performance through cost-effective innovation and self-assessment.

Develop and encourage neighbourhood integration and connectivity in providing green amenities, reducing heat island effects, and increasing soft landscaping as key drivers.

Manage and account for environmental risk and continuously improve the ability to do so.

Restore the environment with mitigation, corrective action, and monitoring for implementation of environmental commitments.

Avoid environmental degradation by minimizing or eliminating harmful releases to air, water, and land.

Prevent pollution and conserve resources by reducing waste, recycling and reusing materials, and preferential purchasing of materials with recycled content.

Design, construct, and maintain infrastructure considering resistance and resilience to extreme weather and other climate change effects such as flooding, drought, extreme temperatures, freeze/thaw cycles, etc.

A6.4.2 Energy and Water

Consider wayside energy storage to capture regenerative braking and energy storage for use during peak power periods for lower overall energy use.

Participate in BOMA BEST (Building Environmental Standards) Program practices:

- Perform transit infrastructure energy and water audits at regular intervals;
- Use these audits to drive energy savings and meet sustainable energy requirements.

Optimise train capacity using Communication Based Train Control to reduce headways as well as power consumption for energy savings.

Demonstrate compliance with energy saving and energy cost sharing targets.

Control efficient use of transit facility heating, cooling, lighting, hot water, electricity, and traction power.

Include electric, natural gas, and cold water consumption metering.

Use industry best practices for Heating, Ventilating, Air Conditioning energy conservation heat recovery and cooling systems.

Maximize water efficiency transit facility design, construction, and maintenance to reduce the burden on municipal water supply and wastewater systems.

A6.4.3 Materials Use and Waste

Implement energy conservation waste management and recycling procedures.

Eliminate non-compostable and non-recyclable items such as plastic bags.

Explore opportunities to use excavated material on-site rather than hauling away.

Divert construction and regular operations waste from landfill back to sites for reuse wherever possible.

Use durable, vandal proof, and easy to maintain local materials with high recycled content.

Use Forest Stewardship Council certified wood from sustainably managed forests.

Reduce excess packaging of incoming commodities.

A6.4.4 Stations, Stops, and Facilities

Use low-emitting paints, sealants, adhesives, carpets, composite wood, and other sustainable products.

Include bike racks and/or lockers in Station design.

Use non-polluting and renewable energy, such as solar photovoltaic, wind, geothermal, low-impact hydroelectric, biomass, and bio-gas strategies.

Take advantage of net metering with local utilities.

Use low emissivity (low-E) glass to allow light to enter while providing thermal insulation.

Incorporate natural daylight to reduce heating loads in winter and lighting needs year-round.

Incorporate natural ventilation to conserve energy wherever possible.

Comply with AHJ green standards and “green roof” by-laws.

Provide "green roofs" with automatic irrigation for drainage and temperature control.

Provide total “green roof” area 50% minimum of ground floor building area with highly reflective “cool roof” materials for the balance of roofing.

Avoid non-renewable or long-renewable materials; instead use more rapidly renewable materials.

Integrate recycled materials in design.

Provide building areas to collect and store recyclables.

Reuse existing buildings or existing building elements with updates of outdated components.

Recycle/reuse/repurpose building materials when buildings must be demolished or significantly altered.

Incorporate salvaged materials in building design.

A6.4.5 Certifications and Compliance

Use green building practices and technologies to achieve minimum LEED Silver Certification per CAGBC.

Provide mechanical and electric systems per provincial and national energy conservation standards and guidelines including OBC, MNECB, and ASHRAE.

Establish expectations for excess soil management and promote beneficial reuse of excavated soil per MOE Management of Excess Soil: A Guide for Best Management Practices.

A6.4.6 Innovation

Consider industry best practices, new technologies, and innovative initiatives wherever possible.

Use metrics for evaluating achievement of sustainability requirements, goals, and objectives in design, construction, and maintenance.

Employ sustainability strategies including the framework for development and implementation of required environmental performance measures related to design, construction, and maintenance.

Develop strategies to incorporate and account for lifecycle cost requirements in design and procurement of construction materials and equipment.

Obtain local regulation information and seek local construction firm and organization insights to identify and clarify opportunities for appropriate and innovative construction practices.

A7 Resilience

A7.1 General

Chapter A7 addresses the importance of resilience in the Metrolinx (MX) Light Rail Transit (LRT) program.

With extreme weather change, planning for resiliency of infrastructure is imperative in mitigating the effects of the elements due to climate change.

Planning for resiliency is also critical to reducing the effects on infrastructure from other natural hazards such as earthquake, fire, etc., as well as other human induced hazards such as terrorism or cyber-attacks.

A7.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Resilience specific references include but are not limited to:

- Ontario Building Code (OBC);
- National Institute of Standards and Technology (NIST) Special Publication 800–30, Guide for Conducting Risk Assessments;
- Trees By-laws – AHJ;
- Ravine and Natural Features Protection By-law – AHJ:
- American Public Transportation Association (APTA): Cybersecurity Considerations for Public Transit;
- APTA: Securing Control and Communications Systems in Rail Transit Environments;
- EN 12663 Standard: Resilience Design of Vehicle Structural Integrity;
- Metrolinx: *The Big Move*, Regional Transportation Plan.

OBC governs where conflicts arise unless otherwise stated.

A7.3 Development Approach

Resilience is the ability to quickly adapt to and recover from known and/or unknown environment changes.

The Resilience Development Approach includes:

- Protective measures supported by robust and fault-tolerant design and construction that reduce structural vulnerabilities and exposure to high level failures;
- Prevention and detection capabilities supported by adaptive threat assessment, real-time decision making, and safeguards of redundant assets to avoid single point failure risks; and
- Response and Recovery operations supported by countermeasures designed to reduce the consequences of adverse events and rapidly restore acceptable operations.

Resiliency development is at the heart of one MX key value, "Thinking Forward," and is central to all three interconnected vision objectives identified by *The Big Move:* A thriving, protected, and sustainable environment.

The MX proactive commitment to resilience development of infrastructure aligns with those of APTA.

As a signatory of APTA, MX is committed to make sure that the three principles of resiliency development, *social*, *economic*, and *environmental*, are embedded in its activities and transit infrastructure development.

Consider resiliency related design approaches in the context of the goals that follow.

A7.4 Goals

The MX LRT program and LRT projects include the following Resilience Goals:

- Full compliance with environmental laws and regulations;
- Strive to exceed compliance by continuous improvement of environmental performance through cost-effective innovation and self-assessment;
- Develop to encourage neighborhood integration and connectivity and provide a safe and seamless travel experience for its patrons;
- Manage and account for environmental risk and continuously improve the ability to do so;
- Restore the environment by providing mitigation and corrective action and monitor to verify that resiliency infrastructure design reduces harsh weather environmental effects;
- Avoid environmental degradation by minimizing harmful releases to air, water, and land;
- Prevent pollution and conserve resources by reducing waste, recycling and reusing materials, and preferential purchase of materials with recycled content.

Design, construct, and maintain infrastructure considering resistance and resilience to extreme weather and other anticipated effects of climate change such as increased flooding/drought, temperature extremes, freeze/thaw cycles on track work, buildings, facilities, etc.

A7.4.1 Climate Change

Develop and deliver resiliency in infrastructure Identifying:

- Waterway flood zones;
- Potential storm water overland flooding areas;
- Potential heavy snow and snow drifting areas;
- Potential high wind areas.

Provide infrastructure to withstand high winds and/or freezing rain due to climate change on:

- Overhead Catenary Systems;
- Station and Stop elements such as canopies, shelters, garbage bins, roofs, and signage;
- Trees at Stops and along guideways.

Locate and/or prune trees to avoid falling trees or branches damaging Stops, catenary, track, etc.

Provide infrastructure resilient to climate change that is able to withstand heavy snow loads on roofs.

Rail expands as it warms up.

Absorbing the heat of bright summer sun it can reach temperatures far in excess of air temperature.

Without the correct precautions, track work will buckle as it expands with heat.

Consider Critical Rail Temperature (CRT) for recommended speed restrictions to reduce buckling forces and prevent potential derailment in resilient track work design

Establish track work and guideway maintenance programs to make sure vegetation clearance reduces the risk of fire in extreme dry weather.

A7.4.2 Light Rail Vehicles

Increase Light Rail Vehicle (LRV) resilience to bomb threats through material selection and structural design.

This will reduce injuries from LRV material fragments and improve structural blast integrity while offering greater safety and security for passengers and staff.

This includes improving the ability of LRVs to remain on the track and move away from immediate threat.

EN 12663 Standard, Resilience Design of Vehicle Structural Integrity, allows wide and interoperable implementation of LRVs offering security resilience by design.

Increase LRV security against firebomb threat through design of fire barriers and fire suppression technology while contributing to passenger safety from accidental or vandalism fires.

Provide design features to prevent the spread of fire and fumes contributing to standard fire protection compliance for LRVs.

Crash Energy Management reduces economic impact of injuries and death, increases resilience, and provides for faster recovery.

A7.4.3 Cyber Security

Improve resilience to cyber incidents by hardening digital infrastructure to be more resistant to penetration and disruption.

Improve ability to defend against sophisticated and agile cyber threats and recover quickly from incidents, whether caused by malicious activity, accident, or natural disaster.

Work with MX LRT in developing, documenting, and formalizing thorough standards, policies, and procedures to protect against and improve resilience to cyber threats.

Work with MX LRT to make sure the capability, maintenance, serviceability, and interoperability of the project information and communication technology infrastructure, including implementation of a thorough system development life cycle process, integrates risk management into the process.

Work with MX to integrate information security into project risk management strategy from the very top to align with the MX strategy, mission, vision, and goals.

Integrate information security with risk management to make sure proper identification and allocation of essential resources improves the ability to mitigate against cyberattacks with increased resiliency.

In order to protect MX and project enterprise information systems, the following basic priorities can dramatically lead to a more resilient and secure system.

Enterprise software and firmware updates: With the constant evolution of cyber threats and attacks, developers, vendors, and third-party security agencies are constantly providing updated software and firmware updates.

By staying up to date, projects arm themselves with the latest patches and tools to prevent cyberattacks from current threats.

Web-interfacing applications: Configure external network applications and connections to minimize unauthorized connections and access.

Such configurations include but are not limited to firewall protection, closing unnecessary port access, authentication and use of secure socket layer connections, and monitoring data exchange.

Transportation agencies traditionally considered their communications and control systems to be proprietary, i.e., security by obscurity and not connected to the outside world, therefore assumed secure.

This assumption and attitude is no longer valid or acceptable.

Communications and control system cyber security requires following APTA guidelines in developing a resilient LRT system.

A7.4.4 Innovation

Employ resilience strategies including a framework for the development and implementation of required environmental performance measures, particularly related to design, construction, and maintenance, and how these account for extreme weather and climate change.

Develop strategies to incorporate infrastructure lifecycle costs in design and procurement as well as construction materials and equipment taking into account projections in potential extreme weather and climate change.

Consider industry best practices, new technologies, and innovative initiatives wherever possible.

Use metrics to evaluate resilience design, construction, and maintenance goals and objectives achievement.

Obtain local regulation information and seek insights from local construction firms and organizations to clarify and inform appropriate opportunities for innovative construction practices.

B1 Alignment, Clearances, Rights-of-Way

B1.1 General

Chapter B1 addresses specific design criteria, values, and direction governing Metrolinx (MX) Light Rail Vehicles (LRV) and Light Rail Transit (LRT) alignments, clearances, and Rights-of-Way (ROW).

For criteria Chapter B1 does not specifically addressed, follow Transit Cooperative Research Program (TCRP) Report 155 - *Track Design Handbook for Light Rail Transit*.

B1.1.1 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Alignment, Clearances, and Right-of-Way specific references include but are not limited to:

- American Railway Engineering and Maintenance-of-Way Association (AREMA): *Manual for Railway Engineering*;
- Association of German Transportation Companies: *Permanent Way Guideline – Turnouts and Crossings*;
- FLEXITY SAP-Nr-590012150: *Wide Body Stainless Steel Dynamic Clearance Document*.

Provide LRT alignments compatible with other LRT systems such as Overhead Contact System (OCS), LRV, and signal system requirements.

OBC governs where conflicts arise unless otherwise stated.

B1.1.2 Design Priorities

Chapter B1 follows design priorities in the following order of precedence:

1. Safety, including protection against derailment;
2. Conformance with LRV Clearance Envelopes;
3. Minimizing speed reduction while maintaining reasonable Right-of-Way cross-sections;
4. Track maintenance and performance; and
5. Compatibility with OCS pole design.

Other design considerations in no particular order include:

- LRV maintenance and performance;
- Effect on adjacent property;
- Ride quality;
- Economy;
- Aesthetics; and
- Passenger comfort and convenience.

B1.1.3 Design Goals

Horizontal Alignment

Consider the following factors in developing optimum horizontal alignments including but not limited to:

- Passenger comfort and convenience;
- Capital and operating costs;
- Maximizing LRV velocity;
- Minimizing running times;
- Minimizing noise and vibration, including curved track squeal;
- Type of construction, e.g., bored tunnel, cut-and-cover box, open cut, at-grade, elevated;
- Station and Stop locations and spacing;
- Potential future extensions;
- Topography;
- Track design;
- Soil conditions;
- Existing and proposed property and buildings;
- Underground plant and equipment; and
- LRV capabilities.

Vertical Alignment

Consider the following factors in developing the optimum vertical alignment including but not limited to:

- Horizontal alignment;
- Building foundations;
- Drainage;
- LRV capabilities; and
- Adjacent non-LRT aerial structures.

Curvature and Superelevation

Curvature and superelevation are related to Design Speed with consideration given to LRV acceleration and deceleration characteristics.

Consider but do not limit to the following factors in developing optimum alignment curvature and superelevation:

- LRV Performance;
- Starting Spacing;
- Special Track Work (STW) Locations and Types;
- Horizontal Alignment; and
- Vertical Alignment.

B1.1.4 Minimum and Maximum Criteria

Strive to exceed minimum requirements.

Specific numbers cited, e.g., limitations on grade, curvature, tangent lengths, spiral lengths, etc., are not targets to be achieved but are limits to be avoided in so far as practical.

Use limiting design values only when no other absolute minimum alignment design constraints apply.

Desired, Acceptable, Absolute Values

Desired values are based on industry best practices and passenger comfort.

Designs that meet or exceed desired values provide a robust operating environment.

Acceptable values define a limit beyond which a tangible operating benefit is either gained or lost.

Base absolute values on safety considerations with potential added effects on maintenance, cost, noise, and useful wheel / track life.

Extensive use of absolute values may result in service problems and unacceptable maintenance costs.

Use absolute values only with justification.

B1.1.5 Design Variances

Design criteria intend to achieve design standards, goals, and priorities.

Individual location constraints may impede the ability to meet a particular design criteria.

Special cases such as these require special consideration and perhaps design variances.

Accepted design variances apply only to special cases by specific request.

Provide each design submission with a table summarizing reviewed and accepted design variances.

B1.1.6 Design Briefs

Provide design briefs with each alignment submission including applicable design calculations as well as notable design features and key design inputs as follows:

- Assumptions made;
- Equations used;
- Design variances sought;
- Reference documents and standards; and
- Any other necessary information.

B1.2 Baselines

Alignment design and construction requires control components as follows:

- Control Lines;
- Reference Lines;
- Track Centre Lines;
- Tunnel Centre Lines; and
- Track Subtangent Systems.

B1.2.1 Control Lines

Project Control Surveys establish project control lines.

B1.2.2 Reference Lines

Reference lines usually represent a centre line of construction, centre line of structure, or centre line of any other member or element.

Provide reference lines with horizontal alignments per Section B1.3 and vertical alignments per Section B1.4.

Reference lines are geometrically related to control lines.

Provide drawings indicating the relationship between control lines and reference lines to correctly establish reference lines in the field.

Reference lines may be used to indicate dimensions of proposed work.

Chainage

Provide independent continuous reference line chainage with one station representing 1000 m.

Stationing

Identify key landmark chainage stationing including:

- Start and end points of horizontal curves and spirals;
- Start and end points of vertical curves as well as points of intersection;
- Points of switch and points of intersection at turnouts;
- Other items such as heel of frog and location of last long tie may be requested on completion of design;
- Ends of passenger platforms;
- Portals, ends of bridge decks, cross-passages, and emergency exits.

Provide chainage signs for inspection and maintenance 50 m on centre along ROW.

Direction

Maintain alignment chainage direction per previously existing chainage.

Where there is no existing chainage, run chainage for any given alignment directed either from west to east or from south to north as appropriate.

Initial Value

Confirm that chainage initial values agree with previously existing chainage values.

If existing chainage is in Imperial Units, convert the last Imperial Station to Metric Units and continue from there with new chainage in Metric Units.

Where there is no existing chainage, provide the initial chainage value for MX LRT review and acceptance.

Points of Intersection

Indicate back and ahead chainage at each reference line point of intersection (PI) to compensate for reference line curve lengths.

Chainage Equations

Where reference lines are realigned, provide a chainage equation indicating back and ahead chainage at a convenient ahead Station past the realigned section in order to compensate for different reference line lengths and maintain the integrity of established chainage past the realigned section.

Use chainage equations at the end of each curve, i.e., at a Point of Tangent or Spiral Transition.

B1.2.3 Track Centre Lines

Track centre line spacing defines LRV paths of travel.

Provide horizontal alignment track centre line spacing per Section B1.3.

Provide vertical alignment track centre line spacing per Section B1.4.

Geometrically relate track centre line spacing to reference lines.

Provide drawings indicating the relationship between reference lines and track centre line spacing to correctly set out track centre line spacing in the field.

Track centre line spacing may be used to indicate proposed work dimensions.

Provide track centre line chainage systems identical in format to reference line chainage systems except that initial values are numerically offset from reference line values by predetermined magnitudes.

Obvious visible magnitude differences between chainages at any cross section serve to distinguish one chainage system from another, clearly identifying which chainage belongs to which track or reference line.

B1.2.4 Tunnel Centre Lines

Tunnel centre lines define Tunnel Boring Machine (TBM) paths of travel.

Derive tunnel centre lines from track centre lines.

B1.2.5 Track Subtangent Systems

Track subtangent systems subdivide track centre line spacing into manageable subtangents with accessible points of intersection, especially on curves.

Track subtangent systems geometrically relate to track centre lines.

Indicate the relationship between track centre line spacing and track subtangent systems to correctly establish subtangent systems in the field.

Use track subtangent systems to lay out:

- Track Centre Lines;
- Inverts;
- Walls and Obverts;
- Walkways and Serviceways;
- Double Ties;
- Track Work.

B1.3 Horizontal Alignment

B1.3.1 Overview

Horizontal alignments comprise horizontal tangents joined by one or more horizontal curves.

Consider horizontal curved track superelevation in horizontal alignment design.

Develop horizontal alignment reference lines and track centre lines.

Round up calculated values for curve lengths, tangent lengths, radii, and other elements to the nearest full metre wherever practical.

B1.3.2 Tangent Track Spacing

Tangent track centre spacing varies depending on type of construction.

Size passenger platforms based on patronage and LRV clearance requirements.

Adequate spacing from one tangent track centre to another may be achieved using:

- Nonconcentric curves with integer-length spirals on reference lines and track;
- Concentric curves with different spiral lengths at each end;
- Reverse curves.

Absolute minimum at-grade or elevated tangent track centre line spacing on shared structures is 3720 mm.

At-grade semi-exclusive ROW centre platform tangent track centre line spacing is 7800 mm minimum.

Tunnel tangent track centre line spacing is 11200 mm minimum.

Yard storage tangent track centre line spacing alternates between 4570 mm and 5790 mm minimum with wider spacing for LRV Operator walkways.

Track spacing may require adjustments to account for curvature and superelevation.

See Section B1.5.

B1.3.3 Design Speed

Definitions

See Chapter A2 – Light Rail Vehicles for LRV Design Speed s.

See Chapter A5 – Operations for maximum LRV operating speeds.

Design Speed is the speed based on track, alignment, actual superelevation, and superelevation unbalance per industry best practices and normal operations.

Safe Speed is the speed above which an LRV becomes unstable or in danger of derailment including with any guideway anomaly.

Criteria

Design Speed is always less than Safe Speed.

Design LRT alignments to maximize Design Speed.

Main line Design Speed for exclusive ROW is 80 kilometres per hour (kph) maximum

Main line maximum Design Speed for semi-exclusive ROW equals posted traffic speed.

Connecting track Design Speed is 30 kph maximum.

Yard Design Speed is 10 kph maximum.

Strive to match Design Speed with appropriate maximum operating speeds wherever possible.

Optimize alignments to minimize the number and magnitude of alignment Design Speed changes.

Apply speed restrictions due to existing site features, curves, STW, and as required near Stations, Stops, and other areas where LRV reduced speeds are required.

B1.3.4 Horizontal Tangent Lengths

Passenger Platforms

Provide tangent track through the entire length of platforms.

Desired tangent length beyond platforms is the length of the longest LRV consist on the line.

Acceptable tangent length beyond platforms is one LRV consist length.

Absolute minimum tangent length beyond platforms is 10 m.

Between Curves

Desired minimum tangent length between curves is the length of the longest LRV consist on the line.

Acceptable minimum tangent length between curves is one LRV consist length.

Main line absolute minimum tangent length between curves is 14 m.

Avoid tangent lengths of 6 m to 16 m for acceptable yard tangent lengths between same direction curves.

Provide tangent length lengths of 9 m to 15 m for acceptable yard tangent between reverse curves.

Absolute minimum yard tangent length between any curves is 3 m.

Provide acceptable minimum tangent lengths between reverse curves per the greater values above.

See Sections B1.3.9 and B1.3.10 for tangent alternatives between closely spaced curves.

Special Track Work

Provide STW only at tangent track.

Acceptable minimum tangent ahead and beyond STW is one LRV consist length.

Absolute minimum tangent ahead and beyond STW is 14 m.

B1.3.5 Circular Curves

The arc of curvature defines circular curves.

Specify circular curves by radii measured in metres from track centre lines.

Minimum main line desired radius with no spiral curve required is 3000 m.

Acceptable minimum main line radius is 150 m, below which track gauge must be widened.

Absolute minimum main line radius for non-tunnel sections is 80 m.

Absolute minimum yard radius is 25 m for use only when absolutely necessary.

Absolute minimum radius for bored tunnel sections is 250 m based on estimated TBM turning capability.

Desired minimum Length of Circular Curve (LC) is 0.57V.

B1.3.6 Superelevation

Passenger comfort related determines allowable speed through superelevated horizontal alignment curves.

Definition

Superelevation: The difference in height measured in millimetres between top of higher (outer) rail and top of lower (inner) rail in a curve.

Appropriately displace tunnel track centre line spacing horizontally and vertically along horizontal curves to accommodate for superelevation.

Superelevation runoff length is proportional to magnitude of actual superelevation governed as follows:

- Desired minimum runoff ≥ 1:500;
- Acceptable minimum runoff ≥ 1:380;
- Absolute minimum runoff ≥ 1:300.

B1.3.7 Spirals

Spiral transition curves, or spirals, are mathematically calculated curves where tangent sections change into curves designed to prevent sudden changes in lateral acceleration.

Apply spirals to main line curves wherever practical including curves without superelevation.

Spirals are not required in Maintenance and Storage Facility track.

Minimum length of spiral is determined by either:

- Maximum rate of change in lateral acceleration; or
- Jerk Rate = 0.03 Gravitational Force per second (G/s).

Thus a spiral is traversed in 3.33 seconds minimum or per maximum runoff.

Round up calculated length of spiral to the nearest metre wherever practical.

Horizontal curve track centre lines and reference lines are concentric for alignment calculation and construction simplicity.

Provide spirals connecting different curve radii of different lengths with equal spiral offsets where concentric horizontal curved track centre line spacing is the same as approach and leaving tangent track centre line spacing, e.g., in tunnel construction.

Provide spirals connecting different curve radii of different lengths with spiral offsets that differ by the increase in track centre lines where concentric horizontal curved track centre line spacing is wider than approach and leaving tangent track centre line spacing, e.g., in underground box construction.

Make sure that inside track spirals meet minimum spiral length requirements.

B1.3.8 Compound Circular Curves

Compound circular curves consist of two or more simple circular curves turning in the same direction joined at a common tangent point, known as the Point of Compound Curve (PCC).

Compound circular curves are preferred over substandard tangent separated curves, known as “broken-back” alignments.

Develop unequal superelevation between compound curves linearly over the full length of spiral transitions.

B1.3.9 Reverse Circular Curves

Reverse curves consist of two adjacent, simple, circular curves turning in opposite directions joined at a common tangent, known as the Point of Reverse Curve (PRC).

See Section B1.3.5 for tangent lengths between reverse curve legs.

Consider joining curves with a reverse spiral for particularly problematic minimum tangents between reverse curve legs.

Limit PRC maximum operating speed per lateral acceleration and jerk rate criteria.

B1.3.10 Concentric Circular Curves

Concentric curves are parallel, simple curves with a common centre or radius point (RP).

B1.3.11 Geometry Approaching Turnouts

Provide tangent track approaching turnouts.

See Section B1.3 for required lengths.

B1.4 Vertical Alignment

B1.4.1 Overview

Vertical alignment, or profile, consists of vertical tangents joined by vertical parabolic curves.

Develop vertical profiles:

- First for the reference line based on reference line chainages; and
- Second for each track based on track centre line chainages.

Top of lower rail elevations represent track vertical profiles.

Round up calculated values to the nearest full metre wherever practical for curved lengths, tangent lengths, and other aspects of vertical alignment.

B1.4.2 Vertical Tangents

Main Lines

Main line absolute maximum sustained grade is 4 percent.

Grades between 4 and 5 percent may be sustained for an absolute maximum distance of 250 m.

Main line absolute maximum sustained grade up to but not exceeding 250 m long is 5 percent.

Where a continuously ascending or descending profile is composed of a series of vertical tangents of varying grades, the weighted average gradient is not to exceed 4 percent.

Where horizontal curves are placed on vertical gradients resulting in significant negative superelevation, reduce Design Speed to mitigate derailment risk for superelevation unbalance less than 100 mm.

Maintenance and Storage Facilities

Provide yard, connecting, and storage tracks either level, pitched away from main line, or in a sag so that LRVs do not drift out onto the main line.

Provide yard and storage tracks with 0.3 percent maximum grade.

Signalized Intersections

Desired maximum grade is 0 percent.

Acceptable Maximum Grade is 2 percent.

Absolute Maximum Grade is 4 percent.

Station and Stop Platforms

Vertical tangents are not required to continue beyond the ends of passenger platforms.

See Chapter B5 – Stations, Stops, and Facilities.

B1.4.3 Vertical Curves

Use only parabolic curves for grade changes.

Avoid broken back vertical curves.

Avoid vertical curves with short horizontal curves.

Coordinate vertical curves and gradients with OCS requirements.

Clearly highlight and address alignments requiring closer than normal OCS pole spacing.

Connect changes in gradients with parabolic vertical curves.

Provide constant rate of change for grades over equal vertical curve horizontal lengths.

Provide positive grades ascending in the direction of increasing chainage.

Consider (G2 minus G1) positive or negative algebraic signs as follows:

- If (G2 minus G1) is less than 0, the vertical curve is a summit or crest curve;
- If (G2 minus G1) is greater than 0, the vertical curve is a sag curve.

B1.4.4 Reverse Vertical Curves

Use reverse vertical curves, i.e., a vertical sag curve next to a crest vertical curve subject to MX LRT review and acceptance of each curve minimum length.

B1.4.5 Special Track Work

Provide zero actual superelevation (Ea) planar STW layouts above switch superelevations on gradients.

Do not allow single STW layout vertical curves or grade changes in turnouts or adjacent turnout connections.

Main Lines

Acceptable maximum grade through main line turnouts is less than 2 percent.

Where grade is equal to or greater than 2 percent, reduce speed through the diverging side of a downhill main line turnout by 1 kph.

Where grade is equal to or greater than 4 percent, reduce speed through the diverging side of a downhill main line turnout by 2 kph.

Absolute maximum grade through main line turnouts is 4.5 percent.

Yards

Acceptable maximum grade through yard turnouts is less than 1 percent.

Where grade is equal to or greater than 1 percent, reduce speed through yard turnouts by 2 kph.

Absolute maximum grade through yard turnouts is 2 percent.

B1.4.6 Combined Horizontal and Vertical Curves

Avoid overlapping horizontal and vertical curves wherever practical.

Where overlapping horizontal and vertical curves is unavoidable, provide as gentle an alignment as practical while avoiding vertical curves within spirals.

If the resulting alignment exhibits one of the following characteristics:

- Horizontal or vertical curvature is close to the absolute limit; or
- Vertical curve radius is similar to or smaller than horizontal radius.

Then determine appropriate speed restrictions using dynamic modelling so that LRV lateral acceleration and jerk rates do not exceed criteria per Section B1.3.7 and there is no derailment related safety compromise.

B1.5 Light Rail Vehicles

B1.5.1 Clearance Envelopes

LRV Clearance Envelopes are defined as the space occupied by LRV Dynamic Profiles, i.e., the maximum movement of LRVs as they travel along the track plus an additional running space of 50 mm.

Provide and maintain permanent structures, equipment, and tolerances outside LRV Clearance Envelopes.

See Chapter A2 – Light Rail Vehicles.

Correct as soon as possible LRV body, wheel, and rail wear resulting in LRV floor and passenger platform gaps out of criteria tolerances.

See Chapter B5 – Stations, Stops, Facilities.

Factors affecting LRT structure clearances but not included in LRV Clearance Envelopes include:

- LRV outswing/inswing along horizontal curves increases as curve radii decrease resulting in increased clearance requirements; and

- Superelevation along horizontal curves to obtain maximum operating speed while maintaining LRV stability and passenger comfort also results in increased clearance requirements.

Maintain LRV Clearance Envelopes clear of construction tolerances applied to adjacent structures.

Maintain LRV Clearance Envelopes clear of serviceways.

See Sections B1.6.3 and B1.6.4.

B1.5.2 Dynamic Profiles

The LRV Dynamic Profile results from the cumulative effects of LRV dynamic body movement, LRV static profile, other LRV characteristics, and LRV car, wheel, and track wear conditions.

Maintain LRV Dynamic Profiles clear of safety zones along safety walkways.

Coordinate with LRV manufacturers to identify appropriate horizontal and vertical clearances.

See Chapter A2 – Light Rail Vehicles.

B1.5.3 Horizontal and Vertical Clearances

Measure LRV horizontal clearances in the horizontal plane from track centre lines.

LRV Horizontal clearances apply only to track centre line arc radial lines or to track centre line tangent 90-degree offset lines to track centre lines.

Measure vertical clearances in the vertical plane.

B1.6 Structure Clearances

B1.6.1 General

Provide structure clearances including dimensions and configurations complete with dimensioned drawings.

Emergency Jacking

Provide vertical clearances from LRV Clearance Envelopes to any ROW overhead structure with sufficient space to allow emergency jacking of an LRV.

Minimum Structure Width

Determine minimum structure width as the sum of:

- LRV Dynamic Profile widths;
- LRV Clearance Envelopes where applicable;
- LRV inswings and outswings;
- Safety walkway clearances;
- Serviceway clearances;
- Permanent equipment not included in serviceways;
- Chorded construction clearances; and
- Track superelevation.

Safety Walkways

Configuration

Provide safety walkways with access steps between walkway and nearest track level rail.

Space safety walkway steps approximately 20 m on centre along alignments.

Tunnel Structures

LRV Dynamic Profiles must not encroach on tunnel tangent track safety walkway safety zones.

Reduce horizontal curve safety walkway walking surfaces to allow for LRV outswing and inswing.

Box Structures

LRV Dynamic Profiles must not encroach on box structure safety walkway safety zones.

Widen box structures on horizontal curves to provide safety walkway and LRV inswing/outswing clearances.

Provide top of safety walkways 290 mm above top of adjacent rails.

Serviceways and Lateral Restraint Curbs

Provide box structure serviceways and tunnel structure lateral restraint curbs opposite safety walkways to accommodate signals, cables, and permanent way equipment.

Maintain permanent way clearance between cables, equipment, serviceways and LRV Clearance Envelopes.

Provide tunnel structure lateral restraint curbs no higher than top of adjacent rails.

B1.6.2 Stations and Stops

Track centre line to edge of passenger platform dimension is 1400 mm.

Provide side platform box section centre columns, where required, with a continuous foundation bench to protect from LRV derailment.

Provide dimensioned drawings indicating critical dimensions at LRT/platform interfaces.

See Chapter B5 – Stations, Stops, Facilities for passenger platform lengths and widths.

B1.6.3 Box Sections

Clearances

Provide appropriate box section invert slab, double tie, and isolated direct fixation track slab clearances.

Determine minimum clearances for STW box section isolated track slabs.

Safety walkway requirements may be modified or waived in certain STW areas, e.g., at crossovers.

Chorded Curve Construction

Measure chorded curve construction horizontal clearance dimensions from track centre lines to inside face of walls normal to track centre lines.

See Section B1.3, Horizontal Alignment, for chorded curve construction clearances.

Provide structures with or affected by horizontal curves with chords of appropriate standard lengths.

Provide double tie lateral restraint curb to track centre line clearances on LRV outswing side of structures.

Chorded construction requires increased track centre line to lateral restraint curb clearances.

Horizontal Curves

LRV outswing, inswing, superelevation, and chord effect may require structure width minimum clearance adjustments along horizontal curves.

Recalculate and verify horizontal curve clearances with final cross sections.

Include LRV speeds and consist lengths, structure wall thicknesses and chord lengths, serviceway/safety walkway widths, and track work superelevations in clearance calculations.

Spirals

Apply LRV Clearance Envelope dimensions the full length of spirals for 14 m of tangents beyond curves.

B1.6.4 Tunnel Sections

Clearances

Provide invert slab, double tie, and isolated track slab tunnel section direct fixation track clearances.

Chorded Construction

Provide lateral restraint curbs affected by horizontal curves in standard length chords.

Provide double tie lateral restraint curb clearances of appropriate dimensions.

Grab Bars

LRV Clearance Envelopes must not encroach on space allocated for grab bars at safety walkway steps.

Encroachment may occur, however, where LRV Clearance Envelopes superelevate into safety walkways.

Offset such encroachment by increasing the face of safety walkway horizontal offset from track centre lines.

Magnitude of grab bar encroachment is a function of superelevation.

Horizontal Curves

LRV outswing, inswing, superelevation, chord effect, tunnel rotation, and grab bar clearances may require horizontal curves adjustments to safety walkway or tunnel widths.

Provide analyses to determine appropriate safety walkway offsets from track centre lines.

B1.6.5 Semi-Exclusive ROW

Clearances

Determine LRV Dynamic Profiles as follows:

- 50 mm minimum between LRV Dynamic Envelope and any physical element or obstruction;
- Minimum dimensions from top of low rail to bottom of overhead structures;
- 3720 mm minimum between tangent track centre lines.

Do not allow LRV Dynamic Profiles to encroach upon safety walkways.

B1.6.6 Retaining Wall Sections

Use the same clearance criteria as box structures.

B1.6.7 Elevated Sections

Provide LRT elevated section clearances and curbs per standard box sections.

Provide LRT elevated sections with closed railings or parapet walls extending 1.1 m minimum above adjacent safety walkways or chain-link fences above any parapet wall extending 2.3 m minimum above top of rail.

See Chapter B2 – Track Work for additional derailment containment requirements.

B1.6.8 Turnouts

Provide minimum turnout clearances between LRV Clearance Envelopes and adjacent structures or elements per Section B1.6.3 and criteria for the particular type of construction.

B1.6.9 Railways

Provide LRT and other railway clearances per MX LRT and Authorities Having Jurisdiction (AHJ).

Verify vertical and horizontal railway clearances in other jurisdictions with appropriate AHJ.

Coordinate structures under the jurisdiction of other agencies with the appropriate owner or AHJ.

B1.6.10 Highways

Provide highway bridge clearances per MTO *Ontario Highway Bridge Design Code*, MX LRT , and AHJ.

Verify other vertical and horizontal clearance requirements with AHJ.

Coordinate other agency structures with the appropriate owner, agency or AHJ.

See Chapter B4 - Structures.

B1.6.11 Parking Lots and Terminal Access Facilities

Provide elevated structure vertical clearances throughout LRT system parking lots as follows:

Line Structures

Provide 4650 mm minimum vertical clearance.

Station Structures

Provide 4650 mm minimum vertical clearance at motor vehicle lanes and bus loops.

Provide 3 m minimum vertical clearance at pedestrian ways.

Take into account vertical alignment, e.g., vertical curves, that may be included in motor vehicle lanes.

B1.6.12 Depth of Cover

Depth of cover is defined as the distance from top of underground LRT structure to finished surface grade.

Minimum depth of cover depends on the method of underground construction, e.g., cut-and-cover or tunnelling, and is generally required under roadways or where utilities cross over LRT structures.

Trunk sewers, for example, may require more than minimum depth of cover to clear LRT structures.

Notify AHJ if minimum depth of cover cannot readily be achieved.

B2 Track Work

B2.1 General

Chapter B2 addresses engineering, materials, and construction for Metrolinx (MX) Light Rail Transit (LRT) track work and interfaces with other LRT elements.

See Chapter B1 – Alignment, Clearances, Rights-of-Way.

Track work, Special Track Work, and best industry practices govern MX LRT track work design including interfaces with other system elements such as guideways, bridges, track slabs, transition slabs, traction power systems, signal systems, drainage, and the like.

Track work is an integrated structure inter-related with the weight of the running rail, tie spacing, track fastener types and sizes, foundation slabs, and elastomer stiffness, etc.

Track work characteristics must not change without considering the impact on public safety, track stability, track stiffness, noise and vibration, electrical insulating characteristics, maintainability and life cycle cost.

MX LRT will consider alternative track work designs with demonstrated equal and appropriate performance along with proven other advantages such as improved maintainability, capital and life cycle cost savings, installation efficiencies, etc.

Coordinate track work design with facilities design to identify areas where additional lateral space is required for placement of wayside equipment such as switch machines and rail lubricators.

B2.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Track Work specific references include but are not limited to:

- Ontario Building Code (OBC);
- American Railway Engineering and Maintenance-of-Way Association (AREMA);
- AREMA Manual for Railway Engineering;
- AREMA Portfolio of Track Work Plans;
- Transportation Research Board Track Design Handbook for Light Rail Transit;
- Association of German Transport Companies: Permanent Way Guidelines, Turnouts and Crossings;
- British Standards Institution (BSI);
- BSI EN 14811: Special Purpose Rail;
- BSI EN 13674-3: Check Rails.

OBC governs where conflicts arise unless otherwise stated.

B2.3 Design

Track work interfaces with civil structures to manage surface runoff in or adjacent to LRT Rights of Way (ROW) without compromising track strength or stability.

LRT track work generally includes but is not limited to:

- Direct Fixation Track for tunnels, underground locations, and elevated structures;
- Direct Fixation and Ballasted Track for at-grade Main Line Track where motor vehicles are prohibited;
- Embedded Track for Main Line at-grade semi-exclusive and shared Right-of-Way (ROW) alignments to allow access by emergency services and maintenance motor vehicles;
- Yard and Shop track, which may be of Direct Fixation, embedded, or ballasted track.

Provide each track work segment type based on balance of functionality, operating criticality, and capital/life-cycle costs.

Provide curbs to deter motor vehicles from entering LRT ROW and facilitate maintenance or emergency vehicle access.

Provide 115RE rail including Special Track Work installed on Direct Fixation and/or Ballasted Track locations per AREMA Chapter 4.

Provide 62R1 grooved rail including special trackwork on Embedded Special Track Work locations per EN 14811.

Provide Continuous Welded Rail.

Provide appropriate track work elastomers to attenuate ground-borne vibration and noise and achieve desired track stiffness.

Provide track work with electric insulation from ground.

Provide Main Line Track with double-point, electrically operated or electro-hydraulic, non-trailable track switches.

Provide Yard Track with trailable track switches.

Provide rail components such as frogs, switches, closures, etc., of 62R1 grooved rail design in standard, pre-selected sizes and geometries for Embedded Special Track Work so that spare units may be installed at multiple locations with sizes per VDV OR 14.

Provide switch clearing devices for switches exposed to the outdoors to prevent ice and snow accumulation.

B2.3.1 Wheel Profile and Track Gauge

Consider the wheel profile supplied by the LRV manufacturer in track design.

See Chapter A2 – Light Rail Vehicles for other LRV characteristics.

B2.3.2 Track Gauge and Rail Cant

LRT track gauge is nominally 1435 mm 16 mm below top-of-rail between inner gauge sides top of rail.

Yard Gauge widening occurs as curve radius decreases per Table B2-1.

Achieve gauge widening by moving the low rail outward as required.

In simple curves accomplish full gauge widening on the tangent approaching point of curve and remove following point of tangent.

In spiraled curves apply and remove gauge widening within the length of spiral.

If the spiral is too short accomplish full gauge widening, place gauge widening in the approach tangents.

If adjacent curves that both require widening are too close together to allow gauge widening run out, maintain widened gauge between the curves.

TABLE B2-1 YARD GAUGE WIDENING

Curvature	Track Gauge
Tangent to R > 150 m	1435 mm
R ≤ 150 m	1437 mm

Special Track Work: Position rails with zero cant from vertical.

B2.3.3 Electric Insulation

Provide track work in direct contact with LRVs with electric insulation from ground.

Concrete slabs qualify as ground for electric insulation purposes.

Provide electric insulation between rails and other track work components and concrete slabs.

For Direct Fixation track, provide electric insulation using elastomeric pads and non-conductive materials to separate rail from the rail fastener assembly.

For Embedded Track, provide electric insulation using an extruded elastomeric rubber “rail boot”.

For Ballasted Track with wood ties, use elastomeric pads and insulating fasteners as required to improve electric insulation performance.

Provide elastomeric pads on concrete ties.

See Chapter C5 – Stray Current and Corrosion Control.

B2.3.4 Vibration Damping

Provide track work with damping in the fastening system and/or track bed for vibration generated in the rail or transmitted to the rail by LRVs before it reaches track slab or tunnel structures.

Provide Embedded Track tangent and curved running rails with extruded elastomeric rubber “rail boots” or similar systems to act as a continuous resilient mechanical barrier between rail and concrete infill material.

Provide rail boot cross sections to control vertical deflection under dynamic track loading.

Provide typical Direct Fixation Track with elastomeric pads below the running rails to control vertical deflection under dynamic track loading.

Provide track bed systems to aggressively mitigate ground-borne noise and vibration for Direct Fixation Track in tunnels or other vibration sensitive locations.

Base damping measures on specific LRVs.

Failure to verify design performance when paired with specific MX LRT LRVs may increase undesirable noise and vibration.

Make sure Special Track Work vibration damping measures does not adversely affected track work stability.

B2.3.5 Tolerances

For system wide track work tolerances comply with design criteria per Table B2-2.

TABLE B2-2 SYSTEM WIDE TRACK WORK TOLERANCES

Parameter	Construction Tolerance	Maintenance Tolerance
Track Gauge Variation (without wear)	-0 mm / +1.5 mm	
Vertical Irregularities – Vertical track alignment deviations for both rails:		
Total deviation (Direct Fixation or Embedded Track)	± 5 mm	
Total deviation (ballasted Yard Track)	TBD	TBD
Total deviation at platforms	± 2.5 mm	
Relative deviation over 1 m length		± 1.5 mm
Relative deviation over 5 m length	± 1.5 mm	± 5 mm
Relative deviation over 50 m length	± 5 mm	
Cross level and superelevation variation (Direct Fixation and Embedded Track)	2 mm	3 mm
Cross level and superelevation variation (ballasted Yard Track)	2 mm	20 mm
Short wave track twist over 4 m from geometric deviations	1% (1:1000)	3.67% (1:273)
Short wave track twist over 4 m, sum of track layout and geometric deviations	4.3% (1:233)	7.0% (1:143)
Track twist over bogie distance, sum of track layout and geometric deviations		4.0% (1:250)
Horizontal Irregularities – Horizontal track alignment deviations for both rails:		
Total deviation (Direct Fixation or Embedded Track)	± 5 mm	
Total deviation (ballasted Yard Track)	5 mm	15 mm
Total deviation at platforms	0 mm toward / 2 mm away	
Relative deviation over 16 m length in tangent track	± 2 mm	
Relative deviation over 4 m length in curved track	± 2.5 mm	
Relative deviation over 1 m length		± 1 mm
Relative deviation over 5m length		± 2.5 mm

Total deviation is measured between the theoretical and actual value at any point in track.

Relative deviation is measured between any point in track and a point in stated distance.

B2.3.6 Loading

See Chapter A2 – Light Rail Vehicles.

Longitudinal loading arises from:

- LRV acceleration and braking;
- Thermal stress within the rail based on rail temperature range per Chapter C5 – Stray Current and Corrosion Control plus appropriate additional allowances for heating from exposure to direct sunlight.

B2.3.7 Corrosion Control

Provide barriers to moisture and electric current for track work corrosion control.

Provide appropriately insulated and coated track materials to mitigate corrosion.

Track work corrosion control criteria do not preclude other measures per Chapter C5 – Stray Current and Corrosion Control.

B2.3.8 Drainage

Provide appropriate drainage to remove water from track.

Provide Main Line tunnel inverts shaped to direct water to drainage channels and from there to appropriate municipal sewers via pump stations.

Direct elevated Main Line flow of water toward support structure drains.

Consider water drainage path in determining location and length of rail support components.

Integrate Maintenance & Storage Facility (MSF) track drainage with overall MSF drainage systems.

Allow Ballasted Track water to filter through clean ballast to sub-grade crowned and graded to direct water to drainage systems.

Shape MSF Embedded Track finished paving surfaces to direct water either to flangeways or to low points between running rails.

Provide storage tracks with sag profiles and 0.3 percent minimum grade to direct drainage water toward track drains at low points.

Provide track drains upgrade of Yard embedded Special Track Work.

Provide track drains downgrade of storage tracks to prevent debris accumulation at switches.

Provided drains upgrade of Yard walkways traversing storage tracks.

Connect track drains with buried pipe to appropriate municipal sewer systems.

Provide additional track drains at reasonable intervals for long sustained grades.

Provide margin drains at platforms or guideway curbs for Main Line Embedded Track where water might otherwise pond.

Prevent water ingress to switch machine boxes.

B2.3.9 Electric Continuity

Electric continuity of track work is essential to facilitate LRV track signals and for negative return of traction power to substations.

See Chapter C2 – Communications and Control.

Provide continuously welded rail for Main Line and Yard Track.

Identify appropriate bonding locations.

Coordinate with traction power design including standard cross-bonding, Special Track Work, and rail expansion joint bonding requirements.

See Chapter C1 – Traction Power.

In isolated cases, bond rail with standard bolted joints per AREMA requirements.

Provide sufficient encapsulation to protect Embedded Track bonds from ground.

B2.4 Systems

Assume a systems approach for track work since it comprises a number of elements, each specifically interacting with other LRT systems.

Provide cause and effect analyses for each interacting element.

Consider associated factors such as safety, ride comfort, noise and vibration, stray current, reliability, maintainability, standard parts, capital costs, and maintenance costs.

Recognize and accommodate the relationship of track work to other LRT system elements such as LRV characteristics, train control, and drainage.

Three distinct types of track work may apply:

- Direct Fixation track;
- Embedded Track; and
- Ballasted track.

Track work may vary to some degree within these track work types depending on location.

The essential elements of track work are:

- Roadbed and Track Foundation Slab;
- Infill Material for Embedded Track Work;
- Ties and Ballast for Ballasted Track;
- Rail;
- Rail Fastening Systems including Elastomers;
- Special Track Work;
- Other Track Work Devices, e.g., rail heaters, lubricators, switch machines, bumping posts, etc.

Maintainability and reliability are particularly import since frequent LRV traffic makes track maintenance during normal operations difficult.

Standard parts are also important in allowing reduced inventories and promoting mass production thereby driving unit costs down and enabling "off the shelf" purchase of items.

B2.5 Classifications

Track work is classified as follows:

- **Main Line Track:** For revenue service LRVs including non-revenue track critical to LRT operations for maintenance purposes that may also be classified as Main Line Track;
- **Yard Track:** For switching, storing, or maintaining non-revenue LRVs at MSFs;

- **Shop Track:** For MSF shops including track embedded in floors and track over maintenance pits;
- **Connecting Track:** Connecting Yard Track to Main Line Track.

B2.6 MX LRT Acceptance

Provide track work components and assemblies compatible with LRV wheel profile and other components, parameters, and characteristics contributing to a safe and efficient LRT system and cost effective relative to other components and assemblies in the same or other LRT system track work.

Base new LRT track work components or assemblies on proven existing technology and submit with satisfactory performance records for MX LRT review and acceptance.

B2.7 Standard Track Configuration

Several track work types and configurations meet various requirements under a range of circumstances per the following sections and as summarized in Table B2-3.

Track work systems indicated in Table B2-3 may serve as the basis for comparison in evaluating alternative track work systems.

TABLE B2-3 TRACK WORK TYPES AND TRACK CONFIGURATIONS

LOCATION	RAIL					TRACK						NOTES
	Double Tee	Single Girder	Double Girder	Restraining Rail	Bridge Guard Rail	Embedded	Embedded DF	Ballasted	Direct Fixation (DF)	DF + Double Tie	Other	
MAINLINE TRACKS												
TUNNEL												
Tangent to R ≥ 150m	X									X		
Curve: R < 150m	X			X						X		
Special Trackwork	X								X			floating slab or alternative for underground STW
EXCLUSIVE AT-GRADE												
Tangent to R ≥ 150m	X								X			
Curve: R < 150m	X			X					X			
Special Trackwork	X								X			
SEMI-EXCLUSIVE AT-GRADE												
Tangent to R ≥ 100m	X					X						
Curve: R < 100m		X				X						
Special Trackwork			X			X						double girder 3m tangent before and after STW
BRIDGE/ELEVATED STRUCT.												
Rail Vehicles Only												
Tangent to R ≥ 150m	X				X				X			2 bridge guard rails (not required if walls crash-rated)
Curve: R < 150m	X			X	X				X			1 bridge guard rail (not required if walls crash-rated)
Special Trackwork	X								X			ensure walls/curbs are crash-rated
Rail & Rubber Vehicles												
Tangent to R ≥ 150m	X						X					
Curve: R < 150m		X					X					
Special Trackwork			X				X					TO BE AVOIDED
YARD & SHOP TRACKS												
DIRECT FIXATION												
Tangent to R ≥ 150m	X								X			
Curve: R < 150m	X			X					X			
Special Trackwork	X		X						X			girder rail or tee rail STW (TBD by design-builder)
BALLASTED												
Tangent to R ≥ 150m	X							X				
Curve: R < 150m	X			X				X				
Special Trackwork	X		X					X				girder rail or tee rail STW (TBD by design-builder)
EMBEDDED												
Tangent to R ≥ 100m	X					X						
Curve: R < 100m		X				X						
Special Trackwork			X			X						double girder 3m tangent before and after STW, 115RE on outside of curves R < 30m
SHOP / CARHOUSE												
Floor	X					X						
Raised	X										X	
Pit	X										X	

B2.7.1 Double Tie Track

Double Tie Track is the most common track work configuration with individual precast concrete tie units on elastomeric supports, each with two pairs of rail fasteners and two running rails.

Provide 115RE Rail for Double Tie Track.

Provide Double Tie Track for tangent track, embedded curved track with radii greater than 100 m, and curved Direct Fixation Track or Ballasted Track with radii greater than 150 m.

Exceptions are described below.

B2.7.2 Single Guarded Track

Single Guarded Track running rails consist of one Tee Rail and one grooved rail.

Single Guarded Track is configured with the Tee Rail on the outside (high) rail and the grooved rail on the inner (low) rail of a curve.

The grooved rail is positioned so that the rail head is on the field (outside) side of the track and the guard is on the gauge (between the running rails) side of the track.

Provide Single Guarded Track for Embedded Track with curve radii less than or equal to 100 m.

B2.7.3 Double Guarded Track

Double Guarded Track features two grooved rails as running rails.

Provide Double Guarded Track on embedded Special Track Work and their tangent lead-ins.

B2.7.4 Restraining Rail Track

Restraining Rail Track includes an additional rail on the gauge side of the low (inner) rail of a curve that takes up lateral forces generated in traversing the curve.

The purpose Restraining Rail Track is to:

- Improve safety with additional LRV truck guidance;
- Divide lateral wheel forces between two rails thus reducing forces on rail fastening systems; and
- Divide rail wear over two rail surfaces thus increasing time between rail replacements.

Restraining Rail begins on tangent track before the start of a spiral or circular curve and extends beyond the end of a spiral or circular curve.

Bond Restraining Rail at joints and to running rails to reduce resistance to electric current return.

Provide Restraining Rail Track on Direct Fixation and Ballasted Track curves with central radii less than or equal to 150 m.

Provide 33C1 (UIC33) Restraining Rail where required per EN 13674-3 Check Rails.

Confirm that Restraining Rail fastener assemblies are compatible with the LRV Dynamic Envelope.

B2.7.5 Bridge Guard Rail

Bridge guard rail contains and guides derailed bogies keeping an LRV upright and on the track structure.

Provide bridge guard rails inside the running rails of Main Line Direct Fixation Track at bridges, embankments, approaches to tunnel portals, overhead structure abutments, and where a derailed LRV would likely affect critical facilities such as high tension power lines or poles.

Position bridge guard rail so the bridge guard rail head does not project above the running rail head.

Consider undercar clearances and rail wear limits in determining the vertical position of bridge guard rail.

Position bridge guard rail horizontally to maximize ease of maintenance and access to running rail fastening systems while making sure to limit lateral travel of a derailed LRV to a safe distance from critical wayside objects and structures.

Extend bridge guard rails on Main Line Track ahead of the beginning of a bridge structure or area being protected on the approach end and beyond the end of the protected structure on the departure end.

Provide bridge guard rail only on the side with no Restraining Rail.

Provide bridge guard rail only on the outside tracks of multi-track bridges.

Provide bridge guard rail ends bent into flares pointing toward the track centres.

Bridge guard rail is not required on track with lateral structural restraints strong enough to contain a derailed LRV based on track and structural design analysis subject to MX LRT review and acceptance.

B2.8 Standard Track Types

Provide Direct Fixation or ballasted Main Line Track for exclusive ROW.

Provide embedded or ballasted Main Line Track for semi-exclusive ROW.

Provide either Direct Fixation, ballasted, or embedded Yard Track.

Provide embedded Shop Track where frequent foot or forklift traffic is required.

Provide Direct Fixation Track over maintenance pits and at LRV car wash facilities.

B2.8.1 Embedded Track

Embedded Track allows emergency vehicles, snow plows, and other maintenance vehicles access to the LRT guideway or ROW with relative ease.

Embedded Track includes roadway or floor paving up to top-of-rail to completely bury supporting structures.

Embedded Track components are thus not readily accessible for inspection or maintenance.

General

Match track profile to roadway profile where Embedded Track crosses an intersection.

Provide track profile flush with roadway profile for Main Line Track in shared ROW.

Provide Continuous Welded Rail on tangent and curved Embedded Track.

Construction

Sub-grade is the material below track work, graded and compacted to the required configuration, supporting loads transmitted through the track structure.

A uniform and stable sub-grade is essential since differential settlement leads to unsatisfactory track geometry.

Geotechnical considerations may require replacement of existing sub-grade material or other measures to achieve a uniform and stable sub-grade.

Uniform and stable sub-grade requirements apply to Embedded Track as well as Direct Fixation track.

Embedded Track foundation slab service design is typically 80 to 100 years.

In order to satisfy strict system wide accessibility requirements for LRV boarding platforms, track bed slabs must not heave due to freeze / thaw cycles.

Provide at-grade passenger platforms and track bed slabs on non-frost susceptible backfill foundations bearing below the frost line.

Provide a soil transition zone of non-frost susceptible backfill beneath the track bed slab at each end of platform for a smooth transition between platform and non-platform areas.

Infill material of appropriate shape and depth provides:

- A flangeway for the LRV wheel and rail bound maintenance vehicles;
- A drivable surface for motor vehicles;

- A walkable surface for pedestrians;
- Access for rail grinding;
- Field side relief to prevent wheel treads from riding on infill concrete as rails wear;
- Surface drainage; and
- Access for future rail replacement.

Expansion Joints

Thermal expansion and contraction generates forces in the rail that are transferred to bridges at structural expansion joints.

Coordinate track work and structural design to determine whether embedded rail expansion joints are required at bridges.

In general, provide a rail expansion joint if the anticipated range of longitudinal expansion at a single joint is greater than 25 mm (1”).

Locate Embedded Track rail expansion joints carefully so that rainwater carried debris does not accumulate in the gaps causing joints to seize.

Drainage

Provide Embedded Track drainage with appropriately shaped top-pour concrete and track drains at low points.

Connect Main Line Track drains through buried pipe to appropriate municipal sewers.

Connect MSF track drains to MSF drainage systems.

Provide additional track drains at reasonable intervals for long sustained grades.

B2.8.2 Direct Fixation Track

Direct Fixation Track includes rail fasteners rigidly connecting rails directly to concrete foundation slabs.

Direct Fixation Track components are exposed and readily accessible for inspection and maintenance.

General

Direct Fixation Track prevents rubber-wheel vehicles from operating on LRT guideways.

Provide Direct Fixation Track for exclusive LRT ROW in tunnels and on elevated guideways.

Direct Fixation Track may also be used for at-grade semi-exclusive ROW and at select non-revenue track.

Analyze bridges with Direct Fixation Track to determine the need for rail expansion joints.

Provide continuous welded rail on tangent and curved Direct Fixation track.

Exclusive At-Grade Rights-of-Way

Provide Direct Fixation Track fastening plates with weather and ultraviolet radiation protective coatings.

In order to satisfy strict system wide accessibility requirements for LRV boarding platforms, track bed slabs must not heave due to freeze / thaw cycles.

Provide at-grade passenger platform foundations bearing below the frost line.

Support track bed slabs adjacent to at-grade passenger platforms on non-frost susceptible backfill.

Provide non-frost susceptible backfill transition zones beneath at-grade track bed slabs at each end of platform for a smooth transition between platform and non-platform areas.

Coordinate design closely to achieve the required tolerances between track work and platform edges.

Provide appropriate tolerances and consider construction sequence for each element.

Elevated Structures

Additional design considerations for Direct Fixation Track on elevated structures include:

- Anchor bolts and associated fastener plate holes placed to avoid cutting embedded structural rebar;
- Whether or not bridge guard rails are required;
- Whether or not rail expansion joints are required;
- Where rail expansion joints are not required, make sure to install rail at recommended rail laying temperatures and to properly de-stress rails; and
- Not to impede water flow to track work drains.

Tunnels

Provide Direct Fixation Track in tunnels as described above.

Consider as well:

- Noise and ground borne vibration mitigation; and
- Reasonably constructed and maintained track work in confined tunnel areas.

Anchor Bolts and Inserts

Provide anchor bolts and inserts to sufficiently resist lateral and vertical LRV forces.

Use corrosion and seize resistant materials.

Embedded female inserts with top-inserted bolts are preferred over embedded bolts with top-installed nuts and washers.

If embedded bolts are used, minimize unused lengths projecting above fasteners to avoid tripping hazards.

Provide sufficient structural slab/double tie embedment depth to resist forces directed through bolts.

Provide anchor bolts consistently throughout the LRT system.

Drainage

Provide inverts below double tie track directing water toward track drain systems.

See Chapter B3 – Civil Works.

B2.8.3 Direct Fixation Embedded Track

Direct Fixation Embedded Track is a hybrid between Direct Fixation Track and Embedded Track.

Provide Direct Fixation Embedded Track on bridge decks for rubber-wheel vehicles to travel on the guideway.

Attach Direct Fixation Embedded Track fasteners directly to bridge decks.

Place paving material up to top-of-rail.

General

Analyze bridges with Embedded Track to determine whether to provide rail expansion joints.

Provide track fastener spacing the same as for typical Direct Fixation Track conservatively assuming that concrete cannot be vibrated below the rail to provide proper vertical support along its length.

Determine anchor bolt fastener plate hole positions taking care to identify, locate, and avoid existing bridge deck reinforcing steel.

MX LRT may consider alternative designs that significantly improve track work function, durability, and maintenance while reducing track work depth, weight, cost, or bridge deck Direct Fixation requirements.

New bridge decks with LRT track work may require vertical recesses to accommodate the height difference between top-of-rail and adjacent roadway paving.

Drainage

Provide Direct Fixation Embedded Track drainage similar to Embedded Track but guide drainage water toward bridge structure drains.

B2.8.4 Shop Track

LRVs travel through MSF Shops for a variety of inspection and maintenance procedures.

Several different types of track may serve depending on the type of work to be carried out in an MSF Shop.

See Chapter B6 – Maintenance and Storage Facilities.

Shop Post Track

As the name suggests, Shop Post Track is built above floors or pits on structural posts, columns, or beams.

Provide Shop Post Track in areas requiring access under LRVs for inspection and maintenance.

Provide Shop Post Track with fully supported bolted rail joints bonded for electrical continuity.

Never weld Shop Post Track rails to structural posts, columns, or beams.

Position Shop Post Track rail joints over fastening plates directly above columns, not on structural beams.

Do not paint Shop Post Track rail head running surfaces to provide solid electrical wheel/rail connections.

Do not use elastic rail clips on Shop Post Track to avoid potential spring-back injuries.

Embedded Shop Track

Provide Embedded Shop Track in areas with movement of people and/or Shop equipment where access under LRVs is not required.

Embedded Shop Track is similar to Main Line or Yard Embedded Track.

Provide Embedded Shop Track with rail enclosure flangeway collapsible material that deflects during LRV movement but returns to flush position when unloaded to minimize tripping hazards.

Submit alternatives to Embedded Shop Track for MX LRT review and acceptance.

Direct Fixation Shop Track

Direct Fixation Shop Track is similar to Direct Fixation Main Line Track.

Provide Direct Fixation Shop Track where drainage is the primary concern with infrequent pedestrian or non-rail equipment movement or access under LRVs, e.g., LRV car wash facilities

Drainage

Provide flat and level Shop Track.

Provide Shop Track drainage and spill containment on LRV car wash tracks and areas with lubricants, battery acid, or other liquids.

B2.8.5 Ballasted Track

Ballasted Track uses running rails fastened to ties set on a graded stone aggregate base, i.e., ballast, with additional ballast placed around and between ties to immobilize them and fix track alignment and profile.

Consider Ballasted Track for use in select at-grade and MSF areas where appropriate.

Limit Ballasted Track to areas where rubber-wheeled motor vehicle traffic access is not required.

Emergency vehicle lanes and paved walkways may still be required within MSF Ballasted Track areas.

See Chapter B6 – Maintenance and Storage Facilities.

Provide appropriate transitions between Ballasted Track and other track.

Ties

Ballasted Track ties may be concrete or hardwood per Chapter B2.9.6.

Provide Ballasted Track ties with 25-year minimum design life regardless tie material.

Determine Ballasted Track tie spacing per tangent, curved, and Special Track Work design.

Ballast

Provide ballast per Chapter B2.9.7.

Fill tie cribs with ballast to 25 mm minimum from top of tie.

Provide walking surfaces between tracks suitable for maintenance personnel with level ballast to match height of ballast in tie cribs.

Continuously Welded Rail

Protect Ballasted Track against track buckling from thermal stress with continuously welded rail.

Provide rail anchoring details with rail laying temperatures per AREMA Manual for Railway Engineering.

Drainage

Provide Ballasted Track drains at regular locations to remove water from track structures.

Connect Ballasted Track drains to municipal sewers or MSF facility drainage systems.

Grade and crown sub-grade and sub-ballast to direct water to drains.

Provide ballast gradation with sufficient voids to allow water to migrate freely to drains.

B2.8.6 Transition Track

Transition Track introduces a gradual change in track or track bed stiffness where two track types meet.

Transition Track works in several ways to:

- Vary Direct Fixation or Double Tie Track fastener spacing;
- Vary number or stiffness of track fastener plate support pads;
- Gradually increase or decrease Ballasted Track tie length and/or spacing; and/or
- Provide concrete transition slabs to decrease ballast depth where Ballasted Track transitions to Direct Fixation or Embedded Track.

Provide Transition Track of sufficient length to traverse at design speed in two seconds minimum.

Provide uniform track stiffness transitioning along the length of Transition Track.

Provide calculations to determine the stiffness of two adjacent track types and identify appropriate increments to adjust stiffness along the length of Transition Track.

B2.9 Track Components

B2.9.1 General

Provide only new Restraining Rail and running rail with head hardness of 365 to 380 Brinell RT.

Tee rail currently installed on existing tangent track slated for rehabilitation may be reused in the same location provided vertical wear does not exceed 5 mm and the rail profile is ground to remove corrugation and optimize rail shape prior to operation.

B2.9.2 Tee Rail

Provide 115RE rail section where Tee Rail is required per AREMA Chapter 4.

Provide fully head hardened Tee Rail of 365 to 380 Brinell hardness.

Provide Tee Rail pre-curved prior to installation for horizontal curves of radius less than 120 m or vertical curves of radius less than 300 m.

B2.9.3 Girder Guard Rail

Provide Girder Guard Rail pre-curved prior to installation for horizontal curves of radius less than or equal to 120 m or vertical curves of radius less than or equal to 300 m.

Provide 62R1 rail section where grooved rail is required per CEN EN 14811.

B2.9.4 Restraining Rail

Provide Restraining Rail fastener assemblies compatible with LRV Dynamic Envelopes.

Provide rail fasteners that do not disturb running rails when maintaining or replacing Restraining Rails.

Avoid using bolted rail joints as they are the weakest part of track work.

Provide 6-hole type joint bars connected by D-bars and lock bolts where necessary.

Standard insulated bolted joints may be used in some locations for signaling or traction power purposes.

Provide 33C1 – UIC33 – rail section where Direct Fixation Track Restraining Rail is required per EN 13674-3 Check Rails.

See Section B2.7.5.

Flash Butt and Thermite Welds

Provide flash butt welds for continuous welded rail in the longest strings practical with electric flash butt welding equipment programmed appropriately for specific rail chemistry.

Where electric flash butt welds are not practical, use thermite welds to join rails and rail strings.

Compromise Joints and Transition Rail

Avoid use of compromise joints for permanent track work.

Instead, use pre-manufactured transition rail for transitions between different rail sections.

Provide each end of transition rail to match the cross section of the rail to which it connects and then weld to adjacent rails.

Provide transition rail for welding to running rail of the same material as adjacent rail.

Line Embedded Track transition rail with the same elastomer as Embedded Special Track Work.

Provide elastomers with track modulus similar to that of booted running rails.

Avoid use of compromise joints and transition rail for Special Track Work.

Insulated Rail Joints

Provide insulated rail joints to electrically isolate contiguous rail per signal or traction power requirements with the following parameters:

- Bonded, i.e., glued butt joints made with 90 degree cuts;
- Identical rail drilling pattern as standard joint bars; and
- Compatible with standard LRT rail fasteners.

Comply with AREMA *Specifications for Quenched Carbon Steel Joint Bars and Forged Compromise Joint Bars* and *Rail Drillings and Bar Punchings*.

Insulate joints at suspended joints to avoid the need for special tie plates in Direct Fixation Track or special steel ties in Embedded Track.

Special modified elastic clips may be required at insulated joints.

Provide track bolts with self-locking nuts.

Provide continuous welded rail epoxy bonded insulated joint bars.

Provide insulated joints with “D-shaped” bar cross sections with clearance for rail fasteners.

Rail Expansion Joints

Provide rail expansion joints to accommodate the full range of potential movement for rail and/or bridge decks with significant thermal expansion and/or contraction.

Provide fixed rail attached to baseplates fastened to one side of structural expansion joints.

Provide movable rail spanning structural expansion joints able to slide relative to fixed rail baseplates.

Provide Embedded Track rail expansion joints to accommodate free movement of the movable rail.

Provide removable plates or gratings flush with Embedded Track top-of-rail to allow access for cleaning and maintaining rubber-wheeled motor vehicle roadway surfaces.

Coordinate track work and structural design to determine whether to use rail expansion joints on bridge decks or approaches with a key consideration being drainage since accumulated debris may cause expansion joints to seize.

Bolted Joints

Bolted joints are the weakest part of track work and thus are not typically used in Main Line Track.

Use bolted joints only with jointed rail.

Provide 6-hole type joint bars connected by D-bars and lock bolts where necessary.

Position bolted joints directly across from one another.

Provide concrete relief joints immediately adjacent to Embedded Track bolted joints to control cracking.

Provide Restraining Rail bolted joints centered over support braces to minimize deflection.

Provide traction power and signal bonds at bolted joints.

See Chapter C2 – Communications and Control.

Rail Grinding

Consider rail profile grinding and rail corrugation grinding clearances and space requirements.

Provide sufficient space for embedded, ballasted and Direct Fixation Track for maintenance activity.

B2.9.5 Rail Fastening Systems

Rail fastening systems secure rail to track structures.

As an integral part of track work rail fastening systems:

- Resist rail rotation under lateral loads;
- Resist rail lateral translation;
- Resist longitudinal rail slip due to LRV acceleration/braking forces or thermal expansion/contraction;
- Absorb vertical vibration energy to reduce noise and vibration as well as track tie/grout pad loading;
- Accommodate running rail vertical shimming at Stations and Stops to compensate for rail wear and maintain accessible LRV/platform height/gap tolerances.

Carefully consider rail fastening systems to optimize overall track stiffness and minimize excessive forces imparted to ties and other track work components.

Provide standard rail fastening systems to the greatest extent possible across MX LRT lines.

Direct Fixation Track Fasteners

Standard Direct Fixation Track Fasteners

Provide Direct Fixation rail fasteners for the appropriate loadings at exclusive ROW, e.g., elevated structures and tunnels, including double tie and at-grade sections.

Provide required lateral and longitudinal restraint for continuous welded rail.

Provide electric insulation for negative return current and proper signal circuit operation.

See Chapter C5 – Stray Current and Corrosion Control.

Provide Direct Fixation Track fasteners to attenuate noise and vibration.

Provide Direct Fixation Track fasteners to resist corrosion with service life of 25 years minimum.

Provide Direct Fixation Track fasteners spacing not to exceed 750 mm.

Provide Direct Fixation Track fasteners with appropriate longitudinal force restraint able to restrain broken rail gaps up to 50 mm (2”) wide.

Coordinate Direct Fixation Track and elevated structures design to determine whether to use low-restraint track fasteners to allow structural expansion and contraction without overstressing the rails.

Consider alternative rail fastening systems to augment typical noise and vibration attenuation but only those rail fastening systems that do not compromise maintenance or reliability.

Special Track Work Direct Fixation Fasteners

Provide Special Track Work Direct Fixation fasteners with electric isolation from ground and attenuating noise and vibration to the greatest extent possible.

Minimize height mismatch between Special Track Work Direct Fixation fasteners and standard Direct Fixation Track fasteners to keep grout pad and plinth heights as consistent as possible.

Ballasted Track Fasteners

Provide Ballasted Track fasteners on wood ties per AREMA Manual for Railway Engineering, Chapter 5, Part 9 or CEN EN 13481-3.

Provide Ballasted Track fasteners with electric insulation from ground per Section B2.3.3.

Provide Ballasted Track base plates to accommodate spikes – not cut spikes -- per material, manufacturing, quality control, and testing requirements of AREMA Manual for Railway Engineering, Chapter 5, Part 1, Tie Plates, or equivalent.

Provide Ballasted Track with pre-installed elastic rail fastener assemblies on concrete ties with dimensions and tolerances per Section B2.3.2 Track Gauge and Rail Cant.

Embedded Track Fasteners

Provide Embedded Track fasteners integral with steel ties.

See Section B2.9.6 Steel Ties for Embedded Track.

B2.9.6 Ties

Track ties are required to:

- Maintain track gauge;
- Distribute vertical and lateral LRV loads to track bed foundations;
- Contribute to track structure stiffness; and
- Anchor track against thermal and dynamic longitudinal and lateral forces.

Provide ties and fasteners per Section B2.3.2 Track Gauge and Rail Cant.

Wood Ties

Provide wood ties made of hardwood and treated with suitable wood preservative for 25 years minimum service life per AREMA Manual for Railway Engineering, Chapter 30, or CEN EN 13415.

Provide anti-splitting devices for ends of wood ties.

Attach rail fasteners to wood ties with screw spikes, not cut spikes.

Pre-drill wood tie rail fastener screw spike holes to prevent splitting when installing base plates.

Provide Special Track Work wood ties in various lengths to suit turnout size and layout with appropriate rail fasteners and tie layouts.

Concrete Ties

Provide pre-stressed reinforced concrete ties with 25 years minimum service life, appropriate pre-installed elastic rail fasteners, and elastomeric pads attached to underside of ties protected from abrasion against ballast per AREMA Manual for Railway Engineering, Chapter 30, or CEN EN 13481-2 and EN 13230.

Provide Special Track Work concrete ties with rail fasteners coordinated and positioned for each layout.

Embedded Track Steel Ties

Provide Embedded Track steel ties fabricated from structural steel and cut to appropriate lengths.

Provide finished product steel ties for proper track gauge and rail cant with minimum additional measuring.

Provide shims as required and weld fastener shoulders in place at appropriate pre-set locations.

Coat entire steel tie units to protect against chloride attack.

Embedded Special Track Work Steel Ties

Provide Embedded Special Track Work steel ties similar to those for tangent and curved track but possibly differing in the some ways, including:

- Length;
- Spacing; and

- Adjustable fastener positioning.

Embedded Special Track Work Plastic Ties

Consider Embedded Special Track Work plastic ties as an alternative if performance, cost, and constructability benefits can be demonstrated.

Submit Embedded Special Track Work plastic ties as an alternative to MX LRT for review and acceptance.

Tie Spacing

Consider factors such as loading, allowable bearing pressure, LRV speed, cost, allowable track deflection, lateral stability, ability to maintain gauge, etc., in determining tie spacing.

Tie spacing must not result in over-stress on ballast, sub-ballast, or sub-grade.

Typical center-to-center tie spacing in MSFs is not to exceed 750 mm.

Provide tie spacing for Special Track Work per applicable plans for turnouts and crossovers.

Provide infill material to support rails throughout entire length of Embedded Track.

Provide steel ties spaced:

- To reliably maintain gauge in tangents and curves; or
- 1.5 m, whichever is less.

Concrete Double Ties

Concrete double ties differ significantly from traditional ties and are only appropriate for use in tunnels.

Do not use concrete double ties for Ballasted Track.

B2.9.7 Ballast

Provide ballast made of crushed granite or trap rock.

Provide ballast gradation, depth, shoulder dimensions, and side slope guidelines on a system wide basis, generally complying with AREMA Manual for Railway Engineering, Chapter 1, Part 2, except where otherwise noted in the MX LRT Design Criteria Manual.

Sub-Ballast

Provide sub-ballast gradation, depth, shoulder width, cross fall, side slope, geotextile requirements, etc., on a system wide basis.

Provide sub-ballast generally complying with AREMA Manual for Railway Engineering, Chapter 1, Part 2.

Place sub-ballast on top of sub-grade.

B2.9.8 Elastomers and Isolating Materials

Provide track work elastomers, isolating materials, and components that electrically insulate rail from ground, attenuate noise and vibration, and facilitate track modulus adjustments.

Provide elastomers and isolating materials suitable to operate for 30 years minimum service life in rail environments.

Attenuate noise and vibration per ISO 3095, Railway Applications – Acoustics – Measurement of Noise Emitted by Railbound Vehicles.

Rail Boots

Extruded elastomeric rail boots absorb LRV impact loads and help protect infill concrete from cracking.

Physically isolate Embedded Track rail from infill concrete using extruded elastomeric rail boots fit snugly around the rail cross section and designed to remain firmly in position until placement of infill concrete.

Rail boot deflection must not exceed elastomer working range.

Rail boot elastomers also provide electric insulation from concrete.

Provide rail boots with cross section and material properties to accommodate deflection and achieve noise and vibration attenuation goals as well as resistance-to-earth values.

See Section B2.3.3 Electric Insulation.

Elastomeric Pads

Provide Direct Fixation Track with electric and vibration isolation through use of:

- Elastomeric pads between bottom of rail and rail fastener plate seat;
- Insulating materials separating rail from plate shoulders and elastic clips; and
- Insulating sleeves separating anchor bolts from plates.

Provide Direct Fixation Track elastomeric pads on double ties, side restraint curbs, and adjacent ties to isolate inverts below.

Provide double tie system elastomeric pads of size and stiffness for prescribed vibration attenuation.

Provide elastomer cross section shapes to allow controlled deflection under LRV dynamic loads without exceeding elastomer working range.

Embedded Special Track Work Encapsulation Material

Provide Embedded Special Track Work encapsulation material to achieve the same results as other Embedded Special Track Work.

Attach insulating elastomers to outside of Special Track Work components since these components may not be of a consistent cross section.

Fully isolate Special Track Work standard joint bars and bolts from infill concrete.

Provide Embedded Track switch materials able to withstand electric de-icing heating element temperatures.

Provide elastomeric bonding materials tough enough to withstand normal track workloads and impacts.

B2.9.9 Special Track Work

STW refers to rail configuration where tracks converge, diverge, or cross.

Standard track work is made simply from rolled rail of constant cross section.

Several STW component rails may be cast or machined with cross sections that vary along their length.

Some Special Track Work, e.g., switches, include moving parts with special power and signal requirements.

Configuration

LRT lines typically use several STW configurations, each serving a different purpose.

Provide appropriate STW configurations based on location, service, space, and maintenance requirements.

Turnouts

Turnouts comprise a switch and a frog allowing LRVs to diverge from or merge with another track.

Where oncoming traffic diverges from one track to two the layout is called a Facing-Point Turnout.

Where oncoming traffic merges from two tracks to one the layout is called a Trailing-Point Turnout.

Main Line traffic typically traverses a tangent through the switch and diverging traffic travels off at an angle.

When both tracks diverge at the same angle from the lead-in the turnout is called an Equilateral.

Single Crossovers

Single Crossovers consist of two turnouts where the track between frogs allowing LRVs continuous passage to transfer between two parallel tracks.

Single Crossovers may be laid out with either facing-point or trailing-point turnouts.

Double Crossovers

Double Crossovers consist of a facing-point crossover and a trailing-point crossover superimposed on one another in an X-shaped configuration.

Two crossovers intersecting require a “diamond” or “crossing”.

Double Crossovers provide maximum service flexibility and shortest travel time in minimum distance.

Double Crossovers are used at terminals and other designated locations.

Universal Crossovers

Universal Crossovers are similar to double crossovers except the facing-point and trailing-point turnouts are laid out in sequence instead of being superimposed.

Universal Crossovers provide the same functionality as double crossovers but eliminate the diamond.

Universal Crossovers require more space than double crossovers and may increase headways at terminals.

Paired Single Crossovers

Paired Single Crossovers are simply two identical single crossovers positioned close together.

Paired Single Crossovers are used at emergency turn backs on semi-exclusive and non-exclusive ROW where one single crossover is placed on each side of roadway intersections.

Paired Single Crossovers allow turn backs from either direction in case of service disruption on one segment.

Three Track Crossovers

Three Track Crossovers allow transfer between two Main Line Tracks and a third, parallel, centre storage or pocket track.

Three Track Crossovers may use Equilaterals but Main Line ends require standard lateral turnouts.

Grand Unions

Grand Unions are where two perpendicular double lines cross at grade with 16 turnouts linking every track.

Streetcar networks use Grand Unions or Partial Grand Unions - those with less than 16 turnouts - extensively at intersections.

Grand Unions complicate track maintenance because numerous rail discontinuities, particularly at diamonds, and thus are not desirable.

Yard entry/exit points may require partial grand unions if the Yard is not located at the end of a line.

Ladders

Ladder are a series of single turnouts in sequence allowing LRVs to diverge to one of several branch tracks.

Ladders are usually found in Yards at the entry point to storage tracks.

Components

Provide 115RE Tee Rail for Main Line STW.

Provide 115RE Tee Rail for Yard and Shop STW except for Embedded STW.

Provide grooved rail Embedded STW based on 62R1 (NP4aM) rail.

Provide monoblock switches and frogs for Embedded Track turnouts with 62R1 section rails connecting embedded STW components rolled from Grade 340GHT steel per EN 14811.

Locate turnouts on planar tangent track.

Do not locate turnouts on super-elevated track.

Provide STW rail exhibiting no rail cant, i.e., inclination.

Provide Embedded and Direct Fixation STW elastomeric materials to damp noise and vibration and accommodate deflection under dynamic loading.

Provide elastomers with physical properties and cross section shapes to allow controlled deflection under LRV dynamic loads without exceeding elastomer working range.

Locate turnouts and crossovers completely at grade or completely on structure.

Do not allow turnouts or crossovers to span structural expansion joints or changes in track work type, e.g., Direct Fixation to Embedded, Double Tie to Direct Fixation, etc.

Sizes

Provide non-embedded Main Line STW with standard lateral turnout geometries per AREMA Portfolio of Track Work Plans.

Equilaterals may be used on centre, storage, tail, or pocket tracks.

Do not use Equilaterals on Main Line Track.

Provide Main Line Double Crossovers with consistent turnout sizes.

Provide straight frogs on Main Line Track.

Provide turnout geometry Value Engineering proposals to meet operating requirements while reducing crossover lengths for MX LRT review and acceptance.

Provide Main Line or MSF Embedded Track turnout geometry per Association of German Transport Companies Permanent Way Guideline, VDV OR 14 – Turnouts and Crossings.

Provide 100 m turnouts with straight end pieces for embedded Main Line terminal crossovers.

Provide 50 m turnouts with straight end pieces for Main Line emergency crossovers.

Provide 25 m to 50 m radius Embedded Yard Track turnouts.

Provide non-embedded Yard Track turnout geometry per AREMA or VDV guidelines.

Do not mix AREMA and VDV non-embedded Yard Track turnouts.

Submit STW Value Engineering proposals for MX LRT review and acceptance.

See Chapter B1 – Alignment, Clearances, Rights-of-Way for other STW geometry requirements.

Switches

Provide non-embedded track turnouts with curved switch points.

Determine switch point lengths per AREMA standards or equivalent.

Recommend whether or not to use switches with tangential geometry.

Provide monoblock, double-tongue, flex-heel embedded switches.

Provide Main Line Track with electric or electro-hydraulic non-trailable switch throw machines.

Yard Track may use trailable switch machines.

Frogs

Provide deep groove frogs for continuous LRV wheel tread transfer support from wing rail to frog point.

Provide 8 mm minimum wide contact areas through full length of frog including transition area.

Consider flange-bearing frogs only for Yard Track.

Where flange-bearing frogs are used, speed restrictions may apply based on LRV characteristics.

See Bombardier document 236-BRA-0119, Track Work Maintenance Recommendation.

Provide 115RE cross section rail for Main Line and Yard Track frogs on Direct Fixation or Ballasted Track.

Provide 62R1 grooved rail section frogs for Embedded Track.

Consider movable point frogs at Direct Fixation Track turnouts where traffic through diverging routes exceeds 20% of total traffic and noise mitigation is essential, subject to MX LRT review and acceptance.

Provide movable point frogs with appropriate space for switch machines as well as power and signal cables.

Provide movable point frogs with locking and detection, otherwise speed restrictions may apply subject to performance analysis and MX LRT review and acceptance.

Provide heated movable point frogs exposed to winter conditions to prevent build-up of ice and snow.

Lift-over frogs, also known as jump-frogs or one-way low-speed frogs, include continuous running surfaces across the normal, i.e., Main Line Track direction, and ramps in the turnout flangeway direction that lift LRV wheel flanges to traverse the Main Line Track rail head.

Consider lift-over frogs only at infrequently used emergency turnouts.

Bogie twist due to wheel lift resulting from cross frog travel is not to exceed 7 percent.

Speed through Main Line side of frogs is unreduced.

Speed across turnout side of frogs is of necessity slow.

Heel location of frogs often governs nearest other track work locations, e.g., other turnouts and/or horizontal / vertical curves.

Switch Machines

Provide ROW switches and moveable point frogs with electric or electro-hydraulic operated remote control switch machines.

Provide Main Line and Connecting Track non-trailable switches with positive mechanical locking features.

Some switches on unidirectional Yard Track may be trailable.

Coordinate switch machine space requirements with train control and other system requirements.

See Chapter C2 – Communications and Control.

Provide sufficient space for switch machine installation, inspection and maintenance.

B2.10 Other Devices

B2.10.1 Rail Lubricators

Provide site-specific wheel/rail friction control measures on Restraining Rail curved track and other areas where noise or high rail wear is expected consistent with AREMA Chapters 4 and 5 and CEN EN 15427.

Locate rail lubricators at start of horizontal curves and point of first full wheel flange rail contact, with optimum location based on curve radius, actual super-elevation, super-elevation unbalance, and LRV speed.

Provide rail lubrication for gauge side of high rail and contact face of Restraining Rail.

Under no circumstances lubricate high rail leaving Restraining Rail dry as this may cause unsafe conditions.

Provide sufficient guideway space for rail lubricator cabinets, compressors, pumps, and drums.

Minimize length of rail lubricator tubing between lubricator pumps and applicator heads.

Protect rail lubricator tubing from impact damage.

Provide lubricants that minimize loss of traction and electric conductivity of negative return rail.

B2.10.2 Switch Clearing

Failure to clear snow and ice from switches may cause switch failure and, in worst cases, derailment.

Prevent accumulation of snow and ice around switch moving parts exposed to winter weather.

Provide switch clearing devices sufficient to keep switches exposed to winter weather free of ice and snow.

Provide switches exposed to winter weather with functioning heating systems remotely controlled and monitored from OCCs.

Provide element heaters for Main Line and Yard Track movable point frog turnouts.

Provide easy access for maintenance of switch clearing devices without requiring track component removal.

B2.10.3 Friction Buffers

Provide Main Line stub-end storage/pocket/tail track with sliding friction buffers able to absorb kinetic energy to safely stop a W1 Tare Weight 3-car LRV travelling at 10 km/h without damage to the LRV or exceeding 0.3 G deceleration rate.

Provide friction buffers hydraulic rams to absorb slow speed impacts of 5 km/h or less with only the friction buffer head contacting the LRV without lifting or derailment and friction buffer shoes that do not extend past the buffer housing.

Optimize each friction buffer speed rating based on site specific conditions and level of LRV protection.

Additional rails between running rails may provide additional storage of buffer shoes.

Coordinate with signal, track work, and civil design.

B2.11 System Interfaces

Consider track work effects on other systems and disciplines and vice versa.

B2.11.1 Traction Power

Coordinate track work and alignment closely with traction power OCS design.

MX LRT has established standard maximum OCS pole spacing.

Final OCS pole spacing and positioning depends on horizontal and vertical track alignment, Emergency Services access, semi-exclusive side street ROW, and Special Track Work locations.

Coordinate track work closely with OCS so that both are mutually compatible.

Use both running rails for traction power negative return.

Provide electric bonded bolted rail joints across joint bars with high conductivity bonds.

Identify cross bonding spacing requirements.

Coordinate track work, traction power, and signal/train control system design.

Take appropriate measures to minimize stray current leaks from track to ground.

See Chapter C1 – Traction Power and Chapter C5 – Stray Current and Corrosion Control.

B2.11.2 Signals/Train Control

Provide additional insulated joints, particularly at Special Track Work, at ends of Stations or other critical areas as may be required depending on signal/train control system requirements.

Coordinate insulated joint locations and placement with signal system design.

See Chapter C2 – Communications and Control.

B2.11.3 Electric Power

Coordinate track work and powered wayside track equipment with electric system design including:

- Powered switches;
- Switch heaters and blowers; and
- Wayside rail lubricators.

Consider track maintenance electric power outlet requirements along alignments in underground sections where fossil-fuel power equipment restrictions may apply.

See Chapter C3 – Facilities Electric Systems.

B2.11.4 Other Interfaces

Be familiar with the entire MX LRT Design Criteria Manual.

Consider the potential effect track work may have on other systems and infrastructure and vice versa.

TABLE B2-4 TRACK WORK INTERFACES

Chapter	Design Consideration	Impact On Track Work
A5 – Operations	Desired operating speeds Purpose and positioning of crossovers Station/Stop Locations	STW for desired speed at crossovers; STW for single track or uni-directional traffic; Identify locations with high rail wear due to LRV braking and acceleration.
B3 – Civil Works	ROW Drainage Roadway Requirements Utilities Mapping Noise and Vibration	Limit on size of wayside track equipment and space to inspect & maintain it; Coordination of track drain locations with appropriate municipal sewers; Determination of track work type; Provision of alternative fasteners or insulation near shallow or sensitive utilities;

Chapter	Design Consideration	Impact On Track Work
		Proximity of Critical Receptors. N&V levels of attenuation required and associated track work design.
B1 – Alignment, Clearances, Rights-of-Way	Curve Locations	Placement of Girder Guard Rail or Restraining Rail; identification of high-wear locations
A2 – Light Rail Vehicles	Wheel-Rail Interface Vehicle Configuration	Rail lubrication requirements, rail grinding requirements, rail wear rates, noise & vibration, loading on track structure; Minimum spacing between switches, selection of single-point or double-point switches.
B6 – Maintenance and Storage Facilities	Shop Layout Yard Walkway Plan	Post, Embedded, or Direct Fixation Shop Track. Location of track drains to intercept water before reaching walkways.
B4 – Structures	Bridge Deck Rebar Placement Bridge Thermal Expansion Location of Fixed Wayside Structures	Determine location of holes in fastener plates for bridge decks; Determine need for rail expansion joints; Determine locations for installation of bridge guard rail.

B3 Civil Works

B3.1 General

Chapter B3 addresses basic civil engineering criteria for Metrolinx (MX) Light Rail Transit (LRT) projects based on passenger safety and comfort, accepted engineering requirements, and Light Rail Vehicle (LRV) stability and performance.

Chapter B3 applies to MX LRT project renovation, alteration, and construction of new and existing streets, roads, access roads, ancillary facilities, and related works such as grading, paving, fencing, drainage, guideways, and Rights-of-Way (ROW).

B3.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Civil Works specific references include but are not limited to:

- Ontario Building Code (OBC);
- Ontario Provincial Standard Specifications (OPSS);
- Ontario Provincial Standard Drawings (OPSD);
- Ontario Provincial Policy Statement;
- Ontario Traffic Manual;
- Ontario Specification for GPS Control Surveys;
- Accessibility for Ontarians with Disabilities Act (OADA);
- Standards for Barrier Free Design of Ontario Government Facilities;
- Ontario Ministry of Transportation (MTO): Geometric Design Standards for Ontario Highways;
- MTO DDS: “Highway Drainage Design Standards”;
- MTO MI-183: Adaptation and Verification of AASHTO Pavement Design Guide for Ontario Conditions;
- MTO Publication SDO-90-01, Pavement Design and Rehabilitation Manual;
- MTO “Drainage Management Manual” (DMM);
- Ontario Ministry of Environment (MOE): Guidelines for Design of Sanitary Sewage Work, Storm Sewer, and Water Distribution Systems;
- Transportation Association of Canada (TAC): Geometric Design Guide for Canadian Roads;
- Manual of Uniform Traffic Control Devices for Canada (MUTCD);
- National Fire Protection Association (NFPA) 101: Life Safety Code;

- NFPA 130: Standard for Fixed Guideway Transportation Systems;
- American Association of State Highway and Transportation Officials (AASHTO): Guide for Design of Pavement Structure;
- AASHTO Roadside Safety Manual: A Policy on Geometric Design of Highways and Streets;
- American Railway Engineering and Maintenance-of-Way Association (AREMA);
- Illuminating Engineering Society of North America (IESNA) RP-8: Design Guide;
- National Research Council - Transit Cooperative Research Program (TCRP) Report 57: Track Design Handbook for Light Rail Transit;
- TCRP Report 69: Light Rail Service Pedestrian and Vehicle Safety.

OBC governs where conflicts arise unless otherwise stated.

B3.3 Acceptance

Submit proposed new additions or modification to municipal roadways, drainage, lighting, traffic signalization, signage, and facilities for MX LRT and AHJ review and acceptance.

Series 400 Highway works, including interchange areas, require MTO review and acceptance.

Provide Civil Works Drawings indicating:

- Tie-ins to existing pavement, curbs, etc.;
- Pavement elevations including direction of surface drainage;
- Cross-fall and longitudinal roadway slopes including crossings to abutting property;
- Cross-sections and details indicating LRT guideways, structures, landscaped areas, and roadway cross-falls;
- Plans and details indicating Overhead Contact System pole locations, light pole locations, bicycle lanes, roadway/walkway structures, limits of construction, and ROW;
- References to standard construction specifications and drawings of AHJ;
- Traffic signalization, pavement markings, and signage plans prepared for and accepted by AHJ.

B3.4 Roads and Paving

Provide roads and streets per specifications, standards, and guidelines of AHJ.

Use MTO, OPSS, and OPSD where no other guidelines apply.

Provide pavement structural cross sections to support anticipated 30 Year service life traffic.

Determine minimum limits of construction to accommodate LRT systems and facilities.

Consider proposed LRT sections and clearance envelopes, roadway sections, roadway drainage, utility relocations, and related geometry issues.

Provide new and replacement streets and facilities owned or maintained by others than MX LRT per requirements of AHJ.

Traffic Lane Widths

Minimum traffic lane widths exclusive of gutter:

Type	Minimum	Preferred
Through Traffic Lanes	3.3 m	3.5 m
Left Turn Lane	3.0 m	3.3 m

Reduce width as necessary in case of ROW constraints.

Number of Traffic Lanes

Typical roadway design longitudinally along LRT lines includes two traffic lanes minimum each direction.

Parking

Parking prohibition for local parking arrangements is recommended where roadway width allows only for the number of through lanes needed, e.g., near intersections and at Stations and Stops.

Street Grades

Provide 0.4% minimum longitudinal grade with 0.5% minimum slope around street curbs and gutters.

Provide 1.0% maximum change in longitudinal slope per 15 m straight horizontal distance without vertical curve transition.

Provide 1.0% minimum/4.0% maximum with 2.0 to 3.0% preferred street cross slopes.

Provide slopes in street intersections with LRT crossings for smooth street and LRT guideway profiles and LRV ride quality for posted speed limits.

Address urban relationships at street and adjacent property interfaces.

Curbs

Provide mountable curbs for emergency vehicle access to/from side streets with 100 mm to top of vertical face including a rounded corner.

Provide outboard portion angled flush to top of inboard face of curb for LRT ROW more than 100 mm above street level.

Provide new non-mountable median curbs 300 mm wide x 150 mm high, e.g., roadways, LRT guideways, ROW separations, and approaching intersections.

Provide 150 mm high curb at embedded track sections.

No curbs allowed where emergency service facilities or driveways front onto LRT ROW.

Curb Ramps

Provide access for the mobility impaired.

Reconstruct or replace existing ramps affected by construction.

Provide new ramps at existing intersections for modified sidewalks and curb returns.

Provide curb ramps at street intersections with brail treatment accepted by AHJ.

Provide LRT Stops with access points to platforms at intersections and ramps at four corners.

Provide and locate Station and Stop curb cuts and ramps to discourage jay-walking but allow egress from medians per requirements of AHJ.

Provide 1.0 m long landings between pedestrian crossings and platform ramps.

Sidewalks

Provide sidewalks per standards of AHJ.

Provide 2.0% minimum/3.0% maximum sidewalk cross slopes.

Reconstruct or replace existing sidewalks affected by LRT construction.

Provide new sidewalks only per MX LRT and AHJ review and acceptance.

Crosswalks

Provide LRT Station and Stop intersections with crosswalks per standards of AHJ.

Street Lighting

Provide LRT ROW with high quality light pole, fixture, and brackets per MX LRT urban design objectives, Design Excellence requirements, and AHJ standards.

B3.4.2 LRT Guideways

Protect at-grade LRT Exclusive ROW guideways from other transport modes.

Provide raised medians 150 mm high typical at LRT guideway mid-block locations.

Provide mountable curbs near half-way point for LRT sections longer than 1 km without any side-streets subject to MX LRT and AHJ review and acceptance.

Provide signage identifying curb cuts for emergency vehicles.

Provide LRT guideway crossings where emergency service facilities or driveways front onto LRT ROW.

Provide LRT guideways flush with adjacent emergency service facility roadway access frontage points.

Provide concrete curbs separating guideway and adjacent traffic while allowing emergency vehicle access where mid-block street-level guideways approach signalized intersections.

Provide LRT guideways level with roadways to allow level LRV crossings through signalized intersections.

Provide emergency vehicle turning radii for driving lanes at LRT guideway intersections.

Provide typical curbs along new, widened, or reconstructed roads owned or maintained by AHJ.

B3.4.3 Driveways

Consider property use, number of driveways, and available ROW width in driveway design.

Provide driveway types and minimum widths per requirements of AHJ.

Replace affected existing driveways in kind unless doing so would create unsafe operations.

Identify and submit opportunities to close driveways or improve LRT ROW streetscape and pedestrian conditions to sites served by adjoining streets or driveways for MX LRT and AHJ review and acceptance.

B3.4.4 Pavement

Replace or widen pavement existing prior to LRT construction with similar materials except when existing pavement is substandard.

Replace substandard pavement with pavement per current specifications, standards, and practices of AHJ.

Under no circumstance provide pavement of less than minimum requirements and standards of AHJ.

B3.4.5 Traffic Management

Provide Traffic Management Plans including detailed design drawings with traffic staging and detour plans throughout work zones for public safety and efficient control and maintenance of vehicle and pedestrian traffic during construction.

Submit Traffic Management Plans for MX LRT and AHJ review and acceptance.

Specific Traffic Management Plan elements include:

- Pavement markings, signs, and traffic control devices to indicate lane change configuration and designated contractor work zone access/egress points;
- Traffic barriers separating work zones/vehicle/pedestrian traffic;
- Traffic signals;
- Detour plans and signs;
- Advance construction notification plans such as variable message signs.

Carefully weigh the many interdependent factors in developing Traffic Management Plans.

Evaluate effect of one prioritized factor on other factors to maintain a balance between safety, mobility, accessibility, and on-going construction activity.

Include necessary lane closures, detour routes, street and sidewalk closures, local access special provisions, access to businesses, bus stop relocations, construction related pavement markings, construction zone signs, and traffic requirements of AHJ.

Provide details of notifications for emergency vehicles, heavy vehicles, cyclists, and pedestrians.

Signals

Provide relocated, temporary, and new traffic signals, signal controllers, pull boxes, poles, and associated equipment requiring changes in design, operation, or placement for AHJ review and acceptance.

Provide new traffic signal installation warrants per MUTCD requirements.

Perform work involving traffic signal equipment by AHJ accepted and licensed electric contractors.

Pavement Markings

Provide pavement markings during construction using non-lead paint only per MUTCD standards for AHJ review and acceptance.

Signs

Provide Traffic Management Plan signage per MUTCD standards for AHJ review and acceptance.

Provide temporary construction signs for AHJ review and acceptance.

Restore existing signs removed during construction as and when required by AHJ.

Lane Closures

Provide lane closures per MUTCD and AHJ standards and guidelines.

Provide lane closure plans for AHJ review and acceptance.

Traffic Detour Plans

Provide Traffic Detour Plans per MUTCD standards for temporary road and/or traffic detours for AHJ review and acceptance.

Include assessment of diverted traffic effect on detour routes.

Include complete signage plans based on sign fabrication/placement/removal protocols and advance signage with appropriately located variable message signs.

Temporary Full Road Closures

Roads will only be closed where no other feasible solution is available.

Where road closure is required, it is essential to minimize delays as follows:

- Avoid peak period closures;
- Maximize working days, i.e., 24 hours/7 days per week, subject to AHJ noise bylaws and Health and Safety Act exemptions; and
- Agree suitable diversion routes with AHJ transportation services/work zone traffic coordinators.

Submit road closure applications with work program/method statements as evidence of need and to confirm start/end dates.

Coordinate road closures and other works or local events with AHJ.

Area roads including repair or reconstruction of detour roads affected by commercial or heavy truck traffic may require separate truck, bus, and car diversions.

Submit proposed road detour conditions as part of road closure applications for AHJ review and acceptance.

Submit road closure application plans indicating roads to be closed and proposed diversion routes.

Identify any diversion route restrictions or obstacles that may affect traffic, e.g., low bridges, narrow roads, one way streets, and width, height, weight and/or vehicle class restrictions.

B3.4.6 Bicycle Facilities

Bicycle Facilities

Provide 1.6 m wide bicycle lanes including width of gutter unless otherwise indicated per Environmental Assessment Studies and accepted by AHJ.

Shared bicycle/pedestrian traffic is not acceptable unless typical 1.6 m wide bicycle lanes cannot be accommodated within street ROW.

Provide bicycle facilities per requirements and standards of AHJ.

B3.5 Storm Drainage

Provide LRT storm drainage systems for storm runoff, erosion, and flooding protection per standards and storm water management policies of Ontario Ministry of Natural Resources (MNR) Conservation Authority, MOE, and MTO for AHJ review and acceptance.

Provide "replacement-in-kind" or "of equal construction" for drainage systems relocated or modified due to LRT construction that do not cross or run parallel with LRT systems, facilities, or guideways per AHJ criteria.

Provide gravity flow drainage in so far as practical.

Provide pump stations for LRT line sections below gravity outfall points.

Do not allow sanitary sewer discharge to enter LRT drainage systems.

Investigate control methods for LRV braking sand and track oil/grease runoff.

Provide Quality Assurance and Quality Control per sewer by-laws of AHJ.

B3.5.1 Systems and Facilities

Provide Drainage Reports to identify and verify sufficiency of drainage systems and facilities.

Present alternatives and recommendations to modify existing drainage systems and facilities.

Protect or upgrade existing drainage systems and facilities to allow existing drainage to flow without diversion to existing outlet points.

Size new drainage systems for design storm frequency specified by AHJ.

Provide drainage systems compatible with adjacent upstream and downstream drainage system sections.

Coordinate drainage pipe locations and elevations at ends of each LRT section.

Provide replacement drainage systems equal to or better than existing drainage systems.

Provide drainage services to support-in-place and maintain operations of adjoining properties.

Alternative temporary drainage facilities or drainage diversion to other collection points may be required.

Comply with MX LRT and AHJ requirements.

B3.5.2 Discharge

Calculate maximum expected drainage area discharge per criteria and standards of AHJ.

Consider mitigating drainage discharge per green standards and design guidelines of AHJ.

B3.5.3 Design Storm Requirements

Provide arterial road storm sewers sized for 10 Year return period storms without surcharge.

Provide LRT guideways, streets, open channels, and walkways for runoff flows in excess of minor system design capacity to accepted public outlets.

Provide combined overland flow systems and minor systems for 100-year return period storms to prevent private property flooding during maximum road flooding levels.

Provide LRT guideways and structures to avoid flood damage up to and including 25-year storm events.

Provide and protect drainage facilities for design storm frequencies as follows:

Drainage Facility	Design Storm Frequency
New culverts and drainage facilities where flooding could damage LRT systems.	100 Year
Road underpasses: Flow spread must leave at least one lane in each direction free of water; LRT guideway space allowances may substitute for traffic lanes.	10 to 25 Year
Longitudinal storm drains in roadways.	10 Year
Parking lot storm sewer systems.	10 Year
Longitudinal drains or sub-drains at low points that could flood roadways or LRT guideways.	10 Year

Except in areas of existing urban property development, new LRT related urban property development including buildings, structures, and associated private services such as parking facilities and septic systems is not allowed within valley and stream ROW.

B3.5.4 Storm Drains

Upsize existing storm sewers per requirements of AHJ.

Supplement any reduction in public retention volume due to roadway widening.

Provide new storm sewers as follows:

- Private Property: Storm drain design criteria generally covers retention basin sizing for development outside Street ROW;

- Public Property: Storm drain design criteria generally covers Street ROW.

For convenience and safety, the 1 in 2 year, i.e., minor storm, maximum arterial road pavement ponding encroachment is:

- No curb overtopping; and
- Flow spread leaving at least one lane in each direction free of water.

LRT guideway structure space allowance may be substituted for traffic lanes.

B3.5.5 Pipe Sizes

Provide surface drainage pipe size diameters as follows:

- Culverts under LRT guideways: 500 mm preferred, 300 mm absolute minimum;
- Storm sewers: 300 mm minimum;
- Single catch basin leads: 300 mm minimum;
- Double catch basin leads: 300 mm minimum;
- Sloped drains: 150 mm minimum; and
- Sub-drains: 150 mm minimum.

B3.5.6 Pipe Clearances

For new track drain pipe passing under LRT guideway structures, 1700 mm minimum clearance from top-of-rail to top-of-pipe is preferred unless otherwise reviewed and accepted by MX RT.

For existing track drain pipe, 1300 mm minimum clearance from top-of-rail to top-of-pipe is required.

Otherwise relocate track drain pipe as needed.

Design exceptions may apply, e.g., pipe installed in steel casing where relocation is not practical due to location, risk, or cost subject to MX LRT and AHJ review and acceptance.

B3.5.7 Pipe Materials

MX LRT criteria allows both rigid and flexible storm sewer pipe including reinforced concrete for pipe 450 mm diameter or greater and Polyvinyl Chloride (PVC) for pipe 375 mm diameter or less.

Provide reinforced concrete pipe per CSA A257.2-03 minimum 65-D.

Verify height of fill per OPSD tables 807.010 and 807.030.

Provide pipe bedding per OPSD 802.010 to 802.053 with non-shrink backfill.

Provide Main Line PVC pipe per SDR 35 CSA B182.2-06 certified ASTM D3034-04a F679-03.

Provide service connection PVC pipe per SDR 28 CSA B 182.2-06 certified ASTM D3034-04a.

Ribbed profile wall PVC pipe is not allowed in storm sewer construction.

Cast-in-place unreinforced concrete pipe is not allowed in the vicinity of LRT projects.

Depth of cover, geotechnical, and loading conditions determine class of pipe, bedding, and backfill type.

Rigid pipe is recommended in areas of high utility congestion where future bedding may be undermined.

In most cases provide non-shrink backfill material.

Evaluate existing circular storm drains under LRT guideways for clearance requirements, material types, and structural strength per required loadings.

Field investigate, review, and document storm drains in addition to examining as-built plans within 3 m of LRT guideways for material types, flow-line grades, and pipe condition.

Include up-to-date videos documenting existing pipe condition.

Provide a second video evaluation of sections with less than 1700 mm cover following initial rail bed compaction and prior to foundation slab concrete placement.

Replace corrugated metal pipe drains with concrete pipe.

Replace drains that do not meet MX LRT and AHJ requirements.

Drains that meet MX LRT design criteria may be left in place with MX LRT and AHJ review and acceptance.

B3.5.8 Manholes

Provide maintenance manholes at changes in pipe size, direction, and trunk line intersections.

Provide storm drain facilities in public ROW per criteria of AHJ.

Size precast storm drain manholes based on incoming and outgoing pipe sizes per standards of AHJ.

Minimum manhole diameter: 1200 mm.

Maximum allowable horizontal spacing between manholes per criteria of AHJ.

Maximum allowable horizontal spacing between manholes as follows:

- Sewer Diameter 300 mm to 975 mm: 110m;
- Sewer Diameter 1050 mm to 1350 mm: 130m;
- Sewer Diameter 1500 mm to 1650 mm: 160m;
- Sewer Diameter 1800 mm and larger: 305m.

Larger diameter storm drains may use greater manhole spacing.

Provide storm drainage design plans for MX LRT and AHJ review and acceptance.

B3.5.9 Underdrains

Underdrains may be required based on geotechnical reports.

Provide underdrains where groundwater may interfere with roadbeds, LRT guideways, or side slope stability:

- Along toe or side of cut slopes to intercept seepage;
- Along toe of fill on the side from which groundwater emanates;
- Across roadways at downhill end of a cut;
- Along perimeters or within paved areas under which groundwater is likely to collect.

Provide underdrains for LRT guideway structures in street ROW.

Provide underdrains to collect surface runoff along LRT guideways, in retained cuts, on retained embankments, and in areas with several adjacent tracks, e.g., LRV Yards.

Underdrains comprise 150 m minimum length x 150 mm minimum diameter perforated concrete or perforated PVC pipe surrounded by 20 mm clear crushed limestone encased in geotextile fabric with effective opening size to prevent material migration into the encasement.

Provide granular backfill behind retaining/gravity walls from top of underdrain to underside of top soil.

B3.5.10 At-Grade Track

Provide at-grade track drainage for LRT Exclusive and Semi-Exclusive ROW with ditches, catch basins, manholes, and/or underdrains.

Provide 0.3% minimum longitudinal track gradient for LRT Exclusive ROW drainage.

Match LRT guideway longitudinal grade with street grades for LRT Semi-Exclusive ROW drainage.

Provide track drainage systems and facilities to prevent water from ponding, contributing to subgrade instability, or covering any part of LRT guideways.

Provide retaining walls where ROW constraints do not allow standard ditch sections.

Consider areas adjacent to LRT guideways where elements such as streets, parking facilities, roads, landscaping, walls, etc., may adversely affect track drainage.

Provide track drains in paved LRT guideways to properly drain pavement between rails.

Connect drain pipes to closest storm drains.

Provide drains spaced 45 m maximum at Special Track Work, switches, and track profile low points.

Provide drains for switch machines, switch indicators, and switch snowmelt junction boxes, signal junction boxes, and train to wayside communication loop junctions.

B3.5.11 Elevated Track

Provide elevated track drainage via longitudinal open channels in track slabs with 0.3% minimum gradient connected to vertical drain pipes recessed in columns or piers upstream of track slab expansion joints.

Provide drain pipes and inlets exposed to ambient conditions with freeze protection electric heat tracing cables to prevent snow build-up and/or ice blockage.

Elevated track drain pipe diameter: 100 mm minimum.

B3.5.12 Yard Track

Provide LRV Yard Track with complete drainage systems and facilities.

Yard Track drainage systems and facilities include but are not limited to perforated underdrains between alternating pairs of tracks connected to laterals, collectors, and outfall structures.

Provide ditches, catch basins, and storm drain pipes to direct surface runoff away from Yard Track areas.

Collect Yard Track underdrain flows with discharge into local storm drain systems.

Provide Yard Track drainage systems and facilities to support MX LRT compliance with AHJ bylaws.

Provide appropriate storm water retention facilities per requirements of AHJ.

Provide Storm Water Management Plans for environmental impact mitigation of Yard Track development, installation, and operation.

Include appropriate controls in Storm Water Management Plans to mitigate storm water quantity and quality effects on both upstream and downstream landowners.

Investigate methods to control braking sand and track oil/grease runoff in addition to complying with requirements of AHJ.

Provide manholes per Section B3.5.8 and main collectors for drainage system maintenance.

Length of individual subdrain runs: 90 m maximum with cleanouts at upper end of each subdrain run.

Provide drains for switch machines, switch indicators, switch snowmelt junction boxes, signal junction boxes, and train to wayside communication loop junctions.

B3.5.13 Above Ground Structures

Provide above ground structure drainage per Storm Water Management Plans.

Do not route roof storm water runoff to underground structure drainage systems in so far as practical.

With design coordination as required consider alternative solutions such as:

- "Green Roofs";
- Landscaped areas for storm water detention and evaporation;
- Storm water storage and re-use; and
- Special construction to improve groundwater recharge.

B3.5.14 Underground Structures

Collect and convey via LRT guideway drainage systems only surface runoff from open cut areas leading to tunnels or box portals, groundwater seepage through underground construction and expansion joints, and ventilation shaft catch basin drainage.

Prevent sanitary sewage from entering guideway drainage systems.

Provide self-cleansing LRT guideway drainage systems.

Provide underground LRT guideway drainage systems requiring no traps or vents.

Box Structures

Underground LRT guideway running structure drainage for box structures and Stations includes concrete troughs formed in structural invert slabs under track ties, the same as tunnel structures.

Storm water flows along the troughs to gravity outlets relying on pumping only when necessary.

Where required, pump stations are at drainage system low points with collection points below gravity outfall elevations.

Tunnels

Underground box running structures guideway drainage includes a concrete trough formed in structural invert slabs located under track ties, the same as tunnel structures.

Tunnel guideway drainage includes a concrete trough formed in structural invert slab located under track ties, the same as underground box running structures.

Storm water flows along the troughs to pump stations at system low points with collection points below gravity outfall elevations.

Do not locate catch basins and manholes in tunnel structures.

Special Track Work

Underground LRT guideway Special Track Work drainage comprises manholes, ballast drains, and recesses connected by buried storm drain pipe.

Pump stations collect storm water near Special Track Work and pump it to storm water manholes to drain by gravity flow to municipal storm sewers.

Underground LRT Guideway Drain Pipe Sizes:

- Storm Water Sewers: 250 mm minimum;
- Catch Basin Leads: 150 mm minimum.

Provide concrete or PVC storm sewers and laterals per CSA standard for the particular pipe diameter.

Encase storm drain pipes in non-shrink fill.

Depth of cover, geotechnical, and loading conditions determine class of pipe, bedding, and backfill type.

Manholes

Provide 840 mm x 1220 mm storm water drain manholes along one track only in multiple box structures.

Locate manholes in isolated slab track work adjacent to track and provide two grating access panels due to restricted space between rail ties.

Locate manholes in double tie track work along the centre of track to coincide with special double ties and provide grating access panels.

Provide manhole bottoms 300 mm deeper than outlets.

Provide manhole platforms and other safety devices per Occupational Health and Safety Act and AHJ requirements.

Maximum manhole spacing: 31 double ties or approximately 4570 mm.

Coordinate manhole and double tie spacing.

Catch Basins/Silt Traps

Double Ties

Provide invert slab catch basins minimum 350 mm x 500 mm x 400 mm deep at centre of tracks.

Provide superelevated curves with 2.5% gradient recessed chases perpendicular to LRT guideways to intercept catch basin storm water.

Provide invert slab silt traps minimum 840 mm x 1220 mm x 300 mm deep at centre of tracks spaced 10 double ties or approximately 1475 mm maximum on center along trough drainage systems.

Do not locate silt traps on contraction joints.

Coordinate catch basin, silt trap, and double tie spacing.

Isolated Track Slabs

Provide ballast drains above isolated track structural slabs at centre of tracks between ties draining into 400 mm x 400 mm x 300 mm deep minimum recesses directly under drains.

Provide minimum 840 mm x 1220 mm x 300 mm deep chases with 1% minimum gradient recessed into structural slabs adjacent and perpendicular to LRT guideways.

Provide manholes, catch basins, and silt traps as above.

Maximum manhole spacing: 45 m.

Underground Pump Stations

Locate pump stations in cross passages and adjacent to Special Track Work at drainage profile low points.

Provide pump stations allowing surface rather than confined space equipment removal/replacement.

Locate pump stations near Stations or at ends of crossovers closest to Stations.

Coordinate pump stations with other passage and shaft drain pipe connections to shared sump pits.

Coordinate pump station vertical profile low points with other facilities drainage requirements.

B3.5.15 Water Resources

Investigate water resources as follows:

- Water quality requirements per local, provincial, federal government and AHJ regulations;
- Project environmental impact studies and mitigation reports;
- Municipal drainage plans;
- Local flooding and drainage records; and
- Regional watershed management plans.

Obtain copies of existing and adjacent municipal storm sewer plans.

Identify existing culverts and storm sewers.

Provide existing and new drainage system and facility condition ratings as part of project hydraulic infrastructure inventories.

Determine proposed LRT alignment effects on existing drainage and sensitive environmental areas.

Provide drainage systems and facilities required to extend existing drainage patterns and systems.

Where drainage patterns need to change due to LRT project conditions and requirements, coordinate and verify that proposed changes are satisfactory and submit MX LRT and AHJ for review and acceptance.

Document coordination and resolution of these issues.

Prepare comprehensive Storm Water Management Reports.

Comply with storm water management permit requirements of AHJ.

B3.5.16 Storm Water Quality

LRT guideway and ROW structures do not qualify as redevelopment and thus do not require 10% storm water pollutant load reduction.

New LRT ROW impervious areas are exempt from storm water quality criteria.

LRT passenger platform areas do not count as additional impervious area.

B3.5.17 Corrosion Protection

Provide stray current and corrosion control for LRT underground drainage systems and facilities.

See Chapter C5 – Stray Current and Corrosion Control.

B3.5.18 Acceptance

Provide storm water drainage systems and facilities per standards and requirements of AHJ.

Submit storm water drainage systems and facilities design and reports for AHJ review and acceptance.

B3.6 Rights-Of-Way and Easements

LRT ROW requirements vary per at-grade, elevated, or underground LRT guideway configuration.

LRT ROW can be further classified as Exclusive, Semi-Exclusive, and Non-Exclusive.

LRT ROW are the composite total requirement of real property interests and uses needed to build, maintain, protect, and operate LRT systems.

Some ROW requirements are temporary, addressing design and construction needs, while other ROW requirements are permanent as prescribed by operating or other needs.

MX LRT intends to acquire and maintain minimum ROW required for LRT projects consistent with LRT system requirements and industry best practices.

Since MX LRT and AHJ accepted ROW Plans form a basis for property acquisition, indicate ownership interests and required uses as well as detailed property dispositions on ROW Plans.

Topography, drainage, ditches, utilities, retaining walls, service roads, construction clearances, and the nature of particular structures and side slopes influence limits and extent of LRT ROW envelopes.

Indicate permanent LRT ROW limits on ROW Plans as unbroken lines using simple curves and tangents.

Do not use spiral curves in LRT ROW descriptions or depictions.

Chords may be used in lieu of curves in special conditions per MX LRT and AHJ review and acceptance.

B3.6.1 Types

Fee Taking ROW

Fee Taking ROW comprise full ownership of property in whole or in part.

Fee Taking ROW is the first type of ROW to be considered for LRT surface or elevated alignments;

If this is impractical, then consider another type of ROW.

Permanent Surface Easements

Permanent Surface Easements are non-possessing interests held by one party in land of another party whereby the other party confers upon the first party partial use of the land for specific purposes.

Permanent Surface Easements with upper limits provide space required for LRT structures and maintenance of LRT structures supporting elevated LRT facilities on private property.

Permanent Surface Easements include definite lateral, upper, and lower limits for basic track width, drainage, supporting slopes, utilities, etc., as described and depicted on ROW Plans.

Consider overall effect of Permanent Surface Easements on affected property.

Permanent Underground Easements

Permanent Underground Easements include entire LRT facilities under the surface of the earth with definite lateral and upper limits as described and depicted on ROW Plans.

Describe and depict Permanent Underground Easement lower limits on ROW Plans only for special limiting features.

Permanent Elevated Easements

Permanent Elevated Easements completely envelope the total elevated portion of LRT facilities with definite lateral, upper, and lower limits as described and depicted on ROW Plans.

Permanent Elevated Easements also include LRT supporting elements that may require special treatment.

Construction Easements

Construction Easements are temporary easements with definite durations in time providing space for use of property during construction as described and depicted on ROW Plans.

Utility Easements

Utility Easements are subject to relevant AHJ regulations.

Treat Utility Easements as ROW with bearings and distances along easement sides, lengths, and widths tied to ROW easement limits as described and depicted on ROW Plans.

B3.6.2 Criteria

The following criteria serve as guidelines for establishing LRT ROW easement limits.

LRT ROW easement limits describe and depict minimum conditions in vertical and/or horizontal planes.

Easement limits describe and depict minimum conditions subject to modification required for additional LRT engineering, alignment, clearance, and/or real estate needs.

At-Grade Alignments

At-grade LRT alignments normally do not require upper limit easements.

Where at-grade LRT alignment upper limit easements are required, provide 5 m minimum vertical clearance from top-of-rail to top of LRV horizontal plane.

LRT at-grade alignments require lateral limit easements for operations, maintenance, and repair.

Provide LRT Semi-Exclusive ROW with 1900 mm minimum lateral limit easements from centerline of nearest track to limit of road traffic lane ROW.

Lower limit easements are defined similar to upper limit easements.

Wherever possible provide 3 m minimum vertical clearance below top-of-rail and lower limit easements except in retained fill sections where lower limit easements include required structural support.

Elevated Alignments

Horizontal plane elevations define LRT elevated alignment upper limit easements.

Provide LRT elevated alignment upper limit easements 5000 mm minimum vertical clearance from top-of-rail to LRV horizontal plane.

Provide LRT elevated alignment lateral limit easements 1000 mm minimum beyond limit of structures.

Maintenance and Storage Facilities may require additional elevated alignment easements.

LRT elevated alignment lower limit easements are ground level easements with specific use restrictions except where crossing other ROW.

LRT elevated alignment lower limit easements include support foundations.

Stations and Stops

LRT Station and Stop easements include entrance structures, concourses, passenger platforms, vent and access shafts, as well as waiting, fare collection, ancillary, and other required support areas.

Provide LRT Station and Stop easements for required pedestrian and vehicle circulation as well as structural, mechanical, and electrical space as well as emergency services, maintenance personnel, and motor vehicle access.

Tunnels

Provide tunnels with appropriate maintenance and fire fighter access shaft easements.

Fire fighter access and vent fan shafts may be located in road ROW but not in roads themselves.

When located on private property, tunnel ROW easement limits are 3 m from outside face of structure.

Storm Drainage

Open Ditches

Channel width capacity for storm water runoff and access/maintenance requirements govern minimum total storm drainage easement width per requirements of AHJ.

Underground Drainage

As a guideline, 3 m minimum storm drainage easement width and 600 mm minimum clearance from outside edge of structure to easement line, subject to AHJ review and acceptance.

B3.6.3 Information Requirements

Curve Data

Circular curves are the only types of curves acceptable for ROW recording purposes.

Reduce spirals to circular curves at ROW easement limits.

Indicate curve data on ROW Plan curve data tables.

Use tangent sections instead of curves to indicate ROW easement limits for extremely flat curves.

Continuous ROW

Although MX LRT may not require public property acquisition, indicate ROW envelopes and identify easement limits as continuous ROW across public as well as private space.

Isolated ROW

Geometrically define ROW boundaries for easement areas supporting new construction such as fire fighter access, vent shafts, and substations.

Indicate ties wherever easements for new construction are not contiguous to ROW boundaries.

Multilevel ROW

LRT ROW may require multilevel easements, i.e., Strata Plans, for example at Station entrances located in private buildings.

Provide separate detailed multilevel easement ROW Strata Plan Drawings for MX LRT use indicating private property interests for each individual proposed stratified level as follows:

- Note and separately indicate each floor and connecting access route such as stairs and escalators affected by LRT facilities;
- Provide separate entries in parcel lists for each level;
- Locate, dimension, and identify each type of strata on every level with appropriate symbols;
- Provide elevations for each strata cross referenced to geodetic datum.

Strata Plan elevations normally are from underside of one strata level to underside of next strata floor.

Public Space ROW

Provide Public Space ROW Plans indicating vaults, fire escapes, signs, display windows, footings, foundations, and other projections into public property space to be removed for LRT construction.

Also account for private property space, buildings, building elements, foundations, etc., that LRT construction or operations may affect.

Underpinning

Provide Preliminary ROW Plans to establish or identify existing structures and locations that may potentially require underpinning.

Where design is further advanced, provide more detailed ROW Plans with required underpinning details indicating easement dimensions, property lines, structural supports, and access for construction.

Street Closings

Provide separate Street Closure Drawings indicating public property to be closed for LRT use during construction per requirements of AHJ.

B3.7 Fencing

LRT perimeter fencing forms an open-ended envelope allowing unrestricted LRV movement with both fence sides easily accessible for regular maintenance so that perimeter lines remain obstruction free from adjacent structures, fences, and vegetation.

Provide fencing to protect LRT ROW, bridges, and track, as well as to discourage pedestrians and motorists from dropping or throwing objects onto LRT guideways, roadways, expressways, or other ROW.

Provide functional as well as visually attractive LRT perimeter fencing parallel to tracks along LRT Exclusive ROW, around LRV MSF property lines, and inside LRT Yard Track areas.

Consider wrought iron, ornamental steel, and other fencing for aesthetic reasons in some areas.

Coordinate with MX LRT Design Excellence requirements for MX LRT and AHJ review and acceptance.

See Chapter A4 – Security for fences and gates.

See Chapter B1 – Alignment, Clearances, Rights-of-Way for fence clearance requirements.

See Chapter C3 – Facilities Electric Systems for fence grounding requirements.

See Chapter C5 – Stray Current and Corrosion Control.

B3.8 Duct Banks

Provide cable duct banks for signal, communications, fare collection, traction power, traffic control, etc.

Underground cables connect LRT ROW Traction Power Substations, Overhead Contact Systems, and negative return rails with extensive duct bank networks, branch ducts, and cable conduit.

Branch duct banks between signal equipment cases, houses, and rooms connect manholes and pull boxes to turnout and crossover wayside equipment.

B3.8.1 Construction

Duct banks not only protect enclosed cable but also prevent damage to duct banks themselves.

Preferred duct bank construction method is PVC or equivalent pipe encased in concrete.

Consider alternative duct bank construction methods, e.g., raceways, subject to MX LRT and AHJ review and acceptance.

Provide ducts and components to form continuous duct bank systems.

Slope duct banks 10 mm in 3 m for drainage.

Limit fibre optic cable bend radii to no less than 10 times largest cable outside diameter or per cable manufacturer recommendations.

Provide duct bank straight section pull boxes and manholes at 120 m maximum on centre.

Provide pull boxes or manholes for cumulative bends less than 270 degrees.

Normally locate pull boxes in non-traffic areas, preferably inside LRT ROW.

Normally locate manholes in ROW areas likely to carry traffic.

Provide manhole floor sump drains that cannot drain into sub-drain systems.

Provide pull boxes and manholes with effective flexible bonding and grounding cables or wires with green insulation per requirements of AHJ.

Provide branch duct banks for stub-up points and branch lines with main duct bank system to stub-up or branch duct bank points.

Provide exposed stub-up points in rigid conduit from bend upward.

Encase branch duct banks in concrete.

Civil limitations due to lower emergency and service walkway heights in tunnel and elevated sections may affect full implementation of embedded conduit.

Provide space proofing for cable wall mounting subject to MX LRT review and acceptance.

B3.8.2 Arrangements

Provide duct bank arrangements including fully embedded segregated conduit as follows.

At-grade Sections

Traction Power/Electric

Single Contact Wire.

Centreline Duct Banks with LRT Poles

Two separate ducts with one 50 mm and two 100 mm street lighting conduits.

Systemwide Duct Banks

Nine minimum 100 mm Main Line at-grade ducts.

Signals

One express/local Main Line 100 mm duct and one spare 100 mm duct.

Three additional local Main Line 100 mm ducts at Interlockings only.

Communications

One primary 100 mm duct, one secondary 100 mm duct, and two 100 mm spare ducts.

Electric

One spare 100 mm duct.

Other

One primary 100 mm duct.

Underground Sections

Nine minimum Main Line ducts under safety/service walkways each side per separation requirements.

Signals

One express/local Main Line 100 mm duct, one spare 100 mm duct, and three local Main Line 100 mm ducts at Interlockings only.

Communications

One primary 100 mm duct, one secondary 100 mm duct, and one spare 100 mm duct.

Electric

One primary 100 mm duct, one secondary 100 mm duct, and two spare 100 mm ducts.

Elevated Sections

Six 100 mm minimum Main Line ducts per side for elevated sections without centre safety walkways.

Left Safety Walkways

Signals

One express/local Main Line 100 mm duct, one spare 100 mm duct, and three additional local Main Line 100 mm ducts at Interlockings only.

Communications

One primary 100 mm duct and one spare 100 mm duct.

Electric

One primary 100 mm duct and one spare 100 mm duct.

Right Safety Walkways

Signals

One express/local Main Line 100 mm duct, one spare 100 mm duct, and three 100 mm local Main Line ducts at Interlockings only.

Communications

One secondary 100 mm duct and one spare 100 mm duct.

Electric

One primary 100 mm duct, one spare 100 mm duct, and traffic signal/communications ducts per AHJ.

B3.8.3 Branch Duct Banks

Signals

Two 100 mm ducts to signal/communications cabinet pull boxes and six 100 mm ducts to crossover signal equipment room pull boxes.

Communications

Four 50 mm ducts to each Station and Stop signal/communications cabinet.

Electric

One 50 mm electrical duct to platform pole and base.

Traction Power

Four 100 mm traction power ducts and two electric spare ducts.

Single Wire 50 mm ducts to Traction Power Substations.

Traction Power

One 50 mm traction power duct to Overhead Contact System poles and bases.

Single Wire

Base.

B3.8.4 Identification

Identify duct banks with LRT outbound direction as facing direction.

Individually number pull boxes and manholes on drawings and in the field.

B3.9 Control Surveys

B3.9.1 Horizontal Control

Provide LRT element and facility Baseline Survey reference horizontal control points.

Provide GPS 2nd order horizontal control point coordinates per Ontario Specification for GPS Control Surveys and AHJ requirements.

B3.9.2 Vertical Control

Provide LRT facility and element vertical control per requirements of AHJ.

B3.9.3 Deep Benchmarks

Provide elevation reference deep benchmarks to monitor ground movement for underground construction not affected by ground movement outside Zones of Influence.

Provide number and location of deep benchmarks required.

Provide deep benchmark surveys and indicate on design drawings.

B3.10 Noise and Vibration

Noise and vibration (N&V) control and its effect on LRT passengers, personnel, and surrounding communities is a necessary and achievable MX LRT program prerequisite.

This Section addresses measurement, modeling, and control of N&V as well as identifying other relevant documents, typical areas of review, and public service area maximum sound level requirements.

B3.10.1 References

Plan, design, and implement MX LRT systems and facilities using N&V criteria per Canadian Transportation Agency, Ontario MOE, and AHJ protocols.

Where established noise criteria protocols cannot be met regardless of proposed mitigation measures, describe, document, record, and obtain noise specific protocol agreements per AHJ requirements.

Consider specific LRT N&V protocol and document references relevant to MX LRT projects including but not limited to:

- MOE Guidance Materials for Preparation and Review of Noise and Vibration;
- Ontario MOE Publication NPC-205;
- Ontario MOE Guideline LU-131;
- Ontario Occupational Health and Safety Act;
- Canadian Labour Code, Occupational Safety and Health Regulation;
- US FTA LRT Noise and Vibration Impact Assessment Manual.

See Table B3-1 summarizing N&V limits for LRT lines, Stations and Stops, and associated receiving areas per various protocols.

See Table B3-2 outlining ground borne N&V criteria.

These protocols set out acceptable N&V limits received in the community as agreed with AHJ.

Provide margins of safety to be sure not to exceed acceptable N&V limits.

B3.10.2 Measurement

Use accepted methods for measuring LRT operations N&V levels received at Stations, Stops, facilities, and adjacent communities.

Refer to MOE Model Municipal Noise Bylaw and AHJ requirements.

Perform noise measurements with instruments meeting or exceeding IEC 61672 or ANSI Standard S1.4 for Class (Type) 1 or 2 Accuracy for Integrating Sound Level Meters.

Provide noise measurement instruments capable of measuring A-weighted decibels (dBA) and C-weighted decibels (dBC) using both “slow” and “fast” RMS time response.

Provide instruments able to measure common environmental noise metrics such as Leq, Lnpercentiles, Lmax, Lmin, and Peak Sound Levels for hearing conservation.

Field calibrate noise instruments before and after use with portable acoustic calibrators per manufacturer specifications.

Certify noise instruments annually by manufacturer or other independent testing facility for compliance with accuracy requirements listed above per manufacturer specifications.

Perform noise measurements only during acceptable weather conditions to avoid adverse effects on measured data.

Acceptable weather conditions include time periods without heavy rainfall or wind speeds over 24 kph.

Perform baseline noise measurements prior to construction to establish existing receptor location ambient noise levels.

Collect community receptor baseline noise data over several days including at least one weekend day.

Perform vibration measurements using instruments meeting manufacturer specifications.

Provide vibration measurement instruments capable of measuring vertical direction vibration velocity levels in decibel format (VdB re: 1 micro-mm/sec) and in engineering units of mm/sec using “slow” RMS time response.

Provide instruments capable of measuring common environmental vibration metrics such as Leq, Lnpercentiles, Lmax, Lmin, and Peak Levels to establish Peak Particle Velocity levels (PPV).

Field calibrate vibration instruments before and after use with a portable vibration calibrators per manufacturer specifications.

Certify vibration instruments annually by manufacturer or other independent testing facility for compliance with accuracy requirements listed above per manufacturer specifications.

B3.10.3 Predictions

Use accepted methods to predict N&V levels from LRT operations received in Stations, Stops, facilities and adjacent communities.

For further requirements refer to MOE Model Municipal Noise Bylaw and AHJ.

Perform noise predictions by calculations, algorithms, or models per acoustic industry best practices.

For community receptors, predict noise levels consistent with ISO Standard 9613 for Outdoor Sound Propagation taking into account factors such as distance, ground conditions, air absorption, wind direction/speed, and shielding from barriers and buildings.

For interior spaces, predict noise levels consistent with accepted acoustic industry best practices taking into account distance, reverberation, and surface absorption.

Alternatively, develop N&V prediction models from empirical data collected under similar operating conditions at other existing facilities.

Provide prediction model output with required N&V metrics per applicable criteria.

Perform N&V predictions in a transparent manner to allow subsequent inspection of assumptions, input data, and calculation results.

Submit proprietary models to MX LRT and AHJ for review and acceptance.

B3.10.4 Acoustics

Provide acoustic input data and general discussion required for awareness of important issues involved in LRT system noise evaluation.

Include maximum sound levels for mechanical systems including ventilation and ancillary equipment.

See Chapter B5 – Stations, Stops, Facilities.

Data necessary to obtain through measurement or modeling includes sound emission levels of mechanical equipment including tunnel ventilation, emergency ventilation, standby diesel generators, and other ancillary equipment.

Obtain source emission level data such as sound power levels (PWL) or A-weighted and/or octave band sound pressure levels (SPL) at specific distances.

Specify wall and ceiling finish reverberation time and material acoustic absorption coefficients.

Reverberation is undesirable in most cases leading to increased interior noise levels and interference in understanding PA system announcements.

Provide interior wall and ceiling acoustic finish materials with 0.7 minimum Noise Reduction Coefficient (NRC) per ASTM Test Method C423.

Provide interior noise levels for hearing protection and conservation per occupational safety and health agencies and AHJ criteria.

Hearing damage potentially occurs when long term time averaged noise levels exceed 85 dBA Leq 8 h or when short term impulse noise exceeds 140 dBC Lmax.

Measure existing LRV sound levels wherever possible.

Provide measurements distinguishing between different LRV types and consists performed as a function of moving and idling LRVs at specific speeds and observation distances.

Provide references to standard prediction methods and community noise criteria.

MOE is the primary criteria reference for community N&V limits.

Predict LRV and facility noise levels using accepted acoustic industry models and methods such as ISO Standard 9613.

Prediction methods may include empirical models based on measurements or analytical models based on accepted equations.

Perform predictions by hand or with commercially available computer modeling software.

In modeling account for frequency-dependent effects of sound source emissions, propagation behaviour, and interaction with obstacles and receptors.

Perform measurements and prediction methods for Station reverberation times consistent with accepted acoustic industry practices.

Design Sound Levels

See Table B3-2 for steady noise source normal operations design sound levels in Station public areas.

See Table B3-3 for Station rooms and areas and traction power substation design sound levels based on:

- Rooms requiring moderately good listening conditions: 50 dBA maximum allowable ambient sound level;
- Rooms requiring average speech communication: 65 dBA maximum level;
- Rooms where speech communication is not an overriding concern: 85dBA maximum level; face-to-face and telephone speech communication still possible over limited distances with louder than normal voice.

B3.10.5 Mitigation

Reduce N&V levels with mitigation measures and methods to minimize LRT system, equipment, and operations N&V effects at sources, along propagation pathways, or directly at receptors.

In general, control measures at source are most effective, serving to reduce, time shift, or eliminate N&V.

Control measures serve to interrupt, block, shield, decouple, and isolate high N&V sources by affecting along propagation pathways.

Examples include noise barriers, enclosures, absorptive materials, silencers, mufflers, isolator springs, and increased distances.

Control measures at receptors serve to directly reduce or change human perception of N&V levels.

Examples include residential soundproofing, sound masking, and receptor relocation.

Strive to achieve an effectiveness goal of 10 decibels reduction (insertion loss) for noise mitigation measures as a result of implementing the particular control measure.

To justify cost, however, a particular mitigation measure should provide not less than a 5 decibel reduction.

Design issues to be aware of include but are not limited to sight line visibility, noise barrier weight, wind loading, silencer/muffler self-generated noise/back pressure, and enclosure airflow/cooling.

Provide vibration isolators functioning at the lowest frequency needing attenuation and avoiding creation of resonance with system natural frequencies.

Communications

See Chapter C2 - Communication and Control for speech intelligibility sound levels.

Areas of Review

Consider and account for relevant input data and situation circumstances in N&V studies.

Address typical areas including but not limited to:

- Track and Station layout, including associated bus facilities;
- LRV operation data such as schedules, headways, LRV speeds, etc.;
- Stationary equipment specifications;

- Track work, trackbed/track slab, and Special Track Work locations;
- Track alignment including curve radii;
- Location of Station entrances, exits, doors, vent shafts, and bus platforms;
- Mechanical equipment mounting and selection;
- Transformer and emergency generator specifications and locations;
- Ventilation equipment specifications and locations including tunnel ventilation;
- Emergency ventilation room and vent shaft locations and layouts;
- Station sound absorbing materials, extent, and locations;
- PA and other communications system speaker locations;
- Anticipated number of Station occupants;
- Location, land use, and day/night sensitivity of nearby community receptors;
- Local soil conditions and groundwater levels;
- Special case receptors involving hypersensitive instruments and devices;
- Unique community events, e.g., festivals, memorials, and the like;
- Expected construction duration, phasing, equipment and methods.

Consider mitigation measure effectiveness including sound absorptive material long term maintenance.

TABLE B3-1 SUMMARY OF TYPICAL NOISE AND VIBRATION LIMIT PROTOCOLS

Source	Receiver	Descriptor	Protocol Limit Requiring Mitigation[1]
LRV Operations	Residence within 100 m, outdoor living area	Leq,24h	Not to exceed 60 dBA Leq,24h
LRV Operations	Residence exterior 15 m or more from track	Leq,16h and Leq,8h	Daytime 07:00-23:00): Not to exceed 55 dBA or ambient Leq,16h, whichever is greater Nighttime (23:00-07:00): Not to exceed 50 dBA or ambient Leq,8h, whichever is greater
Construction	Residence	Time period of clearly audible construction noise restriction	Nighttime (19:00-7:00) or as in municipal bylaw or agreement with municipality
Stationary Equipment	Residence in Class 1 (Urban) areas	Leq,1h	Maximum of quietest ambient Leq,1h or 50 dBA during Daytime (7:00-19:00), 47 dBA during Evening (19:00- 23:00), or 45 dBA during Nighttime (23:00-7:00)

TABLE B3-1 SUMMARY OF TYPICAL NOISE AND VIBRATION LIMIT PROTOCOLS

Source	Receiver	Descriptor	Protocol Limit Requiring Mitigation[1]
Emergency Operations	Patrons inside Stations	Lmax	Not to exceed 115 dBA Lmax during start-up or 92 dBA during constant operation
Hearing Conservation	Labourer occupational exposure	Leq,8h and Lmax	Not to exceed 85 dBA Leq/8h with an exchange rate of 3 dB per halving of exposure time. Also not to exceed 140 dBC Lmax
LRV Passby Noise	All locations beyond 15 m except within 100 m of Special Track Work.	Leq, passby	Not to exceed 80 dBA Leq, passby
LRV Passby Vibration	Ground outside residence	Vertical vibration velocity	For more than 70 events/day: Not to exceed 0.1 mm/sec RMS or 100 VdB RMS re: 1 micro-mm/sec[2]
Construction Vibration	Ground outside structure	Vertical vibration velocity	For major structural damages: Not to exceed 50 mm/sec PPV For minor cosmetic damages: 13 mm/sec PPV (Cat. I buildings) 8 mm/sec PPV (Cat. II buildings) 5 mm/sec PPV (Cat. III buildings) 3 mm/sec PPV (Cat. IV buildings)

Notes:

1. Table B3-1 provides examples only to be updated for specific LRT project noise agreements.
2. Unless such agreements apply, local by-law noise performance requirements apply.
3. Ambient is the sound existing at point of reception in the absence of LRT system noise.
4. Ambient is assumed to be noise from road traffic and existing industry.
5. Ambient specifically excludes transient aircraft and railway noise except pre-existing LRT operations.
6. Special ground borne vibration building requirements per AHJ reference standards.

TABLE B3-2 GROUND BORNE NOISE AND VIBRATION CRITERIA

Source	Receiver	Descriptor	Protocol Limit
LRV Passby Vibration	Ground outside sensitive buildings, e.g., concert halls, TV studios, recording studios, vibration-sensitive research & manufacturing, hospitals with vibration-sensitive equipment, some university research facilities)	Vertical vibration velocity	Not to exceed 0.045 mm/sec RMS or 93 VdB RMS re: 1 micro mm/sec
	Ground outside residences and buildings where people normally sleep (residential buildings, hotels, hospitals); theatres and auditoriums	Vertical vibration velocity	Not to exceed 0.1 mm/sec RMS or 100 VdB RMS re: 1 micro mm/sec
	Ground outside institutional buildings without vibration-sensitive equipment (schools, places of worship, other institutions)	Vertical vibration velocity	Not to exceed 0.14 mm/sec RMS or 103 VdB RMS re: 1 micro-mm/sec
LRV Passby Ground Borne Noise	Inside Concert Halls, TV Studios, Recording Studios	Ground borne noise pressure level	Not to exceed 25dBA re: 20 micro-Pascals
	Inside Auditoriums	Ground borne noise pressure level	Not to exceed 30dBA re: 20 micro-Pascals
	Inside residences and buildings where people normally sleep, e.g., residential buildings, hotels, hospitals, and Theatres	Ground borne noise pressure level	Not to exceed 35dBA re: 20 micro Pascals
	Inside Institutional Buildings without vibration-sensitive equipment, e.g., schools, places of worship, other institutions)	Ground borne noise pressure level	Not to exceed 40dBA re: 20 micro-Pascals

TABLE B3-3 DESIGN SOUND LEVELS FOR STEADY NOISE SOURCES IN STATION PUBLIC AREA

Source Type	Passenger Location	Design Goal	Basis
Ventilation (Except Emergency Ventilation)	Enclosed bus platforms	60 dBA	Normal speech
	All other enclosed public areas	55 dBA	Normal speech
Nearby Street Traffic Noise	Enclosed public areas	55 dBA (hourly Leq)	Normal speech
	Open Station platforms	60 dBA (hourly Leq)	Normal speech
Ancillary Equipment	All public areas	60 dBA @ 1 m	Normal speech

Notes:

1. Design levels are total combined sound levels from all sources of a given source type at any point in public area indicated.
2. For enclosed bus platforms, ventilation system 60 dBA is the baseline design level with no buses at the platform.
3. With buses at the platform, ventilation increases. Keep ventilation system sound levels 5 dBA below sound level of buses at the platform.
4. Typical sound level of a diesel bus idling measured 1.2 m above ground level and 7.5 m behind bus is approximately 75 dBA.
5. If additional ventilation is required in summer, enclosed public area design level may be increased to 60 dBA. Good speech communication is still possible at this sound level.
6. Typical examples of ancillary equipment are escalators and elevators.

TABLE B3-4: STATION DESIGN SOUND LEVELS FOR AMBIENT NOISE OTHER THAN STEADY NOISE SOURCES

Space Designation	Maximum Sound Level (dBA)
Public Areas	
Fare Paid Areas	55
Miscellaneous Public Areas and Passageways	55
Subway and SRT Platforms	55
Public Washrooms	55
Staff Areas	
LRV Operators' Lunchroom	50
LRV Operators' Washroom	65
Bus Operators' Lunchroom	50
Bus Operators' Washrooms	65
Attendants' Room	50
Supervisor's Room	50
Staff Washrooms	65

TABLE B3-4: STATION DESIGN SOUND LEVELS FOR AMBIENT NOISE OTHER THAN STEADY NOISE SOURCES

Space Designation	Maximum Sound Level (dBA)
Retail Areas	
News Stand and Storage	55
Designated Retail Areas	55
Designated Booth Areas	55
Electric Equipment Rooms	
AC Switchboard Room	65
Emergency Power Room	65
Switchgear Room	65
Communication Equipment Room	65
Telephone Equipment Room	65
Traction Power Room	65
Line Mechanic's Service Room	50
Escalator Service Room	85
Elevator Machine Room	85
Security Room	50
Track Patrol Room	65
Pump Room	85
Mechanical Room	65
Valve Room	85
Janitor Service Room	85
Janitor Machine Room	85
Janitor Relamper Room	85
Plant Maintenance and Storage Room	65
Fire Prevention Room	65
Maintenance Rooms	65
Mechanical Storage Rooms	85
HVAC Room	85
Fire Booster Pump Room	85
Signal Rooms	
Local Tower Room	50
Signal Relay Room	65

TABLE B3-4: STATION DESIGN SOUND LEVELS FOR AMBIENT NOISE OTHER THAN STEADY NOISE SOURCES

Space Designation	Maximum Sound Level (dBA)
Signal Power Supply Room	65
Signal Maintainers' Room	65
Signal Maintainers' Washroom	65
Zone Control Panel Room	50
Signal Maintainer's Lunchroom	50
Signal Storage Room	85
M.A. Room	85
Electric Substations	
Entrance Metering	85
Control Room	65
Rectifier Room	65
Cable Room/Pit	85
Washroom	65
Battery Room	65
Lunchroom – Terminal	50
Storage Room	85
Emergency Services	
Fan Room	85
Electric Equipment Including Battery Rooms	85

Notes

1. Table B3-4 maximum sound levels are total combined sound levels for steady noise sources including equipment and ventilation.
2. Excluded are infrequent noise sources, e.g., LRV passbys for track level rooms.
3. Levels are maximum sound levels based on the intended room use, not necessarily typical values based on equipment in the room; Expected sound levels in some rooms may be lower.
4. Control propagation of noise from high sound level areas to adjacent quieter areas.

B4 Structures

B4.1 General

Chapter B4 addresses Metrolinx (MX) Light Rail Transit (LRT) project structures based on passenger safety and comfort, Light Rail Vehicle (LRV) performance characteristics, structural stability, and universally accepted best engineering practices.

The MX LRT program uses Limit States Design Methods throughout for LRT systems.

B4.2 Scope

Chapter B4 addresses MX LRT structures including bridges, cut-and-cover structures, mined and bored underground structures and tunnels, passenger Stations and Stops, earth retaining structures, buildings, and facilities as well as various other structures.

Chapter B4 also applies to underpinning systems for support of LRT buildings and facilities and protection of non-MX LRT buildings and facilities within MX LRT project scope or, in event of deterioration, with potential to impact or interfere with MX LRT facilities, buildings, or operations.

Provide MX LRT structures of suitable size and configuration to allow sufficient space and clearance for LRT System emergency egress, operations, facilities, and wayside elements.

See Chapter B1 – Alignment, Clearances, Rights-of Way.

Provide structures listed in Figure B4.1.1 Group 4 per Ontario Building Code (OBC).

Use the MX LRT Design Criteria Manual (DCM) for structures listed in Figure B4.1.1 Groups 1, 2, 3, and 5 in addition to related OBC, Canadian Highway Bridge Design Code, CSA Standards, and other Authorities Having Jurisdiction (AHJ) regulations and requirements.

MX LRT underground structures criteria per Figure B4.1.1 Group 1 add to these OBC clauses:

- Replace Clauses 4.1.2 and 4.1.3 Specified Loads and Effects and Limit States Design;
- Add to Clause 4.1.4 Dead Load;
- Replace Table 4.1.5.3 Specified Uniformly Distributed Live Loads on an Area of Floor or Roof; and
- Replace Table 4.1.5.10 Specified Concentrated Live Loads on an Area of Floor or Roof.

MX LRT elevated guideway criteria per Figure B4.1.1 Group 2 add to these Canadian Highway Bridge Design Code clauses:

- Add to Section 1, General – Scope;
- Replace Section 3 Clause 3.5 Load Factors and Load Combinations;
- Add to Section 3 Clause 3.7.1 Loads for Respective Structure Types; and
- Add to Section 3.8 Live Loads.

MX LRT Stations criteria per Figure B4.1.1 Group 5 add to these OBC clauses:

- Add to Clause B4.1.4 Dead Load;
- Replace Clause B4.1.3.2 Strength and Stability, including Table B4.1.3.2 Load Combinations for Ultimate Limit States;
- Replace Table B4.1.5.3 Specified Uniformly Distributed Live Loads on an Area of Floor or Roof; and
- Replace Table B4.1.5.10 Specified Concentrated Live Loads on an Area or Roof.

Use load factors and load combinations per Tables B4-2 through B4-6.

TABLE B4-1 DESIGN OF MX LRT STRUCTURES

Group	Type of Structure [2]	Loads	Design Codes [1]
1	Underground Structures Underground Ventilation/ Emergency Access Shafts Underground Portal Structures	Underground Structures.	CSA-A23.3 CSA-S16.1 CSA-O86 CSA-S304.1 AREMA
2	Bridges and elevated structures for MX LRT Culverts Rigid Frame Portals Carrying Highway Traffic Retaining Walls	Elevated Structures.	CSA-S6 Canadian Highway Bridge Design Code CSA-S304.1 AREMA Manual for Railway Engineering and/or ACI 358 4
3	Above Grade Parking and Maintenance Facilities	Loads: MX LRT criteria or OBC; Load and Combination Factors: OBC.	CSA-A23.3 CSA-S16.1 CSA-S413 CSA-O86 CSA-S304.1
4	Administration Buildings Public Parking Garages Retaining Walls Associated with Buildings	OBC.	CSA-A23.3 CSA-S16.1 CSA-O86 CSA-S413 CSA-S304.1
5	Station Buildings3	Loads: MX LRT criteria or OBC; Load and Combination Factors: MX LRT DCM.	CSA-A23.3 CSA-S16.1 CSA-O86 CSA-S304.1
		Load Factors as per above Criteria and Codes	Resistance Factors as per above Criteria and Codes

Notes:

1. Current Version Including Revisions.
2. For tunnel design refer to MX LRT criteria for general guidance.
3. Determine tunnel design criteria and methodology using generally accepted engineering principles for tunnel structures of similar kind subject to MX LRT review and acceptance.
4. Applies to both above and below grade portions of station buildings.
5. For requirements and recommendations not found in MX LRT DCM.

B4.3 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT DCM.

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Structures specific references include but are not limited to:

- Ontario Building Code (OBC) and OBC Supplementary Guidelines;
- Canadian Standards Association (CSA) A23.1/A23.2: Concrete Materials and Methods of Concrete Construction/Test Methods and Standard Practices for Concrete;
- CSA-A23.3: Design of Concrete Structures;
- CSA-O86: Consolidation – Engineering Design in Wood (temporary works only);
- CSA-S6: Canadian Highway Bridge Design Code (CHBDC);
- CSA-S16: Design of Steel Structures;
- CSA-S304.1: Design of Masonry Structures;
- CSA-S413: Parking Structures;
- National Building Code (NBC) of Canada;
- NBC User Guide: Structural Commentaries;
- National Fire Protection Association (NFPA) 101: Life Safety Code;
- NFPA 130: Standard for Fixed Guideway Transportation Systems;
- American Railway Engineering and Maintenance-of-Way Association (AREMA): Manual for Railway Engineering;
- American Concrete Institute (ACI) 358: Analysis and Design of Reinforced and Prestressed Concrete Guideway Structures;
- Federal Highway Administration (FHWA) National Highway Institute (NHI) 09-010: Road Tunnel Manual;
- Ministry of Transportation Ontario (MTO): Prestressed Concrete Manual;
- AHJ Criteria, Standards, Specifications, etc.;

OBC governs where conflicts arise unless otherwise stated.

B4.4 Fire Protection of Structures

Protect Stations, buildings, and tunnel structures per OBC Part 3 “Fire Protection, Occupant Safety and Accessibility” and Chapter A3 – SAFETY.

Provide only materials of inorganic composition containing no organic binder including thermal and acoustical insulation of ductwork and piping.

Provide materials other than concrete, masonry, tile, metals, and similar of certified non-combustible classification as defined by ASTM E136, Determining Non-Combustibility of Elementary Materials.

Flame proofing of materials is not acceptable.

In cases where no suitable material conforms to these requirements, very minor quantities of an accessory material may be submitted for MX LRT review and acceptance.

Protect structural steel members from direct fire exposure based on fire intensity and duration.

Provide concrete encased primary steel members with 5 mm minimum concrete cover.

Provide secondary steel members with cementations spray-on fireproofing per fire rating requirements.

Provide doors and partition walls performing as fire barriers per fire rating requirements.

See Chapter A3 – Safety and Chapter C4 – Heating, Ventilation, Air Conditioning.

B4.5 Dead Loads (D)

For above ground structures, Dead Loads (D) comprise weight of basic structure and weight of secondary elements including miscellaneous systems or facilities applying permanent load on structure as well as weight of other permanent loads planned for future installation.

So that dead load calculations for various materials are consistent throughout, use unit loads as follows:

- Concrete, Plain or Reinforced 24 kN/m^3;
- Steel or Cast Steel 78.5 kN/m^3;
- Cast Iron 72.8 kN/m^3;
- Aluminum Alloys 28 kN/m^3;
- Glass 25.6 kN/m^3;
- Timber 9.6 kN/m^3;
- Ballast, Crushed Stone 19.2 kN/m^3;
- Pavement 24 kN/m^3;
- Rock and Stone Masonry 27.2 kN/m^3;
- Ceilings, Cement Plaster 6.3 N/m^2 (or actual);
- Ceilings, Gypsum Plaster 4.2 N/m^2 (or actual);
- 1 mm Epoxy Terrazzo Tile, 2.5 N/m^2;
- 25 mm Terrazzo plus 5 mm Stone Concrete C4.5 N/m^2;
- Stay-in-Place Forms 6.7 N/m^2;
- Cable Splice Boxes (maximum length 9 m) 2.4 kN/m;
- Acoustic Barrier 5.2 kN/m;
- Groundwater 9.8 kN/m^3.

For cut-and-cover underground structures, Dead Loads (D) comprise weight of basic structure and weight of secondary elements permanently supported by structure as well as weight of earth cover supported by roof of structure acting as a simple gravity load.

B4.6 Transitory/Exceptional Loads

Transitory loads consist of any Live Loads (L) including weight of machinery, equipment, stored materials, persons, transit vehicles, elevators, escalators or other moving objects, including impact (dynamic load allowance), construction loads and loads due to maintenance operations.

Transitory loads also include applicable LRV load effects such as rolling, hunting, normal centrifugal, normal acceleration and braking forces.

Transitory loads also include environmental loads such as loads due to snow, ice and rain, wind, shrinkage and creep, thermal loads including seasonal changes of temperature and thermal gradient effects, and differential settlement and stream flow.

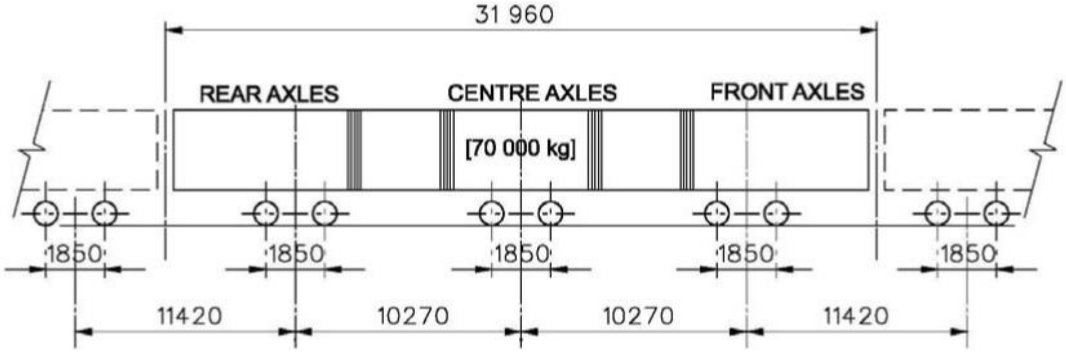
Exceptional loads include earthquake, ice pressure or debris torrent effects, loads due to flooding as well as special loads due to vehicle collision on or under a structure, emergency braking, extreme centrifugal force, derailment, and broken rail loads as well as loads due to broken Overhead Contact System.

These loads apply for MX LRT underground Stations, structures, bridges, and other relevant structures.

B4.6.1 Vehicle Design Loads

See Figure B4-1, LRV Design Loads, for LRV design live load (L), axle spacing, axle load, and car spacing.

FIGURE B4-1 LRV DESIGN LOADS



DESIGN LOADS

MAX TOTAL VEHICLE LIVE LOAD (L)* = 70 000 kg / VEHICLE (686.5KN)
MAX VEHICLE STATIC AXLE LIVE LOAD (L)* = 12 000 kg (117.6KN)
MIN VEHICLE STATIC AXLE LIVE LOAD (L) = 67 00 kg (65.7KN)

	FRONT	CENTRE	REAR
AXLE LOAD *	(xx) kN	(xx) kN	(xx) kN
WHEEL LOAD *	(xx) kN	(xx) kN	(xx) kN

DYNAMIC LOAD ALLOWANCE (DLA) 30% (L)*

ROLLING FORCE (RF) ± 10% X WHEEL LOAD

CENTRIFUGAL FORCE (CF) $\frac{V^2}{Rg} \times (L)$*

NORMAL ACCELERATION/BRAKING (LN) 15% (L) *

EMERGENCY BRAKING (LE) 30% (L) *

* VEHICLE LIVE LOAD (L) VARIES REFER TO CLAUSE 13.3.2.2.2, MAX TOTAL VEHICLE LIVE LOAD(L) AND MAX VEHICLE STATIC AXLE LOAD BASED ON FOLLOWING: VEHICLE TARE WEIGHT+OPERATOR+ALL SEATS OCUPIED+7 STANDEES/m².

Vertical LRV Design Live Load (L) is any combination of LRV axle loads on one or more tracks producing critical design load with as many combined crush-loaded LRVs as a structure can accommodate taking into account breakdown, derailment, evacuation, and/or recovery operation worst-case scenarios.

Verify LRV and maintenance/emergency vehicle design loading with MX LRT Vehicle Engineering.

B4.6.2 Dynamic Load Allowances

Dynamic Load Allowances (DLA) are equivalent static loads expressed as a percentage of vertical LRV Live Load (L) equal to dynamic and vibration effects of moving LRV and structure interactions including LRV response to idling surfaces irregularities including:

- DLA 10% minimum for surface discontinuities in Continuous Welded Rail (CWR) assumed to be minimal due to tight installation tolerances and direct fixation of trackwork to structure;
- DLA 30% minimum for sliding rail expansion joint surface discontinuities at turnout area switch and frog point structures.

Determine DLA allowances per ACI 358.1R PAR. 3.3.1.2.

B4.6.3 Rolling Force

The lateral shifting of LRV weight from one rail to another is known as rolling or lurching.

Apply a Rolling Force (RF) equal to 10 percent of an LRV wheel load downwards on one rail and upwards on other rail for all tracks and wheels.

B4.6.4 Centrifugal Force

An LRV undergoes radial acceleration as it passes through a horizontal curve.

The term for corresponding horizontal radial load is centrifugal load (CF).

Apply CF horizontally at LRV centre of gravity, i.e., 1.7 m above top of low rail for a crush loaded LRV, and at right angles to direction of travel.

Verify LRV centre of gravity location with MX LRT.

Apply normal CF simultaneously to all loaded tracks with magnitude equal to:

$$CF = \frac{V^2}{R \cdot g} \cdot L$$

Where:

V = Velocity of LRV in m/s (maximum 88km/h = 24 m/s); Verify LRV Velocity with MX LRT;

R = Radius of curve in metres;

g = Acceleration due to gravity (9.81 m/s^2);

L = LRV live load without dynamic load allowance.

Extreme centrifugal load (CFe) occurs when an LRV under manual control exceeds speed limit.

Calculate CFe at velocity causing empty LRV to overturn or full crush loaded LRV to reach AHJ specified.

Apply CFe only to one track of a horizontally curved structure.

B4.6.5 LRV Hunting Force

LRV Hunting Force (HF) is the lateral interaction of LRV and elevated structures due to LRV oscillation back and forth between rails causes hunting or nosing load.

For rail and structure design, apply HF at top of rail head at LRV lead axle only, with magnitude equal to 12.5 percent of LRV Live Load excluding dynamic load allowance.

In areas of continuously welded rail HF is:

Bogie Type	HF
Non-steerable	0.08L
Steerable	0.06L

In areas of discontinuities HF is 0.125L

Where L = Vehicle Live Load excluding dynamic load allowance.

Apply HF to one track only of any tangent dual-track structure.

On horizontal curves apply the more critical of HF or CF.

B4.6.6 Longitudinal Forces

Apply crush loaded LRV longitudinal loads at LRV centre of gravity, i.e., 1.7 m above top of rail.

Verify LRV centre of gravity location with MX LRT.

Consider these three longitudinal load cases for double track structures:

- Single track loaded — longitudinal load acting, applicable loads on supporting structure;
- Both tracks loaded — one LRV accelerating, one LRV decelerating — Maximum longitudinal loads acting, and applicable loads on supporting structure;
- Both tracks loaded — both LRVs accelerating or decelerating — longitudinal loads acting in opposite directions, applicable loads on supporting structure.

Longitudinal load acts simultaneously with LRV vertical live load on all wheels and may act in either direction: forward in braking / deceleration or reverse in acceleration.

Apply longitudinal load as follows:

- Emergency Braking: LE = 0.30L
- Normal Braking: LN = 0.15L

Continuously welded rail track can distribute longitudinal loads to adjacent guideway structure components. Consider this distribution in design.

Rail slip joints may prevent transfer and distribution of longitudinal forces.

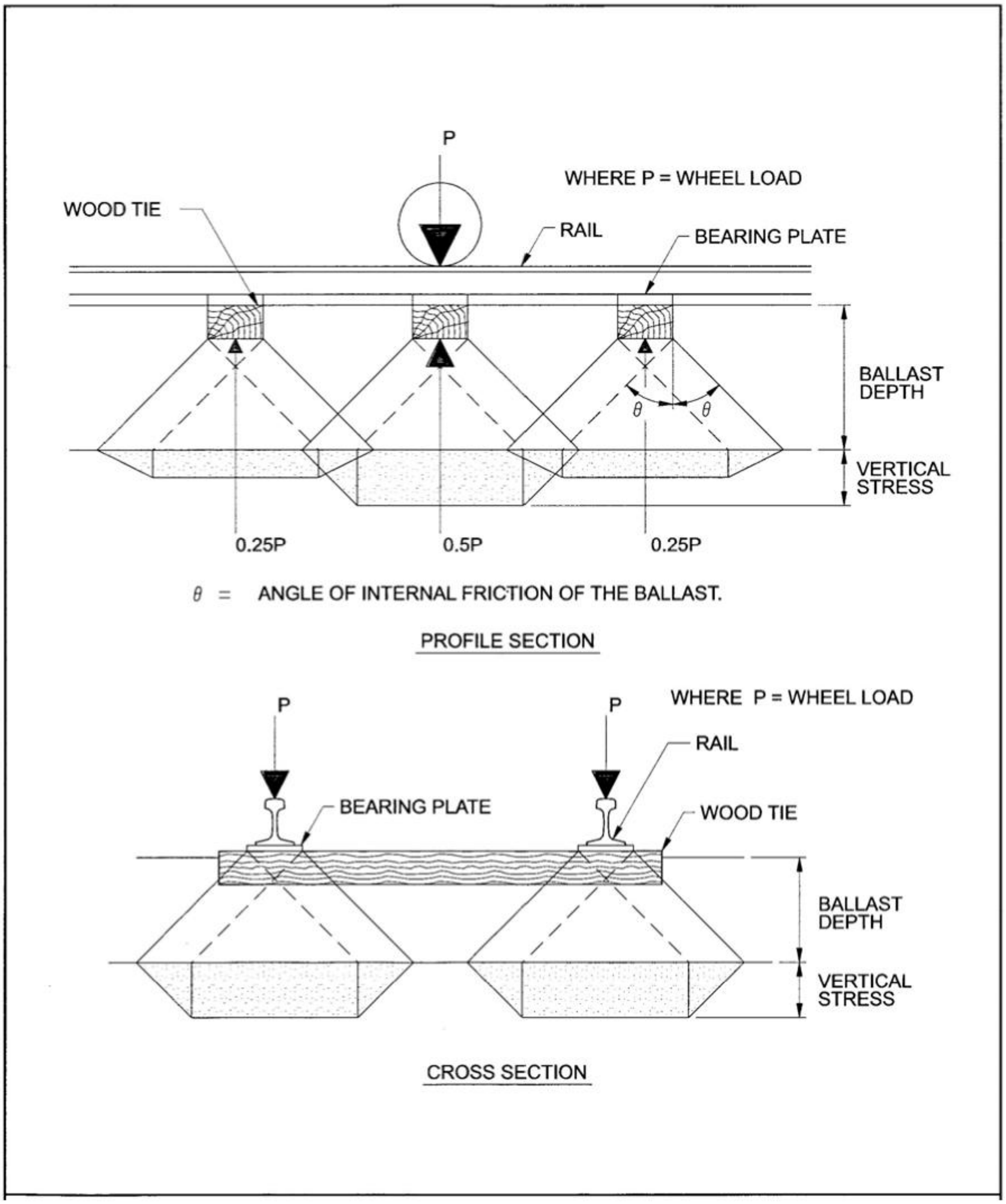
B4.7 LRV Wheel Load Distribution

The LRV load from a group of wheels is distributed over adjacent ties in decreasing magnitude, with proportional part of load on each tie being a function of rail stiffness (section modulus), spacing, size, tie stiffness (concrete or timber), and supporting ballast, sub-ballast, and subgrade stiffness.

B4.7.1 Simplified Wheel Load Dispersion

For simplified wheel load dispersion rail support system, tie and ballast indicated in Figure B4-2, Simplified Wheel Load Dispersion, assume wheel load is uniformly distributed over a 120 mm length of rail (3 ties) with each tie designed for 50% of axle load.

FIGURE B4-2 SIMPLIFIED WHEEL LOAD DISPERSION



B4.7.2 Alternative Support Systems

Alternative support systems for elevated guideways or where noise and vibration mitigation is required.

See Chapter B2 – Track Work.

For these systems assume wheel load is uniformly distributed over a 120 mm length of rail (3 ties) with load pressure distribution indicated as follows:

- Figure B4-3, Concrete Double Tie System Wheel Load Dispersion;
- Figure B4-4, Tie/Ballast/Floating Slab System Wheel Load Dispersion;
- Figure B4-5, Direct Fixation Wheel Load Dispersion.

FIGURE B4-3 CONCRETE DOUBLE TIE SYSTEM WHEEL LOAD DISPERSION

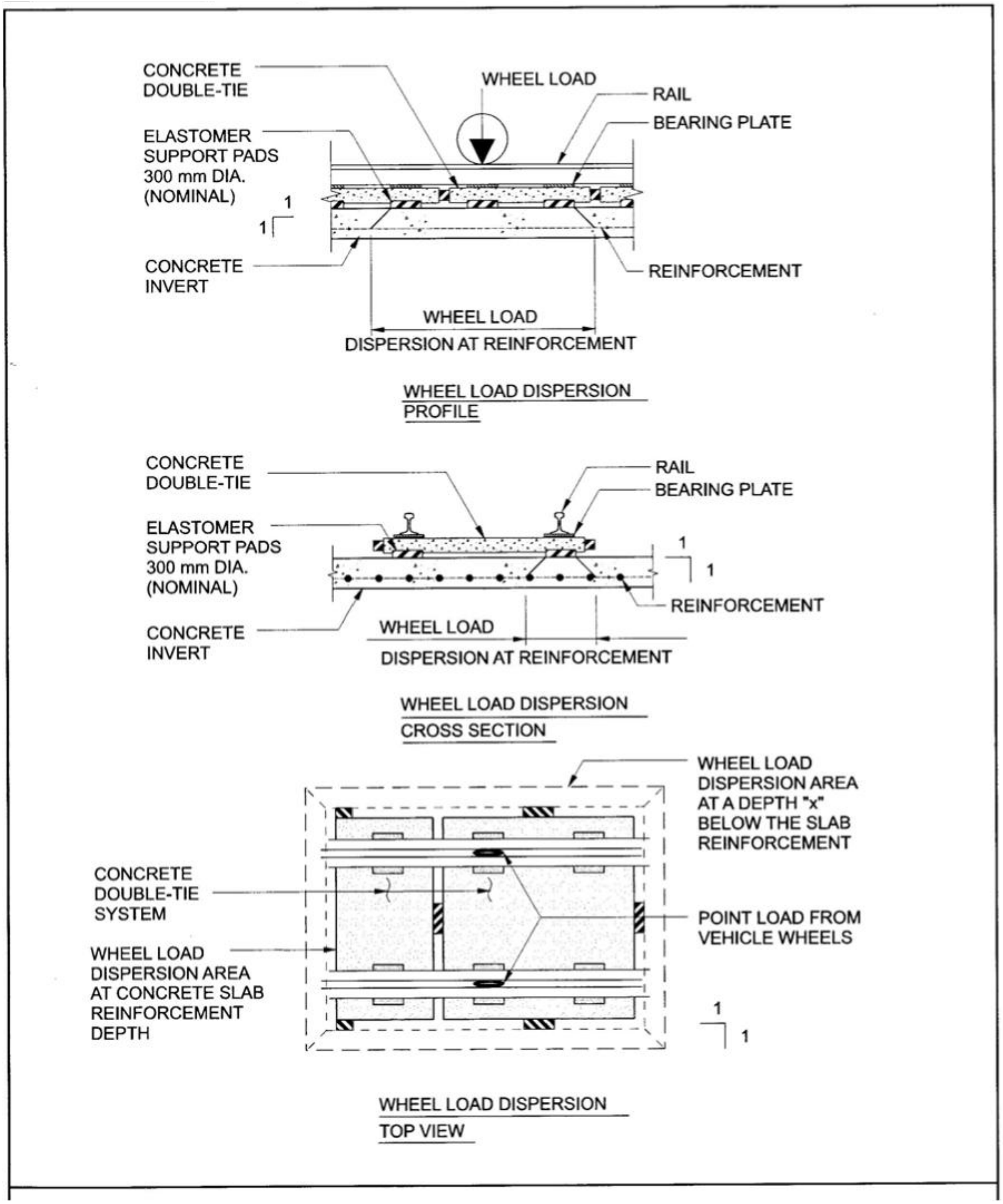


FIGURE B4-4 TIE/BALLAST/FLOATING SLAB SYSTEM WHEEL LOAD DISPERSION

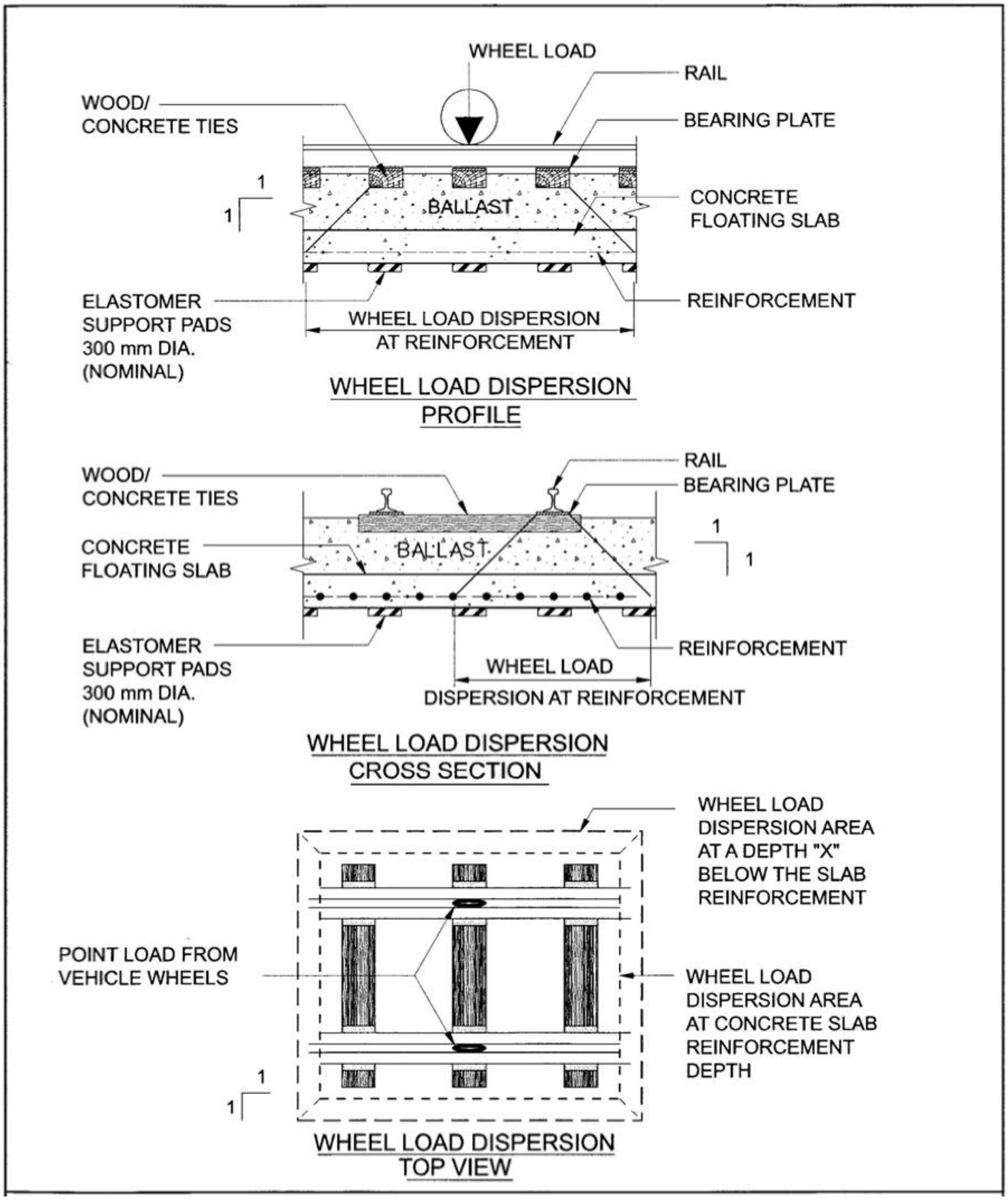
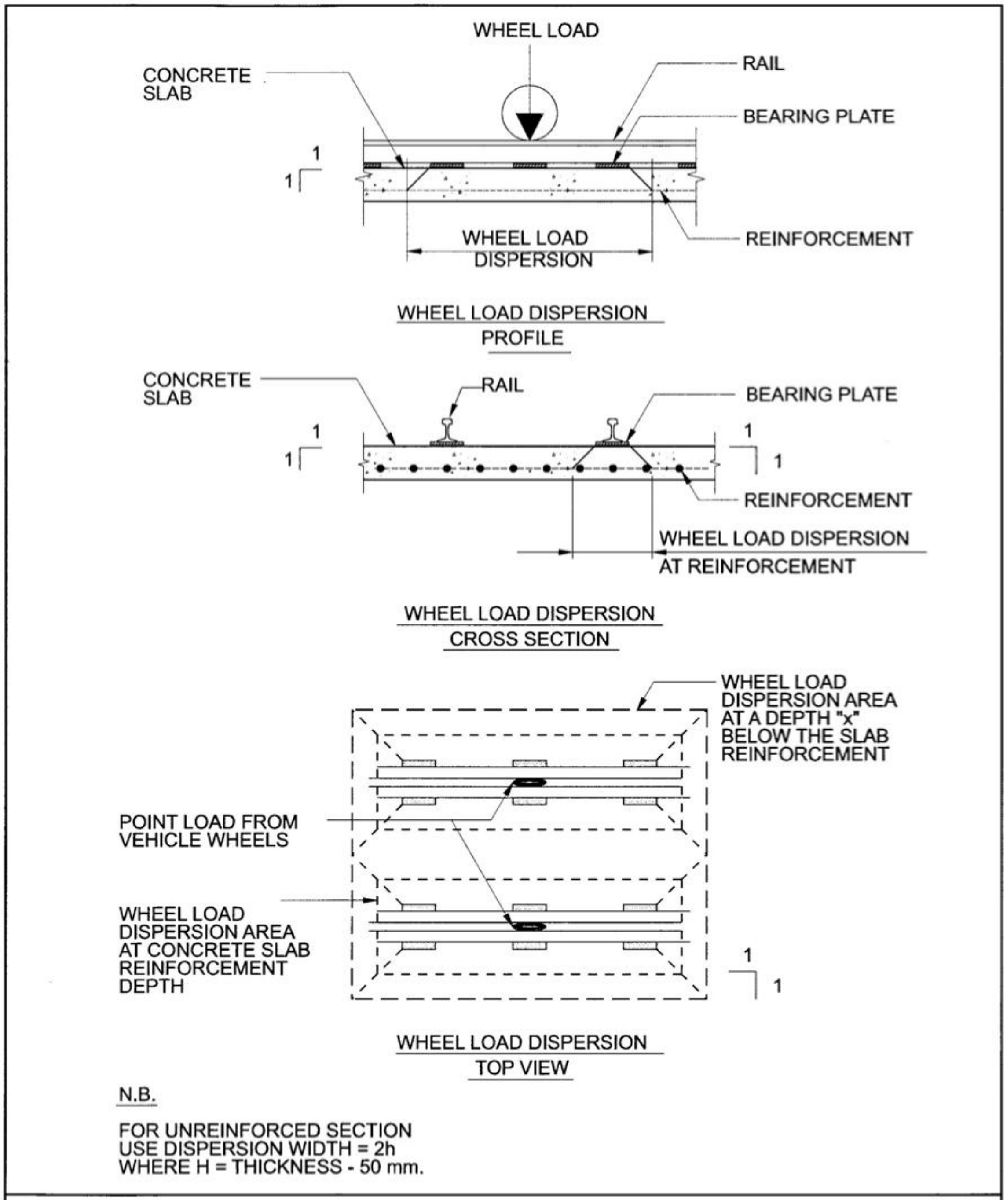


FIGURE B4-5 DIRECT FIXATION WHEEL LOAD DISPERSION



B4.8 Non-Revenue Vehicle Loads

In addition to LRV loads in Section B4.6, evaluate and consider such non-revenue vehicles as work cars, crane cars, and snow removal equipment necessary for maintenance of trackwork and associated facilities.

B4.8.1 Vehicular Traffic Loads

Base vehicular roadway traffic loads on CL-625-ONT truck and CL-625-ONT lane load per CSA-S6-06 Canadian Highway Bridge Design Code.

Base street decking loads on CHBDC loads as well as LRV loads in Section B4.6.

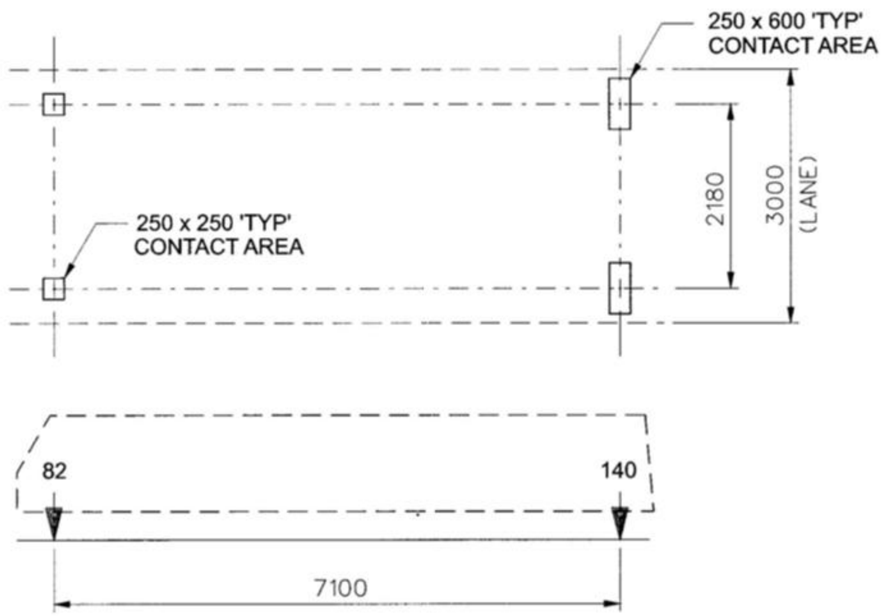
B4.8.2 Bus Live Loads

Axle spacing and load for design bus live load (L) is indicated in:

- Figure B4-6 Standard Floor Diesel Bus Vehicle Design Loading;
- Figure B4-7 Low Floor Diesel Bus Vehicle Design Loading;
- Figure B4-8 Low Floor Hybrid Diesel Electric Bus Vehicle Design Loading.

FIGURE B4-6 STANDARD FLOOR DIESEL BUS VEHICLE DESIGN LOADING

	(FRONT)	(REAR)
AXLE NO.	1	2
AXLE LOAD, kN	82	140
WHEEL LOAD, kN	41	70 (PAIR)

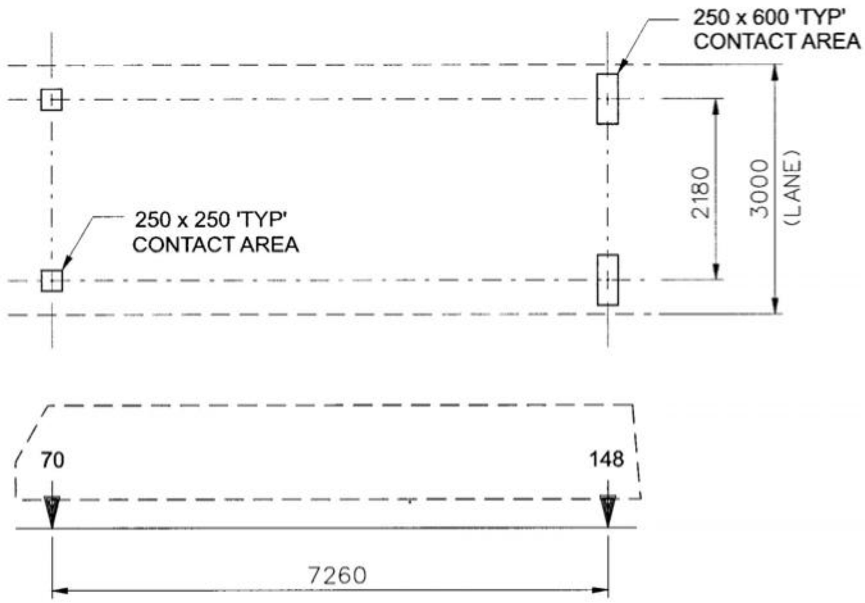


TOTAL LIVE LOAD (L)	22 600 kg/vehicle
DYNAMIC LOAD ALLOWANCE (DLA)	30% (L)
LONGITUDINAL FORCE (LF) (Applied 2000 mm above deck)	5% (L)
CENTRIFUGAL FORCE (CF)	$\frac{V^2}{Rg} \times (L)$
LIVE LOAD REDUCTION	
One or two lanes	0%
Three lanes	10% (L)
Four or more lanes	25% (L)

NOTES:
1. Bus-design axle loads are less than design axle loads for CHBDC-ONT TRUCK. Therefore use bus vehicle loads in restricted right-of -way only.
2. All vehicle dimensions are for structural design purpose only. Actual vehicle dimensions must be obtained from vehicle roster charts available from TTC Operations Branch Vehicle Engineering.

FIGURE B4-7 LOW FLOOR DIESEL BUS VEHICLE DESIGN LOADING

AXLE NO.	1	2
AXLE LOAD, kN	70	148
WHEEL LOAD, kN	35	74 (PAIR)



TOTAL LIVE LOAD (L)	21 900 kg/vehicle
DYNAMIC LOAD ALLOWANCE (DLA)	30% (L)
LONGITUDINAL FORCE (LF) (Applied 2000 mm above deck)	5% (L)
CENTRIFUGAL FORCE (CF)	$\frac{V^2}{Rg} x (L)$

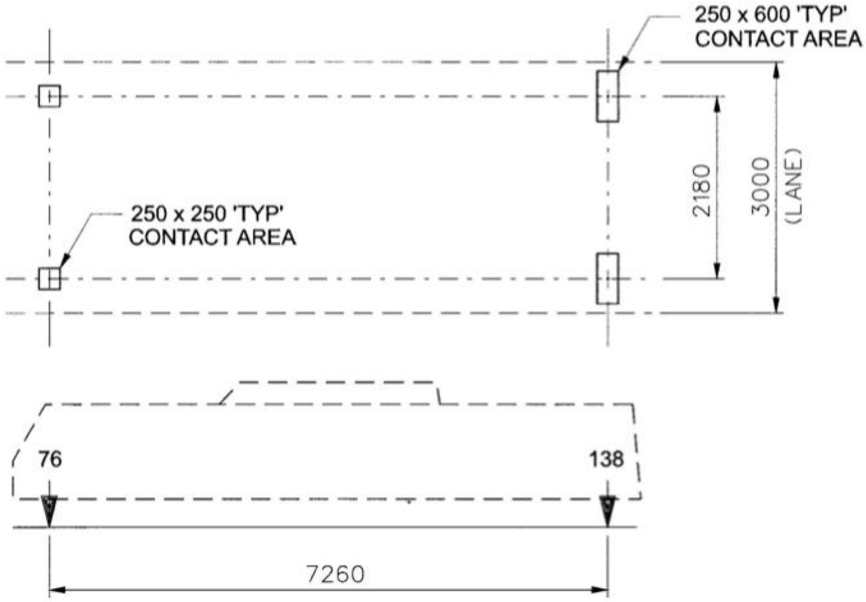
LIVE LOAD REDUCTION

One or two lanes	0%
Three lanes	10% (L)
Four or more lanes	25% (L)

NOTES:
1. Bus-design axle loads are less than design axle loads for CHBDC-ONT TRUCK. Therefore use bus vehicle loads in restricted right-of -way only.
2. All vehicle dimensions are for structural design purpose only. Actual vehicle dimensions must be obtained from vehicle roster charts available from TTC Operations Branch Vehicle Engineering.

FIGURE B4-8 LOW FLOOR HYBRID DIESEL ELECTRIC BUS VEHICLE DESIGN LOADING

	(FRONT)	(REAR)
AXLE NO.	1	2
AXLE LOAD, kN	76	138
WHEEL LOAD, kN	38	79 (PAIR)



TOTAL LIVE LOAD (L)	21 800 kg/vehicle
DYNAMIC LOAD ALLOWANCE (DLA)	30% (L)
LONGITUDINAL FORCE (LF) (Applied 2000 mm above deck)	5% (L)
CENTRIFUGAL FORCE (CF)	$\frac{V^2}{Rg} \times (L)$
LIVE LOAD REDUCTION	
One or two lanes	0%
Three lanes	10% (L)
Four or more lanes	25% (L)

NOTES:
1. Bus-design axle loads are less than design axle loads for CHBDC-ONT TRUCK. Therefore use bus vehicle loads in restricted right-of -way only.
2. All vehicle dimensions are for structural design purpose only. Actual vehicle dimensions must be obtained from vehicle roster charts available from TTC Operations Branch Vehicle Engineering.

B4.8.3 Bus Design Axle Loads

Provide busways designed for design axle loads, or a specified uniform load of 12 kPa located to cause maximum effects, whichever is more critical.

Since bus design axle loads are substantially less than CHBDC vehicle loads, it is of paramount importance to use bus design axle loads only in restricted rights-of-way.

Post signs regarding load limits at busway entrances.

B4.8.4 Other Vehicle Loads

Review situations that may allow access for emergency, construction or other vehicles with MX LRT.

Obtain relevant other vehicle load information and design accordingly.

B4.9 Fire Access Route Vehicle Loads

Consider potential vehicle truck and firefighting equipment loads on elevated or suspended structures.

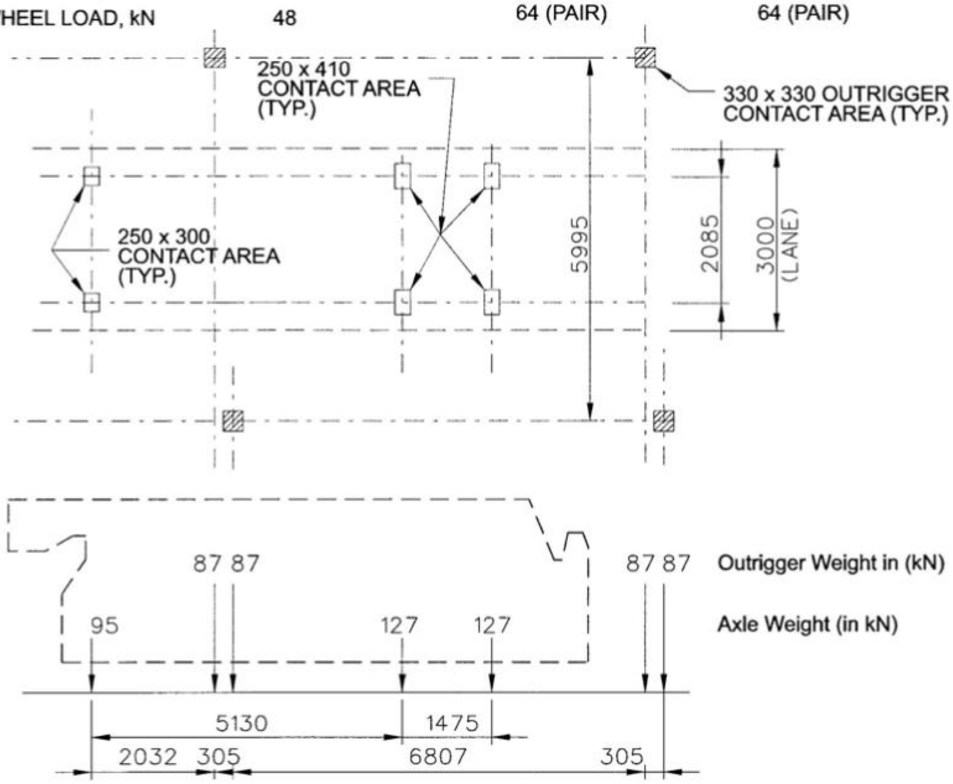
See Figure B4-9 “Aerial Fire Fighting Truck Vehicle Design Loading” for fire truck wheel loads, axle spacing, axle loads and outrigger loads.

Add 30% to those loads for dynamic load allowance.

Note firefighting apparatus design load used on structural drawings.

FIGURE B4-9 AERIAL FIRE FIGHTING TRUCK VEHICLE DESIGN LOADING

	(FRONT)	(REAR)	(REAR)
AXLE NO.	1	2	3
AXLE LOAD, kN	95	127	127
WHEEL LOAD, kN	48	64 (PAIR)	64 (PAIR)



TOTAL LIVE LOAD (L)	35 520 kg/vehicle
DYNAMIC LOAD ALLOWANCE (DLA)	30 % (L)
LONGITUDINAL FORCE (LF) (Applied 2000 mm above deck)	5 % (L)
CENTRIFUGAL FORCE (CF)	$\frac{V^2}{Rg} \times (L)$
LIVE LOAD REDUCTION	
One or two lanes	0 %
Three lanes or more	10 % (L)

NOTE:
FIRE TRUCK DESIGN AXLE LOADS ARE LESS THAN DESIGN LOADS FOR CHBDC TRUCK.
THEREFORE USE FIRE TRUCK VEHICLE LOADS IN RESTRICTED RIGHT-OF-WAY ONLY.

B4.10 Collision Vehicle Loads

Assess whether to consider vehicle collision loads at specific station and stop locations based on grading, adjacent roadway vehicle use, and operating speeds.

At above grade station and stop exposed columns apply an equivalent horizontal static collision load 1.2 metres above grade level.

The collision load is 1,400 kN irrespective of protective barriers where a highway truck may hit a column within 10 metres of road pavement.

B4.11 Floor and Miscellaneous Live Loads

B4.11.1 Public Areas

Design public areas including station platforms, concourses, control areas, stairs, ramps, passageways and unused non-storage areas for a specified live load of 7.2 kPa applied uniformly over entire area, or any portion of area, whichever produces the most critical effects.

Reduce specified live load for structural members supporting large tributary areas per OBC requirements for assembly occupancies.

Also consider a concentrated load of 9 kN applied over an area 75 mm by 75 mm and positioned to cause maximum effects.

Review requirements for transportation of heavy equipment and safes over public areas with MX LRT.

The most critical load conditions govern.

B4.11.2 Equipment Rooms

Design Electric Equipment Rooms, Pump Rooms, Machinery Rooms, Storage Rooms, Service Rooms and Battery Rooms for a specified live load of 12 kPa, or actual equipment load where greater than 12 kPa, applied uniformly over entire area, or any portion of area, whichever produces the most critical effects.

Reduce specified live load for structural members supporting large tributary areas per OBC requirements for non-assembly occupancies.

Also consider a concentrated load of 15 kN applied over an area 75 mm x 75 mm and positioned to cause maximum effects.

The most critical load conditions govern.

B4.11.3 Ventilation Equipment Rooms

Analyze actual equipment loads for Ventilation Equipment Rooms and design for a specified live load of 12 kPa or actual equipment load where greater than 12 kPa, applied uniformly over entire area, or any portion of area, whichever produces the most critical effects.

Also consider a minimum concentrated load of 15 kN applied over an area 75 mm x 75 mm and positioned to cause maximum effects.

The most critical load conditions govern.

B4.11.4 Ventilation Shafts

Protect ventilation shafts from vehicle traffic and surface runoff with barriers and curbs.

Design ventilation shaft gratings for specified uniform load of 12 kPa or concentrated axle or wheel loads per CHBDC Section 3.8.4.3 or CL-625-ONT Truck, located to cause maximum effects, whichever is more critical.

MX LRT may waive these load conditions when pedestrian and vehicle access is clearly not possible.

B4.11.5 Escalator Support Structures

Provide escalator support structures for maximum reactions indicated on escalator manufacturer certified drawings or total specified combined load of 16.3 kN per linear metre, whichever is greater.

Specified combined load is based on 1015 mm escalator step width, 9 kN/m dead load, 3.65 kN/m live load (3.6 kN/m^2) and 3.65 kN/m impact load.

Coordinate location of any intermediate supports with escalator manufacturer.

B4.11.6 Safety Guards and Fences

Design safety guards and fences for a minimum horizontal load of 3.0 kN/m applied 1.0 m above grade or high side of deck at elevated structures, egress routes with a drop of more than 60 mm, and where LRV evacuation may occur between Stations or stops.

B4.12 Environmental Loads

B4.12.1 Importance Category Normal

Design structures for environmental loads per OBC Importance Category Normal unless directed otherwise by MX LRT.

B4.12.2 Snow, Rain and Ice (SL) Transitory Loads

Design structures for snow, rain and ice loads per OBC.

See Section B4.16.5 Elevated Structures — Design Method and Loads.

LRV ice load is included in LRV live load where specified.

B4.12.3 Wind (W) Transitory Loads

Design structures for wind loads per OBC with reference wind pressure, q, based on 50 years return period.

See Section B4.16.5 Elevated Structures – Design Method and Loads.

B4.12.4 Confined Space Transitory Wind Pressure Loads

LRV “piston effect” for structures, tunnels and confined spaces is 2 kPa uniform wind pressure load.

Minimum “piston effect” for other areas is 1.5 kPa uniform wind pressure load.

Consider “piston effect” to act both positively and negatively but not simultaneously.

LRV “piston effect” in restricted or confined spaces such as tunnels and pedestrian cross passages may generate higher wind pressure loads to be determined on a case-by-basis but not less than 2 kPa.

Review and verify “piston effect” wind pressure loads with MX LRT.

B4.12.5 Earthquake (Q) Exceptional Loads

Design structures for earthquake loads per OBC and NBC of Canada.

See Section B4.15.2 Underground Structures – Loads.

See Section B4.16.5, Elevated Structures – Design Method and Loads.

Building codes do not specifically address special purpose structures such as underground transit facilities.

Although generally not critical for underground structures due to magnitude of other loads such as unbalanced earth pressure, address earthquake load in structures to verify and provide sufficient anchorage for architectural, mechanical, electrical, and other service items and equipment in case of earthquake.

B4.12.6 Ventilation Fan Induced Airflow Exceptional Loads

Design structures for ventilation fan induced airflow exceptional loads.

Review and address ventilation fan induced airflow exceptional loads with MX LRT.

Provide sufficient anchorage for architectural, mechanical, electrical and other service items and equipment that may fall within emergency ventilation equipment airstreams.

B4.13 Miscellaneous Loads

B4.13.1 Stream Current (F) Loads

Evaluate loads on pier shafts caused by flowing water per CHBDC Section 3.11.4 – Loads.

B4.13.2 Flooding Loads (FL)

See Section B4.15.2.3 Underground Structures – Water Pressures and Buoyancy.

Review and confirm appropriate flood elevations and bridge pier locations within flood plains based on AHJ groundwater levels and regional flood level records.

B4.13.3 Ice Pressure or Debris Torrent (ICE) Loads

Evaluate debris torrent loads on pier shafts per CHBDC Clause 3.11.7 – Loads.

Evaluated ice pressure loads on pier shafts per CHBDC Section 3.12 – Ice Loads.

B4.14 Load Factors and Load Combinations

In limit states standards the commonly used working stress standard factor of safety is divided into two parts: Load Factor (α) and Resistance Factor (ϕ).

Load Factor applies to a specified load taking into account load variations – loads that may be higher or lower than nominal design load – as well as any approximations and model uncertainties that may occur in load effects analysis.

Resistance Factor applies to theoretical member strengths, or resistance (R), taking into account that member resistance may be less than anticipated due to specified material property variability, dimensions, and workmanship as well as failure types and resistance prediction uncertainties.

Notations:

αD = Load Factor on Dead Loads;

αE = Load Factor on Earth and Water Pressures;

αP = Load Factor on Secondary Prestress Effects;

αL = Load Factor on Live Loads.

See Tables B4-3 and B4-4 for Maximum/Minimum Load Factors.

Use minimum and maximum load factor values given in Figures B4.4.2 and B4.4.3 for ultimate limit states permanent loads in order to maximize total factored load effect.

Consider load combinations and use load factor values including permanent, transitory and exceptional loads given in Figures B4.4.4, B4.4.5, and B4.4.6.

B4.14.1 Total Factored Load Effect

The total factored load effect includes load factors for each combination per Figure B4.4.4, Figure B4.4.5, or Figure B4.4.6.

Multiply each load for every load combination by specified load factor, compute resulting load effects and add together factored load effects to obtain total factored load effect.

Include every significant elastic distortion load effect in each total factored load effect.

B4.14.2 Permanent Loads

Include every permanent load in each total factored load effect.

B4.14.3 Staging Loads

Permanent loads often may not yet be present at various construction stages or may not be present over entire structure.

Construction staging loads may result in more severe total load effects than completed structure loads.

It is safety critical for structural design to analyze and account for every construction staging load.

B4.14.4 Transitory Loads

Include transitory loads in load combinations only if applied staging loads increase total factored load effect.

B4.14.5 Exceptional Loads

Since exceptional loads rarely occur, possibility of more than one exceptional load occurring simultaneously may be neglected.

When possibility of exceptional loads occurring exists at stage being considered, include one load producing largest total factored load effect.

B4.14.6 Resistance Factors

Apply resistance factors in checking ultimate limit states for different types of structures to account for specified material property variability, dimensions, workmanship, failure types, and resistance prediction uncertainties.

B4.14.7 Multi-lane Load Modification Factor

Apply a Multi-lane load Modification Factor for elevated structures design per CSA-S6-06 CHBDC, Section 3.8.4.2 and Table 3.5.

As a structure load on LRT lines, count only dedicated truck load lanes as number of design load lanes.

Reduction factors do not apply to LRV load.

TABLE B4-2 DESIGN LOADS LEGEND

Permanent Loads	
D	Dead load including vertical effects of earth load (or cover) and surcharges
E	Horizontal earth pressure loads including surcharges, water pressure, buoyancy (B).
P	Secondary Prestress Effects.
LR	Longitudinal and radial loads due to track restraint (LR1, LR2, LRT1, LRT2).
Transitory Loads	
L	Live load. LRV live load to include for impact (DLA), rolling (lurching) load (RF), hunting (nosing) load (HF) or centrifugal load (CF), normal acceleration or braking (LN) forces.
W	Wind loads on structure.
V	Wind loads on vehicle.
SL	Snow and ice loads on guideway (SIG) and ice on vehicles (SIV).
F	Load due to stream flow
K	Effects of strains due to thermal (T), shrinkage (SH), creep (CR).
S	Load due to differential foundation settlement.
Exceptional Loads	
CFe	Extreme centrifugal force
LE	Emergency braking.
BR	Broken rail.
CL	Collision with pier or column (by other vehicles)
DR	Derailment load (by transit vehicle).
Q	Earthquake.
ICE	Loads due to ice pressure or debris torrent.
FL	Flooding (underground structures).

TABLE B4-3 UNDERGROUND STRUCTURE AND STATION MAXIMUM / MINIMUM LOAD FACTORS

Load Type	Maximum αD	Minimum αD
Dead Load Factory produced components including trackwork Cast-in-place concrete, wood and all non-structural components Tie and ballast Negative skin friction on piles	 1.25 1.25 1.25 1.4	 0.95 0.90 0.80 0.80
Vertical Earth Load $\gamma = 22$ kN/m^3 minimum IF cover ≤ 3.0 metres IF cover > 3.0 metres	 1.5 1.4	 0.8 0.8
Earth Pressure and Porewater Pressure	**Maximum αE**	**Minimum αE**
Horizontal passive earth pressure[1] Horizontal at-rest or active earth pressure Minimum horizontal earth pressure case[2] Horizontal water pressure Uplift water pressure[3] Surcharge[4]	1.4 1.4 N/A 1.25 1.3 1.5	0.6 0.85 0.5 0.85 0.8 0
Prestress	**Maximum αP**	**Minimum αP**
Secondary Prestress effects Prestress	1.05 1.00	0.95 1.00
Live Load Factors	**Maximum αL**	**Minimum αL**
Transit Vehicle Load Platform and Concourse	1.5 1.5	0 0
Buoyancy	See Geotechnical Reports	

Notes:

1. See Geotechnical Reports for passive earth pressure resistance factor when considered as a load.
2. See Section B4.5.6 for post-construction loading case with minimum horizontal earth pressure.
3. See Geotechnical Reports for buoyancy design of water pressure components.
4. See Section B4.5 for Surcharge loads.

TABLE B4-4 ELEVATED STRUCTURE MAXIMUM / MINIMUM LOAD FACTORS

Dead Load	**Maximum αD**	**Minimum αD**
Factory produced components including trackwork	1.25	0.95
Cast-in-place concrete, wood and all non-structural components	1.25	0.90
Wearing surface / asphalt overlay on structure	1.50	0.65
Tie and ballast	1.25	0.80
Negative skin friction on piles	1.4	0.80
Prestress	**Maximum αP**	**Minimum αP**
Secondary Prestress Effect	1.05	0.95
Prestress	1.00	1.00
Vertical Earth Load γ = 22kN/m^3 Minimum	**Maximum αD**	**Minimum αD**
IF cover ≤ 3.0 metres	1.5	0.8
IF cover > 3.0 metres	1.4	0.8
Earth Pressure and Pore Water Pressure	**Maximum αE**	**Minimum αE**
Horizontal passive earth pressure[1]	1.4	0.6
Horizontal at-rest or active earth pressure	1.4	0.85
Horizontal water pressure	1.25	0.85
Uplift water pressure[2]	1.3	0.8

Notes:

1. See Geotechnical Reports for passive earth pressure resistance factor when considered as a load.
2. See Geotechnical Reports for Buoyancy design of water pressure components.

TABLE B4-5 UNDERGROUND STRUCTURE LOAD FACTORS AND LOAD COMBINATIONS

Load Combination	Permanent Loads				Transitory Loads					Exceptional Loads					
	D	E	P	LR	L	W	SL[1]	K	S	CFe	LE	DR	BR	Q	FL
Fatigue Limit States															
FLS Combination 1	1	1	1	1	0.9	0	0	0	0	0	0	0	0	0	0
Service Limit States															
SLS Combination 1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
SLS Combination 2	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
SLS Combination 3	1	1	1	1	0.9	0	0	0.8	1	0	0	0	0	0	0
SLS Combination 4	1	1	1	1	0.8	0	0.8	0.8	0	0	0	0	0	0	0
Ultimate Limit States															
ULS Combination 1[8]	α_D	α_E	α_P	1	1.5	0	1.5	0	0	0	0	0	0	0	0
ULS Combination 2[9]	α_D	α_E	α_P	1	1.3	0	1.3	1.1[5]	0	0	0	0	0	0	0
ULS Combination 3[2]	α_D	α_E	α_P	1	0	1.6[5]	0	1.2[5]	0	0	0	0	0	0	0
ULS Combination 4[3]	α_D	α_E	α_P	1	1.1	0	0	0	0	1.3	0	0	0	0	0
ULS Combination 5[4]	α_D	α_E	α_P	1	1.1	0	0	0	0	0	1.3	1.3	0		0
ULS Combination 6	α_D	α_E	α_P	1	1	0	0	0	0	0	1	0	0	1.3	0
ULS Combination 7[4]	α_D	α_E	α_P	1	1	0	0	0	0	0	0	0	1.3	0	1.3

Notes:

1. Ground snow load on structure or surcharge, whichever governs.
2. This combination applies to exposed portions of underground structures, e.g., portals.
3. Do not use CF or HF in L.
4. Use one exceptional load only.
5. Table B4-5 based on studies by TTC in 1995 and 2002.
6. Table B4-5 does not apply to tunnel structures.
7. Refer to Figure B4.4.2 for permanent load factors.
8. Use 1.7 factor on CHBDC live load for underground structure.
9. Use 1.6 factor on CHBDC live load for underground structure.

TABLE B4-6 UNDERGROUND STATION STRUCTURE LOAD FACTORS AND LOAD COMBINATIONS

Load Combination	Permanent Loads				Transitory Loads					Exceptional Loads					
	D	E	P	LR	L	W	SL	K	S	CFe	LE	DR	BR	Q	FL
Fatigue Limit States															
FLS Combination 1	1	1	1	1	0.9	0	0	0	0	0	0	0	0	0	0
Service Limit States															
SLS Combination 1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
SLS Combination 2	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
SLS Combination 3	1	1	1	1	0.9	0	0	0.8	1	0	0	0	0	0	0
SLS Combination 4	1	1	1	1	0.8	0	0.8	0.8	0	0	0	0	0	0	0
Ultimate Limit States															
ULS Combination 1[6]	1.4	α_E	α_P	1	1.4	0	0	0	0	0	0	0	0	0	0
ULS Combination 2[7]	α_D	α_E	α_P	1	1.5	0	1.5	0	0	0	0	0	0	0	0
ULS Combination 3[7]	α_D	α_E	α_P	1	1.5	0.4	0	0	0	0	0	0	0	0	0
ULS Combination 4	α_D	α_E	α_P	1	0	0.4	1.5	0	0	0	0	0	0	0	0
ULS Combination 5[8]	α_D	α_E	α_P	1	1.3	0	1.3	1.15	0	0	0	0	0		0
ULS Combination 6	α_D	α_E	α_P	1	0.5	1.6[5]	0.5	1.2[5]	0	0	0	0	0	0	0
ULS Combination 7[1]	α_D	α_E	α_P	1	1.1	0	0	0	0	1.3	0	0	0	0	0
ULS Combination 8[2]	α_D	α_E	α_P	1	1.1	0	0	1	0	0	1.3	1.3	0	0	0
ULS Combination 9	α_D	α_E	α_P	1	1	0	0.2[5]	0	0	0	0	0	0	1.3	0
ULS Combination 10[2]	α_D	α_E	α_P	1	1	0	0	0	0	0	0	0	1.3	0	1.3

Notes:

1. Applies to above and below grade Station portions.
2. Do not use CF or HF in L.
3. Use one exceptional load only.
4. For non-redundant structures where failure of single component could lead to total collapse, multiply ULS permanent, transitory, and exceptional loads by importance factor;
5. 1.15 x (Factored Load Combination);
6. Table B4-6 based on studies by TTC in 1995 and 2002;
7. See Figure B4.4.2 for permanent load factors;
8. This combination may govern for dead load dominant structures; verify for every structure.
9. Use 1.7 factor on CHBDC live load for structure.
10. Use 1.6 factor on CHBDC live load for structure.

TABLE B4-7 ELEVATED STRUCTURE LOAD FACTORS AND LOAD COMBINATIONS

Load Combination	Permanent Loads				Transitory Loads						Exceptional Loads						
	D	E	P	LR	L	W	V	SL	K	S	CFe	LE	DR	CL	BR	Q	ICE & F
Fatigue Limit States																	
FLS Combination 1	1	1	1	1	0.9	0		0	0	0	0	0	0	0	0	0	0
Service Limit States																	
SLS Combination 1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
SLS Combination 2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
SLS Combination 3	1	1	1	1	0.9	0	0	0	0.8	1	0	0	0	0	0	0	0
SLS Combination 4	1	1	1	1	0.8	0.6	0.6	0.8	0	0	0	0	0	0	0	0	0
Ultimate Limit States																	
ULS Combination 1	1.4	α_E	α_P	1	1.4	0	0	1.3	0	0	0	0	0	0	0	0	0
ULS Combination 27	α_D	α_E	α_P	1	1.5	0	0	1	1.1[5]	0	0	0	0	0	0	0	0
ULS Combination 38	α_D	α_E	α_P	1	1.5	0.5	0.5	1	1	0	0	0	0	0	0	0	0
ULS Combination 4	α_D	α_E	α_P	1	0	1.6[5]	0	0	1.2[5]	0	0	0	0	0	0	0	0
ULS Combination 51	α_D	α_E	α_P	1	1.2	0	0	0	0	0	1.3	0	0	0	0	0	0
ULS Combination 62	α_D	α_E	α_P	1	1.1	0	0	0	1	0	0	1.3	1.3	0	0	0	0
ULS Combination 7	α_D	α_E	α_P	1	0	1.3	0	0	0	0	0	0	0	0	0	0	1.3
ULS Combination 8	0.9	0	0.9[5]	1	1	0	0	0	0	0	0	1	0	0	0	1	0
ULS Combination 92	α_D	α_E	α_P	1	1	0	0	0	0	0	0	0	0	1.3	1.3	0	1.3

Notes:

1. Do not use CF or HF in L.
2. Use only one Exceptional Load.
3. For non-redundant structures where single component failure could lead to total collapse, multiply ULS permanent, transitory and exceptional loads by 1.15 x Factored Load Combination importance factor.
4. Table B4-7 based on studies by TTC in 1995 and 2002.
5. Refer to Figure B4.4.3 for permanent load factors.
6. This combination may govern for dead load dominant structures; verify for every structure.
7. Use 1.7 factor on CHBDC truck, lane, or pedestrian live load for elevated structures.
8. Use 1.6 factor on CHBDC live load for elevated structure.

B4.15 Underground Structures

B4.15.1 Scope

Underground structures include:

- Reinforced concrete cut-and-cover box sections;
- Reinforced concrete portions of underground station buildings;
- Tunnels, ventilation shafts and emergency exits using concrete or steel structural lining;
- Reinforced concrete retaining walls and portal structures subject to earth pressure loads;
- Cut-and-cover structure roof, concourse, and intermediate slabs.

B4.15.2 Loads

General

Provide Geotechnical Investigation Reports summarizing load parameters for major underground structures forming an integral part of project design requirements.

Consider temporary and permanent horizontal and vertical loads from:

- Soil/Rock Pressure;
- Water Pressure;
- System Imposed Forces;
- Adjacent Structures;
- Materials and Equipment Surface Storage;
- Major Underground Utility Structures.

Transitory live loads include:

- LRV;
- Surface Vehicle Traffic;
- Storage;
- Utility;
- General Surcharge; and
- Use/Occupancy Loads.

See Geotechnical Reports.

Earth Pressure (D, E)

Vertical pressure (**D**) from superimposed earth load is based on 3 m minimum depth of cover or actual compacted granular material cover with mass density of 22 kN/m^3.

See Section B4.15.6.

For submerged, partially submerged, or alternative fill material conditions, submit recommended densities from Geotechnical Investigation Report for MX LRT review and acceptance.

Consider possible temporary loads from at-grade construction equipment or excavated material stockpiling.

Assume 1 m minimum removed earth load back fill for road and/or utility construction.

See Section B4.15.6, Box Structures.

Design earth retaining structures for horizontal earth pressure (**E**) and abutting earth load surcharges.

Determine E based on parameters including:

- Backfill Material Configuration, Nature and Drainage Properties;
- Retaining Wall or Structure Displacement Characteristics;
- Wall and Backfill Interface Conditions;
- Backfill Material Method of Compaction;
- Existing/Proposed/Future Groundwater Location;
- Artesian Conditions;
- Adjacent Foundations Live and Dead Loads;
- Point Load / Line Load Surcharge Magnitudes;
- Wall or Structure Location Relative to Ground Level.

Water Pressures and Buoyancy (B)

Consider water pressure and buoyancy effects wherever groundwater is found.

Establish high and low water tables for life of structure considering possible future changes in groundwater elevation.

Ignore hydrostatic pore pressure seepage relief except for underground structures such as mined caverns with engineered open waterproofing pore water drainage systems.

Provide hydrostatic pressure diagrams for engineered pore water drainage systems.

Consider two groundwater levels:

- Normal, observed maximum ground water level; and
- Extreme, 0.3 m above 100-year flood level.

In addition, consider construction groundwater levels with respect to structures construction stage.

Base groundwater levels for design of temporary and permanent works on review of available information and data collected from surface investigation program.

Consider variations in groundwater level and possible future significant changes in establishing design groundwater level.

Observe and control groundwater level during construction and backfill operations so that calculated total mass of structure and backfill always exceeds calculated uplift due to buoyancy.

Consider backfill as volume contained within vertical planes defined by outside limits of structure.

Take into account effect of water pressure with respect to construction sequence.

See Geotechnical Reports.

Flooding (FL)

Local flooding may add load to underground structures.

Thus allow for flood elevations based on groundwater levels with design elevations subject to AHJ review.

See Section B4.5.2.3.

Adjacent Building or Other Structures Foundation Loads

Determine horizontal and vertical distribution of loads from foundations of existing buildings.

Consider minimum and maximum loads that can be transferred to an underground structure.

Where possible, base these loads on actual design loads for adjacent structures.

Where this information is not available, use a rational approach approved by MX LRT to evaluate probable load of existing structures.

When performing above analyses, determine need for permanent underpinning of buildings or structures.

See Geotechnical Reports.

Other Surcharge Loads

In lieu of a more precise analysis, where depth of fill over a structure is 60 mm or greater, consider wheel loads to be uniformly distributed over a rectangular area with sides equal to tire contact area dimensions plus either 1.15 times depth of select granular fill or 1.0 times depth of fill in all other cases per CHBDC.

Where areas from several wheels overlap, uniformly distribute total load over area.

Where depth of fill over a structure is less than 60 mm, consider no load distribution beyond wheel contact area.

Distribute railway wheel loads per Figure B4-3.

For underground structures use the more severe of an equivalent 60 mm earth fill live load surcharge, CHBDC CL-625-ONT truck wheel load or lane load, or LRV live load above structure.

See Figure B4.4.4 for live load surcharge factor where roadway or LRV loads govern.

Consider live load surcharge as acting both uniformly over entire structure and adjacent backfill as well as over a portion of structure and backfill to one side (unbalanced condition).

Dynamic Load Allowance

Multiply truck live load dynamic load allowance only above box type underground structures by the factor (1.0 - 0.5 De) but not less than 0.1 where De is depth of earth in meters between top of roof and riding surface or bottom of tie.

Earthquake Load

Earthquake resistant design of underground structures such as soft ground or rock tunnel structures and cut-and-cover box structures requires sufficient strength and ductility per National Building Code of Canada, OBC, CHBDC and CSA Standard A23.3.

Use FHWA NHI-09-010 Road Tunnel Manual for seismic design as guidance in underground structure applications not covered in bridge and building codes.

See Section 28.10.4.1.9 and Section 28.11.5 for Earthquake Load.

B4.15.3 Fireproofing

Provide underground structures meeting NFPA 130 fire proofing requirements as well as other codes, standards and criteria that apply.

Pay special attention LRV fire effects on immediate and long term structural performance.

See Chapter A3 – Safety.

B4.15.4 Construction Methods

Methods and/or sequence of construction influence structural system behavior and load conditions.

Define these conditions in basing a structural analysis on a particular method or sequence of construction.

Also specify a construction sequence where necessary to provide sufficient safeguards against uplift during every stage of construction.

For cut-and-cover construction, consider in detail short-term safety critical conditions that may occur when excavation nears base bearing surface of permanent or temporary retaining walls.

Control groundwater inflow during construction per Geotechnical requirements.

Design and construction of underground structures, whether temporary or permanent, must make sure that movement of adjacent structures and ground does not exceed acceptable levels.

Evaluate effects of movement on adjacent structures.

Identify allowable limits of movement or differential settlement and take protective measures to make sure these limits are not exceeded.

Agree upon protective measures with owner of structure under consideration.

Consider three basic underground structure construction methods:

- Bottom-Up;
- Top-Down; and
- Combined Top-Down/Bottom-Up.

Bottom-Up Construction

Bottom-Up Construction, the simplest technique, involves uninterrupted excavation, usually within temporary retaining walls, followed by conventional construction from base slab up.

Structural advantages of Bottom-Up Construction are:

- Conventional construction methods after temporary retaining walls installation;
- Temporary retaining walls supported by ground anchors provide unrestricted working areas;
- Wide choice of temporary wall construction methods for more competitive generally lower costs.

Structural disadvantages of Bottom-Up Construction are:

- Risk to adjacent structures where dewatering before excavation is required;
- Restrictions may occur for on-street facilities where decking systems are required to maintain traffic;
- Compared to top-down construction, more risk of ground heave / settlement with large amounts of soil removed before compensating weight of structure is placed.

Top-Down Construction

Top-Down Construction involves initial construction of permanent exterior walls by diaphragm walls, secant piling, or some other technique and internal columns whether temporary or permanent.

Excavation down to roof soffit level and construction of roof slab follows, roof slab acting as a strut between exterior walls.

Excavation to lower slab levels then follows with construction of each slab in turn.

Structural advantages of Top-Down Construction are:

- Early permanent works construction is used to carry temporary and permanent loads eliminating need for extensive temporary works;
- Less tendency for bottom heave, especially with early installation of central vertical columns to carry any temporary decks and suspended slabs;
- Reduced overall width with no excavation beyond permanent structural limits is useful where building clearances are minimal, settlement risk is high, and/or traffic lanes must be maintained during construction;
- With sufficient cut-off, groundwater movement is more readily controlled, minimizing draw-down effect on adjacent structures.

Structural disadvantages of Top-Down Construction are:

- Roof slab and temporary decking restrictions complicate excavation;
- Waterproofing finished structure is difficult;
- Permanent diaphragm walls or other modern construction methods involving complex heavy machinery may be difficult in congested work sites;
- Involves specialized contractors;
- Construction must be carefully monitored to mitigate risk of settlement.

Combined Top-Down/Bottom-Up Construction

Combined Top-Down/Bottom-Up Construction as an alternative to bottom-up and/or top-down construction involves initial construction of permanent exterior walls while progressively installing temporary supports during excavation.

Upon completing excavation, construction of remaining permanent structure takes place bottom-up.

Evaluate structural advantages and disadvantages of Combined Top-Down / Bottom-Up Construction on a case-by-case basis.

B4.15.5 Box Structures

Structural Design Considerations

Cut-and-cover reinforced concrete box structures retain earth but are not free to yield significantly.

Combine associated vertical and horizontal loads as indicated in load cases below.

Include dead and live load surcharge pressures.

Use maximum and minimum load factors to assess maximum and minimum box structure load effects.

See Section B4.4, General – Design Load Combinations and Figure B4.4.4.

Case 1

Full vertical load and horizontal load.

Consider four earth fill vertical dead load conditions as follows:

- Final design grade;
- 3 m minimum fill on structure if greater than above condition;

- 1 m fill less than final design grade, in which case do not apply minimum earth load factor to earth load; Use this load case to simulate future roadway repairs/replacement above underground structure;
- Base earth fill height on site survey elevations for existing structure evaluation or structure rehabilitation.

Case 2

Full vertical load and unbalanced horizontal loads.

Calculate unbalanced horizontal loads by applying maximum to one side of box structure and minimum to other side.

Case 3

Maximum vertical load and minimum horizontal load.

Consider full vertical load with maximum and minimum factors on lateral active earth pressure with no groundwater pressures.

This case represents post-construction loads and accounts for possibility of reduced lateral earth pressures initially acting on box structure walls.

Case 4

Also identify any special design load cases where water pressure unbalance may occur.

Unequal Lateral Pressures

For underground concrete box structures that may be subjected to unequal lateral pressures, consider top slab as both restrained and unrestrained against horizontal translations in arriving at maximum shears, axial loads and moments.

Horizontal displacement to height of wall ratio is not to exceed 0.005.

Submit design parameters and assumptions for MX LRT review if ratio exceeds 0.005.

Variations in Elastic Support of Sub-Grade

Consider variations in elastic support of sub-grade for appropriate load conditions.

Do not consider compression loads in box structure top and bottom slab shear design.

Transverse Beams Minimum Clearance

Minimum clearance between transverse beams at a contraction joint: 35 mm.

Buoyant (Uplift) Water Pressure

Consider buoyant (uplift) water pressure in structure rehabilitation where work may reduce ground cover over structure.

Examine options such as excavation staging, lowering groundwater table, degree of soil contact friction with structure walls, and temporary uplift restraints.

B4.15.6 Soft Ground Tunnelled Structures

General

For tunnel design refer to MX LRT design criteria for general guidance that provides a set of general load parameters or conditions to be assessed while permitting flexibility in selection of construction method and lining system most suitable to local geotechnical conditions.

Determine tunnel design criteria and methodology using generally accepted engineering principles for tunnel structures of similar kind subject to MX LRT review and acceptance.

Also determine tunnel design methodology and criteria on a case-by-case basis to suit site specific tunnelling methods and geo-environmental conditions.

MX LRT may consider temporary support systems in certain geotechnical conditions based on observational approach where amount of ground support is modified per measurement of load being carried — such as New Austrian Tunnelling Method (NATM) — upon detailed design proposal review and acceptance.

Provide tunnels constructed to dimensions satisfying MX LRT operating tolerances.

See Chapter B1 – Alignment, Clearances, Rights-of-Way.

Provide vertical tunnel structures used for access, ventilation shafts, or emergency exits for loads listed above.

Tunnel Lining

Provide structural tunnel lining for load and environmental requirements as follows:

- Superimposed surface loads and adjacent building loads;
- Earth pressure and variable water pressures;
- System imposed loads per Section 13;
- Tunnel structure self-weight;
- Temperature and shrinkage;
- Handling loads;
- Erection loads including unequal grouting pressures;
- Additional loads due to tunnel lining openings and driving adjacent tunnels;
- Structural requirements to resist buckling;
- Bending stresses produced by changes in tunnel diameter;
- Tunnel linings to resist any loads applied to them by a tunnel boring machine or shield;
- Suitable sealing gaskets around each segment for precast reinforced concrete segmental tunnel linings;
- Consider cast iron or steel segments in lieu of precast concrete;
- Bolt tunnel lining segments on their longitudinal and circumferential joints;
- Use tapered tunnel lining rings to form curves and adjust vertical and horizontal alignment;
- With two stage tunnel linings, in choosing primary lining fully consider effects of groundwater lowering resulting from tunnel seepage;
- Include measures to prevent loss of ground fines;
- Fill voids with grouting or other suitable measures;
- Completely fill annulus between tunnel lining and ground with cement grout;
- Maintain stability of excavated face and tunnel periphery at all times;
- Corrosion prevention measures for tunnel lining segments including elimination of stray currents in surrounding ground and protection from chemical attack by water borne pollutants;
- Tunnel lining systems able to resist soil and groundwater loads and prevent water ingress with no significant deterioration for design life of structure.

B4.15.7 Rock Tunnelled Structures

General

Rock Tunnelled Structures are generally circular bored tunnels with segmental tunnel linings or rock bolts/ other forms of temporary support followed by a permanent cast-in-place concrete tunnel lining.

Provide segmental tunnel linings per Section B4.5.7.

Establish rock loads and/or mixed face loads with Geotechnical Engineer subject to MX LRT review and acceptance.

Temporary Tunnel Support

Temporary tunnel support systems may consist of spilling rock bolts, mesh, shotcrete, steel ribs with lagging, lattice girders, or a combination thereof, providing ground support or reinforcing ground to support itself.

Provide temporary tunnel support systems designed for:

- Superimposed surface loads;
- Rock or mixed face loads;
- Self-weight;
- Additional loads due to driving adjacent tunnels.

Assess water conditions to determine whether to consider short-term water pressure as a temporary support design load.

Cast-in-Place Tunnel Lining

Provide cast-in-place tunnel lining for load and environmental requirements as follows:

- Superimposed surface loads and loads from adjacent structures;
- Rock or mixed face loads;
- Water pressure;
- Support system imposed forces;
- Self-weight;
- Temperature and shrinkage;
- Additional loads due to tunnel lining openings and driving adjacent tunnels.

Also consider time-dependent bedrock squeeze behavior where indicated by Geotechnical Engineer.

B4.15.8 Ventilation/Emergency Exits Shafts

Ventilation/emergency exit shafts are usually reinforced concrete cut-and-cover construction.

See Section B4.15.6 Box Structures.

Ventilation/emergency exit shafts outside of cut-and-cover construction are designated as underground structures with appropriate loads developed in consultation with Geotechnical Engineer and due consideration of loads generated by proposed construction method.

Design stair and ramp horizontal surface areas for 6kPa uniform specified load.

Determine ventilation/emergency exit shaft and associated access hatch design criteria in consultation with MX LRT.

Emergency ventilation/evacuation requirements and prevention of unauthorized person or accidental material incursion governs ventilation/emergency exit shaft structural design except for more critical requirements of governing codes and standards.

Provide fully-enclosed emergency exits and fire fighter access shafts naturally-ventilated to limit condensation on below grade concrete surfaces.

Protect ventilation/emergency exit shafts from high temperatures to maintain structural integrity and function safely in case of fire.

B4.15.9 Retaining Walls

For design considerations and general factors influencing behavior of retaining walls.

See CHBDC CSA-S6 Section 6, CSA-S304, and AREMA Section C4.6 – Elevated Structures.

Retaining wall design is site specific requiring geotechnical input and understanding construction methods used to build wall.

Retaining walls may require architectural treatment depending on public visibility.

Design retaining walls to resist loads as follows:

- Superimposed surface load and loads from adjacent structures and utilities;
- Support system imposed forces;
- Earth or rock pressure and variable hydrostatic pressure;
- Seismic loads;
- Self-weight;
- Loads generated by construction methods to build wall;
- Thermal, shrinkage and creep stresses;
- Other stresses due to nature of wall material; and
- Other loads identified by Geotechnical Engineer/Geotechnical Design Report.

Analyze retaining walls for:

- Stability against sliding;
- Stability against bearing failure and overturning;
- Overall stability;
- Settlement; and
- Structural strength.

Consider future wall repairs without affecting operations in locating retaining walls.

B4.15.10 Portals

See Section B4.15.2 Underground Structures – Loads.

Design entrance portals carrying traffic loads as Group 2 structures per Figure B4.1.1 and Canadian Highway Bridge Design Code.

Design box structure portals to minimize rate-of-change air pressure rise of an LRV passing through portal.

Air pressure rise is a function of portal entrance cross-section area and LRV entrance speed.

Portal transition section provisions to mitigate air pressure rise include:

- Flared transition sections from tunnel or box structure constant area section to portal opening; and
- Tapering slots in top of portal entrance.

Portal transition sections are not required for LRV design speeds less than 65 km/h.

Provide portal structures configured to allow installation of emergency roll-up doors.

Provide portal structures with a second means of egress for evacuation around portal emergency roll-up doors unless otherwise approved.

Provide power/communication/signal cables without interfering with emergency roll-up doors or frames.

B4.16 Elevated Structures

B4.16.1 Scope

Elevated structures refer primarily to guideways, bridges or elevated platforms supporting transit vehicles including buses.

Use Limit States Design Method for other at-grade or above-grade structures including station structures structurally independent of guideway support structures.

Elevated structures support and retain LRVs while also providing emergency access and egress, support for wayside power distribution, signal and LRV control services, and means to inspect and maintain trackwork and other system components.

Consider operational, aesthetic, and fire/life safety requirements significantly contribute to elevated structures form and function in structural design process.

Non-redundant and single load paths are not desirable for new MX LRT elevated structures.

Only consider using non-redundant structures where no feasible alternative exists and then only upon MX LRT review and acceptance.

B4.16.2 Functional Considerations

Elevated structures must possess sufficient strength and stiffness to safely support LRV and other applied loads structure will be subjected to during its service life.

The elevated structure natural frequency must prevent and avoid harmonic vibration.

Use elevated structure sidewalls for LRV retention in case of derailment, as acoustic barriers and walkway parapets, and to support system cables.

The degree of sidewall noise suppression is a function of sidewall height and proximity to LRV wheels.

Provide sidewalls of minimum height required for LRV retention.

See Section B4.6.1 LRV Design Loads.

Design elevated structures to provide transverse drainage.

Avoid water discharge against any part of an elevated structure.

See Chapter B3 – Civil Work.

Also consider heat tracing or other means of preventing ice accumulation on elevated structures or downspouts.

LRV interaction with elevated structures can affect support, steering, power distribution and traction.

Elevated structure surfaces, both structure and trackwork, may influence ride quality.

LRV and systems specifications present ride quality criteria in terms of acceleration performance, braking performance and jerk rates (rates of acceleration change).

Consider method of rail assembly, use of continuous structures, and attachment of rails to structure for guideways with steel rails.

Use continuously welded rail for main lines except special trackwork because bolted rail joints generate greater noise, reduce rider comfort, increase dynamic impact loads on structure and deteriorate from contact with LRV wheels.

See Section B4.6.3 Dynamic Load Allowances for continuously welded rail loads generated in structure.

See Chapter B2 – Track Work for rail to structure fastening methods and other trackwork considerations.

Consider service load deflection, initial camber, and long-term deflection effects on elevated structures.

Designs that tend to minimize angular discontinuity at beam joints generally provide superior ride although there is no clear definition of how much angular discontinuity can be tolerated.

Continuous elevated structures control these deflections particularly well.

B4.16.3 Special Vehicles

Review need and use of special work vehicles on elevated structures, including those used for snow removal, with MX LRT.

B4.16.4 Aesthetic Considerations

A significant design consideration and necessary factor in public acceptance is to minimize physical presence of elevated structures and consider their aesthetic impact on the community.

Consider matching span lengths, minimizing girder depths, alternative column shapes, and other architectural treatments to enhance aesthetic design of elevated structures.

Factors to consider include:

- Possible walkways outboard of elevated structures;
- Overall width especially in double-track configurations;
- Gaps in elevated structures may allow light passage;
- Overall mass and depth especially where acoustic sidewalls are required;
- Offsets, sloping members, and curved forms may soften shadow lines and/or produce more slender appearance;
- Alternative pier forms (e.g., tapered, circular, etc.);
- Architectural detail and surface treatments;
- Prestressing/post-tensioning anchor block locations and architectural treatment;
- Cross head integration with vertical piers and horizontal elevated structures.

Proper detailing, quality control, fabrication, and installation of elevated structure components are also important aesthetic concerns including:

- Surface finish, color, and texture;
- Joints details;
- Recessed drainage downspouts at piers;
- Systems cables attached to inside face of sidewalls;

- Avoiding concrete staining and spalling from improper inserts etc.; and
- Careful placement and minimizing number of box-outs or other items detracting from elevated structure appearance.

B4.16.5 Design Method and Loads

Section B4.3 general structural criteria, design codes, and manuals apply to every structure and are therefore used in conjunction with criteria provided in Section B4.16.5.

Use load factors and load combinations per Section B4.14.7 Figure B4.14.6.

For structures carrying both LRVs and highway traffic comply with MX LRT Load Factor and Combination requirements for LRV live load and all dead loads.

Dead Loads (D)

Use Dead Loads per Section B4.5.

Live Loads (L) Due to Use and Occupancy

Use LRV live loads per Section B4.6.2.

Consider load case where maintenance or work vehicle load combinations may be more critical LRV loads.

Distribute LRV wheel loads per Section B4.3 and Figure B4-5, Direct Fixation-Wheel Load Dispersion.

Use 4.8kPa for live load on service or emergency walkways combined with a reduced live load for an LRV on elevated structures since walkway load is derived from passengers evacuating LRV.

Use design loads for elevated structure service walkway handrails per Canadian Highway Bridge Design Code, Section 3 – Loads, Clause 3.8.8.2 and 3.8.10.

Although large assemblies of people may not be possible, use an abnormal load of 3 kN/m for emergency evacuation of an LRV.

LRV impact loads per Section B4.6 apply for elevated structures but do not apply for foundation systems.

Environmental Loads

Wind Load (W)

Treat design wind loads for elevated structures and special structures based on reference wind pressure as equivalent static loads.

Reference wind pressure, q, is 0.53 kPa for a return period of 50 years.

For elevated structures, assumed gust effect coefficient, Cg, is 2.0.

The exposure coefficient, Ce, is not less than 1.0 and:

Ce = 1.0 for heights up to 1 m;

Ce = 1.2 for heights between 1 m and 25 m.

Consider overturning, uplift and lateral displacement in addition to applying prescribed loads in design of elevated structure members.

Provide elevated superstructures designed for wind-induced vertical and horizontal drag loads acting simultaneously.

Assumed wind direction is perpendicular to longitudinal axis for structures straight in plan or to an axis chosen to maximize wind-induced effects for structures curved in plan.

Wind load per unit exposed frontal area of elevated superstructure applied horizontally:

Fh = qCeCgCh (horizontal drag load)

Where q, Ce and Cg are as specified; and (1)

Ch = 2.0.

Wind load per unit exposed plan area applied vertically:

Fv = qCeCgCv (vertical load)

Where q, Ce and Cg are as specified; and (2)

Cv = 1.0.

Vertical load, Fv, is taken to act either upwards or downwards.

Account for overturning effects from wind induced moments about longitudinal axis by applying vertical load as an equivalent line load at windward quarter point of transverse superstructure width.

Calculate wind load on an LRV per expression (1) except Ch is taken to be 1.2.

Consider entire LRV length or any part or parts of that length as frontal area producing critical response multiplied by LRV height above a sidewall.

Provide substructure designed for wind loads acting directly on it and wind-induced loads transmitted to it from superstructure.

Consider wind loads for directions both normal to and skewed to longitudinal superstructure centre line.

Resolve wind loads into transverse and longitudinal components using skew angle modification components listed herein applied simultaneously to produce maximum load effects in substructure.

Apply vertical load at either substructure centre line or along windward quarter to produce the more critical effect.

TABLE B4-8 MODIFICATION OF WIND LOADS ON SUPERSTRUCTURE WITH SKEW ANGLE
Reference: Canadian Highway Bridge Design Code

Skew Angle Measured From Line Normal To Longitudinal Axis	**Modification Coefficients**	
	Transverse Horizontal or Vertical Load	**Longitudinal Horizontal Load**
0°	1.00	0.00
15°	0.88	0.12
30°	0.82	0.24
45°	0.66	0.32
60°	0.34	0.38

Provide substructure designed for directly-applied horizontal drag loads using expression for Fh.

Assumed horizontal drag coefficient, Ch, is:

- 0.7 for circular piers;
- 1.4 for octagonal piers; and
- 2.0 for rectangular and square piers.

For wind directions skewed to substructure, resolve loads into components acting horizontally at centroids of end and side elevation exposed areas respectively and applied simultaneously with loads transmitted from superstructure.

Ice and Snow Loads (SIV, SIG)

In normal operations apply an ice accretion load (SIV) to LRV roofs equal to 4 mm average ice thickness.

Assume no ice build-up on LRV vertical surfaces.

During normal operations apply SIV of 9.65 kN/m^3 on elevated structures from deck slab to top of running rails plus additional compacted snow accumulation (SIG) of 4.7 kN/m^3 on walkways to top of sidewall.

Since snow and ice loads during suspended operations are less than LRV live loads during normal operations they are not included as a design case per Section B4.14 Load Factors and Load Combinations.

Evaluate static and/or dynamic ice pressure on piers if site conditions warrant per CHBDC.

Earthquake Load (Q)

Provide sufficient strength and ductility for earthquake resistant design of elevated structures as lifeline bridges.

The Seismic Performance Zone is 2 for a lifeline bridge elevated structure with 0.05 zonal acceleration ratio.

Design multi-span lifeline bridge regular or irregular elevated structures in Seismic Performance Zone 2 by Multimode Spectral Method (MM) per CHBDC Table 4.2,

Single-span elevated structures do not require seismic analysis regardless of Seismic Performance Zone.

Provide elevated structure seismic isolation per CHBDC Chapter 4.10 — Seismic Design.

Multimode Spectral Method

See CHBDC Section 4.5.3.3 — Seismic Design for principles of MM analysis.

MM analysis requires a three-dimensional model and seismic response spectrum.

See CHBDC Section 4.4.7.

Use number of modes in MM analysis to account for 90% superstructure mass participation in direction considered.

Estimate member loads and displacement using an accepted modal combination procedure.

For elevated structures with closely spaced modes within 10% of each other in natural frequency, use Complete Quadratic Combination (CQC) method or absolute sum of modal quantities.

Seismic Design Forces

Obtain elevated structure elastic seismic loads by combining MM analysis results in earthquake load cases per CHBDC Section 4.4.9.2 — Seismic Design.

Divide elastic seismic loads by appropriate response modification factor, R, to determine seismic design loads such as moments for load effects in ductile substructure elements such as columns, piers, and pile bents, per CHBDC Table 4.5.

Refer to seismic design loads so determined as modified seismic design forces.

Use elastic design loads with a response modification factor R = 1.0 to determine seismic design loads for capacity-protected elements such as superstructures, beam / column joints, cap beams, and foundations — including footings, pile caps, and piles but not including pile bents and retaining walls.

Alternatively, design capacity-protected elements with factored resistances equal to or greater than maximum load effects developed by ductile substructure element(s) attaining their nominal resistance.

Provide connectors and restraining features designed to transmit maximum load effects determined from 1.25 x elastic seismic loads (R=1.0) in restrained direction but not to exceed load developed by ductile substructure element attaining 1.25 times its nominal resistance.

Minimum Support Length Requirements

Provide supports at which expansion and contraction takes place designed for minimum support length, N, measured perpendicular to face of support, given by:

$$N = K(200 + \frac{L}{600} + \frac{H}{150}) \cdot (1 + \frac{\psi^2}{8000})$$

(Ref. Canadian Highway Bridge Design Code)

Where:

L = Length in mm of elevated superstructure to adjacent expansion joint, or to end of elevated structure deck. For hinges within a span, L = sum of distances to either side of hinge. For single-span bridges, L = length of elevated structure deck. See CHBDC Figure 4.1.

H = For columns and/or piers: Column or pier height in mm;

For hinges within a span: Average adjacent column or pier heights in mm;

For single-span bridges: 0.0;

For abutments: Average elevated structure column heights supporting deck to next expansion joint in mm.

ø = Skew of support measured from a line normal to span direction in degrees.

K = Modification factor for Seismic Performance Zone 2: 1.0.

Requirements for Concrete Structures

See CHBDC Chapter 4.7 — Seismic Loads.

B4.16.6 LRV Derailment Loads (DR)

Consider both vertical and horizontal LRV derailment loads (DR) to act simultaneously on elevated structures.

Provide guard rails between running rails in addition to or as an alternative to assessment of LRV derailment loads subject to MX LRT review.

Horizontal LRV derailment load magnitude and line of action on a barrier or sidewall is a function of a number of variables including:

- Distance of tracks from barrier or sidewall;
- LRV derailment mass and speed;
- Radius of curve;
- Flexibility of barrier or sidewall; and
- Frictional resistance between LRV and barrier or sidewall.

Due to variables involved, determine magnitude of lateral load, say 50% to 150% of standard LRV weight, distributed over a length of wall, say 5 m, applied at a height above top of wall in conjunction with LRV manufacturer.

The objective is to retain an LRV on an elevated structure following collision impact.

Provide elevated structures and components designed to resist largest effects of a single derailed LRV coming to rest as close as physically possible to barrier or sidewall.

Provide elevated structures, barriers, sidewalls and components designed to resist largest impact effects of a single derailed LRV.

Include an impact factor of 1.0 in wheel loads for elevated structure deck slabs.

B4.16.7 Vehicle Collision Loads (CL)

Provide elevated structure piers per CHBDC highway vehicle collision requirements for any elevated structure pier within 1 m from edge of road pavement irrespective of protective barriers.

The design vehicle collision load (CL) on elevated structures is an equivalent horizontal static load of 1,400 kN applied to pier 1.2 m above grade and 10º to direction of travel.

B4.16.8 Thermal (T), Shrinkage (SH), and Creep (CR) Effects

Provide for structure movements and loads as a result of shrinkage, creep, and temperature variation as well as for presence of thermal gradients through depth of superstructure.

Include load effects that may be induced by restraint of these movements including temporary restraints required during construction and restraints imposed by rail fasteners.

Temperature Effects

Temperature Range

Assume temperature range per ACI 358.1R, PAR.3.4.2.1.

Adjust effective temperature range for applicable superstructure form or type using permissible depth dependent reductions per CHBDC.

Effective Construction Temperature

Assume effective construction temperature per ACI 358.1R, PAR.3.4.2.2.

Heat of hydration for cast-in-place concrete structures may cause higher concrete temperatures than effective construction temperature at time of initial set.

Assume concrete cools 25°C from initial set to effective construction temperature if more precise data not available.

Coefficient of Thermal Expansion

Assume coefficient of thermal expansion (á) = (12.0×10^{-6}/ºC) for normal weight concrete if a specific value for concrete used is not available.

Thermal Gradient Effects

Consider thermal gradient effects per CHBDC and ACI 358.1R, PAR.3.4.2.3.

Rail/Structure Interaction

Consider rail/structure Interaction effects per ACI.358.1R, PAR.3.4.3.

Thermal Rail Forces

Use thermal rail loads per ACI 358.1R, PAR 3.4.3.1.

Continuously welded rail directly fastened to structure creates a load when structure expands or contracts differently than rail.

Continuously welded rail is assumed to be installed in zero stress condition at an effective construction temperature.

If installation temperature is different from assumed baseline temperature, physically stress rail to be compatible with zero stress installation assumptions.

Rail axial thermal stress is determined by the equation:

$$f_r = E_r \cdot \alpha_r \cdot (T_o - T_r) \quad (1)$$

Producing rail axial thermal load equal to:

$$F_r = E_r \cdot A_r \cdot \alpha_r \cdot (T_o - T_r) \quad (2)$$

Where:

f_r = Rail axial thermal stress in MPa;

F_r = Rail axial thermal load in N;

E_r = Rail elasticity modulus of = 200,000 MPa;

α_r = Rail coefficient of thermal expansion, (=12.0 x 10-6/°C);

A_r = Rail cross-section area, e.g., 7258 mm2 for 115lb RE;

T_r = Rail temperature in °C;

T_o = Stress-free rail temperature in °C; and

Where positive rail stress/force is tensile and negative rail stress/force is compressive.

Extreme rail temperatures **T_r** = -35°C minimum to +55°C maximum.

Thermal rail loads produce radial loads acting on vertical or horizontal curved elevated structures.

This radial load per unit length, **F_R**, is expressed as:

$$F_R = \frac{F_r}{R} \quad (3)$$

Where:

F_r = Rail axial thermal load in N see equation (2); and

R = Radius of rail curvature in m.

F_R is radially directed toward center of circular curve for tension in rail and radially directed away from centre of circular curve for compression in rail.

Equations (1), (2), and (3) apply where no rail motion relative to structure occurs.

Where rail motion relative to structure occurs, analyze relaxation of rail to determine its effect on structure.

Factors that may cause rail motion include:

- Axial motion at rail expansion joints;
- Radial and/or tangential rail / structure movement on curved track;
- Tangential movements of structure on tangent track; and
- Broken rail.

Rail Loads

Rail loads result from rail temperature variations from rail installation temperatures.

Use extreme rail temperature to calculate rail / structure interaction forces.

See Section B4.6.7.2.1.

The relative movement of rail attached to structures may be caused by:

- Concrete structure creep after rail installation;
- Concrete structure shrinkage after rail installation;
- Structure temperature variations from rail installation temperatures.

Longitudinal Restraint Forces (LR1, LR2) on Tangent Guideway

Incompatibility of motion between tangent structures and continuous rail causes shear in direct fixation fasteners applying axial loads and uniformly distributed couples to structure.

Fastener restraint malfunction may increase loads applied to structure.

Use tangential interaction load LR1 computed using normal condition fastener restraint for superstructure Service (Specified) Load Design.

Use tangential interaction load LR2 computed using malfunction condition fastener restraint for superstructure Limit States (Ultimate) Design as well as Service (Specified) Load Design.

Consider longitudinal restraint loads to be present in load combinations unless a larger temperature-related load is present.

Establish rail fastener restraint design values for tangent and curved structures based upon trackwork and track fastener technology studies and appropriate fastener selection.

Curved Guideway Radial and Tangential Restraint Loads (LR1, LRT1, LRT2)

Continuously Welded Rail (CWR) loads on horizontal and/or vertical curves transfer radial and tangential loads through rail fasteners to structures.

These radial and tangential restraint loads (LR_1, LRT_1, LRT_2) are a function of temperature range, geometry of structure, rail size, and rail fastener longitudinal restraint as follows:

- LR1 = Loads due to rail fastener longitudinal restraint;
- LRT1 = Radial loads with normal fastener restraint and extreme temperatures;
- LRT2 = Radial loads with malfunction fastener restraint and extreme temperature.

Broken Rail Forces (BR)

Rail fasteners transfer broken rail loads to structure in longitudinal shear.

Rail will slip on both sides of break until reversed rail fastener restraint loads counteract rail tensile load before breaking.

Both unbroken rails and elevated structures resist unbalanced broken rail loads relative to stiffness.

Determined by analysis BR distribution to structure.

Do not consider very small probability of more than one elevated structure rail breaking at the same time.

Provide longitudinal rail fastener restraint to allow no more than 65 mm calculated rail break gap at extreme minimum rail temperature including both rail fasteners slip and elevated structure deflection.

See Figure B4.4.5 for elevated structure broken rail effects.

Unbalanced Thermal Loads

Provide elevated structure rails designed to resist unbalanced thermal loads.

Determine unbalanced thermal loads where they occur for each of these cases:

- In curved transition structures due radial deflection thermal load relaxation;
- In adjacent structures with asymmetric rail fastener / structural configuration;
- At rail joints;
- At abutments;
- At rail anchors;
- At turnouts; and
- Where elevated structures end.

Provide structures resisting unbalanced thermal loads designed for ultimate limit states and serviceability limit states.

Substitute unbalanced thermal loads for LRT_1 and LRT_2 in respective equations,

Shrinkage, Creep and Prestressing (P)

Consider Prestressing secondary stress including elastic shortening, movement, creep and shrinkage effects.

Generally control creep and shrinkage effects by proper concrete mix design and rebar placement.

B4.16.9 Durability

Design elevated structures to minimize effects of such environmental factors as temperature variation, snow, ice, salt, rain, wind, earthquake, solar radiation, deterioration of appearance, structural capacity and performance in their service life.

Enhance elevated structure durability by proper use of materials, concrete selection, and structural detailing/ construction quality control.

Pay special consideration to effects of LRV fire on immediate and long-term elevated structure performance as agreed with MX LRT.

B4.16.10 Fatigue

Assess number of LRVs structure is expected to support during its assumed 75 year minimum design life.

Apply a fatigue service load analysis to beams, crossheads and columns generally based on number of LRV loads applied to structure more than 1×10^6 times.

In certain instances determined on a case-by-case basis governing parameter may be number of LRV, bogie or wheel load passes.

LRV loads in Section B4.6.2 are based on crush load capacity assuming uniform passengers distribution throughout LRV with no freedom of movement.

LRV design capacity is maximum practical capacity of an LRV considering operational requirements while allowing for passenger movement and uneven distribution in an LRV.

LRV live load factor for fatigue limit states is 0.90 reflecting LRV practical design capacity rather than an individual LRV crush load capacity.

See Section B4.6.

The maximum concrete compressive stress due to LTV live load and dynamic load allowance is not to exceed 0.50 f'_c where stress reversals occur.

Stress range for straight reinforcement (rebar) is:

$$F_{sr} = 161.5 - 0.33\ F_{min} \leq 125\ \text{MPa}$$

Where:

F_{sr} = Rebar stress range in MPa;

F_{min} = Algebraic minimum stress level: tension = positive; compression = negative in MPa.

This limit applies to both Prestressed and non-Prestressed reinforcement.

Stress range in bends or welded rebar is not to exceed 65 mPa.

Tack welding of primary rebar is not permitted.

Avoid bends in primary rebar in areas of high stress range.

B4.16.11 Noise and Vibration Control

Incorporate features necessary to mitigate noise and vibration in elevated structures.

Provide flexural members with sufficient stiffness to limit deflections that may adversely affect structural strength or service life.

For unballasted prestressed concrete elevated structures limit predicted long-term total camber growth to span length/2,000 maximum.

For girders of simple or continuous spans limit deflections due to live load plus dynamic load allowance to span length/1,000 maximum.

Limit cantilever arm deflection due to live load plus dynamic load allowance to cantilever arm length/ 300 maximum.

Harmonic resonance can be induced in an elevated structure when structure and passing LRV natural frequencies are similar.

Provide elevated structure spans with first mode vertical vibration natural frequency greater than 3.0 Hz.

B4.16.12 Stray Current Corrosion Control

Depending on technology, elevated structures may require grounding and stray-current corrosion control.

See Chapter C5 – Stray Current and Corrosion Control.

B4.16.13 Uplift

Provide sufficient attachment of superstructure to any load combination producing uplift.

B4.16.14 Structure Deformation and Settlement

Consider structure deformation including foundation settlement for their effect on both structural behavior and trackwork.

Deformation and settlement control through proper structural design is of paramount importance in maintaining system safety and ride quality.

Install and monitor permanent surveyor monuments at supports and mid-spans to measure long-term superstructure deflection, deformation and settlement.

B4.16.15 Construction

Give due consideration to elevated structure construction and erection methods including:

- Design loads;
- Return periods;
- Probabilities of occurrence;
- Expected life of temporary structures;
- Construction stage durations.

Construction dead loads include:

- Form work;
- False work;
- Fixed appendages;
- Stored materials;
- Lifting and launching devices;
- Mobile equipment fixed for long periods at immobile locations.

Construction live loads include:

- Weights of workers;
- Mobile equipment;
- Vehicles;
- Hoists;
- Cranes; and
- Construction structural components.

Identify construction dead and live load limits in contract documents.

B4.17 Reinforced Concrete

Section B4.17 applies to reinforced, precast and prestressed concrete structures.

Depending on type of structure design concrete structures per CSA-A23.3-04 Design of Concrete Structures and CSA-S6-06 CHBDC with design loads, load factors, resistance factors and load combinations per applicable criteria Sections.

Consider fatigue limit state for structural steel in concrete structures where cyclic load applications occur.

See Section B4.19.4 – Fatigue.

Use materials, methods of materials testing, and construction practices for plain and reinforced concrete per CSA and ASTM Standards:

- CSA-A3000-08, Cementitious Materials Compendium (Consists of A3001, A3002, A3003, A3004 and A3005);
- CSA-A23.1/A23.2-09, Concrete Materials and Methods of Concrete Construction/Methods of Test for Concrete;
- CSA-S413-07, Parking Structures;

- ASTM C260-06, Standard Specification for Air-Entraining Admixtures for Concrete;
- ASTM C494 / C494 M-08, Standard Specification for Chemical Admixtures for Concrete;
- ASTM C1017 / C1017 M-07, Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete.

B4.17.1 Materials: Concrete

Specified concrete compressive strength, f'_c, for each part of structure: 30 MPa minimum; 40 MPa maximum.

Submit detailed analysis of higher strength concrete for special circumstances, e.g., precast concrete tunnel liners, for MX LRT review and acceptance.

Proposed use of High Performance Concrete (HPC) requires special QA / QC provisions subject to MX LRT review and acceptance.

Provide air-entrained concrete where exposed to freeze-thaw cycles.

B4.17.2 Materials: Reinforcing Steel

Provide non-prestressed concrete rebar and rebar test methods per following CSA and ASTM Standards:

- ASTM A82/A82 M-07 Standard Specification for Steel Wire, Plain, for Concrete Reinforcement;
- ASTM A185/A185 M-07 Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete;
- ASTM A496/A496 M-07 Standard Specification for Steel Wire, Deformed for Concrete Reinforcement;
- ASTM A497/A497 M-07 Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete;
- G30.18-M92 (R2007) Billet-Steel Bars for Concrete Reinforcement;
- W186-M1990 (R2007), Welding of Rebar in Reinforced Concrete Construction;
- ASTM A775/A775 M-07b Standard Specification for Epoxy Coated Reinforcing Steel Bars.

Meet bend test requirements for respective rebar grades per CSA Standard G30.18.

Rebar grade yield stress is 40 mPa.

Use higher strength rebar subject to MX LRT review.

Provide deformed rebar except spirals and wire mesh may be plain rebar.

Provide Grade 400 for welded rebar with welding per CSA Standard W186.

In areas exposed to de-icing chemicals or other potential corrosion areas, submit proposed solutions including recommended rebar types and/or other corrosion remedies for MX LRT review and acceptance.

B4.17.3 Crack Control

Control cracks by proper distribution of tension rebar and selection of rebar sizes, spacing, ratios and allowable stresses.

Limit concrete crack width to 0.3 mm.

Provide relevant calculations and assumptions used to achieve this requirement.

In models used to calculate crack width consider effects including but not limited to:

- Structural loading;

- Thermal and chemical processes due to hydration;
- Drying shrinkage;
- Temperature changes including during construction; and
- Internal and external restraints depending on casting sequence.

B4.17.4 Rebar Spacing

Provide standard main rebar spacing at 150 mm, and 200 mm, 250 mm, or 300 mm on centre in tunnels, station structures, cut-and-cover structures, elevated structures and retaining walls to simplify rebar details and placement.

Exceptions may include segmental tunnel liners, columns, stairways, and thin slabs.

Provide shrinkage and temperature rebar spaced 25 mm on center maximum with tension lap splices.

Optimize rebar spacing and size for minimum cost.

In spacing rebar consider:

- Ease of concrete placement;
- Room for embedded items;
- Rebar crossing lap splices and blockages that may decrease concrete cover.

Particularly where using larger size rebar selected bar sizes to avoid crowding.

Provide 75 mm minimum lapped rebar clearance for concrete vibrator access.

B4.17.5 Shrinkage and Temperature

Provide minimum reinforcement depending on type of structure per CSA-A23.3-04 Design of Concrete Structures or CSA-S6-06 CHBDC.

Provide 0.002 A_g minimum in each direction (where A_g = section gross area in mm^2) equally distributed to each face for structures designed to CSA A23.3 using maximum joint spacing.

See Section B4.16.3.

Increase to 0.0035 A_g minimum for structural elements serving as a barrier between groundwater and interior spaces such as invert slabs, exterior walls, roof slabs, vent shafts and access routes.

B4.17.6 Concrete Cover

Provide concrete cover and tolerances per:

- Figure B4-11 – Non-Prestressed Members; and
- Figure B4-12 – Prestressed Members.

FIGURE B4-10 NON-PRESTRESSED MEMBERS

TYPE OF MEMBER OR EXPOSURE CONDITION	CAST-IN-PLACE CONCRETE mm	PRECAST CONCRETE mm
1. Concrete cast against and permanently exposed to earth or lagging.	100 ±25	---
2. Concrete not submerged or exposed to earth or de-icing chemicals		
- Principal reinforcement	60 ±20	50 ±10
- Stirrups, ties and spirals	50 ±20	40 ±10
3. Concrete submerged or exposed to earth		
- Principal reinforcement	70 ±20	60 ±10
- Stirrups, ties and spirals	60 ±20	50 ±10
***		
4. Deck slabs, medians, curbs and sidewalks		
- Top	70 ±20	60 ±15
- Soffit for slabs 300 mm thick	40* ±10	40* ±10
- Soffit for slabs 300 mm thick	50* ±10	40* ±10
***		
5. Precast beam stirrups in webs	---	35 +10 -5
6. Concrete, other than components covered in 1 to 5 above, exposed to surface runoff or spray containing de-icing chemicals.	70 ±20	60 ±10
7. Precast concrete tunnel covers**		40 ±5 35 ±5
Notes		
d_d = outside diameter of ducts		
* or 0.5 d_d whichever is greater		
** For precast concrete tunnel liners and when proven by an engineering analysis (which considers concrete properties, concrete cover including its tolerances and chloride concentrations in the surrounding environment) that rebar corrosion in bars parallel to the exposed concrete due to ionic diffusion and water permeability will not commence during the design lifespan of the structure, the cover may be reduced to a minimum of 40 mm for bars parallel to the exposed concrete surface and 35 mm for the ends of bars perpendicular to the surface		
*** FOR FULL DETAILS OF GOVERNING CONCRETE COVER REQUIREMENTS REFER TO CANADIAN HIGHWAY BRIDGE DESIGN CODE, TABLE 8.11.2.2		

FIGURE B4-12 PRESTRESSED MEMBERS.

TYPE OF MEMBER	COVER mm
***	
1. Pretensioning strands	
- tops of decks	70 ± 5
- elsewhere – not exposed	45 ± 5
- elsewhere – exposed to earth or water	55 ± 5
***	
1. Post tensioning ducts	
- top of decks	
- longitudinal ducts	130 ± 15
- transverse ducts **	(90-130) ± 15
- elsewhere – not exposed	60 ± 10(MIN)
- elsewhere – exposed to earth or water	80 ± 15(MIN)

Notes

d_d = outside diameter of ducts

** ducts ($d_d \leq 60$mm) 90mm
ducts ($d_d > 60$mm) 130mm

*** FOR FULL DETAILS OF GOVERNING CONCRETE COVER REQUIREMENTS REFER TO CANADIAN HIGHWAY REINFORCEMENT)

Provide concrete cover fire resistance ratings per:

- OBC Section 3.12 – Rapid Transit Stations; and
- Supplement to National Building Code of Canada Chapter 2 – Fire Life Safety – Performance Ratings.

Concrete cover and tolerances relate to different types of concrete members and exposure to earth, weather, and chemicals.

Increase minimum concrete cover in corrosive or unusually severe exposure conditions or for other considerations such as use of epoxy coated reinforcing steel, waterproofing, high quality durable concrete, or combinations thereof.

B4.17.7 Expansion Joints

Provide expansion joints in above-ground structures and at junction of underground structures with portal structures.

No permanent expansion joints are required in underground structures with relatively uniform internal temperatures and contraction joints.

Provide expansion joints where geotechnical conditions indicate potential differential movement between adjacent sections.

Provide expansion joints with joint filler.

Provide concrete keys to transmit shear loads across expansion joints.

No continuous rebar is allowed through expansion joints.

B4.17.8 Contraction Joints

Provide monolithic concrete slabs and walls with unbonded contraction joints spaced at 18 m maximum to control shrinkage stresses and minimize cracking.

In special circumstances submit contraction joint spacing greater than 18 m for MX LRT review and acceptance.

Provide contraction joints at major structural section transitions, e.g., wall or slab thickness changes.

Provide concrete keys to transmit shear loads across contraction joints.

No continuous rebar is allowed through contraction joints.

B4.17.9 Construction Joints

Provide construction joints to divide a structure into convenient working units and facilitate concrete placement while minimizing construction joint number and locations.

Provide bonded joints where construction joints transfer moment.

Provide continuous rebar through construction joints.

Provide concrete keys to transmit shear loads across construction joints.

B4.17.10 Waterstops

Provide waterstops for entire joint of any kind between external structural units including invert slabs, external walls and roof slabs.

Provide wall construction joints between invert slab and roof level with horizontal water seals only.

B4.18 Prestressed Concrete

Section B4.18 applies to precast and prestressed concrete structures and components.

General concrete requirements including rebar spacing and concrete cover per Section B4.17.

General design requirements for prestressed concrete per CHBDC or A23.3 Design of Concrete Structures unless noted otherwise per DCM.

Design loads, load factors, resistance factors and load combinations per DCM.

Provide prestressed concrete materials, methods of testing, and construction practices per CSA Standards:

- CSA-A23.1-04/A23.2-04 Concrete Materials and Methods of Concrete Construction/Methods of Test and Standard Practices for Concrete;
- CSA-A23.3-04 Design of Concrete Structures;

- CSA-A3000-08 Cementitious Materials Compendium (Consists of A3001, A3002, A3003, A3004 and A3005);
- CSA-A23.4-05 Precast Concrete – Materials and Construction.

Consider fatigue limit state for structural steel in prestressed concrete structures with cyclic load applications per Section B4.19.4 – FATIGUE.

B4.18.1 General Considerations

Proportion prestressed members and components for structure life critical load stages including construction generally including:

- At jacking;
- At prestress transfer;
- During handling, transportation, erection and construction;
- At service limit states after prestress loss allowances;
- At ultimate limit states.

Concrete and prestressing steel stresses at transfer and under load per CHBDC or CSA A23.3 Design of Concrete Structures unless noted otherwise per DCM.

Provide a margin of safety against end anchorage failure or tendon fracture at jacking and after transfer by limiting maximum tensile stress in tendons to avoid inelastic deformation and minimize relaxation loss.

Control cracking by proper stress distribution and rebar placement.

Determine effective prestress, f_{se}, allowing for prestress loss sources as follows:

- Anchorage cone slip (minimum based on manufacturer recommendations);
- Concrete elastic shortening;
- Tendon curvature friction loss;
- Tendon stress relaxation;
- Concrete creep;
- Concrete shrinkage.

Effective prestress immediately after transfer is generally 0.8 to 0.9 of tendon stress.

B4.18.2 Materials: Concrete

Specified concrete compressive strength, f'_c, for each part of structure: 35 MPa minimum; 40 MPa maximum.

Submit detailed analysis of higher strength concrete for special circumstances, e.g., precast concrete tunnel liners, for MX LRT review and acceptance.

Do not prestress concrete until compressive strength determined per CSA Standard CSA-A23.1 or CHBDC is at least 25 mPa for pre-tensioned members and 20 MPa for post-tensioned members.

B4.18.3 Materials: Grout

Specified post-tensioning duct grout 28-day compressive strength: 35 MPa based on 5 mm cubes.

See CSA Standard CSA-A23.2 Test Method A23.2-1B Viscosity, Bleeding, Expansion, and Compressive Strength of Flowable Grout.

Provide non-shrink grout for post-tensioning ducts.

Do not apply or remove load after grouting post-tensioning ducts until grout has reached compressive strength of 20 MPa minimum.

B4.18.4 Materials: Prestressing Steel

Provide high tensile strength / low-relaxation strand or high strength rebar prestressing steel per ASTM A416/A416-M-06, A421/A421-M-05, and A722/A722-M-07, Steel for Prestressed Concrete Tendons.

Unbonded tendons are prohibited in order to maintain sufficient corrosion protection and crack control.

Use unbonded tendon procedures to determine stresses on post-tensioned tendons while unbonded during construction stage stressing.

Do not provide partially prestressed structures without MX LRT approval.

B4.18.5 Anchors and Couplers

Provide anchors tested in unbonded condition developing 95% minimum specified tendon tensile strength without exceeding anticipated set.

Provide anchors to sustain applied loads without slipping, distortion, or other changes causing prestress loss.

Base anchors dimensions and details including any reinforcement immediately behind anchors on tendon and concrete specified strength at transfer.

Provide couplers tested in unbonded condition developing 100% of specified tendon tensile strength without exceeding anticipated set.

Do not locate couplers in vicinity of sharp tendon curvature or maximum moment.

Examine anchors and couplers for fatigue where externally applied loads cause significant changes in stress.

Provide anchor zones reinforced to resist concentrated prestressing tensile, spalling and bursting loads.

B4.19 Structural Steel

Section B4.19 applies to structural steel components and structures.

Comply with:

- Canadian Institute of Steel Construction (CISC) Code of Standard Practice for Structural Steel;
- CSA-S16.1-01 Limit States Design of Steel Structures;
- CSA-S6-06 CHBDC;
- CSA-S136 North American Specification for Design of Cold-Formed Steel Structural Members;
- CSA-G40.20/CSA-G40.21-04 General Requirements for Rolled or Welded Structural Quality Steel/Structural Quality Steels.

Use design loads, load factors, resistance factors and load combinations for type of structure per this DCM.

Use structural steel grades and yield strengths reduced to reflect thickness of material are as follows:

- Rolled and fabricated sections and plates: Grade 350 W;
- Hollow steel sections (HSS): Grade 350 W, Class H;
- Elevated structure members: Grade 350 AT – Charpy V (Specify notch test temperature and energy level);
- Stainless steel: ASTM A167.

Provide structural steel minimum thickness per CBHDC Clause 10.7.2.

B4.19.1 Anchor Bolts

Base anchor bolt design on ASTM A307 or ASTM Standard A36 Steel, F_y = 238 mPa.

Provide 25 mm maximum diameter heavy duty expansion anchors.

B4.19.2 Connections

Provide standard connections per CISC Handbook of Steel Construction.

Submit proposed non-standard connections with shop drawings and design calculations stamped and signed by a Province of Ontario registered Professional Engineer for MX LRT review and acceptance.

Provide arc welding per CSA Standard W59-03 Welded Steel Construction — Metal Arc Welding.

Consider quality control, cost, and constructability in bolted or welded connections.

B4.19.3 Structural Fasteners

Provide bolts, nuts and washers used as structural fasteners per ASTM Standard A325 m.

B4.19.4 Weld Metal Capacity

Base weld metal capacity on use of E480XX electrodes per CSA Standard W59-03.

B4.19.5 Protection of Steelwork

Provide access to every part of a structure for inspection, cleaning and maintenance.

Consider concrete encasement of steelwork, special protective coatings, and corrosion resistant steel.

Provide concrete as encasement of steelwork with 6 mm minimum thickness.

B4.19.6 Protective Coatings

Provide corrosion protection for structural steel members and connections exposed to weather, high humidity, or water.

Provide positive drainage and suitable design and details to minimize localized corrosion from entrapped water, condensation, or other factors.

Establish steelwork exposure, environmental conditions, service life access, inspection techniques, and surface preparation requirements for nature, type and thickness of protective coatings.

General reference standards include Canadian Standards Association (CSA), Steel Structures Painting Council (SSPC), and Canadian Government Specifications Board (CGSB).

Paint

Factors governing paint performance include:

- Design of structure to be painted;
- Surface preparation;
- Exposure to environment;
- Coating type and performance;
- Use of paint materials properly formulated to perform required service;
- Correct film thickness;
- Correct application method;

- Sufficient drying and/or curing time;
- Sufficient and timely maintenance painting.

Provide surface preparation compatible with primer.

Provide intermediate and finish coats compatible with previously applied coats.

Galvanizing

Provide galvanized bolts, nuts and washers for use with galvanized structures per CSA G164-M92 (R2003) Hot Dip Galvanizing of Irregularly Shaped Articles.

Restore galvanized protection where coating damage or abrasion occurs in welding or rough handling.

Suitable coating materials for welded metal or other damaged galvanized areas include:

- Zinc-rich paints;
- Metallic repair solders;
- Sprayed zinc metallizing.

Fire Protection

Provide structural steel with required fire-resistance ratings or exceptions per OBC.

Provide minimum thickness of fire protection materials for steel columns and beams to satisfy fire-resistance ratings per OBC Section 3.13 Rapid Transit Stations and OBC Supplementary Standard SB-2 – Fire-Performance Ratings.

B4.19.7 Fatigue

Provide structural members and components proportioned for fatigue effects due to repeated load application.

Evaluate elevated structures subject to frequent LRV passes and certain equipment support types for fatigue effects including out-of-plane stresses, secondary effects, LRV design load and number of load cycles.

See Section B4.16 – Elevated Structures and CHBDC.

B4.20 Retaining Structures

Section B4.20 applies to permanent open-cut retaining structures including retaining walls, abutments and elevated structure wing walls designed to resist earth pressure, hydrostatic pressure, and surcharge loads such as highway or railway traffic.

B4.20.1 Types

Provide retaining structures required to meet functional, durability, hydrological, and geological technical criteria and recommendations.

B4.20.2 Loads

Refer to Geotechnical Reports.

B4.20.3 Load Factors

Load factors and load combinations for earth retaining structures include:

- OBC Updated August 2006;
- CSA-S6-06 CHBDC;
- AREMA Manual for Railway Engineering.

B4.21 Waterproofing and Moisture Control

This Section addresses waterproofing and moisture control for LRT structures based on user comfort and safety as well as optimum operations and maintenance costs.

B4.21.1 Above-Grade Structures

Provide LRT elevated guideways and at-grade structures including Stops, bus facilities, and other buildings with sufficient roof and deck drainage and waterproofing/moisture control systems for structural durability and safety.

Control penetration of moisture and water through building envelopes to prevent:

- Materials decay and dimensional change;
- Corrosion and surface staining;
- Roof and wall systems breakdown;
- Masonry efflorescence;
- Surface freezing and spalling;
- Equipment damage;
- Condensation.

Water Ingress

Provide measures to mitigate:

- Air pressure that can cause water ingress through cracks in above grade structures when inside pressure is lower than outside pressure;
- Roof leaks and degradation of roofing membranes and other materials occurring from a variety of causes including thermal movement, ponding water, wear or puncture from maintenance operations, and exposure to ultraviolet sun light;
- Tracked in water, salt and snow;
- Wind and weather abrasion.

Water and Moisture Control

Consider the following methods for control and mitigation of water and moisture ingress:

- Rain screen construction;
- Pressure equalization with outer wall venting cavities in heated structures;
- Continuous air and vapor barriers in insulated heated structures;
- Proper flashing for drainage and water control;
- Use of insulation where condensation may occur;
- Effective roof drainage;
- Continuous roof membranes and flashing;
- Waterstops and sealants at concrete construction and expansion joints;
- Air-entrained concrete finished surfaces exposed to weather or freeze/thaw cycles;
- Glazing sealants, condensation control, and drainage;

- Effective control of tracked in water and salt by drainage gutters, drained walk-off grilles, etc.;
- Properly sealed roof and wall penetrations;
- Avoiding water discharge from roofs, downspouts, overhangs, etc., on access ways and entrances;
- Waterproofed penetrations per manufacturers' recommendations.

Provide condensate drainage and avoid condensation and the occurrence of dew point within materials and assemblies to avoid water and frost damage.

Provide materials and assemblies with thermal breaks or low thermal conductivity wherever possible to avoid thermal bridging.

Provide materials to minimize damage if moisture does penetrate into building interiors.

Minimize potential for electrochemical corrosion of metals.

See Chapter C5 – Stray Current and Corrosion Control.

Provide air, water and vapor membranes that minimize risk of puncture during construction and normal use.

Ventilate assemblies to avoid entrapment of moisture.

Provide continuous air/vapor retarders around above grade walls and roofs to prevent water or vapor entering the structure.

Provide joints to accommodate differential movement and reduce water ingress into facilities.

Provide continuity of air, water and vapour barriers.

Provide finishes and assemblies allowing direct transport of water to drains.

Pay particular attention to preventing condensation on unheated ceilings, soffits and overhangs.

Provide concrete elements with the minimum number of joints structurally feasible since joints are the principal source of leaks in concrete structures.

Waterproof joints with the proper sealant type for the environment, materials and conditions suitable for functional integrity and longevity.

Provide joints to receive sealant with depth equal to width unless otherwise stipulated by sealant manufacturers' recommendations.

Provide deep joints with backer rods.

Roofs

Provide roof drains located at low points of roof areas.

Provide roof openings well away from low points where control flow drains are used per AHJ requirements.

Provide sufficient overflow scuppers.

Provide curbs, cants and upstands 10 mm minimum above maximum potential ponding height.

Provide vapor barriers on the warm-in-winter side of roof insulation over heated spaces.

Seal joints and penetrations to prevent air leaking into insulation from inside.

Provide penthouse stairs or other suitable roof access and walkways for maintenance.

Provide an appropriate roofing system after analyzing each specific application.

Consider roofing systems from among the following:

Cold Sheet Membrane Roofing

Conventional single-ply membrane roofing system per AHJ requirements.

No dead flat roof slopes allowed.

Slope roofs for proper drainage per manufacturer recommendations with respect to roofing system and structural support.

Provide 2% minimum slope for cold sheet membrane roofs and roof valleys.

Inverted Roof Membrane Assembly

Consider an Inverted Roof Membrane Assembly (IRMA) with insulation, UV protection and light colored ballast above the membrane for insulated roofs over heated spaces.

Standing Seam Roofing

Metal standing seam roofing manufactured from 0.6 mm minimum (24 gauge), prefinished steel.

Provide flashing of similar material and finish.

Provide 10% minimum slope for standing seam roofing.

Other Roofing Materials

Other roofing materials may be considered depending on type of structure, location and cost effectiveness pending MX LRTI review and acceptance.

Walls

Consider the rain screen principle for above grade walls with a ventilated cavity between outer and inner wythe of wall to prevent transfer of moisture through the wall by unequal air pressure.

Provide sufficiently ventilated cavities free of any means for water to drain into the inner wythe.

Provide cavity ties hot dip galvanized after fabrication.

Provide stainless steel cavity ties for stone wall facing.

Floors

Provide flush slopes and drains to remove water that enters the inside of structures.

Provide horizontal slabs with 1% minimum gradient.

Provide flush floor drains connected to appropriate drainage systems where ponding or water accumulation may occur.

Provide equipment room floor drains with backflow preventers to stop water from entering the room.

Joints

Provide roofing system expansion joints at the following locations:

- Building expansion joints;
- Changes in direction of roof deck material;
- Around exhaust stacks and other sources of differential movement;
- No more than 3 m maximum between control joints;

- At internal junctions of unequal L-shaped roofs.

Avoid L-shaped roofs wherever possible.

Provide several levels of protection for other joints as follows:

- Protect joints from exposure to puncture and vandalism;
- Seal joints with sealant or gaskets;
- Allow space behind sealant or gaskets to allow water to drain from the assembly to drains;
- Do not exceed sealant and caulking manufacturers' maximum/minimum joint width dimension;
- Do not install sealant outside temperature limits of manufacturers' recommendations;
- Use continuous closed cell foam backing rod in joints to be sealed and/or caulked;
- Slip strips in vapor barriers where they span control or expansion joints;
- Allow convex caulking fillets only;
- Joints with swelling rubber waterstops installed per manufacturers' recommendations.

B4.21.2 Below Grade Structures

Provide LRT below grade Stations, structures, equipment rooms, and trainway structures with sufficient drainage and waterproofing/moisture control systems for structural durability and safety.

Control penetration of moisture and water through below grade structures to prevent:

- Public area and service room flooding;
- Materials decay and dimensional change;
- Corrosion and surface staining;
- Roof and wall systems breakdown;
- Masonry efflorescence;
- Surface freezing and spalling;
- Equipment damage;
- Condensation.

Allow no infiltration of water or other liquid over running rails, overhead contact system components or where there is potential damage to equipment, malfunction of electric power distribution systems, lighting, signals, communications or control equipment or other systems required for safe LRT System operations.

Use no material for preventing or sealing out water ingress that may compromise the fire / life safety of the works or durability of structures.

Water Ingress

Groundwater is usually responsible for ingress of water through cracks, joints, conduit, and penetrations in walls, roofs and slabs.

Water, salt and snow are tracked in by public entering the system.

Unheated Stations cause water vapor equalization.

There are, however, heated spaces and unheated passageways where condensation may occur.

Water and Moisture Control

Consider the following methods for control and mitigation of water and moisture ingress:

- Continuous waterproof membranes around structures;
- Insulation and vapor barriers where condensation may occur;
- Geodrains where practical. Note: Do not use geodrains around running structures. Do not reduce hydrostatic pressure to the point where adjacent properties are adversely affected;
- Stainless steel gutters under expansion and contraction joints discharging to cavity drains or down pipes at side walls;
- Waterstops, joint seals and membranes at concrete construction, expansion and contraction joints;
- Air entrained concrete finish surface exposed to freeze/thaw cycles;
- Control of tracked in water and salt with drainage gutters, slopes, drained walk-off grates, etc.;
- Sealing penetrations through walls and slabs;
- Drain platforms to floor drains, not to platform edges, for wheelchair safety.

See Chapter B3 - Civil Works.

Provide condensate drainage and avoid condensation and the occurrence of dew point within materials and assemblies to avoid water and frost damage.

Provide materials and assemblies with thermal breaks or low thermal conductivity wherever possible to avoid thermal bridging.

Provide materials to minimize damage if moisture does penetrate into building interiors.

Provide continuous exterior waterproofing around structures combined where practical at connections between adjoining structures, joints, etc., with hydrophilic seals, waterstops, grout injection or similar measures to achieve watertightness.

Provide waterproofing and boundary condition details at reglets and flashing.

Provide the interface between tunnels, Stations and any ancillary structure with fully watertight joints.

Provide expansion and contraction joints to accommodate anticipated movement without compromising water tightness.

Analyze thermal stresses and strains to avoid early-age concrete cracking.

Discount waterproofing elements in assessing durability of structures.

Do not allow water ingress to cause entry of soil particles into tunnels or ancillary structures.

Provide for collection and drainage of water seeping through roofs, walls, or floors whether or not such structural components are waterproofed.

Provide sufficient drainage to accommodate water infiltration and prevent storm water infiltration from tunnel portals and Stations.

Provide sufficient drainage in station public area floors.

Do not allow water to puddle on platforms.

Provide for any openings or penetrations and appropriate protection measures in waterproofing membranes including but not limited to chamfered corners, external moisture protection, swelling rubber waterstops, etc.

Provide waterproofing membrane details including protection board to minimize risk of puncture during construction and normal operations.

Ventilate assemblies to avoid entrapment of moisture.

Provide only waterproofing membranes and components by the same manufacturer.

Provide only waterproofing systems and components that comply with applicable Volatile Organic Compound (VOC) regulations in effect at time of construction.

Completely waterproof station and underground structure roofs and slope to drain.

Top Slabs

Provide top slab surfaces with 1% minimum cross fall to avoid ponding of water.

Provide full impervious membrane protection for slabs less than 50 mm thick.

Provide full impervious membrane protection for station roofs and finish areas.

Provide running structure top slab surfaces with impervious waterproof membrane below roadways and parking lots where depth of earth cover is less than 120 mm; otherwise provide a 90 mm minimum wide strip of impervious membrane with self-sealing properties over joints.

Provide an impervious full membrane for electric equipment and signal control room outside slabs.

Do not allow expansion or contraction joints in electric equipment and signal control rooms.

Provide joints with waterstops and drainage gutters or joint seals.

Do not allow ducts and conduit in top slabs.

Pay special attention to slabs below roadways, bus bays or other areas exposed to road salt.

Consider membranes, drainage, and epoxy coated or stainless steel re-bar, and various other concrete treatments and additives for top slab water and moisture control.

Walls

Provide cavities between below grade structural exterior walls and interior station finish walls to protect finishes with drains to track level drainage system or other drains.

Provide full impervious membrane with self-sealing properties for underground station exterior wall protection.

Provide impervious membrane with self-sealing properties at joints in a continuous 90 mm minimum wide exterior strip to protect against leaks for below grade structures other than Stations.

Provide joints with waterstops.

Provide boundary condition details such reglets, flashing, laps, etc.

Floors

Provide full impervious membrane with self-sealing properties for underground station exterior floors.

Provide impervious membrane with self-sealing properties at joints in a continuous 90 mm minimum wide exterior strip to protect against leaks for below grade structures other than Stations.

Provide slopes and drains to remove any water that may enter Stations and ancillary structures.

Provide horizontal slabs with 1% minimum gradient.

Provide floor drains connected to an appropriate drainage system where ponding or water accumulation may occur.

Provide platform slabs sloped to floor drains for water from regular maintenance, fire hoses, and sprinklers.

Do not allow floor drains and gutter systems to interfere with way finding systems.

Joints

Provide minimum number of joins feasible with regard to structural and constructability issues.

Provide finishes and assemblies to transport water directly to drains.

Locate joints away from openings for current and future access to structures.

When connecting to existing structures, pay careful attention to protecting existing waterproofing systems as well as methods of repair in case damage occurs.

Equipment Rooms

Completely waterproof the following equipment rooms including surfaces in contact with earth:

- Train control and auxiliary equipment rooms and spaces;
- Substations;
- Switchgear and similar equipment rooms; and
- Fan and pump rooms.

Provide waterproofing and boundary condition details at reglets and flashings.

Provide equipment room floor drains with backflow preventers to stop water from entering the room.

Locate equipment rooms and equipment in rooms to allow repair of leaks while equipment is in operation.

Waterproof with external membranes train control rooms and auxiliary equipment spaces with roofs and walls in contact with earth.

Provide floors subject to hydrostatic pressure sloped to drain and free of expansion or contraction joints.

Provide raised pads for installed equipment.

Provide train control room floor drains with backflow preventers to stop water from entering the room.

Waterproof ventilation and sump pump rooms.

Provide conduit leading from walls or roofs of any of the above rooms or spaces so as to prevent water from running along conduit to equipment.

Do not allow joints in equipment room walls.

Electric Conduit

Provide sufficient measures to prevent water ingress into electric conduit including but are not limited to drain ductbanks and conduit entering the station into a sump pit away from the building structure.

Coordinate and detail conduit runs with waterstop locations to protect against water ingress.

Provide proper conduit bending radii and locate conduit on the dry side of waterstops.

Provide conduit embedded in station invert slabs located above waterstops at joints between sections.

Waterproof conduit at each connection with rubber gaskets or pipe sealant.

Provide conduit on the water side of waterstops with watertight protective boots, heat shrink wrap, or applied waterproofing at conduit joints.

Provide ductbanks formed as contiguous units poured after construction of station invert slabs for major longitudinal conduit runs crossing construction joints at platform level.

Provide watertight traction power conduit, particularly with 25 mm^2 (500 MCM) cable and above, completely protected from water intrusion.

B5 Stations, Stops, Facilities

B5.1 General

Chapter B5 addresses Metrolinx (MX) Light Rail Transit (LRT) Stations, Stops, and Facilities.

Stations are underground or elevated passenger boarding and alighting facilities.

Stations may include Line, Terminal, Turn Back, Interchange, Intermodal, and Mobility Hub Stations.

Some Stations function as one or more of these types:

- Line Stations are within LRT lines and do not intersect with other LRT, subway, or rail stations;
- Terminal Stations are at either end of LRT lines;
- Turn Back Stations are Stations with adjacent storage track or cross over track for turn back operations;
- Interchange Stations connect directly in one continuous fare zone with another transit station;
- Intermodal Stations connect with a station operated by another transit agency.

Consistent with OBC definition, Stations are buildings or parts of buildings used for boarding and alighting passengers of a rapid transit system, but do not include open air shelters or platforms at street level.

Stops are at-grade passenger boarding and alighting areas.

Stations and Stops, in addition to, entrances, concourses, platforms, shelters, wayfinding, signage, visual displays, Kiss n Ride, commuter parking, as well as materials, furnishings, fixtures, and equipment, may include associated facilities as follows:

- Fire Fighter's Access (FFA);
- Bicycle Facilities;
- Retail Facilities;
- Bus Facilities;
- Plaza(s);
- Kiss n Ride areas/Passenger Pick up and Drop Off (PPUDO);
- Taxi Stands;
- Traction Power Substations (TPS);
- Tunnel Ventilation Shafts;
- Emergency Exit Buildings (EEBs);
- Off-street Non-Revenue Vehicle parking.

System-wide standard design promotes compatible, user-friendly, and cost-effective Stations and Stops for safe, efficient and convenient passenger transportation and inter-modal transfer.

Provide Stations, Stops, and Facilities per MX LRT Design Excellence Principles and Requirements.

MX LRT Community Relationship Goals:

- Protect, maintain, and enhance existing context and valued community qualities;
- Promote positive and desirable development.

Coordinate community programs to limit local traffic impact and minimize disruption during construction through strategic partnerships.

Use project construction hoardings for community communication and local business support through graphic material supplied by MX LRT and its strategic partnerships.

B5.1.1 Security and Crime Prevention

Crime Prevention through Environmental Design (CPTED) is action to design the built environment in ways that reduce or remove identifiable crime risks.

It is essential to incorporate CPTED in the initial design stages.

CPTED design principles address visibility, lighting, access control, security hardware, landscaping, vandal resistance, and ease of maintenance.

Use CPTED principles to:

- Build LRT environments that deter opportunities for crime;
- Help deter and control crime of any type; and
- Create a clean, well-lighted, and safe environment.

See Chapter A3 – Safety and Chapter A4 – Security.

B5.1.2 Sustainability

LRT improvements contribute to universal sustainability, improved mobility, and enhanced quality of life for passengers and the general public.

Beyond the inherent benefits of an LRT system itself, how it is planned, designed, built and operated further contributes to regional and environmental sustainability.

MX LRT sustainability goals and objectives are to:

- Identify alternative designs to achieve potential environmental improvements;
- Adopt sustainable approaches to protect the environment within schedule and budget constraints;
- Promote energy efficient improvements such as photovoltaic panels and “green” roofs;
- Use green building practices and technologies to achieve minimum Leadership in Energy and Environmental Design (LEED) Silver Certification per CAGBC.

Concern for sustainability is rooted in a growing awareness that human activity and behavior has the potential for significant environmental, social, economic, ecological, and cost benefits and/or burdens.

Global air pollution, the durable effects of manufactured toxins, degraded natural resources such as fresh water and fisheries, and the cross-border nature of many environmental problems all highlight the need to view human impact on the environment from a broad perspective.

Negative impacts include congestion, fatalities and injuries, noise, air, and water pollution, greenhouse gas emissions, diminishing energy resources, and biological/ecosystem damage.

The challenge of sustainable transportation lies in minimizing these cost and impact burdens while offering strong socio-economic benefits.

LRT offers inherent sustainability benefits compared with automobile travel.

Adopt and follow sustainable design guidelines to further enhance LRT benefits.

B5.1.3 Site Planning

Address system-wide Station and Stop site planning and related site development design as follows:

- Trainways and Rights-of-Way (ROW);
- Interim and Ultimate Platform Configuration;
- Roadways;
- Pedestrian Walkways/Pedestrian Buffers;
- Bicycle Paths;
- PPUDO;
- Parking Areas;
- Passenger Shelters;
- Landscaping/Urban Design Elements;
- Tree Protection;
- Elevators, Escalators, Ramps and Stairs;
- Police, EMS and Fire Services Emergency Response;
- Fare Collection Equipment;
- Signs and Graphics;
- Trash Receptacles;
- Communications and Electric Cabinets;
- Lighting and Light Fixtures;
- Traction Power Substations;
- Emergency Exit Buildings (EEBs); and
- Ventilation Shafts.

Locate Station and Stop site elements to be safe, functional, easily maintained and attractive for passengers and the general public.

B5.1.4 Hierarchy of Pedestrian Access Modes

Consider the full range of user needs recognizing that site constraints resulting in competing priorities may require access goal hierarchy compromises.

Provide Stations and Stops to minimize access mode passenger connecting times.

Pay particular attention to walk-on passengers and passengers with special needs, e.g., access to elevators and ramps.

Provide Stations and Stops in the following general access modes hierarchy:

- Pedestrian Access from Main Thoroughfares;
- Transit Interchanges;

- Fixed Route Feeder Buses;
- Door-to-Door Service and Accessible Transit Drop-Off Areas;
- Automobile and Taxi Drop-Off Areas;
- Bicycle Parking; and
- Automobile and Motorcycle Parking.

B5.1.5 AHJ Requirements

Where referenced source or AHJ requirements conflict, the more stringent requirements govern.

The latest applicable code, regulation and standard at time of design applies.

If a new edition or amendment to a code, regulation, or standard is adopted before design is complete, conform to new requirement(s) to the extent practicable or required by AHJ.

The linear nature of an LRT system touches various parts of the community that may have different land-use, development, and legislative regulations or procedures.

This directly affects Station and Stop site planning and design.

As a result it is important to:

- Identify AHJ at every level of government for each site;
- Include and apply in the planning framework applicable official plans, secondary plans, avenue studies, zoning regulations, urban design guidelines and policies of AHJ;
- Identify and locate jurisdictional boundaries where appropriate;
- Review adopted AHJ master plans and municipal codes.

Submit a complete code analysis prepared by a qualified code consultant for milestone submissions.

B5.1.6 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Station, Stop, and Facility specific references include but are not limited to:

- Ontario Building Code (OBC);
- Ontario Fire Code (OFC);
- Ontario Electrical Safety Code (OESC);
- Ontario Technical Standards and Safety Act;
- Canadian Standards Association (CSA) B651.M90: Barrier-Free Design;
- CAN/CSA-B355: Lifts for Persons With Physical Disabilities;
- CAN/CSA-B44.1/ASME-A17.5: Elevator and Escalator Electrical Equipment;
- CSA 3-T515-M85: Requirements for Handset Telephones;

- National Fire Protection Association (NFPA) 101: Life Safety Code;
- NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems;
- American Public Transportation Association (APTA) RT-EE-RP-001-02: Heavy-Duty Transportation System Escalator Design Guidelines;
- APTA RT-EE-RP-002-03: Heavy Duty Transportation System Elevator Design Guidelines;
- ASME A17.1/CSA-B44: Safety Code for Elevators and Escalators;
- ASME A17.7/CSA B44.7: Performance Based Safety Code for Elevators and Escalators;
- Illuminating Engineering Society of North America (IESNA), Design Guidelines;
- Canadian National Institute for the Blind (CNIB): Going Places - Access Needs of Blind and Visually Impaired Travelers in Transportation Terminals;
- Accessibility for Ontarians with Disabilities Act (AODA);
- AODA: Final Proposed Accessible Built Environment Standard (BES);
- Accessibility Design Guidelines of AHJ;
- MX LRT Principles of Design Excellence.

OBC governs where conflicts arise unless otherwise stated.

B5.1.7 Zoning Plans and Land Use

Zoning has definite near term and future use effects on Station and Stop sites.

While zoning plans may be changed to fit a site with many appropriate physical attributes, also consider emerging land use that may benefit, or detract, from Station and Stop site planning and design.

B5.1.8 Station and Stop Context

"Context" refers to the existing state of development around a prospective site.

Station and Stop context may be residential, commercial, industrial, suburban, urban, or rural in nature.

The current and future character, quality, and land-use of Station and Stop context directly affects site planning and design.

Station and Stop context goals:

- Reflect and contribute to neighborhood and community character and quality;
- Establish new development patterns where appropriate;
- Recognize complementary emerging development patterns to enhance and inform Station and Stop site planning and design;
- Reinforce and guide established, planned and desired development patterns;
- Avoid loss, reduction or destruction of parkland and other public amenity access.

Each Station and Stop derives from the neighbourhood and community context of which it is part.

B5.1.9 LRT Alignment/Rights-of-Way

Use existing public ROW consistent with LRT system-wide goals and objectives wherever possible.

B5.1.10 Site Analysis

Site analysis is the process of gathering, evaluating and testing potential Station and Stop site characteristics against overall development programs and criteria.

Typical Station and Stop site analysis includes:

- Station and Stop Context;
- Views to and from Station and Stop Sites;
- Topography;
- Existing Infrastructure and Building Improvements;
- Land Use;
- Existing Vegetation;
- Drainage;
- General Circulation and Access;
- Significant Ridership Generators;
- Heritage Impact; and
- Value of Buildings and Landscape.

B5.1.11 Adverse Impact Mitigation

Concentrate or diffuse site access as required to mitigate adverse impacts such as noise, vibration, pollution, fumes and traffic on adjacent land uses.

B5.2 Site Circulation

Each transportation mode has specific circulation and operation requirements that must respect and enhance operation and access of other modes in and around LRT facilities.

Underlying site requirements supporting LRT, such as entrances to underground structures, parking, street furniture, operating equipment, shelters, ventilation shafts, and landscaping provide convenience, comfort, accessibility, and enhanced quality of life for passengers and the general public.

B5.2.1 Design Objectives

Performance standard based design objectives provide the fundamental framework for minimizing conflicts, maximizing efficiency, and resolving inter-relationship of Station and Stop activity.

Passenger Flow

Minimize level changes, physical barriers, travel impedance, circulation conflicts, directional disorientation, and crowding.

Provide sufficient and easily understood signs, graphics, and way-finding markers.

Provide fare lines at appropriate points in Stations to delineate paid and unpaid areas with an increased focus on integrating architectural elements to enhance positive human behavior, deter crime, and reduce need for fare enforcement.

Maximize safety, reliability, and fare collection efficiency.

Emergency Access and Egress

See Chapter A3 – Safety.

Passenger Environment

Provide ambient passenger environments with sufficient personal comfort, aesthetic quality, lighting, weather protection and security.

Design Flexibility

Allow for future infrastructure and operating changes with minimal disruption or reconstruction.

Community Enhancement

Promote desired growth with minimal local vehicle and pedestrian traffic impact.

Environmental Considerations

Support and coordinate local planning and improvement initiatives with minimal environmental impact.

Access Modes

Typical Station and Stop passenger access modes include:

- Subway;
- Light Rail Transit;
- Surface Commuter Rail, e.g., GO Transit;
- Freight Rail, e.g., CP Rail;
- Airport Rail, e.g., UP Express;
- Streetcar and Bus;
- Door-to-Door Service and Accessible Transit, e.g., Wheel-Trans;
- Private Automobile and Taxi;
- Bicycle;
- Walking.

There are distinct differences in safety, speed, maneuverability, visibility, space, reliability, and compatibility requirements for each access mode.

Locate Stations and Stops to fit the total overall LRT system plan maximizing pedestrian, bus, private auto and taxi access while minimizing impact on existing structures, utilities, traffic, and green space.

B5.2.2 Pedestrian Access and Circulation

Good pedestrian circulation to, from, and across Station and Stop platforms is essential for safe and smooth LRT operations.

Provide simple, obvious, and comfortable pedestrian circulation patterns including:

- No unnecessary turns and dead ends;
- Clear and simple access to bus, streetcar, parking, and drop-off areas;
- Accessible routes to entrances, concourses, platforms, and trains;
- Sufficient space for street furniture to avoid bottlenecks;
- Sufficient platform space for projected patronage;
- Sufficient fare collection queuing space not to block pedestrian circulation;
- Balanced LRV boarding and alighting;

- Minimum grade changes;
- Sufficient surge, queuing and run-off spaces for changes in circulation direction or mode;
- Sufficient visual transparency for surveillance to discourage vandalism and increase personal safety;
- Good sight lines and visibility along LRT, pedestrian, bus, automobile, and bicycle routes;
- Clear, legible, and consistent signs and graphics; and
- Well-lighted public areas.

B5.2.3 Level of Service

Provide Stations and Stops reflecting passenger volumes to accommodate peak loads from arriving/departing LRVs, entraining occupant load awaiting LRVs and buses.

Provide platforms with clearance times per the more stringent requirements of NFPA 130 and OBC.

B5.2.4 Accessibility

Provide accessible Stations and Stops with safe, direct, convenient, and obstacle-free travel paths for persons with disabilities, able passengers and the general public.

The most stringent of the following codes and standards apply:

- OBC sections 3.8 and 3.13;
- AODA and Final Proposed Accessible Built Environment Standard (BES);
- Accessibility Design Guidelines (ADG);
- CAN/CSA Barrier Free Design;
- CNIB Going Places;

Provide at least one accessible route to a Station and Stop entrance from street, sidewalk, parking area, Kiss n Ride areas, and adjacent development.

Provide at least one accessible path of travel between different transportation modes.

First Responders assist passengers unable to self-rescue or not assisted by other passengers.

Those unable to self-rescue may indicate their location using Blue Light Stations (BLS) at platform ends, Designated Waiting Areas (DWA) in the middle of platforms, or Passenger Assistance Intercoms (PAI) on concourses.

B5.2.5 Intermodal Access

Bicycle Access and Parking

Accommodate passengers arriving by bicycle in a safe and inviting way.

Provide bicycle parking per AHJ guidelines.

Provide Station bike rack and locker space per Threat and Vulnerability Assessment (TVA).

Provide well-lighted bicycle parking areas visible from Station entrances or street to promote security.

There are two types of bicycle parking:

- Outdoor short-term racks using bike posts/rings outside Station and Stop entrances in the public realm; and
- Indoor long-term parking integrated with Station Main Entrance design and not as free-standing structures:

- o Locate at Station Main Entrances fully integrated and consistent with Station architecture;
- o Provide for several hours or overnight secured bicycle parking, as transparent as possible, with access through a lockable door;
- o Provide signs clearly directing cyclists to available bicycle parking;
- o Locate short-term bicycle parking within 30m of Station Main Entrance;
- o Locate bicycle parking adjacent to bicycle-friendly routes;
- o Avoid bicycle route and parking interference with pedestrian circulation and motor vehicle traffic;
- o Maximize bicycle parking visibility from Station and Stop access routes, streets and sidewalks.

Bicycle parking at Stops may include a section of planter areas near platform ends reserved for future platform lengthening or may be in public ROW boulevard areas between sidewalk and street curb.

General requirements for Bicycle Facilities include:

- Provide every Station with outdoor bicycle facilities;
- Some Station entrances may include integrated Indoor bicycle facilities;
- Provide bicycle parking provisions per guidelines of AHJ.

Taxi Stands

Provide designated taxi stands at Stations avoiding significant traffic, Station and bus operation conflicts.

Consider safety issues as well as present and anticipated demand for taxi service.

Provide a taxi stand with four parked taxi spots minimum at terminal Stations.

Provide a taxi stand with two parked taxi spots minimum at line Stations.

Consider taxi stands for Park & Ride, Pick-Up & Drop-Off, and on-street areas.

Parking

Design parking facilities per standards and regulations of AHJ.

Provide one off-street maintenance vehicle parking spot at each Station and Emergency Egress Building (EEB).
In no case reserve on-street parking spots for LRT maintenance vehicles.

Bus Facilities

Provide bus facilities and layouts per standards and regulations of AHJ.

Provide bus facilities reflecting Design Excellence Principles and Requirements.

Provide bus facilities with convenient and accessible access from Street Level to Station areas.

Provide waiting areas at Bus Terminals and Bus Loops to maximize views of incoming and waiting buses.

Some Bus Facilities may include Bus Facility Operator Rooms.

Bus Facilities to be accommodated include:

- Bus Stops, including lay-bys and stops within the public right-of-way, close to Station entrances, and may include third-party agency rider shelters;
- Bus Loop with bus bays for buses, including open, covered bus waiting areas and platforms that are not necessarily within Station fare-paid zones;

- Bus Terminal with enclosed waiting areas that connect multiple bus routes and other transit lines.

B5.2.6 PPUDO Areas

Provide PPUDO areas that are safe, convenient, and accessible, with direct connections from Street Level to Station areas and platforms.

Provide PPUDO areas integrated with Station landscape/streetscapes.

B5.3 Station and Stop Architecture

Stations and Stops are central to transport modal interchange and thus become LRT system focal points.

Key to LRT system operations is that Stations and Stops are safe, efficient, easily understood, user-friendly and inviting for LRT passengers, personnel, and the general public.

Coordinate architectural design principles and urban design requirements per:

- Eglinton Line Architectural Design Philosophy;
- Eglinton Crosstown Design Framework;
- Design Excellence Principles and Requirements;
- Chapter B8 - Urban Design and Chapter B9 Landscape Architecture.

B5.3.1 At-Grade Stop Architecture

At-grade Stops are passenger boarding and alighting areas located in non-exclusive rights-of-way.

Stops may be configured with platforms serving one, two, or three-car Light Rail Vehicles (LRVs).

Provide Stop platform access via ramped walkways not to exceed 5% slope.

Provide waiting passengers with weather protection shelters covering LRV doors.

Design Principles

Arrange platform zones for passenger safety and convenience.

Arrange accessible facilities per the most stringent criteria of AHJ.

Standardize wherever possible using recyclable materials and sustainable construction practices to minimize environmental impact, maintenance requirements, and life-cycle costs.

Platforms

Provide both centre and side platforms to accommodate the longest potential LRV consist.

Provide Stop platforms long enough to accommodate LRVs in three (3) car consists, excluding transition pedestrian walking areas, with access to platforms from crosswalks.

Where initial operation requires only a one-car LRV consist, provide a single car platform with accommodations for a full-length future platform when required.

Provide platform edge to centre line of track dimensions to accommodate the LRV clearance envelope.

For centre platform Stops, provide a minimum of two paths of travel along the entire length of platform between the inside of platform edge strip and any wall, balustrade, railing, or other vertical element.

For side platform Stops, provide one path of travel along the entire length of platform between the inside of platform edge strip and any wall, balustrade, railing, or other vertical element.

Provide side platform Stops with 3 m minimum wide platforms.

Provide centre platform Stops with 5 m minimum wide platforms.

At-grade Stop platforms cross slope: Not to exceed 2% with 1% minimum toward platform edge.

At-grade Stop platforms longitudinal slope: 2% maximum, with exceptions only upon MX LRT review and acceptance.

Provide level boarding integrating unworn top-of-rail to top-of-platform dimension with LRV design.

Provide platform edges with a tactile warning strip 610 mm wide extending full length of platform.

Concentrate fixtures, furniture, and equipment and other fixed elements in a platform furniture zone while maintaining sufficient distance between elements for passenger circulation keeping as much of the platform as possible clear of fixed elements.

Size Stop platform exits to accommodate projected volume of passengers at design year Level of Service "C".

Provide sufficient exits for safe LRV and platform egress under normal and emergency operating conditions.

Provide Passenger Visual Information System (PVIS) signs with real time "Next LRV Arrival" information.

Shelters

Provide Stop platforms with passenger shelters to achieve these objectives:

- Passenger comfort and protection from adverse weather including rain, snow, wind, and sun;
- Passenger security and surveillance;
- Sufficient lighting, particularly along the platform edge;
- Weather and vandalism protection for fare collection and other equipment;
- Alignment of LRV doors with shelters allowing for variable LRV stopping location;
- Minimizing maintenance requirements;
- Fulfillment of MX LRT Design Excellence Principles and Requirements.

Shelters include back lit advertisement panels, benches, CCTV cameras, system signage, Public Address (PA) speakers, lighting, and may include trash receptacles.

Seating

Provide Stop shelters with benches, seating, and leaning rails without interfering with passenger circulation and emergency exiting.
Provide benches and seating backs with full-length armrests to facilitate use by persons with disabilities and prevent lying down or sleeping.

Provide guardrails as leaning rails on side platforms.

CCTV

Provide CCTV for surveillance of platforms and fare collection equipment.

Coordinate location and mounting of CCTV cameras with shelter design and security personnel subject to MX LRT review and acceptance.

See Chapter A4 – Security and Chapter C2 – Communications and Control.

Fare Collection

Locate fare collection and Proof of Payment (POP) equipment under shelter at platform entrances convenient to passengers without obstructing passenger flow even with moderate queuing.

Provide each Stop with two Ticket Vending Machines and two Validating Machines minimum.

Consider passenger movement entering and exiting the platform, moving between platform entrances and exits, boarding and alighting at LRV doors, as well as fare collection and crowding factors.

Trash Receptacles

Provide trash receptacles on sidewalk(s) closest to Stop platforms wherever possible.

Provide Stop platforms and bus terminals with trash receptacles bolted down to avoid removal by unauthorized persons per criteria and standards of AHJ.

See Chapter A4 – Security.

Advertising

MX LRT and/or AHJ may implement agreements for advertising companies to supply digital screens for LRT shelters in exchange for right to integrate advertising panels in shelter design.

Provide platform electric power to back light advertising panels.

Additional communications wiring may be required.

Supplemental power may be provided via self-contained photovoltaic systems integrated in shelters.

B5.3.2 Underground Station Architecture

Stations are for passengers boarding and alighting LRVs in exclusive Rights-of-Way.

With respect to OBC, a Station is defined as a building or part of a building used for the purpose of boarding and alighting passengers of a rapid transit system, but does not include open air shelters at street level.

Thus Stations are subject to OBC requirements whereas at-grade Stops are neither subject to OBC requirements nor require a building permit.

Configure underground LRT Stations with low boarding platforms serving one, two, or three-car LRVs.

Concourses ideally located over platform(s) may facilitate efficient passenger movement.

Station access is via various combinations of elevators, escalators, stairs and direct underground connections to adjoining structures.

Provide Station entrances and exits at grade.

Design Principles

Provide Stations with architecture design principles as follows:

- Civic architecture with lasting value and a characteristic thread that is timeless, durable, and contributes to its context;
- Architectural expression appropriate to the individual character or development quality of each site, neighborhood and/or community;
- Architectural design coordinated with urban design;
- Protect and promote Transit Oriented Development (TOD) opportunities;
- At-grade elements that emphasize individual, contextual, high-quality design, particularly for entrances, ventilation shafts, and substations;
- Station flexibility for unique and individual design focusing on function, form, scale, color, texture, materials, lighting and artwork;
- Station design coordinated with existing infrastructure to maintain and/or enhance existing circulation patterns and systems;

- Station components integrated with a coordinated and cohesive design aesthetic;
- Green Standards coordinated with requirements of AHJ;
- Multiple Station entrances to improve passenger accessibility;
- Avoid non-rectilinear platform and concourse configurations;
- Standard elements to provide a degree of passenger familiarity;
- Address Proof of Payment (POP) fare collection systems and fare queue lines at appropriate points in Stations to delineate paid and unpaid areas with an increased focus on integrating architectural elements to enhance positive human behavior, deter crime, and reduce need for fare enforcement.

Station Box

The underground Station box includes access to entrances and exits, a centre platform for the longest proposed LRV consist, special track work where required, and service areas at both ends.

Ventilation Shafts

Underground Stations include mechanical vent shafts with penetrations at-grade.

Ventilation shafts comprise intake, exhaust, and tunnel ventilation near both ends of a Station box.

Wherever possible integrate vent shafts with other Station infrastructure such as Heating Ventilating Air Conditioning (HVAC) equipment and TPS with Station architecture to create consistent configurations per Design Excellence Principles and Requirements.

Confirm minimum vent shaft height above grade for fire/life safety and security concerns through a Threat and Vulnerability Assessment.

See Chapter A3 – Safety, Chapter A4 – Security, and Chapter C4 – Heating, Ventilating, Air Conditioning for vent shaft sizes and other considerations.

Provide ventilation shafts as simple geometric forms integrated into their context with finishes in a material palette on par with or exceeding adjacent buildings, structures, and community context.

Stand-alone ventilation shafts may be required at some locations, but integrating them into another Station element or at least incorporating other program functions is often more suitable.

Although ventilation shafts are primarily service structures, take care regarding:

- Mechanical requirements;
- Maximum vent shaft grate opening sizes per AHJ;
- Proximity to existing and anticipated built form;
- Appropriate scale relative to existing context;
- Minimizing potential negative impact on existing streetscape;
- Location costs close to Station box weighed against remote location property acquisition costs;
- Anticipation of future development opportunities; and
- Security requirements to prevent introduction of contaminants.

B5.3.3 Emergency Exit Buildings

Emergency Exit Buildings (EEBs) include an emergency exit stair providing means of egress from tunnel sections between underground Stations in case of emergency.

Provide, protect and preserve opportunities for successful integration in siting and orientation of EEBs with new and existing development.
To achieve this, locate EEBs to preserve room for new development and support active and consistent street design over time.

Where opportunities exist to integrate EEBs with new development, orient them perpendicular to the street to preserve larger areas of ground floor space for more active uses to help animate the street.

Where located in a main street or street with consistent setbacks, site EEBs to reinforce the general setback characteristics of adjacent development.

Locate EEBs in main streets to integrate with potential redevelopment over time.

Locate EEBs in main streets on narrow sites with limited redevelopment potential to reinforce general setback characteristics of adjacent development, integrate in scale with surrounding context, and protect for active use opportunities at grade.

Do not locate EEBs at intersections as this reduces visibility in the short term and can lead to a blank façade at intersections when EEBs are integrated with new development in the long term.

Site EEBs facing the street and providing emergency vehicle access.

Provide one off-street LRT parking spot located to minimize and/or reduce impact on surroundings.

When located in a park or street boulevard, site EEBs to minimize impact on mature trees and vegetation.

Design EEBs to enhance and contribute to LRT corridor image with matching finish materials, landscaping and public artwork.

Design EEB façades with low maintenance, graffiti-resistant materials and textures to reduce potential vandalism and maintain a positive image for the LRT system.

B5.3.4 Elevated Station Architecture

Elevated Stations occur along elevated Guideways and include low boarding platforms serving one, two, or three car LRV consists.

Access to areas below platform(s) may facilitate efficient passenger movement.

Access to grade is via various combinations of elevators, escalators, and stairs.

Station entrances and exits are at grade.

Design Principles

Elevated guideways and Stations are a major design responsibility since they impose great and long lasting environmental, physical and visual effects on a community.

Elevated Stations have an advantage over underground Stations in use of surroundings as part of the defining elements at each specific Station location.

Provide elevated Stations with architectural expression appropriate to the individual context of each neighbourhood or community.

Elevated Stations need to appear visually lighter and elevated overhead, with entrances rising from the ground rather than seeming to bring the entire Station down to them on the ground.

Optimize natural light as a key advantage of elevated Stations.

Provide natural ventilation of elevated Stations.

Provide fritted glass and other measures for protection of birds per AHJ.

Consider elevated Station exterior cleaning, maintenance, and safety issues.

Protect for Transit Oriented Development (TOD) opportunities.

Coordinate new Station design with existing infrastructure to maintain and enhance existing systems and circulation patterns.

Provide above-grade Station components integrated with a coordinated and cohesive design aesthetic.

Provide multiple Station entrances to improve passenger accessibility.

Avoid non-rectilinear platform and concourse configurations.

Address challenges of approach to entrances, access under Stations, and other critical areas important to CPTED design strategy.

B5.4 Station Elements

B5.4.1 Station Entrances and Exits

Typical LRT Stations include two entrances minimum: a Main Entrance and a Second Entrance, preferably located on both sides of an LRT alignment corridor and at both ends of Station.

A Third Entrance may be added as required by patronage demand.

Every entrance includes at least one primary entryway with automatic sliding doors and full-width x 3 m deep walk-off mats and drainage pans as well as at-grade bicycle parking and taxi stands.

Coordinate Station entrance design other Station facilities, such as ventilation shafts, with overall Station entrance design and urban design criteria.

Coordinate Station entrance locations with bus routes and associated bus stops.

Provide quick and convenient transfer points.

Provide Station entrances with electronic Passenger Visual Information System (PVIS) signs to give passengers Station and LRV status information.

See Chapter C2 – Communications and Control.

Emergency Egress

Station emergency egress is through Station entrances as well as emergency exits if required. Additional protected egress routes may be required at Interchange Stations.

Fire Fighter Access Routes

Provide Fire Fighter Access (FFA) routes to every Station level over and above public means of access.

See Chapter A3 – Safety.

Entrance Approaches

At-grade entrance approaches to individual Stations define the approach to an entire LRT system facilitating passenger safety, security and convenience.

Locate Station entrance approaches directly from the main street allowing passengers to identify the Station entrance in the context of busy avenue activity.

Provide Station entrance approaches with direct routes between entrances, train and bus platforms, passageways and corridors to avoid disorientation and enhance security.

Main Entrance

Provide each Station with a Main Entrance fully accessible for passengers with disabilities.

Main Entrances include at a minimum sliding doors, a passenger elevator, a pair of escalators, a stair, and the main annunciator panel.

Provide additional services at street level depending on site requirements.

Provide areas for fare collection including queuing space.

Additional concourse areas beneath the Main Entrance may accommodate additional services such as escalator and elevator component storage rooms.

Locate elevators near the main street as a readily identifiable feature.
Minimize concourse elevator corridor lengths.
Allow 3000 mm runoff space at Main Entrance doors without overlapping other runoff spaces.

Second Entrance

Provide a second entrance including sliding doors, a stair and other street level services.

Additional concourse areas beneath a Second Entrance may accommodate additional services or remain unexcavated.

Allow 3000 mm runoff space at Second Entrance doors without overlapping other runoff spaces.

Third Entrance

Provide a third entrance the same as Second Entrances but only as required by patronage demand.

B5.4.2 Station Concourses

Concourses facilitate efficient passenger movement between street level entrances and platforms.

Provide Stations that promote a level of openness between concourse and platform levels.

B5.4.3 Station Platforms

Provide efficient and passenger-friendly Station platforms.

Passengers board and alight LRVs via centre platforms between tracks or side platforms alongside tracks.

Provide and size platforms and Station exits to accommodate projected volume of passengers at Design Year Level of Service “C”.

Provide platforms to accommodate the longest LRV consist.

See Chapter B1 – Alignment, Clearances, Rights-of-Way for platform edge to center line of track clearance.

Provide platforms to satisfy ridership and LOS requirements with minimum widths per OBC, NFPA 130 and as follows.

Centre platforms:

- 8400 mm or as required per OBC for clear path, vertical circulation, and Level of Service;
- 2500 mm minimum passenger circulation clearance from platform edge per OBC;
- 610 mm wide platform edge tactile warning strip extending the full length of platform.

Provide two accessible travel paths minimum along full length of platform between platform edge tactile warning strip and any wall, balustrade, railing, or other vertical element.

Minimum clear exit widths per most stringent criteria of OBC, NFPA 130 and AHJ.

Barrier-free paths of travel may have additional requirements.

Include special demarcation floor strips at Designated Waiting Areas (DWAs).

Optimize grade between Stations per alignment requirements before increasing Station grades.

Station platforms longitudinal slope:

- Desirable: 0.3%;
- Acceptable Minimum: 0.0% level with special measures to ensure Sufficient drainage;
- Acceptable Maximum: 1.0%;
- ABSOLUTE Maximum: 1.5% for individual Stations with grades greater than 1.0% subject to MX LRT review and acceptance.

Station platform cross slopes not to exceed 2% with 1% minimum slope to floor drains away from track.

Slope floors away from escalator, stair and elevator landings.

Concentrate platform fixtures, furniture, and equipment in designated furniture zones while maintaining sufficient circulation clearance between elements keeping platforms clear of fixed elements.

Provide safe egress from LRVs and platforms under normal operations and emergency conditions.

Provide trash receptacles bolted down to avoid removal by unauthorized persons and per standards and requirements of AHJ on platforms, at fare collection areas, and at bus terminals.

Do not provide receptacles for general site, parking, or PPUDO areas.

B5.4.4 Vertical Clearances

Locate any Station element that could be targeted for theft or vandalism, e.g., light fixtures, speakers, cameras, 2750 mm minimum above travelled pathways.

Also consider potential unauthorized use of benches, trash receptacles, canopy framework, and sign units for climbing above 2750 mm platform floor to access these elements.

B5.4.5 Vertical Circulation

Provide vertical circulation based on each Station site plan and configuration to promote safe, clear and intuitive way-finding through every Station level.

Provide LRT Stations and facilities with stairs, escalators, passenger/freight elevators, and ramps with emphasis on the importance of coordination to facilitate installation.

Provide required facilities and systems interfaces for installation and trouble-free operation of elevators, escalators, and associated equipment.

Provide LRT elevators and escalators that meet or exceed APTA quality, durability, service, maintenance, safety, and life-cycle standards.

Elevator and escalator criteria interface with related LRT design criteria as well as safety, quality assurance, maintenance, reliability, and availability.

Provide Station Main Entrances with a pair of escalators, a stair, and an elevator.

Stairs

Provide Station public stairs with 30° incline and Tread Width = √3 x Riser Height for vertical circulation system-wide design consistency.

Provide At-grade, In-Line, Terminal, and Interchange Stations with one public stair in the Main Entrance and one public stair in each second and third entrance.

Stations may require additional emergency exit stairs.

Provide top and bottom of stairs with runoff space 5 m minimum from end of stairs to any obstruction.

Runoff space influences placement of stairs and location of any obstructions at top and bottom of stairs.

Provide Station public stairs as follows:

- 2400 mm minimum width;
- 2200 mm maximum width without intermediate handrails;
- 3650 mm maximum height between landings;
- 2400 mm minimum headroom measured perpendicular to treads;
- Rounded tread nosings;
- Minimum coefficient of friction equal to medium broom finish concrete;
- 860 mm to 960 mm high continuous handrails both sides measured perpendicular to tread;
- 100 mm wide continuous runnel channels both sides flush with inside corner of tread and riser beneath handrails for water runoff, ease of cleaning, and bicycle access.

Escalators

Escalators are the primary means of vertical circulation for moving passengers between Station levels.

Provide escalators specifically designed for heavy-duty public transportation systems suitable for outdoor use with finishes, materials, and components to resist and deter vandalism.

Consider life cycle costs in escalator equipment, design, installation and maintenance.

Provide a pair of escalators minimum from concourse to platform.

Provide an additional pair of escalators from concourse to platform at Interchange Stations to improve service with inter-connection and cross-over between LRT and other transit facilities.

Provide 5000 mm minimum run off space to nearest obstruction at both top and bottom of escalators.

Group escalators in pairs or with stairs to accommodate reverse peak flows from the same landing points.

Availability of an adjacent alternative escalator means that there is access to another escalator when one escalator is out of service.

Stair lower working points are one tread width in front of lowest riser.

Align lower working points of adjacent escalator and stairs to align lower landing handrails.

Paired escalators provide passengers with access to another escalator when one escalator is out of service.

Standard Escalator: 30° incline; 1200 mm step width.

Escalator Vertical Rise: 12 m maximum per OBC.

Provide escalator service rooms with control panels and lubricating systems in the space below escalators.

Escalator service rooms may also house sump pumps/pits and allow access to void spaces under escalators.

Slope escalator service room floors 1% to bottom of escalator pit with floor drain.

Escalator Nominal Width: 1200 mm measured between balustrades 685mm above tread nosing.

Maintenance Access: From escalator landing areas.

See Figure B5-1.

Classification

Provide escalators of three classifications – Class A, B, and C -- applied to range of rise and well way design:

- Class A = 0-20 feet;

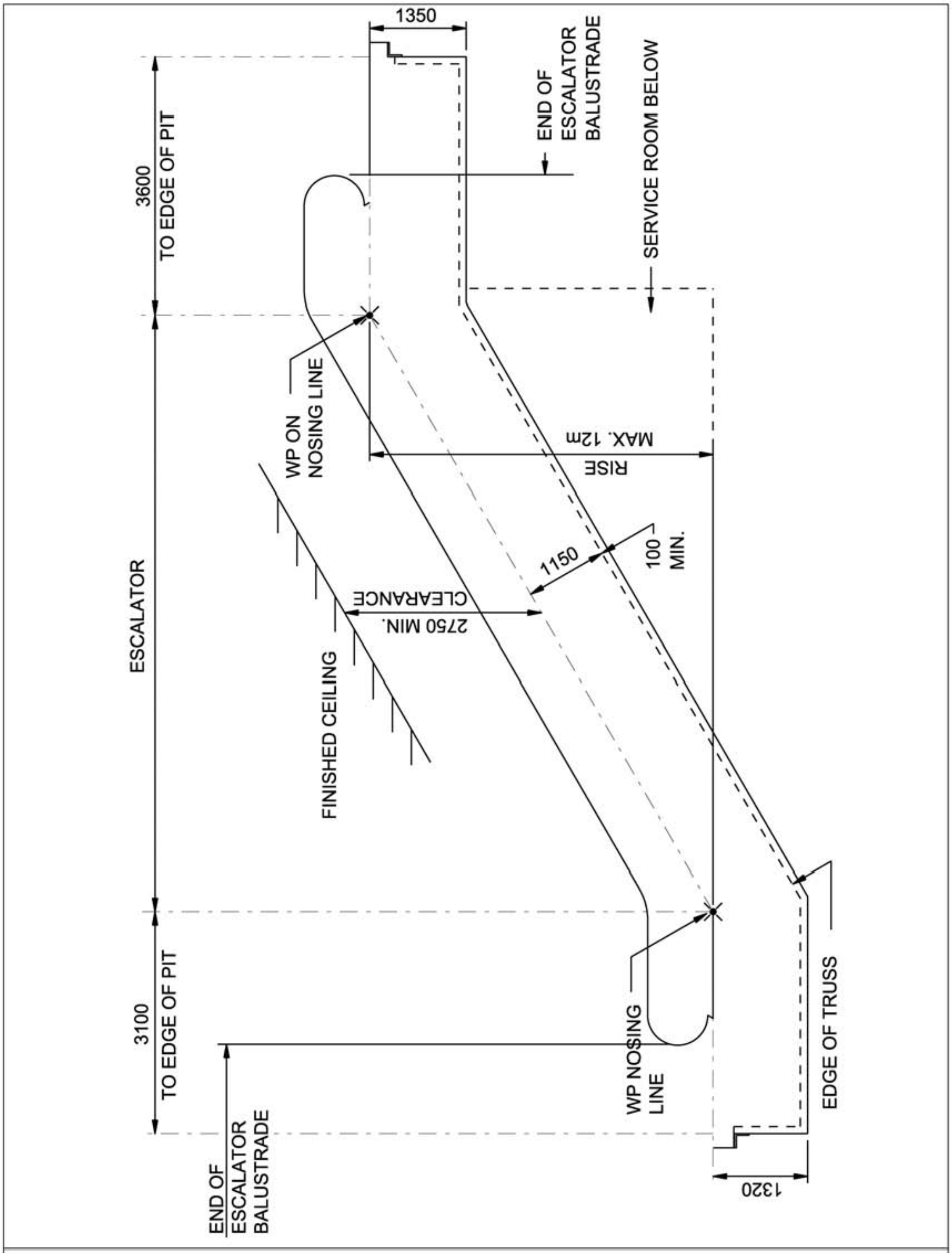
- Class B = 20-35 feet;
- Class C > 35 feet.

Provide Class A and B escalators with three level treads minimum at upper and lower landings.

Provide Class C escalators with four level treads minimum at upper and lower landings.

Locate escalator drive machines and controllers within escalator trusses.

FIGURE B5-1 STATION ESCALATOR PLANNING



Elevators

Provide each Station with at least one accessible path with the shortest route possible from street to platform connected by elevators.

Provide fully automatic passenger and freight elevators between each Station level.

Provide one elevator in the Station main entrance for an accessible route to concourse unpaid area.

Provide another elevator between concourse paid area and platform to complete the accessible route.

Provide street level elevator landings near passenger vehicle loading zones.

Provide passenger elevators in Stations with parking facilities near parking for persons with disabilities.

Provide passenger elevator cars and shaft walls with operable vision glass panels to assist surveillance and facilitate cleaning.

Provide conventional elevator car and shaft wall materials where glass is impractical or will not assist surveillance.

Transit Specific Elevator Requirements

Provide Station passenger elevators for vertical transportation between levels, accommodating those with disabilities, gurneys for injured passengers, and maintenance materials and equipment.

Provide elevators rated for 1,700 kg minimum carrying capacity, or greater carrying capacity for applicable freight rating requirements as may be required.

Provide freight elevators of applicable elevator durability and class rating.

Provide freight elevators with pad hooks.

Provide standard passenger elevator approaches, interior car layouts, controls, and graphics throughout the LRT system for passenger orientation and ease of access.

Provide call buttons, car controls, and Passenger Assistance Intercoms at each elevator landing to operate elevators or contact OCC.

Provide self-cycling elevators for reliable operation especially in cold weather.

Consider elevator maintenance requirements and operation failure data to establish heavy-duty transit suitability.

Cars

Provide elevator cars per the most stringent requirements of AHJ.

Provide elevator cars specifically designed for heavy-duty transit system needs and requirements.

Provide passenger elevators with heavy-duty, non-slip, stain resistant finish flooring.

Provide freight elevators or combined passenger/freight elevators with Class A loading floors.

Provide freight elevators with heavy-duty checker plate stainless steel elevator car finish flooring.

Provide underside of elevator car floors with fireproofing.

Provide “Roll-On – Roll-Off” elevator cars wherever possible to avoid turning stretchers, push chairs, wheelchairs, or goods carts inside the elevator car.

Size passenger elevators to accommodate padded metal patient gurneys with wheels per OBC including space for at least two emergency service providers or the largest maintenance materials and equipment to be moved between levels served, whichever is greater.

Size freight elevators to accommodate the largest maintenance materials and equipment or LRV parts to be moved between levels served.

Doors

Provide elevator door openings 1070 mm wide by 2135 mm high minimum clear dimensions unless special circumstances require larger door openings.

Reliability and Maintenance

In establishing elevator reliability and maintenance requirements, consider that many LRT Stations and facilities may include only one elevator.

Elevator effectiveness is more economically achieved with maintenance features to reduce repair time rather than improved reliability to increase mean time between failures.

Monitoring and Control

OCCs and EMPs monitor Station elevator/escalator operations and systems status.

Provide OCCs and EMPs remote control ability to start and stop escalators per OBC and NFPA 130.

Provide electronic public information signs at Station entrances displaying elevator operational status.

See Chapter C2 – Communications and Control.

Ramps

Provide ramps per the most stringent standards and criteria of AHJ.

B5.4.6 Horizontal Circulation

Corridors and Passageways

Size public corridors to satisfy Level of Service required and meet or exceed the most stringent exiting requirements per OBC and NFPA;

Provide non-public area passageways 1500 mm minimum clear width.

Provide public pedestrian ways, overpasses, underpasses, and tunnels 5000mm minimum clear width and 3000mm minimum clear height unless indicated otherwise or existing to remain.

Emergency Egress

Egress to track level along the length of platforms to satisfy exiting code requirements is prohibited.

Exiting off Station platform ends to trainways where required is acceptable as follows:

- Size platform end doors/gates per code requirements;
- Provide platform end doors/gates with panic hardware;
- Monitor operation of platform end doors/gates;
- Separate egress paths from trainways beyond platform ends with fences or railings to prevent public access and/or crossing tracks;
- Provide fences and railings per OBC requirements for guardrails including but not limited to structural capacity and baluster spacing;
- The path of travel to lead to a public right-of-way.

Crossing tracks to access public rights-of-way at Stops, other than at crosswalks, is strictly prohibited.

Provide Station exit doors as part of emergency egress routes to direct passengers onto MX or public property only.

B5.4.7 Designated Waiting Areas

Provide a Designated Waiting Area (DWA) at every Station platform, Bus Terminal waiting area, and Bus Loops.

Provide DWAs at consistent locations and, wherever possible, near elevators.

Locate Station DWAs at platform longitudinal mid-points with CCTV coverage, Passenger Assistance Intercoms to communicate with OCC, seating, signage, and intensified lighting.

Clearly demarcate DWAs with floor strips and signage.

See Chapter A4 – Security and Chapter C2 – Communications and Control.

B5.4.8 Standard Elements

Provide standard fixtures, furnishings, equipment, and other elements to make Station spaces recognizable and familiar for infrequent users and passengers with special needs.

B5.4.9 Lighting and Light Fixtures

Natural light and transparency enhance Station safety and security.

Introduce natural light into Stations wherever possible as an essential interior environment design element for the benefit of LRT users.

Provide at-grade entrance components to allow as much daylight into Stations as possible.

Provide added-height glazed walls at Station entrances to allow daylight into concourse levels.

Provide artificial lighting to promote safety, articulate architectural elements, enhance spatial perception and reinforce interior architectural character.

Provide standard light fixtures at platform and concourse levels -- This is mandatory.

Use of alternative light fixtures for accent lighting at concourses and entrances is encouraged provided it:

- Functions effectively in an LRT environment containing brake dust;
- Is an industrial type fixture that is robust, vandal resistant, and easily cleanable; and
- Is easily maintained with a service life and overall life cycle cost comparable to standard light fixtures.

Creative use of lighting is encouraged as a major Station design aesthetic element as well as to accomplish design goals as follows:

- Enhance public safety with Crime Prevention Through Environmental Design (CPTED);
- Enhance the feeling of openness, visual comfort and elimination of glare; and
- Provide intuitive orientation.

Variability and differentiation of light levels is encouraged provided they meet minimum Station area light level criteria.

Light fixtures that are one-of-a-kind art objects are not allowed in terms of maintainability and long term availability.

Use creative lighting combined with textures, materials, and colors to visually break up perceived length of long corridors and circulation elements.

Enhance Station entrance visual transparency between interior and exterior areas in both daytime and nighttime.

It is important to see into Station entrances both night and day and to see out at night for awareness of one's surroundings.

Station entrances are subtle, unobtrusive, community safety lanterns at night for streetscape orientation.

Interior and exterior lighting remains on but dimmed for energy conservation during non-revenue hours.

Provide accent light at key walls to expand space and improve vertical illumination, visibility and safety.

Organize light patterns to highlight destination points, create visual hierarchy, assist in way-finding and provide passenger orientation.

Use lighting and signage to establish a hierarchy of way-finding signage, emphasize separation of paid and unpaid areas, and indicate specialty zones such as Designated Waiting Areas (DWAs) and Public Assistance Intercoms (PAIs).

Create visual focal points that can be combined with architectural features or art.

Locate light fixtures to facilitate maintenance and re-lamping.

Locate lighting above stair and escalator landings, not over inclined areas.

B5.4.10 Trash Receptacles

Provide trash receptacles, bolted down to avoid removal by unauthorized persons, at Station platforms and bus terminals per criteria and standards of AHJ.

See Chapter A3 – Safety and Chapter A4 - Security.

B5.4.11 Retail Space

Provide food-related retail space at Terminal and Interchange Stations.

Provide additional retail space, vending, and retail carts at Line Stations at the discretion of MX RT.

Protect for concourse level retail space where required as follows:

Food Related Retail Space

Approximately 30 to 100+ square metres with services brought to retail locations as follows:

- 200 amp minimum electric service with electric panel;
- Mechanical ventilation intake and exhaust;
- 13 mm diameter domestic water supply with drainage;
- Sprinkler system fire protection and smoke/heat detectors hard-wired to Station Attendant Room and OCC annunciation panels.

Other Retail Uses

Approximately 30 to 50+ square metres services brought to the retail location as follows:

- 100 amp minimum electric service with electric panel;
- Mechanical ventilation intake and exhaust;
- 13 mm diameter domestic water supply with drainage;
- Sprinkler system fire protection and smoke/heat detectors hard-wired to Station Attendant Room and OCC annunciation panels.

Retail Carts and Vending Areas

Approximately 60 amps dedicated electric service with sprinkler system fire protection and smoke/heat detectors hard-wired to Station Attendant Room and OCC annunciation panels.

Storage

Provide retail spaces with approximately 30 square metres storage room with electric outlets and sprinkler system fire protection with smoke/heat detectors hard-wired to Station Attendant Room and OCC annunciation panels Adjacency

Location

Locate retail areas in main circulation areas but not obstructing normal passenger flow.

Presence of retail personnel discourages criminal activity.

Strategically plan retail locations to optimize surveillance area coverage.

Locate Automatic Teller Machines in sight of and/or in proximity to retail areas.

B5.4.12 Emergency Response Rooms

Locate Emergency Response Rooms (ERRs) consistently in every Station at platform level near the elevator so that emergency responders know where to find it.

Do not locate ERRs in a space or room with special or restricted keying, e.g., Communications or Electric Equipment Rooms.

Provide ERRs with space for a 610 mm x 2010 mm wheeled stretcher as well as off-loading and temporary storage space.

Unless there is a Station-specific conflict, a Sump Pump Room may serve as the ERR.

Designate the ERR with a standard decal and mark the path to the ERR with platform floor decals.

See *Harmonized Signage and Wayfinding Manual*.

B5.4.13 Fare Collection

Provide full fare control line configurations and arrangements at Interchange Stations and protect for same at Terminal and Line Stations.

Provide fare collection systems and equipment as follows:

- 5 m minimum queuing space both sides of fare control line;
- One accessible fare gate minimum in each full-height fare gate line;
- 1.8 m minimum wide glazed automatic sliding double doors at entrances;
- Fare collection equipment including Ticket Vending Machines, Smart Card Readers, Full Service Vending Machines, Add-Value Machines, etc., strategically located not to conflict with travel paths.

Assume smart card fare collection systems will be incorporated system-wide by the time an LRT system enters service.

Minimum requirements for full-height fare gates, crash gates and glazed double doors are for space proofing purposes only and are not to be assumed as the final fare collection equipment to be used.

Locate fare control lines and associated equipment at each entrance or concourse prior to descent to platform.

Proof of Payment System

See Concept of Operations Proof of Payment (POP) for transition from current fare collection systems.

Incorporate MX LRT adopted POP systems while protecting for a full-height fare gate system.

Incorporate full-height fare gate systems at Interchange Stations where required.

B5.4.14 Service Areas

Locate the following at-grade service areas at one entrance of each Station:

- Refuse Storage Room;
- Temporary Emergency Generator Area;
- Off-Street Emergency/LRT Maintenance Vehicle Parking.

B5.4.15 Signs and Graphics

The basic objective of system signage is to guide people to and through an LRT system safely, efficiently, and effectively in user-friendly ways using simple, strong, and precise graphic style signs with organized, systematic, sensible layouts.

Clear and direct circulation routes at all Station levels enable unimpeded pedestrian movement and intuitive way-finding from Station entrance to platform, LRVs and back.

This is particularly important at Interchange Stations where existing signage may need to be modified and integrated with new signage.

Provide standard signs and graphics system-wide throughout an LRT system giving clear and easily understood information that can be quickly comprehended to promote passenger orientation and facilitate public way-finding.

Proper placement of signs further enhances safe, efficient and effective communications.

Upgrade existing way-finding signage at Interchange Stations accordingly.

System-wide Signs and Graphics includes but is not limited to:

- Station Identification Signs;
- System Maps;
- Station Vicinity (Neighborhood) Maps;
- Safety Signs;
- Regulatory Signs;
- Directional Signs;
- Operational Signs; and
- Advertising Media.

Signage is in both English and French subject to the French Language Services (FLS) Act.

French signage requirements apply to all public-facing communications and mirror English signage requirements 100 percent

French and English are typically located side by side or one above the other on the same sign.

Proper names, street names, and Station names remain “as is” and are not translated.

B5.4.16 Advertising

Until an advertising policy is adopted, assume Station advertising elements similar to existing underground Stations.

Protect for expansion of electronic signage media at all Station locations and levels.

B5.5 Traction Power Substations

Traction Power Substations (TPSs) house electric equipment including transformers, switches and circuits to supply electric power at sufficient voltage to an LRT system.

Average TPS spacing is determined through load flow analysis.

While it is most efficient to locate a TPS as close as possible to an LRT Trainway there may be locations where shifting a TPS a short distance from an LRT corridor is preferable when a need to minimize street impacts or other site constraints or obstacles prohibit locating a TPS adjacent to LRT Trainway.

See Table B5.4 Room List for Traction Power Substations.

Integrate TPSs with Station facilities such as ventilation shafts or entrances wherever possible to minimize property take and neighborhood impact.

Where a TPS must front on a main street, generally site it perpendicular to the street to reduce impact.

In some circumstances it may be more appropriate to locate a TPSS parallel to the street to reduce impact on a surrounding natural area or open space.

Provide TPS access from front and rear where located along a main street to integrate the TPS consistently and in line with adjacent development allowing for a continuous street wall.

Provide TPS related parking to the rear of the TPS with access via a rear lane or side street.

Where parking space is an issue, provide on-street parking or in a nearby parking lot.

Where located in a main street setting or a street with consistent setback characteristics, site the TPS to reinforce adjacent development general setback characteristics and integrate it with adjacent building scale and surrounding context with opportunities for active at-grade uses.

Where it is not possible to maintain existing setbacks along a main street, make land in front of the TPS accessible to the public and provide additional amenities such as bicycle parking, landscaping, seating areas, public art, and the like.

Integrate the TPS with the urban fabric through use of similar or matching finish materials, landscaping, integrated artwork, and the like.

In open spaces locate the TPS to minimize visual impact using smaller single story configurations.

Enclose TPS internal elements on all four sides with access only from within the TPS.

B5.6 System Support Elements

Determine need for system support elements such as communications and signal equipment cabinets, electric cabinets, electric power meters, water meters and valves, and irrigation valves and boxes on a site specific basis.

Provide system support element space in Stations only if it is not already allocated elsewhere such as nearby train control and communications houses or TPS sites.

Where required in a Station, locate it off the platform wherever possible.

B5.6.1 Electric Convenience Outlets

See Chapter C3 – Facilities Electric Systems.

B5.6.2 Hose Bibs and Wall Hydrants

Provide standard flush hose bibs for full coverage with a 2300-mm hose of Station entrances, concourses, platforms, and Stop platforms, shelters, fare collection areas, etc.

Provide non-freeze wall hydrants for internal and external areas where hose connections for cleaning or irrigation purposes are required.

B5.6.3 Public Address System

Provide Public Address (PA) System coverage for every Station area.

Include a means of conveying information to persons with disabilities per most stringent criteria and accessibility guidelines of OBC and AHJ.

See Chapter C2 – Communications and Control.

B5.6.4 CCTV

Provide CCTV cameras for Station and Stop surveillance, fare collection monitoring, etc.

See Chapter C2 – Communications and Control.

Coordinate mounting and location of CCTV cameras with Security personnel and structural design subject to evaluation as part of the Threat and Vulnerability Assessment.

See Chapter A4 – Security.

B5.7 Public Payphones

See Chapter C2 – Communications and Control.

B5.8 Emergency Reporting Devices

Provide Emergency Reporting Devices per OBC and AHJ throughout an LRT Station so that the distance of travel from any point in public areas to such a device is no more than 90 m.

Emergency Reporting Devices may be public telephones with “no-charge” emergency capability.

Plainly indicate Emergency Reporting Device locations by appropriate signs.

Provide Blue Light Stations (BLS) with Emergency Telephones (ETEL) at both ends of Station platforms per NFPA 130.

BLS and ETEL are not required for at-grade Stops.

B5.9 Roof Access and Fall Protection

Provide proper roof access and fall protection.

Provide permanent roof access with fall protection for roofs 3000 mm or more above grade per OBC, OHSA and AHJ requirements.

For roofs less than 3000 mm above grade not requiring regular maintenance access, i.e., with no equipment, roof drains, grills, or skylights, etc., no permanent roof access or fall protection is required.

Provide an OHSA compliant permanent exterior ladder with fall protection for secondary roofs projecting above a primary roof.

Preferred location for roof drains is 2000 mm minimum from roof edge.

Preferred location for roof-top equipment is 3660 mm minimum from roof edge.

Provide roof edges with parapets or guardrails – parapets preferred.

Provide roof parapets or guardrails for locations with roof drains less than 2000 mm or roof-top equipment less than 3660 mm from roof edge.

Provide an interior secured stair with roof penthouse for maintenance access to green roofs.

Provide roof hatches with permanently attached ship ladders, 50 degree maximum inclination, for access to cool, i.e., heat reflecting, roofs with roof-top equipment.

Provide roof hatches with permanently attached vertical ladders for access to cool roofs without roof-top equipment.

B5.10 Wash Rooms

B5.10.1 Staff Wash Rooms

Provide separate accessible staff wash rooms, one for males and one for females, located for convenient use at Stations.

Provide number of fixtures per OBC and AHJ.

B5.10.2 Public Wash Rooms

Provide separate accessible public wash rooms, one for males and one for females, located for convenient use in paid areas at Terminal and Interchange Stations.

Provide barrier free accessible wash rooms equipped with fixtures, grab bars, accessories, door swings, clearances, and turning radii for safe maneuvering of mobility devices per OBC and AHJ.

B5.11 Skylights

Provide skylights to help mark and light logical routes through Stations.

Provide skylights and/or clerestories in Main Entrances in shapes and sizes appropriate to allow natural light diffusion deep down through escalator/stairwells and other openings.

Provide skylights with proven water and air tightness performance characteristics in both heated and unheated spaces.

Provide only skylights allowing maintenance and cleaning without lifts or staging.

Avoid use of skylights where natural light is more readily available through exterior vertical walls.

B5.12 Finish Materials

This section provides directive guidelines and criteria for Station service area materials selection.

Evaluation criteria for finish materials in public and non-public areas include:

- Use;
- Exposure;
- Safety;
- Security;
- Durability;
- Abrasion Resistance;
- Moisture and Frost Resistance;
- Shrinkage Resistance;
- Corrosion Resistance;
- Appearance;
- Constructability;
- Acoustic Properties;
- Sustainability;
- Minimum Maintenance;
- Ease Of Replacement;
- Initial Cost; and
- Lifecycle Cost.

Consider finish materials constructability particularly in existing Station, bus transfer, and other public area applications.

Another important factor in selection of permanent materials is long term availability for repair and maintenance.

Use creative colors, materials, and textures combined with integrated artwork for an individual feel and aesthetic for each Station.

Guidelines for finishes include:

- Flame spread ratings for wall and ceiling finishes per NFPA 130 and OBC;
- Non-combustible materials;
- Wood products fully compliant with combustibility standards;
- Slip resistance, graffiti resistance, and maintainability per OBC;
- Color contrast between surfaces to assist the visually impaired;
- Light colors to improve lighting efficiency;
- Textured materials used in comparable environments with demonstrated maintainability;

- Sound-absorptive materials to reduce unwanted acoustic reflection;
- Colors that provide a sense of safety and security;
- Colors, graphics, contrasting materials and textures clearly delineating paid and unpaid areas.

B5.12.1 Safety

Satisfy safety and security requirements with finish material properties as follows:

- Non-combustible construction per OBC;
- non-toxic in fire conditions;
- Slip resistant flooring, wet or dry, particularly at entrances, stairways, and platforms per accessibility criteria and requirements of OBC and AHJ;
- Non-reflective in way-finding and CCTV areas;
- Secured so as not to be dislodged by vibration, wind pressure, or temperature change;
- Non-abrasive where passengers are likely to brush against, e.g., stairwells, elevator cars, and passageways;
- Colours to complement standard safety colours and enhance lighting levels.

Avoid use of plastic.

Where unavoidable, use only plastic that does not produce dense or toxic smoke.

B5.12.2 Durability

Carefully consider finish material value engineering aspects and life cycle costs.

Provide building and finish materials with excellent wear, strength, and weathering qualities with due consideration of both initial and replacement costs.

Provide colorfast building materials that maintain good appearance throughout their useful service life and are Sufficient for cold weather climate.

Repair or Replacement

Minimize maintenance costs using standard materials that, if damaged, are easily repaired or replaced with little or no impact on LRT operations.

Resistance to Vandalism

Provide materials and details that are difficult to deface, damage, or remove, and operational and maintenance strategies that discourage vandals.

Provide public areas finishes allowing common maintenance methods to readily remove casual vandalism.

Protect surfaces subject to graffiti with a permanent and non-sacrificial type scratch and graffiti-resistant coating.

This includes vehicles, exterior ground level facility surfaces within 4 metres of accessible reach and interior surfaces except floors.

Apply according to the manufacturer’s latest published instructions.

Some of the most important characteristics of graffiti-resistant coatings are:

- Sufficient adherence without damage to substrates;
- Hydrophobicity (water-repellence);

- Environmentally friendly composition and processing;
- Resistance to UV aging and weathering;
- Good Cleaning Efficiency.

Consider as well other strategies to reduce or discourage vandalism such as night lighting and additional highly visible surveillance cameras, design strategies such as barrier plantings and fences, improved maintenance of the general area and rapid graffiti removal.

Consider also new technologies that automatically detect either spray paint or permanent marker, enabling authorities to track and record offenders in real time.

Stations and vehicles fitted with such detection systems use an electronic chemical sensor to detect the vapour of both spray paint and marker pens.

The CCTV systems in the Stations and vehicles record and provide images directly to staff who are further connected to security and the police.

B5.12.3 Maintenance

Provide finish materials on which minor soiling is not apparent, that do not soil or stain easily, and are easy to clean in a single operation using standard cleaning equipment and agents.

Provide finish materials that are able to withstand the rigors of regular cleaning, washing, and high pressure water spray using one-step cleaning processes.

Avoid use of exposed fastenings.

Provide for removal and replacement of damaged finish materials without damage to adjacent areas.

Provide materials with proven maintenance procedures.

Do not use finish materials where maintenance access is awkward or dangerous.

Since finish material joints are a major source of maintenance problems, provide a minimum number of small, non-absorbent, flush joints.

Correctly designate and space control and expansion joints fit for purpose in floors and walls.

B5.12.4 Attachment Systems

Reduce dislodgment hazards due to temperature change, vibration, wind, seismic forces, aging, or other causes using secure mechanical attachment systems and sufficient bonding materials.

B5.12.5 Slip-Resistant Walking Surfaces

Provide slip-resistant walking surface materials for pedestrian and those with disabilities safety per the most stringent accessibility guidelines and OBC criteria.

Provide minimum static coefficients of friction per ASTM C1028 as follows:

	Coefficient of Friction
Public Horizontal Surfaces	0.6
Non-Public Horizontal Surfaces, Exterior	0.6
Non-Public Horizontal Surfaces, Interior	0.5
Platform Edge Strips	Textured, Visually Contrasting Material
Stairs, Ramps, Sloping Sidewalks	0.8

Area Around Equipment	0.6

B5.12.6 Unit Sizes

Provide finish material in unit sizes large enough to reduce number of joints yet small enough to facilitate replacement if damaged.

Monolithic materials may be used that are easily repaired without being noticeable.

Joints

Provide joints to minimize use of caulking.

Generally do not use caulking where exposed to vandals.

Provide tamper resistant and hidden fasteners wherever possible.

Avoid exposed fasteners.

Where are necessary, provide exposed fasteners only without sharp or protruding edges that could cause injury or interfere with maintenance.

Integrate finish material thermal expansion joints wherever possible.

Provide wall expansion joints with covers.

Provide control joints to minimize cracking or spalling.

For joints with compression seals consider the following:

- Use preformed elastomeric seal devices;
- Use only crystallization resistant neoprene at low temperature areas;
- Seals remain in 15% minimum compression at widest opening;
- Approximately 40% uncompressed seal width allowable movement unless otherwise stated and proven by manufacturer.

Minimum Dimensions

Provide finish material clearances and dimensions per criteria listed below:

- 100 mm minimum thickness for finishes below grade against outside walls;
- 50 mm minimum cavity space from inside face of underground structural wall to inside face of interior finish material for seepage drainage, air circulation, and insulation;
- Drain and vent cavity space using only non-oxidizing metals where required;
- 100 mm minimum from beams, columns and slabs to face of finish materials for cables and wiring;
- 40 mm minimum from top of slab to top of finish floor; 50 mm minimum on stair treads;
- 200 mm minimum above suspended ceilings for pipes, ducts, conduit, etc.;
- 4000 mm preferred public space ceiling height not to exceed 4800 mm above finish floor subject to Occupational Safety Act requirements for safety anchor harness platforms.

Provide concourse level Elevating Device Storage Rooms with appropriate ceiling and door dimensions for scissor lifts and accessories where Station spaces requiring regular maintenance exceed 4800mm above finish floor.

Provide additional live load structural floor reinforcement in path of travel to areas requiring scissor lifts.

Provide elevator car dimensions and loading to accommodate scissor lifts where required.

B5.12.7 Waterproofing and Moisture Control

Provide waterproofing and moisture control for structures including Stations, Stops, and Associated Facilities.

Provide public area floor, wall, ceiling and stair finish materials with sufficient moisture absorption ratings.

Provide exterior finish materials with sufficient freeze/thaw resistance ratings.

Provide assemblies to avoid condensation, water, and frost damage.

Control moisture and water penetration through building envelopes to prevent:

- Dimensional change of materials;
- Surfaces corrosion and staining;
- Decay of materials;
- Flooding of pedestrian areas and service rooms;
- Breakdown of system roofing and finished walls;
- Efflorescence of masonry surfaces;
- Surface spalling by freezing;
- Equipment damage; and
- Condensation.

B5.12.8 Corrosion Resistance

Provide protective coating films or insulating membranes where potential for electro-chemical corrosion between metals occurs, for example:

- Aluminum to Stainless Steel, Brass, Bronze, Copper;
- Stainless Steel to Brass, Bronze, Copper Zinc;
- Metals to Concrete.

See Chapter C5 – Stray Current and Corrosion Control.

B5.12.9 Acoustics

Provide public area sound absorbing materials where appropriate to reduce noise levels, echoes and reverberation that can cause interference with Station PA systems, e.g., ceilings, platform train walls, and walls out of public reach.

Provide building elements such as doors and windows to avoid transmission of noise between various public and non-public areas.

Sound Levels

Provide and coordinate Station finish materials so that:

- Maximum Station sound levels are not exceeded;
- Proper acoustic materials achieve maximum effectiveness of PA system speakers.

See Chapter C2 – Communications and Control.

Acoustic Treatment Locations

Provide public area ceiling and wall acoustic treatment 2000 mm minimum above finish floor.

Provide platform ceiling and trainway wall and ceiling acoustic treatment to control train noise.

Provide Elevator Machine Room acoustic treatment to minimize noise levels.

Physical Requirements

Provide interior wall and ceiling acoustic finishes to achieve 0.7 minimum Noise Reduction Coefficient (NRC) per ASTM Test Method C423.

Provide prefabricated panel or spray-on coating acoustic treatment materials per NFPA and OBC cleaning, durability, and fire rating requirements.

B5.13 Specific Finishes

Finish material types and colours aid in orientation and wayfinding.

Provide a limited palette of finish material types and colours used consistently.

A very limited number of special areas may vary finish materials to distinguish them from other areas.

B5.13.1 Floors

General Criteria for Finish Floors:

- Dry, ice free, well drained;
- Low moisture absorption;
- Slip resistant;
- Non staining;
- Non cracking;
- Chemical resistant;
- Salt resistant;
- Abrasion and wear resistant, particularly at escalator landings, stairs, and fare control areas.

Finished Floor Materials	
Public Area	**Acceptable Materials**
Bus platforms, ramps	• Poured-in-place concrete (broom finish)
Entrances, concourses, Station	• Poured terrazzo, quarry tile, large pavers
Platforms, public corridors,	• Poured terrazzo (special hard aggregates, abrasive aggregates, and installation control); thickset installation. No polished surfaces allowed, granite accents
Washrooms	• Poured terrazzo
Platform Edge Detectable Warning System	• Per standard details

Finished Floor Materials	
Public Area	**Acceptable Materials**
Exterior LRT Platforms	• Textured-finish concrete • Stamped-pattern concrete • Quarry tiles (non-slip) • Paver brick (dense hard) • Granite or other natural or manufactured comparable stone • Selected artificial stone materials • Precast concrete
Detectible Warning System at Stairs and Landings	• Tiles per standard details
Accessibility Way-finding System at Platforms and stair landings	• Per standard details
Stairs	• Poured terrazzo and reconstituted granite tile for treads and nosing per standard details
Elevator	• Finish to match standard details
Non-Public Areas	• Finished and sealed concrete • Some specific areas may require epoxy finish as directed by MX RT

B5.13.2 Walls

General Criteria for Interior and Exterior Wall Finishes:

- Protection for outside corners;
- Ease of maintenance for inside corners;
- Low moisture absorption;
- Hard durable surface;
- Chemical resistant;
- Non-combustible;
- Scratch resistant and graffiti resistant;
- Able to accommodate signage and graphics;
- Does not produce toxic smoke when exposed to flame;
- Maximize sight lines;

Wall Finish Materials	
Area	**Acceptable Materials**
Exterior - Public Areas	
Stations	Primary: Glass – bird friendly fritted glass in clear anodized prefinished aluminum framing Secondary: Stone Porcelain enamel coated panels High-finished poured concrete, sealed Precast concrete
Bus platforms, stairwells	Brick Blazed, prefinished, and textured concrete block Stone Glass – bird friendly fritted glass in clear anodized prefinished aluminum framing Porcelain enamel coated panels Poured concrete, sealed Precast concrete Glass block Metals stainless steel (if minimal) aluminum zinc
Interior - Public Areas	
Entrances, corridors, concourse, Station platform, stairwells	Ceramic tile Porcelain enamel coated panels Brick (smooth) Glazed, prefinished, textured concrete block Glass block Metal-faced composite panel
Elevators	Per standard details
Escalators	Per standard details
Railings/Balustrades	Laminated tempered glass, stainless steel frame and supports
Wash Rooms	Porcelain tile Phenolic toilet partitions
Exterior - Non-Public Areas	
Transformer yard	Acoustic concrete block
	Acoustic panel finish

Interior - Non-Public Areas

B5.13.3 Ceilings

General Criteria for Ceiling Finish Materials

- Detailed not to allow ponding of water above ceilings;
- Low moisture absorption;
- Acoustically treated;
- Chemical resistant;
- Not to exceed 4800 mm above finish floor or subject to requirements of OSHA for safety anchors harness or platform lift;
- Dent resistant;
- Sufficiently durable to resist potential impact where ceilings and suspended elements are within reach of passengers carrying large packages or long objects;
- Easy access to ducts and equipment above ceiling but screened from public view.

Ceiling Finish Materials	
Area	**Acceptable Materials**
Exterior - Public Areas	
Bus platform canopy (Soffit & Fascia)	Metal ceiling Precast concrete Exposed smooth concrete finish
Skylight	Aluminum or stainless steel frame
Interior - Public Areas	
Station platforms	Use standard ceiling systems
Entrances and concourses, public corridors	Metal ceilings finished concrete
Elevators	Metal ceiling
Wash room s	Moisture-proof glass reinforced cement panels No gypsum wall board

B5.13.4 Doors and Frames

General Criteria for Doors and Door Frames:

- Non-Combustible;
- Corrosion Resistant;
- Vandal Proof;
- Sound Attenuating;
- Ease of Maintenance, Repair and Replacement;
- Fire ratings as required in horizontal separations;
- Suitable to accommodate hardware functions;
- Standard Size: 2150 mm high x 900 mm wide subject to OBC requirements.

Doors And Frames Finish Materials	
Area	**Acceptable Materials**
Exterior/Interior - Public Areas	
Bus and LRT platforms Station entrances Doors in horizontal circulation path	Heavy duty clear anodized aluminum high quality sliding glass door with laminated tempered glass in aluminum frame
Security night doors and grilles	Laminated tempered glass in anodized aluminum frame
	Stainless steel grille in stainless steel frame
	Anodized aluminum grille in aluminum frame
All doors to non-public space from public areas	Painted hollow metal
Public wash room	Preference – no door, use blind wall
	Stainless Steel
	Painted hollow metal
Exterior/Interior – Non-Public Areas	
Emergency exit buildings' entrance doors All doors in substations All doors to non-public space from nonpublic areas in Stations All doors in the running structures All personnel wash rooms from non-public areas	Painted hollow metal door in stainless steel frame

B5.13.5 Hardware

Develop master keying systems in collaboration with MX RT, AHJ, HMQ Agency, and other third-party Stakeholders as required to accommodate access and security requirements.

Provide power assisted doors activated by a knowing act and, when powered open, that remain in fully open position per ANSI/BHMA Standard A156.19 and accessibility standards and regulations of AHJ.

Provide automatic door operators equipped with controller system and electronic eyes/sensors operating and monitoring door functions and safety sensors with alarm/fire ventilation interface.

B5.13.6 Glazing

Provide at-grade facilities with tempered single glass glazing units, 4.5 sq. m minimum area, vertically oriented and continuous across every street-facing elevation.

MX LRT intent is to maximize glass size and minimize number of mullions.

Provide glazing as follows:

- Transparent and fritted per AHJ bird-friendly development guidelines and approved variations;
- Tinted glass prohibited;
- Shatter-proof;
- Graffiti-resistant;
- Sound attenuating;
- Easily replaceable glazing units and system components;
- Ease of access for cleaning.

Glazing Finish Materials	
Area	**Acceptable Materials**
Exterior/Interior - Public Areas	
Bus and LRT platform above grade	6 mm minimum laminated tempered glass from finish floor elevation to top of door frame height
	6 mm minimum laminated glass above top of door frame height
Insulated windows (heated areas only)	2 layers of 6 mm minimum tempered clear glass, with a 12 mm air space
Skylights	6 mm minimum laminated tempered glass
Entrance and concourse - night doors, glass partitions	6 mm min. laminated tempered glass
Interior - Public Areas	
Stair balustrades Elevator enclosures Escalator balustrades	Laminated tempered glass minimum 10 mm thickness

B5.13.7 Metals

General Criteria for Metal Fixtures, Furnishings and Finishes:

- Stainless steel (public areas);
- Anodized aluminum or galvanized steel (non-public areas);
- Powder coated field repairable steel or aluminum.

Provide stainless steel and metal fabrications as follows:

- Railings, handrails and guardrails integrated with stairways, escalator openings, and ramps per OBC and AODA requirements;
- Factory finished and pre-fit stainless steel and metal fabrications;
- Grade 316 stainless steel per ASTM A167.

B5.13.8 Shelters

General Criteria for Shelter Materials:

- Laminated Tempered Glass;
- Metal Insulated Panels;
- Factory Molded Panels: Class A Fiber Reinforced Polyester or Fiber Reinforced Cement;
- Stainless Steel;
- Powder Coated Field Repairable Steel or Aluminum.

B5.14 Elements of Continuity/Elements of Variability

Provide each Station and Stop, where appropriate, with unique design aspects while consistently using a common vocabulary of elements and features that unify and identify an LRT system as a whole and reflect Design Excellence Principles and Requirements.

Elements of Continuity and Elements of Variability are defined as follows:

Elements of Continuity: Components standard system wide for LRT System and Station identity, functional consistency, efficient operations, and ease of maintenance.

Elements of Variability: Components consistent throughout a particular Station, Stop, LRT site or facility but variable throughout an LRT system in terms of color, texture, materials, form, and assembly.

Variability is an option, not a requirement.

Station and Stop Facility/Component	System-wide Continuity	Station-to-Station Variability
• Station Platform Lighting	X	
• Concourse and Entrance Lighting		X
Finishes		
• Flooring		X
• Walls		X
• Ceilings		X
• Platform Ceilings	X	
• Acoustic treatment		X
• Materials		X
Landscaping		X
Public art		
• Location and subject matter		X
• Quantity		X
Information Devices and Signage		
• Identification signs	X	
• Systems signs, including passenger information devices	X	
• System maps	X	
• Vicinity maps	X	
• Station identification (insignia signs, Station name and numbering of properties)	X	
• Bus information	X	
• PVIS (Passenger Visual Information System)	X	

Station and Stop Facility/Component	System-wide Continuity	Station-to-Station Variability
• Signage and graphics (exterior and interior)		
– Directional	X	
– Identification	X	
– Regulatory	X	
– Operational	X	
• Advertising media		
– Platform video screens	X	
– Billboards	X	
– Electronic billboards	X	
• Vertical Movement		
– Escalators	X	
– Elevators	X	
– Ramps	X	
– Stairs	X	
• Communications		
– TTC telephone	X	
– Public address speakers	X	
– Public telephones	X	
– PAI (Passenger Assistance Intercom)	X	
• Station control and security		
– Intrusion alarms	X	
– CCTV equipment	X	
– Central alarm and control facility	X	
– Emergency alarm Station	X	
• Platform edge	X	
• Platform configuration	X	
• Stop Shelters		
• Form	X	
• Structural elements	X	
• Material/finishes	X	
• Length/extent	X	

Station and Stop Facility/Component	System-wide Continuity	Station-to-Station Variability
Windscreens		
• Form	X	
• Material/finishes	X	
• Length	X	
Stairs and ramps		
• Materials/finishes	X	
• Handrails	X	
• Guardrails	X	
Leaning rails		
• Materials/finishes	X	
• Quantity & placement		X
Doors and hardware		
• Electronic Keying	X	
• Finish	X	
Trash receptacles		
• Materials/finishes	X	
• Quantity & placement		X
Bicycle racks		
• Materials/finishes	X	
• Quantity & placement		X
Bicycle lockers		
• Materials/finishes	X	
• Quantity & placement		X
Benches		
• Materials/finishes	X	
• Quantity & placement		X

B5.15 Platform Edge Doors

Protect underground Station platforms for future installation of Platform Edge Doors (PEDs).

Provide platform edges with electrical stub-outs, associated conduit, and structural load and slab reinforcement details to facilitate later installation of full height, partially segregated type PEDs with minimal revenue service disruption.

Coordinate future PED provisions and installation with applicable code requirements.

B6 Maintenance and Storage Facilities

B6.1 General

Chapter B6 addresses criteria for complete stand-alone Metrolinx (MX) Light Rail Transit (LRT) Maintenance and Storage Facilities (MSFs) including back-of-shop heavy maintenance functions to accommodate LRT project Light Rail Vehicles (LRVs).

Not every function identified here may be required for every MSF.

Establish MSF requirements upon review of existing LRT system operations, proposed LRT systems, and specific LRT system MSF program requirements.

Arrange MSFs with proper space allocation for efficient and effective traffic and work flow to support LRV revenue service for the life of the facility, personnel safety and comfort, and compliance with Authorities Having Jurisdiction (AHJ) codes, standards, and regulations.

Configure MSFs to accommodate future ultimate LRV fleet size, maximum LRV consist length, and projected passenger demand in the ultimate design year.

LRT operations determine MSF functional requirements and ultimate configuration.

Major MSF functional requirements include:

- Reception;
- Dispatch;
- LRV Storage;
- MSF Operating Patterns;
- Shop Circulation;
- Testing and Training;
- Traction Power Substations (TPSs);
- Maintenance of Way (MOW) Building and Storage Areas;
- Vehicle washing facilities using non-potable water; and
- Bicycle parking and storage facilities.

Not every MSF area may need to include LRV maintenance.

MSFs with LRV storage and possibly daily servicing may be appropriate if another MSF provides preventive and corrective maintenance on an LRT line.

Every LRT System needs at least one MSF designed and equipped for LRV heavy repair but not every LRT System MSF may need to include LRV heavy repair.

MSF operations depend on major shop functional areas that may include:

- Heavy Repair;
- Truck and Wheel Repair (Required in Heavy Repair Areas);
- Wheel Truing;
- Undercar Cleaning;

- Car Wash;
- LRV Body Repair and Paint Booth;
- MOW Equipment;
- Traction Power Substation;
- LRV Maintenance Offices and Employee Facilities;
- Transportation Offices and Operator Facilities;
- Materials/Parts Offices and Parts Storage Facilities;
- Training and Conference Facilities;
- Daily Servicing; and
- Preventive/Corrective Maintenance.

B6.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Maintenance and Storage Facility specific references include but are not limited to:

- Ontario Building Code (OBC);
- Green Development Standards of AHJ;
- Accessibility for Ontarians with Disabilities Act (AODA)
- Accessibility Design Guidelines of AHJ;
- CAN/CSA B651.M90: Barrier-Free Design, A National Standard for Canada;
- Ontario Electrical Safety Code (OESC);
- Ontario Fire Code (OFC);
- Ontario Ministry of Environment (MOE) site specific Environmental Project Reports (EPRs).
- Canadian Standards Association (CSA);
- Technical Standards and Safety Authority (TSSA) Ontario;
- National Fire Protection Association (NFPA) 101: Life Safety Code;
- NFPA 130: Standard for Fixed Guideway Transportation Systems;
- Sheet Metal and Air Conditioning Contractors' National Association (SMACNA);
- Model National Energy Code for Buildings (MNECB);
- American Society Heating, Refrigerating, Air-Conditioning Engineers (ASHRAE).

Obtain MOE Certificates of Authorization (CoA) for MSF operations.

Submit site plan issues and obtain concurrence of AHJ.

OBC governs where conflicts arise unless otherwise stated.

B6.3 Program Requirements

B6.3.1 MSF Operations

Secure MSF sites with perimeter fencing.

Provide access gates at main and secondary entrance/access locations.

Provide CCTV perimeter surveillance.

See Chapter A4 – Security.

Provide sufficient illumination for inspection and maintenance at roadways, employee parking areas, LRV storage tracks and aisles, outdoor work areas, main shops, support facilities, and other designated areas.

Provide a network of site roadways and access aisles to promote safe and efficient movement of employee, visitor, delivery, non-revenue LRVs and motor vehicles on site.

Minimize roadway grade crossings of LRV guideways.

Provide sufficient warning devices at road/track crossings, which may consist of signs, flashing lights with bells and, in extremely hazardous locations, flashing lights with bells and gates.

Provide employee parking separate from visitor parking.

Maintenance employee parking need not be separated from operations employee parking.

Provide MSFs with necessary site environmental protection such as wastewater treatment, including oil/water separation, hazardous material storage, air pollution control, and noise mitigation.

Provide fire protection systems meeting the requirements and regulations of AHJ.

MSF fire suppression towers are not allowed.

Minimize future expansion impact to on-going MSF operations/maintenance with appropriate site design.

Provide an MSF Control Room to supervise/view MSF arrival, departure, and storage tracks as well as control/monitor LRV movement and MSF operations.

See Chapter A5 – Operations.

Provide embedded and properly drained MSF storage tracks to facilitate minor maintenance and service operations such as daily inspection, cleaning, minor unscheduled repairs, and snow removal.

Provide dedicated MSF TPSs supplying both AC facility power and DC traction power.

MSF TPSs may also supply power to adjacent LRT Main Line sections.

Provide MSF sites with storm water management systems per AHJ requirements.

Provide site-specific MSF perimeter landscaping and "clear zones."

See Chapter A3 – Safety and Chapter A4 – Security.

B6.3.2 MSF Layout

Provide MSF track work for LRV consists of 1, 2, and 3 cars.

Provide MSF track layouts compatible with projected ultimate design year fleet size including spares.

Assume +15% LRV spares ratio to determine storage and operations requirements.

See Chapter A2 – Light Rail Vehicles.

At-grade level storage tracks are preferred.

Bowl storage track grades may be used consistent with track work requirements with an analysis of bowl versus at-grade level track work benefits subject to MX LRT review and acceptance.

See Chapter B2 – Track Work.

Provide designated track for storage of shop-bound LRVs for MSFs that include shop facilities.

MSF LRV consist changing capability must include track work to allow LRVs to turn and re-orient cabs facing the opposite direction.

When scheduled LRVs request clearance, MSF Controllers must be able to clear LRVs for departure in time consistent with the System Operating Concept.

Provide Transition Zone/Departure Test Areas for single and multiple unit LRV consists assigned to specific tracks prior to entry onto LRT Main Lines thus allowing LRVs to return to MSF storage areas through signal system and track work coordinated design in case of departure test failure.

Transition Zone/Departure Test Area length: approximately LRV length plus 20 m to allow for limited back and forth movement.

Provide double-ended MSF track work configuration wherever possible to promote LRV single direction dispatch and storage circulation flow.

Provide two separate MSF entrance/exit points minimum to LRT Main Line track.

Provide redundant LRV Pull-In/Pull-Out routes wherever possible.

Configure MSF track work to preclude single point failures from crippling MSF operations.

MSF Curve Radius = 25 m absolute minimum but configure track work throughout MSFs to maximize curve radii wherever possible.

Inbound LRVs move to a designated storage track if an LRV is in good working order or to a designated staging track if an LRV requires some type of maintenance.

Provide designated LRV storage areas with suitable permanent static signage.

Provide MSFs with designated LRV access walkways throughout.

Provide dedicated protected MSF test track 250 m minimum long on level, tangent track without turnouts accommodating bi-directional operations for post maintenance testing, brake performance rate tests, and Automated Train Control tests of 3-LRV consists.

Test track separate from other MSF track work is preferred.

Minimize grade changes for repair facilities throughout MSFs particularly on shop repair bay approach tracks where 0% gradient is preferred including:

- Storage and shop bypass track work;
- Multiple leads to logical groups of storage tracks;
- Direct track routes for common MSF LRV service and maintenance movement;
- Shop staging and lay-up tracks; and
- Maintenance-of-way equipment storage tracks.

Also include a full MSF perimeter track wherever possible.

Minimize walking distances between LRV Operator facilities and MSF storage tracks.

Locate operator paths so as not to traverse maintenance and repair areas.

Locate maintenance and repair areas so as not to present opportunities for short cuts between LRV Operator facilities, storage tracks, and employee parking lots.

Section MSF traction power to minimize disruption to MSF operations in case of power outage or maintenance shut-down.

Provide MSF storage tracks with traction power disconnect switches.

Provide CCTV coverage at each switch or groups of switches allowing MSF Controllers to observe switch/interlocking entrances and areas from MSF control consoles prior to operating switches.

Provide MSF with MOW areas including a storage and service building for MOW vehicles and equipment.

See Section B6.3.41.

B6.3.3 LRV Dispatch

MSF LRV movements normally occur only upon MSF Controller radio direction to LRV Operator.

This may require dedicated radio channels.

See Chapter C2 – Communications and Control.

Peak hour LRV dispatches and consist changes takes priority over other MSF operations.

Normal operations require LRV dispatch routes as well as LRV routes to support shop circulation, car wash/undercar cleaning, and other miscellaneous MSF operations and activities.

B6.3.4 LRV Reception

Provide direct access from LRT Main Lines to LRV storage track daily service, car wash, maintenance, and inspection area circulation routes.

Conduct MSF operations between storage areas and shops to avoid disruption to LRV reception/dispatch and LRT revenue service.

MSF Controllers direct arriving LRVs to storage or service locations such as car wash, interior cleaning, etc.

B6.3.5 LRV Storage

Provide LRV storage tracks in lengths that are multiples of maximum LRV revenue service consists.

Provide for LRV movement to and from storage so as not to require reversing and that minimizes other LRV movement conflicts.

Connect storage tracks to ladder tracks at each end and avoid stub-end storage tracks wherever possible.

Use of stub-end storage tracks where necessary subject to MX LRT review and acceptance.

An MSF single storage space length equals coupler to coupler lengths plus 1.0 m minimum clearance between following uncoupled LRVs.

See Chapter B1 – Alignment, Clearances and Rights-of-Way.

Provide clear Emergency Services routes between each group of five storage tracks.

Keep Overhead Contact System (OCS) wires clear of Emergency Services routes.

Morning peak incoming LRVs are normally routed to storage to facilitate LRV dispatch in afternoon base to peak periods or may be routed to service/repair as circumstances warrant.

B6.3.6 LRV Shop Circulation

Not every MSF may require repair facilities.

Where provided, shop and support facility operations must not adversely affect normal LRV dispatch and reception operations necessary to maintain proper headways nor any other MSF support facility operations.

Provide operating circulation routes for various functional and support area requirements including:

- Shop track centres 7.6 m minimum with bi-directional rail access to shop areas;
- Shop bays of appropriate length to support LRV maximum consist lengths;
- Access to preventive and corrective maintenance, heavy repair, wheel truing, and undercar cleaning areas with minimum reverse movements;
- Direct access to daily service sanding and car wash areas;
- Direct access from daily service sanding and car wash areas to storage areas;
- Direct access between shop lay-up storage and parts storage areas;
- Lead track storage capacity at both ends of service/sanding, Preventive/Corrective Maintenance and Heavy Repair Areas so as not to block major MSF routes or run-around tracks;
- Both ends of car wash with minimum clear lead distance equal to maximum LRV consist lengths;
- Access to shop and storage tracks for non-revenue equipment;
- Diesel or gasoline powered non-revenue equipment not allowed to operate or emit exhaust in MSF buildings or enclosed areas;
- Fixed facilities configured to allow forklift access throughout shop areas;
- Shop tracks spaced to allow forklifts to travel between adjacent tracks;
- Perpendicular forklift access to LRVs not required;
- Main shop aisles wide enough to allow scissor lift or sky lift access.

Preventive/Corrective Maintenance

Revenue service LRVs receive maintenance service upon return to MSFs providing service.

Approximately 5% of an LRV fleet is inspected daily during scheduled 1, 2, 6, or 12 month inspection cycles.

Additional LRVs may enter shops daily for unscheduled corrective repairs.

Heavy Repair and Wheel Truing

Heavy repair and wheel truing takes place on other designated shop tracks and facilities.

Heavy repair and wheel truing track includes run-through track adjacent to back-of-shop areas.

Wheel truing areas also include integrated body hoists for LRV shimming.

Automated Train Control Test Track

Provide designated Automated Train Control test tracks approximately 225 m to 250 m long to achieve 30 km/h sustained LRV speeds for testing Automated Train Operation functions with signal systems.

B6.3.7 MSF Security

Provide appropriate door locking, card swipe, or other equivalent measures to secure MSF functional areas such as training, maintenance, transportation, and administration offices without MSF operating constraints.

See Chapter A4 – Security and Chapter C2 – Communications and Control.

B6.3.8 MSF Fire Protection

Provide MSFs with fire hydrants throughout.

See Chapter A3 – Safety.

B6.3.9 Electric Power/Traction Power

Provide MSFs with dedicated on site TPSs to supply MSF facilities electric power and LRV traction power.

Provide MSF OCSs power with one or more substation breakers.

Provide manually operated "No Load" bolted pressure switches to section single tracks or groups of tracks.

Provide traction power emergency cut-offs with emergency telephones throughout MSF shop areas.

See Chapter C1 – Traction Power.

B6.3.10 Signals/Switches

Provide MSFs with powered switches throughout unless unique circumstances apply, e.g., low switch use or high pedestrian traffic areas.

Methods to operate and control powered MSF switches may include:

- MSF central control;
- Wayside control panels strategically placed in powered MSF switch control groups; or
- LRV control using on-board data radio.

Only one powered switch operation and control method is active at any one time.

Powered switch control may comprise each individual switch along a route or multiple switches via setting of routes.

Powered switch protection/interlockings prevent unsafe/conflicting routings within designated parameters.

In any case, direct view of a powered switch must be established before a decision is made to move it, e.g., MSF central control views the powered switch directly or via CCTV.

Position wayside control panels to allow direct view of powered switches.

LRV on-board powered switch control applies only to switches viewed from LRV Operator cabs.

Provide double pointed powered switches.

Provide audible and visual warnings to those in the area prior to operating powered switch points.

See Chapter B1 – Alignment, Clearances, Rights-of-Way.

See Chapter B2 – Track Work for other powered switch requirements.

B6.4 Maintenance Facilities

Every LRT line includes at least one Routine Maintenance MSF and one Heavy Repair MSF.

MSF ground floor maintenance areas include:

- Preventive Maintenance;
- Corrective Maintenance;
- Car Wash;
- Interior Cleaning;
- Daily Inspection;
- Truck Storage;

- Battery Rooms;
- Wheel Truing;
- Undercar Cleaning;
- Parts Cleaning;
- Tool and Storage Areas;
- LRV Body Repair;
- Mechanical/Electrical Rooms;
- Minor Maintenance;
- Sand Fill;
- Parts Cleaning;
- Parts Storage and Offices;
- LRV Maintenance Offices;
- Transportation Offices;
- First Aid; and
- Heavy Repair – only at some MSFs/locations – as follows:
  - Machine Shop;
  - Truck and Wheel Shop;
  - Wheel and Axle Shop;
  - Welding Shop;
  - Sheet Metal and Carpentry Shop;
  - Traction Motor Repair;
  - Major Body Overhaul;
  - Pneumatic Hydraulics Shop; and
  - LRV Painting/Paint Prep Areas.

MSF first or second floor areas include:

- Parts Storage;
- Heating, Ventilating, Air Conditioning (HVAC) Repair;
- Electronics Repair;
- Employee Training;
- LRV Cab Simulator;
- Component Mock-Up Rooms;
- Employee Wash Rooms;
- Employee Lockers;
- Employee Showers;

- Employee Lunchrooms;
- Conference Rooms;
- Storage Areas;
- Visitor Areas;
- Passenger and Freight Elevator Rooms.

B6.4.1 Preventive Maintenance Areas

Preventive maintenance includes routinely schedule tasks, i.e., lubrication, filter replacing, electric systems and components inspection, etc.

Preventive Maintenance Programs include routine tasks scheduled on a 30, 60, 180 day or annual basis.

Locate Preventive Maintenance Areas (PMAs), among the most frequently used, central to MSF shops.

Provide PMA LRV work positions on traction powered thru-tracks.

Provide PMA access platforms and overhead cranes for access to LRV roof mounted equipment.

Do not provide PMA floor pits with lifts or turntables.

Connect PMA track directly to MSF circulation tracks.

See Section B6.4.5 for further information on floor pits.

B6.4.2 Corrective Maintenance Areas

Corrective Maintenance includes trouble shooting, failed equipment repair, unit exchange, and testing.

Corrective Maintenance Areas (CMAs) are also frequently located and used on traction powered thru-tracks.

Provide CMAs with a car lift for at least one LRV spot.

Provide CMA manual turntables and associated embedded track, one at an LRV spot and another between LRV spots, for moving trucks to truck repair or storage areas.

Equip each pit with portable lifts to remove and replace undercar equipment.

For removal of undercar equipment a fork lift or overhead crane raises the equipment from the portable lift to rail level and pushes it along the pit to a location for further handling.

Replacement of undercar equipment reverses the procedure.

Provide access to LRV roof mounted equipment via CMA access platforms and overhead cranes.

CMA track connects directly to MSF circulation tracks.

B6.4.3 Wheel Truing Areas

Provide Wheel Truing Areas (WTAs) with in-floor pit-mounted tandem wheel truing machines that true all wheels on a truck simultaneously whether the truck is on or off an LRV.

Provide two assigned LRV wheel truing spots for proper positioning of LRVs over wheel truing machines and a follow-on spot equipped with LRV body hoist for installing truck shims.

Provide a chip collection system with floor level chip dumpster.

Locate the chip dumpster outdoors wherever possible.

OCSs along the track may facilitate LRV movement in and out of WTAs.

WTA track connects directly to MSF circulation tracks.

B6.4.4 Heavy Repair Areas

MSFs may not use Heavy Repair Areas (HRAs) frequently in initial LRT system operating stages but will need them more often for reactive maintenance such as collision repair or warranty work in later stages.

As LRV fleets age HRA primary focus shifts to major overhauls, modifications, and heavy corrective repairs.

Provide HRAs with equipment such as LRV hoists and LRV body stands to remove undercar components.

Provide HRAs with manual turntables and associated embedded track, one at an LRV spot and another between LRV spots, for moving trucks to truck repair or storage areas.

HRA track connects directly to MSF circulation tracks.

B6.4.5 Floor Pits

Several methods may be used to remove LRV undercar equipment.

Provide floor pits for convenient access to undercar equipment and trucks as follows:

PMA, CMA: 1800 mm full-depth between running rails; 1000 mm partial depth outside running rails.

WTA: Inspection pit inbound side of wheel truing machine; 1800 mm full-depth mounted on steel pedestals outside of and between running rails.

Undercar Cleaning: 1800 mm full-depth mounted on steel pedestals outside of and between running rails.

LRV Body Repair: 1800 mm full-depth between running rails only; no floor pits outside running rails.

Provide floor pit lighting and equipment for undercar inspection/work including but not limited to:

- Ramps for Forklift Access;
- Scissor Lifts;
- Service Fluid Dispensing Reels;
- Access Stairs;
- 120 V AC Ground Outlets;
- Welding System 600 V Three-Phase Outlets;
- LRV Equipment Testing or LRV Movement Stinger System 750 V DC Outlets;
- Compressed Air Outlets;
- Distilled Water Outlets;
- Hot and Cold Water Outlets;
- Cleaning Water and Floor Drains; and
- Material Lifts.

B6.4.6 LRV Roof Access

Provide PMA, CMA, HRA, daily service, and undercar cleaning areas with LRV roof access platforms for safe and convenient access to LRV roof mounted equipment.

Provide LRV roof access platforms with fall protection and access gates requiring deliberate action to operate interlocked to disconnect OCS when open.

Provide for roof top equipment removal to handle any heaviest single LRV component.

Include access to air, water, vacuum, and electric power outlets.

B6.4.7 Undercar Cleaning

Provide fully enclosed undercar cleaning areas with special ventilation, dust collection, and separation equipment for removal of mud, debris, and dust from traction motors and other undercar components.

B6.4.8 Materials Movement

Provide fork lift access to move materials throughout MSFs with sufficient space between tracks to remove LRV equipment and components.

Provide 5 m to 6 m wide aisles at both ends and down the centre of shop areas.

Provide 3,000 kg overhead bridge cranes, individual monorail cranes, and/or jib cranes for to move heavy or bulky materials.

Provide 5,000 kg overhead beam cranes in Truck, Wheel, Axle, and Machine Shops.

Crane capacities above are for preliminary design only subject to final design MX LRT review and acceptance.

Provide traction power interlocking to deactivate OCS when cranes in the area are energized.

Provide portable carts to move smaller items.

B6.4.9 Daily Service Areas

Daily service areas offer only brief visual inspections and minor adjustments during peak periods.

Daily service areas may also provide minor repair work in off-peak periods.

Provide daily service areas with two separate lanes able to handle:

- Longest revenue service LRV consists;
- Interior cleaning, sand fill, and daily inspection lanes; and
- Exterior car washing lanes.

Locate daily service areas along maintenance shop outer walls or, MSF operations and geometry permitting, in buildings separate from maintenance shops.

Provide daily service areas with:

- Pneumatic sand fill hoses along both sides of sand fill bays;
- Access platforms to LRV roof mounted equipment; and
- Employee wash rooms.

Provide OCS along full length of daily service area tracks with grounded interlocking disconnect switches and alarms in case of accidental OCS power.

B6.4.10 Car Wash Areas

Provide automated end-to-end LRV car body and undercarriage wash facilities with air blowers for surface water removal before exiting.

LRVs move through car wash facilities using “wash speed” function.

Do not use rabbits or other LRV car progression systems.

Provide air curtains and/or unit heaters to retain car wash heat in cold weather.

Provide folding doors for security when car wash facilities are not in use.

Use of security doors during peak periods is not recommended due to car wash traffic volume.

Provide OCS along full length of car wash tracks with grounded interlocking disconnect switches and alarms in case of accidental OCS power on, sectioned to remove power to interior cleaning areas without affecting exterior wash areas.

B6.4.11 Major Collision Repair

Provide one Major Collision Repair spot allowing separation of LRV consists into individual cars with floor pit, overhead crane, and space for jigs to replace body panels.

Provide 600 V welding outlets.

Do not provide OCS in Major Collision Repair areas.

B6.4.12 LRV Painting Areas

Provide fully enclosed LRV painting areas with special ventilation equipment, fire separation, compressed air outlets, and explosion-proof light and electric fixtures.

Provide MSFs with HRA one LRV paint prep booth and one LRV paint booth.

Provide MSFs without HRA one LRV paint prep area and one LRV paint booth or, where space is available, one LRV paint prep booth and one LRV paint booth.

Provide LRV painting areas with automatic scaffolding operating on rails along the sides of each track.

Provide LRV paint prep areas with standard movable scaffolding.

Provide LRV paint booths per CEPA, OHSA, NFPA and AHJ requirements.

Provide MSFs with HRA LRV painting areas with increased ventilation, dust collection, and breathing air distribution/dust removal systems.

Provide MSFs without HRAs LRV paint booths with portable ventilation equipment/breathing air distribution systems.

MSFs without HRA LRV painting areas do not require increased ventilation, dust collection, breathing air distribution/dust removal systems.

Do not provide OCS in LRV painting areas.

B6.4.13 Support Shops

Depending on level of repair required, HRAs may include support shop areas as follows:

- Gear Unit Cleaning;
- Pantograph Repair;
- Air Conditioning Repair;
- Sanding Equipment Repair;
- Draft Gear and Coupler Repair;
- Evaporator Repair; and
- General Machining Work.

Special equipment in these areas may include:

- Gear Unit Overhaul Stands and/or Test Racks;
- Pantograph Racks;
- Compressor Test Stands;

- Parts Cleaning Tanks;
- Arbor Presses;
- Hydraulic Presses;
- Pedestal Grinders;
- Lathes;
- Portable Welding Equipment;
- Band Saws;
- Heat Treating Furnaces;
- Drill Presses;
- Pipe Threaders and Stands;
- Pipe Bending Machines;
- Sanders;
- Milling Machines; and
- Work Benches.

B6.4.14 Electric Shops

Electric Shop repair work includes:

- Traction motor repair;
- Auxiliary motor repair including fan and door motors, motor alternators and generators, etc.;
- Miscellaneous electric repairs including jumper cables, pantograph wire, wiring harnesses, etc.;
- Dynamic brake/resistor grid repair; and
- Track brake repair.

B6.4.15 Battery Rooms

Provide Battery Rooms for battery storage and service with special ventilation and fire protection as well as emergency showers and eye wash stations due to the presence of hydrogen gas and hazardous chemicals.

Locate Battery Rooms along exterior walls to best address special ventilation requirements.

Provide Battery Room floors with secondary spill containment.

Provide Battery Room special equipment including:

- Battery Chargers;
- Electrolyte Fill Systems;
- Battery Charging Stands;
- ABC Rated Fire Extinguishers;
- Emergency Showers; and
- Eye Wash Stands.

B6.4.16 Sheet Metal and Carpentry Shops

Provide Sheet Metal and Carpentry Shops for repair work on:

- LRV interiors including ceiling panels, wainscoting, flooring, seating, windows, interior fixtures, etc.;
- LRV exteriors including exterior panels, articulated sections, etc.;
- Mechanical portions of couplers and draft gears, etc.;
- Miscellaneous LRV components, e.g., windshield wipers, piping, conduit, etc.; and
- LRV structural elements, etc.

Sheet Metal and Carpentry Shop special equipment includes:

- Shears;
- Power Brakes;
- Spot Welders;
- Power Rolls;
- Punch Presses;
- Pedestal Drill Presses;
- Band Saws;
- Inch Radial Arm Saws;
- Bench Mounted Belt/Disc Sanders;
- Planers; and
- Wood Lathes.

Provide special venting for welding areas to control airborne particles and fumes.

Locate welding areas along exterior walls wherever possible.

B6.4.17 Truck and Wheel Shops

Provide Truck and Wheel Shops for cleaning and repair of LRV trucks, wheels, axles, and suspension systems.

Work performed in Truck and Wheel Shops includes:

- Disassembly of motor wheel sets;
- Truck cleaning and overhaul;
- Suspension system maintenance; and
- Truck testing.

Truck and Wheel Shop equipment and special ventilation includes:

- Truck assembly stands with lift tables;
- Wheel presses;
- Truck steam cleaning facilities with track connecting to turntables.

Provide embedded track extending to truck cleaning equipment in rooms enclosed by exterior walls.

Provide spare truck and wheel storage space.

Major equipment for mounting wheel hubs on axles and bearing repair is not required.

B6.4.18 Tool and Material Storage Rooms

Provide secured general purpose Tool and Materials Storage Rooms for portable diagnostic test equipment, lubricating pumps, and other specialized hand tools with easy access to other LRV repair and support areas, each with a small office for inventory and sign out records.

B6.4.19 Parts Storage Areas

Provide enclosed Parts Storage Areas with sufficient space for spare glazing element storage racks.

Locate main Parts Storage Areas in a shop corner adjacent to loading areas.

Provide freight elevators for Parts Storage Areas on two floors, with ground level primarily for heavy equipment and high volume expendable materials and upper level for lighter less frequently used parts.

Depending on scope of MSF maintenance, provide ground floor loading areas equipped with one or more hydraulic loading docks as well as a Records Office and QA/QC laboratory area.

Provide forklift access to ground level Parts Storage Areas as well as shop and outdoor delivery areas.

Provide a Supervisor Office and separate Clerical Office including dedicated CCTV door surveillance for enclosed high value Parts Storage Areas.

Locate high value Parts Storage Areas visible from the Supervisor Office.

B6.4.20 Large Component Storage Areas

Provide mezzanine level Large Component Storage Areas if required adjacent to PMA/CMA track for components including but not limited to:

- Pantograph Systems;
- Resistor Grids;
- Convertor Boxes; and
- HVAC Equipment.

B6.4.21 Truck Storage

Provide spare/defective truck storage partial track connected to adjacent hoisting track with turntables.

B6.4.22 Pneumatic/Hydraulic Shops

Provide Pneumatic/Hydraulic Shops in enclosed areas if required to support troubleshooting, minor repair, and testing of pneumatic/hydraulic components such as brake control valves, cylinders and hoses.

Limit repairs to cleaning, inspection, evaluation, disassembly, and functional testing.

B6.4.23 Administration Offices

Provide LRV maintenance and parts management Administration Offices including:

- Visitor reception areas;
- General/clerical offices;
- Supervisory/management offices;
- Kitchens/coffee stations;
- Janitor rooms;
- Wash rooms;
- Medical rooms with stretcher space; and
- Training/small conference rooms.

Provide Transportation Administration Offices including:

- Storage for stationary/records/uniforms;
- Supervisory/management offices;
- General offices/reporting wickets;
- LRV Operator waiting areas;
- Separate kitchens/coffee stations for general office and LRV Operator waiting areas;
- LRV Operator signup areas;
- LRV Operator rest/recreation areas;
- Janitor rooms;
- Wash rooms in both general office and LRV Operator waiting areas;
- Locker rooms in both general office and LRV Operator waiting areas; and
- Training/small conference rooms.

B6.4.24 Employee Locker and Wash Rooms

Provide LRV maintenance and transportation areas with separate male and female Employee Locker and Wash Rooms including showers, first aid supplies, etc., sized for the number of employees in the busiest MSF shift plus changeover periods.

B6.4.25 Employee Lunch Rooms

Provide combined use Employee Lunch Rooms with kitchen facilities and vending machines.

B6.4.26 Employee Training Facilities

Provide enclosed and separately secured computer-equipped Employee Training Facilities with instructor prep rooms, storage areas, and waiting areas adjacent to LRV Cab Simulator Rooms, if required, equipment mock-up rooms and conference rooms.

B6.4.27 Shop Utilities

Heating, Ventilating, Air Conditioning

Provide energy efficient, practical, economical HVAC systems with special ventilation as required in areas such as Battery Rooms, Carpentry and Sheet Metal Shops, Welding Shops, and LRV painting/cleaning areas.

Electric Power

Provide ample electric power capacity to meet MSF building and equipment requirements.

Provide Uninterruptable Power Supply backup power for critical loads.

See Chapter C3 – Facilities Electric Systems.

Traction Power

Provide traction power grounding and sectioning for each LRV repair position.

Auxiliary Power

Provide PMA, CMA and component change-out bays with auxiliary power for LRV onboard systems other than traction power.

High Intensity Lighting

Provide LRV and shop support areas with high intensity lighting, 550 Lux minimum illumination standard.

Provide offices and work areas requiring higher levels of illumination with fluorescent lighting.

Fire Detection/Alarm/Sprinkler Systems

Provide fire detection/alarm/sprinkler systems throughout MSF enclosed areas including manual fire alarm pull boxes with direct connections to OCC.

Provide portable fire extinguishers strategically placed throughout.

See Chapter A3 – Safety.

Mechanical Support Systems

Provide PMA, CMA and HRA with compressed air systems.

Provide LRV undercar cleaning and painting areas with breathing air systems.

Shop Floor Drains

Provide shop floor drains throughout connected to gravity drainage systems with oil/water separators prior to effluent discharge into municipal sewer systems.

Communications

Provide telephone and intercom paging systems throughout maintenance, administration, and TPS areas.

See Chapter C2 – Communications and Control.

B6.4.28 Maintenance of Way Areas

Provide LRT Maintenance of Way (MOW) areas including storage/service buildings with separate rooms for work vehicles and equipment related to:

- Track;
- Structures;
- Electric Systems;
- Overhead Contact Systems;
- Signal Systems; and
- Communications Systems.

Provide MOW employee facilities including lunch rooms, locker rooms, and wash rooms.

Provide MOW track with overhead crane for freight railway flat-bed railcar loading/unloading of LRVs on through-track where available and appropriate or stub track subject to MX LRT review and acceptance.

Provide MOW loop, wye or turntable turning facilities to reorient flat-bed cars/overhead cranes as required.

Propose alternative turning facilities/locations subject to MX LRT review and acceptance.

Provide MOW buildings with storage garages for diesel powered Maintenance Recovery Vehicles to move/recover disabled LRVs in MSFs or Main Lines.

Maintenance Recovery Vehicles may be either steel-wheel or “hi-rail” per MX LRT review and acceptance.

Provide fuelling truck areas for MOW mobile fuelling of non-revenue equipment.

Do not provide built-in gasoline/diesel MOW fuelling facilities.

Provide MOW buildings with railcar service areas and floor pits between rails.

See Section B6.4.38 Outside Storage and Section B6.4.40 Room Requirements Table B6-1.

B6.4.29 Roadway Access and Parking Areas

Provide secure access control for MSF main entrances.

Restrict access to roadways along face of MSF buildings to emergency and shop vehicles only.

Provide Threat and Vulnerability Assessments to determine CCTV surveillance and perimeter intrusion/detection/access control requirements for employees and visitors.

Provide delivery and outdoor storage areas alongside shops designed to accommodate trucks up to HS-20.

Provide roadways for flatbed trucks to maneuver/deliver/load/unload LRVs onto MSF/MOW track.

See Chapter A4 – Security.

Provide entire MSF site perimeters complete with streetscaping and landscaping.

Address MSF site planning, development of built form, and site interface with surrounding neighborhoods per AHJ planning and urban design requirements.

Provide MSF employee and visitor parking per green guidelines and requirements of AHJ.

See Chapter 21 – Lighting for parking area lighting levels.

B6.4.30 Exterior Materials

Provide MSF exterior materials and finishes such as brick, concrete block, pre-cast concrete, and metal siding based on durability and appearance not only to minimize maintenance over the years but also for attractive appearance to surrounding areas.

Provide glazing of double or triple pane insulating glass.

Provide energy efficient Low-E glass where exposed to direct sun light.

Provide insulated roofs and exterior walls per relevant energy codes and requirements of AHJ.

Provide roof and exterior wall materials based on long-term durability, maintainability, and appearance.

Provide stainless steel, copper, or galvanized flashing.

Meet or exceed urban design and planning requirements of AHJ.

B6.4.31 Interior Materials

Provide MSF interior materials and finishes based on durability and appearance not only to minimize maintenance over the years but also for attractive and productive work environments.

Provide shop areas with industrial use finishes including but not limited to the following:

- Sealed concrete shop floors;
- Concrete or concrete block with wainscot 2.4 m minimum above-finish-floor shop walls;
- Glazed or burnish finish concrete block or other approved finish hallway walls;
- Metal stud with 16 mm gypsum-board office partition walls;
- Appropriate floor and ceiling office materials;
- Sound insulation between adjacent offices;
- Floor-to-ceiling ceramic tile floor and wall toilet/shower area finish materials; and
- Corrosion protection toilet/shower ceilings with no painted surfaces.

B6.4.32 Lighting

These criteria do not intend to limit use of new technology or prescribe outdated or inefficient technology.

Provide energy-efficient lighting systems and fixtures as well as traditional and state-of-the-art lighting technologies for economy and durability to achieve lighting per industry best practices and standards.

Minimum light levels include:

- Shop Areas: 550 LUX;
- Roof Access Platforms: 550 LUX;
- Floor Pits: 1100 LUX;
- Storage Areas: 300 LUX; and
- Office Areas: 300 LUX ambient plus additional task lighting.

Provide higher light levels per requirements of AHJ.

Provide lighting to meet specific task requirements.

Maximize natural light from windows/clerestories to reduce artificial light dependence in daylight hours.

Provide suitable floor pit illumination and floor pit side lights aimed upward for undercar work and cleaning.

B6.4.33 Corrosion Control and Safety Grounding

See Chapter C5 – Stray Current and Corrosion Control.

B6.4.34 Acoustics

Locate noise-generating equipment, e.g., pumps, air compressors, wheel truing machines, away from offices and other areas requiring quiet work environments.

Provide and locate HVAC mechanical units to minimize noise and vibration transmission.

Provide wall, ceiling, and floor insulation to further reduce noise transmission to other areas.

Provide perimeter acoustic control per site context and potential neighborhood noise intrusion.

Provide acoustic isolation wherever required.

B6.4.35 Mechanical and Plumbing Systems

Provide shop areas with gas-fired zoned heating systems in.

Consider zoned radiant heating systems subject to MX LRT review and acceptance.

Provide floor pits with wall-mounted hot water radiant heat as well as exhaust air ducts.

Provide floor pits, access platforms, and other shop areas with compressed air at convenient intervals to operate pneumatic tools.

Provide shop building interiors with trench drains in floor pits, along LRV drip lines, and at exterior doors.

Provide environmental control systems for efficient and effective shop heating and cooling.

Provide accessible environmental control and elevator monitoring and control systems.

Provide offices and administration areas with forced-air HVAC zoned as appropriate for use and exposure to heating and cooling loads and demands.

Provide air conditioning for equipment generated heat loads in Signal and Communications Equipment Rooms, Shop Substations, Electronics Shops, Electric Equipment Rooms, and the like.

B6.4.36 Hazardous and/or Flammable Materials

Provide for hazardous shop material recovery/disposal per environmental codes and AHJ requirements.

Provide secure hazardous and/or flammable material storage areas enclosed with fire-rated floors, walls, and ceilings per codes and requirements of AHJ.

B6.4.37 Substations

Provide MSF electric power substations developed and coordinated with traction power needs to meet specific urban design and planning requirements of AHJ.

B6.4.38 Outside Storage

Scrap and Waste

Provide outdoor storage trash containers for normal refuse.

Provide metal containers for waste steel, copper, and other recyclable materials.

Provide refuse collection and recycling bins, dumpsters, etc., conveniently located to work areas.

Site limitations may require waste transfer from local collection points to central collection locations.

Provide separate recycling containers for specific materials such as metal, glass, cardboard, paper, etc.

Provide cardboard carton/trash compactors.

Compressed Gas

Provide outdoor storage secure cages for compressed gas tanks with full tanks separate from empty tanks.

Maintenance of Way

Provide outdoor storage areas for the following MOW equipment and structures:

- OCS poles and hardware;
- Signal equipment;
- Light poles;
- Rail;
- Ties;
- Special trackwork including switches, switch stands, frogs, etc.;
- Other track material including tie plates, spikes, joint bars, insulated joints, etc.;
- Ballast; and
- Wire reels.

Size MOW outdoor storage areas per MX LRT review and acceptance.

B6.4.39 Roof Systems

Provide ULC listed Class-A roof systems per maximum wind/snow load and requirements of AHJ.

B6.4.40 Room Requirements

Room sizes may exceed minimums indicated below.

Propose rooms smaller than minimum indicated below subject to MX LRT review and acceptance.

Heavy Repair facilities may not be required at every MSF.

See Table B6-1 MSF Rooms with Notes below:

TABLE B6-1 MSF ROOMS

Room Designation	Minimum m^2	Facility m^2
1st Floor – Maintenance Building		
Signal/Equipment Room	30	--
Multiuse Room	10	--
Emergency Generator Room	50	--
Building Lobby	50	--
First Aid	15	--
First Aid Waiting Area	--	25
Janitor Room	10	--
Passenger Elevator	10	--
Plant Maintenance & Storage	10	--
Plant Maintenance BACS	30	--
Fire Pump/Sprinkler Room	40	--
Incoming Water Room	15	--
Telephone Closet	--	10
IT Closet	--	10
Electric Room	10	--
Main Electric Room	120	--
High Voltage Electric Room	80	--
DC Distribution Room	70	--
Telecom Room	35	--
Compressor Room	40	--
Battery Storage	15	--
A/C Room	15	--
Bicycle Storage Room	--	35
Communications Room	55	--
Mechanical Storage Room	15	--
Maintenance Support	--	--
Uniform Service Lockers	--	30

Room Designation	Minimum m^2	Facility m^2
Clerk/General Office	60	--
Superintendent Office	15	--
Assistant Superintendent Office	10	--
Planner/Scheduler Office	10	--
Swing Office	--	20
Technology Support Office	--	10
MSF Control Room	35	--
Small Conference Room	20	--
Files/Archive/Records	20	--
Admin Men Wash Room	10	--
Admin Women Wash Room	10	--
Admin Unisex Wash Room	10	--
Work Assignment Area	20	--
Wash Up Area	15	--
PM Foreperson Office	--	30
CM Foreperson Office	20	--
Paint/Body and Service Office	--	20
Shop Women Wash Room	5	--
Shop Men Wash Room	5	--
Battery Shop	55	--
Vendor Storage	--	150
Vendor Office/Work Area	--	40
Small Component Cleaning	70	--
Lube Storage/Pump Room	50	--
Hazardous Waste Storage	25	--
Tool Crib	25	--
Equipment Storage	55	--
Tool Cart Storage	--	85
Engineering Support Room	50	--

Room Designation	Minimum m²	Facility m²
Water Reclaim Room	100	--
Cleaning Supplies Storage	20	--
Materials and Procurement	--	--
Flammables Room	10	--
Expensed Material Room	20	--
High Value Parts Storage	20	--
Loading Dock/Receiving Area	100	--
Storeroom including QA/QC Area	--	1,375
Quality Control Lab	20	--
Supervisors Office	10	--
Storeroom Office	50	--
Stores Records Room	25	--
Paint Storage	25	--
Elevator Parts	10	--
Transportation	--	--
Operator Sign Up Room	55	--
Clerical Area	80	--
Small Conference Room	20	--
Uniform Storage	10	--
Transportation Superintendent	15	--
Transportation Asst. Superintendent	10	--
Transportation Asst. Superintendent – 2nd Office	10	--
Admin Mens Wash Room	10	--
Admin Womens Wash Room	10	--
Operators Waiting Assembly Room	--	185
Recreation Room	--	120
Mens Wash Room/Showers	--	40
Womens Wash Room/Showers	--	40
Route Supervisors Area	--	50

Room Designation	Minimum m^2	Facility m^2
Route Supervisors Locker Room	--	15
Coffee Station	5	--
Archive Storage	40	--
2nd Floor – Maintenance Building		
Service Office	--	10
Telephone Closet	5	--
IT Closet	5	--
Janitor Closet	5	--
Radio Base Station	20	--
Boiler Room	--	30
General Use	--	--
Womens Wash Room	--	20
Mens Wash Room	--	20
Lunch Room	--	175
Large Conference Room	140	--
Small Conference Room	50	--
Special Constables Security Room	20	--
Health and Wellness Room	15	--
Meal Service	--	40
Patio	--	120
Maintenance	--	--
Maintenance Mens Locker Room	--	185
Mens Wash Room	35	--
Mens Shower	20	--
Womens Locker Room	--	30
Womens Wash Room	10	--
Womens Shower	10	--
Training	--	--
Small Classroom	75	--

Room Designation	Minimum m^2	Facility m^2
2nd Small Classroom	--	75
Computer Based Training	60	--
Chair Storage	--	10
Storage	--	20
Instructor's Prep Room	--	50
Lounge/Waiting	--	15
Mock-Up Room	--	170
Simulator Suite	--	130
MOW Building		
Department Use		
Total Electric Department	--	110
Overhead Contact Systems Department	--	155
Signals/Communications Department	--	65
Total Track and Structures Department	--	55
Maintenance Revenue Vehicles Garage	--	155
Work Car Garage with Overhead Crane	--	810
Base MOW Building		
Mechanical Room	--	30
Sprinkler Room	--	10
Janitor Closet	--	4
IT Closet	--	2
Telephone Closet	--	2
Electrical Room	--	20
Mechanical Closet	--	5
Electrical Closet	--	4
Shared Facilities		
Mens Locker Room	--	95
Mens Wash Room	--	20
Mens Shower	--	25

Room Designation	Minimum m^2	Facility m^2
Womens Locker/Wash Room/Shower	--	50
Lunch Room for 20 People	--	90

NOTES:

1. Submit rooms and facilities for MX LRT review and acceptance.
2. Facility dimensions indicative based on 100-LRV fleet.
3. Minimum areas do not depend on LRV fleet size.
4. Facility areas depend on LRV fleet size.
5. MOW buildings based on Satellite MOW Concept complementing other MOW facilities.
6. Where MOW areas not provided at other MSFs, larger MOW areas may be required.

B7 Urban Design

B7.1 General

Chapter B7 addresses essential design and siting principles for at-grade facilities, especially Stations, Stops, and ancillary structures and spaces such as plazas and boulevard streetscapes associated with Metrolinx (MX) Light Rail Transit (LRT) lines.

Chapter B7 provides urban design principles and guidelines for three basic areas:

- Section B7.2 – Underground Line At-Grade Facilities;
- Section B7.3 – Underground Stations and Facilities;
- Section B7.4 – At-Grade Stops and Facilities.

In addition to documents referenced in Chapter A1 – General, address Station and Stop surface elements including relevant Authorities Having Jurisdiction (AHJ) standards such as:

- Official Plans;
- Streetscape Manuals;
- Street Tree Guides and/or Standards;
- Street Furniture Programs;
- Green Standards;
- Accessibility Design Guidelines; and
- Related planning, urban design, landscape, architecture, built form, and transportation guidelines.

Urban design principles and guidelines help shape the built environment of LRT corridors and influence the work of other disciplines.

For example, minimizing vent structures effect on streetscapes and the urban environment around Station entrance buildings in turn affects architecture, mechanical engineering, fire protection, etc.

Provide surface facilities in close collaboration with every affected discipline as the most visible elements of LRT infrastructure focusing on the interaction between at-grade and below-grade elements.

Several alternative design strategies may be required to achieve optimum at-grade design such as combining entrances with ventilation and other support structures to minimize surface facility footprints.

B7.1.1 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

OBC governs where conflicts arise unless otherwise stated.

B7.2 Underground Line At-Grade Facilities

In addition to providing faster, more reliable transit, LRT projects:

- Create impetus for economic investment, real estate development, new land uses, increased density;
- Create public space opportunities;
- Reinvigorate and elevate LRT corridor profiles and the communities along their length;
- Increase mobility levels for people walking, bicycling, or moving through an LRT corridor.

Well-designed LRT projects that are safe, attractive, accessible, sustainable, and easy to use instill a sense of civic pride among LRT users, staff, and the general public, thus improving the perception of public transit and positioning it as a positive transport mode of choice.

Provide underground LRT line at-grade facilities based on the following six urban design principles:

Facilitate Access

The full range of LRT users includes the elderly and disabled, those in wheelchairs or other mobility devices, young children and their caregivers, those who speak languages other than English and French, LRT users with heavy/bulky baggage and bicycles, and those with other needs.

Support accessibility through design that supports intuitive wayfinding and identification of facilities.

Respond to and Integrate with Neighbourhoods

There will be similar Station types and a consistent, system-wide identity, but approach the design of each Station on a site-specific basis and not on a “one size fits all” basis.

Sensitively integrate at-grade LRT element locations, organization, and design into their surroundings, minimizing effect on existing uses and residents while enhancing access for LRT users.

Future Development Opportunities

Design and implementation of an LRT system is a significant investment with the potential to catalyze a whole range of new investments along its corridor.

Optimize Station location and related infrastructure design to facilitate new investment by protecting for intensification and redevelopment of surrounding areas over time.

Safe and Enjoyable LRT Experience

A safe and enjoyable LRT experience extends beyond riding the LRT.

Stations and Stops support an enjoyable LRT experience with facilities and spaces that are safe and comfortable to use by the full range of LRT users.

Enhance enjoyment through high quality design, integration of public art, and incorporation of a full range of user amenities.

Long-Term Sustainability

Provide Stations and Stops with features to reduce environmental effect and promote energy efficiency balanced with the need for long-term maintenance and efficient operations.

Provide high quality materials, planting, and finishes that require less maintenance.

Provide features that minimize water runoff or “heat island” roof impacts for long-term sustainability.

Local Sense of Place

Stations and Stops become significant public spaces and neighbourhood focal points of activity.

Station and Stop entrances, open spaces, and related infrastructure reinforce a unique sense of place while contributing to overall branding and positive image making of an LRT line.

Embed the urban design principles, process, and thinking Chapter B7 presents throughout the planning and design of LRT lines.

Though intended to apply primarily to at-grade Station and Stop elements, these principles also apply to a range of issues including organization of various Station levels, access points, systems, and the like.

B7.2.2 Station At-Grade Facilities

In order to properly frame urban design criteria this section provides information regarding at-grade Station elements that need optimum configuration including:

- Key physical contexts or resources in and around LRT corridors that are valuable not only to their neighbourhoods and cities but to the success of an LRT line;
- Station planning from the point of view of reducing effect on street-level urban environments;
- Station entrance building typologies;
- Opportunities for enhancement of streetscapes to be re-constructed as part of LRT construction.

Underground Station entrances are frequently the most noticeable elements to LRT users as well as the general public.

Each Station, however, will also have a range of functional elements, services, and mechanical requirements that inevitably influence street level elements in quantity, size, and location.

Each Station area may include a range of anticipated at-grade elements and associated facilities including:

- Main Entrance Plazas with landscaping features;
- Main Entrances;
- Secondary Entrances;
- Fire Fighter Access;
- Bus Facilities;
- Bicycle Facilities;
- Retail Facilities;
- Plazas;
- Kiss-n-Ride/Passenger Pick Up and Drop Off Areas;
- Taxi Stands;
- Traction Power Substations;
- Ventilation Shafts;
- Emergency Exit Buildings (EEBs);
- Off-Street Non-Revenue Vehicle Parking.

Each has its own unique set of functional requirements requiring careful consideration.

Station design determines how at-grade facilities fit within each Station area, the specific context of each Station area, and the long-term build-out potential of each Station area.

Spatial and functional requirements represent fundamental prerequisites informing decision making together with sensitivity and responsiveness to their unique context.

Station design begins with a review of existing conditions and, based on this understanding, determination of Station area long-term build-out potential.

Placement and orientation of Station at-grade facilities may then be used to test and support below-grade facility arrangements including concourse, mechanical, and electric system locations.

B7.2.3 Existing and Planned Physical Contexts

Key Destinations

Key destinations and institutions such as schools, recreation centres, or community organization offices represent significant activity generators along an LRT corridor and in many cases act as Station area social/cultural hubs of activity.

New LRT lines support ridership and at the same time enhance access to these community areas and uses.

Heritage Resources

Historic buildings and cultural heritage resources are recognized as local landmarks helping to reinforce the unique identity of places along an LRT corridor and reflecting important periods of growth and development.

Provide at-grade facilities respecting these heritage resources, preserving their settings, and enabling them to continue to contribute to the character of the LRT corridor.

Open Space

Open spaces are important neighbourhood amenities that make high density urban settings more attractive and livable.

At the same time, open spaces are significant activity generators, providing a location and backdrop for community services to attract LRT users.

Open spaces in and around LRT Stations play an important role in supporting LRT functions, enhancing connections between the Station, the neighbourhood, and adjacent uses.

At-grade facilities may enhance existing parks and open spaces while creating new open space opportunities.

Existing Built Context

LRT corridors may have a wide range of buildings that vary in size, age, use, and building type.

Provide underground LRT lines and related Station facilities at-grade to minimize adverse impacts on continuous street frontage as well as existing and future development.

Each unique Station must respond to the distinctive characteristics and issues of its Station area.

Planned Development

While the introduction of LRT lines encourages redevelopment, especially of vacant and under used parcels, take care that at-grade facilities do not “sterilize” these parcels or preclude future development.

Locate entrances and vent shafts to minimize their effect on adjacent property redevelopment potential.

Integrate at-grade facilities with existing and proposed new development.

B7.2.4 Station Area Types

New LRT line underground Station areas may be categorized as three types:

- Main Street Areas;
- Existing Nodes;
- Future Nodes.

These classifications identify each Station area long-term development potential.

They are key factors along with other technical considerations in Station and facility siting and design response not only to existing but also to future urban conditions.

Main Street Areas

Main Street Areas are generally characterized by two and three story mixed use buildings, with lower density residential forms, often detached housing, to the rear.

New underground LRT lines support the existing retail nature of Main Street Areas but smaller parcel sizes and proximity to stable lower-density neighbourhoods will likely limit redevelopment potential to primarily low-to-midrise infill development.

The predominance of smaller individual businesses and multiple land ownership patterns makes Main Street Areas particularly vulnerable to disruption.

New LRT facilities that create or exacerbate gaps in retail street frontage may have significant adverse effect on pedestrian and commercial activity.

The insertion of Station facilities within narrow Rights-of-Way has the potential of confining already limited pedestrian areas, blocking views to buildings, and restricting development rights of adjacent properties.

Existing Nodes

Existing Nodes are higher-density mixed-use Station areas.

New underground LRT lines in Existing Nodes may significantly enhance LRT access and service to an existing cluster of uses, strengthening these areas as destinations and supporting further intensification.

As primarily established areas, Existing Node urban development will be limited in most cases to a few sites or the redevelopment of existing uses on previously assembled parcels.

Given the relative built-out condition of Existing Nodes, at-grade LRT facilities need to be sensitively located in the existing environment, either integrated with adjacent buildings or fit into the streetscape/public realm to reinforce the pedestrian-oriented mixed-use nature of the Station area.

Future Nodes

Future Nodes are Stations and facilities at the intersection of several LRT lines where larger lot sizes and under used parcels create significant redevelopment potential over time.

Future Nodes may be Main Street Areas that have developed on adjacent property over time.

New LRT lines in Future Nodes and availability of larger development parcels will likely drive and support demand for mid-to-high-density mixed-use development in and around Station areas.

While the siting and design of Stations and facilities may be made easier by larger sites and under used parcels in the short term, take care that Station infrastructure does not adversely affected long-term potential of Future Nodes for higher-density mixed-use development.

B7.2.5 Below-Grade and At-Grade Facilities

Coordinating below-grade and at-grade facilities is essential to achieving optimum Station entrances.

Decisions made at either level significantly affect not only performance and cost, but also the effect of facilities on their surroundings and the viability of adjacent development.

A number of potential shifts may help in arriving at optimum Station design capable of balancing both below-grade and at-grade objectives.

Shifts to the program of below-grade facilities may be determined on a Station-by-Station basis and require considering a range of factors including environmental, technical, alignment, and development effects.

In some areas, utilities may complicate potential rearrangement of elements.

In other areas, additional costs of shifting elements may be prohibitive.

In most cases, advantages of short-term savings need to be weighed against effects on existing neighbourhoods and long-term benefits of protecting future development viability.

Shifting Station Box: At some Stations, small shifts in the Station box may be possible to reposition Station entrances or at-grade vent shafts.

Vent Shafts: Consolidation of vent shafts minimizes effects on existing or future development and enables integrating vent shafts in Station entrances or relocating them to the rear of a parcel or site.

Shifting Vent Shafts: Once consolidated, shifts both perpendicular and parallel to the box may assist in minimizing vent shaft effects at-grade, either concealed in or integrated with entrances.

Shifting Entrances: It may be possible to shift entrances from one side to another at concourse level.

Switching Main and Secondary Entrances: It may be possible to relocate Station entrances to more desirable locations by rearranging the concourse from one side of the Station box to the other.

B7.2.6 Station Entrances

Four general Station entrance types respond to existing and planned contexts in each Station area:

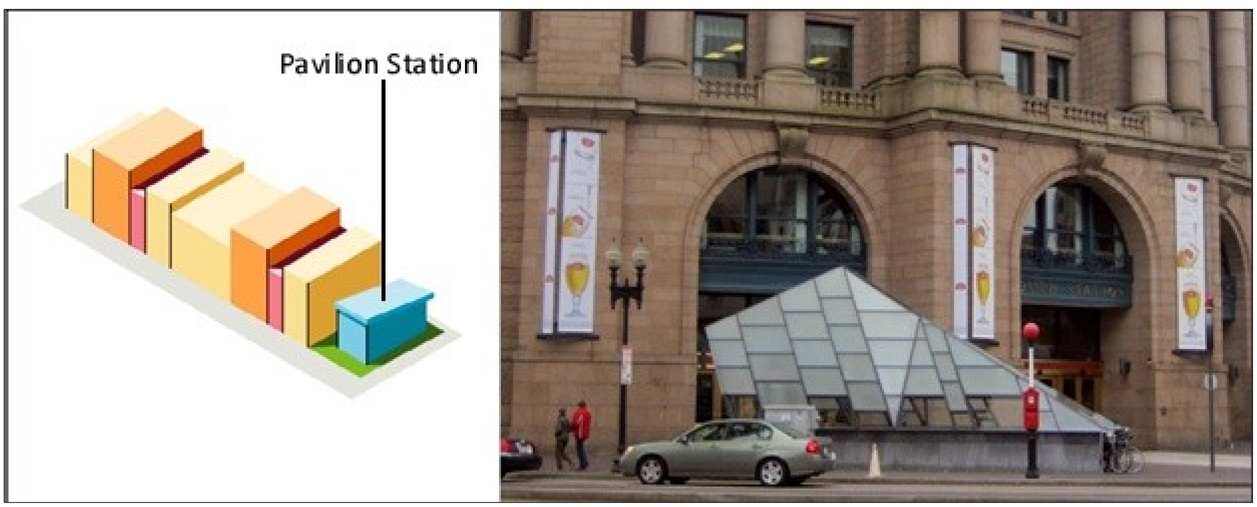
- Pavilion Entrances;
- Integrated Entrances;
- Wrapped Entrances;
- Context Entrances.

Each has its own unique sets of advantages and disadvantages that may apply more or less depending upon individual Station entrance locations and circumstances.

Pavilion Entrances

Pavilion Entrances are free-standing buildings designed to act as focal points along an LRT corridor.

FIGURE B7-1 EXAMPLE OF PAVILION ENTRANCE



Appropriateness

Pavilion Entrances are Station area landmarks on high profile sites anchoring block corners or key views as well as small corner sites with limited potential for integration with existing or future development and in existing or proposed parks and open spaces.

Advantages

Pavilion Entrances act as landmarks along LRT corridors.

Pavilion Entrances stand-alone design allows access from multiple points on several sides of an intersection or open space and facilitates development adjacent to the Station while minimizing Station disruption.

Pavilion Entrances allow greater potential to integrate sustainable features.

Disadvantages

Pavilion Entrances stand-alone nature make it more difficult to integrate or screen at-grade service rooms.

Pavilion Entrances need for space may require larger sites than Integrated or Wraparound Entrances.

Typology

Pavilion Entrances are iconic pavilions with frontage on three of four sides.

In existing open spaces, Pavilion Entrances act as transparent pavilions that sit lightly within a space and integrate with surrounding vegetation, plazas, or parks.

Identify Pavilion Entrances with freestanding or integrated exterior signage to assist with wayfinding.

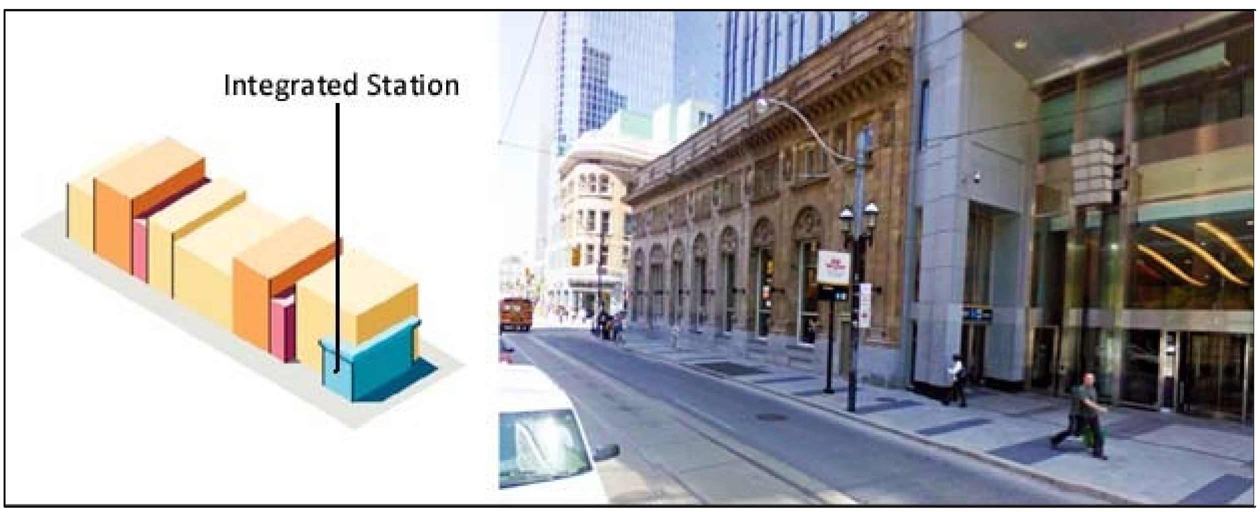
Locate service rooms and maintenance facilities at alternative entrances or below-grade where possible to minimize their effects on Pavilion Entrances.

Integrated Entrances

Integrated Entrances are incorporated in the base of a building.

Integrated Entrances occupy most of the street level in smaller buildings or serve as one of a number of ground floor element in larger buildings.

FIGURE B7-2 EXAMPLE OF AN INTEGRATED STATION



Appropriateness

Integrated Entrances may be used at nodes where existing development may make it difficult to use Pavilion Entrances:

- Where Integrated Entrances coincide with heritage structures to be preserved;
- Where current development applications offer potential Integrated Entrance opportunities;
- Where Integrated Entrances connect to underground pathway systems.

Advantages

Integrated Entrances:

- Help retain and adapt existing heritage structures;
- Provide LRT users with additional building services, amenities, and uses;
- Provide LRT users with connections to buildings, increasing development values and profiles;
- Offer potential for more generous at-grade indoor waiting areas for transferring passengers.

At-grade facilities such as garbage storage or service rooms may be integrated with associated buildings.

Disadvantages

Integrated Entrances:

- May add to Station and facility construction costs in existing or future development;
- May make it difficult to locate infrastructure such as vent shafts within buildings.

Private buildings require alternative LRT branding and wayfinding strategies.

Public access via private property may complicate access and security issues.

Typology

Integrated Entrances and associated at-grade Station elements read as integrated building elements.

Identify Integrated Entrances with freestanding or integrated exterior signage to assist with wayfinding.

Where possible, locate Integrating Entrances in building foyer spaces to provide transferring passengers amenities such as landscaping and street furniture and additional room in winter.

Wrapped Entrances

Wrapped Entrances are free-standing pavilions next to existing development or to be surrounded by future development.

FIGURE B7-3 EXAMPLE OF A WRAPPED STATION

Appropriateness

Wrapped Entrances are appropriate at nodes adjacent to existing development and on sites with future development potential where integration with future development may be limited or undetermined.

Wrapped Entrances are also appropriate on sites with current development applications adjacent to a Station entrance but for reasons such as timing or logistics the development cannot include an Integrated Entrance.

Advantages

Wrapped Entrances may facilitate building over or adjacent to a Station while minimizing Station disruption.

A clear front and back to Wrapped Entrances provides the opportunity to screen at-grade service rooms and facilities such as maintenance or mechanical rooms to the rear of the entrance.

Disadvantages

If implemented prior to adjacent development, Wrapped Entrances may result in rear or side blank walls.

Adjacent development architecture may clash with Wrapped Entrances.

Typology

Wrapped Entrances with clean, simple features lend themselves to integration with adjacent development.

Identify Wrapped Entrances with freestanding or integrated exterior signage to assist with wayfinding.

Preserve adequate primary entrance waiting room for transferring passengers in winter where possible.

Plan for the possibility that the Station entrance will be architecturally altered when future development adjacent to the Station occurs.

Design and site Station vent shafts in Wrapped Entrances to protect for the integration of new development over time.

Context Entrances

Context Entrances reinforce existing urban fabric by filling the front of a Station parcel to abut with adjacent development and create a continuous street wall.

FIGURE B7-4 EXAMPLE OF A CONTEXT STATION

Appropriateness

Context Entrances reinforce a consistent setback and active street frontage on Main Street midblock sites and help fill gaps between existing buildings on midblock sites in Existing Nodes.

Advantages

Context Entrances:

- Fill gaps in the streetscape and promote continuity of active uses along Main Streets;
- Provide a clear front and back to Station entrances beneficial in siting at-grade service areas such as maintenance and mechanical rooms or vent shafts;
- “Infill” design facilitates adjacent development while minimizing Station disruption.

Disadvantages

Context Entrances may restrict rear or side access.

Typology

Context Entrances:

- Reinforce existing street walls through setbacks and building heights consistent with adjacent development In Main Street areas;
- Provide opportunities for additional setbacks, extra sidewalk room, or small plazas on corner lots.

Identify Context Entrances with freestanding or integrated exterior signage to assist with wayfinding.

B7.2.7 Public Realm Improvement Zones

While long-term goals to create pedestrian-friendly environments across the entire length of LRT corridors often apply, Metrolinx RT short-term public realm improvements focus more upon each Station and Stop construction influence area as well as LRT related reconstruction of public Rights-of-Way.

Construction and Mobility Enhancement Zones

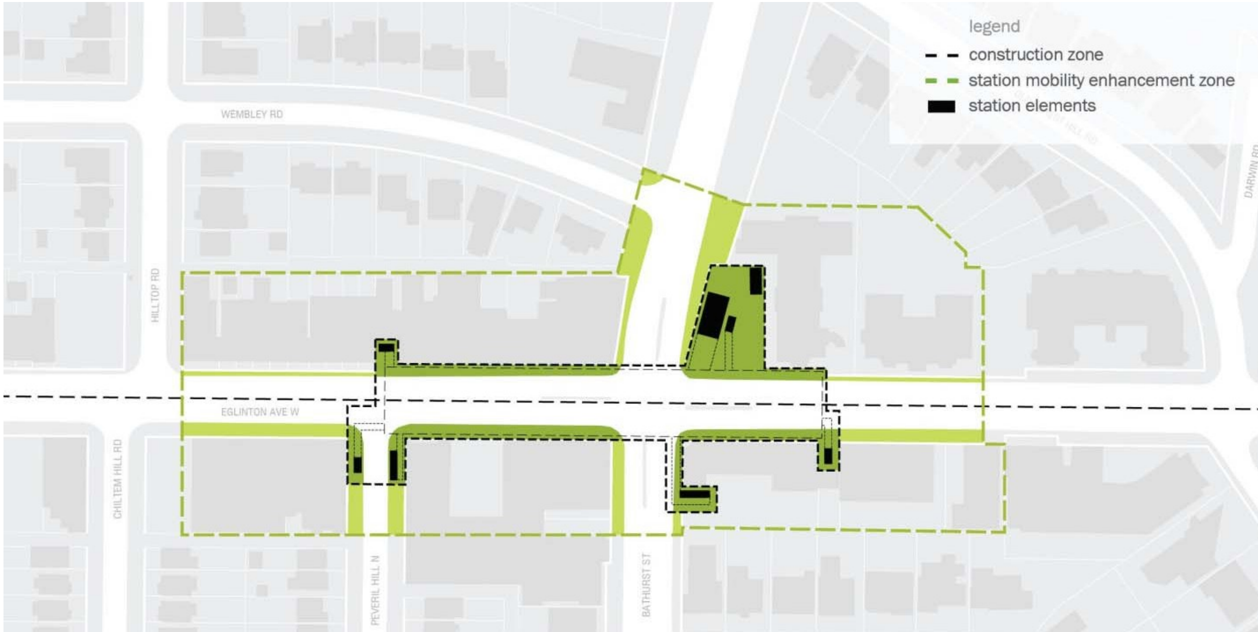
Rebuilding public Rights-of-Way resulting from LRT construction creates a significant opportunity to implement a range of streetscape improvements aimed at integrating LRT works with enhanced LRT access.

Urban design elements such as special paving, planting, wayfinding, and street furniture support and enhance pedestrian access to LRT lines and improve transport mode transfers.

While an LRT project is responsible for public realm improvements in its own Construction Zone, AHJ and local Business Improvement Areas may desire to improve the public realm in wider Mobility Enhancement Zones to promote a more unified and attractive streetscape beyond immediate LRT Construction Zones.

These larger Mobility Enhancement Zones may also soften potentially abrupt transitions from LRT public improvements and existing unimproved streetscapes outside LRT Construction Zones.

FIGURE B7-5 SCHEMATIC EXAMPLE OF CONSTRUCTION ZONE AND MOBILITY ENHANCEMENT ZONE



Strategies for LRT Construction Zones

LRT Construction Zones are areas where through the process of building Stations and rebuilding Rights-of-Way the streetscape is rebuilt to local municipal standards or better.

LRT Construction Zones typically include the portion of the street and public realm running the length of a Station box as well as areas disturbed due to construction of Station facilities.

B7.3 Underground Stations and Facilities

Though intended for urban design of at-grade facilities, these criteria also have implications on a range of below-grade elements including ventilation, access points, and concourse configuration.

As such, it is important to apply these criteria at all stages of LRT project planning and design.

B7.3.1 Siting and Orientation

More than any other element along LRT underground line segments, Station entrances have the potential to affect an LRT corridor image and character, strengthen local connectivity, support place-making opportunities, and protect for future development.

Station entrance locations are determined not just by their ability to provide safe and efficient access to and from underground Station concourses and platforms but also by their ability to:

- Provide access to area destinations such as residential, employment, or retail uses;
- Benefit from and enhance valuable heritage and open space resources;
- Enable and facilitate transfer between transport modes;
- Foster positive development;
- Mark or reinforce neighbourhood centres, nodes, and the like.

Key Destinations

Locate and orient Station entrances to enhance access to key destinations.

Consider physically integrating Station entrances with key destination buildings.

Site and design Station facilities to minimize effect on key destinations so that they do not inhibit maintaining and expanding existing services.

Provide Station entrances complementing and integrating key destination structures of architectural significance.

Where intermodal transfer points such as bus stations are not connected or immediately adjacent to a Station Main Entrance, it may be appropriate to provide an enhanced Second Entrance with escalators or relocate the Main Entrance to better serve the destination subject to other transit agency agreements.

Provide barrier-free Station Second Entrances as may be appropriate where access to Main Entrances from key destinations may be difficult for persons with disabilities.

Heritage Resources

Provide LRT facilities respecting heritage resources and preserving their settings.

Limit direct or indirect effect on heritage resources by Station facilities.

For example, preserve key views of heritage structures.

Locate LRT ancillary facilities such as ventilation shafts and traction power substations to the rear or side of heritage structures where they will not negatively affect the historic setting.

Respectfully and sensitively integrate LRT required additions or modifications to heritage structures.

Provide Station entrances adjacent to designated heritage structures to maximize views of the heritage building and not compete with its image or character.

Maintain existing access to and functions of heritage resources.

Provide Station information and wayfinding signage that does not detract from or obscure sight lines to adjacent heritage structures.

Define strategies to minimize or mitigate effects with AHJ where it appears that LRT facilities may adversely affect heritage resources.

Open Spaces

Provide LRT at-grade facilities to enhance existing parks and open spaces while creating opportunities for new open space to support and enhance the function and image of LRT corridors.

Provide each Station with at least one access point oriented toward a primary avenue.

Provide Stations adjacent to existing or planned open space with an entrance facing the open space.

Provide Pavilion Entrances with access from all four sides with two access points minimum oriented to enhance access to key destinations, transfer points, and avenues.

Provide highly transparent Station entrances in existing open space to maximize views to and through the entrance and enhance natural surveillance.

Minimize effects of entrances on open space wherever possible by reducing scale and eliminating ancillary areas that would add bulk to the entrance massing.

Existing Built Context

Site and design LRT facilities to minimize effect on adjacent areas and respond to existing conditions.

Site Station entrances to reinforce existing property setbacks.

Provide 5 m minimum from adjacent curb lines to Station access points at corner lots and Pavilion Entrances.

Planned Development

While the introduction of LRT lines encourages redevelopment, especially of vacant and under used parcels, take care that at-grade LRT facilities do not “sterilize” these parcels or preclude future development.

Understand and foster Station area development potential.

Locate and orient Station infrastructure and site entrances where they will not adversely affect new development opportunities or intensification of existing uses.

Build below-grade infrastructure to preserve for future building above wherever feasible.

Work with local land owners to identify opportunities to integrate Station facilities in planned development.

Protect for the integration of Station facilities with or adjacent to future development.

Work with AHJ to establish common principles and requirements to support redevelopment.

Provide Station entrances and facilities to integrate with future development opportunities on vacant development parcels.

Avoid locating Stations and facilities on large redevelopment sites with significant intensification potential or where integration of Station entrances with new development over time is likely.

In those situations explore other locations first.

Where other locations are not suitable, locate and integrate facilities with Station entrances to minimize impact.

Main Street Areas and Nodes

Site and design Station elements in Main Street Areas, Existing Nodes, and Future Nodes to minimize impact.

Where LRT facilities will create gaps in Main Street Areas, make every effort to fill those gaps with transparent Station entrances, retail space, bicycle storage, new open space, and other amenities.

Locate LRT facilities on discrete parcels with smaller buildings to limit property frontage affected by demolition of existing buildings for new facilities.

B7.3.2 Station Entrances

Provide Station access points level with adjacent sidewalks and open spaces.

Provide Station entrances with high quality, durable materials contributing to the positive image of the LRT system.

Comply with Chapter B5 – Stations, Stops, and Facilities, and Metrolinx RT Design Excellence Principles and Requirements.

Reduce the visual scale of larger entrances through techniques such as articulated massing and variation in materials, colours, and textures.

Provide Station sustainable features and elements such as green roofs, solar panels, integrated storm water management facilities, and louvres to minimize energy costs and environmental impact.

Station Amenities

Provide weather protection canopies or overhangs at Station entrances, bus stops, and adjacent to public streets with appropriate widths, generally 2250 mm to 3000 mm, for shelter from rain and sun.

Provide transparent canopies to allow day light to reach sidewalks for enhanced visibility.

Provide overhangs with upper floors of structure reinforcing existing street setbacks.

Station Plazas

Station Plazas enhance the image of LRT Stations and provide additional amenities for pedestrians, cyclists, and LRT users.

Station Plazas with distinct pedestrian amenities outside Station Main Entrances reinforce a sense of place.

Station Plazas are particularly appropriate on corner sites where they provide additional space for pedestrians and distinguish the Station along the street.

Provide Station Plazas to enhance the user experience:

- At Pavilion Entrances where the public realm will be critical to establishing the Station setting;
- At Station entrance lots and particularly on corner lots where there is space for amenities such as Station related public art, seating areas, or bicycle facilities;
- At Stations where wrapping Station infrastructure is not feasible and public space may both screen infrastructure and provide additional amenities for Station users;
- Where they may enhance connections to key destinations;
- In neighbourhoods with a shortage of open space.

Work with the local community so that any new open space reflects the unique Station area attributes.

Locate Station Plazas to enhance connections to and from Station access points.

Provide Station Plazas to enhance user comfort with amenities such as seating, trash receptacles, pedestrian lighting, and facilities such as bicycle racks and pumps.

Organize, furnish, and landscape Station Plazas to enhance visibility and facilitate pedestrian traffic to and from Station entrances.

Provide Station Plazas and open spaces to reduce maintenance costs and enhance sustainability with high quality materials, low-maintenance native plantings, permeable paving to filter runoff water, trees for shelter from sun in warmer months and from wind in colder months.

B7.3.3 Integrated Station Design

While Station entrances may be the most prominent visible elements in Station areas, functional and security requirements of other facilities have the potential of significant effect not only on the image and experience of an LRT system but also on the redevelopment potential of each Station area.

Combine Station entrances with additional infrastructure such as vent shafts, HVAC equipment, and traction power substations to fully integrate these elements for a cohesive composition.

See Figure B7-5.

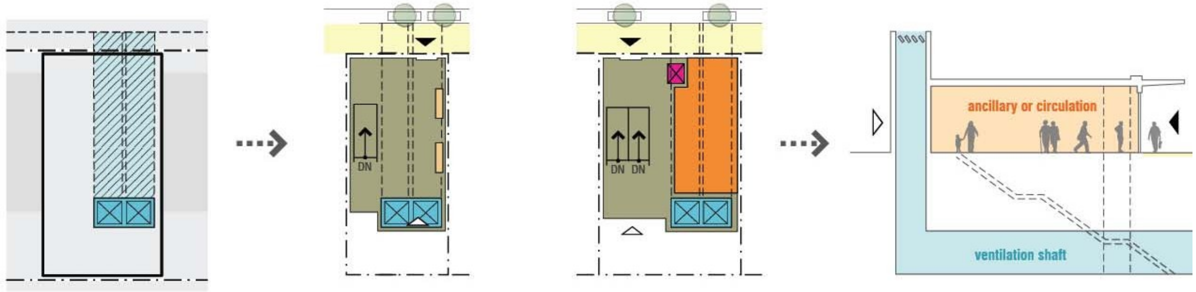
Locate facilities that may restrict development potential or require obtrusive structures to the rear of parcels where Station entrances or future development may screen them.

Do not locate vent shafts in public street Rights-of-Way.

Reduce effect of back-of-house Station facilities.

If operational effect of these facilities cannot be adequately addressed and resolved, consider alternative siting or recommend additional property acquisition to mitigate those adverse impacts.

FIGURE B7-6 EXAMPLES OF INTEGRATION OF BELOW-GRADE MECHANICAL SYSTEMS INTO OTHER STRUCTURES



Integration of Vent Shafts
Stations should be designed to efficiently integrate the mechanical spaces required for the emergency vent shafts at the concourse level (shown hatched)

Secondary Station
When integrated in a secondary station entrance where space is limited, explore locating circulation space above below grade mechanical spaces

Main Station
When integrated in a main station entrance with generous space, explore locating retail or ancillary uses above below grade mechanical spaces

Cross Section

For at-grade facilities such as refuse, storage, maintenance, or mechanical/electrical rooms:

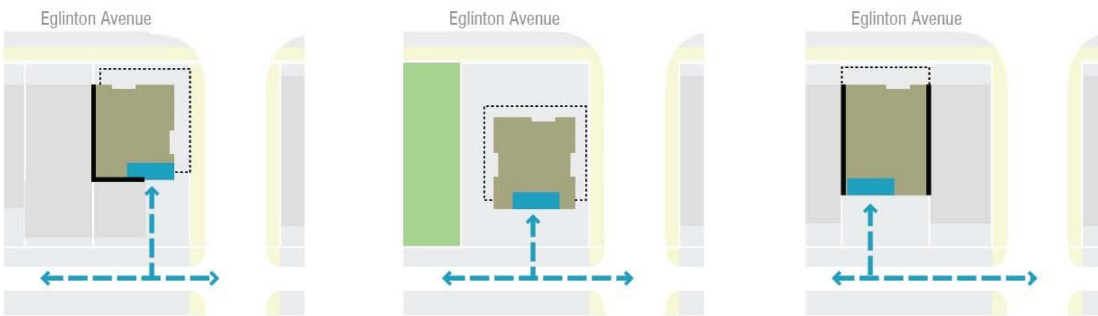
- Provide access from the rear via existing lanes, side yards, or driveways to screen them from the street as shown in Figure B7-7;
- Provide them as an integral part of Station entrances to complement the architecture of the building;
- Provide access routes as integral public realm components that contribute to the character of the surrounding streetscape and open spaces where these elements must be accessed from the front of the Station entrance or through a public space.

See Chapter C4 – Heating, Ventilating, Air Conditioning for detailed technical descriptions including locations, setbacks, adjacencies, segregations, separations, and security requirements.

Where it is not possible to locate vent shafts and other facilities with Station entrances due to space constraints or development impact:

- Integrate them with structures to resemble buildings in scale with the surrounding context and with opportunities for active uses at-grade;
- Site them to the rear of the parcels as shown in Figure B7-7 and facilitate a range of Station area amenities to help screen them; or
- Site them adjacent to existing blank walls to enhance and animate frontage with variations in colour, texture and materials.

FIGURE B7-7 EXAMPLE OF ACCESS OPTIONS FOR REAR SERVICE AREAS



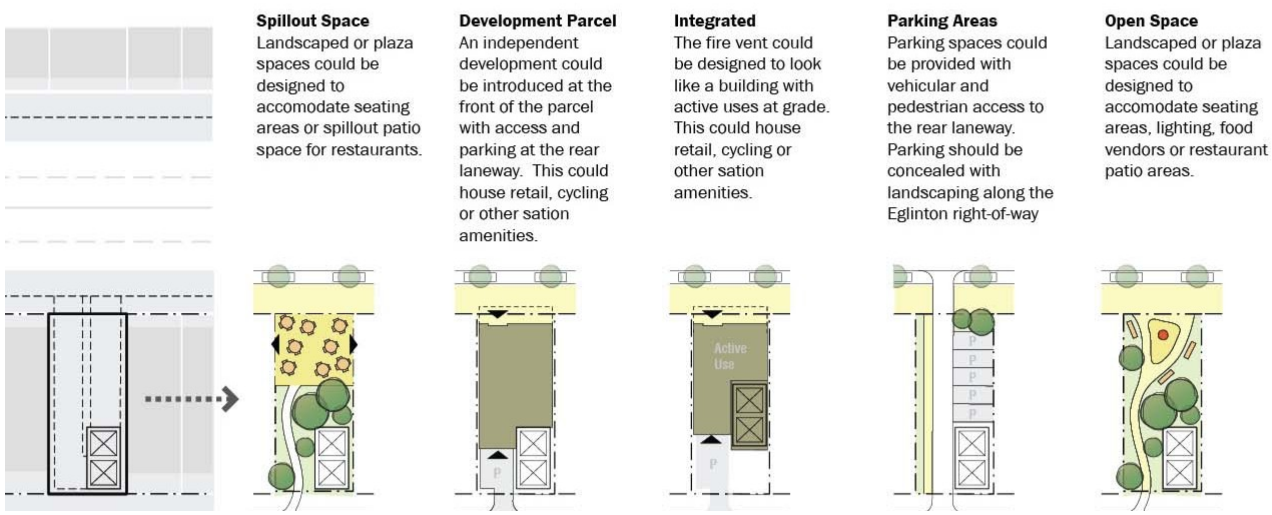
Servicing: Service areas such as refuse or maintenance rooms should be accessed from the rear of the facility via an existing lane or side yard drive.

These may include:

- Spill out space for area restaurants;
- Small plaza spaces capable of accommodating vendors or market uses;
- Sheltered bicycle parking, service, or rental facilities;
- Small shared surface parking lots in support of local businesses; or
- New community open spaces;

Protect properties with laneway access for access to the rear for future service of uses along the street.

FIGURE B7-8 INTEGRATING VENT SHAFTS



Sensitively integrate facilities in parks and open spaces by:

- Locating them where they will not affect existing parks or natural assets such as mature trees or significant landscape features;
- Accommodating vertical plants, vines, or creepers to help screen the structures over time;
- Incorporating design elements and features to diminish their visual prominence;
- Landscaping with low-lying shrubs at-grade; and
- Planting taller trees around them.

B7.3.4 Bus Facilities

Bus routes that cross an LRT corridor provide important connections to neighbourhoods and key destinations, extending and enhancing LRT system access, services, and benefits.

Site bus facilities at LRT Stations to facilitate transfers and minimize walking distances.

Locate Station Main Entrances adjacent to connecting bus stops for accessible connections.

Site larger bus facilities, such as bus stations and loops, to minimize effect on surroundings by orienting Station buildings and open spaces to help buffer adjacent areas from bus operations.

Locate bus terminal entrances to establish direct connections to and from adjacent neighbourhoods while minimizing pedestrian crossing points resulting in pedestrian/bus conflicts.

Where pedestrians must cross a dedicated bus route for access to a bus facility or LRT Station, promote pedestrian safety through use of:

- Paving or markings to alert pedestrians and drivers;
- Single lane crossing points to minimize pedestrian crossing distances; and
- Reduced turning radii to restrict travel speeds and minimize crossing distances.

Where Station entrances are located adjacent to bus stops, integrate Station entrances with waiting areas wherever feasible.

Provide sheltered bus stops where it is not feasible to integrate Station entrances with waiting areas.

Provide bus stops well lit with pedestrian-scaled lighting.

Position bus stops to maintain clear sightlines between surrounding uses and Station entrances.

Provide larger Station entrances where feasible to accommodate passengers waiting at grade for higher anticipated transfer numbers such as at bus stations or terminals.

Incorporate landscaping in the centre of bus loops to break up large areas of asphalt.

Provide larger bus facilities with bio-swales to filter runoff.

Provide benches and trash receptacles for passenger convenience at bus stops and transfer points.

Incorporate bus facilities with comprehensive development plans to facilitate Station area intensification and integration with adjacent properties wherever possible.

B7.3.5 Bicycle Facilities

Bicycling to and from LRT Stations represents an important opportunity to enhance access.

Provide Station entrances with short and long-term bicycle facilities and amenities to facilitate access, especially secured bicycle parking facilities, corresponding to anticipated user demand.

Not all Stations need the same level of bicycle facilities.

Locate bicycle facilities at Station entrances, space permitting, as well as in and around Station areas within LRT Construction Zones.

Target secure sheltered bicycle parking at:

- Interchange, Intermodal, and Terminal Stations;
- Other key transfer points within the LRT system such bus terminals;
- In and around employment clusters and institutional uses.

Provide a range of short-term bicycle facilities such as sheltered racks or ring-and-post racks for Stations serving lower numbers of cyclists.

Provide bicycle facilities in street furnishing zones or other highly visible locations with good access where space adjacent to Stations and Stops is restricted.

Locate bicycle facilities to minimize conflicts with passengers going to and from Station entrances.

Provide wayfinding signage directing cyclists to local facilities as well as nearby bicycling routes and destinations.

Locate wayfinding signage at key bicycle facilities and at the ends of cycling routes leading to and from Station areas.

Avoid barriers to cyclists such as stairs and curbs.

Provide ramps or elevators where stairs lead to and from Station related bicycle facilities.

B7.3.6 Public Realm

Streets and open spaces in and around each Station play an important role in enhancing LRT system access.

The public realm is an important place in facilitating Station access tying together various areas for a more consistent image throughout the LRT system and providing clues to the many diverse places along its route.

General Considerations

LRT users are usually pedestrians at both ends of their journey.

Provide public realm improvements in and around Station areas primarily in LRT Construction Zones.

Prioritize pedestrian accommodation in Stations and facilities and throughout the LRT construction process.

Redevelopment of LRT Construction Zones creates an opportunity to reduce vehicle lane widths enabling more generous sidewalk widths and facilitating planting of street trees.

Coordinate Rights-of-Way cross sections, sidewalk widths, and street tree planting for LRT Construction Zones with AHJ.

Identify and implement sidewalk, streetscape, street tree, and furnishing zone manuals, guidelines, standards, and other urban design tools of AHJ.

Pedestrian Zones

Pedestrian Zones as illustrated in Figure B7-9 are unobstructed pedestrian paths or clearways.

Provide intersections and crossing points to balance the needs of both vehicles and pedestrians using reduced curb radii and eliminating, wherever possible, right turn channels and dedicated turns.

Incorporate unique paving treatments for LRT Construction Zone crossings to alert drivers and pedestrians using high quality materials such as textured concrete or pavers.

Locate primary intersections adjacent to Station Main Entrances to facilitate pedestrian crossings at every sides of the intersection, enhance access, and minimize transfer distances to bus stops.

Sidewalk width may vary depending on Right-of-Way space available.

Provide sidewalks per dimensional requirements and directions of AHJ.

FIGURE B7-9 DESIGNATED “PEDESTRIAN” AND “FURNISHING” ZONES

Furnishing Zones

Furnishing Zones accommodate bus shelters, landscaping, on-street bicycle facilities, street furniture and spill-out space for local businesses between Pedestrian Zones and curbs.

Planting Areas

Provide Furnishing Zones with street trees along primary avenues throughout LRT Construction Zones.

Provides appropriate street tree planting space for Station area utilities relocation along the avenues.

Provide street trees in continuous tree pits with adequate soil volume flush to the sidewalk throughout LRT Construction Zone Rights-of-Way per AHJ.

Provide sufficient vertical space between top of Station box and sidewalk to protect for street tree planting.

Provide tree grates at Station entrances for tree protection and additional pedestrian walking area.

Provide Station Plazas/open spaces with tree planters so long as they do not interfere with pedestrian flow.

Incorporate street furniture such as seating in planting areas.

Coordinate street tree planting arrangements with AHJ.

Provide low maintenance native planting species to minimize upkeep costs and reduce water consumption.

See Chapter B8 - Landscape Architecture.

Pedestrian Lighting

Provide pedestrian lighting throughout LRT Construction Zones including Station Plazas and open spaces.

Provide pedestrian lighting with full cut-off luminaires directing light toward sidewalks with minimum glare and spillage onto surrounding property.

Integrate pedestrian lighting with street lighting wherever possible to minimize streetscape clutter.

Street Furniture

Provide street furniture in Furnishing Zones comprising elements per AHJ street furniture programs except where local Business Improvement Areas or community organizations have entered into agreements to provide alternative street furniture.

Locate street furniture in Furnishing Zones where it will not impede pedestrian flow.

Provide alternative or enhanced street furniture in Station Plazas and open spaces.

Provide additional seating at Station entrances, bus stops, Station Plazas and open spaces.

Provide trash and recycling receptacles at Station entrances, bus stops, Station Plazas, and open spaces.

Locate receptacles at key access points where they will not interfere with pedestrian flow entering and exiting the LRT system.

B7.3.7 Public Art

Public art not only distinguishes Stations along LRT corridors but also reflects the unique characteristics of each Station area and plays an important role in enhancing the overall experience of LRT systems.

Public art manifests itself in many different ways including sculpture, digital art, murals, lighting, surface treatment, etc.

Integrate public art with Station finishes as opposed to freestanding art pieces.

General Considerations

Explore public art opportunities for each Station:

- At platform and concourse levels, where integration of artwork in Station walls, structures, and lighting helps animate and familiarize riders with underground spaces;
- At Station Main Entrances, where integration of artwork with Station building elements helps passengers distinguish Stations and facilities and reflect the unique characteristics of each Station.

Siting and Design

Locate artwork so that it does not detract from wayfinding, information, branding, or signage elements.

Provide public art of high quality, durable, relatively low maintenance materials.

B7.3.8 Wayfinding and Signage

General Considerations

Integrating wayfinding and signage in Stations is an important strategy to improve the daily LRT experience, enhance access, reduce confusion, and facilitate connections between transport modes.

Effective and well-designed wayfinding and signage also contributes to branding LRT Stations and lines as a whole to create a consistent and easily recognizable system image.

Coordinate wayfinding and signage across LRT lines to create a consistent and complimentary pallet of wayfinding and signage elements applied throughout.

Location and Design

Provide intuitively designed wayfinding and signage elements for a wide range of LRT users including first time riders, children, the elderly, and tourists.

Locate each Station name, along with line identification and system branding, on the exterior of Station entrances visible from multiple angles at street level.

Beacons are vertical signs used in street Furnishing Zones to complement Station signage and allow users to identify Station Main Entrances from a distance.

Provide wayfinding and signage elements for LRT users in prominent, convenient, accessible areas such as:

- Station entrances to orient users to various Station facilities and direct transferring passengers to various connecting transport modes;
- Station elevators to identify accessible routes for users with mobility issues, carts, or carriages;
- Station decision points such as stairs or exits to assist in making informed decisions; and
- Key destinations, intersections, and open spaces throughout LRT Construction and Mobility Enhancement Zones to direct people to and from Stations.

Provide wayfinding and signage at Station entrances or open spaces incorporating Neighbourhood Maps identifying streets, parks, and local destinations within 5 to 10 minute walking distances of Stations.

Locate signage in street Rights-of-Way in Furnishing Zones where it will not impede pedestrian flow to and from Stations.

Integrate signage with existing street furnishings such as street lights to reduce visual and physical clutter.

Accessibility

Provide wayfinding and signage per *Accessibility for Ontarians with Disabilities Act*.

Orient wayfinding Neighbourhood Maps in the direction of users and include “You Are Here” indicators.

Complement visual signage in Station entrances with tactile and/or audible signs for visually impaired users.

B7.3.9 Safety and Security

Provide a safe and secure LRT environment essential to an enjoyable experience with the widest range of access particularly for elderly users and those with limited mobility or other physical impairments.

Incorporate Crime Prevention through Environmental Design principles to reduce the incidence and fear of crime throughout LRT systems and in particular in Stations, Stops, Facilities, and the Public Realm.

Provide clearly delineated Designated Waiting Areas, promote natural surveillance, and reduce blind spots.

Provide Station Plazas and open spaces with clear sightlines to and from adjacent streets and entrances.

Provide Station entrances with enhanced security using natural light.

Provide surveillance with glazing adjacent to public streets and open spaces used extensively throughout.

Provide direct sightlines and minimize blind corners from top to bottom of escalator and stair ways.

Improve sightlines and visibility where blind corners are unavoidable using mirrors or windows for views in to and out of escalator and stair ways.

Provide glazed elevator shafts and cars for enhanced safety, security, and surveillance.

Use low-maintenance, graffiti-resistant materials throughout Stations, facilities, Station Plazas and open spaces to minimize vandalism and enhance security.

See Figure B7-10.

FIGURE B7-10 EXAMPLES OF BUILDING TRANSPARENCY

Transparency: Facades facing a street or open space should be designed to promote natural surveillance and contribute to neighbourhood street life.

B7.4 At-Grade Stops, Streetscapes, and Facilities

B7.4.1 Stops

In contrast to underground LRT line segment enclosed at-grade Stations entrances, at-grade LRT alignments have open Stops.

Stops include the full complement of equipment such as ticket vending machines, closed circuit television, pubic address, public visual information systems, etc.

The most visible Stop elements are passenger shelters.

Provide standard Stop shelters throughout an LRT corridor and, to a large extent, throughout LRT systems to give Stops a consistent, easily recognizable appearance and identity.

Provide Stops complementing Station common elements and strategies where LRT lines include both surface and underground segments.

Pay special attention to lighting as part of each Stop architecture.

Provide consistent lighting accenting Stop platforms at night, making Stops appear as a string of lanterns, and contributing to passenger safety, security, and comfort.

Provide special lighting to consistently highlight Stop shelter roof structures from one Stop to the next.

B7.4.2 Streetscapes

Roadway Reconstruction

Provide surface alignments in existing Rights-of-Way thus confining reconstruction to existing curb-to-curb roadways wherever possible.

Certain locations such as portals, transition sections, and Stops intersections may require reconstruction of the public realm boulevard cross section.

Provide roadway and public realm reconstruction, including boulevard cross sections, street construction including lane size, configuration, curb locations, etc., per AHJ.

Streetscape Design Program

Determine LRT corridor Stop locations and amenity levels in pre-design planning.

Include the following LRT corridor urban design analysis considerations.

Official Plan Designations

Do primary artery or cross streets receive special Official Plan designation per AHJ?

Are any intersections Designated Centres on AHJ Official Plans?

This provides an indication of relative intersection hierarchy.

Cross Street Classifications

Pre-design urban design analyses for Stops establish two tier minimum intersection hierarchies beyond official designation cross street classifications as follows:

- First tier intersections include major cross-corridor arterials designated as District Identity Areas and Business Improvement Areas;
- Second tier intersections include minor cross-corridor arterials without any special designation.

This hierarchy is relevant to streetscape design as follows:

- First tier intersections include additional amenities such as benches and special planting;
- Second tier intersections do not include these elements.

Official designation cross street classification urban design criteria are subject to change per mutual agreement between local Business Improvement Areas, Metrolinx RT, and AHJ.

Streetscape Zones

Provide streetscape zones per AHJ.

Include the following components:

- Curbs;
- Curb aprons;
- Streetlights;
- Pedestrian lighting;
- Street furniture;
- Pedestrian Zones; and
- Soft landscape areas.

Landscaping

See Chapter B8 – Landscape Architecture

Pedestrian Access

Reconstruct Boulevard Cross Sections per Metrolinx Accessibility Design Guidelines and AHJ including:

- Handicap curb-cut ramps;
- Cane-detectable warning pavers;
- Traffic signal audible cues; and
- Other urban braille requirements.

Street Furniture

Provide street furniture including benches, vending corrals, trash receptacles, kiosks, built-ins, guardrails, handrails, and fences per street furniture programs and streetscape manuals of AHJ.

Street and Pedestrian Lighting

Replace in kind street or pedestrian light poles, bracket arms, and luminaires removed for LRT construction.

Provide street and pedestrian lighting per AHJ standards barring prior agreements to use other street light, pedestrian light, light pole, bracket arm, and/or luminaire types.

Paving

Replace existing sidewalks removed for LRT construction with sidewalks in kind.

Provide stamped, broom-finish, or saw-cut concrete per AHJ.

Coordinate boulevard cross section textured concrete sidewalks throughout including platform paving.

Beacons

Provide Beacons, often referred to as sign pylons, in Furnishing Zones adjacent to crosswalks of LRT Stop intersections.

Provide two Beacons for one side of intersection Stops, one at both Stop intersection corners.

Provide four Beacons for both sides of intersection Stops, one at each corner of the intersection.

Public Art

Integrate low maintenance artwork through elements such as paving, railings, and shelter panels for distinctive public art at each Stop.

See Chapter B5 – Stations, Stops, Facilities and Section B7.3.7 Pubic Art.

Provide additional art commissioned and funded by others (e.g., Business Improvement Associations) as appropriate in boulevard streetscapes consistent with Metrolinx RT and AHJ public art policy.

B7.4.3 Portals

General

Portals are where LRT alignments transition from underground to at-grade.

Portals need careful consideration for proper integration with streetscapes.

Portals often include significant features in street Rights-of-Way.

Portal retaining walls require wider Rights-of-Way increasing pedestrian crossing distances.

Orient portals away from nearest intersections to reduce visual impact, provide additional places of refuge for pedestrians crossing streets, and minimize traffic conflicts.

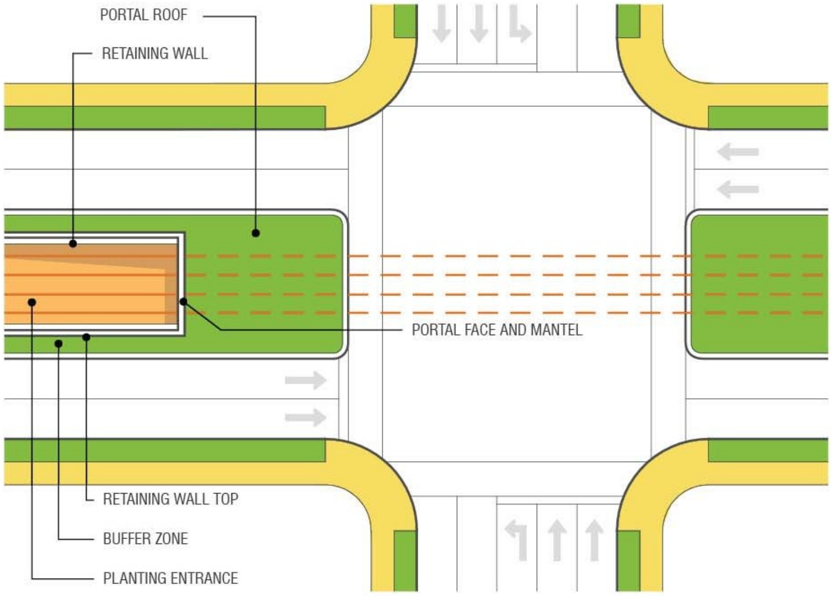
Portal retaining walls are most prominent for Light Rail Vehicle passengers entering and exiting underground sections and pedestrians on the street.

Enhance portal retaining walls with treatments including:

- Textured concrete or other materials for visual relief;
- Special portal wall lighting for evening hours;
- Integration of public art; and/or
- Planter wall systems to soften and reduce visual noise.

Extend portal retaining walls a short distance beyond LRT underground/at-grade segments for design continuity and to blur lines between underground and at-grade segments.

FIGURE B7-11 PORTAL LOCATION RELATIVE TO AN INTERSECTION



Portals should be sited so that their entrance is oriented away from the nearest intersection in order to reduce visual impacts from the intersection and provide an additional place of refuge for pedestrians crossing the street.

Extend portal retaining walls at street level further than required to prevent water runoff entering underground segments and create a safety barrier along the portal edge.

Provide safety railings or guard rails to minimize portal/streetscape visual impact.

Provide graffiti-resistant portal materials, textures, and coatings for reduced vandalism and maintenance.

Portal Buffer Zones

Portals are prominent streetscape features, visible on both sides to Light Rail Vehicle and motor vehicle passengers as well as building occupants.

Provide Portal buffer zones both sides of retaining walls of proper width, drainage, and soil volume to support appropriate planting.

Explore Portal buffer zone opportunities to enhance the LRT system image.

Minimize portal effects on adjacent land uses with planting and landscaping.

Provide landscaping and planting to reinforce prohibited pedestrian access.

Provide shrubs and conifer trees to enhance LRT portals while minimizing falling leaves maintenance.

Provide non-invasive, low maintenance, drought and salt resistant landscaping plants.

Provide landscaping plants to maintain all-season interest and reduce blowing leaves and debris collecting along portal walls.

Portal Face and Mantels

Portal Face and Mantels approached from a distance are prominent LRT streetscape features.

Do not treat them as simple concrete facades.

Incorporate instead textures or lighting to be seen from a distance and help elevate their visual profile.

Portal Roofs

Portal Roofs are most visible to pedestrians and motor vehicles approaching at grade and building occupants from above.

Streetscape conditions such as these present unique events for urban design and landscape opportunities, techniques, and solutions providing relief for pedestrians and motor vehicles crossing portals and streets.

B7.4.4 Emergency Exit Buildings

Emergency Exit Buildings (EEBs) are small structures housing underground LRT segment emergency exits.

Provide EEBs from underground LRT segments between Stations in case of emergency per NFPA 130.

Location and Siting

Site EEB surface exits facing the street for easy access by emergency vehicles and personnel.

Site EEBs in Main Street settings or streets with setbacks consistent with adjacent development setbacks.

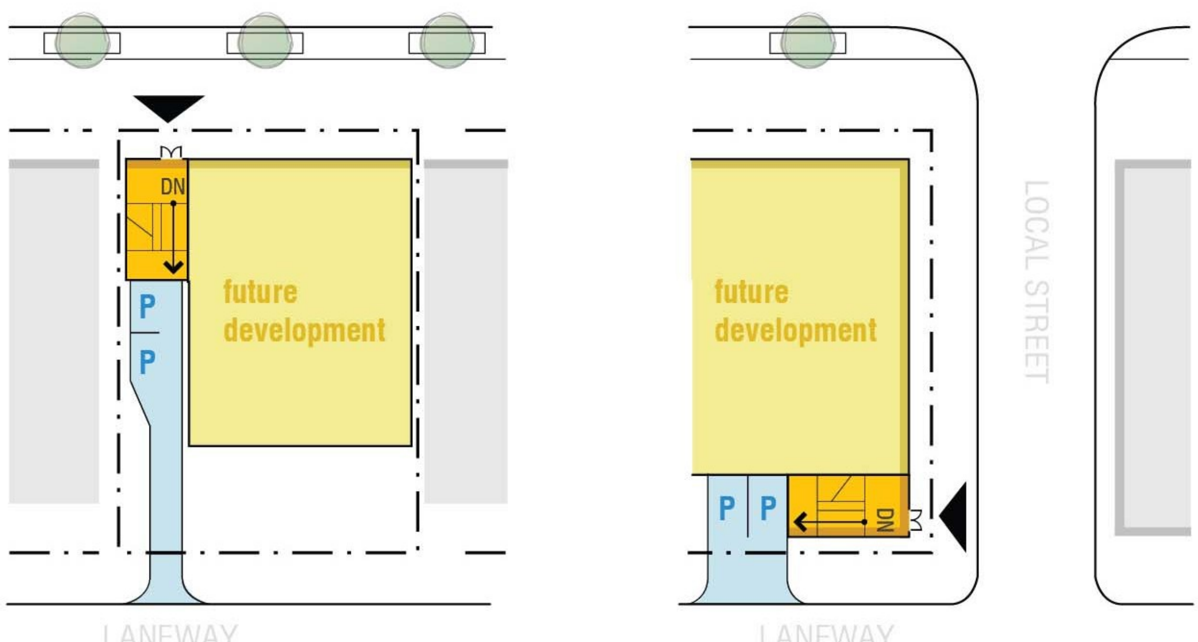
Protect for successful integration with new development opportunities in siting and orientation of EEBs.

Locate EEBs to the side of redevelopment parcels to protect for future development and support consistent street level activity over time.

Where opportunities exist to integrate EEBs in new development, orient EEBs perpendicular to streets to preserve ground floor areas for active use and animate the streets.

See Figure B7-12.

FIGURE B7-12 EXAMPLES OF EEB ORIENTATION



Where opportunities exist to integrate the EEBs within new development they should be oriented perpendicular to the street and away from intersections to preserve larger areas of ground floor space for active uses that can help to animate the street. In these examples parking has been oriented to minimize space requirements and reduce impacts on surroundings.

Do not locate EEBs at intersections, reducing visibility at the intersection in the short term and leading to blank façades at the corners as and when EEBs are integrated with new development over time.

Sensitively site EEBs in streetscapes and parks to minimize their effect on mature vegetation.

Locate EEBs in Main Street Areas to integrate with potential redevelopment over time.

Site EEBs in Main Street Areas on narrow sites with limited redevelopment potential to reinforce adjacent development setbacks.

Integrate EEBs with similar structures in scale and surrounding context.

Design

Provide EEB structures as background elements in the streetscape.

Incorporate EEB seating and other pedestrian amenities when located in or adjacent to open space given the infrequent use and static nature of EEBs.

Provide EEB façades with low maintenance, graffiti resistant textures, treatments, and materials to reduce potential vandalism and maintain the positive image of LRT systems.

Provide EEBs and parking areas as public realm components contributing to streetscapes and open spaces.

Provide EEB parking in nearby existing or on-street lots to minimize surface parking impact.

Orient EEB parking to minimize space required and reduce effects on surroundings.

B7.4.5 Traction Power Substations

Traction Power Substations (TPS) house electric equipment supplying Light Rail Vehicle power.

Average proposed TPS spacing is determined through load flow analysis.

Although preferred TPS locations are as close as possible to trainways, there may be potential to shift TPS short distances from trainways.

With the complexity of LRT corridors, TPS design, siting, and locations are not one-size-fits-all solutions.

In addition to the above options, explore hybrid configurations better to respond to local context such as integrating TPS over or within Stations.

Though perhaps large in scale, TPS may make positive public contributions through urban design.

Successfully integrating TPS means understanding settings and making efforts to integrate structures with surrounding context through careful siting, use of attractive high quality finishes, and appropriate landscaping.

Location and Siting

Locate Station TPS insofar as possible in concourses given their size and potential impact.

Pursue integration of TPS with Stations to minimize property taking and neighbourhood impact.

If TPS must front primary avenues, locate them perpendicular to avenues to minimize street impact.

In natural areas or open spaces it may be appropriate to position TPS parallel to avenues to minimize their effect on surroundings.

Provide TPS front and rear access alongside adjacent development while maintaining a continuous street wall for TPS integration alongside avenues within continuous street frontage.

Provide TPS related parking to the rear with access via rear lanes or side streets.

Provide TPS parking in adjacent lots or on-street parking where parking space is very limited.

Site TPS in Main Street Areas or streets with consistent setbacks to reinforce adjacent development setbacks and integrate them with structures in scale with surrounding context.

Minimize visual effect of at-grade portions of TPS structures in open spaces.

Provide planted wall systems or other landscape treatments to integrate TPS structures with open spaces.

Design

Completely enclose internal TPS elements on all four sides.

Organize TPS elements for access only from within TPS buildings.

Visually screen outdoor transformers on TPS roofs from adjacent property.

If not possible to maintain existing setbacks, the land in front of TPS may be made publicly accessible and landscaped to provide additional amenities such as bicycle parking and seating.

Integrate ancillary uses such as bicycle parking on the front of TPS buildings to promote active streetscapes.

B7.4.6 Overhead Contact Systems

Few elements have as much visual effect as Overhead Contact Systems.

Provide Overhead Contact Systems support poles as visually and aesthetically inconspicuous as possible.

For example, center-poles with double-mast-arms down the middle of an alignment include fewer components and are less visually conspicuous than poles on both sides of an alignment.

B8 Landscape Architecture

B8.1 General

Chapter B9 addresses functional and aesthetic landscape architecture for Metrolinx (MX) Light Rail Transit (LRT) projects.

The basic function of landscape architecture is to provide shade, wind protection, human scale, colour, texture, and spatial definition to the built environment.

Appropriate landscape architecture solutions can change from one locale to another.

Providing high quality customer experience, sustainable development goals, and concern for passenger, operator, and pedestrian safety are critical to the success of any new LRT system.

Support these efforts with high-quality, durable paving materials, plant and tree protection, new planting, appropriate soil preparation, irrigation, and maintenance to achieve clean, well-grown, handsome, and permanent trees, shrubs, and groundcover.

B8.1.1 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Landscape Architecture specific references include but are not limited to:

- Streetscape Manuals;
- Urban Forestry Standards;
- Parks Bylaws;
- Tree Bylaws;
- Ravine and Natural Feature Protection By-laws;
- Green Roof By-Laws and Standards;
- Green Development Standards;
- Green Parking Lot Standards;
- Guides to Standard Planting Options;
- Guidelines for Landscaping Surface Parking Lots;
- Coordinated Street Furniture Programs;
- Accessibility Design Guidelines;
- Barrier-free accessibility standards and regulations;
- MX LRT Design Excellence Principles and Requirements.

OBC governs where conflicts arise unless otherwise stated.

B8.2 Basic Goals

Landscape architecture is an integral component of MX LRT systems.

Provide attractive landscaping and planting to enhance, soften and unify the visual impact of LRT corridors and frame views with quality planting offering shading, screening, colour, and texture.

Develop comprehensive landscaping maintenance plans to provide trouble-free low-upkeep landscapes.

Provide best appropriate trees, shrubs, and groundcover.

Coordinate streetscape Rights-of-Way (ROW) design with utility works.

Identify potential government and non-government stakeholders early in an LRT project and coordinate throughout including but not limited to:

- Municipal planning and traffic departments;
- Economic development boards;
- Parks, forestry, and regional conservation authorities.

Incorporate specific streetscape elements developed by local Business Improvement Areas in LRT streetscape ROW wherever possible.

Apply Crime Prevention through Environmental Design (CPTED) principles to LRT landscape design.

Provide landscaping that does not interrupt Light Rail Vehicle (LRV), motor vehicle, or pedestrian sightlines.

B8.2.1 Trees, Shrubs, and Groundcover

Plants fulfill certain functional demands including but not limited to:

- Shading sidewalks, waiting areas and parking lots;
- Screening and enhancing views;
- Providing spatial definition and identity;
- Diminishing overhead wire silhouettes;
- Enhancing existing vegetation;
- Mitigating glare;
- Adding visual interest through colour, texture, and scale.

Planting also heightens customer experience with the sounds and smells of trees, shrubs, and groundcover.

Planting alone however is not suitable for providing:

- Effective pedestrian barriers in public areas;
- Effective wind-screens in restricted areas;
- Effective sound barriers.

Address these issues primarily with fencing, shelters, and sound walls.

Planting priorities, not necessarily listed in order of importance, include:

- Replace existing work site plants disturbed by LRT construction;
- Enhance transit plazas where appropriate;
- Provide large deciduous trees in public street and boulevard construction zones;

- Soften pedestrian barriers;
- Provide parking lot landmarks (i.e., distinctive reminders of approximate car locations);
- Provide appropriate planter material at Stops in future platform extension footprints.

B8.3 Tree, Shrub and Groundcover Selection

Address local municipal streetscape manuals, green development standards, green parking lot standards, and urban forestry policies in developing landscape plans, streetscape plans, and planting lists.

Provide planting that meets the following criteria:

- Low maintenance;
- Hardy/durable;
- Road-salt tolerant;
- Pest tolerant;
- Requiring minimum watering, pruning, and feeding;
- Neat and small-leafed;
- Minimal plant droppings;
- Moderate growth characteristics;
- Native/indigenous to the area; and
- No invasive species.

Limit species variety but avoid monocultures.

B8.4 Safety

Do not obscure visibility, especially at corners, with trees, shrubs, and other landscaping.

Provide only groundcover and shrubs lower than 600 mm in heavily trafficked areas, leaving chest-high shrubs for use as screens only in carefully selected areas.

Do not allow trees or shrubs to block security camera views.

Use techniques to prevent accumulation of grass, leaves, debris, and other errant plant material on tracks.

B8.5 Landscape and LRV Speed

LRV passengers view the exterior landscape at speeds up to 70 km/h.

Provide landscaping and plants that are therefore clustered and discontinuous.

Provide more sensitive landscaping treatments as LRVs slow down at Stops.

When alighting LRV passengers become pedestrians still more detail becomes visible.

Distribute planting on the general principle of the lower the speed, the higher the plant detail.

B8.6 Existing Trees

Consider adding more trees of the same or visually similar species to reinforce distinctive tree groupings.

Consider adding other approved tree species to reinforce bylaw-protected maintainable tree groupings.

Consider establishing new landscaping patterns to shade pedestrians, screen poles and overhead wires, and delineate LRT routes where new street alignments require existing tree removal.

Refer to tree protection policies and specifications of AHJ for construction near existing trees.

B8.7 Specific Requirements

B8.7.1 Irrigation

Provide automatic irrigation systems with heads supplying water to appropriate planting surfaces but not to adjacent areas.

Group plants with similar needs together.

Irrigate trees and shrubs slowly and infrequently to encourage deep rooting.

Provide at-grade LRT planter areas large enough to hold and spread a good soaking.

Irrigation systems for many trees and shrubs may be abandoned once the plants are well established.

Pipes may be above ground where appropriate.

Provide irrigation systems per local municipal green standards as well as:

- Water efficient landscaping;
- Innovative wastewater technologies;
- Water use reduction;
- Onsite storm water management.

B8.7.2 Overhead Wires

Overhead wires are less conspicuous when interrupted visually by tree branches and foliage or when seen against a background of buildings and landscaping.

Maintain planting clearances from overhead contact system wires and poles.

Encourage utility providers and AHJ to minimize interference with street trees by consolidating poles, wires, and signals wherever possible.

Coordinate landscape work with lighting to reinforce maximize the effects of both.

B8.8 Medians

Space for planting may be available on both sides of the trainway in long stretches for at-grade LRT alignments in street medians.

Provide ground cover, low shrubs, and tall shrubs in appropriate locations to soften the streetscape where it may not be possible to plant large or ornamental trees.

Consider plant material distribution, massing, and grouping as a function of the effects of speed on viewing.

B8.9 Major Pedestrian Walks

Reinforce pedestrian circulation and access to LRT facilities with planting.

Collect minor pedestrian routes from parks, open space, and commuter parking lots into major pedestrian walkways parallel to arterial streets leading directly to cross-walks and overpasses.

Define these walkways by lines of shade trees and supplementary landscaping treatments as appropriate.

B8.10 Green Track

Consider implementing a vegetated track system (Green Track) on portions of the Guideway where feasible.

A green alignment can create better aesthetics and enrich the quality and character of an urban experience along the light rail alignment during the warm seasons; as well as offering advantages such as high capacity water retention, noise reduction and improved air quality.

Development and maintenance of the vegetated track system in the context of GTHA's snow and ice conditions on the road system will have a dramatic impact on operation and maintenance and will require special design and maintenance considerations.

This is especially the case if the current rock salt (Sodium Chloride) continues to be used by the GTHA's transportation services for de-icing and roads and sidewalks clearing operations during the winter.

The large amount of salts splashed from the roads during the winter season, will pose a risk to the plant life immediately adjacent to the roadway and may cause deterioration of the vegetated areas of the Guideways.

In other countries with similar winters to those in the GTHA such as Germany, procedures for handling the snow and ice are different in the types chemicals used for ice-melting, such as potassium formate and sodium formate, that do not harm plant and aquatic life.

B8.10.1 Design

Consider the following during the planning and design process:

- Electrical isolation must be maintained to protect the rail against stray currents;
- Vegetation must be kept away from the rail running surface where it might lubricate the wheel/rail interface and create problems with traction and braking;
- Drainage of the Guideway must deal with the conflicting goals of keeping the vegetation sufficiently moist to sustain growth and keeping the subgrade sufficiently dry to maintain a stable base to support the track and the live loads of the rail vehicles;
- Sustaining growth of the vegetation during dry weather and potential frost and salt and sand damage during the cold season;
- Since snow-plough trucks cannot be used ordinarily because of possible damage to guideway landscaping and because of potential damage caused in areas where street vehicles drive onto the Guideway accidentally, consider using reinforced landscape systems such as unit block grass pavers that will protect the vegetative root zone from potential damage and avoid the topsoil compaction;
- Although the vegetation is to be drought tolerant, consider a permanent drip/sprinkler irrigation system for plant establishment and to supply water during low rainfall and hot periods;
- Take measures to prevent excessive weed growth at the connection of the root foils and the sides of the track;
- Regular Guideway landscape maintenance activities include maintenance of the vegetation, regular visual inspections, mowing, irrigation, etc.;
- Consider using high rail maintenance vehicles and exclude the use of rubber tire maintenance vehicles.

B8.10.2 Green Track Technology and Vegetation

Select vegetation to be used in the track area based on factors such as the local climate, depth of soil available, how well drained the soil will be, presence or absence of a sprinkler/irrigation systems, and maintenance capacity.

A slow-growth plant that reaches a maximum height of approximately 40 mm is preferred to minimize mowing requirements.

Provide green track surface types resistant to track conditions such as drought, salt, frost and cold, heat, urban pollution, pedestrian and traffic crossing, as well as LRV forces and wear and tear.

The two alternative solutions for surface types of the green tracks are grass and sedum.

Sedum is more resilient and requires less maintenance and is available for cold winter climates.

There are many examples of sedum use throughout Canada for green roofs.

B9 Geotechnics

B9.1 General

Chapter B9 addresses geotechnical criteria for Metrolinx (MX) Light Rail Transit (LRT) design, monitoring, and protection of both temporary and permanent earth structures and earth loaded or supported structures.

B9.1.1 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Geotechnic specific references include but are not limited to:

- Ontario Building Code (OBC);
- Canadian Foundation Engineering Manual;
- Canadian Highway Bridge Design Code (CHBDC): CAN/CSA-S6-06;
- Underground Technology Research Council [US-ASCE/SME] Report, “Geotechnical Baseline Reports for Underground Construction”;
- Canadian Standards Association (CSA): Standards for Phase I and II Environmental Site Assessments;
- Ontario Provincial Standard Specification (OPSS);
- Ontario Regulation 278/05: Designated Substance - Asbestos on Construction Projects and in Buildings and Repair Operations;
- Ministry of Labour Guideline: Lead on Construction Projects;
- Ministry of Environment (MOE) Environmental Protection Act;
- MOE Ontario Water Resource Act;
- MOE Ontario Water Taking Regulation;
- Ravine & Natural Feature Protection Bylaws;
- American Society for Testing and Materials (ASTM) Standards;
- Caquot and Kerisel, Tables for Calculation of Passive, Active Pressure and Bearing Capacity of Foundations, Gauthier-Villars, Paris;
- Terzaghi, K., and Peck, R.P., Soil Mechanics in Engineering Practice, John Wiley & Sons Inc., New York;
- Bjerrum L. and Eide O., Stability of Strutted Excavations in Clay, Geotechnique;
- Boscardin, M.D. and Cording, E.J., “Building Response to Excavation Induced Settlement,” Journal of Geotechnical Engineering, Vol. 115, January, 1989, ASCE;
- Poulos, H.G., and Davis, E.H., Elastic Solutions for Soil and Rock Mechanics. John Wiley and Sons.

OBC governs where conflicts arise unless otherwise stated.

B9.2 Limit States Design

B9.2.1 Introduction

Chapter B9 uses Limit States Design for a consistent structural and geotechnical engineering design approach.

A basic premise of Limit States Design in geotechnical engineering is to achieve economical and consistent design using common safety and Serviceability criteria for materials, foundations, and construction types.

A key objective of Limit States Design is to achieve an appropriate level of reliability throughout the structure and foundations for the various materials involved.

A **Limit State** is a condition of a structure beyond which it no longer fulfills the relevant design criteria.

The key Limit States in geotechnical engineering are generally classified as Ultimate Limit States (ULS) and Serviceability Limit States (SLS).

This Design Criteria Manual adopts a factored overall geotechnical resistance approach rather than a factored strength parameter approach.

See the Canadian Foundation Engineering Manual (CFEM) for information on geotechnical aspects of Limit States Design.

See Chapter B4 - Structures for additional Limit States Design criteria, design load combinations, and associated load factors.

B9.2.2 Ultimate Limit States

Geotechnical Ultimate Limit States are primarily concerned with collapse mechanisms in the ground or structure.

In geotechnical design, Ultimate Limit States comprise:

- Exceeding the load carrying capacity of the ground;
- Sliding;
- Overturning;
- Uplift;
- Loss of overall stability;
- Large deformation of ground, e.g., significant movement of slopes or retaining structures, leading to an Ultimate Limit State being induced in the superstructure, substructure, or building.

B9.2.3 Serviceability Limit States

Geotechnical Serviceability Limit States consider mechanisms that restrict or constrain the intended use or occupancy of the structure.

They are usually associated with ground movement that interrupts or hinders the serviceability of the structure.

For geotechnical design, Serviceability Limit States include:

- Movement, e.g., settlement, heaving, sliding, tilting, etc.;
- Deflection;
- Cracking;
- Vibration.

B9.2.4 Design Concept

The concept of geotechnical Ultimate Limit States considers the probability of failure (or reliability) of a foundation or structure by under-estimating its resistance, i.e., applying resistance factors that are less than one, over-estimating the applied load effects, i.e., applying load factors that are typically greater than one, and making sure that the factored geotechnical resistance is equal to or greater than the factored load effects.

The Ultimate Limit States Design equation is expressed as:

$$\Phi R_u > \Sigma \alpha i S_{ni}$$

Where Φ = geotechnical resistance factor;

R_u = ultimate geotechnical resistance;

$\Sigma \alpha i S_{ni}$ = sum of factored load effects for a given load combination;

αi = load factor corresponding to a particular load; and

S_{ni} = specified (or service or characteristic) load component.

For geotechnical Serviceability Limit States, ground movement is not to exceed tolerable values for the structure or adjacent properties.

The Serviceability Limit States geotechnical resistance must be equal to or greater than the service load effects and is expressed as:

$$R_s \geq \Sigma S_{ni}$$

Where R_s = Serviceability geotechnical resistance; and

ΣS_{ni} = Sum of service load effects for a given load combination.

B9.2.5 Design Categories

Items requiring geotechnical design fall into three broad categories as described below.

Category 1

Items in this category are purely geotechnical, i.e., there are no soil-structure interaction effects) and do not affect structures.

They are also not affected by structures.

Examples include unsupported excavation slopes and basal stability.

In this category the problem is purely geotechnical; use a conventional geotechnical design approach with working stresses and global safety factor traditional values.

Category 2

Items in this category relate to the soil and/or groundwater pressure applied to a structure, and include soil-structure interaction effects.

Examples include the design of temporary retaining walls and tunnel linings.

This category is covered in Section B9.4 -Temporary Works.

For Ultimate Limit States in this category, the geotechnical design report establishes the factored earth pressures including groundwater pressures and associated seepage pressures.

If the ground provides resistance, e.g., passive pressure, apply a geotechnical resistance factor to the earth pressure providing resistance at ULS.

If the ground produces a loading action for ULS, e.g., active pressure, vertical load, apply an appropriate load factor to obtain the factored load effect for ULS.

Calculate and check Serviceability Limit States such as movement using appropriate unfactored soil and ground parameters and the corresponding combinations of Serviceability load effects.

Category 3

Items in this category relate to structural loads resisted by the ground.

An example is the design of footings or piles.

In this category, the geotechnical design will typically establish a factored resistance for ULS.

This factored resistance is derived from the calculated ultimate resistance multiplied by a resistance factor.

For safety, the factored resistance must be greater than all combinations of factored load effects for ULS.

See Section B9.9 - Foundations.

Calculate and check SLS, such as ground deformation due to foundation loads, as outlined above.

B9.3 Subsurface Investigations

Perform subsurface explorations per the general principles defined in Infrastructure Ontario AFP – Geotechnical, Hydrogeology, and Environmental Due Diligence Technical Requirements.

B9.3.1 Soil Explorations

Soil Explorations include at least the following types:

- Rotary wash borings through soil;
- Penetration sampling per Infrastructure Ontario Site Investigation Standards and at layer changes;
- Continuous standard penetration sampling will be performed on an as needed basis;
- Undisturbed sampling of cohesive materials, if collectable;
- Coring through boulders found within the soil mass;
- Test pits;
- Rock coring.

B9.3.2 Groundwater

Groundwater investigations include at least the following types:

- PVC groundwater observation wells;
- In-hole permeability tests, slug tests, other tests;
- Pumping tests with observation wells.

B9.3.3 Laboratory Testing

Conduct laboratory tests on soil, rock, and groundwater samples per ASTM or other industry standards.

B9.3.4 Investigation and Design/Baseline Reports

Provide Geotechnical Investigation Reports compiling information obtained for MX LRT review and acceptance.

Provide a Geotechnical Design Summary (GDSR) or Geotechnical Baseline Report (GBR) per the Underground Technology Research Council [US-ASCE/SME] Report, “Geotechnical Baseline Reports for Underground Construction” as appropriate for each construction area.

Establish and publish geotechnical design parameters in Design Memoranda.

B9.4 Temporary Works

B9.4.1 Design Responsibility

Most urban environment LRT construction projects require temporary open-cut or shored excavations.

Provide temporary works sufficient for their expected service life.

Define temporary works in drawings and specifications where one or more of the following conditions apply:

- Easements, permits, or agreements required to construct the works are contingent on a particular system or design of temporary works;
- Obtaining such easements, permits, or agreements is not the responsibility of the General Contractor;
- Temporary works have both a temporary use during construction and form part of the permanent works or where the permanent works are predicated on a particular system of temporary works;
- Temporary works must sufficiently reduce potential impacts to the local groundwater and/or regional hydro-geological regimes, e.g., contaminant migration or changes in groundwater;
- Temporary works must sufficiently reduce potential environmental impacts, e.g., noise, dust, odour, spills, surficial erosion, sediment transport, biophysical and vegetation aspects, etc.;
- There is a risk of the work damaging buildings, structures, or utilities and it is in MX LRT interest to partially or fully specify the temporary works;
- MX LRT directs design and/or partially or fully specifies temporary works.

Perform excavation per current Ontario Occupational Health and Safety Act and Regulations for Construction.

B9.4.2 Open Cut Excavation

Analyze and design the slopes of temporary open-cut excavations using limit equilibrium methods for permanent slopes per Section B9.7.

Apply no load factors or resistance factors in the analyses.

Use drained or undrained shear strength parameters as appropriate in temporary open-cut excavations.

Provide excavations for the more critical of the two conditions where there is any doubt as to which is appropriate for the particular soil conditions in which the open-cut is excavated,.

Use minimum safety factors of 1.3 for drained analysis and 1.5 for undrained analysis against deep-seated failure in open-cut temporary excavations as determined by limit equilibrium analysis.

See also Section B9.7 for permanent conditions.

Assess potential for adverse hydro-geological effects from temporary cut slopes per Section B9.4.1.

Design cut slopes to resist erosion or disturbance from weather-created conditions.

B9.4.3 Temporary Shoring

General

In shoring design take due account of:

- Tolerable ground and structure deformations adjacent to shoring;
- Earth pressure, including effects from surcharge acting on shoring;

- Means of resisting earth pressures;
- Stability of the excavation base;
- Hydrostatic or pore water pressure acting on shoring;
- Presence and condition of nearby structures, i.e., utilities, buildings, etc.;
- Construction staging.

Shoring Options

Consider two basic shoring system elements: the wall itself, i.e., timber sheeting, soldier pile and lagging wall, caisson wall, diaphragm wall, or sheet pile wall, and its additional support elements, i.e., struts, internal frames, rakers, grouted anchors, deadman anchors, etc.

Provide combinations of wall types and support elements suitable for the ground conditions and site conditions.

Provide wall types depending on stiffness requirements related to adjacent structures and services, anticipated installation conditions, site conditions, and cost.

In presence of utilities that are not relocated, provide shoring systems to accommodate working around them with minimum impact and no service interruption.

Provide additional support elements based on wall deformation requirements, space requirements within the excavation, easements available outside the excavation, and installation conditions related to equipment access and ground conditions.

Active Earth Pressure

Active earth pressure on temporary shoring systems design must take into account:

- Stiffness and support characteristics of the wall;
- Groundwater pressures;
- Ground surface surcharge loading, including stockpiles, equipment, compaction efforts, buildings, sloping ground; and
- Ground type and strength.

Use triangular earth pressure distributions for design of cantilever retaining walls, or for yielding support elements, e.g., soil anchors, deadman anchors, rakers, etc.

Base triangular earth pressure distribution for a particular case on the following methods:

- Rankine Theory;
- Coulomb Theory;
- Caquot and Kerisel;
- Tables for Calculation of Passive, Active Pressure and Bearing Capacity of Foundations, Gauthier-Villars.

For design of non-yielding retaining systems where full active earth pressure may not develop, use a suitably higher earth pressure than for a yielding wall.

Design loads on struts and grouted soil anchors are not to be less than those obtained from earth pressure distributions proposed by Terzaghi and Peck illustrated in Figure B9-1 and Figure B9-2.

Provide bulk unit weight of soil (γ), earth pressure coefficient (K), and height of groundwater above excavation base (hw) -- all independent design parameters -- per each site specific Geotechnical Design Report.

In Figure B9-1, only include groundwater pressure where the cohesive soil is fractured or contains sand lenses that may lead to groundwater pressures acting on the wall.

For intact clays (clays or tills without fractures, tension cracks, sand lenses, or varves) the earth pressure diagram may be used without addition of the groundwater pressure.

Water pressure can also be ignored in clays/cohesive tills where the shoring system incorporates a drainage layer behind the shoring wall, such as the case for most soldier pile and lagging shoring systems.

Provide Geotechnical Design Report recommendations whether water pressure can be ignored based on subsurface conditions and anticipated shoring systems.

Trapezoidal earth pressure diagrams, such as those proposed by Terzaghi and Peck, may also be used for design of soldier pile and lagging walls supported by struts.

Figure B9-1 and Figure B9-2 show earth pressures induced by uniform surcharge loading on the ground surface.

Assess pressures due to line and point loads using the methods shown in the CFEM.

Where the shear strength of the soil includes a value for cohesion, c', or undrained shear strength, cu, the calculated active pressure near the top of wall may be negative, i.e., in tension, and is to be ignored.

Large additional forces may be induced by frost action in soils.

Heating or insulation may be used to avoid designing for these forces.

Where heating and insulation are used on a contingent basis, provide sufficient monitoring of the excavation to confirm acceptable performance.

See Chapter B4 - Structures and the CFEM regarding additional forces that may be induced by frost action.

Passive Toe Restraint

For passive earth pressure acting to restrain shoring systems below excavation level take into account:

- Lateral movement of embedded portion of wall;
- Groundwater pressures, including seepage pressures;
- Soil type and strength;
- Effects of disturbance from construction equipment and/or freeze-thaw cycles.

Passive pressures may be obtained from the same reference sources as active pressures.

See Section B9.4.3 Active Earth Pressure.

Where the design method is based on:

- Beam analysis of the wall with elasto-plastic spring elements representing passive resistance; or
- Finite element model; or
- Finite difference model.

Use soil stiffness or modulus values compatible with the model used.

Submit computer programs used for design to MX LRT for review and acceptance prior to use.

For retaining walls relying on passive resistance from embedded portions of the wall below the excavation base, calculate pressure per Figure B9-3.

Take 0.5 as the resistance factor Φ to be applied to the passive pressure.

Consider disregarding passive pressure immediately below the bottom of excavation due to possible disturbance or loosening of ground immediately adjacent to the support wall due to excavation support installation.

FIGURE B9-1 DESIGN LATERAL EARTH PRESSURE DISTRIBUTION BRACED EXCAVATION IN COHESIVE SOILS

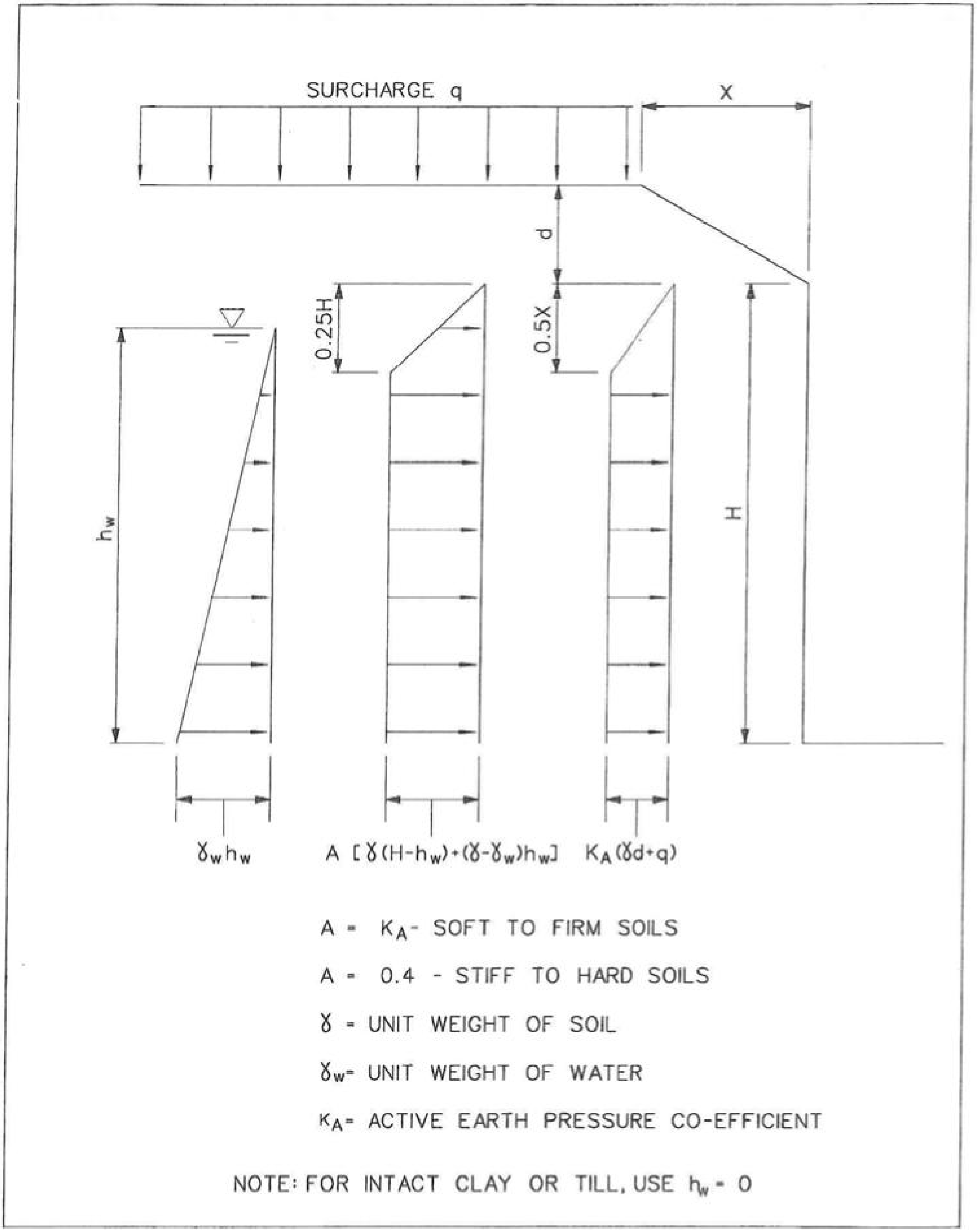
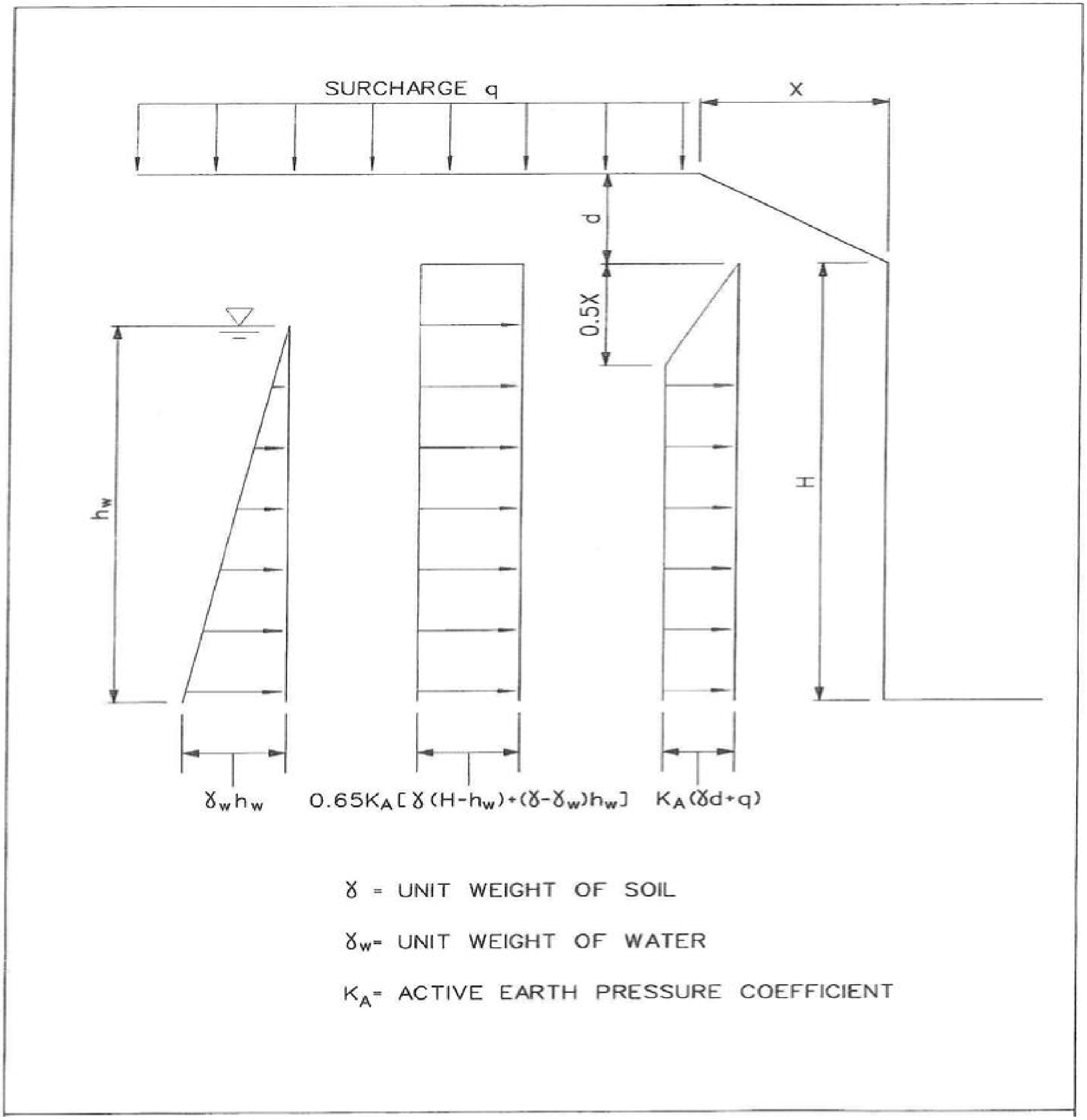


FIGURE B9-2 DESIGN LATERAL EARTH PRESSURE DISTRIBUTION BRACED EXCAVATION IN COHESION-LESS SOILS



B9.4.4 Struts

Either calculate the design load in a strutting system from Figure B9-1 and Figure B9-2 or check using these Figures per Section B9.4.3 Active Earth Pressure.

Generally preload strutted retaining system struts to reduce deflections where buildings or utilities are within the excavation Zone of Influence.

In preloading consider ground type, expected deformation pattern and magnitude within supported ground, and construction sequence.

Apply preload less than that required to induce passive failure in the retained soil.

Confirm actual strut loading through appropriate instrumentation and monitoring.

Do not remove any strut without providing adequate alternative support to the retaining wall.

Alternative support such as replacement struts or tie-backs may be provided by the permanent structure or by compacted backfill placed around or over the permanent structure.

B9.4.5 Anchors and Rakers

General

Anchors are generally placed in rows, the number of rows dependent on anchor capacity, spacing, design earth pressure, and wall height.

For a single row of anchors, the shoring system is statically determinant and anchor load may be calculated using moment and force equilibrium.

For multiple anchor rows, calculate anchor loads on a top down basis per the CFEM method.

Deadman Anchors

Deadman anchors are installed behind shoring systems and rely on passive resistance at their face to mobilize horizontal resistance.

Deadman anchors may be cast-in-place or precast concrete blocks or drilled piers.

Locate deadman anchors outside the active wedge of soil behind the retaining structure.

The active wedge of soil behind the retaining wall and the passive wedge of soil in front of the deadman anchor are not to intersect.

See Figure B9-4 for preferred deadman anchors locations.

Calculate passive resistance mobilized in front of deadman anchors per the same considerations as for passive resistance mobilized at the toe of retaining structures.

See Section B9.4.3 Passive Toe Restraint.

Grouted Anchors (Tiebacks)

The basis of design for grouted anchors, or tie-backs, is fixed (bond) length and free length.

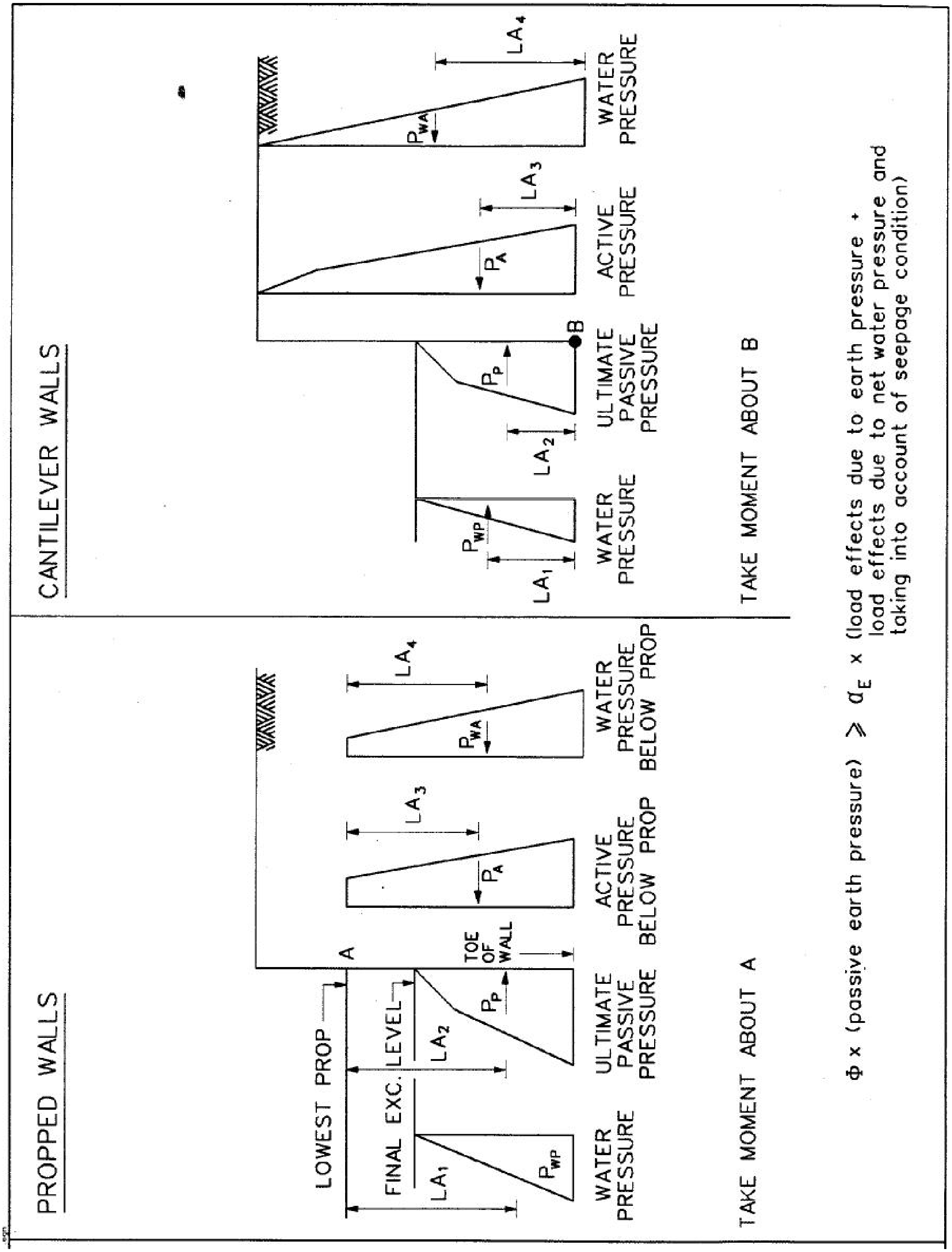
The free length extends beyond the active zone of soil behind the wall and, for design purposes, extends an additional distance beyond the theoretical active wedge of 15% wall height.

The minimum required free length is indicated in Figure B9-5 but is 4.5 m minimum for strand type anchors and 3 m minimum for bar type anchors.

Consider the need for construction easements to install tiebacks and the potential need to distress or remove anchors upon completion.

Also consider whether future construction may disturb the ground around anchors thus reducing their capacity.

FIGURE B9-3 ULTIMATE LIMIT STATES CONDITION – MINIMUM EMBEDMENT OF RETAINING WALLS



Design fixed length of anchor based on surface area of grouted zone and friction or adhesion (bond) stress.

Bond lengths greater than 8 m not recommended as resistance may not be fully mobilized beyond this length.

This does not apply to post-grouted tie-backs/anchors.

Assess ultimate bond stress for cohesion-less soil based on:

- Effective overburden stress;
- Soil type and gradation;
- Relative density;
- Experience with similar soils.

Assess ultimate bond stress for cohesive soils based on:

- Undrained shear strength of the soil;
- Soil plasticity;
- Experience with similar soils.

Anchors may not be suitable for some cohesive soils, e.g., soils with high creep characteristics.

For anchored excavations:

- Safety factor for overall stability of excavation along any theoretical failure plane not intersecting the fixed length of an anchor is to meet or exceed the values per Section B9.4.2;
- Stress (factored load effects) induced by anchor on soil under anchor head is not to exceed the factored bearing resistance of the soil;
- Design anchor head and retaining system to resist both horizontal and vertical components of anchor force without failure or excessive movement;
- Design anchor per criteria for Serviceability Limit States and Ultimate Limit States.

FIGURE B9-4 MINIMUM DEADMAN ANCHOR SETBACK FROM FACE OF RETAINING WALL

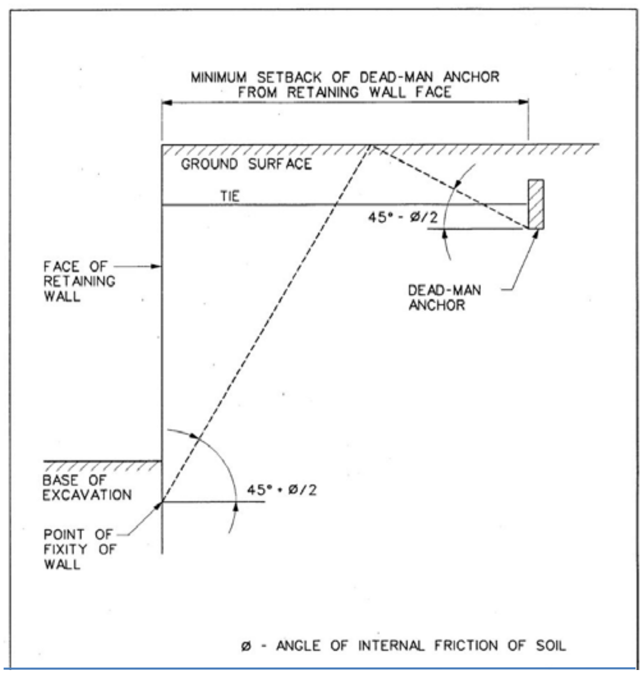
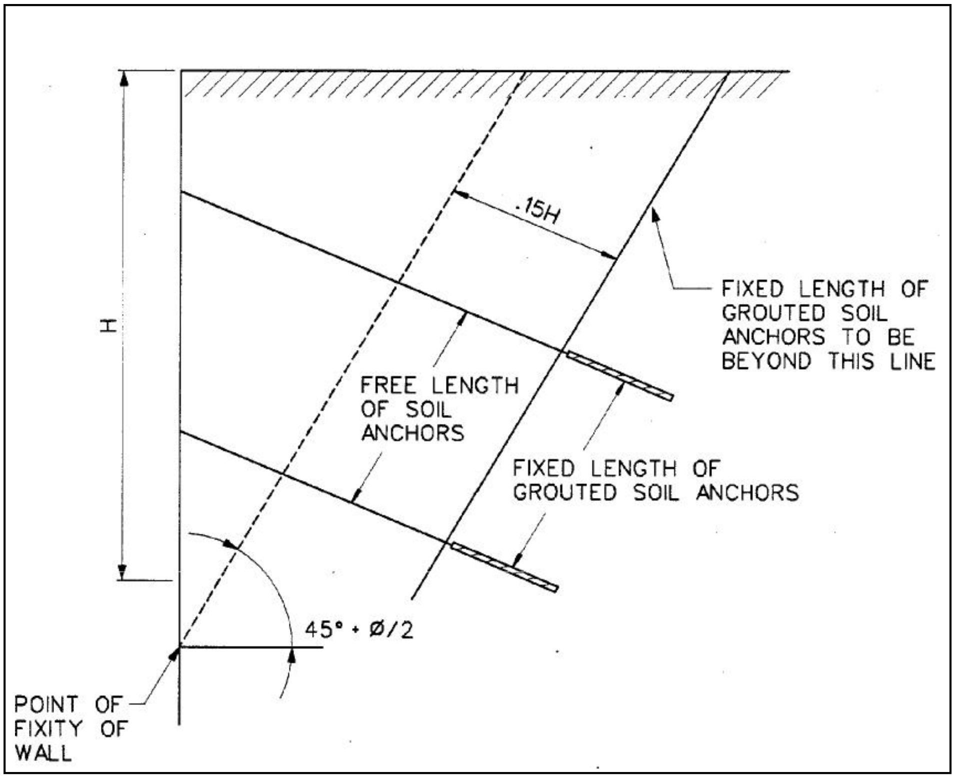


FIGURE B9-5 MINIMUM FREE LENGTH OF GROUTED ANCHORS



Investigate anchors for Serviceability Limit States of excessive anchor displacement and associated wall or excavation movement.

Investigate anchors for Ultimate Limit States of:

- Bearing resistance for deadman anchors;
- Anchor pullout failure;
- Tendon structural failure.

The factored geotechnical resistance of anchors calculated for Ultimate Limit States is nominal resistance multiplied by an appropriate resistance factor, Φ, per TABLE B9-1 below.

TABLE B9-1 RESISTANCE FACTORS FOR ULTIMATE LIMIT STATES FOR ANCHORS

Resistance Category	Resistance Factor Φ
Pullout resistance of geotechnical anchors	
(a) temporary anchorage	0.65
(b) permanent	0.4*
Shearing resistance between grout and tendon (structural)	
(a) temporary anchorage	0.65
(b) permanent anchorage	0.50
Tensile resistance of steel tendon (structural)	
(a) temporary anchorage	0.80
(b) permanent anchorage	0.65

* Creep considerations in clay may require a lower geotechnical resistance factor.

An anchor is considered temporary if:

- It does not form part of a permanent structural system; and
- It will not be required to carry load for more than two years.

Design anchors to safely withstand every combination of factored loads.

Calculate anchor resistance using CFEM suggested methods.

Anchor geotechnical resistance obtained per requirements stated here are for single anchors acting independently.

For anchors to behave independently the minimum horizontal and vertical spacing is the greater of four times the bonded anchor diameter or 20% of the bond length.

Anchor Testing

Conduct three types of test for anchors:

- Performance Tests;
- Proof Tests;
- Lift-Off Tests.

Conduct performance tests on selected production anchors to substantiate design parameters used to define acceptable performance of service anchors.

Conduct performance tests per CFEM procedures.

Performance tests may vary from CFEM with regard to working load and holding times but only at the discretion of the design engineer, per generally accepted principles and current industry practice, supported by published current industry references, and with MX LRT concurrence.

Conduct proof tests on production anchors not subject to performance test per CFEM procedures.

Lift-Off tests use a stressing jack placed over the anchor stressing head to lift it clear of the seating plate and record the tendon load using the jack pressure gauge or load cell.

Conduct lift-off testing per CFEM procedures.

Complete lift-off testing at least 24 hours but no more than 7 days after tieback has been set to design load.

See Table B9-2 for frequency of testing required for both temporary and permanent anchors.

See Table B9-3 for test loads.

TABLE B9-2 ANCHOR TESTING FREQUENCY

Performance Tests	Proof Tests	Lift-Off Tests
Not less than 1 anchor per level of tiebacks and/or 1 per soil type encountered in fixed anchor length per level of tieback. Not less than 5% of anchors at a site and/or at least 1 anchor.	All anchors except those on which a performance test has been conducted.	All anchors.

TABLE B9-3 ANCHOR TEST LOADS

Performance Tests	Proof Tests	Lift-Off Tests
To be determined by anchor designer but not to exceed 0.8 x fpu	1.33 × D.L.	Re-apply load to tendon to lift off wedge plate or anchor nut without unseating wedges or turning anchor nuts

D.L. = Design Load

f_{pu} = characteristic ultimate strength of tendon

Raker Systems

Calculate raker loads by a suitable method such as the top-down basis per CFEM.

Normally use shallow spread footings at the excavation base to resist raker loads.

Design footings per Section B9.9.

Calculate raker footing ultimate bearing resistance considering:

- Soil type and strength;
- Inclination of load;
- Dimensions and depth of footing;
- Pore water pressures.

Horizontal distance between raker footings and base of wall is 1.5 times minimum the depth of wall penetration below excavation base.

Excavation adjacent to raker footings is not allowed.

Adequately protect construction raker footings against frost penetration in winter.

B9.5 Groundwater Control

B9.5.1 General

Groundwater control in, around, and below temporary excavation may be required in order to:

- Prevent excavation base flooding;
- Prevent piping failure at excavation base;
- Prevent excavation uplift/heave;
- Increase passive pressure below excavation base;
- Minimize disturbance of excavation base founding soils;
- Improve stability of temporarily unsupported soils; and
- Decrease pressure acting on excavation support systems.

Methods available for groundwater control include:

- Sumps;
- Cut-off walls; and
- Dewatering systems, e.g., well-points, eductors, deep wells, etc.

Other requirements include obtaining MOE Permits to Take Water and testing for groundwater discharge to sewer systems according to municipal by-laws of AHJ.

Submit applications for permits to discharge water into sewer systems to AHJ for review and acceptance.

B9.5.2 Requirements

Where dewatering is required only to prevent excavation flooding, provide appropriately sized and filtered sump pumps sufficient for groundwater control.

Sumps are unsuitable for groundwater control where groundwater lowering to prevent base failure or disturbance to founding soils is required.

In case of potential base failure, provide wall penetrations and/or groundwater drawdowns required to maintain a stable excavation bottom.

Where excavation base soils are used to found permanent structures or raker footings, provide excavation groundwater control appropriate to maintain groundwater level 0.6 m minimum below excavation base.

Where groundwater control is essential to successfully complete and maintain the excavation, specify and provide the required retaining system piezometric levels for each stage of the work.

Provide monitoring of excavation groundwater pressures at frequencies sufficient to verify successful performance of groundwater control systems.

When groundwater control is specified, consider the need to comply with governing regulations for groundwater extraction and disposal including but not limited to:

- MOE Environmental Protection Act, Ontario Water Resource Act and Water Taking Regulation;
- Toronto and Region Conservation Authority; and
- Toronto Municipal Code for Sewers, Chapter 681.1 (By-Law 457.2000).

Provide monitoring programs for potential dewatering impacts.

Provide contingency plans to mitigate dewatering impacts, e.g., provision of irrigation for groundwater dependent vegetation during the growing season, the period of dewatering, or during drought periods;

Do not allow discharge of extracted water into natural or treed areas or over the face of ravines and slopes.

Prevent potentially adverse hydro-geological impacts per Section B9.7.

Analyze construction effects on the groundwater regime for effects on adjacent structures.

Consider whether to reduce the quantity of groundwater extracted or limit the area extraction affects by:

- Installing cut-off walls and plugs below the excavation;
- Installing recharge wells;
- Using shoring systems designed to minimize groundwater flow, e.g., diaphragm walls, rather than walls that do not restrict groundwater flow, e.g., soldier pile and lagging.

Demonstrate that no negative impact will result to adjacent trees or vegetation that may depend on existing near-surface groundwater conditions per regional conservation and urban forestry AHJ.

B9.5.3 Monitoring

Limit groundwater level fluctuations due to excavation.

Set limits to acceptable groundwater lowering for every type of excavation.

Enforce compliance with these limits.

Groundwater monitoring programs comprise observation wells and piezometers installed and read for a period of time before start of excavation and lasting throughout the construction process.

B9.5.4 Seepage

Estimate seepage into excavation inverts using numerical modeling techniques taking into consideration boundary conditions, soil stratigraphy, and hydro-geological parameters.

B9.6 Retaining Structures

B9.6.1 General

Provide retaining structures to satisfy the criteria for Serviceability Limit States and Ultimate Limit States.

Evaluate Serviceability Limit States using unfactored geotechnical properties and appropriate combinations of loads per Chapter B4 - Structures.

Include the evaluation of horizontal and vertical deformation in analysis of the Serviceability Limit States for retaining structures.

Determine movement of retaining structures and structural tolerances in consultation with structural designers.

Ultimate Limit States for retaining structures include evaluation of:

- Bearing failure;
- Lateral sliding;
- Overturning;
- Overall (global) stability;
- Resistance of supports;
- Structural failure.

Obtain factored resistance by multiplying ultimate geotechnical resistance by an appropriate resistance factor per Table B9-4.

Calculated factored resistance must meet or exceed combinations of factored loads based on friction, i.e., effective stress strength parameters.

TABLE B9-4 RETAINING STRUCTURES ULTIMATE LIMIT STATES RESISTANCE FACTORS

Description	Resistance Factor
Horizontal Passive Soil Resistance Sliding of Footing Based on: • Friction Effective Stress Strength • Cohesion/adhesion Anchor Pullout Resistance	0.5 0.8 0.5 Per Section B9.4.5
Footing Bearing Resistance	Per Section B9.9.4
Overall Stability	1.5 Minimum Safety Factor

Determine total earth pressure acting on each side of the retaining structure (active or passive) taking into account earth load, surcharge, water pressure, and seepage pressure.

Determine nominal earth pressures on retaining structures per CFEM suggested methods.

Determine factored load due to earth pressure, groundwater pressure, and seepage pressure multiplying these pressure components by appropriate load factors per Chapter B4 - Structures.

Where retaining walls are founded on deep layers or strata of cohesive soils, failure occurring along a surface passing at some depth below the wall is a possibility.

Check stability of soil mass containing the retaining wall with respect to the most critical surface of sliding.

Use 1.5 minimum safety factor.

B9.6.2 Basal Stability

General

For each temporary excavation the base must remain stable for each successive stage of excavation including the lowest level.

Base failure conditions depend on subsurface conditions below the excavation bottom.

Conditions where base stability is of particular concern include:

- Weak cohesive soils below the excavation base;
- Cohesion-less soils below the groundwater level at or near the excavation base;
- Relatively impermeable deposits at the excavation base underlain by water-bearing permeable deposits.

Apply procedures per CFEM in basal stability analysis.

Weak Cohesive Soils Below Excavation Base

Excavation base heave in clays occurs as a result of shear failure below the shoring system base.

The safety factor against such failure depends on:

- Total stress (overburden pressure and surcharge) outside the shoring system at excavation base level;
- Undrained shear strength of the clay below the excavation base;
- A stability factor based on excavation geometry.

Use 1.5 minimum global safety factor against base heave.

A higher safety factor may be required to limit settlement in the vicinity of the excavation.

Cohesion-less Soils Below Groundwater Table

Unless prior dewatering is carried out in cohesion-less soils where excavation occurs below the water table, upward seepage into the excavation causes a reduction in soil strength and may result in “quick” conditions.

Provide 1.5 minimum safety factor for sheet pile walls, contiguous caisson walls, tangent pile or secant pile walls, and diaphragm walls penetrating cohesion-less deposits and partially cutting off seepage against piping.

Consider the effect of seepage pressure on passive resistances for upward seepage at toe of wall.

Water-Bearing Permeable Deposits

Water-bearing permeable deposit pore water pressure may heave less permeable over-lying deposits.

Use 1.1 minimum global safety factor where calculated uplift safety factor is ratio of soil weight to maximum possible uplift force.

In calculating uplift resistance with shear strength included, use 1.5 minimum global safety factor against heave.

B9.7 Permanent Cut Slopes

B9.7.1 General

Design permanent cut slopes to:

- Provide adequate safety factor against shallow and deep-seated slope failure modes;
- Resist surficial erosion and slumping types of failure;
- Control discharge of surface water and subsurface seepage;
- Allow for regular maintenance of the slope surface.

B9.7.2 Deep Seated Failure Safety Factor

The minimum design safety factor against slope failure for a given location is related to the degree of certainty or confidence in ground and groundwater conditions per site-specific geotechnical investigations, consequence of failure, methods used to determine soil parameters, and type of ground forming the slope.

In general, use 1.5 minimum safety factor as calculated by limit equilibrium or strength reduction methods for design of permanent cut slopes.

A higher safety factor may be required to accommodate site-specific or special conditions.

In these instances use the minimum design safety factor required per the Geotechnical Design Summary/Baseline Report.

Calculate safety factors using commercially available industry accepted limit equilibrium or strength reduction method computer software with a proven track record accepted by MX RT.

Calculate safety factors using long-term effective stress shear strength parameters with pore water pressure conditions appropriate to final slope geometry and drainage conditions.

Determine the minimum safety factor for each section of slope based on both analysis and search of circular and non-circular slip surfaces specifically including those that may exist through weak layers.

Several different sections of permanent cut slopes require analysis to assess the minimum safety factor.

The sections of slope to consider for analysis include:

- Section of slope formed of the weakest ground;
- Highest section of a slope;
- Section of slope with the steepest surface gradient;
- Section of slope with the highest groundwater conditions;
- Section of slope with the highest external loads/surcharge;
- Section of slope adjacent to critical structures either at top or bottom of slope.

B9.7.3 Surface Treatment

General

Permanent cut slopes require drainage and surface treatment to protect against surface slope failures that can lead to short term service interruptions and may ultimately lead to deep-seated slope failure.

Provide continuous slopes up to 8 m high with constant surface gradient.

For slopes greater than 8 m high, incorporate horizontal surface benches at least 2 m wide with a lined surface drainage ditch or swale for each bench with height between benches based on stability analyses and surface drainage considerations as appropriate.

Surface Drainage

Direct surface water collected behind the slope crest away from the slope surface.

Collect and discharge water falling on the slope surface away from the slope in a controlled manner.

Provide slope ditches, swales, and discharge pipes with discharge capacity per Chapter B3 – Civil Works.

Provide ditch and swale linings of vegetation, stone, or concrete to resist anticipated erosion forces in design storm conditions.

Subsurface Drainage

Provide subsurface drainage for slopes surfaces with water-bearing deposits, layers, seams, or lenses to control seepage, soil piping, and excessive pore water pressure within the slope.

Options for suitable drainage include surface and subsurface drainage blankets, near-surface French drain systems, and interceptor drains behind the slope crest.

Base subsurface drainage systems on slope geometry and location, size, and extent of water-bearing soils.

Provide appropriate filters to adequately control migration of soil into and out of subsurface drains.

Provide drainage works generally per OPSS.

Surface Treatment

Provide cut slope surface treatments to adequately resist wind and water run-off erosion.

Consider surface treatments such as sod, vegetation, legumes, wild grasses, and wild flowers.

Suitable vegetation cover normally offers sufficient erosion protection for slopes with benching and adequate sunlight and moisture to sustain plant growth and where surface run-off behind the crest is well controlled.

Where treed or naturalized slopes, provide adequate topsoil depth, benched as appropriate for stability, ranging from 30 cm for grass, wild flowers, and legumes, to 1.2 m for large-canopy deciduous tree species.

For permanently covered cut slopes, e.g., under bridges, provide inorganic surface treatments such as concrete, shotcrete, and/or suitably sized and placed rip-rap.

Provide filters that are stable under every condition below rip-rap to adequately control wash out of soil fines.

Provide concrete or shotcrete surface treatment with suitable blanket granular underdrains and weep holes discharging to frost-free outlets to adequately control build-up of pore water pressure.

Hydro-Geological Effects

Consider potential adverse hydro-geological effects resulting from permanent cut slopes changing the groundwater regime including:

- Migration or changes in groundwater flow patterns including possible transport of contaminants;
- Loss of adequate bearing under foundations;
- Ground movement;
- Reduction in water level of existing wells, ponds, or other bodies of water outside the Right-of-Way.

Assess the need to treat drain and sump water before disposal both during construction and in the long term.

B9.7.4 Maximum Gradient

The maximum permanent slope gradient calculated from analysis for resistance against deep-seated slope failure may exceed slope surface serviceability requirements.

For vegetated slopes, maintenance requirements, e.g., lawn mowing, replanting, etc., and freeze-thaw cycle soil softening limit the maximum practical slope gradient to 1 vertical in 3 horizontal.

B9.8 Cut-and-Cover Structures

B9.8.1 General

Provide cut-and-cover Stations, structures, and tunnels built in temporary open excavations per Section B9.4.

Specific geotechnical issues to be addressed for permanent cut-and-cover structures include:

- Earth pressure including groundwater pressure;
- Resistance to uplift; and
- Backfill requirements.

B9.8.2 Earth Pressure

Vertical Earth Pressure

Provide cut-and-cover roof structures to resist total overburden pressure calculated based on backfill density and thickness including dead and live surcharge load allowances per Chapter B4 - Structures.

Horizontal Earth Pressure

Use triangular earth pressure distribution appropriate for cut-and-cover propped wall structures.

Apply lateral earth pressure coefficients corresponding to characteristic at-rest (Ko) conditions appropriate to adjacent native ground or backfill soils to determine characteristic earth pressure distribution magnitude.

For structures built against native undisturbed soils, preferably base KO coefficients on in-situ testing methods, i.e., pressure meter, cone penetration, or dilatometer, where available, or a minimum value of 0.5.

Note that KO values higher than 0.5 are present in over-consolidated glacial tills and clays in the GTHA, with typical values measured between 0.4 and 0.9.

Consider compaction stresses higher than calculated for KO conditions per the above basis for relatively shallow cut-and-cover structures with compacted fill adjacent to the structure.

Allow for ground surface live and dead surcharge loads in developing lateral earth pressure distribution.

Provide waterproof underground structures including groundwater horizontal pressure distribution appropriate to maximum anticipated groundwater table elevation.

B9.8.3 Frost

Consider measures to prevent potential build-up of large additional pressures due to frost action on structures including one or more of the following:

- Using free draining non-frost susceptible soils as backfill;
- Removing water within the zone subject to freezing with adequate drainage;
- Providing insulation;
- Providing heating (temporary works only).

Structures where frost penetration is of particular concern include:

- Portals and structures within 20 m of portals;
- Vent shafts and/or openings to the surface.

B9.8.4 Flotation Uplift

For watertight underground structures below the groundwater table, significant flotation uplift forces occur.

See Section B9.10 for bored tunnels.

Resistance to this flotation force is offered by:

- Dead weight of the structure;
- Sufficient tensile capacity and flotation weight of caissons, piles, or retaining walls;
- Weight of permanent backfill placed directly above the structure;
- Structure invert slabs designed to resist flotation uplift pressure.

Calculate flotation uplift force based on anticipated highest groundwater pressure at underside of structure.

Apply 1.0 load factor to calculate flotation uplift forces.

Apply 0.9 resistance factor to calculate flotation resistance.

Maintain resistance against flotation uplift at every stage of construction.

Ignore frictional resistance of soil against flotation uplift in the analysis.

Sufficient temporary pressure relief with a flotation uplift resistance factor of 0.9 may be used.

See Section B9.5 for temporary groundwater control.

Friction piles to assist in resisting flotation uplift forces may be used provided redundancy is built in.

Apply reduction factors to friction pile flotation uplift resistance capacity based on type of structure, loading, soil, and groundwater conditions.

B9.8.5 Backfill

Materials

Backfill above cut-and-cover structures with locally excavated materials meeting current MOE Environmental Protection Act Standards for site use and location wherever possible.

Consult MX LRT for guidance where exceptions occur.

Suitable materials for backfill and compaction must be free of organic matter with maximum particle size half the lift thickness per OPSS and water content within 2% of optimum moisture content for compaction per Standard Proctor Maximum Dry Density Test ASTM D698.

If locally excavated ground is not suitable for backfill, use imported soils per above requirements.

Use non-shrink backfill in selected areas of structures or utilities to meet specific performance requirements.

Open Areas

Where structures, roads, and/or buildings will not be built above, cut-and-cover structure excavations may be backfilled with local material compacted to 90% of its Modified Proctor Maximum Dry Density.

Place backfill in lifts not to exceed 300 mm loose thickness.

Paved Areas

Where paved roads or parking areas will be built above cut-and-cover structures, locally excavated ground may provide suitable backfill so long as the overlying permanent structure accommodates a compacted fill subgrade.

In this case, compact backfill consisting of locally excavated ground to 95% of its Standard Proctor Maximum Dry Density for earth materials per OPSS 501 and AHJ standards.

Place backfill in loose lifts not to exceed 200 mm loose thickness.

Compact pavement granular base and sub-base courses to 100% of its Modified Proctor Maximum Dry Density.

Where narrow excavations, e.g., utility trenches, are to be backfilled below road Rights-of-Way, use unshrinkable fill (TS-13.10) in place of compacted earth materials.

Tapered transition zones are to be designed near the subgrade level so that unacceptable, abrupt differences in subgrade performance do not occur over short distances.

Consider compressibility of in-situ soil and compacted backfill in the geometry of such transition zones.

Other Structures

For other structures such as stations and track foundation slabs built over cut-and-cover structures, provide backfill placement and compaction designed in association with the overlying structures.

To meet the requirements of the overlying structure, imported granular materials may be necessary with compaction densities at 100% of Standard Proctor Maximum Dry Density.

B9.9 Foundations

B9.9.1 General

Foundations are to be designed to transfer loads from the structure to the subsurface such that resulting deformations do not damage the structure.

To achieve this objective the foundation design must:

- Provide adequate security against bearing failure;
- Maintain settlement within tolerable limits;
- Provide adequate resistance to lateral and torsional loads;
- Contain lateral movement within tolerable limits.

These design elements require that the following factors be considered:

- The tolerance of the proposed structure to movement;
- The nature and distribution of applied load effects;
- The type, strength and deformation properties of the ground;
- The groundwater conditions;
- The extent of subsurface data;
- Frost penetration;
- Future excavation or erosion;
- Difficulty and risk during construction;
- Effects of construction on adjacent facilities.

Establish tolerance of proposed structures to movement as part of the structural design and, more specifically, differential settlement as a significant structural input to foundation design for each specific structure.

Guidelines for structural tolerance of framed buildings and load bearing walls are provided in Table B9-5.

Consider each structure individually and use Table B9-5 values only as a guide.

TABLE B9-5 GUIDELINES FOR SETTLEMENT OF FRAMED BUILDINGS AND LOAD BEARING WALLS

Type of Damage	Criterion	Limiting Value
Structural Damage	Angular Distortion	1/150 – 1/250
Cracking in walls and partitions	Angular distortion	1/500 1/1000 – 1/1400; end bays
Visual appearance	Tilt	1/300
Connection to services	Total settlement	50 – 75 mm; sands 50 – 135 mm; clays
Cracking by relative sag*	Deflection ratio	1/2500; wall length/height = 1 1/1250; wall length/height = 5
Cracking by relative hog*	Deflection ratio	1/5000; wall length/height =1 1/2500; wall length/height =5

*For unreinforced load bearing walls.
Reference: Canadian Foundation Engineering Manual

Verify structural tolerances in consultation with the structural designer.

Compare cost and design implications of various foundation alternatives related to structural design alternatives to determine the most economical overall arrangement that satisfies the design requirements.

The principal foundation alternatives available are:

- Spread footings;
- Rafts;
- Deep foundations (driven piles, drilled piers).

Design footings to satisfy the criteria for Serviceability Limit States and Ultimate Limit States.

B9.9.2 Serviceability Limit States

Evaluate Serviceability Limit States using unfactored loads and unfactored geotechnical properties and characteristics.

Include evaluation of the following in Serviceability Limit States for foundation design:

- Settlement;
- Lateral displacement;

See Section B9.9.1 for settlement and lateral displacement design requirements.

B9.9.3 Ultimate Limit States

Include evaluation of the following in Ultimate Limit States for foundation design:

- Bearing resistance;
- Overturning;
- Sliding at the base of footing;
- Loss of overall stability;
- Structural capacity.

Factored resistance for Ultimate Limit States is nominal resistance multiplied by appropriate resistance factor Φ.

Design foundations so that factored resistance is greater than any combination of factored loads.

Use shallow spread footing and deep foundation bearing capacities per Canadian Foundation Engineering Manual methods.

B9.9.4 Spread Footings

General

Consider spread footings as the first option in foundation design as they often provide the most economical foundation alternative for a structure.

Bearing Resistance

The ultimate bearing resistance of shallow spread footings may be determined from Terzaghi's Theory of Bearing Capacity.

In calculating the safe bearing pressure for shallow spread footings, the following factors must be considered:

- The angle of inclination of the applied load;
- The eccentricity of the applied load;
- The shape, dimensions and depth of the footing;
- The in-situ strength of the underlying founding soil and any strength losses which may arise as a result of construction;
- Groundwater pressures and conditions.

Table B9-6 provides Ultimate Limit States geotechnical resistance factors for shallow spread footings.

TABLE B9-6 ULTIMATE LIMIT STATES GEOTECHNICAL RESISTANCE FACTORS FOR SHALLOW SPREAD FOOTINGS

Description	Resistance Factor
Bearing resistance by semi-empirical analyses using laboratory and in-situ test data	0.5
Sliding:	
• Based on friction	0.8
• Based on cohesion	0.6

Reference: Canadian Foundation Engineering Manual

Settlement

Design shallow spread footings to meet settlement tolerances of structures.

The settlement tolerance of a structure is generally based on differential settlement, whereas settlement calculation methods provide estimates of total settlement.

The settlement assessment of a foundation therefore accounts for the variability of subsurface conditions across a site so that the foundation accommodates a range of differential settlements.

Methods available for settlement analysis include:

- Direct empirical correlation with in-situ and laboratory test data;
- Elastic theory;
- Consolidation theory.

Select a design analysis method that is appropriate to:

- The subsurface conditions;

- The available data;
- The level of design refinement required.

More sophisticated settlement theories and calculations only apply where design refinement may provide significant cost benefit and where site data quality is consistent with the analytical technique.

Base settlement design calculations on dead loads plus permanent live loads only.

The presence of deep fills or soft soils may preclude the use of shallow footings.

Consider and evaluate ground improvement methods such as the installation of geo-piers to improve the soil and to allow shallow spread footings as a more cost effective foundation over deep foundations.

Frost Protection

Design shallow spread footings to avoid detrimental effects due to frost action.

The conventional approach for protection of footings is to locate the bearing surface at a depth greater than the design depth of frost penetration.

For Toronto this depth may be taken as 1.2 m.

Evaluate insulation methods to protect foundations where site and design conditions prevent such embedment.

Design of insulated foundations must consider both the required insulation thickness and its placement geometry.

Structures where frost penetration is of particular concern include:

- LRT Surface Platform Foundations;
- LRT Surface Trackbed Slab at Surface Stop Platforms.

At-grade platforms and trackbed slabs must not heave due to frost action in order to meet strict Accessibility for Ontarians with Disabilities Act requirements for LRV level boarding.

Design at-grade platform foundations bearing below frost line.

In addition, support at-grade trackbed slabs adjacent to platforms on non-frost susceptible soil backfill (Granular Type A) placed to depth below frost line.

Provide a 5 m minimum long transition zone of non-frost susceptible soil backfill beneath at-grade trackbed slabs at each end of platform to allow smooth transition between platform and non-platform areas.

Provide geotextile filter fabric between subgrade and backfill material.

Provide suitable drainage such as perforated PVC pipe for non-frost susceptible soil backfill under the trackbed.

B9.9.5 Raft Foundations

General

Raft foundations consisting of large reinforced rigid slabs may be considered as an alternative to shallow spread footings when:

- The combined area of individual spread footings is about half the area of the footprint of the structure;
- Resistance to flotation uplift forces is required;
- Subsurface soil contains weak and compressible lenses;
- Tolerable differential settlements are particularly low.

Bearing Capacity

Raft foundations differ from shallow spread footings only in their dimension.

The bearing resistance design considerations provided in Section B9.9.4.2 are also applicable to raft foundations.

The ultimate bearing capacity of raft foundations does not usually govern their design because of the relatively large width.

Where a raft foundation is founded on or above soft to firm clays, however, the ultimate bearing capacity must be checked and must consider the shear strength of the soil over a depth equal to the raft width.

Settlement and Frost Protection

Design for settlement and frost protection for spread footings and raft foundations per Section B9.9.4.

Slab Design

The structural design of the raft slab is normally based on the theory of slabs on elastic foundations.

Provide a Geotechnical Design Summary Report with design values for modulus of subgrade reaction.

Select modulus of subgrade reaction based on:

- Soil type, compressibility, relative density, or consistency;
- Groundwater level;
- Size, shape and depth of raft slab;
- Depth to rock.

Variations in the subgrade modulus over the raft area must be considered and provided.

Where variations are significant, the designer may consider the placement of engineered fill beneath the raft to provide greater uniformity.

B9.9.6 Deep Foundations

General

Deep foundations transfer structural loads to competent bearing soils or rock located beyond the proposed depth of a structure.

Deep foundations are usually considered where the soils immediately below the structure cannot provide adequate bearing for the structure and where excavation to competent bearing soils is too costly or too risky.

Pile Types

There are a wide variety pile types that can be grouped into two broad categories; driven preformed piles and bored cast-in-place concrete piles.

A listing and grouping of various deep foundation systems is provided in Table B9-7

TABLE B9-7 DEEP FOUNDATION SYSTEMS

Driven Piles		
Large Displacement	Preformed Solid	Timber, precast concrete
	Preformed Hollow	Steel tubes – closed ended Steel box piles – closed ended Concrete tubes
	Formed in-situ	Dynamically cast-in-place Proprietary systems, e.g., Franki piles)
Small Displacement	Preformed	Steel H-piles* Steel tubes – open ended* Steel boxes – open ended*
Bored Piles		
Non Displacement	Formed in-situ	Permanently cased Bored piles (caissons) Temporary supported bored piles (casing or drilling mud) Unsupported bored piles Helical Piers/Anchors (no vibration or dewatering required)

*Consider these piles as large displacement piles over the length driven through competent soils.

Selection of Pile Type

Select suitable type of deep foundation (pile) systems based on the following factors:

- Magnitude, direction and nature of structural loads;
- Depth to the founding stratum;
- Type of founding stratum and its physical properties;
- Groundwater conditions;
- Extent of subsurface data;
- Subsurface conditions between the ground surface and the founding elevation;
- Effect of foundation construction on adjacent structures.

Select deep foundation type and size, specify minimum founding depth or pile set criteria, and determine number of foundation units and group configuration.

Where specific deep foundation types have been excluded based on factors listed above, list these foundation exclusions for MX LRT review and acceptance.

Bearing Capacity

For piles driven to refusal in rock or refusal in soil, the structural capacity of the pile member and not the bearing capacity of the supporting subsoil or rock governs ultimate bearing capacity.

Driving criteria (setting) for the pile must ensure proper bearing while avoiding pile damage due to overdriving.

The designer must provide the set criteria to define pile refusal and specify the pile hammer energy at which the set criteria applies.

Carry out a restrike test to confirm the bearing capacity of driven piles.

Define the schedule of short and long term restrike tests.

For bored piles or piles which are not driven to refusal, the ultimate bearing capacity of the supporting soil or rock must be considered in the design.

In calculating the ultimate bearing capacity of piles the following factors must be considered:

- Type and strength of soils surrounding the pile and below the pile;
- Calculate short term (undrained) and long term (drained) bearing capacity for cohesive soils;
- Depth and diameter of the pile;
- Groundwater conditions;
- Increases or decreases in ground strength that may occur as a result of pile installation;
- Magnitude and relative contribution of end-bearing resistance and of shaft friction resistance;
- Reductions in bearing capacity of individual piles as related to pile group spacing.

The resistance factors for Ultimate Limit States for design of deep foundations are provided in Table B9-8.

Provide nondestructive testing for pile shaft integrity and base contact where installation methods or conditions could result in necking, segregation of concrete, cracking, breakage, or inadequate contact between toe of pile and founding stratum.

Determine the ratio of tested piles to total number of piles installed.

Place concrete for bored piles only using tremie methods.

The distance between bottom of shaft and bottom of tremie pipe is not to exceed 1.5 m.

As the tremie pipe is extracted, bottom of pipe is not to exceed a 1.5 m distance above surface of concrete already poured.

Do not use tapered piles acting as tension piles to resist uplift.

Lateral Capacity

Design piles to adequately resist lateral loads transferred to them from supported structure without allowing movement that would damage the structure or impair its function.

Where the lateral resistance of the soils surrounding the piles is inadequate to resist the horizontal forces transmitted to the foundation or when increased rigidity of the entire structure is required, raking piles may be used in a pile foundation.

Where piles are designed to carry significant lateral loads, test at least one pile in 50, or one pile every 100 m of line structure, to a lateral load of 1.5 times the design lateral load.

Settlement

Settlement of the pile group must be considered in design, as well as differential settlement between pile groups.

Settlement analyses may be based on the elastic methods of Poulos and Davis (Poulos, H.G. and Davis, E.H. [1974. Elastic Solutions for Soil and Rock Mechanics), or on the equivalent footing concept of Terzaghi and Peck.

As with spread footings and rafts, base the settlement calculation on a best estimate of deformation properties.

Multiply the estimate of settlement by an uncertainty factor for design.

For most situations an uncertainty factor of 2 is appropriate.

TABLE B9-8 RESISTANCE FACTORS FOR ULTIMATE LIMIT STATES FOR DEEP FOUNDATIONS

Description	Resistance Factor
Bearing Resistance to Axial Load (a) Semi-empirical analysis using in-situ and laboratory test data. (b) Analysis using static loading test results: • A minimum of one static load test to 1.5 times the unfactored design load per major founding stratum, per pile, or every 200 m of line structure. • A minimum of one advance (pre-production) pile is constructed per site, including at least one pile per main founding stratum, instrumented to measure load distribution along the pile shaft, and loaded to failure, or at least 80% of the calculated ultimate axial resistance, in addition to the static load testing given above. (c) Analysis using dynamic monitoring results In suitable soil conditions, where the capacity of at least 1 pile in 5 is checked using dynamic field monitoring analysis in addition to the static load testing given above, Resistance to Lateral Load	0.5 0.7 0.5 0.5
Resistance to Upward Axial (Tensile) Load (a) Semi-empirical analysis (b) Analysis using load test results:	0.3 0.4

Negative Skin Friction

Negative skin friction, arising from the settlement of relatively compressible soils adjacent to relatively rigid piles, must be assessed by the geotechnical engineer in the design of deep foundation systems.

The magnitude of the negative skin friction load must be calculated considering the following factors:

- The relative deformation between the pile and the adjacent soil over the length of the pile;
- The geometry of the pile and the pile group.

In evaluating the pile capacity, add the negative skin friction load to the dead load of the structure only.

Structural live loads and negative skin friction load do not need to be considered together.

B9.10 Bored Tunnels

B9.10.1 General

This section addresses criteria for the following:

- Tunnel Boring Machine (TBM) excavated tunnels in soils, typically supported by reinforced precast concrete segments bolted together to form continuous ring liners;
- Cast-in-place concrete liner for tunnel sections where precast concrete segments are not employed.

These design criteria also address:

- Design parameters;
- Loads and load combinations;
- Limit States to consider in the design;
- Safety factors;
- Segment design;
- Corrosion control design.

Design structures considering service life durability requirements.

Achieve bored tunnel design service life per applicable design codes, standards, and guidelines, and other professionally engineered industry standards for construction of similar structures.

See Chapter A1 - General.

B9.10.2 Tunnel Design

Design tunnels to be supported by precast concrete segment liners installed as TBM excavation progresses.

Design precast concrete segments for initial and permanent support of ground loads as well as live loads and seismic loads.

Design segments for loading conditions arising from manufacturing, transporting, handling, and erection as well as TBM thrust reaction.

Provide justification/documentation for every tunnel lining design loading case.

B9.10.3 Design Parameters

Precast Concrete

See Chapter B4 - Structures.

Cast-in-Place Concrete for Permanent Structures

See Chapter B4 - Structures.

Reinforcing Steel

See Chapter B4 - Structures.

Structural Steelwork

See Chapter B4 - Structures.

Soil Parameters and Groundwater Levels

The design of all structures will be based on the design parameters and groundwater levels presented in the Geotechnical Investigation Report (GIR) and Geotechnical Design Summary Report (GDSR) or Geotechnical Baseline Report (GBR), augmented as appropriate by Geotechnical Design Memoranda.

Parameters varying from those given in the various reports and/or memoranda listed above, may be used to address special local conditions for the design of particular structures, provided that those varying parameters are justified by site-specific geotechnical data.

B9.10.4 Loads

Basic Design Loads

The applicable loads for the design of TBM bored tunnels are:

- Dead Load;
- Live Load and Surcharge Load;
- Train Load;
- Other Internal Loads;
- Hydrostatic Load;
- Earth Load;
- Grout Pressure;

- Seismic Loads;
- Temperature Load;
- Fire Considerations.

These loads are as described in Chapter A3 – Safety, Chapter B4 - Structures and as follows.

General Surcharge Load

See Chapter B4 - Structures.

Allow for existing or future minor structures for which detailed information currently may not be available.

Use site specific surcharge loads where they are found to be critical load components.

Traffic Live Loads

See Chapter B4 - Structures.

Train Loads

See Chapter B4 - Structures.

Other Internal Loads

Consider other internal loads, such as utilities and fixtures installed on the lining where such loads constitute critical loading components for design of tunnel linings.

Hydrostatic Load

Take into account upper or lower bounds of groundwater level, whichever is more critical for the structure or condition being considered, in deriving hydrostatic loads.

See Chapter B4 – Structures for upper bound of groundwater level, ground surface, or flood levels described under "Hydrostatic Loads".

See Section B9.10.3.5 for lower bounds of groundwater levels.

Soil Overburden/Vertical Earth Pressure

In general, full overburden loads are to be used for the design of permanent structures.

For temporary structures, the earth pressure considered may be less than the full overburden.

Permanent structures, where cover is in excess of three tunnel diameters, may take advantage of ground arching or a reduced ground loading from that of the full overburden loads.

Provide justification for such loadings if used.

Provide documentation for tunnel lining design loading cases.

Lateral Earth Pressure

For permanent structures in general, lateral earth pressures are derived assuming at-rest conditions.

Due to the nature of a structure, e.g., shafts or temporary structures) reduced lateral pressure may be applicable.

Provide recommendations and criteria for lateral pressures per Section B9.10.3.5.

Consider critical combinations for respective vertical and lateral earth pressure maximum and minimum values.

Grout Pressure

Bored tunnels are compound structures consisting of the soil formation surrounding the tunnels and the tunnel liners.

Provide tunnel liners to support varying ground loads comprising earth loads defined above and anticipated grouting pressures, as applicable, per values specified in this section or established on a case-by-case basis by Geotechnical Design Reports or Geotechnical Design Memoranda per Section B9.10.3.5.

Seismic Loads

Use bored tunnel dual-level seismic design criteria with an upper level design earthquake to provide life safety performance objectives and a lower level design earthquake for operational performance objectives as follows:

1. Upper level design earthquake is a Maximum Design Earthquake (MDE**)** where probability of exceeding is approximately 4% in the 100-year design life of the tunnel, which corresponds to the 2% probability of exceeding in 50 years per National Building Code of Canada.

   This design event has a 2,500-year average return period.

   Design underground structures with adequate strength and ductility to survive loads and deformations imposed on the structures during the MDE thereby preventing structure collapse and maintaining life safety.

2. Lower level design earthquake is the Operating Design Earthquake (ODE) where probability of exceeding is approximately 20% in the 100-year design life of the tunnel, which corresponds to the same seismic event for lifetime bridges per Canadian Highway Bridge Code Section 4.4.

This design event has a 475-year average return period.

Design underground structures to respond in an essentially elastic manner when subjected to an ODE with no interruption in LRT service, no collapse, and no damage to primary structural elements, and structures remaining fully operational allowing for a few hours for inspection immediately after an earthquake.

Note that for those structures where analysis using the MDE indicates that the structure remains elastic, analysis using the ODE becomes unnecessary.

Include loading from seismic deformations and ground accelerations in bored tunnel analyses.

During earthquakes, underground structures move together with the surrounding geologic media.

Design structures to accommodate deformation imposed by the ground before, during, and after seismic events.

Bored tunnels undergo three primary modes of deformations during seismic shaking: a) Ovaling deformations; b) Axial deformations; and c) Curvature deformations.

The ovaling deformation is caused primarily by seismic waves propagating perpendicular to the underground structure longitudinal axis.

Vertically propagating shear waves are generally considered the most critical type of waves for this mode of deformation.

The axial and curvature deformations are induced by components of seismic waves that propagate along the longitudinal axis.

Use ground deformation design methods that account for soil-structure interaction in assessing the seismic effect on underground structures.

In lieu of rigorous numerical modelling methods, applicable simplified soil-structure methods provided in Road Tunnel Manual and other references (Hashash *et al.*, 2001, and Wang, 1993) may be used.

Analyze interior structures not rigidly connected to exterior tunnel structures using the response spectra method per Canadian Highway Bridge Code.

Analyze restrained structures that oscillate in phase with or are rigidly attached to tunnels using ground deformation methods.

Fire Load

Design permanent tunnel lining sections in soft ground to resist potential fire effects per Chapter A3 – Safety and Chapter B4 – Structures.

Achieve fire resistance with appropriate liner thickness and additional reinforcement cover protection.

Provide liner concrete mix to minimize concrete spalling during critical fire events.

Other Loads Considered for Precast Concrete Segment Design

- Load due to compression of EPDM gaskets and hydrophilic seals;
- Removal from casting forms;
- Stacking;
- Handling;
- TBM shoving.

B9.10.5 Safety Factors

Uplift Due to Water Pressure

Where tunnels are relatively shallow, check for flotation due to differential water pressure as follows:

Overall safety factor = $\underline{R} \geq 1.2U$

Where: R = Restraining force considering weight and shear resistance of soil

U = Net uplift force considering weight of tunnel

Heave of Shallow Tunnels

Where applicable, check relatively shallow tunnels in clay for heave due to shear failure of the ground at tunnel invert level by the method derived from the basal heave analysis after Bjerrum and Eide:

Overall safety factor: ≥ 1.0 when surcharge is applied;

≥ 1.2 when surcharge is not considered.

B9.10.6 Segment Design

Design Approach

Design segments per Chapter B4 - Structures with additional requirements as stated herein.

Design of Radial Joints.

The joint design for splitting tensile effects due to concentrated loads is based on empirical data.

Due to the reduced width of the bearing faces, transverse tensile stresses occur at the joints.

The eccentricity of the resultant compressive force due to variable stress distribution at radial joints is taken into account by introducing a substitute bearing area, which is defined by a rectangular stress block with the resultant normal force at its center.

Design of Circumferential Joints

TBM thrusting loads acting at circumferential joints cause bursting stresses, as the bearing width of the rams and any joint packings is less than the segment thickness.

Analyses for bursting stresses will be defined as the TBM characteristics are developed.

Effects of Shield Shoving

Additional flexure and torsion may generally be induced on segments, when shoving loads are not equally distributed, due to “steps” along the circumferential joints.

In order to minimize damage during shoving, accurate ring build is crucial.

The use of joint packing will further help to mitigate such effects by reducing load concentration.

Crack Control

Crack widths will be considered and specific criteria for crack width calculations will be developed as lining durability considerations are defined.

In no case will excess crack widths be allowed that compromise the long term durability.

Grooves

Grooves for EPDM gaskets and surfaces for application of the hydrophilic seals are designed to seal under the worst case conditions, making allowance for the casting inaccuracies and ring building errors.

Provide caulking grooves for exposed interior tunnel segment surfaces.

B9.11 Mined Tunnels/Structures

B9.11.1 General

This section presents criteria for design of tunnel sections excavated by non-tunnel boring machine (TBM) mining methods for stations, transitional openings, TBM starter tunnels, cross passages, track crossovers, cut-and-cover underground stations, or emergency exit buildings (or EEB).

Provide temporary ground support systems for sufficient excavation longevity and stability for the expected duration of construction and until the permanent structural lining is in place.

Design construction sequence, initial support, and/or final lining to account for loadings presented in this section and other structure loads that may occur during construction and design life.

Design criteria herein are minimum criteria.

Design temporary support and permanent lining so that proposed mined caverns and tunnels:

- Support loading conditions to which they will be subjected;
- Meet specified long term water-tightness criteria;
- Comply with ground movement criteria;
- Satisfy all service requirements of the structure;
- Provide for short and long term safety of overlying, underlying, or adjacent structures and utilities; and
- Provide for short and long term safety of occupants.

Use the GIR and GBR, augmented as appropriate by Geotechnical Design Memoranda, to define ground conditions at specific underground structure locations.

Consider conditions that influence loads on temporary ground support elements and permanent structural linings including but not limited to:

- Virgin in-situ stress, as well as stress distribution changes associated with excavated opening(s);
- Groundwater elevation, taking into account seasonal and long term variations;
- Overburden thickness, and thickness variations;

- Potential surcharge loads on overburden soils, from overlying or adjacent structures;
- Construction methods and sequences implemented for large opening sequential excavation methods;
- Excavation shape and size, both incremental in sequential excavation method and final configuration;
- Timing of temporary ground support installation relative to the advancing heading;
- Distance from the initial heading back to the follow-on headings in the sequential excavation method;
- Additional load due to proximate excavation of connecting underground structures such as cross passages;
- Ground improvement by grouting;
- Building loads imposed by shallow and deep foundations – pre-existing or components of the proposed construction;
- Station mezzanine loads;
- Dynamic load on invert from trains.

B9.11.2 Geotechnical Information

Perform subsurface investigations at mined tunnel and cavern locations with associated laboratory testing programs to provide required geotechnical information.

The field investigation and laboratory testing programs will generally include the following elements:

Soil Borings/In-Situ Testing

- Standard penetration resistance (N-value) determinations o Disturbed sampling using standard split spoon sampler;
- Undisturbed sampling using thin wall tube samplers;
- Classification of soil samples per industry standard nomenclature, including soil color, type, gradation, plasticity, density, stiffness, compactness/consistency;
- Cone penetration test;
- Pressure meter testing
- Dilatometer testing;
- Vane shear testing.

Laboratory Soil Testing

- Gradation analysis;
- Atterberg limits;
- Shear strength;
- Electrochemical tests.

Groundwater Investigation

- Groundwater observation wells and piezometers;
- In-hole permeability tests;
- Pumping tests with observation wells;

- Groundwater chemical analysis;
- Determination of maximum hydrostatic head;
- Corrosion tests.

B9.11.3 Design Methodology

Design initial support for mined tunnels and underground structures to establish upper and lower solution boundaries that can be adjusted to account for additional investigation and testing.

Design final linings and waterproofing per Chapter B4 - Structures.

Give special consideration to geometric and/or spatial conditions where one underground excavation influences the anticipated behaviour of another connecting or adjacent excavation.

Such conditions may produce higher stress concentration factors than would result from the presence of a single excavation opening in the same geological and stress regime.

B9.11.4 Ground Loads

Calculate ground loads for design of temporary support systems based on geotechnical design parameters per Section B9.11.2.

Apply ground loads as radial pressure, vertical pressure, horizontal pressure, and directional point loads per specific design conditions.

B9.11.5 Seismic Loads

Follow the same criteria outlined above in Section B9.10.4.1.9 for seismic design of mined tunnels and underground structures.

Include racking deformation in lieu of ovaling deformation for design of non-circular underground structures.

Account for the effect of the above ground portion to the below ground portion for structures with one portion above ground and another portion below ground.

B9.11.6 Ground Movement

Base ground movement predictions on stress-strain analyses as follows:

- Maximum distortion at closest point on nearest structure foundation and most critical foundation structure to mined cavern or tunnel;
- Shape of transverse deformation profile; and
- Shape of longitudinal deformation profile.

Develop allowable values for total settlement and angular distortion specifically considering the types and sensitivities of overlying structures and utilities within influence zones of each mined tunnel and cavern section.

Verify numerical model predictions with appropriate geotechnical instrumentation and observations.

Verify results of analyses using data obtained from instrumentation monitoring during construction.

B9.11.7 Temporary Support

Provide temporary support for a time period ending with installation of permanent lining.

Assume that temporary support elements degrade and thus do not contribute to permanent lining support capacity during design life of structure.

Analyze temporary support elements as installed immediately after opening up each increment of excavation.

Provide for safety to personnel and prevent damage to adjacent construction.

General

Conventional mined excavation temporary support is an integral component of sequential multiple heading excavation.

Apply sequential excavation tunnelling methods where conditions are typically deemed not suitable for full face machine driven tunnels, cross sections are large, openings are short, overburden is less than 6 m, and/or geometry is complex, including chambers, cross passages, bifurcations, crossovers, widening, or similar transitional structures.

Ground Characterization, Excavation, Support

Characterize ground conditions and anticipated behaviour in response to tunnelling based on geotechnical information and interpretation to develop excavation and support methods.

Consider the following factors among others in development of excavation and support:

- Size and shape of tunnel opening;
- Subdivision into multiple drifts, as applicable, and drift excavation sequence to complete full tunnel cross section;
- Geotechnical based limitations for width of individual drifts;
- Initial support element installation timing following each excavation increment completion; and
- Pre-support elements such as grouting or other types of ground treatment and face spiling.

Present excavation and support requirements on longitudinal tunnel profiles.

Relate to location by station and anticipated geologic conditions.

Include anticipated ground response to tunnelling.

Provide temporary support comprising an initial shotcrete lining reinforced with lattice girders and welded wire fabric or steel fibre.

Consider any systematic pre-support measures as part of the temporary support.

Provide local support including support measures installed to address specific ground conditions encountered for relevant excavation and support in addition to temporary support.

These may include face stabilization measures such as face doweling support wedges and shotcrete.

B9.12 Existing Structures

B9.12.1 General

Define the general Zone of Influence for the works per Figure B9-6 except for wider site-specific zones of influence per Geotechnical Reports.

See Figure B9-7 for underpinning requirements.

Existing structures are any building, utility, or other structure that ground movement could adversely affect.

B9.12.2 Impact Surveys

Evaluate the impact of works on existing structures in the Zone of Influence.

Provide pre- and post-construction condition surveys for structures in established Zones of Influence.

Condition surveys do not include allowable movement evaluation -- Review Level or Alert Level per Section B9.17.9 -- or the need for pre-construction support measures such as underpinning.

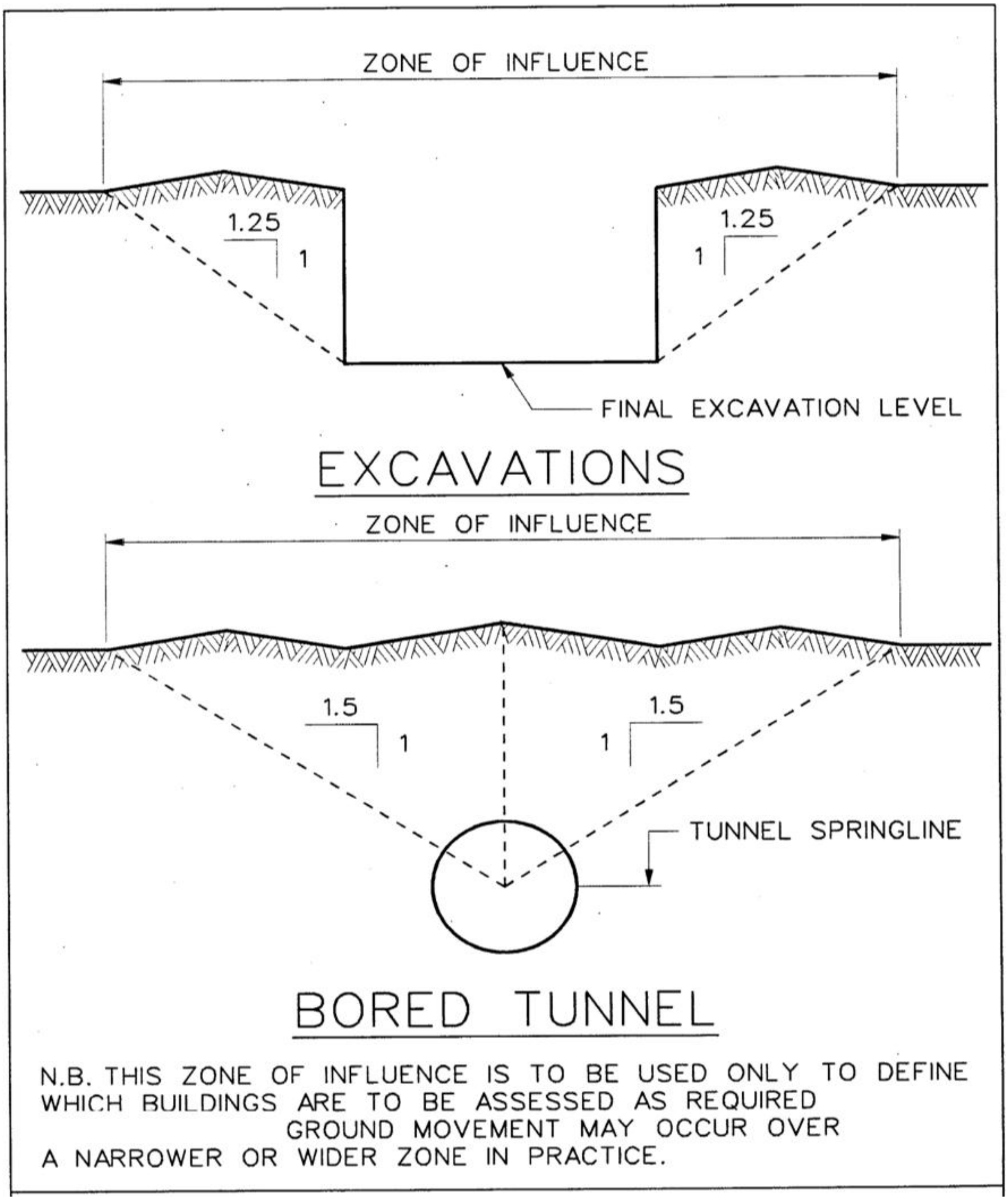
Evaluate and determine Review and Alert Levels.

Evaluate potential effects of construction induced movement for every structure with any part in the Zone of Influence.

Provide Existing Structures Impact Level 1 Evaluation in every case.

In particular cases, also provide an Existing Structures Impact Level 2 Evaluation.

FIGURE B9-6 GENERAL ZONE OF INFLUENCE CRITERIA



Evaluate ground movement arising from construction activity including support of excavation installation, excavation, dewatering, and/or construction induced vibration based on:

- Method and sequence of construction; and
- Normal standards of workmanship carried out under close supervision.

Revise evaluation accordingly if construction sequence or methods change.

Existing Structures Impact Level 1 Evaluation

Conduct preliminary evaluation of potential impact on existing structures within the Zone of Influence.

Level 1 Evaluation includes the following:

- Identifying the existing structure, which include the address, the owner, the contact information, type of construction, number of stories (for buildings), and any historic nature;
- Estimating construction activity associated ground movement at the location of the existing structure;
- Evaluating existing structure conditions and establishing allowable deformation limits;
- Preliminary evaluation of potential damage to existing structure due to imposed ground movement;
- Using these generalized ground movements to determine possible movement, strain, and distortion induced by construction for every structure within the Zone of Influence;
- Assessing and classifying potential damage to structures using such methods as suggested by Boscardin, M.D. and Cording, E.J. for buildings or Attenwell *et al.* for utilities.

Document results of Level 1 Evaluations on Forms 1 or 2 with supporting information and engineering evaluation/calculations as appropriate.

Reassess any structure that from Level 1 Evaluation is expected to suffer more than slight damage using Existing Structures Impact Level 2 Evaluation.

TABLE B9-9 CLASSIFICATION OF VISIBLE DAMAGE (MODIFIED FROM BURLAND ET AL., 1977) [1]

Risk Category	Degree of Damage	Description of Typical Damage and Likely Forms of Repair for Typical Masonry Buildings	Crack Width[2] (mm)	Maximum Tensile Strain (%)	Maximum Slope of Ground[3]
0	Negligible	Hairline cracks	< 0.1	< 0.05	Less than 1:900
1	Very Slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior brickwork visible upon close inspection.	0.1 to 1.0	0.05 to 0.075	1:900 to 1:600
2	Slight	Crack easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible: Some repointing may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15	1:600 to 1:300

TABLE B9-9 CLASSIFICATION OF VISIBLE DAMAGE (MODIFIED FROM BURLAND ET AL., 1977) [1]

Risk Category	Degree of Damage	Description of Typical Damage and Likely Forms of Repair for Typical Masonry Buildings	Crack Width[2] (mm)	Maximum Tensile Strain (%)	Maximum Slope of Ground[3]
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Re-pointing and possibly replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather-tightness often impaired.	5 to 15; or More Than 3 Cracks	0.015 to 0.3	1:300 to 1:150
4	Severe	Extensive repair involving removal and replacement of sections of walls, especially over doors and windows required. Windows and frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably, some loss of bearing in beams. Utility services disrupted.	15 to 25; also depends on number of cracks	Greater than 0.3	Greater than 1:150
5	Very Severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	> 25; also depends on number of cracks	Greater than 0.3	Greater than 1:150

Notes:

1. The table is based on the work of Burland et al (1977), as reproduced in Cording & Boscardin (1985), and includes typical maximum tensile strains for the various damage categories (column 5) used in the Building and Structure Classification.
2. Crack width is only one aspect of damage; do not use alone as a direct measure.
3. The Maximum slopes of ground are based on the methods of Rankin (1987). Risk Categories using the Rankin method are approximately equivalent to those proposed by Burland, although in some cases there may be significant differences.

For utilities, allowable deformation limits typically depend on several factors including construction material, size, length of segments, and age.

In general, damage pipelines and utilities as a result of differential settlement may occur in three ways:

- Excessive strain in pipe material leading to bursting or unacceptable deformation;
- Rotation of joints leading to leaks and/or disconnection of utility segments;
- Axial split at joints leading to leaks and/or disconnection of utility segments.

Establish specific deformation criteria for each utility category.

Table B9-10 above is not all-inclusive of allowable utility distortions for every situation that may occur but is presented as a guideline to be updated where appropriate.

TABLE B9-10 PRELIMINARY EVALUATION OF ALLOWABLE DISTORTION FOR PIPELINES

Utility Description	Allowable Distortion	Basis
Clay, cast iron, plastic, pre-cast concrete pipes with diameter less than 1.5 m and length less than 3 m.	1:200	Deflection of pipe sections not to exceed 0.5 degree at each joint.
A36 type steel pipe with diameter more than 1.5 m.	1:50	Permissible tensile strain of 8 x 10^{-4} for steel.
Cast-in-place concrete and brick arch structures with diameter more than 3 m.	1:5,000	Allowable flexural strain of 2 x 10^{-4} for concrete.

FORM 1: EXISTING UTILITY IMPACT LEVEL 1 EVALUATION SUMMARY

UTILITY LOCATION: ____

PLAN VIEW OF UTILITY

Utility
Utility Owner: ____ Contact Person and Phone Number: ________________________________ Criticality of Service (consequences of shut down): _______________________ Age: ______ Years Depth: ______ m Diameter: ______ mm Wall thickness: ______ mm Material type: ____ ____

ASSUMED CONSTRUCTION METHOD AND SEQUENCE:

ESTIMATED EFFECTS	MAXIMUM SETTLEMENT	
	Maximum tilt	
	Maximum angular distortion	
	Maximum tensile strain	

Damage Category: ____

Recommended special protection measures, including instrumentation (if any):________________________

FORM 2: EXISTING STRUCTURES IMPACT LEVEL 1 EVALUATION SUMMARY

Building Address: ____

Owner and Contacts: ____

PHOTOGRAPHS OF BUILDING

Building
Description: ____ Date Constructed: _______ Years Height: _______ m Frontage: _______ m Width: _______ m Superstructure Details: ____ Foundation Details: ____

ASSUMED CONSTRUCTION METHOD AND SEQUENCE:

Estimated Effects	Maximum settlement	
	Maximum tilt	
	Maximum angular distortion	
	Maximum tensile strain	

Damage Category: ____

Existing Structures Impact Level 2 Evaluation

Level 2 Evaluation consists of Level 1 Evaluation refinement with more detailed analysis of particular existing structure features and detailed consideration of tunnelling and/or excavation methods and sequences.

Level 2 Evaluation analyses ground movement by reference to records of similar types of construction and/or soil-structure analysis using finite difference, finite element, or other suitable methods.

Calculate likely movement strains and distortions for each structure and reassess the damage classification.

Because each case is different and must be treated on its own merits it is not possible to establish detailed guidelines and procedures for Level 2 Evaluation.

Level 2 Evaluation includes at a minimum the following:

- Construction method and sequence;
- Previous movement, if applicable;
- Effect of existing structural members stiffness;
- Foundation of existing structure, if any; and
- Existing structure orientation.

Since many factors are not amenable to precise calculation, conduct or supervise Level 2 Evaluations by an experienced engineer using appropriate engineering judgment based on interpretation of available information and empirical guidelines.

Revise damage classifications per Tables B9-9 and B9-10 accordingly.

See Table B9-5 as a guideline for framed buildings and load bearing walls; revise as required.

Because of inherently conservative Level 1 Evaluation assumptions, Level 2 Evaluations usually result in damage classification reduction.

Revise required mitigation measures accordingly.

B9.12.3 Protection Measures

Negligible to Slight Damage

Protect and repair existing structures.

Provide sufficient instrumentation to confirm that movements are not approaching critical values.

Should instrumentation be deemed inadequate, immediately notify MX LRT and reconcile any differences.

Recommend special protection measures, if any, including instrumentation.

In certain cases MX LRT may deem slight damage to be unacceptable and direct structures be treated as follows.

Damage in Excess of Slight

Incorporate measures to sufficiently reduce construction effects on structures.

Clearly indicate the need for protection measures, including assumptions, in advance of construction.

Consider property expropriation as an alternative to protection, where feasible, if the cost of protection measures is high relative to building or structure value.

Provide sufficient instrumentation to confirm that movements are not approaching Review and Alert Levels.

Determine Review and Alert Levels for each structure per Section B9.17.9.

B9.12.4 Protection Strategy Risk Assessment

Conduct a risk assessment on structures in the Damage in Excess of Slight category to assign a risk matrix to each structure and recommend a protection strategy based on:

- Nature and magnitude of the impact;
- Qualitative assessment such as existing conditions;
- Structure use;
- Whether structure is critical, such as police or fire station;
- Any historic classification;
- Relationship to adjacent structures; and
- Surrounding community.

Include the following criteria in protection strategy risk assessment:

- Effectiveness of identified mitigation measures;
- Cost of mitigation assessed relative to impact;
- Expected risk of unmitigated conditions; and
- Contingency budgets for mitigation measures.

Include the associated mitigation monitoring strategy in any protection strategy.

B9.13 Public Safety

In some cases, movement insufficient to cause significant structural damage may still lead to damage or loss of architectural finishes or other features.

Take measures to maintain public safety wherever necessary.

B9.14 Ground Improvement

Provide ground improvement or ground stabilization as required to minimize groundwater inflow to construction zones and effects of construction on adjacent structures and facilities.

Consider techniques such as ground freezing, permeation grouting, jet grouting, compaction grouting, compensation grouting, spiling, micro piles, root piles, and other stabilization measures.

B9.15 Support and Underpinning

B9.15.1 General

This section governs the support and underpinning of existing structures as necessary to protect from ground movement and subsequent settlement based on evaluations herein and per Section B9.12.

Provide support of existing structures using protection walls around excavation, underpinning existing structures, or a combination of these methods.

Consider construction sequence and effect of protection measures on other construction when determining appropriate protection methods.

Consider Right-of-Way requirements of different protection methods.

Consider underpinning a structure only if estimated movement would exceed allowable limits using protection walls or other measures.

Determine allowable settlement for each structure based on condition assessment and structural analysis.

Discuss and agree the need for underpinning with building owners.

Anticipate some settlement with most underpinning systems.

Take into account such settlement in assessing construction effects on existing structures.

Consider underpinning where required including but not limited to the following methods:

- Jacked Piles;
- Micro Piles;
- Helical Piles;
- Column Pick-Up;
- Foundation Grouting.

Restoration is defined as repair or replacement of structures damaged or altered as a result of construction.

Provide restoration to a condition equal to that existing prior to start of construction.

See Figure B9-6 Underpinning Requirements for Structures in Soil.

The construction excavation area of influence is divided into three zones designated Zone A, Zone B, and Zone C.

In general, structures in Zone A require underpinning capacity with the Zone C required safety factor.

Underpinning generally is also required where building foundations immediately outside Zone A carry a load heavy enough to expand the Zone A active zone.

Lighter structure foundations located in Zone A adjacent to the excavation may not need to be underpinned if a protection wall to carry the loads limits movement to acceptable parameters.

Foundations in Zone B generally do not need to be underpinned.

Provide foundations to resist vertical and horizontal pressures from foundations falling within Zone A and Zone B that are not underpinned.

Underpin heavy structures encroaching on or immediately adjacent to LRT structures prior to LRT works excavation unless the existing structures foundations extend below excavation subgrade and derive full supporting capacity below that level with no detrimental effects.

Consider loss of axial and lateral capacity of existing pile foundations as required.

If underpinning is required, transfer foundation loads to Zone C by walls, drilled piers, or various types of driven, jacked, or drilled piles.

Provide underpinning members completely independent of LRT structures, free standing and isolated from the LRT structure to minimize transfer of train vibration to supported structures.

Provide temporary by jacks at selected points along the foundations for support of lighter structures to compensate for structure movement.

Consider subsequent structure repair, removal, or replacement in lieu of underpinning or temporary support where it appears economically feasible for minor structures or portions of larger structures.

B9.15.2 Loads and Forces

Calculate loads and forces of each structure to be underpinned.

Use original structural analyses, when available, as guides in determining current loads and forces.

B9.15.3 Project Conditions

Operations Maintenance

Schedule underpinning activities to avoid impact on normal day-to-day operations in so far as possible.

Clearly identify impact on day-to-day operations in initial design development.

Utilities Maintenance

Address the need for maintenance of each utility.

Consult the utility owner and define disruption constraints for service disruptions during construction.

See Chapter C6 – Utilities.

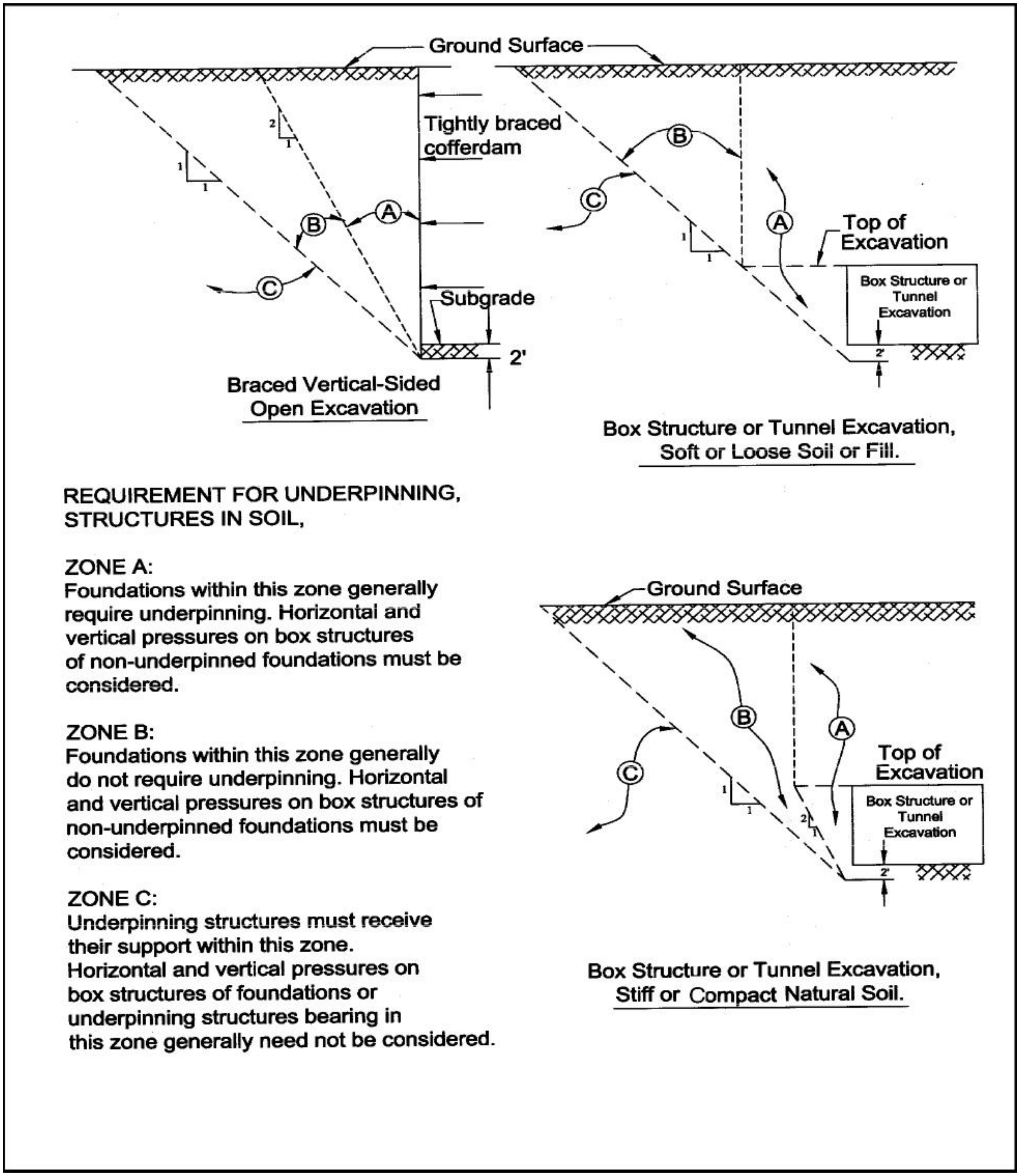
B9.15.4 Load Transfer Monitoring

Fixed Reference Points

Identify fixed reference points prior to initiating load transfer associated with underpinning structures.

Do not include fixed reference points as part of underpinned structures.

FIGURE B9-7 UNDERPINNING REQUIREMENTS FOR STRUCTURES IN SOIL



B9.16 Existing Underground Utility Loads

Check existing utilities below or adjacent to fixed reference points to determine whether they can withstand loads imposed by earth, sub-base, pavement, track, ballast, structures, and vehicle loads for utilities/pipes operating under internal pressure ranging from maximum to zero.

Submit technical evaluations of existing underground utilities structural and functional ability to resist such loads to utility owners for review and acceptance.

Implement appropriate protective measures or relocate existing underground utilities if evaluation shows unacceptable impact.

Perform existing utility condition surveys prior to construction.

B9.17 Instrumentation and Monitoring

B9.17.1 General

Provide monitoring of ground movement, pressure, loads, and strain on adjacent buildings and infrastructure as well as on temporary and permanent works before, during, and after construction excavation and shoring to:

- Assess construction impact on the ground, buildings, utilities, structures, and other facilities in the Zones of Influence to determine any adverse effects;
- Identify causes and distribution of ground movements;
- Verify compliance with performance specifications;
- Verify safety of the works;
- Provide information allowing refinement of future projects for MX LRT review and acceptance.

Provide required number, type, depth, and approximate location in plan of instruments to be installed.

Include the following information with respect to instrumentation:

- Conditions and/or geotechnical issues defining the need to monitor with geotechnical instrumentation;
- Recommended reading/sampling schedule.

Provide instruments to measure performance of permanent works and ground within the Zone of Influence.

B9.17.2 Effects on Facilities

Monitor movement of buildings, infrastructure, and utilities within Zones of Influence per Section B9.12.

Typically install four settlement markers minimum for each building.

Provide sensitive, historic, or critical use structures with additional settlement points.

Provide sensitive, historic, or critical use infrastructure or utilities with crack gauges, convergence gauges, tiltmeters, or other instruments as required to monitor construction effects.

Facilities may be affected by other construction effects, e.g., vibration, changes in groundwater level, or flow direction may have, or be claimed to have, adverse effects on third parties.

Provide appropriate instrumentation where there is potential risk of affecting third parties.

B9.17.3 Ground Movement Causes

Install sufficient geotechnical instrumentation to identify the cause of ground movement and related subsurface to surface movements in addition to monitoring adjacent ground and structures movement.

See Sections B9.17.4 and B9.17.5 for minimum monitoring requirements in urban areas.

Requirements may be reduced or waived where no buildings, utilities, or structures are in the Zone of Influence.

B9.17.4 Bored and Mined Tunnels/Structures

Install surface settlement monitoring points approximately 25 m on centre directly over each tunnel bore or mined tunnel/structure centre line.

Install surface settlement monitoring point major transverse arrays along tunnels/structures at intervals per Figure B9-8.

Typically install approximately 5 settlement arrays per kilometre of twin tunnel.

Locate settlement arrays based on assessed ground conditions, building protection requirements, and access.

Minimum length of array from outside face of tunnel or structure is 25 m.

Provide additional transverse arrays when tunnelling under or adjacent to sensitive structures, major roadways or highways, or as required by MX LRT and AHJ.

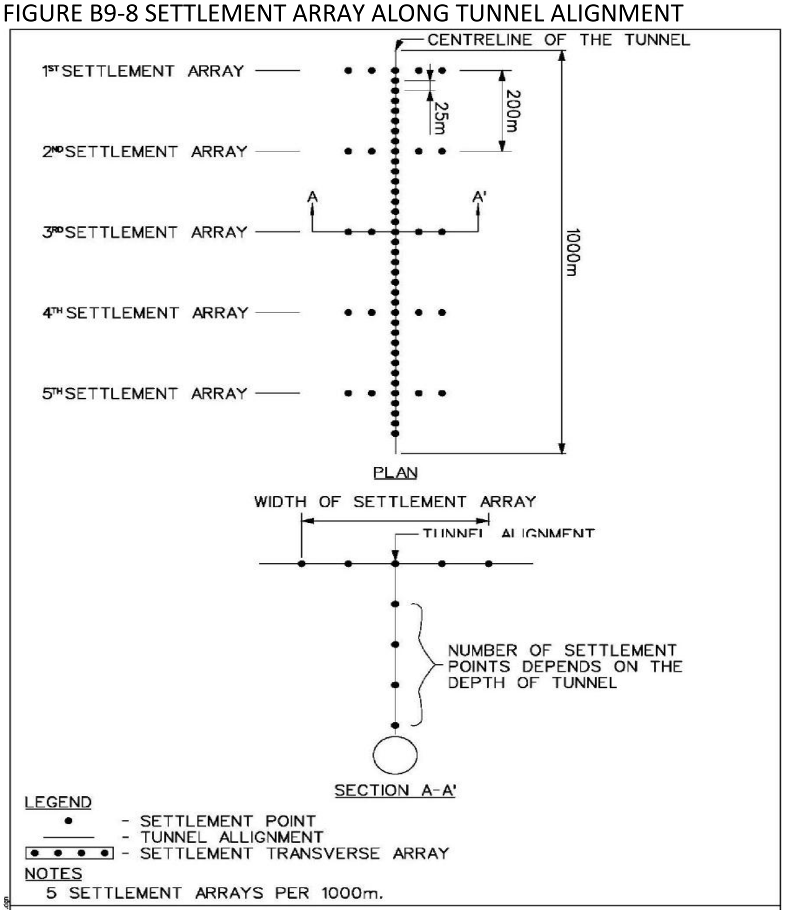
Provide instrumentation to monitor horizontal and vertical subsurface movement and changes in pore water pressure in addition to surface settlement points.

Install at a minimum a single subsurface settlement point to just above the crown of tunnel/structure at every major array of surface settlement points per Figure B9-8.

Concentrate additional instrumentation in major surface settlement array areas where subsurface instrumentation in excess of the minimum is required.

Provide critical large underground excavations with multiple deep instruments to check for ground movement near the perimeter before it progresses to the ground surface.

FIGURE B9-8 SETTLEMENT ARRAY ALONG TUNNEL ALIGNMENT



Install inclinometers to monitor horizontal ground movement.

Conduct installation and reference readings at least two to three weeks before start of construction.

Install inclinometers within 5 m of proposed edge of tunnels/structures.

Install tape extensometer reference points after tunnel boring to monitor convergence of tunnel walls.

Define quantity and location of reference points after finishing concrete liner depending on geological conditions for weak sections and importance of structural elements.

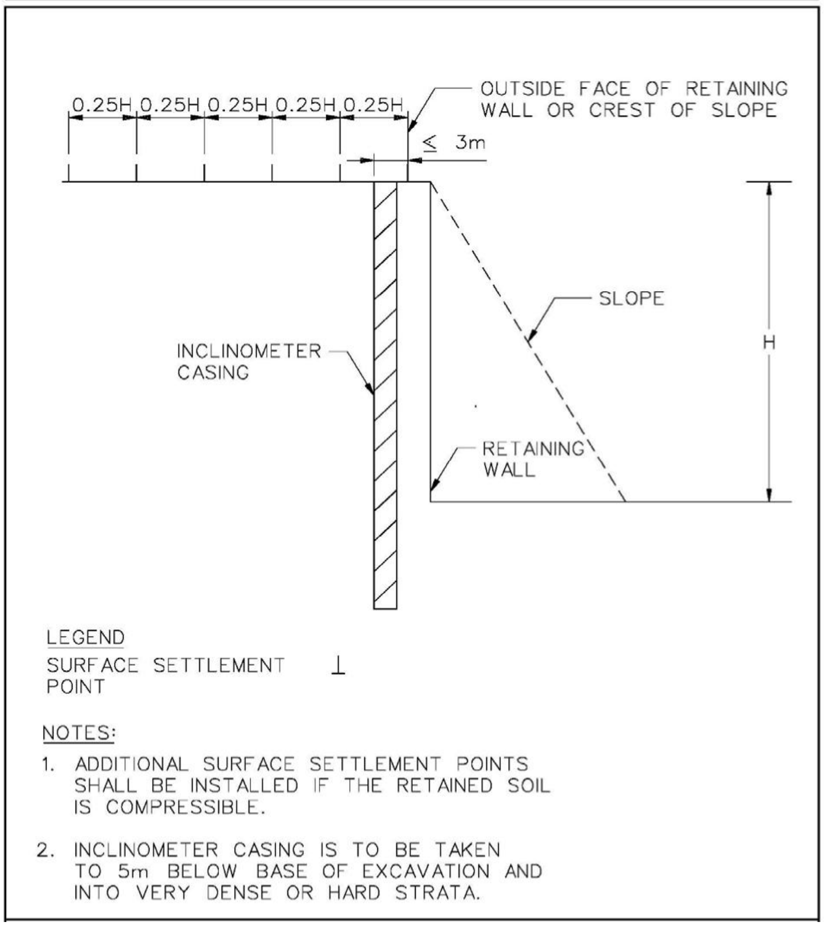
B9.17.5 Cut-and-Cover Excavation

Install one surface settlement/movement monitoring point per 25 m length and within 3 m of outside face of retaining structure or crest of slope.

Install one major transverse array of settlement monitoring point per 50 m length outside retaining structure excavation supports or crest of slope per Figure B9-8.

Provide additional transverse arrays when excavating under or adjacent to sensitive structures, major roadways or highways, or as required by MX LRT or AHJ.

FIGURE B9-9 SETTLEMENT ARRAY FOR CUT-AND-COVER EXCAVATION



In addition to surface settlement/movement points, instrumentation may be used to monitor horizontal and vertical subsurface movement and change in pore water pressure.

At a minimum, install an inclinometer for every major settlement array except where the retained or slope height does not exceed 5 m.

Provide inclinometers with fixed points at least 5 m deeper than potential horizontal movement/sliding surface.

Install heave/settlement gauges or settlement extensometers to measure subsurface settlement.

Provide additional instrumentation concentrated in areas of major surface settlement monitoring arrays or adjacent to critical structures where subsurface instrumentation exceeding the minimum is required.

B9.17.6 Performance Specifications

Provide sufficient monitoring to verify compliance with required performance specifications.

Provide sufficient piezometers for dewatering systems using wells, well points, or eductors to monitor piezometric pressure during dewatering.

Install piezometers typically at intervals not less than one per 50 linear meters of structure.

For shoring systems including struts or tie-backs, monitor stress or loads in struts and tie-backs.

Monitor typically not less than one strut or tie-back per level per 100 linear meters of excavation.

Locate strut or tie back monitors in the area of major settlement monitoring arrays per Section B9.17.5.

B9.17.7 Construction Safety Monitoring

Construction contractors are responsible for the safety of their works.

Construction contractors are thus required to install instrumentation as necessary for the safety of the works.

B9.17.8 Permanent Works Monitoring

Generally do not change monitoring pressures applied to or stresses and strains developed in permanent works without MX LRT prior consent.

Monitor distortion and elevation of permanent bored tunnel linings and cut-and-cover structures.

B9.17.9 Review and Alert Levels

Provide instrumentation programs that specify minimum frequency of instrument readings, periods for which monitoring is required, and Review and Alert Levels.

Review Level corresponds to instrument readings requiring mandatory construction method evaluation by ProjectCo and MX LRT and, if necessary, either action to mitigate detrimental effects on the works and adjacent properties or alteration of construction methods, rates, or sequence.

Specify Alert Levels for critical instruments used to assess safety of the works or adjacent properties.

Alert Level is the instrumentation reading value at which MX LRT or AHJ may order construction operations to cease, secure the site and affected properties, take necessary and agreed upon measures to mitigate unacceptable movement, and maintain public safety of the works.

Alert Level for each instrument represents the maximum permissible ground and structure movement due to construction activity associated with the work, maximum or minimum groundwater level allowed during construction, maximum load or stress that may be imposed on elements of temporary works, or maximum allowed vibration levels.

Do not resume work until allowed to do so by MX LRT and AHJ.

B9.18 Infrastructure Ontario AFP Requirements

See Appendix A Infrastructure Ontario AFP Requirements: Geotechnical, Hydrogeology, Environmental Due Diligence Technical Requirements Final Draft Report V.06, May 11, 2012.

Appendix A
Infrastructure Ontario AFP Requirements

Infrastructure Ontario

AFP – Geotechnical, Hydrogeology, Environmental Due Diligence Technical Requirements

FINAL DRAFT

May 11, 2012

Table of Contents

Introduction

This document provides Geotechnical, Hydrogeology, and Environmental Due Diligence Technical Requirements for owners and consultants that focus on efficient risk management strategies for AFP applications. The purpose of these requirements is to apply a standardized approach for investigation and reporting, which will help to minimize potential risks associated with contract delays and to ensure contractor safety. It also makes for more efficient environmental remediation strategies.

1. All reports, specifically preliminary Geotechnical, Hydrogeology, Phase One ESA & Phase Two ESA, and Designated Substances shall be relied upon.

2. All consultants shall be professionally certified as per the specific sections of this document.

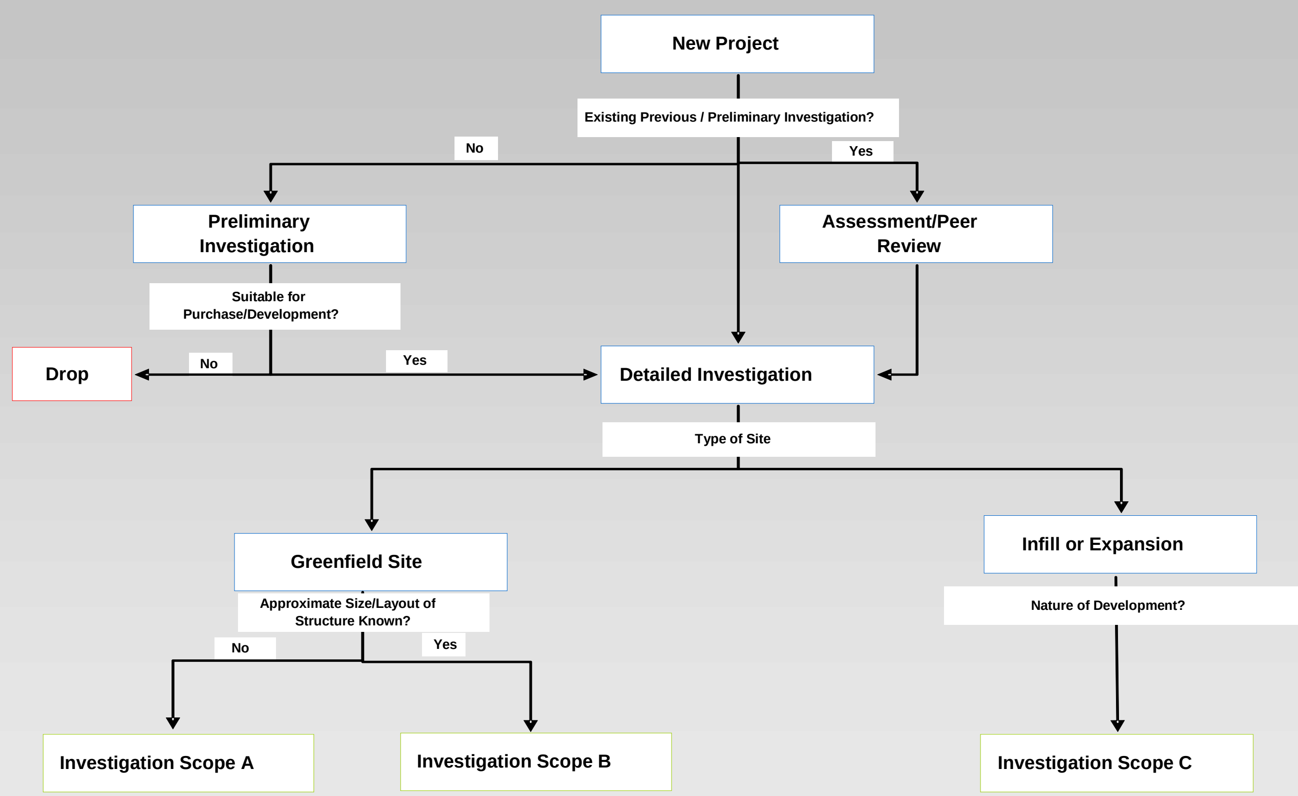
3. The attached flow charts are for reference only and it is up to the Consultant of Record to modify their approach depending on the circumstances.

4. Major changes from past practices include enhanced due diligence in the identification of founding soils, the mandatory introduction of scanning and seismic testing and precise identification of contamination sources and direction of gradient.

5. For Greenfield Sites, the consultant shall determine from the Phase One Report whether to include Electromagnetic (EM) or Ground Penetrating Radar (GPR) scanning for remediation purposes. However, once the structure is located on the site, EM or GPR shall be used for geotechnical purposes.

6. These are minimum standards, and may be modified as necessary to suit local conditions and design intent conditional upon the minimum standards being adhered to.

Decision Tree for Geotechnical/ Hydrogeology Investigations



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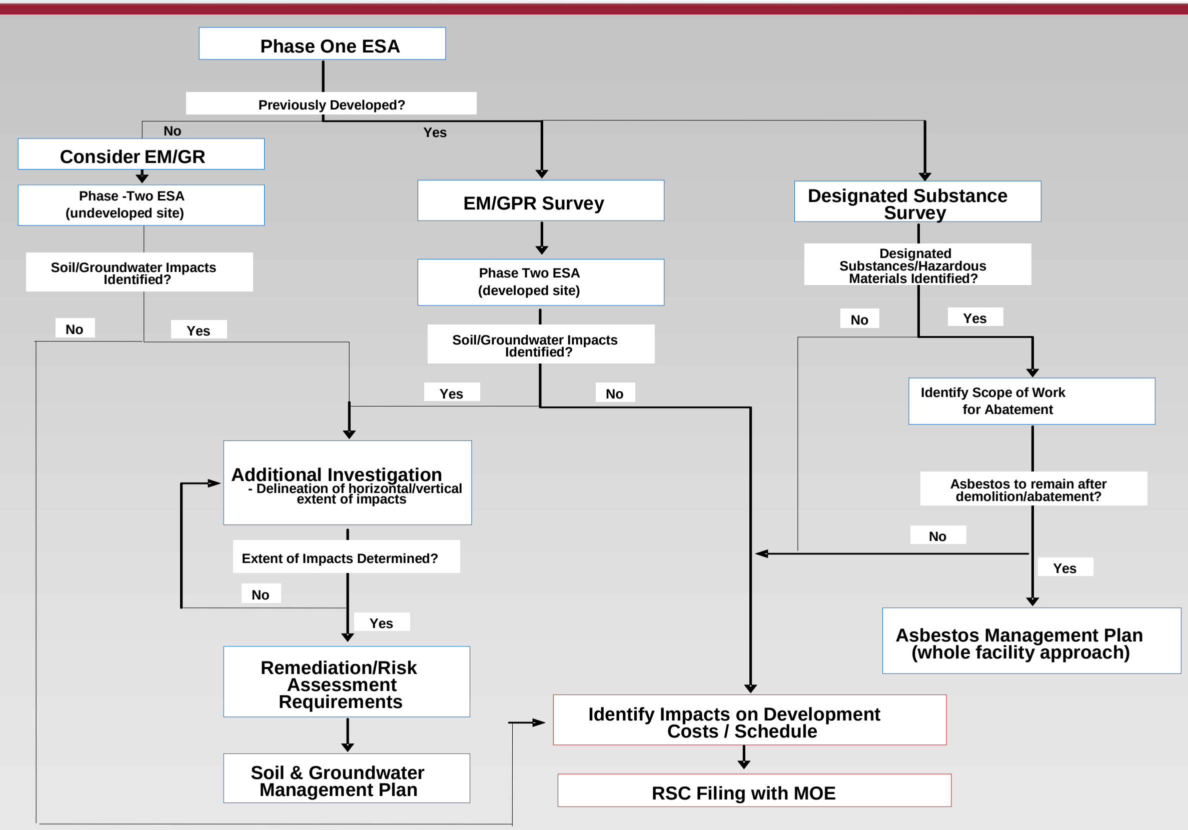
Decision Tree for Environmental Due Diligence



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Geotechnical & Hydrogeology Investigation Scope A: Greenfield - Size & Location of Structure Unknown

All consultants must have a Professional Engineers of Ontario Certificate of Authorization to practice as Geotechnical Consultant and be approved to carry out testing as per MOE guidelines for soil, groundwater and sediment standards for use under part XV.1 of the Environmental Protection ACT, 2004 as amended. The Laboratory must be certified by CCIL (Canadian Council of Independent Laboratories), and has participated and met the MTO correlation program for soil testing.

The geotechnical investigation must conform to the most recent edition of the following standards:

- ASTM D420 "Standard Guide to Site Characterization for Engineering, Design and Construction Purposes"
- ASTM D5434 "Standard Guide for Field Logging of Subsurface Explorations of Soil and Rock"
- ASTM D2488 "Standard Practice for Description and Identification of Soils (Visual Manual Procedure)"
- ASTM D1452 "Standard Practice for Soil Investigations and Sampling by Auger Boring"
- ASTM D1586 "Test Method for Penetration Test and Split Barrel Sampling of Soils"
- ASTM D1587 "Standard Practice of Thin Walled Tube Geotechnical Sampling of Soils"
- ASTM D2113 "Standard Practice for Diamond Core Drilling for Site Investigations"
- ASTM D4220 "Standard Practice for Preserving and Transporting Soil Samples"
- ASTM D5079 "Standard Practice for Preserving and Transporting Rock Core I Samples"
- ASTM D2573 "Test Method for Field Vane Shear Test in Cohesive Soils"
- ASTM D5784 "Guide for the use of Hollow Stem Augers for Geo-environmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices"
- ASTM D6151 "Standard Practice for Using Hollow Stem Augers for Geotechnical Exploration and Sampling"
- Canadian Foundation Engineering Manual 4th Edition. Canadian Geotechnical Society 2006

The geotechnical investigation involves the following phases:

Phase I – Field Program Preparation and Undertaking – Carry out a geotechnical investigation program, including submission of a work plan, communications and process of conduction of field program.

Phase II – Soil Testing and Analysis – The soil sampling program to include soil classification and laboratory testing for soil properties.

Phase III – Completion of a Geophysical Survey – Undertake a survey of the entire property to map geophysical anomalies.

Phase IV – Hydrogeology Study

Phase V – Data Analysis, Consultation, Reporting and Recommendations – The final report to include data analysis and recommendations of design parameters required by the structural engineer for bearing capacities, foundation types, strength, coefficient of earth pressures and consolidation test results. A draft report is to be submitted within three weeks of the completion of the fieldwork. Provision is to be made for meetings and consultation with designers.

1 Phase I – Field Program Preparation and Undertaking

Determine by personal examination, the nature and location of the work, the quality and quantity of the work to be encountered, and the character of equipment and facilities needed during the execution of work.

Stake out all utility locates, sampling and borehole locations using survey methods capable of providing an accuracy of 0.3m for locations and 0.01m for ground surface elevations.

Project Geotechnical Engineer must be present on occasion during the field investigation work and log a minimum of two boreholes in different areas of the site.

Obtain samples of each soil type encountered, the first sample being at a depth not greater than 750mm and whether succeeding samples of sand or silt are dry, moist, or wet. Record penetration values of standard penetration test at the top of each soil stratum, commencing at 750mm down to 3m and not greater than 1500mm thereafter. Boreholes are to be advanced to a depth as established in the Preliminary Geotechnical Report or auger refusal whichever is reached first. In cases where preliminary geotechnical investigations had not been completed previously the depth of investigation should be minimum 6m below the estimated founding elevation generally. If the encountered subsurface soil strata are uniform and competent in the area the depth of investigation may be reduced in some boreholes but not less than 3m below founding elevation. *No borehole shall be terminated in the fill layer*.

If the encountered subsurface soil strata are not competent within the planned depth of investigation e.g. soft clays, the depth of investigation should be increased in test boreholes to suitable depth to ascertain the competent soil strata / bed rock.

If auger refusal is encountered due to rock, the rock should be cored to confirm whether concrete, a boulder or bedrock has been encountered.

At least one borehole per 1 hectare is to be conducted using continuous sampling to accurately determine soil type and stratification thickness.

For non cohesive soils, obtain disturbed samples using a split spoon for soil classification and moisture content (ASTM D1586).

For cohesive soils, obtain relatively undisturbed samples using a thin walled Shelby tube to be sealed and returned the Laboratory for penetration testing determination of shear strength, consolidation and triaxial testing.

For cohesive soils measure shear strength with pocket penetrometer and for soils that have shear strength of less than 100kPa, a field vane test to determine the shearing strength should be conducted.

Take measurements for the methane gas in each of the boreholes during drilling at the suspected soil stratum depth and immediately after completing the drilling in each borehole.

Install piezometers / monitoring wells in the boreholes, at least one piezometer / monitoring well per hectare, with a minimum of three locations, preferably six, whichever is a greater number at appropriate horizon and depths. If water bearing strata are encountered in the boreholes, install piezometers sealed in them. The piezometers / monitoring wells shall be properly surrounded by suitably graded granular material and sealed with bentonite above them and at the ground surface to prevent surface runoff from entering the borehole. Return to the site at least twice to measure water levels in the piezometers / monitoring wells and until water levels have stabilized.

Establish the nature and extent of the field investigation, on the basis of the knowledge of the known / published geotechnical conditions in the area and preliminary known details of the proposed development, to be completed. Special site conditions may be encountered and / or special proposed development requirements may arise that would require changes in nature and extent of the planned fieldwork.

The spacing of boreholes shall be as follows:

Standard Sampling	Maximum Grid spacing 20m
Continuous Sampling	Minimum 1/hectare

Depth of sewer borehole equals depth of proposed sewer excavation x 1.5

Where rock is encountered in the boreholes, the following shall be completed:

- Core drilling should be extended a minimum of 3m in at least three boreholes to confirm whether concrete, a boulder or bedrock has been encountered.
- In the situation where end bearing piles are to be placed in the bedrock, the depth of the coring should be taken to sufficient depth, minimum 5m, to ensure that no weaker strata is present below the bedrock surface which would affect the performance of the pile.
- Where weathered rock is encountered extend the boreholes to sufficient depth to ascertain the presence of un-weathered rock.
- Note water loss and gain and changes in drilling resistance.
- Identify and classify rock in accordance with the Canadian Foundation Engineering Manual 4th Edition (CFEM 4th Edition).

Other field testing that should be carried out when appropriate includes:

- Pressuremeter tests
- Static cone tests
- Dynamic cone tests
- Permeability tests
- Packer tests
- Plate load tests

Site Classification for Seismic Site Response:

- Field program must include the work to determine the top 30 m soil profile properties for determination of seismic site response. The preferred methods are ASTM D4428/D4428M “Test Methods for Crosshole Seismic Testing” and ASTM D7400-08 “Test Methods for Downhole Seismic Testing”. If Multichannel Analysis of Surface Wave (MASW) method is proposed a borehole must be drilled to the auger refusal on bedrock or 30 m depth and determine the soil geotechnical parameters to augment the findings of MASW.

2 Phase II – Soil Testing and Analysis

The soil testing program must conform to the latest edition of the following standards:

- ASTM D422 “Standard Test Method for Particle Size Analysis of Soils” (Hydrometer Analysis)

- ASTM D2166 "Standard Test Method for Unconfined Compression Strength of Cohesive Soil"
- ASTM D2435 "Standard Test Method for One-Dimensional Consolidation Properties of Soil Using Incremental Loading"
- ASTM D2487 "Standard Practice for Classification of Soils for engineering purposes (Unified Soil Classification System)"
- ASTM D4318 "Standard Test Method for Liquid Limit, Plastic Limit and Plasticity Index of Soils"
- ASTM D5311 "Standard Test Method for Load Controlled Cyclic Triaxial Strength of Soils"
- ASTM D6913 "Standard Test Method for Particle Size Distribution (Gradation) of Soils using Sieve Analysis"

In the geotechnical laboratory, the soil samples should all be subject to *tactile* examination by an experienced geotechnical engineer who confirms the field descriptions on the borehole log, and who selects representative samples for detailed testing.

The following minimum testing program is required:

1. Moisture content and unit weight for each sample taken in the boreholes.

2. Perform testing for classification of samples (Unified Soil Classification):
   - Non cohesive soils: (Sand &Gravel) grain size distribution; one test for each strata of different soil.
   - Cohesive soils: grain size analysis including hydrometer; and Atterberg limits.

3. Strength (Unconfined Compression and/or Penetrometer testing of cohesive soils).

4. Obtain three samples for determination of potential sulphate attack on locations proposed for concrete elements.

5. Obtain a minimum of ten samples and determine potential for corrosion attack on soil anchors or rock anchors for each of the following parameters:
   - pH
   - Sulphates
   - Sulphides
   - Chlorides
   - Nitrates
   - Acid making potential of the soil or rock

3 Phase III – Completion of Geophysical Survey, Seismic Refraction Survey, Ground Penetrating Radar Survey, Electromagnetic Survey, Utility Mapping

The application of a geophysical survey on a Greenfield site may be used to assist in quantifying parameters regarding geotechnical studies. Applications such as bedrock profiling can be completed using seismic refraction measurements; GPR surveys can map soil stratigraphy or profile shallow undulating bedrock; and EM surveys can define gross changes in soil type or soil moisture content.

The specific work program of the geophysical survey should be developed from the information about the subsurface conditions at the site from the boreholes and geophysical surveys carried out for the preliminary investigation. Types of geophysical survey that should be considered are described below.

All consultants must have a Professional Geoscientists of Ontario Certificate of Authorization to practice as a geophysical consultant. The geophysical investigation must conform to the most recent edition of the following standards:

- ASTM D6429-99 “Standard Guide for Selecting Surface Geophysical Methods”
- ASTM D4428/D4428M “Test Methods for Crosshole Seismic Testing”
- ASTM D5753 “Guide for Planning and Conducting Borehole Geophysical Logging”
- ASTM D5777 “Guide for Using the Seismic Refraction Method for Subsurface Investigation”
- ASTM D6285 “Guide for Locating Abandoned Wells”
- ASTM G57 “Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method”
- ASCE 38-02 “Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data”
- CSA S250-11 “Mapping of Underground Utility Infrastructure”

Selection of the appropriate geophysical technology and survey procedures should follow ASTM D6429-99 in conjunction and in consideration of all available site history, site investigation objectives and other parameters requiring qualification. As a minimum, a reconnaissance-level investigation should be completed to ascertain a basic geophysical understanding of subsurface site conditions. More detailed coverage may be required in impacted or highly sensitive areas. All data should be captured by GPS and geo-referenced. Data should be presented in both hard copy and soft copy format. A letter report will be prepared which at a minimum shall contain the following information:

- General description of site conditions.
- Description of survey instrumentation and applied technology.
- Description of survey procedures.
- Presentation of data in colour contour map format.
- Discussion of findings.
- Recommendations for follow-up work.

The utility mapping survey will consist of:

- Securing all ‘locates’ from all facility owners.
- Marking the inferred routing of all privately owned underground plant within the survey area.
- Physical demarcation of the inferred position of underground utilities by paint or stakes documented by not-to-scale maps.
- Data capture with GPS and presentation in accordance with ASCE 38-02.
- Utility mapping must meet the “S250-11 - Mapping of underground utility infrastructure” CSA Standard.

Seismic Refraction Survey

To profile top of ‘competent’ rock, a seismic refraction survey can be completed. Care must be taken to review the nearby ‘cultural noise’ (e.g. construction projects, airports, vibrating machinery, etc.) in order to establish the viability of this investigation. The source for the survey must also be considered: a 7kg sledge hammer striking a steel plate should be sufficient to map to 10m depth but explosives may be required for deeper sounding. The data must be captured by an engineering seismograph capable of digital recording to ‘stack’ successive signals and/or filter unwanted ‘noise’. The spacing between geophones should be no greater than the anticipated depth of the bedrock profile and sufficient shot points be engaged in order to permit interpretation of the data completed using the Generalized Reciprocal Method or better. Data should be presented as processed sections as depth below surface (or in units of elevation of topographic information is available) demonstrating variations in bedrock seismic velocities which can be compared to published charts of ‘rippability’.

Multi-channel Analysis of Surface Waves (MASW) for Shear Wave Velocity Measurement and Calculation of Vs30

The MASW survey utilizes a similar set-up to a seismic refraction investigation (e.g. 24 geophones equally spaced). The principle consists of generating an acoustic wave at the surface and digitally recording the surface waves by a linear series of geophones on the surface. A sledgehammer is used as the primary energy source with shots typically being recorded at 4 locations along the alignment. A spread length of approximately 70m gives an approximate depth of investigation of 30m

The main processing sequence involves using the software e.g. SeisImagerSW™ software package, for plotting, picking and 1D inversion of the MASW shot records. The 1D shear-wave velocity depth profiles for each shot record are then plotted. The Vs30 value can then be calculated for site soil classification. Multiple 1D shear wave velocity profiles can be interpolated and plotted to generate 2D pseudo cross-sections of shear wave velocities

A detailed description of the method can be found in the paper Multi-channel Analysis of Surface Waves, Park, C.B., Miller, R.D. and Xia, J. Geophysics, Vol. 64, No. 3 (May-June 1999); P. 800–808.

Ground Penetrating Radar Survey (GPR)

GPR can detect non-conductive targets, soil stratigraphy, bedrock profile and provide detailed definition, position and orientation of other features detected by other geophysical investigations. This work should utilize a pulse EKKO 100 system manufactured by Sensors & Software Inc. or equivalent. The production radar survey parameters should be optimized via a series of tests carried out under the auspices of the radar geophysicist to calibrate the radar findings with known subsurface conditions. As a minimum, these test radar data should be acquired and evaluated with two different radar antennae frequencies (i.e. 50 and 100 MHz) and perhaps even three frequencies (25, 50 and 100 MHz) depending on soil conditions, size of the target feature and required depth of investigation. These optimized radar system parameters should be used to acquire the radar data along parallel profile lines at a separation sufficient to image the target with a station spacing equivalent to a maximum distance of one wavelength of the selected radar frequency. Surveying activities will include the following: positioning of the radar system via an established survey grid or via differential GPS measurements, acquire the radar data as described above where accessible, data processing, preparation of radar sections (annotated for interpreted features where applicable), data interpretation in either processed section format and/or colour contoured time slice sections and/or colour contoured bedrock surface/isopach maps, recommendations for follow-up work along with a survey summary described in a covering letter.

Electromagnetic Survey (EM)

To map, to the reconnaissance level, metallic targets and changes in soil conductivity which may infer the presence of inorganic groundwater contamination, environmentally impacted soils, etc. an EM31 terrain conductivity meter manufactured by Geonics Limited, or equivalent should be used to complete an electromagnetic survey. This activity will include as a minimum: establishing a survey grid for measurement positioning and post-survey reference or capturing data with differential GPS measurements; acquiring the electromagnetic data at a station spacing of between 0.25 and 0.50 the distance between adjacent parallel survey with the survey lines spaced no farther apart than the maximum plan width of the smallest target sought, where accessible; preparing a detailed site map showing surface culture which may affect geophysical findings; data processing and presentation in colour contour map format; data interpretation presented as an ‘anomaly’ plan map; and recommendations for follow-up work along with a survey summary described in a covering letter.

4 Phase IV – Hydrogeology Study

The purpose of a detailed hydrogeology study is to characterize existing hydrogeology conditions, determine the need for and options for groundwater control, quantify potential impacts to the local groundwater regime, and determine the need for and nature of any mitigation measures.

Program Components

The hydrogeology study must address site specific groundwater conditions from both a groundwater control and a site development (Low Impact Development) perspective in the subcatchment area within which the proposed project/development is located. Therefore, in addition to investigations specific to the subject site, it may be necessary to secure access to adjacent properties or road allowances to investigate areas of the subcatchment area beyond the property boundaries. This will have to be determined on a site by site basis.

The level of detail must be sufficient to support submission of any permit applications (e.g. Permit To Take Water) or municipal approvals. The methodology to complete the study requirements is at the discretion of the consultant, but must conform to generally accepted groundwater engineering and hydrogeology practices and must meet the requirements of respective upper and lower tier municipalities and conservation authority / MNR as applicable.

Boreholes and groundwater observation wells must be distributed such that the groundwater conditions are well defined for the site and nearby surrounding area. Any specific on-site features (wells, surface water bodies) are to be investigated.

Fieldwork for hydrogeology studies can be conducted concurrently with Geotechnical and Phase Two Environmental Soil & Groundwater Investigations provided the scope of work for each individual investigation is satisfied.

The following is a description of the requirements and expectations for completing a hydrogeology investigation:

- Geology and Hydrogeology
- Requirements for Proposed Development Plan
- Reporting
- Requirements for Permit to Take Water application
- Additional Considerations

Geology and Hydrogeology

Provide an overview of the regional geological setting.

Drill boreholes to determine the site specific geology (stratigraphy and depth to bedrock). The number of boreholes will depend upon the size of the site and the proposed project area, the background data available, and the expected geological complexity of the area.

Collect soil samples from each borehole and test for grain-size to characterize the soil types and to assist in determining soil hydraulic conductivity.

Relate the local geological data to the regional geological setting.

Establish a network of groundwater observation wells to determine the depth to the water table and vertical and horizontal groundwater gradients.

The number of monitoring wells, temporary drive point / permanent piezometers and nested wells to be installed will depend upon the site size, the complexity of drainage, the number of environmental features, the locations of groundwater divides, and the background data available. Where available, existing observation wells may be used. A minimum of three monitoring wells is needed in each potential water bearing zone.

Survey all monitoring locations for coordinates and geodetic elevation.

Map the groundwater flow conditions (including vertical and horizontal flow components).

Conduct pumping tests, bail-down, slug, or other appropriate field tests to confirm the well is functioning or responding without any residual effects from well construction and assess the hydrogeology characteristics of stratigraphic units (e.g. *in situ* hydraulic conductivity).

Monitor groundwater levels in all observation wells. The monitoring period should be sufficient to demonstrate fully-recovered stable water level conditions in each well.

A minimum of three water table observation wells should be equipped with a data logger to continuously record water levels and provide a detailed record of the response of shallow groundwater to climatic conditions throughout the year.

For all projects where a significant aquifer(s) is encountered, a minimum of three water table observations wells in each aquifer should be equipped with a data logger to continuously record water levels.

Provide estimates of groundwater flux.

Monitor surface water baseflows (non-storm event flows; minimum of three days post precipitation event) upstream and downstream in all identified watercourses. The data will be used to assist in establishing groundwater contribution to stream flow and infiltration as part of the water balance assessment.

Collect a sufficient number of groundwater and surface water samples for laboratory analysis of major ion chemistry to establish the background water quality across the area. The data will be used to assist in the assessment of groundwater/surface water interactions and to establish baseline pre-development conditions.

Map groundwater discharge areas and identify any areas along stream corridors for recharge/discharge function protection.

Complete a water balance analysis to determine the pre-development (based on existing conditions) and post-development (based on the proposed land use plan) interflow and deep recharge volumes. The water balance should utilize the longest and most continuous local daily climate data and a soil-moisture balance approach (e.g., Thornthwaite and Mather) with daily or monthly calculations reported on an average annual basis. Surface water flow data should be used to validate the existing conditions water balance where possible.

Requirements for Proposed Development Plan

Determine the infiltration deficit (pre to post development) for the proposed development area.

Identify hydrogeology opportunities and constraints to maintain the water balance (i.e. to address the reduction of the infiltration deficit).

Identify the type, location and size of Low Impact Development (LID) measures that may be feasible for use based on the site specific geological and hydrogeology conditions.

Evaluate opportunities for groundwater related LID measures and practical Best Management Practices (e.g. as outlined in the MOE Stormwater Management Planning and Design Manual 2003) to balance, or at least in part, make up the post-development infiltration deficit.

Should pre-development infiltration not be maintained, predict the impact on the flows in local streams and the local water table and recommend mitigation measures, if warranted.

Identify areas where hydrogeology conditions may affect construction (e.g. high water table, requirements for dewatering, etc.) and recommend control and mitigation measures, if warranted.

Evaluate the potential for impacts from proposed underground services on shallow groundwater conditions adjacent to cores, linkages and stream corridors. If the potential for negative impact exists, mitigative measures are to be recommended.

5 Phase V – Data Analysis, Consultation, Reporting and Recommendations

Two separate reports are required—Geotechnical Investigation Report and Hydrogeology Investigation Report

Geotechnical Investigation Report

Prepare a site plan indicating the location of all field testing locations, indicating the method and accuracy of carrying out the survey.

Present the data collected in both a hard and soft copy format, which at a minimum shall contain the following information:

- General description of site and sub-soil conditions.
- Any special conditions or irregularities.
- Identify if methane gas detected, implications and recommend measures.
- Construction-Advice on any special construction difficulties that may be encountered.
- Include recommendations for formwork in accordance with soil type defined by OHSA.
- Recommendations as to resistively of soil, as in-situ and fully moistened, and Chloride ion concentration and soil pH.
- Sulphate attack. Exposure classification for concrete subject to sulphate attack in accordance with CSA A23.1.

- Foundations-Recommend types of foundations and their design capacity.
- Comments about drainage and dewatering (if required) describing available methods including well points with expected dewatering rate. Details are presented in the Hydrogeology Report.

Borehole logs shall include the following information:

- Type and hardness of bedrock (if encountered) in accordance with the CFEM 4th Edition.
- Depth to bedrock.
- Ground water elevations (stabilized), including piezometer measurements.
- Elevation of any adjacent body of water.
- Geodetic elevation of ground surface at boreholes.
- Thickness and description of materials just below the ground surface, which have not been sampled, such as topsoil, pavement structures, fill, etc.
- Soil stratification, including thickness of each layer.
- Moisture condition of the soil.
- Results of field and laboratory tests, such as Standard Penetration Tests Field Vane Tests and methane gas if detected.
- Soil classification, properties, shear strength, and moisture content.
- Soil densities.
- Drilling methods and dates drilled.

The report shall provide recommendations for the following items:

1. Requirement for Piles (and/or Caissons):
    - Provide Service Limit State (SLS) and Ultimate Limit State (ULS) foundation design capacities with predicted elevations, at which these will be available, and the accuracy of the prediction.
    - Provide pile design capacities for representative piles that may be applicable to the site allowing for stresses resulting from driving, handling and testing.
    - Identify load testing of deep foundation elements if required.
    - Identify spacing requirements of deep foundations and any group effects.
    - Identify inspection requirements of deep foundation elements.
    - Identify if deep foundation elements are based upon end bearing, friction or a combination of both. Identify lateral and uplift load carrying capacities.
    - Identify potential pile installation difficulties.
    - Provide pile end preparations at the depth required to develop proposed design capacities.

- Recommendations regarding pile type and associated bearing capacity, pile uplift resistance and pile drag down forces, and pile lateral load design.
- Foundation Factor-Recommended site classification for seismic site response in accordance with Table 4.1.8.4.A of OBC 2006.
- Maximum total and differential settlement that may be expected.

2. Spread or Raft Footing and Retaining Walls
    - Provide Service Limit State (SLS) and Ultimate Limit State (ULS) design bearing capacities.
    - Parameters for earth pressures on retaining walls and slope stability analysis.
    - Soil and rock anchor design for permanent or temporary anchors.
    - Classify soil for excavations according to OHSA regulations.
    - Permanent and temporary groundwater control at structures (refer to hydro-geotechnical report).
    - Impact of permanent and temporary groundwater control on settlements of proposed structure and surrounding structures.
    - Related parameters to the prevention of frost heave and special construction procedures for sub-grade protection during winter construction.
    - Maximum total and differential settlement that may be expected.

3. Roads, Sewers, and Underground Utilities
    - Frost depth.
    - Depth and type of road base and sub-base material for roadways and parking areas.
    - Soil parameters to be used for calculation of thrust blocks, and restrained joints, including coefficient of friction, shear angle, and bearing capacity.
    - Concerns as to trench bottom uplift.
    - Pipe bedding (materials), corrosion protection and backfilling requirements with respect to Provincial standards, assuming pipe materials to be steel and/or concrete pressure pipe.
    - Drainage.
    - Lateral soil pressure and pressure distribution for design of below grade walls retaining earth.
    - Soil vertical and lateral sub grade modulus.

4. Slab-on-grade
    - Depth of soil to be removed to obtain bearing capacity for slab-on-grade to support without deleterious settlement. Minimum 50 kPa is required.
    - Modulus of subgrade reaction.

- If depth of topsoil has not been determined by digging test pit, comment on reliability of depth recorded.
- Drainage requirements under slab-on-grade.
- Vapor and moisture barrier requirements under slab-on-grade.
- Sub-grade preparation recommendations.
- Bedrock blasting and removal (if required).

5. Formwork and/or Shoring
   - Complete analysis and establish geotechnical parameters for design of shoring system.
   - Open cut trench excavation, type of shoring system, methods of tunneling, jacking, and boring.
   - The use of native/imported backfill, placement depth of layers, and compaction specification for same.

6. Geotechnical seismic design parameters
   - Complete analysis and establish geotechnical seismic design parameters as recommended in CFEM 4th Edition to meet the requirements of National Building Code of Canada (NBCC 2010) and Ontario Building Code (OBC 2006).

7. Engineered Fill
   - The specific site conditions and / or specific proposed development may require the raise of subgrade. Recommendations should be included for the depth of unsuitable soil for removal, existing subgrade / excavation base verification, backfill material quality, fill placement control, lateral and vertical placement limitations, compaction, drainage, geotechnical resistance at Service Limit State (SLS) and Ultimate Limit State (ULS), anticipated total and differential settlements etc

Hydrogeology Investigation Report

The results of the hydrogeology study must address the issues outlined in the study requirements. The table of contents for the Hydrogeology report must include, as a minimum:

1. Introduction
   - Objectives
   - Scope of work

2. Methodology
   - Drilling, Soil Sampling and Observation Well Installation
   - Groundwater Monitoring
   - Surface Water Monitoring
   - Water Quality Sampling Program

3. Physical Setting
    - Physiography and Topography
    - Drainage:
        - ◊ Surface Water Flow
        - ◊ Surface Water Quality
    - Geology
    - Bedrock Geology
    - Quaternary Geology
    - Hydrogeology
    - Aquifers and Local Groundwater Use
    - Groundwater Conditions
    - Groundwater Quality
    - Groundwater/Surface Water Interaction
    - Climate
    - Water Balance
        - ◊ Pre-Development (existing conditions)

4. Development Impact Assessment
    - Predicted Change in Water Balance
    - Impact on Local Groundwater Uses
    - Impact on Local Surface Water Features
    - Impact on Water Quality

5. Development Considerations
    - Groundwater Recharge Management
    - Opportunities and Constraints
    - Mitigation Measures
    - Construction Constraints
    - Monitoring
        - ◊ Water Quantity
        - ◊ Water Quality

6. Conclusions and Recommendations

In addition to the requirements outlined above, the hydrogeology study must also include the following:

- Requirements for determining the need for dewatering.
- Regulatory requirements for preparing and submitting an application for a Permit To Take Water (refer to MOE guidelines).
- Regulatory requirements for cases where dewatering will result in a water taking exceeding 50,000 l/day (refer to MOE guidelines). An application for a Permit To Take Water should be made on behalf of the owner.
- Regulatory requirements (O.Reg. 903) for decommissioning any on site wells (water supply and/or monitoring wells).

Geotechnical & Hydrogeology Investigation Scope B: Greenfield - Size & Location of Structure Known

All consultants must have a Professional Engineers of Ontario Certificate of Authorization to practice as Geotechnical Consultant and be approved to carry out testing as per MOE guidelines for soil, groundwater and sediment standards for use under part XV.1 of the Environmental Protection ACT, 2004 as amended. The Laboratory must be certified by CCIL (Canadian Council of Independent Laboratories), and has participated and met the MTO correlation program for soil testing.

The geotechnical investigation must conform to the most recent edition of the following standards:

- ASTM D420 "Standard Guide to Site Characterization for Engineering, Design and Construction Purposes"
- ASTM D5434 "Standard Guide for Field Logging of Subsurface Explorations of Soil and Rock"
- ASTM D2488 "Standard Practice for Description and Identification of Soils (Visual Manual Procedure)"
- ASTM D1452 "Standard Practice for Soil Investigations and Sampling by Auger Boring"
- ASTM D1586 "Test Method for Penetration Test and Split Barrel Sampling of Soils"
- ASTM D1587 "Standard Practice of Thin Walled Tube Geotechnical Sampling of Soils"
- ASTM D2113 "Standard Practice for Diamond Core Drilling for Site Investigations"
- ASTM D4220 "Standard Practice for Preserving and Transporting Soil Samples"
- ASTM D5079 "Standard Practice for Preserving and Transporting Rock Core l Samples"
- ASTM D2573 "Test Method for Field Vane Shear Test in Cohesive Soils"
- ASTM D5784 "Guide for the use of Hollow Stem Augers for Geo-environmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices"
- ASTM D6151 "Standard Practice for Using Hollow Stem Augers for Geotechnical Exploration and Sampling"
- Canadian Foundation Engineering Manual 4th Edition. Canadian Geotechnical Society 2006

The geotechnical investigation involves the following phases:

Phase I – Field Program Preparation and Undertaking – Carry out a geotechnical and geo-environmental investigation program, including submission of a work plan, communications and process of conduction of field program.

Phase II – Soil Testing and Analysis – The soil sampling program to include soil classification, geo chemical analysis for soil disposal, if applicable, laboratory testing for soil properties.

Phase III – Completion of a Geophysical Survey – Undertake a survey of the entire property to map geophysical anomalies.

Phase IV – Hydrogeology Study

Phase V – Data Analysis, Consultation, Reporting and Recommendations – The final report to include data analysis and recommendations of design parameters required by the structural engineer for bearing capacities, foundation types, strength, coefficient of earth pressures and consolidation test results. A draft report is to be submitted within three weeks of the completion of the fieldwork. Provision is to be made for meetings and consultation with designers.

1 Phase I – Field Program Preparation and Undertaking

Determine from the relevant party, details of the nature, size and location of the project to be constructed.

Determine by personal examination, the nature and location of the work, the quality and quantity of the work to be encountered, and the character of equipment and facilities needed during the execution of work.

Stake out all utility locates, sampling and borehole locations using survey methods capable of providing an accuracy of 0.3m for locations and 0.01m for ground surface elevations.

Project Geotechnical Engineer must be present on occasion during the field investigation work and log a minimum of two boreholes in different areas of the site.

Obtain samples of each soil type encountered, the first sample being at a depth not greater than 750mm and whether succeeding samples of sand or silt are dry, moist, or wet. Record penetration values of standard penetration test at the top of each soil stratum, commencing at 750mm down to 3m and not greater than 1500mm thereafter. Boreholes are to be advanced to a depth as established in the Preliminary Geotechnical Report or auger refusal whichever is reached first. In cases where preliminary geotechnical investigations had not been completed previously the depth of investigation should be minimum 6m below the estimated founding elevation generally. *No borehole shall be terminated in the fill layer*.

If the encountered subsurface soil strata are not competent within the planned depth of investigation e.g. soft clays, the depth of investigation should be increased in test boreholes to suitable depth to ascertain the competent soil strata / bed rock.

If auger refusal is encountered due to rock, the rock should be cored to confirm whether concrete, a boulder or bedrock has been encountered.

At least one borehole at each corner and centre of the main complex and one at the centre of each wing is to be conducted using continuous sampling to accurately determine soil type and stratification thickness.

For non cohesive soils, obtain disturbed samples using a split spoon for soil classification and moisture content (ASTM D1586).

For cohesive soils, obtain relatively undisturbed samples using a thin walled Shelby tube to be sealed and returned the Laboratory for penetration testing determination of shear strength, consolidation and triaxial testing as outlined for the structural engineer’s requirements if available.

For cohesive soils measure shear strength with pocket penetrometer and for soil that have shear strength of less than 100kPa, a field vane test to determine the shearing strength should be conducted.

Take measurements for the methane gas in each of the boreholes during drilling at the suspected soil stratum depth and immediately after completing the drilling in each borehole.

Install piezometers / monitoring wells in the boreholes, at least one piezometer / monitoring well per hectare, with a minimum of three locations, preferably six, whichever is a greater number at appropriate horizon and depths. If water bearing strata are encountered in the boreholes, install piezometers sealed in them. The piezometers / monitoring wells shall be properly surrounded by suitably graded granular material and sealed with bentonite above them and at the ground surface to prevent surface runoff from entering the borehole. Return to the site at least twice to measure water levels in the piezometers / monitoring wells and until water levels have stabilized.

Establish the nature and extent of the field investigation, on the basis of the knowledge of the known / published geotechnical conditions, the results of the geophysical surveys, and the known details of the structure, to be completed. Special site conditions may be encountered and / or special proposed development requirements may arise that would require changes in nature and extent of the planned fieldwork.

The spacing of boreholes shall be as follows:

Standard Sampling	Maximum grid spacing below proposed structure 15m
Continuous Sampling	One at each corner and centre of the main complex and one at the centre of each wing
Roads, Parking, Other Utilities	40m linear
Bridges & culverts	2/foundation

Depth of sewer borehole equals depth of proposed sewer excavation (D) x 1.5
Standard & continuous sampling combined shall never exceed 15m spacing under structures.

Where surcharge fill and/or certified engineered fill has been placed on an area, additional boreholes are required to sample the soil to determine if consolidation has occurred and to determine expected settlement under load. The boreholes to be placed at carefully selected locations at a maximum 15m grid spacing and continual sampling are to be conducted in all boreholes.

Where rock is encountered in the boreholes, the following shall be completed:

- Core drilling should be extended a minimum of 3m in at least three boreholes to confirm whether concrete, a boulder or bedrock has been encountered.
- In the situation where end bearing piles are to be placed in the bedrock, the depth of the coring should be taken to sufficient depth, minimum 5m, to ensure that no weaker strata is present below the bedrock surface which would affect the performance of the pile.
- Where weathered rock is encountered extend the boreholes to sufficient depth to ascertain the presence of un-weathered rock.
- Note water loss and gain and changes in drilling resistance.
- Identify and classify rock in accordance with the CFEM 4^{th} Edition.

Other field testing that should be carried out when appropriate includes:

- Pressuremeter tests
- Static cone tests
- Dynamic cone tests
- Permeability tests
- Packer tests
- Plate load tests

Site Classification for Seismic Site Response:

- Field program must include the work to determine the top 30 m soil profile properties for determination of seismic site response. The preferred methods are ASTM D4428/D4428M “Test Methods for Crosshole Seismic Testing” and ASTM D7400-08 “Test Methods for Downhole Seismic Testing”. If Multichannel Analysis of Surface Wave (MASW) method is proposed a borehole must be drilled to the auger refusal on bedrock or 30 m depth and determine the soil geotechnical parameters to augment the findings of MASW.

2 Phase II – Soil Testing and Analysis

The soil testing program must conform to the latest edition of the following standards:

- ASTM D422 “Standard Test Method for Particle Size Analysis of Soils” (Hydrometer Analysis)
- ASTM D2166 “Standard Test Method for Unconfined Compression Strength of Cohesive Soil”
- ASTM D2435 “Standard Test Method for One-Dimensional Consolidation Properties of Soil Using Incremental Loading”
- ASTM D2487 “Standard Practice for Classification of Soils for engineering purposes (Unified Soil Classification System)”
- ASTM D4318 “Standard Test Method for Liquid Limit, Plastic Limit and Plasticity Index of Soils”
- ASTM D5311 “Standard Test Method for Load Controlled Cyclic Triaxial Strength of Soils”
- ASTM D6913 “Standard Test Method for Particle Size Distribution (Gradation) of Soils using Sieve Analysis”

In the geotechnical laboratory, the soil samples should all be subject to tactile examination by an experienced geotechnical engineer who confirms the field descriptions on the borehole log, and who selects representative samples for detailed testing.

The following minimum testing program is required:

1. Moisture content and unit weight for each sample taken in the boreholes.

2. Perform testing for classification of samples (Unified Soil Classification):
   - Non cohesive soils: (Sand & Gravel) grain size distribution; one test for each strata of different soil.
   - Cohesive soils: grain size analysis including Hydrometer; and Atterberg limits.

3. Strength (Unconfined Compression and/or Penetrometer testing of cohesive soils). Field vane testing of clay soil below the footing or top

of caissons/piles should be conducted if the undrained shear strength (Cu) measured using a pocket penetrometer is less than 100 kPa.

4. Carry out strength consolidation tests on cohesive soils (three samples) beneath any proposed structural elements (buildings, retaining walls, etc).

5. Obtain three samples for determination of potential sulphate attack on locations proposed for concrete elements.

6. Obtain a minimum of ten samples and determine potential for corrosion attack on soil anchors or rock anchors for each of the following parameters:
   - pH
   - Sulphates
   - Sulphides
   - Chlorides
   - Nitrates
   - Acid making potential of the soil or rock

3 Phase III – Completion of Geophysical Survey, Seismic Refraction Survey, Ground Penetrating Radar Survey, Electromagnetic Survey, Utility Mapping

The application of a geophysical survey for a greenfield site where the existing structures are known can assist in characterizing known, unknown or changes in subsurface conditions. These activities could include an EM or GPR Survey of the entire property to map geophysical anomalies that may be indicative of conductive materials in the subsurface. A utility mapping survey could also assist in providing an inventory of underground infrastructure to prevent damage during subsequent investigations, review existing assets for facility expansion, and consider pathways for drainage and offsite migration of groundwater.

The specific work program of the geophysical survey should be developed from the information about the subsurface conditions at the site from the boreholes and geophysical surveys carried out for the preliminary investigation. Types of geophysical survey that should be considered are described below.

All consultants must have a Professional Geoscientists of Ontario Certificate of Authorization to practice as a geophysical consultant. The geophysical investigation must conform to the most recent edition of the following standards:

- ASTM D6429-99 “Standard Guide for Selecting Surface Geophysical Methods”

- ASTM D4428/D4428M “Test Methods for Crosshole Seismic Testing”
- ASTM D5753 “Guide for Planning and Conducting Borehole Geophysical Logging”
- ASTM D5777 “Guide for Using the Seismic Refraction Method for Subsurface Investigation”
- ASTM D6285 “Guide for Locating Abandoned Wells”
- ASTM G57 “Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method”
- ASCE 38-02 “Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data”
- CSA S250-11 “Mapping of Underground Utility Infrastructure”

Selection of the appropriate geophysical technology and survey procedures should follow ASTM D6429-99 in conjunction and in consideration of all available site history, site investigation objectives and other parameters requiring qualification. As a minimum, a reconnaissance-level investigation should be completed to ascertain a basic geophysical understanding of subsurface site conditions. More detailed coverage may be required in impacted or highly sensitive areas. All data should be captured by GPS and geo-referenced. Data should be presented in both hard copy and soft copy format. A letter report will be prepared which at a minimum shall contain the following information:

- General description of site conditions.
- Description of survey instrumentation and applied technology.
- Description of survey procedures.
- Presentation of data in colour contour map format.
- Discussion of findings.
- Recommendations for follow-up work.

The utility mapping survey will consist of:

- Securing all ‘locates’ from all facility owners.
- Marking the inferred routing of all privately owned underground plant within the survey area.
- Physical demarcation of the inferred position of underground utilities by paint or stakes documented by not-to-scale maps.
- Data capture with GPS and presentation in accordance with ASCE 38-02..
- Utility mapping must meet the “S250-11 - Mapping of underground utility infrastructure” CSA Standard.

Seismic Refraction Survey

If required to profile top of ‘competent’ rock, a seismic refraction survey can be completed. Care must be taken to review the nearby ‘cultural noise' (e.g. construction projects, airports, vibrating machinery, etc.) in order to establish the viability of this investigation. The source for the survey must also be considered: a 7kg sledge hammer striking a steel plate should be sufficient to map to 10m depth but explosives may be required for deeper sounding. The data must be captured by an engineering seismograph capable of digital recording to 'stack' successive signals and/or filter unwanted 'noise'. The spacing between geophones should be no greater than the anticipated depth of the bedrock profile and sufficient shot points be engaged in order to permit interpretation of the data completed using the Generalized Reciprocal Method or better. Data should be presented as processed sections as depth below surface (or in units of elevation of topographic information is available) demonstrating variations in bedrock seismic velocities which can be compared to published charts of 'rippability'.

Multi-channel Analysis of Surface Waves (MASW) for Shear Wave Velocity Measurement and Calculation of Vs30

The MASW survey utilizes a similar set-up to a seismic refraction investigation (e.g. 24 geophones equally spaced). The principle consists of generating an acoustic wave at the surface and digitally recording the surface waves by a linear series of geophones on the surface. A sledgehammer is used as the primary energy source with shots typically being recorded at 4 locations along the alignment. A spread length of approximately 70m gives an approximate depth of investigation of 30m

The main processing sequence involves using the software e.g. SeisImagerSW™ software package, for plotting, picking and 1D inversion of the MASW shot records. The 1D shear-wave velocity depth profiles for each shot record are then plotted. The Vs30 value can then be calculated for site soil classification. Multiple 1D shear wave velocity profiles can be interpolated and plotted to generate 2D pseudo cross-sections of shear wave velocities

A detailed description of the method can be found in the paper Multi-channel Analysis of Surface Waves, Park, C.B., Miller, R.D. and Xia, J. Geophysics, Vol. 64, No. 3 (May-June 1999); P. 800–808.

Electromagnetic Survey (EM)

To map, to the reconnaissance level, metallic targets and changes in soil conductivity which may infer the presence of inorganic groundwater contamination, environmentally impacted soils, etc. an EM31 terrain conductivity meter manufactured by Geonics Limited, or equivalent should be used to complete an electromagnetic survey. This activity will include as a minimum: establishing a survey grid for measurement positioning and post-survey reference or capturing data with differential GPS measurements; acquiring the electromagnetic data at a station spacing of between 0.25 and 0.50 the distance between adjacent parallel survey with the survey lines spaced no farther apart than the maximum plan width of the smallest target sought, where accessible; preparing a detailed site map showing surface culture which may affect geophysical findings; data processing and presentation in colour contour map format; data interpretation presented as an ‘anomaly’ plan map; and recommendations for follow-up work along with a survey summary described in a covering letter.

To map metallic targets an EM61 time-domain metal detector manufactured by Geonics Limited, or equivalent, should be used to complete an electromagnetic survey. This activity will include as a minimum: establishing a survey grid for measurement positioning and post-survey reference or capturing data with differential GPS measurements; acquiring the electromagnetic data in ‘continuous’ mode or with readings spaced no greater than 0.25m intervals along parallel survey lines spaced no farther apart than the maximum plan width of the smallest target sought (e.g. 1m stations to locate a single vertically oriented buried drum) where accessible; preparation of a detailed site map showing surface culture which may affect geophysical findings; data processing and presentation in colour contour map format; data interpretation presented as an ‘anomaly’ plan map; and recommendations for follow-up work along with a survey summary described in a covering letter.

Ground Penetrating Radar (GPR)

GPR can detect non-conductive targets, soil stratigraphy, bedrock profile and provide detailed definition, position and orientation of other features detected by other geophysical investigations. This work should utilize a Noggin 250 system manufactured by Sensors & Software Inc. or equivalent. If the objective of the survey is isolation of discrete targets (e.g. utility location, septic or underground storage tanks, etc.) the radar data can be acquired at the discretion of the radar technician to provide an on-site in-field interpretation which will be documented by marks (paint, flags, stakes, etc.) on the ground and further documented by not-to-scale sketch maps annotated for data interpretation with measured offsets to locally visible landmarks. If the objective is to ‘map’ any extensive feature (greater than 10m x 10m) the radar data will be acquired along profile lines spaced at 0.5m intervals oriented perpendicular to the orientation of the target. Data will be collected at nominal 10cm stations. Surveying activities will include the following: positioning of the radar system via an established survey grid or via differential GPS measurements; acquiring the radar data as described above where accessible; data processing; preparing radar sections (annotated for interpreted features where applicable); data interpretation in either processed section format and/or colour contoured time slice sections, and recommendations for follow-up work along with a survey summary described in a covering letter.

To assist in evaluating indoor conditions, concrete integrity, rebar pattern or spacing, location of post-tensioned cables, voids under concrete, honey combing, concrete spalling or delamination, a GPR survey will be performed with a Sensors & Software Conquest high frequency radar system, or industry equivalent. The data will be acquired in detailed sections measuring 60cm x 60cm where the GPR data will be acquired in two orthogonal directions to image all features within the concrete. Collection of data in 'reconnaissance' mode should be avoided. The data will be processed and displayed as contoured time-slice images and the interpretation of the data will be presented directly on the concrete as markings (paint, chalk, marker, etc.) which will be documented on not-to-scale sketch maps annotated for offset measurements to visible landmark features.

Utility Mapping

As a minimum, the utility mapping survey will consist of: provision of all private locates and delivery of sanctioned 'locates' from all facility owners; physical demarcation of the inferred position of underground utilities by paint or stakes documented by not-to-scale maps. These documents will permit TSSA and OHSA compliant excavation by third parties. Any digital map products of inferred utility positions will be delivered as per ASCE 38-02 Level A. Utility mapping must meet the "CSA S250-11 - Mapping of underground utility infrastructure" Accuracy Level AL 2 Standard.

For detailed investigations, where this information will be used to assist in the design of existing structures and facilities, the utility mapping process should be completed to identify any impediments to either the design and/or construction of proposed underground installations. This process will follow four steps as follows:

- Review and collation of all existing maps of underground infrastructure.
- Capture of engineering topographic data showing all utility appurtenances and geometries.
- Completion of a subsurface site survey to capture the actual (field) location of all underground utilities in order to rectify all differences, missing information, etc. at specific areas along the route. At this time a quality field check of the topographic data will also be completed. Prepare a subsequent drawing which should be sufficient to permit preliminary design.
- Based on the preliminary design and identified utility conflicts, a vacuum excavation study should be completed to determine the

exact vertical and horizontal position of all potential utility conflicts to permit better design and subsequent utility coordination.

Wherever possible and whenever reasonable, existing storm and sanitary drainage should be located via the installation of a transmitting sonde into catch basins and manholes. Every effort should be made to trace the storm and sanitary system using these techniques. Invert measurements should be obtained where accessible from surface. Resolving the storm and sanitary network may necessitate the use of video inspection subcontractors (e.g. for individual unit system outlets (i.e. laterals) that tee into the main sewer lines as "blind" connections) and confined space entry techniques.

The information acquired during this investigation will be transferred onto the digital site map. The digital data will be acquired using survey-grade GPS measurements. The field data will be recorded on not-to-scale field sheets with offset distances measured, using survey tapes and/or measuring wheels, from curb lines, building walls, or other permanent landmark features shown on the digital base map. The final results of this mapping program will be documented in digital plan format. Unless otherwise specified, all drawings will be created to adhere to CI/ASCE Standard 38-02 Level A for the collection and depiction of subsurface utility data.

4 Phase IV – Hydrogeology Study

The purpose of a detailed hydrogeology study is to characterize existing hydrogeology conditions, determine the need for and options for groundwater control, quantify potential impacts to the local groundwater regime, and determine the need for and nature of any mitigation measures.

Program Components

The hydrogeology study must address site specific groundwater conditions from both a groundwater control and a site development (Low Impact Development) perspective in the subcatchment area within which the proposed project/development is located. Therefore, in addition to investigations specific to the subject site, it may be necessary to secure access to adjacent properties or road allowances to investigate areas of the subcatchment area beyond the property boundaries. This will have to be determined on a site by site basis.

The level of detail must be sufficient to support submission of any permit applications (e.g. Permit To Take Water) or municipal approvals. The methodology to complete the study requirements is at the discretion of the consultant, but must conform to generally accepted groundwater engineering and hydrogeology practices and must meet the requirements of respective upper and lower tier municipalities and conservation authority / MNR as applicable.

Boreholes and groundwater observation wells must be distributed such that the groundwater conditions are well defined for the site and nearby surrounding area. Any specific on-site features (wells, surface water bodies) are to be investigated.

Fieldwork for hydrogeology studies can be conducted concurrently with Geotechnical and Phase Two Environmental Soil & Groundwater Investigations provided the scope of work for each individual investigation is satisfied.

The following is a description of the requirements and expectations for completing a hydrogeology investigation:

- Geology and Hydrogeology
- Requirements for Proposed Development Plan
- Reporting
- Requirements for Permit to Take Water application
- Additional Considerations

Geology and Hydrogeology

Provide an overview of the regional geological setting.

Drill boreholes to determine the site specific geology (stratigraphy and depth to bedrock). The number of boreholes will depend upon the size of the site and the proposed project area, the background data available, and the expected geological complexity of the area.

Collect soil samples from each borehole and test for grain-size to characterize the soil types and to assist in determining soil hydraulic conductivity.

Relate the local geological data to the regional geological setting.

Establish a network of groundwater observation wells to determine the depth to the water table and vertical and horizontal groundwater gradients.

The number of monitoring wells, temporary drive point / permanent piezometers and nested wells to be installed will depend upon the site size, the complexity of drainage, the number of environmental features, the locations of groundwater divides, and the background data available. Where available, existing observation wells may be used. A minimum of three monitoring wells is needed in each potential water bearing zone.

Survey all monitoring locations for coordinates and geodetic elevation.

Map the groundwater flow conditions (including vertical and horizontal flow components).

Conduct pumping tests, bail-down, slug, or other appropriate field tests to confirm the well is functioning or responding without any residual effects from well construction and assess the hydrogeology characteristics of stratigraphic units (e.g. *in situ* hydraulic conductivity).

Monitor groundwater levels in all observation wells. The monitoring period should be sufficient to demonstrate fully-recovered stable water level conditions in each well.

A minimum of three water table observation wells should be equipped with a data logger to continuously record water levels and provide a detailed record of the response of shallow groundwater to climatic conditions throughout the year.

For all projects where a significant aquifer(s) is encountered, a minimum of three water table observations wells in each aquifer should be equipped with a data logger to continuously record water levels.

Provide estimates of groundwater flux.

Monitor surface water baseflows (non-storm event flows; minimum of three days post precipitation event) upstream and downstream in all identified watercourses. The data will be used to assist in establishing groundwater contribution to stream flow and infiltration as part of the water balance assessment.

Collect a sufficient number of groundwater and surface water samples for laboratory analysis of major ion chemistry to establish the background water quality across the area. The data will be used to assist in the assessment of groundwater/surface water interactions and to establish baseline pre-development conditions.

Map groundwater discharge areas and identify any areas along stream corridors for recharge/discharge function protection.

Complete a water balance analysis to determine the pre-development (based on existing conditions) and post-development (based on the proposed land use plan) interflow and deep recharge volumes. The water balance should utilize the longest and most continuous local daily climate data and a soil-moisture balance approach (e.g., Thornthwaite and Mather) with daily or monthly calculations reported on an average annual basis. Surface water flow data should be used to validate the existing conditions water balance where possible.

Requirements for Proposed Development Plan

Determine the infiltration deficit (pre to post development) for the proposed development area.

Identify hydrogeology opportunities and constraints to maintaining the water balance (i.e. to address the reduction of the infiltration deficit).

Identify the type, location and size of Low Impact Development (LID) measures that may be feasible for use based on the site specific geological and hydrogeology conditions.

Evaluate opportunities for groundwater related LID measures and practical Best Management Practices (e.g. as outlined in the MOE Stormwater Management Planning and Design Manual 2003) to balance, or at least in part, make up the post-development infiltration deficit.

Should pre-development infiltration not be maintained, predict the impact on the flows in local streams and the local water table and recommend mitigation measures, if warranted.

Identify areas where hydrogeology conditions may affect construction (e.g. high water table, requirements for dewatering, etc.) and recommend control and mitigation measures, if warranted.

Evaluate the potential for impacts from proposed underground services on shallow groundwater conditions adjacent to cores, linkages and stream corridors. If the potential for negative impact exists, mitigative measures are to be recommended.

5 Phase V – Data Analysis, Consultation, Reporting and Recommendations

Two separate reports are required—Geotechnical Investigation Report and Hydrogeology Investigation Report

Geotechnical Investigation Report

Prepare a site plan indicating the location of all field testing locations, indicating the method and accuracy of carrying out the survey.

Present the data collected in both a hard and soft copy format, which at a minimum shall contain the following information:

- General description of site and sub-soil conditions.
- Any special conditions or irregularities.
- Construction-Advice on any special construction difficulties that may be encountered.
- Identify if methane gas detected, implications and recommend measures.

- Include recommendations for formwork in accordance with soil type defined by OHSA.
- Recommendations as to resistively of soil, as in-situ and fully moistened, and Chloride ion concentration and soil pH.
- Sulphate attack. Exposure classification for concrete subject to sulphate attack in accordance with CSA A23.1.
- Foundations - Recommend types of foundations and their design capacity.
- Recommendations for drainage and dewatering (if required) describing available methods including well points with expected dewatering rate.

Borehole logs shall include the following information:

- Type and hardness of bedrock (if encountered) in accordance with CFEM 4th edition.
- Depth to bedrock.
- Ground water elevations (stabilized), including piezometer measurements.
- Elevation of any adjacent body of water.
- Geodetic elevation of ground surface at boreholes.
- Thickness and description of materials just below the ground surface, which have not been sampled, such as topsoil, pavement structures, fill, etc.
- Soil stratification, including thickness of each layer.
- Moisture condition of the soil.
- Results of field and laboratory tests, such as Standard Penetration Tests Field Vane Tests and methane gas if detected.
- Soil classification, properties, shear strength, and moisture content.
- Soil densities.
- Drilling methods and dates drilled.

The report shall provide recommendations for the following items:

1. Requirement for Piles (and/or Caissons)
    - Provide Service Limit State (SLS) and Ultimate Limit State (ULS) foundation design capacities with predicted elevations, at which these will be available, and the accuracy of the prediction.
    - Provide pile design capacities for representative piles that may be applicable to the site allowing for stresses resulting from driving, handling and testing.
    - Identify load testing of deep foundation elements if required.
    - Identify spacing requirements of deep foundations and any group effects.
    - Identify inspection requirements of deep foundation elements.

- Identify if deep foundation elements are based upon end bearing, friction, or a combination of both. Identify lateral and uplift load carrying capacities.
- Identify potential pile installation difficulties.
- Provide pile end preparations at the depth required to develop proposed design capacities.
- Recommendations regarding pile type and associated bearing capacity, pile uplift resistance and pile drag down forces, and pile lateral load design.
- Foundation Factor-Recommended site classification for seismic site response in accordance with Table 4.1.8.4.A of OBC 2006.
- Maximum total and differential settlement that may be expected.

2. Spread or Raft Footing and Retaining Walls
   - Provide Service Limit State (SLS) and Ultimate Limit State (ULS) design bearing capacities.
   - Parameters for earth pressures on retaining walls and slope stability analysis.
   - Soil and rock anchor design for permanent or temporary anchors.
   - Classify soil for excavations according to OHSA regulations.
   - Permanent and temporary groundwater control at structures (refer to hydro-geotechnical report).
   - Impact of permanent and temporary groundwater control on settlements of proposed structure and surrounding structures.
   - Related parameters to the prevention of frost heave and special construction procedures for sub-grade protection during winter construction.
   - Impact of the self-weight settlement of engineered fills.
   - Maximum total and differential settlement that may be expected.

3. Roads, Sewers, and Underground Utilities
   - Frost depth.
   - Depth and type of road base and sub-base material for roadways and parking areas.
   - Soil parameters to be used for calculation of thrust blocks, and restrained joints, including coefficient of friction, shear angle, and bearing capacity.
   - Concerns as to trench bottom uplift.
   - Pipe bedding (materials), corrosion protection and backfilling requirements with respect to Provincial standards, assuming pipe materials to be steel and/or concrete pressure pipe.
   - Drainage.
   - Lateral soil pressure and pressure distribution for design of below grade walls retaining earth.
   - Soil vertical and lateral sub grade modulus.

4. Slab-on-grade
   - Depth of soil to be removed to obtain bearing capacity for slab-on-grade to support without deleterious settlement. Minimum 50 kPa is required.
   - Modulus of subgrade reaction.
   - If depth of topsoil has not been determined by digging test pit, comment on reliability of depth recorded.
   - Drainage requirements under slab-on-grade.
   - Vapor and moisture barrier requirements under slab-on-grade.
   - Sub-grade preparation recommendations.
   - Bedrock blasting and removal (if required).

5. Formwork and/or Shoring
   - Complete analysis and establish geotechnical parameters for design of shoring system
   - Open cut trench excavation, type of shoring system, methods of tunneling, jacking, and boring
   - The use of native/imported backfill, placement depth of layers, and compaction specification for same.

6. Geotechnical seismic design parameters
   - Complete analysis and establish geotechnical seismic design parameters as recommended in CFEM 4th Edition to meet the requirements of National Building Code of Canada (NBCC 2010) and Ontario Building Code (OBC 2006).

7. Engineered Fill
   - The specific site conditions and / or specific proposed development may require the raise of subgrade. Recommendations should be included for the depth of unsuitable soil for removal, existing subgrade / excavation base verification, backfill material quality, fill placement control, lateral and vertical placement limitations, compaction, drainage, geotechnical resistance at Service Limit State (SLS) and Ultimate Limit State (ULS), anticipated total and differential settlements etc.

Hydrogeology Investigation Report

The results of the hydrogeology study must address the issues outlined in the study requirements. The table of contents for the Hydrogeology report must include, as a minimum:

1. Introduction
   - Objectives
   - Scope of work

2. Methodology
    - Drilling, Soil Sampling and Observation Well Installation
    - Groundwater Monitoring
    - Surface Water Monitoring
    - Water Quality Sampling Program

3. Physical Setting
    - Physiography and Topography
    - Drainage:
        - ◊ Surface Water Flow
        - ◊ Surface Water Quality
    - Geology
    - Bedrock Geology
    - Quaternary Geology
    - Hydrogeology
    - Aquifers and Local Groundwater Use
    - Groundwater Conditions
    - Groundwater Quality
    - Groundwater/Surface Water Interaction
    - Climate
    - Water Balance
        - ◊ Pre-Development (existing conditions)

4. Development Impact Assessment
    - Predicted Change in Water Balance
    - Impact on Local Groundwater Uses
    - Impact on Local Surface Water Features
    - Impact on Water Quality

5. Development Considerations
    - Groundwater Recharge Management
    - Opportunities and Constraints
    - Mitigation Measures
    - Construction Constraints
    - Monitoring
        - ◊ Water Quantity
        - ◊ Water Quality

6. Conclusions and Recommendations

In addition to the requirements outlined above, the hydrogeology study must also include the following:

- Requirements for determining the need for dewatering.
- Regulatory requirements for preparing and submitting an application for a Permit To Take Water (refer to MOE guidelines).

- Regulatory requirements for cases where dewatering will result in a water taking exceeding 50,000 l/day (refer to MOE guidelines). An application for a Permit To Take Water should be made on behalf of the owner.
- Regulatory requirements (O.Reg. 903) for decommissioning any on site wells (water supply and/or monitoring wells).

Geotechnical & Hydrogeology Investigation Scope C: Infill or Expansion

All consultants must have a Professional Engineers of Ontario Certificate of Authorization to practice as Geotechnical Consultant and be approved to carry out testing as per MOE guidelines for soil, groundwater and sediment standards for use under part XV.1 of the Environmental Protection ACT, 2004 as amended. The Laboratory must be certified by CCIL (Canadian Council of Independent Laboratories), and has participated and met the MTO correlation program for soil testing.

The geotechnical investigation must conform to the most recent edition of the following standards:

- ASTM D420 “Standard Guide to Site Characterization for Engineering, Design and Construction Purposes”
- ASTM D5434 “Standard Guide for Field Logging of Subsurface Explorations of Soil and Rock”
- ASTM D2488 “Standard Practice for Description and Identification of Soils (Visual Manual Procedure)”
- ASTM D1452 “Standard Practice for Soil Investigations and Sampling by Auger Boring”
- ASTM D1586 “Test Method for Penetration Test and Split Barrel Sampling of Soils”
- ASTM D1587 “Standard Practice of Thin Walled Tube Geotechnical Sampling of Soils”
- ASTM D2113 “Standard Practice for Diamond Core Drilling for Site Investigations”
- ASTM D4220 “Standard Practice for Preserving and Transporting Soil Samples”
- ASTM D5079 “Standard Practice for Preserving and Transporting Rock Core l Samples”
- ASTM D2573 “Test Method for Field Vane Shear Test in Cohesive Soils”
- ASTM D5784 ”Guide for the use of Hollow Stem Augers for Geo-environmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices”
- ASTM D6151 “Standard Practice for Using Hollow Stem Augers for Geotechnical Exploration and Sampling”
- Canadian Foundation Engineering Manual 4th Edition. Canadian Geotechnical Society 2006

The geotechnical investigation involves the following phases:

Phase I – Field Program Preparation and Undertaking – Carry out a geotechnical and geo-environmental investigation program, including submission of a work plan, communications and process of conduction of field program.

Phase II – Soil Testing and Analysis – The soil sampling program to include soil classification, geo chemical analysis for soil disposal, if applicable, laboratory testing for soil properties.

Phase III – Completion of a Geophysical Survey – Undertake a survey of the entire property to map geophysical anomalies.

Phase IV – Hydrogeology Study

Phase V – Data Analysis, Consultation, Reporting and Recommendations – The final report to include data analysis and recommendations of design parameters required by the structural engineer for bearing capacities, foundation types, strength, coefficient of earth pressures and consolidation test results. A draft report is to be submitted within three weeks of the completion of the fieldwork. Provision is to be made for meetings and consultation with designers.

1 Phase I – Field Program Preparation and Undertaking

Determine from the relevant party, details of the nature, size and location of the project to be constructed.

Determine by personal examination, the nature and location of the work, the quality and quantity of the work to be encountered, and the character of equipment and facilities needed during the execution of work.

Stake out all utility locates, sampling and borehole locations using survey methods capable of providing an accuracy of 0.3m for locations and 0.01m for ground surface elevations.

Project Geotechnical Engineer must be present on occasion during the field investigation work and log a minimum of two boreholes in different areas of the site.

Obtain samples of each soil type encountered, the first sample being at a depth not greater than 750mm and whether succeeding samples of sand or silt are dry, moist, or wet. Record penetration values of standard penetration test at the top of each soil stratum, commencing at 750mm down to 3m and not greater than 1500mm thereafter. Boreholes are to be advanced to a depth as established in the Preliminary Geotechnical Report or auger refusal whichever is reached first. In cases where preliminary geotechnical investigations had not been completed previously the depth of investigation should be minimum 6m below the estimated founding elevation generally. *No borehole shall be terminated in the fill layer.*

If the encountered subsurface soil strata are not competent within the planned depth of investigation e.g. soft clays, the depth of investigation should be increased in test boreholes to suitable depth to ascertain the competent soil strata / bed rock.

If auger refusal is encountered due to rock, the rock should be cored to confirm whether concrete, a boulder or bedrock has been encountered.

At least three boreholes in the proposed location of large structures (>250 m^2) is to be conducted using continuous sampling to accurately determine soil type and stratification thickness.

For non cohesive soils, obtain disturbed samples using a split spoon for soil classification and moisture content (ASTM D1586).

For cohesive soils, obtain relatively undisturbed samples using a thin walled Shelby tube to be sealed and returned the Laboratory for penetration testing determination of shear strength, consolidation and triaxial testing as outlined for the structural engineer's requirements if available.

For cohesive soils measure shear strength with pocket penetrometer and soil that have shear strength of less than 100kPa, a field vane test to determine the shearing strength should be conducted.

Take measurements for the methane gas in each of the boreholes during drilling at the suspected soil stratum depth and immediately after completing the drilling in each borehole.

Install piezometers / monitoring wells in the boreholes, at least one piezometer / monitoring well per hectare, with a minimum of three locations, preferably six, whichever is a greater number at appropriate horizon and depths. If water bearing strata are encountered in the boreholes, install piezometers sealed in them. The piezometers / monitoring wells shall be properly surrounded by suitably graded granular material and sealed with bentonite above them and at the ground surface to prevent surface runoff from entering the borehole. Return to the site at least twice to measure water levels in the piezometers / monitoring wells and until water levels have stabilized.

Establish the nature and extent of the field investigation, on the basis of the knowledge of the known / published geotechnical conditions, the results of the geophysical surveys, and the known details of the structure, to be completed. Special site conditions may be encountered and / or special proposed development requirements may arise that would require changes in nature and extent of the planned fieldwork.

The spacing of boreholes shall be as follows:

Standard Sampling	Maximum grid spacing below proposed structure 15m
Continuous Sampling	One at each corner and centre of the main complex, one at the centre of each wing, and at 15m intervals 1) around any structure within the proposed footprint 2) inside the existing structure within the proposed building footprint [at appropriate locations determined by the geotechnical engineer]. 3) along any structure impacted by the proposed excavation
Roads, Parking, Other Utilities	40m linear
Bridges & Culverts	2/foundation

Depth of sewer borehole equals depth of proposed sewer excavation (D) x 1.5
Standard & continuous sampling combined shall never exceed 15m spacing under structures.

NOTE: All boreholes adjacent to active facilities and buildings to be demolished shall be continuous sampling.

Where surcharge fill and/or certified engineered fill has been placed on an area, additional boreholes are required to sample the soil to determine if consolidation has occurred and to determine expected settlement under load. The boreholes to be placed at carefully selected locations at a maximum 15m grid spacing and continual sampling are to be conducted in all boreholes.

Where rock is encountered in the boreholes, the following shall be completed:

- Core drilling should be extended a minimum of 3m in three boreholes to confirm whether concrete, a boulder or bedrock has been encountered.
- In the situation where end bearing piles are to be placed in the bedrock, the depth of the coring should be taken to sufficient depth, minimum 5m, to ensure that no weaker strata is present below the bedrock surface which would affect the performance of the pile.
- Where weathered rock is encountered extend the boreholes to sufficient depth to ascertain the presence of un-weathered rock.
- Note water loss and gain and changes in drilling resistance.
- Identify and classify rock in accordance with the Canadian Foundation Engineering Manual 4th Edition.

Other field testing that should be carried out when appropriate includes:

- Pressuremeter tests

- Static cone tests
- Dynamic cone tests
- Permeability tests
- Packer tests
- Plate load tests

Site Classification for Seismic Site Response:

- Field program must include the work to determine the top 30 m soil profile properties for determination of seismic site response. The preferred methods are ASTM D4428/D4428M "Test Methods for Crosshole Seismic Testing" and ASTM D7400-08 "Test Methods for Downhole Seismic Testing". If Multichannel Analysis of Surface Wave (MASW) method is proposed a borehole must be drilled to the auger refusal on bedrock or 30 m depth and determine the soil geotechnical parameters to augment the findings of MASW.

2 Phase II – Soil Testing and Analysis

The soil testing program must conform to the latest edition of the following standards:

- ASTM D422 "Standard Test Method for Particle Size Analysis of Soils" (Hydrometer Analysis)
- ASTM D2166 "Standard Test Method for Unconfined Compression Strength of Cohesive Soil"
- ASTM D2435 "Standard Test Method for One-Dimensional Consolidation Properties of Soil Using Incremental Loading"
- ASTM D2487 "Standard Practice for Classification of Soils for engineering purposes (Unified Soil Classification System)"
- ASTM D4318 "Standard Test Method for Liquid Limit, Plastic Limit and Plasticity Index of Soils"
- ASTM D5311 "Standard Test Method for Load Controlled Cyclic Triaxial Strength of Soils"
- ASTM D6913 "Standard Test Method for Particle Size Distribution (Gradation) of Soils using Sieve Analysis"

In the geotechnical laboratory, the soil samples should all be subject to tactile examination by an experienced geotechnical engineer who confirms the field descriptions on the borehole log, and who selects representative samples for detailed testing.

The following minimum testing program is required:

1. Moisture content and unit weight for each sample taken in the boreholes.

2. Perform testing for classification of samples (Unified Soil Classification):
    - Non cohesive soils: (Sand &Gravel) grain size distribution; one test for each strata of different soil.
    - Cohesive soils: grain size analysis including Hydrometer; and Atterberg limits.

3. Strength (Unconfined Compression and/or Penetrometer testing of cohesive soils). Field vane testing of clay soil below the footing or top of caissons/piles should be conducted if the undrained shear strength (Cu) measured using a pocket penetrometer is less than 100 kPa.

4. Carry out strength consolidation tests on cohesive soils (three samples) beneath any proposed structural elements (buildings, retaining walls, etc).

5. Obtain three samples for determination of potential sulphate attack on locations proposed for concrete elements.

6. Obtain a minimum of ten samples and determine potential for corrosion attack on soil anchors or rock anchors for each of the following parameters:
    - pH
    - Sulphates
    - Sulphides
    - Chlorides
    - Nitrates
    - Acid making potential of the soil or rock

3 Phase III – Completion of Geophysical Survey, Ground Penetrating Radar Survey, Electromagnetic Survey, Utility Mapping

The application of a geophysical survey as part of an infill, expansion or renovation of existing facilities can be very useful to characterize existing underground conditions and compare with anticipated or suspected situations. A utility mapping survey could also assist in providing an inventory of underground infrastructure to prevent damage during subsequent investigations, review existing assets for facility expansion, and consider pathways for drainage and offsite migration of groundwater.

The specific work program of the geophysical survey should be developed from the information about the subsurface conditions at the site from the boreholes and geophysical surveys carried out for the preliminary investigation. Types of geophysical survey that should be considered are described below.

All consultants must have a Professional Geoscientists of Ontario Certificate of Authorization to practice as a geophysical consultant. The geophysical investigation must conform to the most recent edition of the following standards:

- ASTM D6429-99 "Standard Guide for Selecting Surface Geophysical Methods"
- ASTM D4428/D4428M "Test Methods for Crosshole Seismic Testing"
- ASTM D5753 "Guide for Planning and Conducting Borehole Geophysical Logging"
- ASTM D5777 "Guide for Using the Seismic Refraction Method for Subsurface Investigation"
- ASTM D6285 "Guide for Locating Abandoned Wells"
- ASTM G57 "Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method"
- ASCE 38-02 "Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data"
- CSA S250-11, "Mapping of Underground Utility Infrastructure"

Selection of the appropriate geophysical technology and survey procedures should follow ASTM D6429-99 in conjunction and in consideration of all available site history, site investigation objectives and other parameters requiring qualification. As a minimum, a reconnaissance-level investigation should be completed to ascertain a basic geophysical understanding of subsurface site conditions. More detailed coverage may be required in impacted or highly sensitive areas. All data should be captured by GPS and geo-referenced. Data should be presented in both hard copy and soft copy format. A letter report will be prepared which at a minimum shall contain the following information:

- General description of site conditions.
- Description of survey instrumentation and applied technology.
- Description of survey procedures.
- Presentation of data in colour contour map format.
- Discussion of findings.
- Recommendations for follow-up work.

The utility mapping survey will consist of:

- Securing all 'locates' from all facility owners.
- Marking the inferred routing of all privately owned underground plant within the survey area.
- Physical demarcation of the inferred position of underground utilities by paint or stakes documented by not-to-scale maps.
- Data capture with GPS and presentation in accordance with ASCE 38-02.
- Utility mapping must meet the "S250-11 - Mapping of underground utility infrastructure" CSA Standard.

Multi-channel Analysis of Surface Waves (MASW) for Shear Wave Velocity Measurement and Calculation of Vs30

The MASW survey utilizes a similar set-up to a seismic refraction investigation (e.g. 24 geophones equally spaced). The principle consists of generating an acoustic wave at the surface and digitally recording the surface waves by a linear series of geophones on the surface. A sledgehammer is used as the primary energy source with shots typically being recorded at 4 locations along the alignment. A spread length of approximately 70m gives an approximate depth of investigation of 30m

The main processing sequence involves using the software e.g. SeisImagerSW™ software package, for plotting, picking and 1D inversion of the MASW shot records. The 1D shear-wave velocity depth profiles for each shot record are then plotted. The Vs30 value can then be calculated for site soil classification. Multiple 1D shear wave velocity profiles can be interpolated and plotted to generate 2D pseudo cross-sections of shear wave velocities

A detailed description of the method can be found in the paper Multi-channel Analysis of Surface Waves, Park, C.B., Miller, R.D. and Xia, J. Geophysics, Vol. 64, No. 3 (May-June 1999); P. 800–808.

Electromagnetic Survey (EM)

To map metallic targets an EM61 time-domain metal detector manufactured by Geonics Limited, or equivalent, should be used to complete an electromagnetic survey. This activity will include as a minimum: establishing a survey grid for measurement positioning and post-survey reference or capturing data with differential GPS measurements; acquiring the electromagnetic data in ‘continuous’ mode or with readings spaced no greater than 0.25m intervals along parallel survey lines spaced no farther apart than the maximum plan width of the smallest target sought (e.g. 1m stations to locate a single vertically oriented buried drum) where accessible; preparation of a detailed site map showing surface culture which may affect geophysical findings; data processing and presentation in colour contour map format; data interpretation presented as an ‘anomaly’ plan map; and recommendations for follow-up work along with a survey summary described in a covering letter.

Ground Penetrating Radar (GPR)

To assist in evaluating indoor conditions, concrete integrity, rebar pattern or spacing, location of post-tensioned cables, voids under concrete, honey combing, concrete spalling or delamination, a GPR survey will be performed with a Sensors & Software Conquest high frequency radar system, or industry equivalent. The data will be acquired in detailed sections measuring 60cm x 60cm where the GPR data will be acquired in two orthogonal directions to image all features within the concrete. Collection of data in 'reconnaissance' mode should be avoided. The data will be processed and displayed as contoured time-slice images and the interpretation of the data will be presented directly on the concrete as markings (paint, chalk, marker, etc.) which will be documented on not-to-scale sketch maps annotated for offset measurements to visible landmark features.

GPR can detect non-conductive targets, soil stratigraphy, bedrock profile and provide detailed definition, position and orientation of other features detected by other geophysical investigations. This work should utilize a Noggin 250 system manufactured by Sensors & Software Inc. or equivalent. If the objective of the survey is isolation of discrete targets (e.g. utility location, septic or underground storage tanks, etc.) the radar data can be acquired at the discretion of the radar technician to provide an on-site in-field interpretation which will be documented by marks (paint, flags, stakes, etc.) on the ground and further documented by not-to-scale sketch maps annotated for data interpretation with measured offsets to locally visible landmarks. If the objective is to 'map' any extensive man-made or geological feature (greater than 10m x 10m) the radar data will be acquired along profile lines spaced at 0.5m intervals oriented perpendicular to the orientation of the target. Data will be collected at nominal 10cm stations. Surveying activities will include the following: positioning of the radar system via an established survey grid or via differential GPS measurements, acquiring the radar data as described above where accessible, data processing, preparing radar sections (annotated for interpreted features where applicable), data interpretation in either processed section format and/or colour contoured time slice sections, and recommendations for follow-up work along with a survey summary described in a covering letter.

Utility Mapping

As a minimum, the utility mapping survey will consist of: provision of all private locates and delivery of sanctioned 'locates' from all facility owners; physical demarcation of the inferred position of underground utilities by paint or stakes documented by not-to-scale maps. These documents will permit TSSA and OHSA compliant excavation by third parties. Any digital map products of inferred utility positions will be delivered as per ASCE 38-02 Level A. Utility mapping must meet the "CSA S250-11 - Mapping of underground utility infrastructure" Standard Accuracy Level AL2.

For detailed investigations, where this information will be used to assist in the design of existing structures and facilities, the utility mapping process should be completed to identify any impediments to either the design and/or construction of proposed underground installations. This process will follow four steps as follows:

- Review and collation of all existing maps of underground infrastructure.
- Capture of engineering topographic data showing all utility appurtenances and geometries.
- Completion of a subsurface site survey to capture the actual (field) location of all underground utilities in order to rectify all differences, missing information, etc. at specific areas along the route. At this time a quality field check of the topographic data will also be completed. Prepare a subsequent drawing which should be sufficient to permit preliminary design.
- Based on the preliminary design and identified utility conflicts, a vacuum excavation study should be completed to determine the exact vertical and horizontal position of all potential utility conflicts to permit better design and subsequent utility coordination.

Wherever possible and whenever reasonable, existing storm and sanitary drainage should be located via the installation of a transmitting sonde into catch basins and manholes. Every effort should be made to trace the storm and sanitary system using these techniques. Invert measurements should be obtained where accessible from surface. Resolving the storm and sanitary network may necessitate the use of video inspection subcontractors (e.g. for individual unit system outlets (i.e. laterals) that tee into the main sewer lines as “blind” connections) and confined space entry techniques.

The information acquired during this investigation will be transferred onto the digital site map. The digital data will be acquired using survey-grade GPS measurements. The field data will be recorded on not-to-scale field sheets with offset distances measured, using survey tapes and/or measuring wheels, from curb lines, building walls, or other permanent landmark features shown on the digital base map. The final results of this mapping program will be documented in digital plan format. Unless otherwise specified, all drawings will be created to adhere to CI/ASCE Standard 38-02 Level A for the collection and depiction of subsurface utility data.

4 Phase IV – Hydrogeology Study

The purpose of a detailed hydrogeology study is to characterize existing hydrogeology conditions, determine the need for and options for groundwater control, quantify potential impacts to the local groundwater regime, and determine the need for and nature of any mitigation measures.

Program Components

The hydrogeology study must address site specific groundwater conditions from both a groundwater control and a site development (Low Impact Development) perspective in the subcatchment area within which the proposed project/development is located. Therefore, in addition to investigations specific to the subject site, it may be necessary to secure access to adjacent properties or road allowances to investigate areas of the subcatchment area beyond the property boundaries. This will have to be determined on a site by site basis.

The level of detail must be sufficient to support submission of any permit applications (e.g. Permit To Take Water) or municipal approvals. The methodology to complete the study requirements is at the discretion of the consultant, but must conform to generally accepted groundwater engineering and hydrogeology practices and must meet the requirements of respective upper and lower tier municipalities and conservation authority / MNR as applicable.

Boreholes and groundwater observation wells must be distributed such that the groundwater conditions are well defined for the site and nearby surrounding area. Any specific on-site features (wells, surface water bodies) are to be investigated.

Fieldwork for hydrogeology studies can be conducted concurrently with Geotechnical and Phase Two Environmental Soil & Groundwater Investigations provided the scope of work for each individual investigation is satisfied.

The following is a description of the requirements and expectations for completing a hydrogeology investigation:

- Geology and Hydrogeology
- Requirements for Proposed Development Plan
- Reporting
- Requirements for Permit to Take Water application
- Additional Considerations

Geology and Hydrogeology

Provide an overview of the regional geological setting.

Drill boreholes to determine the site specific geology (stratigraphy and depth to bedrock). The number of boreholes will depend upon the size of the site and the proposed project area, the background data available, and the expected geological complexity of the area.

Collect soil samples from each borehole and test for grain-size to characterize the soil types and to assist in determining soil hydraulic conductivity.

Relate the local geological data to the regional geological setting.

Establish a network of groundwater observation wells to determine the depth to the water table and vertical and horizontal groundwater gradients.

The number of monitoring wells, temporary drive point / permanent piezometers and nested wells to be installed will depend upon the site size, the complexity of drainage, the number of environmental features, the locations of groundwater divides, and the background data available. Where available, existing observation wells may be used. A minimum of three monitoring wells is needed in each potential water bearing zone.

Survey all monitoring locations for coordinates and geodetic elevation.

Map the groundwater flow conditions (including vertical and horizontal flow components).

Conduct pumping tests, bail-down, slug, or other appropriate field tests to confirm the well is functioning or responding without any residual effects from well construction and assess the hydrogeology characteristics of stratigraphic units (e.g. *in situ* hydraulic conductivity).

Monitor groundwater levels in all observation wells. The monitoring period should be sufficient to demonstrate fully-recovered stable water level conditions in each well.

A minimum of three water table observation wells should be equipped with a data logger to continuously record water levels and provide a detailed record of the response of shallow groundwater to climatic conditions throughout the year.

For all projects where a significant aquifer(s) is encountered, a minimum of three water table observations wells in each aquifer should be equipped with a data logger to continuously record water levels.

Provide estimates of groundwater flux.

Monitor surface water baseflows (non-storm event flows; minimum of three days post precipitation event) upstream and downstream in all identified watercourses. The data will be used to assist in establishing groundwater contribution to stream flow and infiltration as part of the water balance assessment.

Collect a sufficient number of groundwater and surface water samples for laboratory analysis of major ion chemistry to establish the background water quality across the area. The data will be used to assist in the assessment of groundwater/surface water interactions and to establish baseline pre-development conditions.

Map groundwater discharge areas and identify any areas along stream corridors for recharge/discharge function protection.

Complete a water balance analysis to determine the pre-development (based on existing conditions) and post-development (based on the proposed land use plan) interflow and deep recharge volumes. The water balance should utilize the longest and most continuous local daily climate data and a soil-moisture balance approach (e.g., Thornthwaite and Mather) with daily or monthly calculations reported on an average annual basis. Surface water flow data should be used to validate the existing conditions water balance where possible.

Requirements for Proposed Development Plan

Determine the infiltration deficit (pre to post development) for the proposed development area.

Identify hydrogeology opportunities and constraints to maintaining the water balance (i.e. to address the reduction of the infiltration deficit).

Identify the type, location and size of Low Impact Development (LID) measures that may be feasible for use based on the site specific geological and hydrogeology conditions.

Evaluate opportunities for groundwater related LID measures and practical Best Management Practices (e.g. as outlined in the MOE Stormwater Management Planning and Design Manual 2003) to balance, or at least in part, make up the post-development infiltration deficit.

Should pre-development infiltration not be maintained, predict the impact on the flows in local streams and the local water table and recommend mitigation measures, if warranted.

Identify areas where hydrogeology conditions may affect construction (e.g. high water table, requirements for dewatering, etc.) and recommend control and mitigation measures, if warranted.

Evaluate the potential for impacts from proposed underground services on shallow groundwater conditions adjacent to cores, linkages and stream corridors. If the potential for negative impact exists, mitigative measures are to be recommended.

5 Phase V – Data Analysis, Consultation, Reporting and Recommendations

Two separate reports are required—Geotechnical Investigation Report and Hydrogeology Investigation Report

Geotechnical Investigation Report

Prepare a site plan indicating the location of all field testing locations, indicating the method and accuracy of carrying out the survey.

Present the data collected in both a hard and soft copy format, which at a minimum shall contain the following information:

- General description of site and sub-soil conditions.
- Any special conditions or irregularities.
- Construction-Advice on any special construction difficulties that may be encountered.
- Identify if methane gas detected, implications and recommend measures.
- Include recommendations for formwork in accordance with soil type defined by OHSA.
- Recommendations as to resistively of soil, as in-situ and fully moistened, and Chloride ion concentration and soil pH.
- Sulphate attack. Exposure classification for concrete subject to sulphate attack in accordance with CSA A23.1.
- Foundations-Recommend types of foundations and their design capacity.
- Comments about drainage and dewatering (if required) describing available methods including well points with expected dewatering rate. Details are presented in the Hydrogeology Study.

Borehole logs shall include the following information:

- Type and hardness of bedrock (if encountered) in accordance with CFEM 4th Edition.
- Depth to bedrock.
- Ground water elevations (stabilized), including piezometer measurements.
- Elevation of any adjacent body of water.
- Geodetic elevation of ground surface at boreholes.
- Thickness and description of materials just below the ground surface, which have not been sampled, such as topsoil, pavement structures, fill, etc.
- Soil stratification, including thickness of each layer.

- Moisture condition of the soil.
- Results of field and laboratory tests, such as Standard Penetration Tests, Field Vane Tests and methane gas if detected.
- Soil classification, properties, shear strength, and moisture content.
- Soil densities.
- Drilling methods and dates drilled.

The report shall provide recommendations for the following items:

1. Requirement for Piles (and/or Caissons):
    - Provide Service Limit State (SLS) and Ultimate Limit State (ULS) foundation design capacities with predicted elevations, at which these will be available, and the accuracy of the prediction.
    - Provide pile design capacities for representative piles that may be applicable to the site allowing for stresses resulting from driving, handling and testing.
    - Identify load testing of deep foundation elements if required.
    - Identify spacing requirements of deep foundations and any group effects.
    - Identify inspection requirements of deep foundation elements.
    - Identify if deep foundation elements are based upon end bearing, friction, or a combination of both. Identify lateral and uplift load carrying capacities.
    - Identify potential pile installation difficulties.
    - Identify potential impact on surrounding structures due to vibration, implications and recommend measures.
    - Provide pile end preparations at the depth required to develop proposed design capacities.
    - Recommendations regarding pile type and associated bearing capacity, pile uplift resistance and pile drag down forces, and pile lateral load design.
    - Foundation Factor-Recommended site classification for seismic site response in accordance with Table 4.1.8.4.A of OBC 2006.
    - Maximum total and differential settlement that may be expected.

2. Spread or Raft Footing and Retaining Walls
    - Provide Service Limit State (SLS) and Ultimate Limit State (ULS) design bearing capacities.
    - Parameters for earth pressures on retaining walls and slope stability analysis.
    - Soil and rock anchor design for permanent or temporary anchors.
    - Classify soil for excavations according to OHSA regulations.
    - Permanent and temporary groundwater control at structures (refer to hydro-geotechnical report).

- Impact of permanent and temporary groundwater control on settlements of proposed and surrounding structures.
- Related parameters to the prevention of frost heave and special construction procedures for sub-grade protection during winter construction.
- Impact of the self-weight settlement of engineered fills.
- Maximum total and differential settlement that may be expected.

3. Roads, Sewers, and Underground Utilities
    - Frost depth.
    - Depth and type of road base and sub-base material for roadways and parking areas.
    - Soil parameters to be used for calculation of thrust blocks, and restrained joints, including coefficient of friction, shear angle, and bearing capacity.
    - Concerns as to trench bottom uplift.
    - Pipe bedding (materials), corrosion protection and backfilling requirements with respect to Provincial standards, assuming pipe materials to be steel and/or concrete pressure pipe.
    - Drainage.
    - Lateral soil pressure and pressure distribution for design of below grade walls retaining earth.
    - Soil vertical and lateral sub grade modulus.

4. Slab-on-grade
    - Depth of soil to be removed to obtain bearing capacity for slab-on-grade to support without deleterious settlement. 50 kPa is required.
    - Modulus of subgrade reaction.
    - If depth of topsoil has not been determined by digging test pit, comment on reliability of depth recorded.
    - Drainage requirements under slab-on-grade.
    - Vapor and moisture barrier requirements under slab-on-grade.
    - Sub-grade preparation recommendations.
    - Bedrock blasting and removal (if required).

5. Formwork and/or Shoring
    - Complete analysis and establish geotechnical parameters for design of shoring system
    - Open cut trench excavation, type of shoring system, methods of tunneling, jacking, and boring.
    - The use of native/imported backfill, placement depth of layers, and compaction specification for same.

6. Geotechnical seismic design parameters

- Complete analysis and establish geotechnical seismic design parameters as recommended in CFEM 4th Edition to meet the requirements of National Building Code of Canada (NBCC 2010) and Ontario Building Code (OBC 2006).

7. Engineered Fill
    - The specific site conditions and / or specific proposed development may require the raise of subgrade. Recommendations should be included for the depth of unsuitable soil for removal, existing subgrade / excavation base verification, backfill material quality, fill placement control, lateral and vertical placement limitations, compaction, drainage, geotechnical resistance at Service Limit State (SLS) and Ultimate Limit State (ULS), anticipated total and differential settlements etc.

Hydrogeology Investigation Report

The results of the hydrogeology study must address the issues outlined in the study requirements. The table of contents for the Hydrogeology report must include, as a minimum:

1. Introduction
    - Objectives
    - Scope of work

2. Methodology
    - Drilling, Soil Sampling and Observation Well Installation
    - Groundwater Monitoring
    - Surface Water Monitoring
    - Water Quality Sampling Program

3. Physical Setting
    - Physiography and Topography
    - Drainage:
        - ◊ Surface Water Flow
        - ◊ Surface Water Quality
    - Geology
    - Bedrock Geology
    - Quaternary Geology
    - Hydrogeology
    - Aquifers and Local Groundwater Use
    - Groundwater Conditions
    - Groundwater Quality
    - Groundwater/Surface Water Interaction
    - Climate

- Water Balance
    - ◊ Pre-Development (existing conditions)

4. Development Impact Assessment
    - Predicted Change in Water Balance
    - Impact on Local Groundwater Uses
    - Impact on Local Surface Water Features
    - Impact on Water Quality

5. Development Considerations
    - Groundwater Recharge Management
    - Opportunities and Constraints
    - Mitigation Measures
    - Construction Constraints
    - Monitoring
        - ◊ Water Quantity
        - ◊ Water Quality

6. Conclusions and Recommendations

In addition to the requirements outlined above, the hydrogeology study must also include the following:

- Requirements for determining the need for dewatering.
- Regulatory requirements for preparing and submitting an application for a Permit To Take Water (refer to MOE guidelines).
- Regulatory requirements for cases where dewatering will result in a water taking exceeding 50,000 l/day (refer to MOE guidelines). An application for a Permit To Take Water should be made on behalf of the owner.
- Regulatory requirements (O.Reg. 903) for decommissioning any on site wells (water supply and/or monitoring wells).

Designated Substances and Hazardous Materials Survey

A Designated Substances and Hazardous Materials Survey must be completed for any building undergoing renovations or demolition. The survey must be completed in accordance with the requirements of the Occupational Health & Safety Act.

For further guidance regarding such surveys, please reference the Infrastructure Ontario document *AFP Designated Substances and Hazardous Materials Survey – Due Diligence, Technical Requirements*.

Environmental Site Assessment, Phase One

A Phase One Environmental Site Assessment (ESA) must be conducted in general accordance with the following requirements and standards:

- The Canada Mortgage and Housing Corporation (CMHC)
- Canadian Standards Association (CSA) Standard Z768-01
- Ontario Regulation 153/04 as amended

1 Assessment Components

The Phase One ESA must include the following applicable components:
- Records review
- Interviews
- Site reconnaissance
- An evaluation of the information gathered from the records review, interviews and site reconnaissance
- Electromagnetic (EM) or Ground Penetrating Radar (GPR) Survey

Records Review

Records Review must meet the specific objectives, requirements and additional requirements as per Schedule D Phase One Environmental Site Assessment Part II Record Review of O. Reg. 153/04.

Make all reasonable inquiries to obtain the general records of Phase One property, Environmental Source Information records and Physical Setting Sources records of the Phase One study area and Site Operating records of the Phase One property in case there is a need for an enhanced investigation property for review. A records review of the Phase One property and Phase One Study area including but not limited to applicable federal and provincial databases:

- National PCB Inventory
- National Pollutant Release Inventory
- Water Well Information System
- Permits To Take Water
- Waste Disposal Sites
- Records of Site Condition
- Certificates of Property Use
- Waste Generator and Receiver Information (Ontario 347)
- Inventory of PCB Storage Sites
- Private & Retail Fuel Storage Tanks (TSSA)
- Coal Gasification Plants and Coal Tar and Related Tar Industrial Sites

- Certificate of Approvals
- Environmental Compliance Reports
- Environmental Orders
- Spills, Notices, Offences, or inspection reports of the Ministry
- Well Head Protection areas
- areas of natural significance maintained by MNR.

The records review must also include a review of:
- aerial Photographs
- Topographical, Physiography and Geological Maps
- Fire Insurance Plans
- Title Search
- previous Phase One ESA's
- all other environmental reports including Geotechnical Reports pertaining to the subject site.

Where the subject site is an enhanced investigation property, the following additional information should be reviewed where applicable:
- regulatory permits
- Material Safety Data Sheets,
- underground utility drawings
- inventories of chemical, usage and storage areas
- inventory of above ground storage tanks and underground storage tanks
- environmental monitoring data
- records of spills
- HWIN waste generator registration
- current and historical waste storage locations
- production and maintenance records
- emergency response and contingency plans
- environmental audit reports
- any earlier relevant reports and studies
- site plan of facility showing areas of production and manufacturing.

Interviews

Interviews must be performed to meet the specific interview objectives in accordance with Schedule D Phase One Environmental Site Assessment Part III Interviews of O. Reg. 153/04. This includes the current and previous owner or occupant of the site and any other person(s) the Qualified Person (QP) deems relevant to meeting the general and particular objectives of the Phase One ESA. In the case of an enhanced investigation property, an interview must be performed with at least one person with detailed knowledge of site activities.

Site Reconnaissance

Site reconnaissance must be performed to meet the specific objectives of site reconnaissance in accordance with Schedule D Phase One Environmental Site Assessment Part IV Site Reconnaissance of O. Reg. 153/04, including access to all areas within the building made accessible by the current owner. Areas not accessed must be flagged and a rationale detailing why they were not accessed. An investigation of the Phase One study area must be conducted. The site reconnaissance will document general description of any buildings on-site and other improvements, and in the case of enhanced investigation property, it will document hazardous materials and/or manufactured products on-site, any wastes or raw materials at subject site and details of any aboveground and/or underground storage tanks, drums, bins, etc. The site reconnaissance will also document any exterior areas of stained soil, stressed vegetation, fill and/or debris areas, and any details available for any unidentified and/or hazardous substances found at the subject site. In accordance with CSA Standard Z768-01, designated substances will also be identified during the site reconnaissance.

Review and Evaluation of Information

The QP shall review, evaluate and interpret the information obtained from the records review, the interviews and the site reconnaissance components of the Phase One environmental site assessment so as to achieve the general and specific objectives of a Phase One environmental site assessment.

The review and evaluation of information must be performed and presented in accordance with Schedule D Phase One Environmental Site Assessment Part V Review and Evaluation of Information of O. Reg. 153/04 including but not limited to a table of areas of potential environmental concern, a table of current and past uses of the Phase One property and a phase one conceptual site model in MOE approved format.

The QP shall also consider and document how any uncertainty or absence of information obtained in each of the components of the phase one environmental site assessment could affect the validity of the conclusions, tables and model.

Completion of Geophysical Survey: Electromagnetic Survey and /or Ground Penetrating Radar Survey

The application of a geophysical survey as part of an environmental investigation can be very useful to characterize existing underground conditions and compare them with anticipated or suspected situations such as a search for unknown or undocumented buried objects, disposal pits, debris, buried geo-environmental hazards, landfill boundaries, metallic objects (drums, tanks, debris, etc.); change in soil type or condition; and, to confirm or refute site history (fire insurance plans, previous land use, tank pulls, etc.).

The specific work program of the geophysical survey should be developed within the context of the information about the subsurface conditions at the site gathered from the boreholes and geophysical surveys carried out for the preliminary investigation. Types of geophysical survey that should be considered are described further in sections below.

All consultants must have a Professional Geoscientists of Ontario Certificate of Authorization to practice as a geophysical consultant. The geophysical investigation must conform to the most recent edition of the following standards:

- ASTM D6429-99 “Standard Guide for Selecting Surface Geophysical Methods”
- ASTM D5753 “Guide for Planning and Conducting Borehole Geophysical Logging”
- ASTM D5777 “Guide for Using the Seismic Refraction Method for Subsurface Investigation”
- ASTM D6285 “Guide for Locating Abandoned Wells”
- ASTM G57 “Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method”

Selection of the appropriate geophysical technology and survey procedures should follow ASTM D6429-99 in conjunction with, and in consideration of, all available site history, site investigations and other parameters requiring qualification. As a minimum, a reconnaissance-level investigation should be completed to ascertain a basic geophysical understanding of subsurface site conditions. More detailed coverage may be required in impacted or highly sensitive areas. All data should be captured by GPS and geo-referenced. Data should be presented in both hard copy and soft copy format. A letter report will be prepared which at a minimum shall contain the following information:

- General description of site conditions.

- Description of survey instrumentation and applied technology.
- Description of survey procedures.
- Presentation of data in colour contour map format.
- Discussion of findings.
- Recommendations for follow-up work.

Electromagnetic Survey (EM)

An EM31 terrain conductivity meter manufactured by Geonics Limited, or equivalent should be used to complete an electromagnetic survey. The goal of this work is to map, to the reconnaissance level, metallic targets and changes in soil conductivity which may infer the presence of inorganic groundwater contamination, environmentally impacted soils, etc. This activity will include, as a minimum:

- establishing a survey grid for measurement positioning and post-survey reference or capturing data with differential GPS measurements
- acquiring the electromagnetic data at a station spacing of between 0.25 and 0.50 the distance between adjacent parallel survey with the survey lines spaced no farther apart than the maximum plan width of the smallest target sought, where accessible
- preparing a detailed site map showing surface culture which may affect geophysical findings
- data processing and presentation in colour contour map format
- data interpretation presented as an ‘anomaly’ plan map
- recommendations for follow-up work along with a survey summary described in a covering letter.

Ground Penetrating Radar (GPR)

GPR can detect non-conductive targets, soil stratigraphy, bedrock profile and provide detailed definition, position and orientation of other features detected by other geophysical investigations. This work should utilize a Noggin 250 system manufactured by Sensors & Software Inc. or equivalent. If the objective of the survey is isolation of discrete targets (e.g. utility location, septic or underground storage tanks, etc.) the radar data can be acquired at the discretion of the radar technician to provide an on-site in-field interpretation which will be documented by marks (paint, flags, stakes, etc.) on the ground and further documented by not-to-scale sketch maps annotated for data interpretation with measured offsets to locally visible landmarks. If the objective is to ‘map’ any extensive feature (greater than 10m x 10m), the radar data must be acquired along profile lines spaced at 0.5m intervals oriented perpendicular to the orientation of the target. Data will be collected at nominal 10cm stations. Surveying activities will include the following: positioning of the radar system via an established survey grid or via differential GPS measurements; acquiring radar data as described above where accessible; data processing; preparing radar sections (annotated for interpreted features where applicable); data interpretation in either processed section format and/or colour contoured time slice sections; and recommendations for follow-up work along with a survey summary described in a covering letter.

2 Reporting

The Phase One ESA report shall meet the specific objectives and include the specified and additional sections as mentioned in the Schedule D: Phase One Environmental Site Assessment Part VI: Phase One Environmental Site Assessment Report of O. Reg. 153/04. The Phase One ESA report shall also document observations of designated substances.

The specific objectives of a Phase One ESA report are: (1) document the presence or absence of areas of potential environmental concern; and, (2) provide a record of a Phase One ESA of a Phase One property that demonstrates, in a manner that is clear and can be assessed, tested and reconstructed, how the Phase One ESA of the property was carried out, and, in particular, to document and demonstrate

i. how the general and specific objectives of a Phase One ESA were achieved and how each of the minimum requirements for such objectives were met,

ii. whether further investigation is required in order to submit a record of site condition for filing,

iii. that there exists an adequate basis for any further investigation that may be needed, and

iv. that there is a basis for any required certifications.

The Phase One ESA report format must include as minimum the sections, headings and subheadings as specified in the Table 1: Mandatory Requirements for Phase One Environmental Site Assessment, of the above referenced Schedule D.

Environmental Site Assessment, Phase Two

A Phase Two Environmental Site Assessment (ESA) must be completed prior to Request For Proposal (RFP) for the proposed AFP projects. A Phase Two ESA must be conducted in accordance with the requirements of the O.Reg. 153/04 as amended, the Protocol for Analytical Methods Used in the Assessment of Properties Under Part XV.1 of the Environmental Protection Act as amended [currently as of July 1, 2011] and CSA Standard Z769.

1. Assessment Components

- Planning of site investigation.
- Conducting site investigation.
- Review and evaluation of the information gathered through the site investigation.
- Phase Two ESA report.

Planning Site Investigation

Site investigation planning shall be completed to meet the specific objectives and requirements as per Schedule E Phase Two Environmental Site Assessment Part II Planning Site Investigation of O. Reg. 153/04.

Conducting Site Investigation

The site investigation shall be conducted in a manner to meet the specific objectives and requirements as per Schedule E Phase Two Environmental Site Assessment Part III Conducting Site Investigation of O. Reg. 153/04.

Review and Evaluation of Information

The review and evaluation of information shall be completed in accordance with Schedule E Phase Two Environmental Site Assessment Part IV Review and Evaluation of Information of O. Reg. 153/04.

Phase Two ESA Report

The Phase Two ESA report shall meet the specific objectives and include the specified and additional sections as mentioned in the Schedule E: Phase Two Environmental Site Assessment Part V: Phase Two Environmental Site Assessment Report of O. Reg. 153/04.

The specific objectives of a Phase Two ESA report are:

(1). document the presence or absence of contaminants in the land or water on, in or under the phase two property

(2). document the determination of the location of one or more contaminants in the land or water on, in or under the phase two property.

(3).provide a record of the Phase Two ESA of the Phase Two property that demonstrates, in a manner that is clear and can be assessed and reconstructed, how the Phase Two Environmental Site Assessment of the property was carried out, and, in particular, to document and demonstrate,

i. how the general and specific objectives of a Phase Two ESA, including each of its components, were achieved and how the minimum requirements for the objectives were met,

ii. to document the basis for certifications in a record of site condition as to whether all or that part of the Phase Two Property that may comprise the RSC property meets the applicable site condition standards or standards specified in a risk assessment for one or more contaminants, and

iii. to document information needed to undertake a risk assessment of the Phase Two property with respect to one or more contaminants.

The Phase Two ESA report format must include as minimum the sections, headings and subheadings as specified in the Table 1: Mandatory Requirements for Phase Two Environmental Site Assessment, of the above referenced Schedule E.

2. Undeveloped Properties

For a Phase Two ESA completed for a vacant parcel of land that has never been developed shall include the following investigation and testing components:

- Program Components
- Laboratory Testing
- Quality Assurance/Quality Control

Program Components

- A minimum of eight boreholes, plus an additional one borehole per hectare. Geotechnical boreholes can be utilized, provided that continuous sampling was completed.
- Combustible gas levels will be measures in all retrieved soil samples as a preliminary screening method for hydrocarbons and volatile organic compounds (VOCs).
- Selection of the soil samples for chemical analysis to be based on the “worst case” scenario based on visual, olfactory or other means (e.g. highest headspace combustible gas measurements.
- Monitoring wells must to be installed in a minimum of four of the boreholes. Prior to sampling, all monitoring wells to be purged by

removing at least three well volumes or until the well is dry and allowed to recover.

- The investigation must determine the groundwater flow direction and gradient if applicable.
- Survey ground surface elevation at all borehole locations (relative to a geodetic datum).
- Undertake an Electromagnetic (EM) or Ground Penetrating Radar (GPR) Survey of the entire property to map geophysical anomalies that may be indicative of conductive materials in the subsurface. Ideally, this would be completed prior to finalizing the Phase Two program sampling components in order to investigate any anomalies identified in the EM or GPR survey.

Laboratory Testing

Chemical analysis to be performed by a CAEAL accredited laboratory and be in accordance with the Ontario Ministry of the Environment Standards according to the requirements of O.Reg. 153/04 under the Environmental Protection Act

Laboratory testing to include:

- Analysis of a minimum of two fill and two native soil (or surficial and lower native soils if fill is not present) samples from each borehole.
- Groundwater samples to be collected and submitted for analysis from each monitoring well.
- Chemical testing shall be conducted for herbicides and pesticides and inorganic and general chemistry (MOE Decommissioning) parameters in soil; and volatile organic compounds (VOCs) and metals, hydrides and pH in groundwater, as well as any other parameters of concern identified in the Phase One ESA.

Quality Assurance/Quality Control

Analysis of a quality assurance/quality control (QA/QC) samples shall be completed that consists of 10% of the analytical testing program, with a minimum of one trip blank, one blind duplicate, and one equipment blank.

When soil vapour samples are to be analyzed for volatile contaminants, including volatile organic compounds, one trip blank sample shall be submitted for laboratory analysis with each laboratory submission.

3. Improved Properties

For a Phase Two ESA completed on a parcel of land that is (or has previously been) developed, the investigation shall consist of the following:

- Program Components

- Laboratory Testing
- Quality Assurance/Quality Control
- Assessment of Current/Former Site Improvements
- Assessment of Light Non-Aqueos Phase Liquids (LNAPLs)
- Assessment of Dense Non-Aqueous Phase Liquids (DNAPLs)
- Additional Reporting Considerations
- Additional Procedural Considerations

Program Components

- Completion of an electromagnetic (EM) or ground penetrating radar (GPR) survey of the entire property. Ideally, this would be completed prior to finalizing the Phase Two program sampling components in order to investigate any anomalies identified in the EM or GPR survey.
- A minimum of twelve boreholes, plus two additional boreholes per hectare . Geotechnical boreholes can be utilized, provided continuous sampling was completed.
- Combustible gas levels will be measured in all retrieved soil samples as a preliminary screening method for hydrocarbons and volatile organic compounds (VOCs).
- Selection of the soil samples for chemical analysis to be based on the “worst case” scenario based on visual, olfactory and other means (e.g. highest headspace combustible gas measurements.
- Monitoring wells to be installed in a minimum of six of the boreholes. Prior to sampling, all monitoring wells to be purged by removing at least three well volumes or until the well is dry and allowed to recover.
- The investigation must determine the groundwater flow direction and gradient if applicable
- Survey ground surface elevation at all borehole locations (relative to a geodetic datum).

Laboratory Testing

- Analysis of a minimum of two fill and two native soil (or surficial and lower native soils if fill is not present) samples from each borehole.
- Groundwater samples to be collected and submitted for analysis from each monitoring well.
- Chemical testing shall be completed for inorganic and general chemistry (MOE Decommissioning) parameters in soil and volatile organic compounds (VOCs) and metals, hydrides and pH in groundwater, as well as any other contaminants of concern identified within the Phase One ESA.

Quality Assurance/Quality Control

Analysis of a quality assurance/quality control (QA/QC) samples shall be completed that consists of 10% of the analytical testing program, with a minimum of one trip blank, one blind duplicate, and one equipment blank.

When soil vapour samples are to be analyzed for volatile contaminants, including volatile organic compounds, one trip blank sample shall be submitted for laboratory analysis with each laboratory submission.

Assessment of Current/Former Site Improvements

The following describes the minimum requirements for how specific current and/or historic conditions shall be investigated during the Phase Two ESA:

- Current/former presence of an Underground Storage Tank (UST) – a minimum of four boreholes in/around each tank location. Groundwater monitoring wells to be installed in all of the borehole locations.
- Septic system – a minimum of one monitoring well located immediately down-gradient of the holding tank or septic bed(s) and analysis of VOCs in groundwater.
- Surface staining/stressed vegetation – one borehole in each location.
- Current/former pad-mounted transformer(s) – one borehole in proximity to the transformer location with analysis of PCBs in soil.
- Paved areas – assessment of both fill and native soils for electrical conductivity (EC) and sodium adsorption ratio (SAR).
- Potential soil and/or groundwater impacts under the existing building onsite – boreholes/monitoring wells to be located in the areas of concern within the building footprint using appropriate interior drilling methods.
- If soil and/or groundwater impacts are identified, additional investigation must be completed, as required, to delineate the horizontal and vertical extent of such impacts. Waste classification testing of impacts soils must be completed in accordance with O.Reg. 558/01.

Assessment of LNAPLs

In areas being assessed for the presence of Light Non-Aqueous Phase Liquids (LNAPLs) such as petroleum hydrocarbons, the following must be completed:

- The monitoring well must installed so the screen spans the groundwater table;
- An interface probe must be used to identify the presence of free-phase liquid product.
- Aesthetic observations will be carried out on groundwater samples to determine the presence/absence of sheen or odours.

Assessment of DNAPLs

If the Phase One ESA identifies the current/former use of Dense Non-Aqueous Phase Liquids (DNAPLs), commonly known as chlorinated solvents, on the subject or adjoining properties, the Phase Two ESA must include the installation of a minimum of three monitoring wells in each of the first and second water bearing zones.

Laboratory analysis of soil and groundwater must be completed for VOCs at each well location.

If laboratory results identify concentrations of chlorinated solvents within one order of magnitude of the applicable MOE Standard, additional investigation must be conducted in order to assess the concentrations of such parameters at greater depth (i.e. at the base of that water bearing zone).

Additional Reporting Considerations

In addition to the requirements in the Table 1: Mandatory Requirements for Phase Two Environmental Site Assessment, of the above referenced Schedule E, O.Reg. 153/04, the final report shall include the following items:

- Whether a UST is (or was formerly) present on the property and its anticipated location.
- A discussion on the presence/absence of soil and/or groundwater impacts onsite.
- The likelihood of contaminants migrating onto or off of the subject site.
- The presence/known areas of soils with aesthetic impacts (i.e. odours, staining, etc.) and/or mixed materials (i.e. wood, concrete rubble, brick pieces, steel, etc.) where additional costs would be incurred for off-site disposal of these materials.
- Drawings showing the known extent of any soil and/or groundwater impacts identified.
- Cross-sections displaying the soil stratigraphy and known extent of any soil/groundwater impacts in two (2) axes across the site.

Additional Procedural Considerations

In addition to the requirements outlined above, the Phase Two ESA must also include the following procedures:

- Borehole drilling must include continuous sampling through the entire borehole.
- Boreholes converted to monitoring wells must be drilled using either hollow stem augers or casing.
- All monitoring wells to be installed in accordance with O.Reg. 903.
- Borehole/monitoring well locations must assess any potential environmental issues raised in the Phase One ESA.
- The investigation must assess all potential off-site issues (i.e. migration onto or off of the subject site).

C1 Traction Power

C1.1 General

Chapter C1 addresses Metrolinx (MX) Light Rail Transit (LRT) Light Rail Vehicle (LRV) propulsion by Overhead Contact System (OCS) via Traction Power Substation (TPSS) supply and distribution through LRV/OCS interface pantographs.

Both running rails, bonds, and cabling of each track complete OCS electric current return paths to TPSS.

See Chapter A2 – Light Rail Vehicles.

Traction power systems provide sufficient electric power for safe and efficient LRV operations under many diverse LRT climate conditions.

Specific TPSS requirements include:

- Utility AC supply;
- Transformer/rectifiers converting AC power to DC power;
- DC distribution;
- Overhead Contact Systems;
- Negative return.

Coordinate traction power systems with other LRT/LRV components including civil works, utilities, signals, communications, electric power, and train control systems.

C1.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Traction Power specific references include but are not limited to:

- Ontario Building Code (OBC);
- Ontario Electrical Safety Code (OESC);
- Canadian Electrical Manufacturers Association (CEMA);
- Canadian Standards Association (CSA);
- Occupational Health and Safety Act (OHSA);
- National Electrical Manufacturers Association (NEMA);
- National Fire Protection Association (NFPA);
- American National Standards Institute (ANSI);
- American Railway Engineering and Maintenance of Way Association (AREMA);
- ASTM International (ASTM);

- American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE);
- Illuminating Engineering Society (IES);
- Institute of Electrical and Electronics Engineers (IEEE);
- Insulated Cable Engineers Association (ICEA);
- Underwriters' Laboratories (UL).

OBC governs where conflicts arise unless otherwise stated.

C1.3 Traction Power Systems

Traction power systems include specific elements as follows.

C1.3.1 Traction Power Substations

TPSS provide the interface between local electric utility power and LRT DC traction power systems.

TPSS control utility-supplied primary AC power and rectify to DC power required to operate LRVs.

Provide TPSS in standard sizes and configuration wherever possible with fully compatible and interchangeable equipment to minimize parts inventory.

TPSS generally include but are not limited to:

- Conduit systems;
- Metering equipment;
- Utility AC supply connections;
- AC switchgear;
- Transformer/Rectifier units with primary/secondary connecting cables and buses;
- DC switchgear;
- Negative buses and negative drainage panels;
- DC distribution system connections;
- TPSS enclosures including foundations, lighting, fire/security systems;
- Heating and ventilation;
- Grounding systems;
- Protective relay systems;
- Station and Stop batteries and battery chargers;
- TPSS control systems;
- Telephone systems;
- Data communications interface cabinets; and
- Other equipment as required for safe, complete, maintainable, and efficient traction power supply.

TPSS may include power sources and feeders for LRT Stations where required.

See Chapter C3 – Facilities Electric Systems.

C1.3.2 DC Feeders

DC feeder systems comprise positive feeder breakers, positive and negative disconnect switches, and cables connecting OCS positive and negative busses to negative return rails.

DC positive feeders include supplemental parallel feeder cables or conductors to maintain voltage within acceptable limits during normal and LRT contingency operations.

DC positive feeders originate from TPSS DC switchgear load side and continue to OCS connection points through conduit / cables to guideways and disconnects.

DC negative returns originate from OCS negative busses and return to TPSS through conduit / cables via negative return rail.

Negative return systems may also include impedance bonds as required.

C1.3.3 Overhead Contact Systems

OCS comprise electric, mechanical, and structural equipment between LRV pantographs and DC positive feeder systems including:

- Contact wire;
- Messenger wire;
- Supporting structures, foundations, and guying systems;
- Overhead feeders;
- Ancillary wires;
- Hangers;
- Insulators;
- Conductor supports;
- Tensioning devices;
- Cantilever arms or head spans;
- Sectionalizing equipment;
- Disconnect switches;
- Shorting switches;
- Lightning arresters; and
- Grounding devices.

See Section C1.6.

Sectioning

Sectioning is the separation and isolation of OCS sections between TPSS allowing LRT contingency operations during electric outages using crossovers to maintain continuity of service.

OCSs form a continuous bus along guideways in each direction of travel.

Provide TPSS with four DC breakers powering each track in each direction independently and electrically operating OCS in parallel.

Provide sectioned OCS with electric insulators and insulated overlaps.

OCS sections may require disconnect switches with overlaps and section insulators to isolate OCS sections.

Environment

Provide traction power systems to operate continuously in required environments and conditions.

C1.4 Traction Power Substations

TPSS supply LRVs with nominal 750 volt DC traction power via OCS.

TPSS may be free-standing or incorporated in LRT Stations.

Provide two rectifier branches and space for future third rectifier branches at TPSS exceeding 1500 kW.

Maintenance and Storage Facility (MSF) TPSS are free-standing buildings providing facility power to yards and shop buildings and traction power for the yard, shops, and possibly the Main Line.

Locate TPSS as close as possible to guideways but no more than 50 m from Right-of-Way centre lines.

Provide TPSS equipment rated for extra heavy duty traction power electric service.

Provide transformer / rectifier units with 6 percent or lower voltage regulation.

Design TPSS to be compatible with surrounding environments and streetscapes.

Locate TPSS so as not to impede pedestrian movement.

Coordinate TPSS siting and appearance with AHJ.

Equip each TPSS with telephone service, smoke detectors, and intrusion detection systems.

C1.4.1 Operating Requirements

Traction Power Substation system ratings:

- Nominal Catenary Voltage: 750 VDC;
- Maximum Catenary Voltage: 925 VDC (TBD with LRV);
- Minimum LRV Operating Voltage: 525 VDC (TBD with LRV);
- Maximum Normal Operations Rail to Ground Voltage: 50 VDC;
- Maximum Contingency Operations Rail to Ground Voltage: 70 VDC.

LRVs are equipped with regenerative braking.

Traction power systems include natural receptivity only with no additional means of accepting regenerative power or feeding regenerative power back to local electric power utilities.

C1.4.2 Locations, Ratings, Spacing

Size and space TPSS using validated computer programs with inputs of LRV performance characteristics, limiting speeds, schedules, and track profiles to determine TPSS ratings, number, and locations.

TPSS may be located at passenger Stations.

Consider other factors such as availability of real estate and accessibility to utility networks for primary power connections.

Upon identification of suitable sites, perform the computer analysis again to verify sufficient power supply throughout the line without low voltage conditions.

Add rectifier units and change substation locations and transformer/rectifier ratings as needed to meet system operating requirements.

General operation parameters are:

- Normal Operation: TPSS spacing and rating with every TPSS operating to supply sufficient system power to maintain required LRV performance during peak period operations;
- Contingency Operation: TPSS spacing and rating with any one TPSS out of service to supply sufficient power to maintain peak period operations with DC voltage above minimum levels, rail voltages below maximum allowable levels, and protect electric conductors from overloading.

C1.4.3 Primary Power

Local electric utilities provide primary power service.

Provide each TPSS with two diverse primary feeders for system reliability and, where possible and cost effective, a dedicated underground diverse supply feeder serving no more than two TPSS.

C1.4.4 Equipment

TPSS are designed to operate unattended and include, as main components, a transformer/rectifier with associated AC switchgear, DC switchgear, and ancillary devices.

Provide TPSS switchgear for local control panel operation or remote operation from the SCADA system.

Provide metal-clad, arc-resistant, draw-out type AC switchgear comprising a three-phase feeder and automatic bus tie circuit breakers with required protective devices, such as over-current and under-voltage detection, so that the switchgear can serve as a disconnect from the primary incoming service as well as a protective device for transformer/rectifier units.

Provide means to remove and test AC circuit breakers.

Provide transformer/rectifier units with extra heavy traction power duty cycle ratings.

Provide self-cooled, self-ventilated, dry type transformer/rectifier units in suitable enclosures and equipped with five-position, full-capacity, no load tap changers.

Provide silicon diode type rectifiers in free-standing, high-resistance, grounded metal, natural convection air cooled enclosures.

Connect transformer/rectifier units per ANSI C34.2, Circuit 31, producing 12-pulse double-way output.

Provide draw-out type DC switchgear comprising main cathode breakers and single-pole, high-speed DC feeder breakers rated to interrupt maximum available fault current.

Provide feeder breakers with adjustable, direct-acting, instantaneous, long-time, and rate-of-rise current protection devices as well as automatic re-closing and load-measuring devices.

Provide a hard-wired transfer trip scheme between feeder breakers, DC tie-breakers, and adjacent TPSs.

Provide DC feeder breaker protective schemes to open breakers feeding a fault section.

Provide only direct-acting reverse-current cathode breaker trip devices.

Provide indoor metal-enclosed type switchgear assemblies.

Provide means to remove and test DC circuit breakers.

Provide testing equipment for DC circuit breakers.

Provide metering to meet utility revenue requirements as well as, at a minimum:

- AC line current;
- AC bus voltage;
- DC positive bus voltage;

- DC rectifier current;
- DC feeder voltage;
- DC feeder current.

Provide each TPSS with an enclosed self-ventilating local control panel to centralize local control, remote control, and indication functions, complete with annunciators, mimic displays, metering equipment, control switches, and interconnecting SCADA system terminals.

Provide only DC controlled equipment.

Include 130 volt control batteries with associated battery chargers able to control the traction power system for eight hours minimum.

Provide necessary ancillary equipment such as surge protectors, interconnecting buses, control wiring, etc., for safe, efficient, and complete TPSS operation.

Provide space for the addition of stray current measurement and mitigation equipment.

Provide each TPSS with an emergency eye wash station near the control battery, a portable fire extinguisher, and tool cabinet with tools to maintain the equipment.

C1.4.5 Grounding

TPSS grounding systems provide for the safe condition and operation of equipment per IEEE standards.

Touch potentials are not to exceed 50 volts DC in normal operation, 70 volts DC in contingency operation.

Provide each TPSS with one internal ground ring bus connected to the grounding system.

Connect non-current carrying AC equipment metal enclosures and parts to the TPSS grounding system.

Insulate non-current carrying DC equipment metal enclosures and parts from ground and connect to the TPSS grounding system through a ground fault detection system that annunciates grounded conditions and, in case of energized enclosure or equipment parts, disconnects the TPSS from power sources.

C1.5 DC Feeders

Provide DC feeder systems comprising insulated copper conductor cables with conduit, ducts, and manholes necessary to distribute DC power from TPSS to OCS and divide return current from running rails into two sections: positive feeders and negative feeders.

Positive feeders connect DC feeder breakers to OCS interface points.

Negative feeders connect DC cables from running rails to the TPSS negative bus.

C1.5.1 Cables

Provide insulated, non-shielded, single conductor feeder cables suitable for use in wet or dry locations and rated 2,000 VDC at 90°C conductor temperature for normal operations, 130°C for emergency operations, and 250°C for short circuit conditions.

Provide copper conductors per ASTM B189 with class C or D stranding per ASTM B8 and Ethylene Propylene Rubber insulation and flame retardant, low-smoke, non-halogen jacket or cross-linked, polyethylene, flame retardant, low-smoke insulation.

Size feeders to accept normal, maximum overload, and short-circuit currents with temperatures not to exceed insulation design limits.

Provide standard feeder sizes using multiple conductors to meet different current requirements so that voltage drops do not affect required traction power voltage levels under normal and overload conditions.

Provide sufficient support for cables installed in exposed locations.

Provide lightning protection where cables enter or leave underground conduit to minimize adjacent equipment damage in a lightning strike.

C1.5.2 Duct Banks and Conduit

Provide feeder duct banks comprising fiberglass reinforced epoxy duct or Schedule 40 PVC conduit encased in concrete buried in the ground or embedded in tunnel walkways.

Provide duct banks, conduit size, manhole spacing, duct gradients, maximum total turn degree angles, and minimum embedment depth below grade per OESC requirements.

Include 25% spare capacity additional number of ducts with two ducts minimum for future installations.

C1.6 Overhead Contact System

OCS includes LRV traction power contact wires and physical support members.

Operations, maintenance, environmental, technical, and local climate conditions as well as economic considerations form the OCS basis of design.

An OCS comprises:

- Conductors, including contact wire;
- Messenger wires;
- In-span fittings;
- Jumpers;
- Conductor terminations; and
- Associated hardware.

An LRV draws traction power from the OCS by physical contact of pantograph with contact wire.

Coordinate the dynamic performance characteristics of the OCS / LRV pantograph interface to maintain contact for proper current collection in every operating condition.

OCS physical support members comprise:

- Foundations;
- Poles or masts;
- Guys;
- Insulators;
- Brackets;
- Cantilevers; and
- Other assemblies and components.

OCS physical support members maintain proper alignment, contact, and registration of contact wires with LRV pantographs in every operating condition.

Provide grounded and double insulated OCS support members throughout.

Traction power systems are electrically continuous from TPSS to TPSS.

Provide OCS section continuity at TPSS to isolate each electric section.

Provide OCS section continuity and flexibility while any track is out of service.

Provide OCS sectioning at special track work and yards for flexibility in operations and maintenance.

Provide jumpers, switches, or breakers of the same ampacity as OCS to maintain electric continuity where insulated separation in contact wire is required, e.g., at special track work.

Provide OCS support poles, cantilevers, components, etc., designed for local environmental conditions and urban design requirements of AHJ.

C1.6.1 Configuration

For at-grade and elevated guideways, OCS comprise an auto-tensioned simple catenary contact wire carried by droppers or hangers from messenger wire suspended from support poles.

Head span configurations may be used in multi-track areas.

Balanced weight anchor support poles are to be internally weighted.

Coordinate OCS pole locations to maintain unobstructed vehicle access at emergency services facilities and designated side streets subject to MX LRT and AHJ review and acceptance.

Provide MSF OCS with single wire fixed terminations.

Provide MSF OCS with single or back-to-back pole-mounted cantilever arm, cross span, or head span support depending on yard layout.

Provide tunnels with fixed-termination low-profile OCS.

Coordinate OCS anchor inserts with tunnel design.

Pay particular attention in coordinating OCS feeder and sectioning requirements with tunnel section heights.

C1.6.2 Height, Gradients, Clearances

Provide OCS height, gradients, and clearances per OESC, CSA, AREMA, and AHJ requirements.

Consider OCS wire sag and installation tolerances including track work construction and maintenance.

Nominal contact wire heights for various alignment conditions include:

- 4800 mm at Exclusive ROW at-grade or elevated sections;
- 3900 mm at Exclusive ROW tunnel sections;
- 5500 mm at Semi-Exclusive ROW / mixed use sections.

Address height exceptions on a site specific basis subject to MX LRT and AHJ review and acceptance.

Position messenger wire directly above contact wire high enough to allow desired maximum spans with sufficient mid-span height for hangers of suitable length and satisfy any need for lower OCS solutions.

At turnouts, crossovers, and overlaps, grade messenger wire to allow mechanical clearance at crossing points with adjacent equipment.

At bridges, consider lowering OCS height and keeping contact wire level for sufficient clearance but make sure not to over reduce OCS spans.

At tunnels, consider OCS height, span length, and support loading limitations to achieve required mechanical and electrical clearances while optimizing spans for reduced construction and maintenance costs.

Base LRV Speeds and Vertical Gradients on the following values:

LRV Speed km/h	Vertical Gradient mm/meter
80	7
70	8
60	9
50	11
40	14
30	18
20	27

Do not exceed these values without MX LRT review and acceptance.

Do not exceed one half the vertical gradient value stated above for gradient changes from one OCS span to the next except in yards.

Include full allowance for LRV dynamic displacement operating conditions including track work and OCS installation and maintenance tolerances.

C1.6.3 Structural Loads

Provide for structural loads per OESC, CSA and AREMA standards and requirements.

C1.6.4 Stagger, Span, and Sweep.

Stagger: The lateral displacement of contact wire left or right of track centre line at OCS supports.

Stagger contact wire on both tangent and curved track.

Stagger contact wire on tangent track primarily to achieve uniform wear on pantograph collector strips.

Stagger contact wire on curved track primarily to achieve tangent / cord geometry required for straight contact wire to negotiate the curve.

Consider the following effects:

- OCS conductor blow off;
- Contact wire height;
- Contact wire stagger;
- Contact wire mid-span offset;
- Contact wire stagger on tangent track;
- Contact wire deviation due to track work movement;
- Mast deflection due to imposed loads;
- LRV dynamics;
- Pantograph width and sway;
- Track tolerances;

- OCS construction tolerances; and
- Pantograph security factors.

Provide no more than five equal and adjacent OCS spans to minimize potential harmonic oscillation.

C1.6.5 Contact/Messenger Wire

Provide contact wire per ASTM B47.

Provide messenger wire per ASTM B189 with stranding per ASTM B8, Class B or higher.

Consider the effects of temperature change, including ambient, solar, current, and radiant heat, in contact / messenger wire tension calculations for both operating and non-operating conditions.

Provide OCS safety factors per OESC, CSA, AREMA, and requirements of AHJ.

C1.6.6 Support Poles

Base support pole heights on 500 mm maximum above top mast bracket and as uniform as practical to limit number of spares required.

Consider exceptions on a case-by-case basis only when standard pole height is perceptibly inappropriate.

OCS support poles may serve as joint-use poles to support lighting fixtures, PA systems, CCTV, passenger information signs, and LRT signals where necessary.

Consider these other elements in support pole loading calculations.

Also consider OCS electrical and mechanical clearances and secondary equipment maintenance as well as visual impact of various equipment on OCS support poles.

Provide reinforced concrete support pole foundations capable of withstanding design loads imposed during installation, operation, and maintenance.

Provide support pole foundations to limit total effect of foundation rotation and support pole deflection at contact wire to 50 mm maximum during LRV operations.

Coordinate support pole foundation design with track work design and underground utilities.

Provide support pole and guy anchor foundations per established geotechnical / structural engineering practices and codes and standards of AHJ.

Provide support pole grounding, strength, and load ratings per OESC.

Provide support pole finishes per MX LRT Design Excellence requirements and urban design criteria of AHJ.

C1.6.7 Clearances

Maintain clearances between live conductors including pantographs and any fixed grounded structures per AREMA Chapter 33 Part 2.

Static Clearance is between OCS and any grounded structure when not subject to pantograph pressure.

Passing Clearance is between OCS or pantograph and any overhead structure with a moving LRV under actual operating conditions.

Provide 38 mm minimum clearance to steady arms and registration arms.

Provide 76 mm minimum mechanical clearance under adverse conditions from pantograph to any fixed item except cantilevered steady arms and registration arms.

Include full allowance for LRV dynamic displacement related clearances under operating conditions including track work/OCS construction and maintenance tolerances.

See Chapter A2 – Light Rail Vehicles and Chapter B2 – Track Work.

Cantilevers

Provide single track back-to-back cantilevers on centre support pole brackets mount with hinge pins to allow longitudinal movement.

Provide registration arms allowing sufficient pantograph uplift while maintaining required mechanical clearance under any operating condition.

Head Spans

Provide head span supports where cantilever arms are not practical, e.g., at multitrack sections, and allow for longitudinal OCS movement due to temperature variations.

Provide head span insulation so that live or potentially live wires remain within LRT ROW wherever possible.

Cross Spans

Provide cross spans for wide support systems and single contact wire support, e.g., in yards.

Attachments

Do not attach OCS to bridges or other non-OCS support structures wherever possible.

Minimize the number of OCS attachments to non-OCS support structures where clearance limitations or long track lengths, e.g., under bridges, make such attachments necessary.

Provide resilient OCS attachment assemblies to minimize pantograph and contact wire bounce.

Perform clearance and loading studies at each bridge to identify suitable clearances and imposed bridge loads under any operating condition.

C1.6.8 Disconnects

Provide manual or motorized disconnects to support sectioning as required.

Provide locking mechanisms to prevent unauthorized operation of switches and disconnects.

Provide track level mounted electric operated disconnect switches.

Provide DC tie breakers midway between TPSS locations at underground Stations connecting opposite running OCS circuits for voltage stability and regenerative braking energy distribution.

C1.6.9 Tensioning

Provide balance weights inside support poles and/or spring-pneumatic systems for constant OCS tensioning throughout the operating temperature range.

Define OCS consequential hogging and perform dynamic analysis where weight stops are used to verify sufficient performance under the most onerous conditions.

Consider different tunnel section operating temperature ranges for OCS tensioning.

C1.6.10 Performance

Base OCS technical performance requirements on economic, operations, maintenance, and local climate conditions.

Coordinate OCS and LRV dynamic performance characteristics to maintain electric current collection within acceptable limits.

Provide OCS to accommodate LRV and associated LRT system physical characteristics, performance requirements, clearance envelopes, signal and communications systems, etc.

Provide OCS to meet LRV interaction / current collection operating criteria per AREMA Chapter 33.

C1.7 Negative Return Paths/Stray Current Control

Provide continuous welded rail forming OCS to TPSS negative return paths.

Provide bolted rail connection electric bonded joints.

Provide insulated rail joints with impedance bonds to maintain DC negative return circuit continuity.

Ground negative return rails in yards.

Isolate running rails from ground.

Monitor potential stray current conditions.

Provide cross bonds to mitigate and control stray current.

See Chapter C5 – Stray Current and Corrosion Control.

C2 Communications and Control

C2.1 General

Chapter C2 addresses Metrolinx (MX) Light Rail Transit (LRT) project Communications and Control functions and performance requirements.

Provide Communications and Control systems to minimize hazards to passengers and personnel in:

- Normal operating conditions;
- Emergency conditions;
- Probable failure conditions of transit systems or functions including communications subsystems;
- Using or maintaining Communications and Control subsystems.

See Chapter A3 – Safety and Chapter A4 – Security.

C2.1.1 LRT Operations

MX LRT Projects include underground and elevated Stations and at-grade Stops in both Exclusive and Semi-Exclusive Rights-of-Way (ROW).

LRT surface alignments may include Semi-Exclusive ROW guideways in roadway medians where LRV Operator line-of-sight will govern Light Rail Vehicles (LRV) movement.

Main Line routes operate under full Automatic Train Protection (ATP)/Automatic Train Operations (ATO).

Operations Control Centres (OCC) monitor and direct operations for each LRT system.

See Chapter A5 – Operations.

C2.1.2 Functions and Assemblies

Similar units perform similar functions within each Communications and Control subsystem.

In no case does the equipment or hardware used in one portion of an LRT system differ from that used in another portion performing the same function under similar operational and environmental conditions.

Both new and existing LRT systems require Communications and Control conformance program wide.

Provide modular Communications and Control systems using electrical and mechanical components organized in cabinet-mounted plug-in assemblies.

Do not mix equipment associated with two subsystems in one plug-in assembly.

Locate equipment serving similar functions in the same relative cabinet positions wherever possible.

Attempt to minimize the effects of early component or subsystem obsolescence due to continuous advances in Communications and Control system technology.

Use open system architecture concepts for product interoperability between two or more manufacturers wherever available.

Provide Commercial Off-the-Shelf standard devices when such equipment meets MX LRT design criteria.

Limit special design and custom assemblies to devices requiring such features to meet MX LRT design criteria.

Choose equipment and materials previously accepted for the application by MX LRT unless the accepted equipment does not meet current MX LRT design criteria.

Provide Communications and Control hardware and software upgrades at end of product life cycle, when a product becomes obsolete, or the manufacturer no longer supports a product, whichever comes first.

C2.1.3 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Communications and Control specific references include but are not limited to:

- Ontario Building Code (OBC);
- Ontario Electrical Safety Code;
- Accessibility for Ontarians with Disabilities Act (AODA);
- Canadian Standards Association;
- Underwriters Laboratories of Canada (ULC);
- Electrical and Electronic Manufacturers Association of Canada;
- Industry Canada;
- Internet Engineering Task Force (IETF);
- International Organization for Standardization (ISO);
- National Electrical Manufacturers Association (NEMA);
- National Fire Protection Association (NFPA);
- Building Industry Consulting Services International (BICSI);
- Institute of Electrical and Electronics Engineers (IEEE):
  - IEEE 802.1b: LAN Management;
  - IEEE 802 1d: MAC;
  - IEEE 802.1g: Remote MAC Bridging;
  - IEEE 802.1q: Virtual Bridged LAN;
  - IEEE 802 1p: Quality of Service for Traffic Prioritization;
  - IEEE 802.3: CSMA/CD Access Method and Physical Layer Specification;
  - IEEE 802.3ae: 10 Gigabit Ethernet;
  - IEEE 802.3af: Power over Ethernet IEEE 802;
  - IEEE 802.3u: Fast Ethernet;
  - IEEE 802.11a/b/g/n: Wireless Local Area Networks;
  - IEEE 802.16d: WiMAX.
- Metro Ethernet Forum (MEF):
  - MEF 2: Requirements and Framework for Ethernet Service Protection;

- MEF 3: Circuit Emulation Service Definitions, Framework, and Requirements in Metro Ethernet Networks;
- MEF 4: Metro Ethernet Network Architecture Framework Part 1, Generic Framework;
- MEF 6.1: Metro Ethernet Services Definitions Phase 2;
- MEF 7: EMS-NMS Information Model;
- MEF 8: Implementation Agreement for the Emulation of PDH Circuits over Metro Ethernet Networks;
- MEF 9: Abstract Test Suite for Ethernet Services at the UNI;
- MEF 10.1: Ethernet Services Attributes Phase 2;
- MEF 11: User Network Interface (UNI) Requirements and Framework;
- MEF 12: Metro Ethernet Network Architecture Framework Part 2: Ethernet Services Layer;
- MEF 13: User Network Interface (UNI) Type 1 Implementation Agreement;
- MEF 14: Abstract Test Suite for Traffic Management Phase 1;
- MEF 15: Requirements for Management of Metro Ethernet Phase 1 Network Elements;
- MEF 16: Ethernet Local Management Interface;
- MEF 17: Service OAM Framework and Requirements;
- MEF 18: Abstract Test Suite for Circuit Emulation Services;
- MEF 19: Abstract Test Suite for UNI Type 1;
- MEF 20: UNI Type 2 Implementation Agreement;
- MEF 21: Abstract Test Suite for UNI Type 2 Part 1 Link OAM.

- Electronic Industries Association [EIA]:
  - EIA 603: Radio Transmitters;
  - EIA 204-D: Radio Receivers;
  - EIA 329-A.1: Radio Antennas;
  - EIA RS-316: Radio Electrical Performance;
  - EIA-310-D: Cabinets, Racks, Panels, and Associated Equipment.
- European Committee for Electro-technical Standardization (CENELEC):
  - EN 50121: Railway Applications - Electromagnetic Compatibility;
  - EN 50126: Railway Applications: The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS);
  - EN 50128: Railway Applications: Communication, Signal and Processing Systems – Software for Railway Control and Protection Systems;
  - EN 50155: Railway Applications: Electronic Equipment Used on Rolling Stock;
  - EN 60571: Electronic Equipment Used on Rail Vehicles;
- IEC 61373: Railway application - Rolling Stock Equipment - Shock and Vibration Test;
- IEC 60529: Degree of Protection Provided by Enclosures (Ingress Protection Code).

OBC governs where conflicts arise unless otherwise stated.

C2.2 Communications and Control Systems

Communications and Control systems include:

- OCC computer systems;
- Human Machine Interface application software;
- Wayside communications systems;
- Telephone systems;
- Two-way trunk radio communications;
- Public Address Systems;
- Closed Circuit Television (CCTV) Security;
- Passenger Visual Information Systems (PVIS).

Supervisory Control and Data Acquisition (SCADA) systems enable data exchange between remote Programmable Logic Controllers (PLC) for monitoring and relaying events and alarms from:

- Signal systems;
- Tunnel ventilation systems;
- Fire alarm systems;
- Elevators;
- Encroachment detection systems;
- Stations, Stops, Facilities;
- Traction Power Substations (TPS); and
- Wayside equipment.

See Chapter B6 – Maintenance and Storage Facilities.

Connect Communications and Control systems over common Wide Area Networks (WAN) serving as the backbone transmission network using fibre optic and/or other media combinations.

Provide redundant optical switching and paths to interconnect Stations, Stops, and Facilities with OCC.

C2.2.1 GPS Master Clock

A dedicated Ground Positioning Satellite (GPS) Master Clock sends synchronized signals to central computer and subsystem servers.

The Master Clock along with the GPS receiver generates time signals synchronizing OCC subsystems, slave system clocks, and Stations, Stops, Facilities, and Maintenance and Storage Facility (MSF) clocks.

Subsystem devices use Master Clock time signals solely for synchronization.

If the Master Clock cannot transmit a time signal to these systems, they work on their own internal clock until the Master Clock time signal is restored.

Configure the GPS Master Clock to automatically signal Daylight Savings Time.

Provide each subsystem with configurable time synchronization at the system level and to synchronize with the Master clock.

Provide the Master Clock with capability to synchronize the time for every connected subsystem in case it does not receive a GPS signal and backup time information during a power failure.

When power resumes, the Master Clock again generates the time signal, every subsystem self-resets to follow Master Clock time and synchronizes automatically without human intervention.

C2.2.2 Equipment Grounding

Properly ground Communications and Control equipment to an independent equipment grounding system.

See Chapter C3 – Facilities Electric Systems for grounding details.

C2.2.3 Type Testing

Provide weather resistant Communications and Control equipment exposed to outdoor environment.

Provide vandal resistant Communications and Control equipment installed in public areas.

Provide only Communications and Control equipment and systems passing the Environmental Qualification Test within the specified temperature range and Electro Magnetic Conductivity (EMC)/Electro Magnetic Interference (EMI) Tests by test certifying AHJ.

Provide LRV onboard Communications and Control equipment and systems passing both those tests as well as an additional vibration test.

C2.2.4 Reliability, Availability, Maintainability

Provide feasible Mean Time between Failure (MTBF) and Mean Time to Repair (MTTR) targets in Project Agreements.

Communications and Control systems subdivide broadly into two groups:

- Wayside/Station/Stop/MSF/OCC Communications and Control systems; and
- LRV onboard Communications and Control systems.

C2.2.5 Outside and Inside Plant Communications Infrastructure

Provide outside plant infrastructure comprising underground duct banks, splice enclosures, wireways, and pull boxes along the entire guideway.

Provide secondary Communications and Control conduit physically separated from primary conduit for redundant fibre optic and telephone cable to protect Communications and Control systems.

See Chapter A4 – Security.

Provide new fibre optic lines for LRT routes.

Provide spare fibre optic lines in primary and secondary ducts to serve future demand as well proposed cellular radio Distributed Antenna System (DAS) per Section C2.2.10.

Interconnect LRT fibre optic plant terminations with existing fibre optic lines at the nearest splice cabinet or facility subject to limitations of existing spare fibre optic lines.

Provide Stop platforms with a single floor mounted Communications and Control cabinet and Stations with Communications and Control Equipment Rooms to house signals, communications, and fare collection interfaces and equipment including:

- Secure, tamper proof, lockable cabinet doors per climate data and operating conditions per Chapter C4 – Heating, Ventilating, Air Conditioning;
- Standard EIA rack units for Communications and Control equipment, multiple battery modules, uninterrupted power supply units, and AC circuit breaker panels;

- Smoke detection sensors wired to PLC and SCADA monitored at OCC;
- Entry space to terminate conduit from underground duct banks;
- Copper grounding plates sized to connect shielded cable entering the cabinet, electrically isolated and insulated from any local grounds in the cabinet.

Communications equipment interfaces with and provides local connectivity to devices at Stations and Stops including but not limited to:

- Telephones;
- Cameras;
- PVIS;
- Public Address (PA) systems;
- Fare collection systems;
- Supervisory control systems;
- Fire alarm systems;
- Cable terminal blocks;
- Splice enclosures;
- Switches/routers; and
- Other electronic equipment.

Coordinate program wide the EIA rack unit space layouts for Communications and Control systems, fibre optic distribution panels, and incoming cable.

Cables and Conduits

Communications devices use different cable types based on the application including but not limited to:

- UTP Ethernet cable - Cat 5, Cat 6;
- Single-mode/multi-mode fiber optic cable;
- Twisted pair acoustic wire;
- Twisted pair telephone wire; and
- Control cable.

See Chapter C3 – Facilities Electric Systems for cable conduit.

Provide exposed locations such as Stops with cable in Liquidtight Flexible Metal Conduit installed in concealed raceways.

Provide indoor concealed Station and facility spaces with cable in Electrical Metallic Tubing.

Provide exposed but not concealed Station areas with cable in Intermediate Metal Conduit.

Provide elevated guideway with primary and secondary duct banks.

Provide underground duct banks with fibre optic cables through inner-ducts.

C2.2.6 Closed Circuit Television

Provide CCTV video monitoring and recording in public and non-public areas for system wide safety and security in surveillance of passenger movement, MSF LRV movement, intrusion detection, and security control throughout LRT Systems.

Monitor and record CCTV per the Ontario Freedom of Information and Protection of Privacy Act and APTA Standards Development Program Recommended Practice.

Provide and locate CCTV cameras per Ontario Information and Privacy Commissioner "Guidelines for the Use of Video Surveillance Cameras in Public Places" and "Privacy and Video Surveillance in Mass Transit Systems: A Special Investigation Report MC07-68."

See Chapter A4 – Security.

Provide CCTV systems network access to remotely monitor real-time video and download recorded video from any site for post-incident investigation purposes to law enforcement AHJ.

Provide CCTV monitoring per security requirements for LRT locations as follows:

- Passenger Platforms and Designated Waiting Areas (DWAs);
- Station Bus Bays;
- Stations Concourses and Elevator, Escalator, and Stair Landings;
- Elevators Car Interiors;
- Ticket Vending Machines;
- Fare Collection Areas;
- Passenger Assistance Intercoms (PAIs);
- Tunnel Portals;
- MSFs;
- Equipment Rooms (Provide Access Control Tied to CCTV);
- TPS Entrance Doors;
- Station Entrances and Exits;
- Crowd Control Areas;
- Onboard LRVs, See Chapter A2 – Light Rail Vehicles;
- Other Facilities Identified for Security Purposes.

Determine CCTV camera locations with site surveys and identify on design drawings.

OCC monitors CCTV when an incident is reported and conducts surveillance in coordination with AHJ.

Monitor real-time video only when triggered by an intrusion and/or emergency reporting device.

Activate CCTV recording when intrusion occurs at locations equipped with remote access control devices.

Provide an Enterprise Security Management System (ESMS) / CCTV video management system open architecture interface to record intrusion and/or access control events.

Provide Guideway Intrusion Detection Systems (GIDSs) that are not using video analytical technology with a CCTV system Interface to start video recording and OCC live monitoring of any intrusion event.

Provide video recording/storing at sites such as Stations and MSFs with the capability to retrieve video content over the network and transfer / store images onto removable media, e.g., DVD, after an incident.

Provide a Graphic User Interface (GUI) supported application, managed by directory servers, to address, manage, and view CCTV events, recordings, and storage systems in appropriate scalable LRT systems.

Provide Station Security Rooms with a network port for CCTV access.

Provide CCTV with Power over Ethernet (PoE).

Recording and Storage

Aggregate, record, and archive CCTV signal feeds from each Station, Stop, and other camera location to intermediate hub locations.

Determine primary and secondary recording locations in secure Communications Equipment Rooms.

Simultaneously stream and record video from source to secondary backup locations to safeguard availability of stored video in case of disaster and protect content and equipment per Chapter A4 – Security.

Record video content onto an archive server with Network Attached Storage using open standards.

Enable recording and archiving at a central location.

Make recorded CCTV content available 10 minutes before and 10 minutes after an event activated by PAI.

Provide video recording and storage equipment in secured cabinets to prevent unauthorized tampering.

Monitor CCTV cabinets and rooms via CCTV.

Provide access control with intrusion alarms.

Locate CCTV cameras for full coverage of Station and Stop fare collection equipment.

C2.2.7 Telephone Systems

Telephone systems provide voice communications between LRV Operators as well as between passengers and LRT field personnel, administrative staff, MSF and OCC operators, security, and emergency services.

Locate any public access telephone per OBC.

Indicate emergency reporting devices including telephones with appropriate signage.

The telephone system comprises telephone types for specific applications the follows.

LRT Telephones

Dedicated PBX systems serve internal LRT telephones for administration and operations.

Provide LRT telephone voice and data networks over common WAN backbone infrastructure.

Provide LRT telephone networks capable of unlimited access to the Public Switched Telephone Network (PSTN) including long distance and 911 emergency services.

Enable incoming and outgoing call restrictions, with the exception of 911 access, including possible sources and/or destinations to:

- Single numbers, e.g., to/from OCC;
- Single exchanges, e.g., within LRT network;
- Single calling areas, e.g., local calls only, no long distance.

Provide LRT Internet Protocol (IP) driven telephones connected over the LRT Wide Area Network (WAN).

Provide LRT telephone systems with Radio Communications System Interface using Integrated Communications System hardware and OCC application software platforms.

See Section C2.2.10.

Provide the PBX telephone switch serving LRT systems with redundant functionality and automatic switchover to a redundant system at a Backup OCC with no service interruption.

Provide PBX telephones at MSF, OCC, and LRT security offices with leased circuits to PSTN as back up.

Customer Information Telephones

Provide dedicated Customer Information Services (CIS) telephones at Stations and Stops adjacent to Ticket Vending Machines (TVMs) with restricted outgoing call access for non-emergency services.

Provide CIS telephones with labeled call buttons, e.g., PRESTO or INFORMATION, programmed to route calls to relevant service centres.

The purpose of CIS telephones is to:

- Report fare vending problems related to smart card/credit card transactions;
- Route calls to Interactive Voice Response (IVR) systems with prompts to reach call centre operators;
- Route calls to LRT Customer Information Centre operators;
- Obtain passenger trip and other LRT service information.

Passenger Assistance Intercom

Passenger Assistance Intercoms (PAIs) are clearly visible AODA/OBC compliant hands-free emergency reporting devices in Station and Stop Paid Areas and Designated Waiting Areas (DWAs) with speaker-phone push-to-talk buttons labeled “PUSH FOR HELP” to initiate communications with OCC PAI operators.

The primary purpose of PAIs is to report security incidents and initiate emergency response operations.

OCC performs primary PAI monitoring.

OCC PAI operators place and receive PAI calls at designated consoles.

PAIs provide OCC PAI operators with indications of incoming calls, calls in progress, call origin and destination locations, e.g., Station name, platform, DWA, or concourse.

Terminating a PAI call is only possible from the OCC PAI monitoring console.

OCC PAI monitoring consoles are able to monitor multiple PAIs and receive multiple PAI calls.

PAI calls are placed in queue so that the OCC PAI operator misses no calls or events.

Periodically test each PAI instrument and report fault events logged by the PAI application.

Activation of a PAI within CCTV coverage range, especially at DWAs, automatically triggers the associated CCTV camera to display event location video images at the OCC emergency management work station.

Emergency Management Panels

Provide a central fire alarm receiver and redundant server system at OCC to monitor alarm, trouble, and supervisory events received at Fire Alarm Control Panels (FACPs) per ULC.

Connect with redundant fibre optic cables and switches wherever there is access to the WAN or through leased telephone or cellular GSM data circuits where fibre optic connection is not available.

Also report fire alarms from FACPs as indicated on each Emergency Management Panel (EMP).

Provide independent annunciation of fire alarms and supervisory alarms at EMPs.

Periodically test fire alarm transmitters/receivers and annunciate a system trouble alarm at OCC if communications failure occurs between any FACP and the central receiver system.

Monitor and log fire alarms and events by SCADA, as a secondary source only, using its interface with the fire alarm server system.

Equip EMPs to function as Command Posts including:

- Fire alarm system annunciators and control units;
- Voice communication devices;
- Keys for access to every Station area;
- Mimic graphic display panel indicating Station rooms and layouts;
- Drawings and manuals as appropriate.

EMP voice communication devices include:

- Microphone connected with the Station PA system;
- LRT Telephone;
- Fire Fighter Master Handset communicating with other Fire Fighter Handsets.

The EMP microphone provides primary announcements in the Station that can over-ride OCC announcements but cannot be over-ridden.

EMP originated PA announcements activate OCC PA console lights indicating the Station PA system is in use.

OCC operators initiate, communicate, and coordinate fire and/or other emergency events with Emergency Services using telephone 911 and/or OCC voice radio.

Fire Fighters Handsets

Provide Fire Fighters Handsets per AHJ.

Blue Light Stations

A Blue Light Station (BLS) is a location indicated by a blue light with a hardened Emergency Telephone (ETEL) in a robust IP rated enclosure and a push button to deactivate traction power.

See Chapter A3 – Safety and NFPA 130 for BLS requirements.

PBX switches also serve BLSs.

BLS ETEL calls may terminate any other calls in the LRT telephone system.

Provide each BLS ETEL with a dedicated telephone circuit identifying the ETEL location when initiating a call.

Dedicated telephone circuits cannot be party lines.

Test each BLS periodically to verify operating status and report events to telephone system management.

Provide Blue Light Stations:

- At ends of Station platforms;
- At tunnel portal entrance points;
- Within 1.5 m of tunnel cross-passage doorways to other tunnels;
- Within 1.5 m of tunnel exit doors;
- At top of Emergency Exit Building stairs;
- At Fire Fighter Access (FFA) locations;
- In enclosed trainways as approved per AHJ.

Provide signs at each Blue Light Station per MX LRT standards.

Public Pay Phones

Provide public pay phones for convenience as well as for reporting emergencies.

Enable 911 Emergency Calls free of charge.

Provide public pay phones at Park'n'Ride lots and in Station paid and unpaid areas per OBC Section 3.13.

Provide Stations with separate Public Telephone Equipment Rooms.

See Chapter B5 – Stations, Stops, Facilities.

C2.2.8 Public Address Systems

Provide LRT Stations and Stops with Public Address (PA) systems to broadcast one way voice announcements as follows:

- To Station passengers;
- At tunnel portals to address trespassers;
- OCC Operator prerecorded or live messages across Stations and Stops in case of emergency with provisions to address only particular areas;
- Real-time "Next LRV" announcements at passenger platforms triggered by Automatic Train Supervision;
- Emergency evacuation messages originating at FACP paging devices and OCC taking precedence over any other messages;
- Messages exclusively for operations/maintenance staff at specific locations by zone selection.

Provide PA / PVIS system interfaces for OCC initiated Text-to-Speech converted messages.

Provide PA system / Guideway Intrusion Detection System (GIDS) interface to trigger automatic announcements warning passengers to stay away from the platform edge.

Provide PA systems to prevent single points of failure that would cause loss of broadcast to any PA zone.

Monitor PA amplifier/controller/speaker lines to detect failures.

Provide PA systems to broadcast live announcements, prerecorded announcements, prerecorded emergency announcements, ad hoc announcements, and background music.

Provide PA system capacity to store at least 100 prerecorded messages.

Provide PA system capability to edit, delete, and add prerecorded messages as and when needed.

Record and store in an archive server OCC initiated PA emergency and schedule delay announcements only, with storage duration per MX LRT policy.

Provide FACP capability to broadcast local emergency announcements through PA systems.

Provide PA system capability to control priority of simultaneous announcements in this order:

1. FACP Emergency Announcements;
2. OCC Emergency Announcements;
3. OCC Live Announcements;
4. Station Live Announcements;
5. OCC Prerecorded Announcements;

6. Station Prerecorded Announcements;
7. Background Music.

Equipment and Audio Characteristics

Provide PA system ambient noise monitors placed for automatic adjustment of audio levels.

Maintain uniformly distributed PA system sound level measured 1.5 m above finish floor.

Minimum desired sound levels are:

- Station Platforms: The greater of 10dB above ambient level up to 98 dBA maximum;
- Stops: 76 dBA day time; 70 dBA night time;
- Yards: 78 dBA;
- Main Repair Areas: 78 dBA;
- Offices and Other Areas: 70 dBA.

Provide PA systems to meet minimum speech intelligibility requirements per NFPA 72 or comply with more stringent industry standards that may apply.

Enable OCC PA system supervision and control via the fibre optic network allowing full networking of the distributed system of amplifiers, gateways, and controllers using IP addressing for full integration of PA systems with Communications and Control systems.

Interconnect head-end PA servers over fibre optic WAN to enable PA broadcasts of live announcements and prerecorded messages to selected zones.

Provide paging devices with zone selection software for OCC operators and field personnel.

Minimize unwanted PA system noise without reducing emergency communications effectiveness per AHJ.

Ontario Ministry of Environment Model Municipal Noise Control By-law prohibits amplified sound clearly audible in designated quiet zones and residential area points of reception at certain times of day.

PA sound levels are not to exceed 6 dB maximum above ambient noise levels.

The speech intelligibility parameter for routine PA system messages is defined by a Speech Transmission Index (STI) value between 0.5 and 0.6.

C2.2.9 Passenger Visual Information Systems

PVIS broadcast visual information in both English and French to Station, Stop, and LRV passengers.

Automatic Train Supervision triggers “Next Station or Stop” arrival announcements to head-end LRV PVIS.

Provide PVIS displays at Station ground level main entrances to display service announcements and elevators operating status.

Provide appropriate English to French software enhancement such as French Unicode or similar.

Provide PVIS display technology to achieve the optimum compromise between appearance and legibility.

Do not obstruct PVIS display lines of sight but coordinate with other signs to achieve architectural harmony.

Coordinate PVIS displays locations and lines of sight with Station and Stop architecture for the benefit of both boarding and alighting passengers under varying lighting conditions.

Deliver OCC operator initiated emergency or ad hoc messages via PVIS as well as other systems.

Also provide PVIS applications integrating PA systems to send speech-converted-to-text messages.

Provide PVIS interfaces with third party media content providers to broadcast infotainment fillers, MX LRT policy allowing, but with LRT system messages overriding infotainment at any time.

C2.2.10 Radio Networks

LRT Radio Networks provide real-time voice and data coverage throughout at-grade and underground sections using licensed Radio Frequency (RF) spectrums in multi-channel Digital Mobile Radio trunk systems.

Conduct RF studies to assess traffic load capacity for additional channels/talk groups required to support LRV, MSF, and other users within the scope and geographic boundaries of LRT projects.

Provide signal strength for 2-watt portable radio to be heard with 20 dB quieting at OCC or dispatch centres.

No “dead zones” with less than 20 dB quieting longer than 10 m allowed.

LRT Radio Networks are safety critical for LRT system operations.

Equip LRVs and non-revenue Maintenance of Way vehicles with mobile radio transceivers.

Provide portable transceivers for LRV Operator and LRT personnel radio network communications.

Assign LRV Operator and line controller talk groups to restrict communications to the assigned talk group.

At-Grade Sections

At-Grade Sections include a Master Site and Backup Site with redundant network equipment at each site.

Provide surface coverage available on 99% of LRT service areas 99% of the time;

Provide a frequency plan with at least one control channel and several traffic channels available from a shared pool of channels for LRT use.

Conduct RF engineering traffic and LRT user need studies to determine the number of LRT channels.

Underground Sections

Provide a Distributed Antenna System (DAS) in underground Stations and tunnels using leaky coax cables and a combination of antenna arrays.

Mount antenna arrays and leaky coax cable on tunnel walls to provide best signal coverage – 12 dB SINAD minimum – in both transmission directions without impairing LRV operations in underground sections.

The required degree of RF coverage is as follows:

- From LRV mobile radio to wayside service along running structures: 99% length of line including tail tracks 99% of time;
- For other areas within the running structure including LRVs, EEBs, cross passages, Fire Fighter Access routes: 97% of the area 99% of time;
- Remaining 3% of area: Absence of coverage not to extend more than 1 m in any direction;
- Station public areas: 95% of the area 99% of time;
- Remaining 5% of area: Absence of coverage not to extend more than 3 m in any direction;
- Other indoor areas, e.g., TPS, MSF, equipment rooms, passageways: 95% of area 99% of time.

Distributed Antenna System

Provide underground sections with Distributed Antenna Systems (DAS) including redundant RF equipment for seamless connectivity to above ground systems to maintain LRT operating unit communications.

Underground DAS are to operate without performance degradation as well as transmit and receive Master Site 800 MHz RFs to Police, Fire, and Emergency Services.

Interfaces

LRV cab mounted mobile radio equipment interfaces with LRV PA systems for distribution of OCC radio channel broadcast audio messages.

See Chapter A2 – Light Rail Vehicles.

Master-Site node control equipment provides an interface with LRT telephone switches to enable portable or mobile radios to transmit and/or receive calls to pre-designated analog/digital extensions of LRT and public telephone systems.

LRV mobile radios interface with LRV Maintenance Diagnostic System computers to send non-vital data messages.

Head-end base stations are able to bridge assigned LRT radio voice channels with Emergency Services radio voice channels through OCC operators.

Operations and Maintenance

Non-proprietary Network Management Systems: Provide required software applications enabled by open Applications Programming Interface to conduct radio system operations and maintenance.

LRT operations voice radio communications: Record and retain for 5 years on digital audio recorders backed up by two redundant Network Attached Storage locations.

Provide portable radio communication handsets for LRT operations and maintenance use.

Radio System Backup Power

Provide LRT radio network equipment sites with backup power.

C2.2.11 Cell Phones

Existing cell phone service provider base stations cover at-grade and elevated LRT ROW.

Consider underground cell phone communications infrastructure subject to MX LRT review and acceptance.

If accepted, provide cell phone RF signal distribution throughout underground sections as follows:

- Radiating coaxial cable antennas; and
- Fibre optic bi-directional amplifiers.

Mount coax antennas on Station concourse and platform ceilings as well as in tunnel structures.

Mount fibre optic amplifiers on a Station room wall, typically with 2 m^2 area reserved.

Assign and connect fibre optic amplifiers with dedicated fibre optic pairs to head-end radio base stations.

Provide conduit between fibre optic distribution panels and fibre optic amplifier equipment rooms.

Head-End base station equipment is typically located in nearby facilities off of LRT property.

Provide 100 mm conduit between base stations and nearest Station fibre optic distribution panels.

Provide an OCC supervisor work station web client to connect with cell phone service provider Network Management systems allowing OCC to shut down LRT underground cell phone service in case of emergency.

Cell phone service providers supply and install RF transmission lines and equipment designed and tested to mitigate noise and interference and comply with Electro-Magnetic Compatibility (EMC) standards.

Cell phone service providers also conduct interference and intermodulation studies wherever necessary so as not to impair performance of other safety critical radio networks.

C2.2.12 Wayside Wireless Networks

Supported Applications

Wayside wireless networks comprise wayside based full duplex broadband wireless communications infrastructure supporting broadband wireless communication applications

Wayside wireless networks connect with wireless communication devices providing backhaul connectivity to OCC, MSF, and other LRT operation centres.

Wayside wireless networks are able to serve the following applications:

- LRV CCTV live video on demand;
- Ticket validation and proof of payment verification;
- Trackside infrastructure.

ATC has its own dedicated wayside wireless network.

Network Requirements

Provide LRT wayside wireless network RF coverage as follows:

- Underground: Provide end-to-end platform RF coverage to enable LRV-to-wayside wireless network links to access points and allow LRVs within reach of a platform or stopped at a Station to seamlessly transmit/receive video and data;
- At-Grade and Elevated: Provide RF coverage to establish LRV communication links in the vicinity of Stations and Stops;
- MSF Storage Tracks: Provide RF coverage throughout.

Provide LRV/wayside communications radio link interfaces per proven industry standard wireless protocols for railroad environments.

Consider redundant LRV radio links if economically feasible and justified.

Provide wayside radios with access to nearest dark fibre optic and switched network for backhaul connectivity to OCC using WAN services.

Calculate and determine required data throughput for CCTV downlinks and uplinks.

Provide live wireless CCTV image resolution and frame rates per Section C2.2.6.

Provide end-to-end, IP driven, Quality of Service enabled networks no different from fixed IP scenarios in so far as IP traffic payload relevant to each application is concerned.

Provide adapters to convert native data format to IP where native data / IP interfaces are not available.

Onboard mobile access routers and other optional wireless solutions presented by LRV suppliers.

Related interfaces with LRV CCTV may be addressed in future subject to MX LRT review and acceptance.

Coordinate with MX LRT for seamless communications between LRV and wayside wireless systems.

Stations and Stops

Provide wireless access points with Ethernet interfaces to connect with Station and Stop IP/Ethernet switching nodes for access to WAN fibre optic systems.

C2.2.13 Wide Area Networks

Wide Area Network (WAN) infrastructure -- also referred to as “Backbone Network” -- enables voice, video, data, and train control signal communications with Stations, Stops, MSFs, OCCs, BOCCs, Enterprise Networks, and other transit control centres.

Each communications subsystem, e.g., Telephone, Radio, CCTV, PA, PVIS, and SCADA has a physical connection to add or drop traffic onto the WAN.

Consider the following in WAN design:

- Single mode fibre optic transmission media;
- Communications duct banks;
- Fiber optic cable plant and splice enclosures;
- Optical transmission equipment;
- Ethernet switches/IP routers;
- Software platforms providing service and operations support for each subsystem;
- Redundant fibre optic cables in physically separated duct banks with provisions for an additional cable in the same conduit using an inner-duct.

Network Topology and Design Principles

The topology of overall WAN architecture is based on:

- Access Network Nodes; and
- Core Network Nodes (for traffic aggregation) to accommodate transport of multi-service traffic through interconnected closed fibre optic rings dedicated to each LRT line.

Individual fibre optic rings may interconnect at Interchange Stations, where different LRT lines cross, or where LRT lines cross existing lines or Stations.

Evaluate options for optimum use of available fibre optic resources in connecting to existing operations.

Ring topology eliminates single points of failure caused by cable and/or equipment cuts in network spans.

Configure the WAN along each LRT line in ring topology in which each ring comprises one or more pairs of transmit/receive fibre optic cables from primary and secondary cables for redundancy.

Provide each LRT line with its own dedicated ring interconnected to other rings through core network node equipment.

Provide Stations, Stops, MSF, TPS, OCC, and BOCC at the least with core network nodes capable of adding and dropping traffic in the fibre optic ring.

Provide primary and secondary fibre optic cables in physically separate duct banks connecting redundant network nodes (switches/routers) to reroute traffic for 99.99% availability in case of cable or node failure.

Provide network recovery times per carrier class IP/MPLS industry standards.

Fibre Optic Networks

Fibre optic networks are multi-service platforms transporting layer 2/3 packet switched traffic such as real-time broadband services, e.g., IP, video, IP voice, as well as mission critical applications.

Consider industry trends and current best practices and propose fibre optic networks to achieve:

- Scalable and cost efficient network upgrades to meet future bandwidth demands without retiring or replacing one or more nodes;
- Deterministic performance per industry guidelines for recovery time required for mission critical data including signals and communications;
- Signal data network performance requirements coordinated with signals equipment suppliers;

- Core networks that allow modular upgrades and migration paths to next generation switching and long haul transport technologies;
- Ability to add to or interface with Wave Division Multiplexing service nodes where constrained by lack of fibre optic resources connecting to other fibre optic networks.

Verify that equipment suppliers offer hardware and software to avoid obsolescence.

Packet Switched Networks

Provide packet switched networks to support SCADA, PLC, PA, PVIS, CCTV, IP, GIDS, non-mission-critical enterprise, and wireless access point data traffic as follows:

- Differentiated services using packet classification, packet queuing, and Quality of Service enabled, Ethernet driven access network layers;
- IP routing and/or Ethernet over SONET core network layer scalable throughputs;
- Negotiation of bandwidth driven by class of service;
- Transport of multiple virtual LANs;
- Protection switching, traffic rerouting, and recovery per current industry standards.

Use open standards based protocols as follows:

- Latest IEEE 802.3 Ethernet protocols and standards;
- IP Routing – RIP 1 & OSPF;
- Port auto sensing and auto negotiation;
- DHCP;
- 802.1x dynamic port based sensitivity;
- VLAN and VPN support.

Signal Systems Data

Provide redundant and independent dark fibre optic cable in physically diverse ducts reserved for WAN signal systems data only and not for WAN communications systems data use.

Fare Collection Systems Data

Provide WAN dedicated fibre optic cables between Station and Stop fare collection equipment and OCC fare collection system servers or gateways and/or other locations to be determined.

Network Management

Provide OCC Network Management Systems for fibre optic WAN functions, operations, and maintenance with capabilities as follows:

- Configuration Requirements;
- Alarm Monitoring and Event Reporting;
- Performance Monitoring; and
- Fault Diagnostics.

Provide fibre optic WAN networks with Layer 1 and 2 Ethernet and Layer 3 and 4 TCP/IP connecting site based hosts, servers, and other Communications and Control systems and equipment.

Other Transit Control Centres

Other transit systems may be limited by fibre optic availability to connect to LRT systems.

Equip multi-service core nodes with wavelength (λ) services to transport multiple LRT data traffic using a single pair of existing fibre optic cable from LRT service node to another transit system.

The following requirements apply in selecting the most viable solution and product:

- Multi-wavelength (λ services) capable modules;
- Dedicated wavelengths for LRT lines;
- Wavelength splitters to bypass traffic through existing optical nodes;
- Long-haul small form-factor pluggable modules;
- Development of wavelength plan for LRT services.

C2.2.14 Supervisory Control and Data Acquisition

The Supervisory Control and Data Acquisition (SCADA) system provides OCC with master monitor and control functions for remote input/output field devices.

SCADA monitors and/or controls traction power systems, tunnel ventilation systems, MSF subsystems, and remotely located electronic equipment throughout LRT systems.

SCADA displays operating status, stores and retrieves event information, processes alarms, and generates incident reports.

SCADA is capable of both hardware and software automatic failover at system element level.

SCADA transmits real-time event and alarm data from remote sites including Stations and Stops to OCC Graphic User Interface work stations via WAN.

SCADA WAN transmissions include the following functional elements:

- Monitor and control of TPS equipment and emergency trip switch power on/off status;
- Monitor FACPs and interfaces with EMPs;
- Annunciation and transmission of facility fire alarms to central fire alarm receiver/communicators independent of SCADA;
- Monitor Uninterruptible Power Supply (UPS) analog points;
- Secondary monitoring and annunciation for information only of Station, Stop, MSF, and OCC intrusion events via ESMS interface;
- Monitor elevator/escalator operating status/alarms from OCC with real time data feed to PVIS;
- Monitor elevator/escalator work shop SCADA work stations to rapidly deploy work crews;
- Monitor GIDS interface with equipment and power status;
- Monitor Stations and Stops, MSF and OCC communications systems equipment;
- Monitor and control Station SCADA/PLC/automated building systems interface to receive and transmit critical alarms to OCC.
- Monitor Signals System interfaces;
- Monitor and control with facility equipment interfaces;
- Monitor secure area Access Control Systems;
- Monitor and control plumbing, drainage, and tunnel ventilation equipment.

Define ventilation control scenarios embedded with command sequences for SCADA operation of fans and dampers in case of emergency.

Provide remote locations with Ethernet driven Master Input/Output PLCs.

Connect program wide SCADA systems with MSF Master PLCs.

Run OCC SCADA database servers with Human Machine Interface application software.

PLCs operate on both full-duplex and unattended modes.

PLCs use Ethernet RJ45 connections to WAN switches for communication.

Provide SCADA/Ethernet/PLC software per IEEE 802.3.

OCC SCADA database servers continue to operation in case of Station/Stop/MSF SCADA equipment failure.

Upon return to service SCADA automatically resumes normal equipment monitoring and control.

Elapsed time from SCADA change-of-status detection and display at OCC is not exceed 3.0 seconds.

No single SCADA equipment malfunction or user action / lack of action may cause an unsafe condition.

LRT systems must continue to operate safely and normally should SCADA or other Communications and Control systems become completely inoperative for any reason.

Provide SCADA capability to perform orderly systems start up and shut down.

SCADA Hardware

Redundant fibre optic cables connect remote Station input/output modules at to the nearest Master PLC, which then communicates with central SCADA servers using TCP/IP protocol over WAN.

Provide SCADA multiprocessor computing servers with redundant hard drives and hot failover capability.

Provide hard drive capacity to store one week of rolling data and software necessary to mirror hot backup.

Provide work stations running operating systems supporting JAVA virtual machines.

Provide client-server systems connected by redundant 1 GB/s Local Area Network switches with dual Ethernet interfaces.

SCADA Software

Provide highly reliable SCADA software available to perform in large-scale applications supporting and scalable to 20,000 minimum points, capable of future addition of remote PLCs and connection to multiple remote work stations using open architecture for third party software to extract and exchange event data using industry standard methods.

Examples of typical scenarios include:

- Data exchange with a fire alarm server and/or remote PLC;
- Fault tolerant architecture minimizing single point of failure impact and providing for central system expansion and upgrades;
- Seamless integration between subsystems and programs;
- Fully integrated Graphic User Interfaces (GUIs) providing LRT operators with real-time information and control through use of maps, schematic displays, and dynamic objects;
- Work stations without operator restrictions other than password and associated permissions;
- Standard interfaces to monitor and control various PLCs from various manufacturers;
- Continuous 24/7/365 operation with automatic failover to redundant components.

Provide SCADA software incorporating the following protocols and standards as a minimum:

- Ethernet and TCP/IP networking standards;
- ODBC and SQL database standards;
- Web based interface standards: HTML, DHTML, JSP, XML, CSS, Javascript, etc.;
- Modbus and DNP 3.0 protocol for data acquisition devices using both serial and TCP/IP;
- Scalable Vector Graphics W3C representing graphics in standard XML;
- Protocols for communications with other Transit Control Centres.

Software Licensing

Provide royalty-free license to use SCADA software and related third-party software valid for specified sites with no license key or other mechanisms preventing users from expanding or using the software to its full capabilities and no additional licenses required to expand the number of points, field devices, work stations and/or other data tables.

Provide license with full development capability on work stations limited only by user permissions.

Connection to Existing SCADA

Communicate and display LRT related events and alarms originated at shared transit facilities on existing SCADA work station by allowing operators to host sessions locally with the LRT SCADA to monitor and control LRT specific events at shared facilities.

Configure network security services between LRT SCADA and other SCADA to interconnect with the LRT SCADA servers by geography and/or by work station.

C2.2.15 Power Supply

Load Classification

Power load classifications defining communication systems and equipment electric power distribution are:

- Essential – Momentary loss of communications is acceptable during changeover and the system does not require manual intervention to restore operating status prior to changeover;
- Critical –UPS back up independent of normal and essential power supply, defined as unacceptable change in operating status, e.g., loss of a call in progress, loss of calls in a queue, or loss of data and/or video stored in electronic memory.

Essential and Critical loads include those where failure to operate satisfactorily would:

- Curtail LRT operations;
- Cause health and safety hazards; or
- Result in property damage.

UPS must operate protected systems in stable state for minimum specified durations.

Monitor each UPS feed circuit by SCADA for loss of power.

See Chapter C3 – Facilities Electric Systems.

Equipment Classification

Communications equipment classifications are as follows:

Equipment	Critical	Normal
Telephone switches and servers, PAI, Firefighter Handsets, ETS. Note: Staff, PAI or other VoIP telephones supplied with 48V DC in equipment rooms via telephone cable.	Y	
Radio Equipment. Note: Radio devices whether at-grade or underground are classified as critical.	Y	
Public Address Systems. Note: Head-end, distribution equipment, and auxiliary devices at Stations and Stops are classified as critical.	Y	
Wide Area Network optical nodes, switches, power supplies, etc.	Y	
SCADA	Y	
Fare Collection Equipment	Y	
ATC Communications. Note: Whether in Stations, tunnels, or surface locations are classified as critical.	Y	
CCTV – DVRs, servers, switches, cameras at tunnel portals, Designated Waiting Areas	Y	
CCTV - Cameras at Stops, Station concourses, MSFs		Y
PVIS	Y	
Wireless Access Points.		Y
OCC equipment critical to operations	Y	

Circuit Requirements

Provide separate power circuit breakers for individual subsystems.

Provide separate power circuits from independent and isolated power supplies for communications racks requiring redundant power supply.

Feed each redundant power supply separately where two independently fed UPS units with two separate distribution panels are available.

C2.2.16 OCC Systems

Overview

LRT systems go through various operating phases from start-up to LRV launch, revenue service, LRV withdrawal, ongoing maintenance, and operations management.

Each phase requires specific operating procedures supported by systems/applications for safe and efficient outcomes from many and various situations including equipment failure, brown-outs, guideway intrusion, fire, and other emergencies.

Provide application platforms with open architecture systems and IP enabled devices for cost-effective operation enabled “one stop” solutions for communications, control, and command functions as well as ease of maintenance and LRT system standardization.

Provide integrated supervisory control systems to support the following situations:

Normal Mode: Normal service start up, revenue operation, and service shut down without major disruption.

Incident Mode: An incident that does not result in major service delay or injuries, e.g., LRV stalled in tunnel.

Emergency Mode: Emergency situation causing serious injury or major service delay, e.g., LRV fire in tunnel.

OCC systems must also meet the challenges of catastrophic human failure.

Automation is crucial for routine functions such as real-time retrieval of information and interaction with passengers anywhere in the system.

Consider multi-media approaches to develop management tools allowing LRT operators to configure unique predefined scenarios to assist with real-time operating situations and requirements.

One such scenario might be a passenger initiated conversation with OCC via onboard LRV PAI and/or CCTV.

Consider such scenarios, operation processes and procedures, and emergency management requirements in developing Integrated Communications Control Systems (ICCS) applications and tools.

Integrated Communications Control Systems

Use ICCS concepts to explore complex cross-functional business processes between interconnected systems handling a broad range of situations in a consistent and controlled manner.

ICCS scope includes communications subsystem integration as demand for available information increases allowing information use and sharing to support effective incident management and decision making.

ICCS with incident management tools and user-friendly GUIs enable OCC operators to originate and receive PA, PAI, Radio, and Telephone calls or announcements as well as transmit PVIS messages.

Provide ICCS with high resolution computer work stations, audio headsets, keyboards, and microphones.

ICCS use non-proprietary protocols to establish communications interfaces with the following subsystems:

- ESMS;
- CCTV System;
- PA System;
- PVIS;
- PAI.
- Telephone Switches/Servers and Voice/Data Radio to patch radio and telephones calls.

Provide ICCS with Graphic User Interface.

Determine and provide the level of ICCS software integration required with various subsystems.

Integrate communications system operating functions – traditionally provided by different vendors – through ICCS using application programming interfaces to optimize the overall operating experience.

Provide audio / visual incident management tools using a single work station to integrate communications.

ICCS Functionality

ICCS provide LRT operators with an integrated communications, control, and command platform to monitor and communicate with hardware in the field via easy to use graphic user interface front ends and reliable server back ends.

ICCS also provide a central repository for system wide alarms and events, planned response mechanisms to streamline activities in the case of an incident, and collection of statistical data for later analysis.

ICCS comprise primary software components as follows:

- Core Components;
- Graphic User Interfaces; and
- Application Specific Agents.

Graphic User Interfaces

GUIs provide OCC operator work stations with audio-visual views of an LRT system.

Include standard screens or custom GUIs for project specific components.

Application Specific Agents

Application Specific Agents are server-side processes that integrate various ICCS subsystems and devices.

Application Specific Agents allow other applications to query the status of devices and request status changes to those devices.

Application Specific Agents implement business logic and conversion to particular protocols required to communicate with other subsystems.

Standard Core Components

Standard Core Components are necessary to implement basic ICCS functions responsible for:

- Managing Application Specific Agents;
- Launching GUIs;
- Providing configuration data;
- Archive functions;
- Basic and group remote control general mechanisms;
- Alarm management including alarm filtering and prioritization;
- Event management;
- Severity levels;
- Time schedule programs;
- Trend logging;
- Tagging and inhibition of points;
- System security based on operator identification and rights;
- Communication mechanisms between servers; and
- Avalanche filtering.

Operating Tools and Applications

ICCS provides operating tools and applications for the above functions as well as provisions for other features yet to be determined.

See Chapter A5 – Operations.

Maintenance Management Systems

Provide Maintenance Management Systems (MMS) to assist LRT staff in planning, scheduling and management of maintenance work and to minimize service downtime.

MMS comprise the following capabilities:

- Maintenance as well as management and purchasing of materials with additional related features such as permit, life-cycle cost, and electronic documentation;
- Asset Management, Work Management, Preventive and Corrective Maintenance, Materials and Permits Management, and Electronic Document Control;
- Computerized asset management, works maintenance, stocks inventory, and equipment purchases.

C2.2.17 Onboard LRV Systems

Onboard LRV Communications and Control systems provide the following:

- PA;
- PVIS;
- Cab-to-Cab Intercom;
- PAI;
- CCTV;
- LRV Radio;
- Wireless Networks;
- WAN.

See Chapter A2 -- Light Rail Vehicles.

Public Address / Passenger Visual Information Systems

LRV onboard PA systems broadcast audio messages and announcements at the same time as onboard LRV PVIS display visual messages and announcements from OCC and LRV Operators in both English and French.

LRV Operators activate onboard LRV PA systems from the cab transmitting voice announcements from common PA/PAI handsets/microphones to PA amplifiers and speakers in each LRV car.

Ambient noise monitors placed along the car connected to PA amplifiers automatically adjust audio levels.

LRV Operators may suppress exterior speakers for late night operations.

Maintain uniformly distributed LRV PA system sound levels measured 1.5 m above finish floor.

Minimum desired PA sound levels are:

- 10 dB above ambient noise up to 98 dBA maximum; or
- 78 dBA.

OCC consoles make PA announcements to individual LRVs or entire LRV fleets via LRT voice radio systems.

OCC PA announcements override other communications.

Provide LRT PA/PVIS messages and announcements including but not limited to:

- LRV Destination;
- Station Arrival;
- Station Name;
- Door Opening;
- Door Closing;

- Station Departure;
- Next Station;
- Special Messages.

ATS signals trigger LRV PA/PVIS announcements.

Cab-to-Cab Intercoms

LRV cab-to-cab intercoms allow LRV Operators to communicate with each other in full duplex mode.

Only LRV Operators may activate cab-to-cab intercom communications with each other.

Passenger Assistance Intercom

Provide each PAI with a speaker and microphone for passengers to communicate with the LRV Operator.

Once a passenger activates an LRV PAI an audible alert signals the LRV Operator to answer.

Once answered, the LRV Operator transmits to the respective PAI via a common PA/PAI handset.

PAI allow passengers to alert LRV Operators in case of emergency.

An audible alarm tone and flashing alarm button lights on the LRV main console to alert the LRV Operator when a passenger presses the PAI emergency call button.

The LRV Operator is able to talk to passengers only when the flashing alarm button is pressed to acknowledge and answer the emergency call.

Once acknowledged, the LRV main console alert tone lowers to a more comfortable volume level and the LRV Operator begins communications with passengers.

The LRV Operator voice is heard only on the specifically activated PAI.

During LRV Operator and PAI caller communications, the LRV Operator is able to initiate one or another communications function such as PA Broadcast or Cab-to-Cab intercom, but not both simultaneously, while putting the PAI caller on hold.

The LRV Operator is able to re-establish PAI passenger communication once Cab-to-Cab intercom or PA broadcast communications end.

If an LRV Operator does not acknowledge a PAI emergency call in a configurable fixed period of time, the LRV onboard voice radio transceiver automatically routes the PAI call to an OCC radio console.

Functions/Priority

LRV PA and PAI systems allow LRV and OCC operators to perform the following functions:

- Broadcast PA from LRV Operators to LRV passengers;
- Broadcast PA from OCC to LRV passenger throughout the LRV fleet via voice radio;
- Discreet communications between and among LRV Operators via cab-to-cab functions;
- Discreet communications with passenger via PAI.

Functional priority is:

- LRV Cab-to-Cab communications;
- OCC to LRV PA to be used only in case of emergency;
- PAI calls;
- LRV Operator initiated PA messages.

CCTV

Each LRV includes CCTV cameras on each side of each end of the LRV car facing backward from the cab to monitor and record passenger activity and displays images in the LRV Operator cab.

Upon door enables command, CCTV displays images from the foremost and rearmost cameras of the LRV side on which doors are being operated.

While in motion, CCTV displays images from the foremost cameras on each side.

DVRs in each LRV Operator cab record video images from LRV onboard CCTV cameras on removable hard disk drives configurable to store up to 72 hours minimum continuous recording before overwriting occurs.

In case of PAI activation, recorded video images from the respective cameras are overwrite protected.

See Section C2.2.12 for onboard LRV CCTV real time streaming over wireless media.

C3 Facilities Electric Systems

C3.1 General

Chapter C3 addresses Metrolinx (MX) Light Rail Transit (LRT) program and project Facilities Electric Systems required for safe and reliable operations, security, and comfort including:

- Underground and Elevated Stations;
- At-Grade Stops;
- Transfer Facilities;
- Maintenance and Storage Facilities (MSFs);
- Tunnels and Ancillary Tunnel Spaces;
- Parking and Roadways;

Light Rail Vehicles (LRVs) require electric traction power, a companion to Facilities Electric Systems.

See Chapter C1 – Traction Power.

Facilities Electric Systems include:

- AC Incoming Service and Distribution;
- AC Emergency Power;
- AC Low Voltage Secondary Distribution.

Facilities Electric Systems equipment and materials include:

- Grounding and bonding;
- Fasteners and support equipment;
- Electrical identification;
- Wire, cable, and wire management;
- Wiring devices;
- Boxes and enclosures;
- Metering;
- Uninterruptible Power Supply (UPS) equipment;
- Motors;
- Transformers;
- Switches;
- Motor controllers;
- Panel boards;
- Switch boards;
- AC low-voltage switchgear.

C3.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Facilities Electric Systems specific references include but are not limited to:

- Ontario Building Code (OBC);
- Ontario Electrical Safety Code;
- Canadian Electrical Code (CSA) C22.1: Part I, Safety Standard for Electrical Installations;
- CSA C22.2 No. 0: General Requirements, Part II;
- C22.2 No. 4: Enclosed and Dead-Front Switches;
- C22.2 No. 18: Outlet Boxes, Conduit Boxes and Fittings;
- C22.2 NO. 18.2: Nonmetallic Outlet Boxes;
- C22.2 No. 18.3: Conduit, Tubing, and Cable Fittings;
- C22.2 No. 26: Construction and Test of Wireways, Auxiliary Gutters and Associated Fittings;
- C22.2 No. 31: Switchgear Assemblies;
- C22.2 No. 38: Thermoset-Insulated Wires and Cables;
- C22.2 No. 40: Cutout, Junction and Pull Boxes;
- C22.2 No. 41: Grounding and Bonding Equipment;
- C22.2 No. 42: General Use Receptacles, Attachment Plugs, and similar Wiring Devices;
- C22.2 No. 45.1: Rigid Metal Conduit;
- C22.2 No. 51: Armoured Cables;
- C22.2 No. 75: Thermoplastic-Insulated Wires and Cables;
- C22.2 No. 83: Electrical Metallic Tubing;
- C22.2 No. 111: General-Use Snap Switches;
- C22.2 No. 126.1: Metal Cable Tray;
- C22.2 No. 210: Appliance Wiring Material Products;
- C22.2 No. 211.1: Rigid Types EB1 and DB2/ES2 PVC Conduit;
- C22.2 No. 211.2: Rigid PVC (Unplasticised) Conduit;
- C22.2 No. 227.2.1: Liquid-Tight Flexible Nonmetallic Conduit;
- C22.2 No. 2515: Aboveground reinforced thermosetting resin conduit (RTRC) and fittings;
- American National Standards Institute (ANSI) A13: Scheme for Identification of Piping Systems;
- ANSI C80.6: Electrical Intermediate Metal Conduit (EIMC);

- ANSI 77: Specification for Underground Enclosure Integrity;
- ANSI Z535.1: Standard for Safety Colors;
- ANSI Z535.2: Environmental and Facility Safety Signs;
- ANSI Z535.3: Criteria for Safety Symbols;
- ANSI Z535.4: Product Safety Signs and Labels;
- ANSI Z535.6: Product Safety Information in Product Manuals, Instructions, and Other Collateral Materials;
- ASTM C857: Standard Practice for Minimum Structural Design Loading for Underground Precast Concrete Utility Structures;
- Electronic Industry Association (EIA) RS-310C: Racks, Panels, and Associated Equipment;
- Institute of Electrical and Electronic Engineers (IEEE) C37.20.3: Standard for Metal-Enclosed Interrupter Switchgear;
- IEEE C57.12.01: Standard General Requirements for Dry-Type Distribution and Power Transformers;
- IEEE C57.12.51: Standard for Ventilated Dry- Type Power Transformers;
- IEEE C57.12.91: Standard Test Code for Dry-Type Distribution and Power Transformers;
- IEEE C62.41.1: Guide on Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits;
- IEEE 81: Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System;
- IEEE-141: Recommended Practice for Electric Power Distribution for Industrial Plants;
- IEEE 1100: Recommended Practice for Powering and Grounding Electronic Equipment;
- MIL-PRF-55629/1G: General Specification for Circuit Breakers, Magnetic, Unsealed or Panel Seal, Trip-Free;
- National Electrical Contractors Association (NECA) 1: Good Workmanship in Electrical Contracting;
- NECA 101: Standard for Installing Steel Conduit (Rigid, IMC, EMT);
- NECA 105: Standard for Installing Metal Cable Tray Systems;
- NECA 111: Standard for Installing Nonmetallic Raceways (RNC, ENT, LFNC);
- National Electrical Manufacturer’s Association (NEMA) 250: Enclosures for Electrical Equipment (1000 Volts Maximum);
- NEMA KS 1: Heavy Duty Enclosed and Dead-Front Switches (600 Volts Maximum);
- NEMA PB 1: Panel boards;
- NEMA ST 20: Dry Type Transformers for General Applications;
- National Fire Protection Association (NFPA) 70: National Electrical Code;
- NFPA 70E: Standard for Electrical Safety in the Workplace;
- NFPA 101: Life Safety Code;
- NFPA 110: Standard for Emergency and Standby Power Systems;

- NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems;
- Underwriters' Laboratories (UL) 44-18: Thermoset-Insulated Wires and Cables;
- UL 98: Enclosed and Dead-Front Switches;
- UL 489: Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures;
- UL 891: Switchboards;
- UL 924: Emergency Lighting and Power Equipment;
- UL 1449: Surge Protective Devices;
- UL 1558: Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear;
- UL 1561: Dry-Type General Purpose and Power Transformers;
- UL 2196: Tests for Fire Resistive Cables.

OBC governs where conflicts arise unless otherwise stated.

C3.3 Electric Load Classifications

Electric loads fall into one of these classifications:

- Normal Loads;
- Essential Loads;
- Critical Loads.

C3.3.1 Normal Loads

Normal Loads can tolerate occasional prolonged interruptions.

A non-redundant power circuit from a single electric utility or Traction Power Substation (TPS) service feeder can thus serve Normal Loads.

Typical Normal Loads include but are not limited to:

- Normal lighting, above-grade Stations and Stops;
- Miscellaneous above-grade distribution;
- Parking and roadway lighting;
- Advertising signs;
- Sanitary drainage pumps;
- Fire jockey pumps.

C3.3.2 Essential Loads

Essential Loads can tolerate only momentary interruptions.

A redundant power circuit from two electric utility service feeders, two TPS service feeders, or a single feeder from either an electric utility or TPS service feeder plus an alternative power feeder, e.g., a generator, can thus serve Essential Loads.

Typical Essential Loads include but are not limited to:

- Normal lighting, underground Stations;
- Emergency ventilation equipment;

- Tunnel ventilation equipment;
- Elevators and escalators;
- Storm and ground water drainage pumps;
- Fire booster pumps.

C3.3.3 Critical Loads

Critical Loads can tolerate neither prolonged nor momentary interruptions.

UPS must serve Critical Loads.

Typical Critical Loads include but are not limited to:

- Emergency lighting;
- Tunnel lighting/systems;
- Designated Waiting Area (DWA) lighting;
- Emergency signs;
- Blue Light Stations (BLS) including Blue Globe Light and Passenger Assistance Intercoms;
- Platform edge doors (PEDs);
- Passenger Station doors interlocked with emergency ventilation;
- Ventilation supervisory controller;
- Emergency Management Panels (EMPs);
- Fiber optic systems;
- Critical signal systems;
- 600 and 208 volt switchgear control power;
- Systems Control and Data Acquisition (SCADA) systems;
- Fire Alarm Systems;
- Emergency Trip Systems (ETS);
- Public Address (PA) systems;
- Passenger Assistance Intercoms (PAIs);
- Passenger Visual Information Systems (PVIS);
- Internal Telephone/PAX;
- Closed Circuit Television (CCTV) and other security loads;
- Radio/Antenna systems;
- Fare collection systems,

C3.4 Future Equipment

Coordinate with other disciplines and include provisions for future equipment including but not limited to:

- Elevators;

- Escalators;
- Fare vending equipment;
- Signal equipment;
- Communications equipment;
- Advertising signs.

Provide future equipment electric distribution capacity, future circuit breakers space, and rough-in conduit.

Plan rough-in work to avoid surface-mounted conduit in future.

C3.5 Demand Factors

Size transformers, switchgear, switchboards, panel boards, and Motor Control Centers (MCC) using demand factors as follows.

Load	Load Factor
Lighting and Signs	1.0
Elevators	0.5
Escalators	0.85
Ventilation Equipment	0.8
Air conditioning equipment	0.7
* Heating equipment	1.0
* Drainage and Ejector Pumps	0.5
Signal and Communication Equipment	1.0
Fare Vending Equipment	0.5
Convenience Outlets	1.5 amps per receptacle yoke

* Lesser of non-coincident heating and air conditioning loads may be excluded.

Size each bus to 125% connected load demand for two-bus equipment with interconnected tie-breakers.

C3.6 Utilization Voltages

Provide equipment requiring AC power as follows.

Equipment	Utilization Voltage
Lighting	
Fluorescent Lighting	347 V-1PH (preferred) or 120 V-1PH
HID Lighting	347 V-1PH
Maintenance Lighting (Elevator Pits, Escalator Machine Rooms, etc.)	120 V-1PH
Convenience outlets	120 V-1PH
Motors	
1/2 HP and Larger	575 V-3PH

Equipment	Utilization Voltage
Smaller than 1/2 HP	115 V-1PH
Motor Controller Power	115 V-1PH
Duct Heaters	
Below 8 kW	347 V-1PH
8 kW and Above	600 V-3PH
Water Heaters	
2,900 Watts or less	120 V-1PH
2,900 Watts to 5,500 Watts	347 V-1PH
Above 5500 Watts	600 V-3PH
Unitary Air Conditioning Equipment	
Below 12,000 BTUH	115 V-1PH
12,000 and 60,000 BTUH	332 V-1PH
Above 60,000 BTUH	575 V-3PH
Chillers	575 V-3PH

C3.7 Electric Service/Distribution

C3.7.1 Underground Stations

Underground Station safety considerations require higher electric system reliability.

For underground Stations serving emergency ventilation equipment in Stations, tunnels, or other underground facilities, provide two incoming service feeders at no less than 13.8 kV (nominal) three-phase, 60 Hz supply voltage from TPS (preferred) or Authorities Having Jurisdiction (AHJ) electric utility provider.

Provide TPS service for underground Stations at/or near TPS.

Provide service feeder directly from electric utility provider through 13.8 kV or 27.6 kV MV-AC switchgear covering second source contingency for underground Stations not at/or near TPS.

Provide circuits for each incoming service feeder from separate and independent utility providers or TPS MV-AC feeders electrically and physically isolated from each other.

Do not route two independent feeders in common trenches or ducts.

Provide service feeders with supply capacity 100% demand plus 25% spare for future loads.

Provide three-phase mirrored unit substations.

Include fusible medium-voltage switches, transformers, 600/347V low-voltage main-breaker switchgear and tie-breakers.

Designate bus sections of mirrored substations as “Bus 1” and “Bus 2.”

Include kirk-key interlocks to be sure main breakers for “Bus 1” and “Bus 2” cannot be closed without first closing matching medium-voltage switches and likewise that medium-voltage switches cannot be opened without first opening the matching main breakers on the 600-volt side.

Size tie-breakers, buses, and mains of each “Bus 1” and “Bus 2” no less than the sum of 125% of connected loads plus two buses combined planned future loads.

Provide digital metering on line side of each main breaker.

Provide additional circuit breakers at 600-volt switchgear “Bus 2” for future emergency generators.

Provide kirk-key interlocks to prevent simultaneous emergency generator and 600V main breaker closing.

Provide space at grade to locate future temporary emergency generators with non-fused disconnect means—400 A, 600V, 3 Phase, 4 Wire—pre-wired to 600V switchgear “Bus 2” emergency generator breakers for quick generator connection as backup power to critical UPS and selected emergency/standby loads.

Provide redundant, three-phase, double-isolation UPS.

Feed UPS from a single circuit breaker from different buses on the 600-volt switchgear.

Provide digital metering on line side of each main breaker.

Provide equipment and coordinate revenue metering on line side of each main breaker for mirrored substation fed directly from AHJ electric utility.

Provide two 600:208/120V three-phase transformers and a 208/120V switchboard equipped with two independent buses designated as “Bus 1” and “Bus 2” each equipped with main breaker interconnected through tie breaker.

Size tie-breakers, buses, and mains of each “Bus 1” and “Bus 2” no less than 125 percent the sum of connected loads plus planned future loads of two buses combined.

Provide digital metering on line side of each main breaker.

Locate MV-AC switchgear and MV/600V transformers in MV-AC Switchgear Rooms.

Locate MCC 600V and 208V power distribution equipment in AC Switchboard Rooms.

C3.7.2 Station Uninterruptible Power Supply

Provide UPS for continuous, regulated AC power to critical loads such as transit operations, safety, and security systems under normal and abnormal conditions including loss of utility AC power.

Evaluate and confirm UPS configuration as the basis of required reliability, availability, and maintainability (RAM) plan guidelines.

UPS may be configured with two double-isolation UPS Mains and static bypass inputs for UPS on a single-input connection to meet UPS RAM targets.

Size UPS to provide 100 percent connected and planned emergency loads.

Provide UPS connections in parallel/redundant arrangements to complete each independent UPS battery string.

Rectifier/Charger

Oversize UPS rectifier/charger to bring the battery string to full charge from complete discharge within 24 hours when delivering full rated load and within four hours when operating at half rated load.

Comply with battery manufacturer instructions regarding battery terminal voltage and charging current required to maximize battery life.

Provide means to safely equalize charged batteries.

Inverter

Provide UPS pulse-width modulated, Insulated Gate Bipolar Transistor inverters with sinusoidal output.

Provide bypass phase synchronization window adjustment to optimize compatibility with local engine generator set.

Provide inverters to synchronize input frequency unless input frequency falls outside frequency tolerance.

Batteries

Provide UPS with valve-regulated, premium, heavy-duty, recombinant, lead-calcium factory-assembled batteries in isolated compartments or matching cabinets complete with battery disconnect switches.

Size each battery string for 90 minutes at 100 percent UPS rated load.

Provide manual switching for UPS to connect to one or both battery strings.

Static Bypass Transfer Switch

Provide UPS with a solid-state static bypass transfer switch to accommodate uninterrupted transfer.

Provide contactor or electrically-operated circuit breakers for automatic UPS electric switch isolation.

Provide static bypass switches rated at 100% full UPS load continuous duty current.

Maintenance Bypass Switch

Provide UPS with single manually-operated Maintenance Bypass Switch or arrangement of switching devices with mechanically-actuated contact mechanisms arranged to re-route loads around rectifier/chargers, inverters, and static bypass transfer switches.

Provide Maintenance Bypass Switch arrangements with interlocks inhibiting maintenance bypass unless UPS is in static bypass mode.

Provide Maintenance Bypass Switches allowing UPS component safe service replacement without load interruption.

Controls and Alarms

Provide UPS displays, indicators, controls, sensors, transducers, and support wiring as follows.

Paralleling Cabinets

Provide paralleling cabinets to combine and control outputs of up to three redundant UPS, synchronize UPS output, and balance loads equally among UPS connected in parallel.

Provide peer-to-peer synchronization protocol rather than master-slave arrangements.

Size paralleling cabinets no less than 125% of any single UPS rating.

UPS Operation Sequence

Design UPS to operate in the following sequence:

1. Normal condition: Load supplied with power flowing from normal power input terminals of both UPS1 and UPS2 through rectifier/charger/inverter and battery connected in parallel with rectifier/charger output.
2. Abnormal Supply Conditions: If normal supply deviates from specified and adjustable voltage, voltage waveform, or frequency limits, battery supplies energy to maintain constant, regulated inverter power output to load without switching or disturbance.
3. Interrupted Supply Conditions: If normal power interrupted, energy supplied by battery through inverter continues to supply regulated power output to load without switching or disturbance.

4. Power Restored at Normal System Supply Terminals: Controls automatically synchronize inverter with external source before transferring load; Rectifier/charger then supplies power to load through inverter and simultaneously recharges batteries.
5. Battery Discharged/Normal Supply Power Available: Rectifier/charger charges battery; upon reaching full charge, rectifier/charger automatically shifts to float-charge mode.
6. Any UPS Element Fails/Normal Supply Power Available: Static bypass transfer switches load to normal AC supply circuit without disturbance or interruption.
7. UPS Fault Occurs/Current Flows Exceeding UPS Overload Rating: Static bypass transfer switch operates bypassing fault current to normal supply circuit for fault clearing.
8. Fault Cleared: Static bypass returns load to UPS system.
9. Disconnected Battery: Does not interfere with UPS voltage regulation or output bus frequency.

C3.7.3 Transient Voltage Surge Suppression

Provide integrally-mounted, bolt-on, solid-state, parallel-connected, modular field-replaceable sine-wave tracking and filtering Transient Voltage Surge Suppression (TVSS) modules per IEEE C62.41 and UL 1449.

Provide additional features as follows:

- 200 kA TVSS fusing;
- Integral disconnect switch;
- Redundant replaceable modules;
- LED indicator light for power and protection status;
- SCADA interface.

Provide TVSS units to withstand 240kA per phase total 8 x 20 microsecond surge current with 12,000V IEEE C62.41 Category C capability.

TVSS Panel Boards

Provide integrally-mounted, plug-in, solid-state, parallel-connected, modular field-replaceable sine-wave tracking and filtering TVSS Panel Boards per IEEE C62.41 and UL 1449.

Provide additional features as follows:

- 120 kVa TBSS fusing;
- Integral short-circuit protection and disconnect switch;
- LED indicator light for power and protection status;
- SCADA interface.

Provide TVSS Panel Boards to withstand 120kA per phase total 8 x 20 microsecond surge current and 9,000 IEEE C62.41 Category C1 capability.

C3.7.4 Low Voltage Transformers

Provide ventilated, dry-type, 600:208/120V delta-wye transformers with grain-oriented, non-aging silicon steel core and continuous copper windings with ratings as follows:

- Capacity: 125% of load demand;
- Insulation Class: 220˚C;

- Temperature Rise: 80˚C at 40˚C ambient.

Provide NEMA 250 Type 2 ventilated enclosure with encapsulate core and coil to seal out moisture and air/sound level/winding taps per NEMA ST 20.

Provide K-rated transformers where required for non-linear loads with K-rating per IEEE Standard 1100.

Comply with UL 1561 and test units per IEEE C57.12.91.

C3.7.5 Panel Boards

Configure panel boards as main lug panels where directly fed from overcurrent devices.

Configure as main breaker panels where directly fed from transformers.

Do not use series ratings.

Provide panel boards as follows:

- Hard-drawn copper phase, neutral, and ground bus/bus connectors;
- Only bolt-on circuit breakers;
- Circuit breakers rated no less than calculated short-circuit current at terminals;
- NEMA 250 Type 1 panel board enclosures in general;
- NEMA 250 Type 4X in exterior areas or unheated spaces;
- Galvanized steel Type 1 enclosures with baked-on finish;
- Gutter extensions where required of same gauge and finish as panel boards;
- Continuous hinged front cover with machine-printed directory card and transparent card holder;
- Door-in-door feature for panel boards rated over 250 amps;
- Each panel with vault-type latch and tumbler locks keyed to Metrolinx RT standards;
- Two locks for panel boards taller than 1.0 m;
- 600/347V, three-phase, four-wire panel boards per NEMA PB 1 power and distribution type.

Three-phase, three-wire panel boards not allowed.

Comply with NEMA PB 1 lighting and appliance branch circuit type for 208/120V three-phase four-wire and 230/120V single-phase three-wire panel boards.

C3.7.6 Elevated Stations

Elevated Station safety considerations require higher electric system reliability.

Provide for adequate electric service loads to serve elevated Stations unlikely to require emergency ventilation now or in future.

Provide full capacity TPS service at or near elevated Stations where incoming service is inadequate.

Provide AHJ electric utility service feeders for elevated Stations without TPS at or near the Station.

Provide electric service per NFPA 130 for approach tunnels with Fire/Life Safety components or emergency ventilation systems.

See Chapter C1 – Traction Power.

Replace existing small 10kW emergency/standby generators with UPS.

Provide future Platform Edge Doors with separate UPS.

Test for salvaged useful life and existing large emergency/standby generators.

Re-use in new designs per test recommendations.

C3.7.7 At-Grade Stops

At-Grade Stop Electric Service Cabinets

Provide At-Grade Stop platforms with Electric Service Cabinets housing normal electrical distribution equipment for general lighting and backlit signage per NEMA 250 Type 4X.

Include features and capabilities as follows:

- Main Disconnect Switch;
- Electric Service Provider Revenue Meter;
- A 120/240V 24-space Main Circuit Breaker Panel;
- Two Lighting Contactors.

Coordinate revenue meters with electric service providers.

Provide street panels with unswitched circuits for normal platform loads.

Wire 120V shelter lighting, pole lighting, backlit signage, irrigation controls, receptacles, and systems cabinet loads to street panels.

Provide lighting contactors for curfew or non-curfew lighting element revenue service controls.

Provide shelter and pole lighting circuits through curfew schedule lighting contactors.

Provide backlit signage circuits through non-curfew schedule lighting contactors.

Control one lighting contactor with curfew dusk-to-dawn schedule that:

- Closes at dusk;
- Opens after revenue service has concluded for the day;
- Recloses before revenue service begins;
- Opens at dawn.

Control other lighting contactors with non-curfew dusk-to-dawn schedule that:

- Closes at dusk;
- Opens at dawn.

Provide SCADA for lighting contactors.

At-Grade Stop Systems Cabinets

Provide At-Grade Stops with Systems Cabinets serving signals, communications, fare collection, Public Address, and CCTV equipment.

Provide Systems Cabinets with open rack structures per EIA-RS-310C including:

- Rack-mounted UPS sized for signals, communications, and fare collection equipment loads meeting battery back-up requirements;
- Rack-mounted circuit breaker distribution assemblies for critical communications, signals and fare collection loads equipped with timer-interlocked main breakers;
- Rack-mounted circuit breaker distribution assemblies for non-protected loads such as cabinet heaters, smoke detectors, fans and receptacles within Systems Cabinets;

- Rack space for communications and signals equipment.

Provide circuit breaker distribution assemblies pre-wired and equipped with branch circuit breakers rated for UPS critical loads and interlocked main breaker assemblies for switching to unregulated 120/240V AC input when UPS removed for service.

Provide thermostat-controlled highly-reliable equipment cooling fans.

Provide line voltage photoelectric smoke detectors with Form C relays.

At-Grade Stop Systems Cabinets are exposed to outdoor environment.

See Chapter C4 – Heating, Ventilating, Air Conditioning.

Provide Systems Cabinet cooling analysis.

Provide fan-forced cooling to protect on-board equipment and components.

Provide natural ventilation where cooling analysis demonstrates equipment operates without failure 24/7/365 within design temperature range.

C3.7.8 At-Grade Stop Systems UPS

Provide At-Grade Stop Systems Cabinets timer circuit controlled battery backup UPS for communications, signals and fare collection equipment.

Provide required quality UPS to critical loads for durations per Table C3-1 below:

TABLE C3-1 CRITICAL LOADS FOR DURATIONS

Served UPS Application	Critical load Location	Duration
Signals	Wayside Equipment	90 minutes
	Central Equipment/OCC	180 Minutes
	Yard	90 minutes
Communications	Surface Locations	30 minutes
	Underground Stations	180 minutes
	Central	180 minutes
	Yard	90 minutes
Fare Collection	All Locations	30 minutes
Fire/Life Safety	All locations	180 minutes

Develop RAM Plan and specific RAM requirements.

Provide UPS including batteries to meet UPS specific reliability requirements as outlined in the RAM plan.

Integrate UPS equipment including batteries housed in At-Grade Stop System Cabinets as a system per environmental conditions.

See Chapter C4 – Heating, Ventilating, Air Conditioning.

C3.7.9 Maintenance and Storage Facilities

For Maintenance and Storage Facilities provide two incoming service feeders at supply voltage no less than 13.8 kV nominal three-phase, 60 Hz from TPS.

Provide each incoming service feeder circuit from separate and independent TPS MV-AC feeders electrically and physically isolated from each other.

Do not route two independent feeders in a common trench or duct.

Provide service feeders with capacity to supply 100 percent demand plus 25 percent spare for future loads.

Provide a three-phase mirrored unit substation.

Include fusible medium-voltage switches, transformers, 600/347V low-voltage main-breaker switchgear, and tie-breakers.

Designate the bus sections of mirrored substations as “Bus 1” and “Bus 2.”

Include kirk-key interlocks to ensure that main breaker for “Bus 1” and “Bus 2” cannot be closed without first closing the matching medium-voltage switch; likewise, that the medium-voltage switch cannot be opened without first opening the matching main breaker on the 600-volt side.

Size tie-breakers, buses, and mains of each “Bus 1” and “Bus 2” no less than the sum of 125% of connected loads plus two buses combined planned future loads.

Provide digital metering on the line side of each main breaker.

Provide additional circuit breakers at 600-volt switchgear “Bus 2” for future emergency generator.

Also include kirk-key interlocks to prevent emergency generator breakers and 600V main breakers simultaneous closing.

Provide space at grade to locate a future temporary emergency generator with non-fused disconnect means (400A, 600V, 3 Phase, 4 Wire) pre-wired to 600-volt switchgear “Bus 2” emergency generator breaker for quick generator connection as backup power to critical UPS and selected emergency/standby loads.

Provide a redundant three-phase double-isolation UPS.

Feed UPS from a single circuit breaker from different buses on the 600-volt switchgear.

Provide two 600:208/120 V three-phase transformers and a 208/120V switchboard equipped with two independent buses, designated as “Bus 1” and “Bus 2,” each equipped with a main breaker, and interconnected through a tie breaker.

Size tie-breakers, buses, and mains of each “Bus 1” and “Bus 2” no less than the sum of 125% connected loads plus two buses combined planned future loads.

Provide digital metering on line side of each main breaker.

Provide multiple 600:208/120V three-phase transformers and main breaker panel boards located as required for efficient secondary low-voltage distribution.

C3.8 Coordination and Load Studies

Prepare an engineering analysis on each distribution system including a short-circuit analysis with protective device evaluation, a protective device coordination study, load flow/voltage drop study, and a motor starting study.

Comply with IEEE 141.

Include time-current characteristic curves, a single-line diagram, and an analysis narrative describing system coordination, recommended ratings, and protective relay settings to maximize selectivity.

Prepare computer calculations using commercially available short-circuit and coordination software.

Provide design fault levels of 500 MVA for 13.8 kV or 800 MVA for 27.6 kV systems as applicable.

Lower fault assumptions may be used if justified by AHJ written affirmation but not less than 80 MVA.

Provide 20 MVA for platform circuits served by Operations Control Centres (OCC).

With energy information obtained from short-circuit study, perform an arc flash study to determine PPE levels for equipment identified in NFPA-70 (110.16).

Perform a load flow/voltage drop study to determine steady state load profile during full simultaneous loading plus system voltage profile transient effect analysis during motor starting conditions.

C3.9 Documentation

Provide plans and details on drawings showing physical arrangement and elevations with dimensions for major mechanical and electrical equipment, raceways, cable trays, junction boxes, and other items in sufficient detail to coordinate electrical design and construction with mechanical, architectural, structural, and other disciplines.

Provide schedules on drawings that allow easy reference of electrical information.

Provide motor and equipment schedules identifying mechanical equipment such as air conditioners, fans, escalators, elevators, and heaters.

Provide feeder schedules listing equipment served by feeders such as switchgear, condensers, transformers, switchboards, panel boards, MCC, and major mechanical equipment, particularly equipment fed from 600-volt switchgear.

Identify source and load; cable type, size, and quantity; wire management information such as conduit type and size, and plan mark or ID.

C3.10 Equipment and Materials

Provide equipment, components, and materials listed and labeled by Canadian Standards Association (CSA), Underwriters Laboratory Canada (ULC) or other testing agency acceptable to Metrolinx RT and marked for intended use.

Provide equipment and materials designed to operate under site conditions when not installed in conditioned spaces as follows:

- Altitude: 176 m Above Mean Sea Level;
- Temperature: -20˚C through +32˚C;
- Humidity: 95% with condensation.

Wire and Cable Materials:

- OESC, NFPA-70, and NFPA-130, Raceway Materials;
- OESC, NFPA-70, and NFPA-130, Wiring Devices.

Provide only heavy-duty, side-wired, non-illuminated 347V 20 Amp premium grade lighting toggle switches.

Single-pole three-way and four-way toggle switches allowed for continuously-occupied non-public areas per CSA C22.2 No. 111.

Provide dual-technology, that is, both passive infrared and ultrasonic, occupancy sensors for non-public areas not continuously occupied that automatically adjust time delay and sensitivity to accommodate changing occupancy patterns.

Provide only 125V 20 Amp premium grade CSA 5-20RA convenience duplex receptacles in public areas per CSA C22.2 No. 42.

Provide tunnel receptacles 750mm above finished walkway surface.

Provide GFCI protection per code.

Install devices in cast metal boxes 60mm minimum deep with integral grounding screws and for exposed installations threaded hubs.

Provide stainless steel device covers for flush mounted devices and cast malleable iron or weatherproof malleable iron for exposed installations.

Provide concealed and surface mounted boxes per CSA C22.2 No. 18.

Provide cabinets and enclosures not covered by C22.2 No. 18. Per CSA C22.2 No. 40.

Provide surface-mounted boxes and enclosures per NEMA 250 in these locations:

- Conditioned Spaces: NEMA 250 Type 1;
- Unconditioned Spaces: NEMA 250 Type 4X;
- Outdoor Locations: NEMA 250 Type 4X stainless steel.

C3.11 Unit Substation Switchgear

Provide equipment with busway and busway interconnections in a unit substation arrangement where a medium voltage switch, transformers, and a secondary distribution section are required.

Provide substation equipment with conveniently divided sections for ease of shipping, installation, space allocation, maintenance, and access.

C3.11.1 Incoming Medium Voltage Sections

Provide enclosed three-pole single-throw primary air-interrupter switch with manual stored-energy operator with single frame mounted fuses per IEEE C37.20.3.

Provide key-interlock equipped switches to prevent fuse access doors opening without open switch.

Provide air-interrupter switch with second interlock to prevent opening or closing without open or closed secondary main.

Provide current-limiting fuses with integral blown-fuse indicators.

Provide windows for ease of viewing switch-blade positions with doors closed.

Provide removable phase barriers between adjacent blades and fuses.

C3.11.2 Medium Voltage Transformers

Provide indoor ventilated encapsulated coil primary and secondary 23.1.1 medium voltage transformers per IEEE C57.12.01, IEEE C57.12.50, and IEEE C57.12.51.

Provide 220˚C insulation with 80˚C temperature rise at 40˚C ambient temperature.

Provide transformer units with 5% minimum impedance.

Provide transformers no less than 80% sum of demand load plus specified allowance for future growth.

Provide Class AA/FFA air-cooled transformers with future forced air rating.

Provide dry type outdoor transformers similar to indoor transformers except with outdoor enclosures per code requirements.

C3.11.3 Secondary Distribution

Provide secondary distribution buses with continuous current rating no less than sum of demand loads on connected feeders.

Where switchgear line-up includes two buses, size each bus no less than sum of both buses plus specified allowance for future growth.

Provide removable non-ferrous plates for cable connector installation with top and bottom entry only.

Provide each bus with termination lugs rated no less than main breaker for portable generator set.

Provide continuous 51 mm x 6 mm ground bus running entire length of switchgear near bottom of cabinet suitably perforated for solderless lug connectors.

Bolt equipment grounds directly to ground bus.

Provide incoming feeder cable terminations as follows:

- Standard ball-type grounding stud installed on ground bus in each incoming feeder termination compartment approximately 300 mm from compartment door;
- Standard grounding stud installed on each incoming feeder termination compartment;
- Grounding connection consisting of 75 mm long minimum ground bus with 64 mm^2 minimum clearance in cable termination compartment accessible location to accommodate ground clamp;
- Doors and instrument cover plates flexible copper braid bonding; and
- Clear permanent label indicating location of ball-type ground stud.

Provide molded case circuit breakers on secondary distribution bus to serve single motor loads (for example, fans, elevators, escalators, chillers, condensers, fan-coil units, air handlers, as well as UPS, lighting panels, and other panels serving individual loads rather than other circuit panels).

Provide draw-out circuit breakers on main breakers secondary distribution buses, tie breakers, generator breakers, MCC breakers, and distribution panel breakers serving other circuit panels.

Provide switchgear for secondary distribution bus mains less than 1,500 Amps per UL 891 with motor-operated insulated-case circuit breakers for draw-out circuit breakers.

Provide switchgear for secondary distribution bus mains 1,500 Amps and greater per UL 1558 with motor-operated metal-clad power circuit breakers for draw-out circuit breakers.

Provide metering and controls operating on 125V DC control power system.

C3.11.4 DC Charger and Batteries

Provide 125 V DC charger and batteries providing reliable power for secondary distribution bus metering and control operation.

Provide battery and charger in a single cabinet with circuit breaker distribution board and monitoring/controls specifically designed for switchgear control DC supply power.

Provide batteries and chargers sized to simultaneously trip and rewind insulated case and power circuit breakers 50 times in a 24 hour period while maintaining constant load of switchgear/switchboard meters, indicating lights, and relays.

C3.12 Lighting

LRT Systems require lighting for safe and reliable operations, security, and comfort of passengers and employees alike.

Section C3.1.28 addresses LRT facility lighting systems as follows:

- Underground Stations;
- At-Grade Stops;
- Transfer Facilities;
- Dedicated Rights-of-Way;
- Pedestrian Walkways;
- Elevated Guideways;
- Tunnels and Tunnel Ancillary Spaces;
- Parking and Roads;
- MSFs; and
- OCCs.

These criteria specifically exclude LRV lighting.

References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to:

- Ontario Building Code (OBC);
- Ontario Electrical Safety Code;
- CAN3-S157-M83: Strength Design in Aluminum;
- CSA C22.1: Canadian Electrical Code, Part I, Safety Standard for Electrical Installations;
- CSA C22.2 No. 0-M91: Canadian Electrical Code, Part II, General Requirements (Standards for Construction);
- CSA C22.2 NO 141-02 Unit Equipment for Emergency Lighting;
- CSA C22.2 No. 206-M Lighting Poles;
- CSA C22.2 No. 250 Luminaires;
- CSA C653 Optical Efficiency of Roadway Luminaires;
- CAN/CSA G164-M92 (R2003) - Hot Dip Galvanizing of Irregularly Shaped Articles;
- CSA W59-03 (R2008) - Welded Steel Construction (Metal Arc Welding);
- Transportation Association of Canada (TAC): Guide for the Design of Roadway Lighting;
- TTS 808.210 Signal Heads; Toronto Transportation Services;
- TTS 808.200 Material specification for Traffic Signal Arms, Hangers, Fittings and Hardware; Toronto Transportation Services;
- UL/ULC 467: grounding and Bonding Equipment; Underwriter Laboratories;

- UL/ULC 1029 Standard for Safety of High-Intensity-Discharge Lamp Ballasts; Underwriter Laboratories;
- UL/ULC 1598 Standard for Safety of Luminaires, Underwriter Laboratories;
- UL/ULC IEUR: Guide Information for Luminaire Poles;
- The American Association of State and Highway Officials (AASHTO) Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals;
- ASTM A48/A48M: Standard Specification for Gray Iron Castings;
- ASTM A53/A53M: Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc- Coated, Welded and Seamless;
- ASTM A325M-03: Standard Specification for Structural Bolts, Steel Heat Treated 830 MPa, Minimum Tensile Strength;
- ASTM A325M-03: Stan22-93a: Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings;
- ASTM B221: Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes;
- ASTM B26/B26M: Standard Specification for Aluminum-Alloy Sand Castings;
- ASTM-B85/B85M: Standard Specifications for Aluminum - Alloy Die Coatings;
- ASTM B241/B241M: Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube;
- ASTM D522-93a: Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings;
- ASTM D714: Standard Test Method for Evaluating Degree of Blistering of Paints;
- ASTM D1654: Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments;
- ASTM D3359: Standard Test Methods for Measuring Adhesion by Tape Test Subjected to Corrosive Environments;
- ASTM F436M: Standard Specification for Hardened Steel Washers;
- ASTM F1554 - 07a: Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength;
- ANSI/NEMA C78.1372-1996: American National Standard for Electric Lamps-70-Watt, M98 Single-Ended Metal-Halide Lamps;
- ANSI/NEMA C81.61: Electric Lamp Bases and Holder;
- ANSI/NEMA C82.4: Ballasts for High Intensity Discharge and Low Pressure Sodium Lamps;
- ANSI/NEMA C136.10: Standard for Roadway Lighting Equipment, Locking-Type Photo Control Devices;
- ANSI/NEMA C136.14: Standard for Roadway Lighting, Enclosed Side-Mounted Luminaires for Horizontal Burning High Intensity Discharge Lamps;
- ANSI/NEMA C136.15-2009: American National Standard for Roadway and Area Lighting Equipment-High-Intensity Discharge (HID) and Low-Pressure Sodium (LPS) Lamps in Luminaires-Field Identification;

- ANSI/NEMA C136.22-2004(R2009): American National Standard for Roadway and Area Lighting Equipment-Internal Labeling of Luminaires;
- ANSI/NEMA C136.31: Standard for Roadway Lighting Equipment Luminaire Vibration;
- CIE 171-06 Test Cases to Assess the Accuracy of Lighting Computer Programs, Commission Internationale de L'Eclairage;
- IEC 60529: Degrees of protection provided by enclosures (IP Code);
- IEC 50529: Classifications of protection provided by enclosures (IP Code);
- IEC 60598: Degrees of Protection provided by Enclosures for Luminaires (IP Code);
- ISO 7415:1984: Plain washers for high-strength structural bolting, hardened and tempered;
- Lighting Handbook Reference and Application, 10th Ed: Illumination Engineering Society of North America (IESNA);
- IESNA RP-8-00 (R2005): American National Standard Practice for Roadway Lighting;
- IESNA RP-16-96: Nomenclature and Definitions;
- IESNA LM-31-95: Photometric Testing of Roadway Luminaires Using Incandescent Filament and High Intensity Discharge Lamps;
- IESNA LM-50-99: Photometric Measurements for Roadway Lighting Installations;
- IESNA LM-63-95: Standard file format for Electronic Transfer of Photometric Data;
- NEMA C82.4 -2002: American National Standard for Ballasts for High-Intensity Discharge and Low-Pressure Sodium (LPS) Lamps (Multiple-Supply Type);
- NEMA: Standards for Tubular Steel, Aluminum and Pre-stressed Concrete Roadway Lighting Poles;
- NEMA 250: Enclosures for Electrical Equipment;
- National Fire Protection Association (NFPA) 130: Standard for Fixed Guideway Transit and Passenger Rail Systems;
- NFPA 70: National Electrical Code; NFPA 101: Life Safety Code;
- NFPA 110: Standard for Emergency and Standby Power Systems; U.S. Green Building Council Leadership in Energy and Environmental Design (LEED) – EB-08.

OBC governs where conflicts arise unless otherwise stated.

C3.12.1 Coordination

Coordinate lighting levels in areas with CCTV cameras so that lighting levels match camera sensitivity.

Coordinate disciplines to avoid interference with physical elements such as ductwork, fire protection piping and components, communications conduit, ducts, and other similar physical elements.

Coordinate disciplines to make provisions for anticipated future equipment including but not limited to variable message signs and advertising signs.

Provide electrical distribution capacity, space for future circuit breakers, and rough-in conduit to future equipment locations.

Plan rough-ins to avoid surface-mounted conduit in future.

Metrolinx RT anticipates that other AHJ may ultimately maintain certain lighting elements.

Meet AHJ design and equipment standards insofar as they do not conflict with these criteria.

Incorporate AHJ standard details and specifications to maintain Metrolinx RT lighting equipment.

C3.12.2 Performance Criteria

Lighting Classification

Classify lighting systems as Normal Lighting or Emergency Lighting as follows:

Normal Lighting:

Lighting that can tolerate occasional prolonged interruptions (greater than 10 seconds).

Subject to other criteria, there are no limitations.

Normal Lighting examples include:

- Underground Station Lighting;
- Elevated Station Lighting;
- At-Grade Stop Lighting;
- Tunnel Lighting;
- Parking and Roadway Lighting;
- At-Grade Pedestrian Walkway Lighting;
- Advertising Signs.

Emergency Lighting:

Lighting that cannot tolerate prolonged interruption (greater than 10 seconds).

Emergency Lighting examples include:

- Emergency Station Lighting;
- Emergency Tunnel Lighting;
- Emergency Exit Signs;
- Escalator Comb and Newel Lighting.

Minimum Illumination Levels

Table C3-2 identifies LRT elevated, underground and at-grade passenger facility illumination levels.

Table C3-3 identifies other LRT function illumination levels.

Illumination levels are minimum average maintained horizontal illumination in lux unless noted otherwise.

Areas of Convergence

Provide lighting systems to accommodate pedestrian and vehicle circulation patterns paying particular attention to decision points, conflict areas, and elevation or environment changes including:

- Escalator, Stair, and Elevator Landing Areas;
- Ramps;
- Tunnel Crossovers;
- Platform Edges;
- At-Grade Stop Boarding/Alighting Areas;

- Fare Collection Areas;
- Station Entrances and Exits;
- Portals;
- Roadway Intersections and Crosswalks.

Provide lighting level contrast to distinguish these areas from surrounding areas.

See Tables C3-2 and C3-3 for conflict area and decision point enhanced illumination levels.

Station Entrances

Emphasize Station entrances and signage with enhanced Illuminate levels.

Shield and aim exterior lighting downward to reduce glare and avoid light trespass to adjacent areas.

Station Interior Spaces

Provide Station interior lighting to be appealing and provide position and orientation awareness.

Consider actual materials and colors accounting for wall, ceiling, and floor light reflection.

Provide public area lighting to assist passengers visually along preferred circulation paths.

Emphasize system graphics, information messages, and fare collection equipment.

Direct passengers to circulation elements leading to platforms.

Clearly illuminate platforms to produce an environment enhancing the ability to detect, recognize, and identify persons, objects, and events.

Pay particular attention to color and contrast.

Provide platform edges with higher intensity illumination than waiting areas to emphasize transition between Station and LRV.

Minimize track area lighting to highlight contrast with platform edges.

Illuminate artwork sufficiently without compromising safety, maintenance, and security.

Provide DWA with higher Illumination levels than general waiting areas.

Provide and locate luminaires to minimize passenger and CCTV camera glare.

Provide accent lighting to eliminate dark ceiling areas and enhance spatial recognition.

Landscape Lighting

Integrate and coordinate landscape lighting with feature planting.

Shield and generally beam downward landscaping luminaires.

Aim luminaires into planting materials to preclude light trespass beyond where up-lighting for proper visual effect is required.

Provide landscape lighting and controls considering plant foliage seasonal effects.

Illuminated Signage

Provide lighting with normal power supply to emphasize information and directional signage.

Illuminate signs and graphics internally or externally.

Provide exterior at-grade exit and Station identification sign lighting with emergency power supply.

Provide designated advertising sign areas with normal power supply electric receptacles.

Underground Tunnel Lighting

Provide illumination sufficient for maintenance access and safe/secure emergency egress per NFPA 130.

Mount safety luminaires to direct light down from horizontal and away from approaching LRV.

Select, locate, aim, and shield luminaires to preclude interference with LRV signals.

Provide threshold, transition, and interior tunnel lighting.

Provide higher illumination levels for tunnel portal threshold transition zones in daylight periods and lower illumination levels in darkness periods.

See Table C3-3.

Provide intermediate lighting levels half the intensity of daylight levels during twilight hours as a transition between ambient daylight and darkness.

Provide light level sensors and controls for appropriate lighting levels and to preclude flicker.

Directly feed tunnel luminaires as critical loads by mini-subs from panels fed by redundant and UPS.

Provide tunnel area flicker analyses using LRV speed/distance graphs.

Space tunnel luminaires so that LRV operators traveling at constant speed do not observe flicker between 4 and 11 hertz for 20 seconds or longer.

Elevated Guideways

Provide safety luminaires directing light downward from horizontal and away from LRV direction of travel.

Select, locate, aim, and shield luminaires to preclude interference with signals.

Provide illumination along elevated guideway pedestrian walkways.

Provide and mount guideway luminaires to minimize light pollution and trespass.

Provide illumination under elevated guideways for public-access pedestrian walkways and vehicle roadways.

Locate luminaires to minimize shadows in public access areas.

Illuminate emergency access/egress stairs leading to grade.

Provide circuits to emergency power.

At-Grade Stops

Provide At-Grade Stop interior lighting to be appealing and provide position and orientation awareness.

Clearly illuminate platforms to produce an environment enhancing the ability to detect, recognize, and identify persons, objects, and events.

Pay particular attention to color and contrast.

Provide public area lighting to assist passengers visually along preferred circulation paths.

Emphasize system graphics, information messages, and fare collection equipment.

Direct passengers to circulation elements leading to platforms.

Provide platform edges with higher intensity illumination than waiting areas to emphasize transition between Station and LRV and assist passengers in boarding and alighting.

Consider actual materials and colors accounting for wall, ceiling, and floor light reflection.

Minimize track area lighting to highlight contrast with platform edges.

Provide and locate luminaires to minimize light pollution and passenger/CCTV camera glare.

Roadways

Provide economically-spaced, pole-mounted luminaires on outside edges of roadways, traffic islands, and median barriers for uniform pavement illumination and sufficient area illumination reasonably free of glare.

Provide visibility levels enabling LRV operators, motorists, and pedestrians to see significant roadway details such as road alignment, direction, surroundings and obstacles on or about to enter the roadway quickly, distinctly, and with certainty.

Provide enhanced lighting to alert drivers approaching intersections.

Provide enhanced lighting at traffic areas with increased collision potential, e.g., intersections, merges, and crosswalks, per TAC and IESNA RP-8-00.

Pedestrian Walkways

Pedestrian walkways may be street sidewalks addressed by roadway lighting or independent pathways.

Provide economically-spaced, pole-mounted luminaires for safe and secure pedestrian walkways.

Minimize maintenance, exposure to vandalism, and interference from foliage/tree growth.

Provide enhanced pedestrian illumination in commercial areas with night-time pedestrian activity.

Provide enhanced high contrast pedestrian illumination at conflict areas (for example, traffic intersections and crosswalks, for easy recognition by LRV operators and motorists).

Provide pedestrian walkway illumination per TAC and IESNA RP-8-00.

Provide pedestrian luminaires and poles aesthetically compatible with roadway luminaires and poles in the same Rights-of-Way.

Locate pedestrian and roadway luminaires on the same poles wherever possible.

C3.12.3 Illumination Quality

Consider lamp life, lumen depreciation, color rendering, glare, and total light distribution as factors affecting illumination quality per Transportation Association of Canada (TAC).

Veiling Luminance (Glare)

Position overhead luminaires to minimize veiling luminance or use luminaires with appropriate intensity distribution so that most light passes in front of and across the observer perpendicular to direction of view thus minimizing specular reflection.

Improve lighting quality by reducing veiling luminance and increasing contrast for increased visual performance.

Pursue higher contrast up to maximum attainable levels to achieve greater percentage performance improvements as a function of illuminance.

Provide luminaires directing most light below the horizontal plane in direction of work plane to reduce connected load as an added benefit.

Lamp Colour

Provide better color-rendering lamps for improved close visual clarity where allowable light power densities are limited.

High pressure sodium with poor color-rendition may be acceptable on roadways and parking areas, but avoid at passenger/pedestrian walkways for better facial recognition and close visual acuity.

Light Trespass

Position outdoor luminaires to minimize glare to LRV operators, motorists, and adjacent properties, particularly in residential areas.

Strategies for minimizing light trespass include:

- Careful selection of optical distribution;
- Cutoff optics;
- House-side shields.

See TAC or IES TM-11-00 for environmental zone requirements.

C3.12.4 Energy Conservation

Achieve lighting energy conservation by jointly reducing power input and hours of use.

Minimize hours of use by optimized switching, automatic controls, and advantageous use of daylight.

Reduce power input by selecting the most energy efficient lamp and luminaire for the application.

See the LEED certification system for a framework to identify and implement practical and measurable green building design, construction, operations and maintenance solutions.

Automatic Lighting Controls

Lighting controls are devices for turning on/off and dimming lights.

Consider automatic lighting controls wherever practical for selecting various arrangements.

Provide control strategies based on types of security lighting as follows.

Continuous Lighting:

Continuous Lighting illuminates an area during combined hours of darkness and hours of operation, e.g., at-grade Stops, platforms, LRV approaches, and parking lots.

Suitable Continuous Lighting controls include timers and photo sensors.

Standby Lighting:

Standby Lighting is similar to Continuous Lighting but does not operate continuously.

Standby Lighting turns on automatically when area activity is detected or manually as necessary by someone to occupy a space.

Standby Lighting is suitable only for “instant on” lamps.

Standby Lighting includes, for example, utility closets, offices, and wash rooms.

Suitable Standby Lighting controls include discrete on/off switches, occupancy sensors, and dimmers.

C3.12.5 Documentation

Provide plans and details indicating physical arrangements of luminaires, poles, circuit panels, and controllers such as contactors, motion sensors, timers, photocells, and other items.

Coordinate with architectural, structural, mechanical, electrical, and other disciplines.

C3.13 Equipment and Materials

C3.13.1 General Requirements

A system-wide standard approach to lighting promotes cost-effective procurement of lamps, luminaires, and ancillary equipment while simplifying installation, repair, maintenance, and replacement.

Provide a high degree of lighting component standardization to achieve consistency of lighting levels and appearance throughout an LRT system.

Provide standard lamps and luminaires to achieve system-wide design and perceptual unity and simplify maintenance to the maximum extent practical.

Provide equipment, components, and materials marked for its intended use, listed and labelled by the Canadian Standards Association (CSA), Underwriters Laboratory Canada (ULC), or other testing agency acceptable to Metrolinx RT.

Provide materials and equipment not installed in conditioned spaces to operate in site conditions as follows:

- Altitude: 176 m AMSL;
- Temperature: -20 thru +32 degrees C;
- Humidity: 95% with condensation;
- Voltage Variation: +/-10% of nominal.

Comply with Canadian Electrical Code Parts I and II, and Ontario Electrical Safety Code.

C3.13.2 Lamps

Lamps Not Allowed

For maximum lamp life and minimum energy consumption, end-of-life issues, and hazardous waste, lamps not allowed include:

- Incandescent lamps;
- T12 fluorescent lamps;
- Low pressure sodium lamps of any kind;
- Mercury vapour lamps of any kind.

C3.13.3 Luminaires

Provide luminaires on the basis of physical characteristics, photometric performance, intended lamp, color, color rendering index, lamp life, first cost, and maintenance costs.

Minimize types of luminaires system-wide.

Provide lighting equipment in continuous production for a minimum of five (5) years that is durable and easily maintained for the life of a facility and with documented proven track record of five (5) year availability so that maintenance parts are available in future.

Platform Edge Luminaires

Provide platform-edge luminaire features as follows:

- Continuous row-mounted gasketed and enclosed fluorescent fixtures;
- Housings of heavy-gauge, continuously-welded, 316 stainless steel with knockouts for linear, continuous row mounting, rated IP-65 per IES 60529 for covered ceiling- or wall-mounting;

- Lenses of UV-resistant pearlescent polycarbonate or DR impact-grade acrylic with continuously hinged lens housings;
- Two TLCP-compliant T8 linear fluorescent lamps per housing;
- Electronic Ballasts with less than 10% Total Harmonic Distortion.

Designated Waiting Area Luminaires

Provide platform DWA luminaire features as follows:

- Ceiling recessed lens down high pressure sodium light fixtures;
- Housings of die-cast aluminum with white powder coat finish, square and gasketed;
- Lenses of spun aluminum with regressed splay trim, white Fresnel type;
- 100-watt pulse-start high pressure sodium lamps;
- ANSI S54 type ballasts.

Tunnel Luminaires

Provide tunnel luminaire features as follows:

- Single open strip fluorescent fixtures;
- Housings of heavy-gauge, continuously-welded, 316 stainless steel, rated IP-65 per IES 60529 and covered ceiling- or wall-mounting;
- Lenses of clear, shatterproof fluorescent tube sleeve;
- TLCP-compliant T8 or T5 linear fluorescent tube lamps;
- Electronic ballasts with less than 10% Total Harmonic Distortion.

Pole Luminaires

Provide street and pedestrian pole luminaire features as follows:

- Flat-glass, full-cutoff roadway or pedestrian luminaires;
- Housings of polyester powder-coated die-cast aluminum with stainless steel bail latch rated IP-66 per IEC 60529;
- Custom arms of 6063-T6 aluminum tubing subject to Metrolinx RT review and acceptance;
- Lenses of removable tempered flat glass;
- TLCP-compliant high-pressure sodium and pulse-start metal halide ET-18 lamps;
- Optical Reflectors with cutoff classification and Type II or Type III distribution;
- Constant wattage isolated autotransformer type ballasts designated for -40°C exterior environment with swing-down access and positive-locking disconnect plugs for ease of maintenance per NEMA C82.4 and UL 1029;
- NEMA Wattage Label per ANSI C136.22 for inside and ANSI C136.15 for outside luminaires;
- Fuse protection per ballast manufacturer recommendation.

See Figures 21-1 through 21-8 for luminaire aesthetics subject to Metrolinx RT review and acceptance.

Submit alternative luminaires for Metrolinx RT review and acceptance of aesthetic appearance, durability, maintainability, performance and energy efficiency.

Provide pedestrian walkway pole-mounted luminaires per additional requirements as follows:

- 100-watt high pressure sodium lamps;
- ANSI S54 type ballasts;
- Luminaire mounting positions 760mm from centre of pole 5.2 m above finish grade.

At-Grade Stop Platform Luminaires

Provide at-grade Stop platform luminaire features as follows:

- 150-watt pulse-start metal-halide lamps;
- ANSI M102 type ballasts;
- Luminaire mounting positions 760 mm from center of pole 5.2 m above finish grade.

See Figures 21-1 through 21-8 for at-grade Stop platform luminaire aesthetics.

Street Lighting Luminaires

Provide street lighting luminaire features as follows:

- 250-watt high pressure sodium lamps;
- ANSI S50 type ballasts;
- Luminaire mounting positions 3m from center of pole 7.8m above finish grade.

See Figures 21-1 through 21-8 for street lighting luminaire aesthetics.

C3.13.4 Pole Assemblies

Provide continuously-extruded aluminium special shape pole shafts with cast-aluminium base plates.

Provide poles one dovetail anchor channel on each side to conceal continuously-adjustable locking brackets supporting arm-mounted luminaires, banners, planters, and other elements along the entire height of shaft.

Attachment provisions of wraparound collars or strapping devices are not allowed.

See Figures 21-1 through 21-8 for pole shaft aesthetics.

Final pole configurations subject to Metrolinx RT review and acceptance.

Provide nominal pole assembly heights as follows:

- Heavy Duty Signal Poles: 9.2 m;
- Light Duty Signal Poles: 6.1 m;
- Pedestrian/Stop Light Poles: 5.2 m;
- Roadway Light Poles: 7.8 m.

Provide aluminium shafts per ASTM B221 6061-T6.

Provide cast aluminium mounting bases per ASTM B26 356.

Provide single pole mounting base plates 470 mm maximum diameter.

Offset reinforced hand holes 460 mm above pole base 90 degrees from luminaires.

Conceal lower pole shaft 2.3 m above base plate with cylindrical, two-piece decorative sleeves and integral top transition compatible with complex pole cross-sections.

Provide captive retaining hardware for decorative sleeves to secure the two halves in the field.

Submit alternative pole designs for Metrolinx RT review and acceptance of aesthetic appearance, durability, and maintainability.

Provide strength analysis to determine adequacy of each pole to resist wind load stresses without failure, permanent deflection, or whipping in steady wind speeds per Ontario Building Code.

Include Equivalent Projected Area of each pole, mast arm, signal arm, signal, luminaire, and field modifications such as cladding, shrouds, and banners.

In maximum wind loading calculations include elements in addition to arm-mounted luminaires as follows:

Roadway and Pedestrian Lighting Poles

- Two arm-mounted planters, each weighing 45 kg, extending 760 mm from centerline of pole shaft;
- Two banners comprising two arms, each supporting a 760 mm wide by 920 mm high flexible air-flow sign and each extending 760 mm on opposite sides of pole shaft;
- Calculate worst case relative orientation of banners and planters;
- One arm-mounted roadway luminaire;
- One arm-mounted pedestrian luminaire;
- Two CCTV Cameras.

Special consideration: Coordinate strength analysis with enhanced stiffness as may be required for pole-mounted CCTV cameras.

Heavy Duty Signal Poles

- One Pedestrian/Traffic signal device per TTS 808.210;
- One Traffic signal with arms, hangers, fittings and hardware per TTS 808.200;
- Two Medium-sized fixed directional/information signs per TTS 808.210;
- Two CCTV Cameras.

Special consideration: Coordinate strength analysis with enhanced stiffness as may be required for pole-mounted CCTV cameras.

Light Duty Signal Poles

- One Pedestrian/Traffic signal device per TTS 808.210;
- One Traffic signal arms, hangers, fittings and hardware per TTS 808.200;
- Two CCTV Cameras.

Special consideration: Coordinate strength analysis with enhanced stiffness as may be required for pole-mounted CCTV cameras.

Maintain minimum horizontal pole distances from surface and underground features as follows:

- Fire Hydrants and Storm Drainage Piping: 1.5 m;
- Water, Gas, Electric, Communication, and Sewer Lines: 3 m;
- Trees: 5m from trunk.

Provide concrete pole foundations including reinforcement and anchor bolts for wind and gravity loads.

Provide high-strength galvanized GR 55 steel anchor bolts and hardware per ASTM F1554.

Provide pole manufacturer steel templates.

Mount poles with levelling nuts.

Tighten top levelling nuts to pole manufacturer recommended torque level.

Grout void between pole base and foundation with non-shrink or expanding concrete grout.

Provide base cover or shroud.

Provide grout drain holes with above-grade 13mm FRE conduit to drain condensation from interior of poles.

Provide equipment grounding conductor bonding pole to equipment ground bar in source circuit panel.

Local ground electrodes or grounding rods not allowed.

C3.13.5 Exit Signs

Provide interior space exit signs per NFPA 101 and OBC.

Provide Station and interior space exit signs per OBC.

Tritium non-electric exit signs not allowed.

C3.13.6 Exit Lighting

Provide evacuation routes with 10 lux minimum illumination levels per NFPA 101 and OBC including evacuation routes off platform ends.

Elevated guideways and trainways beyond platform ends are areas of safety.

Directly feed tunnel exit signs as critical loads by mini-subs from panels fed by redundant and UPS.

Directly feed non-tunnel exit signs as critical loads from panels fed by redundant and UPS.

C3.13.7 Security Lighting

See Table C3-4 for security lighting illumination levels related to access management per IESNA G-1-03, Guideline for Security Lighting for People, Property, and Public Spaces.

TABLE C3-2 STATION AND STOP ILLUMINATION LEVELS

Illumination for Stations at Floor Level	Criteria Level (lux)
Every Station	
Platform edge (not at-grade stops)	220 (1)
Passageways Enclosed	110
Stair and Escalator Landings	220
Stair and Escalator Treads	110 (1)
Faregates	220
Fare Vending and Validator	220 (2)
Electric, Communications and Signal Rooms	550
Utility Closets, Other Non-Equipment Rooms	220
Toilets	220
Underground Stations	

Illumination for Stations at Floor Level	Criteria Level (lux)
Platform Open to Vault Above	110
Designated Waiting Areas (DWA)	220
Mezzanine	110
Platform Under Mezzanine	110
Station Entrances (within 10 m of entrance)	33
Elevated Stations	
Platform (Under Canopy)	110
Platform (Outside Canopy)	110
At-Grade Stops	
Shelters	55
Platform edge (not underground Station s)	110
Pedestrian Entrance	110

1. Illumination level is minimum maintained point, not average.
2. Illumination level is vertical.

TABLE C3-3 EXTERIOR AND TUNNEL ILLUMINATION LEVELS

Illumination at Floor Level	Criteria Level (lux)
Tunnels	
Passenger Emergency Egress (on tunnel walkway)	2.7(1)
Tunnel Interior Zone	10
Tunnel Transition Zone (day)	20 (2)
Tunnel Threshold Zone (day)	400 (2)
Tunnel Portals (night)	10
Tunnel Cross Passage	15
Ancillary Rooms	110
Ventilation Shaft	25
Emergency Exitway from Tunnel	50
Firefighter Access	100
Elevated Guideway	
Elevated Walkways	10(1)
Guideways At Grade	
Shared Roadways	(3)

Illumination at Floor Level	Criteria Level (lux)
Dedicated Rights-of-Way	22
Yards and Shops	
Yards	33
Vehicle Storage	33
Track Switch Area	50
Shop Areas	550
Roof Access Platforms	550
Shop Pit Areas	1100
Shop Storage Areas	300
Office Areas (ambient with additional task lighting)	300
Illumination for Exterior and Tunnels	**Criteria Level**
Parking	
Parking Lots	33
Parking Structure: Parking Vestibules, Ramps, and Comers	110
Parking Structures: Covered Decks	55
Parking Structures: Roof Decks	33
Miscellaneous	
Pedestrian Walkways	33
Kiss & Ride (areas not elsewhere defined)	33
Pedestrian Bridge	33
Pedestrian Tunnel	44
Roadway Lighting (public right-of-way)	(3)
Sidewalks Adjacent to Roadway	
• high nighttime pedestrian traffic	22 (4)
• moderate nighttime pedestrian traffic	11 (4)

1. Illumination level is minimum maintained point, not average.
2. Night time illumination level in tunnel is 10lux.
3. Comply with illuminance criteria for roadway lighting in IESNA RP-8-00, Subsection 3.1.
4. Comply with recommended illuminance criteria in IESNA RP-8-00, Tables 5, 6, and 7 for pedestrian walkway lighting in conflict areas.

TABLE C3-4 SECURITY LIGHTING ILLUMINATION LEVELS

Security/Access Management Illumination Levels on the Ground	Criteria Level (lux)
Perimeter Fence	5
Guard/Gate House (Interior Dimmable)	300
Entrances/Active/Vehicular Gates, Search Areas	100
Inactive Gates	50

FIGURE C3-1 STREET/PEDESTRIAN LIGHTING SYSTEM (NOT TO SCALE)

FIGURE C3-2 PED/STOPS LUMINAIRE/ARM (NOT TO SCALE)

FIGURE C3-3 STREET LUMINAIRE/ARM (NOT TO SCALE)

FIGURE C3-4 STREET SIGNAL/LIGHTING SYSTEM (NOT TO SCALE)

FIGURE C3-5 STREET SIGNAL/LIGHTING SYSTEM (NOT TO SCALE)

FIGURES C3-6, 7 AND 8 PEDESTRIAN SIGNAL/LIGHTING SYSTEM (NOT TO SCALE)

C3.14 Enclosed Switches

Provide heavy duty, single-throw safety switches for each motor load per UL 98 and NEMA KS 1.

Molded-case switches allowed for non-motor loads per Electrical Identification criteria and UL 489.

Provide NEMA 250 Type 1 switch enclosures for conditioned spaces.

Provide Type 4X stainless steel switch enclosures for exterior locations, unconditioned tunnel areas and ancillary rooms.

C3.15 Variable Frequency Drives

Provide factory-packaged Variable-Frequency Drive (VFD) power converters comprising 12-pulse rectifier, DC bus and Insulated Gate Bipolar Transistor/Pulse Width Modulated inverter with integral disconnect/over-current/over-load protection.

Perform harmonic analysis studies for each VFD application and provide input line conditioning based upon those studies to limit Total Demand Distortion and Total Harmonic Distortion.

Provide only cable specifically rated to accommodate corona effects, common-mode noise/radiated emissions, and VFD output circuit localized overheating.

Do not exceed manufacturer maximum installed circuit length.

Provide output line conditioning based on manufacturer recommendations.

Do not oversize output filtering thus reducing VFD efficiency.

Provide remote unitized VFD drives instead of MCC-mounted equipment where VFD drives installed in central MCCs cannot be achieved without exceeding manufacturer maximum installed circuit lengths.

Provide VFDs remote fed from MCCs through fully-rated MCCB feeder tap units.

Provide NEMA 250 Type 1 unitized VFD enclosures for conditioned spaces.

Provide Type 4X stainless steel enclosures for exterior locations, unconditioned tunnel areas and ancillary tunnel rooms.

C3.16 Reduced Voltage (Soft) Starters

Provide factory-packaged solid-state reduced voltage “soft” starters for smooth step-less acceleration and deceleration to eliminate high inrush current and damaging mechanical torque on startup and minimize mechanical wear on stopping for three-phase motor loads over 25hp identified for control as a VFD.

Provide units with integral disconnect/overcurrent/overload protection.

C3.17 Motor Control Centers

Consolidate motor controllers into one or more MCC.

Configure MCC as main lug panel where fed directly from an overcurrent device located in same room.

Configure MCC as main breaker where fed directly from a transformer or from an overcurrent device in a different room.

Determine overhead or underground routing of MCC mains cabling.

Provide MCC cabinet and mains correctly reflecting mains cable entry points.

Provide non-plated copper vertical and horizontal bus rated for short-circuit currents as determined in short-circuit study.

Provide only Motor Circuit Protector disconnect means and solid state or bimetallic overload on individual full-voltage motor controllers.

Provide MCCs with Type C Class I control wiring.

C3.18 Wayside Traction Power Inverter

Provide ruggedized DC-AC inverter producing pure sinewave 120V 60 Hz from OCC 750V DC traction power

Provide weather-resistant cover and adjacent circuit breaker with weather boot for each receptacle.

Instrumentation:

- Analog ammeter;
- Analog voltmeter;
- Status light indicating inverter “on” condition.

Alarms:

- Major and minor alarm form “C” contacts;
- Major alarm signifies condition where unit has or is about to shut-down;
- Minor alarm signifies condition that if allowed to persist may trigger major alarm, or condition requiring service or other maintenance.

C3.19 Installation

Electric Equipment Identification

Provide asset numbered tags on switchgear, switchboards, panel boards, MCCs, transformers, contactors, disconnects, transfer switches, and generators.

Obtain Metrolinx RT guidance on asset numbers.

Grounding Electrodes

Bond ground rods, structural steel, cold water service pipe, and Ufer concrete-encased grounding electrodes to facilities electrode systems.

Avoid natural gas piping and pipe connected to an active cathodic protection system.

Provide at least one test well near the service entrance of each Station or facility consisting of a ground rod driven through a hole drilled in the bottom of a hand hole.

Provide exothermic welds for bonding and grounding connections in soil or below-grade unconditioned spaces.

Provide Ufer grounds consisting of 6m coil #4 AWG (25 mm^2) minimum bare copper conductor on each side of side-platform Station tracks.

Extend Ufer grounds to structure ground electrode system with same size conductor as Ufer ground.

Provide grounding electrodes in hand holes and maintenance holes.

Provide ground rod and #1/0 AWG (53 mm^2) grounding electrode conductor.

Bond exposed metal parts with #4 AWG (25 mm^2) insulated copper conductor.

Test and report ground electrode systems per IEEE 81 Equipment Grounding

Provide insulated equipment grounding conductors with feeders and branch circuits.

Do not use raceways as sole equipment grounding path.

Provide equipment grounding conductors sized per OESC.

Provide equipment grounding conductors re-sized to reduce voltage drop to circuit conductors.

Provide equipment grounding conductors for duct-mounted electrical devices operating at 120V and more. Bond conductors to air ducts and connected metal piping.

Provide separate insulated equipment grounding conductors for each electric water heater and heat trace cable. Bond conductors to heater units, piping, connected equipment, and metal components.

Provide equipment grounding conductors to each light standard and shelter.

Do not substitute ground electrodes for equipment grounds.

Provide separate grounding per TIA/ATIS J-STD-607-A in addition to grounding and bonding per OESC.

Provide radial grounding systems at each Station or facility as follows:

- Single 750 KCmil riser conductor on multi-level Stations and facilities, or one on each side of side platform tracks;
- Tap multiple 250 KCmil floor bus conductors on each level;
- Single 250 KCmil floor bus conductors on single-level Stations and facilities, or one on each side of side platform tracks.

Signal System Grounding

Provide properly grounded signal equipment and cables for electrical noise shielding and electronic equipment voltage stabilization.

Provide grounding and grounding resistances per IEEE Standard 142 - Recommended Practice for Grounding of Industrial and Commercial Power Systems, OESC, and other applicable codes.

Provide grounding and grounding resistances for computer, microprocessor interlocking, and electronic signal control equipment per signal system supplier recommendations and requirements.

Provide ground fault detection monitoring outgoing ungrounded power and critical supply power with ground fault alarms reported to OCC.

Provide signal equipment grounding protection taking into account OCS.

Signal System Lightning Protection

Provide lightning and surge protection effective in protecting power supplies and equipment from damage and malfunction.

Provide as many types, stages, or layers of protection needed to protect each circuit and equipment type.

Provide effective internal and separate external surge protection for every electronic and solid state device.

Incorporate latest concepts and practices in addition to levels of protection to minimize lightning and other surge effects including, e.g., running grounding cables separately and with as few bends as possible, etc.

C3.19.1 Wire and Wire Management

Provide raceway and tray system penetrations so as not to degrade wall, floor, or roof structural strength, fire resistance ratings, or water tightness.

Do not exceed equivalent of three quarter-bends in a continuous conduit run without a pull box, condulet, hand hole or service hole.

Conceal public space conduit to maximum extent possible in masonry or concrete or shield and blend with the architecture.

Provide raceways for future wiring not installed in initial build out to accommodate projections from architecture, landscape architecture, traction power, signals, communications, fare collection, and other systems that may require additional raceways.

Provide 30 percent space capacity in raceways to be available after commissioning.

Provide extra capacity available as empty raceway and not as spare raceway space except for wire ways and cable trays.

Provide separate raceway systems to segregate voltage level service, classification, or duty wires and cables.

Where space does not allow segregation provide galvanized steel isolation barriers between each service for different service cables in same wire way or cable tray.

Segregate emergency circuits from other circuits.

Segregate fire alarm initiating and signal circuits or other life safety circuits in red-painted conduit, boxes, and fittings.

Arrange conduit systems self-draining into non-critical locations and never into equipment.

Provide cable trough as required along track bed in non-public areas with trough and cover structural load ratings sufficient to prevent deformation under expected traffic conditions.

Provide duct bank for service entrance conductors from either TPS or AHJ utility service provider.

Rebar between ducts within concrete containment envelopes are not allowed.

Slope duct banks 1/300 for drainage.

Identify underground line locations with 103mm wide PVC marker tape installed 450mm above top of duct bank, direct buried cable, or conduit per ANSI Z535.1 through ANSI Z535.5 with color and printing as follows:

- Direct-Buried Power Conduits: Red-Colored tape inscribed ELECTRIC LINE;
- Duct banks: Red-Colored tape inscribed ELECTRIC LINE, HIGH VOLTAGE and with red color pigment in top of duct bank concrete pour;
- Direct-Buried Systems Conduits: Orange-Colored tape inscribed:
  - Telephone Cable;
  - Communications Cable;
  - Signal Cable;
  - Train Control; or
  - Fibre Optic Cable.

C4 Heating, Ventilating, Air Conditioning

C4.1 Introduction

Chapter C4 addresses design criteria for Metrolinx Light Rail Transit (LRT) Heating, Ventilating, and Air Conditioning (HVAC) systems.

HVAC systems control temperature, air velocity, air pressure change rates, dust, odors and noise providing acceptable environment comfort levels for normal, congested, and emergency LRT system operations.

C4.2 Scope

These criteria address LRT system facilities HVAC functional, operational, and control requirements for:

- Maintenance and Storage Facilities (MSFs)
- Operation Control Centres (OCCs)
- Traction Power Substations (TPSs)
- Stations and Stops
- Ancillary Spaces
- Tunnels

See Chapter A2 – Light Rail Vehicles for Light Rail Vehicle (LRV) HVAC requirements.

See Chapter A3 – Safety and Security, Chapter C1 – Traction Power, and Chapter C2 – Communications and Control for related HVAC criteria.

C4.3 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

HVAC specific references include but are not limited to:

- Ontario Building Code (OBC);
- Ontario Fire Code (OFC);
- Occupational Health and Safety Act (OHSA) – Regulation 851, Industrial Establishments;
- Ontario Ministry of Labour (MOL) Engineering Data Sheet – Garage Ventilation;
- Ontario Ministry of Environment Standards on Sound Control Guidelines and Polices;
- Technical Standards and Safety Authority (TSSA);
- Canadian Standards Association (CSA);
- Ontario Electrical Safety Code (OESC);
- Canadian Electrical Code (CEC);

- Model National Energy Code for Buildings (MNECB);
- NFPA 130: Standard for Fixed Guideway LRT and Passenger Rail Systems;
- NFPA 259: Standard Test Method for Potential Heat of Building Materials;
- NFPA 70E: Standard for Electrical Safety in the Work Place;
- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE);
- Sheet Metal and Air-Conditioning Contractors' National Association (SMACNA);
- American Conference of Governmental Industrial Hygienists (ACGIH) Industrial Ventilation Manual of Recommended Practice;
- American Society for Testing and Materials (ASTM);
- Underwriters' Laboratories (UL) & Underwriters' Laboratories of Canada (ULC).

OBC governs where conflicts arise unless otherwise stated.

C4.4 Functional Requirements

MSFs include HVAC for offices, employee areas, shops and yard rooms, and occupied spaces.

OCCs include HVAC for offices, employee areas, operations control rooms, computers, and miscellaneous electronics equipment rooms.

TPSs include HVAC for structures and rooms not included in system-wide contracts.

See Chapter C1 – Traction Power for TPS HVAC pre-packaged unit systems.

Miscellaneous wayside structures, at-grade stops, and elevated stations may include ancillary room HVAC.

At-grade stop and elevated station public areas open to ambient air do not include HVAC.

Underground station public areas include HVAC or mechanical ventilation only if:

- A station requires mechanical ventilation in case of emergency; or
- HVAC is part of a joint development project.

Underground station offices, employee areas, occupied spaces and ancillary rooms include HVAC.

LRV piston effect supplemented by mechanical ventilation as required provides ventilation for underground station public areas, trainways, platforms, stairways, concourses, entrances, and connections to grade.

Provide platform exhaust systems where required subject to Subway Environment Simulation (SES) and Computational Fluid Dynamics (CFD) modelling to capture LRV heat release and extract station air through ducts in both normal and congested operations.

Provide LRT tunnels with outside air Emergency Ventilation Systems to assist passenger evacuation.

Provide ventilation shafts with reversible fans, fan dampers, sound attenuators, and dampers for forced ventilation during congested and/or emergency operations at the ends of stations or between stations.

Provide tunnel booster fans and/or local extraction ducts to reduce the effects of short-circuited airflow at tunnel crossovers and pocket/storage tracks where required in both congested and emergency operations.

C4.5 Tunnel Ventilation Operating Modes

Normal Operations: LRVs move through the system according to schedule.

Optimize HVAC system performance for normal operations since this is the predominant operating mode.

Congested Operations: Delays or operating problems prevent the free flow of LRVs through the system.

LRVs may wait in Stations or Stops at predetermined locations along LRT routes.

Delays may range from 30 seconds to 20 minutes although longer delays may occur on occasion.

Tunnel ventilation systems may provide sufficient air flow over stationary LRVs in tunnels to maintain an appropriate quantity of fresh air for passenger physiological needs.

Sufficient air flow to maintain LRV air-conditioning condenser unit inlet temperatures below unloading temperatures for acceptable internal environments.

Passenger evacuation or immediate exposure of passengers to track related danger does not normally occur during congested operations.

Emergency Operations: Generally result from an LRV malfunction.

The most serious emergency is an LRV fire in a tunnel disrupting traffic and requiring passenger evacuation.

Emergency ventilation systems maintain a tenable environment for means of egress from the emergency incident to a point of safety.

C4.6 Normal and Congested Operations

C4.6.1 Outdoor Provide Conditions

Outdoor design conditions determine HVAC system required capacities.

Provide HVAC equipment for extreme weather condition degraded capacity continuous operation.

Summer and winter design temperatures per 2.5% January and July temperature figures for Authorities Having Jurisdiction (AHJ), OBC Supplementary Standard SB-1 Table 1.2.

Mean wind speed and prevailing direction for summer (July) and winter (January) per Canadian Climate Normals, Wind, and Environment Canada.

C4.6.2 Indoor Design Conditions

Underground Stations

Averaged Over One LRV Headway Time Interval:

- Summer Dry Bulb Temperature: Not more than 6°C above ambient;
- Winter Dry Bulb Temperature: Heating not provided; Humidity not controlled.

Horizontal Air Velocity Platform, Concourse, Entrances:

- Average: Not greater than 3 m/s;
- Maximum: Not greater than 5 m/s.

Sloping Air Velocities Escalators and Stairs:

- Evaluate upward air velocities at escalators and stairs;
- Attempt to limit peak upward air velocities to 2.5 m/s;
- Submit peak upward air velocities greater than 2.5 m/s for MX LRT review and acceptance;
- Peak air velocity is the largest magnitude allowed at any time except in case of emergency.

Air Pressure Transients:

- Air pressure change 420 Pa/second maximum for total air pressure change greater than 700 Pa.
- Underground Station Enclosed Retail Areas:

- HVAC is tenant responsibility.

Summer:

- 24°C Dry Bulb Temperature;
- 50% Relative Humidity.

Winter:

- 16°C.

Tunnels

Provide system and facilities equipment in tunnels operating continuously at full capacity in temperatures up to 34°C and for short periods in temperatures up to 43°C without decreasing life expectancy.

Provide Station and tunnel HVAC equipment capable of limiting tunnel Summer Dry Bulb Temperature to ambient temperature plus 6°C in normal and congested operations.

Minimum Dry Bulb Temperature:

- Heating not provided.

Humidity control:

- Not provided.

Air Velocity:

- No control required for unoccupied tunnels.

Air Pressure Transients:

- Air pressure change 420 Pa/second maximum for total air pressure change greater than 700 Pa.

C4.6.3 Ancillary Rooms and Other Facilities

Ancillary rooms with solid state electronic equipment such as HVAC controls, SCADA, remote terminal units, telephones, computers and printed circuit boards may require more robust cooling and ventilation.

Analyze each room individually.

Provide HVAC to achieve room temperatures for optimum equipment operation.

Tables C4-1 through C4-3 list indoor design conditions for MSFs, OCCs, and ancillary rooms.

C4.6.4 Light Rail Vehicles

LRV HVAC systems operate at design capacity with condenser air inlet temperatures less than 38°C.

LRV HVAC operate at reduced capacity with condenser air inlet temperatures between 38°C and 43°C.

See Chapter A2 – Light Rail Vehicles.

C4.7 Emergency Operations

C4.7.1 General

The Design Fire Scenarios for Emergency Operations are:

- LRV fire in tunnel;
- LRV fire in Station; and
- Other fires in Station.

Provide Emergency Ventilation System, number of fans activated in an emergency, type of ventilation equipment, and built-in system reliability to meet the Design Fire Scenarios.

LRV Fire in Tunnel

During an LRV Fire in tunnel the following parameters apply:

- LRV Fire Heat Release Rate: See Chapter A2 – Light Rail Vehicles; and
- LRV Fire Heat Load: See Chapter A3 – Safety and Chapter A4 – Security.

For emergency ventilation purposes, a means of egress includes both the open tunnel and the annulus between the LRV and tunnel walls.

Maintain a tenable environment for 2 hours minimum but not less than the actual evacuation time with appropriate ventilation for at least one means of egress from the fire site to a point of safety.

Maximum temperature in a means of egress is not exceed 60°C ignoring radiant heating effects.

Air velocity in a means of egress is not exceed 11 m/s.

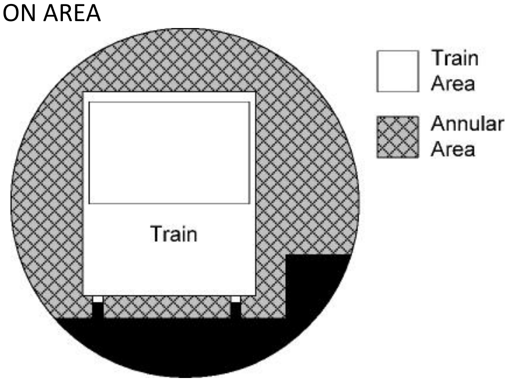
The Emergency Ventilation System basis of design includes the following conditions:

- Two LRV per Ventilation Zone;
- One Critical Fan Out of Service;
- One Cross-Passage Open;
- Adjacent tunnel as a means of egress (tunnel ventilation equipment capacity and emergency ventilation operating modes account for adjacent tunnels acting as means of egress).

Maintain critical air velocity in tunnel annulus required to control direction and spread of smoke and hot gases from a fire with full heat release in the means of egress.

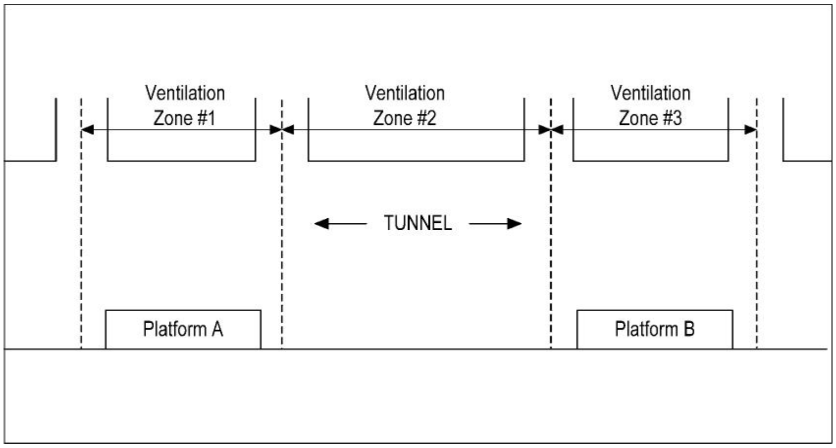
Base critical air velocity calculations on annulus cross section area, which is calculated by subtracting the LRV cross section area from the tunnel full cross section area per SES User’s Manual.

FIGURE C4-1 ANNULAR CROSS SECTION AREA



A tunnel ventilation zone is defined as the area between two adjacent shaft inlets and/or portals.

FIGURE C4-2 VENTILATION ZONES



LRV Fire in Station

Maintain a tenable environment for two hours minimum but not less than the actual evacuation time during an LRV fire at a Station platform, excluding the platform area directly adjacent to the fire, unless an Engineering Analysis demonstrates how those unable to self-rescue can reach a point of safety in less time.

This includes identifying and coordinating with first responders.

Air temperature in the means of egress is 60°C maximum ignoring radiant heating.

C4.8 Design Methods

C4.8.1 General Requirements

Calculate hourly, daily, weekly, monthly and yearly heating and cooling loads, corresponding load profiles and estimated energy consumption for Stations, MSFs, rooms and spaces using the latest versions of heating and cooling load software or equivalent application.

Calculate HVAC room heating and cooling loads including 10% general engineering design safety factor.

Consider whether to accommodate increases in heating/cooling loads now or in future.

Determine air-conditioned space humidity level capacity requirements for humidity control equipment.

Implement humidity control in spaces only where conditions exceeding allowable operating limits would damage or deteriorate electronic equipment used there.

Provide floor-mounted equipment concrete housekeeping pads 100mm minimum above finish floor.

Provide HVAC system drainage through waste drains only.

Do not connect mechanical equipment drains directly to any drain system.

Provide instead indirect drain connectors with air gaps.

Provide oil separators where required by code.

C4.8.2 Energy Conservation by Design

Provide HVAC equipment demonstrating appropriate and optimized energy efficient measures.

Provide, study, and report energy conservation by design means and methods for Metrolinx RT review.

Include feasibility reports with energy conservation techniques, potential benefits, equipment/space requirements, operations, maintenance, and cost effects.

C4.8.3 Ventilation Rates

Base number of air changes per hour (total air circulated) on heating and cooling loads, odor control, and applicable codes, whichever greater.

Provide in any case no less than four air changes per hour.

Outside air intake for HVAC occupied spaces: 7 litres/second/person minimum.

Minimum ventilation requirements for plant maintenance and workshop rooms varies with intended use per ASHRAE 62.1-2007, Ventilation for Acceptable Indoor Air Quality, and OBC Articles 6.2.1.1 and 6.2.2.5.

Provide mechanical cooling where ventilation alone is inadequate for required indoor temperatures.

Provide ventilation systems for hazardous or flammable storage areas per Ontario Fire Code and NFPA.

Use ventilation rates found there to establish minimum equipment capacities based on 100% fresh air exchange at indicated levels.

Consider recirculation and energy recovery systems to conserve energy for rooms with full air exchange rate required only under peak or worst case conditions, e.g., peak hour operation in design cooling days.

Consider mechanical cooling where ventilation alone will not maintain required room temperatures.

C4.8.4 Occupied Space Fresh Air/Outside Air

Provide fresh air effectively distributed to occupied spaces with an air change effectiveness equal to or better than 0.9 per ASHRAE 129 (1997), Measuring Air Change Effectiveness.

Provide ventilation systems for cross ventilation of effective air distribution into occupied spaces.

Shield outside air intakes and exhaust outlets from weather and screen as noted per OBC.

Filter outside air supplied to air conditioning duct systems to reduce airborne pollution.

Locate outside air intakes to avoid introduction to occupied spaces of dirt, debris, fumes, odors, noise, and irritants from traffic and other external sources.

Provide a central outside air handling unit containing fan, filter and heater sections supplying outside air. Locate outside air intakes to avoid short circuiting exhaust air.

Provide heating and cooling capacity sufficient to condition the total amount of fresh air to the required design conditions using summer and winter external design temperatures.

Where practical, automatically control actual fresh air levels to occupied spaces for energy conservation and Green Initiatives purposes.

Provide Carbon Dioxide sensors and other fresh air capacity modulation/step control devices as part of the HVAC equipment to maintain 600 ppm optional to 700 ppm maximum Carbon Dioxide in occupied spaces.

Regardless of minimum fresh air exchange rates required by occupancy, other factors requiring higher fresh air exchange rates, e.g., to limit exposure to contaminants produced in the work area, take precedence.

Provide carbon monoxide monitors in areas with hydrocarbon vapors.

Provide sufficient make-up air to counter exhaust requirements.

Assume 2 persons minimum for fresh air requirements in unoccupied equipment rooms.

C4.8.5 Room Pressurization

Use room pressurization ventilation as required between adjacent rooms such as workshops and maintenance facilities to mitigate infiltration of contaminants for the comfort of workers and/or reliability of equipment.

Achieve room pressurization ventilation primarily by HVAC airflow balancing with surplus supply air coupled with reduced exhaust or relief air and control dampers.

Provide differential pressure sensors to achieve the required room pressure and maintain positive or negative pressurization for critical room conditions such as dust and odor control.

Provide rooms exposed to pressure pulses from LRV operations requiring infiltration control as follows:

Intake and exhaust openings routed to atmosphere; or

Intake and exhaust openings terminating within the same area but separated to prevent short circuiting; or

Back draft dampers to prevent unfiltered air entering through exhaust or relief ductwork.

Attribute the net difference between room supply air and exhaust or relief air to exfiltration through door and wall cracks calculated per good engineering practice such as the ASHRAE Handbook – Fundamentals.

Provide rooms requiring positive or negative pressurization with tight fitting door and wall construction.

C4.8.6 Exhaust Air

Discharge to atmosphere exhaust air from the following:

- Washrooms;
- Janitor Rooms;
- Janitor Machine Rooms (used to charge floor cleaning machines);
- Battery Rooms (where hydrogen gas is produced);
- Hazardous Materials Rooms;
- Retail Spaces; and
- Refuse Storage Rooms.

Provide means of energy recovery where feasible for the above.

Provide a complete seal between supply and exhaust air for heat recovery systems of Battery Rooms and Hazardous Material Rooms.

Discharge to atmosphere exhaust air at grade level from Escalator Service Rooms.

Locate exhaust outlets in well-ventilated areas remote from public areas where exhaust air cannot be discharged to atmosphere.

Discharge directly to atmosphere exhaust air containing contaminates in compliance with regulations and requirements of the AHJ.

Consider discharging exhaust air from remaining rooms into tunnel areas so long as it does not contain contaminants and with proper design to prevent back draft from LRT operations onto passengers.

Review exhaust requirements, emissions capture and control technology, and associated Ministry of Labor compliance levels for maintenance operations including:

- Diesel Engine Power Work Cars;
- Tunnel Structural Repair Activity;
- Rail Repair and Replacement including Welding and Grinding;
- Wheel Truing;
- Cleaning and Power Washing;

- Sanding; and
- Painting.

Discharge to atmosphere exhaust air from mechanical rooms containing refrigeration equipment or any space subject to accidental release of toxic or flammable vapors, fumes, dust or mist.

Also consider discharging to atmosphere exhaust air with emissions that may occur in parking/storage garages, battery charging areas, machining and metal finishing shops, mixing and woodworking operations.

Generally do not connect exhaust ducts with exhaust ducts used for any other purposes.

Make-up Air

Provide adequate make-up air to every room or space where air is exhausted.

Adverse building pressure is not to affect gas-fired equipment operation per CSA B149.1 and B149.2.

Process equipment requiring make-up air includes but is not limited to:

- Parts washers;
- Emergency ventilation systems;
- Vacuum cleaning systems;
- Paint tables, etc.

Regardless of room specific pressurization requirements, maintain overall facilities pressure, i.e., balance between total make-up air and total exhaust air, essentially neutral (+/- 0.5%) or slightly positive (1% to 5%) pressurization.

This includes process equipment exhaust and combustion air requirements for gas-fired equipment.

Natural gas equipment is not allowed in underground LRT facilities.

Humidity Control

Maintain LRT operations and maintenance office area humidity levels per ASHRAE 55 Guidelines.

Critical Area Redundancy

Provide 100% backup to primary HVAC equipment for LRT systems, safety, and operations vital equipment rooms or where failure of primary HVAC equipment cannot be tolerated for even short periods of time.

Provide redundancy with a third back-up unit of equal size, i.e., 50% of the total load or N+1 unit where two equipment units equally share a room load.

Provide backup equipment with automatic start-up and alarm activation upon primary equipment failure.

Protect critical room intakes from smoke re-entrainment.

Rooms and equipment requiring 100% HVAC systems backup include but are not limited to:

- OCC Rooms;
- Uninterrupted Power Supply (UPS) Rooms with interlocked battery chargers and ventilation;
- Elevator Machine Rooms;
- Transformer Rooms and Electrical Switchgear Rooms;
- Communication Equipment Rooms;
- Fire Pump Rooms;

- Fire Fighter Vestibules, Lobbies, Access Shafts and Stairways; and
- Emergency Ventilation Fans, Fan Motor Starters and Control Equipment Rooms.

Air Distribution System Provide Velocities

Provide air distribution system velocities to minimize pressure loss, energy consumption, air-borne noise generation, drafts, and dust intake for required system performance.

Provide HVAC system supply and return air ducts materials for low velocity air distribution systems and Tunnel Ventilation System ductwork for medium velocity air distribution systems per ASHRAE Handbook – Fundamentals design air velocities below:

- Station/tunnel concrete ventilation ducts, plenums and shafts: 9 m/s nominal; 11 m/s maximum;
- Other concrete ventilation ducts, plenums and shafts: 7.5 m/s nominal; 9 m/s maximum;
- Exhaust Fan Dampers: 7.5 m/s maximum over gross area;
- Fan Sound Attenuators: 6 m/s maximum over gross area;
- Relief Shaft Dampers: 5 m/s maximum over gross area;
- Exhaust and Return Grilles: 2.5 m/s maximum over gross area;
- Transfer Grilles and Louvers: 1.25 m/s maximum over gross area;
- Air Outlets, Intakes and Diffusers: Required throw and noise criteria; and
- Variable Air Volume (VAV) Terminals: Required air flow, pressure, and noise criteria.

Noise Criteria

Provide sound control for HVAC systems per ASHRAE Handbook of Systems and Applications, Sound and Vibration Control.

C4.9 Tunnel and Station Ventilation Basis of Design

Use an SES Computer Program for modeling and simulating LRV movement, airflow, humidity, air and wall temperatures, and emergency tunnel fire scenarios to demonstrate that the tunnel ventilation system meets design requirements.

Use CFD in a commercially available program with prior MX LRT review and acceptance for three dimensional Station modeling and transient simulation of Station fire emergency scenarios to demonstrate that the Station ventilation system meets design requirements.

Perform SES and CFD calculations to determine tunnel and Station ventilation basis of design.

C4.9.1 Normal Operations

Perform SES to study how the ventilation systems behave in normal operations.

Focus the first SES for normal operations with LRV movement to:

- Confirm that SES LRV movements agree with traction power and signaling simulations;
- Provide transient pressure analysis of LRV portal entry/exit speeds for Station and onboard passengers;
- Confirm LRV model can be used for full normal operation simulations.

During normal operations tunnel ventilation fans do not operate and associated fan dampers remain closed.

Depending on the season, relief shaft dampers may remain open or closed.

During summer operations, relief shaft dampers remain open.

During extreme winter weather relief shaft dampers remain closed to allow LRV heat to warm the system.

C4.9.2 Full Normal Operations

Perform SES for full normal operations to analyze the environment inside the underground LRT system under different circumstances demonstrating environmental variables meet design requirements.

Operating schedules affect airflow during normal operations.

Perform at least two SES with moving LRVs at different locations.

Perform first SES with LRVs in each direction starting at the same time.

Perform second SES with LRVs in one direction shifted half a headway.

Analyze results of these two SES runs to determine if the system meets temperature and air velocity criteria.

Verify other SES that effectively shift headways also meet the design criteria.

Use SES to confirm resistance of tunnel-to-tunnel ventilation is small enough to maintain air velocities at or below required criteria.

In addition to rush-hour simulations, check air velocity criteria during off-peak hours assuming only one LRV moving through the system.

C4.9.3 Congested Operations

Perform SES for congested operations to confirm mechanical ventilation is not needed with LRVs stopped in tunnels for up to 30 minutes.

Use SES for congested conditions with ambient air temperature and tunnel air and wall temperatures determined in normal operations analysis.

Assume peak loaded LRVs stopped in middle of longest ventilation zone for 30 minutes with bulk temperature surrounding LRVs never to exceed congested peak temperature.

If congested peak temperature is exceeded, consider need for congested operations mechanical ventilation.

C4.9.4 Emergency Operations

Perform emergency operations SES to determine Emergency Ventilation System requirements including:

- Maximum LRV numbers in incident tunnel;
- One open cross passage;
- One fan failure; and
- Worst case fire location for each ventilation zone for one track.

Note locations requiring highest fan capacities and use for cold flow field tests.

Provide cold air velocities for later Testing and Commissioning in the SES Final Report per NFPA 130.

C4.9.5 Maintenance Simulations

Provide SES emergency operation fan capacities to model ventilation sufficient for diesel equipment maintenance operations.

Use adjacent upstream and downstream shafts to ventilate tunnels as required.

C4.10 Maintenance and Storage Facilities

C4.10.1 General Office Areas and Shops

MSF HVAC systems may consist of VRV/VRF units or split-package air-conditioners with air distribution system, controls, drives and accessories.

Ventilate gas-fired furnace flue gases to atmosphere in compliance with the codes of the AHJ.

Provide IRI rated combustion controls for gas and oil fuel heating equipment with appropriate safety certificates from the AHJ.

Provide air-conditioning systems, except as noted otherwise, to modulate from the minimum outside air required for ventilating up to 100% outside air.

Provide a ducted supply and return air system with registers located in each conditioned office space.

Provide thermostat control of HVAC system operation.

HVAC chilled water/heat pump systems may include chillers, cooling towers/fluid coolers, chemical treatment systems, water circulating pumps, air-handling units with relief systems, return-air fans, etc.

Provide HVAC system ductwork and controls for general office areas separate from shop areas.

Consider VAV systems for general office space energy savings.

Base cooling loads on the sum of the following heat gains:

- Occupancy;
- Lighting Load: of 22w/m^2 or actual load;
- Power Load: 11w/m^2 or actual load;
- Ventilation and make-up air;
- Solar and transmission gains; and
- Equipment heat rejection based on use factor.

Base heating loads on the sum of the following heat loads:

- Transmission heat load;
- Ventilation air heat load; and
- Equipment heat loads.

C4.10.2 Spray Paint Areas

Provided heating as recommended by spray paint equipment suppliers.

Provide air changes per hour (ventilating rate) and supply/exhaust air filtration as recommended by the spray paint equipment supplier, but not less than the rate required by applicable codes of the AHJ.

C4.10.3 Mechanical Equipment Rooms

Provide Mechanical Equipment Room heating and ventilating per Section C4.6.3.

C4.10.4 Locker Rooms

Provide Locker Rooms with HVAC from general office area or toilet room HVAC units.

Provide Locker Rooms with separate HVAC package units when general office areas or toilet rooms cannot supply HVAC.

C4.10.5 Toilet Rooms

Provide maintenance shop toilet rooms with heating, ventilation, and secondary air transferred from adjacent locker rooms.

Provide general office toilet rooms with HVAC from general office HVAC units.

Control toilet room exhaust fans by light switch with time delay on light off but operating continuously when offices are occupied.

C4.10.6 LRV Operator Lunch Rooms

Provide LRV Operator Lunch Rooms with HVAC from general office units or their own HVAC package units.

C4.10.7 Undercar Blow-Down Cleaning Facilities

Blow-Down cleaning removes dust with either compressed air or water for routine service and inspection.

It is not to be confused with long-term cleaning, which occurs at intervals greater than one service and inspection cycle.

Confirm adequacy of Blow-Down criteria with the AHJ prior to Final Design.

Assume a manned Blow-Down facility that may be used for purposes other than Blow-Down rather than a dedicated Blow-Down facility with industrial robots.

Comply with ACGIH Industrial Ventilation Handbook and MOL Engineering Data Sheet - Garage Ventilation.

System Concept:

Provide supply and exhaust ventilation and discharge systems to remove airborne dust from cleaning vehicle under-carriage equipment for operating personnel safety and comfort.

Comply with Ontario Ministry of Environment Regulations 419.

Ventilation Requirements:

Provide 10 air changes per hour for the total enclosed area with air extraction rate for pit areas of 20 l/s minimum per square meter and supply air less than exhaust air.

Provide roof-mounted exhaust fans and unit or package HVAC make-up air unit equipment and accessories.

Locate make-up air equipment on the roof with air distribution near work platforms.

If the Blow-Down booth is inside an MSF building, locate exhaust fans and split-type HVAC package make-up air units on the booth roof.

Mount air-cooled condensers for split type HVAC package units on building roofs.

Locate exhaust air grilles near booth and pit floor with minimum face velocity of 0.9m/s.

Provide air distribution ductwork, air filters, and automatic temperature controls.

Provide dynamic precipitator type wet scrubbers with water sprayer and freeze protection to remove dust particles before discharged treated air to atmosphere.

Discharge water/dust slurry to sanitary sewers after clarification.

Controls:

Provide manual control of supply and exhaust ventilation systems.

Energize heating systems at temperatures below 20°C.

Interlock make-up air and exhaust systems to prevent operation of one system without the other.

Interlock scrubbers operation with exhaust air and water supply systems.

Interlock summer-winter on-off switch with under-car cleaning equipment compressed air and electric power supply.

Interlock compressed air and water supply so that ventilation system failure positively shuts off and disables cleaning operations.

Interlock Blow-Down facility doors so that cleaning equipment compressed air and power supply shut off automatically when any door is opened.

C4.11 Operations Control Centres

These criteria apply to OCC HVAC systems.

C4.11.1 HVAC System Concept

Provide HVAC system with 100% duty/standby capacity.

Analyze OCC HVAC systems including air-handling units, chillers, cooling towers/fluid coolers, chemical treatment systems, water circulating pumps, and exhaust/relief fans.

Provide backup AC consisting of a split-type package unit with remote air-cooled condenser for:

- Main Control Rooms;
- Security Control Rooms;
- CCTV Rooms;
- Communications Equipment Rooms; and
- Computer Equipment Rooms.

Include HVAC provisions for maintaining required humidity levels for Computer Equipment Rooms.

C4.11.2 Standby Power

Connect OCC HVAC system to standby power supply.

See Chapter C3 – Facilities Electric Systems.

C4.12 Ancillary Rooms

These criteria apply to Ancillary Room HVAC systems.

C4.12.1 Communications and Signal Rooms

See Chapter C2 – Communications and Control.

System Concept:

Provide HVAC systems to satisfy minimum outside air requirements.

Filter and recirculate approximately 90% of supply air and exhaust 10% by exfiltration to maintain positive room pressure.

Calculate cooling loads based on the sum of the following heat gains:

- Occupancy;
- Internal equipment load;
- Lighting load of 22 w/m^2 or actual lighting;
- Outside air load; and
- Solar and transmission gain.

Equipment and Accessories:

Provide Direct Expansion split-system Air-Handling Units (AHU) in a room adjacent to or space within Communications and Signal Rooms.

C4.12.2 Computer Equipment Rooms

OCC HVAC system concepts apply to Computer Equipment Room HVAC systems.

Consider separate stand-alone HVAC package units with humidity control for Computer Equipment Rooms.

Provide alarm monitoring/handling HVAC systems similar to Elevator Machine Rooms for Computer Equipment Rooms.

C4.12.3 Electric Equipment Rooms

System Concept:

Provide supply and exhaust ventilation systems maintaining positive room pressure.

Ventilation capacity based on the sum of the following internal heat gains:

- 2% of installed transformer capacity;
- Heat rejected by electric equipment;
- Solar and transmission gains; and
- Lighting load of 22 w/m^2 or actual lighting load.

C4.12.4 Battery Rooms

Provide maintenance-free batteries.

Provide continuous exhaust ventilation per battery manufacturer recommendations and code requirements.

C4.12.5 Escalator Machine Rooms and Spaces

System Concept:

Provide Escalator Machine Room and Space heating as part of escalator machine design.

Provide Escalator Machine Room and Space HVAC to achieve ambient air temperature and humidity in the range specified by the manufacturer for safe and normal escalator operation.

Locate only escalator equipment in Escalator Machine Rooms and Spaces per CSA B44.

Controls:

Provide HVAC system controls and alarm monitoring/handling for Escalator Machine Rooms/Spaces similar to Elevator Machine Rooms.

C4.13 Traction Power Substations

System Concept:

Provide ventilation systems for enclosed TPSs to remove heat generated by electric equipment and limit operating temperatures to the prescribed operating conditions.

Provide 100% filtered outdoor supply air.

Discharge exhaust air to atmosphere.

Base ventilation capacity on the sum of the following internal heat gains:

- Lighting load of 22 w/m^2 or actual lighting load;
- Solar and transmission gains; and
- Heat rejected by electric equipment.

Do not take ventilation air from the tunnel or discharge exhaust air into the tunnel.

Maintain positive room pressure when the TPS ventilation system is in operation.

Provide fans with sound levels so that in normal operations with both duty fans operating TPS inside noise levels do not exceed maximum prescribed Noise and Vibration criteria.

Provide a small continuously operating pressurization fan with filter for underground facilities.

C4.14 Station Retail Areas

These criteria apply to HVAC systems for Underground and Elevated Station Retail Areas.

Tenants are responsible for air-conditioning their Retail Areas.

C4.15 Station Public Areas

C4.15.1 Air Distribution

Station public area ventilation is largely achieved by LRV generated piston-effect air movement supplemented as required by mechanical ventilation.

Where supplemental mechanical ventilation is required, distribute supply air through ductwork.

Provide separate exhaust ductwork air intake near the ends of Station platform and concourse depending on smoke zone arrangements per NFPA 130.

C4.16 Integrated Station and Tunnel Ventilation Systems

These criteria apply to integrated Station and tunnel ventilation systems.

Conform to NFPA 130 requirements.

C4.16.1 System Concept

Tunnel and Station ventilation systems supply fresh air to the passenger environment while Emergency Ventilation Systems direct smoke and heat away from means of egress and maintain a tenable environment in case of fire.

Provide ventilation systems capable of moving air at required velocities in either direction in tunnels and guideways.

The three factors affecting Station and tunnel ventilation supply/exhaust operating modes are LRV location, fire location, and means of egress.

Interlock fan and relief shaft dampers so that fan dampers open and relief shaft dampers close when the fans start while corresponding plenum dampers operate to direct airflow into the appropriate trainways based on incident location.

Fan damper power-off mode is open.

Relief shaft damper power-off mode is closed.

During congested operations, LRV piston effect ceases to move air in the incident tunnels.

Heat given off by LRV air-conditioners and LRV propulsion system residual heat causes surrounding tunnel air temperatures to increase.

C4.16.2 System Arrangement

Provide four fans for the typical two-track underground Station, two at each end of the Station as well as tunnel ventilation/draught relief shafts at each end of the Station.

Arrange fans horizontally or vertically in fan rooms or shafts.

Provide fan, relief shaft and plenum dampers separating fan room from trainway.

Locate relief shaft dampers nearest to shafts extending to grade.

Isolate fan motor starters and related control devices from ventilation airflow by a two-hour rated fire separation or more depending on the facility fire compartment.

C4.16.3 Equipment and Accessories

Tunnel Ventilation Fans:

Provide axial-flow tunnel ventilation fans with internally mounted, direct-drive motors and adjustable-pitch blades to allow change in pressure vs air flow capacity either for system balancing or system modification.

Minimum acceptable supply air flow capacity is 90% of exhaust air flow capacity with total fan efficiency of not less than 60% in exhaust flow mode.

Provide fans with modular, rectangular sound attenuators on both intake and discharge sides.

Exact length of sound attenuators is based on Dynamic Insertion Loss (DIL) levels.

Provide heavy-duty, industrial-grade, parallel-blade isolation, fan, plenum and relief shaft dampers able to withstand differential static pressure across the dampers of 1,500 Pa minimum/4,000 Pa maximum for 2 million reversals.

Provide each damper module with two end switches: one to indicate full open position; the other to indicate full closed position.

Furnish each damper operator with auxiliary limit switches at each end of the motor travel.

Provide easy access to damper components, bearings and pivot points for maintenance and lubrication.

Protect ventilation shafts from sand, debris and water ingress.

Provide and protect lubrication lines and fittings where required 1.5 m maximum above finish floor.

Ductwork:

Provide ventilation system ductwork able to withstand fan shut-off pressure if operated against a closed damper.

Maintain effective piston-effect ventilation for enclosed or partially enclosed Station areas.

Consider the following:

- Platform Edge Doors (PED);
- Relief openings, louvers, etc., at enclosed entrances;
- Relief infiltration and exfiltration shaft openings; and
- Partition transfer ducts and grilles.

C4.16.4 Station Ventilation System Control

Provide a control system for ventilation fans, supplementary ventilation fans, and dampers, operating both remotely from OCCs and locally at respective Station ventilation equipment.

Provide Station Emergency Management Panels (EMPs), Motor Control Centers (MCCs) and Local Control Panels to control and annunciate fan and damper operating modes and positions.

Station EMPs activate corresponding Station and tunnel ventilation systems while Local Control Panels activate normal, congested, emergency, and incident operation modes as well as maintenance and testing equipment.

MCCs activate only equipment similar to Local Control Panels.

C4.16.5 Tunnel Ventilation System Control

Provide OCC primary control of tunnel ventilation systems with three sources of information:

- Track circuit occupancy showing LRV locations;
- Telephone communication to site-specific tunnel locations; and
- Two-way radio communication with LRV Operators.

After receiving information from an LRV Operator, the OCC operator assesses the situation, determines the safest means of egress and then, if need be, activates the appropriate tunnel ventilation system according to a predetermined ventilation mode table.

To make this decision, the following information is needed:

- Location in tunnel of incident LRV from LRV Operator;
- Location of fire on LRV from LRV Operator;
- Location of other LRVs near the incident LRV from LRV control boards.

Response time for determining means of egress and implementing ventilation mode is kept to minimum using computers that store ventilation equipment operating modes as a function of any given incident.

Computers are redundant and guide operators in proper activation of required ventilation modes.

Control system functions as follows.

LRV Operator voice communication at the scene of the incident advises the OCC operator of:

- Incident LRV location in the system;
- Relative location of fire onboard LRV; and
- Proposed evacuation route.

OCC operator inputs the above information into the computer.

In response, the computer displays:

- Information input by the OCC operator;
- Schematic display of tunnel ventilation systems;
- Ventilation equipment to be activated; and
- Proposed mode of operation and airflow direction.

Upon examining the displayed output to determine reasonableness, OCC then instructs the computer to proceed with operating each required ventilation element in the mode indicated and in proper sequence.

The computer fully automates ventilation system emergency operations and minimizes response time to implement life-critical decisions.

Tunnel ventilation system reaches full operational mode within 180 seconds and maintains required airflow rates for a minimum of 2 hours but not less than the NFPA 130 required 1 hour minimum time of tenability.

Report mode success and alarm status to the OCC operator.

See Chapter C2 – Communications and Control for SCADA interfaces and details.

C4.17 HVAC Equipment and Materials

C4.17.1 General

Provide energy efficient mechanical equipment per ASHRAE 90.1.

Provide safe, clear and ready access on both sides of units for HVAC equipment, fans, coils, and air filter maintenance as recommended by equipment manufacturers.

C4.17.2 Air Handling Units

Provide factory packaged AHU with 33°C dry bulb ambient air entering the condenser; -9.4°C sub-cooling; and saturated suction temperature of 4.4°C at 49°C condensing temperature.

Provide evaporator side cooling section equipment with minimum airflow capacity to achieve 400 CFM per nominal ton of cooling capacity (54 L/s per kW) to prevent coil freeze up.

Maximum cooling capacity of any single refrigeration circuit is limited to 5 nominal tons (18 kW).

Provide two or more cooling/compressor circuits for systems greater than 5 nominal tons (18 kW) cooling capacity for efficient part load operation.

Include an economizer section providing up to 100% free cooling when ambient conditions are favourable for equipment with refrigerated cooling.

Determine the percentage of available capacity for operational equipment redundancy to offset possible system failures.

Provide refrigerants per the latest rules and regulations of the AHJ.

Provide only ARI Certified cooling systems meeting the highest current industry standards.

Register refrigerant piping for systems over 5 tons capacity per TSSA requirements, the Ontario Boilers and Pressure Vessels Act, CSA B51 and CSA B52.

Locate condenser units in accessible areas as follows:

- Outdoors protected from brake dust and other debris;
- On roofs protected from refrigerant and lubricant damage 1m around the condenser unit; and
- Provide hose bibs within 30m of the condenser unit for washing the coil.

Discharge condenser unit heat to atmosphere and not to platform, concourse, public areas or any other enclosed spaces.

Do not locate condenser units in tunnels, shafts or any other areas subject to heavy brake dust and debris.

Take air for ducted condenser units from areas free of brake dust and other contaminants.

Provide a matching redundant cooling system or alternative back-up cooling system where cooling is critical to LRT operations.

C4.18 Air Distribution Systems

C4.18.1 General

Provide air distribution systems based on the latest edition of the ASHRAE Handbook of Fundamentals.

Size supply ducts using equal pressure drop or static regain method as appropriate.

C4.18.2 Pressure Losses

Pressure loss calculations per ASHRAE Handbook of Fundamentals.

Static pressure differential across supply/return air terminals is not to exceed 60 Pa with the system operating at full capacity.

Static pressure differential across air grilles/registers is not to exceed 150 Pa with the system operating at full capacity.

C4.18.3 Supply Air Registers and Diffusers

Provide supply air grilles, registers and diffusers for the required air-throw and spread with the least amount of draft and noise and adjustable double-deflection louvers/spin taps or opposed-blade adjustable volume dampers key-operable through the face of the register.

Provide square, rectangular, circular, or linear ceiling diffusers with opposed-blade adjustable throw and volume dampers and adjustable air extractors.

Closely coordinate with architectural and lighting design.

C4.18.4 Variable Air Volume Terminals

Provide pressure-independent system-powered VAV terminals to reset air volume as determined by control thermostats regardless of any changes in system air pressure and requiring no more than 250 Pa static pressure regardless of air quantity.

Provide VAV terminals with double shell construction casing and sandwiched foamed-in-place insulation meeting SMACNA standards complete with factory furnished system-powered actuators, controls, and thermostats.

C4.18.5 Exhaust and Return Air Grilles

Provide exhaust and return air grilles equipped with fixed, non-see-through blades or louvers equipped with opposed-blade, adjustable-volume dampers key-operated through the face.

Paint ductwork behind them matte black.

C4.18.6 Volume Dampers

Provide adjustable, opposed-blade vibration-free volume dampers equipped with locking quadrants and stiffened blades to close off branch ducts serving multiple outlets.

C4.18.7 Splitter Dampers

Provide single-bladed vibration-free splitter dampers adjustable through locking quadrants in multiple duct fittings for initial balancing in lieu of individual opposed-blade volume dampers in each branch of multiple duct fittings.

C4.18.8 Fire Dampers

Provide UL or ULC listed fire dampers suitable for the intended purpose in ducts passing through fire-rated floors, walls, and barriers.

C4.18.9 Back-draft and Relief Dampers

Provide multi-bladed gravity type back-draft and relief dampers with neoprene blade edge cushioning.

Provide back-draft or motorized shutoff dampers on exhaust fans where more than a single fan discharges into a common exhaust.

Provide weighted relief dampers in exhaust ducts and openings where positive pressure is required by forced air supply and relief exhaust.

C4.18.10 Air Extractors

Provide movable blade, pivoted air extractors in branch duct connections and registers and diffusers with inadequate space for multi-bladed volume dampers.

C4.18.11 Turning Vanes

Provide elbows with full center-line radius at least 1.5 times the width of duct.

Provide elbows with double radius type turning vanes where full-radius curves are not feasible.

C4.18.12 Access Doors

Provide service access doors in ducts and plenums for fans, dampers, turning vanes, coils, filters, etc.

Provide hinged plenum access doors with latches operable from both inside and outside and door edges resting against neoprene gaskets or similar sealing material with appropriate temperature rating for its intended application to form an airtight enclosure.

Provide hinged, toggle-tab or wing-nut fastened duct access doors resting against felt or neoprene gaskets or similar sealing material with appropriate temperature rating for its intended application.

Provide sheet metal insulation for access doors in insulated ducts and plenums.

C4.18.13 Flexible Duct Connections

Provide flexible connections from fans and AHU to ductwork with flexible material not less than 100 mm wide with the length of each joint adequately sized to accommodate both horizontal and vertical deflection.

Provide flexible connections for emergency ventilation exhaust fans able to withstand 250°C air temperature for 2 hours minimum but not less than 1 hour minimum time of tenability per NFPA 130.

C4.18.14 Air Filtration

Provide air filter with MERV ratings per ASHRAE Standard 52.2 (2007): Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particles Size.

Filter mean air velocity: no greater than 2.5 m/s with airflow distributed evenly across entire filter face area.

C4.18.15 Thermal and Acoustic Insulation

Provide indoor ducts with composite insulation including metal jacket or kraft facing and adhesive to attach insulation to jacket or facing that meets fire and smoke hazard ratings per ASTM E84, NFPA 255, and UL 723 and/or equivalent ULC procedures.

In addition to those ratings, adhesive is not to exceed flame spread of 25, fuel contribution of 50, and smoke development of 50.

Provide accessories such as adhesive, mastic, cement, tape, and cloth for fittings of similar ratings.

Provide insulation for:

- HVAC supply and return ducts;
- Outside air intake ducts subject to condensation;

- Outside air intake ducts to associated HVAC units;
- Heated outside air ductwork in unheated space to associated HVAC systems;
- Emergency generator exhaust flues;
- Exhaust ducts in unheated space between dampers and louvers or within 1m of exterior;
- Ducts at AHU acoustically lined minimum 3 m;
- Ducts between rooms acoustically lined to prevent crosstalk;
- Ducts between men and women washrooms acoustically lined to prevent cross-talk.

C4.19 At-Grade Ventilation Shafts

Provide at-grade ventilation shafts and terminals sized, designed, and spaced per the following criteria for normal, congested and emergency operation scenarios.

Compute maximum air velocity through louvers using louver gross free face area exclusive of any supports.

C4.19.1 Normal and Congested Operations

Optimize fan shafts, relief shafts, external air louvers and bird screens for pressure losses and fan air power with due regard for cost and environmental impact.

- External louver net free area: 50% minimum of total louver gross area;
- Maximum air velocity at louver face: 2.5 m/s;
- Maximum air velocity in shafts: 11 m/s;
- Peak supply air intake velocity: 6 m/s maximum.

Locate supply air intakes 2.5 m minimum above grade and away from public areas.

Mitigate issues such as ingress of water through external louvers.

Shield outdoor air intake and exhaust outlet exterior openings from snow and rain.

Provide corrosion resistant screens or louvers.

Orient louver discharge away from public areas, stairways, Station entrances, and fresh air intakes.

Peak discharge velocity limited by noise criteria.

C4.19.2 Emergency Operations

Restrict sidewalk level discharge with respect to urban design of the site and requirements of the AHJ.

Locate shaft discharge bottom louver 3 m minimum above sidewalk level and away from public areas.

Peak discharge velocity limited by noise criteria.

Locate shaft terminations within Road Rights-of-Way.

Locate shaft terminations in the ROW as close as possible to property lines.

Shaft and grating sizes may vary to suit available at-grade space using length: width ratio = 6:1 maximum.

Avoid long and/or narrow shaft configurations as “dead” zones occur at edges of shaft.

Avoid expanding shafts into sidewalks wherever possible.

Avoid locating shafts adjacent to curbs as snow removal and storage may block shafts.

See Chapter A4 - Security for additional ventilation opening requirements.

C4.19.3 Shaft and Opening Locations

Provide surface shafts with as direct routes as possible to atmosphere and to facilitate ease of airflow to and from underground facilities.

Locate shafts above sidewalks to avoid impacts to pedestrians, Station entrances, stairways, adjacent building fresh air intake and window openings, vehicle crossings, and to minimize exhaust air recirculation.

Wherever possible locate shaft openings in median strips or in off-street locations, suitably screened with planters or other surface treatments that form an integral part of the surrounding site.

Under no circumstance locate shaft openings in roadways, driveways, near motor vehicle stops, or anywhere fuel, fuel fumes, or high concentrations of exhaust fumes may be drawn into the shafts.

Slope above grade shaft roofs to minimize ingress of water.

Locate shafts and openings in the following order of priority:

- Open space areas at grade or above grade;
- Medium strips of divided roads and highways;
- Sidewalks; and
- Rooftops.

Avoid sudden transitions in shaft cross section and minimize number of bends and elbows.

Use turning vanes to reduce pressure losses.

Streamline obstructions in fan shaft passages.

Provide air ducts of smooth concrete or sheet metal.

Separate shafts may be combined into common shafts but under no circumstances may intake and exhaust shafts be combined into a common shaft.

Provide shafts with 5 m minimum horizontal and vertical separation between intake and exhaust to prevent recirculation.

Provide shafts with 12 m minimum horizontal separation from the closest Station entrance, air intake/exhaust shaft, or surface emergency egress door.

Where this is not feasible, horizontal separation may be reduced to 4.5 m minimum by raising the shaft opening 2.5 m minimum above the closest Station entrance, air intake/exhaust shaft, or surface emergency egress door.

Provide emergency ventilation shaft openings with 12 m minimum separation from other Station and building openings to prevent re-entrainment of smoke or short-circuiting the Emergency Ventilation System.

If the separation requirements above cannot be met, perform a recirculation study using CFD to model street level conditions under various wind directions and velocities to determine if emergency ventilation smoke discharge will be drawn into Station or other building air intakes.

Adjust emergency ventilation shaft openings to minimize recirculation and maintain tenable environments.

See Chapter A4 - Security for additional requirements.

As a minimum, prevent surface run-off draining into shafts with shaft opening elevations higher than surrounding grade level.

Drain shafts into the storm drainage system.

C4.20 Piping

C4.20.1 General

Provide piping systems per all applicable sections and requirements of ANSI B.31, ANSI B16.10 and CSA.

C4.20.2 Insulation

Provide indoor piping with composite insulation including metal jacket or kraft facing and adhesive to attach insulation to jacket or facing that meets fire and smoke hazard ratings per ASTM E84, NFPA 255, and UL 723 and/or equivalent ULC procedures.

In addition to those ratings, adhesive is not to exceed flame spread of 25, fuel contribution of 50, and smoke development of 50.

Provide accessories with similar ratings for components such as adhesives, mastics, cements, tapes, and cloths for fittings.

C4.20.3 Freeze Protection

Analyze piping system installations for potential water line freezing during winter months.

Provide electric-resistance tape as required in addition to insulation.

Provide drainage for pipes subject to freezing.

C4.20.4 Pumps

Provide single or double action suction pumps, arranged to be maintained without disconnection or removal of piping, as conditions require with the following characteristics:

- Pump Type: Non-Overloading;
- Maximum Pump Speed: 1,800 RPM; and
- Operating Efficiency at Provide Flow: Within 5% of Maximum Efficiency.

C4.21 Natural Gas Service

Natural gas equipment is not allowed in underground LRT facilities.

This section addresses natural gas equipment in above ground facilities such as MSFs.

Size natural gas piping per CSA B149.1 with additional requirements as noted.

Provide thermal expansion with Canadian Gas Association certified flexible connections.

C4.22 Monitoring and Control

OCC, Station EMPs, and Station Control Rooms operate ventilation systems in all modes and fans in predefined groups.

Locate Building Automation Control Systems (BACS) in Station Control Rooms.

Provide OCC system-wide monitoring of facilities including but not limited to the following:

- Verification of correct fan and motorized damper status in normal and emergency modes;
- Fan status: Exhaust, Supply, Off and Alarm modes;
- Fans in automatic or manual/remote or local control.

BACS local controls override EMPs and OCC controls in all modes.

Fan control hierarchy is:

- MCC – highest;
- EMP;
- SCR BACS;
- OCC – lowest.

Take local control of fans only when OCCs and SCRs are inoperative or LRT staff have more detailed knowledge of safe means of egress and smoke propagation to determine required air flows.

BACS provide central computerized control and monitoring to achieve energy efficient mechanical and electric building services throughout the LRT system.

BACS maintain indoor climate within a specified range and provide lighting control based on occupancy.

BACS also monitor performance of mechanical and lighting systems, indicates device failures, alarm conditions, and notifies building engineering staff.

Each BACS application is capable of manual override.

Determine individual monitoring and control points when setting up the Sequence of Operations.

C4.23 Controls and Interlocks

C4.23.1 General

Do not locate room ventilation controls in Station EMPs.

Do not locate HVAC controls in public areas wherever possible.

Provide tamper and vandal proof HVAC controls located in public areas.

Provide occupied rooms with the means to:

- Adjust room temperature set point without affecting adjacent rooms;
- Activate/deactivate room HVAC systems when occupied/unoccupied;
- Change cooling and heating modes where applicable.

C4.23.2 Building Automation Control Systems

Building Automation Control Systems (BACS) monitor space temperature in rooms subject to damage from freezing conditions.

BACS monitor rooms with equipment subject to malfunction or damage in outdoor conditions per manufacturer recommended operating conditions.

BACS monitor space temperature in occupied and unoccupied rooms and other spaces during working-hours, morning warm-up, night setback, etc.

BACS monitor rooms with special features or critical requirements subject to individual space requirements including but not limited to:

- Humidity;
- Carbon Dioxide;
- Room pressure relative to other spaces or ambient conditions;
- Carbon Monoxide, NOx, etc.;

- Other contaminants or pollutants; and
- Compressed air systems.

Provide an alarm for each room or space when critical aspect maximum/minimum tolerances are exceeded.

Provide BACS alarms transmitted through SCADA to OCC.

Provide BACS server interface for remote SCADA Programmable Logic Controller for each facility to receive and transmit high priority alarms/events.

Provide BACS interface for master clock time signals.

C4.23.3 Motor Starter Control

Provide HVAC equipment with BACS supervised intelligent motor starter controls.

Control motors larger than 11.2 kW (15 horsepower) with soft starters or variable frequency drives.

C4.23.4 Equipment Interlocks and Shut Down

Provide Station room area ventilation system shut down controls adjacent to the equipment they control.

Provide automatic ventilation system shut down when the following occur:

- Fire alarm;
- Smoke detector alarm;
- Emergency Ventilation System activation.

Provide equipment shut down contacts via interlocking system device per OBC or other safety related issues.

Provide HVAC equipment smoke detectors for ducts serving multiple fire compartments.

Provide ventilation for rooms protected by clean agent systems with controls to stop ventilation equipment and isolate rooms upon system activation, then purge rooms once incidents are resolved.

Unless ventilation air may adversely affect operation of special suppression systems, dedicated exhaust systems not shared with other spaces may continue to run so long as exhaust air discharges directly to atmosphere.

Do not provide ventilation systems serving Battery Rooms, Electric Equipment Rooms, or Elevator Machine Rooms with automatic shut down so as not to allow smoke migration into adjacent areas and rooms.

Provide ventilation air flow using positive failsafe methods.

Provide differential pressure air flow switches with upstream pitot tubes facing into air streams and downstream pitot tubes facing away from air streams.

Hard-wire air proving switches to interlocked ventilation equipment.

C4.24 Noise and Vibration Control

Provide acoustic control of HVAC systems serving occupied spaces so as not to exceed an NC level of 35 per ASHRAE Handbook HVAC Applications – Noise and Vibration Control.

C4.25 Equipment Access

C4.25.1 General

Provide for the installation and removal of completely factory-built equipment units.

Provide openings with adequate clearances and dimensions for equipment installation and removal without special disassembly or special construction/demolition.

Provide slab and floor hatches or removable gratings for underground equipment installation and removal.

Trainway equipment openings may be allowed in close coordination with LRT system requirements and MX LRT review and acceptance.

Provide monorails, lifting hooks, hoisting beams and removable panels as required for equipment installation and removal.

TABLE C4-1 MSF INDOOR DESIGN CONDITIONS

Space	Winter[1] (°C DB)	Summer[2]	
		(°C DB)	(% RH)
General Offices	22	24	50
Shops	18	--	--
Lunch Rooms	22	24	50
Locker Rooms	22	24	50
Staff Room	22	24	50
Conference Room	22	24	50
Training Room	22	24	50
Crew Room	22	24	50
Toilets	22	--	--
Showers	22	--	--
Storage Areas	9	40	--
Custodial Room	18	--	--
High Voltage Switchgear Room	18	40	--
Low Voltage Switchgear Room	18	40	--
Electric Equipment Room	9	40	--
Mechanical Equipment Room	9	40	--
Battery Room	25	30	--
Computer Room	22[3]	24	50
UPS Room	25	30	--
Standby Power Generator Room	9	40	--
Electronic Equipment Room	22[3]	24	50
Signal Equipment Room	22[3]	24	50
Yard Control Room	22	24	50
Elevator Machine Room	13	32[4]	--

TABLE C4-2 OCC INDOOR DESIGN CONDITIONS

Space	Winter[1] (°C DB)	Summer[2]	
		(°C DB)	(% RH)
General Offices	22	24	50
Reception Area	22	24	50
Staff Rooms	22	24	50
Conference Room	22	24	50
Training Room	22	24	50
Crew Room	22	24	50
Main Control Room	22	24	50
Tape Storage Room	22	24	50
Computer Room	22[3]	24	50
Electronics Shops	22	24	50
Storage Areas	9	40	--
Locker Rooms	22	24	50
Showers	22	--	--
Toilets	22	--	--
Custodial Rooms	18	--	--
High Voltage Switchgear Room	18	40	--
Low Voltage Switchgear Room	18	40	--
Electrical Equipment Room	9	40	--
Mechanical Equipment Room	9	40	--
Electronic Equipment Room	22[3]	24	50
Signal Equipment Room	22[3]	24	50
UPS Room	25	30	50
Standby Power Generator Room	9	40	--
Closed Circuit Television Room	22	24	50
Security Control Room	22	24	50
Battery Room	25	30	50

TABLE C4-3 ANCILLARY ROOMS INDOOR DESIGN CONDITIONS

Space	Winter[1] (^{0}C DB)	Summer[2] (^{0}C DB)	Summer[2] (% RH)
Electronic Equipment Rooms	22[3]	24	50
Traction Power Substations	--	40	--
High Voltage Switchgear Room	18	40	--
Low Voltage Switchgear Room	18	40	--
Electric Equipment Rooms	9	40	--
Mechanical Equipment Rooms	9	40	--
Elevator Machine Rooms	13	32[4]	--
Telephone Equipment Rooms	9	40	--
Battery Rooms	25	30	--
Toilets	22	--	--
Custodial Rooms	18	--	--
Trash Rooms	9	--	--
Storage Rooms	9	--	--
Water Meter Vaults	9	--	--
Valve Rooms	9	--	--
Pump Rooms	9	40	--
Sewage Ejector Rooms	9	40	--
Computer Room	22[3]	24	50
Signal Equipment Room	22[3]	24	50
UPS Room	25	30	50
Standby Power Gen. Room	9	40	--
Station HVAC Control Room	22	24	50
Multipurpose Room	22	24	50

Notes to Tables C4-1 through C4-3

1. Winter temperatures based on:
    - Rooms occupied by physically sedentary personnel: 22°C;
    - Rooms occupied by physically active personnel: 18°C;
    - Rooms requiring temperature maintained well above freezing to avoid maintenance problems: 9°C;
    - Rooms requiring no heating may be ventilated by transfer air: No value provided.
2. Summer temperatures based on:
    - Rooms occupied by personnel dressed in office attire: 24°C;
    - Rooms with solid state electronic equipment: 24°C to avoid maintenance problems;
    - Rooms cooled by ventilation only: 40°C;
    - Rooms requiring no cooling may be ventilated by transfer air: No value provided.
3. Provide humidity control to maintain electronic equipment within manufacturer specifications where:
    - °C: Degrees Celsius;
    - °CDB: Degrees Celsius Dry Bulb;
    - %RH: Percent Relative Humidity.
4. Computer Room HVAC Systems: Maintain room temperatures 26°C on 40°C day; 18°C on -20°C day.
5. UPS and Battery Room HVAC Systems: Maintain room temperature 26°C on 40°C day.
6. Rooms and spaces with no humidistat: Design RH range of +5% to facilitate equipment selection.
7. Rooms with humidistats, e.g., Computer Rooms, Tape Storage Rooms, etc.: Design RH range of +3%.
8. Elevator Machine Rooms: Temperatures lower than 32°C may be required for electronic equipment.

C5 Stray Current and Corrosion Control

C5.1 General

C5.1.1 Summary

Chapter C5 addresses Metrolinx (MX) Light Rail Transit (LRT) systems stray current and corrosion control in three categories:

1. Stray Current Corrosion Control;
2. Soil and Water Corrosion Control; and
3. Atmospheric Corrosion Control.

Meet the following objectives for each of these categories in order of priority below:

- Provide continuity of operations by reducing or eliminating corrosion related failures;
- Maximize MX LRT facilities design life by avoiding premature failure due to corrosion;
- Minimize annual operating and maintenance costs associated with materials deterioration;
- Minimize deleterious effects to facilities of others caused by LRT operations stray earth currents;
- Minimize installed cost of corrosion control elements.

For LRT systems designed and built in segments, apply corrosion control criteria throughout design, construction, installation, and start-up of every segment.

Stray Current Corrosion Control

Use the following principles for stray current corrosion control as a guide:

- Maximize conductivity of return circuits;
- Maximize resistance between return circuits and earth;
- Maximize resistance between earth and underground metal structures; and
- Maximize resistance of underground metal structures.

Provide stray current control measures for traction power and track systems to minimize stray flow of Direct Current (DC) into surrounding environments.

Apply protective measures to maintain stray earth currents within acceptable ranges and avoid deterioration of buried metal structures and facilities.

Obtain recording charts during Baseline Stray Current Tests to determine magnitude and effects of stray currents on existing installations and to serve as documented reference for future investigations.

Soil Corrosion Control

Determine and document soil and groundwater corrosive characteristics during Baseline Corrosion Control and Geotechnical Surveys.

Use data analysis obtained or supplemental on-site measurements as the basis for corrosion control design.

Protect structures from environmental conditions using approved protective coatings, insulation, cathodic protection, and electrical continuity.

Atmospheric Corrosion Control

Determine atmospheric corrosion conditions such as temperature, relative humidity, wind direction and velocity, solar radiation, and amount of rainfall during Baseline Corrosion Control and Geotechnical Surveys.

Identify areas with corrosive atmosphere, e.g., industrial, marine, rural, etc.

Select and design materials and coatings to protect metal structures and hardware from atmospheric corrosion based upon survey recommendations.

Grounding

These criteria recognize the differences between safety grounding and corrosion control requirements.

Review grounding design with corrosion control certified personnel for potential conflicts with corrosion control design of Traction Power Substations (TPSs), passenger Stations and Stops, Maintenance and Storage Facilities (MSFs), elevated structures, and wayside facilities.

Electrically separate lightning protection grounding systems from electrical grounding systems.

C5.1.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Stray Current and Corrosion Control specific references include but are not limited to:

- Ontario Building Code (OBC);
- Ontario Electrical Safety Code;
- Canadian Standards Association (CSA) A23.1/A23.2: Concrete Materials and Methods of Concrete Construction/Test Methods and Standard Practices for Concrete;
- CSA C22.1: Canadian Electrical Code, Part I, Safety Standard for Electrical Installations;
- CSA C22.2 No. 0-10: Canadian Electrical Code, Part II, General Requirements;
- CSA C22.3 No. 4: Control of Electromechanical Corrosion of Underground Metallic Structures;
- CSA A3001: Cementitious Materials Compendium;
- National Association of Corrosion Engineers (NACE) SP0169: Control of External Corrosion on Underground or Submerged Metallic Piping Systems;
- NACE SP0187: Design Considerations for Corrosion Control of Reinforcing Steel in Concrete;
- NACE SP0290: Standard Practice - Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures;
- American Concrete Institute (ACI) 222: Protection of Metals in Concrete Against Corrosion;
- ACI 318: Building Code Requirements for Structural Concrete and Commentary;
- ACI 439 4R-09: Report on Steel Reinforcement;
- ASTM G165: Standard Practice for Determining Rail-to-Earth Resistance;

- ASTM D512: Standard Test Methods for Chloride Ion in Water;
- ASTM D516: Standard Test Method for Sulfate Ion in Water;
- ASTM G51: Standard Test Method for Measuring pH of Soil for Use in Corrosion Testing;
- ASTM C876: Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete;
- U.S. Department of Transportation (DOT) Federal Highway Administration (FHWA)-National Highway Institute (NHI) 00-044: Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes;
- National Fire Protection Association (NFPA) 130: Standard for Fixed Guideway Transit and Passenger Rail Systems.

OBC governs where conflicts arise unless otherwise stated.

C5.1.3 Coordination

Coordinate corrosion control design with other related disciplines.

Coordinate corrosion control measures for structures owned by others to resolve conflicts such as interference with cathodic protection designs and minimize impact on others.

Expandability

Design corrosion control systems to easily expand to the entire LRT system without major reconfiguration, reconstruction, redundancy, or duplication of equipment.

Submit corrosion control systems prior to implementation for MX LRT review and acceptance.

MX LRT discourages corrosion control system experimental design, equipment, and research prototypes.

Existing Conditions

Identify unique and special design cases such as existing building foundations, parallel power lines, and unusual soil conditions early in the project.

Submit evaluation of special design cases and recommend appropriate design mitigation measures.

C5.2 Stray Current Corrosion Control

When correctly applied, stray current corrosion control systems tend to minimize LRT system facilities and structures stray current corrosion.

Stray current may be reduced to such low levels that the corrosive effect on buried structures is negligible.

Stray current corrosion control starts with identifying structures and systems that stray current may affect typically including but not limited to:

- Track work components;
- Traction power system components;
- Metallic pipes and casings; and
- Reinforced concrete structures.

Prevent direct or indirect connections of positive or negative traction power electric circuits with ground.

Design track work and traction power components to minimize LRT system stray current.

Use only clean, well-drained ballast comprising high resistivity materials.

Conduct baseline stray current tests to determine magnitude and effect on existing structures.

Use collected baseline readings to mitigate LRT system stray current effects.

Use modelling studies to predict anticipated stray current magnitudes.

Base stray current corrosion control systems on modelling studies results.

C5.2.1 Traction Power Substations

Separate TPS into three electrically isolated sections:

1. Mainline;
2. Yards; and
3. Shops.

Maximize TPS spacing to keep Main Line track-to-earth potential within safe operating levels.

Provide a separate DC traction ground electrode at each TPS.

Electrically isolate DC ground electrodes from TPS facilities.

Provide each TPS with a stray current monitoring cabinet accommodating four negative drainage circuits.

Provide insulated cable in non-metallic conduit from stray current drainage buses inside TPS enclosures to adjacent underground stray current drainage bus pull boxes.

Base cable and drainage circuit sizes and quantities on existing and planned structures in the area.

Include provisions to monitor track-to-earth potential at each TPS.

C5.2.2 Positive Distribution

Resistance-to-Earth

Except during emergency or fault conditions, operate positive distribution systems as electrically continuous buses with no breaks.

Permit intentional electrical segregation of Main Line, yard, and shop positive distribution systems as the only type of segregation.

Overhead Contact System Grounding

Interconnection of electrical ground for adjacent Overhead Contact System (OCS) support poles is not permitted except at elevated structures.

Avoiding these interconnections eliminates possible transfer of stray current from one portion of the LRT system to another due to an electrically continuous grounding system.

Provide electrically interconnected elevated structure OCS poles and connect them to a ground electrode.

C5.2.3 Negative Distribution

Include the following industry accepted strategies for electrically isolated rail systems to control stray current at the source:

- Continuously welded rail;
- Special track work rail bonding jumpers at mechanical rail connections;
- Concrete tie insulating pads and clips;
- Paved track rail and fastening system insulating material;

- Ballast 45 mm minimum below bottom of rail;
- Concrete elevated structures insulated direct fixation fasteners;
- Roadway and pedestrian crossing rail coated with coal-tar epoxy;
- Cross-bonding cables between rails to maintain equal rail potential throughout;
- Impedance bonding tap insulated connections from housing case;
- Insulated switch machines at switch rods;
- Insulated signal boxes/equipment from rail and paved Right-of-Way; and
- Rail insulating joints installed prior to bumping posts.

Resistance-to-Earth

Provide Main Line running rails, including special track work and other ancillary system connections, with the following initial construction and in-service resistance per 300 m of track for both rails:

- Ballasted track: 300 ohms initial, and 200 ohms in-service;
- Direct fixation track: 500 ohms initial, and 400 ohms in-service;
- Embedded track: 200 ohms initial, and 100 ohms in-service.

Provide resistance with insulating track fasteners, such as, tie plates, rail clips, and direct fixation fasteners.

Consider supplemental insulated negative drainage return cables for extensive existing utility or major high pressure transmission pipeline locations.

Provide dielectric materials to electrically insulate the rails from devices such as switch machines, train control installations or other LRT systems.

C5.2.4 Embedded Track

Electrically isolate rails, rail fasteners, signaling equipment, and related metal components from ground by coating and insulating components.

Consider insulation through the use of the rail boot.

C5.2.5 Maintenance and Storage Facilities

Provide MSFs with a separate dedicated DC traction power supply electrically segregated from the yard traction power system in both positive and negative circuits.

Electrically ground shop tracks to MSF grounding systems

Electrically isolate MSF tracks from Yard Track with rail insulating joints.

Locate insulating joints so that parked Light Rail Vehicles (LRVs) do not electrically short MSF and yard traction power systems for periods longer than required to move the LRVs into or out of the MSF.

C5.2.6 Yards

Locate the traction power segregation point between Yards and Main Line so that yard and Main Line tracks are electrically isolated from each other and from ground connections.

Include the following industry accepted strategies for Yard Track:

Use only clean, well drained ballast comprising high resistivity materials.

Maintain 45 mm minimum clearance between ballast (where used) and rail surfaces / electrically connected metal track components.

For embedded Yard Track, electrically isolate rails, rail fasteners, signaling equipment, and related metal components from ground by coating and insulating components.

Consider insulation through the use of the rail boot.

Provide insulated joints at dead end tracks designed to isolate bumping posts or similar electrically grounded devices.

C5.2.7 Drainage

Provide water drainage systems to prevent accumulated water from contacting rails, rail insulating joints, metal rail components, insulators, or rail ties.

Provide non-metallic drainage pipes except where prohibited by AHJ.

C5.2.8 Bonding

Elevated Structures

Tack weld longitudinal reinforcement bar (rebar) overlaps for electrical continuity.

Tack weld collector bars of same size as transverse rebar to longitudinal rebar at expansion/contraction joints, ends of construction segments, and ends of contractual segments.

Provide additional transverse collector bars at intermediate locations along elevated structures to maintain 75 m maximum spacing between collector bars.

Install two bonding cables minimum between sides of an electrical break in structure.

Electrically insulate structural deck members from support piers and abutments.

Provide test facilities at intermediate locations and at each end of structure to maintain 75 m maximum spacing between test points.

Provide facilities to house test wires from collector bars.

Provide ground system with test stations at each end of structure and at regular intermediate locations.

Retaining Walls

Tack weld longitudinal rebar overlaps in both faces of retaining walls including top and bottom bars of footings for electrical continuity.

Make longitudinal rebar in footings electrically continuous to longitudinal rebar in walls.

Install collector bars, bonding cables, and test stations per Elevated Structures subsection above.

Utilities

Replace and relocate utilities installed by agreement between MX LRT and utility owners per AHJ include the following provisions:

- Provide electrical continuity using insulated copper wire across mechanical joints where electrical continuity cannot otherwise be secured;
- Provide electrical access to utility structures via test facilities installed at 60 m nominal intervals;
- Use only non-metallic pipe and conduit unless metallic materials are required for specific engineering purposes or regulatory requirements;

- There are no special requirements if non-metallic materials are used.

These provisions apply to ferrous and reinforced concrete cylinder pipe only.

Other materials and structures require MX LRT review and acceptance.

Based on specific structural characteristics, provide corrosion control measures in addition to electric bonding including some combination of electric isolation, protective coatings, or cathodic protection in order not to adversely affect existing performance in the environment.

Provide utility structures maintained in place by others with corrosion control measures per AHJ.

Determine the need for stray current monitoring facilities with utility companies and/or AHJ.

C5.2.9 Quality Control

Coordinate corrosion control measures with other engineering disciplines to avoid conflict.

Submit shop drawings, material catalogue cuts, and additional information related to corrosion control for MX LRT review and acceptance.

Conduct material testing prior to delivery from manufacturers or during construction if necessary.

C5.3 Soil and Water Corrosion Control

This section provides criteria for corrosion control systems and measures for LRT structures and systems exposed to soil and ground water.

Identify structures and systems that soil and water corrosion may affect.

These typically include but are not limited to:

- Ferrous Pressure piping, e.g., water, fire, gas, sewage ejectors, etc.;
- Buried and at-grade reinforced concrete structures;
- Hydraulic elevator cylinders;
- Support pilings;
- Underground storage tanks;
- Other underground structures.

Provide corrosion control measures for all facilities regardless of location or material where corrosion related failure may affect safety or threaten continuity of LRT operations.

C5.3.1 Materials and Structures

Ferrous Pressure Pipe

Provide cathodic protection for new MX LRT buried cast iron, ductile iron, and steel pressure pipe applying the following corrosion control strategies:

- Use protective coatings for external surfaces of pipe;
- Provide electrical insulation for interconnecting pipe sections and other structures, segregating them into discrete electrically insulated sections depending on total length of pipe;
- Provide electrical continuity through installation of insulated copper wire across all mechanical joints except at intended insulators;

- Provide permanent test/access facilities at 60 m maximum intervals to permit verification of continuity, coating and insulator effectiveness, and protection levels at insulated connections.

See Section C5.3.5 Cathodic Protection for sacrificial anode protection requirements.

Concrete Pressure Pipe

Apply the following strategies for reinforced concrete pipe and steel cylinder prestressed concrete pipe:

- Provide low permeability concrete by controlling water/cement ratio to 200 ppm maximum chloride concentration per ASTM D512;
- Use Type GU Portland cement except as noted in Table C5-1 Acceptable Cement Types below.

TABLE C5-1 ACCEPTABLE CEMENT TYPES BASED ON SULFATE CONCENTRATION OF SOIL AND GROUNDWATER

Acceptable Cement Type	Percent Water Soluble Sulfate (as SO_4) in Soil Samples (ppm)	Sulfate (as SO_4) in Groundwater (ppm)
Type GU	0 to 0.10	0 to 150
Type MS	0.10 to 0.20	150 to 1,000
Type HS	Over 0.20	Over 1,000

Concrete Types

Apply the following strategies for concrete in contact with soil:

- Type GU Portland cement except as noted in Table C5-1 Acceptable Cement Types above;
- Maximum 200 ppm chloride concentration per ASTM D512 in mixing water for concrete and admixtures combined;
- 50 mm (two inch) minimum cover on soil side of rebar for concrete poured within a form and 75 mm (three inch) minimum cover on soil side of rebar for concrete poured directly against soil.

Gravity Flow Pipe

Apply internal and external sacrificial metal coating and organic coating to corrugated steel piping.

Apply the following strategies for cast or ductile iron piping:

- Internal mortar linings with bituminous coating; Exception: not required on cast iron soil pipe;
- Bonded protective coating on external surfaces of pipe in contact with soil;
- Bituminous mastic coating on external surfaces of pipe 150 mm both sides of concrete/soil interface.

Apply the following strategies for reinforced concrete non-pressure pipe:

- Water/cement ratios per minimum provisions of American Water Works Association (AWWA);
- Maximum 250 ppm chloride concentration in total concrete mix (mixing water, cement, admixture, and aggregates) per ASTM D512;
- Type GU Portland cement except as noted in Table C5-1 Acceptable Cement Types above.

Support Pilings

Provide support pilings using a steel shell filled with reinforced concrete and the concrete as the load bearing member for maximum corrosion protection.

Consider use of protective coatings and cathodic protection for metal supports exposed to soil.

Electrically isolate anchor bolts from columns with insulating pads, sleeves and washers for steel columns supported on concrete foundations.

Evaluate need for special measures based on type of structure, analysis of soil borings for corrosive soil characteristics, and anticipated corrosion related structural deterioration.

Non-Metallic Materials

Evaluate appropriate use of plastics, fiberglass, and other non-metallic materials for pressure pipe to aid in corrosion control considering the following:

- Manufacturer recommendations;
- Mechanical strength and internal pressure limitations;
- Elasticity/expansion characteristics;
- Comparative costs;
- Expected service life;
- Failure modes;
- Local codes;
- Prior experience with proposed non-metallic material in similar applications.

Hydraulic Elevator Cylinders

Apply the following strategies for steel hydraulic elevator cylinders:

- External protective coatings resistant to deterioration by petroleum products such as hydraulic fluid;
- Outer concentric Fiberglass Reinforced Plastic (FRP) casing with thickness, diameter, and resistivity sufficient to prevent moisture intrusion – including at the bottom – and to minimize electrical insulation between the cylinder and earth;
- Sand or alternate dielectric fill between the cylinder and FRP casing with 25,000 ohm-cm minimum resistivity, pH between 6 and 8 per ASTM G51, 200 ppm maximum chloride concentration per ASTM D512, and 200 ppm maximum sulphate ion concentration per ASTM D516;
- Cathodic protection system;
- Permanent test facilities installed on the cylinder, anodes, and earth reference for periodic retesting and evaluation of the protection system;
- Removable moisture proof sealing lid installed on top of casing prior to cylinder installation with top of casing permanently moisture sealed after cylinder installation.

Electric Conduit

Provide non-metallic conduit unless metal conduit is required for specific engineering purposes, utility owner standards, or regulatory requirements.

Where metallic conduit is used apply the following strategies:

- Galvanized steel with Poly Vinyl Chloride (PVC) topcoat or other coatings acceptable for direct burial conduit, couplings and other fittings;
- Galvanized steel with 75 mm minimum concrete cover in duct banks;
- Standard threaded joints or bond wires installed across non-threaded joints for electrical continuity.

C5.3.2 Coatings

Apply coal tar, coal tar tape, or coal tar epoxy coating systems with high electrical resistance to buried metal structures requiring coatings.

Provide mill applied coatings whenever possible.

Provide compatible tape coatings for joints and field touch-ups.

Provide appropriate surface preparation, suitable application procedures, proper number of coats, and minimum dry film thickness for each coating system.

C5.3.3 Electric Insulation

Provide non-metallic inserts, insulating flanges, couplings, unions, and concentric support spacers for electrical insulator corrosion control devices per the following:

- 10 megohms minimum resistance prior to installation and mechanical and temperature rating appropriate to the structure in which it is installed;
- Sufficient electrical resistance after insertion into the operating piping system so that no more than two percent of a test current applied to the device flows through the insulator including current flow though conductive fluids if present;
- Protective coating applied over all components for devices installed in chamber of otherwise exposed to partial immersion or high humidity;
- Specified need for and location of insulating devices in corrosion protection;
- Permanent test facilities when devices not accessible or when specialized equipment needed for access;
- 150 mm minimum separation clearance between new and existing structures where possible;
- Special provisions to prevent electrical contact with existing structures when field conditions do not allow 150 mm clearance.

C5.3.4 Electric Continuity

Provide underground non-welded pipe joint electrical continuity per the following:

- Direct burial insulated stranded copper wires of minimum length needed to span devices being bonded;
- Wire size or number of bond wires based on electrical characteristics of structure and resulting network to minimize degradation and attenuation of cathodic protection;
- Minimum two wires per joint for redundancy.

C5.3.5 Cathodic Protection

Provide cathodic protection systems consistent with the design life of the buried metal structure.

Where feasible provide cathodic protection as sacrificial galvanic anodes to minimize corrosion and interaction with other underground facilities.

Provide impressed current systems only where sacrificial systems are not technically or economically feasible.

Cathodic protection systems using forced drainage of LRT induced stray DC currents requiring connection to the negative system are prohibited.

Restrict cathodic protection design to Cathodic Protection Specialists certified by the National Association of Corrosion Engineers International (NACE).

Comply with NACE SP0169.

Theory in Use

Use the following parameters in theoretical design of cathodic protection systems:

- Cathodic current density: 0.1 mA/m^2 minimum of bare area;
- Current requirements;
- Anticipated current output/anode;
- Assumed percentage of bare surface area: 1.0 percent minimum;
- Indicated total number of anodes, size, and spacing;
- Anticipated anode life;
- Anticipated anode bed resistance.

Provide cathodic protection systems so that the sum of anticipated anode life and time to failure based upon corrosion rates anticipated at 90 percent cumulative probability level is not less than 50 years.

Impressed Current Cathodic Protection

Provide impressed current cathodic protection rectifier systems using variable voltage and current output rectifiers.

Rate rectifiers 50 percent minimum above calculated operating levels to overcome higher than anticipated ground bed resistance, lower than anticipated coating resistance, or presence of interference bonds.

Also consider other conditions which may result in increased voltage and current requirements.

Test Facilities/Stations

Provide test facilities / testing stations comprising two structure cables, one reference electrode, conduit and termination boxes to permit initial and periodic tests of cathodic protection levels, interference currents, and system components such as anodes, insulated fittings, and continuity bonds.

Specify location and types of test facilities for each corrosion control cathodic protection system.

C5.3.6 Backfill Material

Apply the following criteria to non-native fill used for backfilling concrete or ferrous structures:

- Acidity between 6 and 8 pH per ASTM G51;
- 250 ppm maximum chloride ion concentration per ASTM D512;
- 200 ppm maximum sulphate ion concentration per ASTM D516.

Submit test reports for all imported backfill.

Do not use non-compliant backfill without MX LRT review and acceptance.

C5.3.7 Water Treatment

Provide heating and air conditioning chiller, condenser and boiler supply and return chemical treatment systems to minimize internal corrosion and prevent component fouling.

Provide water treatment systems to prevent corrosion rates in excess of 50 microns per year for steel and 2.5 microns per year for copper.

Provide only chemical treatment systems that comply with environmental protection requirements.

Include appropriate measures and provide sufficient space for water treatment equipment requirements in corrosion control systems.

C5.4 Atmospheric Corrosion Control

This section provides criteria for corrosion control systems and measures for LRT structures and systems exposed to atmospheric conditions.

Atmospheric corrosion control is based on maintaining structural and aesthetic integrity of LRT facilities and reducing maintenance costs applying the following criteria:

- Materials with established performance records for intended service;
- Sealants to prevent accumulation of moisture in cracks and crevices;
- Protective steel and metal coatings, both barrier and sacrificial coatings;
- Avoiding use of dissimilar metals, recesses or crevices that may trap moisture.

Identify structures that atmospheric corrosion may affect.

Typically these include but are not limited to:

- OCS structures and hardware;
- LRVs;
- Elevated and Main Line structure exposed metal surfaces;
- Passenger station and stop exposed metal;
- Rights-of-Way and enclosure fences;
- Yards and Shops exposed metal surfaces;
- Electrical, mechanical, signals and communications devices and equipment;
- TPS housings.

C5.4.1 Materials

Provide metals exposed to atmospheric conditions using the following guidelines:

Steel and Ferrous Alloys

Apply coatings to external surfaces of carbon steel and cast iron exposed to the atmosphere.

Exception: rail and rail fasteners do not require coating.

Protect high strength low alloy steel similar to carbon steel except where used as weathering steel exposed to the outside atmosphere.

Address coating of metal contact surfaces, crevice sealing, and surface drainage in corrosion control.

Stain adjacent structures where applicable.

Pay particular attention to stainless steel grades and post fabrication treatments so that adopted solutions are fit-for-purpose.

Aluminum Alloys

Provide anodized finish for best weather resistance.

Alodine and irridite conversion coatings may also be considered if anodizing is not economical.

Copper Alloys

Copper and its alloys may be used exposed to weather without additional protection.

Avoid bimetallic couplings.

Magnesium Alloys

Apply barrier coating to magnesium alloys where long term appearance is critical.

Avoid bimetallic couplings.

Zinc Alloys

Zinc and its alloys can be used where exposed to weather without additional protection.

Avoid bimetallic couplings.

C5.4.2 Coatings

When comparing compatibility of metal surfaces to be coated, evaluate organic and metal coatings for proven past performance, resistance to chalking, color and gloss retention, and service life of the coating.

Organic Coatings

Provide organic coating systems comprising:

- Wash Primer;
- Primer;
- Intermediate Coat; and
- Finish Coat.

C5.5 Grounding

C5.5.1 Elevated Structures

Stray current corrosion control grounding is not required for elevated structures, poles, handrails, cable trough components and other exposed metal elements associated with personal safety.

Limit stray current corrosion control grounding to elevated structures bonded steel reinforcement.

Consider electrical interconnection of stray current control and personal safety grounding elements on a case-by-case basis.

Not Allowed: electrical interconnection of stray current corrosion control grounding with power neutrals.

C5.5.2 Coordination

Consider and incorporate grounding and bonding concepts identified in TCRP Report 155.

Coordinate corrosion control systems with grounding electrodes, standards, and other TPS requirements.

Provide stray current and corrosion control systems compatible with adjacent rail and transit facilities and grounding requirements.

Coordinate the following for compatible elevated structure grounding and corrosion control:

- Ground electrode component materials;
- Ground electrode locations;
- Elevated component electrical continuity details; and
- Pier support and insulation details.

C6 Utilities

C6.1 General

Chapter C6 addresses utilities affected by Metrolinx (MX) Light Rail Transit (LRT) projects.

Consider LRT system requirements, public and private utility authority needs and obligations, traffic and utility service needs, and adjacent property requirements.

These criteria do not supersede or negate Federal, Provincial, or Municipal legislation governing utility construction and relocation.

C6.2 References

Comply with industry best practices and latest editions of most stringent codes and standards of Authorities Having Jurisdiction (AHJ) including but not limited to those listed in the MX LRT Design Criteria Manual (DCM).

Generally, Ontario-mandated codes and standards legally govern unless the Project Specific Output Specification or Project Agreement specifically states that a more stringent code or standard applies.

Where duplicate codes or standards exist the more stringent governs.

Utilities specific references include but are not limited to:

- Construction Standards for Sewers and Water mains – AHJ;
- Construction Standards for Roads – AHJ;
- Municipal Consent Requirements (MCR) for Installation of Plant – AHJ;
- Trees By-laws – AHJ;
- Wet Weather Flow (WWF) Management Guidelines – AHJ;
- Design Criteria for Sewers and Water mains – AHJ;
- Water Supply By-law – AHJ;
- Sewers By-laws – AHJ;
- Field Services Manual – AHJ
- Respective Utilities Current Standards – AHJ;
- Ontario Safe Drinking Water Act (SDWA);
- Canadian Standards Association (CSA) Z662-07: Standard for Oil and Gas Pipeline Systems;
- CSA C22.3 No. 1: Overhead Systems;
- CSA 22.3 No. 7: Underground Systems;
- CSA B137.3-99: Standard for Rigid Conduit Polyvinyl Chloride (PVC) Pipe;
- National Energy Board: Excavation and Construction Near Pipelines;
- Third Party Requirements in the Vicinity of Natural Gas Facilities;
- Trans-Northern Pipelines Inc.: Contractor’s Guidelines;

- Public Service Works on Highways Act (PSWHA);
- American Society of Civil Engineers (ASCE) Standard Guideline: Collection and Depiction of Existing Subsurface Utility Data;
- Ontario Provincial Standard Specification (OPSS) 1802: Material Specification Smooth Walled Steel Pipe;
- American Water Works Association (AWWA) C200-05: Standard for Steel Water Pipe;
- AWWA C301-07 and C303-02: Standards for Concrete Pressure Pipe;
- Electric Safety Authority/Technical Standards: Safety Guidelines for Excavation in Vicinity of Utility Lines.

OBC governs where conflicts arise unless otherwise stated.

C6.3 Utility Locations and Relocations

Safe and continuous LRT operation is of paramount importance for MX RT.

Access to LRT Rights-of-Way (ROW) for construction or maintenance is restricted to MX LRT authorized personnel and others under their direct supervision only.

Consider and identify relocation, replacement, adjustment, protection, and/or abandonment of existing utilities only where actual conflicts occur between LRT and existing utilities including whether:

- LRT design, construction, maintenance, and/or operation interferes with an existing utility providing its intended service in its existing location, or prevents reasonable access to valves, vaults, manholes and hand holes, or precludes operation and/or maintenance per established utility criteria;
- A utility in its existing location poses a potential safety hazard upon completion of LRT construction;
- Roadway or structural grade changes for the sole benefit of LRT compromise reasonable utility criteria for minimum cover;
- Imposed stresses due to LRT works pose a threat to existing utility depth, location, or soil integrity;
- LRT works interfere with existing utility location, installation, or maintenance.

C6.3.1 At-Grade LRT Requirements

MX LRT projects comprise four at-grade zones:

- Zone 1 LRT ROW;
- Zone 2 Utility Restriction Areas (URAs);
- Zone 3 Beside URAs; and
- Zone 4 Below URAs.

See Attachment A, Figure 1.

LRT ROW/URA restrictions protect both LRT and existing / new utilities.

LRT ROW/URA requirements apply to both LRT and utilities in the vicinity of LRT.

C6.3.2 At-Grade Zone 1 LRT ROW Requirements

Zone 1 LRT ROW applies to at-grade or surface LRT.

Zone 1 LRT ROW expressly prohibits new utility design or construction.

Relocate Zone 1 LRT ROW existing utilities outside Zone 1 LRT ROW unless MX LRT approves otherwise.

Zone 1 LRT ROW in embedded track sections is the area within the track bed width between Top of Rail and 1300 mm below Top of Rail.

C6.3.3 At-Grade Zones 2, 3, and 4 LRT URA Requirements

See Attachment B – Schedule A for municipal utility restrictions within, beside, or below LRT URAs.

Additional LRT URA water main and sewer requirements include large trunk or sub-trunk sanitary or storm sewers that may remain below Zone 4 URAs with access through Zone 1 URAs or by offset chambers per AHJ.

Identify critical service utilities, maintain their service during construction, and include methods to do so.

Implement trenchless methods that do not impact LRT trackbed structural integrity for construction under LRT guideways.

Provide water main crossing valves on both sides of URAs to allow pipe replacement under guideways without interrupting LRT service.

Minimum water main and services cover depth: 1800mm from Top of Rail to top of water main to minimize frost damage risk.

For metal pipe remaining in service comply with AHJ guidelines.

See Chapter C5 – Stray Current and Corrosion Control.

Provide new or replacement longitudinal water mains and appurtenances per AHJ.

Consult with AHJ on any variances that may negatively impact remaining public services.

MX LRT reserves the right to allow criteria deviations on a case-by-case basis in, beside, and below URA Zones 2, 3 and 4.At-Grade LRT General Requirements

For at-grade LRT, encase in larger diameter casing pipe or conduit any pipelines crossing below LRT ROW that carry water, oil, gas or other highly flammable, volatile, or pressurized substances.

Provide casing pipes capable of withstanding Light Rail Vehicle (LRV) loads and incorporate stray current and corrosion control measures,

See Chapter C5 – Stray Current and Corrosion Control.

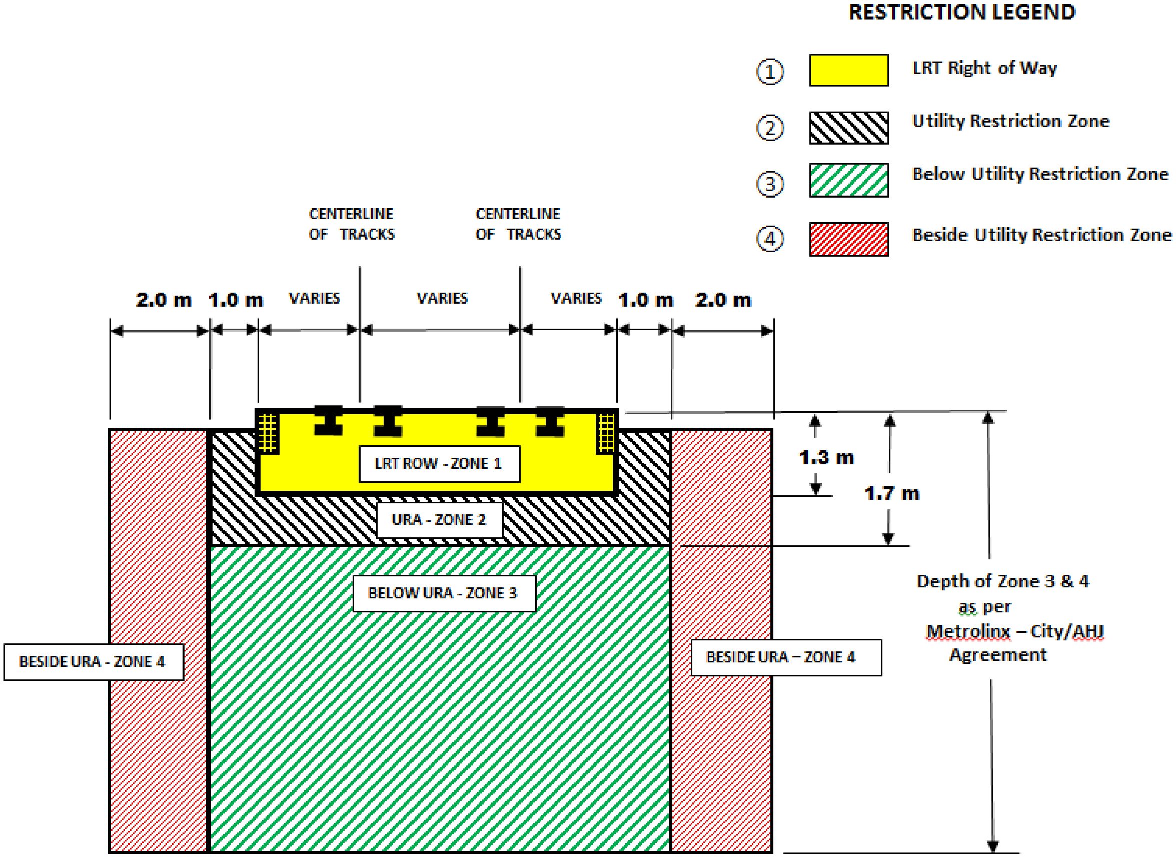
Utilities cross LRT ROW at right angles on tangent track or radially to the reference line on curved track.

Except for utilities serving or crossing at-grade LRT facilities, locate utilities outside the LRT ROW so that repair or replacement does not affect LRT operations.

Locate utilities under at-grade LRT trainways below top of sub-grade with depth of cover per loading, freeze/thaw, and utility owner/AHJ requirements.

Attachment A

FIGURE C6-1: UTILITY ZONE SEQUENCE



Schedule A

Requirements for Existing and New Water Infrastructure in Vicinity of At-Grade LRT Surface ROW

Utility Type	ZONE 1 Utility Free Area (Top of Rail to 1.3 m below Top of Rail)	ZONE 2 Utility Restriction Area (1.3 to 1.7 m below Top of Rail)	ZONE 3 Below Utility Restriction Area (below 1.7 m from Top of Rail)	ZONE 4 Beside Utility Restriction Area (2.0 m width below grade)
Existing Longitudinal				
Water Mains	Relocate	Relocate	Relocate	≤ 300mm Ø: Relocate > 300 mm Ø: May remain
Sanitary	Relocate	Local: Relocate Large Trunk or Sub-trunks: May remain if access secured through Zone 1 or offset Access Chambers per AHJ	Local: Relocate Large Trunk or Sub-trunks: May remain if access secured through Zone 1 or offset Access Chambers per AHJ	May remain
Storm Sewer	Relocate	May remain if access secured through Zone 1 or offset Access Chambers per AHJ	May remain if access secured through Zone 1 or offset Access Chambers per AHJ	May remain
All Service Connections	Relocate	Relocate	Relocate	May remain if safe working conditions maintained
New Longitudinal				
Water Mains	Not Permitted	Not Permitted	Not Permitted	Not Permitted
Sanitary Sewer	Not Permitted	Not Permitted	Not Permitted	Not Permitted
Storm Sewer	Not Permitted	Not Permitted	Not Permitted	Not Permitted
All Service Connections	Not Permitted	Not Permitted	Not Permitted	Not Permitted
Existing Crossings				
Water Mains	Relocate	May remain if insulated & enclosed in steel casing Relocate access chambers	May remain if insulated & enclosed in steel casing Relocate access chambers	May remain
Water Service Connections	Relocate	Relocate to below URA	May remain	May remain
Sanitary Sewer	Relocate	May remain Relocate access chambers	May remain Relocate access chambers	May remain
Sanitary Service Connections	Not permitted	Relocate to below URA if grade permits or replace to URA zone	May remain	May remain

Utility Type	ZONE 1 Utility Free Area (Top of Rail to 1.3 m below Top of Rail)	ZONE 2 Utility Restriction Area (1.3 to 1.7 m below Top of Rail)	ZONE 3 Below Utility Restriction Area (below 1.7 m from Top of Rail)	ZONE 4 Beside Utility Restriction Area (2.0 m width below grade)
Storm Sewer & Service Connections	Not permitted	May remain Relocate access chambers	May remain Relocate access chambers	May remain
New Crossings				
Water Mains	Not permitted	Not permitted	Permitted if in steel casing or heavy duty carrier pipe	Permitted Access Chambers not permitted
Water Service Connections	Not permitted	Not permitted	Permitted if in steel casing or heavy duty carrier pipe	Permitted
Sanitary Sewer	Not permitted	Not permitted	Permitted Access Chambers not permitted	Permitted Access Chambers not permitted
Sanitary Service Connections	Not Permitted	Not Permitted	Permitted	Underground infrastructure permitted
Storm Sewer	Not permitted	Not permitted	1) Underground infrastructure permitted 2) Access Chambers not permitted	1) Underground infrastructure permitted 2) Access Chambers not permitted
Storm Sewer & Service Connections	Not permitted	Not permitted	Permitted Access Chambers not permitted	Permitted Access Chambers not permitted

Schedule B

Requirements for Existing and New Private Utility Infrastructure in Vicinity of At-Grade LRT Surface ROW

Utility Type	ZONE 1 Utility Free Area (Top of Rail to 1.3 m below Top of Rail)	ZONE 2 Utility Restriction Area (1.3 to 1.7 m below Top of Rail)	ZONE 3 Below Utility Restriction Area (below 1.7 m from Top of Rail)	ZONE 4 Beside Utility Restriction Area (2.0 m width below grade)
Existing Longitudinal				
Hydro, Telecom Cables, Traffic Signals	Relocate	Relocate	Relocate	May remain
Gas	Relocate	Relocate	Relocate	Relocate uncased gas pipelines
New Longitudinal				
Locate outside the Guideway				
Existing Crossings				
Hydro, Telecom Cables, Traffic Signals including Local Connections	Relocate	In duct & encased: May remain In duct only: May remain if encased No duct: Include duct & encase or relocate	In duct & encased: May remain In duct only: May remain if encased No duct: Include duct & encase or relocate	May remain
Gas & Gas Services	Relocate	May remain if encased in steel casing	May remain if encased in steel casing	May remain if encased in steel casing
New Crossings				
Hydro, Telecom Cables, Traffic Signals	Not Permitted	Not Permitted	Permitted in heavy duct	Permitted in heavy duct
Gas & Gas Services	Not Permitted	Not Permitted	Permitted if in steel casing or heavy duty carrier pipe	Permitted if in steel casing or heavy duty carrier pipe
Sanitary Sewer	Relocate	May remain Relocate access chambers	May remain Relocate access chambers	May remain
Sanitary Service Connections	Not permitted	Relocate to below URA if grade permits or replace to URA zone	May remain	May remain
Storm Sewer & Service Connections	Not permitted	May remain Relocate access chambers	May remain Relocate access chambers	May remain
Water Mains	Not permitted	Not permitted	Permitted if in steel casing or heavy duty carrier pipe	Permitted Access Chambers not permitted

Utility Type	ZONE 1 Utility Free Area (Top of Rail to 1.3 m below Top of Rail)	ZONE 2 Utility Restriction Area (1.3 to 1.7 m below Top of Rail)	ZONE 3 Below Utility Restriction Area (below 1.7 m from Top of Rail)	ZONE 4 Beside Utility Restriction Area (2.0 m width below grade)
Water Service Connections	Not permitted	Not permitted	Permitted if in steel casing or heavy duty carrier pipe	Permitted
Sanitary Sewer	Not permitted	Not permitted	Permitted Access Chambers not permitted	Permitted Access Chambers not permitted
Sanitary Service Connections	Not Permitted	Not Permitted	Permitted	Underground infrastructure permitted
Storm Sewer	Not permitted	Not permitted	1) Underground infrastructure permitted 2) Access Chambers not permitted	1) Underground infrastructure permitted 2) Access Chambers not permitted
Storm Sewer & Service Connections	Not permitted	Not permitted	Permitted Access Chambers not permitted	Permitted Access Chambers not permitted