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SCHEDULE 15-2
DESIGN AND CONSTRUCTION REQUIREMENTS

PART 8
UNDERGROUND STRUCTURES

ARTICLE 1 INTRODUCTION

1.1 General

(a) This Article 1 describes the design and construction requirements related to Underground Structures.

(b) The scope comprises all underground construction required within the Project limits primarily consisting of Tunnels, Underground Station Boxes, shafts, portals and any Underground Structure work required for the completion of, headwalls, sumps and pumping stations. Refer to Schedule 15-2, Part 1, Article 2 – Physical Layout for a description of the underground sections of the alignment.

(c) The scope includes temporary decking and support of excavations for Underground Structures, shafts, and retaining walls.

(d) The scope includes installation of Track, walkways, lighting, fire protection, OCS, Tunnel ventilation and all other systems necessary within Tunnels for operation of the system.

(e) The requirements of Schedule 15-2, Part 4 – Stations shall apply to Underground Station Boxes.

(f) DB Co shall determine the specific means and methods for construction of Underground Structures using Cut-and-Cover methods consistent with the design and construction criteria specified herein.

(g) DB Co shall perform excavations and install temporary excavation support and initial support in a manner consistent with the requirements of Schedule 15-2, Part 2, Article 9 – Protection of Existing Adjacent Structures to minimize ground and Structure movement and deformation. Soil excavation and backfill shall be sequenced such that unbalanced soil loading on EAS will not exceed 1m.

1.2 Scope

(a) DB Co shall integrate the design and construction requirements of this Part 8 with other contract requirements including the following:

(i) Operational performance requirements for determination of the interior Tunnel space to accommodate Track alignment and Tunnel opening size relative to minimum clearance envelopes and required infrastructure - refer to Schedule 15-2 – Design and Construction Requirements:

A. Part 1 – General Requirements;

B. Part 2 –Civil and Guideway;

C. Part 3 –Systems; and

D. Part 4 –Stations.

(ii) Permanent retained earth structures other than Underground Structures – Schedule 15-2, Part 2, Article 7 – Geotechnical Design Criteria and Requirements;

(iii) Protection of EAS during construction – refer to Schedule 15-2, Part 2, Article 9 – Protection of Existing Adjacent Structures;

(iv) Structural design requirements for structural elements located underground but not meeting the definition of Underground Structures such as retaining walls, building and bridge foundations– refer to Schedule 15-2, Part 2, Article 4 – Structural Design Criteria and Requirements;

(v) Corrosion control and stray current protection - refer to Schedule 15-2, Part 3, Article 12 – Corrosion Control;

(vi) Geotechnical requirements – refer to Schedule 15-2, Part 2, Article 7 – Geotechnical Design Criteria and Requirements; and

(vii) Environmental requirements – refer to Schedule 17 – Environmental Obligations.

(b) DB Co shall sequence construction to mitigate impacts to the surrounding infrastructure, including vehicular and pedestrian circulation, access to and egress from adjacent structures, and disruption to existing Utilities. Such construction sequencing shall consider the order of execution of the work, including the need for multiple shifts, night-time or weekend work and material deliveries and removal of excavated materials. Refer to Schedule 15-2, Part 1 Article 5 – Implementation Constraints, and Schedule 15-2, Part 7 – Traffic and Transit Management and Construction Access.

(c) DB Co shall perform a detailed geo-referenced 3D survey of the "as-built" Tunnel alignment and all Underground Structures using digital mapping and laser scanning technology. The survey shall provide the actual "as-built" condition of the Underground Structures including but not limited to documentation of the condition of the interior face of the structural concrete. Scanning shall be performed before installation of the Underground Structure systems and finishes. Submit a digital copy of the survey to the City for record in accordance with Schedule 10 – Review Procedure. The scanning system and digital imagery shall be capable of meeting the following minimum technical requirements:

(i) Measurement range accuracy: +/- 10mm

(ii) Angular accuracy: 0.002 degrees

(iii) Recording distance: 2m to 300m, with the capability of recording at ranges less than 2m and more than 300m

(iv) Field of View: Full 360 degrees without gaps.

(v) Scan precision: 5mm

(vi) Point cloud spacing: 5mm

(vii) Colour image resolution: three - 36 megapixel cameras, series of photos taken a minimum of every 3m along the underground structure axis

(viii) Pixel size: distance dependent (2mm to 5mm depending on profile size)

(d) Where exterior waterproofing of Existing Adjacent Structures adjacent to Cut-and-Cover excavations is required to be removed to facilitate construction or is otherwise damaged during construction, it shall be repaired or replaced in-kind by DB Co to ensure future leakage into Existing Adjacent Structures is less than or equal to pre-construction conditions.

(e) Means of Egress

(i) DB Co shall provide means of egress for Emergency evacuation of a Train at any point within the Tunnels and open cut sections in conformance with NFPA 130 and the Safety Management System. Emergency evacuation to the surface from Underground Structures shall be through the Underground Stations and the Tunnel Portals. No EEBs shall be located within the Tunnel sections.

(ii) Emergency Egress including but not limited to routes, cross passages, walkways and egress components shall conform with the requirements of NFPA 130.

(iii) Where continuity of the egress route requires walking down to the Track level to reach the evacuation point at an Underground Station Platform, handrails and guards shall be provided at the stairs leading down from the walkway to the Track.

(iv) At locations where trains are expected to reverse direction, a walkway, equal to the length of the train, shall be provided to allow the driver to safely exit the cab at one end of the train, walk to the cab at the other end of the train, and reboard. This walkway shall avoid encroachment into the dynamic envelope of a Revenue Vehicle on an adjacent Track.

(v) DB Co shall provide a storage facility room exclusively for the use of ESP with internal dimensions of 2.0m x 3.0m x 2.8m height. The room shall be located along the portal sidewall and accessed from the emergency walkway, located no more than 2m from the Tunnel opening.

1.3 Codes, Standards and Regulations

(a) The design and construction of the Works shall comply with the criteria contained in this Article 1, and all standards, regulations, policies, Applicable Law, guidelines or practices applicable to the Project. The codes, standards, and references indicated in this Clause 1.3 shall be utilized for the design and construction of the Underground Structures indicated in this Article 1, except as explicitly indicated in other Articles. The structural design shall conform to the most current edition of the following codes and standards.

(i) CAN/CSA-S6 Canadian Highway Bridge Design Code

(ii) CAN/CSA A23.3 Design of Concrete Structures

(iii) CAN/CSA A23.1/A23.2 - Concrete Materials and Methods of Concrete Construction/Test Methods and Standard Practices for Concrete;

(iv) CAN/CSA S16 - Design of Steel Structures

(v) CAN/CSA O86 - Engineering Design in Wood

(vi) AREMA Manual for Railway Engineering

ARTICLE 2 TEMPORARY SUPPORT OF EXCAVATION

2.1 Scope

(a) This Article 2 specifies structural design and performance criteria for the temporary SOE for Cut-and-Cover Structures including but not limited to:

(i) temporary excavation support and underpinning systems; and

(ii) temporary traffic support, including pedestrian, vehicular and rail traffic, as applicable.

(b) If any SOE components are incorporated into the permanent Works, the SOE components shall also meet all requirements for permanent Works including, but not limited to Design Life, durability and waterproofing.

(c) Existing temporary SOE

(i) Where the SOE systems used for the construction of existing buildings adjacent to the alignment interfere with the construction of the Underground Structures, DB Co shall ensure these SOE systems are not part of the existing building's permanent foundation and can be removed without impact to the building.

2.2 General Structural Design Criteria

(a) DB Co shall design for temporary excavation support, underpinning, and temporary traffic support, including pedestrian, vehicular and rail traffic systems that, in conjunction with the selected sequencing, means and methods for excavation and construction of the Cut-and-Cover Structures, is in compliance with the requirements of this Project and Relevant Authorities.

(b) Design and construction of all temporary SOE work including decking and retaining walls shall be in conformance with the requirements of CAN/CSA-S6 and Schedule 15-2, Part 2, Article 7 – Geotechnical Design Criteria and Requirements, as applicable and the additional requirements herein.

2.3 Materials

(a) DB Co shall select materials for strength, geometry, initial set, toughness, and other qualities required for the means and methods selected to perform the Works and in accordance with requirements, standards, specifications and information specified herein.

(b) Temporary works constructed of reinforced concrete shall meet the minimum design requirements of Table 8-2.1; as defined by CSA A23.1 Concrete materials and methods of concrete construction;

Table 8-2.1: Temporary Works Minimum Design Criteria

Application	Exposure	Minimum Required Compressive Strength f'_c (MPa)	Acceptance Age of Required Compressive Strength (days)	Nominal Maximum Aggregate Size (mm^2)	Cement Type
Shotcrete	C-2	40	28	28	GU or GUb
Precast Concrete for Temporary Road Deck	C-1	55	28	20	GU or GUb

(c) Temporary ground anchoring systems used for temporary excavation support or initial support shall consider the location of utilities and comply with right of way restrictions, all requirements of Article 2.5 of Schedule 15-2, Part 1 – General Requirements, and Schedule 20 – Lands.

(d) Traffic decking surfaces shall provide a static coefficient of friction not less than 0.5 as determined by ASTM D2047, F609. Timber decking, if used, shall be surfaced with asphalt or other uniform covering that will provide a coefficient of friction of at least 0.5. Uncovered timber will not be permitted.

2.4 Loads

(a) Temporary works shall be designed using the applicable loads and load combinations from Schedule 15-2, Part 2, Article 4 – Structural Design Criteria and Requirements, as required per CAN/CSA-S6 for construction loads and loads on temporary structures.

(b) The potential for unsymmetrical vertical loads or unbalanced horizontal loads due to variations in ground conditions or properties and construction sequencing shall be accounted for as follows:

(i) Lateral soil loading on temporary excavation support for Underground Structures shall be based on the soil properties as determined by DB Co, the type of support proposed and the means and methods for construction. This shall also apply to temporary excavation support that is incorporated into the permanent Underground Structure.

(ii) Rock loading on temporary excavation support for Underground Structures: Lateral rock loading and the type of support proposed and the means and methods for construction shall be determined by DB Co. This shall also apply to temporary excavation support that is incorporated into the permanent Underground Structure.

(c) Seismic loads need not be considered for the design of temporary excavation support.

2.5 Monitoring Requirements:

(a) DB Co shall integrate the following monitoring requirements with the monitoring requirements in Schedule 15-2, Part 2, Article 7 – Geotechnical Design Criteria and Requirements.

(b) Where applicable the City will turn over existing instrumentation installed by other contractors in Existing Third Party Infrastructure prior to any excavation within the ZOI of the EAS as defined in Schedule 15-2, Part 2, Article 7 – Geotechnical Design Criteria and Requirements, to DB Co who shall:

(i) incorporate the instrumentation into the GIMP;

(ii) continue to read the instruments at the frequencies specified in the GIMP; and

(iii) decommission instrumentation when not required per the GIMP and restore the Site, surfaces or area disturbed by the instrumentation installation.

(c) Temporary excavation support and initial support shall be monitored using a management system incorporating Review Levels and Alert Levels, as outlined in Schedule 15-2, Part 2, Article 9 – Protection of Existing Adjacent Structures.

(d) DB Co shall develop review procedures to ensure that the excavation and support for Underground Structures are proceeding as planned, and shall consider all relevant factors when evaluating the performance of the temporary excavation support and initial support.

(e) DB Co shall develop contingency plans and mitigation measures to address temporary or initial support that fails to meet the performance requirements developed by DB Co in accordance with the requirements of Schedule 15-2, Part 2, Article 9 – Protection of Existing Adjacent Structures.

2.6 Crossing and Underpinning of Existing Facilities

(a) This section applies to Temporary SOE for:

(i) Underground Structures that cross over and pass within close proximity of the WNC combined sewer.

(ii) Locations where the Underground Structures pass within close proximity of Existing Adjacent Structures within the Project ZOI and the analysis requirements of Schedule 15-2 Part 2 Article 9 - Protection of Existing Adjacent Structures indicate mitigation measures are necessary.

(b) DB Co shall develop and submit in accordance with Schedule 10 – Review Procedure SOE plans for the construction of Underground Structures crossing over and in close

proximity to the existing facilities. The plans shall include methods for installing and maintaining the SOE without damaging and imposing loads on the existing facilities.

(c) Protection of Existing Utilities within the limits of the Cut-and-Cover construction shall be in accordance with Schedule 15-2, Part 2, Article 8 – Utility Infrastructure Design Criteria.

(d) DB Co shall install and monitor instruments on temporary SOE and EAS in accordance with the GIMP requirements of Schedule 15-2, Part 2, Article 7 – Geotechnical Design Criteria and Requirements, to monitor any settlement or deformations of the EAS resulting from Cut-and-Cover construction activities.

ARTICLE 3 CUT-AND-COVER STRUCTURES

3.1 Scope

(a) The scope of work includes designing, furnishing, and constructing permanent Cut-and-Cover Structures.

3.2 Durability Criteria

(a) DB Co shall design Cut-and-Cover Structures that are durable and structurally sound to achieve the Design Life specified in Schedule 15-2, Part 1, Article 4 – Design and Construction, and durability requirements specified herein.

(b) Durability – DB Co shall prepare and submit a durability report for the Underground Structures that incorporates the design recommendations of CSA S478-95 (R2007) Guidelines on Durability in Buildings with consideration of the corrosive properties of the soil and groundwater in contact with the Underground Structures. The report shall include the results of durability modelling to demonstrate that the design of Underground Structures meets the Project specified Design Life. Develop and submit results from a durability model of the concrete Structure using a widely accepted software package such as Life365 or Stadium. The model shall be used to demonstrate expected life cycle performance consistent with the Project requirements. Refer to ACI 201.2R Guide to Durable Concrete for information regarding causes of concrete deterioration and recommended methods to prevent such deterioration.

(c) Cut-and-Cover Structures shall be constructed of reinforced concrete meeting the minimum design requirements of Table 8-3.1 as defined by CSA A23.1 Concrete materials and methods of concrete construction;

Table 8-3.1: Permanent Underground Structures Minimum Design Criteria

Application	Exposure	Minimum Required Compressive Strength f'_c (MPa)	Acceptance Age of Required Compressive Strength (days)	Nominal Maximum Aggregate Size (mm^2)	Cement Type
Permanent Concrete Structure	C-3	40	28	28	GU or GUb
Permanent Concrete Structure <2m from top of roadway	C-XL	50	56	28	GU or GUb

Shotcrete	C-2	32	28	28	GU or GUb

(d) Cast-in-place concrete and constituent materials shall comply with CSA A23.1

(e) Concrete reinforcement shall conform to the requirements of the applicable Standards listed in CSA A23.1. The use of steel fibers as the sole and primary source of concrete reinforcement shall not be permitted.

(f) Permanent ground anchoring systems used in the Tunnel and Underground Station Boxes shall consist of steel bars, wires or strands and be corrosion protected.

(g) Structural steel shall meet the material requirements specified in Clause 4.11 of Schedule 15-2, Part 4 – Stations. Structural steel in Underground Structures shall not be permanently exposed to earth or in contact with the ground.

(h) Cast in place and post installed concrete anchoring systems shall meet the design requirements of CSA 23.3 Annex D and be corrosion resistant. The use of adhesive anchoring systems to support overhead components in Underground Structures shall not be permitted.

(i) DB Co shall develop and implement a quality control program for the construction of Cut-and-Cover reinforced concrete structures and submit the program quality control plan in accordance with Schedule 10 – Review Procedure. At a minimum the quality control plan shall address the procedures for proportioning, producing, mixing and placing concrete per the standards of CSA A23.1. All records and quality documentation included in the quality control plan shall be made available to the City upon their request.

3.3 Structural Design Criteria

(a) The structural design of Underground Structures shall comply with the requirements of CAN/CSA-S6 for the ultimate limit states and serviceability limit states for structural concrete and the criteria specified herein, whichever is more stringent. Underground Structures with components designed using structural steel shall comply with the requirements of Schedule 15-2, Part 4, Article 4 – Structural Design Criteria.

(b) DB Co shall determine the appropriate level and scope of analysis for the Underground Structures based on criteria such as ground conditions, loading conditions and Cut-and-Cover construction methods unless otherwise noted herein.

(c) DB Co shall develop and apply loads and load combinations in accordance with the following requirements:

(i) The Underground Structures shall be designed using the applicable design loads defined in Clause 4.5 of Schedule 15-2, Part 2 – Civil and Guideway, except for seismic loads which shall follow the criteria herein.

(ii) Seismic Loads and Design Criteria

A. Site Classification shall be determined per the requirements in Clause 7.12 of Schedule 15-2, Part 2 – Civil and Guideway.

B. Design levels for MDE and ODE are defined in Clause 7.12 of Schedule 15-2, Part 2 – Civil and Guideway.

C. The general procedure for seismic design of Underground Structures shall be based on the ground deformation approach. Underground Structures shall be designed to accommodate the deformations imposed by the ground before, during and after the seismic event. Seismic design of Underground Structures shall consider two loading components: (1) the racking deformations due to the vertically propagating shear waves and (2) inertial forces due to vertical seismic motions. Determine both ODE and MDE level design considering soil-structure interaction effects.

D. Estimates of displacement capacity for Underground Structures shall not exceed the material strain limits of Table 8-3.2:

Table 8-3.2: Material Strain Limits for Earthquake Design Levels

EQ	Material	Strain Limit
ODE	Steel	0.0010
	Concrete	0.002
MDE	Steel	0.0020
	Concrete	0.0033

(iii) The Underground Structures shall be designed using the modified load factors of Table 8-3.3. For loads not included in Table 8-3.3 refer to CAN/CSA S-6 and Schedule 15-2, Part 2, Article 4 – Structural Design Criteria and Requirements for load factors.

Table 8-3.3: Load Factors for Underground Structures

Load	αmax	αmin
Dead (self weight)	1.25	0.9
Dead (earth backfill)	1.25	0.9

At rest and Active Earth Pressure	1.5	0.9
Hydrostatic (normal elevation)	1.25	0.9
Hydrostatic (flood elevation)	1.0	0
Live	1.5	0

(iv) The Underground Structures shall be designed using the applicable load combinations for ultimate (ULS) and serviceability (SLS) limit states of CAN/CSA-S6. Load combinations for ultimate strength design shall satisfy the minimum requirements of CAN/CSA-S6 for reinforced concrete buried structures. The additional load combinations of Table 8-3.4 shall also be used for the design,

Table 8-3.4: Additional Load Combinations for Underground Structures

Load Combination	Notes
SLS 1 = D	
SLS 2 = D + E	Buoyancy, consider with and without backfill, use 100 year flood elevation
SLS 3 = D + E + L	Construction, surcharge without backfill cover, use normal hydrostatic elevations
SLS 4 = D + E + L + K	Service check for cracking of concrete
ULS 1 = 1.4D(self weight)+1.5D(backfill)	
ULS 2 = αD + αE	
ULS 3 = αD + αE + αL + 1.25K	
ULS 4 = αD + αE + αL	Use 100 year flood elevation for Hydrostatic, consider with and without L
ULS 5 = αD + αE + 0.5L + EQ	Consider with and without backfill and L

(v) Vent shaft damper supports, ancillary walls and doors located within or adjacent to the Tunnel and Underground Stations, any divider walls and any equipment installed within the Underground Structures shall be designed to withstand the air pressures and cyclic loading generated by moving trains and mechanical

ventilation systems. Pressures shall be determined based on Revenue Vehicle and ventilation system design and performance data provided by the manufacturers.

(vi) Underground Structures shall be designed to resist temporary construction loading developed from the Cut-and-Cover construction means, methods and sequencing selected by DB Co.

(vii) DB Co shall engage with the City during design to determine if future development plans that will potentially load Underground Structures are available for inclusion in the design. Refer to Clause 9.6 of Schedule 15-2, Part 2 – Civil and Guideway, for future adjacent construction requirements and protection of Project Infrastructure for DB Co design role as it pertains to future development within the Underground Structure ZOI. Refer to Clause 2.10 of Schedule 15-2, Part 1 – General for future works in the design and construction of the Project that shall be protected for and included in the design and construction of Underground Structures.

(d) Hydrostatic loading shall consider the 100 year flood elevation for the determination of Underground Structure buoyancy. Uplift resistance for Underground Structures due to buoyancy loads shall follow the requirements for Cut-and-Cover Structures in Schedule 15-2, Part 2, Article 7 – Geotechnical Design Criteria and Requirements.

(e) Temporary excavation support and initial support shall not be used as measures to relieve the design loads on a permanent structural lining unless the initial support can achieve the required design life. Underground Structures that incorporate temporary excavation support into the permanent work shall include the unsymmetrical vertical and unbalanced horizontal loads of Clause 2.4(b), of this Part 8 in addition to the long term loads of Clause 3.3(c) of this Part 8.

(f) Structures shall be designed to prevent collapse and minimize damage from derailment. Where safety guard rails are not provided, or are ineffective in preventing impact, columns and walls situated within 7.5m as measured perpendicular from the centerline of a Track and not protected by reinforced concrete benches, platforms or crash barriers, shall be designed to withstand derailment forces.

(g) DB Co shall comply with the following design requirements for fire resistance of Underground Structures:

(i) The structural integrity and Design Life of the Underground Structures subjected to the design fire outlined in Article 7– Tunnel and Station Ventilation Design Criteria, of this Part 8, shall not be compromised during the fire event.

(ii) Explosive spalling of concrete shall be mitigated by methods such as the inclusion of micro polypropylene fibres to the concrete mix for permanent linings or by providing a fire resistant interior lining.

(iii) The development of gas temperature shall correspond to recognized temperature versus time curves per ITA Fire Guidelines Figure 2.4 unless Project-specific curves are developed by DB Co.

(iv) DB Co shall design the Underground Structures following exposure to a fire by incorporating degradation in material properties due to temperature to ensure that Underground Structures shall not collapse following exposure to a fire.

(v) All structural steel members shall be protected from direct fire exposure based on the specified fire intensity outlined in Article 7 – Tunnel and Station Ventilation Design Criteria, of this Part 8.

3.4 Waterproofing

(a) DB Co shall design and construct Underground Structures located in regions of sensitive clays susceptible to stress increase and potential settlement from groundwater drawdown as undrained structures. Refer to Schedule 15-2, Part 2, Article 7 – Geotechnical Design Criteria and Requirements, identifying regions of the alignment subject to groundwater drawdown restrictions. Undrained structures are defined as structures that do not employ a drainage system that actively lowers the groundwater level to relieve hydrostatic pressure on the structure.

(b) DB Co shall apply permanent concrete treatments such as sealers and coatings to ensure that any water present on internal surfaces does not affect the safety, durability and function of the Underground Structures.

(c) DB Co shall meet the following criteria for water-tightness throughout the design life for new Underground Structures and new portions of existing Underground Structures:

(i) A maximum overall water infiltration rate $0.2L/m^2$ of Underground Structures perimeter per day measured over any 1000m length of Underground Structure not to exceed $0.4L/m^2$ of Underground Structures perimeter per day measured over any 10m length of Underground Structure.

(ii) Underground Structures shall have:

A. no identifiable or visible flow of water into the structure; and

B. no drips or seepage of water:

i. on walkways or egress passageways; or

ii. over the rail surfaces; or

iii. over the OCS; or

iv. where water has the potential to freeze on surfaces of Underground Structures; or

v. where the dripping of water has the potential to cause damage to equipment or the malfunctioning of any electrical power, signaling, lighting, control or communication equipment, or to compromise electrical clearances;

C. no water penetration into embedded conduits and pull boxes; and

D. soil particles shall not enter into the structure through water ingress.

(iii) Public areas of stations, corridors and passageways and all electrical rooms including communications and signal rooms, shall be watertight. Where cavities are provided behind finishes, the cavities shall be:

A. drained and vented and

B. include cleanouts or other access points to allow inspection for compliance with the maximum overall water infiltration rate.

(d) DB Co shall comply with the following additional provisions for new Underground Structures and new portions of existing Underground Structures:

(i) Underground Station Boxes shall be designed and constructed with a permanent waterproofing system around the entire perimeter of the Underground Station Box. If the Underground Station Box incorporates the SOE systems into the permanent structure meeting the requirement of Clause 2.1(b) of this Part 8, the Underground Station Box shall be designed and constructed with a permanent waterproofing system applied to the exterior of the invert and roof slabs with a 100 mm minimum drained and vented wall cavity for drainage behind finishes in exterior station walls and exterior walls of electrical and equipment rooms. The waterproofing systems shall include terminations as required to ensure the Station water tightness criteria is achieved and incorporate the groundwater drawdown restrictions of Clause 3.4(a) of this Part 8, and as determined by evaluation of geotechnical conditions.

(ii) Provide waterstops in all slab and wall construction joints of Underground Structures, including joints and transitions between existing and new Underground Structures.

(iii) The number of construction joints in Underground Structures shall be the minimum necessary to facilitate construction without inducing shrinkage stresses that result in shrinkage cracks exceeding the crack limits specified herein.

(iv) Design concrete to limit the crack width on the exterior face of exterior walls to 0.25 mm and the interior face of exterior walls to 0.35mm.

(v) Design shall prevent the freezing of any water in the Tunnels, Underground Station Boxes and portals from groundwater infiltration and surface drainage.

The design shall ensure there is no buildup of ice and snow over the top of rails, walking surfaces and in drainage structures.

(e) DB Co shall prepare and submit in accordance with Schedule 10 – Review Procedure a report detailing the waterproofing plan that includes at a minimum:

(i) proposed methods and details for meeting the specified maximum water infiltration rate;

(ii) DB Co's previous experience with similar waterproofing systems, effectiveness of those systems and lessons learned that will be implemented on the Project;

(iii) remedial measures to achieve and maintain the water tightness criteria beyond construction and throughout the Design Life; and

(iv) measures to facilitate inspection of the Underground Structures at potential leaks and any remedial measures proposed to protect and/or restore the structure to achieve the required Design Life.

(f) The existing Underground Structure at Baseline Station is required to meet all of the water tightness criteria of Article 3.4.(c) except as modified herein:

(i) A maximum overall water infiltration rate of $0.75L/m^2$ of Underground Structures perimeter per day measured over any 300m length of Underground Structure not to exceed $1.5L/m^2$ of Underground Structures perimeter per day measured over any 10m length of Underground Structure;

(ii) Existing leaks documented in the reference documents and any additional water infiltration noted during design and construction that results in the exceedance of the infiltration rate requirements in Clause 3.4(f)(i) of this Part, and does not meet the criteria of Clause 3.4(c)(ii) of this Part, shall require leak remediation. DB Co shall design and construct leak remediation solutions which at a minimum shall consist of but not be limited to the following:

A. Concrete repairs of cracks, spalls and other defects where water is infiltrating the structure;

B. Remedial grouting using chemical or cement grouting methods based on available Baseline Station structure, subsurface geotechnical, and adjacent structure information;

C. Water infiltration management designs that collect and divert water away from the elements and Station Box locations identified in Clause 3.4(c) of this Part and discharge into the existing Station Box drainage system. Modifications to the existing Station Box to accommodate a water infiltration management system shall comply with the clearance

requirements of Article 2.12 of Schedule 15-2, Part 2 – Civil and Guideway; and,

D. Sealing around the perimeter of concrete penetrations and openings.

3.5 Crossing of West Nepean Collector

(a) DB Co shall develop and submit plans in accordance with Schedule 10 – Review Procedure for the section of Tunnel crossing over the existing WNC. The submittal shall include at a minimum:

(i) Structural drawings for the Tunnel crossing including details showing the means of isolating the Tunnel structure from the WNC. A minimum clear separation distance of 150mm shall be maintained between the outside face of the WNC lining and the outside face of the Tunnel structure through construction and the Design Life of the Tunnel.

(ii) Detailed analysis presented in a CLAR-2 report per Schedule 15-2, Part 2, Article 9 – Protection of Existing Structures, including all stages of construction using 2D and/or 3D finite element and finite difference simulation methods demonstrating that the Tunnel crossing design does not impose load on the WNC during construction and operation of the Tunnel. The analysis shall include the possibility of future settlement of the Tunnel and the transmission of Vehicle vibrations into the surrounding ground focusing on the impact to the WNC structure at the Tunnel crossing. The Tunnel crossing design shall include mitigative measures for the control of both Tunnel crossing and WNC ground settlements and Vehicle vibrations.

(iii) Physical alterations to the existing WNC may be considered if the design and construction of the Tunnel crossing cannot provide the minimum separation distance of 150mm, providing the following design and construction criteria are followed,

A. A detailed physical condition assessment presented in a CLAR-2 report shall be performed for the section of WNC requiring physical alterations to verify the integrity of the WNC and establish the WNC structural properties. The results of the physical condition assessment shall be used to determine the extent of WNC that can be removed and replaced without reducing the existing structural load capacity and hydraulic performance of the WNC.

B. WNC removals and replacement shall be subject to approval from the City. DB Co shall submit a WNC removal and replacement plan including at a minimum;

i. Results of the physical condition survey including as-built dimensions and structural properties,

ii. A Work plan with drawings showing the extent of removals including the sequencing of removals, means and methods of removals, temporary liner support if necessary and replacement section if necessary.

iii. Schedule identifying the calendar months and duration of WNC removals and replacement work. The schedule shall be coordinated with the City taking into consideration maximum seasonal volumes of storm and sanitary water conveyed by the WNC.

ARTICLE 4 MECHANICAL DESIGN CRITERIA

4.1 Scope

(a) This Article 4 contains mechanical criteria developed for the Underground Structures, and where applicable the Stations. These criteria govern the functional requirements for Track drainage and sub drainage facilities, and fire protection systems.

4.2 Codes, Standards and Regulations

(a) DB Co shall ensure that the design and construction of the Works complies with the criteria contained in this Article 4, and all standards, regulations, policies, Applicable Law, guidelines or practices applicable to the Project. Mechanical systems design shall apply, but not be limited to, all Applicable Codes & Standards as referenced in Schedule 15-2, Part 4 – Stations. In the event of a conflict between criteria, commitments or requirements contained within one document when compared with another, refer to Schedule 15-2, Part 4, Article 5 – Mechanical Design Criteria for order of precedence.

4.3 General Requirements

(a) The requirements include mechanical systems located in the Underground Structures. Mechanical systems will consist of Track drainage, sub drainage, Tunnel ventilation and Tunnel fire protection systems.

(i) All equipment, pipes, supports, accessories, and their connections to the Structure, shall be designed to resist seismic force and to accommodate seismic deflection in accordance with OBC 4.1.8.18.

(ii) Any anchorages into Tunnel concrete shall not compromise the water tightness of the Tunnel.

4.4 Track Drainage System

(a) DB Co shall design and construct the Track drainage system to collect water from all underground Track sections utilising a gravity flow system into pumping stations, consisting of, but not limited to Tunnel invert slab drainage troughs, catch basins, maintenance holes and drainage pipework.

(i) Track drainage troughs shall be designed to contain the design flow and prevent any overflow from occurring,

(ii) The system shall be designed such that flow blockages can be located by maintenance personnel, the design shall provide access for maintenance personnel to remove the blockage.

(iii) The pumping stations shall discharge the Track drainage water as permitted by the City. DB Co shall be responsible for obtaining any required discharge permits.

Refer to Schedule 15-2 Part 2, Article 5 – Drainage and Stormwater Management Design Criteria, for Track Drainage and SWM design criteria.

(iv) Drainage system components including drainage troughs subject to near and below freezing temperatures shall be heat traced.

(b) Water entering the Track areas is expected to be from, but not limited to, the following sources:

(i) Rain water entering the Tunnels from the portals

(ii) Rain water entering the Tunnels from ventilation shafts

(iii) Water discharged during fire-fighting operations within the Tunnels and/or stations

(iv) Water discharged during Tunnel wash-down

(v) sub-drainage

(c) DB Co shall design and construct the drainage pump stations as per the following:

(i) Pumping stations shall be provided at low points in the Tunnel alignment and portals. Tunnel pumping stations shall be accessed through the tunnel and shall remain completely below grade with no pump station structures at or above grade.

(ii) Pumping stations shall be designed to support the same loads used in the Tunnel design as specified in Clause 3.3 of this Part 8.

(iii) Pumping stations shall include a concrete sump pit, submersible pumps, water level controllers, and pumps control panel, and discharge to an oil and grit separator

(iv) Pump selection and number of pumps shall be designed to accommodate the design flow rates and incorporate redundancy, so that drainage of the Underground Structure and emergency egress routes is maintained at all times. Pumping stations shall include a minimum of two pumps providing duplex pump systems with a back-up power source. The pumps shall be designed with sufficient capacity to meet the underground drainage requirements while one pump is not in operation. Pump sets shall be either the submersible or self-priming type with proven reliability and be capable of handling grit through interception and pumping.

(v) Pumping stations shall be configured to allow pumps and accessories to be retrieved for servicing without requiring confined space entry.

(vi) Pumping stations shall be equipped with monorail lifts, stainless steel ladders in pits, stainless gas-tight sump covers, and grease sensors

(d) DB Co shall design and construct the pumping station control panels as per the following:

(i) Control panels and all accessories located in the pumping station, including cable connectors, fittings, indicating lights, push buttons, supporting mountings, etc. shall be constructed of materials to suit the environment of an Underground Structure, exposed to dust dirt and moisture.

(ii) Control panels shall operate the pumps in stages based on pre-determined water levels monitored by the sump water level monitoring system

(iii) Control panels shall facilitate the placement of local indicating lights & warning lights and provide alarm(s) back to the TOCC via. the SCADA system

4.5 Tunnel Dry Standpipe System

(a) DB Co shall provide a manual, dry, Class I, standpipe system conforming to OBC, NFPA 14 and NFPA 130 throughout each Underground Structures section.

(b) DB Co shall ensure that the dry standpipe system including fire valves is located over and along the egress walkway side of the Tunnel.

(c) DB Co shall include the following components in the standpipe system:

(i) Fire department connections at station fire-fighter's access points;

(ii) Automatic air release valve assemblies to accelerate the charging of the standpipe lines; and

(iii) Fire valves located at 60m intervals along each Tunnel walkway of the Underground Structure.

(iv) Manual drain valves, heat traced drum drips.

(d) DB Co shall ensure that fire hydrants are located unobstructed and not more than 45m from the Tunnel cross passages or dry standpipe fire department connections.

(e) DB Co shall design and construct fire shut-off valves with signage to allow diversion of the system feed points from either end of the looped system at stations and/or cross passages as applicable to serve each full section of the dry fire line.

(f) DB Co shall design and construct fire valve sites to incorporate a 65mm fire hose valve positioned to discharge perpendicular to the Track.

(g) DB Co shall ensure that piping shall be steel pipe minimum Schedule 40 and meet NFPA standards.

(h) DB Co shall ensure that pipe sleeves shall be galvanized steel, minimum two sizes larger than carry pipe. Where pipe penetrates exterior structures, pipe sleeve shall be provided with water-proof seal.

ARTICLE 5 ELECTRICAL DESIGN CRITERIA

5.1 Introduction

(a) DB Co shall be responsible for the design, construction, testing and Commissioning of electrical distribution and lighting within the Underground Structures. This work shall be coordinated with electrical work within and adjacent to Stations specified in Schedule 15-2, Part 4 – Stations.

(b) DB Co shall ensure that electrical spaces are properly located and sized to facilitate the operation, installation and maintenance of equipment. Electrical system for the Underground Structures shall be designed to accommodate at least 25% spare capacity to protect for future growth and expansion of the power distribution systems.

(c) DB Co shall provide accessibility to permit removal and replacement of major equipment. Installation and removal routes of such equipment shall be clearly identified and dimensioned and included on submissions outlined in Schedule 10 – Review Procedure.

(d) DB Co shall ensure that electrical power distribution equipment is heavy duty construction selected to provide equipment longevity and shall be designed to provide lower arc flash potential during maintenance, high arc flash energy dispersion. Refer to Clause 6.1(i) of Schedule 15-2, Part 4 – Stations, for existing equipment and electrical distribution requirements for the existing Underground Structure at Baseline Station.

(e) DB Co shall design and construct all electrical equipment to be individually identified by a unique number matching the equipment schedule identification developed for the existing Confederation Line. The label shape, letter size, color coding and background color shall be standardized to match labels used on existing Confederation Line equipment. Identifying labels shall be designated for: cable trays, conduits, pull/junction boxes, cables/wires lighting fixtures including blue lights, maintenance receptacles and all electrical and electronic equipment (mini-substations, control cabinets, switches, etc). In addition to identification labels, approval labels shall be provided as required per either CSA or ULC.

(f) DB Co shall ensure that anchorages into Tunnel concrete shall not compromise the water tightness and structural integrity of the Tunnel.

(g) DB Co shall provide fixtures, equipment and raceways that are watertight and will not be damaged under Tunnel pressure washing operations.

5.2 Codes, Standards and Manuals

(a) DB Co shall design and construct the Works to comply with the criteria contained in this Article 5, and all standards, regulations, policies, Applicable Law, guidelines or practices applicable to the Project, including but not limited to each of the following Reference Documents. In the event of a conflict between criteria, commitments or requirements

contained within one document when compared with another, refer to Schedule 15-2, Part 4, Article 6 – Electrical Design Criteria for order of precedence:

(i) Refer to Schedule 15-2, Part 4, Article 6 – Electrical Design Criteria, for Design Codes, Standards, Regulations, and Guidelines.

5.3 Basis for Design

(a) DB Co shall design and construct the Work in accordance with the Electrical Load Classification as follows:

(i) Refer to the Clause 6.3(a) of Schedule 15-2, Part 4 – Stations, for Electrical Load Classification.

(b) DB Co shall perform calculations as per the following:

(i) Refer to Clause 6.3(b) of Schedule 15-2, Part 4 – Stations, for descriptions of the calculation requirements for the following:

A. short-circuit study;

B. protective device coordination study;

C. voltage drop including cables and motors;

D. grounding system study; and

E. lighting illumination calculations.

(ii) Arc flash Hazard calculations shall be extended to the high energy low voltage equipment with expected high arc fault current and/or protected by instantaneous only or time delayed protection settings.

(c) DB Co shall design and construct the Work in accordance with the electrical safety provisions as follows:

(i) Equipment ground fault "annunciation only" shall be provided where equipment ground fault protection is required by code or standard engineering practice for equipment or feeders serving Level 2 Emergency Systems.

(ii) Personnel ground fault protection shall be provided on branch circuits that have equipment or outlets for which personal protection is required either by code or standard engineering practice.

(iii) Arc flash Hazard warning labels shall be provided on the equipment as per required code. Flash boundary and incident energy values shall be displayed

5.4 Functional Requirements

(a) DB Co shall design and construct the electrical service as per the following:

(i) All Underground Structures electrical distribution shall comply with all Applicable Codes and standards including NFPA 130 and all other relevant standards referenced by NFPA 130,

(ii) For Underground Station feeder requirements for emergency systems, refer to Clause 6.4 of Schedule 15-2, Part 4 – Stations.

(b) DB Co shall design and construct system duct banks and pull-boxes as per the following:

(i) Duct banks and handholes shall be designed in accordance with the seismic criteria defined for the Project. Duct banks shall be designed to include at least 25% spare capacity to protect for future growth and expansion of each system accommodated in the duct bank. All ducts shall be roped.

(ii) Provide segregation between system within the duct-bank and pull-boxes. Provide dedicated pull-boxes for systems. Size pulls boxes accordingly to accommodate the manufacturer recommended cable bending radius. In addition to identification labels, approval labels shall be provided as required per either CSA or ULC.

(iii) Provide minimum two hour fire rating for the rooms within Underground Structures accommodating the equipment providing the power distribution inside the Underground Structures. Rate the equipment and distribution (conduits, wires) in accordance with the NFPA-130.

(c) DB Co shall design and construct Grounding and Bonding as per the following:

(i) All non-current-carrying metal enclosures and all alternating current equipment enclosures shall be securely connected/bonded to the grounding system. Provide local grounding for each major distribution system within the Underground Structures.

(d) DB Co shall design and construct Emergency and standby power sources as per the following:

(i) Refer to Schedule 15-2, Part 4, Article 6 – Electrical Design Criteria for emergency and standby power services.

(e) DB Co shall design and construct maintenance receptacles as per the following:

(i) Provide 120V/20A maintenance duplex GFI receptacles complete with water-resistant enclosure and cover spaced every 100m. Refer to Schedule 15-2, Part 4, Article 6 – Electrical Design Criteria for receptacle functional requirements. No more than two outlets shall be connected to a branch circuit.

(f) DB Co shall design and construct lighting as per the following:

(i) Lighting design shall be consistent across all Underground Structures. Provide sufficient illumination to provide safety and security for:

A. Passenger Emergency egress as per NFPA-130;

B. Blue lighting within the Underground Structure and portals as per NFPA-130; and,

C. Maintenance accesses as per Schedule 15-2, Part 4 – Stations.

(ii) Emergency power for lighting in the Underground Structure shall comply in terms of back-up time with the requirements of NFPA-130.

(iii) In the addition to the requirements highlighted in Schedule 15-2, Part 4 – Stations, for design, calculation, and validation of the results, lighting in the Underground Structures shall be selected, located, and/or aimed to accomplish their primary purpose while producing a minimum glare and interference with task accuracy for the Operators.

(iv) Lighting system shall be designed so that the failure of any single luminaire or lighting circuit shall not result in less than 2.7 lux.

(v) DB Co shall design and construct transitional lighting from underground to surface sections of the Project. The length of threshold/transition lighting shall be based on operating speeds and the corresponding safe stopping distance. DB Co shall review and take into account the given criteria in the American National Standard Practice for Tunnel Lighting – ANSI/IESNA RP-22 and TC – RTD 10 Transport Canada Road/Railway Grade Crossing Technical Manual: Guide for the Design of Roadway Lighting Transportation Association of Canada.

A. Lighting control systems shall be monitored and controlled through the facility BAS system. Where facility remote control system is not provided, a central-key/timer control system including override switches for controls in service areas shall be provided.

(vi) Lighting for exterior access to Underground Structures areas shall be designed to consider security, CPTED and CCTV requirements as per Guideline for Security Lighting for People, Property, and Public Spaces, IESNA G-1-03;

(vii) A TVA has been completed for the Confederation Line, as outlined in Schedule 15-2, Part 1, Article 7 – System Safety and Security Certification. DB Co shall update the TVA as per the requirements of Schedule 15-2, Part 1, Article 7 – System Safety and Security Certification, and shall ensure that the determination of the appropriate type of lighting is included.

(viii) Minimum illumination levels are outlined in Table 8-5.1

Table 8-5.1: Underground Structures

Location	Average Minimum Lux	Emergency
Passenger Emergency Egress (Tunnel Walkway)	15	15
Tracks, Cross-Overs and Catwalks	20	10
Track Switches	50	10
Tunnel Interior Zone	20	10
Tunnel Transition Zone (day)	50	N/A
Tunnel Threshold Zone (day)	500	N/A
Tunnel Portals (night)	20	10

**Note: 1.) All lighting, including, but not limited to Normal and Emergency lighting illumination levels, shall be designed to meet or exceed OBC, accessibility requirements, and security requirements including but not limited to, AODA, COADS, CPTED, CCTV and CAN/CSA B651 requirements. 2.) Illuminated areas and values not listed in this table shall be per 5.4 (f)(v) above.*

(g) DB Co shall design and construct power distribution within Underground Structures and portals as per the following:

(i) Provide power distribution within Underground Structures for each system requiring a power supply (voltage level, type of load (normal, essential or critical) to be coordinated with Schedule 15-2, Part 4 – Stations.

(ii) Primary switching rooms for incoming services including any underground TPSS shall be:

A. Designed in coordination with **[REDACTED]** and in accordance to **[REDACTED]** specification GSC002: Primary Voltage Service Specification.

B. Coordinated with **[REDACTED]** in terms of switchgear location and placement within rooms.

C. Designed for a 3 hour fire envelope.

(h) DB Co shall design and construct metering and monitoring as per the following:

(i) Remote monitoring shall be provided to:

A. Underground Structures main panelboard breaker position; and

B. Voltage availability at the main buses.

ARTICLE 6 SYSTEMS INTERFACE

6.1 Scope

(a) DB Co shall develop all system and infrastructure requirements within the Underground Structures as detailed in Schedule 15-2, Part 3 - Systems.

6.2 Systems to Tunnel Infrastructure Interface

(a) DB Co shall develop designs to integrate with the Underground Structures including but not limited to the following elements:

(i) Tunnel invert design; and

(ii) FLS; and

(iii) Tunnel and Station Ventilation; and

(iv) OCS design; and

(v) Communication systems design; and

(vi) Tunnel portal intrusion detection system design; and

(vii) conduit provisions; and

(viii) Emergency egress requirements.

6.3 General Interface Requirements

(a) DB Co shall be responsible for designing the Tunnel interface to provide the required clearance for the Revenue Vehicle to maintain for safe operation.

(i) DB Co shall develop and provide a swept path analysis along the length of the ROW to confirm that all elements including safety walkway and all system elements and equipment are clear of the required envelope of the train as defined in Schedule 15-2, Part 2, Article 2 – Geometric Design Criteria, for Track alignment.

(ii) DB Co shall analyze impact to clearance envelopes based on Track form and invert design.

(iii) DB Co shall ensure that all Electric Traction installations as defined in Schedule 15-2, Part 3, Article 13 – Traction Power System can be accessed when standing on the safety walkway.

(b) DB Co shall design the OCS to adhere to the vehicle manufacturer requirements for:

(i) nominal operating height as per Schedule 15-2, Part 3 – Systems;

(ii) maximum rate of change of the pantograph as per Schedule 15-2, Part 3 – Systems;

(iii) electrical clearances as per AREMA, OESC and CSA standards; and,

(iv) any additional considerations to ensure safe operation of the Vehicle.

(c) DB Co shall ensure that equipment and raceways are appropriately designed and sealed to prevent water and material infiltration during Tunnel cleaning operations.

6.4 Interface with Tunnel

(a) Anchorages into Tunnel concrete shall not compromise the water tightness of the Tunnel.

(b) DB Co shall ensure that all system interfaces with the Tunnel structure conform to the limits set out by the existing Tunnel liner. Limitations include the following:

(i) drill depth limitations into the liner;

(ii) drill point locations;

(iii) loading considerations;

(c) DB Co shall be responsible for determining loads from the OCS in accordance with the requirements of Schedule 15-2, Part 3, Article 14 – Overhead Contact System.

6.5 Invert and Cabling Requirements

(a) DB Co shall determine all cabling requirements within the Underground Structures;

(b) DB Co shall maximize the use of embedded conduits, or cable raceways as applicable, within Underground Structures;

(c) DB Co shall ensure that pull boxes are provided at a maximum spacing of 120m or a total cumulative bend radius of 270 degrees;

(d) DB Co shall ensure that pull boxes are adequately grounded and bonded in accordance with OESC;

(e) DB Co shall ensure that there are sufficient cross conduit connections within the invert to support system installation as well as future system requirements. Cross conduit connections shall consist of the following as a minimum:

(i) location requirements: Within 10m of the start of a Tunnel segment (Cut-and-Cover section boundary) and a maximum spacing of 300m; and

(ii) minimum cross conduit requirements: 2-50mm I.D. Schedule 40 PVC conduits if embedded, RGS if exposed.

(f) DB Co shall ensure that cable provisions along the Underground Structures include a minimum spare capacity for future system expansion;

(i) a minimum of 25% spare capacity to support future system installation; and

(ii) provision along the Tunnel walls to allow for surface mounted cable installation running the length of the Tunnel

ARTICLE 7 TUNNEL AND STATION VENTILATION DESIGN CRITERIA

7.1 Scope

(a) The scope includes the requirements for the design, installation, testing and Commissioning of the Emergency ventilation systems for the Tunnels and for the Underground Stations.

7.2 Codes, Standards and Manuals

(a) The design and construction of the Works shall comply with the criteria contained in this Article 7, and all standards, regulations, policies, Applicable Law, guidelines or practices applicable to the Project, including but not limited to each of the following Reference Documents, In the event of a conflict between criteria, commitments or requirements contained within one document when compared with another, refer to Schedule 15-2, Part 1, Article 1 – Reference Documents for order of precedence:

(i) OBC;

(ii) OFC;

(iii) OESC;

(iv) CSA;

(v) CEC;

(vi) OHSA;

(vii) ANSI/AMCA Standard 210-07 | ANSI/ASHRAE 51-07, "Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating"

(viii) ANSI/AMCA 250-12, "Laboratory Methods of Testing Jet Tunnel Fans for Performance

(ix) AMCA Standard 300, Test Code for Sound Rating Air Moving Devices;

(x) AMCA Standard 301, Methods for Calculating Fan Sound Ratings from Laboratory Test Data;

(xi) ANSI;

(xii) ASHRAE Handbooks; Particular references shall be made to the following sections of ASHRAE:

A. ANSI/ASHRAE Standard 62.1-2010;

(xiii) MNECB;

(xiv) ASME;

(xv) ASTM;

(xvi) APTA, Rail Transit Committee, Guidelines for Design of Rapid Transit Facilities;

(xvii) DOT Recommended Emergency Preparedness Guidelines for Rail Transit Systems;

(xviii) NEMA;

(xix) SMACNA;

(xx) ULC; and

(xxi) NFPA - Particular references shall be made to the following sections of NFPA:

A. NFPA Standard 70, National Electrical Code;

B. NFPA Standard 90A, lnstallation of Air-conditioning and Ventilating Systems;

C. NFPA Standard 130, Fixed Guideway Transit and Passenger Rail Systems;

D. NFPA Standard 204, Smoke and Heat Venting; and

E. NFPA Standard 502, Standard for Road Tunnels, Bridges and Other Limited Access Highways.

7.3 Emergency Ventilation

(a) General Requirements

(i) DB Co shall design and construct all Underground Structures including Underground Station Boxes in accordance with the ventilation requirements of NFPA 130.

(ii) Ventilation system(s) shall be provided for the control of heat and smoke in an emergency as required by NFPA 130.

(iii) DB Co, with City involvement for SCADA integration as stated in Schedule 15-2 Part 3 – Systems and the requirements of this Part 8, shall design and provide an Emergency ventilation system including all Emergency fans, dampers, controls, and accessories of the Emergency ventilation system as required by NFPA 130.

(iv) The design shall include provisions for the installation, removal and replacement of the ventilation system equipment.

(v) Manufacturers recommended clearances shall be provided around ventilation system equipment to facilitate maintenance, repair, installation, removal and replacement.

(vi) All ventilation system's equipment and controls shall be of similar appearance and functionality at all stations to minimize training requirements, and to provide easier operations and facilitate use.

(vii) DB Co shall perform SES analyses and CFD analyses of the ventilation system to validate the design.

(viii) DB Co shall conduct SES and CFD analyses for fire cases at the Station Platform, storage Tracks, running Tunnels and other areas including concourse areas to demonstrate that the design of the Underground Stations and Tunnels can provide the required tenability criteria based on NFPA 130. DB Co shall implement necessary modifications to the design (such as smoke baffles, barriers and additional fan capacity) to meet the tenability criteria based on the SES and CFD study results.

(ix) DB Co shall develop the SES and CFD modelling criteria. The criteria shall address and include the following sections at a minimum and shall be submitted in accordance with Schedule 10 – Review Procedure before the analyses are performed:

A. Applicable Codes and standards;

B. Tenability criteria and time of tenability calculations for Stations, and Tunnel;

C. Fire scenario development;

D. Fire detection time and ventilation system start up time;

E. Modelling input data and assumptions.

F. Acceptable limits and other constraints; and

G. Methodology.

(x) The ventilation zones shall be coordinated with the signaling system, Traction Power blocks, Train operation plans, and the Emergency response plans. Refer to Article 6 – Systems Interface, of this Part 8.

(xi) Ventilation zones shall be designed for one Train per ventilation zone in the Tunnel segments. More than one Train per ventilation zone shall be permitted if the following condition is met:

A. The Train control system shall be capable of removing non-incident Trains in the same time frame as the activation of the ventilation response and prior to the de-energization of the Traction Power. Refer to 7.2.5 and A.7.2.5 of NFPA 130 for additional information.

(b) System Operational Requirements

(i) DB Co shall ensure that the following operational requirements are met or exceeded by the Tunnel ventilation system.

A. System Operation

i. DB Co shall develop requirements for ventilation scenarios.

ii. DB Co shall develop ventilation modes to be implemented through the SCADA system as per Schedule 15-2, Part 3, Article 8 – SCADA System.

iii. The ventilation system's modes of operation shall be initiated from the TOCC or BCC through the SCADA system.

iv. The SCADA system shall include a schematic display of the Tunnel ventilation system indicating all the ventilation elements to be activated and their modes of operation.

v. All fans, dampers and modes of operation shall be monitored and controlled through SCADA system.

vi. All exit doors and cross passage doors shall be monitored and controlled through SCADA system.

vii. A ventilation control panel for local control of the Tunnel ventilation system shall be provided at each Underground Station/Facility that has an active controllable Tunnel ventilation system.

viii. The local ventilation control panels shall be capable of overriding the TOCC or BCC.

ix. Ventilation control panels shall be used in accordance with the operational and safety procedures and controls, to be developed to mitigate the Emergency scenarios developed in the system hazard analysis

x. The ventilation control panel shall be secured or located in a secure area of the Station.

(c) DB Co shall design and construct the Emergency ventilation systems to meet the following performance requirements:

(i) Emergency ventilation fans for Stations and Tunnels

A. Axial-flow fans - Station Emergency ventilation fans

i. Fans shall be of the axial-flow type, with internally mounted, directly driven motor and shall be reversible.

ii. Fans shall have adjustable-pitch blades, fitted to permit changes in fan-operating characteristics for future system modification.

iii. Fan motors shall be operated by variable frequency drives for commonality with existing City ventilation fans.

iv. The flow capacity in either direction (exhaust and supply) shall be equal to or greater than the rated capacity.

v. Fans shall be selected to have a total efficiency of not less than 60 percent in the forward (exhaust) flow mode.

vi. Each fan shall be provided with modular sound attenuators on both the inlet and discharge sides of the fan. Additional sound lining shall be provided as required so that maximum noise levels from ventilation systems do not exceed allowable limits. Any additional sound lining shall be accounted for in determining the pressure of the fan.

B. Jet fans – Tunnel Emergency ventilation fans

i. Jet fans shall be of the vane-axial type, and shall be equal or greater than the rated static thrust in either direction (forward and reverse mode).

ii. Jet fans shall be provided with appropriate sound attenuators.

iii. Fan power curve shall not exceed 100 percent of the motor rating at any point. The brake horsepower for reverse (supply) flow shall not exceed the brake horsepower for (exhaust) flow.

iv. There shall be no OCS supports installed within the length of the jet fan assembly including the attenuators. The first set of OCS supports shall not be less than 0.3m or more than 0.5m past the inlet or outlet of the jet fan assembly. The next set of supports, in either direction, shall be the maximum allowable distance per criteria in Article 6 – Systems Interface of this Part 8. OCS supports shall not be installed in the high velocity jet of the fans.

v. The design and layout of the fans shall provide maintenance access with the option to lower and raise the fans at the Track level from overhead supports without requiring removal of the OCS.

vi. A local disconnect switch shall be provided at each jet fan location.

C. Emergency ventilation dampers

i. Dampers shall be parallel-blade, industrial, heavy-duty type, weatherproof design. Two limit switches shall be provided in each damper actuator for remote monitoring of damper position, one for open and the other for closed position. Damper leakage at shutoff shall be less than or equal to UL555 Class1 Extended.

ii. By-pass dampers shall be specified to fail-close while fan dampers will be specified to fail in the position determined by the ventilation design.

iii. Where supported by an engineering analysis, the use of bypass dampers may be removed from the design.

(d) Equipment requirements

(i) DB Co shall design and construct the Emergency ventilation fans for Stations and Tunnels per the following equipment requirements:

A. Axial-flow fans - Station Emergency ventilation fans

i. Axial flow fans shall be suitable for operation individually or in parallel with other fans as applicable. Fan components shall meet the following minimum design criteria or otherwise approved equal;

1 Impeller;

1. Hub and blades of aluminum-alloy casting suitable for the specified performance and Underground Structure environment.

2 Fan housing including motor mounts and supports;

1. Hot-rolled steel.

2. Minimum gage 3.

3. Flange thickness shall be not less than fan housing thickness.

3 Support bolts, nuts, and washers;

1. Bolts shall be not less than 1/2 inch minimum in diameter. All bolts shall be Type 316 stainless steel conforming to ASTM A 193, Grade B8M on B8MA.

2. Nuts compatible for use with the above bolts shall be alloy steel conforming to ASTM A 194, Grade 2H.

3. Washers and lock washers used on the fans and components shall be of Type 316 stainless steel.

4 Motors;

1. Squirrel cage induction motors

2. Service Factor: 1.15

3. Minimum NEMA insulation Class H

4. Minimum NEMA temperature rise Class F

5. Motor bearings: Minimum L-10 rating equal to 40,000 hours at maximum capacity and maximum speed based on the bearing load imposed by the driven equipment.

5 Monitoring and instrumentation;

1. Fan/motor bearing vibration monitoring

2. Motor speed

3. Flow switches

4. Bearing temperatures

5. Minimum two 100 ohm, three wire platinum resistance type temperature RTD sensing detectors for each stator (phase) winding.

6 Encasements, enclosures, terminal boxes, junction boxes;

1. NEMA 4X stainless steel

ii. Sound attenuators for axial-flow fans shall consist of components that meet the following criteria or otherwise approved equal;

1 Shells;

1. Minimum 10 gage

2. ASTM A240, Type 304 stainless steel

2 Flanges and stiffeners;

1. Minimum gage 3 Type 304 stainless steel bent plate or ASTM A276 stainless steel angles

3 Splitters including the nose and tail and the face sheets;

1. Minimum 18 gage

2. ASTM A293 or ASTM A240, Type 304 stainless steel

4 Filler;

1. Inorganic mineral or glass fiber, inert, vermin-proof and resistant to high humidity conditions.

2. The filler material shall be protected with glass fiber cloth and stainless steel screen.

B. Jet fans – tunnel emergency ventilation fans

i. Jet fan components shall meet the following minimum criteria or otherwise approved equal;

1 Motor;

1. Service Factor: 1.15

2. Minimum NEMA insulation Class H

3. Minimum NEMA temperature rise Class F

4. Bearings: Minimum L-10 life rating equal to 40,000 hours at maximum capacity and maximum speed based on the bearing load imposed by the driven equipment

2 Impeller;

1. Hub and blades of aluminum-alloy casting suitable for the specified performance and environment

3 Fan housing including motor mounts and motor supports;

1. Hot-rolled steel

2. Minimum gage 3

3. Flange thickness shall be not less than fan housing thickness.

4 Support bolts, nuts, and washers;

1. Bolts and studs shall be not less than 5/8 inches in diameter with a nut, 2 plain washers and a lock washer.

2. All bolts and studs shall be of galvanized steel conforming to ASTM A 193, Grade B8M on B8MA.

3. Nuts compatible for use with the above bolts shall be alloy steel conforming to ASTM A 194, Grade 2H.

4. Washers and lock washers used on the fans and components shall be of galvanized steel.

5 Monitoring and instrumentation;

1. Fan/motor bearing vibration monitoring

2. Motor speed

3. Flow switches

4. Bearing temperatures

5. Minimum two 100 ohm, three wire platinum resistance type temperature RTD sensing detectors for each stator (phase) winding.

6 Encasements, enclosures, terminal boxes, junction boxes;

1. NEMA 4X stainless steel

7 Sound attenuators

1. Exterior casing: Minimum gage 18 hot dipped galvanized steel

2. Perforated sheets: Minimum gage 22 stainless steel

3. In fill material: Vermin free and moisture resistant inorganic mineral wool or glass fiber acoustic

8 Mesh screen: Hot dipped galvanized steel

C. Emergency ventilation dampers shall meet the following minimum criteria or otherwise approved equal;

i. Damper type: Parallel or opposed acting, multiple blade tunnel ventilation dampers

ii. Minimum net free area: 80%

iii. Frames;

1 Minimum gage 7 AISI Type 304 stainless steel

2 Minimum 152mm web

iv. Blades;

1 Blade positions: Fully open and fully closed

2 Minimum AISI Type 304 stainless steel

3 Minimum gage 14

v. Blade shafts;

1 Minimum 19mm diameter

2 Stainless steel rounds conforming to the requirements of ASTM A276, Type 304 or 303, Condition A, Class C conditioning

vi. Linkage

1 Minimum AISI Type 304 stainless steel

vii. Mullions

1 Minimum AISI Type 304 stainless steel

viii. Actuator;

1 Furnish with internal position limit switches

2 Motor;

3 Minimum NEMA insulation Class F

4 Minimum NEMA temperature rise Class B

D. Equipment nameplates shall be fabricated from AISI Type 304 or 316 stainless steel or otherwise approved equal.

(e) Smoke Dispersion/Recirculation Study

(i) DB Co shall undertake smoke dispersion analyses for Emergency ventilation systems to demonstrate the following:

A. Smoke discharged from Emergency ventilation shafts, Tunnel portals and Station openings to atmosphere is not drawn into the Station entrances or other Station air intakes;

B. Smoke discharged from Emergency ventilation shafts, Tunnel portals and Station openings to atmosphere is not drawn into Non-Station Entrances or air intake shafts of adjacent buildings including known future buildings;

C. Smoke re-circulation studies shall confirm that a minimum total smoke dilution ratio of 35:1 is reached at all air intakes to achieve a potential 10m visibility of make-up air; and,

D. Smoke re-circulation studies shall account for all wind conditions (wind speed, wind direction and frequency of occurrence).

(ii) Based on the study, the location of the Station facilities shall be adjusted to minimize recirculation impacts or other mitigating measures shall be identified and implemented.

(f) FLS Protocols

(i) DB Co shall be responsible for reviewing and if necessary updating the current FLS protocols based on the final design of the Emergency ventilation systems in compliance with Schedule 15-2, Part 1, Article 7 – System Safety Certification, and the following:

A. The development of the protocols shall involve a collaborative process involving DB Co, the City and the AHJ over FLS issues. This process shall be led and managed by DB Co;

B. The protocols shall include fan ventilation scenarios for the Emergency evacuation and ventilation of Stations and Tunnels in response to all potential FLS risks including but not limited to risks identified as a result of risk analysis;

C. Fan ventilation scenarios to outline the responsibilities of, the Operator, the City and ESP;

D. The role of the fire alarm annunciator panels in Stations is to be defined as part of the overall FLS system;

E. SOP shall be developed and agreed upon by all parties; and

F. The development of SOPs and FLS protocols shall be in full compliance with Schedule 15-2, Part 1, Article 7 – System Safety Certification, and this Article 7.

(g) Design Criteria

(i) DB Co shall apply the Design Criteria outlined in Tables 8-7.1, 8-7.2, and 8-7.3 to the Tunnel and Underground Station Emergency ventilation systems for Emergency ventilation including the associated Tunnel ventilation shaft structures and equipment.

Table 8-7.1: Design Fire Heat Release Rate

Location	**Maximum Fire Size**	**Minimum Growth Rate**
Guideway/Stations (Vehicle Fire)	13.2 MW	11.72 W/s^2*
Station Platform/Concourse (Trash Fire at station)	1.0 MW	46.89 W/s^2

* The growth rate of the Vehicle design fire shall be, at a minimum, the value listed in this table and can be adjusted for characteristics of the Vehicle.

Table 8-7.2: Air Velocity Criteria

Location	**Description**	**Velocity**
Guideway	Emergency Operation Maximum	11.0 m/s in areas where passengers may be present
Emergency	Emergency Operation	9.14 m/s max

Location	Description	Velocity
ventilation shafts and ducts		

(h) Noise Criteria

(i) Noise criteria shall comply with the Guidelines for Design of Rapid Transit Facilities as listed by the Rail Transit Committee, APTA and as required in Table 8-7.3.

Table 8-7.3: Ventilation Equipment Noise Limits

Scenario	Target Noise Level (NC)
Emergency Operation	70

(ii) During Emergency operations, the Tunnel ventilation noise shall not exceed Lmax 85 dB(A) within the Tunnel, and combined with the ventilation noise shall not exceed NC 70 as measured within the Station.

(iii) Refer to Schedule 17, Part 9 – Noise and Vibration, for information on external noise level restrictions.

(i) Smoke ventilation shaft locations

(i) Ventilation shafts shall not be located in the Tunnel sections between the East Portal and Cleary Station, Cleary Station and New Orchard Station, New Orchard Station and the West Portal.

(ii) The design shall account for air recirculation between exhaust shafts, intake shafts, portals and open Station openings. Openings for Emergency smoke ventilation shafts on the surface shall be separated by a minimum stretched string distance not less than the recommended distance determined by a detailed smoke dispersion/recirculation study in accordance with Clause 7.3 of this Part 8, from the closest Station entrance or exit and air intakes operating in supply mode serving the Station.

(iii) Openings for Emergency smoke ventilation on the surface shall be separated by a minimum horizontal distance of 12m from unprotected outside air intake or other openings of all other adjacent structures;

(iv) Where the above distance is not practical, the minimum distance shall be 4.5m if the closest shaft opening is raised a minimum of 2.5m above the Station entrance or exit, unprotected outside air intake or other openings. The final configuration and separation distances shall be supported by a detailed smoke dispersion/ recirculation study in accordance with Clause 7.3 of this Part 8;

(v) The minimum distance at grade between the edges of adjacent openings for outside air intakes, protected by smoke dampers, and openings for Emergency smoke ventilation shall be as follows:

A. $d = 0.25 \times (L1 + L2)$

i. Where: d = minimum distance between the edges of the adjacent openings, in meters,

ii. L1 + L2 = lengths of the adjacent parallel sides of the openings, in meters

(vi) Ventilation shaft openings on the surface shall be located to provide as direct a route to atmosphere as possible, to facilitate ease of airflow to and from the underground sections; Shaft openings shall include design features that mitigate the vulnerabilities identified in the TVA of Schedule 15-2, Part 1, Article 8 – Security and Emergency Management.

(vii) Ventilation shafts shall not terminate in driveway surfaces at parking garage entrances or other surfaces utilized for daily vehicular access;

(viii) Where not located in a sidewalk, vent shafts shall terminate a minimum 150 mm higher than any adjacent surface to exclude run-off drainage into the shaft; and

(ix) Gratings and louvers shall be of high security and tamper proof construction.

7.4 Normal Operation Requirements

(a) DB Co shall design the Underground Structures such that ventilation during normal operation is provided by the "piston effect" of the Trains moving through the Tunnels.

(b) DB Co shall design the Emergency ventilation fans to be capable of being used to maintain Tunnel air temperatures.

(c) Design Criteria

(i) DB Co shall apply the Design Criteria outlined in Tables 8-7.4, 8-7.5, 8-7.6 and 8-7.7 to the Tunnel and Station Emergency ventilation systems for normal operation including the associated Tunnel ventilation shaft structures and equipment.

Table 8-7.4: Outside Ambient Design Conditions (Ottawa, ON)

Description	Data	Source	Comment
Summer dry bulb design temperature	28.9°C	ASHRAE Fundamentals	1% occurrence
Summer wet bulb design temperature	20.8°C	ASHRAE Fundamentals	1% occurrence
Winter dry bulb design temperature	-24.2°C	ASHRAE Fundamentals	99.6% design value

Table 8-7.5: Air Temperature Design Criteria

Guideway – Normal Operation	
Maximum Average Temperature at Peak System Headway	Ambient + 3°C

Table 8-7.6: Air Velocity Criteria

Location	Description	Velocity
Public Areas of Station	Maximum velocity	5.10 m/s
Exterior inlets and outlets	Normal Operation/at sidewalk	2.5 m/s based on net free area of terminal gratings
	Normal Operation/not at sidewalk	Maximum velocity to be determined by site specific requirements.

(ii) Noise Criteria

A. Noise due to fan operation shall not exceed the allowable limits in areas accessible to the public. Noise criteria shall comply with the Guidelines for Design of Rapid Transit Facilities as listed by the Rail Transit Committee, APTA and as required in Table 8-7.7.

Table 8-7.7: Ventilation Equipment Noise Limits

Area	Target Noise Level (NC)

Platforms	45
Mezzanines	45
Station Booths	40
Retail	45

B. Refer to Schedule 17, Part 9 – Noise and Vibration, for information on external noise level restrictions.

(iii) Pressure Wave Criteria

A. DB Co shall ensure the design accounts for total changes in pressure greater than 0.69 kPa, in areas normally occupied by the public and employees, the maximum rate of pressure change shall be limited to 414 Pa/s.

B. DB Co shall design doors, support systems, and equipment exposed to changes in air pressure due to Train movement to withstand the expected repetitive pressure transient loading and pressure reversals.

7.5 Congested/Maintenance Operation Requirements

(a) DB Co shall design and construct the Tunnel ventilation system to be used to maintain temperatures, exhaust the fumes, and provide required fresh air to the Vehicles and patrons during a non-fire Emergency case, maintenance operation and non-Revenue Vehicle operation.

(b) DB Co shall design and construct the Tunnel ventilation system to be capable of diluting diesel fumes to acceptable concentrations during maintenance operations with the use of diesel stock or equipment.

(c) DB Co shall design and construct sliding doors located in the walls separating the Revenue Service and maintenance/Vehicle Storage Tracks at the Baseline Station LMSF with spacing coinciding with the length of the rolling stock to be used at the Station.

(d) Design Criteria

(i) DB Co shall apply the Design Criteria outlined in Table 8-7.8 to the Tunnel and Station Emergency ventilation systems including the associated Tunnel ventilation shaft structures and equipment.

Table 8-7.8: Air Temperature Design Criteria

Guideway – Congested Operation	
Maximum Temperature for Train A/C and electrical equipment	45°C
Maximum 5 min Local Peak Temperature	45°C

(ii) Refer to normal operation Design Criteria in Clause 7.4(c)(ii) of this Part 8 for ventilation equipment noise limits.