Article 5. Seismic 5-1

Article 5. Seismic

5.1 General

(a) This Article 5 [Seismic] specifies the seismic requirements and criteria for and in respect of the Design and Construction of the Work.

(b) Without limiting any other provisions of this Agreement, the Primary Contractor shall carry out all seismic, structural and geotechnical investigations, analyses, assessments, determinations, testing and development of inputs necessary to perform the Work in accordance with this Article 5 [Seismic].

(c) The seismic Design provided, performed or carried out by or on behalf of the Primary Contractor pursuant to this Agreement shall conform to, comply with and satisfy all of the requirements of this Agreement and all professional engineering principles and practices generally accepted as best industry practice in the Province of British Columbia.

5.2 Peer Review

5.2.1 Seismic Peer Review Panel

(a) The seismic Design of the Project shall, in addition to the Design and Construction Certification Procedures, be subject to an independent peer review by a peer review panel (the "**Seismic Peer Review Panel**"), appointed in accordance with Article 5.2.2 [Selection of Seismic Peer Review Panel] of this Part 2.

5.2.2 Selection of Seismic Peer Review Panel

(a) The Province shall appoint one member to the Seismic Peer Review Panel, which member shall be:

(i) available as of the Effective Date; and

(ii) generally available until the Substantial Completion Date.

(b) The Primary Contractor shall appoint one member to the Seismic Peer Review Panel, which member shall be:

(i) available on the Effective Date; and

(ii) generally available until the Substantial Completion Date.

(c) A third member of the Seismic Peer Review Panel shall be appointed by the first two members appointed in accordance with Articles 5.2.2(a) and (b) of this Part 2, as applicable. In the event that the first two members of the Seismic Peer Review Panel fail to agree upon the appointment of the third member of the

Seismic Peer Review Panel within 20 Business Days after the Effective Date, then either of the Province or the Primary Contractor may apply to the BCICAC for the appointment of the third member of the Seismic Peer Review Panel, in which case the BCICAC shall appoint the third member in accordance with Article 14 of the BCICAC's Domestic Commercial Arbitration Rules of Procedure.

(d) Unless otherwise agreed by the Province and the Primary Contractor, the third member of the Seismic Peer Review Panel appointed in accordance with Section 5.2.2(c) of this Part 2 shall serve as the chair of the Seismic Peer Review Panel.

(e) The Seismic Peer Review Panel members shall be Professional Engineers recognized as leading experts, and suitably qualified by education and/or profession or occupation in the areas of:

(i) structural and geotechnical seismic design;

(ii) structural and geotechnical seismic analysis;

(iii) soil liquefaction, and lateral spreading;

(iv) seismic ground motion;

(v) soil structure interaction; and

(vi) development of seismic codes and standards.

(f) The Province shall appoint a representative to act as the facilitator of the Seismic Peer Review Panel activities, including meetings, coordination and communications (the "**PRP Facilitator**"). The functions and responsibilities of the PRP Facilitator shall be to:

(i) coordinate with the Primary Contractor to schedule all presentation meetings to the Seismic Peer Review Panel;

(ii) in accordance with Articles 5.2.4 [Function of the Seismic Peer Review Panel] and 5.6 [Seismic Design Strategy Memorandum], both of this Part 2, receive and distribute all submittals and revised submittals from the Primary Contractor to the Province's Representative and the Seismic Peer Review Panel;

(iii) receive and distribute all submittals and revised submittals from the Province's Representative to the Primary Contractor and the Seismic Peer Review Panel;

(iv) host and formally document all formal Seismic Peer Review Panel meetings where the Primary Contractor and/or Province Representative is present, and distribute the minutes of such meetings to the Province's Representative, the Primary Contractor and to the Seismic Peer Review Panel;

(v) upon completion of each Seismic Peer Review Meeting, compile all Seismic Peer Review Panel review comments on submittals and revised submittals from the Primary Contractor and the Province's Representative, and distribute such comments to the Primary Contractor,

the Province's Representative and the Seismic Peer Review Panel within 7 Business Days of such meeting;

(vi) receive the responses of the Primary Contractor or the Province's Representative to the Seismic Peer Review Panel's comments and revised submittals in response to such review comments, and distribute the same to the Province's Representative, the Primary Contractor and the Seismic Peer Review Panel, as applicable; and

(vii) document and distribute to the Province's Representative and the Primary Contractor, as applicable, the approval of or rejection and comments regarding the Primary Contractor's submittals, revised submittals, and responses to review comments by the Seismic Peer Review Panel within 5 Business Days of such approval or rejection and comments.

(g) In coordination with the PRP Facilitator, and in accordance with Articles 5.2.4 [Function of the Seismic Peer Review Panel] and 5.6 [Seismic Design Strategy Memorandum], both of this Part 2, the Primary Contractor shall:

(i) provide a written request to schedule a Seismic Peer Review Panel meeting a minimum of 20 Business Days in advance of such meeting (or such other time period as the parties and the Seismic Peer Review Panel members may agree); and

(ii) submit all submittals, resolution of comments, and revised submittals for review and approval of the Seismic Peer Review Panel a minimum of 10 Business Days (or such other time period as the parties and the Seismic Peer Review Panel members may agree) in advance of the corresponding scheduled Peer Review Panel meeting.

(h) In coordination with the PRP Facilitator, the Province's Representative shall provide any comments regarding:

(i) the Primary Contractor's submittals, resolution of comments, and revised submittals for review within 5 Business Days of receipt of the applicable submittal, resolution of comments or revised submittal; and

(ii) the comments of the Seismic Peer Review Panel with respect to the Primary Contractor's submittals or revised submittals within 5 Business Days of receipt of any such comments.

(i) A quorum of the Seismic Peer Review Panel shall be 3 members. Decisions of the Seismic Peer Review Panel shall be made by a majority of the panel members.

5.2.3 Access and Communications

(a) The Province and the Primary Contractor shall permit the Seismic Peer Review Panel to have such access to the Site and to all documents and records relating to the Design and Construction of the Project (other than records and

communications which are legally privileged) as the Seismic Peer Review Panel reasonably requires to carry out its responsibilities.

(b) The Province and the Primary Contractor shall share equally the costs of the Seismic Peer Review Panel members, including all actual and reasonable disbursements paid by the Seismic Peer Review Panel members in order to perform their services.

(c) The Province and the Primary Contractor agree to cooperate with each other generally in relation to all matters within the scope of or in connection with the operations and requirements of the Seismic Peer Review Panel.

(d) All instructions and representations issued or made by either the Province or the Primary Contractor to the Seismic Peer Review Panel, or any of its members, shall be simultaneously copied to the other and both the Province and the Primary Contractor shall be notified of and entitled to attend all inspections performed by or meetings involving the Seismic Peer Review Panel.

5.2.4 Function of the Seismic Peer Review Panel

(a) The following submittals shall be subject to peer review and approval by the Seismic Peer Review Panel:

(i) all Seismic Design Strategy Memoranda (SDSMs), including any revised submittals thereof;

(ii) all interaction analyses and associated seismic documentation prepared by the Primary Contractor as part of the Design of the Project; and

(iii) submittals by the Primary Contractor if the requirements set out in the SDSM in respect of a structure have not been met, which presentations shall take place at the Interim Design and/or the Final Design in respect of the applicable structure.

(b) In undertaking any review required under Article 5.2.4(a) of this Part 2, the Seismic Peer Review Panel shall focus on the following aspects of the strategy for seismic Design and analyses:

(i) adequacy of the geotechnical data used and reasonableness of the assumptions made by the Primary Contractor to develop the geological and geotechnical models used in the ground response analyses;

(ii) applicability of the computer software used by the Primary Contractor for ground response and soil-structure interaction analyses with respect to capability of such software to incorporate non-linear soil effects, pre- and post-liquefaction stress-strain-strength relations, non-linear structure effects, and modeling methodology;

(iii) appropriateness of the soil and structure input parameters used by the Primary Contractor in the ground response and soil-structure interaction response analyses; and

(iv) appropriateness of the interpreted results used by the Primary Contractor for the Design of the foundations of the Structures.

(c) After undertaking a peer review of any of the submittals set out in Article 5.2.4(a) of this Part 2, the Seismic Peer Review Panel shall, within 10 Business Days (or such other time period as the parties and the Seismic Peer Review Panel members may agree) of the applicable Seismic Peer Review Panel meeting, issue a written notice to the Primary Contractor (copied to the Province's Representative) either:

(i) approve the submittal once all outstanding Seismic Peer Review Panel comments are addressed; or

(ii) reject the submittal and provide comments as to why the Seismic Peer Review Panel rejected the applicable submittal.

5.3 Codes and Standards

(a) The Primary Contractor shall, in carrying out the seismic Design and analyses of all structures other than Fixed Facilities, ensure that the seismic Design and analyses procedures comply with the requirements set out in this Article 5 [Seismic], and the provisions of the following codes and standards, which shall apply in the order of descending precedence:

(i) BC Supplement to CAN/CSA-S6-06;

(ii) CAN/CSA-S6-06;

(iii) ATC-32;

(iv) MCEER/ATC-49;

(v) AASHTO LRFD Bridge Design Specifications; and

(vi) Appendix E [Methods of Seismic Analysis of Slopes contained in Guidelines for Legislated Landslide Assessment for Proposed Residential Developments in BC (May 2008)].

(b) The Primary Contractor shall, in carrying out the seismic Design and analyses of the Fixed Facilities, ensure that the seismic Design and analyses procedures comply with the requirements set out in this Article 5 [Seismic], and the provisions of the following codes and standards, which shall apply in the order of descending precedence as applicable:

(i) British Columbia Building Code (BCBC); and

(ii) Canadian Foundation Engineering Manual.

(c) The geotechnical resistance factors (Φ) provided in ATC-49/AASHTO are not permitted for the design of deep foundations.

(d) The following geotechnical resistance factors shall be used in the Design of deep foundations associated with the different Seismic Performance Levels for structures identified in Article 5.4.2 [Required Seismic Performance Levels] of

this Part 2, and for Fixed Facilities in Article 5.8 [Fixed Facilities and Existing Facilities] of this Part 2:

(i) Static Design – Deep Foundations

Φ= 0.5 with 5% of the piles subjected to dynamic testing
Φ= 0.6 with static load testing carried out for each representative soil profile
Φ= 0.7 with static load testing carried out for each representative soil profile and the test piles instrumented to measure distribution of resistance.

(ii) Seismic Design – Deep Foundations

Immediate Use Performance (100-Year Return Period Earthquake Event Level): Φ factor shall be the same as for Static Design

Repairable Performance (475-Year Return Period Earthquake Event Level and Subduction Earthquake Event Level): Φ factor shall be the same as for Static Design

Repairable Performance (975-Year Return Period Earthquake Event Level): Φ factor shall be 0.8

Life Safety/No-Collapse Performance (975-Year and 2,475-Year Return Period Earthquake Event Levels): Φ factor shall be 1.0

(iii) Regardless of the resistance factor used, the Prime Contractor shall ensure that the structures meet the Seismic Performance Levels defined in Article 5.4.2 [Required Seismic Performance Levels] of this Part 2.

5.4 Seismic Performance Level Requirements for Structures

5.4.1 General

(a) The Primary Contractor shall ensure that the seismic Design for all structures, excluding the Fixed Facilities, complies with the requirements of the Seismic Performance Levels specified in this Article 5.4 [Seismic Performance Level Requirements for Structures].

(b) Without limiting the generality of Article 5.4.1(a) of this Part 2, the Primary Contractor shall ensure that the seismic Design for all structures, excluding the Fixed Facilities, complies with the following:

(i) for that part of the Evergreen Line from:

A. west of Queens Street at station 519+300 to west of Moray Street at Sta. 521+000; and

B. east of the Ioco Station at station 521+750 to east of Bond Street at Sta. 522+800,

the seismic Design shall comply with the four Seismic Performance Levels set out in Article 5.4.2(a) of this Part 2; and

(ii) for those parts of the Evergreen Line other than the areas described in Article 5.4.1(b)(i) of this Part 2, the seismic Design shall comply with the three Seismic Performance Levels set out in Article 5.4.2(b) of this Part 2.

5.4.2 Required Seismic Performance Levels

(a) The Primary Contractor shall ensure that the seismic Design for all Structures, excluding the Fixed Facilities, for that part of the Evergreen Line described in Article 5.4.1(b)(i) of this Part 2 complies with the following:

(i) for the 100-Year Return Period Earthquake Event Level, the required Seismic Performance Level shall be the Immediate Use Performance Level;

(ii) for the 475-Year Return Period Earthquake Event Level, the required Seismic Performance Level shall be the Repairable Performance Level;

(iii) for the 975-Year Return Period Earthquake Event Level, the required Seismic Performance Level shall be the Life-Safety/No-Collapse Performance Level; and

(iv) for the Subduction Earthquake Event Level, the required Seismic Performance Level shall be the Repairable Performance Level.

(b) The Primary Contractor shall ensure that the seismic Design for all Structures, excluding the Fixed Facilities, for that part of the Evergreen Line described in Article 5.4.1(b)(ii) of this Part 2 complies with the following:

(i) for the 100-Year Return Period Earthquake Event Level, the required Seismic Performance Level shall be the Immediate Use Performance Level;

(ii) for the 975-Year Return Period Earthquake Event Level, the required Seismic Performance Level shall be the Repairable Performance Level; and

(iii) for the Subduction Earthquake Event Level, the required Seismic Performance Level shall be the Repairable Performance Level.

(c) Article 5.5 [Seismic Input and Analysis Requirements] of this Part 2 sets out the seismic input and ground motion requirements that the Primary Contractor shall use for the seismic Design of the Guideway in order to satisfy the requirements of each of the applicable Seismic Performance Level.

(d) Article 5.7 [Guideway Seismic Design Requirements] of this Part 2 sets out the seismic Design requirements for Guideway structures that the Primary Contractor shall meet in order to satisfy each of the applicable Seismic Performance Level.

(e) The specified limits of allowable damages for the performance design of a Permitted ERS and other components of Guideway structures are set out in Articles 5.7.3.3 [Performance Requirements and Permitted ERSs] and 5.7.3.4 [Potentially Permitted ERSs and Other Components], both of this Part 2, as applicable.

5.5 Seismic Input and Analysis Requirements

5.5.1 General

(a) The Primary Contractor shall carry out the Design of all structures using the applicable input firm-ground motions specified in this Article 5.5 [Seismic Input and Analysis Requirements]. Without limiting the generality of the foregoing, the Primary Contractor shall, in order to confirm that each of the applicable Seismic Performance Levels can be achieved, be responsible for:

(i) analyzing and determining those areas of the Alignment that are underlain by soils likely to experience liquefaction, lateral spreading, and movements when subjected to ground motions from an earthquake event at each of the applicable Earthquake Event Levels and performing all required site-specific ground response and soil-structure interaction analyses for the Design of all structures;

(ii) analyzing and determining those areas of the Alignment that are underlain by soils susceptible to partial liquefaction (cyclic mobility) and movements when subjected to ground motions from an earthquake event at each of the applicable Earthquake Event Levels and performing all required site-specific ground response and soil-structure interaction analyses for the Design of all structures; and

(iii) analyzing and determining those areas of the Alignment that are underlain by soils unlikely to experience liquefaction or cyclic mobility when subjected to ground motions from an earthquake event at each of the applicable Earthquake Event Levels. Where the Primary Contractor identifies such areas, the Design of any structures within such areas may be carried out using force-based methods or site-specific ground response and soil-structure interaction analysis methods.

(b) The Primary Contractor shall, in the seismic Design of the Project, include the interaction of the Guideway and the tracks, as well as the interaction of all other components fixed to the Guideway with the Guideway itself.

5.5.2 Seismic Inputs

(a) The Primary Contractor shall, in carrying out the Design of the structures:

(i) apply, as seismic inputs for the Design, the site-specific firm-ground motion time-histories and design response spectra provided in Appendix

M [Site-Specific Firm-Ground (Class C) Response Spectra and Associated Ground Motion Time-Histories] to Schedule 4;

(ii) use the firm-ground records provided in Appendix M [Site-Specific Firm-Ground (Class C) Response Spectra and Associated Ground Motion Time-Histories] to Schedule 4 to develop location-specific ground motion inputs appropriate to the Design as set out in Article 5.5.5 [Slope and Embankment Analysis Requirements] of this Part 2;

(iii) ensure that, for any Design based on inelastic time-history analysis, the design response shall be:

A. the mean response quantity obtained from analysis using the full suite of three sets of records, provided in Appendix M [Site-Specific Firm-Ground (Class C) Response Spectra and Associated Ground Motion Time-Histories] to Schedule 4, where a set of records is defined as two orthogonal records and the relevant vertical input for each applicable Earthquake Event Level; and

B. the maximum response quantity obtained from analysis when using the single set of records provided in Appendix M [Site-Specific Firm-Ground (Class C) Response Spectra and Associated Ground Motion Time-Histories] to Schedule 4 for the Subduction Earthquake Event Level, where a set of records is defined as two orthogonal records and the relevant vertical input; and

(iv) take the peak vertical ground acceleration equal to 2/3^{rds} of the peak horizontal ground acceleration as set out in Appendix M [Site-Specific Firm-Ground (Class C) Response Spectra and Associated Ground Motion Time-Histories] to this Schedule 4.

5.5.3 Soil-Structure Interaction Analysis Requirements

(a) Soil-structure interaction analysis for foundation design undertaken by the Primary Contractor shall use de-coupled or coupled methods as follows:

(i) subject to Articles 5.5.3(a)(ii) and (iii) of this Part 2, de-coupled methods of analyses shall be used as a minimum;

(ii) coupled methods of analyses shall be used at a minimum of four sections for that part of the Evergreen Line extending from west of Moray Street at Sta. 521+000 to east of Bond Street at Sta. 522+800 to confirm the results of the de-coupled methods of analyses; and

(iii) analysis sections undertaken pursuant to Article 5.5.3(a)(ii) of this Part 2 shall be located where changes in ground slope, structure type and configuration, and site soil conditions occur and where de-coupled methods of analyses have been performed.

(b) Soil-structure interaction analysis software used by the Primary Contractor shall take into consideration the following:

(i) the non-linear behaviour of the soil and the applicable structure and the simultaneous application of horizontal and vertical input ground motions; and

(ii) the pre-earthquake and post-earthquake stress-strain response of the geologic materials modeled.

(c) Mean input parameters of the range demonstrated by testing shall be considered by the Primary Contractor in undertaking all analyses required under this Article 5.5.3 [Soil-Structure Analysis Requirements].

(d) The Primary Contractor shall ensure that:

(i) all analyses required under this Article 5.5.3 [Soil-Structure Analysis Requirements] shall be carried out by Professional Engineers who have demonstrated experience in soil-structure interaction analysis; and

(ii) all analysis methodologies, assumptions, and input parameters used in the seismic Design shall, in addition to the Design and Construction Certification Procedures, be documented and subjected to peer review and approval by the Seismic Peer Review Panel, in accordance with Article 5.2 [Peer Review] of this Part 2.

(e) For the purposes of Article 5.5.3(a) of this Part 2, the de-coupled and coupled methods of analyses mean the following:

(i) in the de-coupled method of soil-structure interaction analysis, the soil and the structure are modeled separately, and an analysis is performed of the soil-structure system in multiple steps. The soil and the structure may be represented to different degrees of detail and the analysis accounts for inertial loads, kinematic interaction effects, possible separation effects between the soil and the foundation, and soil and structure behavior in an approximate manner; and

(ii) in the coupled method of soil-structure interaction analysis, the soil and the structure are modeled together, and an analysis is performed of the complete soil-structure system in one step. The soil and the structure are represented to the same degree of detail and the analysis accounts for the possible separation effects between the soil and the foundation, and soil and structure behavior.

5.5.4 Ground Response and Deformation Analysis Requirements

(a) Ground response analysis for location-specific response spectra and liquefaction assessment for all foundation designs carried out by the Primary Contractor shall use one-dimensional or two-dimensional methods as follows:

(i) two-dimensional methods of analyses shall be used for that part of the Evergreen Line extending from west of Moray Street at Sta. 521+000 to east of Bond Street at Sta. 522+800 and within 40m on either side of the Alignment centerline; and

(ii) one-dimensional methods of analyses may be used for the remaining areas.

(b) Ground response analysis software utilized by the Primary Contractor in carrying out the seismic Design shall include the non-linear and hysteretic soil behaviour using either equivalent linear or incremental elastic methods. For those soil profiles where it is demonstrated that the earthquake-induced shear stresses exceed the strength of soil, incremental elastic methods that consider strain rate-adjusted shear strength of soils shall be used by the Primary Contractor. The results of equivalent linear and incremental elastic methods shall be assessed by the Primary Contractor for consistency when multiple Earthquake Event Levels are involved and the results shall not be mixed or combined.

(c) Ground deformation analyses shall be carried out by the Primary Contractor to consider two or three-dimensional methods.

(d) Mean stiffness and damping parameters (equivalent linear) and mean stiffness and strain rate adjusted strength parameters (incremental elastic) of geological materials modeled and input firm-ground motions provided in Appendix M [Site-Specific Firm-Ground (Class C) Response Spectra and Associated Ground Motion Time-Histories] to Schedule 4 shall be used by the Primary Contractor in all ground response analyses. Mean input parameters of the range demonstrated by testing shall be used by the Primary Contractor in all analyses required under this Article 5.5.4 [Soil-Structure Analysis Requirements].

(e) The design location-specific acceleration response spectra prepared by the Primary Contractor shall correspond to the mean spectra computed from the input ground motions given in Appendix M [Site-Specific Firm-Ground (Class C) Response Spectra and Associated Ground Motion Time-Histories] to Schedule 4 for each Earthquake Event Level.

(f) The Primary Contractor shall ensure that:

(i) all evaluations shall be carried out by Professional Engineers who have demonstrated experience in all the specified ground response analysis methods; and

(ii) all analysis methodologies, assumptions, and input parameters used by the Primary Contractor shall be documented in the SDSM and subjected to peer review and approval by the Seismic Peer Review Panel, in accordance with Article 5.2 [Peer Review] of this Part 2.

5.5.5 Slope and Embankment Analysis Requirements

(a) Seismic deformations experienced by slopes and embankments shall be evaluated by the Primary Contractor using simplified or detailed ground response analysis methods as follows:

(i) the simplified methods of analyses may be used for slopes and embankments where the soil stratigraphic profile results in a defined failure plane and to estimate plausible upper and lower bounds for ground movements; and

(ii) detailed ground response analysis methods are required when estimates of both the pattern and magnitude of movements need to be established for the seismic Design and the Primary Contractor shall use the ground motions provided in Appendix M [Site-Specific Firm-Ground (Class C) Response Spectra and Associated Ground Motion Time-Histories] to Schedule 4.

(b) Analyses required under this Article 5.5.5 [Slope and Embankment Analysis Requirements] shall:

(i) include the effects of the simultaneous application of horizontal and vertical ground motions on movements and stability; and

(ii) take the peak vertical ground acceleration equal to 2/3^{rds} of the peak horizontal ground acceleration as set out in Appendix M [Site-Specific Firm-Ground (Class C) Response Spectra and Associated Ground Motion Time-Histories] to this Schedule 4.

(c) Analysis methods required under this Article 5.5.5 [Slope and Embankment Analysis Requirements] shall include reduced post-earthquake soil shear strength and shear stiffness of geologic materials resulting from development of high excess pore water pressures.

(d) Where the Primary Contractor uses simplified methods of analyses, upper bound movements shall be used for the seismic Design of the Structures.

(e) Where the Primary Contractor uses detailed methods of analyses, mean movements shall be used for Design of the Structures.

5.5.6 Retaining Wall Analysis Requirements

(a) The Primary Contractor may evaluate retaining walls supporting less than 5m of soil at the soil-wall interface using simplified methods of analyses that consider variations in the dynamic lateral earth pressures with wall movements/rotations as described in AASHTO [Section 11: Abutments, Piers, and Walls] to confirm compliance with the Seismic Performance Level requirements specified in this Article 5 [Seismic]. The peak ground acceleration defined in Appendix M [Site-Specific Firm-Ground (Class C) Response Spectra and Associated Ground Motion Time-Histories] to Schedule 4 for the applicable Earthquake Event Levels, as modified by the short-period site coefficient defined in BCBC, applicable for site soil classes, shall be used in the design of such retaining walls.

(b) The Primary Contractor shall evaluate retaining walls supporting 5m or more of soil at the soil-wall interface using soil-structure interaction analysis methods specified in Articles 5.5.3 [Soil-Structure Interaction Analysis Requirements] of

this Part 2, this Article 5.5.6 [Retaining Wall Analysis Requirements] and the input firm-ground motions provided in Appendix M [Site-Specific Firm-Ground (Class C) Response Spectra and Associated Ground Motion Time-Histories] to Schedule 4.

(c) Analyses required of the Primary Contractor under this Article 5.5.6 [Retaining Wall Analysis Requirements] shall include:

(i) the effects of the simultaneous application of both horizontal and vertical ground motions on movement and stability; and

(ii) the mean input soil shear strength and shear stiffness parameters for geologic materials demonstrated by testing and shall account for the degradation of these parameters due to cyclic loading effects.

(d) Retaining walls defined in Article 5.5.6(a) of this Part 2 do not require peer review and approval by the Seismic Peer Review Panel.

5.5.7 Tunnel Analysis Requirements

5.5.7.1 Design Procedure

(a) The Primary Contractor shall carry out preliminary analyses for the Design of the Tunnel by ignoring the stiffness of the Tunnel and imposing computed "free-field" ground deformations on the Tunnel, in accordance with the following:

(i) as this simplified procedure is generally applicable for tunnels embedded in geologic materials that are stiffer than the Tunnel, the Primary Contractor shall confirm the validity of the results by carrying out soil-structure interaction analyses at representative locations that account for the actual soil-structure system in place; and

(ii) in cases where Bored Tunnel is embedded in geologic materials that are softer than the Tunnel, the Primary Contractor shall base the Design on soil-structure interaction response analyses in accordance with Article 5.5.3 [Soil-Structure Interaction Analysis Requirements] of this Part 2.

(b) The Primary Contractor shall ensure that the seismic Design of the Tunnel is in compliance with the requirements of the Seismic Performance Levels applicable to the Earthquake Event Levels, as set out in Article 5.4 [Seismic Performance Level Requirements for Structures] of this Part 2.

(c) For the purposes of Article 5.5.7.1(a) of this Part 2, the Primary Contractor shall interpret the terms "stiffer" and "softer" using the principles set out in Wang (1993).

5.5.7.2 Bored Tunnel Analysis Requirements

(a) The Primary Contractor shall carry out the Design of the Bored Tunnel and the dividing wall separating the inbound and outbound sections of the Bored Tunnel

to withstand the ovaling/racking, axial and curvature deformations and differential deformations imposed by the ground and all seismic loads.

(b) Without limiting the generality of Articles 5.5.7.1 [Design Procedure] and 5.5.7.2(a), both of this Part 2, in carrying out the Design of the Bored Tunnel and the dividing wall separating the inbound and outbound sections of the Bored Tunnel, including those sections constructed using either precast concrete segmental lining or cast-in-place concrete lining, as applicable, the Primary Contractor shall, as applicable:

(i) include seismic loads due to ovaling deformations and axial and curvature deformations;

(ii) perform soil-structure interaction analyses at a minimum of two locations selected to cover changing geological and tunnel structure conditions along the Bored Tunnel alignment in accordance with Article 5.5.3 [Soil-Structure Interaction Analysis Requirements] of this Part 2 in order to confirm the results of ovaling deformations established from the "free-field" method;

(iii) be responsible for the selection of a minimum of two locations along the Bored Tunnel alignment for carrying out the soil-structure interaction analyses in accordance with Article 5.5.3 [Soil-Structure Interaction Analysis Requirements] of this Part 2 and the evaluation of critical sections where contrasting soil types/stiffness exist;

(iv) design the Bored Tunnel lining so as to withstand the seismic ground strains caused by axial and curvature deformations of the ground;

(v) design the interfaces between the Bored Tunnel and the larger Structures, such as the Transition Tunnel structures, as flexible joints to accommodate the differential movements during a seismic event;

(vi) design the interfaces between the Bored Tunnel and the dividing wall separating the inbound and outbound sections of the Bored Tunnel to accommodate the differential movements resulting from the applicable Earthquake Event Levels; and

(vii) design the Tunnel and the dividing wall separating the inbound and outbound sections of the Bored Tunnel so as to prevent the ingress of water during and following the 975-Year Return Period Earthquake Event Level.

5.5.7.3 Transition Tunnel Analysis Requirements

(a) The Primary Contractor shall carry out the Design of the Transition Tunnel to withstand the racking deformations imposed by the ground and all seismic loads.

(b) Without limiting the generality of Article 5.5.7.1 [Design Procedure] of this Part 2 and this 5.5.7.3 [Transition Tunnel Analysis Requirements], in performing the Design of the Transition Tunnels, the Primary Contractor shall:

(i) include the seismic loads due to racking deformations and dynamic earth pressures;

(ii) account for ground accelerations;

(iii) obtain the critical racking deformation demand using both soil-structure interaction analysis and dynamic earth pressure methods;

(iv) perform soil-structure interaction analyses in accordance with Article 5.5.3 [Soil-Structure Interaction Analysis Requirements] of this Part 2 at a minimum of two sections selected to cover changes in geological and tunnel structure conditions at the Transition Tunnel zones from the Bored Tunnel to the reinforced concrete box structure;

(v) design the Transition Tunnels so as to:

A. accommodate the seismic ground strains caused by axial and curvature deformations of the ground; and

B. prevent ingress of water during and following the 975-Year Return Period Earthquake Event Level.

5.5.8 At-Grade and Elevated Guideway Analysis Requirements

5.5.8.1 General

(a) The Primary Contractor shall ensure that the seismic Design of each of the at-grade Guideway and the elevated Guideway complies with the requirements of the Seismic Performance Levels applicable to the Earthquake Event Levels, as set out in Article 5.4 [Seismic Performance Level Requirements for Structures] of this Part 2.

5.5.8.2 Design Procedure

(a) Where the Primary Contractor has determined that the soils underlying the at-grade or elevated Guideway are likely to experience liquefaction, or partial liquefaction (cyclic mobility) and/or undergo movements when subjected to shaking from an earthquake event at the applicable Earthquake Event Levels, the Primary Contractor shall use the results of the site-specific ground response and soil-structure interaction analyses undertaken in accordance with Articles 5.5.3 [Soil-Structure Interaction Analysis Requirements] and 5.5.4 [Ground Response and Deformation Analysis Requirements], both of this Part 2, to carry out the Design of the at-grade Guideway and the elevated Guideway.

(b) The Primary Contractor shall, using the site-specific response spectra or methods reviewed and approved by the Peer Review Panel, design each of the at-grade Guideway and the elevated Guideway in soils that the Primary Contractor has determined are unlikely to experience liquefaction, lateral spreading, and

movements when subjected to shaking from an earthquake event at the applicable Earthquake Event Levels.

(c) The Primary Contractor shall ensure that the effects of vertical acceleration inputs as set out in Article 5.5.2 [Seismic Inputs] of this Part 2 are assessed and accounted for in the seismic Design of the Guideway.

(d) The Primary Contractor shall base the seismic Design of Guideway foundations on the location-specific geotechnical models and data that the Primary Contractor is required to develop pursuant to this Article 5 [Seismic].

(e) The Primary Contractor shall, in the Design of the Guideway, consider spatial variations of ground motions that result from differential site response due to different soil profiles at the Guideway foundations, which spatial variations shall include amplification of seismic wave amplitude and out of phase ground movement.

(f) The Primary Contractor shall ensure that:

(i) the seismic Design of the Guideway foundations complies with the Seismic Performance Level requirements at the applicable Earthquake Event Levels, as set out in Article 5.4 [Seismic Performance Level Requirements for Structures] of this Part 2, and the requirements of the BC MoT Supplement to CAN/CSA-S6-06;

(ii) the Design of the Guideway foundations, as Capacity-Protected Components, complies with the BC MoT Supplement to CAN/CSA-S6-06;

(iii) inertial loading from the Structure and the loading from ground displacements is accounted for in the Design of the Guideway foundations; and

(iv) settlements and other displacements resulting from seismic ground shaking are accounted for in the Design of Guideway foundations.

5.5.9 Analysis Requirements for Earth-Retaining Structures, Slopes and Embankments Impacting Seismic Performance of the Guideway

5.5.9.1 General

(a) Any earth-retaining structures, slopes or embankments that are located within 10m to the nearest Guideway foundations have the potential to induce additional seismic loads and ground displacements on such foundations and are classified as structures impacting the Seismic Performance Level of the Guideway.

(b) The Primary Contractor shall ensure that the seismic Design of the earth-retaining structures, slopes and embankments referred to in Article 5.5.9.1(a) of this Part 2 complies with the Seismic Performance Level requirements at the applicable Earthquake Events Levels, as set out in Article 5.4 [Seismic Performance Level Requirements for Structures] of this Part 2.

5.5.9.2 Design Procedure

(a) The Primary Contractor shall ensure that the seismic Design of such earth-retaining structures, slopes and embankments referred to in Article 5.5.9.1(a) of this Part 2 complies with the following, as applicable:

(i) with respect to the Design of the earth-retaining structures, the Design shall be based on combined static and seismic earth pressures anticipated on such earth-retaining structures for the ground motions that correspond to the applicable Earthquake Event Levels;

(ii) the earth-retaining structures, slopes and embankments shall have the capacity to withstand the combined static and seismic loading imposed by the applicable Earthquake Event Levels;

(iii) lateral and rotational displacement of the earth-retaining structures, slopes and embankments shall be included in the seismic Design; and

(iv) the effects of vertical acceleration inputs as required by Article 5.5.2 [Seismic Inputs] of this Part 2 shall be included in the seismic Design.

(b) The Primary Contractor shall ensure that:

(i) the seismic Design of the global stability of those earth-retaining structures, slopes, and embankments referred to in Article 5.5.9.1(a) of this Part 2 are carried out as set out in Articles 5.5.5 [Slopes and Embankment Analysis Requirements] and Article 5.5.6 [Retaining Wall Analysis Requirements], both of this Part 2; and

(ii) performance shall be such that it does not affect the ability of the Guideway to meet the Seismic Performance Levels referred to in Article 5.4 [Seismic Performance Level Requirements for Structures] of this Part 2.

5.5.10 Analysis Requirements for Earth-Retaining Structures, Slopes and Embankments Not Impacting Seismic Performance of the Guideway

5.5.10.1 General

(a) Any earth-retaining structures, slopes or embankments that are located farther than 10m from the nearest Guideway foundations do not have the potential to induce additional seismic loads and ground displacements on the foundations and are classified as structures not impacting the Seismic Performance Level of the Guideway.

(b) The Primary Contractor shall ensure that the seismic Design of the earth-retaining structures, slopes and embankments set out in Article 5.5.10.1(a) of this Part 2 is performed using the methods of analyses described in Article 5.5.10.2 [Design Procedure] of this Part 2.

(c) Earth-retaining structures, slopes and embankments identified in this Article 5.5.10 [Analysis Requirements for Earth-Retaining Structures, Slopes and

Embankments Not Impacting Seismic Performance of the Guideway] do not require peer review and approval by the Seismic Peer Review Panel.

5.5.10.2 Design Procedure

(a) The Primary Contractor shall ensure that the seismic Design of the earth-retaining structures, slopes and embankments referred to in Article 5.5.10.1(a) of this Part 2 complies with the following, as applicable:

(i) the seismic Design shall be based on dynamic earth pressures anticipated for the ground motions that correspond to the applicable Earthquake Event Levels;

(ii) such earth-retaining structures shall be structurally capable of withstanding the combined static and seismic earth pressures during each of the applicable Earthquake Event Levels;

(iii) the effects of vertical acceleration inputs as required by Article 5.5.2 [Seismic Inputs] of this Part 2 shall be included in the Design of each earth-retaining structure;

(iv) new or modified retaining walls, slopes and embankments shall be designed such that existing adjacent and dependent buildings meet the seismic performance requirements of BCBC and the Appendix E [Methods of Seismic Analysis of Slopes contained in Guidelines for Legislated Landslide Assessment for Proposed Residential Developments in BC (May 2008);

(v) the earth-retaining structures, slopes, and embankments shall be designed so that they will not experience permanent lateral movements and settlements larger than 2% of the retained fill height due to seismic actions; and

(vi) the analyses for the Design of the earth-retaining structures, slopes, and embankments shall be carried out using location-specific soil properties.

5.5.11 Other Retaining Walls, Slopes and Embankments

(a) New or modified retaining walls, slopes and embankments that are not covered in either of Articles 5.5.9.1(a) or 5.5.10.1(a) of this Part 2 shall be designed by Primary Contractor to ground motions that correspond to the 475-Year Return Period Earthquake Event Level, and so as to not block access and/or damage site services and utilities.

5.5.12 Soil Liquefaction Assessment Requirements

(a) The Primary Contractor shall:

(i) assess the potential for soil liquefaction and related ground deformations along the Alignment in accordance with this Article 5.5 [Seismic Input and Analysis Requirements]; and

(ii) in its liquefaction assessment, include the effects of an earthquake event at the Subduction Earthquake Event Level on soil liquefaction and associated consequences.

(b) The effects of soil liquefaction that the Primary Contractor shall evaluate in its liquefaction assessment include the following:

(i) lateral spreading of ground with gentle slopes and vertical settlements;

(ii) slope movements and potential for flow slide failures;

(iii) loss of bearing capacity, punching failure, and settlement of shallow foundations;

(iv) soil movement-induced lateral loads, downdrag loads, and loss of load carrying capacity of deep foundations;

(v) increased lateral earth pressures on walls and buoyancy forces on underground structures and Utilities; and

(vi) all other effects that will impact the Seismic Performance Level of the structures.

(c) The Primary Contractor shall carry out the Design of the foundations of all structures to accommodate the soil loads imposed on them due to liquefaction-induced ground deformations.

(d) Subject to acceptance of the seismic Design by the Province's Representative in accordance with the Consent Procedure, acting reasonably, limited inelastic deformation of piles and shafts may be permitted in order to resist liquefaction-induced loading, provided that the seismic Design of the foundations of any structure remains in compliance with the Seismic Performance Level requirements set out in Article 5.4 [Seismic Performance Level Requirements for Structures] of Part 2.

5.5.13 Analysis Requirements for Slope Failures and Landslides

(a) The Primary Contractor shall ensure that:

(i) the potential for seismic loading-induced slope failures and landslides along the Alignment are accounted for in the seismic Design of the Structures;

(ii) the impact of potential slope movements and landslides on the Structures are accounted for in the seismic Design of the affected Structures;

(iii) the Design of each Structure and its foundations takes into account the potential slope movements and landslides and meets the Seismic Performance Level requirements set out in Article 5.4 [Seismic Performance Level Requirements for Structures] of this Part 2;

(iv) the seismic Design of the Guideway incorporates slope stability analysis and design that account for existing conditions affected by the construction of the Guideway; and

(v) slope stability reductions to existing slopes resulting from the construction of Guideway foundations are not permitted.

5.6 Seismic Design Strategy Memorandum

(a) The Primary Contractor shall, in accordance with the requirements of this Article 5.6 [Seismic Design Strategy Memorandum], prepare and submit for peer review and approval by the Seismic Peer Review Panel a seismic design strategy memorandum (the "**SDSM**") in respect of each structure, highlighting in sufficient details the design strategy and approach that the Primary Contractor proposes to use with respect to the seismic Design of the applicable structure.

(b) Each SDSM prepared by the Primary Contractor shall include the following:

(i) the assumptions and seismic design approach;

(ii) the design strategy to meet required performance goals for each Seismic Performance Level;

(iii) any Permitted ERSs or Potentially Permitted ERSs in seismic load paths, and the corresponding limits of inelastic response;

(iv) the step-by-step detailed methodology and assumptions for analysis and design;

(v) the methodologies used to demonstrate compliance with global and component performance requirements;

(vi) the methodologies used to evaluate inelastic strains and deformations in any proposed ERS components;

(vii) the component and foundation properties used in global dynamic analyses;

(viii) the seismic ground motion input for each applicable Seismic Performance Level;

(ix) the following to a sufficient level to develop the seismic strategy;

A. the global modal characteristics of the structure, including primary modes of vibration with minimum of 90% mass participation;

B. the global seismic demands, including maximum deflections and displacements; and

C. the local component performance as determined in local substructure push-over analyses to demonstrate component performance compliance with the required performance goals,

and shall be based on a capacity-protected and performance-based design approach, as described in this Article 5 [Seismic].

(c) The Primary Contractor shall, in the SDSM of each structure type, consider the applicable category for the Structure, based on features affecting seismic design strategies, including:

(i) typical single span structures with similar span length, soil conditions and ground motions;

(ii) typical regular structures with similar number of spans per frame, span lengths, substructure skews, substructure number of columns, heights and stiffnesses, foundation types, soil conditions, and ground motions; and

(iii) other categories for non-typical or irregular structures, including bridges.

(d) The Primary Contractor shall submit each SDSM to the Seismic Peer Review Panel for peer review and approval in accordance with Article 5.2 [Peer Review] of this Part 2. In the event that an SDSM is rejected by the Seismic Peer Review Panel, the Primary Contractor shall submit for peer review and approval by the Seismic Peer Review Panel in accordance with Article 5.2 [Peer Review] of this Part 2 a revised SDSM that addresses all of the comments made by the Seismic Peer Review Panel.

(e) Notwithstanding Section 2.7 [Early Commencement of Work] of Schedule 2, the Primary Contractor shall not submit the Final Design of a Structure to the Province's Representative or proceed with construction activities in respect of any components of a Structure dependent on seismic design strategy until the SDSM for the applicable Structure has been reviewed and approved by the Seismic Peer Review Panel.

(f) Any seismic Interim Design submissions and seismic Final Design submissions submitted by the Primary Contractor to the Province's Representative shall comply with the applicable SDSM reviewed and approved by the Seismic Peer Review Panel. The comments provided by the Province's Representative with respect to each of the Interim Design and Final Design shall be based on and shall not be inconsistent with the SDSM reviewed and approved by the Seismic Peer Review Panel.

5.7 Guideway Seismic Design Requirements

5.7.1 General Requirements

(a) Without limiting any other applicable provisions of this Article 5 [Seismic], the Primary Contractor shall carry out the Design of the Guideway in compliance with the seismic requirements of this Article 5 [Seismic], including the following:

(i) seismic inputs as set out in Article 5.5 [Seismic Inputs and Analysis Requirements] of this Part 2;

(ii) the Seismic Performance Level requirements as set out in Article 5.4 [Seismic Performance Level Requirements for Structures] of this Part 2;

(iii) component level seismic performance requirements as set out in Articles 5.7.3.3 [Performance Requirements and Permitted ERSs] and 5.7.3.4 [Potentially Permitted ERSs and Other Components] of this Part 2; and

(iv) the applicable provisions of the standards and codes as referenced in Article 5.3 [Codes and Standards] of this Part 2.

(b) Following confirmation of approval of the SDSM in respect of a Structure by the Seismic Peer Review Panel, and in advance of commencing any construction activities in respect of such Structure, the Primary Contractor shall submit complete seismic Interim Design submissions for the Structure in accordance with Article 2 [Design and Construction Certification Procedures], Part 3 of Schedule 4, which submissions shall demonstrate compliance of the seismic Design with the approved SDSM for the applicable Structure and shall include:

(i) the design plans and specifications as required by this Agreement;

(ii) supporting engineering documents for:

A. the Structure itself, and the bearings, foundation and other devices and component properties to be used in the analyses;

B. the foundation properties;

C. the global modal analysis results, with minimum of 90% mass participation;

D. ground motions;

E. global seismic demands;

F. the local push-over analyses and component demands;

G. the design strength and ductility of the Structure's components;

H. the demand-capacity comparisons;

I. the conformance checks with the seismic performance requirements set out in this Article 5 [Seismic]; and

J. the Primary Contractor's response to any comments made by the Seismic Peer Review Panel or by the Province's Representative in respect of the SDSM.

5.7.2 Earthquake Resisting Systems and Capacity Protected Components

5.7.2.1 Permitted ERSs and Capacity Protected Components

(a) The Primary Contractor's seismic design strategy for each Guideway structure, as reflected in the applicable SDSM, shall include the following:

(i) identifying each of the Permitted ERS components and Capacity-Protected Components;

(ii) in accordance with the capacity-protected design approach, providing that the strength of all Capacity-Protected Components shall be stronger

than the overstrength capacity of any Permitted ERSs adjacent to or in the seismic load path of the applicable Capacity-Protected Components;

(iii) for seismic design strategies that will include inelastic response of a Permitted ERS, setting out the procedures to conduct global time history and/or local stand-alone push-over analyses of substructure systems, as applicable, to demonstrate performance-based compliance of the Permitted ERS components with the Seismic Performance Level requirements specified in Article 5.7.3.3 [Performance Requirements and Permitted ERSs] of this Part 2. For the inelastic response of the components of a Permitted ERS of a substructure, the analyses undertaken by the Primary Contractor shall include nonlinear push-over analyses of the substructure system up to calculated seismic displacement demands to establish ductility demands, and to determine ductility capacities associated with the applicable Seismic Performance Level; and

(iv) providing that all Capacity-Protected Components shall remain elastic during an earthquake event at all applicable Earthquake Event Levels.

(b) The Primary Contractor's seismic design strategy for a Permitted ERS in a Guideway structure, as reflected in the applicable SDSM, the Interim Design submissions and the Final Design submissions, shall clearly demonstrate:

(i) the function of the Permitted ERS as incorporated in the Design of the Guideway structure in protecting Capacity-Protected Components; and

(ii) the compliance of the Design of the Guideway structure with the requirements of each of the applicable Seismic Performance Levels.

(c) The Primary Contractor shall, with respect to any existing Guideway structures:

(i) which will be changed in part or in whole as part of the Work; or

(ii) with increased seismic demands due to increased mass or seismic interaction with new Guideway structures,

comply with the design and Seismic Performance Level requirements of this Article 5 [Seismic]. Existing Guideway structures with increased seismic demands may require retrofit or replacement by the Primary Contractor to meet the applicable Seismic Performance Level requirements as set out in Article 5.8.2 [Seismic Design Requirements at Lougheed Town Centre Station] of this Part 2.

(d) As part of the Work, the Primary Contractor is not required to retrofit or replace any existing Guideway structures which:

(i) are to remain with minor changes only; and

(ii) will not have an increase in their seismic demands due to increased mass or seismic interaction with new Guideway structures,

to meet the Seismic Performance Level requirements.

5.7.2.2 Potentially Permitted ERSs

(a) The use of an ERS other than a Permitted ERS requires the acceptance of the Province's Representative, acting reasonably, in accordance with the Consent Procedure. Examples of Potentially Permitted ERSs include:

(i) minor inelastic response of piles below ground, so long as seismic performance requirements set out in Article 5.7.3.4.7 [Foundations] of this Part 2 are met, and pile component integrity and performance are not jeopardized; and

(ii) sacrificial (fuse) shear keys, allowing for sliding of the superstructure to limit seismic loads, the use of which are permitted in respect of the Life-Safety/No-Collapse Performance Level only.

(b) The Primary Contractor shall, in its submissions to the Province's Representative for the acceptance of a Potentially Permitted ERS, provide proof to substantiate compliance of the Potentially Permitted ERS with the Seismic Performance Level requirements set out in Article 5.7.3.4 [Potentially Permitted ERSs and Other Components] of this Part 2, which submissions shall be made as part of the SDSM, or a submission to amend the SDSM, in respect of the applicable Guideway structure.

5.7.3 Design Procedure for Guideway Structures

5.7.3.1 Procedural Steps

(a) In carrying out the seismic Design of the Guideway structure, the Primary Contractor shall carry out the following procedural steps:

(i) the ground motion step, which step consists of preparing the ground motion level for each of the Earthquake Event Levels applicable to the Guideway structure segment location as determined in accordance with Article 5.4.1(b) of this Part 2;

(ii) the SDSM step, which step consists of developing a SDSM for each Guideway structure in accordance with Article 5.6 [Seismic Design Strategy Memorandum] of this Part 2 and identifies the proposed use of any Permitted ERS or a Potentially Permitted ERS in respect of such structure;

(iii) the analytical modeling step, which step consists of carrying out the following analyses:

A. seismic demand and component performance analyses shall be based on representative analytical modeling and component performance representation;

B. where inelastic response of ductile column plastic hinging is part of the seismic design strategy, dynamic analyses shall include representative analyses to determine upper bound seismic deflection and displacement demands;

C. detailed inelastic deformation analyses of ductile column plastic hinges shall be evaluated in local push-over analyses of substructure systems, subjected to the imposed deflections and displacements from the global analyses. Representative analytical modeling features shall include the following:

(1) expected steel and material properties;

(2) spine/beam elements for superstructure, bent cap, columns, and other linear flexure components, as applicable;

(3) effective component properties representing the expected performance of the applicable component within analysis models;

(4) for deflection and displacement analyses, column section properties shall be based on cracked section properties as determined by column moment-curvature analyses; and

(5) spring elements with translational and rotational properties to represent abutments, pier and column foundations, member end joints, expansion joints and other discontinuities, as applicable;

(iv) the seismic demand analysis procedure step, which step shall be based on representative analytical idealization of structure stiffness, mass and damping distribution, using applicable global dynamic analysis methods suited for the type of structures. For a typical Guideway structure, at a minimum, applicable dynamic analysis methods to be considered by the Primary Contractor shall correspond to the specified analysis methods for lifeline bridges in CAN/CSA-S6-06-Table 4.2 and Article 4.6 [Guideway Design Criteria] of this Part 2, including:

A. single mode (SM) dynamic analysis;

B. uniform load (UL) method;

C. multi-mode (MM) response spectrum analysis*; and

D. time history (TH) analysis *

* - Analysis requires 3-dimensional spine and spring models representing structure components, discontinuities, and foundation stiffness, mass, and damping distribution, using a commercially available and validated software; and

(v) for non-typical structures or features, other detailed analysis methods, such as nonlinear dynamic analyses, finite element analyses, and local inelastic pushover analysis of substructure systems, as applicable, shall be carried out by the Primary Contractor, subject to peer review and approval of the proposed analysis methods by the Seismic Peer Review Panel as part of the applicable SDSM.

(b) The results of the analyses undertaken by the Primary Contractor pursuant to Articles 5.7.3.1(a)(iii) through (iv) of this Part 2, as applicable, shall be included as part of the Interim Design submissions and the Final Design submissions in respect of the applicable Guideway structure.

(c) The analysis methods used by the Primary Contractor shall be appropriate for the type, regularity, and complexity of the applicable Guideway structure, and are subject to peer review and approval by the Seismic Peer Review Panel as part of the applicable SDSM. At a minimum, the analysis methods used by the Primary Contractor shall comply with provisions of CAN/CSA-S6-06-Section 4.4.5 for lifeline bridges for zone 4.

(d) The primary demand parameters determined by the Primary Contractor from global dynamic analyses undertaken in respect of a Guideway structure shall be deflection and displacement demands.

(e) The inelastic component behavior of ERS ductile components, such as the ductile response of columns when used in the seismic design strategy, shall be determined by the Primary Contractor via non-linear analyses, or equivalent step-by-step linearized push-over analyses, of substructure models with inelastic component response representation, such as column plastic hinging, foundation nonlinearities, or other nonlinearities as permitted and present.

(f) The Primary Contractor shall evaluate demand strains for a column plastic hinging Permitted ERS via nonlinear section analyses to demonstrate compliance with seismic performance requirements as specified in Article 5.7.3.3 [Performance Requirements and Permitted ERSs] of this Part 2. Prior to undertaking such evaluation, the Primary Contractor shall obtain the approval of the Seismic Peer Review Panel for the proposed method of non-linear section analysis in respect of the applicable Permitted ERS and shall include the preliminary results of such evaluation in the SDSM relating to the applicable Permitted ERS.

(g) Depending on the seismic design strategy selected by the Primary Contractor, and subject to displacement demands for each Earthquake Event Level, the Primary Contractor shall conduct local deformation and strain-based push-over analyses of substructure systems in order to:

(i) assess the response of a Permitted ERS or a Potentially Permitted ERS, as applicable;

(ii) establish strain demands for each component of the substructure system;

(iii) demonstrate compliance with the specified seismic performance requirements set out in Articles 5.7.3.3 [Performance Requirements and Permitted ERSs] and 5.7.3.4 [Potentially Permitted ERSs and Other Components], both of this Part 2, as applicable;

(iv) account for the Guideway foundation soil-structure interaction effects;

(v) develop strain limits corresponding to component level performance requirements as set out in Articles 5.7.3.3 [Performance Requirements and Permitted ERSs] and 5.7.3.4 [Potentially Permitted ERSs and Other Components], both of this Part 2, as applicable, in accordance with the approved SDSM;

(vi) demonstrate with supportive design documents that the strain demands of a Permitted ERS or a Potentially Permitted ERS are within specified seismic performance requirements as set out in Articles 5.7.3.3 [Performance Requirements and Permitted ERSs] and 5.7.3.4 [Potentially Permitted ERSs and Other Components], both of this Part 2, as applicable;

(vii) demonstrate seismic demand on all capacity-protected components are within range of their elastic strength; and

(viii) account in the Design for lateral drift of the columns and the resulting P-Delta effects.

The Primary Contractor shall include the results of the analyses undertaken by in accordance with this Article 5.7.3.1(g) in respect of a Guideway structure in the Interim Design and the Final Design of the applicable Guideway structure.

5.7.3.2 Seismic Design of Guideway Structure Components

(a) The Primary Contractor shall ensure that the seismic Design of the components of each Guideway structure complies with the following:

(i) where the Primary Contractor proposes to use bearing and base isolation as a Permitted ERS, such use shall be subject to validation testing for the range of response and performance requirements;

(ii) where the Primary Contractor proposes to use seismic dampers as a Permitted ERS, such use shall be subject to validation testing for the range of response and performance requirements;

(iii) subject to proof of compliance with the Seismic Performance Level requirements for each of the Earthquake Events Levels, such proof to be provided by way of by way of analyses and testing, local damage to bridge bearings under the Life-Safety/No-Collapse Safety Performance Level objectives may be proposed as a Potentially Permitted ERS;

(iv) where the Primary Contractor proposes to use fused bearing behavior, such as sliding, as well as behavior of isolation bearings, as a Permitted ERS, such use shall require detailed non-linear dynamic analyses of ground motion time histories, corresponding to the Earthquake Events Levels, accounting for soil-structure interaction and potential non-linear behavior in soils and structural components;

(v) an ultimate system displacement capacity of at least 25% greater than demands determined from non-linear dynamic analyses shall be required for the Design of base-isolated Structures at each applicable Earthquake Event Level; and

(vi) where the Primary Contractor proposes to use bearings, base isolations, or damper design behavior as Permitted ERSs, such use shall require the Primary Contractor to demonstrate compliance with the applicable seismic performance requirements set out in Article 5.7.3.3 [Performance Requirements and Permitted ERSs] of this Part 2 and certified laboratory testing corresponding to the range of seismic design performance of the applicable Permitted ERS, the results of which shall be included with the Interim Design submissions and the Final Design submissions of the applicable Guideway structure.

5.7.3.3 Performance Requirements and Permitted ERSs

5.7.3.3.1 General

(a) The Primary Contractor shall carry out the Design of the Guideway structure components in accordance with the following:

(i) Permitted ERSs shall be limited to ductile substructure elements, such as columns, braced frames, and moment resisting frames, as well as special devices such as base isolation and energy absorption devices, all as described in Section 4 of CAN/CSA-S6-06 for design of Capacity-Protected elements, and in compliance with the Seismic Performance Level requirements set out in Article 5.4 [Seismic Performance Level Requirements for Structures] of this Part 2;

(ii) the seismic response of a Permitted ERS shall be limited to the allowable range of response within specified Seismic Performance Level requirements for that component;

(iii) the Design shall include strain-based component inelastic response for a Permitted ERS, corresponding to each of the Seismic Performance Levels set out in Article 5.4 [Seismic Performance Level Requirements for Structures] of this Part 2; and

(iv) all Capacity-Protected Components shall remain elastic.

(b) The Primary Contractor shall ensure that the seismic Design of Guideway structural components complies with the Seismic Performance Level requirements, including, where a ductile reinforced concrete column is used, the specific strain-based limits for ductile reinforced concrete columns, set out in each of Articles 5.7.3.3.2 [Immediate Use Performance Level], 5.7.3.3.3 [Repairable Performance Level] and 5.7.3.3.4 [Life-Safety/No-Collapse Performance Level], all of this Part 2, as well as the equivalent performance of other applicable Permitted ERS Components.

(c) The Primary Contractor shall, for columns other than ductile reinforced concrete columns, submit for the acceptance, acting reasonably, of the Province's Representative in accordance with the Consent Procedure, the proposed supportive material that will demonstrate seismic performance levels equivalent

to the Seismic Performance Level requirements for ductile reinforced concrete columns referred to in Article 5.7.3.3.1(b) of this Part 2.

5.7.3.3.2 Immediate Use Performance Level

(a) The Primary Contractor shall carry out the Design of the components of the Guideway structure to meet the Immediate Use Performance Level in accordance with the following requirements:

(i) all components other than Permitted ERS shall remain essentially elastic with no measurable damage;

(ii) damage to the Guideway, if any, shall be limited to the components of a Permitted ERS, and such damage to a Permitted ERS shall be limited to minor damage capable of inspection and repair without disruption to passenger service of the Evergreen Line;

(iii) where a ductile reinforced concrete column is used as a Permitted ERS, allowable performance shall be as follows:

A. maximum strains shall be within limits of plastic hinging as defined by CAN/CSA-S6-06;

B. allowable concrete strain shall be limited to ec=0.004; and

C. allowable steel strain shall be limited to es=0.0021 unless the Primary Contractor demonstrates as part of the applicable SDSM that a higher design strain results in elastic behavior (i.e., no structural damage and minimal to no concrete cracking); and

(iv) for the components of a Potentially Permitted ERS, and subject to acceptance by the Province's Representative, acting reasonably, in accordance with the Consent Procedure, strain limits with equivalent performance levels may be used.

5.7.3.3.3 Repairable Performance Level

(a) The Primary Contractor shall carry out the Design of the components of the Guideway structure to meet the Repairable Performance Level in accordance with the following requirements:

(i) all components other than Permitted ERSs shall remain essentially elastic with no measurable damage;

(ii) damage to the Guideway shall be limited to the Permitted ERS, which damage shall be limited to repairable damage only;

(iii) for a reinforced concrete column Permitted ERS, allowable performance shall be as follows:

A. maximum concrete and steel strains shall be within limits of plastic hinging as defined by CAN/CSA-S6-06;

B. for confined concrete strain, using the industry accepted Mander's Model for confined concrete or an equivalent method, and

moment-curvature analysis, provide confinement to prevent crushing of the confined core concrete;

C. for steel strain, the following (corresponding to 75% of the ultimate strain plateau) applies:

(1) 25M bars, es=0.0113;

(2) 30M bars, es=0.0094;

(3) 35M bars, es=0.0086;

(4) 45M bars, es=0.0056; and

(5) 55M bars not permitted; and

(iv) for the components of a Potentially Permitted ERS and subject to the acceptance of the Province's Representative, acting reasonably, in accordance with the Consent Procedure, strain limits with equivalent seismic performance levels may be used.

5.7.3.3.4 Life-Safety/No-Collapse Performance Level

(a) The Primary Contractor shall carry out the Design of the components of the Guideway structure to meet the Life-Safety/No-Collapse Performance Level in accordance with the following requirements:

(i) all components other than Permitted ERSs shall remain essentially elastic;

(ii) any damage to the Guideway shall be limited to the Permitted ERS, and the damage to the Permitted ERS shall be limited to the specified limits to ensure life safety and structure stability and to avoid structure collapse;

(iii) for a ductile reinforced-concrete Permitted ERS, allowable performance shall be as follows:

A. maximum concrete and steel strains shall be within limits of plastic hinging as defined by CAN/CSA-S6-06;

B. for confined concrete strain, using the industry accepted Mander's Model for confined concrete or an equivalent method, and moment-curvature analysis, provide confinement to prevent crushing of the confined core concrete; and

C. for steel strains, be limited to the following (corresponding to a reduced ultimate strain, es(ru), that is 2/3 of the expected ultimate strain):

(1) es(ru)=0.09 (30M and smaller);

(2) es(ru)=0.06 (35M and larger); and

(iv) for the components of a potential permitted ERS and subject to the acceptance of the Province's Representative, acting reasonably, in accordance with the Consent Procedure, strain limits with equivalent seismic performance levels may be used.

5.7.3.4 Potentially Permitted ERSs and Other Components

5.7.3.4.1 General

(a) The Primary Contractor shall, in the seismic Design of the Guideway structures, ensure that the Guideway's superstructure, bent caps, column end joints, expansion joints, foundations and any base isolation utilized comply with the requirements of the Seismic Performance Levels set out in Article 5.4 [Seismic Performance Level Requirements for Structures] of this Part 2.

(b) For Guideway structure components other than Permitted ERSs, the Primary Contractor shall undertake a comparable level of Design and analysis as is outlined for Permitted ERSs in Article 5.7.3.3 [Performance Requirements and Other Components] of this Part 2, and shall, as part of the applicable submissions for Interim Design and Final Design, satisfy the Province's Representative that the requirements of the equivalent seismic performance levels will be complied with.

5.7.3.4.2 Superstructure

(a) The Primary Contractor shall, in the seismic Design of the Guideway structures, ensure that all superstructure components are treated as Capacity-Protected Components that will remain elastic during an earthquake event at all applicable Earthquake Events Levels and Seismic Performance Levels.

5.7.3.4.3 Bearings and Seat Widths

(a) The Primary Contractor shall, in the seismic Design of the Guideway structures, ensure compliance with the seismic performance requirements for shear keys, adequate seat width, and other design features in the event of a failure of the bearings.

5.7.3.4.4 Bent Caps

(a) The Primary Contractor shall ensure that bent cap components (which are capacity-protected components) remain elastic at all applicable Earthquake Event Levels and Seismic Performance Levels.

5.7.3.4.5 Fixed Column End Connections

(a) The Primary Contractor shall ensure that fixed column end connections, including bent cap-column joints and column-footing joints (which are capacity-protected components), remain elastic at all applicable Earthquake Event Levels and Seismic Performance Levels.

5.7.3.4.6 Expansion Joints

(a) The Primary Contractor shall, in the seismic Design of the Guideway structure components, account for expansion joints opening and closing during each Earthquake Event Level and shall ensure that, notwithstanding Article 5.4.2

[Required Seismic Performance Levels] of this Part 2, such expansion joints will perform in accordance with the following Seismic Performance Level requirements:

(i) with respect to the 100-Year Period Earthquake Event Level, the Immediate Use Performance Level shall apply, and minimal damage as a results of joint closure will be permitted, as long as service can be maintained;

(ii) with respect to the 475-Year Period Earthquake Event Level, the Repairable Performance Level shall apply, and some repairable damage as a result of joint closure impact can be permitted, as long as damage is localized and repairable;

(iii) with respect to the 975-Year Period Earthquake Event Level, the Life-Safety/No-Collapse Performance Level shall apply, and more severe joint closure damage can be permitted, as long as adjacent components remain in place and structure stability is not compromised; and

(iv) at all Earthquake Event Levels and Seismic Performance Levels, the Primary Contractor shall ensure adequacy of joint seat width to prohibit unseating.

5.7.3.4.7 Foundations

(a) The Primary Contractor shall, in the seismic Design of the Guideway structure, ensure that the foundation components, including the footings and pile caps, and the fixed column connection to footings and pile caps, are Capacity-Protected Components which shall remain elastic during an earthquake event at all Earthquake Event Levels.

(b) If minor damage of individual piles is shown to result in compliant performance with the applicable Seismic Performance Level requirements, the Primary Contractor may propose the use of such piles as a Potentially Permitted ERS. Unless the Primary Contractor receives acceptance, acting reasonably, of such use pursuant to the Consent Procedure, piles shall be considered Capacity-Protected Components requiring elastic response during an earthquake event at applicable Earthquake Event Levels.

(c) The seismic Design and performance of all piles, whether a Permitted ERS or a Capacity-Protected Component, shall comply with the following:

(i) the seismic Design of the piles shall be based on the approaches outlined in Clause 4.5.5 of ATC-32;

(ii) the seismic Design of the pile foundations shall address the effects of inertial loading from the Structure and the loading from ground displacements due to seismic shaking;

(iii) settlements that result from liquefaction of soils shall be identified and accounted for in the seismic Design of the piles; and

(iv) spread-footing design for seismic effects shall be based on the approach outlined in Clause 4.5.6 of ATC-32, with the exception of load factors and combinations which shall instead be based on the BC MoT Supplement to CAN/CSA-S6-06.

(d) In addition to the requirements set out in Article 5.7.3.4.7(c) of this Part 2, and unless piles have been accepted as a Potentially Permitted ERS in respect of a Guideway Structure, the Primary Contractor shall design all piles as Capacity-Protected Components with demand loads in accordance with the BC MoT Supplement to CAN/CSA-S6-06.

5.8 Fixed Facilities and Existing Facilities

5.8.1 Seismic Design Requirements of Fixed Facilities

(a) The Primary Contractor shall carry out the Design of all Fixed Facilities in accordance with the requirements set out in:

(i) this Article 5.8 [Seismic], as applicable; and

(ii) Article 4.9.2 [Seismic Approach for Combined Stations/Guideway Structures] and Article 4.9.3.3.2 [Live Loads Due to Use and Occupancy, BCBC, Division B – Subsection 4.1.5], both of this Part 2.

(b) The Primary Contractor shall carry out the Design of all Fixed Facilities such that the support, fixation, and attachment of components, including electrical, mechanical, and Systems components, are considered as essential to providing emergency operation of the system during and immediately following a disaster in accordance with a "Post Disaster" Importance Category as that term defined in the BCBC.

(c) The Primary Contractor shall carry out the Design of all Fixed Facilities, excluding the support, fixation, and support requirements set out in Article 5.8.1(b) of this Part 2, to a "High" Importance Category as that term is defined in BCBC.

(d) The Primary Contractor shall ensure that the Design of the Fixed Facilities complies with:

(i) the acceleration response spectra applicable to the Site Class, as both terms are defined in BCBC; and

(ii) the dynamic analysis procedures identified in BCBC.

(e) The Primary Contractor shall ensure that the seismic Design of the Fixed Facilities complies with the 2475-Year Return Period Earthquake Event Level.

(f) The Primary Contractor shall, in respect of the seismic Design of the Fixed Facilities, comply with the location-specific ground response analysis requirements set out in BCBC.

5.8.2 Seismic Design Requirements at Lougheed Town Centre Station

(a) The Primary Contractor shall not, as part of the Work, retrofit or replace the existing Guideway structures supporting the existing Lougheed Town Centre Station.

(b) The Primary Contractor shall carry out the Design for the Lougheed Town Centre Station in accordance with the requirements set out in Article 4.9.2 [Seismic Approach for Combined Stations/Guideway Structures] of this Part 2.

(c) The Primary Contractor shall ensure that the seismic Design for the existing Guideway at Lougheed Town Centre Station complies with the following:

(i) for the 100-Year Return Period Earthquake Event Level, the required Seismic Performance Level shall be the Immediate Use Performance Level; and

(ii) for the 475-Year Return Period Earthquake Event Level, the required Seismic Performance Level shall be the Repairable Performance Level.

(d) The Primary Contractor shall carry out the seismic and structural Design of the Lougheed Town Centre Station in compliance with the following:

(i) the roof structure Design shall be generally consistent with the structural loading of the original Lougheed Town Centre Station design;

(ii) the Station structure shall be connected to the existing Guideway structure without structural or seismic upgrades to the existing Guideway structure;

(iii) the cantilevered platform roof structure shall meet the requirements of Article 10 [Architecture] of this Part 2 and the applicable Preliminary Station Design Drawings;

(iv) if the roof structure cannot be designed to meet the requirements of Articles 5.8.2(d)(i) through (iii), all of this Part 2, using the seismic and structural requirements of the BCBC, the 1998 BCBC may used for the seismic and structural analysis and Design only; and

(v) if the 1998 BCBC is used for seismic and structural analysis and Design of the roof structure pursuant to Article 5.8.2(c)(iv) of this Part 2, the Primary Contractor shall carry out the seismic and structural Design of the Lougheed Town Centre Station to a "Post-Disaster" Importance Category, as that term is defined in the 1998 BCBC.

(e) Where the Primary Contractor demonstrates that any of the seismic or structural requirements of this Article 5.8.2 [Seismic Design Requirements at Lougheed Town Centre Station] or Article 4.9.2 [Seismic Approach for Combined Stations/Guideway Structures] of this Part 2 cannot be met without altering the existing Lougheed Town Centre Station and/or Guideway, the Primary Contractor may make alternate submissions to the Province's Representative, acting reasonably, pursuant to the Consent Procedure regarding:

(i) the seismic and structural requirements for the new works at Lougheed Town Centre Station;

(ii) the analysis of the interactions of the new works at Lougheed Town Centre Station with the existing station and Guideway structures; and

(iii) the Seismic Performance Level requirements set out in this Article 5 [Seismic].

5.9 Other Structures

(a) For any structures not specifically addressed in this Article 5 [Seismic], the Primary Contractor shall undertake a comparable level of Design and analysis as is outlined for the Guideway in Article 5.7 [Guideway Seismic Design Requirements] of this Part 2 and shall satisfy the Province's Representative that the requirements of the equivalent seismic performance levels will be complied with.