Province of British Columbia | Ministry of Transportation and Highways

MEMORANDUM

Distribution: See attached List

11 March 1994
195-20/TECH

Re: Seismic Design and Rehabilitation Criteria
Technical Circular T-2/92

Procedure for obtaining the AASHTO Acceleration Coefficient referred to in the second paragraph of Sections 2.3.1.1.B and 3.3.1.1.B of the Seismic Design and Rehabilitation Criteria is revised as follows.

> In the absence of a relationship between Canadian seismicity (as outlined in the Supplement to the National Building Code of Canada (NBCC) 1990) and the AASHTO Acceleration Coefficient, the AASHTO Acceleration Coefficient shall be taken as numerically equivalent to the Zonal Acceleration Ratio "a". The Zonal Acceleration Ratio, a, shall be determined from one of the following procedures:
>
> 1) From Figure J-1 of the Supplement to the NBCC in conjunction with the Table J-1 of the Supplement to the NBCC. Interpolation shall not be used for sites located between contour lines or between a contour line and a local maximum or minimum.
>
> 2) From the design data table provided at the end of Chapter 1 of the Supplement to the NBCC in conjunction with the Table J-1 of the Supplement to NBCC. For locations not listed in the design data table, the highest value for adjacent tabulated locations shall be used unless site specific data is obtained.
>
> 3) A site specific Zonal Acceleration Ratio may be obtained from the Pacific Geoscience Centre in Sidney, B.C. The site specific Zonal Acceleration Ratio shall be taken as the Peak Horizontal Ground Acceleration(G) for a 10% probability of being exceeded in 50 years (or 0.0021 a year).

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Technical Circular T-2/92
February 14, 1992

TO: ALL H.Q. DIRECTORS: Prof. Services, Planning & Major Projects
ALL REGIONAL MANAGERS Prof. Services, Planning & Operations
ALL DISTRICT HIGHWAYS MANAGERS

SUBJECT: **SEISMIC DESIGN AND REHABILITATION CRITERIA**

PURPOSE:

To provide guidance on the criteria to be used in earthquake resistant design, evaluation and retrofitting of all Ministry works.

BACKGROUND:

Past practice has incorporated state-of-the-art structural and geotechnical analyses into new designs and into the assessment of existing infrastructure on an ad-hoc basis. A formal approach to earthquake resistance design, evaluation and rehabilitation is needed to respond to the issue of the Ministry's seismic preparedness with respect to its infrastructure. The attached "Seismic Design and Rehabilitation Criteria" fulfills this requirement.

PROCEDURE:

Procedures outlined in Section 2 (Planned New Facilities) and in Section 3 (Existing Facilities) of the attached **"Seismic Design and Rehabilitation Criteria"** shall be used for all Ministry works.

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SEISMIC DESIGN AND REHABILITATION CRITERIA FOR TRANSPORTATION FACILITIES

1.0 General

With the growing awareness of seismic design requirements, The Ministry of Transportation and Highways has been incorporating state-of-the-art structural and geotechnical analyses into new designs and into the assessment of existing infrastructure on an ad-hoc basis. A formal approach to earthquake resistant design, evaluation and rehabilitation is needed to respond to the issue of the Ministry's seismic preparedness with respect to its infrastructure. "Seismic Design and Rehabilitation Criteria" presented in this paper covers all Ministry works, including planned and existing Earthworks, Structures (above and below ground) and Marine infrastructure that could be affected by earthquake induced motions. Since the application of the criteria to planned new facilities will have different implication than the application to the existing facilities, this paper will address "Planned New Facilities" and "Assessment and Retrofitting of Existing Facilities" separately. The primary goal in establishing the criteria is to minimize public risk associated with loss of life during earthquakes and to preserve important transportation routes for use after earthquakes. A secondary purpose is to reduce post-earthquake repairs.

1.1 Basic Premises:

Seismic Design Strategy needs to be compatible with the three intrinsic primary goals:

- to minimize hazards and risks associated with the use of transportation facilities and to enhance public safety;
- to provide and maintain adequate transportation facilities for the public;
- to ensure that public funds are effectively spent.

Under the guidance of these goals the following are proposed:

1.1.(a) Seismic safety shall be given priority consideration in the allocation of resources for transportation infrastructure.

1.1.(b) Earthquake risks and consequences of exposure to earthquakes shall be compatible with the risks and consequences generally accepted for other natural hazards e.g. floods.

1.1.(c) Seismic safety conditions in existing structures shall be identified and prioritized for correction. It is economically unrealistic to suggest that every structure be immediately retrofitted to withstand earthquakes without some damage.
The ultimate goal is to see that all transportation facilities in

the Province will be capable of withstanding moderate to severe earthquakes without collapse (sudden loss of load carrying capacity). With this in mind, a long term strategy and program for the seismic strengthening of existing substandard infrastructure will be developed and adhered to.

1.1.(d) "Seismic safety" taken broadly will not only minimize direct injury or death to individuals who are on or near the structures, but also minimize indirect injury due to the closure of structures critical to a transportation system which would support emergency response to a large scale civil disaster. Since MoTH has been assigned to be the Primary Agency for transportation under B.C. Earthquake Response Plan, MoTH will lead in establishing "Emergency Service Priority Routes" throughout British Columbia in consultation with other agencies (P.E.P., Surface Emergency Planning Canada, Municipalities etc.).

1.1.(e) Actions for rapid, effective and economic response to and recovery from damaging earthquakes shall be developed and implemented. This will be outlined in the Ministry's Earthquake Preparedness and Response Plan for each Region.

2.0 SEISMIC DESIGN CRITERIA FOR PLANNED NEW FACILITIES

2.1 Scope

Earthquake resistant design must be considered for all permanent Ministry works:

a) Structures, Underground Structures, Tunnels and Snow-Sheds;
b) Foundations, Bridge-End Fills, Retaining Walls and Large Culverts;
c) Earth and Rock Slopes and Embankments;
d) Dykes and Marine Infrastructure.

2.2 Classification of Facilities

Planned facilities shall be classified in order of importance:

2.2.1 Class I (Important) Facilities

Facilities performing vital functions that must remain functional following earthquakes, or facilities, failure of which will cause harm to inhabited adjacent area. Class I facilities are considered to be essential to emergency response capabilities.

Until a comprehensive classification system is developed in accordance with 1.1.(c) which will also be used for new facilities and 1.1.(d), Class I facilities shall fit the following criteria:

2.2.1.1 Structures, Foundations, Bridge-End Fills and Retaining Walls

Facilities performing vital functions that must remain functional following earthquakes or facilities failure of which will cause harm to inhabited adjacent area, or facilities which satisfy the following criteria:

Summer Average Daily Traffic projected for design (SADT)>50000 vehicles/day AND Total Length of Structure>240 m. for Region 1.

Total Length of Structure>240 metres for Regions 2,3,4,5, and 6.

2.2.1.2 Embankments, Slopes, Dykes and Marine Infrastructure

Facilities performing vital functions that must remain functional following earthquakes or facilities failure of which will cause harm to inhabited adjacent area or facilities which satisfy the following criteria:

Projected Summer Average Daily Traffic (SADT)>50000 vehicles/day AND Height of Fill/Cut>10 metres for Region 1 (height criteria will be waived for embankments crossing areas with liquefaction potential).

Height of Fill/Cut>10 metres or embankments crossing areas with liquefaction potential for Regions 2,3,4,5 and 6.

2.2.2 Class II (Standard) Facilities

All other permanent facilities which are not included in Class I.

2.3 Design Standards

2.3.1 Seismic Ground Motions

Discussions on the possibility of a very large subduction earthquake of Richter Scale Magnitude 9 on the Cascadia subduction zone are found in the current literature. However, because of uncertainties associated with a subduction event, and because such an event is not currently addressed in the National Building Code, earthquake induced ground motions shall be estimated on the basis of probabilistic analysis of historical earthquakes as recommended by the National Building Code of Canada 1990. A Richter Magnitude of M7 would be appropriate to associate with the 475 year return period earthquake. This is consistent with the approach adopted in the UBC/Industry Task Force Report dated June 1991 on Earthquake Design in the Fraser Delta.

Potential consequences of ground liquefaction shall be evaluated at the preliminary design stage for all facilities. The extent of site improvement to prevent the occurrence of liquefaction for the design earthquake or other measures (including structural) that can be taken to achieve a liquefaction-resistant design shall be reviewed on a case by case basis. Structural and geotechnical design shall be compatible for all facilities.

Effects of tsunamis or earthquake generated tidal waves shall be given consideration in designing facilities for coastal areas.

2.3.1.1 Structures

The following design standards will apply to all above ground structures including Bridges, Bridge Foundations, Snow-Sheds, and Ferry Loading Ramps.

Until such time as Ministry design standards utilizing a two level Design Approach can be developed, seismic design shall be in accordance with American Association of State Highway and Transportation Officials (AASHTO) - Standard Specifications For Seismic Design of Highway Bridges (1990). Deviations from this standard are allowed and required for Class I structures as outlined in 2.3.1.1.A.

Current AASHTO seismic design criteria are based on a one-level approach, i.e., an analysis is performed for only one-level of earthquake loading and all forces and displacements are derived from this analysis. This approach focuses on collapse prevention during the design seismic event, and allows substantial damage to occur as part of the mechanism for resisting the design earthquake. It is implicit in this one-level approach that small to moderate earthquakes will be resisted elastically (i.e. without significant damage). However, the level of seismic loading at which the onset of damage would occur is unknown. Further, the ability of the structure to withstand extreme earthquakes, which are more severe than the design event, is also not checked.

A two-level earthquake design approach could permit the introduction of fully elastic performance under a moderate design event and inelastic response (but no collapse) under an extreme design event. The lower level event (1 in 100 year return period earthquake) would be used to establish design forces, adequate structural strength, and to ensure no damage for that event; the second level event (1 in 1000 year return period earthquake) would be used to determine maximum displacements and to ensure that there is no potential for collapse under a severe earthquake. This approach would be most suitable for important structures which must remain functional following earthquakes.

A two-level seismic design approach will require more complex analytical methods and code revisions which are currently evolving. The Ministry will endeavour to adopt these procedures for Class I Facilities. However, until this methodology can be developed the following design ground motions shall be used:

2.3.1.1.A Class I Structures

Site specific seismic response spectra shall be used for Class I Structures. The design response spectra shall be obtained by using the appropriate site specific response for the 1 in 475 year return period earthquake magnitude. This earthquake corresponds to a 10% probability of exceedance in 50 years. Until specific design spectra are developed for British Columbia, the design spectra shall be based on a mean plus one standard deviation of response spectra results produced by analyses of input records. Spectral values shall not exceed corresponding maximum values used by the California Department of Transportation. (It is noted that the magnitude of ground motions for this design spectra corresponds roughly to those of a 1 in 1000 year return period earthquake for the Lower Mainland with a 4.8% probability of exceedance in 50 years). The spectra for vertical ground motions may be determined with sufficient accuracy by multiplying ordinates of the spectra for horizontal motion by 2/3.

2.3.1.1.B Class II Structures

Standard AASHTO seismic response spectra shall be used for Class II Structures. The design spectra is based on a 1 in 475 year return period earthquake. This earthquake corresponds to a 10% probability in 50 years. The spectra for vertical ground motions may be determined with sufficient accuracy by multiplying ordinates of the spectra for horizontal motion by 2/3.

In the absence of a relationship between Canadian seismicity (as outlined in the Supplement to the National Building Code of Canada (NBCC) 1990) and the AASHTO Acceleration Coefficient, the AAHSTO Acceleration Coefficient, A, shall be taken as numerically equivalent to the Zonal Velocity Ratio, v, given in the Supplement to the National Building Code of Canada (NBCC) 1990, or obtained from the Pacific Geoscience Center in Sidney, B.C.

2.3.1.2 Embankments, Bridge-End Fills, Retaining Walls, Earth and Rock Slopes, Dykes and Underground Structures

All planned Class I and Class II Embankments, Bridge-End Fills, Retaining Walls, Earth and Rock Slopes, Dykes and Underground Structures shall be designed using 1 in 475 year return period earthquake induced base rock peak accelerations and Class I facilities shall be checked against collapse under 1 in 1000 year return period earthquake input. For Class II Facilities, large deformations could be permitted to occur under 1 in 475 year or longer return period earthquake which would necessitate repairs and periods of closure.

Dynamic analyses will be used in calculating the horizontal response of Class I facilities where feasible. Horizontal ground motion values will be obtained as indicated in 2.3.1.

For vertical response, the ground motion values will be taken as 2/3 of the horizontal motion values.

Effects of probable tsunamis or earthquake generated tidal waves occurring near a high tide shall be given consideration in designing facilities for coastal areas.

The rationale behind higher return periods for the new facilities is that the new facilities will be exposed to earthquake hazards for longer periods than the existing infrastructure. It is also more economical, particularly for foundations, to improve the ground for new structures (which would have the required ductility) than trying to retrofit the foundation of an old rigid structure.

2.3.1.3 Performance Criteria for New Facilities

Class I Facilities will remain functional at 1 in 475 year return period earthquake and not suffer sudden loss of load carrying capacity at 1 in 1000 year earthquake. Repairable damage and interruption to traffic will be considered at 1 in 1000 year earthquake event.

Class II Facilities may have minor damages and temporary closures at 1 in 475 year earthquake and may undergo major repairs and closures at 1 in 1000 year earthquake event.

3.0 SEISMIC ASSESSMENT AND RETROFITTING CRITERIA FOR EXISTING FACILITIES

3.1 Scope

Existing facilities include:
a) Structures, Underground Structures, Tunnels and Snow-Sheds;
b) Foundations, Bridge-End Fills, Retaining Walls and Large Culverts;
c) Earth and Rock Slopes and Embankments;
d) Dykes and Marine Infrastructure.

3.2 Classification of Existing Facilities

As indicated in 1.1.(c) seismic safety conditions in existing structures shall be identified and prioritized for correction. As the retrofit of existing facilities is a very expensive proposition, the selection of facility will have to be realistic. For retrofit prioritization purposes four categories of facilities are proposed:

3.2.1 Category I Facilities

Facilities performing vital functions that must remain functional following earthquakes or facilities, failure of which will cause harm to inhabited adjacent area. Category I facilities are considered to be essential to emergency response capabilities (those measures undertaken immediately after the earthquake has occurred and for a limited time period thereafter). Until a comprehensive priority ranking system is developed in accordance with 1.1.(c) and 1.1.(d), Category I facilities shall satisfy the following criteria:

3.2.1.1 Category I Structures, Foundations, Bridge-End Fills and Retaining Walls

Facilities performing vital functions that must remain functional following earthquakes, or

facilities, failure of which will cause harm to inhabited adjacent area, or

facilities which satisfy the following criteria:

Summer Average Daily Traffic (SADT)>50000 vehicles/day AND Total Length of Structure>240 m. for Region 1.

Total Length of Structure>240 metres for Regions 2,3,4,5 and 6.

3.2.1.2 Category I Embankments, Slopes, Dykes and Marine Infrastructure

Facilities performing vital functions that must remain functional following earthquakes, or

facilities failure of which will cause harm to inhabited adjacent area, or

facilities which satisfy the following criteria:

Summer Average Daily Traffic (SADT)>50000 vehicles/day AND Height of Fill/Cut>10 metres for Region 1 (height criteria will be waived for embankments crossing areas with liquefaction potential).

Height of Fill/Cut>10 metres or embankments crossing areas with liquefaction potential for Regions 2,3,4,5 and 6.

3.2.2 Category II Facilities

Until a comprehensive priority ranking system is developed in accordance with 1.1.(c) and 1.1.(d), Category II facilities shall satisfy the following criteria:

Facilities that are considered to be critical to continuing post-earthquake recovery efforts (those measures undertaken to restore normal conditions) but whose service can be temporarily interrupted until minor repairs can be made, or,

Facilities given high Priority Ranking (in "Seismic Rehabilitation of Bridges") and confirmed by review of two senior engineers.

3.2.3 Category III Facilities

Until a comprehensive priority ranking system is developed in accordance with 1.1.(c) and 1.1.(d), Category III facilities shall satisfy the following criteria:

Facilities that are required to maintain general transportation service levels, or,

Facilities given low to intermediate Priority Ranking (in "Seismic Rehabilitation of Bridges") and confirmed by review of two senior engineers.

3.2.4 Category IV Facilities

Facilities that are not included in Categories I, II or III above.

3.3 Assessment Criteria and Design Standards

3.3.1 Seismic Ground Motions

Earthquake induced ground motions shall be estimated on the basis of probabilistic analyses of historical earthquakes as recommended by the National Building Code of Canada 1990. Deterministic methods for establishing Maximum Credible Earthquake conditions will not be used.

Potential consequences of ground liquefaction shall be evaluated for Category I and II facilities. The extent of site improvement to prevent liquefaction from occurring or other measures (including structural) that can be taken to improve the foundation against liquefaction shall be reviewed on a case by case basis. Structural and geotechnical improvements shall be compatible.

Effects of tsunamis or earthquake generated tidal waves shall be considered in assessing Category I facilities in coastal areas.

3.3.1.1 Structures

The following criteria will apply to all above ground structures including Bridges, Bridge Foundations, Snow-Sheds, and Ferry Loading Ramps.

3.3.1.1.A Category I Structures

Category I Structures shall be evaluated against collapse and damage using the 1 in 475 year earthquake seismic response spectra. These facilities shall also be assessed to determine whether or not they would remain functional in the event of a 100 year return period earthquake.

Site specific seismic response spectra shall be used for Category I Structures. Design response spectra shall be obtained by using appropriate site specific response for both the 1 in 475, and the 1 in 100 year return period earthquake magnitudes. The design spectra shall be based on a **mean** of response spectra results produced by analyses of input records.

Seismic response spectra for vertical ground motions may be determined with sufficient accuracy be multiplying ordinates of the spectra for horizontal motion by 2/3.

Structural evaluation methods are currently being developed. Therefore evaluation procedure for each facility will be selected as deemed appropriate.

3.3.1.1.B Category II and III Structures

Category II and III Structures shall be evaluated against collapse and damage using standard AASHTO design spectra for the 1 in 475 year earthquake. These facilities shall also be assessed to determine whether or not they would remain functional in the event of a 100 year return period earthquake.

In the absence of a relationship between Canadian seismicity (as outlined in the Supplement to the National Building Code of Canada (NBCC) 1990) and the AASHTO Acceleration Coefficient, the AAHSTO Acceleration Coefficient, A, shall be taken as numerically equivalent to the Zonal Velocity Ratio, v, given in the Supplement to the National Building Code of Canada (NBCC) 1990, or obtained from the Pacific Geoscience Center in Sidney, B.C.

3.3.1.1.C Category IV Structures

These structures will not be evaluated.

3.3.1.2.A Category I Embankments, Bridge-End Fills, Retaining Walls, Earth and Rock Slopes, Dykes and Underground Structures

Existing Category I Embankments, Bridge-End Fills, Retaining Walls, Earth and Rock Slopes, Dykes and Underground Structures shall be evaluated against collapse using 1 in 475 year return period earthquake induced ground motions. These facilities shall also be assessed to determine whether or not they would remain functional in the event of a 100 year return period earthquake.

3.3.1.2.B Category II, and III Embankments, Bridge-End Fills, Retaining Walls, Earth and Rock Slopes, Dykes and Underground Structures

Existing Category II and III Embankments, Bridge-End Fills, Retaining Walls, Earth and Rock Slopes, Dykes and Underground Structures shall be evaluated against collapse using 1 in 475 year return period earthquake. Repairs requiring interruption to traffic would be considered for these facilities in earthquakes with 100 year or longer return period.

3.3.1.2.C <u>Category IV Embankments, Bridge-End Fills, Retaining Walls, Earth and Rock Slopes, Dykes and Underground Structures</u>

These existing facilities will not be evaluated.

<u>3.3.2 Performance Criteria for Existing Facilities</u>

Subject to the constraints discussed in "3.4 Retrofit Criteria" the ultimate goal is to prevent collapse and achieve the following performance:

Category I Facilities will essentially remain functional at 1 in 475 year return period earthquake but minor damages and closures may be expected.

Category II & III Facilities may undergo major repairs and closures at 1 in 475 year earthquake event.

Category IV Facilities performance in earthquakes may remain unknown as these facilities are not evaluated.

<u>3.4 Retrofit Criteria</u>

As existing structures cannot be made to achieve the stated standards immediately, staging of retrofit work will be inevitable. Consequently, Category I Facilities in Regions 1, 5 and 6 will have to be retrofitted first. Retrofitting itself may involve staged upgrading of individual facility (i.e. immediate minimum retrofitting and subsequent upgrading). With proper retrofitting it is believed that collapse is preventable and that damage can be held to a minimum, so that the transportation system can remain functional during repairs. However retrofitting many older structures to this standard may not be cost effective.
If the incremental cost of retrofitting existing structures to the same standards adopted for new facilities is of the order of 15%, the higher design level will be considered. With this in mind a comprehensive retrofit strategy will be developed.

Feasibility of alternatives to rehabilitation, varying from installation of early warning systems to closure or replacement of the facility shall be evaluated.

4.0 EARTHQUAKE ENGINEERING RELATED DATA COLLECTION AND ANALYSES

Much of the engineering work required to comply with the criteria proposed in this paper is relatively unprecedented, and available information for seismic design is limited at the present time. Therefore:

a) A program of problem-focused research on earthquake engineering issues pertinent to MoTH responsibilities;

b) A continuing program of professional development in earthquake engineering,

have been established and will be continued, and

c) A program of seismic instrumentation to provide measurements of the response of transportation structures during earthquakes,

will be implemented.

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