A Preliminary Survey of Seismic Provisions in Canadian Construction Codes and Standards

T. Onur
OS Consulting

M.R. Seemann
University of Victoria

M. Gerin
Marc Gerin Consulting

SUMMARY:
Designed to minimize life, property and economic loss, Canada's seismic mitigation provisions for structural elements have largely developed in isolation of one another, and as such are promulgated through a variety of, model codes, standards, guidelines, and best practices. Provincial governments have the option to adopt these or other national and international standards in whole or in part, or to modify these provisions to suit their specific needs. This study catalogues existing Canadian construction codes, reviews their developmental history and regulatory authority, and focuses on profiling the characteristics of their respective seismic provisions. The paper is offered to initiate and facilitate an informed discussion regarding relative seismic risk and design levels currently used for various Canadian structures (e.g. buildings, bridges, power plants, dams).

Keywords: Seismic design, Canada, seismic risk, construction codes, risk tolerance

1. INTRODUCTION

In Canada, the coordination and approval of national structural design standards to mitigate disasters is the purview of Industry Canada. This federal government department facilitates the development and use of national and international standards to ensure efficient and effective standardization occurs for the safety and well-being of Canadians through the Standards Council of Canada (SCC), a crown corporation. The SCC oversees the National Standards System which includes standards development organizations, product/service certification bodies and inspection bodies (SCC, 2009).

A number of standards development organizations have been involved in the development and establishment of structural design guidelines, standards and codes in Canada. Over the past several decades, individual standard development was largely driven by the need for consensus on professional best practices and standards were largely developed in isolation of one another.

This paper provides a survey of seismic provisions in Canadian construction codes and standards that apply to twelve structure types. It highlights hazard levels (and risk when available) assumed in various seismic provisions and aims to initiate conversations around the need to explicitly identify risk tolerance with various stakeholders (such as public, various levels of government, emergency managers, insurance industry) as well as the engineering community.

2. CONSTRUCTION CODES AND STANDARDS

Canadian seismic design provisions for twelve structure types are reviewed in this section. National-level codes and standards are surveyed for buildings; farm buildings; highway bridges; dams; nuclear power plants; concrete containment structures for nuclear power plants; off-shore structures; towers and antennas; oil and gas pipelines; liquefied natural gas (LNG) facilities; railroad structures; and tunnels. Each of these structures is designed to a different code, standard or guideline, and for those that do not have a formal national design code in Canada, we cite "accepted practices".

The following sections summarize for each code or standard, the name, the issuing agency, the scope, the revision history, and whether seismic provisions are present. Additionally, for those codes with seismic provisions, the seismic hazard upon which the design loads are based, the considerations related to risk tolerance and the risk level for which the structure is designed are identified.

2.1. Buildings

Most buildings in Canada are designed according to the National Building Code (NBC) of Canada. The NBC is a model code and has to be adopted by the provinces and territories in Canada to become legally enforceable. Provinces choose whether to adopt it as is, adopt it with modifications, or not adopt it. In this paper we focus on the NBC rather than address each province's building code.

The NBC is developed and maintained by the Canadian Commission on Building and Fire Codes, an independent committee established by the National Research Council of Canada (NRC). It was first issued in 1941, updated roughly every five years (1953, 1960, 1965, 1970, 1975, 1977, 1980, 1985, 1990, 1995, 2005) and was most recently revised in 2010.

While the NBC includes detailed seismic provisions, they are not mandatory for buildings that are 3 stories or less in height, with a building area not exceeding 600 m^2, and classified as residential, commercial, low-hazard industrial or medium-hazard industrial occupancies.

The seismic hazard assessments that underlie the NBC's seismic provisions are largely carried out by the Geological Survey of Canada (GSC). GSC hazard model updates are typically in lock step with the NBC release timelines and are an integral part of the development of NBC's seismic provisions.

In 2005 the seismic hazard level used by the NBC changed from ground motions with 10% probability of exceedance in 50 years to 2% in 50 years. Additionally, the NBC became an objective-based code in 2005. Its stated primary objective is "to provide an acceptable level of safety for building occupants and the general public as the building responds to strong ground motion; in other words, to minimize loss of life". Strong ground motion is defined as having a "2% probability of exceedance in 50 years at a median confidence level". At this level of ground shaking, extensive structural and non-structural damage is deemed likely, and it is assumed with a reasonable degree of confidence that the building will not collapse. The NBC expects that buildings designed in compliance with its seismic provisions will have limited damage at ground shaking levels well below the 2% in 50-year ground motions. However, "well below" and "limited damage" are not defined explicitly and quantitatively.

Two key phrases are used in NBC when describing design objectives: "limit the probability" and "unacceptable risk". The first phrase is a reflection of the NBC's recognition that it cannot entirely prevent undesirable situations and their consequences from happening. The second phrase is the NBC's acknowledgement that it cannot eliminate all risk and that the "acceptable risk" is the residual risk that remains after complying with the provisions of the NBC. Neither of these terms is defined quantitatively.

The probability level chosen for seismic design (2% in 50 years) is a ground shaking exceedance level, i.e. there is a 2% chance that the ground shaking to which a building is designed will be exceeded in 50 years (or a rate of 0.000404 per annum), but whether or not the structure will collapse at this higher ground shaking is uncertain. Hence, the actual level of risk, i.e. the probability of collapse, or more directly related to the objective of the code, the probability of casualties, is not directly addressed and is difficult to gauge.

The NBC uses two force modification factors, a ductility-related factor and an overstrength-related factor to reduce the design loads associated with the 2% in 50 years ground motions. In addition, importance categories for seismic design of buildings are used, which allows modification of seismic loads by deterministic multiplicative factors (0.8 for low importance, 1.0 for normal importance, 1.3

for high importance and 1.5 for post-disaster buildings). These factors are an indirect way to achieve various performance objectives. Because of these factors, the actual seismic hazard associated with the design loads is unknown.

2.2. Farm Buildings

Farm buildings in Canada have to conform to a different standard than the NBC. Like NBC, the National Farm Building Code of Canada (NFBC) is published by the NRC through its Canadian Commission on Building and Fire Codes. It was first issued in 1964, updated almost in lock-step with the NBC until 1995 (1965, 1970, 1975, 1977, 1983, 1990, 1995), and has not been updated since.

NFBC does not require farm buildings of low human occupancy (an occupant load of not more than one person for each 40 m^2) to be designed for earthquake loads. Farm buildings with higher occupancy are designed using NBC.

2.3. Highway Bridges

Bridges in Canada are generally designed according to the Canadian Highway Bridge Design Code (CHBDC). As in buildings, the legal mandate for establishing design and construction requirements for highways and highway bridges lies with the provincial and territorial governments in Canada. Hence the CHBDC needs to be adopted by provinces and territories to become law.

The CHBDC is developed and maintained by the Canadian Standard Association (CSA), and is also referred to as CAN/CSA-S6. The current edition of the CHBDC is S6-06 which was released in 2006. Two supplements have since been issued (S6S1-10 in 2010 and S6S2-11 in 2011), however, neither of these supplements includes revisions to the seismic provisions.

S6-06 is the tenth edition of CAN/CSA-S6. The first edition was published in 1922, with subsequent editions published in 1929, 1938, 1952, 1966, 1974, 1978, 1988 and 2000. The first comprehensive seismic provisions were included in the 2000 edition and were based on the 1994 American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications. The 2006 seismic provisions are based primarily on the 2005 AASHTO LRFD Bridge Design Specifications.

The seismic design provisions of S6-06 were developed using the general principles that: a) structural components remain essentially elastic during low to moderate levels of earthquake shaking; and b) high levels of earthquake shaking should not cause collapse of the bridge.

While the commentary to the code lists various performance objectives for three levels of ground shaking and three bridge importance categories (i.e. lifeline, emergency-route, other), the actual design requirements only consider the design earthquake, which is defined as ground motions with a 10% probability of exceedance in 50 years. The design objective for regular bridges is to prevent collapse (i.e. life safety) when subjected to the design earthquake. Importance factors are used to modify the design forces for emergency-route and lifeline bridges to achieve more stringent performance objectives, still with the design earthquake. The code, however, does not require calculation of expected damage or evaluation of functionality. The net effect of the importance factors is that emergency-route bridges are designed for reduced ductility demands and lifeline bridges are designed to remain elastic for the design ground motions.

2.4. Dams

The Dam Safety Guidelines (DSG) document provides, at the national level, procedures for seismic design of dams in Canada. As with other structures discussed above, regulation of dam safety in Canada is primarily the responsibility of the provinces and territories. As its name suggests, the DSG constitutes merely guidelines unless it is adopted in part or in whole by provinces and territories.

The DSG is published by the Canadian Dam Safety Association. The publication of the first DSG in 1995 was a culmination of many years of effort by working groups across Canada. It was revised in 1999 and 2007.

First of many principles of dam safety that the DSG stipulates is: "The public and the environment shall be protected from the effects of dam failure, as well as release of any or all of the retained fluids behind a dam, such that the risks are kept as low as reasonably practicable". This is somewhat similar to the NBC's "limit the probability" phrase. However unlike NBC, due to the possible high-consequence nature of dam failure, the DSG stipulates that the dam owners estimate potential consequences of dam failure in terms of loss of life, injury, general disruption of the lives of the population in the inundated area, environmental and cultural impacts, and damage to infrastructure and economic assets. Generally, the DSG document deals with risk management more directly than other codes, and specifies a more formal process while acknowledging that the actual level of protection is still unknown.

The life safety risk guidelines in the DGS are stipulated in two categories; individual risk (can be thought of as the risk to a hypothetical member of the public living in the zone that can be impacted from a dam failure) and societal risk (generally refers to hazards that can impact society and generate socio-political response).

Societal risk is defined across two dimensions; number of fatalities (N) and probability of more than N fatalities. The maximum level of societal risk related to life safety is specified to be less than 0.001 or 10^{-3} per annum for loss of one life. As the number of lives lost increases, the maximum level of acceptable risk gets much lower (e.g. 0.00001 or 10^{-5} per annum for loss of 100 lives). This is a true measure of risk (i.e. both probability and consequence considered) unlike the ground shaking probabilities used by the building code, which are hazard based and hence consequences (collapse, loss of life, etc.) are not part of the probability level considerations.

Individual risk, according to the DSG, should be calculated in terms of the "maximally exposed individual", i.e. an individual who permanently lives downstream of the dam. In this case, the maximum level of individual risk should be less than 0.0001 or 10^{-4} per annum according to the DSG. To assess this probabilistically, the probability of each event needs to be multiplied by the conditional probability of failure of the dam given that the event occurs, and that, in turn, needs to be multiplied by the conditional probability of loss of life given that the dam fails. As this can get challenging to compute, DSG suggests that in case there is insufficient information available and simplification is necessary, the two conditional probabilities be assumed to be equal to 1 (i.e. if the event occurs, there will be loss of life) to be conservative. For earthquakes, this assumption would work only beyond a certain ground shaking threshold; otherwise it would be too conservative to assume every earthquake will cause loss of life.

The DSG document also allows "deterministic" assessments instead of fully probabilistic risk-based methods in determining design earthquake levels. What is referred to as "deterministic" by the DGS is similar to the building code's approach, which is to consider ground motion exceedance probabilities (or hazard) as the basis of earthquake design instead of risk. These are provided for five different classes of dams from "Low" (no population at risk, minimal short-term environmental and cultural loss, no long-term environmental and cultural loss) to "Extreme" (more than 100 permanent residents at risk, major loss of critical fish or other wildlife habitat, restoration or compensation in kind of environmental or cultural loss is not possible, extreme losses affecting infrastructure or services). The corresponding annual exceedance probabilities for mean earthquake design ground motions vary from 0.002 for "Low" to 0.0001 for "Extreme" class of dams.

It is interesting to note that for "High" and "Very High" classes of dams, the DSG allows a reduction in earthquake design ground motion, provided that the design ground motion value can be demonstrated to conform to "societal norms of acceptable risk". While those norms are left undefined, this is the only code surveyed in this paper that actually refers to risk levels that are acceptable by the society.

DSG categorically prescribes that seismic hazard assessments be performed for earthquake design of dams, independent of the GSC's national seismic hazard estimates. There are three principle reasons for this: 1) As the GSC's seismic hazard assessments are primarily carried out with the building code in mind, they focus more on urban areas, which may result in unconservative hazard values in remote areas where dams are usually built; 2) Ground motion values calculated for the building code represent "median" hazard, not "mean" hazard as the DSG requires; and, 3) Building code hazard values are provided for a country-wide reference ground condition and hence are not site-specific (while the DSG allows site conditions to be considered as part of the structural analysis, it encourages site specific hazard calculations as an alternative).

2.5. Nuclear Power Plants

Nuclear power plants constructed in Canada have to follow the "Design Procedures for Seismic Qualification of Nuclear Power Plants" to determine the seismic loading that needs to be used for design.

This standard is published by the Canadian Standard Association (CSA), and is also referred to as the CSA N289.3. It is part of a series of standards under the CSA N289 banner: CSA N289.1 which provides guidelines for identifying structures and systems requiring seismic qualification based on nuclear safety considerations; CSA N289.2, which provides the appropriate seismic ground motion parameters to be determined for a particular site; CSA N289.3, which is the subject of this section; CSA CAN3-N289.4-M86 (R2008), which provides design requirements and methods for seismic qualification of specific components and systems by testing methods; and, CAN/CSA-N289.5-M91 (R2008), which establishes the requirements for seismic instrumentation and for seismic inspection of structures and systems before and after a seismic event.

N289.3 was originally published in 1981 and was updated in 2010 (N289.3-10). After CSA publishes this document, it has to be adopted by the Canadian Nuclear Safety Commission (CNSC) to become law. CNSC also publishes regulatory documents to establish a set of comprehensive design expectations.

Nuclear power plants in Canada are designed for mean ground motions with a rate of exceedance of 0.0001 or 10^{-4} per annum or smaller. However, it should be noted that N289.3-10 allows the use of standard-shape response spectrum in design, anchored to the peak ground acceleration (PGA). If this method is used to calculate the spectral accelerations for design, only the PGA can be guaranteed to have the probability of exceedance mentioned above, not the rest of the response spectrum.

N289.3-10 concedes that while conventional seismic design procedures ensure an adequate design from a "deterministic point of view", they do not quantify the actual probability of failure or consider the actual seismic vulnerability of the designed structure. In light of this, in order to ensure safety, N289.3-10 requires the consideration of seismic capacity at ground shaking exceedance rates that are lower than the 10^{-4} per annum, i.e. detailing for post-elastic behaviour and energy absorption during events that generate ground shaking that is beyond the design ground motions.

2.6. Concrete Containment Structures for Nuclear Power Plants

Concrete containment structures for nuclear power plants in Canada have to conform to their own set of standards. The "Design Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants" is published by CSA and is a series of standards issued under the CSA N287 banner. CSA N287.3 includes the design requirements including seismic provisions.

N287.3 was originally published in 1978 and was updated in 1982 and 1993. The 1993 edition was most recently reaffirmed in 2009; hence the current document is N287.3-93 (R2009).

N287.3-93 (R2009) requires that the concrete containment structures respond elastically when subjected to the seismic design ground motions (same ground motion exceedance rates as those for nuclear power plants as outlined in the previous section). And beyond those ground motions, it requires the concrete containment structures to still achieve inelastic deformation without failure.

2.7. Offshore Platforms

Offshore platforms in Canada have to conform to the "Code for the design, construction, and installation of offshore structures". The Code consists of a series of five standards published by CSA. Seismic provisions are defined in the first one, CAN/CSA-S471 "General requirements, design criteria, the environment, and loads". It was originally published in 1989 and was updated in 1992 and 2004. The 2004 edition was most recently reaffirmed in 2008; hence the current document is CAN/CSA-S471-04 (R2008).

CAN/CSA-S471 defines design objectives for offshore platforms in terms of two safety classes: Safety Class 1, where failure would result in great risk to life or high potential for environmental damage; and Safety Class 2, where failure would result in small risk to life and low potential for environmental damage. To meet the objectives, the standard defines annual target reliability levels of $1 - 10^{-5}$ (0.99999) for Safety Class 1, and $1 - 10^{-3}$ (0.999) for Safety Class 2. A safety class is assigned for each particular loading condition under consideration, and may be assigned to the structure as a whole or to individual structural elements. CAN/CSA-S471 is the only construction code/standard surveyed in this paper that has reliability-based design objectives.

Expected ground motions are to be calculated for events with an annual rate of exceedance of 10^{-4} to 10^{-3} for Safety Class 1 and 10^{-2} for Safety Class 2, which are considered to be consistent with the Safety Class 1 and Safety Class 2 failure consequences described above.

CAN/CSA-S471 requires that a site specific earthquake hazard investigation be carried out and that the ground motions be in the form of response spectra, time histories or other representations that contain information concerning amplitudes, frequency content, and duration. Procedures for earthquake hazard investigations are described in general terms in Annex F (note: annexes are not mandatory code requirements).

Earthquakes and related earthquake effects (liquefaction, slope instability, turbidity currents, and tsunamis) are classified as "rare environmental events" and are to be considered with companion frequent environmental processes (waves; wind; wind-driven, tidal and background currents; and ice).

2.8. Oil and Gas Pipelines

Oil and gas pipeline construction in Canada must conform to the "Oil and Gas Pipeline Systems" standard, which is published by CSA as CSA Z662. It covers the design, construction, operation, and maintenance of oil and gas industry pipeline systems that convey liquid hydrocarbons such as crude oil and liquid petroleum products, natural gas liquids, liquefied petroleum gas, oilfield water or steam, and carbon dioxide used in oilfield enhanced recovery schemes.

Z662 was originally published in 1994 and was updated in 1996, 1999, 2003 and 2007. The latest edition was released in 2011 (Z662-11).

Z662 requires seismic hazards to be considered for offshore steel pipelines; and the designers are referred to CAN/CSA-S471 for the methodology by which seismic hazards are to be considered.

For onshore pipelines, Z662 does not consider seismic loads as part of operating loads. And as such, it does not include explicit seismic design requirements. However, it requires designers to determine whether or not additional strength or protection against seismic damage needs to be provided. Non-mandatory, 'informative' guidelines on risk assessment and 'reliability-based design and assessment' of onshore pipelines are included as annexes.

2.9. Towers and Antennas

Towers and antennas have to conform to the standard for "Antennas, Towers, and Antenna-Supporting Structures" in Canada. This standard is published by CSA as CSA S37. It covers the design of most communication structures such as structural antennas, antenna towers, antenna-supporting structures, and roof- and wall-mounted structures.

S37 was originally published in 1965 and was updated in 1976, 1981, 1986, 1994 and 2001. The 2001 edition was most recently reaffirmed in 2011 incorporating two intermediate updates that were not released as separate editions, one in 2004 and 2006; hence the current document is S37-01 (R2011).

S37 considers wind and ice as the principal loads that govern the design (stability, strength, and serviceability) of these structures and does not consider these structures to be a direct threat to life safety during earthquakes. Consequently, it does not contain mandatory requirements to take into account the effects of earthquakes.

However, S37 makes a notable exception for towers of critical importance such as post-disaster communication systems in high earthquake zones and dedicates an appendix to earthquake design (note: material provided in the appendix is not a mandatory design requirement).

While Appendix M in S37 identifies three performance concerns appropriate for telecommunication towers; life safety, interrupted serviceability (no service during shaking; serviceable after shaking), and continuous serviceability (serviceable during and after shaking); it leaves the determination of the actual performance levels to the owner, depending on the tower's economical value and the function of the structure.

Appendix M combines these performance categories with levels of seismicity in a matrix to determine at which locations design should be checked for various performance levels.

High seismicity areas are defined where the ground shaking (in terms of peak horizontal ground acceleration) is 0.3g or higher; low seismicity areas are defined where the ground shaking is less than 0.15g; and moderate seismicity areas as between the two. The probability level associated with these ground motions is 10% chance of exceedance in 50 years or a rate of exceedance of 0.0021 per annum - the same as the 1995 NBC.

2.10. Liquefied Natural Gas Facilities

Liquefied Natural Gas (LNG) facilities built in Canada have to conform to the "Liquefied Natural Gas (LNG) - Production, storage, and handling" standard. This standard is published by CSA as CSA Z276. It was originally published in 1972 and was updated in 1973, 1978, 1981, 1989, 1994, 2001, and 2007. The most recent edition was released in 2011; hence the current document is referred to as Z276-11.

Z276 applies to the design, construction, operation, and maintenance of a) facilities for the liquefaction of natural gas and b) facilities for the storage, vaporization, transfer, handling, and truck transport of LNG.

Z276 includes explicit seismic design criteria for LNG tank systems and their associated systems. It requires a site-specific investigation to determine the characteristics of seismic ground motion at the site for three levels of ground motion: 1) the safe shutdown earthquake (SSE) with the mean-hazard probabilistic ground motion having a 2 % probability of exceedance within a 50-year period; 2) the operating basis earthquake (OBE) with the mean-hazard probabilistic ground motion having a 10 % probability of exceedance within a 50-year period; and 3) the aftershock level earthquake (ALE), defined as half of the SSE ground motion amplitudes. For SSE, Z276 also requires the deterministic 84th percentile spectral response for the Cascadia subduction zone ground motion to be calculated and used if it is higher than the probabilistic ground motion at each period of interest. Cascadia subduction zone ground motion is not considered for the OBE. Z276 is the only code surveyed that considers seismic hazard due to aftershocks, albeit in a simplified manner.

For the various levels of ground motion described above, Z276 includes performance requirements as follows: LNG storage tank systems and their associated systems remain operable during and after the OBE; SSE does not cause loss of containment capability of the primary container; and it is possible to isolate and maintain the LNG tank system during and after the SSE.

In addition, Z276 requires the secondary liquid container or impounding system, to be designed, as a minimum, to withstand an SSE while empty and the ALE while holding the volume equivalent to the primary containment liquid at the maximum normal operating level. It also requires no loss of containment capability in the secondary container after the SSE or ALE.

Shop-built LNG containers and their support systems; and buildings or structural enclosures which do not contain or are not used to handle LNG, flammable refrigerants, and flammable gases are required to be designed for the seismic ground motion specified in the NBC.

2.11. Railroads

There are no national codes or standards regarding railroads and accompanying structures including railway bridges in Canada. Each railway determines its own requirements for various aspects of design. For seismic design, the most common reference used is the Manual for Railway Engineering (MRE) published by American Railway Engineering and Maintenance-of-Way Association (AREMA, 2009). AREMA publishes the MRE as recommended practice to railroads and others concerned with the engineering, design and construction of railroad fixed properties (except signals and communications), and related services and facilities. Chapter 9 in the MRE concerns the seismic design of railway structures.

2.12. Tunnels

While there are a collection of specific guidelines or requirements regarding fire protection, ventilation, etc., there are no formal national design codes or construction standards that include seismic provisions for tunnels in Canada. Consequently, various accepted references for checking loads on a tunnel due to earthquake ground motions are generally used.

3. DISCUSSION

A number of points for discussion emerge from this survey of construction codes and standards in Canada. Five of the more salient topics centre around: the expression of hazard levels; the deterministic factors used in conjunction with probabilistic hazard; design objectives; risk perception and risk tolerance; and public oversight and coordination.

3.1. Probability of Exceedance, Rate of Exceedance, and Return Period

The codes and standards surveyed above, all describe a hazard level for which the ground motions are to be calculated as input to design. One or more of three expressions of hazard level are used in various codes and standards interchangeably:

Annual Rate of Exceedance: Although some codes refer to this as annual or per annum “probability of exceedance", it is strictly speaking "rate" of exceedance (i.e. how many times in a year the ground motion will be exceeded). For example, 2% chance of exceedance in 50 years corresponds to a rate of exceedance of 0.00040405 per annum.

Return Period: The reciprocal of the annual rate of exceedance is the return period. In the example above, the return period of ground motion that has a 0.00040405 rate of exceedance per annum is 2,475 years. This metric is sometimes confused with return period of "earthquakes" but is in fact the return period of a certain level of ground shaking.

Probability of Exceedance: This expression of hazard has to be accompanied by a time frame (typically 50 years for buildings). It describes the actual probability of exceeding a certain level of ground shaking in a given time frame.

Probability of exceedance provides the most clarity in expressing hazard, enabling a conversation regarding acceptable levels of hazard. In the above example for instance, is it acceptable that in 50 years, there is a 2% chance that the actual ground shaking levels will be higher than the ground shaking levels used for design?

On the other hand, in terms of comparing seismic hazard levels across various codes and standards, annual rate of exceedance is the most convenient since it is not reliant on a given time frame (e.g. 50 years). That said, such a comparison based on hazard alone is not representative of the true risk levels or the actual design load levels, for reasons explained in Sections 3.2, 3.3, and 3.4 below.

3.2. Probabilistic Hazard, Deterministic Design Loads

Hazard by itself does not reflect the actual design levels. This is because the probabilistically determined hazard factors are multiplied or divided by a number of deterministic factors such as importance factors, ductility factors and overstrength factors. After this process, it is difficult to determine the hazard and risk levels that are actually achieved.

3.3. Objective-based Codes

Canadian codes and standards are generally objective based with one or more design objectives. The "objectives" and "performance requirements" in Canadian codes are generally implicit and assumed to have been met if the design procedures outlined in the code are followed, i.e. there are no requirements to check that the design actually meets the specific objectives.

Clearer objectives and measurable metrics to test whether or not those objectives are actually met are needed in the development and the application of the codes. For example, preventing collapse is assumed to be equivalent to the building code's stated objective, which is to minimize life loss. While most of the life loss during an earthquake does result from collapsed buildings, buildings at other damage levels can cause significant loss of life as well. Hence explicitly defining more than one objective may be desirable, such as limiting damage at more frequent ground shaking levels in addition to the preventing life loss at rare, strong ground shaking levels. The current design requirements may already be achieving this second goal, but until the code objectives are made more explicit and closely tied to design loads, it is unclear whether these objectives are being met.

3.4. Risk Perception and Risk Tolerance

Risk tolerance decisions with respect to construction codes in Canada are generally made based on the best estimates of those involved in the code development process. Because no explicit performance criteria are laid out and no quantitative metrics are used to assess whether or not the performance objectives have been met, default testing of the design is left to future earthquakes.

There is a gap in public's expectation of how structures around them should or will perform during an earthquake and the expectations of the engineers. For example, after a strong earthquake, a standing building with extensive, non-repairable damage will be considered a successful design by an engineer, but will likely elicit questions from the public.

3.5. Public Oversight and Coordination

Although there is generally a public review process for all the codes developed in Canada, this process often happens when the code is close to being finalized, and it involves extensive technical material. Non-technical stakeholders such as general public, community decision makers, emergency managers, and insurance/reinsurance businesses involved in catastrophe risk are often uninformed that a review process is ongoing and when they are aware that they can provide feedback, they find the contents daunting to review. One possible solution would be to hold discussions about risk tolerance and performance goals before the code development process starts and make them open to all stakeholders. Then the more technical committees can work on how to achieve these goals and reduce seismic risk in the country to levels that are deemed acceptable by all stakeholders.

While such intentions exist conceptually in some codes, further effort is needed to operationalize them. For example, the building code refers to “unacceptable risk”, but does not specify to whom it is unacceptable, nor by what measures the risk is assessed. Similarly, the dam code refers to “societal norms of acceptable risk”, but does not stipulate how the societal norms are identified.

More formal coordination between national codes will allow for: 1) better integration of societal risk tolerance into the code development process, 2) the establishment of explicit and measurable performance objectives; 3) a migration toward risk-based rather than hazard-based assessments, and 4) a standardization of expressions of seismic hazard and risk.

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