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DEVELOPMENT OF SEISMIC RISK ASSESSMENT POLICIES FOR PUBLIC/PRIVATE STAKEHOLDERS

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ABSTRACT

Halsall Associates Limited has worked over the past two years with several different stakeholders to develop policies and guidelines related to seismic risk assessment of existing buildings. Stakeholders included municipalities, corporations, and Government agencies. The methodology and approach to the seismic assessments varied depending on the portfolio of buildings managed by each stakeholder. This paper discusses the different approaches taken with each stakeholder to develop an appropriate policy related to their existing buildings.

Introduction

Halsall Associates Limited (Halsall) has worked with several different stakeholders to develop seismic assessment programs/policies. This paper summarizes the assessment programs developed with the Department of Foreign Affairs and International Trade (DFAIT), Canada Post, and the City of Ottawa. As part of these projects a review of current industry standards related to seismic evaluation of existing buildings was carried out, as well as research into the programs/policies of other organizations.

Key factors in the development of the seismic assessment program included:

- An evaluation program that is consistent with current Canadian Code requirements;
- Establishing an appropriate reduction factor to be used when comparing the assessed lateral load capacity of an existing building to the current Code requirements; and
- Organizing the inventory of buildings into priority groups for further assessment.

Existing Evaluation Standards

Various evaluation standards/guidelines are available and are used in the industry to seismically evaluate existing buildings.

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Commentary L of the User's Guide – National Building Code of Canada (NBC) 2005 Structural Commentaries

The earthquake provisions of Part 4 of the National Building Code of Canada (NBC) are intended for the design of new buildings. They are not intended for the evaluation or upgrading of existing buildings. Commentary L of the User's Guide – NBC 2005 Structural Commentaries, provides guidance on the use of the Part 4 provisions for existing buildings. Where it can be shown that the resultant life-safety is generally equivalent to that required by the NBC, and the building is known to be functional, some relaxation from current Code design criteria may be appropriate. Commentary L suggest that the minimum life-safety requirements of the current earthquake Code provisions will be met if the existing building is capable of resisting a reduced load of 60% of the 2005 NBC earthquake forces.

A benchmark version of a Code or standard is the earliest version that satisfies the life-safety intent of the current requirements. Earthquake requirements have changed considerably over the years and consequently buildings designed to earlier Codes often do not provide a level of life-safety that meets the intent of current requirements. The benchmark year for earthquake requirements is 1970. Buildings designed with earlier editions than the 1970 NBC likely do not have adequate earthquake resistance to satisfy the minimum life-safety requirements of the current Codes and should be evaluated. That being said, there are many buildings designed after 1970 that also likely do not have adequate earthquake resistance. The benchmark year is just one of the triggers used to evaluate seismic condition of existing buildings.

Seismic Assessment of Existing Buildings

There are several guidelines that have been produced related to the seismic assessment of existing buildings. In Canada, the National Research Council (NRC) has published three documents to address seismic assessment of existing buildings:

- NRC Manual for Screening Buildings for Seismic Investigation;
- NRC Guideline for Seismic Evaluation of Existing Buildings; and
- NRC Guideline for Seismic Upgrading of Building Structures.

These documents have been modeled after similar guidelines published in the United States. In the United States the National Earthquake Hazards Reduction Program (NEHRP) and the Federal Emergency Management Agency (FEMA) are the agencies responsible for addressing earthquake risk and preparedness across the country. The following FEMA/NEHRP documents have been published to address seismic evaluation of existing buildings:

- FEMA 154-157: Rapid Visual Screening of Buildings for Potential Seismic Hazards;
- FEMA 310: Handbook for Seismic Evaluation of Buildings; and
- ASCE/SEI 31-03: Seismic Evaluation of Existing Buildings.

The ASCE/SEI 31-03 standard evolved from the FEMA 310. This document is the most current evaluation standard available in the industry, and is compatible with ASCE/SEI 41-06 Seismic Rehabilitation of Existing Buildings. It evaluates existing buildings for a maximum considered earthquake with a probability of exceedence of 2% in 50 years.

The NRC evaluation guidelines were published in 1993 and were based on the NEHRP Handbook for Seismic Evaluation of Existing Buildings produced by FEMA. The NRC guidelines adapted the NEHRP/FEMA procedures to suit the 1990 NBC and were compatible with the 1995 NBC. With the introduction of the 2005 NBC, significant changes to the methods used to establish earthquake loads and structural resistance have been developed. The NRC guideline evaluates existing buildings using a seismic hazard that is based on a 10% in 50 year probability rather than 2% in 50 year probability that the current NBC uses. As well, the treatment of soil conditions and site classification has been changed significantly between the 1990 NBC and the current Code. The procedures of the NRC screening procedures are not compatible with the 2005 NBC seismic provisions. Until the NRC develops an updated seismic screening procedure, organizations carrying out seismic screenings with the existing procedures will have to develop a means to incorporate the updated Code data to evaluate seismicity and soil condition impacts.

The approach taken in the ASCE/SEI 31-03 standard to establish seismic hazard and seismic demand on buildings more closely matches the requirements of the current NBC compared to the NRC guidelines.

Approaches Taken by Other Organizations

A review of the approaches taken by other organizations and was undertaken prior to the development of seismic assessment polices.

Public Works Government Services Canada (PWGSC)

Public Works Government Services Canada (PWGSC) has specific policies regarding seismic assessment of crown-owned buildings in moderate to high seismic zones. Moderate to high seismic zones are based the on effective seismic zone (Z_e) for Canadian localities and is based on the 1990/1995 NBC values for acceleration zone and velocity zone. Zones of moderate to high seismicity are defined as zones where Z_e is greater than or equal to 2 (Z_e ranges from 0 to 6). The effective seismic zone is equal to the velocity zone, except where the acceleration zone is greater than the velocity zone, in which case the effective seismic zone is equal to the velocity zone plus one. The acceleration and velocity zonal information was published with the climatic data for Canadian communities in the previous editions of the NBC. However, the 2005 NBC climatic data does not list these values. It is expected that PWGSC will revise the policy to suit the new method of defining seismic hazard for Canadian communities.

Seismic screenings are to be completed on all PWGSC buildings in zones of moderate to high seismicity. Seismic screenings are to be included in each building's Asset Management Plan. For buildings that do not have previous seismic screenings completed, such a screening is to be completed and included in the Building Condition Report. PWGCS requires that funding for the seismic screenings of individual buildings be included in the existing annual budget for the building. For buildings with a SPI greater than 30, a detailed seismic assessment is mandatory and must be completed within a reasonable period and not later than the subsequent fiscal year.

PWGSC maintains a seismic database of crown-owned buildings that includes information regarding the effective seismic zone, seismic screening results, records of more detailed seismic assessments where they have been carried out, and scope and costs of seismic improvements where such improvements have been included as part of a renovation.

When significant projects are being planned for buildings located in zones of moderate or high seismicity, a detailed seismic assessment is mandatory and must be conducted in the project-planning phase. A project is considered to be significant when any of the conditions noted exist:

- Work includes stripping of many finishes and the exposure of structural elements in the entire facility or substantial portions of it, such as complete wings or full floors;
- The work changes the use or intended use of the facility as indicated by a change in Occupancy classification as per the NBC;
- The work provides for adding significant weight to the existing building such as the addition of one or more storeys;
- The work involves removal or modification of key seismic resisting elements of the existing building such as planned removal of walls, braces, or sections of the building; and
- The project costs are at or above 50% of the replacement costs for the building.

PWGSC policy regarding seismic upgrading of the building structure is that it is not mandatory if the building's structure's seismic resistance meets or exceeds 60% of the seismic load requirements for new building construction as specified by the current NBC. If the main building structure's seismic resistance does not meet 60% of the NBC requirements, seismic upgrading of the main structure is required, and this upgrade must have a seismic resistance of at least 60% of the NBC requirements. Consideration shall be given to upgrading the building to 100% or greater of the NBC requirements. The level of seismic upgrade selected is to be based on issues including financial costs, functional and operational requirements for the building, and heritage conservation for important buildings. The seismic upgrade is to also address non-structural components.

City of Vancouver, British Columbia

The municipality of the City of Vancouver has developed its own Building Code that is primarily adopted from the NBC and adapted to suit local issues. In 1991 the City of Vancouver carried out a seismic assessment of all City owned buildings including detailed studies of the seismic capacity of community centres and City Hall. These buildings may be required to play a significant role in the City's response to a major seismic event.

Also in 1991, the City of Vancouver authorized a seismic risk assessment of privately owned buildings. Approximately 1150 buildings were short listed by the City of Vancouver from an inventory of approximately 8,000 older commercial and multi-unit residential buildings. These buildings were generally selected from pre-1975 buildings. This assessment consisted of a rapid screening of the seismically vulnerable buildings using the NRC rapid screening methodology with some modifications to accommodate Vancouver's heritage buildings.

The City of Vancouver's Building Code triggers seismic upgrading of private buildings when there is a renovation exceeding twice the assessed value of the property; a major addition; or a major change in occupancy (comprising at least the total floor area of a storey). In the absence of these triggers, seismic upgrade is not required. Generally the policy of the City is that a building that legally conforms at the time of its construction and is properly maintained may remain in service indefinitely. The seismic upgrading specified under the Vancouver Building Code By-law is required to achieve at least 75% of current Code seismic force levels. Seismic upgrade projects may be phased over a period of up to five years.

British Columbia Ministry of Education

In 2004 the British Columbia Ministry of Education carried out a $2 million seismic assessment of existing schools located in high-risk seismic zones of the province. The assessment was carried out to determine the potential risk of structural damage that could result from a large earthquake. This project included the review of over 850 schools over a three-month period.

The assessment of the schools was done with tool developed by the University of British Columbia's civil engineering department and the Association of Professional Engineers and Geo-scientists of British Columbia (APEGBC). The assessment tool called UBC-100 is a multi-page checklist that examines the site, materials, and construction methods of each school building. Subsequently, the APEGBC was retained by the Ministry of Education to develop "Bridging Guidelines for the Performance Based Seismic Retrofit of British Columbia School Buildings". The Bridging Guidelines present a modified approach to determine seismic demand that complements the requirements specified in the 2005 NBC, with the intent to still achieve a life safety level of performance of the school buildings.

The first step of the seismic safety plan for individual school buildings is a feasibility study. The feasibility study consists of two stages. The first stage is a study to confirm the results of the initial assessment that identified the building at some level of seismic risk and that the building should be seismically upgraded. This includes an evaluation of the building to determine whether its capacity meets the seismic demand as outlined in the Bridging Guidelines, including the effects of any renovations or modifications that have occurred since the 2004 assessment. Also as part of the first stage of the feasibility study it has to be confirmed that the building is still required by the school board, and that the estimated costs for the seismic upgrade do not exceed 70% of the replacement cost of the building. The second stage includes carrying out a more detailed evaluation of seismic deficiencies identified in the assessment, and then developing a conceptual seismic retrofit option.

Department of Foreign Affairs and International Trade (DFAIT)

Halsall worked with the Department of Foreign Affairs and International Trade (DFAIT) to assist in the preparation of an RFP to undertake seismic evaluations of all Canadian Government owned and leased facilities around the world. The development of the technical portions of the RFP included reviewing the various evaluation standards/guidelines that are available and are used in the industry to seismically evaluate existing buildings. The two primary standards that formed the basis of the evaluation guidelines included ASCE/SEI 31-03 (Seismic Evaluations of existing Buildings) and NRC Guidelines for Seismic Evaluations of Existing Buildings.

Halsall recommended that the seismic evaluations for the required buildings being carried out based on the ASCE/SEI 31-03 standard. The Statement of Work (SOW) for these evaluations noted modifications that would be required to the ASCE/SEI standard to suit Canadian Code requirements.

A multi-phase seismic evaluation and retrofit program was prepared. The phases included the seismic evaluations, schematic retrofit options, preparation of contract documents, and contract administration. DFAIT facilities were organized into three groups. The first and second groups included facilities owned by DFAIT and located in zones of high seismicity and moderate seismicity respectively. The third group included facilities leased by DFAIT. Group 1 and 2 facilities were to be evaluated based on the immediate occupancy criteria, and group 3 facilities were evaluated based on life-safety criteria. A Tier 1 evaluation was required for all DFAIT facilities. A full Tier 2 evaluation was required for all group 1 facilities. A Tier 2 evaluation was also required for non-compliant items of Tier 1 for group 2 and 3 facilities.

A database of information for each facility was compiled that included information about each facility such as existing documentation available, size and age of each facility, and previous studies undertaken. DFAIT also compiled the 2% in 50 year earthquake short-period response acceleration, $S_a(0.2)$, and the one-second response acceleration, $S_a(1.0)$ for each facility. Existing geotechnical information available for each site was assessed by DFAIT to provide an appropriate Site Classification. Where geotechnical information was not available, a Class 'D' site was assumed.

The SOW for the DFAIT facilities also included the requirement to develop a full three-dimensional model of the building in order to carry out either a linear-static or linear-dynamic analysis. The lateral load capacity of the seismic force resisting system was to be evaluated against the 2005 NBC equivalent static base shear and over-turning moments. These analyses were based on importance factor of 1.0 and ductility factors and over-strength factors comparable with conventional construction.

The ASCE/SEI 31-03 evaluation procedure was modified to suit Canadian Code requirements. The procedures to calculate the effective seismic weight, natural period, and storey shears and moment distribution were modified as per the 2005 NBC.

An important consideration for the seismic evaluations is the reduction factor to be used when comparing the assessed capacity of the buildings to the current Code requirements. The ASCE/SEI standard uses a factor of 0.66 to reduce the calculated spectral accelerations (based on 2% in 50 year earthquake) used to determine the seismic forces/displacements due to the maximum considered earthquake. This factor was selected to provide a 50% margin of safety between the loss of the first primary element and collapse. However, for older buildings that may have been design for a seismic hazard based on a 10% in 50 year earthquake, this margin of safety may not exist. The NRC guideline, and the standard generally used by PWGSC, is that existing buildings meeting 60% of the current seismic Code requirements will meet the minimum life-safety requirements of the Code. It should be noted that for buildings where the performance requirement is immediate occupancy compared to life safety, a reduction factor of 0.6 may be inappropriate. For this assessment program, the spectral accelerations S_{D1} and S_{DS} were modified to $0.6F_vS_a(1.0)$ and $0.6F_aS_a(0.2)$ respectively.

For facilities that did not meet the 60% of the current Code requirements, schematic retrofit options were to be developed. Retrofit options for the DFAIT facilities were to be developed to provide a seismic force resisting system capable of supporting 100% of the forces/displacements required by the 2005 NBC. For each retrofit option, increasing the seismic resistance to 150% of the 2005 NBC, or decreasing the seismic resistance to 60% of the 2005 NBC was also to be considered.

Canada Post

On a National level, Halsall worked with Canada Post to provide technical information to assist in the development of a policy to assess the seismic risk of their corporate facilities across the country. The intent of this work was to discuss key issues identified by Canada Post including a discussion of current Codes and practices with respect to management of seismic risk assessment from a facility management perspective, and a discussion of the approaches taken by other organizations to assess seismic risk. Halsall also undertook an initial review of Canada Post facilities to assess the level and distribution of seismic risk across the country. A modified version of the NRC rapid screening tool was developed to undertake this work. Criteria used in this rapid screening included location of the facility, age of the facility, and the occupancy density for the facility.

Canada Post provided a database of information for over 3000 of their facilities across the country. This database included several fields of information related to each facility and was used to identify Canada Post facilities in zones of moderate to high seismicity.

The first phase of this assessment was to establish the probable seismic hazard for each facility based on its location. The majority of Canada Post facilities are low-rise structures less than 5 stories in height. The 2005 NBC spectral acceleration at a period of 0.2 seconds ($S_a(0.2)$)parameter was used to establish the seismic hazard for these buildings. For the purpose of this study sites were grouped into the following seismic hazard zones:

- Low – $S_a(0.2) \leq 0.12g$
- Moderate/Low – $0.12g > S_a(0.2) > 0.35g$
- Moderate/High – $0.35g$ / $S_a(0.2) > 0.75g$
- High – $S_a(0.2)$ / $0.75g$

The probable seismic hazard zone forms an initial indicator that can be used to establish whether further seismic assessment is required. Facilities located in low seismic hazard zones have a very small risk of seismic activity that would cause damage. The 2005 NBC exempts new buildings from the earthquake requirements of the Code if the building is located at a site where $F_aS_a(0.2) \leq 0.12g$. Facilities located in any of the three other seismic hazard zones are at some level of risk for seismic activity that would cause damage.

Seismic Risk Factor

An actual seismic screening for each Canada Post facility was beyond the scope of the study. A modified seismic risk assessment based on the available information listed in the facility database was carried out. The intent of this evaluation was to develop a priority list for Canada Post to use when scheduling future seismic screening/assessment projects.

In addition to facility location and probable seismic hazard zone, there are other considerations that should be evaluated to assess the seismic risk of the buildings. As discussed previously, the age of the building and the size of the building are also important factors that contribute to the building's seismic risk. Buildings designed and constructed prior to 1970 have a higher risk of seismic damage during an earthquake since their design did not include any specific provisions to resist earthquake forces. The size of the building provides a measure of the risk associated with the building if damaged during an earthquake. The NRC seismic screening guidelines calculate a building importance factor that contributes to the building's seismic priority index. The building importance factor is based on the occupied area of the building, the occupation density based on the primary use of the building, and a duration factor that is estimated based on the average number of weekly hours the building is occupied.

The database provided by Canada Post of their facilities includes information regarding the size of occupied area for each facility, and the date when Canada Post first occupied the building. Although the date when Canada Post first occupied the building does not necessarily indicate when the building was constructed, it was assumed that facilities first occupied by Canada Post close to 1970 were constructed close to this seismic risk indicator.

For the purpose of this study, the building size as a means of a seismic risk indicator was divided into three ranges as follows:

- Building Size < 1500ft^2 – Low
- Building Size between 1500ft^2 and 15,000ft^2 – Medium
- Building Size > 15,000ft^2 – High

The rational for the above ranges is based on both the calculation of building importance using the NRC seismic screening guidelines, as well as discussions with Canada Post.

Using the building's size and the date when Canada Post first occupied the building, in conjunction with the probable seismic hazard based on the building's location, a seismic risk factor for each building was determined. The seismic risk factor is calculated by assigning a score to each of the three evaluation criteria listed above. The importance of each criteria item with respect to the other criterion is reflected in the max score possible for each criterion. For this assessment, the most important factor is the probable seismic hazard based on the physical location of the facility, followed by the criterion that establishes a measure of the buildings age and finally the size of the building. Table 1 outlines the three evaluation criteria used to calculate the seismic risk factor, as well as their relative importance with respect to the other criterion. A maximum score of 10 is possible. Facilities located in Low probable seismic hazard zones are assigned a seismic risk factor equal to zero.

Table 1. Evaluation of Seismic Risk Factor

Criteria	Max Score	Evaluation Score
Seismic Hazard	5	High = 5 Moderate/High = 4 Moderate/Low =2 Low = 0
Building Size (Importance)	2	High = 2 Medium = 1 Low = 0
Date of Occupancy	3	Pre 1970 = 3 1970 to 1990 = 2 1990 to 2000 = 1 2000 to present = 0
Total	10	

Based on the results of the seismic risk factor evaluation, the facilities in each province were sorted to establish a priority list for facilities that should be seismically assessed first. The highest priority for Canada Post for additional seismic assessments are buildings that score 8 or higher when evaluated with this procedure. To result in a score of 8 or higher means that the building has scored high in all three of the evaluation criteria. Buildings with scores between 5 to 7 would be the next priority for additional seismic assessments, followed by buildings with scores between 3 to 5. Buildings with scores of 2 or less would have the lowest priority for additional studies.

City of Ottawa

In conjunction with the City of Ottawa and other local structural consultants, a policy was developed regarding seismic upgrade requirements for existing buildings undergoing additions. In cases where the additions are planned to older buildings (more than 5 years old), the City of Ottawa felt that a clear policy was required to assess whether seismic upgrading is required. This policy was developed by reviewing how other municipalities treated similar cases, as well as ensuring that it is consistent with the National/Ontario Building Codes and commentaries. Criteria related to size and mass of the addition were established to form the basis as to whether a seismic assessment is required. Performance criteria based on current Codes were established to trigger a seismic upgrade and establish the level of upgrade required.

Criteria were established by the City of Ottawa for existing buildings with planned new connected additions with respect to seismic upgrade requirements. The seismic capacity of the existing building is required to be assessed if any of the following criteria for the new addition are exceeded:

- The addition increases the original mass of the building by more than 10%;

- The addition increases the area of the original building gross floor area by more than 10% with a maximum area increase less than 500m^2; or
- The addition increases the area of the original building gross floor area by more than 500m^2 and increases the mass of the original building by more than 2%.

For additions that trigger a seismic assessment, the performance level of the existing structure is to be calculated based on the provisions of the 2006 Ontario Building Code. If the performance level of the existing seismic force resisting system is greater than or equal to 60% of the current Code requirements, then the addition can proceed without seismic upgrading provided that the performance level of the existing structure is not reduced. For structures whose performance level is less than 60% of current Code requirements a seismic upgrade is required as part of the addition. For post disaster buildings the seismic upgrade is to be to 100% of current Code requirements. For non-post disaster buildings, the seismic upgrade is to be to 75% of the current Code requirements.

Conclusions

The Canadian standards, published by the NRC, for seismic evaluations of existing structures are out of date with respect to the current 2005 NBC provisions. The ASCE/SEI 31-03 standard provides an evaluation method that is more compatible with the current Canadian codes. Modifications to the NRC screening procedures are required if they are to be used in a current assessment program. For existing buildings, a reduction factor of 60% of current code requirements is consistent with other Canadian governmental agencies and municipalities.

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