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Overview of NBC 2015 Commentary for Seismic Evaluation and Upgrading of Existing Buildings

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ABSTRACT

The NBC 2015 User's Guide proposes new procedures for seismic evaluation and upgrading of existing buildings depending on the level of alteration to the building. In this paper, the different hazard levels to be used for different assessment/upgrading levels, as suggested in the Commentary L of the NBC 2015 are compared with the minimum requirements of the Part 4 of NBC 2015 for new buildings for all 679 locations across Canada provided in climatic and seismic data section (Appendix C) of the NBC. The results of this study shed some lights on of the new recommendations in the Commentary L of the NBC 2015 for seismic evaluation and upgrading of existing buildings. Discussion is provided on the Commentary L proposed "force compliance percentage", "drift compliance percentage", and the requirements for "drift limits to be satisfied".

Keywords: Seismic Evaluation, Seismic Upgrading, Existing Buildings, Seismic Hazard, National Building Code of Canada.

INTRODUCTION

Existing buildings were designed and built based on the building codes and standards that were in effect at the time of their construction which typically were less stringent compared to the new building codes. More stringent requirements are provided in the newer building codes based on the information obtained during the last few decades and lessons learnt from several high intensity earthquakes causing severe damages. The main changes in the building codes aim to address the shortcomings of previous provisions both on the prescribed level of seismicity, and the required detailing of structural elements to dissipate energy. In seismic assessment or upgrading of existing buildings, a lower reliability index might be acceptable, which translates to a larger acceptable probability of failure. This is due to the fact that upgrading existing buildings to comply with more stringent requirements of more recent building codes and design standards is, in many instances, very costly. As a result, building owners are willing to accept a relatively higher risk of suffering damages and losses due to strong ground motions.

The National Building Code of Canada (NBC) provides minimum requirements for construction of new building structures in Canada. The User's Guide in Commentary L of the NBC provides some guidance on the structural evaluation and upgrading of existing buildings. The first edition of the Commentary L was published for the NBC 1995 user's Guide [1] under the section entitled "Application of NBC Part 4 of Division B for the Structural Evaluation and Upgrading of Existing Buildings"; in which, different load factors were introduced for different load cases (i.e. Dead. Live, snow, wind, and Earthquake) depending on the applicable reliability level. An average earthquake load reduction factor of 0.6 was introduced for all levels of reliability and remained unchanged in the User's Guide of the NBC 2005 [2] and the NBC 2010 [3]. The User's Guide of the NBC 2015, however, has provided new suggestions to introduce three levels of assessment/upgrading of existing buildings using different seismic hazard levels, i.e. earthquakes with different return periods compared to the specified 2475 year earthquake return period in Part 4 of the NBC [4].

SEISMIC EVALUATION OF EXISTING BUILDINGS

Background

While the fundamental requirements of structural design criteria for existing buildings are the same as those for new buildings, there are yet some distinct differences between them as follows:

- **Economics**: The additional cost of achieving a higher degree of structural safety is marginal for the design of new buildings (due to more complete design flexibility and construction quality control). However, for structural evaluation and retrofit of existing buildings, the difference in cost between a compliant or noncompliant existing building can be significant;

- **Heritage**: Many existing buildings have heritage value, which requires preserving existing materials and minimum intervention. Therefore, the heritage criterion is of high significance to some existing buildings, which requires minimum destruction as a consequence of either retrofit or potential future damage;
- **Uncertainties**: For existing buildings, the uncertainties in both loads and resistance vary largely, and cover a wide range. In other words, the uncertainties might be greater than that in new buildings (e.g. hidden components or details, deterioration), or lower (e.g. measured properties, load tests, or satisfactory past performance);
- **Past performance**: In existing buildings, a satisfactory past performance provides direct information on building safety and serviceability, depending on the age and type of the buildings.

For investigation of existing buildings, most building codes and guidelines, specify force levels lower than that those prescribed by the criteria for new buildings. This lower force levels are rooted in the greater acceptable seismic risk (i.e. acceptable higher level of earthquake damages) in existing buildings compared to new buildings. In other words, the performance of existing buildings could be somewhat lower than the current standard before triggering the requirement for a costly seismic upgrading. This acceptance is based on an appraisal of the cost-benefits of the reduction of damage level due to seismic upgrading and on a rationalization that life safety threats will be substantially reduced even if the possible earthquake damage level may be higher than that anticipated for new buildings.

It should also be noted that existing buildings have generally a smaller chance of experiencing the code-level event (smaller return period) over its remaining life span (which is lower than 50 years), compared to new buildings which are to be designed for 2% probability of exceedance in 50-year period (2475-year return period), or 10% probability of exceedance (475-year return period) according to the NBC 2015 and NBC 1990, respectively. Nevertheless, when the intent of a seismic evaluation or upgrading is to extend the life span of existing buildings for a time period approaching the 50-year design life used for new buildings, the use of reduced force levels for evaluation or upgrading is not appropriate. This is due to the fact that the expected risk of failure of such buildings will be similar to that of new buildings. Most provincial building codes in Canada, such as Ontario or British Columbia building codes acknowledge such increased risk in their requirements for major renovation of an existing building.

NRC 1993 Guidelines and Commentary L Prior to the NBC 2015

The NRC 1993 Guidelines [3] for seismic evaluation of existing buildings offer guidance for engineers for evaluating existing buildings to determine potential earthquake hazards and identify buildings (or building components) that present unacceptable risk to human lives [5]. A building does not meet the life-safety objective of these Guidelines if in an earthquake one or more of the following events occurs:

- The entire building collapses.
- Portions of the building collapse.
- Components of the building fail and fall.
- Exit and entry routes are blocked, preventing the evacuation and rescue of the occupants.

The identification of the life-safety hazards in an existing building consists of determining whether any of the above events could potentially happen during an earthquake. Hence, a major portion of the NRC 1993 Guidelines is dedicated to directing the evaluating engineer on how to determine the presence of any weak links in the building that could precipitate component or structural failure. The NRC 1993 Guidelines deal with life-safety objectives, and do not address other objectives such as damageability or building performance under special conditions. The buildings treated in the Guidelines are ordinary buildings with ordinary occupancies, not unusual or special structures, or structures devoted to industrial processes.

The single reduction factor recommended in the Commentary L of the NBC 1995 is based on a comprehensive study [6], [7], which defined the earthquake load reduction factor, as a function of the structural redundancy levels (little, average, and high), and the risk category (low, medium, and high) of buildings. Originally, the proposed reduction factors ranged from 1.0 for buildings with high risk category and little redundancy down to 0.4 for buildings with high redundancy and low risk category. The 0.6 factor was proposed for average redundancy and medium risk category buildings. The first version of the Commentary L included alternative dead, live, wind and earthquake load factors for structural evaluation of existing buildings other than post-disaster buildings. The gravity load factors where developed based on different levels of reliability index of existing buildings, and for the earthquake loads a single load factor of 0.6 was proposed for the sake of both simplicity and practicality in the Commentary L for all reliability levels, which remained unchanged until the NBC 2015 Commentary L.

NBC 2015 COMMENTARY L

A new procedure is suggested in the Commentary L of the NBC 2015 for seismic evaluation and upgrading of existing buildings. The flowchart in Figure 1 , adopted from [4] demonstrates the different requirements for minimum voluntary seismic evaluation and upgrading, minor and major renovations, as well as horizontal and vertical additions to existing buildings [4]. The seismic assessment and upgrading of existing buildings is suggested to be performed according to different assessment/upgrading levels, each of which corresponds to a ground motion with a specified return period, as defined below:

- Level 1: This assessment/upgrading level is for minimum voluntary seismic upgrading. The spectral response acceleration values corresponding to 0.5 times those with a probability of exceedance of 5% in 50 years (earthquakes with return period of 975 years) is suggested. For minimum voluntary upgrading, it is also required to address the restraint of falling hazards, such as parapets, as well as any other deficiencies including weak storeys, discontinuities in the SFRS, inadequate capacity, excessive irregularity including torsional eccentricity and incomplete lateral load paths.
- Level 2: This assessment/upgrading level is for significant renovation extending life of building and/or minor vertical or horizontal additions, the use of spectral response acceleration values with a probability of exceedance of 10% in 50 years (earthquakes with return period 475 years) is suggested.
- Level 3: This upgrading level is for significant renovations and minor horizontal or vertical additions that do not comply with level 2, the use of spectral response acceleration values with a probability of exceedance of 5% in 50 years (earthquakes with return period of 975 years) is suggested.
- Code Level: This upgrading level is for significant vertical or horizontal additions to an existing building. As prescribed in part 4 for new buildings, the Code Level seismic hazard corresponds to spectral accelerations with a probability of 2% exceedance in 50 years (earthquakes with return period of 2475 years).

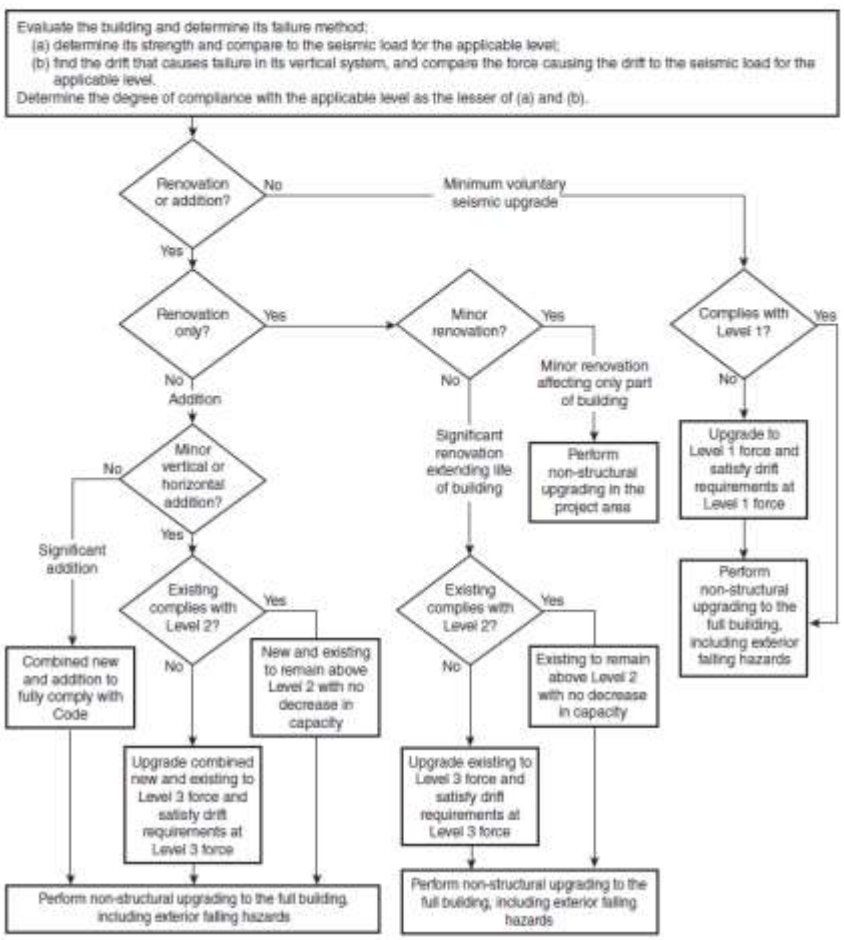

Figure 1 Flowchart for seismic assessment and upgrading of existing buildings (From Commentary L of the NBC 2015 [4]).

It is noteworthy that, in previous editions of Commentary L of NBC, a single earthquake load factor of 0.6 was used in seismic evaluation, which was adopted from the NRC 1993 evaluation guidelines. Compared with the previous editions of Commentary L, the suggested procedure in Commentary L of the NBC 2015 (Figure 1) presents a new procedure for seismic upgrading of existing buildings.

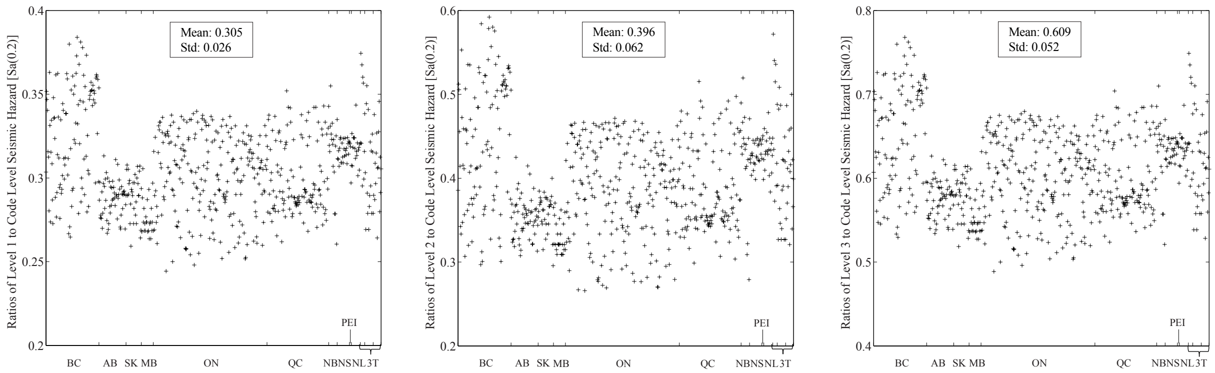

Figure 2: Ratios of Level 1, Level 2, and Level 3 seismic hazards to Code Level seismic hazard [$S_a(0.2)$]

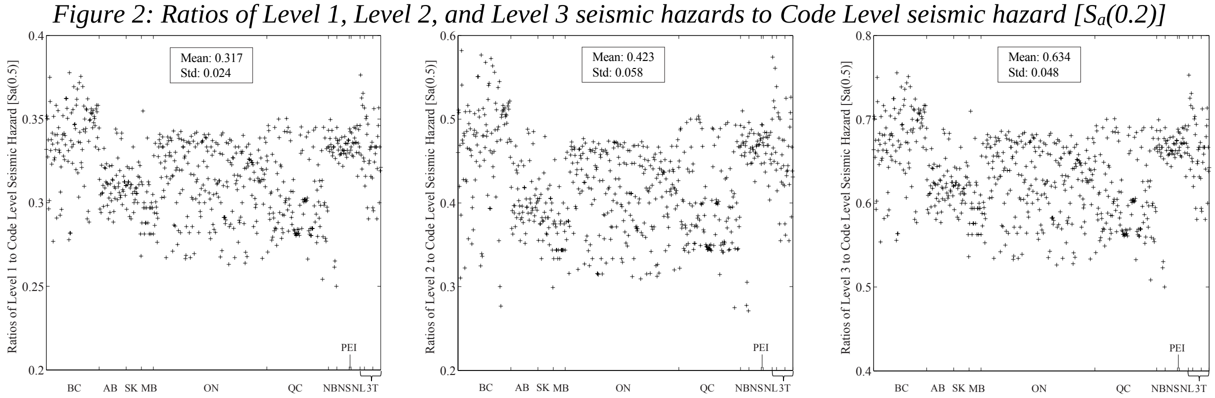

Figure 3: Ratios of Level 1, Level 2, and Level 3 seismic hazards to Code Level seismic hazard [$S_a(0.5)$]

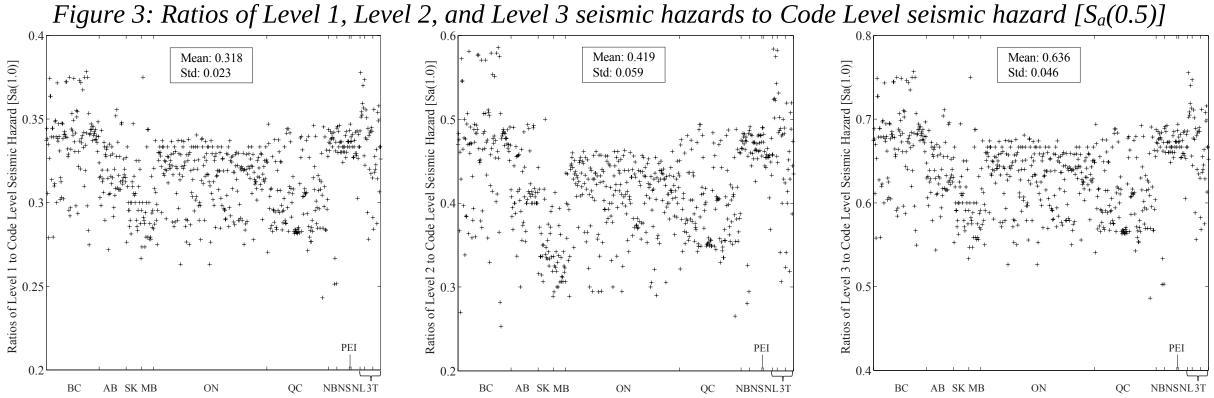

Figure 4: Ratios of Level 1, Level 2, and Level 3 seismic hazards to Code Level seismic hazard [$S_a(1.0)$]

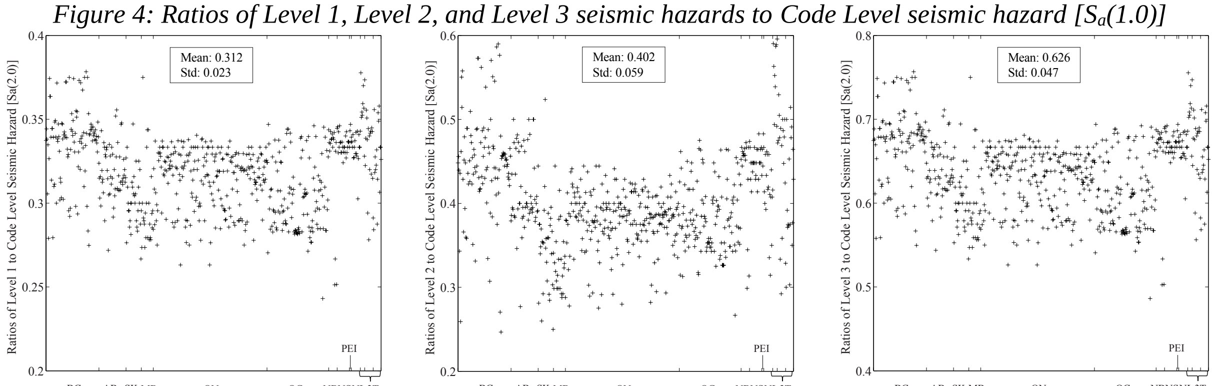

Figure 5: Ratios of Level 1, Level 2, and Level 3 seismic hazards to Code Level seismic hazard [$S_a(2.0)$]

In this paper, the aforementioned three levels of ground motions are investigated for 679 locations across Canada. The seismic hazards expressed as 5% damped spectral accelerations with 2% probability of exceedance in 50 years for 679 locations are provided in Appendix C of Division B of the NBC 2015 (Code Level), and the 5% damped spectral accelerations with probability of exceedance of 5% and 10% in 50 years were retrieved from the National Resources Canada (NRCan). The ratios of each of the three seismic hazard levels to the Code Level seismic hazards are then calculated for all 679 locations. Figures 2 through 5 provide the ratios of Level 1, Level 2, and Level 3 to Code Level corresponding to the spectral response accelerations at 0.2, 0.5, 1.0, and 2.0-second period, namely $S_a(0.2)$, $S_a(0.5)$, $S_a(1.0)$, and $S_a(2.0)$, respectively.

Horizontal axes in diagrams within Figures 2 to 5 represent the number of total sites (679 locations in different provinces and territories) where seismic data are provided in the NBC 2015 and by the NRCan. On the horizontal axes, all ten (10) provinces of Canada are shown with their abbreviations in their geological order from west to east (BC for British Columbia, AB for Alberta, SK for Saskatchewan, MB for Manitoba, ON for Ontario, QC for Quebec, NB for New Brunswick, NS for Nova Scotia, NL for Newfoundland and Labrador, PEI for Prince Edward Island), while the three territories (Northwest Territories, Yukon, and Nunavut) are shown with 3T (for graphical clarity) at the far right side of the horizontal axes. As it can be noted, the ratios of Level 1, Level 2, and Level 3 to Code Level seismic hazards of the locations in British Columbia (BC) present larger variations, mainly due to the large variation of seismicity in this province from areas close to Cascadia subduction zone to interior regions beyond Rocky Mountains. However, Prairie Provinces (Alberta, Saskatchewan, and Manitoba) as well as smaller Atlantic Provinces (Nova Scotia, New Brunswick, and PEI) have the least variation of data due to similarities of seismicity across these provinces.

The values of the mean and standard deviations for each set of ratios are also calculated as shown in the figures 2 through 5. The mean ratio of Level 1 to the Code Level seismic hazards for new buildings are very close to 0.3 for all periods (0.305, 0.317, 0.318, and 0.312 for 0.2, 0.5, 1.0, and 2.0 second period spectral accelerations, respectively). The mean ratio of Level 2 to the Code Level seismic hazards for new buildings are close to 0.4 for all periods (0.396, 0.423, 0.419, and 0.419 for 0.2, 0.5, 1.0, and 2.0 spectral accelerations, respectively). The ratios for Level 3 to the Code Level seismic hazards for new buildings are twice the Level 1 values, as the Level 1 is 0.5 times the Level 3 spectral accelerations.

The ratios of the three levels to the Code Level for three cities (Vancouver, Ottawa, and Quebec City) are shown for different periods in Figure 6. As it can be noted, there are minimal variation in these ratios for different periods calculated for Ottawa and Quebec City. The ratios of the three levels to the Code Level seismic hazards in Vancouver are larger than those calculated for Ottawa and Quebec City.

According to proposed procedure in the Commentary L of the NBC 2015 (see Figure 1), for an existing building founded on Site Class C with capacity less than about 30% of the prescribed seismic loads required by the Part 4 of the NBC 2015, a seismic upgrading to 30% of the requirements of the new buildings is recommended for a voluntary mitigation of the seismic risk of the building by upgrading. It should be noted that the mean ratio of Level 3 to Code Level seismic hazard for all spectral accelerations at 0.2, 0.5, 1.0, and 2.0 seconds are very close to the earthquake reduction factor of 0.6 used in the previous editions of the Commentary L , (see Figure 2 through 5). This is also true for eastern cities like Ottawa, or Quebec City, while for the City of Vancouver the ratio of Level 3 to the Code Level for new buildings is closer to 0.7 for all periods, (see Figure 6).

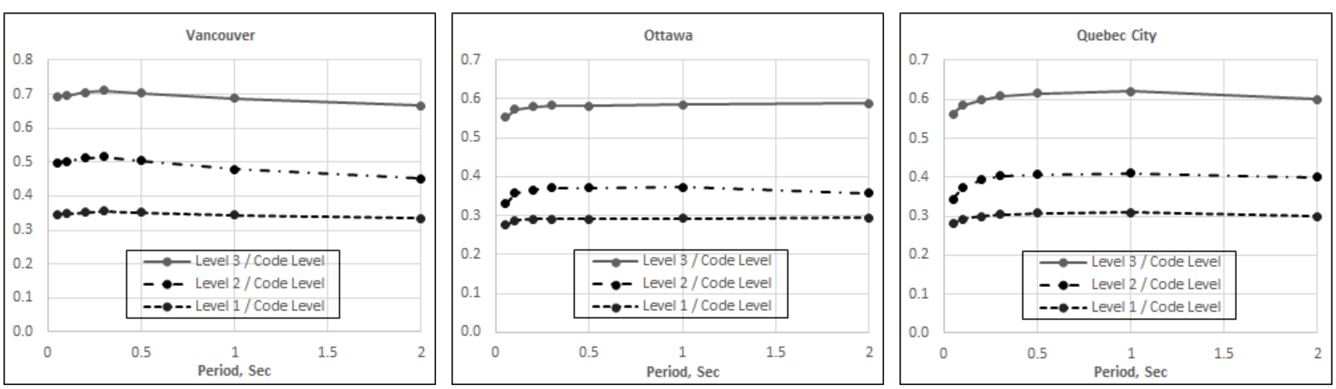

Figure 6: Ratios of Reduced Seismic Hazard Levels to Code Level Seismic Hazard for Vancouver, Ottawa, Quebec City

It should be noted that the different seismic hazards in Figure 1 (Level 1, Level 2, and Level 3) need be adjusted for Site Class on which the existing building is founded. As explained in the Commentary J of the NBC 2015, the site coefficients *F*(T), *F*(PGA), and *F*(PGV), are dependent of the values of the PGA_{ref} (reference Peak Ground Acceleration) for site Class D and E, while they are the same for Site Class A, B, and C [4]. Typically, the lower PGA_{ref} values correspond to larger site coefficients on Site Class D and E, respectively. Therefore, the variability of ratios in Figures 2 through 6 will be smaller for Site Class D and E, while these ratios remain unchanged for Site Class A, B, and C.

Table 1 presents the ratios of Level 3 to Code Level seismic hazards as a matrix of seismic zones and spectral response accelerations. Six seismic zones, namely Very Low (VL), Low (L), Moderate (M), Moderately High (MH), High (H), and Very High (VH) have been defined in a Semi-Quantitative Seismic Risk Screening Tool [9]. All 679 locations are grouped into corresponding seismic zones, respectively. In each seismic zone, the mean values of spectral accelerations are used to calculate the ratios. The seismic zone and building periods have negligible effects on the ratios of Level 3 to Code Level seismic hazard. This implies that 0.6 factor seems to be appropriate for Very Low, Low, Moderate, and Moderately High seismic zones, while for the High and Very High seismic zones the mean values of the ratio of Level 3 seismic hazards to the Code Levels are closer to 0.7. Note that the majority of High and Very High seismic zones are in the west coast, including Vancouver (see Figure 6).

Table 1: Ratios of Level 3 to Code Level Seismic Hazard for different Spectral Response Accelerations and Seismic Zones

Seismic Zone	Max[$S_a(0.2)$, $S_a(0.5)$]	$S_a(1.0)$
Very Low	0.60	0.64
Low	0.62	0.65
Moderate	0.60	0.61
Moderately High	0.60	0.62
High	0.67	0.67
Very High	0.69	0.65

ACCEPTABLE LEVEL OF SEISMIC RISK

Seismic risk is the product of the probability of failure due to earthquake ground motions and the consequences due to the building failure (fatalities, injuries, and economic losses, etc.). Earthquake hazards on the other hand, are typically expressed as levels of ground motions with certain chance of exceedance in 50 years. Although uniform seismic hazard spectra with a probability of exceedance of 2% in 50 years have been used in the seismic design of new buildings [8], the seismic risk of new buildings is inconsistent given the variations in the probability of failure of buildings and their corresponding consequences of failure. The probability of failure of a building is dependent on the loads, the degree of structural redundancy, the type of seismic force-resisting system and construction materials, etc. It has been shown that for the majority of 679 locations across Canada, the 2% in 50 years ground motions conservatively result in 1% chance of failure for buildings with some variations [10].

One of the key parameters for classification of the consequence of failure in buildings is number of the occupants at risk, which is a function of building use and occupancy, the building size, and the number of storeys. For existing buildings, the seismic risk also relies on the quality of inspection which deals with uncertainties in both the applied loads and the material strength. These uncertainties might be greater than that of new buildings, in cases where there is limited information available on structural elements (including their structural details, or their deterioration state); or, the uncertainties might be less than that of new buildings, where there are well documented information, measured structural properties, load tests, or satisfactory past performances. Another key factor is seismic evaluation of existing buildings is the structural redundancy. The presence of structural redundancy results in better ultimate performance in a building, and it tends to mitigate local overloading. In a redundant building, the failure of a single member, connection, or component does not adversely affect the lateral and vertical stability of the structure. In structures with no redundancy, all components must remain operative for the structure to retain its integrity and lateral stability [3].

In order to improve the suggested procedure as shown in Figure 1 which only defines different levels of seismic hazards for seismic evaluation and upgrading of existing buildings, other key parameters (i.e. structural redundancy, the quality of inspection, and the consequence of failure) can be included in the seismic evaluation and upgrading guidelines. A risk-based seismic evaluation or upgrading procedure for existing buildings requires clear identification of probability of failure of reduced ground motions and the consequence of failure. The suggested procedures in the Commentary L of the NBC 2015 for seismic evaluation and upgrading of existing buildings benefits from several improvements as follows [11]:

1. The seismic evaluation and upgrading of existing building is dependent on the scope of alteration, if any, to the existing building. Similar to the requirements in the Part 11 of the 2012 Ontario Building Code, or the 2014 Vancouver building Bylaw, where seismic upgrading is not required for minor renovations. For major renovations and additions, however, complying with full level loads as prescribed in part 4 of the Code is required.

2. Reduced levels of upgrading for existing buildings are provided, while the level of upgrading was not specifically prescribed in previous editions of the NBC.
3. Drift limitations are to be considered to determine drift compliance percentage.
4. Additional requirements are provided to ensure that falling hazards are mitigated in the seismic upgrading of existing buildings.

In the seismic evaluation of existing buildings, and determining its failure mode, as proposed in the Commentary L of the NBC 2015, it is required to find the drift that causes failure in the building's vertical system. Determining the drift corresponding to the failure of vertical load bearing elements requires: 1) special analyses (e.g. pushover analysis or nonlinear dynamic analysis); and 2) the failure criteria of vertical load bearing elements for different structural systems are to be obtained from ASCE/SEI 41. ASCE/SEI 41 is a performance based standard that provides limitations for Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP), while the basic objective of the NBC is "near collapse" [12]. Next step for improvements of the Commentary L of the NBC 2015 should include identification of acceptable drift limits for different structural elements, as well as to define failure criteria at specific points on pushover curves.

By introduction of the different reduced levels of seismic hazard in the Commentary L of the NBC 2015, the associated seismic risk upon failure of an existing building would vary. The 0.6 earthquake load reduction factor, as introduced in the Commentary L of the NBC 1995, was developed based on acceptable reliability indices and levels of risk to be close to other risk to human life at less than 4% in 50 years. Similarly, for a load factor close to 0.33 (Level 1 as suggested in the Commentary L – NBC 2015), the risk is expected to increase to about 15% in 50 years for an existing building for a given consequence class. For a risk-informed decision making purpose, it would be of interest to building owners to correlate the appropriate level of risk when selecting the level of hazards for seismic evaluation and upgrade of their existing buildings.

For the minimum voluntary seismic upgrading path, while the non-structural components are to be upgraded to the 100% seismic requirements of NBC 2015, the structural system is proposed to be seismically evaluated for loads corresponding to Level 1. If the building is not compliant, it is proposed to be upgraded to Level 1 forces. In the ASCE/SEI 41-17, different performance objectives provide Structural and Non-structural Performance Levels at specifically defined Seismic Hazard Levels for buildings based on the different Risk Categories. Building performance is directly related to the extent of damage that would be sustained by the building and its systems during a seismic event. The next step in Canada would be to identify specific performance levels for both structural and non-structural elements of different structural systems at a reduced seismic hazard to avoid premature failure of the structural elements, and consequently unacceptable level of seismic risk.

CONCLUSIONS

A comparison of the three levels of seismic hazards, namely Level 1, Level 2, and Level 3, suggested in the Commentary L of the NBC 2015 with the seismic design requirements in Part 4 of the NBC showed that the three levels of seismic hazards corresponded to approximately 30%, 40%, and 60% of the seismic hazard level for the design of new buildings, respectively. The suggested procedure in the Commentary L can be further improved by including the effect of key parameters such as: structural redundancy, consequence of failure, and quality of inspection.

The procedures suggested in the Commentary L of NBC 2015 provides different scenarios for seismic evaluation and upgrading of existing buildings depending on the level of alteration, the recommendation for upgrading levels. Special care is required in the use of minimum volunteer seismic upgrading (upgrading to Level 1) and major renovation projects in buildings that comply with Level 2 (no structural upgrading) in cases where the remaining occupancy time of a building may be extended. Furthermore, the Commentary L of the NBC 2015 recommends that non-structural components of buildings to be upgraded to meet the NBC requirements for new buildings, in minimum voluntary upgrading while upgrading the structural elements to Level 1 forces. Special care is required to ensure that the building structure will not suffer significant damage at Level 1 forces in order to protect the investment in upgrading the non-structural components. In addition, drift limitations need to be developed for different levels of probability of failure, and consequence of failure in a risk-based approach in order to help building owners make risk informed decision for the appropriate level of seismic upgrading.

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