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Development of Seismic Provisions for Commentary L of NBCC 2015

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ABSTRACT

Canada's building codes are intended for the design of new buildings and give requirements that produce seismic systems that reflect the latest research and findings from recent earthquakes. Older buildings have seismic systems that are often not compliant with these requirements. The protocols that must be followed when upgrading, renovating, or expanding an existing building are often not well defined, and the structural engineer is often caught between an owner who does not want to spend on seismic upgrading, a building authority with little guidance regarding approaches, and a structural assessment that states the building is seismically deficient. National Building Code (NBC) Commentary L of NBC 2015 is the only part of the Canadian code system that addresses existing buildings. The 2015 seismic provisions of Commentary L present a departure from previous editions of this commentary to give the engineer guidance on upgrading that is more in line with ASCE 41-13 provisions. The upgrading requirements under NBC 2015 Commentary L now take account of the level of work being done to the building and the current seismic resistance of the building. This paper discusses the development of the protocols given in NBC 2015 Commentary L and uses examples of how the commentary provisions would be applied to building that is being renovated or expanded.

Keywords: Seismic Upgrading, Heritage Buildings, Code Requirements, Seismic Hazard Mitigation

INTRODUCTION

During the development cycle for the 2015 edition of the National Building Code, the Standing Committee on Earthquake Design (SCED) was asked to update the references on Commentary L. In doing so, it was realized that the seismic provisions of Commentary L had become somewhat outdated and did not reflect the current thinking on seismic upgrading of buildings, such as:

- It is necessary to examine both the force level that the building can resist as well as the expected drift. Many heritage buildings have brittle gravity load systems and it is necessary to limit the drift that the building so that these elements do not fail. The limitation of drift is also necessary to protect the components of the building such as cladding and parapets.
- There is a reduced design force level of upgrading for existing buildings, usually for both economic and practical reasons. The upgrading of an existing building to fully meet current code requirements is often impractical and upgrade costs are often very high.
- The use of a risk-based assessment for seismic upgrading for buildings is more effective than requiring that the building comply with a specified percent of code. A risk-based assessment requires that the building meet a seismic objective defined by the commentary for an event with a return period less than that required for a new building.
- Seismic upgrading must address both the strength of system to resist minimum loads and the deflection of the system so that brittle elements in the system can continue to carry the gravity load that they need to carry.
- During a renovation of a building, the extent of seismic upgrading required is usually based on the extent of the work to be done. While is not common for a partial renovation to require a substantial upgrading of the building, it is expected that the falling hazards in the project area will be mitigated. Conversely, if the renovation is extensive, then it is expected that a portion of the renovation budget be allocated to seismic upgrading.

Commentary L was modified to address the changes in philosophy of seismic upgrading. This paper discusses the modifications.

SEISMIC PROVISIONS FOR EXISTING BUILDINGS

The National Building Code (NBC) and the derivative provincial codes and city bylaws are primarily for the design of new buildings. Engineers faced with modifying existing buildings often have very little guidance, especially when it comes to the seismic provisions. Guideline provisions for existing buildings are provided in Commentary L. These provisions are not in the main body of the code and are for the guidance of engineers and the authority having jurisdiction.

Seismic Provisions in Commentary L prior to NBC 2015

The first edition of Commentary L was in the 1995 edition of the structural commentaries. The commentary was intended to give guidance for the "structural evaluation and upgrading of existing buildings to give a level of performance that is appropriate, based on the intent of the current National Building Code requirements." The commentary noted that "Earthquake requirements provide the greatest difficulty in the application of Part 4 and referenced structural design standards to existing buildings." The commentary recommended that a "triggering level for upgrading" of 60% of the current NBCC requirements be used. The commentary did not state to what level the upgrading should be if the building fails to meet 60% of the building code requirements.

Commentary L for NBC 2015

During the development cycle for the 2015 edition of the National Building Code of Canada (NBCC), the Standing Committee on Earthquake Design (SCED) was asked to update the references on Commentary L for the 2015 edition of the structural commentaries to NBC. In doing so, it was realized that the seismic provisions of Commentary L had become somewhat outdated and did not reflect the current thinking on seismic upgrading of buildings. The desire was to update the seismic provisions of Commentary L, providing more guidance while better reflecting the current philosophy of seismic design, all in a standalone document.

Dealing with Seismic Upgrading in Other Canadian Codes

Many of the codes that are derived from NBC have very little guidance on seismic upgrading for the engineer or the authority having jurisdiction. The 2012 British Columbia Building Code states that a renovation should not decrease the life safety and building performance below a level that already exists, with the result that a building with a totally deficient seismic system could have a large life-extending renovation without requiring that any seismic upgrading be done as part of the work. The 2013 edition of Vancouver Building Bylaw has a more compressive approach, with Part 11 of the bylaw covering the renovation of existing buildings. Included in Part 11 are levels of seismic upgrading S1 to S4 and flowcharts that define which level of upgrading should be undertaken. For example, a building undergoing a minor renovation that does not add area or height would be required to have an S2 upgrade that mandates that falling hazards be mitigated in the project area. On the other end of the scale, a building undergoing an extensive renovation with addition of area or height would require the seismic system be brought up to meet 75% the building bylaw, including addressing both the lateral system and any falling hazards. As an additional reference, ASCE-41 is a comprehensive document covering the seismic mitigation of buildings; while it was not developed to dovetail with Canadian codes, it does provide an extensive and compressive guide.

Drift Limits and Importance of Drift Control

It is necessary to examine both the force level that the building can resist as well as the expected drift. Many heritage buildings have brittle gravity load systems and it is necessary to limit the drift that the building is experiencing so these brittle gravity load elements can continue to do their work in supporting the weight of the building. Some buildings, particularly heritage buildings built of non-ductile materials, can have very low resistance to seismic forces or the drift that is imposed by those seismic forces. Renovations that add mass to the building or increase the irregularity or height of the building will increase the risk of collapse and should be mitigated. Similarly, renovations that extend the life of the building increase the risk to occupants and should have at least part of the project budget spent on seismic mitigation.

Reducing the Seismic Upgrading Levels for Existing Buildings

Buildings built in a time when seismic codes were essentially nonexistent or just being developed frequently used a variety of brittle materials such as stone, brick, or lightly reinforced concrete that are both weak and brittle when exposed to the impacts of seismic loading. These buildings often have weak and soft storeys and incomplete load paths. To fully upgrade them to meet the full requirements of current seismic codes would be almost impossible and very expensive. Thus, building authorities have often permitted the seismic upgrading of buildings to less than full code levels. Over time, upgrade requirements have evolved from a simple "bolts-plus" approach, where only floors are bolted to walls and falling objects such as parapets are addressed by stating that a certain percentage of code be met. This percentage will often vary depending on the authority having jurisdiction and the extent or cost of the renovation. In keeping with the provisions of ASCE-41, the upgrading levels recommended by Commentary L are risk-based and based on using events with a lower return period for each upgrading level. The levels have been chosen to align with return periods that are easily available from the Earthquakes Canada website.

Establishing the Upgrade Levels

The desire in having a risk-based seismic upgrading system is to choose selected return periods and upgrading design targets for the analysis. The result is a more consistent upgrading level than is achieved by assigning a set percentage of base code. The levels are chosen so that the seismic coefficients can be determined using the seismic risk "Hazard Calculator" on the Earthquakes Canada website, which gives the seismic values for the following return periods for any location in Canada:

- 2% in 50 years (full code 1:2475 years)
- 5% in 50 years (1:1000 years)
- 10% in 50 years (1 in 475 years)
- 40% in 50 years (1 in 100 years)

Table 1 below provides data on the fair assessment and upgrade levels outlined in Commentary L for Vancouver and Quebec City, and provides comparison of this data to similar ASCE 41 risk levels.

Table 1. Assessment and Upgrade Levels for Risk-based Seismic Upgrading

			Vancouver			Quebec City		
Hazard Return Periods:	**Remark**	**Provided by Earthquakes Canada?**	**$S_a(0.2)$**	**$S_a(0.5)$**	**PGV**	**$S_a(0.2)$**	**$S_a(0.5)$**	**PGV**
2% in 50 Years	Full Code	Yes	0.848	0.751	0.553	0.493	0.265	0.225
5% in 50 Years	Commentary L Level 3 ASCE 41 BSE-2E	Yes	0.579	0.512	0.365	0.294	0.163	0.134
10% in 50 Years	Commentary L Level 2	Yes	0.420	0.368	0.253	0.192	0.108	0.085
0.5*(5% in 50 years)	Commentary L Level 1	By calculation	0.290	0.256	0.183	0.147	0.082	0.067
20% in 50 Years 40% in 50 Years 50% in 50 years	ASCE 41 BSE-1E – ASCE 41 base level	No Yes No	0.185	0.154	0.095	0.072	0.041	0.029

Level 1: Use response spectrum values that correspond to one-half (0.5) of those for a 5%/50 years (5% in 50 years is 1/1000 per annum) probability. The 5%/50 years spectral values can be obtained from Earthquakes Canada "Hazard Calculator." These values should then be divided by 2.

Level 2: Use response spectrum values that correspond to those for 10%/50 years (1/475 per annum) probability. The 10%/50 years spectral values can be obtained from Earthquakes Canada "Hazard Calculator."

Level 3: Use response spectrum values that correspond to those for 5%/50 years (1/1000 per annum) probability. The 5%/50 years spectral values can be obtained from Earthquakes Canada "Hazard Calculator."

There are several advantages to using a risk-based approach to seismic upgrading, but one of the most obvious is the necessity to increase the seismic upgrading requirements for buildings located on soft soil sites relative to those located on firm soil sites. This effect is due to non-linearity in the foundation factors, where smaller earthquakes with a higher probability of occurrence are more magnified on soft sites than are large earthquakes with a lower probability of occurrence. This is discussed in the next section where levels 1 through 3 are discussed in more detail.

Code Compliance of Various Levels

Traditionally in Canada, if a building is upgraded to a level less than full code levels, then it is upgraded to a percentage of full code. This percentage is usually defined by the authority having jurisdiction without consideration of risk levels or site conditions. Due to the non-linearity of the foundation factors, the percentage code compliance for the upgrading levels using NBC Commentary L vary both with what is being done and with the site conditions. This is illustrated in Figure 1.

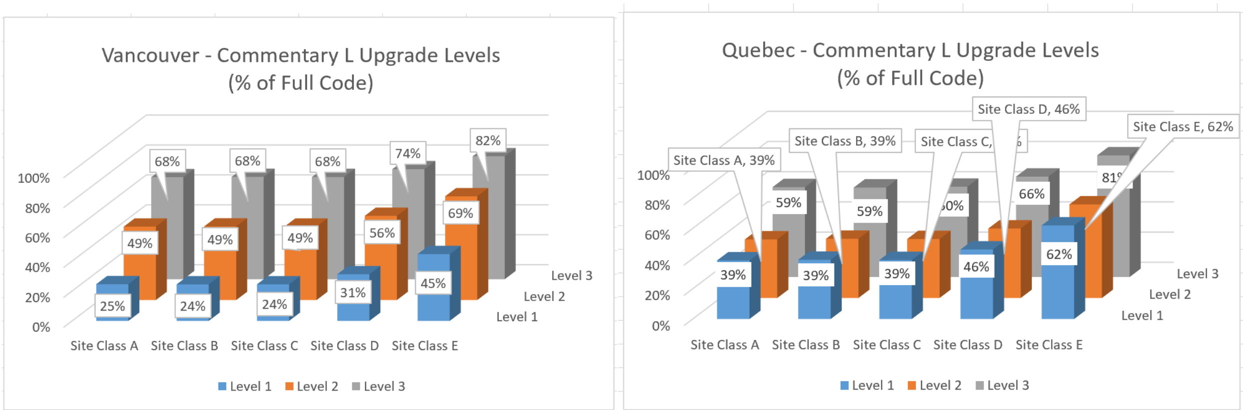

Figure 1. Percentage Code Compliance for Levels 1, 2, and 3 for various site conditions as outlined in NBC 2015 Commentary L

Reducing the Falling Hazards

A concern with seismic upgrading has always been the restraint of parts of the building that could be a significant hazard to occupants in the building, occupants exiting the building, and people outside the building. Significant potential for injury or death can occur from the collapse of brick veneer, unreinforced parapets, and unreinforced chimneys. The bracing and tying back of these items is of importance to those both inside and outside the building. In most seismic regions of Canada, particularly those in the east, non-structural building components have posed a greater risk in recent earthquakes than the building structures themselves. In addition, seismic upgrading can often be carried out much more easily for non-structural components than for the building structure as part of maintenance. It is recommended that CAN/CSA-S832 "Seismic Risk Reduction of Operational and Functional Components (OFCs) of Buildings" are followed for the seismic upgrading of non-structural components in combination with NBC 4.1.8.18.

Suggested Definitions

To help users determine the difference between a minor and major renovation definitions were added to Commentary L. Samples from these definitions are as follows:

Vertical Addition: A vertical addition is an addition that increases both the area and the height of the building with or without increasing its footprint. Vertical additions are usually built at least in part on the existing building. However, a structurally connected addition that is taller than the original building without being on the footprint of the original building is also considered a vertical addition.

Horizontal Addition: A horizontal addition is an addition that increases the area of the building without increasing its height and that may or may not increase the footprint of the building.

Major renovation: A major renovation is an extensive renovation to the architectural, structural, mechanical and electrical components in a major portion of the building that extends the useful life of the building. The renovation may or may not involve removal of the wall and ceiling finishes in the project area. A change of use is also considered a major renovation.

Minor addition: A minor addition is an addition having a total weight that is less than 10% of the weight of the existing building.

Minor renovation: A minor renovation is a limited renovation to the architectural, mechanical and electrical components in a portion of the building. The renovation may or may not involve some structural work but does not increase the occupied area of the building. A minor renovation is limited to one floor in a building with three or more storeys and to a part of one floor in a one- or two-storey building; a renovation affecting a larger part of the building is considered a major renovation. Minor renovations must not reduce the capacity of the Seismic Force Resisting System (SFRS).

Minor renovation involving structural components: A minor renovation involving structural components is a minor renovation that involves a change to the structure of the existing building (e.g., a renovation that creates an additional opening in a shear wall}. The renovation may increase the vertical or lateral capacity of the existing building but must not reduce its lateral capacity.

Voluntary seismic upgrade: A voluntary seismic upgrade is a non-mandatory upgrade of the SFRS. Upgrading to Level 1, the minimum assessment / upgrading level, is recommended. Non-structural upgrading is also recommended.

A Flowchart Approach to Seismic Upgrading

A flowchart provides direct and quickly understood guidance to seismic upgrading requirements. Flowcharts have been used before in the structural commentaries to NBC; in particular, for laying out the provisions for wind design. A flowchart is presented in Commentary L for suggested upgrading requirements for buildings that are being renovated and expanded as well as those that are undergoing a voluntary upgrade. It is expected that during any renovation or expansion to a deficient building at least some of the project budget should be spent on seismic upgrading. The seismic upgrading required will depend on the extent of the renovation or addition and the present resistance of the building. The flowchart in Commentary L is reproduced in Figure 2.

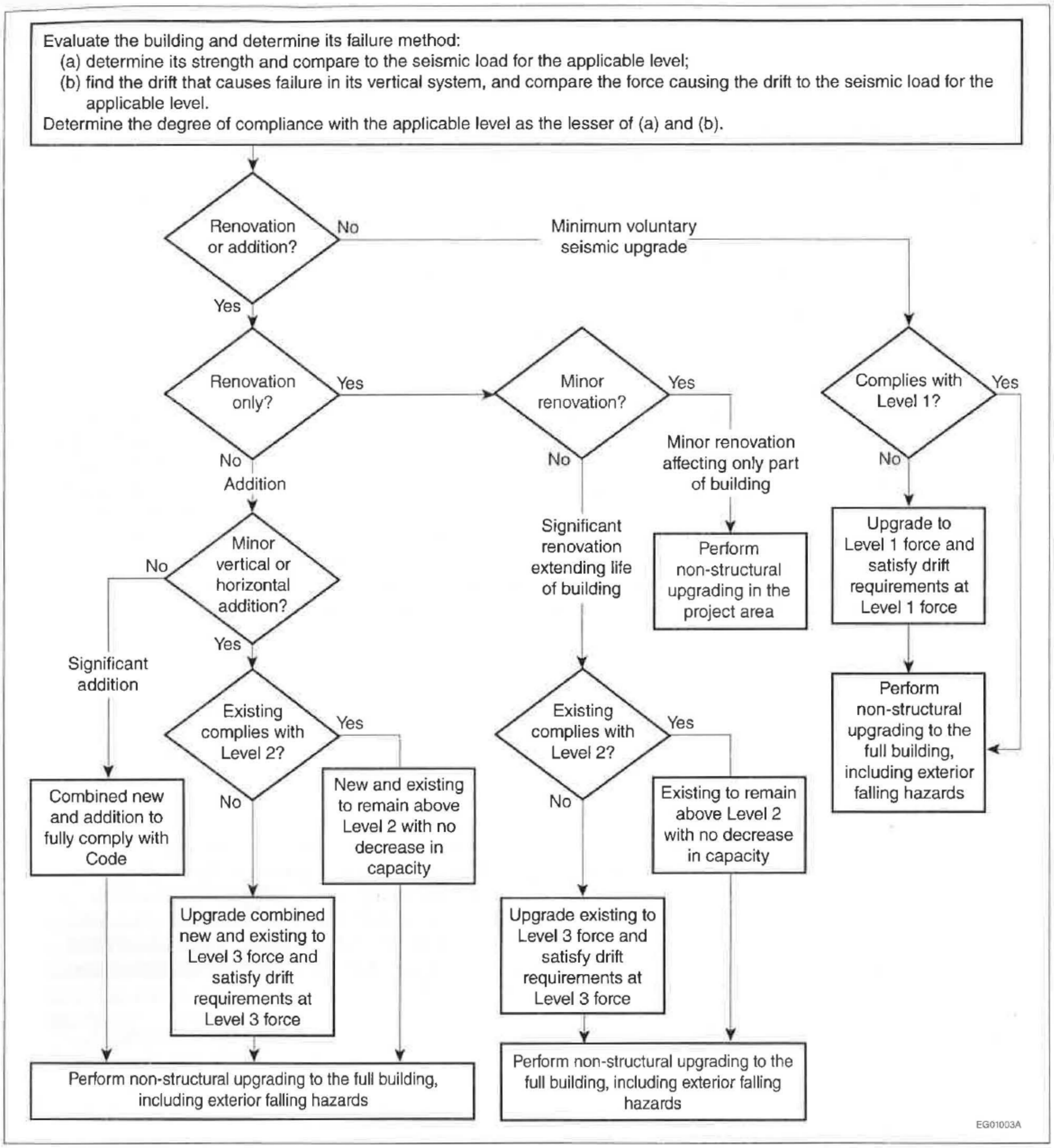

Figure 2. Upgrading Flowchart.

Evaluating the Building Capacity

In evaluating the capacity of the existing building to resist forces, an evaluation needs to be made of the appropriate R_dR_o values to be used in the analysis. Buildings that are new with well-documented systems can have their ductility determined using the detailing requirements of existing material standards. Buildings that possess structural systems with little ductility should use R_dR_o = 1.0. The percentage of code is a measure of the degree of compliance of the building when compared to current code values considering both drift capability and existing strength as measures of compliance. Determine the existing strength (lateral load resisting capacity for earthquake loading) of the building using appropriate R_dR_o values and using appropriate material factors in accordance with current material standards or using guidelines such as ASCE-41. Determine the existing strength as a percentage of current code lateral force requirements. If the building has a seismic system that substantially complies with present systems with a defined R_dR_o then use the R_dR_o appropriate for that system. For systems including unreinforced masonry that do not have a defined system in the current code, use R_dR_o=1.0 when looking at force compliance. When evaluating deflections, use R_dR_o=1.0 forces to determine the deflections. Drift compliance is determined by establishing the drift where failure of the vertical load carrying system occurs, usually from the brittle failure of a column or short wall segment. Use the lower of percentage drift compliance and percentage force compliance to define the percentage of code compliance.

A Scorecard for Commentary L

The points covered by Commentary L can be examined in comparison to other provincial codes, city building bylaws, and reference documents used for seismic upgrading of buildings. The comparison is shown in Table 2 and covers the 2012 British Columbia Building Code, the 2014 edition of the Vancouver Building Bylaw, the seismic upgrading protocols established for schools in British Columbia, and ASCE 41.

Table 2. Scorecard for Commentary L by Comparison to Other Codes and Standards

	BCBC 2012	VBBL (2014)	School Seismic U/G	NBCC 2010 (Commentary L)	ASCE 41
Mitigation Depends on what is being done	No	Yes	No	No	Yes
Reduced level of upgrading for existing buildings	Upgrading not required so Yes	Yes	Yes	No	Yes
Drift limitations based on material are a criteria	No	No	Yes	No	Yes
Addressing risks of Non-Structural Hazards	No	Yes	Yes	Yes	Yes
Performance based upgrading level	No	No	Yes	No	Yes

Table 2 shows that, despite the brevity of NBC 2015 Commentary L, it captures the five fundamental concepts of seismic upgrading outlined at the start of this paper.

Examples of Application 1 – Voluntary seismic upgrade of a heritage hotel. This example is a seven-storey building with unreinforced brick walls for lateral and vertical resistance. Building is currently used as single room occupancy hotel and will be renovated. Use and size of building will not change. Building is on site class C in Vancouver.

There are several almost derelict but often described as heritage hotels in Vancouver that were built in 1912. These buildings have timber floors with weak diaphragms, multi-wythe brick bearing walls, soft storeys, and weak transfer mechanisms for lateral loads at the top of the ground floor level. They have a very brittle and almost nonexistent seismic system with a soft and weak storey at the ground level often in both directions. The building poses a significant risk of failure and life safety to those inside the building and those outside the building during an earthquake.

The path as per the flowchart in Figure 2 is:

- Renovation or Addition → No
- Minimum Voluntary Seismic Upgrading → Yes
- Complies with Level 1 → No
    - →Upgrade existing to Level 1 force levels and satisfy drift requirements at Level 1force level.
    - →Perform non-structural upgrading to the entire building including exterior falling hazards.
    - (note for Vancouver on site class C the upgrading requirements for Level 1 are 24% of full code).

Several of these buildings were upgraded from 2012 to 2016 as part of an effort to provide housing for the homeless. There was no addition to the buildings and no change of use – the usual triggers for upgrading. However, with their very deficient seismic systems, it was unreasonable not to do something to mitigate the seismic issues that threatened the life safety of those inside and outside the building. Upgrading was done to a level similar to Level 1 and has been described in references 5 and 8. This provided the buildings with a competent SFRS, eliminated the soft and weak storey and tied back the falling hazards such as unreinforced parapets.

Examples of Application 2 – Five-storey concrete building built in 1975. Seismic system of lightly reinforced concrete walls, site class B located in Vancouver.

This typical Canadian building is quite often given a "facelift" that refurbishes all systems except the seismic system. Under Commentary L, one would evaluate the building under full code loading and find that at R_d=1.5 one would get approximately 50% of code force compliance and drift causes failure in columns carrying gravity load at approximately 25% of code forces.

The path is:

- Renovation or Addition → Yes
- Renovation only → Yes
- Significant renovation extending life of building → Yes
- Existing complies with Level 2 → No (Level 2 on site class **B** in Vancouver requires a compliance of 49% for both drift and force level).
    - →Upgrade existing to level 3 force levels and satisfy drift requirements at Level 3 force level.
    - →Perform non-structural upgrading to the full building including exterior falling hazards.
    - (for Vancouver on site class B the upgrading requirements are 49% of full code).

An upgrading level of 75% of code would be required by the 2014 edition of the Vancouver Building Bylaw for this case. Note that in its present condition, the building almost fully complies with the force levels we are upgrading to; however, at the expected drift from that force levels the gravity columns have failed, leading to building collapse. Therefore, there is a need to upgrade to limit the drift these columns experience or to modify the columns to improve their ductility so that they do not fail.

Examples of Application 3 – Three-storey concrete building with some heritage features located in Vancouver owner wishes to completely gut the building and add an extra floor. Building is 70 years old and efficiently designed to comply with the codes of the day that had minimal seismic requirements.

This is an example where not much analysis on the existing building is required. Having been designed efficiently to the codes of the day, we know that it does not comply with current code and it also does not comply for the addition of an extra floor.

The path as per flowchart in Figure 2 is:

- Renovation or Addition → Yes
- Renovation only → No (addition)
- Minor Vertical or Horizontal addition → No
    - →Combined new and addition to fully comply with code.
    - →Perform non-structural upgrading to the full building including exterior falling hazards.

This is an example where there really should be no relaxations for the heritage aspects; the building is being torn apart and expanded with its life considerably increased, and with the forces increased by the addition, it should be made fully compliant with the code. When following through Commentary L, one finds that the completed building must comply with the 100% of code from a seismic standpoint.

Mandatory Seismic Upgrading

At present, there is no requirement in Canada to seismically upgrade a building that is being neither renovated nor expanded. An owner may consider a voluntary seismic upgrade to mitigate the risk to occupants and improve the probability of continuity of service under minor events. Jurisdictions such as California and New Zealand, where the effects of recent earthquake damage have been experienced, have mandatory upgrading requirements for vintage or heritage buildings.

CONCLUSIONS

a) Commentary L provides the only guidance in the NBC system for the renovation of existing buildings built to previous codes that often had only rudimentary or nonexistent seismic provisions and are deficient from a seismic standpoint.

b) Seismic upgrading through Commentary L for NBC 2015 provides a way to evaluate and seismically mitigate buildings that is more consistent with the current philosophy of seismic upgrading than was provided in previous editions of the commentary.

c) The provisions for seismic upgrading in NBC 2015 Commentary L provide:
   a. Guidance as to the force level that the building should be capable of resisting.
   b. Require consideration of drift that will often govern the design.
   c. Require consideration of non-structural falling hazards such as parapets.

The provisions of Commentary L for NBC 2015 are not a complete seismic upgrading protocol; however, they are intended to provide guidance as to the philosophy of seismic upgrading and the extent.

ACKNOWLEDGMENTS

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REFERENCES

[1] Canadian Commission on Building and Fire Codes, National Research Council of Canada. *National Building Code of Canada* (NBC) 2015. Ottawa, 2015.

[2] Canadian Commission on Building and Fire Codes, National Research Council of Canada. *Commentary L Application of NBC Part 4 of Division B for the Structural Evaluation and Upgrading of Existing Buildings User's Guide* (*NBCC) 2010 (Part 4 of Division B)*. Ottawa, 2011.

[3] Canadian Commission on Building and Fire Codes, National Research Council of Canada. *Commentary L Application of NBC Part 4 of Division B for the Structural Evaluation and Upgrading of Existing Buildings User's Guide* (*NBC) 2015 (Part 4 of Division B)*. Ottawa, 2016.

[4] NBC 2015 compatible seismic values with various return periods at specified latitude and longitudes can be found on the Determine 2015 National Building Code of Canada Seismic Hazard Values page on the Earthquake Canada website at http://www.earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/index_2015-en.php.

[5] Andy Metten, P.Eng., Struct.Eng.; John Sherstobitoff, P.Eng.; and Ron DeVall, P.Eng. Structural Engineering Consultants of BC (SEABC) seminar on Seismic Upgrading Provisions in Commentary L of NBC 2015 and the Upgrading of Heritage Buildings presented in Vancouver on November 30, 2017.

[6] Vancouver Building Bylaw (VBBL) 2014, Part 11 (Existing Buildings).

[7] ASCE 41-13 Seismic Rehabilitation of Existing Buildings. American Society of Civil Engineers, 2014.

[8] Andy Metten, P.Eng., Struct.Eng. *Seismic Upgrading of Heritage Buildings on the Downtown Eastside of Vancouver.* 11th Canadian Conference on Earthquake Engineering, Victoria, July 2015.