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NEW SEISMIC RISK SCREENING TOOL FOR EXISTING BUILDINGS IN CANADA

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Abstract: This paper summarizes a new seismic risk screening tool for existing buildings in Canada. The tool consists of methodologies for seismic risk screening of structural and non-structural components of existing buildings. The tool aims to identify and prioritize existing buildings with potential unacceptable seismic risk for further seismic evaluation. The seismic risk of the structure is based on the probability of building collapse and identified consequences of failure to life safety. The global seismic risk of non-structural components is qualitatively assessed based on seismic demand of the most critical non-structural components and identified consequence of failure to life safety. Calculated structural and non-structural scores are compared with corresponding structural and non-structural components thresholds, which are function of consequences of building failure. In general, the scoring systems reflect the expected seismic risk for different seismic zones. An example of seismic screening of a concrete shear wall building in Montreal and Vancouver illustrates the use of the seismic risk screening tool.

1 INTRODUCTION

A large number of existing buildings in Canada can potentially suffer severe damage or collapse in the event of strong ground shaking. The assessment and mitigation of seismic risk in large portfolios of existing buildings presents technical and economic challenges to building owners. To address these challenges, the National Research Council Canada (NRC) developed in the 1990s a series of manuals and technical guidelines for seismic screening (NRC 1993b), evaluation (NRC 1993a), and upgrading (NRC 1995) of existing buildings, based on seismic assessment guidelines in the United States (FEMA 1988, 1992, 1997) and in accordance with the 1990 edition of the National Building Code of Canada (NRC 1990). Specifically for seismic screening, the NRC developed a manual for seismic risk screening that provided a qualitative methodology based on amplification of seismic demand due to different design parameters. Given its qualitative nature, the NRC screening manual was primarily used for prioritization. Based on the NRC screening methodology, Saatcioglu et al. (2013) proposed a seismic screening software that incorporated updated seismicity and soil classifications used in the 2010 edition of the National Building Code of Canada (NRC 2010). The modified screening procedure and methodology, however, maintained the qualitative elements of the original NRC screening manual.

New seismic screening methodologies have emerged in North America in the last two decades. The Federal Emergency Management Agency (FEMA) released the second and third editions of the FEMA 154 handbook entitled "Rapid Visual Screening of Buildings for Potential Seismic Hazards" (FEMA 2002, 2015), which adopted the HAZUS earthquake loss estimation methodology to determine structural scores. The screening methodology in FEMA 154, however, cannot be directly used to evaluate the seismic risk of existing buildings in Canada due to the differences in seismicity and building seismic design and construction practices from those in the United States. Some researchers have adapted existing FEMA methodologies to quantitatively assess the seismic risk of existing buildings in Canada (Ventura et al. 2005; Karbassi and Nollet 2008; Tischer, Mitchell, and McClure 2014). These methodologies, however, were developed for specific regions or provinces and thus cannot be used nationwide. In addition, the application of some of these methodologies (Pina et al. 2010) were limited only to school buildings.

Given the need of a quantitative methodology for seismic risk assessment of existing buildings across Canada, Public Service and Procurement of Canada (PSPC) requested NRC to develop a new seismic risk screening tool (Fathi-Fazl, Cai, et al. 2018a). The new screening tool consists of a quantitative seismic risk scoring system for building structures and a qualitative seismic risk scoring system for non-structural components. Structural scores and non-structural components scores are calculated separately and compared with corresponding structural and non-structural components thresholds to determine whether the seismic risk of a given existing building is unacceptable, thus triggering further seismic evaluation. The objective of the new tool is to ensure an acceptable and consistent seismic risk of structural systems and non-structural components with the focus on minimizing threats to life safety of occupants of existing buildings. Higher performance objective related to operation and functionality of existing buildings is out of scope of the tool. Nevertheless, for buildings with higher consequences of failure, the seismic risk associated with the life safety is eligible to be assessed using the new tool. The tool has the intent to assist building owners and managers in making risk-informed decision on whether it is required further seismic evaluation. A general review of the structural and non-structural seismic risk scoring methodologies is presented herein.

2 STRUCTURAL SEISMIC RISK SCORING

2.1 Methodology

The structural seismic risk scoring methodology is largely based on the HAZUS earthquake loss estimation methodology. Determination of the structural scores involves (1) constructing building capacity curves, (2) determining seismic demand spectra, (3) calculating peak spectral displacement, (4) developing fragility curves, (5) calculating probability of complete damage state and collapse factor, and (6) determining basic scores and score modifiers.

The methodology has been customized to suit Canadian building seismic design and construction practices, specifically for three key parameters: (1) building code edition, (2) building design parameters, and (3) level of seismicity. In addition, the methodology incorporates a number of new features:

1. Additional building attributes, including (1) building importance, (2) building deterioration and age, and (3) remaining occupancy time; and

2. Specific structural thresholds for different consequences of failure in existing buildings.

The methodology quantitatively evaluates the probability of failure of existing buildings based on generic building capacity and fragility curves for different building types. Furthermore, a new classification of consequences of failure proposed by Fathi-Fazl and Lounis (2017) was adopted to identify different levels of consequences of failure in existing buildings. A structural score that is defined as the negative common logarithmic of the probability of collapse of a given existing building is compared with a specified structural threshold that corresponds to the level of consequences of failure of the building, which is associated with an acceptable probability of collapse. By comparing the structural score with the corresponding threshold, the need for further structural seismic evaluation is determined. Additional details of the methodology can be found elsewhere (Fathi-Fazl, Cai, et al. 2018a).

2.2 Structural Scoring Procedure

Figure 1 illustrates the procedure for structural scoring of existing buildings. The structural scoring procedure begins by identifying the applicable seismic zone and building type based on the seismic force-resisting system (SFRS). A basic structural score is calculated based on the probability of collapse for a given SFRS and the code level earthquake associated with the applicable seismic zone. Then, one or more applicable score modifiers are calculated for applicable building attributes. The final score is determined by adding the basic structural score and applicable score modifiers and is then compared with a corresponding structural threshold to establish whether further structural seismic evaluation is required.

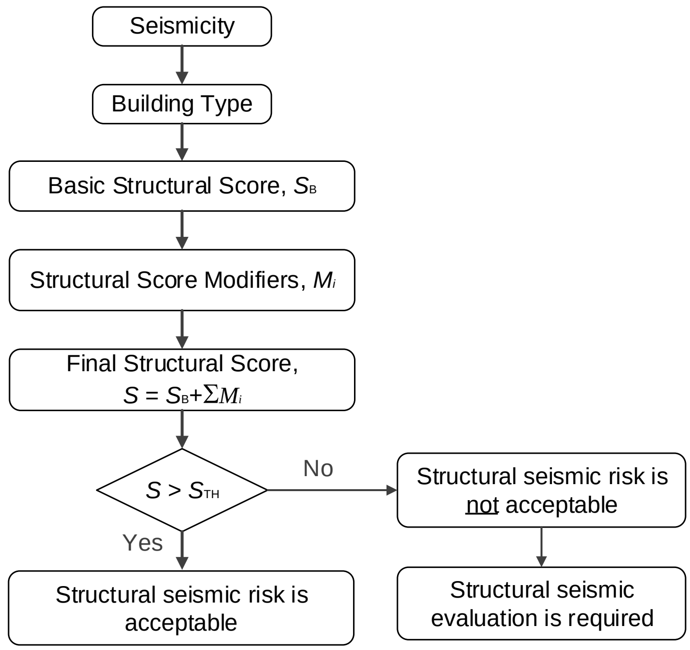

Figure 1: Structural scoring of existing buildings

2.3 Seismic Zones

Table 1 provides six seismic zones for seismic risk screening and their corresponding Modified Mercalli Intensity (MMI). The seismic zones were developed by Fathi-Fazl et al. (2018) from empirical relationship between spectral response accelerations at short periods ($S_a(0.2)$ and $S_a(0.5)$) and long periods ($S_a(1.0)$) and MMI scale. The thresholds associated with MMI scales are consistent with the thresholds regarding the system restrictions placed on SFRSs listed in Table 4.1.8.9. of the 2015 edition of NBC (NRC 2015).

Table 1: Seismic zones

Seismic Zone	$\mathrm{Max}[S_a(0.2), S_a(0.5)]$		$S_a(1.0)$		MMI
	$>$	$\leq$	$>$	$\leq$	
Very Low (VL)		0.10g		0.05g	V
Low (L)	0.10g	0.20g	0.05g	0.10g	VI
Moderate (M)	0.20g	0.35g	0.10g	0.15g	VII
Moderately High (MH)	0.35g	0.75g	0.15g	0.30g	VII $\frac{1}{2}$
High (H)	0.75g	1.15g	0.30g	0.50g	VIII $\frac{1}{2}$
Very High (VH)	1.15g		0.50g		IX+

2.4 Building Types

Table 2 provides a list of sixteen model building types (MBT) considered for seismic risk screening. The MBT are largely based on the buildings types in the 1993 NRC screening manual, with the addition of manufactured homes (MH).

Table 2: Model building types (MBT)

Material	MBT	Description of MBT
Wood	WLF	Wood, light frame
	WPB	Wood, post and beam
Steel	SMF	Steel moment frame
	SBF	Steel braced frame
	SLF	Steel light frame (hot rolled or cold-formed steel)
	SCW	Steel frame with concrete shear walls
	SIW	Steel frame with infill masonry shear walls
Concrete	CMF	Concrete moment frame
	CSW	Concrete shear walls
	CIW	Concrete frame with infill masonry shear walls
	PCF	Precast concrete frame
	PCW	Precast concrete wall
Masonry	RML	Reinforced masonry bearing walls with wood or metal deck diaphragms
	RMC	Reinforced masonry bearing walls with concrete diaphragms
	URM	Unreinforced masonry bearing wall buildings
Other	MH	Manufactured homes

2.5 Basic Score

Basic scores S_B correspond to the probability of collapse of building types given code level earthquakes for different seismic zones. S_B are calculated for low-rise (1-3 storeys) buildings with pre-benchmark design (i.e. originally designed in accordance with a seismic code edition in which significantly improved seismic code requirements have not yet been adopted and enforced), normal importance category, no deficiencies or credits, and foundation soil classified as site class C.

2.6 Score Modifiers

Ten structural score modifiers are incorporated in the seismic risk screening tool to address the effect of different conditions on building seismic performance: (1) building irregularities, (2) design code edition, (3) original building importance, (4) site class, (5) building height, (6) building deterioration and age, (7) redundancy, (8) pounding, (9) seismic upgrading, and (10) remaining occupancy time. The calculations of these modifiers are based on the deficiency-based method in FEMA P-154 (FEMA 2015), which accounts for the effect of a building condition by changing parameter values associated with the condition while keeping remaining parameter values unchanged. Note that original building importance, building deterioration and age, and remaining occupancy times are not addressed in FEMA P-154, but they are included in this seismic screening tool.

2.7 Structural Score Thresholds

Table 3 lists the structural score thresholds for seismic risk screening for different levels of consequences of failure of existing buildings and acceptable probability of collapse in 50 years. The thresholds are determined based on acceptable probability of collapse of building for different consequences of failure over a life span of 50 years. The classification of consequences of failure is based on the synthesis of different classifications in existing codes, standards and guidelines in Canada, United States, Europe, Australia, and New Zealand. The key requirements that govern the classification are occupancy, building size, number of occupants, number of storeys, mobility and age of the occupants, voluntary and involuntary nature of occupants' presence in a building. The classification consists of three classes (Low, Medium, and

High), which are divided in five levels: (1) Very Low, (2) Low, (3) Medium, (4) High, and (5) Very High. Additional details of the classification can be found elsewhere (Fathi-Fazl and Lounis 2017). For seismic risk screening, Low and Medium levels are combined (Table 3).

Table 3: Structural score thresholds

Consequence of Failure	Structural Score Threshold	Acceptable Probability of Collapse in 50 years
Very Low (VLC)	1.7	2%
Low and Medium (LC & MC)	2.0	1%
High (HC)	2.3	0.5%
Very High (VHC)	2.6	0.25%

3 NON-STRUCTURAL SEISMIC RISK SCORING

3.1 Methodology

The methodology for seismic risk screening of non-structural components incorporates a seismic risk screening scoring system that qualitatively assesses the seismic risk of the most critical non-structural components that are permanently attached to building structures. Global non-structural components scores are determined for critical non-structural components of buildings and are compared with threshold scores determined for maximum vulnerability and consequence of failure for a threshold seismic intensity (i.e., intensity VI in the Modified Mercalli Intensity scale – MMI VI). The scoring system has the capability of determining the seismic risk of specific individual or group of non-structural categories. By comparing the structural score with the corresponding threshold, the need for further non-structural seismic evaluation is determined. Additional details of the methodology can be found elsewhere (Fathi-Fazl, Cai, et al. 2018b).

3.2 Classification of Non-Structural Components

Non-structural components are categorized based on their architectural and operational function. A comprehensive description of different non-structural components, equipment, and building contents, including the sources of earthquake damage can be found elsewhere (FEMA 2011). The non-structural categories for seismic risk screening are divided in three main groups, following the categorization in the 2015 edition of NBC (NRC 2015). These groups are:

1. Architectural and elements of structures, including glazing systems,
2. mechanical and electrical components, and
3. other components.

3.3 Seismic Risk Scoring Procedure

Figure 2 illustrates the procedure for seismic risk scoring of non-structural components. The non-structural components score consists of a basic score determined from the seismic demand of nominally designed non-structural components and modifiers to account for the change in seismic demand due to the variation of structural and non-structural components parameters. The calculated score is then compared with corresponding thresholds to assess the need for further seismic evaluation. The non-structural components score is based on the performance and vulnerability of non-structural components and the potential consequences to life safety rather than the probability of collapse or damage.

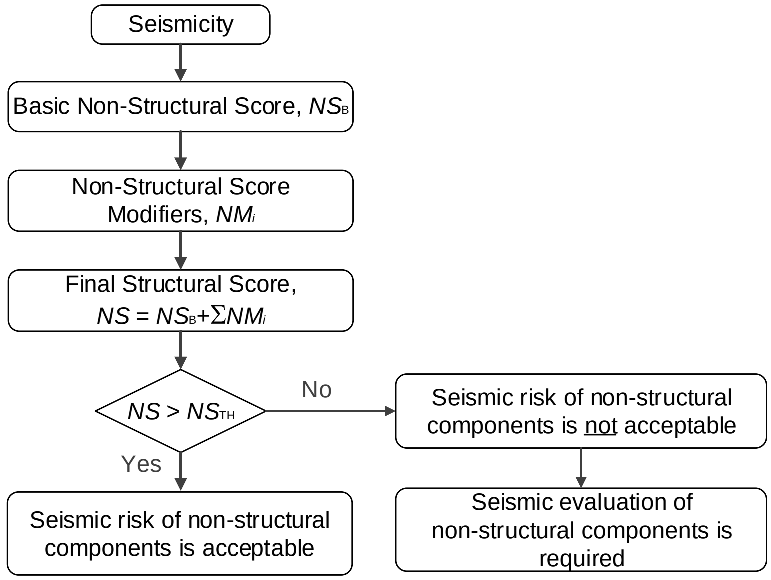

Figure 2: Non-structural scoring of existing buildings

3.4 Basic Non-Structural Components Score

The basic score considers baseline parameters for nominal response of non-structural components, i.e. nominal horizontal force factor S_p, low-rise building (i.e., less than three stories with seismic response controlled by short periods), and building located on Site Class C. The nominal S_p assumes rigid components that are located on the ground floor and have nominal ductility capacity. The basic non-structural components score, NS_B, is calculated for different Seismic Coefficients, V_p/W_p, which are obtained from the design seismic force equation in NBC 2015.

3.5 Non-Structural Components Score Modifiers

The non-structural components score modifiers are based on prescribed and qualitative parameters that reflect the effect of amplified seismic demands on the seismic response of non-structural components. The modifiers are determined by comparing scores for modified parameter with the basic score. The modifiers are (1) site class, (2) structural response (model building type, component elevation, building irregularities, pounding, and building deterioration and age), (3) non-structural components response, (4) non-structural components design code edition, and (5) remaining occupancy time.

3.6 Non-Structural Score Threshold

The acceptable non-structural components score thresholds are determined for different levels of consequences of failure, which combines the importance of the building and the component factor for the most critical non-structural components. A basic threshold corresponds to the least possible non-structural components score and acceptance criteria for Low (L) seismic zone. Table 4 provides the non-structural components score thresholds for different levels of consequences of failure.

Table 4. Non-Structural Components Score Thresholds

Consequence of Failure	Non-Structural Score Threshold
Very Low (VLC)	40[1]
Low and Medium (LC & MC)	40[1] 45[2]
High (HC)	45[1] 50[3]
Very High (VHC)	45[1] 50[3]

[1] Non-hazardous components
[2] Components constituting falling hazard
[3] Components containing hazardous materials or constituting falling hazard

4 Special Conditions

Seismic risk screening of heritage buildings is not within the scope of the seismic risk screening tool due to the potential social consequences resulting from the failure of such highly regarded buildings. Nevertheless, the seismic risk screening tool may be used to assess the heritage buildings associated with the risk to life safety of the occupants in these buildings. In addition, the seismic risk screening tool flags buildings for further seismic evaluation if any of the following conditions is identified: (1) unknown model building type, (2) current consequence of failure is higher than original consequence of failure, (3) site class F, (4) any of geologic hazards (i.e. liquefaction, landslide potential, and surface fault rupture), and (5) significant building deterioration/damage. These conditions might significantly affect the seismic performance of existing buildings, and thus require further seismic evaluation.

5 EXAMPLE OF SEISMIC RISK SCORING

Seismic risk scoring of a hypothetical pre-1970 reinforced concrete shear wall building is conducted for two locations in Canada: Montreal in eastern Canada (moderately high seismic zone) and Vancouver in western Canada (high seismic zone). The characteristics of the building and geotechnical conditions are provided in Table 5.

Table 5: Characteristics of building

Characteristic	
Model building type	Concrete Shear Wall (CSW)
Number of storeys	10
Occupied area	15 000 m^2
Design NBC	1965
Year built	1969
Occupancy (original and current)	Office
Building importance	Normal
Site Class	C
Vertical irregularity	No
Horizontal irregularity	Yes, torsion
Deterioration/Damage	No
Redundancy	Yes, in both directions
Pounding	No
Seismic upgrading	No
Remaining occupancy time	> 10 years
Geologic hazards	No
Falling hazards	Yes, heavy cladding

Table 6 provides the calculated structural and non-structural components scores, along with corresponding thresholds. The results show that the structural seismic risk is acceptable for eastern Canada, yet it is not acceptable for Vancouver. The higher risk in Vancouver is mainly due to the higher seismicity and corresponding expected lower performance. The non-structural seismic risk is not acceptable for both locations, reflecting the expected damage of non-structural components in moderately high and high seismic zones. Assessment of the acceptable risk indicates that further seismic evaluation is required for non-structural components of the building in Montreal and for both structural and non-structural components of the building in Vancouver.

Table 6: Seismic risk screening results

Location	Structural			Non-Structural		
	Score	Threshold	Acceptable Risk[1]	Score	Threshold	Acceptable Risk[1]
Montreal	2.9	2.0	Yes	29	45	No
Vancouver	1.6	2.0	No	25	45	No

[1] Acceptable risk for scores greater than the corresponding thresholds

6 SUMMARY

A seismic risk screening tool for existing buildings in Canada has been developed. The seismic risk is assessed with a quantitative structural scoring system and qualitative non-structural components scoring system. The quantitative structural scoring system is based on the probability of collapse of existing buildings, while the qualitative non-structural components scoring system is based on the increase in seismic demand of the most critical non-structural components of existing buildings. Both the structural and non-structural components seismic risk scoring systems consist of a basic score and a number of score modifiers accounting for parameters affecting the seismic risk of structural and non-structural components of existing buildings. The resulting scores are compared with corresponding score thresholds associated with the consequences of failure of existing buildings to determine the need for further seismic evaluation. The application of the screening tool was demonstrated by scoring a hypothetical concrete shear wall building located in two cities in eastern and western Canada.

7 ACKNOWLEDGEMENTS

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