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Overview of NRC's New Seismic Risk Screening Tools for Existing Wood Light Frame Buildings under Part 9 of the NBC

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ABSTRACT

There are currently no Canadian guidelines for seismic risk assessment of existing wood light frame buildings under Part 9 of the National Building Code of Canada (WLF-P9). This paper overviews two newly developed seismic risk screening tools, namely, Level 1 – Preliminary Seismic Risk Screening Tool (PST) and Level 2 – Semi-Quantitative Seismic Risk Screening Tool (SQST), for existing WLF-P9 buildings, which aim to bridge this gap. The development of these two screening tools was based on Level 1 – PST and Level 2 – SQST originally developed for existing buildings under Part 4 of the NBC with several major modifications and additions to incorporate the unique characteristics and seismic behaviour of WLF-P9 buildings. For example, in Level 1 – PST (WLF-P9), the seismic risk acceptance criteria table has been modified so that existing WLF-P9 buildings in higher seismicity areas are eligible to be exempted from further assessment; in Level 2 – SQST (WLF-P9), building foundation deficiency is incorporated in both structural and non-structural scoring systems. These two screening tools are intended to provide building owners with cost-effective solutions to assess the seismic risks of their WLF-P9 buildings and to prioritize potentially hazardous buildings for further assessment.

Keywords: Seismic risk assessment, preliminary screening, detailed screening, life safety, existing wood light frame buildings.

INTRODUCTION

Earthquakes are one of most destructive natural disasters that can cause significant casualties and monetary losses. According to a study by the Insurance Bureau of Canada [1], a magnitude 9.0 earthquake in British Columbia can cost at almost $75 billion and a magnitude 7.1 earthquake in eastern Canada can cost at almost $61 billion. For building owners with large portfolios of existing buildings in seismically active regions, assessing and mitigating the seismic risks of their buildings presents technical and economic challenges. There is a growing need for risk-informed and cost-effective tools to assess and manage the seismic risks of existing buildings. To address this need, Lounis et al. [2] and Fathi-Fazl et al. [3] from the National Research Council Canada (NRC) developed a multicriteria and multilevel framework for seismic risk assessment and management of existing buildings in Canada, which consists of three levels of assessment, including Level 1 – Preliminary Seismic Risk Screening Tool (PST), Level 2 – Semi-Quantitative Seismic Risk Screening Tool (SQST), and Level 3 – Seismic Evaluation Guidelines (SEG). The framework aims to ensure a consistent and acceptable level of seismic risk within a building inventory while minimizing the costs for performing seismic risk assessment.

The Level 1 – PST [4-6] is completely new to Canada and is intended as a simple screening tool that assist building owners in quickly identifying and exempting buildings with acceptably low risks to human life on the basis of four key criteria, including seismicity, building design period, consequences of failure, and remaining occupancy time. It also identifies a list of conditions that if present will directly trigger seismic evaluation without conducting detailed screening. More details on the Level 1 – PST can be found elsewhere [5-6].

The Level 2 – SQST [7-9] supersedes the outdated NRC Manual for Screening of Buildings for Seismic Investigation developed by the NRC in the early 1990s [10], and is intended to follow Level 1 – PST to identify and exempt buildings with acceptably low risks to human life from seismic evaluation. It includes a structural scoring system [11] that estimates the structural seismic risk by calculating the probability of structural collapse given a Code level shaking, and a non-structural component scoring system [12] that qualitatively estimates the global seismic risk caused by non-structural components that can pose life safety

threats. The Level 2 – SQST also includes a ranking procedure to help building owners prioritize potentially hazardous buildings for seismic evaluation. More details about the Level 2 – SQST can be found elsewhere [7-8].

The Level 1 – PST and Level 2 – SQST have been designed to be completed by trained screeners using paper-based screening forms. A webpage application hosted by NRC [13] is also available to help trained screeners complete Level 2 – SQST without the need to fill out paper-based screening forms. It is noteworthy that Level 1 – PST and Level 2 – SQST are intended to cover existing buildings under Part 4 of the National Building Code of Canada (NBC) (i.e., Part 4 buildings). Existing wood light frame buildings under Part 9 of the NBC (WLF-P9) are not within the scope of Level 1 – PST and Level 2 – SQST. Similarly, WLF-P9 buildings are not covered by the outdated NRC screening manual [10].

According to the NBC 2020 [14], Part 9 buildings are three storeys or less, having a building area of no more than 600 square meters, and having major occupancies classified as residential, office/service, retail, or medium- and low-hazard industrial. In Canada, WLF-P9 buildings constitute a large proportion of the residential building inventory in Canada. The 2021 census of private dwellings by Statistics Canada [15] indicates there are more than 10 million residential WLF-P9 buildings. Assessing and mitigating the seismic risks of WLF-P9 buildings can have significant impact on improving the seismic resilience of Canadian residential building stock.

Currently, no Canadian guidelines are available for building owners to assess the seismic risks of their WLF-P9 buildings. To address this gap, the Seismic Resilience Team at NRC's Construction Research Centre initiated an internal R&D project in 2019 pertaining to the development of two-level seismic risk screening tools for existing WLF-P9 buildings, namely, Level 1 – PST (WLF-P9) and Level 2 – SQST (WLF-P9), based on Level 1 – PST and Level 2 – SQST originally developed for existing Part 4 buildings. Several major modifications and additions have been made to incorporate the unique characteristics and seismic behaviour of WLF-P9 buildings. A pilot study was conducted in 2021 for seven selected Public Services and Procurement Canada buildings, which demonstrated the applicability of the newly developed screening tools to existing WLF-P9 buildings in various levels of seismicity. This project was completed in March 2022 and the two screening tools were published online in March 2023 [16-17]. This paper aims to give an overview of the Level 1 – PST (WLF-P9) and Level 2 – SQST (WLF-P9) with a focus on the major modifications and additions brought to the original Level 1 – PST and Level 2 – SQST.

OVERVIEW OF THE LEVEL 1 – PST (WLF-P9)

The Level 1 – PST (WLF-P9) is completely new to Canada and is intended as a simple criteria-based tool for quickly identifying existing WLF-P9 buildings with acceptably low risks from further assessment on the basis of four key criteria, namely, seismicity, building design period, and remaining occupancy time, and consequences of failure. Table 1 and Table 2 present the acceptance criteria for post-benchmark and non-benchmark WLF-P9 buildings, respectively. A WLF-P9 building is eligible to be exempted from further seismic assessment if all applicable criteria in Table 1 and Table 2 are met. Each acceptance criterion in Table 1 and Table 2 is briefly explained in the following.

Post-benchmark WLF-P9 buildings refer to WLF-P9 buildings designed in accordance with Part 9 of the NBC 2010 or newer. The NBC 2010 is chosen as the benchmark NBC edition because significantly improved seismic provisions were first introduced in Part 9 of this NBC edition [16].

Table 3 presents the thresholds of spectral accelerations for each site seismic category (SSC) in Table 1 and Table 2. The thresholds were determined by establishing equivalent relationships between the modified Mercalli intensity scale and spectral acceleration parameters (S_a) for design ground motions per the NBC [6,18]. S_a(0.2,X) and S_a(1.0,X) in Table 3 represent the design spectral accelerations at short and 1-second periods corresponding to 2% probability of exceedance in 50 years, respectively.

Table 1: Seismic risk acceptance criteria for post-benchmark WLF-P9 buildings [16]

<table>
<tr><td rowspan="4">Site seismic category (SSC)</td><td colspan="3">Post-benchmark building</td></tr>
<tr><td>Structure</td><td colspan="2">Non-structural components</td></tr>
<tr><td>Consequences of failure (COF)</td><td colspan="2">Consequences of failure (COF)</td></tr>
<tr><td>VLC & LC & MC</td><td>VLC</td><td>LC & MC</td></tr>
<tr><td>SSC-0 & SSC-1</td><td rowspan="5">☐ Met</td><td rowspan="2">☐ Met</td><td>☐ Met</td></tr>
<tr><td>SSC-2</td><td rowspan="3">☐ Not Met</td><td rowspan="3">☐ Not Met</td></tr>
<tr><td>SSC-3</td></tr>
<tr><td>SSC-4</td></tr>
<tr><td>SSC-5</td></tr>
</table>

Note: HC & VHC do not apply to post-benchmark WLF-P9 buildings. The remaining occupancy time does not apply to post-benchmark WLF-P9 buildings.

Table 2: Seismic risk acceptance criteria for non-benchmark WLF-P9 buildings [16]

<table>
<tr><td rowspan="3">Site seismic category (SSC)</td><td colspan="6">Non-benchmark building</td></tr>
<tr><td colspan="3">Structure</td><td colspan="3">Non-structural components</td></tr>
<tr><td colspan="3">Consequences of failure (COF)</td><td colspan="3">Consequences of failure (COF)</td></tr>
<tr><td>VLC & LC & MC</td><td>HC</td><td>VHC</td><td>VLC</td><td>LC & MC & HC</td><td>VHC</td></tr>
<tr><td>SSC-0 & SSC-1</td><td rowspan="2">☐ Met</td><td colspan="2" rowspan="2">☐ Met</td><td rowspan="2">☐ Met</td><td>☐ Met</td><td>☐ Met</td></tr>
<tr><td>SSC-2</td><td>☐ Met if $n \leq 10$
☐ Not Met if $n >10$</td><td rowspan="3">☐ Not Met</td></tr>
<tr><td>SSC-3</td><td colspan="2">☐ Met if $n \leq 10$
☐ Not Met if $n >10$</td><td>☐ Met‡ if $n \leq 10$
☐ Not Met if $n >10$</td><td>☐ Met‡ if $n \leq 5$
☐ Not Met if $n >5$</td></tr>
<tr><td>SSC-4</td><td>☐ Met if $n \leq 10$
☐ Not Met if $n >10$</td><td>☐ Met if $n \leq 5$
☐ Not Met if $n >5$</td><td rowspan="2">☐ Not Met</td><td>☐ Met‡ if $n \leq 5$
☐ Not Met if $n >5$</td><td colspan="2" rowspan="2">☐ Not Met</td></tr>
<tr><td>SSC-5</td><td colspan="3">☐ Not Met</td><td>☐ Not Met</td></tr>
</table>

Note: HC & VHC do not apply to existing WLF-P9 buildings designed as per the NBC 2005 or newer. *n* stands for remaining occupancy time (in years).

‡ This only applies to existing WLF-P9 buildings designed as per the NBC 1965 or newer.

Table 3: Thresholds of design spectral accelerations at short and 1-second periods for each site seismic category [6,18]

Site seismic category (SSC)	S_a**(0.2,X)**		S_a**(1.0,X)**	
	$>$	$\leq$	$>$	$\leq$
SSC-0 (Very Low)		0.10 g		0.05 g
SSC-1 (Low)	0.10 g	0.20 g	0.05 g	0.10 g
SSC-2 (Moderate)	0.20 g	0.35 g	0.10 g	0.15 g
SSC-3 (Moderately High)	0.35 g	0.75 g	0.15 g	0.30 g
SSC-4 (High)	0.75 g	1.15 g	0.30 g	0.50 g
SSC-5 (Very High)	1.15 g		0.50 g	

The consequences of failure classification proposed by Fathi-Fazl and Lounis [19] and Fathi-Fazl et al. [20] is introduced to classify the consequences of failure of existing WLF-P9 buildings. Key factors that govern the classification of consequences of failure include the use and occupancy, building size, building height, and ability and mobility to escape. Five levels of consequences of failure, namely, Very Low Consequences (VLC), Low Consequences (LC), Medium Consequences (MC), High Consequences (HC), and Very High Consequences (VHC), are defined in terms of these key factors. Because of small size and low rise of WLF-P9 buildings, the consequences of failure of a vast majority of WLF-P9 buildings are classified as Very Low. For example, the consequences of failure of all residential WLF-P9 buildings are classified as Very Low. As a result, most WLF-P9 buildings with remaining occupancy times more than 10 years are eligible to be exempted from further structural assessment in low (i.e., SSC-0 and SSC-1) and moderate (i.e., SSC-2 and SSC-3) seismicity areas (see Table 2).

The remaining occupancy time refers to the number of years of intended occupancy of an existing building. Compared to a new building, an existing building has a smaller probability of experiencing a Code level earthquake over its remaining occupancy time. A remaining occupancy time factor (κ) proposed by Fathi-Fazl et al. [6] is used to reduce Code level seismic hazards for buildings with remaining occupancy times of 10 years or shorter. The values of κ are equal to 0.31 and 0.46, respectively, for remaining occupancy times of 5 years or less and between 5 years and 10 years [6]. Applying κ to seismic hazards could lower the SSC of WLF-P9 buildings with shorter remaining occupancy times. Therefore, WLF-P9 buildings in higher seismicity areas could be eligible to be exempted from further assessment. It should be noted that κ does not apply to VHC WLF-P9 buildings because these buildings are intended to provide emergency services after a Code level earthquake regardless of their remaining occupancy times.

Compared to the original Level 1 – PST for Part 4 buildings, Level 1 – PST (WLF-P9) can exempt WLF-P9 buildings in higher seismicity areas from further assessment. For example, non-benchmark VLC Part 4 buildings are eligible to be exempted from further structural seismic assessment in low seismicity areas [6], but non-benchmark VLC WLF-P9 buildings are eligible to be exempted from further structural seismic assessment in low and moderate seismicity areas, and even up to high seismicity area if their occupancy times are 10 years or shorter. Considering that the seismicity level of the majority of Canada ranges from low to moderate, using Level 1 – PST (WLF-P9) could exempt the majority of WLF-P9 buildings from further structural assessment, thus significantly reducing the costs for performing further structural assessment.

OVERVIEW OF THE LEVEL 2 – SQST (WLF-P9)

The Level 2 – SQST (WLF-P9) is also completely new to Canada and is intended as a detailed screening tool for building owners to identify and exempt WLF-P9 buildings with acceptably low risks to human life from seismic evaluation. It includes three key components, namely, structural scoring system, non-structural component scoring system, and ranking procedure. In the following sections, the structural and non-structural scoring systems are briefly reviewed. The ranking procedure is not reviewed because it is adopted as is from the original Level 2 – SQST for Part 4 buildings. Refer to Fathi-Fazl et al. [9] for more details on the ranking procedure.

Structural Scoring System

The structural scoring system is based on the quantitative approach in the original Level 2 – SQST [9] that estimates the structural seismic risk by calculating conditional probabilities of structural collapse of existing buildings. The structural seismic risk of a WLF-P9 building is represented by a structural score (*S*) in Eq. (1).

$$S = S_B + \sum_i M_i \tag{1}$$

where S_B is a structural basic score that is defined as the negative common logarithm of the probability of collapse of a building when subjected to a code-level earthquake (CLE):

$$S_B = -log_{10}[P(Collapse|CLE)] \tag{2}$$

where *P*(*Collapse*|*CLE*) is the probability of the structure being in a complete damage state, *P*(*Complete Damage*|*CLE*), times a Collapse Factor, *CF*, defined as follows:

$$P(Collapse|CLE) = P(Complete\ Damage|CLE) \cdot CF \tag{3}$$

where *P*(*Complete Damage*|*CLE*) is obtained from the seismic fragility curve associated with the complete damage state. *CF* is defined as the expected collapsed area divided by the total floor area.

Nine structural score modifiers (*M*) are considered to address the following conditions affecting the structural seismic risk, including (1) building foundation deficiency, (2) building irregularity, (3) building design period, (4) site class, (5) building deterioration and age, (6) redundancy, (7) pounding, (8) remaining occupancy time, and (9) structural upgrading. M_i for each condition is calculated by Eq. (4).

$$M_i = S_{Condition\ i} - S_B \tag{4}$$

where $S_{condition\ i}$ is the modified structural score for condition *i* and is calculated as follows:

$$S_{Condition\ i} = -\log_{10}(P[COL|CLE, Condition\ i]) \tag{5}$$

where *P*[*COL*|*CLE*,*Condition i*] is the probability of collapse of the building given a *CLE* and condition *i*. It is calculated by modifying the parameter values regarding condition *i* while keeping the other parameter values unchanged.

Compared to the original structural scoring system for Part 4 buildings, several major modifications/additions were made to the structural score modifiers and are summarized in Table 4.

Non-Structural Component Scoring System

The non-structural component scoring system is based on the qualitative approach in the original Level 2 – SQST [9] that estimates the global seismic risk caused by non-structural components by calculating the seismic forces on non-structural components. The global seismic risk caused by non-structural components in a WLF-P9 building is represented by a non-structural component score (*NS*) in Eq. (6).

$$NS = NS_B + \sum_i NM_i \tag{6}$$

Table 4: Summary of major modifications/additions to the structural score modifiers

M_i in the new Level 2 – SQST (WLF-P9)	**M_i in the original Level 2 – SQST**	**Modifications/Additions**
Building foundation deficiency (M_{BF})	--	M_{BF} is added to incorporate the effect of building foundation deficiency.
Building irregularity (M_{IR})	Building irregularity (M_{IR})	Irregularities that are unique in WLF-P9 buildings are added and those that are not applicable to WLF-P9 buildings are removed.
Building design period (M_{DP})	Building design period (M_{DP})	Pre-NBC and benchmark NBC editions are identified for WLF-P9 buildings.
--	Original building importance (M_{BI})	M_{BI} is not applied to WLF-P9 buildings because the Importance Category is not considered in the design of WLF-P9 buildings.
--	Building height (M_{BH})	M_{BH} is not considered because all WLF-P9 buildings are low-rise buildings.
Site class (M_{SC})	Site class (M_{SC})	No modification/addition is made.
Building deterioration and age (M_{DA})	Building deterioration and age (M_{DA})	The deterioration types that are unique in WLF-P9 buildings are added and those that are not applicable to WLF-P9 buildings are removed.
Redundancy (M_{RE})	Redundancy (M_{RE})	No credit is applied to redundant WLF-P9 buildings because redundancy is one of the baseline assumptions for calculating S_B.
Pounding (M_{PO})	Pounding (M_{PO})	Separation distances that prevent pounding are updated for WLF-P9 buildings.
Remaining occupancy time (M_{RO})	Remaining occupancy time (M_{RO})	No modification/addition is made.
Seismic upgrading (M_{UP})	Seismic upgrading (M_{UP})	Seismic upgrading cases are updated for WLF-P9 buildings.

Table 5: Summary of major modifications/additions to the non-structural component score modifiers

NM_i in the new Level 2 – SQST (WLF-P9)	**NM_i in the original Level 2 – SQST**	**Modifications/Additions**
Site class (NM_{SC})	Site class (NM_{SC})	No modification/addition is made.
Structural response (NM_{SR})	Structural response (M_{SR})	Building foundation deficiency is incorporated in the calculation of M_{SR}; irregularities are updated for WLF-P9 buildings (see Table 4); separation distances that prevent pounding are updated for WLF-P9 buildings (see Table 4); deterioration types are updated for WLF-P9 buildings (see Table 4).
--	Component response (NM_{CR})	NM_{CR} is removed because no significant improvement was made to the design of non-structural components and connections in WLF-P9 buildings.
Design period (NM_{DP})	Design period (NM_{DP})	Design periods are updated for WLF-P9 buildings.
Remaining occupancy time (M_{RO})	Remaining occupancy time (M_{RO})	No modification/addition is made.

where NS_B is the non-structural component basic score and is calculated as follows:

$$NS_B = 49 - 26log_{10}(V_p/W_p) \tag{7}$$

where V_p and W_p are the lateral seismic force on a non-structural component and the weight of the non-structural component, respectively, in accordance with the NBC 2020. The coefficients 49 and 26 are calibrated so that the maximum value of *NS* in Eq. (6) is equal to 100 assuming remaining occupancy time greater than 10 years.

NM_i is the non-structural component score modifier for condition *i* and is calculated as follows:

$$NM_i = -26log_{10}(F_i) \quad (8)$$

where F_i represents a change in the seismic demand due to the modified parameter. Positive and negative values of NM_i represent score credits and penalties, respectively, corresponding to the beneficial and detrimental effects that the modifying parameters have on the seismic risk of non-structural components.

Compared to the original non-structural component scoring system for Part 4 buildings, several major modifications/additions were made to the non-structural component score modifiers and are summarized in Table 5.

CONCLUSIONS

This paper overviewed two newly developed seismic risk screening tools, namely, Level 1 – Preliminary Seismic Risk Screening Tool (PST) and Level 2 – Semi-Quantitative Seismic Risk Screening Tool (SQST), for existing wood light frame buildings under Part 9 of the NBC (WLF-P9). The development of Level 1 – PST (WLF-P9) and Level 2 – SQST (WLF-P9) was based on the Level 1 – PST and Level 2 – SQST that were originally developed for existing buildings under Part 4 of the NBC (i.e., Part 4 buildings), from which several major modifications and additions have been made to reflect the unique characteristics and seismic behaviour of WLF-P9 buildings. It is expected that, with the implementation of the Level 1 – PST (WLF-P9) and Level 2 – SQST (WLF-P9), building owners are able to conduct cost-effective assessment to identify and exempt WLF-P9 buildings with acceptably low risks and to prioritize potentially hazardous WLF-P9 buildings for further assessment. This would eventually help improve the seismic resilience of Canadian residential building stock.

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REFERENCES

[1] IBC, "Study of impact and the insurance and economic cost of a major earthquake in British Columbia and Ontario/Québec," Insurance Bureau of Canada (IBC), Toronto, 2013.

[2] Z. Lounis, R. Fathi-Fazl, H. Almansour, D. Cusson and J. Singh, "Framework for seismic risk management of existing buildings (available upon request with client's permission)," National Research Council Canada, Ottawa, 2016.

[3] R. Fathi-Fazl, Z. Lounis and Z. Cai, "Multicriteria and multilevel framework for seismic risk management of existing buildings in Canada," *Journal of Performance of Constructed Facilities*, vol. 34, no. 2, 2020.

[4] R. Fathi-Fazl, E. Jacques, Z. Cai, B. Kadhom, B. Saassouh and D. Motazedian, "Development of a preliminary seismic risk screening tool for existing buildings in Canada," *Canadian Journal of Civil Engineering*, vol. 45, no. 9, pp. 717-727, 2018.

[5] R. Fathi-Fazl, Z. Cai, E. Jacques and B. Kadhom, "Level 1 – Preliminary Seismic Risk Screening Tool (PST) for existing buildings, Part 1: user's guide," National Research Council Canada, Ottawa, 2020.

[6] R. Fathi-Fazl, Z. Cai, E. Jacques and B. Kadhom, "Level 1 – Preliminary Seismic Risk Screening Tool (PST) for existing buildings, Part 2: supporting technical documentation," National Research Council Canada, Ottawa, 2020.

[7] R. Fathi-Fazl, Z. Cai, W. Cortés-Puentes, E. Jacques and B. Kadhom, "Level 2 – Semi-Quantitative Seismic Risk Screening Tool (SQST) for existing buildings, Part 1: user's guide," National Research Council Canada, Ottawa, 2020.

[8] R. Fathi-Fazl, Z. Cai, W. Cortés-Puentes, E. Jacques and B. Kadhom, "Level 2 – Semi-Quantitative Seismic Risk Screening Tool (SQST) for existing buildings, Part 2: supporting technical documentation," National Research Council Canada, Ottawa, 2020.

[9] R. Fathi-Fazl, Z. Cai, W. Cortés-Puentes and F. Fazileh, "Semi-quantitative seismic risk screening tool for existing buildings in Canada," *Canadian Journal of Civil Engineering,* vol. 49, no. 7, pp. 1281-1294, 2022.

[10] NRC, "Manual for screening of buildings for seismic investigation," National Research Council Canada (NRC), Ottawa, 1993.

[11] R. Fathi-Fazl, Z. Cai, E. Jacques and W. Cortés-Puentes, "Methodology for seismic risk screening of existing buildings in Canada: Structural scoring system," *Canadian Journal of Civil Engineering,* vol. 48, no. 3, pp. 250-262, 2021.

[12] W. Cortés-Puentes, Z. Cai and R. Fathi-Fazl, "Methodology for seismic risk screening of existing buildings in Canada: Non-structural component scoring system," *Canadian Journal of Civil Engineering,* vol. 48, no. 3, pp. 263-273, 2021.

[13] NRC, "Semi-Quantitative Seismic Risk Screening Tool (SQST)," National Research Council Canada, October 2020. [Online]. Available: Semi-Quantitative Seismic Risk Screening Tool (SQST) - National Research Council Canada. [Accessed 10 May 2023].

[14] NRC, National Building Code of Canada, Ottawa: National Research Council Canada (NRC), 2022.

[15] Statistics Canada, "Type of dwelling reference guide, census of population, 2021," March 2022. [Online]. Available: Type of Dwelling Reference Guide, Census of Population, 2021 (statcan.gc.ca). [Accessed 10 May 2023].

[16] Z. Cai, R. Fathi-Fazl, F. Fazileh and W. Cortés-Puentes, "Level 1 – Preliminary Seismic Risk Screening Tool (PST) for existing wood light frame buildings under Part 9 of the NBC, Part 1: user's guide," National Research Council Canada, Ottawa, 2023.

[17] Z. Cai, R. Fathi-Fazl, F. Fazileh and W. Cortés-Puentes, "Level 2 – Semi-Quantitative Seismic Risk Screening Tool (SQST) for existing wood light frame buildings under Part 9 of the NBC, Part 1: user's guide," National Research Council Canada, Ottawa, 2023.

[18] D. Motazedian, R. Fathi-Fazl, Z. Cai and F. Fazileh, "An update on the seismic categorization for seismic risk assessment of existing Canadian buildings," *Canadian Journal of Civil Engineering,* vol. 50, no. 4, 270-281, 2023.

[19] R. Fathi-Fazl and Z. Lounis, "Identification of consequences of failure criteria for seismic risk management of existing buildings (available upon request with client's permission)," National Research Council Canada, Ottawa, 2017.

[20] R. Fathi-Fazl, Z. Lounis and Z. Cai, "Semi-quantitative classification of consequences of failure for seismic risk management of existing buildings," *Journal of Structure and Infrastructure Engineering,* vol. 17, no. 5, 664-675, 2021.