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Publisher's version / Version de l'éditeur:
https://doi.org/10.1139/cjce-2021-0256
Canadian Journal of Civil Engineering, 49, 2022-01-12

Semi-quantitative seismic risk screening tool for existing buildings in Canada

By

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Abstract

The National Research Council Canada (NRC) recently developed a semi-quantitative seismic risk screening tool (SQST) for existing buildings in Canada. The SQST aims to supersede the Manual for Screening of Buildings for Seismic Investigation developed by NRC in the early 1990s. The SQST consists of three key components: (1) a structural scoring system that quantitatively assesses the structural seismic risk based on probability of collapse; (2) a non-structural component scoring system that qualitatively assesses the seismic risk of non-structural components based on seismic demand; and (3) a ranking procedure that prioritizes potentially hazardous buildings for seismic evaluations and possible upgrading. The SQST intends to inexpensively identify and exempt buildings with acceptable life safety risk and optimize the allocation of resources to assess the seismic risk of portfolios of buildings. Seismic screening with the SQST can be completed with either paper-based screening forms or a web-based application. The applicability of the SQST is demonstrated by conducting a pilot study for 33 existing buildings across Canada.

Keywords: seismic risk management, seismic risk screening, structural scoring system, non-structural component scoring system, prioritization

1. Introduction

There are thousands of existing buildings in Canada that could potentially suffer severe damage or collapse in the event of strong ground shaking. Assessing and mitigating seismic risk in large portfolios of existing buildings present technical and economic challenges to building owners such as Public Services and Procurement Canada (PSPC). To address these challenges, the National Research Council Canada (NRC) developed a series of manuals and technical guidelines for seismic screening (NRC 1993a), seismic evaluation (NRC 1993b), and seismic upgrading (NRC 1995) of existing buildings, based on the 1990 edition of the National Building Code of Canada – NBC (NRC 1990).

A few decades later, the seismic requirements in the NBC 2015 (NRC 2015) have become more stringent than those in the NBC 1990 on which existing NRC guidelines were based. Moreover, substantial work has been done in other countries in the area of seismic risk management of buildings, which provides valuable data and new methodologies for seismic screening, evaluation, and upgrading of existing buildings. Therefore, there is a clear need to update the NRC guidelines developed in the early 1990s to consider the stricter requirements of the current NBC and to address the current knowledge gaps.

With this in mind, the NRC developed a multi-criteria and multi-level seismic risk management framework for existing buildings in Canada (Lounis et al. 2016; Fathi-Fazl et al. 2020a). The framework consists of three key levels of assessment (see Figure 1):

- Level 1: Preliminary Seismic Risk Screening Tool (PST);
- Level 2: Semi-Quantitative Seismic Risk Screening Tool (SQST); and

- Level 3: Seismic Evaluation and Upgrading Guidelines (SEG).

Level 2 – SQST is designed to follow Level 1 – PST (Fathi-Fazl et al. 2018; Fathi-Fazl e al. 2020b; Fathi-Fazl e al. 2020c). It consists of three key components: (1) a structural scoring system that quantitatively assesses the structural seismic risk based on the probability of collapse (Fathi-Fazl et al. 2020d; Fathi-Fazl et al. 2020e; Fathi-Fazl et al. 2021a); (2) a non-structural components scoring system that qualitatively evaluates the seismic risk of non-structural components based on the seismic demand of critical non-structural components (Fathi-Fazl et al. 2020d; Fathi-Fazl et al. 2020e; Cortés-Puentes et al. 2021); and (3) a ranking procedure that prioritizes buildings with potentially unacceptable seismic risk for Level 3 – SEG (Fathi-Fazl et al. 2020d) based on structural and non-structural components priority indices. Level 2 – SQST requires a site visit because certain key building information such as building deterioration and non-structural hazards needs to be collected or verified on site.

2. Research significance

This paper presents Level 2 – SQST of the NRC's multi-criteria and multi-level seismic risk management framework, which aims to supersede the existing NRC Manual for Screening of Buildings for Seismic Investigation (NRC 1993a). Level 2 – SQST adopts a methodology based on exterior and interior visual screening of buildings using screening forms completed by trained screeners with basic knowledge in seismic design and assessment of buildings. The seismic risk of existing buildings is assessed by employing the structural scoring and non-structural component scoring systems. While buildings with acceptable life safety risk are exempt from further seismic assessment, buildings identified as potentially hazardous are flagged for seismic evaluation using Level 3 – SEG (Fathi-Fazl et al. 2021b), which is conducted by experienced professionals in seismic design and assessment of buildings. Given that Level 2 – SQST is intended to be a quick visual screening tool, in some cases, hazardous details may not be as evident and some seismically hazardous structures may not be identified as such. On the other hand, some buildings identified as potentially hazardous may prove to be adequate. Such cases should be the exception rather than the rule.

Level 2 – SQST can also be used to prioritize buildings requiring Level 3 – SEG. Buildings spread over a large region or across the country can be ranked based on the structural and non-structural component prioritization indexes that are functions of structural and non-structural scores and consequences of failure of the buildings. This process significantly reduces the time and effort to complete seismic risk assessment of large building portfolios.

Unlike the NRC 1993 screening manual which utilizes a qualitative seismic priority index to rank existing buildings in moderate and higher seismic zones for further seismic assessment (only exempting existing buildings in very low and low seismic zones from further seismic assessment), Level 2 – SQST quantitatively estimates structural seismic risks of existing buildings and compare them with acceptable structural seismic risk. Given this, Level 2 – SQST is capable to exempt existing buildings with acceptable structural seismic risk located in moderate and higher seismic zones from further structural seismic assessment. In addition, Level 2 – SQST assesses the global seismic risk posed by most critical non-structural components by a qualitative yet comprehensive non-structural component scoring system which takes into account many key parameters that can affect the seismic demands of non-structural components.

Compared with Level 3 – SEG, which requires a higher level of knowledge in structural and earthquake engineering and takes significantly more time and labour, Level 2 – SQST may only require about 2 days (assuming 8 hours per day) to screen an existing building by a trained screener. It is acknowledged that this estimate can vary significantly from less than one day to one week, depending on the availability and completeness of existing documentation, degree of complexity of the building, time spent on travel and site visit, experience of trained screeners, etc.

3. Overview of the Level 2 – SQST methodology

The development of Level 2 – SQST is based on a critique of the literature on seismic risk screening methodologies in Canada (NRC 1993a; Ventura et al. 2005; Karbassi and Nollet 2008; Saatcioglu et al. 2013; Tischer et al. 2014; CSA 2014; EGBC 2017), the United States (FEMA 2012; FEMA 2015; CBSC 2016), and other countries (JBDPA 2001; Grant et al. 2007; NZSEE 2017) with substantial modifications and additions to suit Canadian seismic hazards, seismicity, seismic design and construction practices. This section presents an overview of three key components in Level 2 – SQST, including structural scoring system, non-structural component scoring system, and ranking procedure. Technical details of the structural scoring methodology and non-structural component scoring methodology can be found elsewhere (Fathi-Fazl et al. 2021a; Cortés-Puentes et al. 2021).

3.1. Structural scoring system

The structural scoring system follows the third edition of FEMA P-154 (FEMA 2015) yet has been substantially modified to suit Canadian seismic hazards, seismicity, seismic design, and building construction practices (Fathi-Fazl et al. 2021a). In addition, it incorporates a number of new score modifiers: (1) original building importance, (2) building deterioration and age, and (3) remaining occupancy time. Furthermore, a semi-quantitative classification is utilized to identify the consequences of failure associated with the risk to human lives (Fathi-Fazl et al. 2020f). Finally, a number of acceptable structural thresholds are determined for buildings with different levels of consequences of failure.

The structural seismic risk is represented by a structural score (S) that is the sum of a structural basic score (S_B) and a series of structural score modifiers (M_i) for addressing building characteristics that affect the seismic performance of the building:

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

where S_B 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 equal to the probability of the structure being in a complete damage state, $P(Complete\ Damage|CLE)$, times a collapse factor, CF:

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

Figure 2 illustrates the methodology to calculate $P(Complete\ Damage|CLE)$. The capacity-spectrum method is used to calculate the building response, d_p, which is described as the intersection of the building capacity curve and the locus demand spectrum. $P(Complete\ Damage|CLE)$ is obtained from the seismic fragility curve associated with the complete damage state. The uncertainties in seismic demand, building capacity, and thresholds of complete damage state are captured in the development of locus demand spectrum, building capacity curve, and seismic fragility curve (Fathi-Fazl et al. 2021a). CF is defined as the expected collapsed area divided by the total floor area. They are dependent on model building type and building irregularity.

Figure 3 presents a flowchart of the structural scoring methodology. A total of six seismic zones (see Table 1) are defined to describe the lowest to highest seismicity across Canada. The thresholds of spectral response accelerations are determined by establishing equivalent relationships between the Modified Mercalli Intensity (MMI) scale and spectral response acceleration parameters (S_a) for design ground motions per the NBC 2015 (Fathi-Fazl et al. 2018; Fathi-Fazl et al. 2020c). These thresholds are then adjusted to be consistent with the thresholds of spectral accelerations at short and long periods provided in Table 4.1.8.9 in Part 4 of the NBC 2015 (NRC 2015). Sixteen model building types (see Table 2) are primarily adopted from the NRC 1993 screening manual (NRC 1993a). Ten structural score modifiers are considered in the scoring procedure. Structural scores (S) are compared with acceptable structural thresholds (S_{TH}) to determine whether the structural seismic risks are acceptable. S_{TH} values (see Table 3) are recommended thresholds based on acceptable probabilities of failure in building codes and standards (ASCE/SEI 2016; NIST 2012).

3.2. Non-structural component scoring system

The non-structural component scoring system adopts a qualitative but comprehensive scoring approach that assesses the global life safety risk posed by the most critical non-structural components (including both acceleration-sensitive and drift-sensitive non-structural components) in existing buildings (Cortés-Puentes et al. 2021). It is not intended to assess the seismic risk of individual components, but used as a secondary component of Level 2 – SQST to prioritize existing buildings with potentially unacceptable non-structural seismic risks for further seismic assessment.

The scoring system is based on the lateral forces on the most critical non-structural components. The lateral force on a non-structural component is calculated in accordance with the NBC 2015 design equation provided below.

$$V_p = 0.3F_aS_a(0.2)I_ES_pW_p \tag{4}$$

where F_a is the site coefficient for the design spectral acceleration at the short period of 0.2 seconds, $S_a(0.2)$ is the design spectral acceleration at the short period of 0.2 seconds, I_E is the earthquake importance factor, S_p is the non-structural horizontal force factor, and W_p is the seismic weight of the non-structural component.

The force factor S_p is a function of the seismic coefficient factor C_p, the response amplification factor A_r, the height factor $A_x = (1+2h_x/h_n)$, and the component response factor R_p. A_x is proportional to the ratio of the height in the structure where the non-structural component is located, h_x, to the height of the uppermost portion of the building, h_n. The horizontal force factor S_p is determined as follows:

$$S_p = C_pA_rA_x/R_p \quad 0.7 \le S_p \le 4 \tag{5}$$

Non-structural component scores (NS) are calculated as the sum of non-structural component basic scores (NS_B) and applicable score modifiers (NM_i). The NS_B score is based on the ratio of the seismic design force to the seismic weight and is calculated as follows:

$$NS_B = 33 - 1.26log_{10}(V_p/W_p) \tag{6}$$

where V_p and W_p are obtained from Eq. (4) by calculating the seismic demands of non-structural components with several assumptions. The coefficients of 26 and 1.26 in Eq. (6) are obtained from the calibration of the scoring system. The calibration aims to avoid negative values of NS_B and to obtain a maximum non-structural score of 100 before considering a bonus score for short remaining occupancy time.

NM_i values are used to address the effects of different key parameters affecting the reference seismic demands of non-structural components (see Eq. (4)) and are calculated as follows:

$$NM_i = -26log_{10}(F_i) \tag{7}$$

where F_i is the change in value of V_p /W_p due to parameter *i*.

Figure 4 presents a flowchart of the non-structural component seismic risk scoring methodology. *NS* values are compared with acceptable non-structural component thresholds (NS_{TH}) to determine whether life safety risks are acceptable. Table 4 provides acceptable non-structural component thresholds as a function of consequences of failure and the presence of non-structural component hazards.

3.3. Ranking of a building inventory based on Level 2 – SQST results

3.3.1. Structural and non-structural priority indexes

Although the structural and non-structural component scores provide an estimate of the seismic risk of buildings, the ranking of scored buildings cannot be based solely on these scores. This is because Level 2 – SQST considers different structural and non-structural component thresholds for a variety of consequences of failure and non-structural component hazards. To include the acceptable thresholds in the ranking, the Structural Priority Index, PI_S, and the Non-Structural Component Priority Index, PI_{NS}, are determined with the following equations:

$$PI_S = 10^{(S_{TH}-S)} \tag{8}$$

$$PI_{NS} = 10^{[(NS_{TH}-NS)/25]} \tag{9}$$

where S_{TH} and NS_{TH} are the acceptable structural and non-structural component thresholds, respectively, and *S* and *NS* are the structural and non-structural component scores, respectively.

The power of 10 is used to convert logarithmic scales of structural and non-structural component scores to linear scales. A building with a PI_S of 1.0 or a PI_{NS} of 1.0 indicates that the seismic risk posed by the building structure or non-structural components equals the acceptable seismic risk defined in Level 2 – SQST. A PI_S or PI_{NS} greater than 1.0 represents an potentially unacceptable seismic risk and a PI_S or PI_{NS} of less than or equal to 1.0 means an acceptable seismic risk. Both PI_S and PI_{NS} range from 0 to approximately 200, with greater values of PI_S or PI_{NS} representing higher structural or non-structural component seismic risks. Based on Eqns. (8) and (9), a building is exempt from Level 3 – SEG only if both PI_S and PI_{NS} are less than or equal to 1.0. The building is flagged for Level 3 – SEG if either PI_S or PI_{NS} is greater than 1.0.

3.3.2. Ranking procedure

Ranking of a building inventory for Level 3 – SEG is determined in accordance with PI_S and PI_{NS}. Based on these two indexes, three priority levels are suggested:

1. First Priority corresponding to PI_S
2. Second Priority corresponding to PI_{NS}
3. Exempt corresponding to buildings not requiring Level 3 – SEG.

In this ranking, buildings with higher PI_S and PI_{NS} are ranked with higher priority. This ranking aims to comprehensively address the needs for Level 3 – SEG. Figure 5 illustrates the ranking procedure for a building inventory. For each scored building, PI_S and PI_{NS} values are calculated. If both PI_S and PI_{NS} values are less than or equal to1.0, the building is exempt from Level 3 – SEG. If not, the ranking priorities are assigned based on PI_S. If the PI_S value is greater than 1.0, the building is ranked as First Priority. Higher priority is assigned to buildings with higher PI_S values. Buildings with equal PI_S values will be ranked based on their corresponding PI_{NS}. Buildings with

PI_S less than or equal to 1.0 are exempt from structural seismic evaluation. These buildings, however, require the non-structural evaluation and are ranked with the Second Priority ranking, based on PI_{NS}. The ranking process is repeated for all scored buildings. The First, Second, and Exempt rankings are combined to obtain a unified ranking for the building inventory.

4. Level 2 – SQST screening forms

Level 2 – SQST screening forms should be completed by trained screeners based on the building information collected in the office and during the site visit. Each screening form is divided into the following parts:

1. Part A: Data collection
2. Part B: Structural scoring
3. Part C: Non-structural component scoring
4. Part D: Decision support

Part A (see Figure 6) provides space for documenting collected data, including building identification, seismic data, model building type, building design information, building occupancy and consequences of failure, building characteristics, geological and falling hazards, building damage, non-structural hazards, photographs, and sketches. In case of any doubt about building information, one should assume the worst case scenario in the screening. For example, if there is any doubt about the presence of building irregularity, one should assume the irregularity is present. If the worst case scenario triggers seismic evaluation, the building should be flagged for Level 3 – SEG. Nevertheless, Level 2 – SQST is still recommended to be implemented to gain the knowledge and understanding of the building.

Part B (see Figure 7) provides the structural basic score (S_B) values, structural score modifiers (M_i), and minimum structural score (S_{MIN}) values associated with each of the sixteen model building types. Note that S_B and M_i values are dependent on the seismic zone because the seismicity affects the probability of collapse that is used to calculate S_B and M_i. Figure 7 presents Part B for the moderately high seismic zone as an example. Based on the building information identified in Part A, S_B and applicable M_i associated with the identified model building type are circled. The structural score (S) is then compared with the acceptable structural threshold (S_{TH}) to determine whether the structural seismic risk is acceptable.

Part C (see Figure 8) provides the non-structural component basic score (NS_B) and non-structural score modifiers (NM_i). NS_B is a function of spectral response acceleration at 0.2 seconds ($S_a(0.2)$). Based on the building information identified in Part A, NS_B is calculated, and applicable NM_i are circled. The non-structural component score (NS) is then compared with the acceptable non-structural component threshold (NS_{TH}) to determine whether the seismic risk of non-structural components is acceptable.

Part D (see Figure 8) provides decision support statements based on the screening results in Part A through Part C, specifically whether the building structure and non-structural components require Level 3 – SEG. In addition, a comment section is provided for documenting any comments that the screener wishes to make regarding the overall screening of the building.

5. Level 2 – SQST web-based application

Level 2 – SQST also provides a web-based application (NRC 2021) as an alternative to filling out paper-based screening forms. The application is designed to be consistent with the accessibility and visibility requirements of all government of Canada webpages. The application can be accessed from different platforms with different operating systems (Windows, Android, iOS, etc.). After the landing page, as shown in Figure 9 (https://nrc.canada.ca/en/research-development/products-services/software-applications/semi-quantitative-seismic-risk-screening-tool-sqst), users need to review the limited use licence agreement and acknowledge reading the Level 2 – SQST User's Guide (Fathi-Fazl et al. 2020d). The application collects all relevant building information in 9 steps including: 1) model building type, 2) general building information, 3) seismic data, 4) site information, 5) building occupancy, 6) consequences of failure, 7) building irregularities, 8) other building parameters, and 9) hazards. After completing all 9 steps, the application will provide screening results on the final report page which includes five parts, namely Part A through Part E. Part A (Data Collection) provides a summary of all data input for verification by the user. Part B (Structural scoring, see Figure 10) tabulates the structural basic score, structural score modifiers, minimum structural score, final structural score, structural score threshold, and structural priority index. Part C (Non-structural component scoring, see Figure 10) includes the non-structural component basic score, non-structural component score modifiers, final non-structural component score, non-structural component score threshold, and non-structural priority index. Part D (Decision support, see Figure 10) provides separate decision support statements for the building structure and non-structural components. Part E (User's note) provides the user with a space to document any comments or assumptions made for future reference. It is important to note that the application does not record any of the screening results; users can print the final report page for their records.

6. Pilot studies using Level 2 – SQST

The NRC used Level 2 – SQST to assess the seismic risk of thirty-three (33) buildings managed by PSPC. These buildings were selected based on the following key parameters: (1) seismic zone,

(2) model building type, (3) building design period, (4) site class, and (5) building height. Twenty-eight (28) buildings were located in moderately high seismic zone, while 5 buildings are located in moderate, high, and very high seismic zones (3, 1, and 1, respectively). The distribution of buildings in terms of building design period is as follows: four (4) pre-NBC1953, twenty (20) between NBC 1953 and NBC 1970, eight (8) between NBC 1975 and NBC1995, and one (1) post-NBC 2005. Table 5 lists the key attributes of the buildings in this study. Note that the building identifiers have been removed for confidentiality reasons.

Structural and non-structural component scores were determined and compared with acceptable structural thresholds. Table 6 provides the structural and non-structural scores for the screened buildings along with corresponding priority indexes. The results indicate that the structural seismic risks of 13 buildings are acceptable. Seventeen (17) buildings were assessed with potentially unacceptable risk and were flagged for structural seismic evaluation. These buildings were located in moderate to very high seismic zones (1 in moderate, 14 in moderately high, 1 in high, and 1 in very high), which reflects the increase in the risk as the seismicity level rises. The remaining 3 buildings were not scored due to unknown model building type or significant building damage.

The screening results were compared with available seismic analysis and assessment studies to assess the acceptance criteria in Level 2 – SQST. Seismic analysis and assessment studies for 28 building sections were performed by consultants retained by PSPC. Specifically, one building was assessed by the NRC 1993 screening manual only, 8 buildings were assessed by both the NRC 1993 screening manual and the NRC 1993 seismic evaluation guidelines, and 19 buildings were assessed by the NRC 1993 seismic evaluation guidelines only. These studies assessed the conformance to the PSPC seismic standard, in which the structural seismic risk is deemed acceptable if any one of the following criteria is met: (1) the structural priority index is less than or equal to 2 per the NRC 1993 screening manual, and (2) all seismic force-resisting elements are able to resist at least 60% of the seismic loads prescribed by the latest NBC edition per the NRC 1993 seismic evaluation guidelines. It should be noted that Level 2 – SQST adopts a quantitative approach based on the probability of collapse, which is different from the qualitative approach in the NRC 1993 screening manual and the quantitative approach based on comparing demands with capacities in the NRC 1993 seismic evaluation guidelines. It is therefore not appropriate to directly compare the results from these three different approaches. In this study, the comparison was made with respect to the number of buildings whose seismic risks are potentially unacceptable and thus flagged for further seismic assessment. The screening results obtained from Level 2 – SQST are generally in line with the seismic assessment results from the previous studies for all 28 building sections.

The non-structural component seismic risks of 11 buildings are deemed acceptable given their non-structural component scores being less than the corresponding non-structural component thresholds. Potentially unacceptable seismic risks of non-structural components were determined for 19 buildings (17 located in moderate and moderately high, 1 in high, and 1 in very high seismic zones). However, most of the non-structural component scores are slightly smaller than the corresponding acceptable score thresholds (see Table 6).

In addition to the preceding 33 buildings, PSPC used Level 2 – SQST to assess the seismic risks of 6 buildings managed by Parliamentary Precinct Branch located in National Capital Region (Canada). The screening results were peer reviewed by NRC. Due to the limit of space and confidentiality reasons, the screening results are not provided herein.

7. Summary

This paper presents the Level 2 – Semi-Quantitative Seismic Risk Screening Tool (SQST) of a multi-criteria and multi-level seismic risk management framework developed by the National Research Council Canada (NRC). The methodology adopted in Level 2 – SQST is based on identifying the key building features affecting the building's seismic risk. Level 2 – SQST aims to supersede the qualitative seismic risk screening manual developed by the NRC in the early 1990s. The screening tool ensures an acceptable and consistent seismic risk while minimizing the life safety threats and optimizing the allocation of resources for seismic evaluation and possible upgrading of portfolios of buildings.

Level 2 – SQST is designed to be completed by trained screeners using Level 2 – SQST screening forms. Each Level 2 – SQST screening form includes four parts: Part A (data collection), Part B (structural scoring), Part C (non-structural component scoring), and Part D (decision support). Since the data collection requires visual screening (exterior and interior) of buildings, a site visit is required. Alternatively, trained screeners may complete Level 2 – SQST using a web-based application developed by NRC. Instead of completing the paper-based screening forms, the web-based application consists of a multi-step process to conduct seismic risk screening of existing buildings. Based on the input data, the application automatically calculates structural and non-structural component scores and structural and non-structural priority indices and provides decision support statements for the screened buildings.

Level 2 – SQST has been applied to assess the seismic risk of thirty-three (33) existing buildings managed by PSPC, which were selected based on a number of key parameters. Calculated structural and non-structural component scores along with a comparison with existing seismic analysis and assessment studies demonstrate the applicability of Level 2 – SQST for seismic risk screening of existing buildings in Canada.

Acknowledgements

The authors wish to acknowledge the financial support and technical feedback from Public Services and Procurement Canada (PSPC) and the Sustainable Resilient Infrastructures and Communities Unit (SRIC) R&D program of the NRC's Construction Research Centre.

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Table 1: Canadian seismic zones and corresponding thresholds (Fathi-Fazl et al. 2021a)

Seismic Zone	Max[$S_a(0.2)$, $S_a(0.5)$]		$S_a(1.0)$		Mean Values	
	>	≤	>	≤	Max[$S_a(0.2)$, $S_a(0.5)$]	$S_a(1.0)$
Very Low		0.10 g		0.05 g	0.07 g	0.03 g
Low	0.10 g	0.20 g	0.05 g	0.10 g	0.14 g	0.07 g
Moderate	0.20 g	0.35 g	0.10 g	0.15 g	0.26 g	0.12 g
Moderately High	0.35 g	0.75 g	0.15 g	0.30 g	0.51 g	0.20 g
High	0.75 g	1.15 g	0.30 g	0.50 g	0.87 g	0.41 g
Very High	1.15 g		0.50 g		1.40 g	0.70 g

Table 2: NRC model building types (Fathi-Fazl et al. 2021a)

Model Building Type	Name
WLF	Engineered Wood Light Frame
WPB	Engineered Wood Post-and-Beam
SMF	Steel Moment Frame
SBF	Steel Braced Frame
SLF	Steel Light Frame
SCW	Steel frame with Concrete shear Walls
SIW	Steel frame with Infill masonry Walls
CMF	Concrete Moment Frame
CSW	Concrete Shear Walls
CIW	Concrete frame with Infill masonry Walls
PCW	Precast Concrete Walls
PCF	Precast Concrete Frame
RML	Reinforced Masonry bearing walls with Light wood or metal deck diaphragms
RMC	Reinforced Masonry bearing walls with Concrete diaphragms
URM	Unreinforced Masonry bearing wall buildings
MH	Manufactured Homes

Table 3: Acceptable structural thresholds (S_{TH}) for various consequences of failure (Fathi-Fazl et al. 2021a)

Consequences of failure	Acceptable structural thresholds (S_{TH})	Acceptable probabilities of collapse in 50 years
Very low	1.7	2%
Low and medium	2.0	1%
High	2.3	0.5%
Very high	2.6	0.25%

Table 4: Acceptable non-structural component thresholds (NS_{TH}) for various consequences of failure (Cortés-Puentes et al. 2021)

Consequences of failure	Non-structural component thresholds (NS_{TH})	
	Non-hazardous components[a]	Hazardous components[b]
Very low	35	40
Low and medium	35	40
High	40	45
Very high	40	45

[a] Buildings not containing hazardous non-structural components.
[b] Buildings containing hazardous non-structural components (falling hazards or hazardous materials).

Table 5: Summary of key building attributes of the screened buildings

Building		Seismic zone	Building type	Design NBC	Site Class	Bldg. height
Number	Section					
1	A	Moderately High	CMF, CIW	1970	A	Mid-rise
	B		CMF			Low-rise
	C		CMF			Mid-rise
2	-	Moderately High	SIW	Pre-1953	B	Mid-rise
3	A	Moderately High	CMF, CSW	1970	A	High-rise
	B		CMF, CSW			Mid-rise
	C		CMF, CSW			High-rise
	D		CMF, CSW			Mid-rise
	E		CMF			Low-rise
	F		CMF, CSW			Low-rise
4	A	Moderately High	CSW	1970	A	High-rise
	B					
	C					
	D					
5	A	Moderately High	CSW	1975	A	High-rise
	B		CSW			High-rise
	C		CSW			High-rise
	D		SMF, CMF			Mid-rise
	E		CMF			Mid-rise
	F		CMF			Low-rise
6	-	Moderately High	SIW	Pre-1953	C	High-rise
7	-	Moderately High	WPB, CMF	1960	Unknown	Low-rise
8	-	Moderately High	SIW	1953	A	Low-rise
9	-	Moderately High	CSW	1965	A	High-rise
10	-	Moderately High	PCW	1980	Unknown	Mid-rise
11	-	Moderately High	CSW	1965	B	High-rise
12	-	High	CSW, PCW	1995	C	Low-rise
13	-	Moderately High	CSW	1970	A	High-rise
14	-	Very High	CMF	1960	D	Mid-rise
15	-	Moderate	WLF	1960	E	Low-rise
16	-	Moderately High	CSW	2005	A	High-rise
17	A	Moderate	CMF	Pre-1953	Unknown	High-rise
	B		Unknown	Pre-1953	Unknown	High-rise

Table 6: Level 2 – SQST screening results of the screened buildings

Building		Structural Scoring[1]				Non-structural component scoring[2]			
Name	**Section**	***S***	S_{TH}	$S < S_{TH}$	PI_S	***NS***	NS_{TH}	$NS < NS_{TH}$	PI_{NS}
1	A	1.4	2.0	Yes	4.0	38	40	Yes	1.2
	B	1.3	2.0	Yes	5.0	38	40	Yes	1.2
	C	3.5	2.0	No	0.03	47	40	No	0.5
2	-	2.5	2.0	No	0.3	45	40	No	0.6
3	A	0.5	2.0	Yes	31.6	38	40	Yes	1.2
	B	0.5	2.0	Yes	31.6	38	40	Yes	1.2
	C	0.5	2.0	Yes	31.6	38	40	Yes	1.2
	D	1.0	2.0	Yes	10.0	38	40	Yes	1.2
	E	1.3	2.0	Yes	5.0	38	40	Yes	1.2
	F	0.5	2.3	Yes	63.1	38	45	Yes	1.9
4	A	2.6	2.3	No	0.5	39	45	Yes	1.7
	B	2.6	2.3	No	0.5	39	45	Yes	1.7
	C	4.2	2.0	No	0.01	47	40	No	0.5
	D	2.1	2.0	No	0.8	39	40	Yes	1.1
5	A	1.2	2.3	Yes	12.6	41	45	Yes	1.4
	B	1.2	2.0	Yes	6.3	41	40	No	0.9
	C	1.2	2.0	Yes	6.3	41	40	No	0.9
	D	2.3	2.0	No	0.5	47	35	No	0.3
	E	0.5	2.0	Yes	31.6	41	40	No	0.9
	F	1.2	2.0	Yes	6.3	41	40	No	0.9
6	-	1.8	2.0	Yes	1.6	36	40	Yes	1.4
7[3]	-	N/A	N/A	N/A	N/A	N/A	N/A	Yes	2.1
8	-	2.7	2.0	No	0.2	39	40	Yes	1.1
9	-	4.0	2.3	No	0.02	47	45	No	0.8
10[4]	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11	-	4.0	2.3	No	0.02	45	40	No	0.6
12	-	1.9	2.3	Yes	2.5	41	45	Yes	1.4
13	-	2.8	2.3	No	12.6	39	45	Yes	1.7
14	-	0.3	2.0	Yes	50.1	24	40	Yes	4.4
15	-	2.7	2.3	No	0.4	39	40	Yes	1.1
16	-	6.2	2.0	No	6E-05	68	40	No	0.08
17[3]	A	0.7	2.0	Yes	20.0	33	40	Yes	1.9
	B	N/A	N/A	N/A	N/A	N/A	N/A	Yes	1.4

[1] Further evaluation required if $S < S_{TH}$.
[2] Further evaluation require if $NS < NS_{TH}$.
[3] Level 2 – SQST is not applicable (N/A) for structural scoring and non-structural scoring due to unknown model building type.
[4] Level 2 – SQST is not applicable (N/A) for structural and non-structural scoring due to significant building damage.

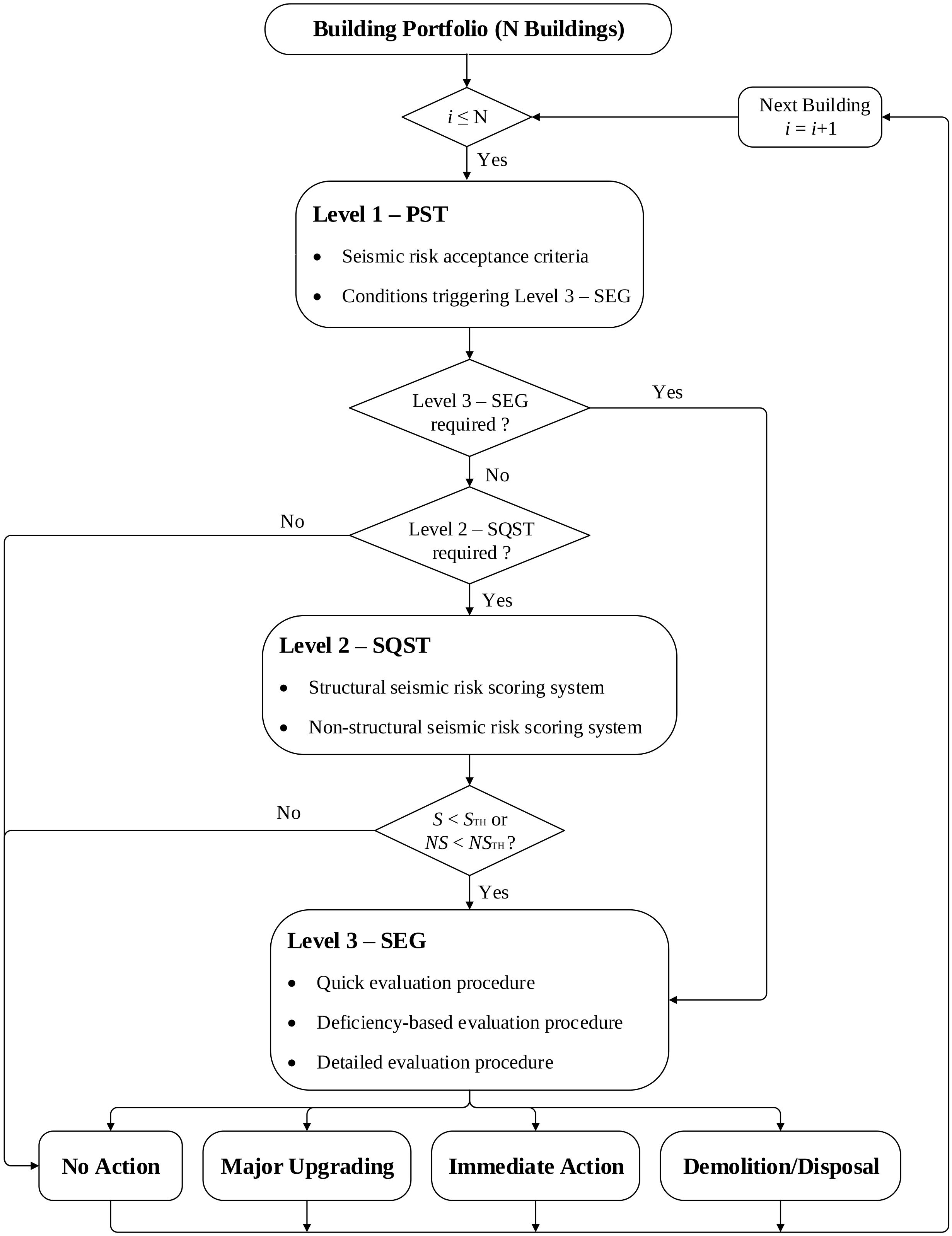

Figure 1: Flowchart of NRC seismic risk management framework (Fathi-Fazl et al., 2020a)

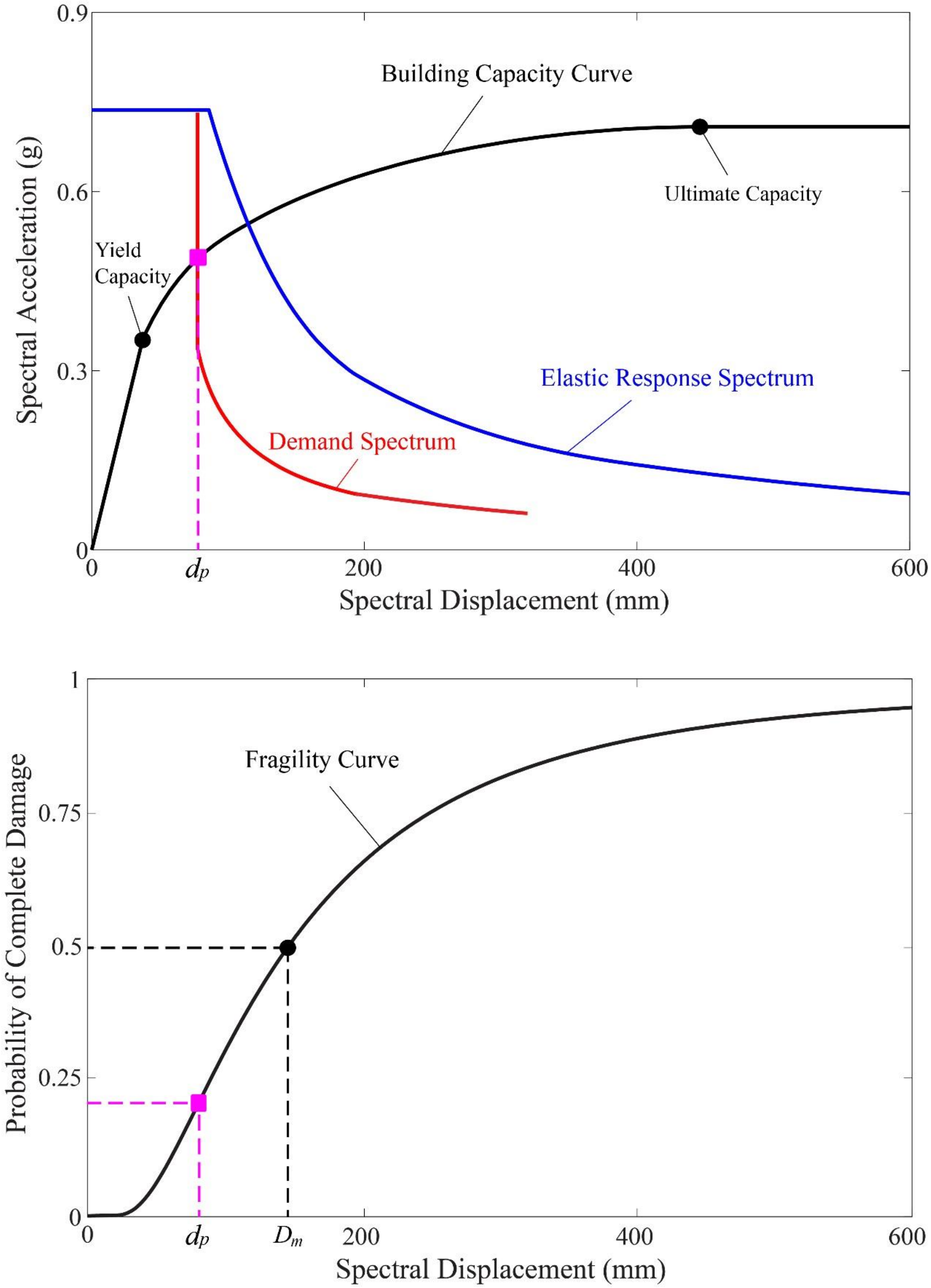

Figure 2: Methodology for calculating probability of complete structural damage (Fathi-Fazl et al. 2021a)

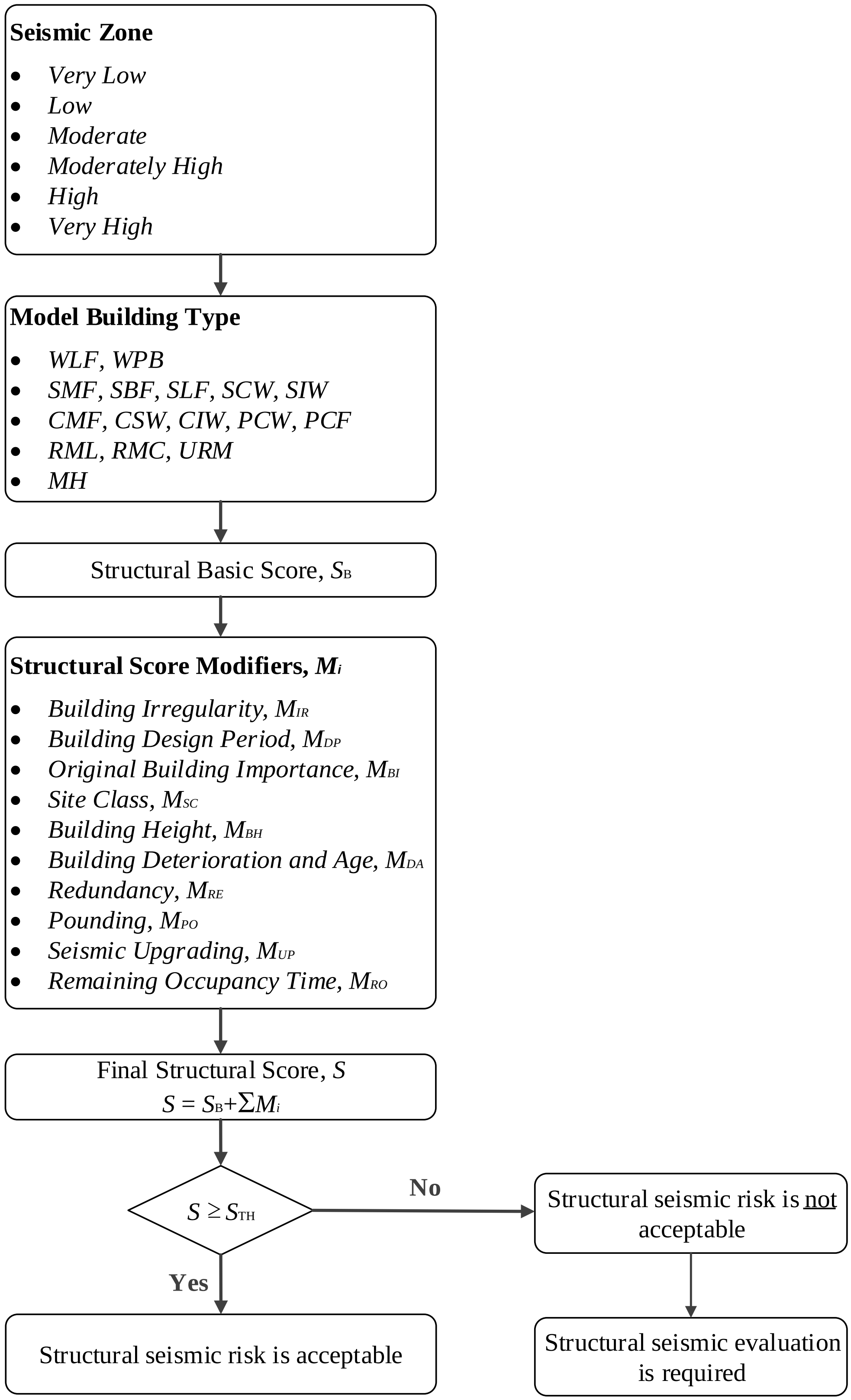

Figure 3: Flowchart of structural scoring methodology (Fathi-Fazl et al. 2021a)

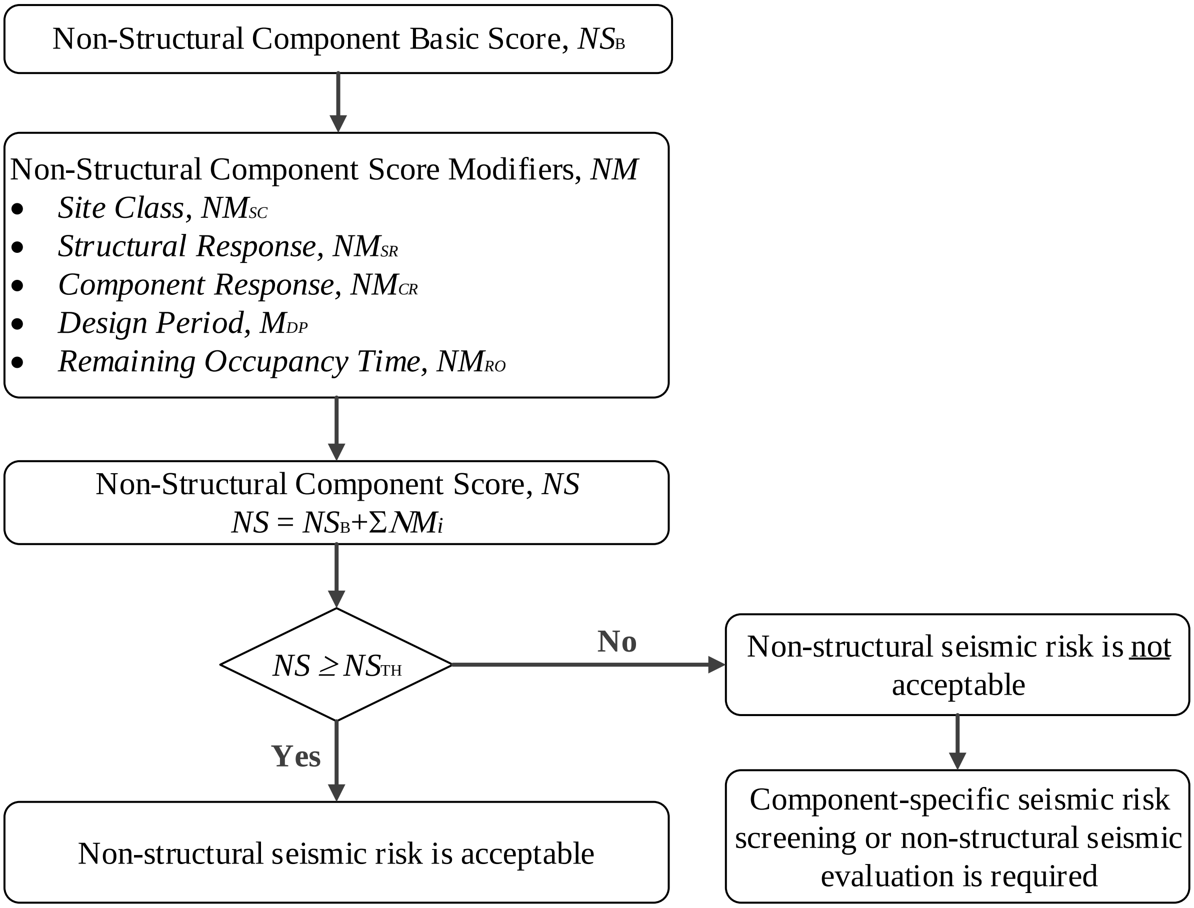

Figure 4: Flowchart of non-structural component scoring methodology (Cortés-Puentes et al. 2021)

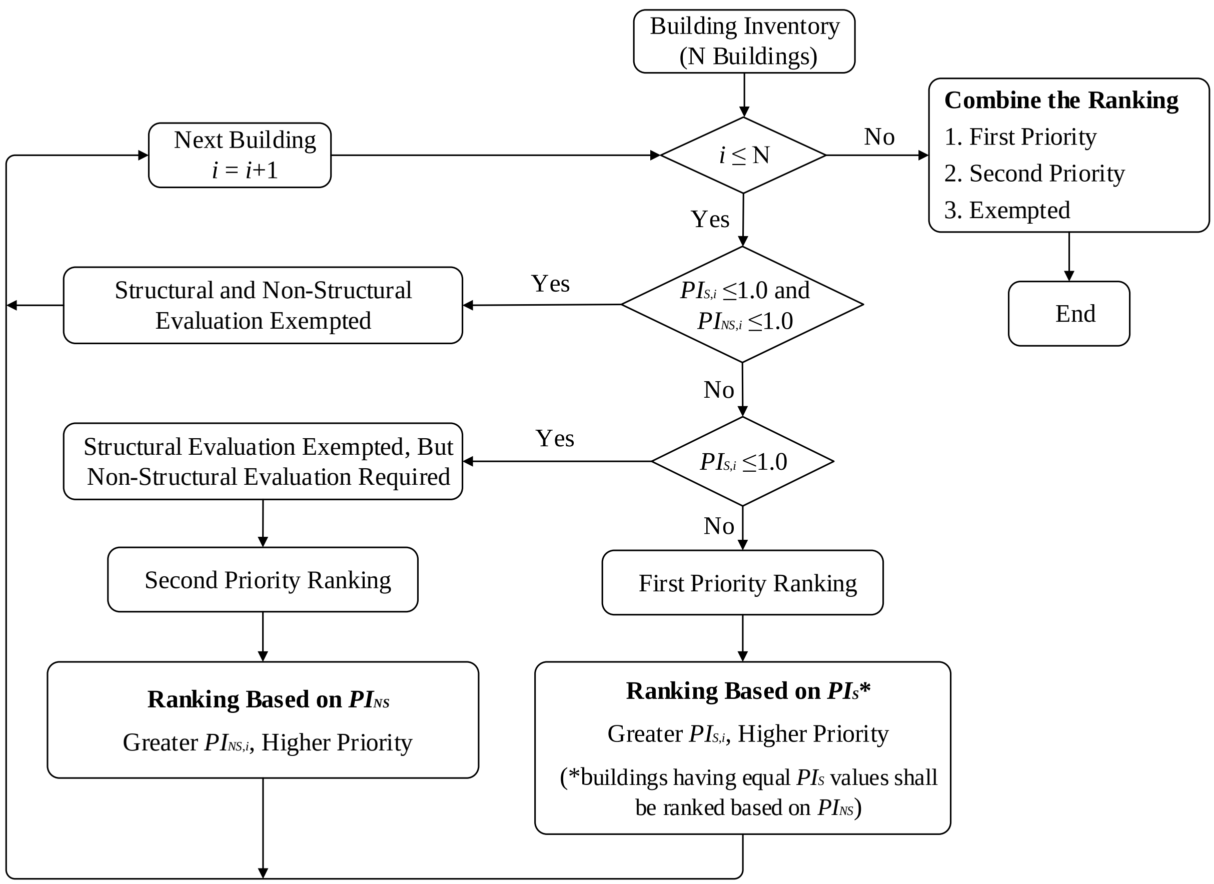

Figure 5: Ranking of a building inventory for Level 3 – SEG

Level 2 – SQST Screening Form[†]

PART A: DATA COLLECTION

Building name: **Federal heritage designation[1*]:** ☐ Yes ☐ No

Street address: **City/Province:** **Postal code:**

Seismic data[2]: $S_a(0.2)$= $S_a(0.5)$= $S_a(1.0)$= PGA= PGA_{ref}=

Model building type[3]: WLF WPB SMF SBF SLF SCW SIW CMF CSW CIW PCW PCF RML RMC URM MH DNK (Do Not Know)[*]

Year built[4]: **Original design NBC[5]:** **Pre-code NBC edition[6]:** **Benchmark NBC edition[3]:**

Screener: P.Eng./ing.: ☐ Yes ☐ No **Date/Time:**

No. of storeys[9]: **Total floor area (m²)[10]:**

Occupancy[11]: Office Public Commercial Industrial Educational Residential Care/Treatment Parking Public Assembly Passenger Stations Other________________

Original Occupancy:________________

Increase in structural loads due to a change of occupancy: ☐ Yes ☐ No

Consequences of failure (COF)[12]: ☐ Very Low (VLC) ☐ Low (LC) ☐ Medium (MC) ☐ High (HC) ☐ Very High (VHC)

Original COF:____________________

COF higher than original COF: ☐ Yes ☐ No

1. Building irregularities[13]: ☐ Yes, Severe Vertical ☐ Yes, Moderate Vertical ☐ Yes, Horizontal ☐ None

2. Building design period: ☐ Pre-code ☐ Pre-benchmark ☐ Post-benchmark

3. Original bldg. importance[14]: ☐ Low ☐ Normal ☐ High ☐ Post-Disaster ☐ DNK (assume Normal for scoring)

4. Site Class: ☐ A ☐ B ☐ C ☐ D ☐ E ☐ F[*] ☐ DNK (assume E for scoring)

5. Building height ☐ Low-rise (1-3 storeys) ☐ Mid-rise (4-7 storeys) ☐ High-rise (> 7 storeys)

6. Bldg. deterioration[15]: ☐ Negligible ☐ Moderate ☐ Significant[*]

Bldg. age (years)[16]: ☐ > 30 ☐ ≤ 30

7. Redundancy[17]: ☐ Yes ☐ None ☐ DNK (assume None for scoring)

8. Pounding[18]: ☐ Yes, Type 1 ☐ Yes, Type 2 ☐ Yes, Type 3 ☐ Yes, Type 4 ☐ None

9. Seismic Upgrading[19]: ☐ Yes, Case 1 ☐ Yes, Case 2 ☐ Yes, Case 3 ☐ Yes, Case 4 ☐ Yes, Case 5 ☐ None

10. Remaining occupancy time (years)[20]: ☐ ≤ 5 ☐ > 5 and ≤ 10 ☐ > 10

Geologic hazards[21]:
- **Liquefaction:** ☐ Yes[*] ☐ No ☐ DNK
- **Landslide potential:** ☐ Yes[*] ☐ No ☐ DNK
- **Surface fault rupture:** ☐ Yes[*] ☐ No ☐ DNK

Falling hazards from taller adjacent building[22]: ☐ Yes ☐ No

Building damage[23]: ☐ Yes[*] ☐ No

NON-STRUCTURAL HAZARDS[24]

Exterior falling hazards: ☐ Yes ☐ No ☐ DNK (assume Yes for scoring)

Interior falling hazards: ☐ Yes ☐ No ☐ DNK (assume Yes for scoring)

Hazardous materials: ☐ Yes ☐ No ☐ DNK (assume Yes for scoring)

EXTENT OF REVIEW

Exterior: ☐ Yes ☐ No **Interior:** ☐ Yes ☐ No

Drawings reviewed[25]: ☐ Yes ☐ No

Site Class source:__________________________________

Geologic hazards source:______________________________

BUILDING PHOTO

BUILDING SKETCH

Comments:

☐ Additional comments on separate page(s)

[†] Review the back page for the intent and scope of the tool and explanations of the superscripts on this page. [*] If circled or selected, skip Part B & Part C of the form and proceed to Part D.

Figure 6: Part A (data collection) of Level 2 – SQST sample screening form

PART B: STRUCTURAL SCORING **Moderately High Seismic Zone**

				WLF	WPB	SMF	SBF	SLF	SCW	SIW	CMF	CSW	CIW	PCW	PCF	RML	RMC	URM	MH
Model building type				**WLF**	**WPB**	**SMF**	**SBF**	**SLF**	**SCW**	**SIW**	**CMF**	**CSW**	**CIW**	**PCW**	**PCF**	**RML**	**RMC**	**URM**	**MH**
Structural basic score, S_B				**5.3**	**5.2**	**3.6**	**3.8**	**3.9**	**4.0**	**3.3**	**2.9**	**3.9**	**3.0**	**3.8**	**3.1**	**3.7**	**3.7**	**2.8**	**4.1**
Structural score modifiers, M_i	**1. Building irregularities** ***(circle and sum applicable vertical and horizontal irregularity modifiers)***	None		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Vertical	Moderate	-1.2[1]	-1.2[1]	-0.9[1]	-0.9[1]	-1.0[1]	-1.0[1]	-0.9[1]	-0.9[1]	-1.0[1]	-0.9[1]	-1.0[1]	-0.9[1]	-1.0[1]	-1.0[1]	-0.9[1]	NA
			Severe	-1.8	-1.8	-1.4	-1.5	-1.5	-1.5	-1.4	-1.4	-1.6	-1.4	-1.5	-1.4	-1.5	-1.5	-1.3	NA
		Horizontal		-1.6	-1.6	-1.2	-1.3	-1.3	-1.3	-1.1	-1.1	-1.3	-1.1	-1.3	-1.2	-1.3	-1.3	-1.1	NA
	2. Building design period	Pre-code		-0.3	-0.7	-0.3	-0.4	-0.3	-0.6	-0.3	-0.2	-0.8	-0.3	-0.7	-0.5	-0.7	-0.7	-0.2	-0.5
		Pre-benchmark		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Post-benchmark		1.8	1.9	1.9	1.3	1.3	1.4	NA	2.0	1.6	NA	1.4	2.0	1.5	1.5	NA	1.7
	3. Original building importance	Low		-0.5	-0.6	-0.3	-0.3	-0.3	-0.4	-0.4	-0.3	-0.5	-0.4	-0.5	-0.4	-0.5	-0.5	-0.4	-0.5
		Normal		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		High		0.5	0.5	0.3	0.3	0.4	0.4	0.4	0.3	0.5	0.4	0.4	0.4	0.5	0.5	0.5	0.5
		Post-disaster		0.8	0.9	0.6	0.6	0.6	0.7	0.8	0.5	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.9
	4. Site Class	A		1.1	1.2	1.0	1.0	1.0	1.0	1.2	0.9	1.1	1.1	1.0	0.9	1.1	1.1	1.2	1.2
		B		0.9	1.0	0.8	0.8	0.8	0.8	1.0	0.7	0.8	0.9	0.8	0.8	0.9	0.9	1.0	1.0
		C		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		D		-0.2	-0.4	-0.3	-0.4	-0.2	-0.4	-0.6	-0.3	-0.4	-0.6	-0.5	-0.4	-0.4	-0.4	-0.6	-0.8
		E (1-3 storeys)		-0.4	-0.9	-0.7	-0.9	-0.4	-0.9	-1.2	-0.6	-0.8	-1.0	-1.0	-0.8	-0.9	-0.9	-1.2	-1.4
		E (> 3 storeys)		-1.2	-1.4	-1.0	-1.0	NA	-1.1	-1.2	-0.9	-1.1	-1.1	NA	-1.0	-1.2	-1.2	-1.1	NA
	5. Building height	Low-rise (1-3 storeys)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Mid-rise (4-7 storeys)		0	0.1	0	0.1	NA	0.2	0.2	0.1	0.4	0.3	NA	0.3	0.4	0.4	0.2	NA
		High-rise (> 7 storeys)		NA[2]	NA[2]	-0.2	0.1	NA	0.1	0.2	-0.2	0.4	0.2	NA	0.3	0.4	0.4	NA[2]	NA
	6. Building deterioration and age (years)	Negligible	Age ≤ 30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Age > 30	-0.1	-0.3	-0.1	-0.1	-0.1	-0.2	-0.3	-0.1	-0.3	-0.3	-0.2	-0.2	-0.3	-0.3	-0.3	-0.4
		Moderate	Irregular bldg.	-0.1	-0.3	-0.1	-0.1	-0.1	-0.2	-0.4	-0.1	-0.4	-0.4	-0.2	-0.3	-0.3	-0.3	-0.4	-0.4
			Regular bldg.	-1.2	-1.5	-0.9	-1.0	-1.0	-1.2	-1.2	-0.9	-1.3	-1.2	-1.2	-1.1	-1.2	-1.2	-1.1	-0.8
	7. Redundancy	Yes		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		None		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8. Pounding ***(circle and sum applicable modifiers with a cap of -1.7)***	None		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Type 1		-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
		Type 2		-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
		Type 3		-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
		Type 4		-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
	9. Seismic upgrading	Case 1		1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
		Case 2		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
		Case 3		0.5	0.7	0.3	0.4	0.3	0.6	0.3	0.2	0.8	0.3	0.7	0.5	0.7	0.7	0.2	0.5
		Case 4, Case 5, or None		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10. Remaining occupancy time (years)[3]	≤ 5		2.9	3	2.3	2.4	2.4	2.5	2.6	2	2.6	2.5	2.5	2.3	2.6	2.6	2.6	2.8
		> 5 and ≤ 10		1.8	1.9	1.4	1.5	1.5	1.6	1.8	1.3	1.7	1.7	1.6	1.5	1.7	1.7	1.8	1.9
		> 10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Structural score ($S = S_B + \sum M_i$)																			
Min structural score, S_{MIN}				**2.0**	**1.3**	**0.9**	**0.9**	**1.3**	**0.8**	**0.7**	**0.5**	**0.6**	**0.5**	**0.5**	**0.4**	**0.6**	**0.6**	**0.4**	**1.2**
Final structural score ($S \geq S_{MIN}$)																			
Consequences of failure (COF)				VLC				LC & MC				HC				VHC			
Structural threshold, S_{TH}:				**1.7**				**2.0**				**2.3**				**2.6**			
Check of $S < S_{TH}$:				☐ Yes		☐ No													
Structural priority index ($PI_S = 10^{(S_{TH}-S)}$):																			

[1] In case where both moderate and severe vertical irregularities are identified, circle severe vertical irregularity modifier only. [2] If NA, score modifiers for mid-rise building configuration may be used. [3] The remaining occupancy time does not apply to buildings with very high consequences of failure (VHC).

Figure 7: Part B (structural scoring) of Level 2 – SQST sample screening form for moderately high seismic zone

PART C: NON-STRUCTURAL COMPONENT SCORING

Non-structural component basic score	**$NS_B = 26\,[-\log_{10}(0.3 \times Sa(0.2)) + 1.26]$**	***NS_B*=**

Non-structural component score modifiers, NM_i

	Site Class	$PGA_{ref} \le 0.1g$	$PGA_{ref} = 0.2g$	$PGA_{ref} = 0.3g$	$PGA_{ref} = 0.4g$	$PGA_{ref} \ge 0.5g$	
Site Class	A	5	5	5	5	5	***Circled score =***
	B	3	3	3	3	3	
	C	0	0	0	0	0	
	D	-2	-1	0	1	1	
	E	-5	-2	-1	1	2	

Structural response	Model building type	Building height				***Circled score (circle and sum applicable modifiers with a cap of -20) =***
		Low-rise (1-3 storeys)	Mid-rise (4-7 storeys)	High-rise (>7 storeys)		
	WLF WPB SMF CMF PCF SLF DNK	-8	-3	-3		
	Other buildings	0	0	0		
	Irregularities	None	Moderate	Severe		
	Vertical	0	-3[1]	-8		
	Horizontal	0	-8			
	Pounding	None	Type 1	Type 2	Type 3/Type 4	
		0	-3	-5	-8	
	Building deterioration and age (years)	Negligible		Moderate		
		Age ≤ 30	Age > 30	Irregular bldg.	Regular bldg.	
		0	-3	-3	-6	

Non-structural component response	Component response (ductility)	Original Design NBC		***Circled score =***
		Pre-2005	Post-2005	
		0	10	

Non-structural component design period	Horizontal force factor	Original Design NBC				***Circled score =***
		Pre-1953	1953-1970	1975-1995	Post-2005	
		-5	-3	0	5	

Remaining occupancy time (years)[4]	Remaining occupancy time	≤ 5	> 5 and ≤ 10	> 10	***Circled score =***
		15	10	0	

Non-structural component score	$NS = NS_B + \sum NM_i$	***NS* =**

Non-structural component threshold, NS_{TH}	Consequences of failure	Non-hazardous[2] components	Hazardous components	**NS_{TH} =**
	VLC	35	40	
	LC & MC	35	40	
	HC	40	45	
	VHC	40	45	

Check of $NS < NS_{TH}$: ☐ Yes ☐ No	**Non-structural priority index ($PI_{NS}=10^{(NS_{TH}-NS)/25}$):**

PART D: DECISION SUPPORT

Level 3 – Seismic Evaluation required?

☐ Yes, if any of the following conditions apply

- ☐ Do Not Know (DNK) model building type
- ☐ Federal heritage designation
- ☐ Increase in structural loads due to a change of occupancy
- ☐ Consequences of failure higher than original consequences of failure
- ☐ Site Class F
- ☐ Presence of any geologic hazards
- ☐ Significant building deterioration/damage
- ☐ Structural score less than structural threshold
- ☐ Non-structural component score less than non-structural component threshold

☐ No, none of the conditions above apply[3]. Structural seismic risk does NOT exceed the acceptable seismic risk.

Comments:

☐ Additional comments on separate page(s)

[1]In case where both moderate and severe vertical irregularities are identified, circle severe vertical irregularity modifier only. [2]Non-hazardous means no falling hazards and hazardous materials. [3]Non-existence of Site Class F, any geologic hazards, and no significant building deterioration/damage shall be verified by certified geotechnical and structural engineers, respectively. [4] The remaining occupancy time does not apply to non-structural components in buildings with very high consequences of failure (VHC).

Figure 8: Part C (non-structural component scoring) and Part D (decision support) of Level 2 – SQST sample screening form

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Semi-Quantitative Seismic Risk Screening Tool (SQST)

From: National Research Council Canada

Figure 9: Landing page of the web-based application for Level 2 – SQST (NRC 2021)

▼ Part B: Structural scoring

Structural score modifiers

Vertical irregularity	Horizontal irregularity	Building design period	Original building importance	Site class	Building height	Building deterioration and age	Redundancy	Pounding	Seismic upgrading	Remaining occupancy time
0	-1.3	0	0	0	0.4	-0.3	0.5	0	0	0

Structural basic score	Minimum structural score	Final structural score	Structural score threshold	Structural priority index
3.9	0.6	3.2	2.3	0.126

▼ Part C: Non-structural component scoring

Non-structural component score modifiers

Site class	Model building type	Vertical irregularity	Horizontal irregularity	Pounding	Building deterioration and age	Component response	Design code period	Remaining occupancy time
0	Structural response (sum no less than -20 for final score)					0	-3	0
	0	0	-8	0	-3			

Non-structural component basic score	Final non-structural score	Non-structural score threshold	Non-structural priority index
51	37	45	2.089

▼ Part D: Decision support

Structural decision support: No, Level 3 - SEG structural evaluation is not required.

Non-structural decision support: Yes, Level 3 - SEG non-structural evaluation is required:

- Non-Structural Score less than Non-Structural Threshold

Figure 10: Final report page of the web-based application for Level 2 – SQST (NRC 2021)