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Toward Updating NRC's Seismic Evaluation Guidelines for Existing Buildings in Canada

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ABSTRACT

This paper presents an overview of the seismic evaluation guidelines (SEG) under development by the National Research Council Canada (NRC) that aim to update the outdated NRC seismic evaluation guidelines developed in the early 1990s. The SEG includes three tiers of seismic evaluation procedures, namely, Tier 1 Quick Evaluation, Tier 2 Deficiency-Based Evaluation, and Tier 3 Detailed Evaluation. The Tier 1 procedure updates the initial quick evaluation procedure of the outdated NRC guidelines and is intended as an economical tool to identify potential key seismic deficiencies that may require further evaluation by completing a set of applicable checklists. The Tier 2 procedure updates the detailed analysis procedure of the outdated NRC guidelines and is intended to follow the Tier 1 procedure to determine if the potential key seismic deficiencies represent actual seismic deficiencies. The Tier 3 procedure is completely new to Canada and is used when Tier 1 and Tier 2 procedures are not permitted. It can also be used to further evaluate the seismic deficiencies identified in the Tier 2 procedure. A flowchart is developed to help building owners select appropriate evaluation procedures for performing seismic evaluation of existing buildings. The SEG is intended to provide building owners with a set of cost-effective tools for assessing the compliance of their buildings with the objectives of the SEG and flag non-compliant buildings for risk mitigation (e.g., seismic upgrading and decommissioning).

Keywords: Seismic risk assessment and management, seismic evaluation, seismic deficiency, existing building.

INTRODUCTION

Reconnaissance missions from past major earthquakes have demonstrated that existing buildings that were designed to conform to older seismic provisions are usually vulnerable and prone to experience severe damage or collapse in the event of strong ground shaking. For owners of large portfolios of existing buildings such as Public Services and Procurement Canada, one of the key concerns is whether the level of seismic risk in their buildings is acceptable. There is a growing need for risk-informed tools that can assist building owners in assessing the seismic risks of their buildings and recommending risk-mitigation actions. To address this need, Lounis et al. [1] and Fathi-Fazl et al. [2] from the National Research Council Canada (NRC) developed a multi-criteria and multi-level framework for seismic risk assessment and management of existing buildings in Canada, which consists of three levels of assessment as follows: (i) Level 1 – Preliminary Seismic Risk Screening Tool (PST) [3-5], (ii) Level 2 – Semi-Quantitative Seismic Risk Screening Tool (SQST) [6-10], and (iii) Level 3 – Seismic Evaluation Guidelines [11]. The framework aims to provide building owners with a set of cost-effective tools for assessing the seismic risks of their buildings while minimizing the costs for performing such assessments.

The Level 1 – PST is completely new to Canada and is intended as a simple screening tool that assist building owners in quickly identifying buildings with potential unacceptable life safety risk on the basis of a number of key criteria. It also identifies special conditions that directly trigger seismic evaluation using Level 3 – SEG without conducting detailed screenings using Level 2 – SQST.

The Level 2 – SQST supersedes the outdated NRC Manual for Screening of Buildings for Seismic Investigation developed in the early 1990s [12], and is intended to follow Level 1 – PST to identify and exempt buildings with acceptable life safety risk from seismic evaluation by implementing structural and non-structural scoring systems. It also provides a ranking procedure to prioritize potential hazardous buildings for seismic evaluation using Level 3 – SEG.

The Level 3 – SEG updates the outdated NRC Guidelines for Seismic Evaluation of Existing Buildings developed in the early 1990s [13], and is intended to assist building owners and evaluating engineers in evaluating the compliance of the existing buildings flagged by either Level 1 – PST or Level 2 – SQST with the objectives of Level 3 – SEG. Building owners may decide to perform seismic evaluation using Level 3 – SEG without using less expensive Level 1 – PST and Level 2 – SQST. The Level 3 – SEG consists of three tiers of evaluation procedures in the ascending order of accuracy and thoroughness, namely, Tier 1 Quick Evaluation, Tier 2 Deficiency-Based Evaluation, and Tier 3 Detailed Evaluation. A seismic evaluation process is included to help building owners and evaluating engineers select appropriate evaluation procedures to perform seismic evaluation of existing buildings. It is expected that, through this process, non-compliant buildings are identified and flagged for risk mitigation (e.g., seismic upgrading and decommissioning).

The development of Level 3 – SEG started in 2018 and is expected to be completed in 2024. In the past 5 years, NRC has made significant efforts in developing the three tiers of evaluation procedures and engaging national and international experts from six universities (five in Canada and one in New Zealand), ten consulting firms, and other government departments (e.g., Public Services and Procurement Canada) to collaborate in the areas of peer review of evaluation procedures, inspection quality classification, pilot studies, and recommendation on the use modelling parameters and acceptance criteria for nonlinear dynamic analysis. More details on the development of Level 3 – SEG can be found elsewhere [11]. This paper aims to give an overview of the Level 3 – SEG with a focus on the evaluation process and three-tier evaluation procedures developed for performing a cost-effective seismic evaluation of existing buildings in Canada.

OVERVIEW OF THE LEVEL 3 – SEG

The development of Level 3 – SEG started with a comprehensive literature review of building codes, standards, and guidelines in Canada [13-28], the U.S. [29-37], New Zealand [38], and Japan [39]. This review aims to track the evolution of seismic provisions in building codes and standards in Canada and the U.S., comprehend seismic evaluation methodologies recently developed in Canada and other countries, and identify the knowledge gaps to apply these methodologies to update the outdated NRC guidelines. Based on this review, three tiers of evaluation procedures were developed. More technical details on the development of the evaluation procedures can be found elsewhere [11].

To gain hands on experience from designers/practitioners to ensure the ease of use of the evaluation procedures, the NRC commissioned seven consulting firms with experience and expertise in the areas of seismic design and analysis to conduct pilot studies on 12 existing Public Services and Procurement Canada buildings across the country.

In the following sub-sections, the evaluation process and evaluation procedures are briefly reviewed.

Level 3 – SEG Evaluation Process

The seismic evaluation of an existing building is recommended to be performed in accordance with the evaluation process as shown in Figure 1. The Tier 1 and Tier 2 procedures aim to efficiently evaluate the seismic adequacy of existing buildings by using simplified procedures based on force-based approaches. The Tier 1 procedure focuses on identifying potential key seismic deficiencies in a building, and the Tier 2 procedure is used when potential seismic deficiencies are identified through the Tier 1 procedure. These two evaluation procedures are intended to serve as cost-effective solutions and are not permitted to be used under certain conditions. Examples of such conditions include unknown model building type, use of base isolation and/or additional damping systems, and presence of geologic hazards. Despite of these conditions, building owners may still use the Tier 1 procedure as a starting point to gain a better understanding of potential key seismic deficiencies in their buildings. The Tier 3 procedure is to be used when the use of the Tier 1 and Tier 2 procedures is not permitted. Unlike the Tier 1 and Tier 2 procedures, the Tier 3 procedure can be used for any building within the scope of Level 3 – SEG. In the following sub-sections, the three tiers of evaluation procedures are overviewed.

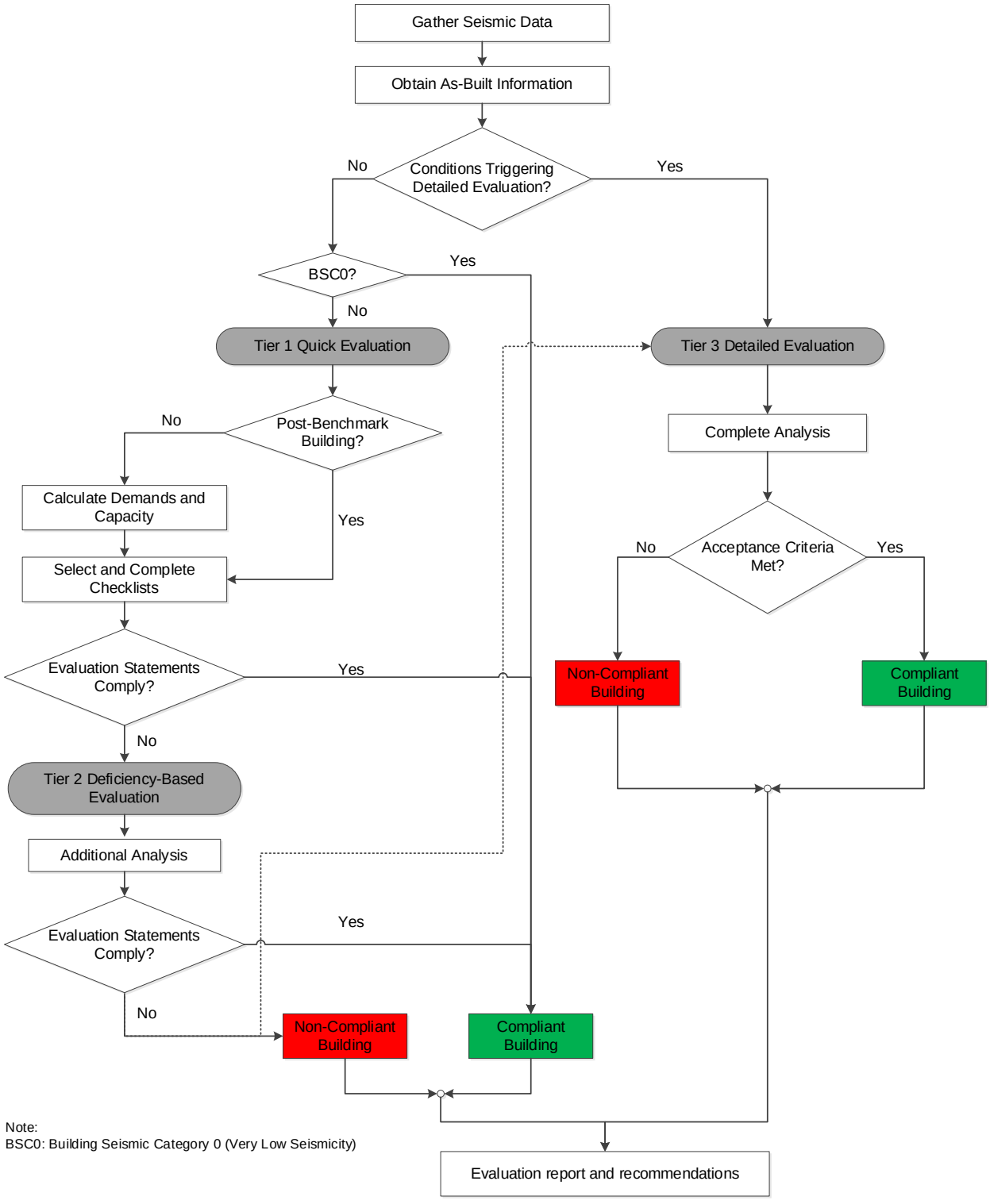

Figure 1: Level 3 – SEG evaluation process [11]

Overview of the Tier 1 Procedure

The Tier 1 procedure [40-41] aims to supersede the initial quick evaluation procedure of the outdated NRC guidelines [13]. The procedure covers seismic assessment of both structural and non-structural elements, and requires the review of construction documents, on-site inspection, and calculations. Twenty (20) checklists (including one low seismicity checklist, one basic

configuration checklist, seventeen structural checklists, and one non-structural checklist) are developed to uncover key seismic deficiencies that prevent a building from meeting the required objectives, mainly based on lessons learned from previous major earthquakes. A total number of 350 evaluation statements are provided in these checklists to help building owners and evaluating engineers identify potential key seismic deficiencies in existing buildings. These evaluation statements were developed based on a comprehensive review of seismic evaluation standards and guidelines in Canada and the U.S., including [13], [30-31], [33-35]. The general requirements, limits, and thresholds in the evaluation statements were determined by reviewing the design and evaluation standards and guidelines in Canada and the U.S., and other relevant studies [42-50]. A list of design and evaluation standards and guidelines is provided in Table 1 and Table 2.

Table 1: Structural design standards in Canada and the U.S.

Material	**Canada**	**U.S.**
Steel	CSA S16-19	ANSI/AISC 341-16 ANSI/AISC 360-22
Concrete	CSA A23.3-19	ACI 318-19
Wood	Part 9 of the NBC 2020 2017 Wood Design Manual CSA O86-19	2021 IRC 2021 SPDWS
Masonry	CSA S304-19	TMS 402/602-22
Cold-formed steel	CSA S136-19	AISI S100-16 (R2020)

Table 2: Standards and guidelines for design and assessment of non-structural components

Non-Structural System	**Design and Assessment Standards and Guidelines**	
Non-structural components (operational and functional components)	CSA S832:14 (R2019)	FEMA E74
Steel storage racks	CSA S16-19 CSA A344.1-05 CSA A344.2-05	ANSI MH16.1-2021
Fire suppression systems	NFPA-13	NFPA-13 ASCE/SEI 25-05
HVAC systems	ASHRAE 2012 SMACNA 2009	ASHRAE 2012 SMACNA 2009
Life safety systems	CSA C282-19	NFPA 110
Elevators and escalators	CSA B44-2019	ASME A17.1-2019
Ceilings	CAN/CSA-A82.31-M91	ASTM C635/C635M-17 ASTM C841-03 ASTM E3090/E3090M-20
Masonry partitions, parapets, and veneers	CSA S304-19 CSA A370:14 (R2018)	TMS 402-22

Major updates with respect to the initial quick evaluation procedure of the outdated NRC guidelines are summarized below:

- The limit states criteria are made consistent with the NBC 2020 and corresponding CSA structural design standards.
- Building seismic categories are defined to describe various seismicity levels.
- A list of conditions that trigger Tier 3 Detailed Evaluation are introduced.
- Benchmark NBC editions are used to identify post-benchmark buildings that are eligible to be exempted from structural seismic evaluation.
- A set of earthquake load factor matrices are proposed to determine seismic base shear demands for evaluation (V_{QE}).
- A remaining occupancy time factor (κ) is used to account for the smaller probability of experiencing a Code level earthquake for a building with remaining occupancy time of not greater than 10 years.
- An additional step is introduced to assist evaluating engineers in selecting appropriate checklists based on the calculated estimated minimum seismic base shear capacity (V_E) and V_{QE}.
- A guidance is included to assist evaluating engineers in calculating V_E.

- Additional evaluation statements are incorporated to identify the potential seismic deficiencies that are not captured in the initial quick check evaluation procedure based on a detailed review of the Tier 1 checklists in ASCE/SEI 41-17 [35].
- The organization of evaluation statements is modified based on a critical review of the Tier 1 Screening checklists in ASCE/SEI 41-17 [35].

Overview of the Tier 2 Procedure

The Tier 2 procedure [51] aims to supersede the detailed analysis procedure of the outdated NRC guidelines [13] and is intended to follow further evaluate the potential seismic deficiencies identified through the Tier 1 procedure. The development of this procedure was based on a comprehensive review of linear analysis procedures in the NBC 2020 [15], Canadian Highway Bridge Design Code [52], and ASCE/SEI 41-17 [35]. The building analysis requirements and capacity calculations have been made compatible with the NBC 2020 seismic provisions [15] and corresponding CSA structural design standards, respectively. Similar to the Tier 1 procedure, a set of earthquake load factors and a remaining occupancy time factor are applied to the seismic hazards prescribed by the NBC 2020. The procedure allows the use of the Equivalent Static Force Procedure (ESFP) and Modal Response Spectrum Method (MRSM) to evaluate the impact of potential seismic deficiencies identified through the Tier 1 procedure. The selection of appropriate analysis procedure has been made consistent with the seismic provisions of the NBC 2020, as shown in Figure 2. The Linear Numerical Integration Time History Method is not recommended at this level of evaluation because it requires extensive expertise on ground motion selection and its scaling and is more costly than the MRSM.

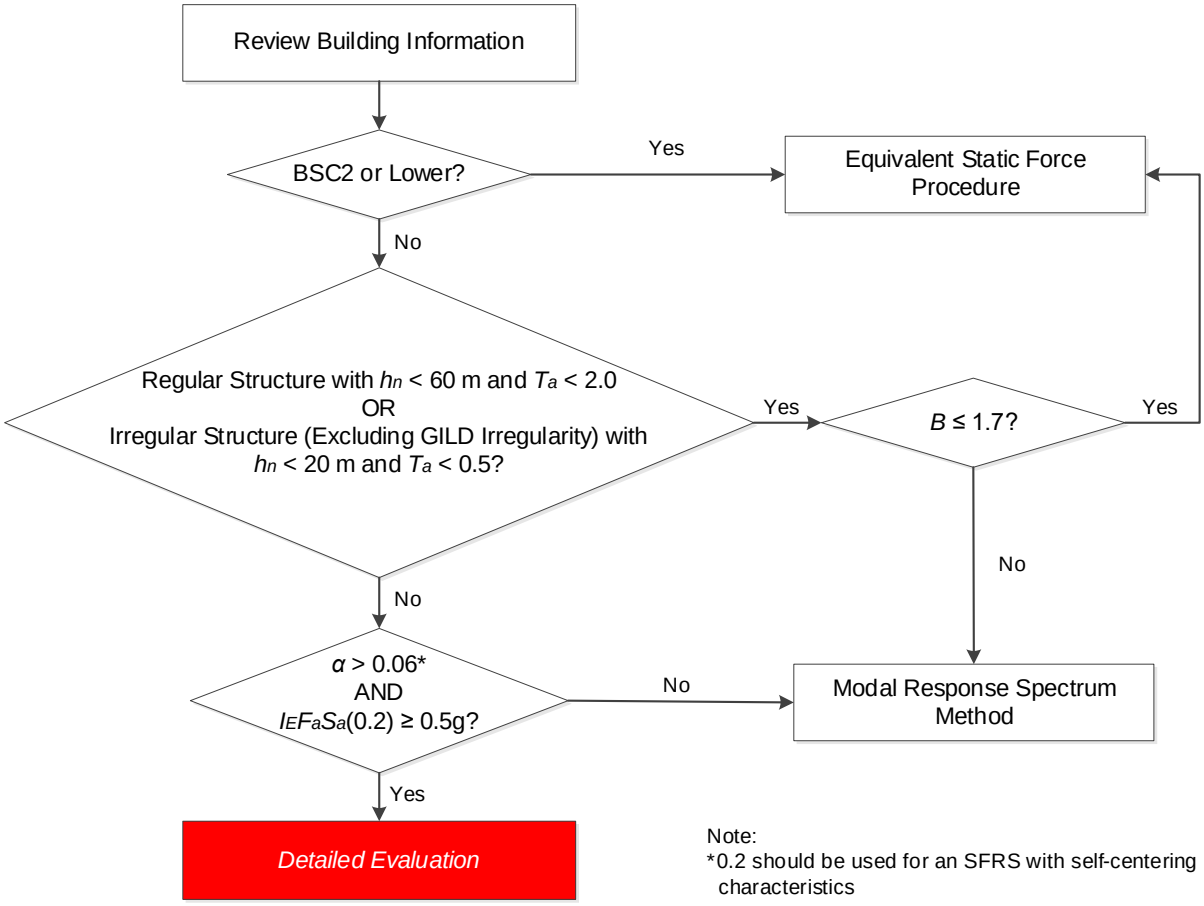

Figure 2: Minimum requirements for performing the analysis of a building [11]

The analysis of each potential seismic deficiency should be sufficient to either confirm the deficiency or demonstrate the adequacy of the building. The scope of the Tier 2 procedure needs not to expand beyond the evaluation of the potential key seismic deficiencies identified through the Tier 1 procedure.

Major updates with respect to the detailed analysis procedure in the outdated NRC guidelines are summarized below:

- The limit states criteria are made consistent with the NBC 2020 and relevant CSA structural design standards.
- An additional step is introduced to assist evaluating engineers in selecting appropriate analysis procedures.

- The analysis procedures (i.e., ESFP and MRSM) are made compatible with the NBC 2020 seismic provisions.
- The building seismic categories are defined to describe various seismicity levels.
- A set of earthquake load factor matrices are used to determine seismic base shear for evaluation.
- A remaining occupancy time factor is used to account for the smaller probability of experiencing a Code level earthquake for a building with remaining occupancy time not greater than 10 years.
- Procedures for evaluating potential seismic deficiencies are updated in accordance with the NBC 2020 seismic provisions and corresponding CSA structural design standards.
- Additional procedures are developed for evaluating potential seismic deficiencies that are newly introduced into the Tier 1 procedure.

Overview of the Tier 3 Procedure

The Tier 3 procedure does not exist in existing Canadian guidelines. It is intended to be used when Tier 1 and Tier 2 procedures are not permitted. It may also be used to further evaluate the seismic deficiencies identified through the Tier 2 procedure. The Tier 3 procedure allows the use of both force-based and performance-based methods to evaluate the compliance existing buildings with the objectives of Level 3 – SEG.

The force-based methods include MRSM and Numerical Integration Linear Time History Method (LTHM). The building analysis requirements and capacity calculations have been made compatible with the NBC 2020 seismic provisions and corresponding CSA structural design standards. Similar to Tier 1 and Tier 2 procedures, a set of earthquake load factors and a remaining occupancy time factor are applied to the seismic hazards prescribed by the NBC 2020 to calculate seismic demands with respect to the ultimate limit state. A lower seismic hazard level is permitted to be used to calculate the interstorey drift ratios with respect to the service limit state.

The performance-based methods include Nonlinear Static Analysis Procedure and Nonlinear Dynamic Analysis Procedure. There are currently no Canadian guidelines for performing nonlinear analysis of existing buildings. Due to the lack of Canadian guidelines, the state of the practice in Canada often refers to ASCE/SEI41 for guidance. Given the differences in seismic design and construction practices in the U.S. and Canada, ASCE/SEI41 should be used with caution. One of key challenges in developing Canadian guidelines for nonlinear analysis of existing buildings is to recommend modelling parameters that are used to establish backbone curves and to recommend acceptance criteria that are used to determine the compliance of existing buildings with the objectives of Level 3 – SEG. To deal with this challenge, Fazileh et al. [53] proposed the following steps:

1. Review historical CSA standards relative to those of the U.S. to identify if any specific changes in CSA standards that result in unique component detailing found in Canadian buildings that causes seismic vulnerabilities.
2. Review available literature to identify the availability of data on unique component detailing in Canadian buildings.
3. Identify gaps to apply the modelling parameters and acceptance criteria used in the U.S. seismic evaluation standards and guidelines to the unique component detailing identified above.

The NRC has implemented the steps above through the collaboration with national and international experts from six universities (five in Canada and one in New Zealand), which resulted in recommendation of nonlinear modelling parameters and acceptance criteria for nonlinear analysis of existing buildings in Canada.

CONCLUSIONS

This paper presented an overview of the Level 3 – Seismic Evaluation Guidelines (SEG) that are used to assist building owners in performing the last level of assessment of NRC's multi-criteria and multi-level framework for seismic risk management of existing buildings. The Level 3 – SEG aims to update the outdated seismic evaluation guidelines developed by NRC in the early 1990s. It has been designed to provide practical and cost-effective solutions to assist building owners in evaluating the compliance of existing buildings with the objectives of Level 3 – SEG and in making risk-informed decisions to achieve a consistent and acceptable level of seismic risk in their buildings. To this end, a three-tiered evaluation process is recommended to be followed to select appropriate evaluation procedures (i.e., Tier 1 Quick Evaluation, Tier 2 Deficiency-Based Evaluation, and Tier 3 Detailed Evaluation). Note that the analysis procedures in Tier 1 and Tier 2 procedures have been made compatible with force-based analysis methods in the NBC 2020 and corresponding CSA structural design standards, which makes them more practical and friendly to practising engineers. The Tier 3 procedure further provides guidance for performing nonlinear analyses of existing buildings according to a performance-based approach, which is expected to be used by experienced and competent engineers with extensive knowledge in nonlinear modelling and analyses of buildings. The combined use of force-based and performance-based approaches for different tiers of evaluation aims to minimize the costs of performing such evaluations, which is especially important for building owners with large portfolios of existing buildings. Pilot studies have been conducted by seven consulting firms commissioned by NRC to evaluate the compliance of twelve existing Public Services

and Procurement Canada buildings with the objectives of Level 3 – SEG. The objective of the pilot studies is to gain hands on experience from designers/practising engineers to ensure the ease of use of the evaluation procedures.

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