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COMPARISON OF SEISMIC SCREENING METHODS FOR SCHOOLS IN A MODERATE SEISMIC ZONE

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Abstract. *An ongoing project at McGill University is aimed at designing an adapted seismic screening method for schools in the province of Québec, Canada. As part of this project the "FEMA154 Rapid Visual Screening of Buildings for Potential Seismic Hazard" and the "NRC92 Manual for Screening of Buildings for Seismic Investigation" were used to assess the potential performance of 100 school buildings located in the city of Montréal. Results for both methods are in reasonable agreement, with 65% of the buildings requiring a detailed evaluation according to FEMA154 and 50% according to NRC92. The evaluation highlighted particular characteristics of the structures. School buildings are generally low-rise, of a limited number of structural types and have a high incidence of features that could affect seismic performance, such as steps in elevation and re-entrant corners. Findings were also used to identify advantages and shortcomings of each screening method. NRC92 is largely based on expert opinion, which makes the method difficult to update. FEMA154 uses a more rational methodology for calculating the vulnerability scores; however the nonlinear static seismic analysis procedure employed doesn't consider latest improvements in building codes. Updating the procedure increases the basic scores on average by 24%, with higher scores indicative of better performance. When using FEMA154 it has to be considered that seismicity and soil amplification factors were developed for the United States. NRC92, although conceived for the Canadian context, has to be updated to include latest findings in seismic hazard parameters and soil classification. Since schools typically have a high incidence of irregularities, accounting for them in the screening phase is essential. FEMA154 only considers vertical and plan irregularities and it was found that this is insufficient to capture the characteristics of the evaluated schools. NRC92 partially overcomes this shortcoming by specifying seven different types of irregularities. In conclusion it was recognized that the clear analytical procedure behind FEMA154 allows updating and adapting the method to its use outside its intended scope. Therefore the screening procedure currently under development is largely based on this method, incorporating key characteristics of NRC92.*

1 INTRODUCTION

Schools deserve special attention regarding earthquake performance because of their unique occupancy and important post-earthquake role. However experience in the past has demonstrated that they are especially vulnerable. This was illustrated by the effects of the 1997 Cariaco earthquake in Venezuela. Two out of five collapsed buildings were schools, and more than half the casualties were students [1]. There have been many other examples that have demonstrated that school buildings are especially vulnerable to damage in moderate to strong earthquakes (e.g. [2, 3]). Different reasons have been proposed to explain the observed poor performance, including the age of school buildings and that their complex structural features compromise seismic safety [4].

The protection of children is paramount in society because they provide for future generations and represent an especially vulnerable segment of society. It has also been argued that safe schools must be considered a basic right in countries where school attendance is obligatory [5]. In addition, school buildings play a key role in restoring the normal functioning of society after an earthquake. Immediately following a seismic event they can be used as shelters, and their operation permits parents to return to work. In 2005 the Organization for Economic Co-operation and Development, acknowledging these facts, published recommendations on the earthquake safety of schools. In this document, the organization suggests that "Member countries take steps to establish and implement programs of school seismic safety" [6]. The first step to ensure effective risk reduction in existing buildings is the assessment of this risk.

Seismic screening methods for schools are needed as the first phase in vulnerability assessment projects. One example of the successful application of the technique is the evaluation of all schools located in zones with high seismicity of the province of British Columbia, Canada. This study, conducted in 2004, found that 82% of the more than 850 evaluated schools were at moderate or high risk, and consequently a state of the art tool for the detailed evaluation and strengthening of the province's schools was developed [7]. Presently the schools identified to be the most critical are being reassessed and retrofitted [8, 9].

2 SEISMIC SCREENING METHODS

Seismic screening methods, more specifically rapid visual screening or score assignment procedures, are intended to be coarse screening procedures using little resources per building. This is achieved by evaluating a limited number of features that influence seismic performance and assigning an overall score to each building. An ideal screening method will identify all those buildings that are potentially seismically hazardous, while limiting the number of buildings that will pass a more detailed evaluation [10].

Seismic screening methods can be classified as observed or predicted vulnerability procedures, or hybrid methods, depending on the type of source information used. Observed vulnerability procedures use statistics of damages in past earthquakes, sometimes combined with expert opinion, to determine the probable behavior of structures under future seismic events. The main setback of this approach is the possible insufficiency of observational data, and the subjectivity in judging data. The method also lacks analytical justification. Predicted vulnerability methods try to overcome these shortages by using analytical procedures to determine the probable behavior of a structure subjected to earthquake loading. The limitation of this approach is the time and computational effort required by detailed analytical analyses. Therefore a balance between effort and precision has to be found [11].

The first comprehensive rapid visual screening method was developed in the United States by the Applied Technology Council under contract to the Federal Emergency Management Agency [12, 13]. This method, published as the FEMA154 report, *Rapid Visual Screening of*

Buildings for Potential Seismic Hazard, is probably the most widespread RVS tool, and there is considerable guidance on its application (e.g. [14, 15]). The method has served as a prototype for the development of screening tools in other countries, as for example in Switzerland [16] and Italy [17]. The current Canadian seismic screening method, *Manual for Screening of Buildings for Seismic Investigation* (NRC92) [18], is also largely based on the first edition of FEMA154. There are other methods, developed independently, such as the procedure of the New Zealand Society for Earthquake Engineering [10]. This method judges existing buildings by comparing them to current New Zealand standards. Another example is the Japanese Seismic Index Method, a multiphase screening procedure that estimates the vulnerability of an existing building by a seismic performance index calculated for every story in each main direction and based on key characteristics of the building. This method has been used to evaluate low- and mid-rise reinforced concrete buildings in Japan since 1975 [19].

For the present research FEMA154 and NCR92 were evaluated, due to their relevance at the global and national level, respectively. A more detailed description of the two methods follows.

2.1 FEMA154

FEMA154 was first published in 1988 [20, 21], but was significantly improved in 2002 with the release of its second edition. The screening is done by visual observation of the building, and can be completed by means of a sidewalk survey, although entering the building and consulting existing plans and other documentation is recommended. Based on this inspection a data collection form is completed. Initially the lateral load resisting system has to be identified and related to one of the 15 predefined building types. A basic structural hazard score is provided for each building type. To consider specific characteristics of the building that could affect its seismic performance, the score is then altered by adding or subtracting score modifiers to obtain the final structural score. Score modifiers related to building height, vertical and horizontal irregularities, year of construction and soil type are provided. Higher final structural scores correspond to a better seismic performance, and usually they range from 0 to around 6. It is recommended that buildings with a score of 2 or less should be evaluated in more detail.

The basic structural hazard score (*BSH*) for each building type is defined as the negative of the logarithm (base 10) of the probability of collapse (*P*) of the building, given a ground motion corresponding to the maximum considered earthquake (*MCE*), as shown in Equation 1.

$$BSH = -log_{10}[P(collapse\ given\ MCE)] \quad (1)$$

The probability of collapse is the probability of the building being in complete damage state times the fraction of the buildings in complete damage state that collapse.

To determine the probability of being in complete damage state first the spectral displacement is calculated using a nonlinear static seismic analysis procedure. The technique used is the capacity spectrum method [22], depicted in Figure 1.a. The capacity spectrum method, an equivalent linearization technique, is based on the assumption that the maximum inelastic deformation of a nonlinear single degree of freedom system can be estimated from the maximum elastic deformation of a linear elastic single degree of freedom system which has natural period and damping values higher than the original one. The inputs of the method are the force-deformation relationship of the structure, commonly known as push-over curve, and the seismic demand. Both are plotted in acceleration-displacement response spectrum format. In this format periods can be represented by radial lines, and the equivalent period is assumed to be the secant period at the intersection of the capacity spectrum and the seismic demand spectrum reduced for equivalent damping. The equivalent damping is estimated based on the area under the capacity curve. Since both equivalent period and damping are dependent on the estimated maximum spectral displacement, an iterative process is followed for its calculation.

The estimated spectral displacement is used to determine the probability of complete damage state from a fragility curve corresponding to the building type, as can be seen in Figure 1.b. This value is multiplied by the fraction of buildings that will collapse being in complete damage state to obtain the probability of collapse and calculate the basic structural hazard scores. A similar procedure is used to calculate the score modifiers.

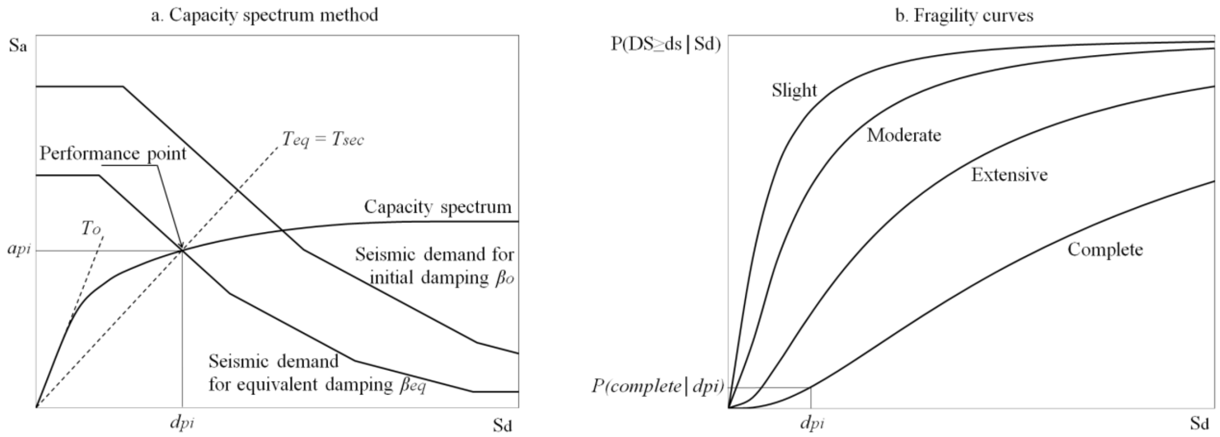

Figure 1: Estimation of the probability of complete damage state of a building class [13].

2.2 NRC92

The NRC92 procedure was developed in Canada in 1992. Similar to FEMA154, the practical implementation of NRC92 relies on a data collection form that can be filled out by visual inspection of the building. It is expected that the exterior as well as the interior is evaluated, and recommended that building plans are considered. The user first has to identify the lateral load resisting system and correlate it to 15 different building types, very similar to those of FEMA154. High importance is given to the identification of building irregularities, differentiating between seven different types. Non-structural hazards also have to be identified.

A structural index is computed by multiplying five factors. They are related to local seismicity, soil conditions, lateral load resisting system, vertical and horizontal irregularities and building importance. A non-structural index is also computed, based on the observed non-structural hazards, the soil conditions and building importance. The final score, called the seismic priority index, is the sum of a structural index and a non-structural index. In contrast to FEMA154, a high final score indicates high priority for refined seismic vulnerability analysis of the building. It is suggested that buildings with a score less than 10 be treated as low priority, 10 to 20 as moderate priority, 20 to 30 as high priority and more than 30 as potentially hazardous requiring immediate attention.

NRC92 is largely based on the first edition of FEMA154. In this first edition the same types of scores and modifiers as the second edition are used, however calculations are mainly based on engineering expert opinion. The basic structural hazard scores were calculated as the negative of the logarithm (base10) of the probability of damage (D) exceeding 60% of the building value, given a ground motion represented by the NEHRP effective peak acceleration, as shown in Equation 2.

$$BSH = -log_{10}[P(D \geq 60\%)] \tag{2}$$

To determine the probability of occurrence of different levels of damage given a specified ground motion, expert opinion was used (ATC-13 report [23]). This report was concerned exclusively with buildings constructed according to Californian building practices, and again expert opinion was sought out to make the results applicable to other regions of different seismicity. The score modifiers were also calculated based on expert criteria.

To develop NRC92 the method was adapted to Canadian seismicity and building practice. The scoring system was also modified to consider structural and non-structural components in the evaluation, and the importance of the building, related to occupancy and use.

3 BACKGROUND: SCHOOLS IN QUÉBEC

The present study is conducted in the province of Québec, Canada, considered a moderate seismic zone. Most of the population is located in the St. Lawrence River valley, the province's most active seismic zone. The region with highest seismicity, LaMalbaie, has spectral accelerations response values of Sa(0.2s) = 2.3g for short periods and of Sa(1.0s) = 0.6g for long periods, with a probability of exceedence of 2% in 50 years. More typical values are those of the two largest cities of the province, Montréal with Sa(0.2s) = 0.69g and Sa(1.0s) = 0.14g, and Québec City, with Sa(0.2s) = 0.59g and Sa(1.0s) = 0.14g. These two cities account for half of the province's population.

In Québec moderate and strong earthquakes have occurred in the past, and they will most certainly occur in the future. The large events have a relatively long return period (several centuries) and hence the general population has the impression that earthquakes are not likely in the region. Although Québec's earthquakes in the past have not caused loss of human life, extensive property damage has been reported. Some examples are the 1935 Timiskaming earthquake (magnitude 6.2) and most recently the 1988 Saguenay earthquake (magnitude 6.0) [24].

Since experience in strong earthquakes is limited in Eastern Canada, reported seismic damage to schools has been mostly to non-structural elements. There was considerable damage reported to one Collegiate and Vocational School in Cornwall after the 1944 Cornwall-Massena earthquake [24]. The 1988 Saguenay earthquake produced architectural damage to 33 out of 42 public schools of the two most affected communities [25]. The site visit team also drew attention to the dangers of unreinforced masonry infill walls, and warned about the abundance of them particularly in schools and hospitals [26].

A school inventory report from the Québec Ministry of Education [26] has classified all the provincial public school buildings into five main structural/architectural categories and determined their general seismic vulnerability features relating the structural type to the construction year. The five categories and their province-wide occurrence are presented in Figure 2, totaling approximately 3600 schools. No distinction between different buildings at each location was made. About one half of the schools were built before 1960, i.e. before modern earthquake-resistant design procedures were introduced in the *National Building Code of Canada* (NBCC), and were therefore classified as the more vulnerable schools of the province. This inventory was a first step in the vulnerability assessment of schools in Québec and its results highlighted the need for more detailed studies. Clearly, a detailed school-by-school evaluation is not feasible on a large scale and the development of a screening method adapted to address the specific characteristics of the building inventory is necessary.

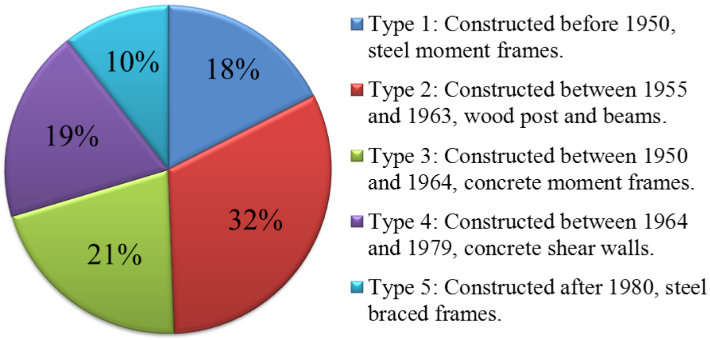

Figure 2: Initial classification of school buildings in Québec [26].

4 EVALUATION OF SCHOOL BUILDINGS

The goal of this research is to design such an adapted seismic screening method for school buildings of the province of Québec. As part of the study the seismic vulnerability of sixteen high schools (secondary education level) comprising a total of 102 individual buildings is being studied. These schools are designated as post-critical shelters on the island of Montréal, mostly based on their location and their capacity to shelter a large number of disaster victims. A detailed database of the characteristics of the school buildings was created. Information from plans, site visits and the city's seismic microzonation map [27] was used.

It was found that most school buildings are low rise: over 3/4 of them are three stories high or less, with the tallest being six stories high. The floor area varies between 200 and 5300m^2, with an average value of 2000m^2. It is noted that 87% of the structures were built in the 1960s and 1970s. The most common lateral load resisting systems, which account for 80% of the studied buildings, are: concrete frames with infill masonry shear walls, concrete shear walls and steel moment frames. As expected the evaluated schools are complex structures, with features that could potentially affect their seismic behavior. Buildings with re-entrant corners, steps in elevation, potential for pounding, exterior cladding and heavy partition walls are common. Table 1 summarizes the most common features and their percentage of occurrence. According to the seismic microzonation map of Montréal, eight of the 16 school campuses are located on soils prone to ground motion amplification [28].

Feature	% of Buildings
Irregular building plan	40%
Steps in elevation view	40%
Heavy masonry partition walls	90%
Potential for pounding	99%
Exterior cladding	80%
Site effects	50%
Deterioration	35%

Table 1: Features that could affect seismic performance and their occurrence in evaluated schools buildings.

Preliminary assessments using the FEMA154 and NRC92 seismic screening procedures were performed. Cut off scores were used as recommended for each method. Results of FEMA154 suggested that 65% of the buildings should undergo a detailed evaluation. NRC92 results were similar, finding 12% of the buildings with low priority for future interventions, 38% moderate priority, 34% high priority and 16% potentially hazardous. There is relatively good agreement in the results obtained with the two methods given that 80% of the buildings that didn't comply with the screening of FEMA154 were classified as having high priority of intervention or being potentially hazardous by NRC92. The large proportions of buildings requiring detailed evaluation (65% according to FEMA and 50% according to NRC92) appear somewhat alarmist for a moderate seismicity environment and provide further motivation for the development of better adapted screening methods that can identify more precisely the installations that need detailed seismic vulnerability assessment.

A companion study evaluated the seismic risk of operational and functional components of fourteen of the sixteen schools [29], according to the procedure in CAN/CSA S832-06 standards, *Seismic risk reduction of operational and functional components (OFCs) of buildings* [30]. Around 450 typical components were evaluated in total, from which 20% were rated high and 54% moderate risk. The most common problem identified was lack of restraint of the non-structural components.

5 ADVANTAGES AND SHORTCOMINGS OF EACH METHOD

5.1 Procedures behind score calculations

Supporting documentation for NRC92 is limited and this creates challenges for any attempt of updating the procedure. An update of NRC92 is needed because it was largely based on the first edition of FEMA154, which has been thoroughly revised. On the other hand, FEMA154 uses a more sound methodology for calculating the vulnerability scores than NRC92, with the calculations based on the capacity spectrum method as described in ATC-40 [22]. However the application of ATC-40 has raised concerns in the past, compared with other simplified analysis methods with poor agreement. Furthermore, when comparing to results of response history analysis, significant differences could be found [31]. Some studies demonstrated that the estimated maximum deformations can be underestimated by as much as 50% [32]. Recognizing this concern, in 2004 a thorough evaluation of the existing method was conducted and an updated procedure was published in the FEMA440 report [33]. In this evaluation it was found that for short-period structures, with period less than 0.5s approximately, the peak displacements are largely overestimated. For higher periods the ATC-40 methodology can either overestimate or underestimate the displacements, depending on the assumed hysteretic behavior of the evaluated building. The main modification of the method was the update of the expressions for the calculation of the equivalent or effective period (T_{eff}) and damping (β_{eff}). Approximate equations, that are independent of the hysteretic curve and post-elastic stiffness ratio of the capacity curve used, are repeated in the Equations 3 to 5, were μ is the ductility demand, T_0 and β_0 are the elastic damping and period, respectively.

For $1.0 < \mu < 4.0$:

$$\beta_{eff} = 4.9(\mu - 1)^2 - 1.1(\mu - 1)^3 + \beta_0$$
$$T_{eff} = [0.20(\mu - 1)^2 - 0.038(\mu - 1)^3 + 1]T_0 \qquad (3)$$

For $4.0 \leq \mu < 6.4$:

$$\beta_{eff} = 14.0 + 0.32(\mu - 1) + \beta_0$$
$$T_{eff} = [0.28 + 0.13(\mu - 1) + 1]T_0 \qquad (4)$$

For μ > 6.5:

$$\beta_{eff} = 19\left[\frac{0.64(\mu-1)-1}{[0.64(\mu-1)]^2}\right]\left(\frac{T_{eff}}{T_0}\right)^2 + \beta_0$$
$$T_{eff} = \left\{0.89\left[\sqrt{\frac{(\mu-1)}{1+0.05(\mu-2)}}-1\right]+1\right\}T_0 \qquad (5)$$

Based on these equations, scores for FEMA154 were recalculated in the present study. Figure 3 shows a comparison between the basic structural hazard scores presented in FEMA154 and the updated values. On average the values increased 14% for high seismicity, 29% for moderate seismicity and 28% for low seismicity. Increased values are related to a better earthquake performance. This result was expected, since the basic structural hazard scores are calculated for low rise buildings with relatively short periods, and the capacity spectrum method as presented in ATC-40 tends to overestimate the predicted maximum displacement values for short periods.

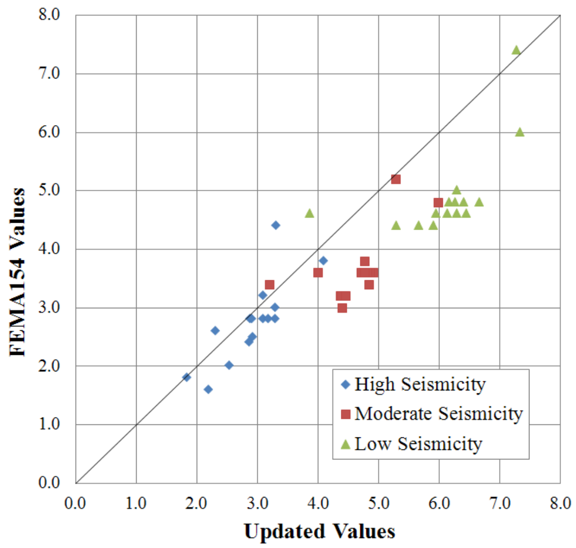

Figure 3: Comparison between the basic structural hazard scores of FEMA154 and recalculated values with updated capacity spectrum method.

5.2 Spectral response acceleration values

FEMA154 targets seismicity of the United States. Three seismicity regions (high, moderate and low) are defined based on design spectral acceleration values for periods of 0.2 and 1.0 seconds, S(0.2s) and S(1.0s). Limiting values were taken from FEMA310 [34], ignoring local site effects. To determine the median spectral acceleration response values for each seismic region first each county was classified based on the maximum S(0.2s) and S(1.0s) values. The median of these maximum values was calculated for each region and used for the score calculations. The median values and the basic structural hazard scores and modifiers were recalculated [35] considering the seismicity of Québec's cities as specified in the 2005 edition of the NBCC [36], considering the same boundaries for the seismicity regions.

Although the spectral accelerations in Canada and the United States are calculated with the same probability level, 2% in 50 years, there are differences in the calculations that account for cross-border inconsistencies, as for example the use of the median seismicity values in Canada versus the mean values in the United States. Furthermore when using FEMA154 in Canada, one difference in philosophy has to be addressed: in the United States the spectrum is reduced by 2/3 for design purposes [37], while in Canada this reduction is not used. This will have an impact on the calculated scores, and the use of the same limiting values that define the three seismicity regions is questionable, since they were conceived considering the reduction factor. When analyzing the case of the city of Montréal for example, a city identified as having moderate seismicity, with S(0.2s) = 0.69g and S(1.0s) = 0.14g for Site Class C, it was found that it would be classified by FEMA154 as moderate seismicity if applying the 2/3 reduction factor and high seismicity if not.

NRC92, although conceived for the Canadian context, has yet to be updated to consider the latest findings regarding seismic hazard. The seismicity used by the method is specified in the 1990 NBCC [38], with seismic hazard maps developed in 1985. The effective seismic zone of the site of interest is calculated according to the peak ground acceleration and peak ground velocity with probability of being exceeded of 10% in 50 years. New models were developed for the 2005 NBCC, which include latest findings related to historical seismic events, new attenuation laws, a better description of the site conditions and the explicit consideration of uncertainty [39].

5.3 Site classification

Design spectral accelerations are determined by the expected seismic excitation and local geotechnical conditions at the site. Both in the US and in Canada soil is classified into six categories, from type A to F, ranging from hard rock (type A) to poor soil (type F). For the classification of each type, the parameters used are the measured shear wave velocity or standard blow count. Ground motion amplification factors for short and long periods, F_a and F_v, dependent on the expected intensity of shaking, are defined for each site class. For the US, the reference soil is type B, meaning that F_a and F_v values are equal to one for soil type B [37]. In the seismic provisions of the 2005 NBCC, the American classification system was adopted with small changes. However the reference soil in Canada was defined as type C, to be consistent with previous editions of the NBCC [40]. Therefore F_a and F_v values for the same soil type are lower in Canada. This implies that when using FEMA154 with spectral acceleration values and soil definitions from Canada the site effects are overestimated.

The four different soil types considered by NRC92 have foundation factor F, ranging from 1.0 to 2.0. These factors, based on design practice of the time, do not consider the differences between short and long period responses and the influence of the intensity of shaking.

5.4 Configuration irregularities

The findings of the initial evaluation demonstrated that schools are complex structures: it was found that 80% of the examined buildings have some type of irregularity, with almost 40% having at least one vertical and one plan irregularity. While FEMA154 only differentiates between vertical and plan irregularities, NRC92 identifies seven different types of irregularity: vertical and horizontal irregularity (torsion), short concrete columns, soft story, pounding, major modifications and deterioration. The effect can be appreciated when studying the influence of different irregularities that can be classified as vertical (e.g., steps in elevation view, building on hill, soft story) on the score results. NRC92 classified 40% of school buildings with only one vertical irregularity as high priority and 70% with two vertical irregularities as high priority. Using FEMA154 the percentage of buildings in need of a detailed assessment was 90% and 100% for each these two case. This demonstrates that the NRC92 approach gives greater differentiation when more than one irregularity exists.

In FEMA154 score modifiers for vertical irregularities were based on engineering judgment. For high and moderate seismic zones, the modifiers were chosen so that if it were the only modifier considered, the final score would be below the cut-off score of 2. For low seismicity, modifiers similar to those of moderate seismic zone were adopted. For the calculation of the plan irregularity modifiers, an increase of 50% in the spectral acceleration response values was used. This approach seems appropriate when evaluating general building stock, where irregularities in plan and elevation should be rather uncommon. When evaluating schools however, due to the prevalence of configuration irregularities, a more detailed evaluation is desirable. Finding a balance between the simplicity of the method and the detailed identification of irregularities is challenging. An example on how this can be achieved can be found in the screening procedure of New Zealand [10]. Even in a first phase evaluation, four critical structural features have to be identified (plan and vertical irregularities, short columns and pounding potential) and the effect on the structural performance of each has to be classified as severe, significant or insignificant. Guidance on how to classify the severity is provided. For buildings with an L-shape plan, for example, the effect on structural performance is determined by comparing the length and the width of the wings.

5.5 Potential for pounding

When insufficient or no separation is provided between adjacent buildings they will likely suffer from pounding during a strong earthquake. This will induce high amplitude shock loadings, and experience in past earthquakes has demonstrated that this problem can even cause buildings to collapse. During the 1985 Mexico City earthquake, 15% of building collapses could be attributed to these severe pounding effects [41].

While FEMA154 doesn’t consider pounding, NRC92 incorporates it in calculating the score, and the limiting distance between buildings is defined in terms of the velocity related seismic zone (dependent on the expected peak ground velocity) and number of stories. Since the 2005 edition of NBCC stipulates the seismic demand in terms of spectral acceleration values only, other expressions have to be found.

Experience in past earthquakes has demonstrated that there are special circumstances where the effect of pounding is most critical. Adjacent buildings with different heights, periods and masses are the most vulnerable. Floors at different elevations will allow the slabs of one building to impact columns of the other building generating shear failure and partial or total collapse. In absence of these adverse factors, pounding usually will only induce local damage [42]. Given the high incidence of potential for pounding in the evaluated schools, the identification of the probable severity of damages is important in the rapid visual screening phase.

5.6 Non-structural components

Another important aspect considered by NRC92 while ignored by FEMA154 is the evaluation of non-structural components. Solving non-structural component related problems is not only a cost-effective first step for retrofit, these problems can also be life-threatening or produce injuries while not leading to collapse of the structure. Furthermore, if the installations should be operational immediately after the event, as is the case with post-critical shelters, non-structural damage should be limited. In a moderate seismic zone non-structural damage can be more widespread than structural damages or collapse, as has been demonstrated by experience in past earthquakes in Québec [26].

The initial evaluation highlighted the extensive use of heavy partition walls in schools, many of them made of unreinforced masonry blocks and often without restraint at the top of the walls. This is especially worrisome considering the potential life safety hazard that out-of-plane failure can cause even in a moderate earthquake. A detailed inventory of these walls must be made to better assess the risks. Key characteristics for wall performance include thickness, height and effective lateral support. The wall density and location will furthermore help to prioritize the cases where corrective measures are necessary.

5.7 Building importance

Schools fall into two distinct classes regarding importance: post-disaster shelters and ordinary schools which all belong to the post-critical building category according to NBCC. The different performance objectives should be acknowledged by the seismic screening method used. While ignored by FEMA154, NRC92 asks for the calculation of a building importance factor based on the occupancy and use of the building. For school buildings, the structural index is increased between 20 and 50%, compared with a normal occupancy building. For post-disaster buildings which have to remain fully functional after the earthquake, the increase is between 50 and 100%.

5.8 Cut-off scores

While FEMA154 only suggests one cut-off score, classifying a building either as safe or as requiring an in depth examination, NRC92 has four distinct categories: low, moderate or high priority for future intervention or potentially hazardous. This more detailed classification gives a better sense of the hazard of each building and the need for detailed evaluation.

The scores of FEMA154 are directly related to the probability of the building to collapse given the maximum considered earthquake. A score of 1 indicates a probability of collapse of 1 in 10 or 10%, a score of 2 a probability of 1%, a score of 3 a probability of 0.1%, etc. Based on these numbers a detailed ranking system is presented in Table 2, as used in the evaluation of schools and other critical public facilities in Oregon [43].

Classification	Probability of collapse	Score
Very high	100%	≤ 0.0
High	≥ 10%	0.1 – 1.0
Moderate	≥ 1%	1.1 – 2.0
Low	< 1%	> 2.0

Table 2: Proposed ranking to be used with FEMA154 [43].

6 IMPROVED SCREENING METHOD

The clear analytical procedure behind the score calculations of FEMA154 makes it possible to update and adapt the method to its use outside its intended scope. NRC92 on the other hand, based largely on expert opinion, is difficult to modify. The RVS method under development therefore uses FEMA154 as a template, modifying it to serve the purpose of evaluating schools in Québec. Some key features of NRC92 are being incorporated.

The scores and modifiers are being recalculated according to Equation 1, with spectral displacements estimated by the capacity spectrum method of FEMA440. The classification of lateral load resisting systems used is that of NRC92, analogous to FEMA154. The seismicity is represented by Montreal's acceleration response spectrum and local site conditions are considered by using the corresponding Canadian ground motion amplification factors F_a and F_v specific to Montréal's seismicity.

Major changes will be introduced in the treatment of irregularities. The classification used in the NRC92 procedure will be adopted, since it covers the findings of the initial evaluation of the schools. Furthermore, the effect of each type of irregularity on the seismic performance was classified as severe, significant or insignificant. The detrimental effect of the irregularities will be represented by increased spectral response acceleration values.

The evaluation of architectural components (partitions, cladding and exterior finishes) will be included, using the findings of the detailed examination of the unreinforced heavy partition walls to define the appropriate screening mechanism.

7 CONCLUSIONS

The following conclusions were made from this preliminary study:

- The importance of having earthquake resistant schools has been discussed. Not only do schools have unique occupancy characteristics, but they play a key role in response and recovery efforts after a seismic event. Unfortunately they tend to be especially vulnerable.
- In the province of Québec, a moderate seismic zone located in eastern Canada, efforts are currently being made to assess the potential performance school buildings. Seismic screening is appropriate as a first phase of the vulnerability assessment, since with around 3600 schools, a detailed evaluation for each building is not feasible.
- Two seismic screening methods are relevant when evaluating seismic vulnerability of buildings in Canada: NRC92, developed nationally and FEMA154, developed in the US, having similar construction and design practices. Both methods were used to evaluate 16 school campuses comprising around 100 independent buildings located in the city of Montréal. According to the method in FEMA154, 65% of the buildings should undergo a detailed evaluation. With the NRC92 method, 34% of the buildings were classified as having high priority for future intervention and 16% as potentially hazardous. Results of both evaluations are in reasonable agreement.
- Data indicates that school buildings are generally low-rise and have a limited number of types of lateral load resisting systems. Features that could affect seismic performance are common. This characterization is in accordance with findings of similar studies in other countries, and could explain the large proportion of damage to schools observed in past earthquakes.
- The methodologies employed for the score calculation of both evaluated screening methods are outdated. NRC92 is largely based on expert opinion and therefore difficult to update. On the contrary FEMA154, based on the capacity spectrum method, can be revised to include latest findings. An average increase of 24% on the basic structural hazard scores was obtained when updating FEMA154, with higher scores indicative of a better performance. The clear analytical procedure behind FEMA154 also makes it possible to adapt the method to its use to other countries.
- The high incidence of irregularities (80% for the evaluated schools) makes their detailed evaluation essential. FEMA154 groups the irregularities in two categories and quantifies their effect estimating the worst possible scenario. This not only fails to capture each building's specific characteristics, but also leads to over-conservative results. NRC92 partly overcomes these shortcomings defining seven different types of irregularities.

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