



Evaluating Seismic Vulnerability of Residential Buildings by Rapid Evaluation Method (REM)

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26.1 Introduction

Increased development and urbanization of a city may cause higher risk from seismic events, even in areas of moderate seismicity, such as the area of investigation of the present study. The city of Jeddah in Saudi Arabia is expanding rapidly in terms of building and population. The objective of the study is to specifically address the rapid evaluation of many buildings in Jeddah with steps to determine hazard, assess building stock, and compute vulnerability through a scoring method.

Earthquake hazard mitigation research focuses on evaluating potential building damage scenarios from different magnitude events. The methods facilitate prevention by gathering information about building condition and expected damage so that the most vulnerable buildings can be strengthened to mitigate risk (Shah et al. 2018). When many buildings are too irregular and have a wide variety of material properties, comprehensive structural analysis and evaluation are time-consuming. Alternative methods have been applied in many cases and provide a

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S. Dhiman, R. Samaratunge (eds.), *New Horizons in Management, Leadership and Sustainability*, Future of Business and Finance,
https://doi.org/10.1007/978-3-030-62171-1_26

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reasonable compromise of time, cost and efficiency. The visual screening method, a low-cost or cost-effective method developed by researchers, is based on the inspection of structural systems, time and mode of construction, and materials used. Assessing buildings by means of the rapid evaluation method (REM) requires less expertise and time. As a preseismic assessment tool, score assignments from REM may be applied to evaluate the relative vulnerability of structures in a neighborhood. This study follows previous research methods and interprets score assignment values of FEMA (2002) to buildings in the case study area with a research question: to what extent can the rapid evaluation method (REM) assess the vulnerability of residential buildings in Jeddah?

26.2 Evaluating Vulnerability

The seismic vulnerability of building stock can be determined by expert opinions offering the possibility to estimate damage before an earthquake occurs. For the assessment, one of the main ingredients in a loss model is an accurate, transparent, and conceptually sound algorithm to assess the seismic vulnerability of the building stock, and in fact many tools and methodologies have been proposed over the past 30 years for this purpose (Calvi et al. 2006). In the case of analytical approaches, vulnerability is expressed as a critical acceleration causing a damage mechanism to occur based on the identification of collapse mechanisms, yielding the equivalent shear capacity (Benedetti and Pezzoli 1996). Detailed analyses are time-consuming, and these evaluations correspond to the methods of structural analysis and design. The main disadvantage is that they should be performed for every investigated building individually; therefore, alternative methods have been developed to enable the rapid evaluation of large building stock.

Visual screening methods, based on systems calibrated by experts, allow for the quantification of structural vulnerabilities more easily than do analytical approaches. There is no need for detailed calculations and multiple scenarios. In the case of observed vulnerability (Haddar 1992; Castano and Zamarbide 1992), the damage is defined as a ratio of the replacement cost or the degree of loss of all affected buildings considering the number of casualties, too. The relationship between damage and earthquake intensity is valid only for the region where it was developed. Another method is to ask experts to estimate the expected percentage of damage caused by a given intensity, which is implied in macroseismic scales, e.g., the European macroseismic scale (EMS) (Grünthal 1998). These scales are used to evaluate the possible damages after an earthquake (Fäh et al. 2001).

Score assignment methods determine seismically hazardous structures by identifying structural deficiencies. Quantitative information is gathered to determine the level of damage according to the severity of a potential seismic event. Potential structural deficiencies are identified from observed correlations between damage and structural characteristics. The main aim is to determine if a building needs a more detailed investigation or not. Score assignment methods have been successfully applied recently to seven European cities in the RISK-UE European project

(Mouroux et al. 2004). In Japan, the JBDPA (Japanese Seismic Index Method) describes three seismic screening procedures to estimate the seismic performance of a building: a seismic performance index (strength, ductility etc.), time-dependent deterioration of the building, and a seismic judgment index for the safety of structure (Fukuyama et al. 2001).

26.3 The REM Procedure

The REM procedure can be used for ranking a neighborhood's seismic rehabilitation needs by designing seismic hazard mitigation programs, developing inventories of buildings with specific seismic vulnerability information, planning postearthquake building safety evaluation efforts, and determining insurance ratings. The REM approach relates common building structural, material and construction features to the seismic building capacity curves. The building capacity curve (also known as the push-over curve) is a plot of a building's lateral-load resistance as a function of some characteristic lateral displacement. This is derived usually from a static push-over analysis that defines the relationship between static equivalent base shear versus a building's roof displacement. Standard building capacity curves for different classes of buildings have been developed from many possible combinations of structural systems and materials. It is assumed that the final push-over state corresponds to building collapse or ultimate limit state. The capacity curve of the building is compared to the demand spectrum corresponding to a low-, moderate-, or high-demand seismic event. Depending on the relation between the capacity (resilience) of the building and the demand (intensity) of the seismic event, the building will have some probability of collapse. A low capacity with high demand will generate a high probability of collapse, while a high capacity with low demand will generate a low probability of collapse.

The REM procedure by commonly used methods (EMS, FEMA 155) does not require the performance of any structural analyses; rather, the evaluator must collect data to determine (i) the primary structural lateral-load-resisting system scoring with a basic structural score and (ii) building attributes that modify the seismic performance expected of this lateral-load-resisting system, such as applied code, height, irregularity of the building, and soil conditions. To complete the evaluation process, a wide variety of data is required. The collected data are classified (grouped) into one of many (perhaps as many as ten) categories. An essential step in a risk analysis is to ensure a uniform interpretation of data and results. When dealing with vulnerability models, the classification system should group together structures that would be expected to behave similarly during a seismic event. The need for a deeper diversification of building behaviors has led to more elaborate classification systems, where consideration is given to primary parameters affecting building damage and loss characteristics, such as the basic structural system, the seismic design criteria (code level), the building height (low-rise, midrise, high-rise), as well as nonstructural elements affecting nonstructural damage. For masonry buildings, the EMS (European Microseismic Scale) classification considers seven typologies, various

materials, techniques of installation, and construction. FEMA 155 classifies masonry structures according to reinforcement only. The detailed EMS classification was not needed in the study because this type of building in Jeddah would fall into the category of “unreinforced masonry”, regardless of its other features.

For reinforced concrete, the EMS differentiates the construction only about the seismic-resistant system (frame or shear wall); FEMA also determines one more category for RC: a concrete frame with unreinforced masonry infill, which is typical of this region as well. These differences favored the use of FEMA 155 for this research tailored to the most used building construction of the area and creating a checklist. According to FEMA 155, the probability of collapse is represented by a Basic Structural Hazard Score (BSH), which represents the average probability of surviving a seismic event, the maximum considered earthquake (MCE) (Eq. 26.1). The BSH scores are estimated from the building fragility and capacity curves of the HAZUS Technical Manual (NIBS 1999), representing an ‘average’ score for buildings in each class used for large-scale economic studies:

$$BSH = -\log_{10} [P(\text{collapse given MCE})] \quad (26.1)$$

Additional building features, so-called Score Modifiers (SMs) specific to that building, may increase or decrease the BSH score, resulting in the final Structural Score (S) (Eq. 26.2).

$$S = BSH \pm SMs \quad (26.2)$$

26.4 Data Collection

Conducting a cluster analysis with population and building data, two districts were selected for the investigation and to carry on a survey. The objective of the survey was to collect information on residential buildings in two districts. One of the districts represents a developing urbanized area, Al-Salamah, and the other a typical old area, Al-Balad. This selection offers the possibility to compare the vulnerability of buildings constructed according to different seismic codes and to make assumptions about the rest of the city based on typical structures of districts. In accordance with previous inventories for score assignment (Kegyegs-Brassai 2014) and knowledge about the most used building construction of the area, a checklist was prepared to group the building points into three major areas:

- Identification of the buildings (district, street, number)
- General data (age and function of the buildings, regularity in plan and elevation, the position of the building, changes in function, previous damages etc.)
- Structural data (construction system, quality of materials, workmanship); and
- Other remarks

The visual inspection was conducted by trained staff during the field survey done through the period of June to August 2016. Data were uploaded onto an online

Table 26.1 Main features of examined buildings

Analyzed buildings	Al-Balad	Al-Salamah
Number of buildings	308	714
<i>General building condition</i>		
Good	54%	81%
Minor restoration needed	46%	17%
<i>Construction period</i>		
1965–1975	32%	–
1976–1982	31%	6%
1983–2007	13%	64%
After 2007	1%	30%
<i>Structural system</i>		
Column beam system with fitted walls (steel, RC, wood)	12.34%	2.94%
Column beam system with infill walls (steel, RC, wood)	72.08%	95.66%
Load-bearing walls (masonry, stone, mixed, clay)	12.34%	1.26%
Others	3.25%	0.14%

interface with a total number of 1192 filled questionnaires (Shah et al. 2016). After a validation procedure, the remaining 1022 buildings (11–15% of the buildings in a district) were evaluated and scores were assigned based on FEMA 155. The primary findings (Table 26.1) show that the typical structure of the buildings was a column beam system with infill walls. The proportion of this type of building was even higher in the recently built area of Al-Salamah District (Shah et al. 2016).

26.5 The Database

The survey data were entered into an Excel spreadsheet. For some complex decisions, a series of evaluation functions were programmed in Visual Basic for Applications (VBA), which resides within the Excel software. These functions could read a building record, decide the basic hazard score, then read additional information to determine score modifiers. The only general requirement was that the building records remained consistent in their description of the various features of the building. A similar set of VBA routines was developed for evaluating hazards in Gyor, Hungary (Kegyés-Brassai 2014), and more detailed information about the routines can be found there. Using the programmed functions also made it easier to detect data entry errors and to examine possible scenarios where soil types or building performance can be modified.

26.6 The Results

Classification of the buildings was the first step to perform in the analysis considering the vertical structure of the building and the material of this structure. Most structures were classified as concrete moment-resisting frames with infill walls (Table 26.2).

The basic structural score was determined for each building based on the visual inspection considering the structural system and the moderate seismicity of the region (Table 26.3).

Additional modifiers were applied to account for the proximity of neighboring buildings, construction practices, the building code used for the design, and plan/profile irregularities:

1. Vertical irregularity modifier was determined based on mass compactness or irregularity and the relation to adjacent buildings in the case of the older city part. There are strict rules according to new codes for the distance between the adjacent buildings from 1.8 to 2 m. However, in the Al-Balad area, the buildings are built closely having separate infill walls with a few centimeters of dilatation.
2. Construction code modifier was used in case of buildings built before 1983 with a pre-code modifier, and a post-code modifier was taken into account for buildings constructed after 2007 according to the new code. The Saudi Building Code was enacted in 2007.
3. Mid-rise modifier was determined for buildings having more than four stories.
4. Soil score modifier was evaluated based on interviews with a soil testing company (Al Jazar Consultant Office). According to their finding (Table 26.4), the typical soil is a mix of coral in the top level of the soil and *sabkhas* in most of the areas in Al-Salamah District. Mud soil is usually in Al-Balad District.

Soil type D was assumed for this analysis based on information from soil testing companies and publications concerning the soil analysis of the area.

Based on BSH scores and score modifiers, a final structural score can be obtained. A final score greater than or equal to 2.0 would indicate that no further seismic

Table 26.2 Number of examined buildings concerning structural class

Analyzed buildings	Al-Balad	Al-Salamah
W1 (wood frame)	1	–
S3 (light metal buildings)	1	2
S5 (steel frame with infill walls)	–	5
C1 (concrete moment-resistant frame)	37	19
C2 (concrete shear walls)	9	6
C3 (concrete frame with infill walls)	176	676
RM1 (reinforced masonry)	46	2
URM (unreinforced masonry)	38	4
<i>Total</i>	308	714

Table 26.3 Typical BSH scores and examined buildings

BSH of analyzed buildings	Al-Balad	Al-Salamah
3,00	37	19
3,20	176	676
3,40	38	4
3,60	55	13
3,80	1	2
5,20	1	0
<i>Total</i>	308	714

Table 26.4 Soil analysis in Al-Salamah

Depth [m]	Soil type
1	Sand silt with mud and brownstone – medium density
2	
3	Coral crumbly has been extracted gravel or sand graded light grey to white – very incoherent to medium density
4	
5	
6	
7	
8	
9	Soft sand to an average roughness with brown silt – medium density
10	

Al-Mhaidib (2002)

evaluation is needed. Scores lower than 2.0 indicate that additional evaluation is warranted.

A bar chart of scores for Al-Balad and Al-Salamah are shown in Figs. 26.1 and 26.2. In Al-Balad, most of the 300 structures evaluated fall well below the 2.0 level, with some reaching a negative score. The distribution shown in Fig. 26.1 is typical when there are only a few varieties of buildings examined. This means that there is a limited combination of features and scores to be counted, and so there are four clusters of scores: the lowest around -0.7 , the next 0.4 , a third around 1.1 , and finally a few buildings at 2.3 . Negative scores would indicate unreinforced masonry construction of multiple stories with a “soft” ground floor, irregular plan or profile, and perhaps neighboring buildings directly attached to it.

In the newer Al-Salamah District, the buildings are generally reinforced concrete with masonry infill, built according to more recent codes, with a higher quality of construction. Most of the buildings pass the 2.0 score threshold. Since more than 700 buildings were examined in this district, the bar chart is somewhat misleading; there are still a significant number of structures below the 2.0 threshold.

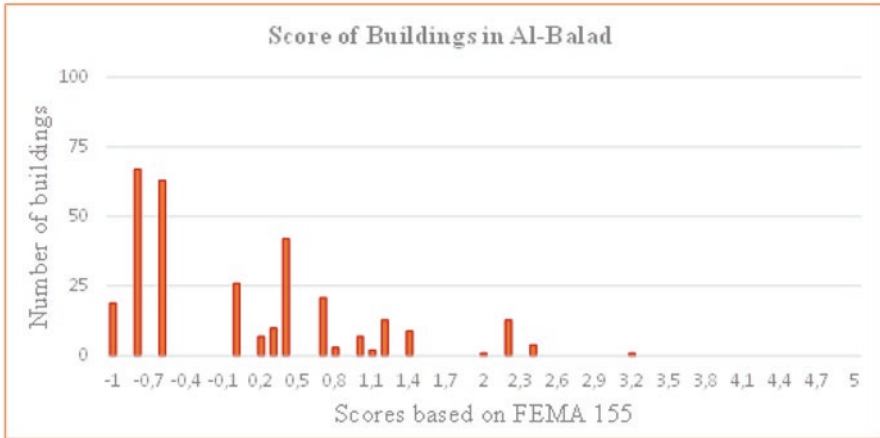


Fig. 26.1 Scores of buildings in Al-Balad District

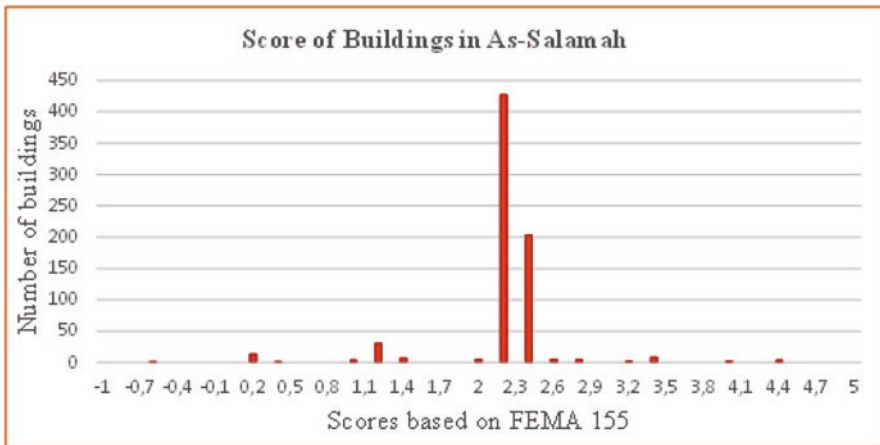


Fig. 26.2 Scores of buildings in Al-Salamah District

26.7 Comparison of Results

Figure 26.3 illustrates the influence of time of construction as well as the type of building. In Al-Balad District, most of the buildings are older, while in Al-Salamah District, a much higher percentage is newer construction. The impact is perhaps due to the changes to Saudi Arabian building codes in the 1980s and 1990s. The same trend can be found in many cities. Note that the tops of the two highest bars were shortened to fit the graph more easily. Thus, the applied REM could access the vulnerability of residential buildings in the study area and brought results for the relevant actors for further action.

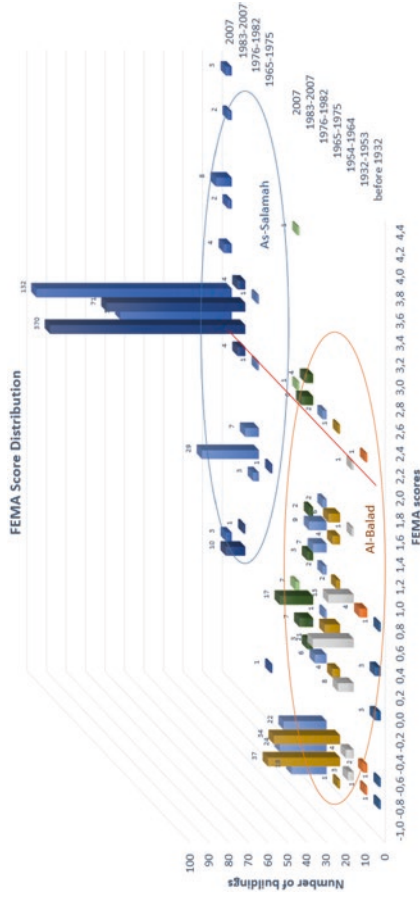


Fig. 26.3 Final Structural Score distribution of evaluated buildings

26.8 Conclusions and Further Research

Seismic risk is a public safety issue that requires appropriate risk management measures and intends to protect citizens, properties, and infrastructure. A seismic risk analysis aims to estimate the consequences of seismic events in an investigated area on a regional or state level. The evaluation demonstrates the relative ease and low cost of the REM system. Districts, or even city blocks, can be delineated on the basis of how much seismic rehabilitation will be needed. However, since most of the scoring is based on experience in the US and other countries, a more rigorous evaluation of structural performance under seismic loads would be helpful. Calibrating the scoring system to a specific building stock will create more confidence in the evaluation system.

The results of the investigation so far show the influence of age on expected seismic performance, the different levels of vulnerability, and the areas where intervention is needed. This is due mainly to the evolution of building codes, building material quality, and construction methods. Modern designs tend to be more regular in form as well. The presented case study is offering the steps that should be performed to determine the seismic risk of a city rather than being a finalized risk assessment for the city of Jeddah. This study offers the method that can be applied for further analysis of the city but stressing the clear differences of vulnerabilities for residential buildings constructed based on different seismic codes. Further research will be directed toward other districts in the city, as well as performing more rigorous analyses (pushover, dynamic response) on selected typical building types. Additional work on determining the impact of soft, *sabkhas* soils on the response of short, medium, and tall buildings is also necessary.

Lessons Learned

1. Earthquake hazard mitigation research is focused on evaluating potential building damage scenarios from different magnitude events.
2. Mitigation methods facilitate prevention by gathering information about building condition and expected damages, and therefore the most vulnerable buildings can be strengthened to mitigate risk.
3. If many buildings are too irregular and have a wide variety of material properties, comprehensive structural analysis and evaluation would be time-consuming and expensive.
4. Alternative mitigation methods could be applied to provide a reasonable compromise of time, cost, and efficiency.
5. The visual screening method is a low-cost or cost-effective method, which is based on the inspection of structural systems, time and mode of construction, and materials used. As a preseismic assessment tool, score assignments from REM may be applied to evaluate the relative vulnerability of structures in a neighborhood.

Reflection Questions

1. What is the focus of earthquake mitigation research for potential residential buildings?
2. What are the alternative mitigation methods that could be applied for residential buildings to provide reasonable time, cost, and efficiency?
3. What methodology could be applied to assess the seismic vulnerability of residential buildings in an easy and low-cost way?
4. What could be done for seismic vulnerable residential buildings by applying REM?
5. What could be the easiest application of vulnerability assessment method for residential buildings?

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