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Research Article

Seismic Risk Assessment for Sreemangal Town: Exploring the Use of Reliability-Based and RVS-FEMA 154 Methods for Building Safety in Bangladesh

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Abstract

In the present study, the vulnerability of the building stock of a small but important town (Srimangal Municipality under the Moulvibazar district of Bangladesh), located in the most earthquake-prone Sylhet region, was assessed. Besides, the applicability of two methods of vulnerability assessment (Reliability-Based Method and FEMA 154) for Bangladesh was also checked. 17.5% of the studied buildings were found vulnerable, and 65% of buildings were safe according to both methods. Most of the masonry buildings (85.71%) are at risk, as they are old and constructed before introducing Bangladesh National Building Code (BNBC) in 1993. For Bangladesh context, the Cut-Off Score of FEMA 154 was proposed as 1.5 instead of 2.0 in this study. The comparison between the two methods shows that the results obtained from the analysis were close enough to each other and both models gave reliable results. However, the lack of sophisticated damage data for the Reliability-Based Method could lead the results to be varied from the results obtained from another method. On the other hand, Basic Scores and Score Modifiers in FEMA set for developed countries might be calibrated for Bangladesh to decrease the result gaps. In conclusion, both methods were found suitable to use for vulnerability assessment of buildings in Bangladesh.

Keywords

Sreemangal, Sylhet, Earthquake, Basic Score, Vulnerability Assessment of Buildings, Reliability-Based Method, FEMA 154, Damage Study

1. Introduction and Background Study

Earthquakes are one of nature's deadliest, and most unpredictable events. Tectonic plate movement, volcanic activity, and man-made eruptions are the causes of sudden, powerful earthquakes. In recent times, earthquakes have occurred very frequently around the world. According to a report published by Dyvik (2024), due to the earthquake, the highest damage in history till now after 1980 occurred in Japan and the economic loss was equivalent to $34.2 billion [1]. It is observed that a

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large number of lives face death, and a vast number of structures are distorted in earthquakes and also natural landscapes.

Bangladesh is located near the boundary of two active plates, the Eurasian plate in the East and North and the Indo-Australian plate in the west. For this reason, the country is under threat of different magnitudes of earthquakes at any time. The Dauki Fault System near the northern boundary of Sylhet makes it a zone of high seismic risk.

Various methods have been used to determine the feasibility of earthquakes in this region. One such method is Gumbel's extreme value distribution method used by Ray et al. (2019). This probabilistic approach finds that the return period for an earthquake with a magnitude of more than 6.5 is 53 years and the likelihood of its repetition in 100 years is 85%. It has been noted that the probability of an earthquake of magnitude 7.0 or higher in 100 years for this region is 48.5% with a return period of 151 years [2]. Research work of Shadmaan & Popy (2023) was done to locate the vulnerable areas of Sylhet district. It shows that 9% area of the region falls under the high vulnerability category, 48% is high, 31% moderate, 4% low, and 8% is under the very low category [3]. A study was done by Ahmed (2007) on the present condition of the building, possible destruction, and proper technical measures for the alleviation of losses. The study found many of the buildings in the city area are old, non-engineered, without foundations, without continuous lintels, and of irregular shape [4]. A study by Sarkar et al. (2010) has shown that due to an M 7.6 earthquake 65% of the Sylhet City area will be affected by intensity X, 28% area will be affected by intensity IX, and 5.5% area will be affected by intensity VIII. Nearly 15320 buildings are expected to be damaged. There will be 47549 (about 15% of the total population) fatalities, and nearly 25875 (around 54%) will have major injuries (requiring hospitalization) [5]. There is also a study on the seismic safety of the school and college buildings of Sylhet City that has been carried out by Ahmed et al. (2011). This study is an outcome of the combination of the survey with the FEMA 154 Method and the Modified Turkish Method. It was found that 7.55%, 9.31%, and 11.36% of school and/or college buildings have been highly vulnerable to earthquakes when the distance of fault is within 9-15 km, 5-8 km, and less than 4 km respectively [6]. In the study of Mazumder and Ahmed (2011), buildings are classified in different damage grades for different intensities by using the European Macro-seismic Scale. It was found that at scale IX damage grade was G3, G4, and G5 with 60%, 26.7%, and 13.3% buildings respectively [7].

So, it is seen that several research works were performed on seismic vulnerability assessment for the Sylhet City and the whole region, but no work was found on Sreemangal Municipality which is also an important town in Sylhet region and experienced an earthquake (named as 'Sreemangal Earthquake') of magnitude 7.6 in 1918. The Epicenter of this earthquake was within the Sreemangal Upazila. The earthquake destroyed many brick buildings, bridges, and important infrastructures (Sabri, 2001) [8]. The intensity was so violent that it spread to Sylhet, Moulvibazar, and its surrounding region. It almost affected an area of about 74000 sq. km (Stuart, 1920) [9]. That is why the present study is important to evaluate the risk of earthquakes in Sreemangal town. Besides, the applicability of the two methods for vulnerability assessment established in the USA and Japan will be checked for the Bangladesh context through this study.

2. Objectives of the Study

1) To survey and categorize the building stock of the town
2) To identify the vulnerability of the buildings by different methods and suitability of application of the methods for vulnerability assessment in Bangladesh
3) To compare the results for understanding the validity of the assessment

3. Research Questions

1) What are the existing building parameters that can make the buildings vulnerable to earthquakes?
2) How many buildings in the town are vulnerable to earthquakes and to what extent?
3) How much do the assessment results performed by different methods (developed in the United States and Japan) differ and why?
4) To what extent are the vulnerability assessment approaches developed in the United States and Japan acceptable for Bangladesh?

4. Methodology

4.1. Study Area

Sreemangal (Figure 1) is a rapidly growing municipality which is positioned in the northeast region of Bangladesh under the Moulvibazar district. It is located at 24.3083^{o} North 91.7333^{o} East. Sreemangal, a British-era municipality (founded in 1935), is classified as an "A" class municipality. It is a significant urban hub in the region which is famous for tea gardens, tourism, and trading. The Municipality has a total area of 2.58 square kilometers and a population of 40,753 (Islam, 2018) [10]. Sreemangal is in the Bengal basin covering most of Bangladesh and part of India. Because of the intricate interpolated tectonic context and the junctions between the Indian shield and the methodically folded Indo-Burma range, it is seismically active (Karim et al., 2021) [11].

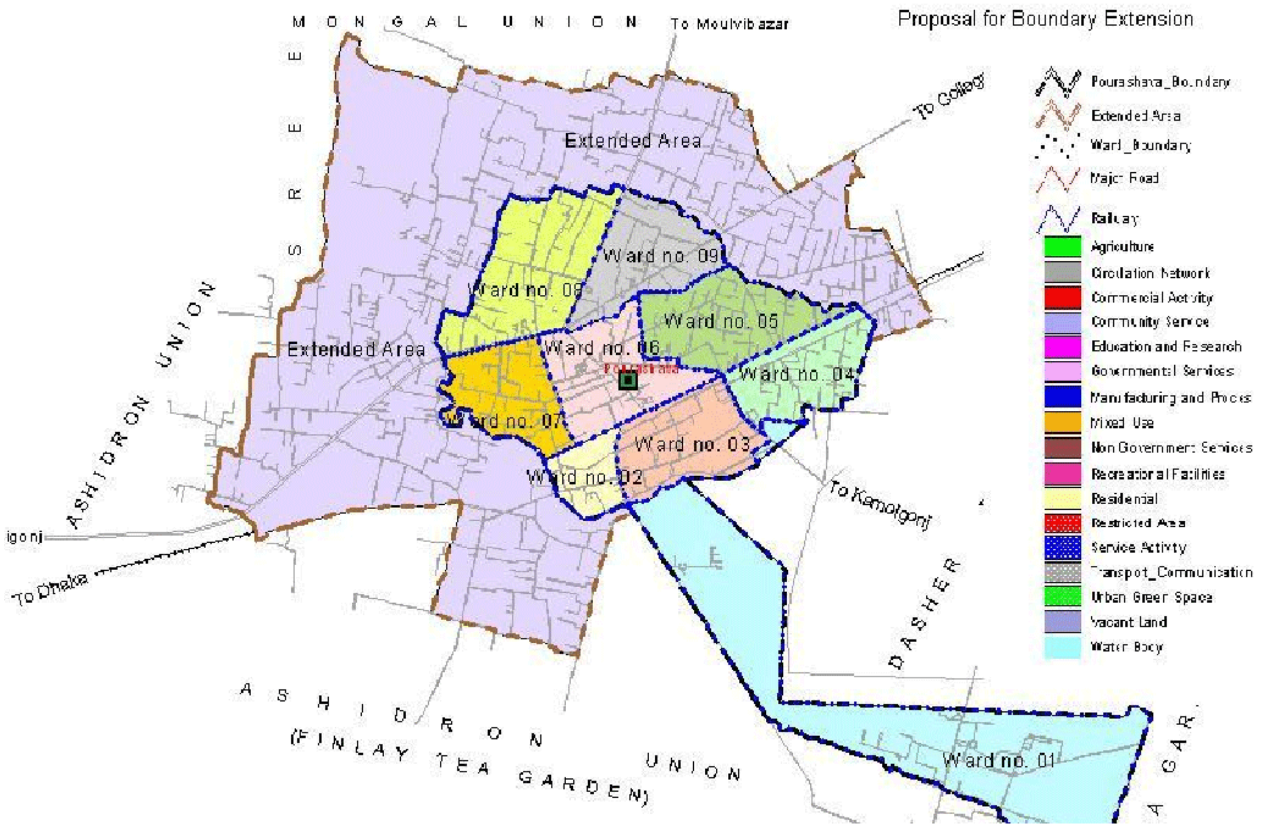

Figure 1. *Map of Sreemangal municipality (source: google.com).*

4.2. Methods of Vulnerability Assessment

Two methods have been used in this study for seismic evaluation. These are the Reliability-Based Model (RBM) and Rapid Visual Screening (RVS).

4.2.1. Reliability-Based Model (RBM)

This method is a different way to define the damage state. It engages strength-related damage indices and doesn't involve any response analysis of the structure. The model is parallel to that proposed by Shibata (l980) [12]. It considers the seismic resistance capacity of the existing buildings and the potential seismic force on them to assess the seismic risk. This model engages the building resistance characteristics and ground motion properties particular to Japan which introduces a Seismic Resistance Index and a Seismic Force Index. It denotes the probability of occurring a certain level of damage by comparing the seismic resistance index and force index. It is assumed that the indices for the seismic resistance capacity of buildings in the area and the earthquake force exerted on buildings are both modeled by random variables having certain probability distributions.

The probability of failure in a Reliability-Based Model can be expressed as follows:

$$P\text{ (Failure)} = P\text{ (Quantity of resistance} \leq \text{Quantity of force)} \quad (1)$$

The methodology of Shiga (1977) is used to develop a Seismic Resistance Index [13]. This is the ratio of total shear force exerted on the structure to the weight of the structure. To find out the nominal value for the total shear force exerted in a structure there are three indices as follows:

$$\text{WI} = \frac{A_w}{\Sigma A_f} \quad (2)$$

$$\text{CI} = \frac{A_c}{\Sigma A_f} \quad (3)$$

$$\tau_{avg} = \frac{F}{A_c + A_w} \quad (4)$$

Here, WI = Wall Index, CI= Column Index, τ_{avg} = The average shear stress on column and wall (kg/cm^2), A_w = Total area of the reinforced concrete wall in one direction on the first floor (cm^2), A_c = Total area of the columns on the first floor (cm^2), $\sum A_f$ = Total floor area (m^2).

In the present study, the analysis by Shiga (1977) of the observed damage to low-rise reinforced concrete buildings around Hachinohe and Misawa cities in the 1968 Tokachi-Oki Earthquake has been considered [13]. It may be assumed that the present structural behavior of the buildings in Bangladesh is likely to be the structural condition of the buildings in Japan in 1968 as there are no damage studies on Bangladesh are available.

From the observation, in the event of the 1968 Tokachi-Oki Earthquake, most of the severely damaged reinforced concrete buildings had only a small amount of walls, an investigation was undertaken on the relation between the extent of earthquake damage and the number of walls in reinforced concrete low-rise buildings located in the eastern part of Aomori Prefecture of Japan, e.g., Hachinohe city and Misawa city where damage to the building was most severe (Shiga, 1977). A value of 1.00 and 1000 kg/m^2 for lateral base shear coefficient and average unit floor weight of the buildings are respectively adopted by Shiga for that region [13]. To calculate the nominal shear strength of the buildings the average shear stress is plotted versus wall and column area indices to see the distribution of the damage patterns. Using the resulting plots, two critical values of the average shear stress that separates the damaged and undamaged buildings are found. One value demonstrates the shear stress on the walls and the other on the columns. From Figure 2 it is seen that most of the undamaged buildings have a Wall-Area Index of more than 30 cm^2/m^2 as well as the average shear stress is less than 12 kg/cm^2. When the Wall-Area Index is zero then the critical value of average shear stress which divides the damaged and the undamaged buildings is supposed to be 12 kg/m^2. This value is the nominal ultimate stress of columns. Again, when the Column-Area Index is zero then the critical value dividing the damaged and the undamaged buildings is 30 cm/m^2. For this value, the nominal ultimate stress of the wall is taken as 33 kg/m^2. So, the nominal lateral strength of any building is determined considering $12A_c$+$33A_w$.

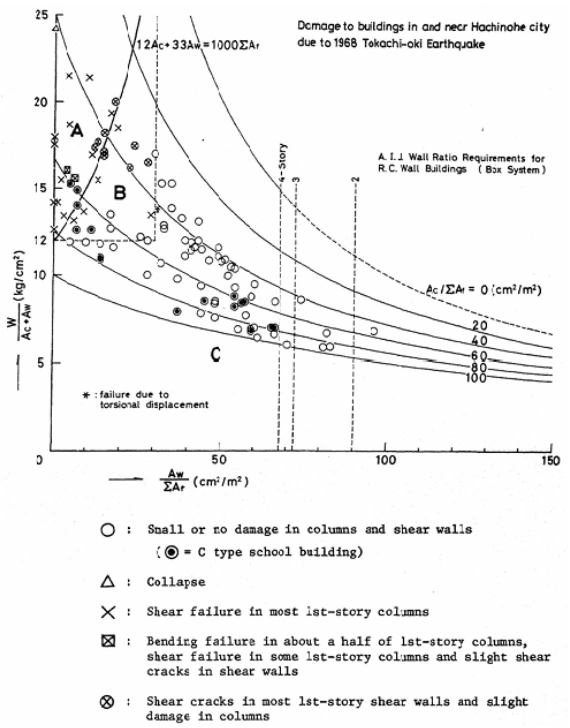

Figure 2. *Wall-Area index, Column-Area index, and Average Shear Stress in walls and columns (Shiga, 1977).*

The building structures observed in the present study for Sreemangal have no shear walls. So, the nominal ultimate stress of the wall is avoided and a new equation to find out the nominal lateral strength of the building structures in the study area considering only $12A_c$. The average unit floor weight of the buildings in Sreemangal is calculated as 741 kg/m^2. The Seismic Resistance Index C_R is the ratio of total shear force exerted on the structure to its weight. C_R is calculated from the following equation:

$$C_R = \frac{12A_c}{741\sum A_f} \tag{5}$$

Dynamic properties of the buildings (such as sub-soil condition, period, damping), ground motion intensity (in terms of peak ground acceleration or peak ground velocity), and the return period are the factors for determining The Seismic Force Index C_S. The following equation was used to calculate C_S (Askan, 2002) [14]:

$$C_S = \mathrm{S(T)}.\ \gamma.\ \frac{A_{max}}{g} \tag{6}$$

Where S(T) is the spectrum coefficient as a function of the characteristics period associated with the local site condition and building natural period 'T'. T = Fundamental period of vibration in seconds. S(T) was defined considering the guidelines of the Bangladesh National Building Code (BNBC 2020). The soil condition of the study area is floodplain soil (Islam, 2018) [10]. Site class- SD (Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil) is considered. The value of gravitational acceleration, g is 9.81 m/s^2. A_{max} is the maximum ground acceleration. The value of A_{max} for the study area is 0.18g (Sarkar et al., 2010) [5]. γ is a reduction coefficient that depends on the function of the damping factor, h. In this study damping factor is assumed as 5%. It is expressed as follows (Shibata, 1980) [12]:

$$\gamma = \frac{1.5}{1+10h} \tag{7}$$

The probability of damage is assessed by comparing the Seismic Resistance Index and the Force Index and is expressed as follows (Askan & Yucemen, 2010) [15]:

$$\mathrm{P\ (Failure)} = \mathrm{P}\ (C_R \leq \alpha Cs) \tag{8}$$

Where α is a damage state factor which expresses the level of damage and taken as in Table 1. So, a building can be categorized as shown in Table 2 to identify its vulnerability.

A detailed analysis of the buildings may be required when the C_R value is equal to or below the Cs value of moderate state and those buildings are identified as vulnerable buildings.

Table 1. *Damage State Factor.*

Damage state	Damage State Factor, α
Light	2.00
Moderate	1.00
Severe	0.58

Table 2. *Classification of buildings according to C_R and C_S values.*

Condition	Damage state
$C_R > 2C_S$	Not vulnerable
$C_S < C_R \leq 2C_S$	Light
$0.58\ C_S < C_R \leq C_S$	Moderate
$CR \leq 0.58\ Cs$	Severe

4.2.2. Rapid Visual Screening (RVS)

A quick assessment of buildings may be carried out by Rapid Visual Screening (RVS). This process includes a quick visual assessment and the collection of data about the building from the owner, maintenance staff, and records of the local building department to pinpoint the buildings' weak points. The Federal Emergency Management Agency (FEMA) of the USA published a guidebook in 1988 that contained the RVS process, named FEMA 154, which is currently in use in California, USA.

Bangladesh is a developing country where the infrastructure is not as advanced as in the USA. The present infrastructure of Bangladesh cannot be compared with that of the USA. So, although FEMA 154 was updated several times after its launching, an older version of FEMA (2^{nd} version of FEMA 154, published in 2002) was taken in this study to evaluate the buildings [16].

Each building is given a Basic Score that is based on the building's observed earthquake performance and lateral load-resisting structural system. This Basic Score is modified by some observed parameters to get the Final Score. The parameters considered in the RVS are seismic hazard intensity, building type, height of the building, soil type in the foundation, plan irregularity of the building, vertical irregularity of the building, and conformity to the seismic building code in the design. The total of the fundamental score and the modifiers determines the final score. As the observed buildings were Concrete Moment Resisting Frame (C1) and Un-reinforced Masonry (URM), Basic Scores were taken as 2.5 and 1.8 respectively (considering the high seismicity region).

One of the important parameters for earthquake vulnerability assessment is to identify whether existing seismic code was used for design. As BNBC (Bangladesh National Building Code) was first published in 1993, it is assumed that buildings constructed before 1993 (Pre-Code Year) were designed without using proper seismic codes. On the other hand, The Government promulgated the Building Code as legally binding on all concerned by S.R.O. No. 84-Law/2006 dated 22 May 2006 published in the Bangladesh Gazette on 15 November 2006. So, the year 2006 was taken as the Post-Benchmark year.

FEMA fixed a Cut-Off Score to distinguish vulnerability categories. If the Final Score of a building is more than the proposed Cut-Off Score, the building will show appropriate seismic performance. On the contrary, if a building has a Final Score equal to or below the Cut-Off Score, the building may be vulnerable to earthquakes, and design professionals with expertise in earthquake design should examine it. The Cut-Off Score depends on the economic condition of the country and the current seismic design standards. Based on current seismic design requirements, a score of 2.0 is recommended by FEMA as a Cut-Off Score which is mainly used for developed countries e.g., the United States.

5. Findings of the Study and Discussion

5.1. Building Inventory Survey

5.1.1. The Number of Stories

Invention is conducted on the 40 surveyed buildings in the study area, to check whether the surveyed building stock represents building inventory. Figure 3 shows the analytical description of the study. It is seen from the graph that the maximum buildings are two-story (45%), followed by three-story (25%).

5.1.2. Types of Buildings According to Load Bearing Capacity

Among 40 buildings, MRF (Moment Resisting Frame) type buildings were found to be 31 (77.5%), and URM (Un-reinforced Masonry) type buildings were found to be 9 (22.5%).

5.1.3. Foundation Type

The foundation types are divided into 4 groups in the study area. Most of the surveyed buildings have column footing (57.5%). Other buildings have brick footing (22.5%), raft foundation (2.5%), and RCC pilling (17.5%).

5.1.4. Pre-Code and Post-Benchmark Status

Among the surveyed buildings 32.5% of buildings were constructed before the Pre-Code Year. 37.5% of buildings were built in and after 2006, the Post-Benchmark Year.

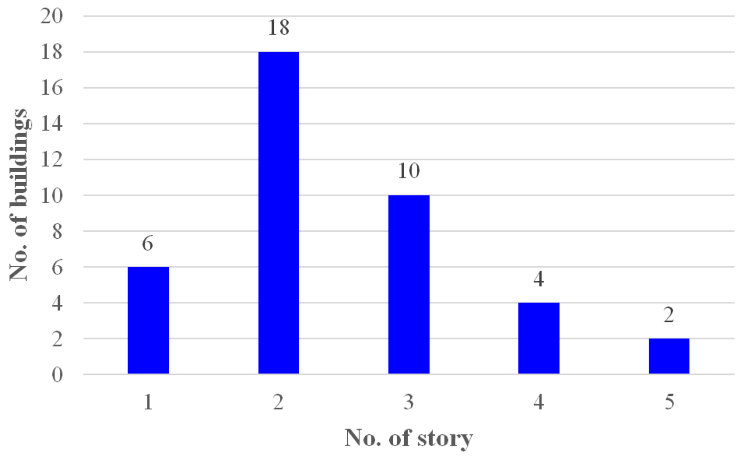

Figure 3. No. of story vs. no. of buildings.

5.2. Results from the Reliability-Based Model

After calculating the Seismic Resistance Index and the Seismic Force Index of the surveyed buildings and comparing the values according to Table 2, the vulnerability level of the buildings was determined. Tables 3 and 4 show the vulnerability level of the building according to no. of story and structural system respectively.

Table 3. Results of Reliability-Based Model according to no. of stories.

No. of stories	Not vulnerable	Light	Moderate	Severe	Total
1	0 (0%)	2 (33.33%)	3 (50%)	1 (16.67%)	6 (100%)
2	9 (50%)	5 (27.78%)	4 (22.22%)	0 (0%)	18 (100%)
3	6 (60%)	4 (40%)	0 (0%)	0 (0%)	10 (100%)
4	4 (100%)	0 (0%)	0 (0%)	0 (0%)	4 (100%)
5	2 (100%)	0 (0%)	0 (0%)	0 (0%)	2 (100%)
Total	21 (52.5%)	11 (27.5%)	7 (17.5%)	1 (2.5%)	40 (100%)

Table 4. Results of Reliability-Based Model according to building types.

Types of buildings	Not vulnerable	Light	Moderate	Severe	Total
MRF	21 (67.74%)	10 (32.26%)	0 (0%)	0 (0%)	31 (100%)
URM	0 (0%)	1 (11.11%)	7 (77.78%)	1 (11.11%)	9 (100%)
Total	21 (52.5%)	11 (27.5%)	7 (17.5%)	1 (2.5%)	40 (100%)

It is observed that the one-story and two-story buildings are more vulnerable. Among the one-story buildings, 66.67% and among the two-story buildings, 22.22% fall under the moderate to severe category. This is because most of the dwellers of low-rise buildings in Sylhet region do not bother about proper design and construction. 88.89% of masonry buildings were found vulnerable (moderate to severe), as most of the masonry buildings are very old and all of them were constructed before introducing BNBC in 1993.

For the comparisons of methods "Not Vulnerable" and

"Lightly Vulnerable" are considered as "Not Vulnerable", as well as "Moderate" and "Severe" are supposed to be "Vulnerable" in the Reliability-Based Model. So, 20% of total buildings belong to the vulnerable category according to this model.

5.3. Results from RVS- FEMA 154

Tables 5 and 6 show the summary of results according to the number of stories and building types. It is found that 37.5% of buildings are vulnerable according to FEMA.

FEMA also revealed that the one-story and two-story buildings are more vulnerable than others. Among the one-story buildings, 83.33% and among the two-story buildings, 38.89% achieved a Final Score ≤ 2. It is observed that most of the MRF buildings have a Final Score greater than 2, hence not vulnerable. On the other hand, no score for URM buildings is greater than the Cut-Off Score according to the FEMA method and all these buildings are vulnerable.

According to FEMA instructions, buildings with a Final Score ≤ 2 require further detailed analysis for vulnerability to determine the level of actual risk.

Table 5. Results of the FEMA 154 according to no. of stories.

No. of stories	Final Score > 2	Final Score ≤ 2	Total
1	1 (16.67%)	5 (83.33%)	6 (100%)
2	11 (61.11%)	7 (38.89%)	18 (100%)
3	7 (70%)	3 (30%)	10 (100%)
4	4 (100%)	0 (0%)	4 (100%)
5	2 (100%)	0 (0%)	2 (100%)
Total	25 (62.5%)	15 (37.5%)	40 (100%)

Table 6. Results of the FEMA 154 according to building types

Types of buildings	Final Score > 2	Final Score ≤ 2	Total
MRF	25 (80.64%)	6 (19.36%)	31(100%)
URM	0 (0%)	9 (100%)	9 (100%)
Total	25 (62.5%)	15 (37.5%)	40 (100%)

5.4. Comparison Between the Reliability-Based Model and the RVS Model- FEMA 154

5.4.1. Qualitative Comparison

A comparative review of the two methods has been demonstrated here about the aspects considered in each of the methods. An especial attention is paid to the applicability of the methods in Bangladesh. FEMA 154 data collection form includes building information (size, use, etc.), sketches, photographs, and relevant data that help to develop the inventories of the building. The advantages of FEMA 154 are its simplicity, quickness, relatively low cost, and provision of effective estimates to assess future planning. However, it gives the results only in terms of the structural score without any explanation or specification for a particular building type and incorporates only Pass or Fail results, which is its shortcomings. The Reliability-Based Model engages a few simple structural and geotechnical parameters. The scores for the Reliability-Based Model are dependent on floor area, total column area on the first floor, spectrum coefficient, and maximum ground acceleration. The Seismic Resistance Index increases with the increase in total column area on the first floor. The increasing number of stories increases the Seismic Force Index. The Seismic Resistance Index is obtained from the analysis of the observed damage to reinforced concrete buildings after an earthquake. The Resistance Index is based on the relation of earthquake damage to wall or column ratio as well as nominal shear stress in columns and shear walls. Thus, the resistance capacity can be calculated and the prediction of the extent of earthquake damage is made. As there is no proper damage study in Bangladesh, so for finding out the damage probability of the buildings by applying this method may not be appropriate. The advantages of the Reliability-Based Model are also its simplicity and relatively low-cost to gather the field data. But sometimes the method becomes somewhat tougher as residents of the buildings do not co-operate the screeners and restrict their entry to the house to take some very important data like structural measurements. FEMA 154 and Reliability-Based Model both conform to the requirements of modern seismic design codes. In Bangladesh, the building design code has been initiated in 1993. So, in most cases, buildings have been constructed by following the procedures of building codes with some exceptions. Hence, it can be said that these methods may be suitable for countries like Bangladesh where seismic design codes are of practical use.

5.4.2. Quantitative Comparison

The Reliability-Based Model shows that (Figure 5) 20% of buildings are vulnerable while FEMA 154 shows that 37.5% of buildings are vulnerable. In both methods, the percentage of vulnerable buildings is lower than those of not vulnerable. According to Tables 4 and 6, among URM buildings, 88.89% are vulnerable in RBM, while 100% are vulnerable in FEMA. On the other hand, among MRF buildings, 0% are vulnerable in RBM, while 19.36% are vulnerable in FEMA.

A comparison can be made for the assessment of each individual building too. In Figure 4, a comparison has been made taking the Cut-Off Score 2 to see how many buildings show the same or different damage state in both methods. It is found that 20% of total buildings are vulnerable according to both methods, while 62.5% of buildings are not vulnerable in both methods. Overall, 82.5% of buildings demonstrate the same damage state in both methods. However, results for 17.5% of buildings do not match (vulnerable according to one method, while not vulnerable according to another method).

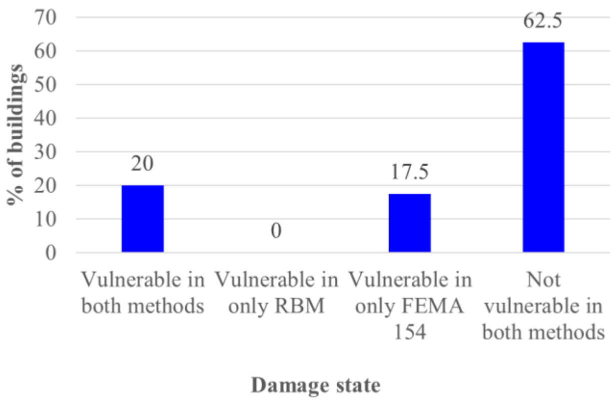

Figure 4. Comparative result of damage state in both methods (FEMA Cut-Off Score 2).

5.4.3. Modification in FEMA 154 and Revised Quantitative Comparison

It is seen from previous discussions that there are significant differences in the outcomes of the assessment methods. To minimize the differences, a modification in Cut-Off Score can be suggested.

Considering Bangladesh's construction practices and economic condition, the Cut-Off Score for buildings can be taken as 1.5 (Ahmed et al., 2022) [17]. Therefore, a score of 1.5 indicates a chance of 1 in $10^{1.5}$ that the building will collapse. Considering the Cut-Off Score of 1.5, the results are given below in Tables 7 and 8.

Table 7. Results of FEMA 154 according to no. of stories considering Cut-Off Score of 1.5.

No. of stories	Final Score > 1.5	Final Score ≤ 1.5	Total
1	2 (33.33%)	4 (66.67%)	6 (100%)
2	11 (61.11%)	7 (38.89%)	18 (100%)
3	8 (80%)	2 (20%)	10 (100%)
4	4 (100%)	0 (0%)	4 (100%)
5	2 (100%)	0 (0%)	2 (100%)
Total	27 (67.5%)	13 (32.5%)	40 (100%)

Table 8. Results of FEMA 154 according to building types considering Cut-Off Score of 1.5.

Types of buildings	Final Score > 1.5	Final Score ≤ 1.5	Total
MRF	26 (83.87%)	5 (16.13%)	31 (100%)
URM	1 (11.11%)	8 (88.89%)	9 (100%)
Total	27 (67.5%)	13 (32.5%)	40 (100%)

The new results are more aligned with RBM and Bangladesh context. Figure 5 demonstrates that after considering the Cut-Off Score as 1.5, the percentage of vulnerable buildings decreases to 32.5%, which is closer to that of RBM (20%). The difference between the percentages of vulnerable buildings in the two methods is now only 12.5%.

Among URM buildings, 88.89% are vulnerable according to RVS (instead of 100%), while among MRF buildings, 16.13% are vulnerable according to RVS (instead of 19.36%) (Tables 6 and 8).

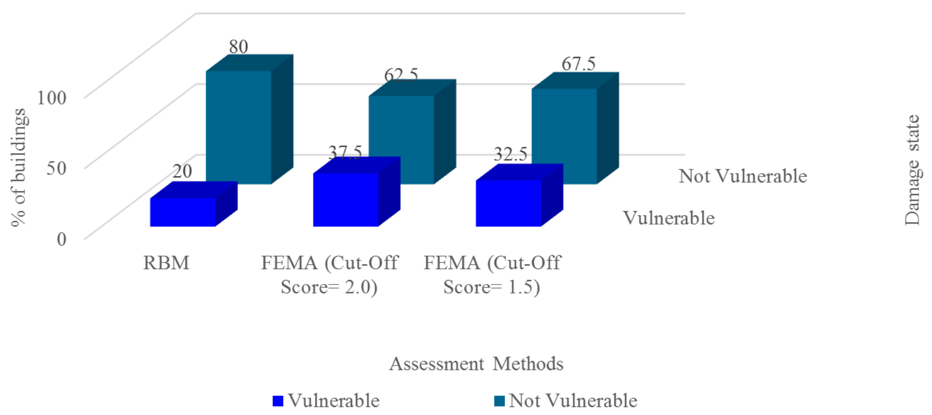

Figure 5. Comparative results of two methods.

The results of individual building assessments are shown in Figures 6 and 7. In Figure 6, a revised comparison chart was made considering the Cut-Off Score as 1.5. It is found that 17.5% of total buildings are vulnerable according to both methods (which was 20%). 65% of buildings are not vulnerable in both methods (which was 62.5%). Overall, 82.5% of buildings demonstrated the same damage state in both methods, which remained the same as before. However, results for 17.5% of buildings do not match. This value also remained the same but distributed among methods. Most of the masonry buildings (85.71%) are vulnerable according to both methods. In Figure 7, the vulnerability levels of individual buildings are shown (according to their ID) through a Ven diagram.

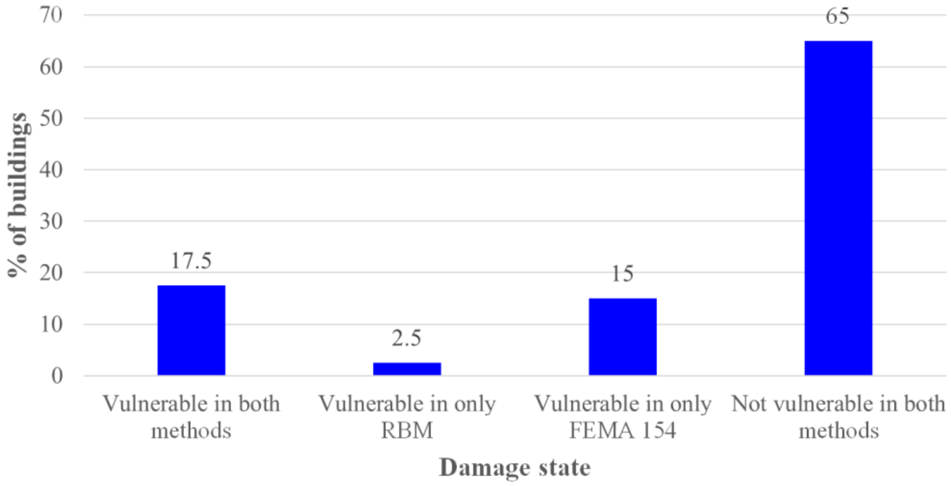

Figure 6. Comparative result of damage state in both methods (FEMA Cut-off Score 1.5).

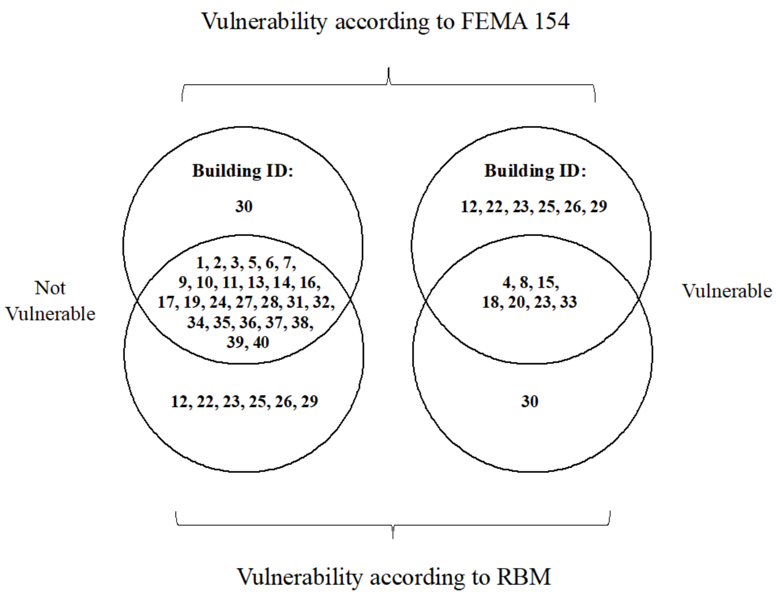

Figure 7. Damage states of individual buildings in both methods (considering FEMA Cut-Off Score 1.5).

6. Conclusion and Recommendations

In the present study, the vulnerability of the building stock of a small but important town, Sreemangal, located in the earthquake-prone region of Bangladesh, was assessed. Besides, the applicability of two methods of vulnerability assessment (Reliability-Based Method and FEMA 154) for Bangladesh was also checked.

17.5% of the studied buildings were found vulnerable, and 65% of buildings were safe according to both methods. Most of the masonry buildings (85.71%) are at risk.

For Bangladesh context, the Cut-Off Score of FEMA 154 was proposed as 1.5 in this study. The comparison between the two methods shows that the results obtained from the analysis were close enough to each other and both models gave reliable results. However, the lack of sophisticated damage data for RBM could lead the results to be varied from the results obtained from another method. On the other hand, Basic Scores and Score Modifiers in FEMA set for developed countries might be calibrated for Bangladesh to decrease the result gaps. In conclusion, both methods were found suitable to use for vulnerability assessment of buildings in Bangladesh and thus recommended for use.

Abbreviations

RBM	Reliability-Based Model
RVS	Rapid Visual Screening
FEMA	Federal Emergency Management Agency
BNBC	Bangladesh National Building Code
MRF	Moment Resisting Frame
URM	Unreinforced Masonry Building

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Author Contributions

Ashish Broto Kairi: Conceptualization, Data curation, Formal Analysis, Writing – review & editing, Visualization

Mushtaq Ahmed: Investigation, Methodology, Resources, Supervision, Validation

Sumitra Chandra Nath: Writing – original draft, software

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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