Structural Vulnerability of Buildings to Earthquake of Ward No. 14, Mymensingh Municipality, Bangladesh

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Abstract

Loss of life and economy as well as damage in an earthquake is increased due to structural vulnerability. To reduce those losses and damages, it is necessary to understand the concept of structural vulnerability. With this in mind a project was undertaken by United Nations Development Program (UNDP) and Mymensingh Municipality in which a study was carried out to assess the structural vulnerability of the existing buildings of Ward no. 14, Mymensingh Municipality, Bangladesh. According to Bangladesh National Building Code (draft BNBC 2017), Mymensingh municipality is located in Zone 4 possessing an acceleration of 0.36g. This high acceleration can cause severe damage to buildings which were built according to BNBC 1993 considering an acceleration of 0.25g. For this purpose, total 707 buildings were assessed according to the guideline of FEMA P-154 which is known as Rapid Visual Screening (RVS) Method. Different vulnerability features e.g. soft story, plan irregularity, pounding etc. were focused in this assessment. The study reveals that about 53 percent buildings show the above-mentioned structural defects. About 36% buildings are below cut-off score (based on seismic design criteria) and are vulnerable to earthquake. 28% buildings are unreinforced masonry (URM) which are more vulnerable in earthquake. Different damage levels of the assessed buildings, recommended by European Macroseismic Scale (EMS-98), were identified. Above 97 percent of surveyed structures show a high probability of Grade 3 damage and a very high probability of Grade 2 damage. RVS scores of buildings are seen with respect to number of stories, usage and structure type. Using ArcGIS 10.5, vulnerable buildings of different damage grades are represented in a map which shows their spatial location and distribution in Ward-14.

Keywords: *Earthquake, Structural Assessment, RVS, Seismic Vulnerability, Mymensingh*

1 Introduction

According to World Risk Report (2016), Bangladesh is the fifth most vulnerable country to disasters (UN, 2016). Tectonically, Bangladesh lies in high seismic zone at the junction of three plates- Indian Plate, Eurasian Plate and Burmese Microplate. The intersection of three plates have resulted in the generation of three active faults- Madhupur fault (MF), Dauki Fault (DF), and Plate Boundary Fault (CDMP, 2010; Akhter, 2010). In the last 150 years, Bangladesh has experienced damages of five earthquakes with magnitude over 7.0 (Richter scale) (Shaw *et. al.,* 2013). Historical trend of seismic events and some recent tremors in the country or adjoining areas indicate that Bangladesh is at high risk of earthquake (GoB, 2015; Rahman *et.al.*, 2015). Rapid urbanization, population growth, migration and development of economic activities have induced a rapid increase in earthquake vulnerability (GoB, 2015). Besides earthquake, the country is highly susceptible to structural collapse as seen from the incidents in Old Dhaka (2004), Spectrum collapse (2005) and the collapse of Rana Plaza (2013) resulting in the deaths and injuries of more than thousands. Therefore, a severe earthquake or structural collapse in this country will cause serious human casualty, damages of infrastructures and social loss (Alam *et.al*., 2008).

In order to reduce the losses caused by earthquake, an assessment of structural vulnerability in urban areas is necessary. A number of methods have been introduced over the years in order to assess the seismic vulnerability of structures. Many of these are time consuming and require detailed calculation such as detailed engineering assessment, assessment of structural vulnerability by ASCE Tier-1, ASCE Tier-2 guidelines etc. Rapid Visual Screening (RVS) method for moderate seismicity developed by Federal Emergency Management Agency (FEMA), USA is also a method for vulnerability assessment. RVS was chosen to get an initial idea regarding the structural vulnerability of the existing infrastructures of Ward-14, Mymensingh as it is a procedure that provides speed and can use screeners who are not necessarily structural engineers. As screening could be done quickly, large portfolios of buildings could be evaluated in a cost-effective manner. It is applicable for Bangladesh due to its cost-effective and easy approach.

This investigation was carried out under a project titled as "Assessment of Seismic Exposure, Building and Socio-economic Exposure Assessment and Contingency Planning for Ward 14 of Mymensingh Municipality" undertaken by UNDP and Mymensingh Municipality. This study intended to i) identify the vulnerable building of Ward-14 on the basis of RVS score ii) highlight the features which make the structures vulnerable to earthquakes iii) identify the structure types and usage which are most vulnerable iv) look at the percentage of vulnerable buildings by comparing the RVS scores and damage grades. In this paper, the methodology of seismic vulnerability assessment and scoring procedure have been described. After analyzing the results, they have been represented by generating a map. The map has been generated by using ArcGIS 10.5 which show the spatial location of vulnerable buildings.

2 Methodology of the Study

2.1 Selection of Study Area

According to the seismic zoning map of the Bangladesh National Building Code (BNBC), Mymensingh town lies in an active earthquake prone area of Bangladesh. Figure 1 shows the seismic zoning map of BNBC in which Mymensingh falls in Zone 4 with a seismic coefficient of 0.36g (according to updated BNBC 2017: yet to be implemented) which was 0.25g in BNBC 1993. It is also located in close proximity of Madhupur Fault, Dauki Fault and Plate Boundary Fault-2. Figure 2 represents that there are few earthquakes around Mymensingh with magnitude of 5.5 to 7.5. In the past, Great Indian Earthquake of 8.4 Mw in 1897 has caused massive destruction and changed the main flow of Brahmaputra River in Mymensingh area (Sarker *et.al*. 2010).

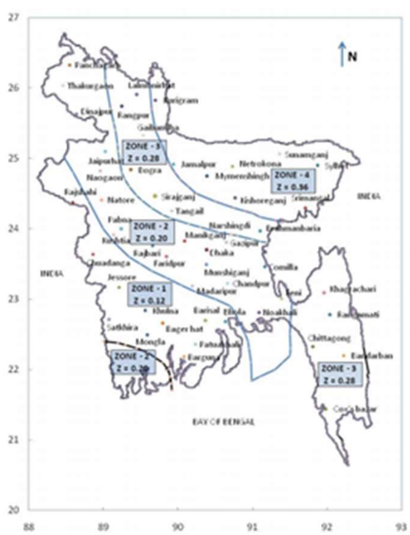

Figure 1. Proposed seismic zoning map for Bangladesh (BNBC, 2017)

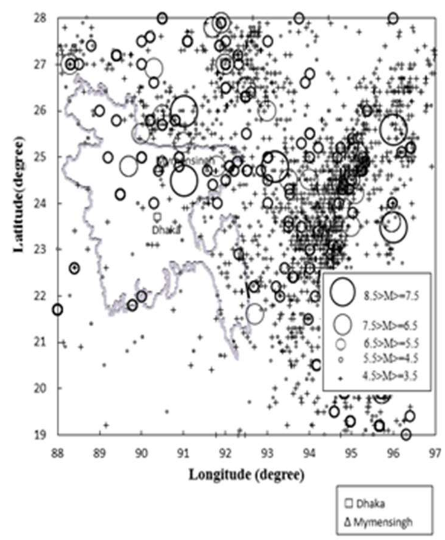

Figure 2. Earthquake in and around Bangladesh (Source: Data is offered in courtesy of Dr. T. M. Al-Hussaini)

The geotechnical and geophysical investigation under CDMP- II shows that almost 90% of the soil in Mymensingh Municipality area is loose/ soft soil which has very high liquefaction susceptibility (CDMP, 2014). The study area of the research is Ward-14 of Mymensingh Municipality, which can be characterized by high population density and narrow passages inside the ward (BBS, 2011; Field Survey, 2017). It contains important public service buildings including Mymensingh Medical College and private clinics adjacent to Dhaka-Mymensingh Highway. Considering the past occurrences of earthquakes and the present condition of structures, soil, accessibility and development pattern of Ward-14, major earthquake can cause immense destruction of life and property in the area.

2.2 Sampling and Data Collection

According to project requirement, 707 buildings were surveyed. High rise buildings, buildings with mixed use containing both residential and private clinics and buildings that can be used as shelters in times of earthquake such as schools, mosques etc. were included in the survey. To complete the data set and look at the deviation of results some low rise and tin shade buildings were also included in the survey. For the ease of carrying out the survey the whole ward was divided into six clusters. One cluster was covered by 2 teams and in total 12 teams were engaged in the survey procedure. Each team comprised of three members, one civil engineer and two helping personnel. The time frame of primary data collection survey was April 2017 to November 2017.

2.3 Data Analysis

The method used for building vulnerability assessment is Rapid Visual Screening (RVS) method, by which a total of 707 buildings were assessed. A data collection form is used in this survey process which is prescribed by FEMA.

2.3.1 FEMA Rapid Visual Screening Procedure

Seismic vulnerability of the structures was assessed based on the scores calculated by FEMA Rapid Visual Screening procedure. The purpose of FEMA P-154, developed by ATC (Applied Technology Council) under contract to FEMA, was to provide a methodology to evaluate the seismic safety of a large inventory of buildings quickly and inexpensively, with minimum access to the buildings, and determine those buildings that require a more detailed examination (FEMA, 2015). It is a sidewalk survey process that enables to classify the surveyed buildings into two categories: those which indicate risk to life and those that may be seismically hazardous and should be investigated in more details by a design professional experienced in seismic design.

Another widely used RVS (Turkish) method is not applicable here as it is only valid for RCC structures up to 7 stories. But Ward 14 had almost 28% structures which were unreinforced masonry. The screening process was conducted by a person who fill ups a data collection form. The form contains space for documenting building identification information, including its use and size, a photograph of the building, sketches, and documentation of pertinent data related to seismic performance. Completion of the Data Collection Form in the field begins with identifying the primary structural seismic force-resisting system and structural materials of the building. Basic Scores for various building types are provided on the form, along with score modifiers which are circled by the screener. The basic score is modified by adding or subtracting scores based on special attributes of the building and final score is obtained. This same procedure was followed in this study. The cut off score for the buildings has been set as 1.5 for this study. Higher scores correspond to better seismic performance and lower potential of collapse.

3 Results and Discussion

For the assessment of structural vulnerability, a score for each of the buildings surveyed was calculated using recommended method of FEMA P-154 which indicates the seismic performance of the buildings. The scores are based on the probability of building collapse and average expected ground shaking levels for the seismicity region (FEMA, 2015). A cut-off score (here 1.50) is suggested based on the present seismic design criteria. The buildings should be investigated by a design professional experienced in seismic design, if the buildings receive a score less than the cut-off score. The building is considered to have adequate seismic resistance to prevent collapse during a rare earthquake, if a building receives a score higher than cut-off score.

Figure 3 shows the relation between numbers of buildings and corresponding RVS Score. About 36% buildings are dangerous and it is essential to take effective measures for those to minimize damage and losses of life and resources. Figure 4 shows the same relation in addition to which the numbers of each type of the structures for specific ranges of RVS score is shown.

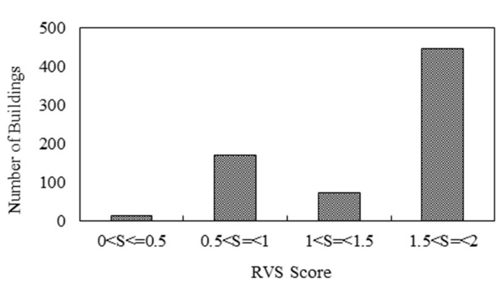

Figure 3. Relations between Number of Buildings & Building Score (RVS)

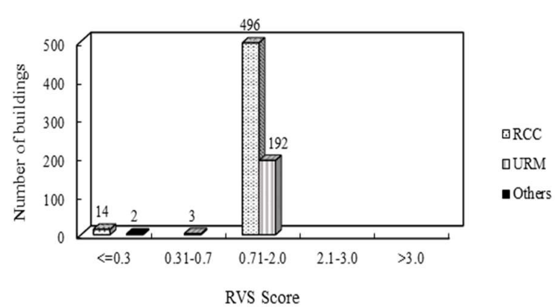

Figure 4. Distribution of buildings according to RVS score and type (RCC/URM) (Source: Field Survey, 2017)

3.1 Structural Vulnerability Analysis

The RVS (Rapid Visual Screening) method formulated in FEMA P-154 was used to assess the seismic vulnerability of the structures. The issues which were mainly focused in this method, were issues which make structures vulnerable to earthquake, such as identifying building type, plot size and shape, clear distances from surrounding structures, road width and basic information of the building: year of construction, no. of story, overhang, vertical irregularity etc. Some vulnerability features of the surveyed buildings are summarized in Table 1.

Table 1. Characteristics of buildings surveyed

Characteristic of building	Percentage of total buildings
With Soft Story	4
With Vertical irregularity	4
With Plan irregularity	13
With Setback	18
With Pounding	14

(Source: Field Survey, 2017)

3.1.1 Vertical Irregularity and Plan Irregularity

Among all the RCC buildings in the surveyed area, 96% hadt soft story and the rest 4% did not have soft story.

Only 18% buildings had setback. Buildings with moderate vertical irregularity is 4 %. These are vulnerable to damages during an earthquake. About 87% of the buildings which were surveyed had a regular plot shape and about 13% buildings had an irregular shape. Buildings with irregular plan tend to be more vulnerable to earthquake as the irregular portions will accumulate earthquake forces.

3.1.2 Pounding

About 14 % of the total buildings in the surveyed area tend to have pounding effect.

3.1.3 Structure Type

Categorization of RVS and earthquake vulnerability level has been adopted from Rahman et. al., 2015. According to this, the number and types of buildings with different RVS scores are depicted in Figure 4. The area included RCC (Reinforced Cement Concrete) buildings, URM (Unreinforced Masonry) buildings and others such as tine-shaded structures. 28% of the total buildings are URM. Considering the lack of lateral load resistance and very low tensile strength of masonry, these URM buildings can be stated as more vulnerable than other 72%.

3.1.4 Structure Use

During RVS, information on use of the structures were collected. From Table 2 it can be noticed that among the 707 surveyed buildings, 570 were residential (80.6%). In the highest vulnerable category, 1.7% are residential, 0.14% are educational (primary school) and 0.28% are with mixed activity. Most of the residential buildings (78.6% of total sample) and all of the hospital buildings (3.81%) are moderately vulnerable. Critical facilities like schools, mosque etc. which can be used as emergency shelters also fall into the moderately vulnerable category.

Table 2. Distribution of buildings according to RVS score and use

RVS score and Vulnerability Category	Structure Use							Total
	Resid-ential	Educati-onal	Mosque	Hospital	Commercial	Mixed	Others	
<= 0.3 (Very high)	12	1	0	0	1	2	0	**16**
0.31-0.7 (High)	2	0	0	0	1	0	0	**3**
0.71-2.0 (Moderate)	556	7	2	27	27	56	13	**688**
>2 (Low)	0	0	0	0	0	0	0	**0**
Total	**570**	**8**	**2**	**27**	**29**	**58**	**13**	**707**

(Source: Field Survey, 2017)

3.1.5 Number of Story

The relationship between number of story and RVS score is shown in Table 3. As seen from the table, one-storied buildings are predominant in the study area and the number of high-rise buildings (greater than 7 stories) is very insignificant. Among the highest vulnerable category, 0.5% buildings are 1-storied, 1.55% are 2 to 4 storied and 0.14% are 5 to 7 storied in total sample buildings. In the high-vulnerable category, there are only 1-story buildings whereas in the moderate vulnerable category, height of the buildings varies from 1 to 8-story.

3.2 RVS and Damage Grade

Damage potential of structures were identified in Table 4 according to RVS score (Sinha and Goyal, 2004). From Figure 5 it can be interpreted that most of the buildings of the surveyed area fall in the third category which corresponds to RVS score of 0.7 to 2.0 (moderately vulnerable). This means that most of the buildings of this area have high probability of grade 3 damage and very high probability of grade 2 damage.

Table 3. Distribution of buildings according to RVS score and number of stories

RVS score and Vulnerability Category	No. of Story				Total
	1	2 to 4	5 to 7	>7	
<= 0.3 (Very high)	4	11	1	0	**16**
0.31-0.7 (High)	3	0	0	0	**3**
0.71-2.0 (Moderate)	374	251	61	2	**688**
>2 (Low)	0	0	0	0	**0**
Total	**381**	**262**	**62**	**2**	**707**

(Source: Field Survey, 2017)

Table 4. Expected damage level based on RVS score

RVS Score	Damage Potential
S < =0.3	High probability of Grade 5 damage; Very high probability of Grade 4 damage
0.3 < S < =0.7	High probability of Grade 4 damage; Very high probability of Grade 3 damage
0.7 < S <= 2.0	High probability of Grade 3 damage; Very high probability of Grade 2 damage
2.0 < S <= 3.0	High probability of Grade 2 damage; Very high probability of Grade 1 damage
S > 3.0	Probability of Grade 1 damage

(Source: Sinha and Goyal, 2004)

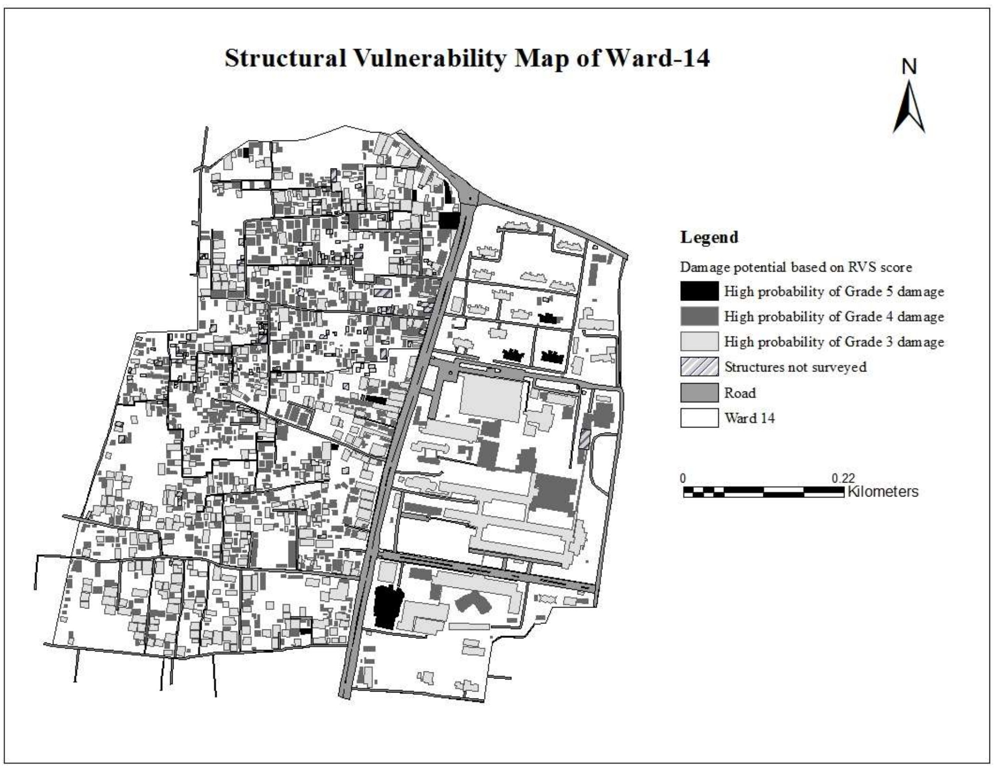

Figure 5. Distribution of structures according to level of probability of damage (Source: Field Survey, 2017)

4 Limitation

The advantage of RVS procedure relates to its intrinsic limitation. Without the drawings and calculations often, the limited review of the exterior results in less accurate reviews. Again, determining the seismic force resisting system is integral to any seismic evaluation. Since large number of buildings are often screened and the level of expertise can vary widely, errors are inevitable. It is essential to have a thorough quality assurance program to minimize the extent of the errors (FEMA P-154, 2015).

5 Conclusion and Recommendation

The study reveals that about 36% of the total surveyed buildings in ward 14, Mymensingh lied below the cut off score which indicates that these buildings are vulnerable to seismic forces. In addition to this, 58% buildings were vulnerable considering different vulnerability features and most residential buildings and some hospital buildings are at moderate risk. There are total 36 buildings which can be used as shelters (educational facility, hospital and mosque) and these have a high probability of Grade 3 damage and very high probability of Grade 2 damage. Moreover, more than 97% buildings are found to incur 'Substantial to heavy damage (moderate structural damage, heavy non-structural damage)' and about 3% buildings are found to incur very heavy damage and even destruction.

Since RVS is a visual screening method, the buildings possessing a score below the cut off margin are recommended to be investigated through a 'Detailed Engineering Assessment (DEA)' by professionals experienced in seismic assessment. This will give a more detailed insight regarding the vulnerability of the buildings. It may also be helpful to understand the effectiveness and reliability of RVS procedure.

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