Review Article **Open Access**

Seismic Loss Estimation for Ward 14 of Mymensingh, Bangladesh

Ansary MA[1]* and Akhter T[2]

[1]Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

[2]Urban and Regional Planning, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh

*Corresponding author: Ansary MA, Professor, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, Tel: 01711343288; E-mail: ansary@ce.buet.ac.bd

Abstract

Mymensingh municipality is highly vulnerable to earthquake as it is located in close proximity of Madhupur Fault, Dauki Fault and Plate boundary Fault-2 as per a recent finding. As a result of rapid urbanization, economic expansion, population growth, urban-rural migration has made the locality more vulnerable to earthquake. This paper aims to assess the seismic vulnernability and potential economic loss at the event of earthquake for ward 14 of Mymensingh Municipality. For the assessment of seismic hazard, 12 borehole tests and 8 microtremor array measurements have been done. Based on the data of those tests, earthquake intensity map has been prepared using Geographic Information System (GIS) for the study area. For the estimation of economic loss caused by earthquake, potential building damage and human casualty have been estimated. For the assessment of potential building damage, a building inventory of the study area for 735 buildings has been done and potential building damage has been calculated by using fragility curves. Based on the occupancy rate of the study area, possible human injury and death rate have been estimated by using Morbidity Model proposed by Coburn. Combining the building vulnerability and human casualty, the potential economic loss at the event of earthquake for the study area has been estimated.

Keywords: Earthquake; Microzonation; Loss; Casualty; City

Introduction

Mymensingh district is located at 24°45' north latitude and 90°25' east longitude in Dhaka division on the west bank of Old Brahmaputra River. The municipality of Mymensingh was established in 1869 and its jurisdiction area covers 21.73 sq. km. with a total population of 258,040 people and density of 9,414 persons per sq.km (BBS). Mymensingh municipality lies in one of the most earthquake-prone areas of Bangladesh [1]. The occurrence of a major earthquake can destroy any densely populated area where most structures are built on a soft soil. 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 high liquefaction susceptibility. The foundations and supports of structures built on this highly liquefiable sediment can fail, causing damage or destruction during major earthquakes (CDMP). From seismic zoning map of Bangladesh it can be seen that Mymensingh falls in Zone 3 with a seismic coefficient of 0.25 g in BNBC [2,3]. However in the draft version Bangladesh National Building Code, Mymensingh falls in Zone 4 with a seismic coefficient of 0.36 g (Two-third of the value is 0.24 g) which is shown in Figure 1 (Proposed BNBC) [4]. The Great Indian Earthquake of 12 June, 1897 caused complete demolition of the city due to a surface wave magnitude 8.1 [1]. The Indian Plate is moving northeast at a rate of 5 cm/year slowly colliding with the Eurasian Plate which formed the Himalayan Mountains and giving rise to the severest earthquake [5]. Enormous Dauki fault is also located in the northern border of Bangladesh. Large Shillong Plateau has formed as a result of movement along with the fault. The area around the Himalayan region is highly susceptible to earthquake because of differential energy accumulation in this region [6]. Table 1 shows the information of

recent and past earthquakes which occurred in Mymensingh. Figure 2 shows the location of earthquake epicenters having magnitude greater than 4 in and around Bangladesh for the period 1762 to 2009. It is visible from the figure that several earthquakes having magnitude 5.5 to 7.5 have occurred in and around Mymensingh.

The research paper aims to represent a comprehensive loss assessment at the event of earthquake. There are 21 Wards within Mymensingh City Corporation among which Ward 14 has been selected as the study area for this research. Figure 3 shows the location of the study area with respect to Mymensingh district and Mymensingh City Corporation. The study area lies in one of the earthquake prone areas of Bangladesh. Earthquakes striking such dense communities can cause terrible destruction to life and property [7]. Recent earthquakes in Haiti (2010), Japan (2011), New Zealand (2011) and Nepal (2015) have demonstrated the amplification of risk to the population due to urbanization in earthquake prone areas [8,9]. The purpose of the study is to evaluate the potential damage of buildings and human casualty based on the earthquake loading according to the Bangladesh National Building Code 2017 using Geographical Information System and to provide a basis of the comprehensive estimations of potential loss under such events.

Geology of Study Area

Mymensingh district lies in the northern outlier of Madhupur Tract and within old Brahmaputra flood plain. Old Brahmaputra flood plain is located in the northeastern part of the Indian Plate which comprises low-lying alluvial plain of the latest Holocene period. The plain is bordered by Modhupur Tract and the Sylhet Depression in the East which is shown in Figure 4. Mymensingh is situated on the bank of Brahmaputra River and alluvial deposit of this area consists of flood sand to overbank silt and ponded clay [1]. The colors of the deposited

materials are yellowish brown or gray to reddish-gray silt clay. Oxidized upper 0.5 m unit includes highland alluvial and some Holocene slope wash deposit adjacent to higher ground [10]. According to PWD, the average elevation of the floodplain is less than 15 m [2]. Other than Brahmaputra River, numerous channels; Sutia and Khiro River are the prominent rivers that drain this flood plain. Old Brahmaputra River and these channels have formed the drainage network of Mymensingh. In Figure 5, Rivers in and around Mymensingh can be seen. Mymensingh is situated in the south of Sutia River, east of Khiro River and south-western of Old Brahmaputra River. The out fall of Sutia River and Khiro River is the Banar River which is at the southern part forms the outlier of Mymensingh [2].

Tectonic activities of an area convey some expressions to the geomorphology of that area. Tectono-geomorphic evidence of past and present is important for the understanding of tectonic activities of an area. Mymensingh lies in the eastern part of Jamuna valley which is situated in the central part of the Bengal Basin. On the regional context, the Bengal Basin lies to the northeastern part of the Indian Plate which is characterized by complex tectonic environment [1]. Some tectonic elements are active and are creating many tectono-geographic features. The examples of some lineaments produced by these features are Madhupur lineament, Manikganj lineament, Nagarpur lineament. These lineaments depict four tectonic blocks e.g. Nagarpur block, Saturia block, Jamalpur block and Madhupur block shown in Figure 6. Madhupur block is the raised one on the east of Jamuna valley. Each block is characterized by certain tectonic geomorphic features [11]. Mymensingh is located on the northeastern part of the above-mentioned block.
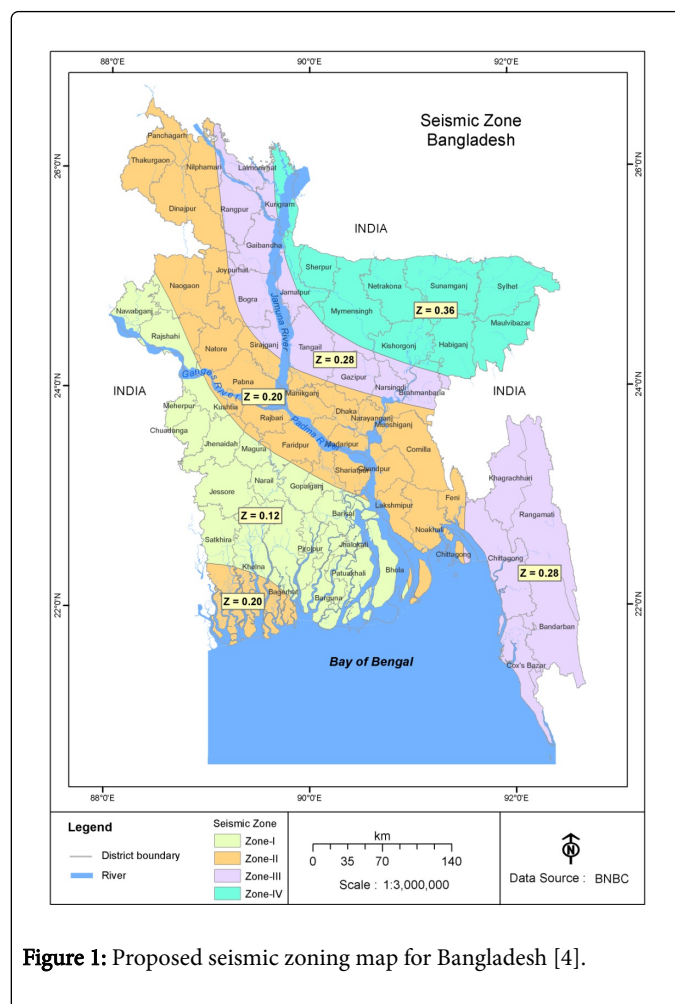

Figure 1: Proposed seismic zoning map for Bangladesh [4].

Name of Earthquakes	Fault	Magnitude	Epicentral Distance (Km)	Focal Depth (Km)
1885 Bengal Earthquake	Modhupur	7.0	94	72
1897 Great Indian Earthquake	Assam	8.1	151	60
1918 Srimangal Earthquake	Sub-Dauki	7.6	146	14
1923 West Durgapur Earthquake	-	7.1	81	33
1930 Dhubri Earthquake	Dhubri	7.1	93	60
2008 Modhupur Earthquake	Modhupur	4.2	35	25
2008 Haluaghat Earthquake	Haluaghat	4.8	10	40
2008 Mirzapur Earthquake	Modhupur	4.6	45	20
2015 Gafargaon Earthquake	-	4.0	20	14

Table 1: Information of some historical earthquakes that affected Mymensingh.
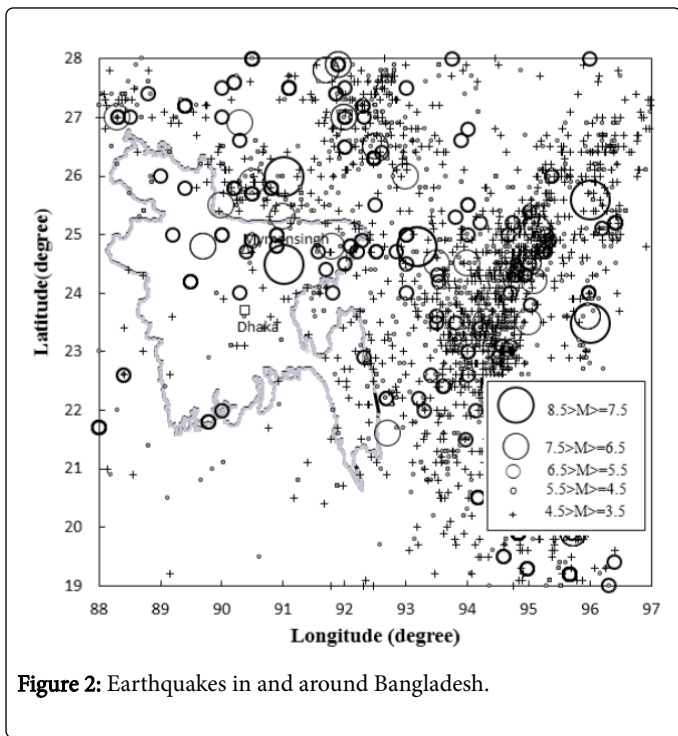
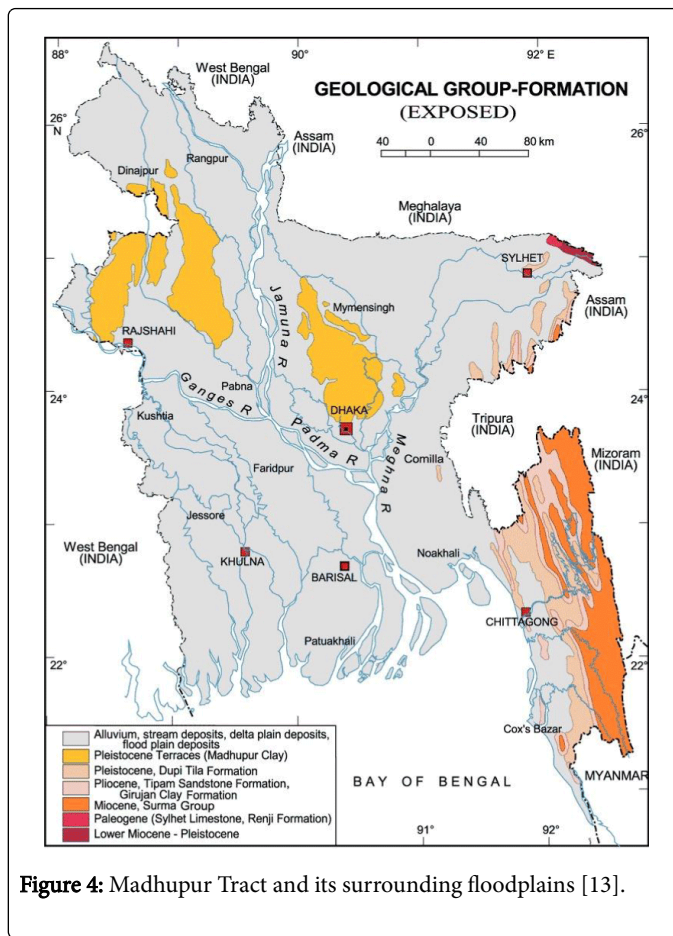**Figure 2:** Earthquakes in and around Bangladesh.

Figure 4: Madhupur Tract and its surrounding floodplains [13].
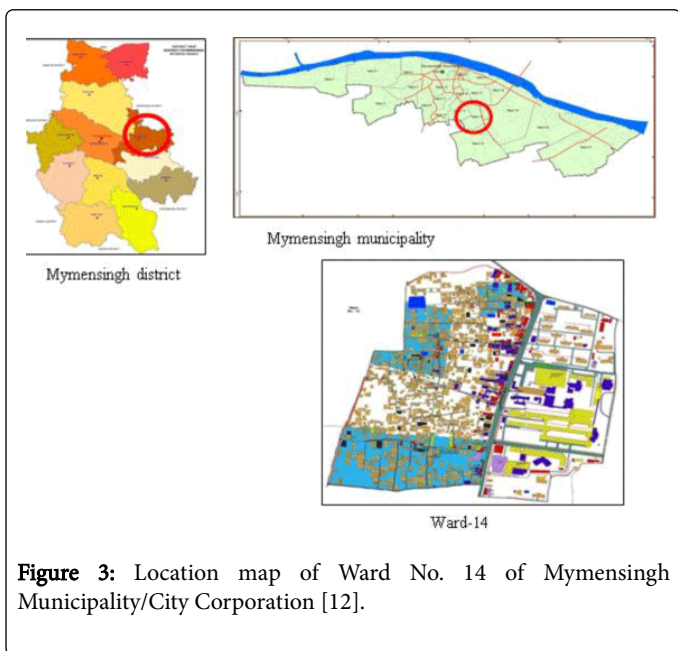

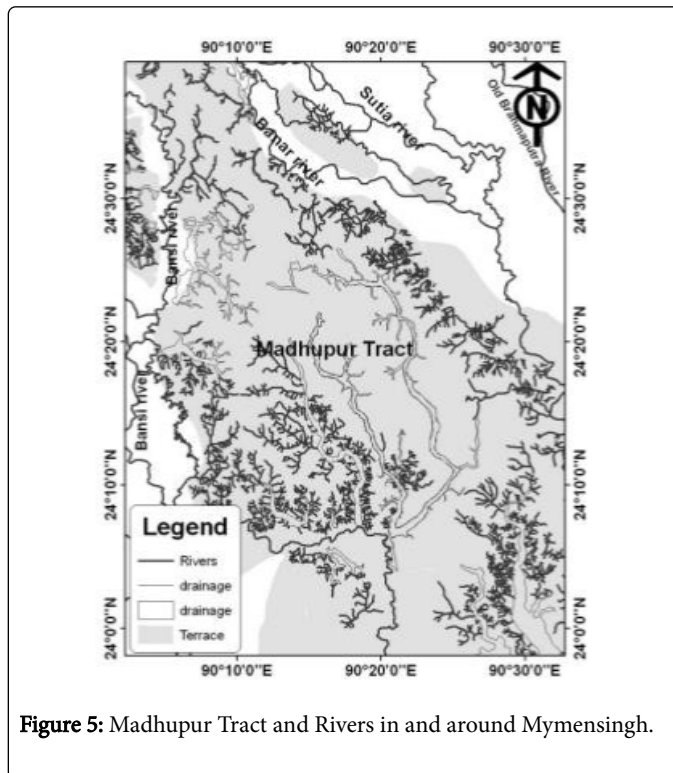**Figure 3:** Location map of Ward No. 14 of Mymensingh Municipality/City Corporation [12].

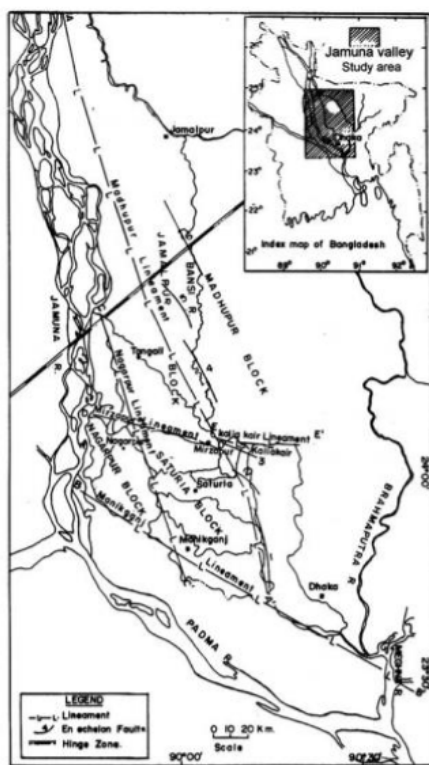**Figure 5:** Madhupur Tract and Rivers in and around Mymensingh.

Figure 6: Tectonic and lineament map of the eastern part of Jamuna valley [11].

Study Area Profile

Demographic profile of study area

The total population of Ward 14, Mymensingh is 12,142 and the population density is 22,485 per sq. km. having an area of 0.54 sq. km. The ratio of male and female population of the study area is 47.06 percent and 52.94 percent respectively. The total number of households in the area is 2,194 and average family size is 4.5. The percentage of population aged below 30 years is 63.3% and 36.7% people of the study area are aged above 30 years (Field Survey, 2017). The literacy rate of study area is 75.1%. The primary occupations of people in the study area are: service (80.6%), agriculture (11.7%) and industry (7.6%). Mymensingh Medical College and Hospital which is a regional health facility situated in this area.

Land use characteristics of study area

In the study area the major land use of study area is agricultural use, open space, barren land, water body etc. (38.8%). Road network covers a large portion of the land parcel (21.8%). Another major land use of the study area is residential land use (15.1%). The share of land for health facility is 13.3% as Mymensingh Medical College and Hospital is situated in the study area which occupies a large portion of the area (Figure 7).
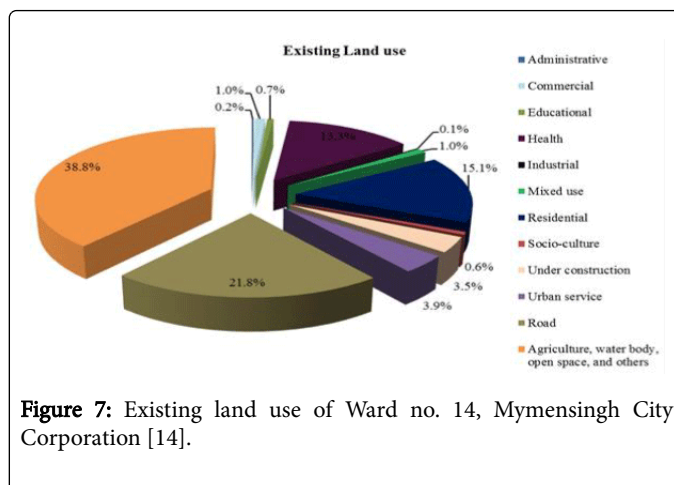

Figure 7: Existing land use of Ward no. 14, Mymensingh City Corporation [14].

Building characteristics of study area

In the study area, there are 1,611 buildings among which 535 building are RCC structures, 208 of them URM structures and rest are semi-pucca, kutcha and under construction buildings. Most of the buildings in the study area lack setback space around them and the adjacent road networks are too narrow for vehicular movements (Field Survey, 2017).

Methodology of the Study

Selection of study area

Among 21 Wards of Mymensingh City Corporation (municipality), Ward no. 14 has been selected as the study area. In this area, Mymensingh Medical College has been located which is a regional health facility. The population density of this area has been increased over time and the construction of buildings has taken place without considering the vulnerability of earthquake. The road network of the study area is too narrow for any rescue mission at any emergency situation (Field Survey, 2017). In this regard, the study aims to assess the potential loss of the study area after occurrence of an earthquake event. To conduct the study, the area has been divided into 6 clusters as shown in Figure 8.

Seismic exposure assessment

For the purpose of seismic exposure assessment, twelve boreholes up to 30 m depth together with disturbed and undisturbed soil samples were collected from the study area as shown in Figure 8. Also eight Microtremor array measurements with five sensors were carried out by the field study team as shown in Figure 8. From previous studies, it has been found that the study area is not susceptible to liquefaction [2]. Also the collected twelve borelogs show general existence of clay soil up to a depth of 25 m, which means chance of liquefaction occurrence is low. For these reasons, the liquefaction analysis has been excluded from the study.
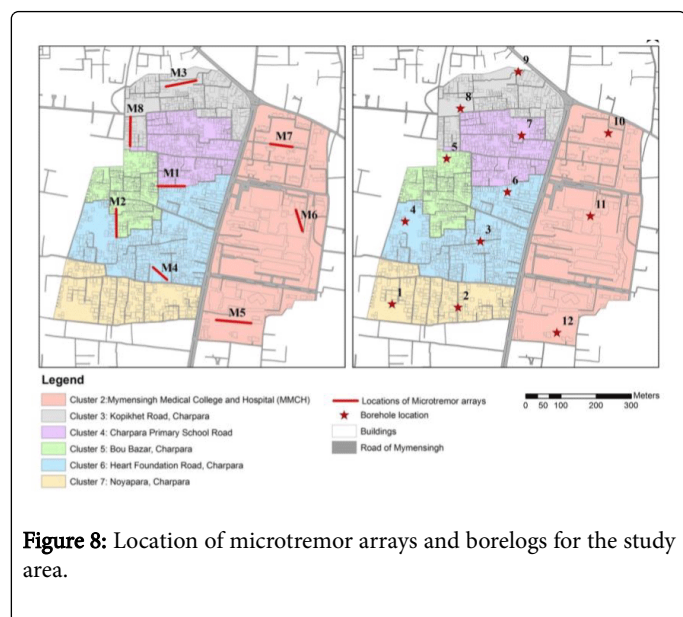
Figure 8: Location of microtremor arrays and borelogs for the study area.

No.	Type	Description
1	EMSB1	1-storied brick masonry of fired bricks with cement or lime mortar, roof is either of GI sheets or other materials
2	EMSB2	2-storied or taller brick masonry of fired bricks with cement or lime mortar
3	EMSC	Reinforced concrete frame with low ductility, designed for vertical load only
4	EMSD	Reinforced concrete frame with moderate ductility, designed for both vertical and horizontal loads
5	EMSF	Mainly bamboo, wooden and steel structures

Table 2: Building Typology of Bangladesh [15].

Cluster	Housing Unit	EMSB1	EMSB2	EMSC	EMSF
2	56	0	35	22	0
3	131	21	26	84	2
4	136	8	15	110	3
5	97	31	28	34	5
6	198	27	19	150	2
7	117	0	0	117	0
Total	735	80	126	517	12

Table 3: Building Classification.

Building vulnerability assessment

In the study area 1,611 buildings have been found in the field survey, among them semi-pucca buildings are predominant (52%). The percentages of pucca and katcha buildings are 38.5% and 9.5% respectively. For building vulnerability assessment, 735 buildings were surveyed among them 517 buildings were Reinforced Cement

Concrete structures, 206 of them were Unreinforced Mansonry structures and 12 of them were tin-shade structures. Table 2 shows building typology according to Ansary [15] and Table 3 shows the study area building distribution according to Table 2.

Result of Building Inventory Survey

Storey and average floor area of the buildings of the study area

More than 58% of surveyed buildings of the study area are one to two storied and 33% of surveyed buildings are three to four storied. About 10% buildings are five or more storied, most of those higher storied buildings are situated along the Dhaka-Mymensingh highway opposite to the Mymensingh Medical College and Hospital (Field Survey, 2017). Figure 9 shows cluster wise distribution of buildings in the area according to number of stories.

Figure 10 shows the floor area of surveyed buildings with respect to building storey and number of buildings of the study area. Most of the one storied buildings have less than 2500 sq. ft. floor area where most of the 6 or more storied buildings have floor area greater than 8500 ft. It has also been found from the field survey that among RCC structures, the percentage of soft storey is about 4%, which are vulnerable during earthquake [16]. In Figure 11, cluster wise average floor area of surveyed buildings of the study area can be seen. In clusters 3 to 7, the average floor area of one storied buildings are less than 1000 sq.ft. For clusters 4 to 7, the average floor area of two and three storied buildings is below 3500 sq.ft. For most of the four or more storied buildings, average floor area is found to be greater than 5000 sq.ft. In cluster 2, where Mymensingh Medical College and Hospital is located, floor area is greater than any other clusters.
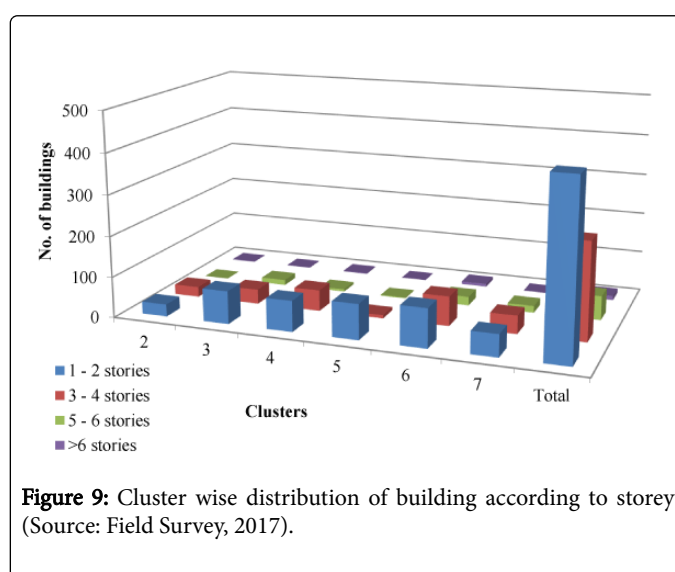

Figure 9: Cluster wise distribution of building according to storey (Source: Field Survey, 2017).
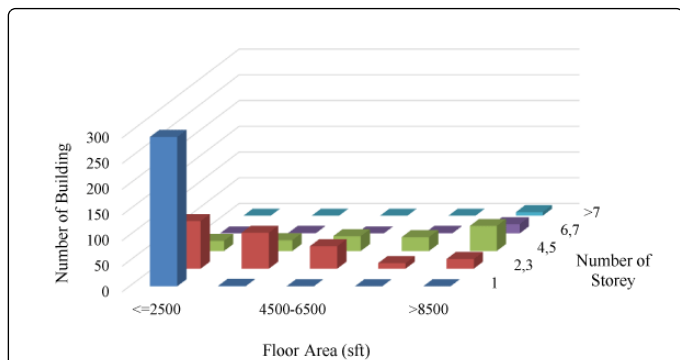
Figure 10: Cluster wise distribution of building according to storey and floor area (Source: Field Survey, 2017).

Figure 11: Cluster wise distribution of average floor area of buildings (Source: Field Survey, 2017).

Figure 12: Construction year of the surveyed buildings (Source: Field Survey, 2017).

Construction year of buildings of the study area: Among 735 surveyed buildings (Figure 12), it has been found that 58% buildings of the study area have been constructed after 2000. It can be concluded from the Figure 12 that the area is going through the phase of new development. From the Figure 12, it can also be seen that most of the EMSB structures are 20 or more year old indicating higher vulnerability. The construction of EMSC structures using RCC beam and columns have also started more than 20 years ago. The area has faced significant growth of EMSC structures (about 20% of total surveyed buildings) after 2011. Most of these RCC buildings are basically non-engineered and extremely vulnerable (Field Survey, 2017).

One-Dimensional Site Response Analysis

In this study, 1D site response analysis for eight locations within the study area has been used to estimate surface response of those locations. The required soil profiles and PS-log data have been collected using SPT-N value profile, extensive laboratory soil investigations and microtremor arrays for obtaining shear-wave velocity profiles. According to the draft BNBC 2017, the input PGA in rock is 0.24 g (which is two-third of provided 0.36 g value in the code). At each location, nine different input motions having a PGA value of 0.24 g have been used to obtain mean site response. Figure 8 has already shown locations of borehole logs and microtremor arrays at ward 14. Table 4 presents depth versus soil layers and shear-wave velocity at location 2.

Soil Type	Layer Thickness (m)	Vs (m/s)
Silt Clay	4.5	170
Silty Fine Sand	6	170
Silty Clay	8	180
Silty Clay	8.5	266
Clayey Silt	1.5	266
Fine Sand	9	266
Fine Sand	9.5	266
Fine Sand with Gravel	17	962

Table 4: Depth vs Soil layers and Shear-wave velocity at location 2.

From the one-dimensional site response analysis, it has been found that the cluster 6 has the highest PGA value (0.68 g) whereas the average PGA value lies between 0.4-0.5 g in other clusters. By using the following Trifunac and Brady equation, the intensity of earthquake in the clusters of the study area have been determined [17].

$$logPGA=0.014+0.3(MMI) \qquad (1)$$

The high value of PGA in the clusters of the study area indicates that the area is highly susceptible to earthquake disaster. From Figure 13, it is visible that the occurrence of an earthquake event will have an intensity of VIII-IX in the study area. It can also be seen that cluster 2A, 6 and 7 are the most vulnerable areas and may result in severe damage to structures and high fatality and injury level.
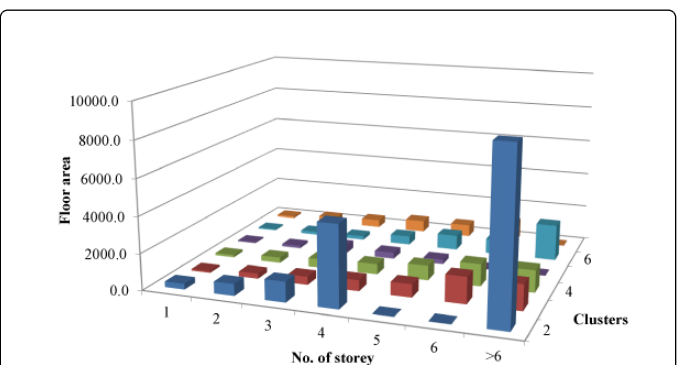
available for structures of Bangladesh, Indian and Nepalese curves may be the most suitable for Bangladesh. In this study, fragility curves for the buildings of study area were prepared by calibrating the existing fragility curves of Arya and Bothara et al. (Figure 14) [24,25].
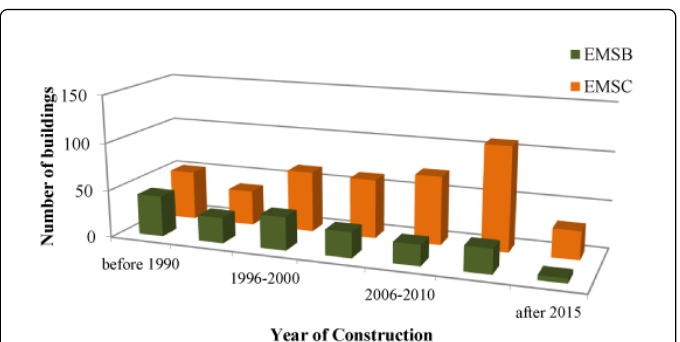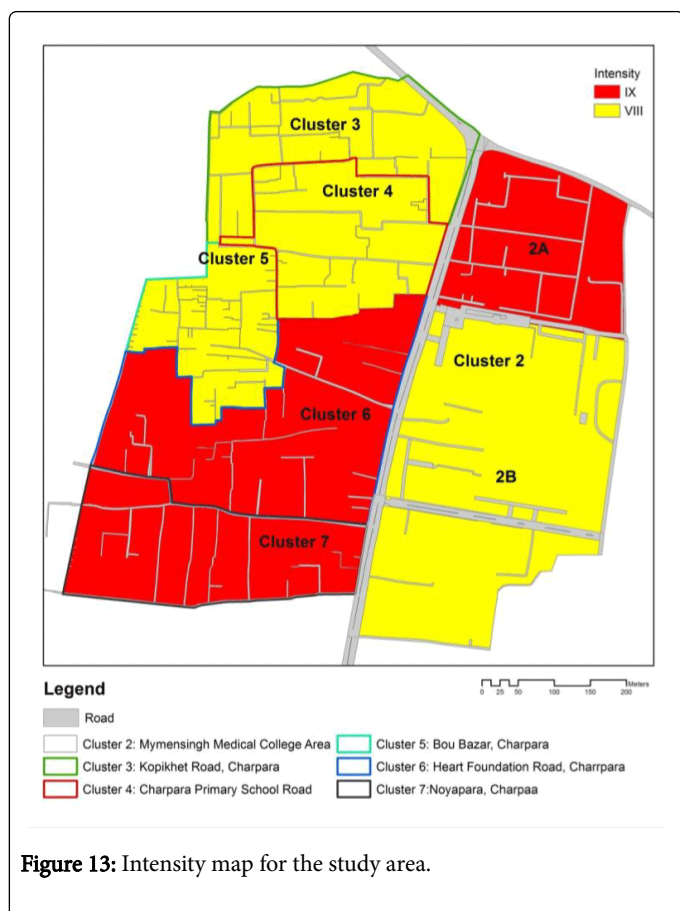
Figure 13: Intensity map for the study area.

Figure 14: Fragility curves for different type of buildings based on EMS intensity [30].

In the study of Arya and Bothara et al. the damage type of buildings were not mentioned [24,25]. Later Segawa et al. figured that those curves are for heavily damaged structures [31]. In this study, the percentage of complete (Damage Grade G5) and partial (Damage Grade G4) damage of EMSB and EMSC structures are 25% of total damaged buildings. About 40% buildings (Damage Grade G3) are susceptible to be heavily damaged and 15%-20% buildings ((Damage Grade G2 and Damage Grade G1) are subjected to low and moderate damage [24].
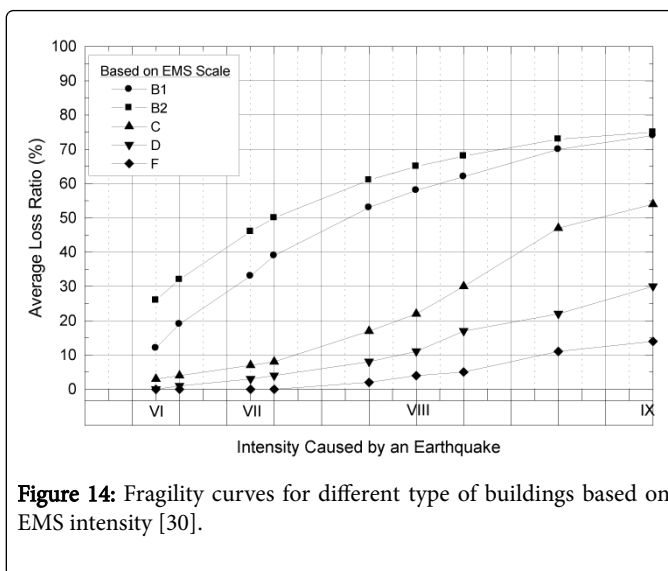
Assessment of Seismic Damage

During strong earthquakes, building structures of an area may experience irreparable damages or collapse [18]. The quantification of damage to buildings due to earthquakes has utmost importance. For the prediction of seismic damage of buildings, Seismic Damage Indices are widely used [19]. In this study, fragility curves are used in the FEMA/NIBS methodology to estimate building damage from ground shaking of earthquake [20]. Fragility curves are log-normal functions that can predict the probability of structural and non-structural damage states for a given level of earthquake response [21]. Fragility curves can be defined as a conditional probability that provides a possibility that a structure will meet or exceed a specified damage level for a given ground motion [22]. Though fragility curves are specific to structural typologies, they can be adapted to any region for similar building typologies and ground conditions, and to derive vulnerability functions using consequence functions [23]. For Indian Buildings, a number of fragility curves are prepared by Arya [24] and for Nepalese buildings prepared by Bothara et. al. [25]. A number of fragility curves are also prepared for different types of structures and for different earthquake intensities [21,26-29]. As there are no fragility curves

Estimation of building damage

From the previous section, it has been found that the clusters of the study area are located in severe earthquake zone. Incidence of an earthquake at the intensity of VIII-IX will result in heavy damage of life and property [32]. Table 5 shows the possible damage of different types of structures within the clusters of the area. From the table, it can be seen that 51% of the surveyed buildings are going to be affected by earthquake. The damage rate is highest in cluster 2A and 6 compared to other clusters (73% and 58% respectively) as the clusters are most vulnerable to earthquake (Figure 13). The other clusters will also face severe destruction to earthquake. More than half of the surveyed buildings are estimated to be affected at an event of earthquake having VIII-IX intensity level. Among different types of buildings within the study area, Unreinforced Masonry structures will be affected the most (72% and 69% respectively) compared to other structures [33,34]. From the experience of Nepal earthquake, it has been found that the performance of RCC structures are better compared to other structures [35].

Cluster	Total No. of Building	Possible No. of Destroyed Buildings					Cluster wise Total No. of Destroyed buildings/Cluster wise Total No. of buildings	Cluster wise Total No. of Destroyed buildings/Total No. of buildings
		B1	B2	C	F	Total		
2A	18	0	13	0	0	13	73%	2%
2B	38	0	12	9	0	21	53%	3%
3	131	13	18	25	0	56	42%	8%
4	136	5	11	47	0	63	47%	9%
5	97	19	19	10	0	48	50%	7%
6	198	20	14	81	0	115	58%	16%
7	117	0	0	59	0	59	50%	8%
Total	735	58	87	230	0	375	51%	51%

Table 5: Estimation of Building Collapse as a result of earthquake.

From the map, it is visible that cluster 3 and 4 will be less affected to earthquake compared to other clusters depending on the number and type of buildings. When the damage is estimated in terms of number of buildings, cluster 6 will have highest number of buildings liable to be damaged. Cluster 6 is larger than other clusters and also densely populated and the roads are too narrow for vehicular movement (Field Survey, 2017). On the other hand, the buildings of cluster 2A are URM structures which made the cluster vulnerable to earthquake (Figure 15).
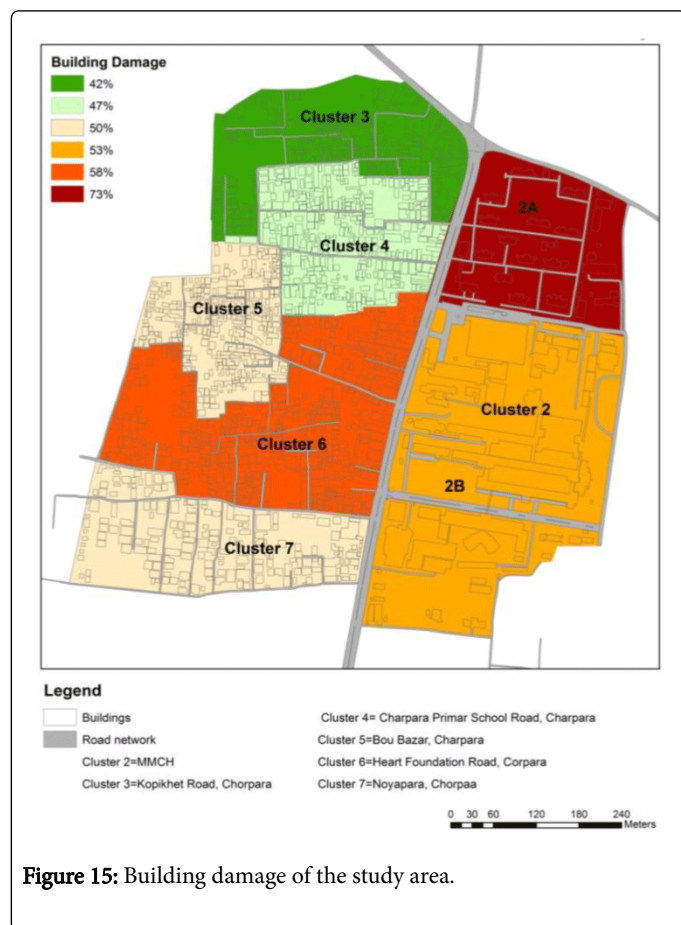

Figure 15: Building damage of the study area.

From the research of Arya, Jain, et al., NSET and DEQ-UOQ, the different damage state of buildings for the study area has been projected and obtained result is presented in Table 6 [24]. From Table 6, it is also visible that among 375 buildings, 94 of them will be subjected to partial to total collapse and 150 of them will be heavily damaged. A total of 244 buildings are assumed to require reconstruction. Whereas 131 buildings will require retrofit as they will face low to moderate damage at the event of earthquake.

Cluster	Total No. of buildings	Total no. of affected buildings	Complete and partial collapse (25%)	Heavily damaged structures (40%)	Moderately damaged structures (15%)	Low damaged structures (20%)
2A	18	13	3	5	2	3
2B	38	21	5	8	3	4
3	131	56	14	22	8	11
4	136	63	16	25	10	13
5	97	48	12	19	7	10
6	198	115	29	46	17	23
7	117	59	15	24	9	12
Total	735	375	94	150	56	75

Table 6: Calculation of collapse of buildings at the event of earthquake [15].

Human casualty

To assess the levels of human casualty caused by earthquake, the estimation of average fatality and injury levels have been used. To derive these figures, mortality prediction model for different types of structures has been used. This prediction model is prepared based on the investigation of human casualty of previous century due to occurrence of several major earthquakes [36]. The total number of people that may be killed due to building damages can be represented by:

$$Ksb = Db*[M1b * M2b * M3b * M4b] \qquad (2)$$

Where Db=Total number of damaged household of type b,

M1=Occupant density (Population per household)

M2=Occupancy of buildings at the time of earthquake

M3=Proportion of occupants trapped by collapse of buildings

M4=Proportion of occupants killed or injured in the earthquake.

The occupancy cycle proposed by Coburn and Spence shown in Figure 16 for residential and business structures. The occupancy rate can vary for these buildings depending on the occurrence period of the earthquake. Depending on the time of earthquake, the occupancy rate can be found (Figure 16). Human casualty also depends on the type of buildings. It has been observed that the number of death of trapped occupants due to building collapse of multi-storied masonry and reinforced concrete buildings are high compared to masonry buildings [15]. The data on occupancy of the clusters are already available for the study area.

Figure 16: Building occupancy at the event of earthquake [36].

Potential death of the occupants at the event of earthquake has been estimated in Table 7. In the study area, Mymensingh Medical College is situated where people from all over Mymensingh come for medical treatment. The occupancy at the day is high in this cluster compared to night. The occurrence of earthquake at night will cause more death and injury to the residents as most people will be at their house and have a chance to get trapped [30]. Total 1,635 and 1,848 people are estimated to be dead at the occurrence of earthquake at day and night time respectively (13.5% and 15.2% of total population). About 2,063 and 2,325 people are also calculated to be injured. More than 95,000 people were dead in the Mw 7.9 Sichuan earthquake of May 12, 2008 in China. Haiti Mw 7.0 earthquake caused death of more than 230,000 people; 25% population of the capital Port-au-Prince and about 300,000 were injured [37]. Mw 9.0 Japan (2011) earthquake caused death of about 20,000 people whereas Nepal (2015) earthquake caused more than 8000 deaths and more than 19000 casualties in Nepal Earthquake [34,38,39].

Economic Loss Estimation

The potential damage of buildings and human casualty has been calculated in this section of the paper. Earthquake loss due to building damage refers to the physical damage states which are the most significant contributor to the particular loss. Human injury and deaths are heavily influenced by the complete or partial collapse of buildings. In contrast, direct economic loss (including repair/retrofit cost) is accumulated from significant loss contribution of any structural and non-structural damage [20]. The economic loss of such damages will be calculated in Table 8. The estimation is done based on the following assumptions-

- New construction cost of total to partially collapsed and heavily damaged buildings- BDT 2,000 per sq.ft
- Retrofit of low to moderately damaged buildings- BDT 400 per sq.ft
- Subsidy to the family members for one fatality- BDT 10,00,000 [40].
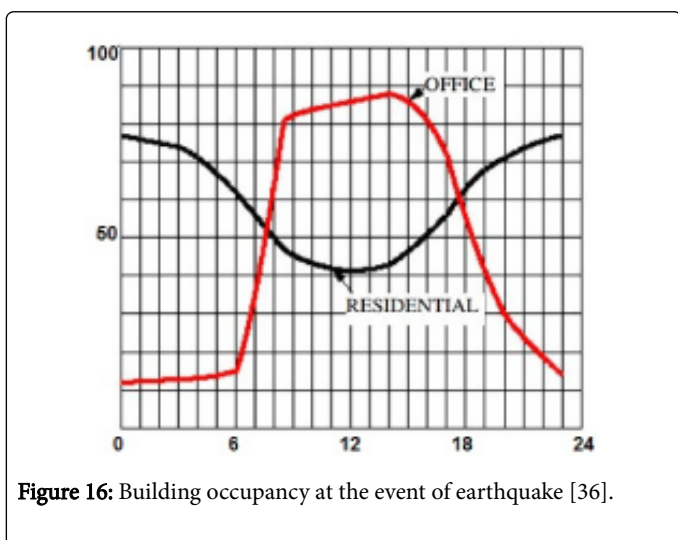- Medical bills for a hospitalized person- BDT 50,000 [40].

Cluster	Occupancy/Day	Occupancy/Night	Total number of destroyed buildings	Death/Day	Death/Night	Injury/Day	Injury/Night
2A	4161	373	21	93	180	116	225
2B	2006	1837	13	478	96	597	120
3	1635	1607	56	115	133	151	169
4	362	691	63	159	197	201	247
5	2719	2900	48	28	68	38	87
6	1323	2480	115	613	823	774	1038
7	362	691	59	149	351	186	439
Total	12,206	9,888	375	1,635	1,848	2,063	2,325

Table 7: Possible human casualties on different clusters of the study area.

On the basis of the assumptions in this section, potential economic loss at the event of an earthquake occurrence in the study area has been calculated. The direct economic loss is estimated to be BDT 1,30,222.4 lakhs (USD 160 Million) in the study area which is vigorous for a Ward. The Mymensingh Municipality in co-ordination with Government should encourage the residents and other stakeholders to follow the earthquake resistance guideline in order to construct buildings provided in national building code. An earthquake event may result in massive destruction of lives and properties in the area so

it is necessary to ensure minimum loss to the individuals, society and nation.

Cluster	Number of building	Possible no. of collapsed building	Possible no. of partial to total collapse heavily damaged building	Average floor area	Cost of new construction (In lakhs)	Possible no. of low to moderate damaged building	Average floor area	Cost of retrofitting (In lakhs)
2A	38	21	8	3101.7	524.2	5	3101.7	56.5
2B	18	13	14	24818.1	6775.3	7	24818.1	729.7
3	131	56	36	1316.7	941.4	19	1316.7	101.4
4	136	63	41	1532.4	1275.0	22	1532.4	137.3
5	97	48	31	748.4	476.7	17	748.4	51.3
6	198	115	75	1146.8	1729.4	40	1146.8	186.2
7	117	59	38	1469.4	1127.0	21	1469.4	121.4
Total	735	375	244	17,167.4	84,137.4	131	17,167.4	9,061.0
Note: 1 USD=Tk 80 BDT								

Table 8: Economic loss estimation of the study area.

Item		Physical Damage	Loss (In lakhs)
Human Injury	Day	2063	1031.5
	Night	2325	1162.5
Loss of human lives	Day	1635	16350
	Night	1848	18480
Total to partial collapse , heavy damage of buildings		244	84137.4
Low to moderate damage of buildings		107	9061.0
Total Loss			1,30,222.4

Table 9: Total Economic loss of the study area.

Table 9 provides calculation of the direct losses of earthquakes. There may be many indirect losses such as damage of lifelines, business interruption losses, relocation cost, transport loss, debris removal cost, cost of reliefs etc. [30]. Due to data unavailability, estimation of such losses are excluded from the study.

In 2017, the world has faced $306 billion dollars losses caused by different disasters which is almost double as 2016's cost $188 billion dollars [41]. According to Nepal Government, the overall damage of earthquake in 2015 is estimated to be at about $10 billion; nearly half of the Gross Domestic Product (GDP) [42]. Government of Japan has reported that, earthquake (2011) rebuilding cost is estimated to be $309 billion [38]. The Haiti earthquake (2010) caused between $7.8 billion to $8.5 billion in damage [37]. The direct and indirect loss of Bhuj earthquake (2001) was $5 billion; 5% of which is covered by insurance. For Turkey earthquake (1999), the loss was estimated to be $7-$40 billion (about $900 million was covered by insurance). The loss of Kobe earthquake was $100 billion (10% covered by insurance), for Northridge earthquake it was $35 billion; 30% of which covered by insurance [30]. For the study area, the total direct loss is estimated to be about BDT 1,30,222.4 lakh in taka (USD 160 Million) in this study.

Major Findings and Recommendations

Almost 70% area will be affected by intensity level of VIII whereas 30% of study area will be affected by intensity IX. Cluster 2A, 6 and 7 will be mostly affected by earthquake compared to other clusters (Figure 13).

The number of casualties may differ with the occurrence time. A total of 3698 people (30.5% of total population) and 4173 people (34.4% of total population) are calculated to be affected at the event of earthquake at day and night time respectively (Table 6).

Among 735 surveyed buildings, about 375 buildings including RCC, URM and tin shade buildings are estimated to be damaged; 230 of them are RCC structures which is 31.3% of total surveyed buildings (Table 5) and 14.2% of total buildings of the study area.

A number of educational institutions and health facilities located in study area including Mymensingh Medical College are found to be vulnerable (Field Survey, 2017). Immediate actions should be taken to retrofit the vulnerable buildings to ensure structural strengthening for the preparedness of earthquake.

After occurrence of earthquake, a large number of people will require temporary shelters because of massive destruction of their residence [43]. In this regard, potential temporary shelters should be identified within the locality and facilitated with necessary amenities.

For safe and immediate evacuation of the residents and others, Evacuation Route Planning should be introduced for the study area.

From field survey, it is found that the roads of study area are too narrow for vehicular movement. For proper evacuation roads should be widened so that vehicular movement is possible within the Ward [44,45].

Occurrence of earthquake will result in severe injury to death of a number of people. Many people will require medical facilities after earthquake. To provide medical treatment to the injured people by an earthquake, the safe and non-vulnerable health facilities should be identified.

The massive destruction of an earthquake event will generate tons of debris which should be removed for rapid evacuation. Debris Management Plan should be introduced in the study area.

Earthquake may also affect the utility lines of the study area. It may also cause damage to emergency services. Proper planning and act should be introduced to respond during disaster.

Community level training and awareness program should be introduced. People of all ages and socio-economic groups should be trained to make quick response during earthquake [46-48]. Introduction of safety drills have an impact on reduced death rate in Nepal Earthquake.

The location of children, aged and disabled people within the community should be identified for the rapid evacuation and the data base should be continuously updated.

The occurrence of earthquake will not affect a Ward but also cause massive destruction to the surrounding areas. The loss estimation has been done only for Ward 14 of Mymensingh City Corporation; the total cost may exceed several million dollars. For example: earthquake of 1999, September 21, Taiwan city caused at least 2,297 people killed, 8700 injured, 600,000 people left homeless, and about 82,000 housing units damaged [49].

Conclusions

In recent times earthquake has become a regular phenomenon in Bangladesh. The impact of an earthquake having high intensity will result in vigorous destruction to cities like Dhaka, Chittagong, Mymensingh. As short-term earthquake forecasting is not available globally; the best way to reduce potential damage and fatality is preparedness and response. The impact of such events should be reduced for both structural and non-structural features by taking initiatives. Immediate response to affected communities should be ensured by proper planning, response and management. The local, central government and other agencies should collaborate with each other for proper functioning during disaster. Emergency vehicles should be ensured for the rescue and transporting injured to the hospitals considering the road width of the area. Regular maintenance of the electricity, water and gas pipelines should be ensured and the firefighting and rescue teams should be well aware of the connectivity lines. Debris removal should be done within the shortest hours for the evacuation of the trapped people. In this study, the potential damage caused by earthquake has been estimated for Ward 14 of Mymesingh. Such studies should be introduced for the other Wards of Mymensingh and integrated Earthquake Management Plan should be introduced to reduce the potential loss. Regular workshop and training should be held for awareness raising and capacity building of these localities. Government, public and private sectors and the individuals should come forward to ensure the minimum loss of life and property at the event of an earthquake.

References

1. Sarker JK, Ansary MA, Rahman MS, Safiullah AMM (2010) Seismic hazard assessment for Mymensingh, Bangladesh. Environ Earth Sci 60: 643.

2. Sarker JK, Ansary MA, Islam MR, Safiullah AMM (2010) Potential losses for Sylhet, Bangladesh in a repeat of the 1918 Srimangal earthquake. Environ Econ 1: 12-31.

3. BNBC (1993) Bangladesh National Building Code. HBRI-BSTI.

4. HBRI (2015) BNBC (Bangladesh National Building Code-Draft). (2015). Retrieved 28 May, 2017, https://www.scribd.com/document/363364110/33951114-BNBC-1993-pdf

5. Molnar P, Tapponier P (1975) Cenozoic tectonic of Asia, effects of a continental collision. Science 189: 419-426.

6. Bilham R, Gaur VK, Molnar P (2001) Himalayan seismic hazard. Science 293: 1442-1444.

7. Badal J, Vázquez-Prada M, González Á (2005) Preliminary quantitative assessment of earthquake casualties and damages. Natural Hazards 34: 353-374.

8. Doocy S, Daniels A, Packer C, Dick A, Kirsch TD (2013) The human impact of earthquakes: a historical review of events 1980-2009 and systematic literature review. PLoS currents 5.

9. Shapira S, Levi T, Bar-Dayan Y, Aharonson-Daniel L (2018) The impact of behavior on the risk of injury and death during an earthquake: a simulation-based study. Natural Hazards 1-16.

10. Alam MK, Hassan AKMS, Khan MR, Whitney JW (1990) Geological Map of Bangladesh. Government of the People's Republic of Bangladesh, Geological Survey of Bangladesh.

11. Islam MK, Hassan M, Majlis ABK, Nizamuddin M (1995) Structure and tectonics of the eastern part of the Jamuna valley, Bangladesh: a tectono-geomorphic approach. Bangladesh J Geol 14: 15-23.

12. Mymensingh Municipality. Retrieved 28 May, 2017, from http://www.mymensinghmunicipality.gov.bd/

13. Reimann K (1993) Geology of Bangladesh. GebrFCder Borntraeger, Berlin-Stuttgart.

14. Urban Development Directorate (UDD), Ministry of Housing and Public Works, GoB. (2015). Mymensingh Strategic Development Plan (MSDP) Project, 2011-2031. Retrieved 28 May, 2017, from: http://www.msdp.gov.bd/MSDP_Monograph.pdf

15. Ansary MA (2004) Seismic Loss Estimation of Dhaka for an Intensity of VII. Oriental Geographer 48: 1-16.

16. Crowley H, Pinho R, Bommer JJ (2004) A probabilistic displacement-based vulnerability assessment procedure for earthquake loss estimation. Bulletin of Earthquake Engineering 2: 173-219.

17. Trifunac MD, Brady AG (1975) On the Correlation of Seismic Intensity with Peaks of Recorded Strong Ground Motion. Bulletin of the Seismological Societyof America 65: 139-162.

18. Saleemuddin MZM, Sangle KK (2017) Seismic damage assessment of reinforced concrete structure using non-linear static analyses. KSCE J Civ Eng 21: 1319-1330.

19. Sinha R, Shiradhonkar SR (2012) Seismic damage index for classification of structural damage-closing the loop. In The 15th world conference on earthquake engineering.

20. Kircher CA, Reitherman RK, Whitman RV, Arnold C (1997) Estimation of earthquake losses to buildings. Earthquake spectra 13: 703-720.

21. Kircher CA, Nassar AA, Kustu O, Holmes WT (1997) Development of building damage functions for earthquake estimation. Earthquake Spectra 13: 663-682.

22. Saruddin SNA, Nazri FM (2015) Fragility curves for low-and mid-rise buildings in Malaysia. Procedia Engineering 125: 873-878.

23. Porter K, Silva V, Wald DJ, Wyss B (2010) GEM1 Seismic Risk Report: Part 2. GEM Foundation, Pavia, Italy.

24. Arya A (2000) Non-Engineered Construction in developing countries-An Approach toward Earthquake Risk Prediction. Bulletin of the New Zealand Society for Earthquake Engineering 33: 187-208.

25. Bothara JK, Parajuli YK, Arya AS, Sharpe RD (2000) Seismic safety in owner-built buildings. In 12th World Conference on Earthquake Engineering, Paper no. Auckland, New Zealand 2130.

26. Fah D, Kind F, Lang K, Giardini D (2001) Earthquake scenarios for the city of Basel. Soil Dynamics and Earthquake Engineering 21: 405-413.

27. Yamazaki F, Murao O (2000) Vulnerability Functions for Japanese Buildings Based on Damage Data due to the 1995 Kobe earthquake. Proc. of 3rd Japan-UK Workshop on Implications of Recent Earthquakes on Seismic Risk, London 91-102.

28. Yamaguchi N, Yamazaki F (2001) Estimation of Strong Motion Distribution in the 1995 Kobe Earthquake Based on Building Damage Data. Int J Earthquake Eng Struct Dyn 30: 787-801.

29. Bommer JR, Spance M, Erdik S, Tabuchi N, Aydinoglu E, et al. (2002) Development of an earthquake loss model for Turkish Catastrophe Insurance. J Seismology 6.

30. Ansary MA (2003) Economic Loss Estimation of Dhaka Due to an Earthquake of Intensity VIII. Journal of Bangladesh Insurance Academy 52: 107-132.

31. Segawa S, Kaneko F, Ohsumi T, Kagawa H, Fujitani H (2002) Damage Estimation of Buildings in Kathmandu Valley and Proposals for Improvement of the Earthquake Resisting Capacity. Proc, 11th Japan Earthquake Engineering Symposium.

32. Towhata I (2008) Geotechnical earthquake engineering. Springer Science & Business Media.

33. Dizhur D, Lumantarna R, Ismail N, Ingham JM, Knox C (2010) Performance of unreinforced and retrofitted masonry buildings during the 2010 Darfield earthquake. Bulletin of the New Zealand Society for Earthquake Engineering 43: 321.

34. Hossain ASMF, Adhikari TL, Ansary MA, Bari QH (2015) Characteristics and Consequence of Nepal Earthquake 2015: A Review. Geotechnical Engineering Journal of the SEAGS & AGSSEA 46: 114-120.

35. Sun B, Yan P (2015) Damage characteristics and seismic capacity of buildings during Nepal Ms 8.1 earthquake. Earthquake Engineering and Engineering Vibration 14: 571-578.

36. Coburn AW, Spence RJS, Pomonis A (1992) Factors Determining Human Casualty Levels in Earthquakes: Mortality Prediction in Building Collapse. Proceedings of the 10th World Conference on Earthquake Engineering, Madrid, Spain 10: 5989-5994.

37. Amadeo K (2018) Haiti Earthquake Facts, Its Damage, and Effects on the Economy. The Balance.

38. Amadeo K (2011) Japan's 2011 Earthquake, Tsunami and Nuclear Disaster. The Balance.

39. Malovichko AA, Gabsatarova IP, Kolomiets MV, Chepkunas LS (2016) The catastrophic earthquake of April 25, 2015, in Nepal: Analysis of seismological data. Seismic Instruments 52: 195-206.

40. Shahid MH (2016) Assessment of Lessons Learned in Rana Plaza Disaster. A Dissertation Submitted to Postgraduate Programs in Disaster Management. Dhaka: Brac University.

41. Rathi A (2017) Global disasters in 2017 cost $306 billion-nearly double the cost of 2016. QUARTZ.

42. Madhura K (2015) The economic damage from the Nepal earthquake is almost half of the country's GDP. Quartz India.

43. Kilci F, Kara BY, Bozkaya B (2015) Locating temporary shelter areas after an earthquake: A case for Turkey. Eur J Operational Res 243: 323-332.

44. Alam MK (1988) Geology of Madhupur Tract and its adjoining areas in Bangladesh. Geolsurv Bangladesh Rec 5: 23.

45. Alam M, Ansary MA, Chowdhuary RK, Uddin AJ, Islam S, et al. (2008) Evalution of Building's Vulnerability to Earthquake in Old Part of Sylhet and Construction Safety Rules. IUST Int J Eng Sci 19: 33-43.

46. Ansary MA, Noor MA, Rashid MA (2004) Site Amplification Characteristics of Dhaka City. J Civ Eng 32: 1-16.

47. Douglas J (2003) Earthquake ground motion estimation using strong-motion records: a review of equations for the estimation of peak ground acceleration and response spectral ordinates. Earth-Science Reviews 61: 43-104.

48. Okada S, Takai N (2000) Classifications of structural types and damage patterns of buildings for earthquake field investigation. In Proceedings of the 12th world conference on earthquake engineering, Auckland, New Zealand 30: 1-8.

49. Sarker JK (2011) GIS based methodologies of seismic Hazard and risk analysis for Bangladesh. PhD Thesis, Department of Civil Engg, BUET.