An Analysis of Seismic Risk for the Building Stocks in the Sylhet City Corporation, Sylhet, Bangladesh: A Case Study on Ward No. 1

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Abstract

Bangladesh is one of the most earthquake-prone countries in the world because of the difference in energy between the Indian and Burma plates. Frequent earthquakes could lead to massive loss of property and destruction. This study aims to determine the seismic risk of building stocks in Sylhet City Corporation (SCC). Amongst 28 wards, Ward No. 1 was selected, as it is one of the preferable residential areas and has almost 2143 buildings. By following Sloven's formula (1960), 320 buildings were randomly selected. The level-I observational survey is conducted with a checklist to see the status of the buildings. General information was analyzed through descriptive statistics. The Modified Turkish Method, proposed by Socuoglu and Yazgan, was followed to find out the building's performance score., A fragility curve calibrated for 475 years, given by Alam et al. 2018, was followed to detect the probable damage number of buildings. It is found that one-story buildings are most prominent here (58.75%). Almost 40% of the construction period is under 20 years (116 buildings). The floor area covered nearly the entire plot meaning there is no vacant place on the owner's land. Buildings are classified into five groups which are EMSB1 (40%), EMSB2 (32.19%), EMSC (22.81%), EMSD (0.64%), and EMSF (4.38%). There are 63, 23, and 199 buildings with soft stories, a heavy overhang porch, and short columns, respectively. Buildings' apparent quality is divided into three categories likely good (41), moderate (264), and poor (15). The analysis revealed that 79.06% (253) have a high building performance score, wherein 7.19% (23) and 13.75% (44) have moderate and poor performance scores, respectively. For 0.8, 0.9, and 1 peak ground acceleration (PGA), the probable number of damaged buildings will be 224, 227, and 230, respectively. Based on the building's performance score, the weighted analysis shows that 77% of the area is free from seismic risk due to the building stocks.

Keywords: Seismic Risk, Buildings, Ward No. 1, Performance Score, Probable Damage.

1. Introduction

Over the past few years, weather conditions have become gradually extreme and are reaching a hostile position. On the back screen, cosmic, inner earth crust, and man-made causes are responsible for creating this situation (IPCC, 2007). Recently, we have encountered the invisible danger of 'earthquakes' (USGS, 2016). Earthquakes above six magnitudes on the Richter scale have increased to such an extent that a few days before the event, one cannot imagine it (USGS, 2016). Soon, this incident will grow at an alarming rate.

The Himalayan range is 2100 km, generally considered a seismically active front. Experts stated that there might be one or two earthquakes whose magnitude on the Richter scale will be 8.1 to 8.3. This may happen tomorrow or after 500 years. This region will be severely affected if jolting occurs near Nepal, India, Bangladesh, and Pakistan. Infrastructure and economic activities will collapse, affecting more than 50 million people (Bilham et al., 2001).

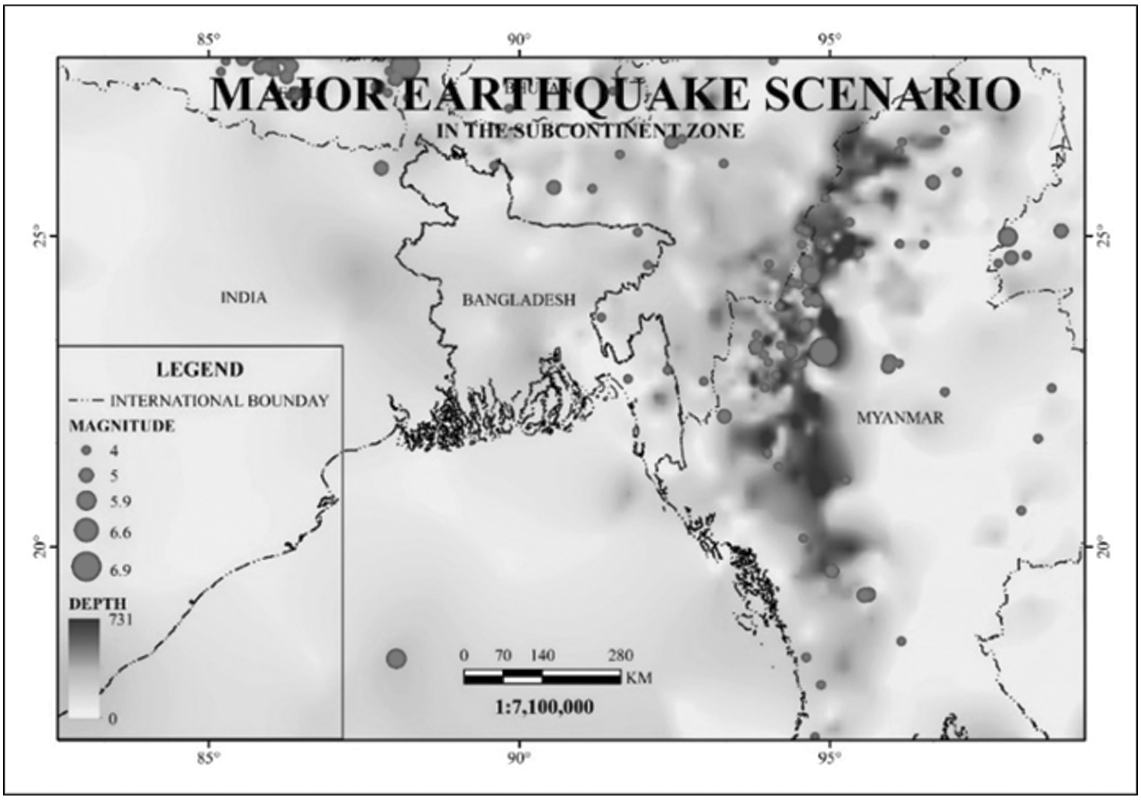
Bangladesh didn't face large-scale earthquakes in a long period (Islam, 2014). In 1950, an earthquake happened in Bangladesh called the "Assam Earthquake." The magnitude of this quake was 8.5 on the Richter scale. The epicenter was Assam state, India, which was 780 miles far away from the capital Dhaka. That was the last time the country faced a powerful Earthquake

(Rahman, 2016). According to seismologists, Bangladesh stands on the verge of devastating earthquakes that may happen anytime (Alam, 2009). The Bengal Basin, which occupies most regions of Bangladesh, is highly vulnerable to earthquake activities (Miller, 2016). It is also included that Bangladesh is surrounded by high seismic areas (Ali and Choudhury, 2001). It has experienced several moderate earthquakes during the last ten years (Figure 1) (USGS, 2016).

In the years between 2009 to 2015, Bangladesh faced four significant earthquakes. In 2016, this region also felt three major quakes with epicenters not far away. One occurred in Manipur, India, and with other two in Myanmar. The intriguing fact was that all magnitude levels were above 6.7. Between January 3 and 4, 2017, Bangladesh experienced 5.5 and 5.1 level shakes, respectively. The time between these moderate-level earthquakes was only 9 hours (USGS, 2016). These happened in the subduction zone (Durjoy, 2017), where the Indian and Burma plates are locked (Indiaspend, 2016). Because of their countermotion, immense pressure occurred. They are usually stuck together beneath the mountains of North-East India and Myanmar (Steckler et al., 2016). Because of these tremors, cracks were seen on the roads and in the cropland. Also, soil liquefaction occurred in the Kamalganj Upazila, Moulvibazar (Daily Star, 2017). Though this scenario is a general consequence in the alluvial area, it happened for the first time in our country. Soon, a large-scale eruption may happen. After these tremors occur, researchers believe the chances of a mega-earthquake occurring beneath the Bengal basin's thrust fault will also increase. The level of jolting might be above 7. (Steckler et al., 2016) During the tremor, building collapse is one of the major causes of people's death. Therefore, it's high time to analyze the seismic risk of urban building stocks.

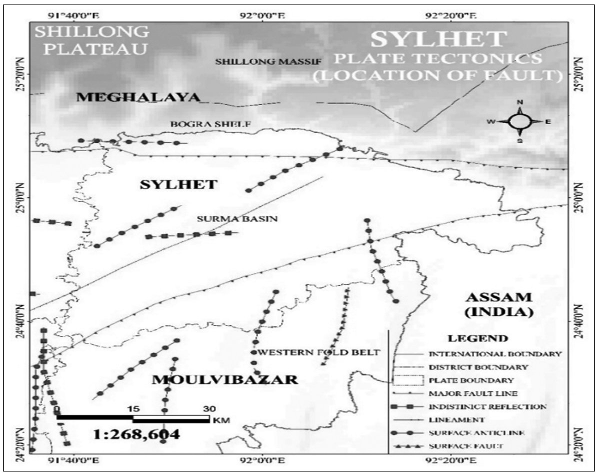
2. Rationale of the Study

Sylhet, one of the most important cities in northeastern Bangladesh, faces a higher risk of an earthquake than any other region. This region has two major active fault lines and some moderate faults. (Banglapedia, 2015).



Data Source - USGS 2016, Base Map Source - Diva GIS, Prepared by - Author.

Fig. 1: Last 10 Years Earthquake Scenario Near and In Bangladesh



Data Source - Banglapedia, 2015, Base Map Source - BARC, 2016, Prepared by - Author.

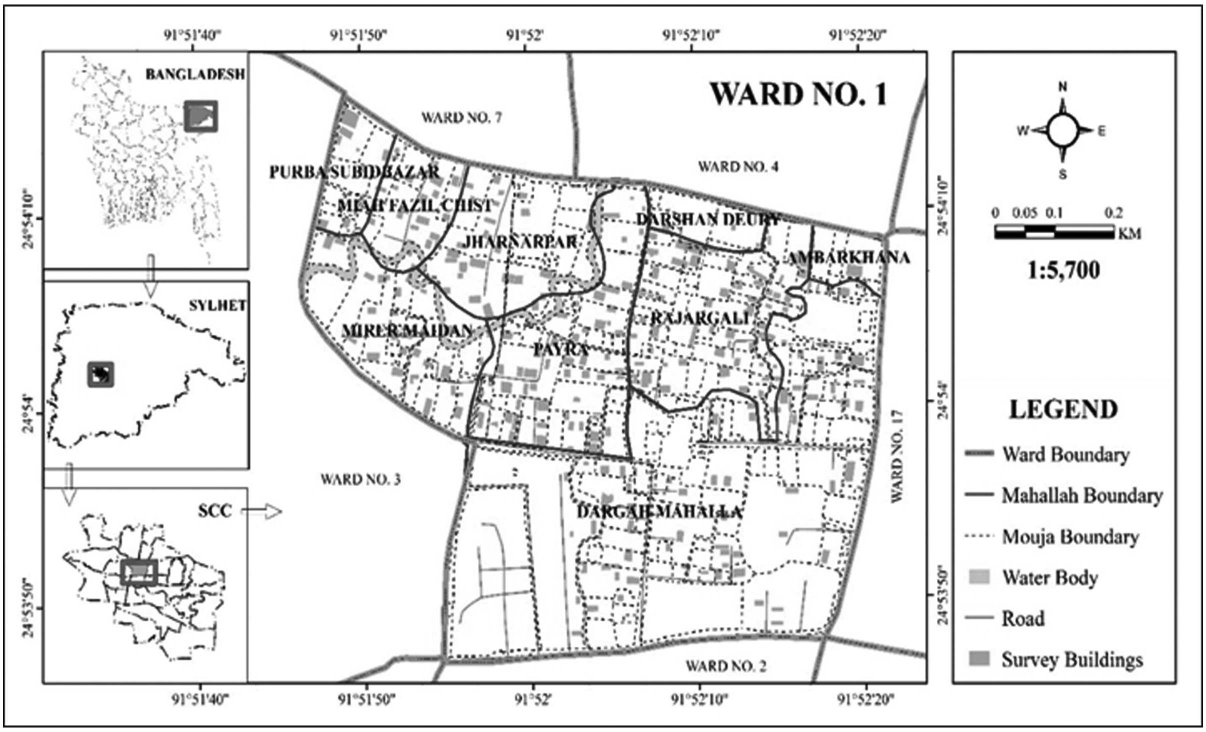
Fig. 2: Location of Fault in Sylhet Region

Experts opine that the landforms of Sylhet don't support high-rise buildings (SCC, 2016). It is observed that now a days, people in this area have started to build high-rise buildings which increases the vulnerable risk (Field Observation, 2016).

The Sylhet region is situated only 200 km away from the Dauki fault (Figure 2). If the quake's epicenter is the Dauki fault and the level is 6, it is enough to damage the region tremendously. If the level rises to 8 or more, it is assumed that nothing will be present, and only leftover debris will be found (SCC, 2016).

3.2. Data Collection

Data collection is a vital part of the research, which has been carried out with data from both primary and secondary sources. Preliminary data have been collected from field surveys through a checklist, whereas the secondary data have been collected from hard copies and shapefile from different sources. Socuoglu and Yazgan proposed a procedure to analyze the seismic risk for the building stocks in 2003. According to them, a simple two-level field survey must be conducted to determine the desired result. One is a level-I survey, mainly based on field observation, and the other is a level-II survey, which is primarily an instrumental-based survey. Due to the instrumental limitation in this study, only a level-I survey was conducted based on the checklist below.



Base Map Source - SCC, 2016, Prepared by - Author.

Fig. 3: Study Area Map

a. The number of stories above ground
b. Presence of Soft Story (Yes or No)
c. Presence of Heavy Overhang (Yes or No)
d. Apparent Building Quality (Good, Moderate, or Poor)
e. Local Soil Conditions (Stiff of Soft)
f. Topographical Effect (Yes or No)

3.3. Sampling Method

Due to the short time, studying the whole area was impossible. As well as needed ample time to ensure the accuracy of finding results. Sloven's formula (1960) is one of the best-fitted formulas (1) to get the desired result through a random sampling technique (Altares et al., 2003)

$$n = \frac{N}{1 + Ne^2} \quad (1)$$

Where, $\mathrm{n} = \mathrm{no.\,of\ samples}$, $\mathrm{N} = \mathrm{total\ population}$, and $\mathrm{e} = \mathrm{margin\ of\ error}$.

3.4. Data Classification

To find out the present scenario of buildings collected data was broadly divided into three parts.

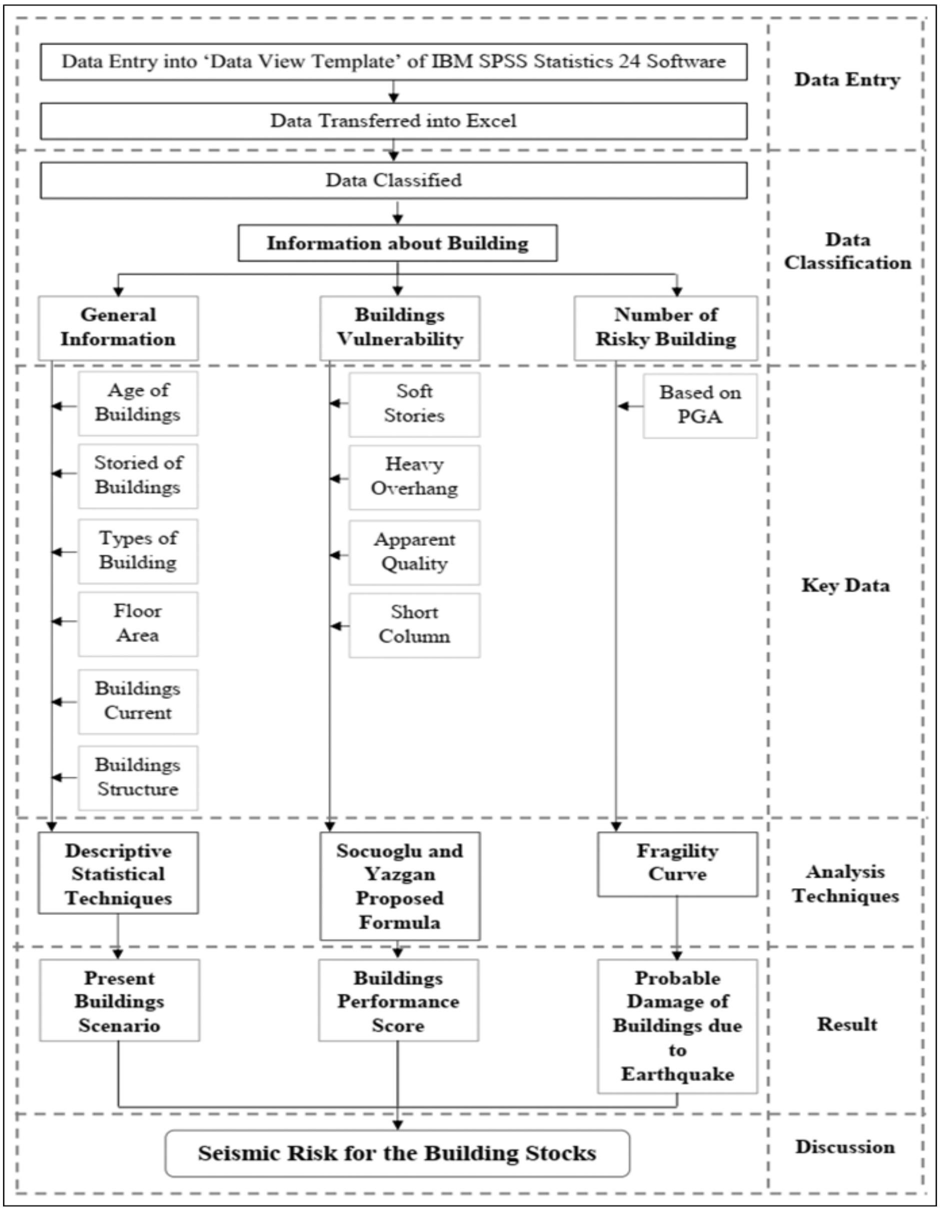


Fig. 4: Data Analysis Framework

I. General information like age, stories, types, present conditions of buildings, the structure of buildings, etc., were included in the first part.

II. To find out the vulnerability level of buildings, the second part only included building designs like whether the design had soft stories or not, apparent quality, whether the porch or corridor of the buildings was heavy overhang or not, column status, and topography of the residential area.

III. The third part was the Peak Ground Acceleration (PGA) value needed to ascertain probable damage to buildings in the study area.

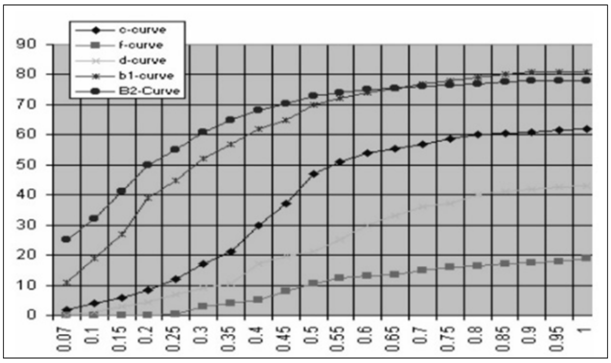
3.5. Data Analysis

Throughout the data collection process, physical data of sample buildings have been collected quantitatively. Then input the data into IBM SPSS Statistics 24 and joined with the GIS shapefile. Data is then processed and analyzed by statistical tools. Analyzed data have been classified, tabulated, and presented in maps, tables, and graphs using MS-Excel 2016, IBM SPSS Statistics 24, and ArcGIS 10.4.1, respectively. The data analysis framework is given in Figure 4. General information like the number of stories, age of buildings, floor area, building types, etc., was analyzed through descriptive statistics.

Socuoglu and Yazgan's formula (2) was followed to determine the building's performance score, given below.

$$PS = \{Initial\ Score - \sum (Vulnerability\ Parameter) \times (Vulnerability\ Score)\} \quad (2)$$

From APPENDIX I and II, necessary values were obtained and plotted into the equation to acquire the expected result.



Source - Alam et. al (2008)

Fig. 5 : Fragility Curve for Different Building Types

Table 1. Damage Ratio for Different Types of Buildings at Different Earthquake Intensity

Type of House	Probable No. of Houses		
	0.8 PGA	0.9 PGA	1 PGA
EMSB1	0.79	0.8	0.81
EMSB2	0.75	0.76	0.77
EMSC	0.6	0.61	0.62
EMSD	0.4	0.42	0.43
EMSF	0.16	0.17	0.18

Source - Alam et. al (2008)

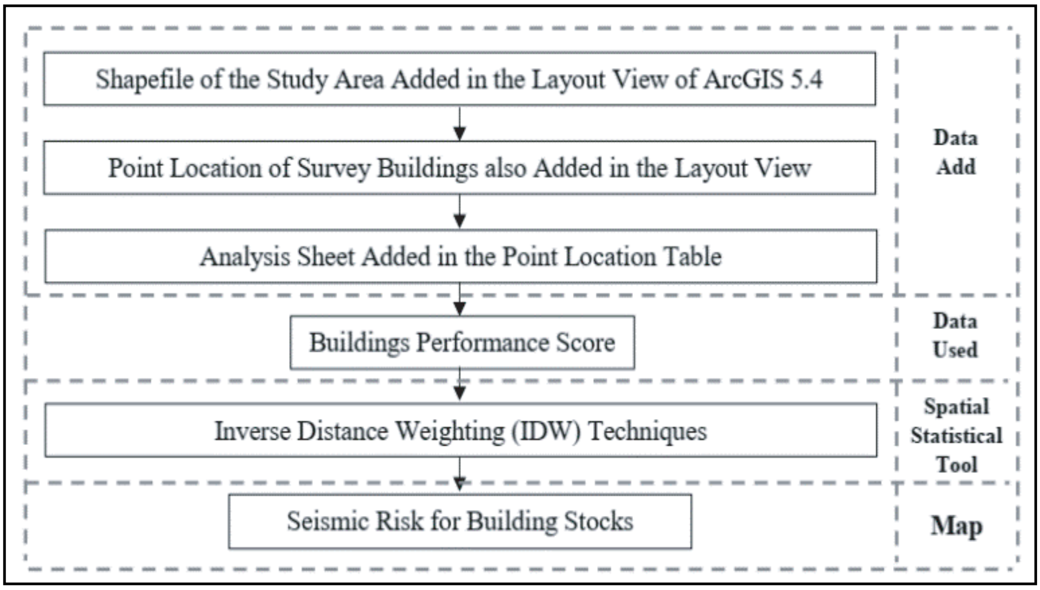


Fig. 6: Map Producing Techniques

Here, based on the characteristics of the building (like seismic zone, foundation, no. of stories, soft story, overhang, quality, column, etc.), the cut-off score was considered 120 (purposively). Below 120, buildings are vulnerable. If a score is found between 120 to 140, buildings are moderately vulnerable, and more than 140 means that buildings are safe.

To find out the probably damaged number of buildings in the study area, the fragility curve method was used (Figure 5). From the isoseismic hazard map of some deadly quakes, it concluded that the intensity of more significant Earthquakes in this region was 0.9g. This study considers only 0.8g, 0.9g, and 1g of PGA to estimate the number of damaged buildings.From the fragility curve calibrated for 475 years, the percentage of different types of buildings was determined and given in Table 1.

Geographic Information System (GIS) techniques were used to produce the study area map, building typology, and seismic risk for the building stocks (Figure 6). Inverse distance weighting (IDW) techniques were utilized to determine the weighted value of point data.

3.6. Data Presentation

Data was generally represented descriptively. Based on requirements, data was also represented by graphs, tables, and maps.

4. RESULTS AND DISCUSSION

4.1 Number of Stories

This area is mainly dominated by one-story buildings (58.75%). Two (15.31%), three (11.25%), and four stories (9.38%) buildings are also abundant here (Figure 7). The buildings above four stories are minimal (5.32%). The highest high-rise building in this study area has 13 floors.

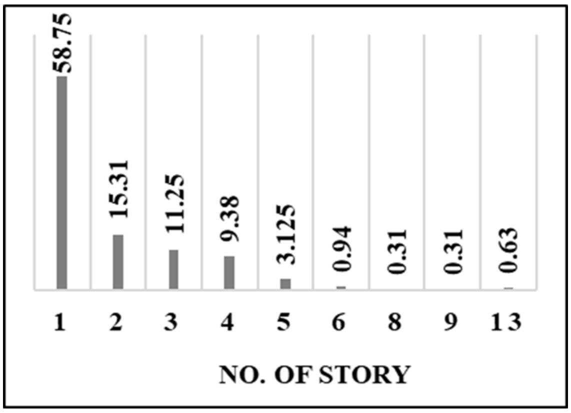


Fig. 7 : Number of Stories

4.2. Floor Area

Owners of the study area buildings don't follow the building construction regulation, due to which the Floor Area Ratio (FAR) of the building is almost equal to the floor area of the buildings. During the construction period, they did not leave a single plot piece. Moreover, the floor area varies from 217 square feet to 5100 square feet (Figure 8). Most buildings (31.25%) have 501 - 1000 square feet of floor area.

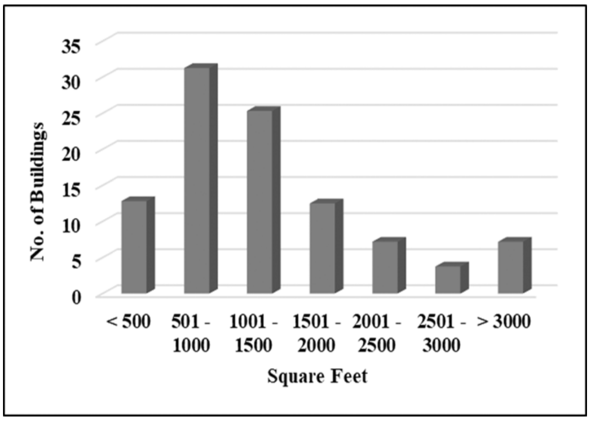


Fig. 8 : Floor Area of Building

4.3. Age

Of the 320 building samples, around 40% of the buildings in this ward are less than 20 years old, indicating the continuous growth of urbanization (Figure 9). However, about 15% of the buildings in the region are more than 30 years old, relating to a higher vulnerability factor, especially if one considers that the predominant type of older building is the EMSB type. There are significant growths in EMSC constructions using RCC beams and columns, which started only 20 or 30 years ago. Although some buildings are made of RCC, they are non-engineered and highly vulnerable.

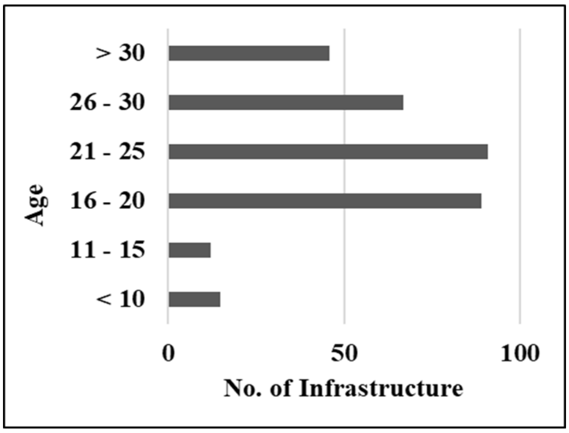


Fig. 9 : Age of Infrastructures

4.4. Types

From the extrapolation of surveying data, it is found that 40% is one-storied brick masonry (EMSB1) with roofs generally built by GI sheet or other materials, others are one-storied brick masonry (EMSB2) (14.38%), two-storied or taller brick masonry (EMSB2) (17.81%), reinforced concrete frame with low ductility (EMSC) (22.81%), reinforced concrete frame with moderate ductility (EMSD) (0.64%), and bamboo, wooden and steel structure (EMSF) (4.38%). (Figure 10) Based on 320 surveys, building type and weighted score for other buildings were determined through inverse distance weighting (IDW) techniques.

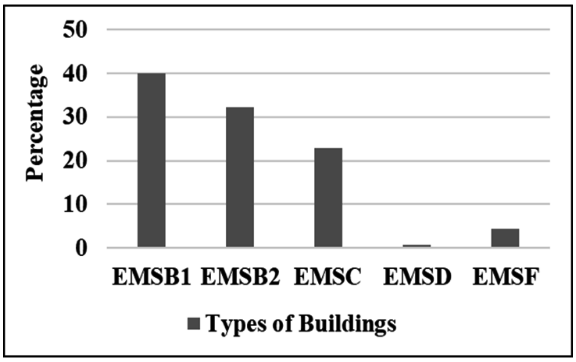


Fig. 10 : Types of Building Percentage

Figure 11 shows that most of the area was dominated by semi-pucca (EMSB1), one and two-storied buildings (EMSB2 and EMSC). Reinforced Cement Concrete (RCC) Buildings are rare in this region. The survey found that respondents would prefer to take help from a consultant during the construction or management of the house.

4.5. Buildings' Current Condition

Buildings' current condition is classified into four categories: none, light, moderate, and severe or collapsed. Among 188 one-story buildings, 46 were found to be without any damage. The number of light, moderate, and severe buildings are respectively 93, 38, and 11. For two, three, four, five, or more than six-storied buildings, 4, 6, 3, 1, and 1 numbered buildings have no damage. Within 49 two-storied buildings, 4, 21, and 20 numbered buildings are found in light, moderate, and severe conditions, respectively. 18, 8, and 4 numbered buildings are in light, moderate, and severe conditions, respectively, for three-story buildings. As well as 9, 12, and 6 numbered buildings are observed in light, moderate, and severe conditions, respectively, for four-story buildings. In this area, high-rise buildings are more damaged than others (7 and 6 for five and more than six storied buildings).

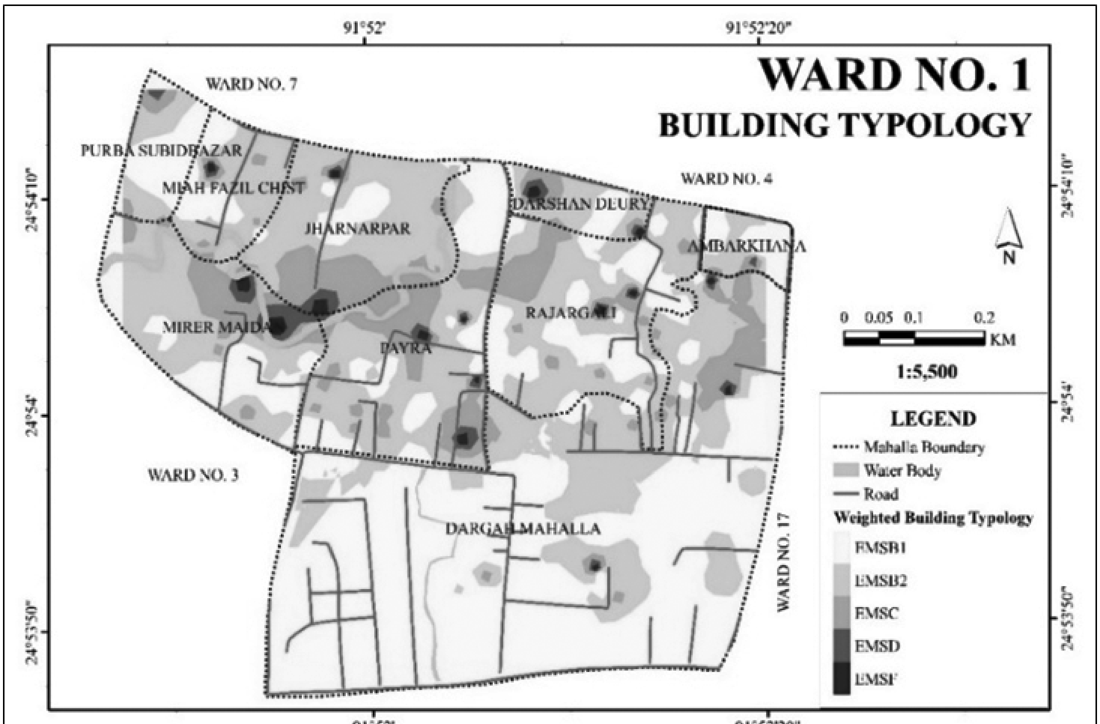


Fig. 11 : Weighted Building Typology.

4.6. Presence of Soft Stories

Among the 320 surveyed buildings, 63 have soft stories (Figure 12). Most of this type is found in high-rise buildings. These buildings are grouped by the damage grades and the number of stories, and then their number is normalized relative to the total number of buildings in each group. For all story numbers, it is evident that with increased stories, the buildings with soft stories indicated higher damage ratios than those without soft stories. Notably, almost all severely damaged buildings have soft stories. This is an important observation because if a building with a soft story is vulnerable to seismic damage, it is very likely that this damage will be either moderate or severe, significantly when the number of stories exceeds two.

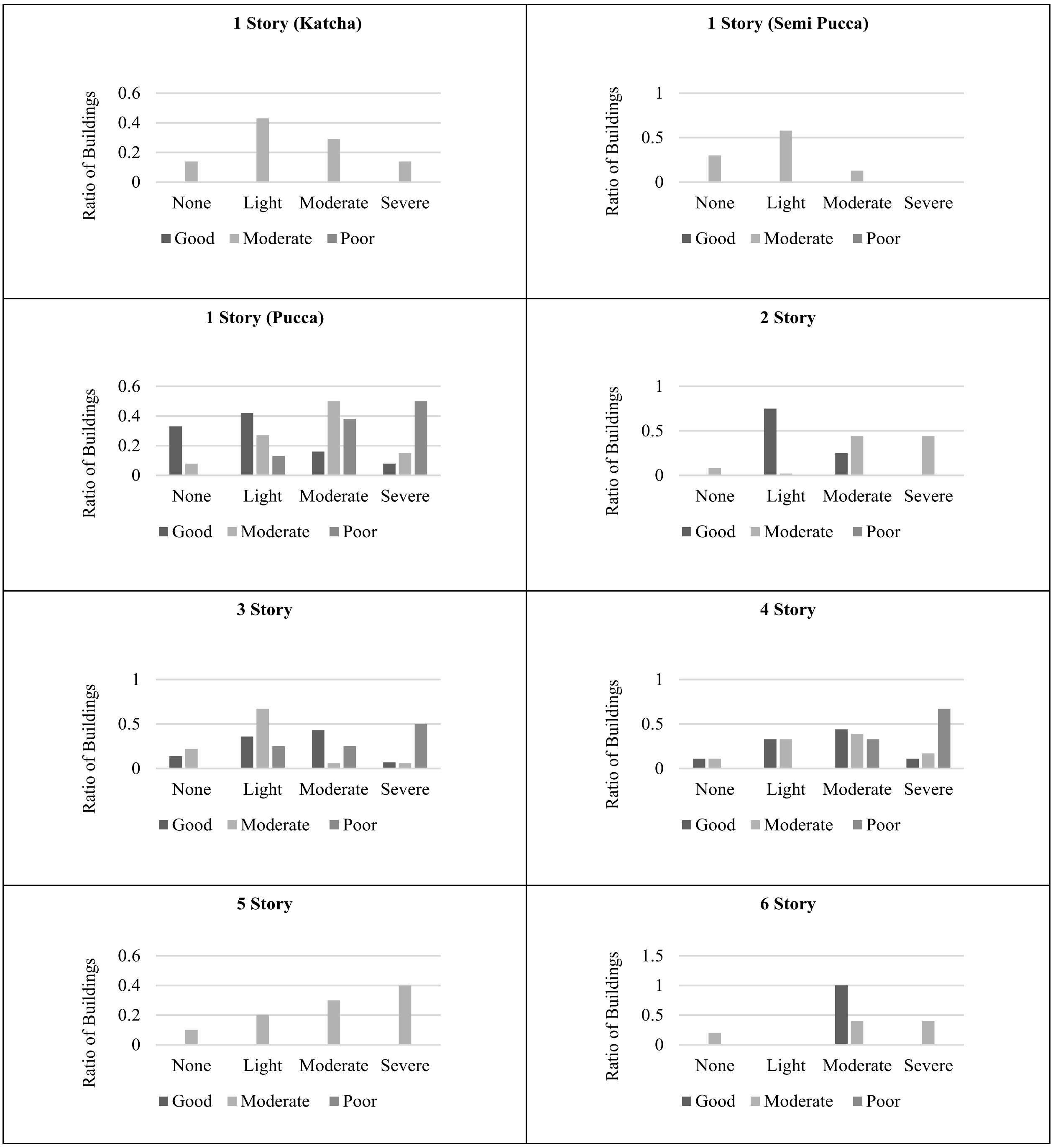


Fig. 12 : Normalized wrt. Presence of Soft Stories

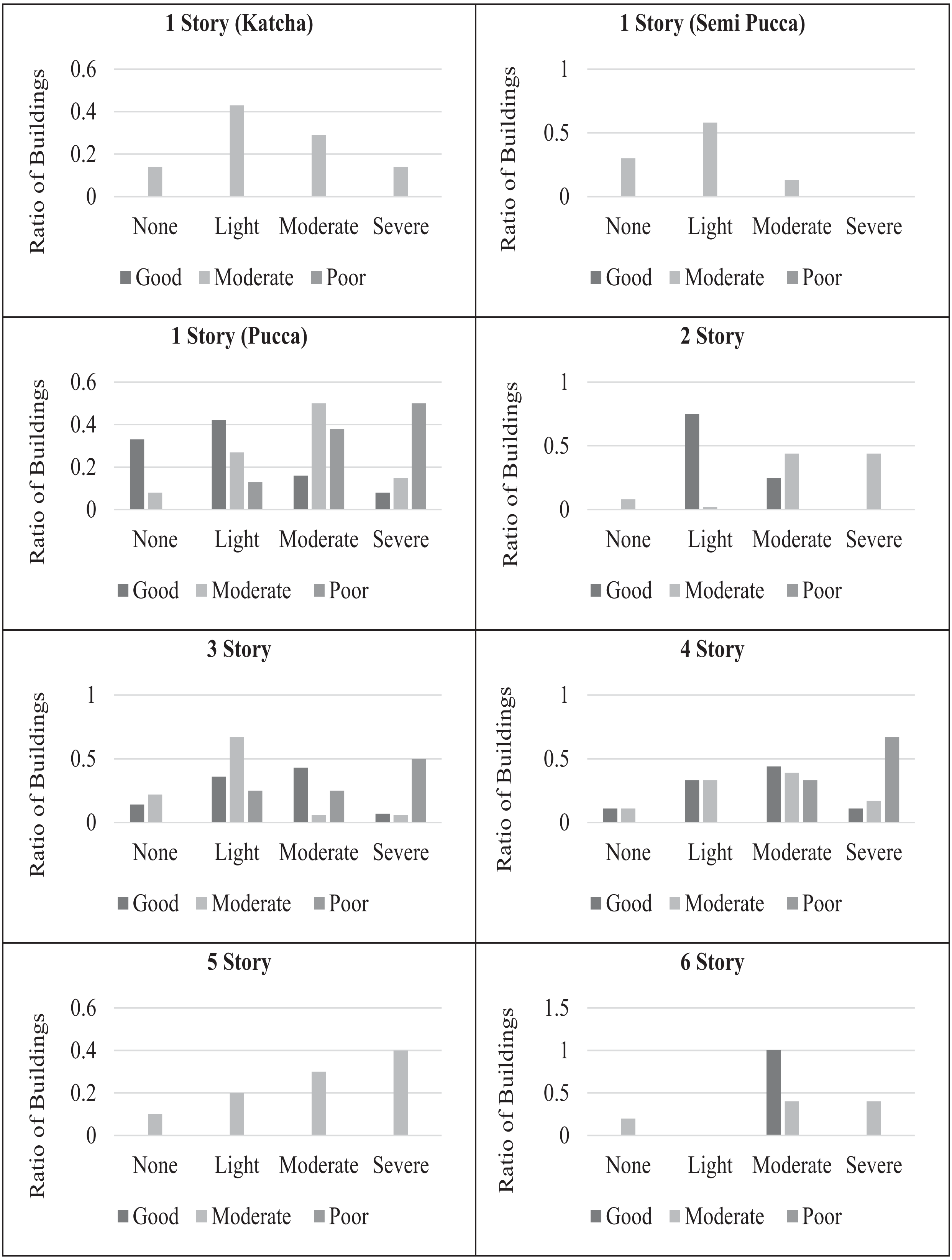


Fig. 13 : Normalized wrt. Presence of Apparent Building Quality

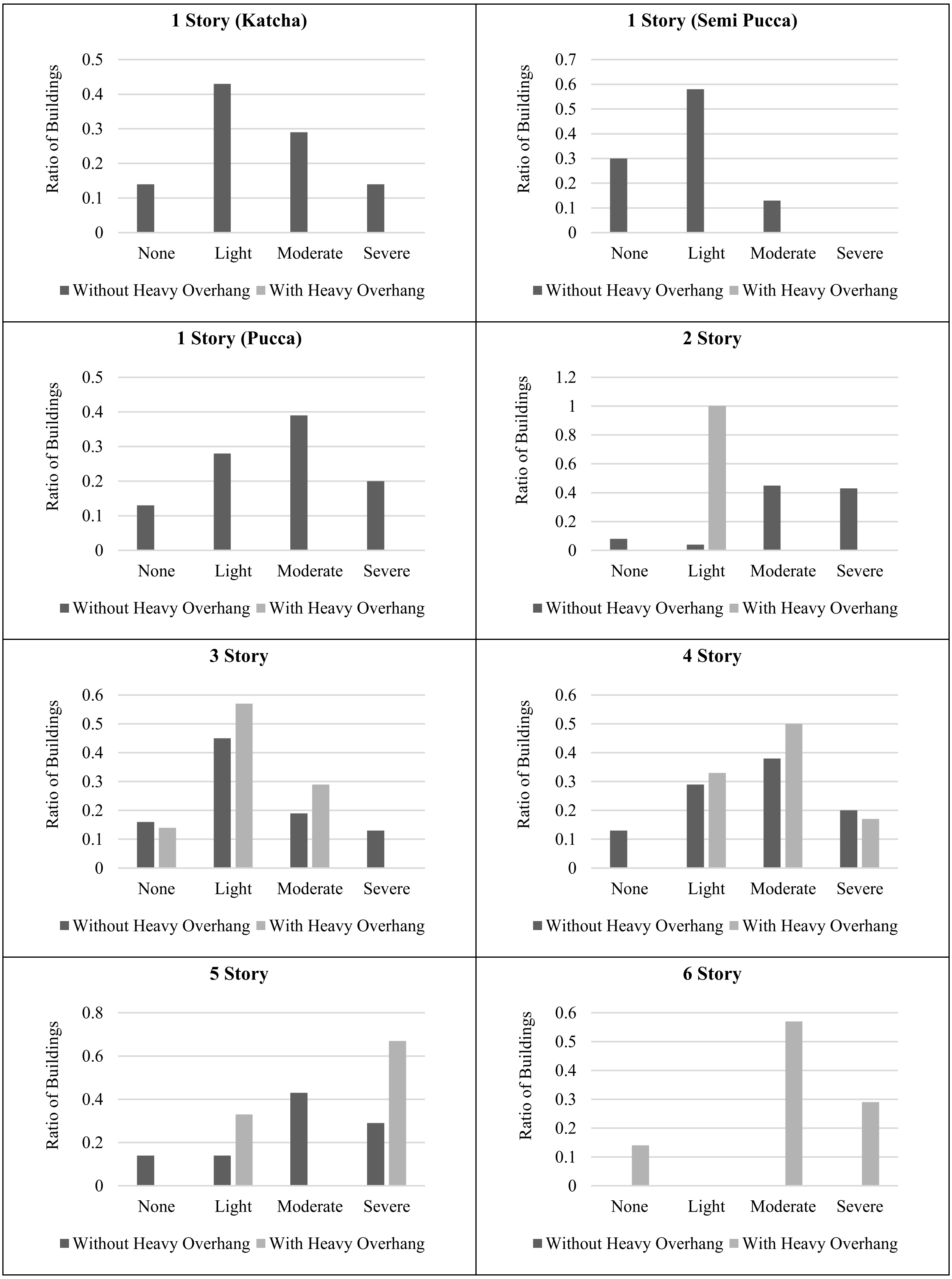


Fig. 14 : Normalized wrt. Presence of Heavy Overhang

4.7. Apparent Building Quality

The quality classification of 320 surveyed buildings revealed that 41 are good, 264 are moderate, and 15 are poor (Figure 13). From the observation survey, it is determined that moderate or severely damaged buildings have lesser quality than the others. It is especially true for 3 and 4 stories.

4.8. Presence of Short Columns

Among the 320 surveyed buildings, it is observed that 199 buildings had short columns.
It is alarming that almost all high-rise buildings have this type of column.

4.9. Presence of Heavy Overhang

There were 23 buildings with heavy overhangs, among a total of 320 (Figure 14). Almost all the undamaged buildings were free of heavy overhangs. Regarding the presence of overhangs, there is a constantly increasing trend in the damaged building ratios of 2 to 6 and above stories.

4.10. Building Performance Scores

The selected buildings are mainly low-rise residential buildings with three to six or more than six stories above the ground. A total of 320 representative residential buildings are analyzed using the Turkish method.

For Sylhet City, the expected intensity of an earthquake is around VIII to IX (Modified Mercalli Intensity Scale). According to the current seismic zone map of the building code, the PGA of this region is 0.9g. Corresponding PGV can be between 20 cm/sec to 40 cm/sec. Hence, the performance score Zone III is considered. Building performance scores below 120, 120 to 140, and over 140 indicate the high-risk, moderate, and low-risk groups, respectively. Figure 15 illustrates that most of the houses in Ward No. 1 were free from danger. This result was found due to the absence of high-rise buildings. From level 1 scoring, it was found that 44 buildings are vulnerable, 23 are moderate, and the rest of the 253 buildings are safe. The table indicates that with the rise of the building, vulnerability increased.

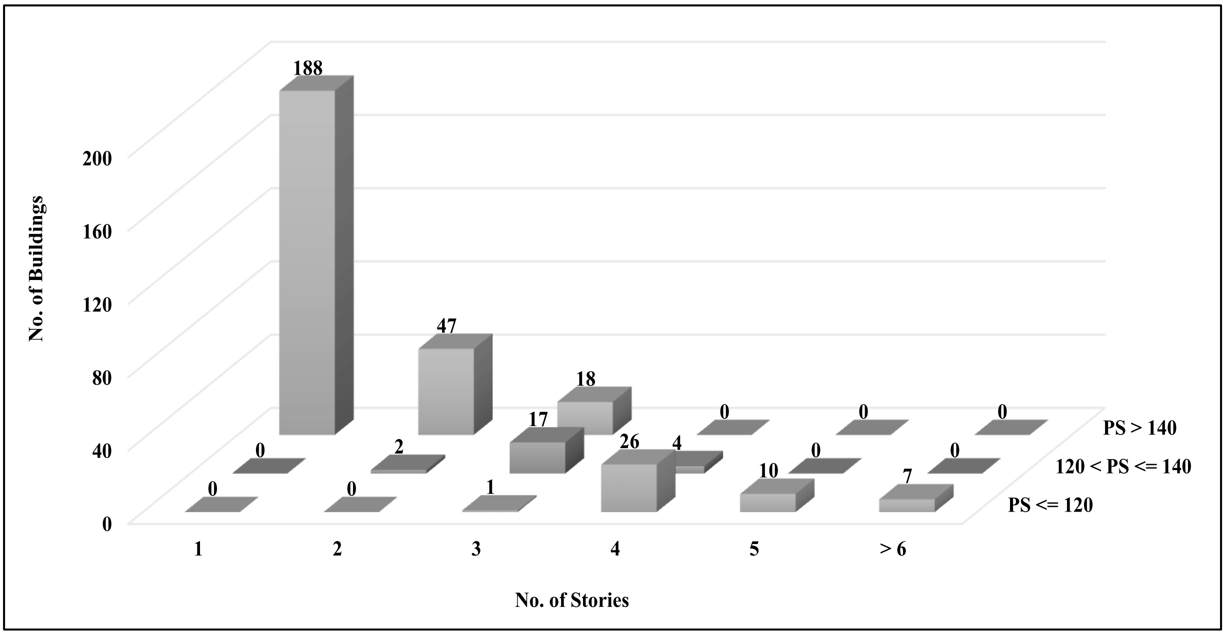


Fig. 15 : Relation Between Stories and Performance Score

The cross-section profile depicted a high-weighted buildings performance score, indicating this zone's low seismic risk (Figure 16).

4.11. Probable Damages due to earthquake

Most of the buildings in this region are non-engineered. People designed and constructed these structures without proper technical qualifications. These buildings are built by conducting inappropriate analysis, and the quality of construction could be better.
A few non-engineered buildings are constructed with the help of brick masonry that has a light roof. The performance of these buildings is expected to be similar to that of engineered buildings that use cement mortar

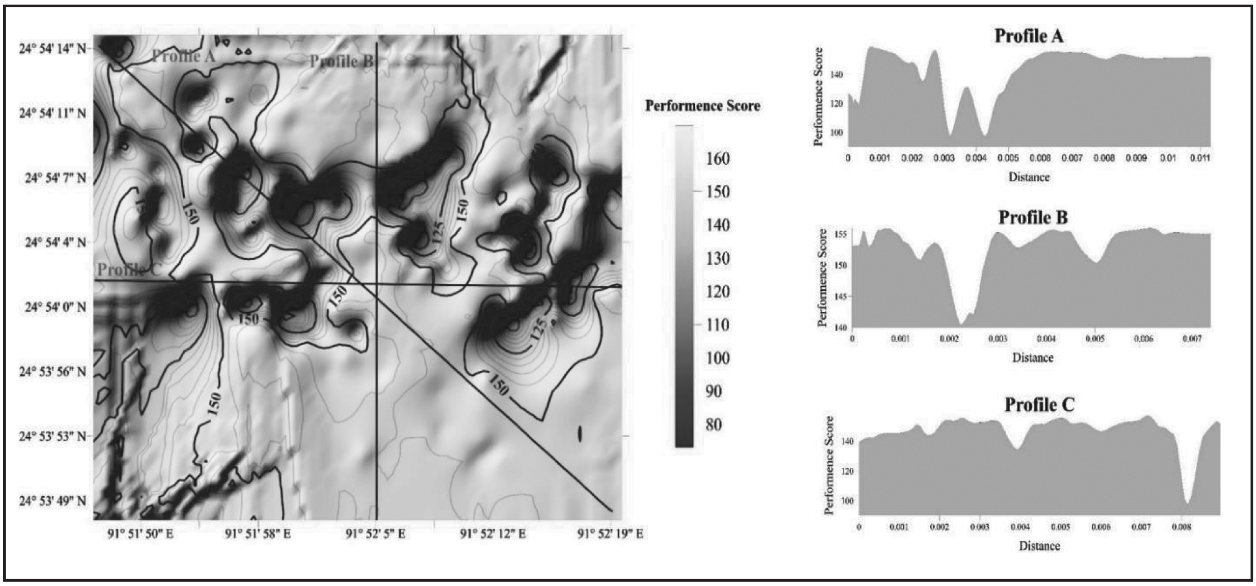


Fig. 16 : Cross Section Profile of Buildings Performance Score

in construction. Most other non-engineered buildings are made from amateur materials like GI sheets, wood, thatch, etc. The behavior of these buildings is expected to be very poor during the time of the earthquake. However, the lightweight material of these structures may be responsible for trapping fewer people. Estimated damage to PGA value 0.8 (%g), 0.9 (%g), and 1.0 (%g) is shown in Table 2. (%g) and 1.0 (%g) the damaged percentage is 70.05% and 70.75%, respectively.

Table 2. Probable Damage Due to Earthquake in Ward No. 1

Type of House	Probable No. of Houses		
	0.8 PGA	0.9 PGA	1 PGA
Building with RCC Frame and Brick Wall	44	45	46
Masonry Building with RCC Roof	77	78	79
Masonry Building with CI Sheet and Roof	101	102	103
Houses Constructed with Mud, Bamboo, Wood, CI Sheet	2	2	2

Alam et al. (2008) found that more than 68% of buildings will be damaged by 0.8 (%g), wherein 0.9

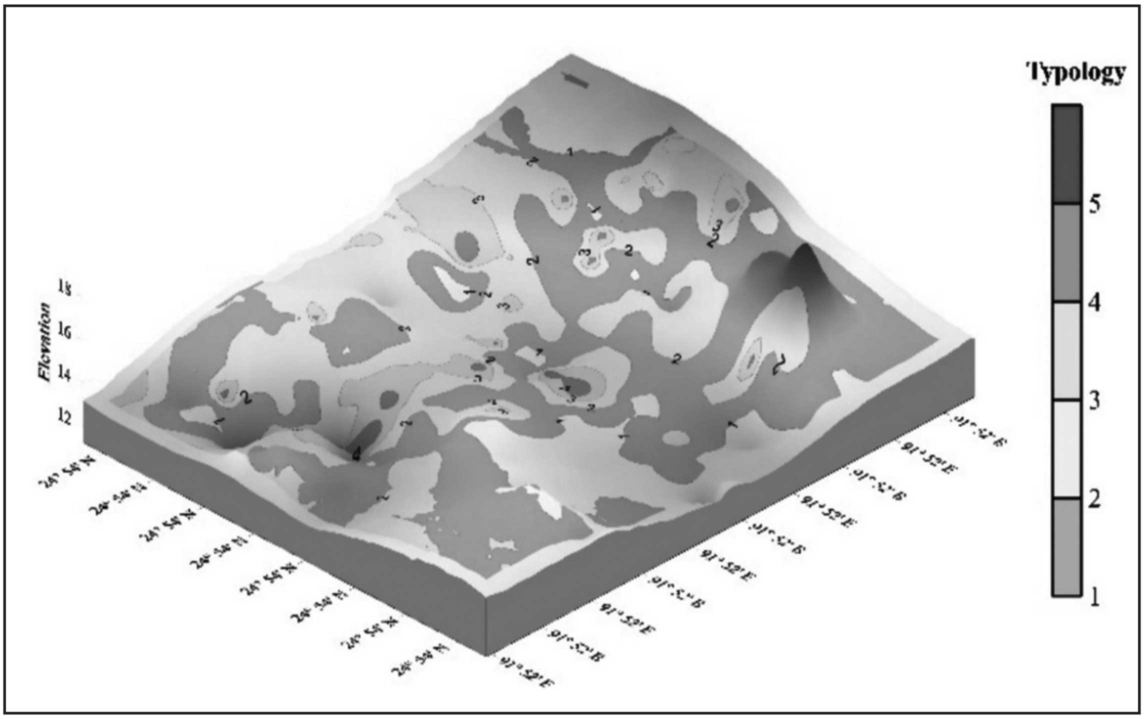
5. CONCLUSION

The vulnerability of a place depends on various features like topographical profile, infrastructure characteristics, socioeconomic characteristics, etc.

In urban areas like Sylhet City Corporation, the vulnerability level of a comprehensive earthquake generally depends on its infrastructure capacity. As the Sylhet zone is situated in the highly active seismic region, buildings constructed or established must have a quake resistance capability score. Otherwise, it can cause severe consequences as earthquakes do not kill people; buildings do by trapping people inside. Through eyesight observation in the study area, the feasibility of the building was tried to find out.

The observation and related secondary data found that most buildings were constructed during the 1990s, suggesting that urbanization was starting. Past data also alludes to this fact. At that period, people were less concerned about this devastating hazard, and earthquake resistance building code was formed well after urbanization. But people in this area are fortunate that there has been little demand for high-rise buildings since urbanization. Frequently seen low rise 1 or 2 storied buildings are sufficient to function in the study area. Along with that, this area has a flat topographic profile. Near the edge of the ward, boundary elevation was seen as undulating.

After the data analysis, it was observed that most of the houses were situated in the flat plain area where more



[***Here Typology 1 - EMSB1, 2 - EMSB2, 3 - EMSC, 4 - EMSD, and 5 - EMSF and Elevation Represents in Feet***}

Fig. 17 : Relative View of Area's Topographic Profile and Buildings Typology.

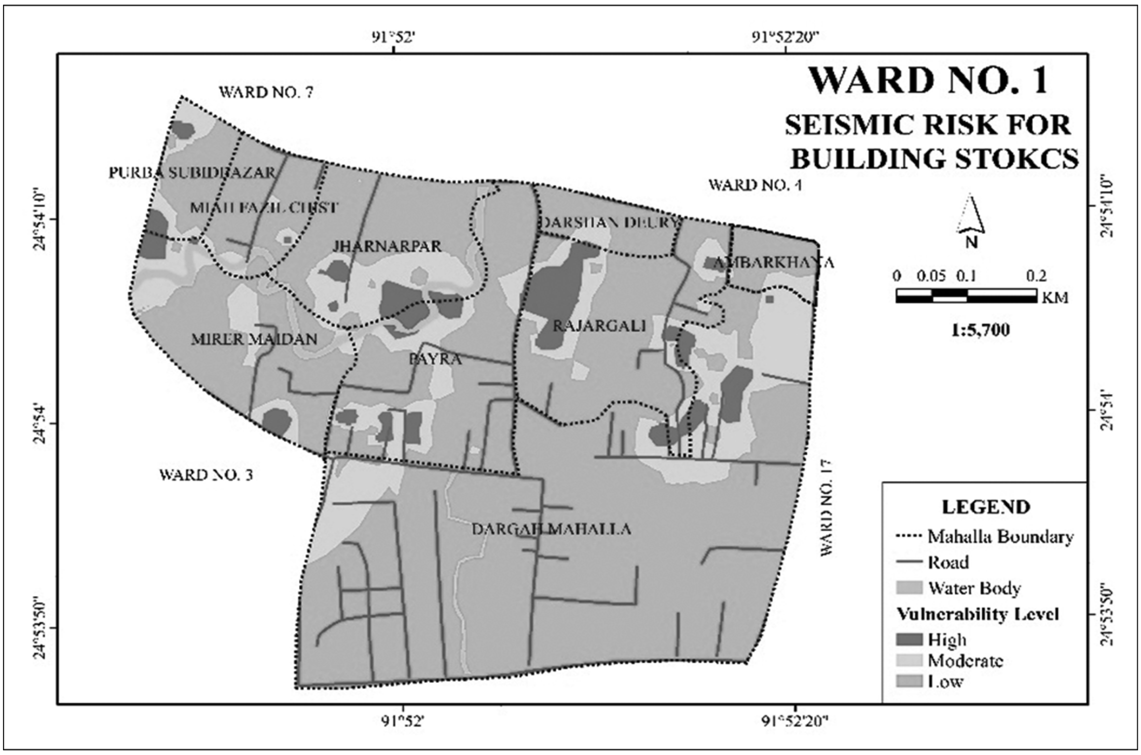


Fig. 18 : Buildings Vulnerability Level

than 50% were semi-pucca or low-rise pucca buildings (Figure 17).

A building's vulnerability is defined based on building stock, stories, infrastructure material, and architecture model. It is found that most of the places are free from danger (Figure 18). Few places face high risk because of the combination of very high and low-rise buildings which aren't constructed under proper authority.

But there is a chance of increased risk because of inadequate open space in the residential area, narrow roads, the inactive outreach program to insist people make quake-resistant buildings, etc. So, people must be conscious before constructing buildings directly related to vulnerability.

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APPENDIX I - Initial and Vulnerability Scores for Level - 1 Survey

No. of Stories	**Initial Score (On Soil Zoning)**			**Soft Story**	**Heavy Overhang**	**Apparent Quality**	**Short Column**
	60<PGV<80	40<PGV<60	20<PGV<40				
1,2	90	125	160	-5	-5	-5	-5
3	90	125	160	-10	-10	-10	-5
4	80	100	130	-10	-10	-10	-5
5	80	90	115	-15	-15	-15	-5
6,7	70	80	95	-15	-15	-15	-5

Source : Sucuoglu and Yazgan, 2003

APPENDIX II - Vulnerability Parameters

Soft Story	No (0)	Yes (1)	
Heavy Overhang	No (0)	Yes (1)	
Apparent Quality	Good (0)	Moderate (1)	Poor (2)
Short Column	No (0)	Yes (1)	
Topographic Effect	No (0)	Yes (1)	

Source : Sucuoglu and Yazgan, 2003