DOI:https://doi.org/10.18485/ijdrm.2022.4.2.5

Research article

SEISMIC VULNERABILITY ASSESSMENT OF EXISTING BUILDINGS BY RAPID VISUAL SCREENING METHOD: A STUDY ON WARD 27 IN DHAKA SOUTH CITY CORPORATION

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Received: 18 August 2022; Accepted: 28 December 2022; Published: 31 December 2022

Abstract: With the rapid growth of urbanization, the possibility of hazard has increased. Owing to high population concentrations and economic activities, the likelihood of hazards in urban areas is more nuanced than in rural areas. Vulnerability assessment of hazards has been a hot topic in the field of Engineering and Urban and Regional Planning. Due to the complicated hazard characteristics, not only engineering but planning approaches are required in order to effectively mitigate hazards. In recent years, the rapid growth of Dhaka cities has accelerated the pressure on existing buildings, and there is a need to establish adequate seismic safety screening methods for existing buildings specific to building typologies. Dhaka City is in danger of an earthquake and several incidents have occurred. In most situations, the lack of appropriate precautionary steps, administrative inefficiency, inadequate funds for equipment and lack of public knowledge make the situation worse. Ward 27, an old part of Dhaka City, was chosen for seismic vulnerability assessment in this survey. For seismic vulnerability assessment, a sample of 300 buildings was evaluated using Rapid visual screening (RVS) process by Federal Emergency Management Agency (FEMA). The rapid visual screening process is the initial stage in the assessment of existing buildings. The survey focuses on earthquake issues such as building type, size and shape of the plot, specific distances from surrounding structures, road width and basic building information. The use of Rapid Visual Screening (RVS) in the field of research allows screened buildings to be divided into two categories: those that are expected to have sufficient seismic efficiency and those that could be seismically unsafe and that should be further studied.

Keywords: Earthquake; Seismic Vulnerability; Rapid Visual Screening; Dhaka City.

1. Introduction

In terms of disaster risk, Bangladesh is the fifth most disaster-prone country in the world, with natural disasters striking the country almost every year on average (WEC, 2011). History of seismic events and current tremors reported in Bangladesh and nearby regions indicate that Bangladesh is at high risk of earthquakes, and that large-scale quakes will occur in the near future, according to the International Seismological Union. Three active and shoving tectonic plates, as well as a shallowly dipping mega thrust, all of which have the potential to unleash massive earthquakes, are located beneath Bangladesh's tectonic plates (Apu & Das, 2020; Steckler et al., 2016). The country of Bangladesh has been devastated by five earthquakes with magnitudes greater than 7.0 on the Richter scale in the last 150 years (Shaw et. al., 2013). Factors like population growth, migration, and the expansion of economic activities in metropolitan areas have all been suggested as factors that are contributing to the rise in earthquake risk (GoB, 2015). In addition to earthquakes, Bangladesh is prone to structural collapse, as evidenced by the deaths and injuries caused by the collapses of Old Dhaka (2004), the Spectrum (2005), and Rana Plaza (2013). There is no way to predict what would happen if there is a major earthquake or structural collapse in this country (Alamet.al., 2008).

It marks 400 years since the founding of Dhaka city, which has progressed without the benefit of a master plan, with structures created on the spur of the moment. Construction of buildings on artificially sand pilings along the recent floodplains of the Buriganga, Turag, Balu, and Sitalakhya Rivers has reached a maximum number, both engineered and non-engineered (Rahman et al., 2015). Buildings were constructed without the use of an earthquake-prevention mechanism in the majority of instances (Ahmed et al., 2010). Three zones are shown on Bangladesh's seismic hazard zone map to have seismic coefficients of 0.04 g, 0.05 g, and 0.08 g, respectively, based on the data. The seismic coefficients for three different zones in Bangladesh are depicted in Figure 1. The danger level in Dhaka, which is located in the northwest of the country, is as high as 0.05 grams per kilogram of body weight (BNBC, 1993).Table 1 shows the five major faults in Bangladesh's subsurface (EMF, 2014). Seismogenic data and small-magnitude earthquake occurrences near Dhaka Megacity suggest that these faults could cause a major earthquake at some point in the future. It is critical to determine how vulnerable the Dhaka Megacity is to an upcoming earthquake (Khan, 2016).

Vulnerability assessment is a key phase in risk assessment, which translates the level of danger. The vulnerability assessment examines areas such as demographic clusters, age-specific demographics, and developmental stresses. According to the 1994 UNDP, "vulnerability depends on the degree of failure of the element at risk at a certain level of severity. It is usually an element that is at risk at a certain degree of seriousness. Generally speaking, the percentage of loss (between 0: no damage at 1: total risk) is expressed as the percentage of loss (between 0: no damage at 1: total damage) for the stated risk." The appraisal is undertaken so that populations can establish tailored interventions to minimize their exposure and their risk for failure (Sterlacchini, 2011).

With the Rapid Visual Screening (RVS) method, the author hopes to determine the seismic susceptibility of existing buildings in Dhaka. When it comes to evaluating existing structures, the rapid visual screening method is the first step. As a result of the application of Rapid Visual Screening (RVS) in the field of research, screened buildings may be separated into two categories: those that are expected to have appropriate seismic efficiency and those that may be seismically unsafe and should be further investigated.

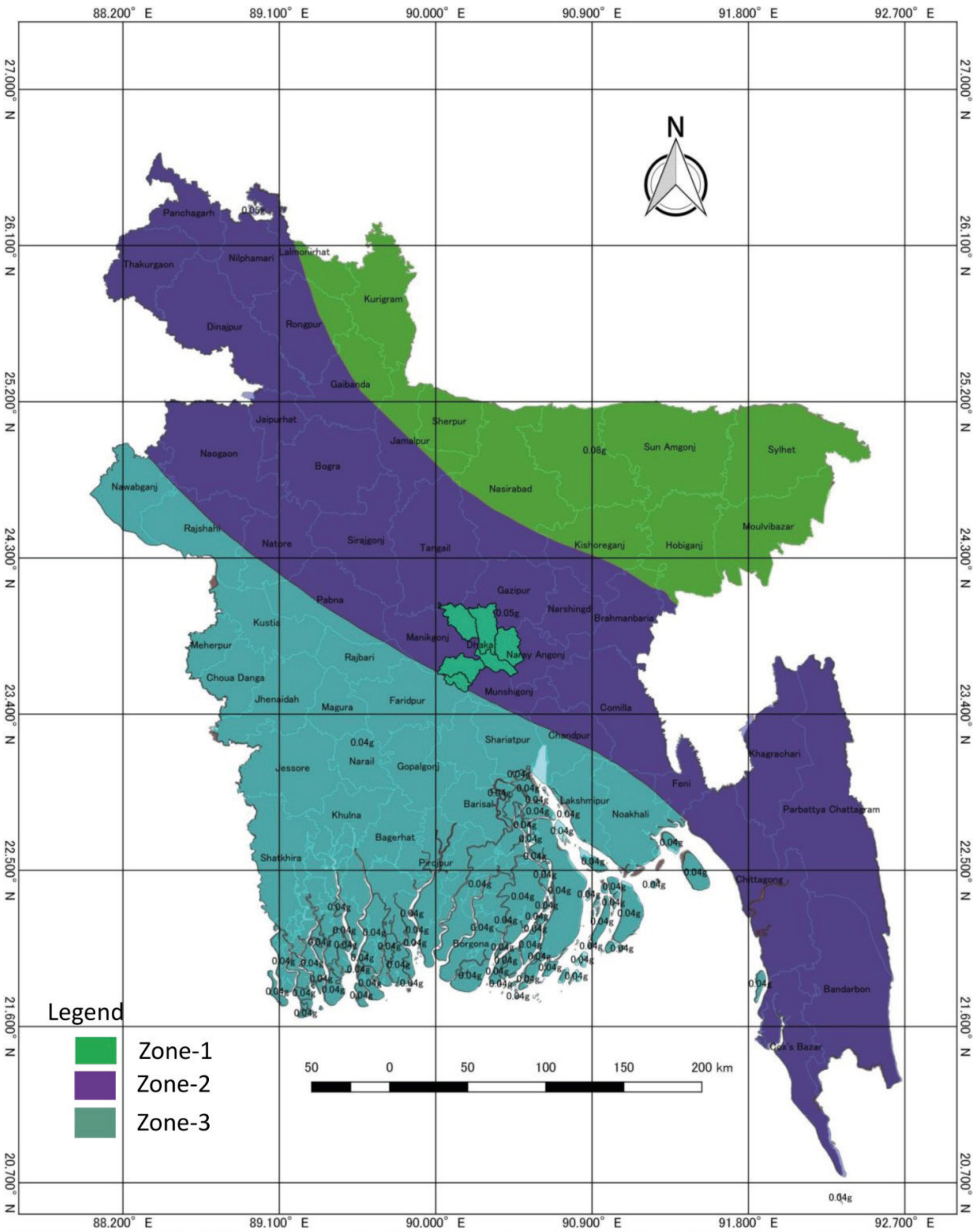


Figure 1. Zones at risk from earthquakes in Bangladesh (BNBC-1993).

Table1: Fault Line Sources and Estimated Maximum Magnitude

Source	EstimatedMaximumMagnitude
Madhupur Fault	7.5
Dauki Fault	8.0
Plate Boundary Fault 1	8.5
Plate Boundary Fault 2	8.0
Plate Boundary Fault 3	8.3

1.1 FEMA Rapid Visual Screening

FEMA has created a test system for the identification of possible seismic hazards in structures. The fast visual screening system is constructed without structural calculations. Usually on site, the inspection, data gathering and decision-making processes take place. The seismic numerical and risk screening is focused on this. The RVS system can be combined with the community planning database on GIS and can also be used for specialized tools for risk analysis. The suggestion is that a seasoned seismic architecture specialist should investigate buildings with a score less than that of the 'cut-off' score. The value of the "cut off" score and the option of the RVS type depend on the seismic zone of the region. The approach also allows for a quick and fast reassessment of the vulnerability of buildings already surveyed on the basis of the availability of new information that could become accessible in the future due to scientific or technical advances (Ballarin et al., 2017).

1.2 Seismic Vulnerability Assessment by FEMA- Rapid Visual Screening (RVS) Method

RVS method was used in this analysis to quantify the seismic susceptibility value. The mild seismicity data collection system FEMA-154, which is applicable to Bangladesh, was used. The scores are based on the projected amounts of land shaking in the district, as well as the city's or region's seismic preparation and construction activities. The "cut-off" score of 2 is used for this study, according to FEMA 154. Based on the impact on the seismic force, the potential damage to the structure can be graded in a number of ways. This information would be used to decide if a higher-level evaluation of the building is needed. In general, a score of S 0.7 implies a high degree of insecurity, necessitating further inspection and rehabilitation of the residence. The sense of the "cut off" score and the RVS style choice are determined by the earthquake zone of the city. Buildings with a score of S less than the cut-off score should be investigated by a seismic architecture specialist with expertise.

Table 2: List of Building Type Classifications

Building code	**Building description**	**Building code**	**Building description**
W1	Light wood-frame residential and commercial buildings Smaller than or equal to 5000 square feet	**C2**	concrete shear-wall buildings
W2	Light wood-frame buildings larger than 5000 square feet	**C3**	Concrete frame buildings with unreinforced masonry infill walls
S1	Steel moment-resisting frame buildings	**PC1**	Tilt-up buildings
S2	Braced steel frame buildings	**PC2**	Precast concrete frame buildings
S3	Light metal buildings	**RM1**	Reinforced masonry buildings with flexible floor and roof diaphragms

S4	Steel frame buildings with cast-in-place concrete shear walls	**RM2**	Reinforced masonry buildings with rigid floor and roof diaphragms
S5	Steel frame building with unreinforced masonry infill walls	**URM**	Unreinforced masonry bearing-wall buildings (Also made to include wattle and daub structures- building technique which utilizes a woven lattice of wood strips daubed with wet such as clay and straw.)
C1	Concrete moment-resisting frame buildings		

(FEMA P-154: Rapid Visual Screening for Potential Seismic Hazards, December 2015).

1.3. Variables of Seismic Vulnerability

Seismic building risk depends on different variables of seismic hazard, i.e. building form, number of floors, vertical irregularity, and plan irregularity. The following factors are described below:

1.3.1 Building types

In urban areas of Bangladesh, a wide range of architectural styles and building materials are used. Local materials like mud and straw, as well as semi-engineered materials like burnt brick and stone masonry and engineered materials like concrete and steel, are used. The use of building materials affects the seismic vulnerability of different building shapes. As local materials are used without engineering inputs, the volatility of a building is usually larger and the instable strength of produced materials the less.

1.3.2 Plan Irregularity and Vertical Irregularity

Irregularity of the building plan is a divergence of two dimensions from a rectangular plan. This discrepancy of the plan contributes to inconsistencies in the distribution of steadiness and weight, which in turn increases the probability of damage location under heavy ground upset. Regularity of the plan is promoted in earthquake-resistant structure (Rahman, 2014).

1.3.3 Set Back Rule

The setbacks are meant to provide illumination, ventilation, and safety to adjacent buildings as well as the projects under consideration. The setbacks are the minimum needed open space between the property's boundary and the proposed building to be constructed on the plot. A construction or a specified section of it must be set back from the Side Lot Line by a certain number. They function as traffic areas surrounding buildings in larger neighborhoods and facilitate car parking. When it comes to high-rise buildings, it is important not only to move fire tenders around the structure, but also to discourage the fire from spreading to surrounding properties. Therefore, they are perceived to be a significant planning parameter. A setback is a distance measured back from the property line and must be kept clear of every structure for the purposes of road widening, protection, air and fire control, etc. The setback needed for the upper floor extends to the entire house.

1.3.4 Soft Storey

Several modern buildings have been planned with the unusual feature of leaving the ground floor exposed for parking, i.e., the ground storey columns do not have any curtain walls separating them from one another. Open ground floor buildings, often known as soft storey buildings, are frequent names for these types of constructions. Only columns support the ground floor of this open ground floor structure, and all partition walls and columns support the top floor of this open ground floor structure. A number of open ground floor constructions have collapsed during earthquakes around the world, indicating that they are not well-suited for earthquake-prone areas. Because there are no partitions between the top and lower floors, the upper level is significantly more static than the open floor. This results in a structure where the top level moves virtually as if it were a single block, and where much of the lateral movement is confined to the soft ground floor (Jahan, 2011).

1.3.5 Short Column and Pounding Effect

A short column is one that has a slenderness ratio of 30 to 120-150 and high compression and bending. As the short columns are steeper than the large columns, they are more susceptible to seventeen 17 seismic forces, resulting in higher damage during an earthquake. Existing constructions with short columns can be repaired in various ways to avoid damage from upcoming earthquakes (Rahman, 2014).

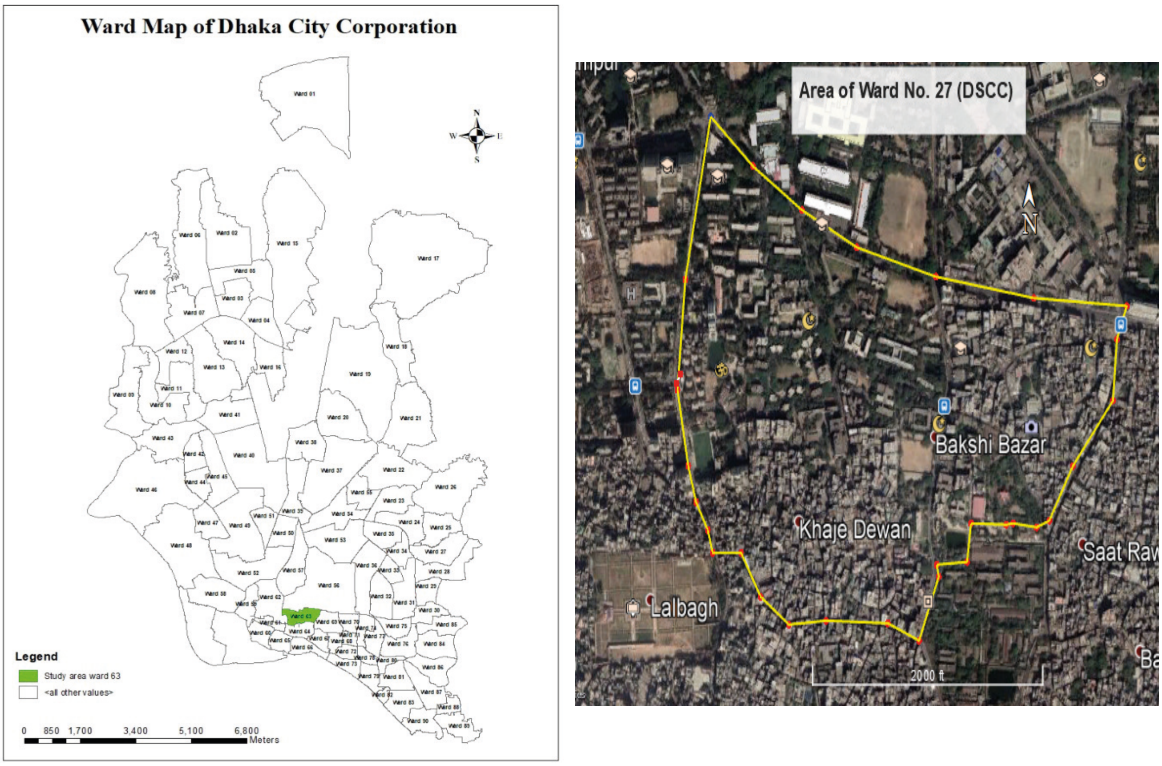


Figure 2: Location of the research area

2. Materials and Methods

2.1 Research Area Selection

Ward No. 27 (formerly ward 63) is situated in Old Dhaka on the northern side of the Buriganga River. The ward covers an area of around 107.48 hectares (Rajuk, Detailed Area Plan, 2010-2015). The ward is administered by the Dhaka South City Corporation's Lalbagh Thana (DSCC). Ward 56 is to the north, Ward 64 is to the south, Ward 69 is to the east, and Ward 62 is to the west of the research district. Lalbag Fort is located on the Ward's northern border.

2.2 Collection of Data

The study is primarily focused on primary data gathered by field survey. The secondary data has been gathered from various sources. The map of the research area has been collected from DSCC. GIS data like building shape files, highways, administrative boundaries, local facilities, etc. have been collected from RAJUK (DAP, 2015).

2.2.1 Types and Uses of Structure

The study area consists primarily of pucca structures, which are approximately 80.67 percent. The other types included Semi pucca 13.67%, katcha 4.33% and under construction are about 1.33% of all buildings. According to RAJUK (2015), about 59.63% of buildings are residential and 16% are for mixed use. The shape file shows that 62.67 percent of buildings are solely for residential use. Commercial and commercial apps account for 5% and 3% of overall applications, respectively. Public facilities, which mostly include mosques, cultural centers, and clubs, account for 4%; education and research account for 1.67 percent; and mixed use accounts for 19.67 percent.

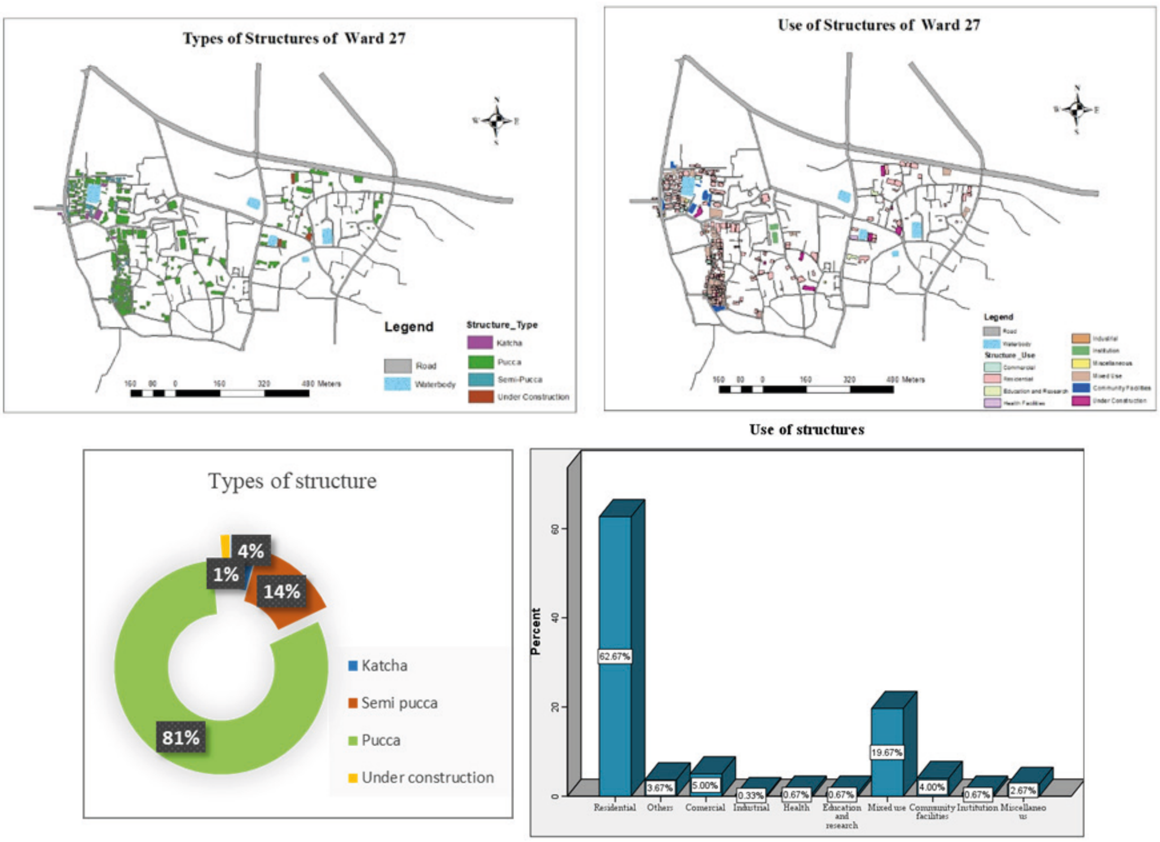


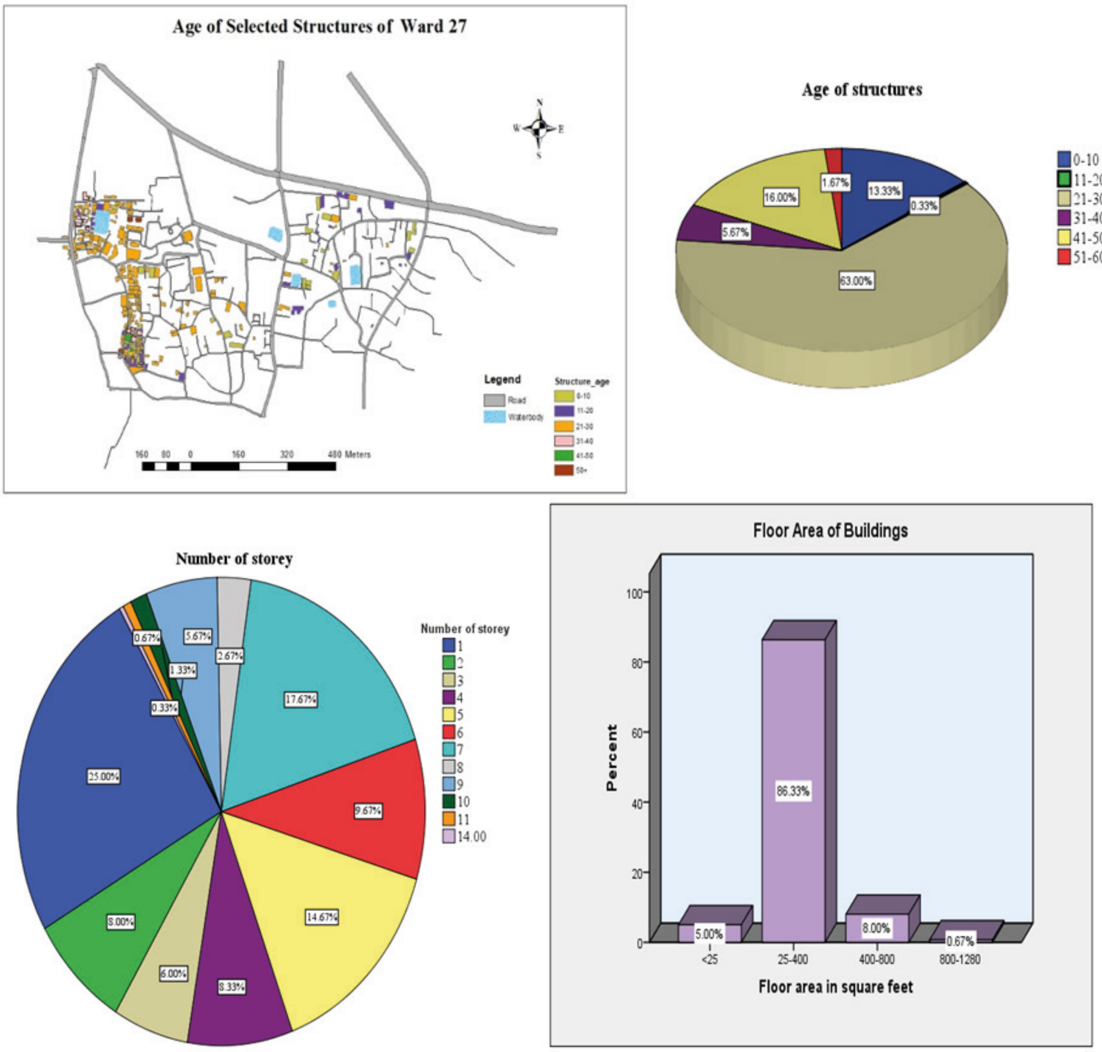
Figure 3: Types and uses of selected structures of ward no. 27

2.2.2 Age, number of storey and floor area of selected structures

Due to the exponential growth of the population, the majority of the current structures have recently been demolished and reconstructed. 33 percent of structures were constructed 11 to 20 years ago, 63 percent were constructed 21 to 30 years ago, 5.67 percent were constructed 31 to 40 years ago, 16 percent were constructed 41 to 50 years ago, and 1.67 percent was constructed 31 to 40 years ago. Figure shows distribution of age of buildings.

When RAJUK (2015) data was compared, it is observed that the proportion of one-story buildings declined from 71.74 percent to 25%, whereas the proportion of four-story, five-story, and six-story buildings increased significantly. Buildings of 7, 8, 9, 10, and 11 floors were also added. The research area has expanded vertically as vacant land has become scarce and population and economic growth have increased.

The building owners in the sample area do not follow the RAJUK Building Construction Law. As a result, the building's floor size is almost equal to the number of floors in this ward. The plot's total land area is equivalent to the floor space of the house. The floor space varies from 25 square feet to 1280 square feet. The bulk of the buildings (86.33 percent) have a residential floor space of 25-400 square feet. Buildings with a surface area of 400-800 square feet, mostly commercial shops and shantytowns, account for 0.67 percent of the total

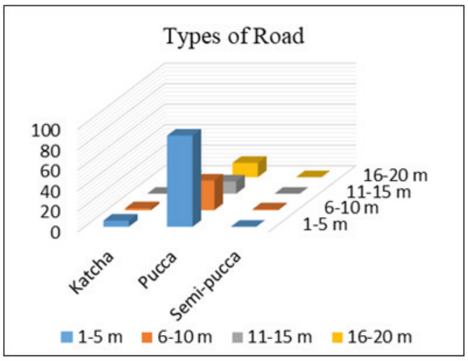


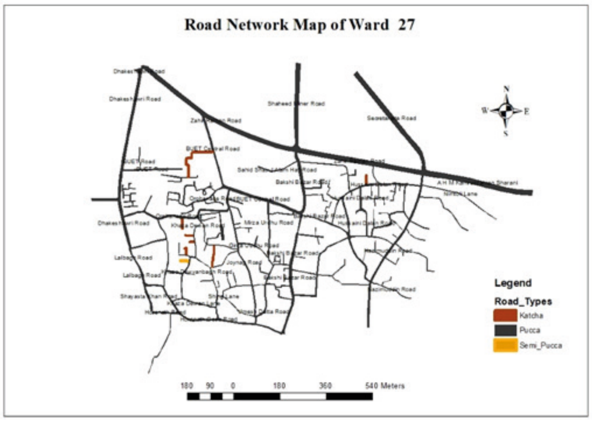
Source: RAJUK, DAP (2015)

Figure 4: Age, number of storey and floor area of selected structures of ward no. 27

2.2.3 Transportation network

The main roads through the area are A H M Kamruzzaman Sharani, Zahir Raihan Road, Dhakeshawri Road, and Lalbagh Road. From the GIS shape file, BUET Central Road, Secretariate Road, Bakshi Bazar Road, Shaheed Miner Road are considered as secondary road. The Horonath Gosh Road, Orphanage Road, Hussaini Dalan Road, Khaza Dewyanbagh Road, Umesh Datta Road, Shayasta Khan Road etc. are regarded as tertiary road of this area. The area's road network is unrefined and confusing because the streets and lanes are twisting, narrow, and link to one another in such a way. A variety of dark lanes and streets of differing widths have been discovered at numerous points along their length. As a result, with the vast amount of land used for the road network, the entire system was designed without proper planning and design. From the GIS shape file, it has found that most of the roads are 0.99 m – 20 m wide among which most of them are pucca and the width of semi pucca road is 2 m. The width of katcha road is 1m-3.05 m.





Source: RAJUK, DAP (2015)

Figure 5: Transportation network map of ward 27

2.2.4 Data Processing and Assembling

The raw data has been edited to remove possible errors and processed to suitable format to ease the data analysis. In this required correction and estimation, the collected data has been compiled and analyzed manually. It has been processed in a certain way after gathering data from primary and secondary sources. Maps have been digitized according to collect data by Arc GIS 10.3 software. After digitizing attribute data have been prepared with the help of same software. Furthermore, some of the data gathered have been coded so that it can be readily interpreted and used for research. Data has been presented in tabular, graphic and other formats. The mathematical package used for this are Microsoft Excel 2013 and SPSS 23.

2.2.5 Interpretation of Final Score

Using the FEMA P - 154, data sheet of rapid visual screening for the existing building is prepared. After filling up the factors related to seismic vulnerability the final score (S) has been calculated.

Table 3. Score of RVS According to Damage Potentiality

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

(FEMA P-154: Rapid Visual Screening for Potential Seismic Hazards, December 2015)

From the structural score predicted from data sheet, building having above grade 2 damage will require further investigation regarding seismic vulnerability. Generally, the score S < 0.7 indicates high vulnerability requiring detailed evaluation and retrofitting of the building. The buildings with grade 1 or grade 2 damage do not require further evaluation.

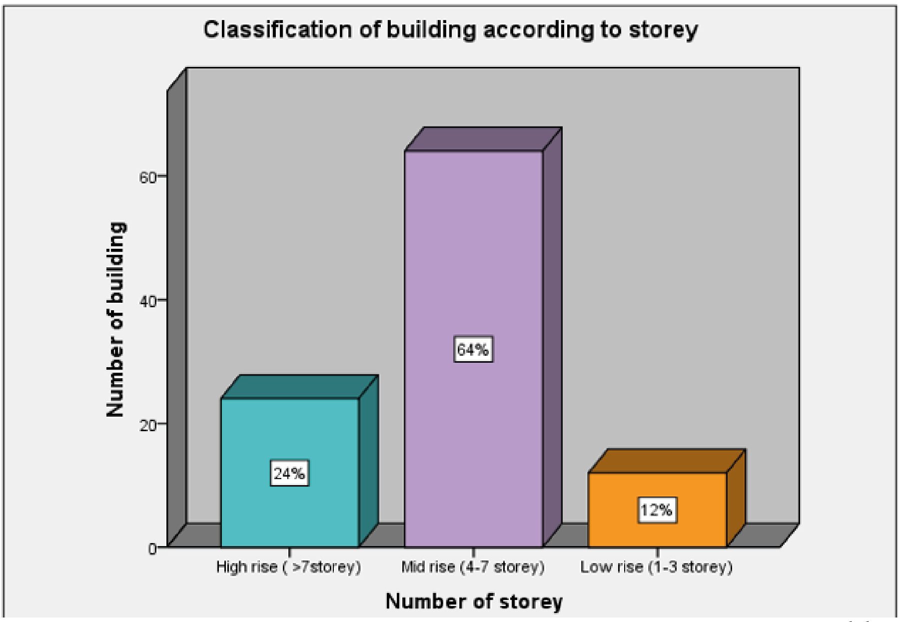
3. Results and Discussion

3.1. Seismic vulnerability analysis

The primary objective of this research is to evaluate vulnerability of seismic hazard buildings. To conduct the evaluation, a total of 300 structures, including residential, industrial, colleges, college, government, etc, covering 17.5 per cent of existing buildings, have been surveyed. Physical survey has been carried out for these 300 buildings. RVS method has been used to assess the seismic vulnerability of the existing buildings in the study area.

3.1.1 Number of storey

From the field survey 2020, it is evident that 24% of buildings are >7 storey, 64% of buildings are 4-7 storey and 12% of buildings are 1-3 storey.



Source: Field survey, 2020

Figure 6: Distribution of buildings according to number of storey

3.1.2 Construction type

The research area consists entirely of safer RVS (FEMA) buildings (23 percent). Of them, pucca, C3 form is the top 9.2%, pucca URM is 2.3%. Total highly fragile group of structures fell into 12%. This category does not have a semi-pucca building. In this group, 23 percent of the system falls under relatively low levels of vulnerability. 11.4% is of the C3 type, and 0.8% of the buildings of the pucca type are C2. If this is the case, 1.3% is C3 style and 4.1% is semi-pucca type URM houses.

Table 4: Construction type of building according to RVS score

	Construction Type						Total
RVS	Katcha	Pucca			Semi pucca		
Score	0	C2	C3	URM	C3	URM	
0.31-0.7	0	0.5	9.2	2.3	0	0	**12**
0.71-2	0	0.7	9	8.43	4.54	3	**25.67**
2.01-3	0	0.8	24.4	5.4	0.4	4	**35**
3.01-4.4	0	0.8	11.4	5.4	1.3	4.1	**23**
0	4.33	0	0	0	0	0	**4.33**
Total	4.33	2.8	54	21.53	6.24	11.1	100

3.1.3 Uses of building according to score

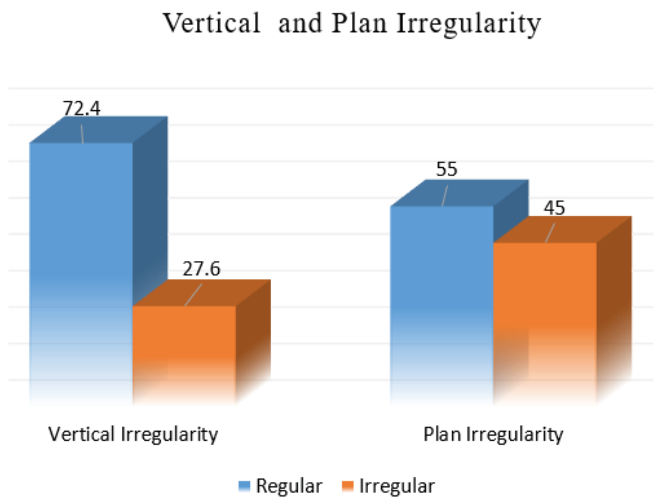
Among high vulnerable category, 24.88% buildings are residential, 13.33% are commercial and 18.18% are industrial in total sample buildings. Among moderate vulnerable category, 30.22% buildings are residential, 22.22% are commercial, 9.09% are industrial and 25% are official buildings in total sample buildings. 26.67% buildings are residential, 33.33% are commercial and 18.18% are industrial in total sample buildings among the moderately low vulnerable buildings. Among low vulnerable buildings, 18.22% buildings are residential, 24.44% are commercial, 54.55%are industrial and 25% are official buildings. Table below indicates different uses of building according to RVS score.

Table 5: Different uses of building according to RVS score

RVS Score	Different uses of building (Number)								
	Residential	Commercial	Industrial	Govt.	Assem-bly	Historic	Emergen-cy service	Office	School
0.31-0.7	56	9	2	0	0	0	0	0	0
0.71-2	68	10	1	0	0	0	0	1	0
2.01-3	60	15	2	0	0	0	2	2	2
3.01-4.4	41	11	4	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0

3.1.4 Vertical irregularity and plan irregularity

From the field survey, it is found that 27.6% of buildings in the region are vertically irregular and 72.4% buildings are vertically regular. About 55% of the sample buildings have a regular shape (square or rectangular) and 45% of buildings are found to have irregular (T-shaped, L shaped, etc.).



Source: Field survey, 2020

Figure 7: Vertical irregularity and plan irregularity of buildings.

3.1.5 Final output from RVS score

The RVS (FEMA) system is used to assess a building's vulnerability to seismic danger. The RVS (FEMA) method has been used to evaluate 287 of the 300 surveyed structures, the rest of the buildings are katcha and have not been considered. The data has been mainly obtained by visual inspection. Among high vulnerable category, 58% buildings are less or equal 6-storey and 42% buildings are above 6- storey. Among moderate vulnerable category, 63 % buildings are less or equal 6-storey and 37% buildings are above 6 -storey. Among moderately low vulnerable category, 74% buildings are less or equal 6 -storey and 26 % buildings are above 6 -storey in total sample buildings. Among low vulnerable category, 77 % buildings are less or equal to 6-storey and the buildings which above 6- storey are 23%.

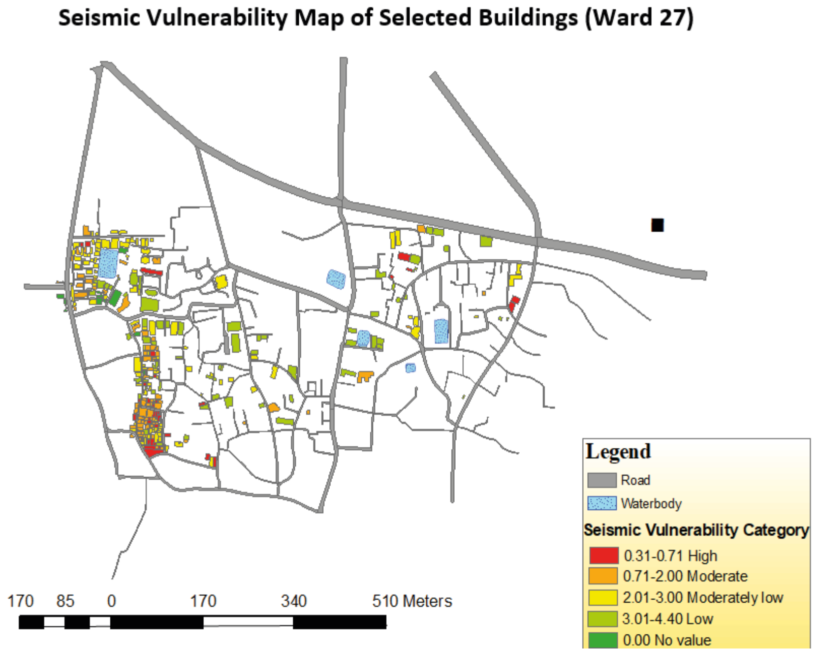
Table 6: RVS score of buildings according to vulnerability category

RVS Score	No. of Buildings (Floor less or equal six)	No. of Buildings (Floor above six)	Frequency	Percent	Vulnerability category
.31-.70	21	15	36	12	High vulnerability
.71-2.0	49	28	77	25.67	Moderate vulnerability
2.01-3.0	77	27	104	35	Moderately Low vulnerability
3.01-4.4	54	16	70	23	Low vulnerability
0.00	-	-	13	4.33	-

Source: Field survey, 2020

Among 300 surveyed buildings, 13 katcha structures (4.33 percent) are found to be out of scoring due to their construction materials among the 300 surveyed buildings. About 23 percent of buildings received a score of 3.01 to 4.4, 35 percent received a score of 2.01-3.0, and 25.67 percent received a score of 0.71-2.0 where 12% of the structures were scored 0.31.70. The Figure 8 shows seismic vulnerability scenario in the study area.

The buildings surveyed occupy 17.5% of the current structures in the study city. About 54 percent of buildings are C3 style and pucca type, and 6.24 percent are C3 type semi-pucca type buildings. 21.53 per cent land Unreinforced masonry buildings (URMs) and pucca and 11.1 per cent are URM and semi-pucca. One-storey buildings are the largest with 25 per cent occupancy. About 27.6 percent of buildings are vertically irregular and 45 percent of buildings are irregular in shape. Pucca and apartment structures appear to be more fragile than the other. The tallest structure in the research area is a 14-story building. According to RVS (FEMA), the majority of buildings in Ward 27 are now deemed to be of less seismic concern (61 per cent), although another 39 per cent require further evaluations. Most buildings (23 per cent) are structurally sound, 35 per cent are moderately fragile. About 25.67 per cent of buildings are moderately susceptible where 12 per cent of buildings are extremely vulnerable to seismic hazards.



Source: Author, 2020

Figure 8: Seismic Vulnerability Map of Selected Buildings (Ward 27)

4. Conclusion

For specific stakeholders, vulnerability evaluation is a tool for making decisions on how to respond to and adapt to threats. Using the FEMA 154 Rapid Visual Screening approach, you may quickly and easily detect potentially hazardous buildings in the preliminary screening phase. This method is the fastest and cheapest way to assess a building. There is only a small fraction of Dhaka City that has been studied. More than half of all buildings surveyed were determined to be of the C3 structural type, which has four to five floors and residential occupancy. The seismic risk for the majority of the buildings in the study region is still 61 percent; while an additional 39 percent needs to be evaluated. Map layers are developed based on the results of the vulnerability assessment.

Policymakers may be able to prioritize special consideration areas or hotspots for disaster management if the method is implemented throughout the city. Seismic hazards can be accounted for in terms of social aspects of vulnerability. If a region has a high level of seismic activity, it can be determined whether or not there is a significant risk. As part of spatial planning, it is essential to have a common understanding of what is needed to reduce vulnerability. With this research, local citizens are given a lot of opportunity to contribute to help them reduce their own risk of becoming victims of natural disasters. Many countries have found that involving local residents in disaster response planning is an effective way to reduce catastrophe risk.

5. References

X. S.-i.-. Martin, “The Global Competitiveness Report 2011,” World Economic Forum, 2011-12.

Apu, N., & Das, U. (2020). Tectonics and earthquake potential of Bangladesh: A review. International Journal of Disaster Resilience in the Built Environment, 12(3), 295–307. https://doi.org/10.1108/IJDRBE-06-2020-0060

Steckler, M. S., Mondal, D. R., Akhter, S. H., Seeber, L., Feng, L., & Gale, J. (2016). Locked and loading megathrust linked to active subduction beneath the Indo-Burman Ranges. Nature Geoscience, 9(8), 615–618.

Shaw, R., Mallick, F. & Islam, A. (2013). Disaster Risk Reduction Approaches in Bangladesh. Springer, 103.

GoB. (2015). Atlas: Seismic Risk Assessment in Bangladesh for Bogra, Dinajpur, Mymensingh, Rajshahi, Rangpurand Tangail City Corporation / Paurashava Areas, Bangladesh. Ministry of Disaster Management and Relief,Government of the People's Republic of Bangladesh.

Alam, M., Ansary, M. A., Chowdhuary, R. K., Uddin, A. J., Islam, S., and Rahman, S. (2008). Evaluation ofBuilding's Vulnerability to Earthquake in Old Part of Sylhet and Construction Safety Rules. IUST InternationalJournal of Engineering Science, Vol. 19, No.3.

Rahman, M.Z.; Siddiqua, S.; Kamal, A.S.M.M. Liquefaction hazard mapping by liquefaction potential index for Dhaka City, Bangladesh. Eng. Geol. 2015, 188, 137–147.

Ahmed, M.Z.; Islam, K.; Roy, K.S.; Arafat, M.S.; Al-Hussaini, T.M. Seismic vulnerability assessment of RCF buildings in old town of Dhaka city. In Proceedings of the 3rd International Earthquake Symposium, Dhaka, Bangladesh, 5–6 March 2010

DDC. Bangladesh National Building Code 1993; Development Design Consultants for Housing and Building Research Institute: Dhaka, Bangladesh, 1993.

URP- phase 1. Bangladesh Urban Resilience Project, Environmental Management Framework (EMF) Draft; The World Bank: Washington, DC, USA, 2014.

Khan, A.A. Geophysical characterization and earthquake hazard vulnerability of Dhaka Mega City, Bangladesh, vis-à-vis impact of scenario earthquakes. Nat. Hazards 2016, 82, 1147–1166.

S. Sterlacchini, “Vulnerability Assessment: concepts, definitions and methods,” in National Research Council of Italy, Milan Italy, 2011.

M.Ballarin, C.Balletti, P.Faccio, F. Guerra, A.Saetta and P.Vernier, “SURVEY METHODS FOR SEISMIC VULNERABILITY ASSESSMENT OF HISTORICAL MASONRY BUILDINGS,” The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,, p. 55, 2017.

N. Rahman, “Vulnerability Assessment of Earthquake and Fire Hazard and Formulating Risk Reduction Strategies at Community Level,” Dhaka city, June 2014.

I. Jahan, “Earthquake Vulnerability and Evacuation Plan for Old Dhaka,” Dhaka, 2011. “Rajuk,Detail Area Plan,” Dhaka, 2010-2015.

FEMA P-154: Rapid Visual Screening for Potential Seismic Hazards, Washington DC: American Society of Civil Engineers, December 2015.

Conflicts of Interest: The authors declare no conflict of interest.