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A Study on Determination of Seismic Susceptibility in Existing Buildings in Ward No-18 of Dhaka North Using Rapid Visual Screening (RVS) Method

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Abstract

The research work presents a comprehensive analysis of the Rapid Visual Screening (RVS) method applied to 200 buildings in Ward No. 18 of Dhaka North City. The study focused on assessing the seismic vulnerability of these structures, categorizing them into damage grades based on the RVS evaluation. Strikingly, the findings revealed that 191 out of the 200 buildings were classified as damage grade 5, signifying severe structural deficiencies. In contrast, only 9 buildings were identified with a lesser degree of vulnerability in grade 3. Furthermore, the research categorized the buildings based on their construction characteristics, distinguishing between pre-code and post-code structures. The majority, comprising 181 buildings, belonged to the pre-code category, while 19 were post-code constructions. The structural types were further delineated, with one concrete moment-resisting building, 120 concrete shear buildings, and 79 concrete frame buildings with unreinforced masonry infill walls. The alarming outcome of the study indicates a critical situation, with approximately 94.5% of the assessed buildings found to be in a vulnerable condition. This highlights the urgent need for seismic retrofitting and structural reinforcement measures in the examined area to mitigate the potential risks posed by earthquakes. The research contributes valuable insights for urban planners, policymakers, and stakeholders, emphasizing the imperative for proactive strategies to enhance the seismic resilience of structures in Dhaka North City's Ward No. 18.

Keywords: Rapid visual screening, FEMA-154, building vulnerability, vulnerability assessment, damage grade.

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 (Sharma S, Soederberg S) [1]. 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) [2, 3]. 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) [4]. 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). It is impossible to forecast what would occur in this nation in the event of a significant earthquake or structural collapse (Alamet.al., 2008) [5]. An earthquake's effect is determined by its depth, magnitude, distance from the epicenter, and local

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geological factors. Devastating consequences from earthquakes might include landslides, tsunamis, and building collapses. The majority of the building stock in today's rapidly urbanizing world is made up of historic structures or structures with significant historical value. Because these buildings were built using antiquated seismic design concepts, they do not adhere to the sophisticated seismic resistance requirements of today. The United States created the first national seismic code in 1988 as a standard methodology for quick vulnerability assessments. Since then, numerous other nations have developed national seismic codes, each with unique local construction and design approaches and considerations. In order to include the most recent developments in seismic research, the codes underwent additional modifications. There are three steps to assessing seismic vulnerability: a basic walk-down survey in the first stage, a more thorough structural analysis of the buildings that didn't meet the cut-off score in the second stage, and a comprehensive study of damage inspections and various behavior patterns combined with a structural analysis in the third stage. However, with so many buildings, it is not possible to do a thorough study of each one due to a lack of funding and personnel resources, which emphasizes the value of conducting a straightforward walk-down survey (Bolt BA, Dreger D) [6]. Based on assessments of seismic susceptibility, structures with different degrees of damage can be categorized using rapid visual screening (RVS). The best seismic characteristics for this method to work with are the building's age, soil classification, seismic zone, material quality, number of stories, and so on. One of the best approaches is RVS, but running it becomes difficult when some parameters are lacking.

MATERIALS AND METHODS

The evaluation of the RVS score is dependent on certain building factors. Structure irregularity, heavy overhang, short columns, soil conditions, apparent building quality, pounding effect, building height, and diaphragm action are some examples of these factors. are some of the construction factors. The building's performance score has been determined using the previously stated factors.

WORKING METHODOLOGY

The methodology of the paper comprises of three major stages which are presented in Figure 1. Selection of area of region of the city for Rapid Visual Screening. Selection of Moderate Seismicity RVS forms. The earthquake capacity of a building is estimated by means of seismic vulnerability procedures. The seismic susceptibility of a building can be evaluated using a variety of techniques. The RVS is a score assigning procedure including determination of seismically risky structures by evaluating structural insufficiency. The examination, data gathering, and conclusion process is usually conducted at the site and requires around half an hour depending upon the size of building. Vulnerability of structures can also be suggested by an expert who is working in this field (Guéguen P, Michel C, LeCorre L; Srikanth T, Kumar RP, Singh AP, Rastogi BK, Kumar S) [7, 8].

Selected Area for Survey

The Dhaka North zone ward no-18 Baridhara J & K block as well as Gulshan-2 has been chosen for the assessment. The selected region ward no. 18 was chosen due to its urban nature and diverse building typologies. As per the census 2023, ward number 18 has 1815 households with 8210 of population as shown in Figure 2.

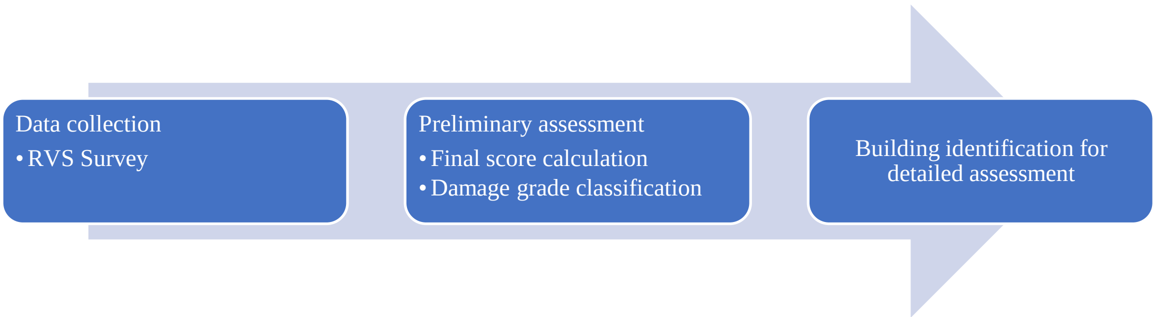


Figure 1. Vulnerability assessment flow chart.

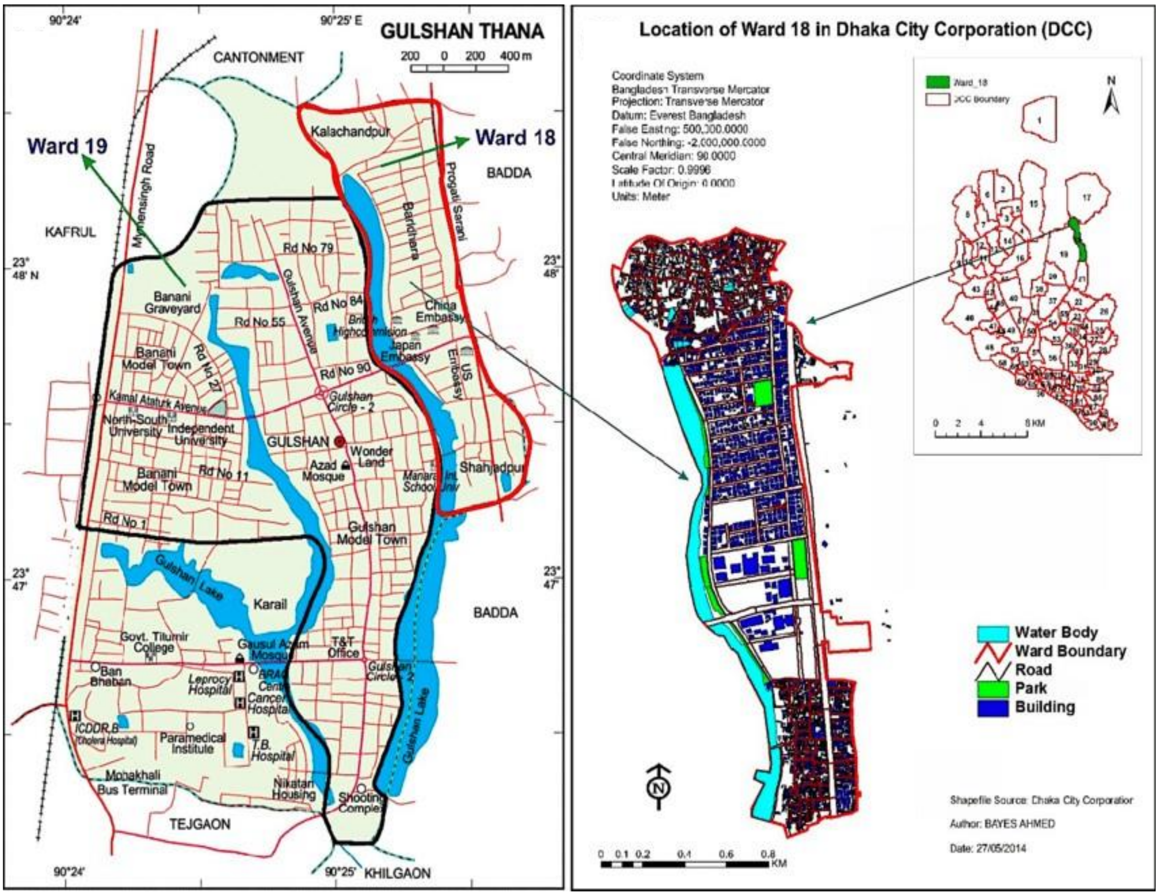


Figure 2. Map showing the selected survey area (Baridhara K & J Block).

Seismic Vulnerability Assessment

Buildings that are deemed seismically dangerous must undergo additional assessment by a qualified specialist in seismic assessment and design (Anbazhagan P, Giridhar VT, Ganesha RK, Shreedhara V; Sinha R, Goyal A) [9, 10]. The structures surveyed are categorized according to their level of vulnerability using the five damage ratings of EMS-98. The assessment's final score serves as the cutoff point below which additional research is advised.

Building Parameters

Major parameters affecting the performance of the building that are being used to calculate the score during the survey hang the forms, are seismicity of the region, type of structure, plan and vertical irregularities, age of the buildings, type of soil etc. (FEMA) [11].

Occupancy

A building's utilization is referred to as its occupancy. While a building's occupancy is not always directly related to the structural hazard or the likelihood of suffering significant damage, it is taken into consideration when allocating priority for mitigation (Spence R, So E, Scawthorn C) [12].

Occupancy Classes

The following definitions of the nine general occupancy classes—which are simple to identify in a quick visual screening. Utilize occupancy classes while assessing the stock of buildings (Shapiro D, Rojahn C, Reaveley LD, Smith JR, Morelli U) [13]. Rapid Observation of Vulnerability and Estimation of Risk (ROVER) Red ROVER module allows HAZUS's Advanced Engineering Building Module (FEMA, 2003) to be exported as a file (FEMA, 2011). This makes it possible to map HAZUS occupancy classes to FEMA 154 RVS occupancy classifications.

The are some occupancy classes in RVS are described below:

- *Assembly:* Building codes generally use a threshold of 300 persons, and this is the case here as well. Examples include community centers, and auditoriums.
- *Commercial:* Retail and wholesale establishments, banks, dining establishments, and parking lots are all included in the commercial occupancy class.
- *Office:* Professional services, managerial, and clerical occupations are typically found in office buildings.
- *Residential:* This type of occupation class includes residential structures including homes, townhomes, hotels, motels, apartments, condos, and homes for the elderly or disabled.
- *School:* This occupancy class covers all private and public educational establishments, ranging from daycare centers to universities.

Soil Types

Soil type information is extracted from each building owner, in their soil survey or information from governmental entities. Rocks are representative of soil types A, B, and C; hard dirt is representative of type D; and soft soil is representative of type E. site soil classification using BNBC 2020 guidelines as shown in Table 1.

Plan Irregularity

The inconsistency in a structure's layout that results in structural eccentricity is referred to as plan irregularity. Plan irregularity has been shown to decrease a structure's ability to withstand seismic loads by raising stress concentrations in previous earthquakes. Structural plans with reentrant corners that feature plan shapes such as E, L, T, U, +, etc. are classified as plan irregular. If there are any plan abnormalities, a building is linguistically identified as Yes; if not, it is designated as No.

Vertical Irregularity

Considerations pertaining to usage and architecture are frequently the source of vertical irregularities in structures. The location of a building on a steep slope, large wall openings, weak or soft stories, variations in floor heights, and in-plane or out-of-plane setbacks can all cause vertical irregularity. Weak story, soft story, and setbacks are examples of abnormalities in the lateral load-resisting system that enhance the chance that structures would sustain damage in the event of an impending earthquake. The lateral load-carrying system at floor level experiences strength variation and a significant variance in structural system stiffness, which cause soft and weak stories to combine as shown in Table 2.

Number of Stories

In the event of an earthquake, building height is a crucial performance metric since taller structures have the potential to bend and sustain damage. Furthermore, the amount of floors that can be created is limited by building design requirements based on the building type and the seismic hazard of the surrounding area.

Pre-Code

Buildings created and built before the year the jurisdiction's seismic laws were first enacted and put into effect. It is contemplated when the building was constructed before the new seismic codes were proposed in its respective space (Daniell JE, Wenzel F, Khazai B, Santiago JG, Schaefer A) [14].

Table 1. Classification for seismic site response.

Site class	Soil profile name	Vs30 (Meters/second)
A	Hard rock	Vs > 1500
B	Rock	760 < Vs ≤ 1500
C	Very dense soil and soft rock	360 < Vs ≤ 760
D	Stiff soil profile	180 < Vs ≤ 360
E	Soft soil profile	Vs < 180

Table 2. Building types according to FEMA.

W1	Light wood-frame residential and commercial buildings smaller than equal to 5,000 square feet
W2	Light wood-frame buildings larger than 5,000 square feet
S1	Steel moment-resisting frame buildings
S2	Braced steel frame buildings
S3	Light metal buildings
S4	Steel frame buildings with cast-in-place concrete shear walls
S5	Steel frame buildings with unreinforced masonry infill walls
C1	Concrete moment-resisting frame buildings
C2	Concrete shear-wall buildings
C3	Concrete frame buildings with unreinforced masonry infill walls
PC1	Tilt-up buildings
PC2	Precast concrete frame buildings
RM1	Reinforced masonry buildings with flexible floor and roof diaphragms
RM2	Reinforced masonry buildings with rigid floor and roof diaphragms
URM	Unreinforced masonry bearing-wall buildings

Post-Code

It is contemplated when the building was designed and constructed after the new seismic codes were raised in their respective jurisdiction, this may differ for each type of building. After obtaining the final score, we proceed to associate 5 degrees of damage as shown in Table 3. Grade 1 show results of minor damage, grade 2 is equivalent to moderate damage with small cracks in the walls and beams, grade 3 means severe damage, causing cracks in the beam-column interaction and the coupling of the wall joints, grade 4 which is very incident causes collapse in the floors by the structural failure of its columns, also grade 5 already has a destructive character, causing the failure from its upper floor to its foundation of the building. In addition, these values must exceed the value of S(min)=2 to indicate that it is no longer necessary to perform a deep analysis to determine its vulnerability, otherwise the study will be a more detailed analytical method.

Damage Potential based on RVS Score

According to the guidelines provided by the European Macro Seismic Scale (EMS-98), harm to all and there are Five grades—grades 1 through grade 5—have been established for buildings (RCC or Masonry). RVS score indicates the extent of harm.

Grades of Damageability of RCC Buildings Classification of Damage to Buildings of Reinforced Concrete

Damage to reinforced concrete buildings is typically classified into different grades based on the severity of the damage as shown in Table 4.

Table 3. RVS score.

RVS score	Damage potential
$S < 0.3$	High probability of grade 5 damage; very high probability of grade 4 damage
$0.3 < S < 0.7$	High probability of grade 4 damage; very high probability of grade 3 damage
$0.7 < S < 2.0$	High probability of grade 3 damage; very high probability of grade 2 damage
$2.0 < S < 3.0$	High probability of grade 2 damage; very high probability of grade 1 damage
$S > 3.0$	Probability of grade 1 damage

Table 4. Grades of damageability of RCC building.

Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)	• Fine cracks in plaster over frame members or in walls at the base. • Fine cracks in partitions and infills.
Grade 2: Moderate damage (Slight structural damage, moderate non-structural damage)	• Cracks in columns and beams of frames and in structural walls. • Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)	• Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. • Spalling of concrete cover, buckling of reinforced rods. • Large cracks in partition and infill walls, failure of individual infill panels.
Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)	• Large cracks in structural elements with compression failure of concrete and fracture of rebar's; bond failure of beam reinforcing bars; tilting of columns. • Collapse of a few columns or of a single upper floor.
Grade 5: Destruction (very heavy structural damage)	• Collapse of ground floor parts (e.g. Wings) of the building.

COMPLETING THE LEVEL 1 DATA COLLECTION FORM

This section explains how to fill out the Level 1 Data Collection Form. Pre-field planning, which includes determining the kind of soil and selecting a data collection form based on the seismicity level of the region to be screened, is assumed to have already been finished as shown in Figure 3.

The following procedures are used in order to complete the Level 1 Data Collection Form for each structure that is screened:

1. Checking and updating the data related to building identification.
2. Sketching a plan and elevation view on the Data Collection Form, counting the stories, and figuring out the building's layout while exploring it.
3. Taking pictures of the structure.
4. Figuring out and recording occupancy.
5. Examining the kind of soil and any geologic risks found during the pre-field planning phase.
6. Determining building flaws, adjacency problems, and any possible external falling dangers.
7. Including any remarks regarding peculiar situations or factors that might influence the screening.
8. Completing the Data Collection Form with the Basic Score after determining the building's material, seismic force-resisting system, and gravity load-carrying system (preferably by going inside the structure to help with this procedure).
9. Mark the appropriate seismic performance attribute score modifiers (soil type, irregularities, and design date) on the Data Collection Form.

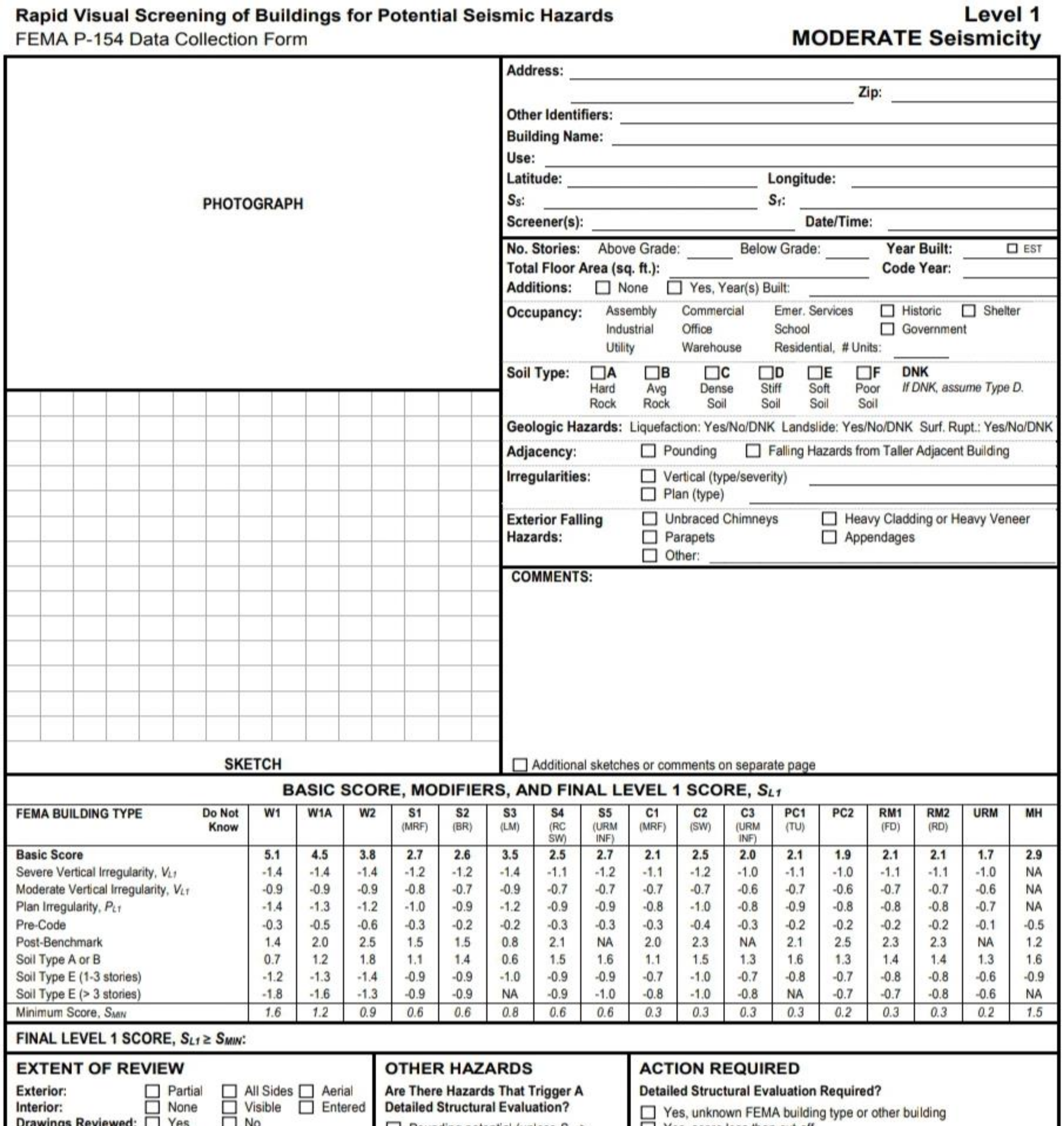
DATA COLLECTION

The data needed for the full study project are included in this part. This study aims to assess the sensitivity of structures to seismic hazards.

Two hundred structures have been surveyed in order to carry out the study as shown in Figure 4. These 200 structures have undergone a physical survey. The classifications used to classify the number of stories are Low Rise (1 to 3 stories), Mid-Rise (4 to 7 stories), and High-Rise (8 or more stories). About 16.5% of buildings were low rise, 58.5% buildings were mid-rise and 25% buildings were found high rise building (Agrawal SK, Chourasia A) [15].

From Figure 5, it is found that the study area has numerous storied buildings consisting from story 2 to 14 stories. 6 stories buildings were found maximum comparing to other stories building.

From Figure 6, we see that about 90% buildings were found to be constructed before 2020 (Pre-Code) and only 10% buildings were found to be constructed after 2020 (post-code). Figure 6 shows distribution of pre and post code buildings.



Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form

Level 1
MODERATE Seismicity

PHOTOGRAPH

Address:
Zip:
Other Identifiers:
Building Name:
Use:
Latitude: Longitude:
S_S: S_1:
Screener(s): Date/Time:

No. Stories: Above Grade: Below Grade: Year Built: ☐ EST
Total Floor Area (sq. ft.): Code Year:
Additions: ☐ None ☐ Yes, Year(s) Built:

Occupancy: Assembly, Industrial, Utility, Commercial, Office, Warehouse, Emer. Services, School, Residential, # Units: ☐ Historic ☐ Shelter ☐ Government

Soil Type: ☐A Hard Rock ☐B Avg Rock ☐C Dense Soil ☐D Stiff Soil ☐E Soft Soil ☐F Poor Soil DNK *If DNK, assume Type D.*

Geologic Hazards: Liquefaction: Yes/No/DNK Landslide: Yes/No/DNK Surf. Rupt.: Yes/No/DNK

Adjacency: ☐ Pounding ☐ Falling Hazards from Taller Adjacent Building

Irregularities: ☐ Vertical (type/severity) ☐ Plan (type)

Exterior Falling Hazards: ☐ Unbraced Chimneys ☐ Heavy Cladding or Heavy Veneer ☐ Parapets ☐ Appendages ☐ Other:

COMMENTS:

SKETCH

☐ Additional sketches or comments on separate page

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

FEMA BUILDING TYPE (Do Not Know)	W1	W1A	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM	MH
Basic Score	**5.1**	**4.5**	**3.8**	**2.7**	**2.6**	**3.5**	**2.5**	**2.7**	**2.1**	**2.5**	**2.0**	**2.1**	**1.9**	**2.1**	**2.1**	**1.7**	**2.9**
Severe Vertical Irregularity, V_{L1}	-1.4	-1.4	-1.4	-1.2	-1.2	-1.4	-1.1	-1.2	-1.1	-1.2	-1.0	-1.1	-1.0	-1.1	-1.1	-1.0	NA
Moderate Vertical Irregularity, V_{L1}	-0.9	-0.9	-0.9	-0.8	-0.7	-0.9	-0.7	-0.7	-0.7	-0.7	-0.6	-0.7	-0.6	-0.7	-0.7	-0.6	NA
Plan Irregularity, P_{L1}	-1.4	-1.3	-1.2	-1.0	-0.9	-1.2	-0.9	-0.9	-0.8	-1.0	-0.8	-0.9	-0.8	-0.8	-0.8	-0.7	NA
Pre-Code	-0.3	-0.5	-0.6	-0.3	-0.2	-0.2	-0.3	-0.3	-0.3	-0.4	-0.3	-0.2	-0.2	-0.2	-0.2	-0.1	-0.5
Post-Benchmark	1.4	2.0	2.5	1.5	1.5	0.8	2.1	NA	2.0	2.3	NA	2.1	2.5	2.3	2.3	NA	1.2
Soil Type A or B	0.7	1.2	1.8	1.1	1.4	0.6	1.5	1.6	1.1	1.5	1.3	1.6	1.3	1.4	1.4	1.3	1.6
Soil Type E (1-3 stories)	-1.2	-1.3	-1.4	-0.9	-0.9	-1.0	-0.9	-0.9	-0.7	-1.0	-0.7	-0.8	-0.7	-0.8	-0.8	-0.6	-0.9
Soil Type E (> 3 stories)	-1.8	-1.6	-1.3	-0.9	-0.9	NA	-0.9	-1.0	-0.8	-1.0	-0.8	NA	-0.7	-0.7	-0.8	-0.6	NA
Minimum Score, S_{MIN}	*1.6*	*1.2*	*0.9*	*0.6*	*0.6*	*0.8*	*0.6*	*0.6*	*0.3*	*0.3*	*0.3*	*0.3*	*0.2*	*0.3*	*0.3*	*0.2*	*1.5*

FINAL LEVEL 1 SCORE, $S_{L1} \geq S_{MIN}$:

EXTENT OF REVIEW
Exterior: ☐ Partial ☐ All Sides ☐ Aerial
Interior: ☐ None ☐ Visible ☐ Entered
Drawings Reviewed: ☐ Yes ☐ No
Soil Type Source:
Geologic Hazards Source:
Contact Person:

LEVEL 2 SCREENING PERFORMED?
☐ Yes, Final Level 2 Score, S_{L2} ☐ No
Nonstructural hazards? ☐ Yes ☐ No

OTHER HAZARDS
Are There Hazards That Trigger A Detailed Structural Evaluation?
☐ Pounding potential (unless S_{L2} > cut-off, if known)
☐ Falling hazards from taller adjacent building
☐ Geologic hazards or Soil Type F
☐ Significant damage/deterioration to the structural system

ACTION REQUIRED
Detailed Structural Evaluation Required?
☐ Yes, unknown FEMA building type or other building
☐ Yes, score less than cut-off
☐ Yes, other hazards present
☐ No
Detailed Nonstructural Evaluation Recommended? *(check one)*
☐ Yes, nonstructural hazards identified that should be evaluated
☐ No, nonstructural hazards exist that may require mitigation, but a detailed evaluation is not necessary
☐ No, no nonstructural hazards identified ☐ DNK

Where information cannot be verified, screener shall note the following: EST = Estimated or unreliable data OR DNK = Do Not Know

Legend: MRF = Moment-resisting frame; BR = Braced frame; RC = Reinforced concrete; SW = Shear wall; URM INF = Unreinforced masonry infill; TU = Tilt up; MH = Manufactured Housing; LM = Light metal; FD = Flexible diaphragm; RD = Rigid diaphragm

Figure 3. Rapid visual screening of building for seismic hazards.

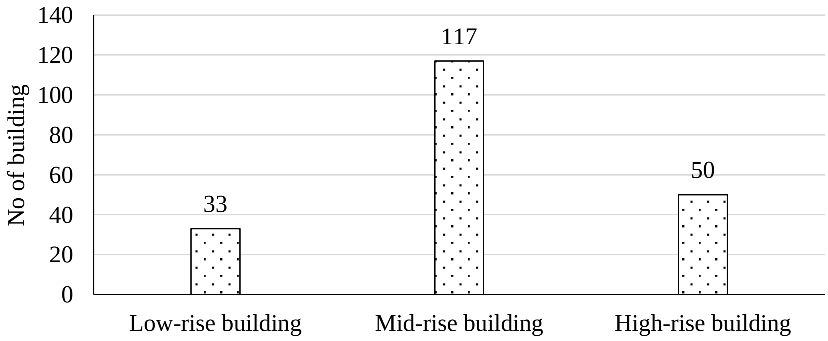


Figure 4. No of buildings vs. buildings categorized.

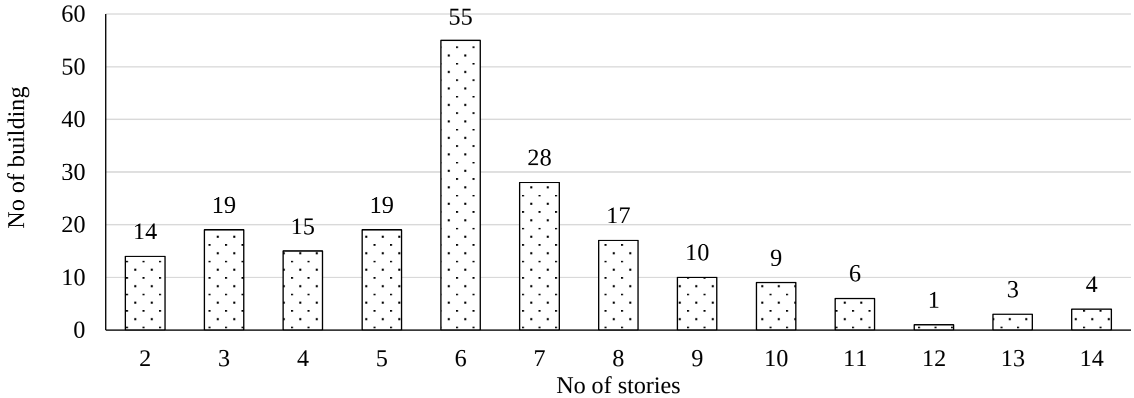


Figure 5. Story wise building numbers.

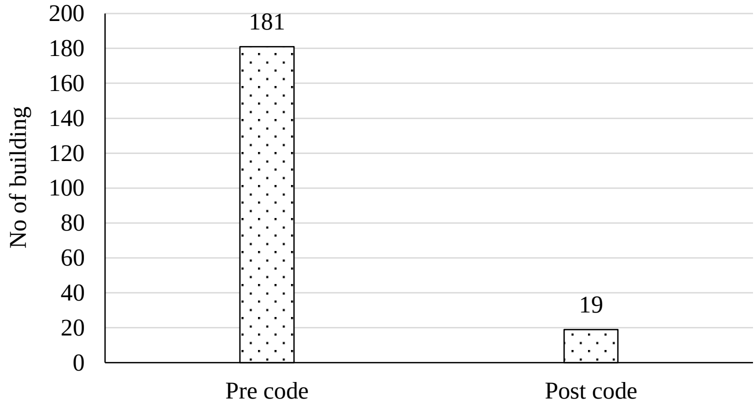


Figure 6. Distribution of pre-code and post-code building.

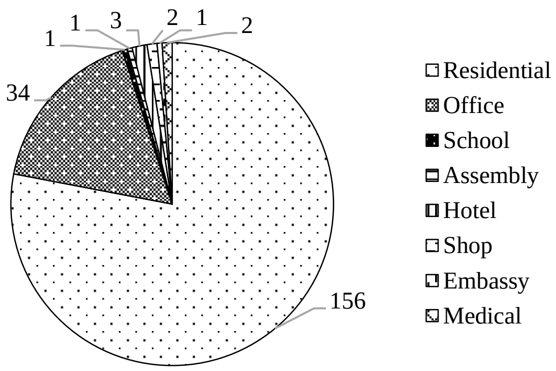


Figure 7. Building types.

Here, we can see from Figure 7 out of 200 buildings, there were 156 residential buildings, 34 office buildings, 3 hotel buildings, 2 shop, 2 medical building, 1 school building, 1 assembly building 1 embassy building (Yadollahi M, Adnan A, Zin RM) [16].

Figure 8, we found out of 200 buildings, only 1 building has been found as concrete moment resisting frame building whereas 120 buildings were found as concrete shear wall buildings and rest of 79 buildings were concrete frame with URM infill walls.

Out of 200 buildings, there were 191 buildings which RVS score was found below 0.3 which means high probability of damage grade 5. Left over buildings RVS score was found in between 0.7 to 2.0 which indicates damage grade 3 as shown in Figure 9.

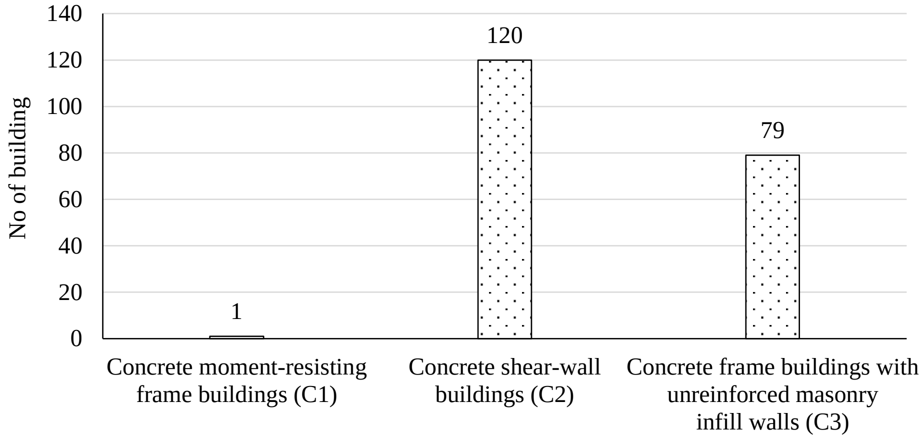


Figure 8. No of buildings vs. FEMA buildings type.

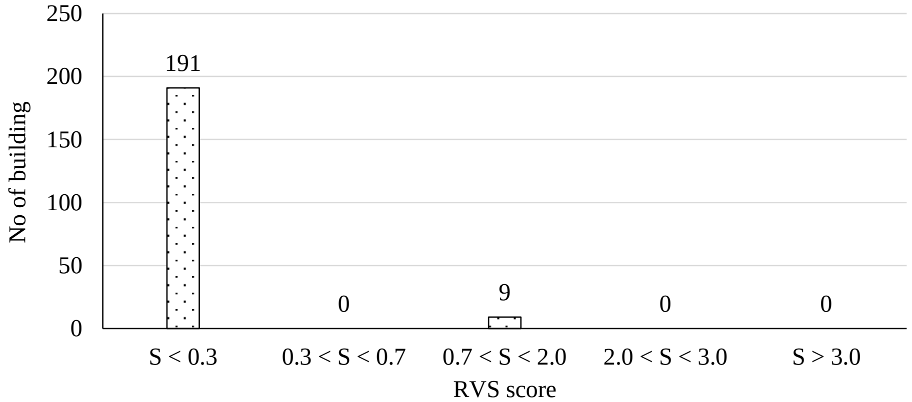


Figure 9. RVS scores vs. no. of buildings.

CONCLUSIONS AND RECOMMANDATIONS

In the research region, 95.5% of the structures have a seismic risk of damage grade 5, whereas only 4.5% of the buildings had damage grade 3. The identified damage grade provides a clear opportunity for intervention, emphasizing the importance of adopting proactive measures to mitigate future risks and protect the community. The findings also show that existing vulnerabilities in the city's infrastructure necessitating a strategic and systematic approach to address these challenges. The high damage rate highlights the necessity for educational initiatives on emergency preparedness, ensuring that residents are informed about potential risks and mitigation strategies. Successful implementation of the RVS method requires collaboration between government bodies, local authorities, and the community to create a universal and effective strategy. At the preliminary screening stage, we may quickly and simply identify potentially dangerous buildings by using the FEMA-154 Rapid Visual Screening approach, which is one of the quickest and least expensive ways to examine a building.

Limitations of the Study

Only 200 building samples have been used in this entire study. More samples would have provided more accurate results. Only one ward has been selected for this research work, where as there are lots of wards in Dhaka city.

Recommendations

This research project has only looked at a limited portion of Dhaka City. Increasing the sample size beyond 200 buildings to enhance the representativeness of the study, providing a more comprehensive understanding of the RVS method's effectiveness in Dhaka City, Ward 18. Execute a long-term observation strategy to monitor the chosen buildings' resilience over time. This can offer valuable insights into the sustainability and durability of the RVS method in real-world conditions. Establish training programs for local builders and construction workers to ensure proper implementation of the RVS method.

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