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Research Article

Application of RVS and Turkish Method to Detect Seismic Vulnerability of Existing RC Building in Jaurul Nagar, Bogura

Md. Mahbur Rahman[1], Md. Abu Sayed[*,2], Md. Shefat Islam[3], Md. Emran Ali[4]

[124]*Lecturer, Pundra University of Science and Technology,Bangladesh*

[3]*Undergraduate Student, Pundra University of Science and Technology,Bangladesh*

Keywords

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India-Burma-Eurasia plate,
Reinforced Concrete (RC), Rapid Visual Screening (RVS),
Seismic susceptibility.

Abstract

According to the National Earthquake Information Center (NEIC), there are around 55 earthquakes each day around the planet, for a total of 20,000 annually. Fortunately, most are too weak to inflict harm; nevertheless, bigger earthquakes, depending on location and other conditions, can result in casualties, injuries, and property damage especially in earth earthquake-prone regions like Bangladesh, which is located where the India-Burma-Eurasia plates meet, confronts considerable seismic dangers, particularly in areas such as Bogura, which are classified as seismic zone III. This study assesses the seismic susceptibility of reinforced concrete (RC) structures in Bogura, Bangladesh, utilizing the Tier 1 technique of the Turkish Seismic Susceptibility Assessment Method, which is based on FEMA's (Federal Emergency Management Agency) Rapid Visual Screening (RVS) procedure. The study intends to improve earthquake resilience in Jahurul Nagar, a densely populated neighborhood of Bogura, by providing insights into efficient urban planning and risk mitigation techniques. Field observations of 408 buildings examined features such as soft storeys, heavy overhangs, pounding consequences, and soil characteristics. Heavy overhangs (41%), pounding possibilities (58%), short columns (27%), and soft stories (27%) were highlighted as key vulnerabilities. The study classified examined buildings as safe, moderate, or unsafe, indicating different levels of seismic susceptibility. Low-rise buildings performed better overall, however mid- and high-rise structures demonstrated major risks. These findings highlight the need for targeted measures to improve the seismic resilience of RC buildings in Bogura, particularly taller structures, in order to effectively limit possible seismic risks.

1. Introduction

Bangladesh is regarded one of the most vulnerable countries, having a high risk of earthquakes due to its geographical location between 20.35°N and 26.75°N latitude and 88.03°E to 92.75°E longitude. Even a moderate or medium-magnitude earthquake on the Richter scale can result in considerable human and property losses. Existing buildings in earthquake-prone locations must be assessed to ensure they can withstand future earthquakes. The current state of buildings, infrastructure, and other physical structures differs by city or town in Bangladesh. To take appropriate preventive steps, it is critical to determine the magnitude of such fluctuations. The earthquake activity in Bangladesh is depicted in Figure 1. According to BNBC 2020, there are four seismic zones, as illustrated in Figure 2. Zone 1, which comprises the southwest, has the least amount of seismic risk. Parts of the center region, including Dhaka, are in Zone 2, which experiences moderate earthquake activity. Zone 3, which is more prone to earthquakes, includes areas like Mymensingh and parts of northern Bangladesh. Sylhet and Chattogram are located in Zone 4, the most seismically active region, which is near significant fault lines and tectonic boundaries. By helping to guide the design and construction of earthquake-resistant buildings, this updated zoning plan ensures greater preparedness and resilience against potential seismic disasters.

In recent years, the country has seen an increase in the frequency of earthquakes, indicating a higher likelihood of big earthquakes [1]. As a result, Proper structural evaluation of existing buildings in earthquake-prone areas is becoming a significant issue. This form of assessment can aid in minimizing structural damage through upgrading buildings and allocating rescue resources [2]. According to Sinha et al. (2001), both engineered and non-engineered buildings sustain significant structural damage during earthquakes [3].

M. I. Mostazid et al. (2019) used Rapid Visual Screening (RVS) and the Turkish approach to assess the seismic susceptibility of RCC buildings in Dinajpur municipality's sixth ward. During field observation, eight separate criteria were surveyed, including soft stories, heavy overhangs, pounding effects, soil conditions, and so on. A total of 333 structures were surveyed in the study region of interest. The examination identified seismic susceptibility elements, including heavy overhanging (35%), pounding possibilities (24%), short column (28.5%), and soft story (22%) [4]. Using the same characteristics and methodologies, another study was carried out at the Rampur Ward (25th WARD) of Chittagong City Corporation. A total of 400 structures were surveyed in the study region of interest. After the level I survey, 179 of the 400 buildings are safe, 39 are unsafe, and 182 are classified as moderate [5]. The investigation yielded a comprehensive inventory of the study area's buildings, including damage categories.

*Corresponding Author: sayedce.1807323@std.hstu.ac.bd
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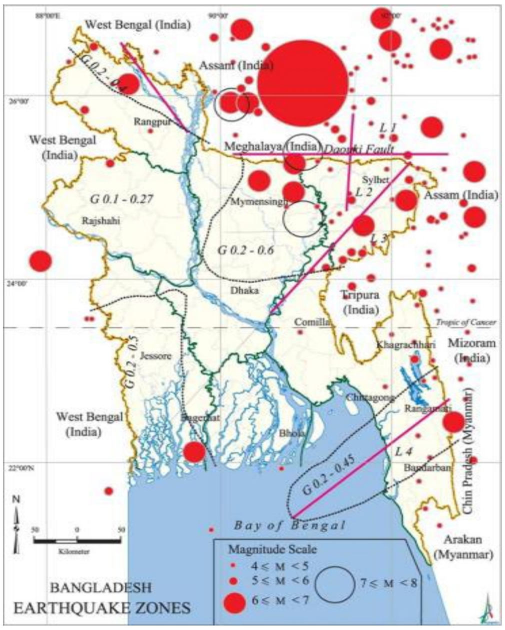


Figure 1. Seismic Activity of Bangladesh
[Source: https://en.banglapedia.org/index.php/Earthquake]

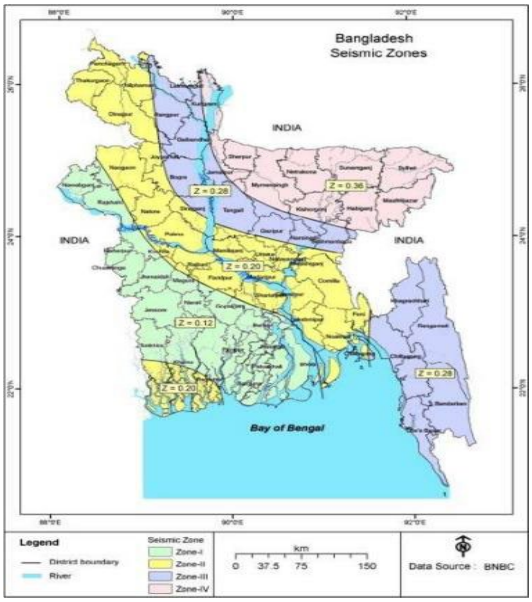


Figure 2. Seismic Zone of Bangladesh
[Source: Bangladesh National Building Code, 2020]

Nurullah Bektaş et. al. (2022) applied RVS method to the buildings of Albania. The paper covered the time-consuming RVS techniques (such FEMA 154, which takes 15 to 30 minutes, whereas NRCC takes an hour) and gave a summary of the areas in which the techniques are used (pre-earthquake: FEMA 154, NRCC, NZEE, etc.; post-earthquake: GNDT, EMS, etc.). For field practitioners (such as engineers and architects), this evaluation of the conventional RVS approaches provides a thorough guide and reference [6]. Nurullah et. al. also suggests augmentation techniques (such as machine learning and fuzzy logic) for researchers to apply in future advancements. A study for Rapid Visual Screening to assess building safety during earthquakes was carried out by Ehsan et al. (2020). In order to gather information, they established a research team at Middle East Technical University (METU) to conduct street studies. Three different methods for estimating the possible seismic damage to the existing reinforced concrete buildings in Bingöl, Turkey, are provided in this paper [7]. The findings of these three approaches are evaluated by expressing them in terms of the structural damage state and comparing them practically to the actual damage that was found. The Turkish RVS (EMPI) has a high degree of effectiveness in assessing the susceptibility of buildings in the Bingöl region, according to the study's findings. Actually during the street survey, the RVS approach visually inspects structures without going inside. This process can take anywhere from 15 to 30 minutes for each building. Building type, number of stories, soft and weak stories, short columns, presence of irregularities in elevation and plan, year of construction, building location, soil type, seismic zone, building appearance quality, and other useful features are all part of this visual investigation. Without performing any structural calculations, a structural score is calculated based on the data gathered to estimate the building's expected damage and determine whether it requires further evaluation. The time and resources saved by this process can be efficiently applied to the buildings that require a thorough evaluation [8] [9] [10]. Mathavanayakam Sathurshan et. Al. (2023) applied RVS method to the typical buildings of Srilanka. It was shown that the proposed RVS method is capable of capturing the seismic risks of such typical RC-MIW Sri Lankan school buildings [11].

Bogura, located in Bangladesh's northwestern area, is an important urban hub with a rich historical and cultural heritage. Geographically, it is located in the heart of the Bogura District, part of the Rajshahi Division, and is crossed by the Karatoa River. Bogura, despite its continuous urban growth and economic prominence, is located in an area of considerable seismic activity due to its proximity to the Dauki Fault and Madhupur Trench. According to studies, many buildings in Bogura are not earthquake-resistant, raising concerns about the city's susceptibility to seismic risks. A thorough seismic risk assessment and the effective deployment of earthquake-resistant construction practices are vital to protecting the city's infrastructure and population [1].

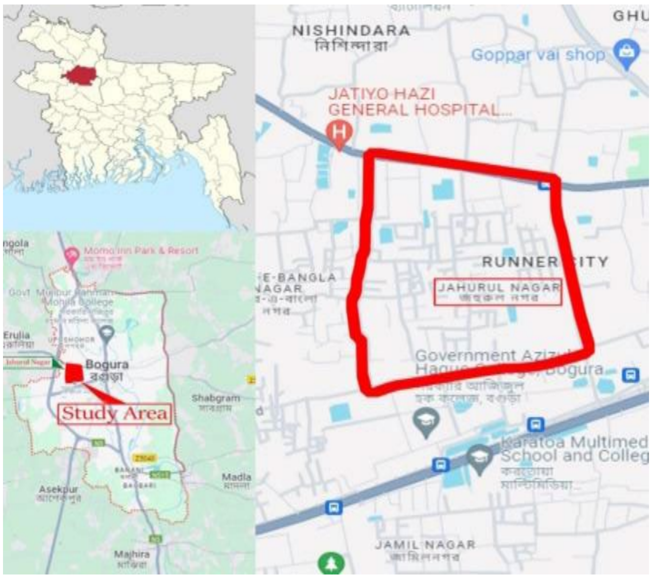


Figure 3. Map of Study Area

The purpose of this study is to examine the seismic susceptibility of Jahurul Nagar, Ward No. 04, inside Bogura Municipality, located in the Bogra District of the Rajshahi Division of Bangladesh. Figure 3 depicts the map of the study area. According to BNBC 2020, Bogura is in seismic zone III, which has a zone coefficient of 0.28 and is considered moderate-risk. Jahurul Nagar, a residential, haphazardly and highly inhabited region, is critical for local administration, urban infrastructure, public services, and community development. It is bounded by Nishindara, Sher-e-Bangla Nagar, Runner City, and Azizul Haque College, and includes neighborhoods such as Chak Brindaban/Kamargari, Chak Sutrapur, Methar Para, Kha Para, Nishindara (Jahurul Nagar), and Showdagor Para. According to the 2011 Bangladesh census, Bogura Sadar Upazila has 131,862 homes and a population of 555,014. Ward 4 had a population of 19,524 people (9,192 men and 7,547 women), 4,000 homes, an average household size of 4.1, a population density of 1,173 per square kilometer, and a sex ratio of 119. A map [Figure 3] in the paper depicts Jahurul Nagar's location and neighboring landmarks, providing critical information for the creation of efficient mitigation solutions. This study aims to investigate the seismic susceptibility of existing reinforced concrete (RC) structures using the Rapid Visual Screening (RVS) method and the Turkish seismic assessment approach on the study area. The study focuses on identifying structural faults, prioritizing high-risk structures, and comparing the effectiveness of these two methods in detecting seismic risks. By investigating the susceptibility of RC structures, the study seeks to provide practical recommendations for retrofitting and design improvements to improve earthquake resilience. Furthermore, the research seeks to increase urban catastrophe preparedness by outlining a systematic methodology for merging RVS and Turkish techniques into wider seismic risk assessments for vulnerable metropolitan areas.

2. Methodology

2.1. Turkish method and FEMA 154 & 310

In order to quickly evaluate seismic susceptibility, the Turkish Tier 1 technique uses FEMA's rapid visual screening process. This is in line with FEMA's strategy of giving priority to structures that require additional assessment or upgrading following earthquakes. Using FEMA's rapid visual screening, the Tier 1 technique of the Turkish Method classifies structures according to age and material in order to rapidly assess seismic vulnerability. The Turkish Method and FEMA 154 & 310 guidelines both use the walkdown approach, which is a methodical post-disaster evaluation of buildings to determine damage and guarantee safety. FEMA rules offer defined processes for conducting walkdowns in the United States with an emphasis on safety and risk mitigation, whereas the Turkish Method concentrates on visual inspections and documentation. According to FEMA's strategy of prioritizing safety and risk reduction, the Tier 1 technique of the Turkish Method incorporates FEMA's rapid visual screening to quickly assess seismic susceptibility with the goal of classifying buildings for additional assessment or post-earthquake retrofitting.

2.2. Theoretical framework

A condensed form of the theoretical framework for seismic vulnerability assessment for the selected area, concentrating on the Turkish Method Tier 1 that uses FEMA's Rapid Visual Screening (RVS), is shown in [Figure 4]. Three primary processes comprise the framework's structure: gathering data, calculating, and doing an initial evaluation. These steps make it easier to spot buildings that could need more thorough examination in later tiers.

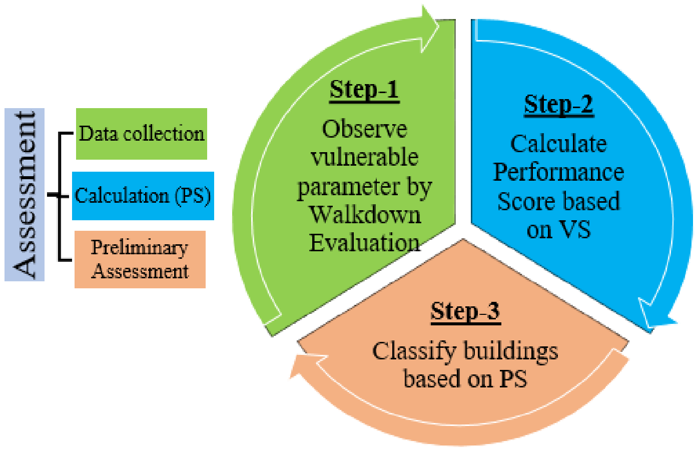


Figure 4. Theoretical Framework of Methodology

2.3. Data collection and evaluation process

The method created by Sucuoglu and Yazgan (2003) has been applied to gather the existing reinforced concrete buildings data. Trained observers use walk-down visits to conduct the first survey level from the sidewalk. Simple structural and geotechnical criteria that are easily observable from the sidewalk must serve as the foundation for a street survey technique. It is anticipated that an observer will need no more than ten minutes to gather information about a single building from the sidewalk. The following criteria were chosen for this study's representation of building vulnerability:

- The number of stories above ground (1 to 7)
- Presence of a soft story (Yes or No)
- Presence of heavy overhangs, such as balconies with concrete parapets (Yes or No)
- Apparent building quality (Good, Moderate or Poor)
- Presence of short columns (Yes or No)
- Pounding between adjacent buildings (Yes or No)
- Topographic effects (Yes or No)

Table 1. Prepared Form for Data Collection

		Soft storey		Heavy overhang		Apparent quality			Short columns		Pounding effects		Topographic effects	
Building Id	No of storey	Does not exist (0)	Exist (1)	Does not exist (0)	Exist (1)	Moderate(1)	Poor (2)	Good (0)	Does not exist (0)	Exist (1)	Does not exist (0)	Exist (1)	Does not exist (0)	Exist (1)
001														
002														

After the walk down visit at every existing RC building, the data were so arranged as mentioned in the Table 1. Figure 5 depicts a few typical buildings in the study region.

A base score is a standard by which a building's seismic susceptibility is measured in the Turkish method of seismic risk assessment, taking into consideration a number of variables such as structure type, location, and other attributes. Areas are categorized according to seismic risk using base score zoning, which frequently uses Peak Ground Velocity (PGV) to gauge the intensity of ground shaking. This zoning directs mitigation actions and aids in prioritizing regions for more evaluation.

The intensity zones are expressed using the corresponding PGV ranges created for Istanbul according to Sucuoglu and Yazgan (2003), because there isn't a PGV map for Bogura. Buildings are given varying base scores according to their number of stories and the site's seismic hazard level, as indicated in Table 2. The Zone III base score is utilized in this computation since Bogura is located in Seismic Zone III, a moderate seismic zone, according per BNBC 2020.

Table 2. Base Scores for concrete buildings (Ahmed et. al. 2012)

	Base Scores(BS)		
No. of stories	Zone I 60<PGV<80)	Zone II (40<PGV<60)	Zone III (20<PGV<40
1or 2	100	130	150
3	90	120	140
4	75	100	120
5	65	85	100
6 or 7	60	80	90

A building is given a numerical rating known as the Vulnerability Score (VS), which is determined by evaluating these factors. It establishes the structure's total seismic susceptibility. Each vulnerability parameter's presence or severity determines the VS score. By classifying structures into varying degrees of risk, the scoring method helps determine the order of importance for seismic mitigation and retrofitting measures. An example table for determining vulnerability ratings using the above parameters is Table 3.

Again in the context of assessing seismic vulnerability using the Turkish technique, the Vulnerability Score Modifier (VSM) stands for particular characteristics or elements that influence a building's overall seismic risk. Each vulnerability parameter is given a numerical weight or coefficient called VSM, which highlights how crucial it is in affecting seismic risk. Each parameter is given a value by VSM, which guarantees a more thorough and nuanced assessment by modifying the overall vulnerability score according to the importance of these variables. This method provides a thorough understanding of a building's seismic risk by enabling a customized assessment that considers each building's distinct features. The assessment framework of the Turkish method's updated scores for each vulnerable parameter is summarized here in Table 4.

Table 3. Vulnerability Score for concrete buildings (Ahmed et. al. 2012)

	Vulnerability Scores (VS)					
No. of stories	Soft Story	Heavy Overhangs	Apparent Quality	Short Column	Pounding Effects	Topographic Effects
1or 2	0	- 5	- 5	- 5	0	0
3	- 15	- 10	- 10	- 5	- 2	0
4	- 20	- 10	- 10	- 5	- 3	- 2
5	- 25	- 15	- 15	- 5	- 3	- 2
6 or 7	- 30	- 15	- 15	- 5	- 3	- 2

Table 4. Vulnerability Score Modifier

Parameter	VSM
Number of Stories Above Ground	Varies from 1 to 7
Presence of a Soft Story	Yes = 1, No = 0
Presence of Heavy Overhangs	Yes = 1, No = 0
Apparent Building Quality	Good = 0, Moderate = 1, Poor = 2
Presence of Short Columns	Yes = 1, No = 0
Pounding Between Adjacent Buildings	Yes = 1, No = 0
Topographic Effects	Yes = 1, No = 0

After a building's location and vulnerability criteria are established through walk-down surveys, Eq. (1) can be used to compute the seismic performance score (PS). The vulnerability scores (VS), base scores (BS), and vulnerability score multiplies (VSM) that are to be applied in Eq. (1) are specified in Tables 1 and 2, respectively.

$$PS = BS - \sum (VSM \times VS) \tag{1}$$

Using this formula, the performance score (PS) gives a general idea of how seismically vulnerable the building is.

Greater seismic risk is indicated by buildings with higher scores, which calls for more thorough evaluations or retrofitting procedures to guarantee seismic resistance. Buildings are divided into three risk classes according to the Seismic Performance Score (PS) in the Turkish Seismic Vulnerability Assessment Method's preliminary assessment methodology.

Figure 5. Some typical buildings at Study area

Using the Seismic Performance Score, the following updated classification criteria [Table 5] are used for RC (Reinforced Concrete) buildings.

Table 5. Risk group classification criteria

Risk Groups	PS Score Range
Unsafe	PS > 60
Moderate	60 > PS >100
Safe	PS > 100

3. Results and Discussions

3.1. Analysis of vulnerable parameter

In Jahurul Nagar, a well-known neighborhood in Bogura, the RC buildings are a collection of residential and commercial buildings that have grown considerably over time. These buildings, like many other metropolitan centers in Bangladesh, are susceptible to earthquakes because they are situated in an area with moderate seismic activity, which is impacted by neighboring tectonic features including the Madhupur and Dauki faults. The fact that many of these structures were built prior to the implementation of contemporary seismic design rules raises questions regarding their earthquake resistance. Recognizing at-risk structures and putting remedial measures in place need a thorough evaluation of these RC buildings' seismic susceptibility and structural integrity.

Variables of vulnerability were evaluated following a walk down assessment of 408 reinforced concrete (RC) buildings, ranging in size from one story to seven stories. The existence of these characteristics is depicted in [Figure 6], which is plotted horizontally by vulnerability type and vertically by presence level. According to the results, 110 buildings had short columns, 108 had soft storey weaknesses, and 166 buildings had excessive overhangs. The most common effect was the pounding effect. In terms of apparent quality, 162 buildings were categorized as having good quality, 159 as having moderate quality, and 87 as having low quality. A thorough picture of the prevalence and distribution of structural vulnerabilities in the buildings under inspection is given by this data.

3.2. Classification of buildings based on PS

Based on an initial seismic vulnerability assessment for existing reinforced concrete (RC) buildings using the Turkish method, Figure 7 represents the analysis of each vulnerable parameter at 408 numbers of buildings as well as Figure 8 and Figure 9 show the distribution of different storied buildings (from one to seven stories) across three risk groups—Safe, Moderate, and Unsafe. The horizontal axis classifies the risk classes, and the vertical axis shows the number of structures.

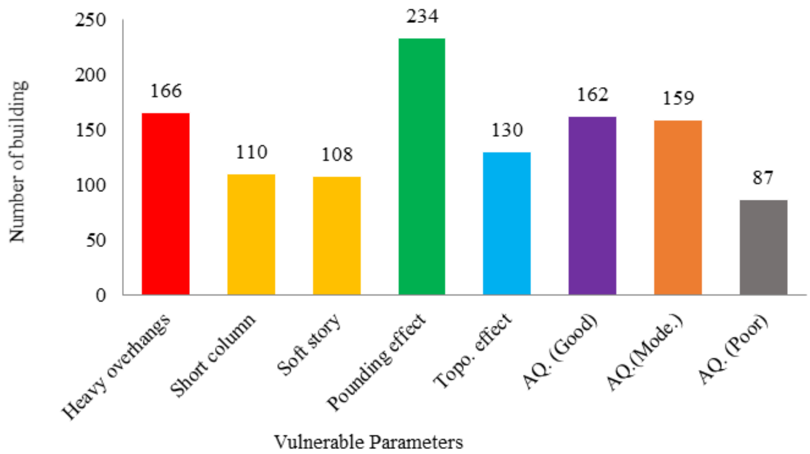
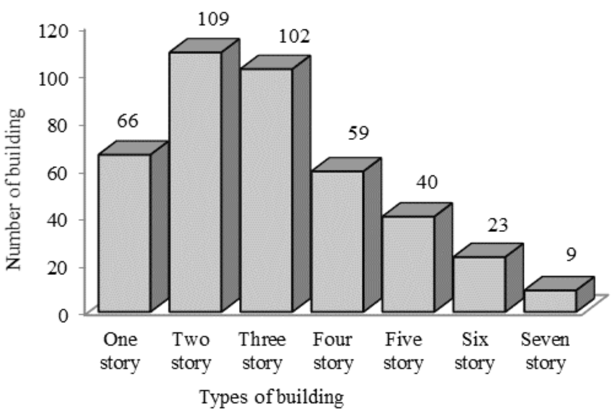


Figure 6. Overall Analyses after RVS

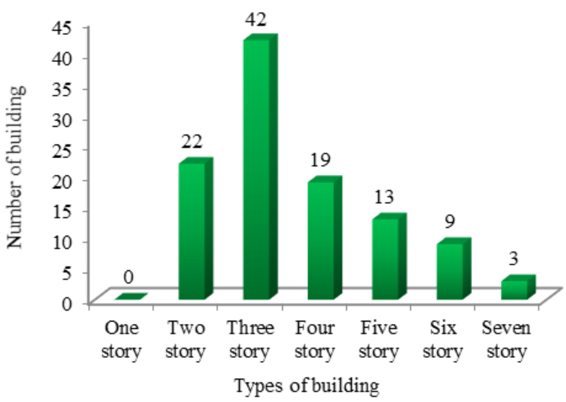
According to the assessment, a significant proportion of buildings in the "Safe" category are one-story, two-story, and three-story, with counts of 66, 109, and 76, respectively. This implies that shorter structures typically have a lesser seismic risk. There are also a lot of four-story buildings in the "Safe" category about 28 structures in total. Notably, there aren't any "Safe" structures that are five, six, or seven stories tall.

There are 29 five-story buildings in the "Moderate" hazard group, which is the most common building type. Three-story (26) and four-story (23) buildings are next in line. Further evidence that susceptibility rises with height comes from the fact that there are fewer six-story (12) and seven-story (3) buildings categorized as "Moderate."

This study employs the Turkish assessment methodology and the Rapid Visual Screening (RVS) method to assess the seismic vulnerability of existing reinforced concrete (RC) buildings. In order to ensure efficient risk mitigation techniques, the research attempts to identify and categorize structures according to their vulnerability to earthquake-induced damage. A variety of RC structures in various seismic zones will be covered in the study, taking into account elements like material quality, structural configurations, and prior changes. By contrasting the outcomes of real-world case studies, the accuracy and applicability of both approaches will be examined. This study offers important insights for policymakers, engineers, and disaster management authorities in improving earthquake preparedness and resilience, making it especially pertinent for metropolitan regions vulnerable to seismic risks.



Types of Buildings



Presence of soft story

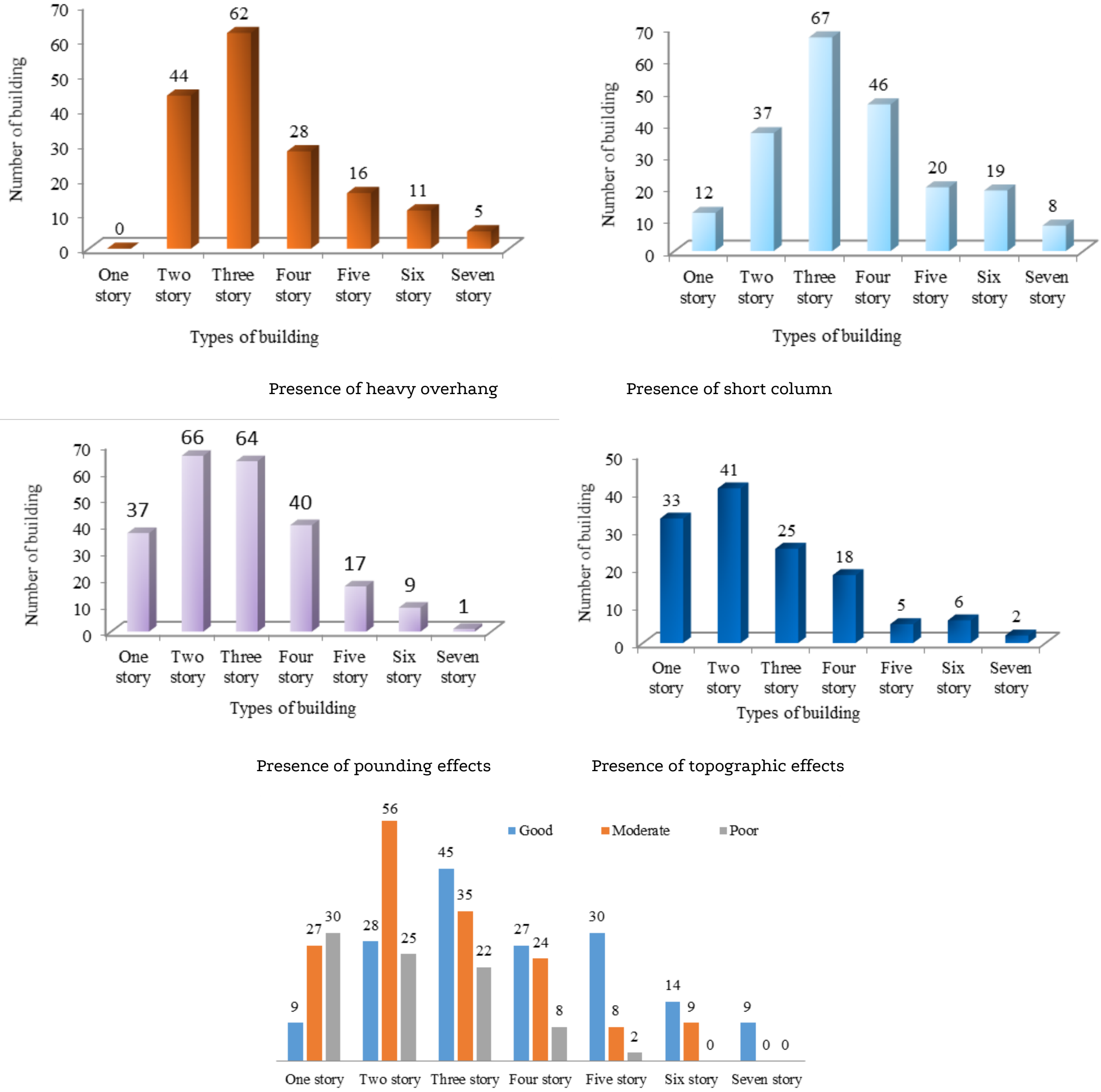


Figure 7. Analysis of each vulnerable parameter

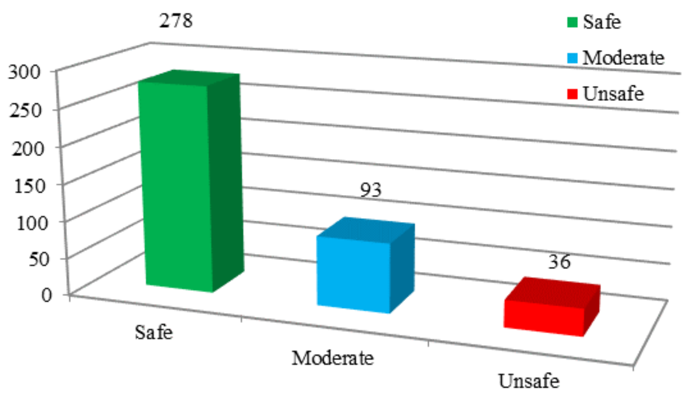
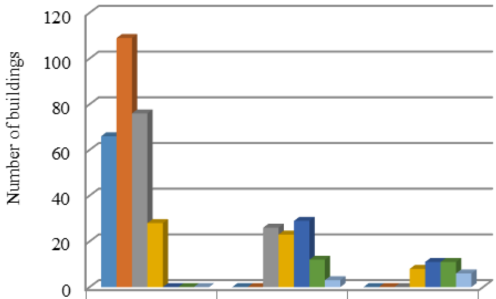


Figure 8. Risk groups after preliminary assessment



	Safe	Moderate	Unsafe
One story	66	0	0
Two story	109	0	0
Three story	76	26	0
Four story	28	23	8
Five story	0	29	11
Six story	0	12	11
Seven story	0	3	6

Figure 9. Risk groups after preliminary assessment

4. Conclusions

The data clearly shows that, using the Turkish method, shorter buildings (one to three floors) are often safer in terms of seismic risk. Since lower buildings are often more stable and resilient to earthquakes due to fewer sway and torsion effects, this result is consistent with general seismic engineering principles. On the other hand, as buildings get taller, the vulnerability rises. Significant counts in both the "Moderate" and "Unsafe" categories are present in the five-story buildings, suggesting the urgent need for more structural investigation and possible reinforcing. The significance of strict seismic design and retrofitting procedures for taller structures is highlighted by the inclusion of six-story and seven-story buildings in the higher-risk category. In order to increase the resilience of mid- to high-rise reinforced concrete buildings against future earthquakes, the preliminary study emphasizes the need for focused seismic risk mitigation techniques. In order to guarantee safety and reduce seismic risk, the findings support ongoing monitoring, evaluation, and strengthening of existing buildings. The key findings of this study are,

Safe Category: 278 buildings (68.1%) fit into this category; these are primarily one- to three-story buildings with lesser seismic vulnerability.

Moderate Category: The intermediate risk category includes 93 buildings (22.8%), most of which are mid-rise structures, suggesting that vulnerability increases with height.

Unsafe or Risky Category: 36 buildings (8.8%) fall within the risky category. Many of these buildings are higher (five to six stories), making them more vulnerable to seismic damage because of their bulk and height.

The necessity for focused measures to improve the resilience of mid- and high-rise RC buildings is highlighted by key findings that show a substantial link between building height and seismic vulnerability. The study emphasizes how crucial it is to make well-informed policy and urban planning decisions in order to successfully address seismic threats. The following suggestions are put forth in order to reduce seismic risks and improve the resilience of buildings in Bogura:

- ❖ Improve the Standards for Structural Design:
    - To reduce seismic risks, make sure all new construction complies with the most recent seismic design rules, especially for mid-rise and high-rise buildings.
    - To decrease seismic forces, use cutting-edge design strategies like base isolation and energy-dissipating components.
- ❖ Retrofitting Dangerous Structures:
    - Give the 8.8% of dangerous buildings that require retrofitting top priority, concentrating on structural reinforcements including jacketing columns, adding shear walls, and strengthening beam-column junctions.
    - To increase stability during earthquakes, use foundation strengthening procedures for tall buildings.
- ❖ Frequent Evaluations of Structure:
    - All existing buildings should have their seismic vulnerability evaluated on a regular basis, with a focus on those classified as dangerous or intermediate.
    - Assess the structural integrity of important components using cutting-edge methods such as non-destructive testing (NDT).
- ❖ Regulate the mass and height of the building:
    - Unless strong seismic design safeguards are put in place, new buildings in high seismic risk areas should not be taller than necessary and promote the use of lightweight building materials to cut down on mass and seismic pressures.
- ❖ Create policies for seismic retrofitting:
    - Provide government-sponsored retrofit incentives, including tax breaks or subsidies, to entice building owners to make improvements and make retrofitting requirements necessary for structures that are deemed dangerous.
- ❖ Training and Awareness of the Community:
    - Inform engineers, contractors, and building owners about earthquake-resistant building techniques and get locals ready for earthquake emergencies, hold workshops and drills.
- ❖ Enhance urban planning
    - To prevent overcrowding and guarantee adequate distance between structures, enforce zoning regulations and enable safe movement during emergencies, high-density areas should be designed with open spaces and evacuation routes.

- Set up monitoring systems:
  - Buildings should have seismic monitoring technology installed in order to identify structural damage early and make use of these systems to help guide retrofit choices and guarantee continued safety.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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