# Vulnerability Assessment of Typical Residential Buildings of Chattogram City Corporation with Post Seismic Hazard Consideration


**Md. Ridwan Alam Adnan**



**DEPARTMENT OF DISASTER ENGINEERING AND MANAGEMENT**
**CHITTAGONG UNIVERSITY OF ENGINEERING & TECHNOLOGY**
**CHITTAGONG, BANGLADESH**


**December, 2024**

# Vulnerability Assessment of Typical Residential Buildings of Chattogram City Corporation with Post Seismic Hazard Consideration

**A Project Report**

**Submitted to the**
**Department of Disaster Engineering and Management**
**Chittagong University of Engineering and Technology,**
**Chittagong in partial fulfillment of the requirements for the degree**
**of**
**MASTER OF ENGINEERING**
**in**
**DISASTER ENGINEERING AND MANAGEMENT**

**by**
**Md. Ridwan Alam Adnan**

**CHITTAGONG UNIVERSITY OF ENGINEERING & TECHNOLOGY**
**CHITTAGONG, BANGLADESH**
**December, 2024**

# CERTIFICATION

The thesis/project report titled “Vulnerability Assessment of Typical Residential Buildings of Chattogram City Corporation with Post Seismic Hazard Consideration” submitted by Md. Ridwan Alam Adnan, Roll No.: 19MDEM005F, Session: 2019-2020 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering in Disaster Engineering and Management on 12th December, 2024.

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______________________________

**Dr. Maruful Hasan Mazumder**

Professor

Department of Disaster Engineering and Management, CUET

# DEDICATION

I would to dedicate this work to my beloved father, **Late Alhaj Md. Badiul Alam** and my beloved mother, **Rahana Begum**. They are my source of inspiration and encouragement.

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| | | |
|---|---|---|
| BNBC | - | Bangladesh National Building Code |
| EQ | - | Earthquake |
| FS | - | Factor of Safety |
| FEMA | - | Federal Emergency Management Agency |
| ASCE | - | American Society of Civil Engineers |
| NEHRP | - | National Earthquake Hazards Reduction Program |
| GIS | - | Geographic Information System |
| NRC | - | National Research Council |
| PGA | - | Peak Ground Acceleration |
| RVS | - | Rapid Visual Screening |
| RC | - | Reinforced Concrete |
| SPT | - | Standard Penetration Test |
| VAM | - | Vulnerability Assessment Methods |

# ACKNOWLEDGEMENT

Firstly, I would like to express my gratitude to Almighty Allah for giving me the chance to complete my Master of Engineering from Chittagong University of Engineering & Technology (CUET). This research could not have been possible without the support of a number of individuals and I would like to extend my sincere thanks to them. First and foremost, I would like to express my immense gratitude to **Dr. Maruful Hasan Mazumder** without whom the research would not have seen its completion. His role was more than a supervisor and no less than a parent. Many thanks to all Faculty members and course teachers of the Department of Disaster Engineering and Management.

At the same time, I am very much thankful to all staff of CUET, all of my classmates for their support during my hard time. I owe my deepest gratitude to Engr. Hedayet Ullah who always encouraged me to keep on working.

Lastly, my heartfelt thanks go to my parents and my siblings for their continuous support and prayer throughout my study. Without their inspiration I could not complete my study.

# ABSTRACT

The seismic hazard map of Bangladesh shows that the northern and eastern regions of Bangladesh are particularly susceptible to seismic hazards. There is a high risk that a moderate to strong earthquake may result in widespread damage especially in the densely populated urban set up of Bangladesh. Being the second largest metropolis in Bangladesh, Chattogram has been built up to accommodate fast-growing population of Bangladesh. In this project, building data is collected by conducting Rapid Visual Screening (RVS) survey in a typical residential area of the city. Commonly used methods of RVS is used to collect general information of typical reinforced concrete buildings of the study area and an assessment of seismic vulnerability of the buildings is done with emphasis given post seismic hazard consideration as well. A comparative analysis of the results using FEMA 154, FEMA 310 and ASCE 41-13 RVS methods show that there exist significant problems of seismic vulnerability of buildings in the study area in relation to building parameters such as load path discontinuity, soft stories, weak brick joints, horizontal and vertical plan irregularities, strong beams/weak columns, diaphragm discontinuity etc. The results of FEMA 154 RVS method indicates that 35% of the buildings of the area fall below a cut-off vulnerability score of 2. With an average 49% percent of non-compliance of building vulnerability parameters of FEMA 310, an average or relative score of vulnerability score of 2.1 is calculated. The results of these two RVS methods seem to be an underestimate of the conditions of seismic vulnerability considering the poor conditions of buildings observed during the field study. When compared to the results of average 60% non-compliance of building vulnerability parameters of the ASCE 41-13 checklist, the relative score of seismic vulnerability of 1.9 better represents the observed poor conditions of buildings' physical conditions. According to FEMA 154, the percentage of buildings with cut-off score less than 2 is high in areas with insufficient width of roads which is indicative of the fact of narrow exit pathways or insufficient evacuation facilities during emergency situations. A few guidelines of BNBC regulations may be considered important considerations for mitigation of risks of post seismic hazards. Therefore, RVS checklists of parameters may need inclusive considerations of some additional parameters in the checklist of building vulnerability parameters such as front road width, electric and gas lines distance, built purpose and rescue facility etc. which are required to ensure earthquake resilient residential infrastructures and urban seismic resilience.

# বিমূর্ত

বাংলাদেশের সিসমিক হ্যাজার্ড ম্যাপে দেখা যায় যে, বাংলাদেশের উত্তর ও পূর্বাঞ্চল সিসমিক ঝুঁকিতে বিশেষভাবে সংবেদনশীল। বিশেষ করে বাংলাদেশের ঘনবসতিপূর্ণ শহুরে স্থাপনায় মাঝারি থেকে শক্তিশালী ভূমিকম্পের ফলে ব্যাপক ক্ষয়ক্ষতির উচ্চ ঝুঁকি রয়েছে। চট্টগ্রাম বাংলাদেশের দ্বিতীয় বৃহত্তম মহানগর হওয়ায় বাংলাদেশের দ্রুত বর্ধমান জনসংখ্যার সংস্থানের জন্য এখানে দ্রুত নগরায়ন হয়েছে। এই প্রকল্পে, চট্টগ্রাম শহরের একটি সাধারণ আবাসিক এলাকায় রেপিড ভিজ্যুয়াল স্ক্রিনিং (আর.ভি.এস) জরিপ পরিচালনা করে ভবনের তথ্য সংগ্রহ করা হয়। সাধারণভাবে বহুল ব্যবহৃত কিছু আর.ভি.এস পদ্ধতি প্রয়োগের মাধ্যমে উক্ত এলাকার আর.সি কংক্রিটের তৈরি আবাসিক ভবনগুলির তথ্য সংগ্রহ করা হয় এবং এর ভিত্তিতে ভবনগুলির ভূমিকম্প ঝুঁকি মূল্যায়ন করা হয়, যাতে ভূমিকম্প পরবর্তী কিছু ঝুঁকির বিষয় মূল্যায়নের উপরও বিশেষভাবে জোর দেয়া হয়েছে। এফ.ই.এম.এ ১৫৪, এফ.ই.এম.এ ৩১০ এবং এ.এস.সি.ই ৪১-১৩ আর.ভি.এস পদ্ধতি ব্যবহার করে ফলাফলগুলির একটি তুলনামূলক বিশ্লেষণে দেখা যায় যে, ভবনগুলোর ভূমিকম্প ঝুঁকি বৃদ্ধিতে কিছু গুরুত্বপূর্ণ দুর্বলতা বা নিয়ামক বিষয় যেমন লোড পাথের অধারাবাহিকতা, সফট স্টোরি, দুর্বল ইটের জয়েন্ট, ভবন নির্মাণের ক্ষেত্রে আনুভূমিক ও উল্লম্ব পরিকল্পনায় অনিয়ম, মজবুত বিম/দুর্বল কলাম, ডায়াফ্রাম বিচ্ছিন্নতা ইত্যাদির বিশেষ ভূমিকা রয়েছে। এফ.ই.এম.এ ১৫৪ আর.ভি.এস পদ্ধতির ফলাফল মূল্যায়নে দেখা যায় যে, ৩৫% ভবন দুর্বল ভবন হিসেবে কাট-অফ স্কোর ২ এর নিচে রয়েছে। ভবনগুলোর মূল্যায়নে এফ.ই.এম.এ ৩১০ আর.ভি.এস পদ্ধতির ৪৯% প্যারামিটার নন-কমপ্লায়ান্ট হয়, যার ভিত্তিতে ভবনগুলোর একটি গড় বা আপেক্ষিক ঝুঁকির তুলনামুলক মান ২.১ নির্ণয় করা হয়েছে। তথাপি, মাঠ পর্যায়ে ভবনগুলোর দৃশ্যমান অনেক ঝুঁকির বিষয় পর্যালোচনায় আনলে উক্ত দুটি আর.ভি.এস পদ্ধতির নির্ণীত ঝুঁকি সূচকের প্রাক্কলন অবমূল্যায়ন হিসেবে বিবেচনা করা যায়। এ.এস.সি.ই ৪১-১৩ আর.ভি.এস পদ্ধতিতে ভবনগুলোর মূল্যায়নে ৬০% প্যারামিটার নন-কমপ্লায়ান্ট হয়, যার ভিত্তিতে ভবনগুলোর নির্ণীত আপেক্ষিক ঝুঁকি সূচকের মান ১.৯ কে মাঠ পর্যায়ে দৃশ্যমান খারাপ অবস্থা বিবেচনায় একটি অপেক্ষাকৃত ভাল বা গ্রহণযোগ্য ঝুঁকি সূচক হিসাবে বিবেচনা করা যায়। এফ.ই.এম.এ ১৫৪ পদ্ধতির মূল্যায়নে, রাস্তার অপর্যাপ্ত প্রস্থের এলাকায় কাট অফ স্কোর ২ এর কম তথা ঝুঁকিপূর্ণ ভবনের সংখ্যা বেশি পাওয়া যায় যা অপ্রশস্থ বহির্গমণ রাস্তা বা জরুরী প্রয়োজনের সময় অপর্যাপ্ত উদ্ধার বা অপসারণ সুবিধার নির্দেশক। এক্ষেত্রে বি.এন.বি.সি প্রবিধানের কয়েকটি গাইডলাইন বা নির্দেশিকা ভূমিকম্প পরবর্তী বিপদের ঝুঁকি কমানোর জন্য গুরুত্বপূর্ণ বিবেচনা হিসাবে বিবেচিত হতে পারে। তাই, আর.ভি.এস পদ্ধতির প্যারামিটারগুলির চেকলিস্টে কিছু অতিরিক্ত প্যারামিটার অন্তর্ভুক্ত করা যেতে পারে যেমন ভবনের সামনের রাস্তার প্রস্থ, বৈদ্যুতিক এবং গ্যাস লাইনের দূরত্ব, নির্মাণের উদ্দেশ্য এবং উদ্ধার সুবিধা ইত্যাদি; যা ভূমিকম্প সহনশীল আবাসিক অবকাঠামো এবং নগরীর সিসমিক ঝুঁকি সহনশীলতা নিশ্চিতকরণের জন্য প্রয়োজন।

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# CHAPTER 1

## INTRODUCTION

### 1.1 Background and Statement of the Problem

Bangladesh is located in a seismically active region with five geological fault lines crossing through the country. Historical evidence suggests that Bangladesh may be affected by moderate to strong earthquakes due to its proximity to the collision boundary of the northeast-moving Indian plate and Eurasian Plate (BNBC 2006). Stress and strain build up as tectonic plates at the earth’s outer shell slowly move and interact with each other causing the deformation of rocks. The energy released during an earthquake comes from the gradual accumulation of stress and strain in the earth's crust over time. Eventually, a rupture on a fault starts to grow unstably and energy is released into seismic waves and heat from friction on the fault lines. This release of strain energy stored in the earth’s crust lets it move and poses earthquakes.

The country has been divided into four seismic hazard zones and the seismic hazard map of Bangladesh shows that the northern and eastern regions of Bangladesh are particularly susceptible to seismic hazards (BNBC 2020). A few strong earthquakes with a magnitude over 7.0 have affected parts of Bangladesh in the last 150 years and some of them had their epicentres near the country (Sadat et al. 2010; Alam et al. 2008). There is a high risk that a moderate to strong earthquake may result in widespread damage, especially in the densely populated urban settings of Bangladesh.

The general status of residential buildings or other human settlements in Chattogram City is not earthquake resilient or safe even against a moderate level of earthquake. There are many semi-engineering or non-engineered buildings constructed within the city. In these contexts, some of the typical urban residential buildings of Chattogram may be tagged as highly vulnerable to earthquake hazards since the city is situated in mostly high-risk zone 3 having a PGA of 0.28g (BNBC 2020). Several buildings in Chattogram leaned and suffered significant damage due to the earthquake in 2016 (BNBC 2020).

The seismic vulnerability of a city depends not only on the structural performance of the buildings of the city but also on other facilities related to the city (SATREPS-TSUIB 2022). According to the socioeconomic status of the country, Bangladesh has a very limited habitable area to accommodate its ever-growing population. Residential buildings in

Chattogram City are typically built very close to each other creating obstacles to rescue facilities or escape pathways, with inadequate fire safety systems or emergency exits, inadequate width of building front road and lacking necessary safety standards or requirements stated in BNBC, 2020. Therefore, risks or vulnerability due to earthquakes are not only confined to risk factors of buildings themselves but also are integrally linked to numerous other external factors which are particularly important for post-seismic hazard mitigation and for improving overall urban seismic resilience. Against this backdrop, seismic vulnerability or risk is likely to be extremely high in the densely populated urban areas of the country especially if some of the secondary or post seismic hazards are taken into account for assessment of seismic vulnerability of residential buildings of city areas.

Current practice for seismic vulnerability assessment of buildings in Bangladesh relies mostly on visual inspection to tag buildings as being either safe or unsafe for occupancy (National Plan for Disaster 2010). Visual inspection indicates building behavior during an earthquake which may require a follow-up action by detailed engineering assessment for holistic prediction of the capacity of a building to withstand future earthquakes. Seismic Vulnerability Assessment (SVA) methods are generally classified into three main groups depending on their level of complexity. The first and simplest level is known as Rapid Visual Screening (RVS) or Walk-down Evaluation. This preliminary screening does not require any analysis as its goal is to determine the critical buildings that require immediate interventions for seismic risk mitigation. The procedures in FEMA 154 (1988), FEMA 310 (1998) Tier 1, ASCE 41-13 (2014) and the procedure developed by Sucuoglu and Yazgan (2003) are examples of walk-down survey procedures (Mukhlis et al. 2016). The second or third level or preliminary assessment methodologies are applied when a more in-depth evaluation of building stocks is required. These analyses require data on the dimensions of the structural and non-structural elements in the most critical story. The procedures by FEMA 310 (1998) Tier 2 and Ozcebe et al. (2003), later complemented by Yakut et al. (2003) can be listed as examples of preliminary survey procedures (Mukhlis et al. 2016). The procedures in the third level employ linear or nonlinear analyses of the building under consideration and require the as-built dimensions and the reinforcement details of all structural elements.

The project is aimed at conducting a first-level preliminary assessment by RVS to assess the seismic vulnerability of a few representative residential building structures of a ward of Chattogram City Corporation. Choosing rational methods and parameters of common RVS methods, seismic vulnerability assessment is performed on several randomly selected residential buildings of Chattogram City Corporation area. The nature and type of construction of selected residential buildings of the study area generally represent the typical status of common residential building structures in the Chattogram city corporation area. Although there is no checklist or guideline to assess the seismic vulnerability of buildings in the BNBC code, there are provisions of standards of fire safety systems, buildings' front road width and other relevant safety features that are closely linked to ensure post-seismic hazard mitigation. Therefore, a few additional factors that are generally stated in BNBC regulations as safety standards for disaster resilience of urban seismic resilience of Bangladesh are compared for consistency as well as recommending for possible integration in RVS methods for Bangladesh. A major emphasis in this regard has been given to considering secondary effects of earthquake or scenario analysis for post-seismic hazards in the contexts of existing urban setup, and typical physical and environmental conditions of the country.

## 1.2 Research Issue and Justification

Seismic vulnerability assessment requires comprehensive study to predict and mitigate the harmful effects of earthquakes. Development of seismic resilience requires improved infrastructure design, public awareness to respond and mitigate risks as well as other facilities to mitigate urban environmental risks in post-seismic hazards' context. There are also questions related to the post-earthquake environment more specifically related to socio-economic conditions of urban areas in Bangladesh that have only been partially answered or not answered at all. In future, a major earthquake may potentially harm urban infrastructures and the huge population in Chattogram if remedial steps are not taken from the perspectives of integrated development for urban seismic resilience. While progress has been made in understanding likely earthquake mechanisms in this region, many other aspects remain unresolved, especially in the current development and expansion of urban residential facilities in the city There are major setbacks or flaws in constructive practices commonly observed in urban residential buildings of the city that are unexpected in engineering practices. The problems or deficiencies may cause severe hazards in many aspects of planning or construction for seismic resilience.

These unconventional problems of densely populated urban residential areas of Bangladesh are not typically considered in common RVS methods of seismic vulnerability assessment. These additional factors may be obstacles/hindrances to life-saving services, easy access of firefighters/military personnel, emergency response teams, etc. In this perspective, the following general parameters that are common with FEMA 154, FEMA 310 and ASCE 41-13 methods including a few BNBC guidelines may be taken in first-level SVA analysis through RVS methods.

1) Construction year, building types and story number
2) Soft story
3) Pounding effect
4) Heavy overhang and falling hazards
5) Soil condition and geologic site hazards
6) Plan irregularities
7) Load pathway
8) Emergency escape, assembly and fire rescue services etc.

These factors are very common for determining building behavior during an earthquake and for assessing possible effects on urban seismic resilience especially in a post-seismic hazard context. Therefore, the project is focused on assessing the seismic vulnerability of typical residential buildings of Chattogram city by choosing rational parametric considerations suited to specific urban infrastructural and environmental contexts of Bangladesh.

## 1.3 Problem Definition

Chattogram city, situated in southeastern Bangladesh, is at significant risk of earthquakes due to its proximity to multiple active tectonic plates. However, the city's infrastructure remains ill-prepared for a major seismic event, thereby endangering the lives and livelihoods of its residents. A primary concern in Chattogram city is the absence of earthquake-resistant infrastructure. Numerous buildings, both residential and commercial, have been constructed using substandard materials and inadequate building codes. Consequently, these structures are highly susceptible to damage or collapse during an earthquake, posing severe risks to occupants, including potential injuries or fatalities.

Additionally, the lack of public awareness and education regarding earthquake preparedness exacerbates the situation. Many of the city residents are unfamiliar with essential safety measures to undertake during an earthquake, such as seeking shelter under sturdy desks or tables or evacuating buildings promptly and safely. Furthermore, the absence of coordinated emergency response planning and limited resources aggravates the city's vulnerability to a major earthquake. Hospitals, emergency services, and critical infrastructure may not possess the necessary capabilities to effectively manage the extensive casualties and damage resulting from such an event. In conclusion, Chattogram city faces a significant challenge regarding its preparedness and resilience in the face of a major seismic event. Resolving this issue necessitates a comprehensive approach, encompassing enhanced building codes and regulations, public education and awareness campaigns, as well as investments in critical infrastructure and emergency response planning.

## 1.4 Objective of the Study

As RVS is done from the outside of a building, some important interior features of inaccessible buildings cannot be inspected. Consequently, there may be invisible risks that may lead to improper evaluation of seismic vulnerability. A few additional factors that are uncommon in common RVS methods of screening but are specifically relevant to hazards associated with a post-earthquake environment of our country will be integrally considered with vulnerability assessment methods. The major objectives of the project are:

i. To assess the effects of a few additional factors in the common RVS methods that may increase seismic risk or vulnerability of typical residential buildings of Chattogram City.

ii. To compare among different RVS methods and check consistency in RVS score among different methods.

iii. To assess the seismic vulnerability of typically common residential buildings in Chattogram city.

iv. To evaluate possible incorporation in seismic vulnerability assessment aspects using the analytical hierarchy of urban planning aspects of Bangladesh.

The outcomes of the study may help in formulating the following

i. Recommendations can be made for further detailed analysis of highly vulnerable buildings found from the assessment.

ii. Findings of the study may be employed for decision-making in any future development work in residential projects.

iii. Increase the awareness of the structural vulnerability among politicians, city officials, directors, emergency chiefs, maintenance personnel and representatives from engineering and architectural societies.

# CHAPTER 2

## LITERATURE REVIEW

### 2.1 General

Earthquakes are among the most devastating natural disasters, capable of wreaking havoc on the human environment. Even a moderately strong earthquake can result in an alarmingly high number of fatalities. Over the past century, Bangladesh has experienced several catastrophic earthquakes. However, in recent times, this region has been fortunate enough to avoid any major destructive earthquakes. The impact of earthquakes has been somewhat mitigated by the fact that they have primarily occurred in sparsely populated areas away from major cities. As a result, human casualties and economic losses have been relatively limited. Nevertheless, earthquakes are rare events that unleash tremendous devastation within a matter of seconds, often leading to significant economic crises for affected countries, such as the devastating Haiti earthquake of 2010. Despite being situated in a seismic zone, many people and policymakers in Bangladesh remain unaware of the inherent seismic risks associated with the region.

### 2.2 Tectonics

Bangladesh is uniquely positioned at the convergence of three tectonic plates: the Indian, Eurasian, and Burma plates, as shown in Figure 2.1. In the north, the Indian and Eurasian plates interact, while in the east, the Indian and Burma plates converge. The continuous movement of the Indian Plate northeast and the Burma Plate northwest signals the dynamic nature of this region. Additionally, the Shillong Plateau to the north, along with the east-west trending Dauki Fault on its southern edge, plays a vital role in this geological framework, as illustrated in Figure 2.1. The possible connection of the Dauki Fault to the northern subduction fault in Sylhet highlights the complex relationships affecting Bangladesh's seismic activity, which is crucial for public safety.

**2.2.1** Plate Boundary Fault 1 (PBF-1): According to Shishikura et al. (2008, 2009), the most recent event along the PBF occurred during the 1762 earthquake, and the estimated recurrence period is 900 years. The probability of a future earthquake occurring within the next 50 years is 1.1%. This probability is considered low because 246 years have passed since the last event, compared to the 900-year recurrence period.

**2.2.2** Plate Boundary Faults 2 and 3 (PBF-2 and PBF-3): The timing of the latest event and its recurrence period along the PBF2 and PBF3 are currently unclear. However, based on the OZ55 event recorded on June 5, 2023, which suggests a recurrence interval of 900 years- drawing parallels with PBF1- we can infer that if the last event occurred before the 16th century, there is a significant probability of over 6.7% for another event to occur within the next 50 years. This highlights the urgency of our attention to these patterns.

**2.2.3** Dauki Fault (DF): The most recent event is linked to the catastrophic Great Assam Earthquake of 1897. Historical analysis suggests that the prior earthquake took place in 1548. With a recurrence period of 349 years and only 111 years since the last occurrence, we face a 7.0% likelihood of experiencing another earthquake within the next 50 years. It's crucial to consider this probability when planning for future safety and preparedness measures.

**2.2.4** Madhupur Blind Fault (MF): The 1885 earthquake (Ms7.0) is regarded as the latest event for characteristic earthquakes on the Madhupur Fault based on the existing documents. The recurrence period is unknown. If the recurrence period is 350 years by analogy with the Dauki Fault, the 50-year probability is 8.7%.

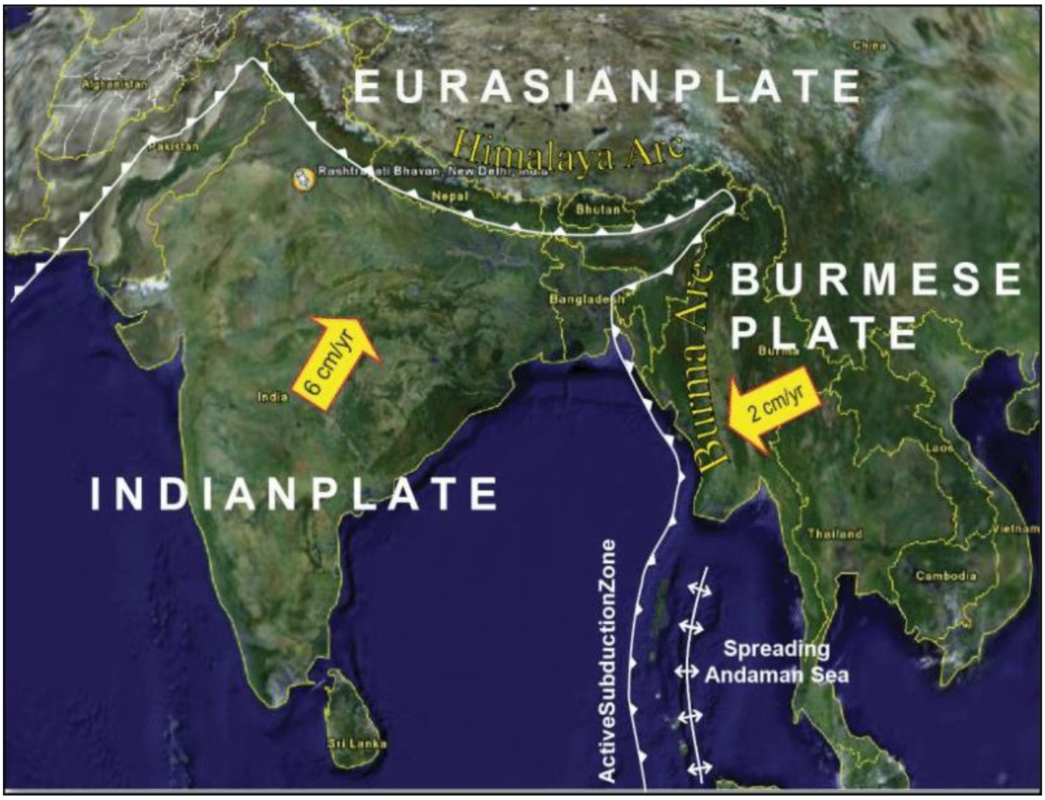


**Figure 2.1:** Boundary between the Indian Plate and the Eurasian Plate

(Source: S.H. Akhter, Background: Google Earth)

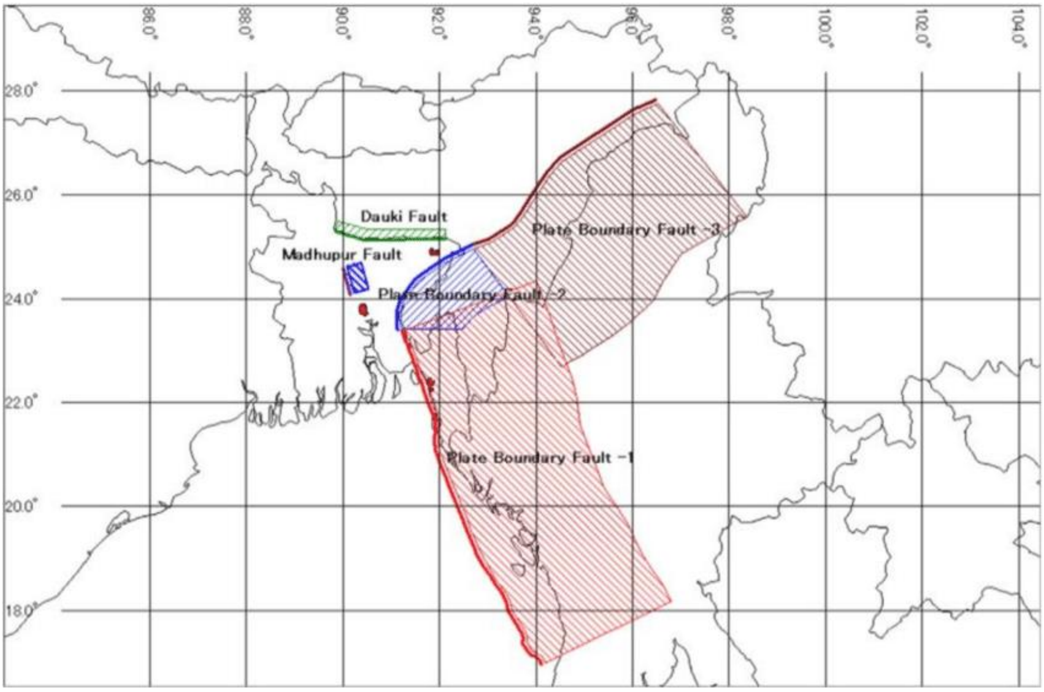


**Figure 2.2:** A scenario of Earthquake Fault Model after CDMP (2009)

## 2.3 History of Earthquake, Seismic Sources and Magnitudes

Bangladesh is situated in a seismically active area and has experienced numerous earthquakes in its history. The country is at ongoing risk of future earthquakes because of this location. Some notable earthquakes that have occurred in and around Bangladesh are presented in Table 2.1 and Figure 2.3. As shown in Figure 2.4, Bangladesh experiences significant seismic activity, particularly along the boundary between the Indian and Eurasian Plates and the Dauki Fault. Bolt (1987) conducted a thorough analysis of the seismic sources in and around Bangladesh, leading to crucial insights about the maximum likely earthquake magnitude in the region.

**Table 2.1:** Major earthquakes dated in/around Bangladesh for the last 100 years

| Date | Name of the Earthquake | Magnitude | Epicentre |
|---|---|---|---|
| July 18, 1918 | Srimangal Earthquake | 7.6 | Srimangal, Maulvi Bazar, Sylhet, Bangladesh |
| July 3, 1930 | Dhubri Earthquake | 7.1 | Dhubri, Assam (Near Rangpur district, Bangladesh) |
| January 15, 1934 | Bihar-Nepal Earthquake | 8.3 | Darbhanga, Bihar, India |
| February 11, 1936 | Bihar Earthquake | 7.5 | Northern Bihar, India |
| August 16, 1938 | Manipur Earthquake | 7.2 | Manipur, India (Near Bangladesh) |
| 23 October, 1943 | Assam Earthquake | 7.2 | Hojai, Assam, India |
| 15 August, 1950 | Assam Earthquake | 8.4 | Assam, India |
| 21 March, 1954 | Manipur-Burma Earthquake | 7.4 | Manipur-Burma border |
| 8 August, 1988 | Rangpur Earthquake | 6.0 | Rangpur, Bangladesh |
| 21 November, 1997 | Bandarban Earthquake | 7.1 | Mizoram-Myanmar border |
| 26 December, 2004 | Cox Bazar Earthquake | 7.0 | Bonda Aceh, Indonesia |
| 12 September, 2007 | Tsunami due to earthquake (Cox Bazar) | 8.5 | Bengkulu, Sumatra |

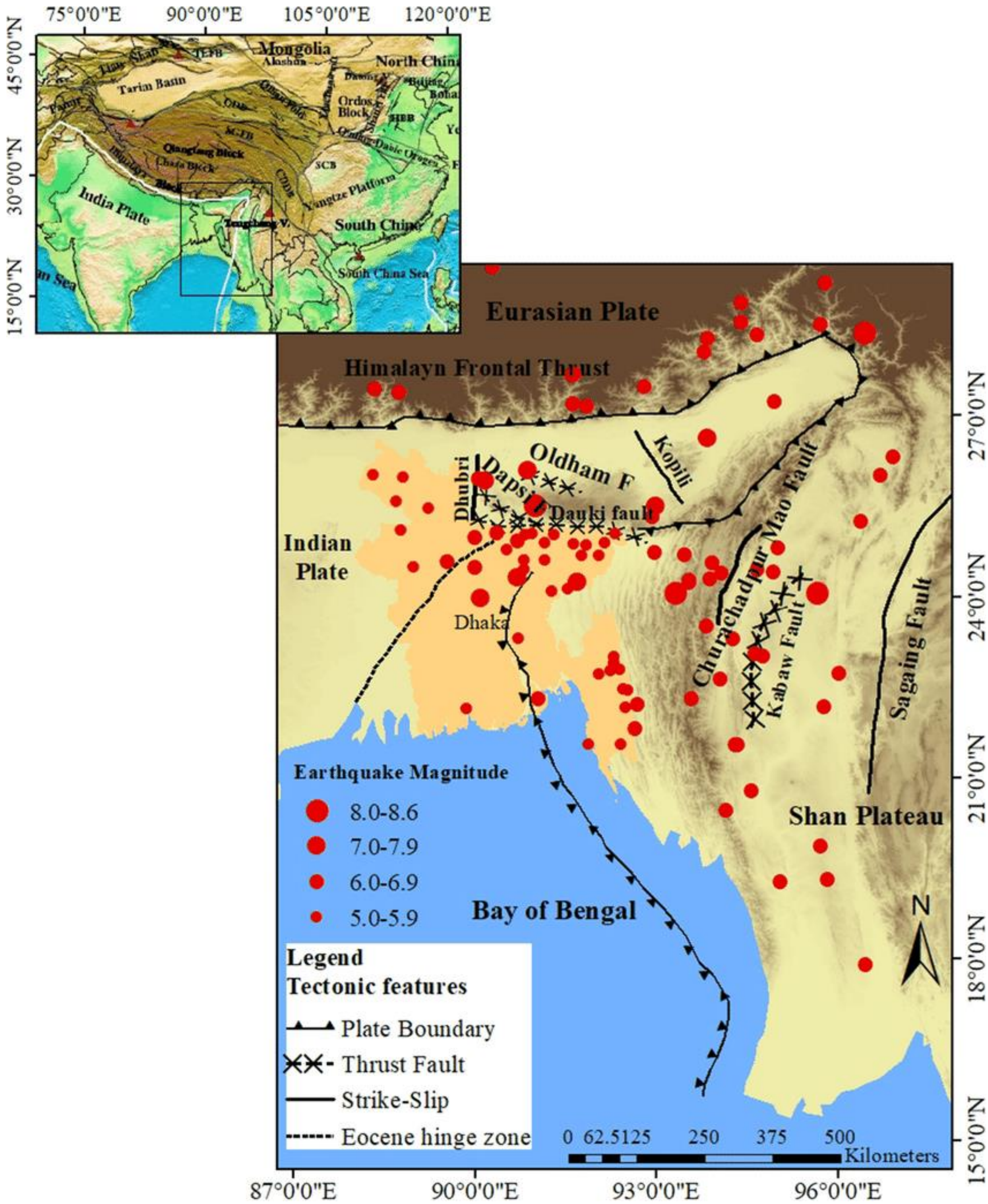


**Figure 2.3:** Historical earthquakes in the tectonic map of Bangladesh and the surrounding region

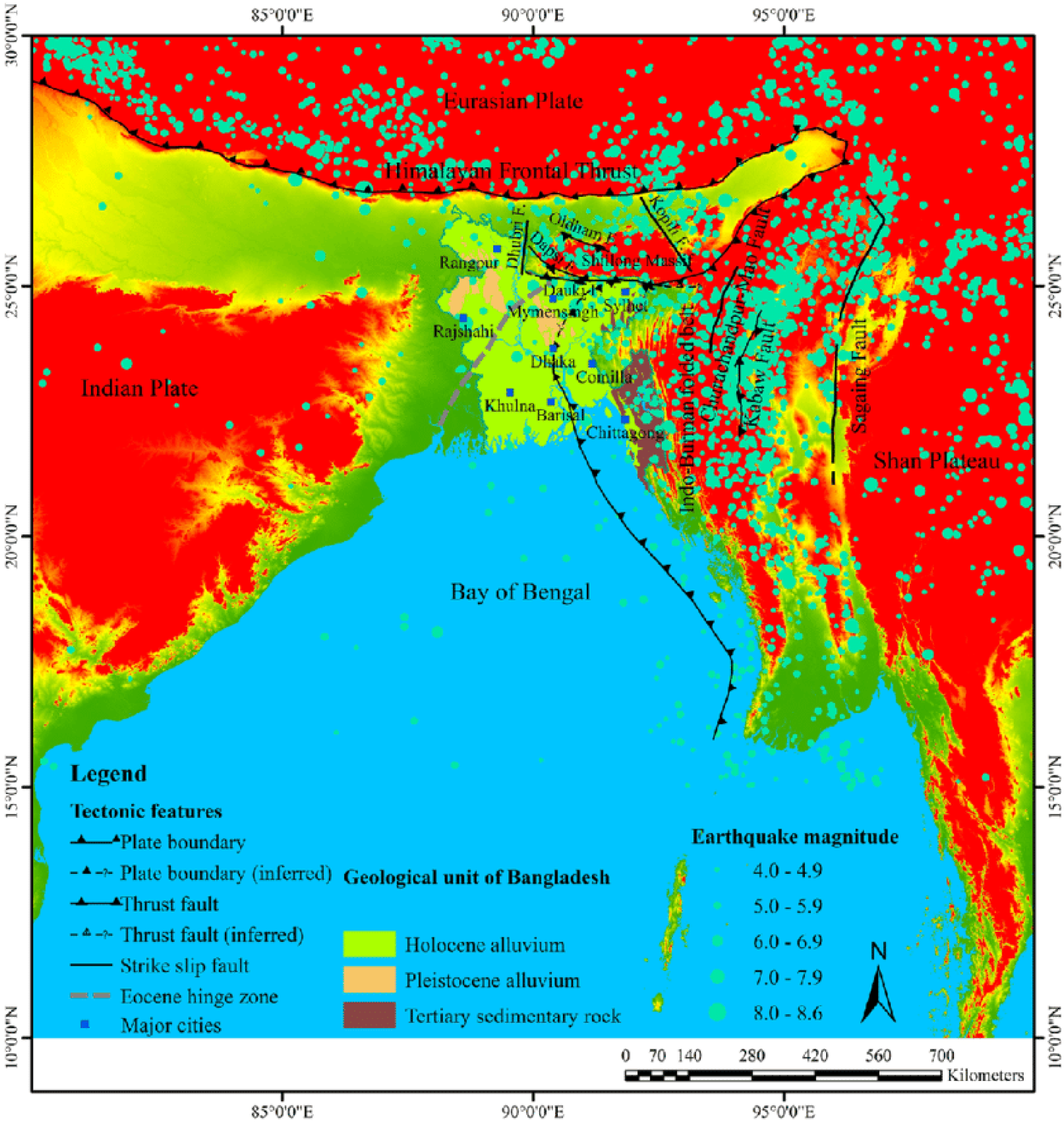


**Figure 2.4:** Seismotectonic map of Bangladesh and surrounding regions showing epicenters of Earthquakes (declustered catalogue)

By examining factors such as fault length, characteristics, and historical earthquake data, he established a comprehensive understanding of potential seismic threats. The results, detailing the maximum magnitudes of earthquakes in various tectonic blocks, are crucially outlined in Table 2.2, emphasizing the importance of preparedness in vulnerable areas.

**Table 2.2:** Significant seismic sources for Bangladesh, from Bolt & B.A. (1987)

| Location | Maximum Earthquake Magnitude |
|---|---|
| Assam fault zone | 8.5 |
| Tripura fault zone | 7.0 |
| Sub-Dauki fault zone | 7.3 |
| Bogra fault zone | 7.0 |
| Shillong Plateau | 7.0 |

According to Table 2.2, the Assam and the Tripura fault zones contain significant. faults capable of producing magnitude 8.6 and 8.0 earthquakes, respectively, in the Future. Similarly, earthquakes with a maximum magnitude of 7.5 in the Sub-Dauki fault zone and Bogra fault zone are not unlikely events.

## 2.4 Seismic Zoning Maps of Bangladesh

The seismic zoning of Bangladesh, as depicted in Figure 2.5(a), is based on the maximum ground motions expected from significant earthquakes affecting large areas. Currently, the country is classified into three generalized seismic zones: Zone I with a zone coefficient (Z) of 0.25, Zone II with Z at 0.15, and Zone III at 0.075. However, research conducted by Sabbir (2006) reveals inconsistencies between the seismic zoning and zone coefficients of BNBC 1993 and those of neighbouring India, highlighting a critical need for an update to the current seismic zoning in BNBC 2006.

In response to this urgent requirement, the building code BNBC 2020 introduces the Maximum Credible Earthquake (MCE) based on a return period of 2,475 years. As shown in Figure 2.5(b), the updated seismic zoning map for Bangladesh now features four zones: Zone 1 with a coefficient of 0.12, Zone 2 at 0.20, Zone 3 at 0.28, and Zone 4 at 0.36. These revised zone coefficients reflect the Peak Ground Acceleration (PGA) values on rock or rigid soil sites, ensuring greater safety and resilience against potential seismic events. Updating our seismic zoning code is not just beneficial- it is essential for the protection of lives and infrastructure in Bangladesh.

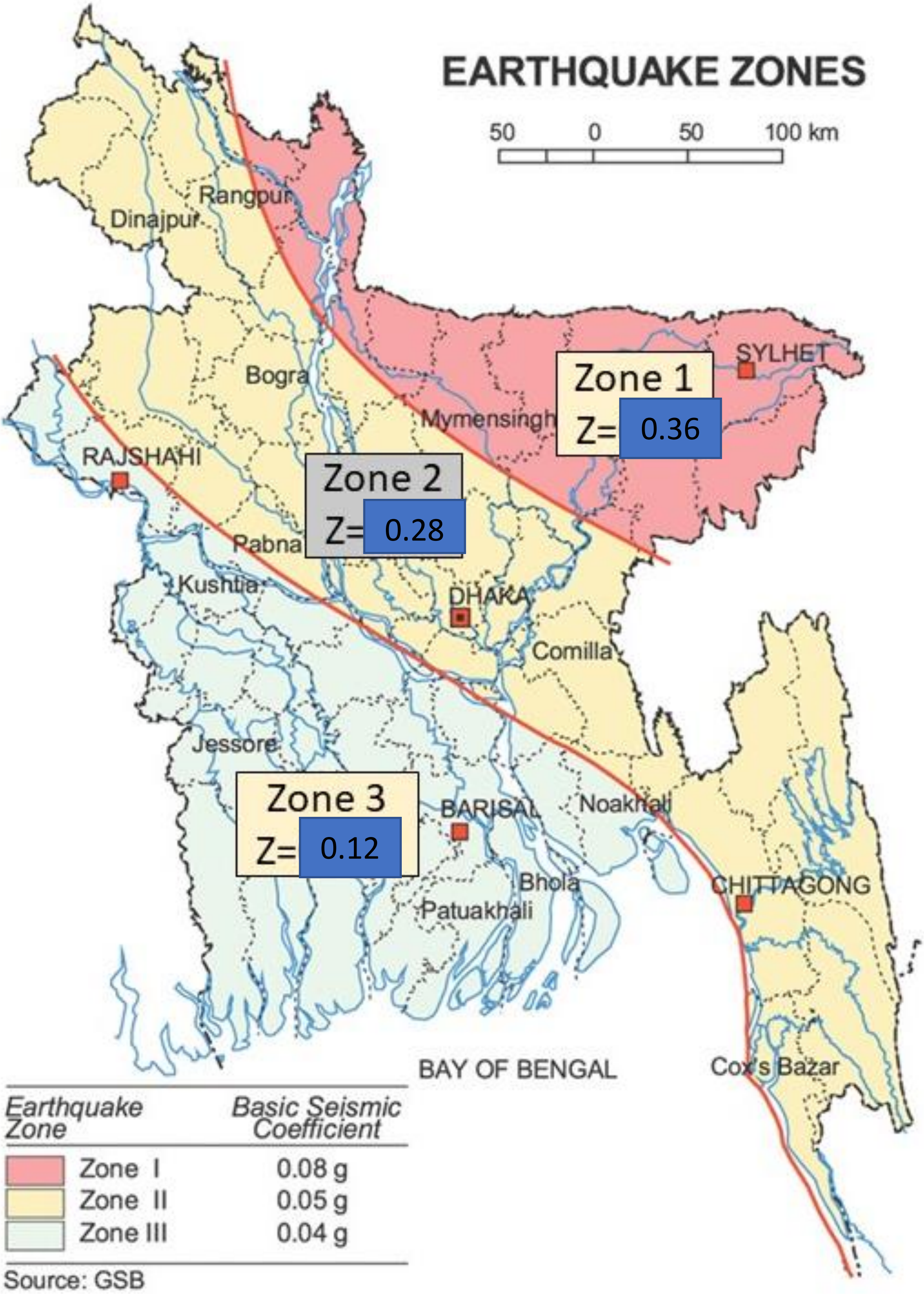


**Figure 2.5(a):** Seismic Zoning Map of Bangladesh (BNBC 2006)

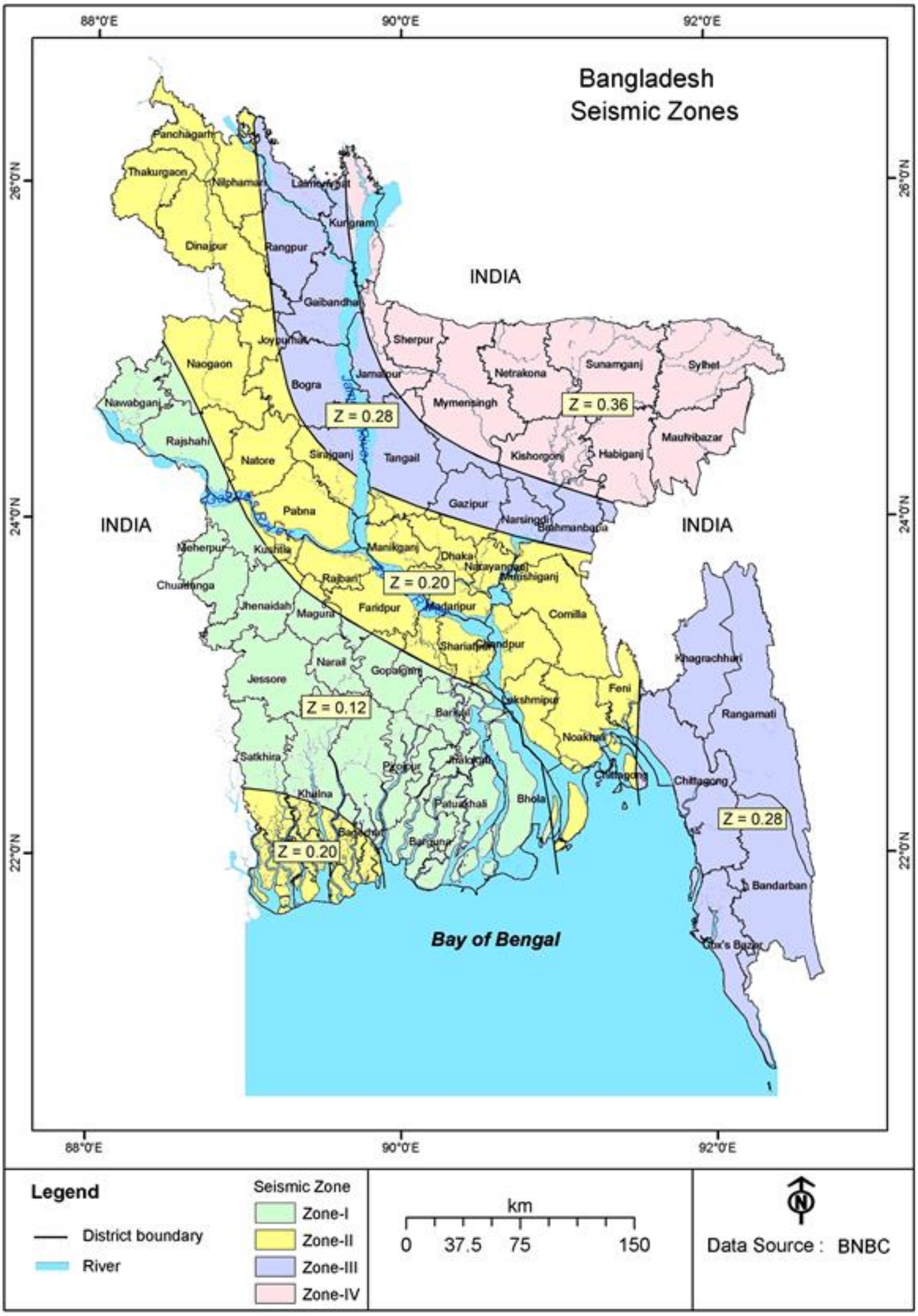


**Figure 2.5(b):** Seismic Zoning Map of Bangladesh (BNBC 2020)

## 2.5 Population and Construction Trends of Bangladesh

After its independence in 1971, Bangladesh has made several human censuses; but here the figure shows the population growth in comparison with the previous censuses done from 1901 to 2011. Bangladesh has one of the highest rates of growth of urban population in the world as the 2011 Census Preliminary Results shown in Figure 2-6. a. At the district level, the highest density (inhabitants/km2) is in Dhaka (8,111) and Narayanganj district (4,139), and the lowest is in Bandarban district (86) as mentioned in the census report. At the district level, population density is shown in Figure 2-6. b.

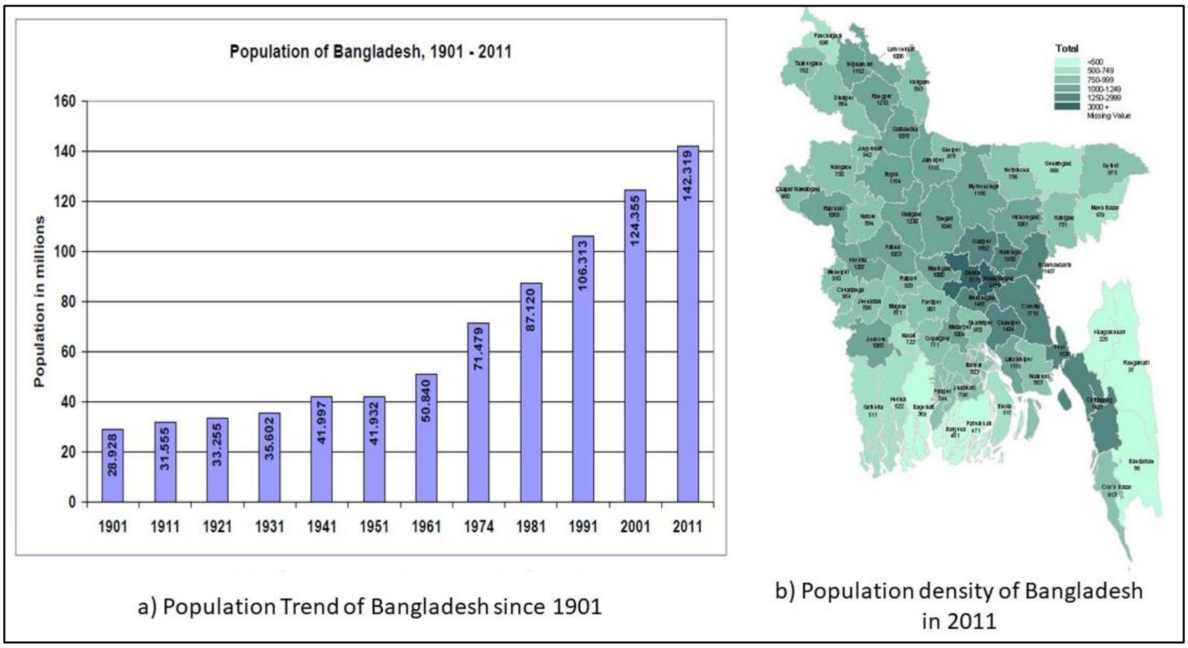


**Figure 2.6:** Population trend in Bangladesh, from Population & Housing Census (2011)

## 2.6 Chattogram in the Seismic Zoning Maps of Bangladesh

This section will give an overview of the study area, i.e., Chattogram City and Sea Beach area in context of earthquake. It also gives a general idea about its geography. Location, area and its susceptibility for seismic events in the future as well as effects due to earthquake like liquefaction and tsunami. It also addresses the functioning of the city, characteristics of built from and settlement structure of the study area.

### 2.6.1 General Characteristics

Chattogram city stands as not only the major urban center of Chattogram district but also the heartbeat of Bangladesh as its second-largest city. Nestled between latitudes 22°14' and 22°24' N, and longitudes 91°46' and 91°53' E, it graces the banks of the historic Karnaphuli River. This vibrant city is crucial to the Bangladeshi economy, primarily through the Port of Chattogram- one of the world's oldest ports, once marked on Ptolemy's map. Serving as the nation's primary maritime gateway, it boasts the title of the busiest international seaport on the Bay of Bengal and ranks as the third busiest in South Asia. Moreover, the Chattogram Stock Exchange is one of the pivotal financial pillars of the country. In addition, numerous companies based in Chattogram are leading players within the expansive industrial landscape of Bangladesh, underscoring the city's importance as an economic powerhouse.

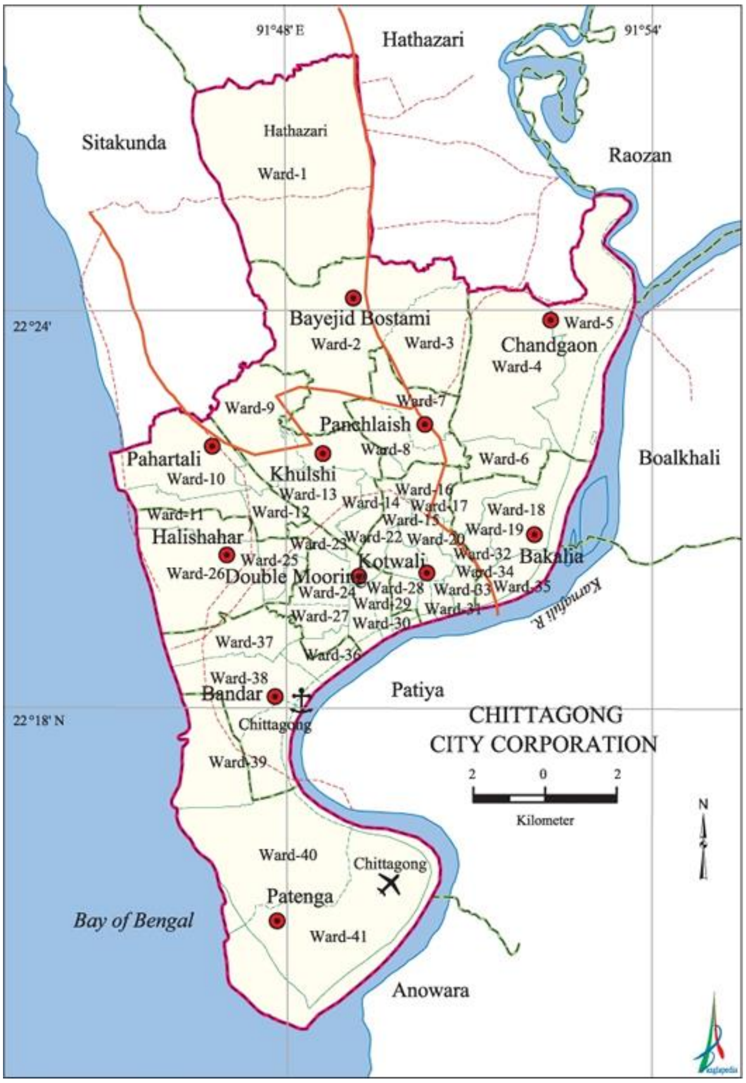


**Figure 2.7**: Map of Chattogram city

### 2.6.2 Population and Economy Growth in Chattogram City

The concentration of population and economic activity in urban areas is increasing rapidly. The growing number of people living in towns and cities is referred to as urban growth (UNICEF, 2012). Urbanization is the process in which a rising proportion of individuals reside together in a densely populated area that offers public utilities (Murtaza, 2012). This phenomenon affects all countries, primarily due to increasing population growth (Tamilenthi et al., 2011). The population is a defining characteristic of a city. Currently, there are over 300 cities worldwide with populations exceeding one million (Allen, 2014). The urban population is expected to grow significantly in the next four decades, particularly in developing countries (Islam, 2013). Consequently, rapid urban growth brings forth new challenges of urbanization, especially when resources are limited.

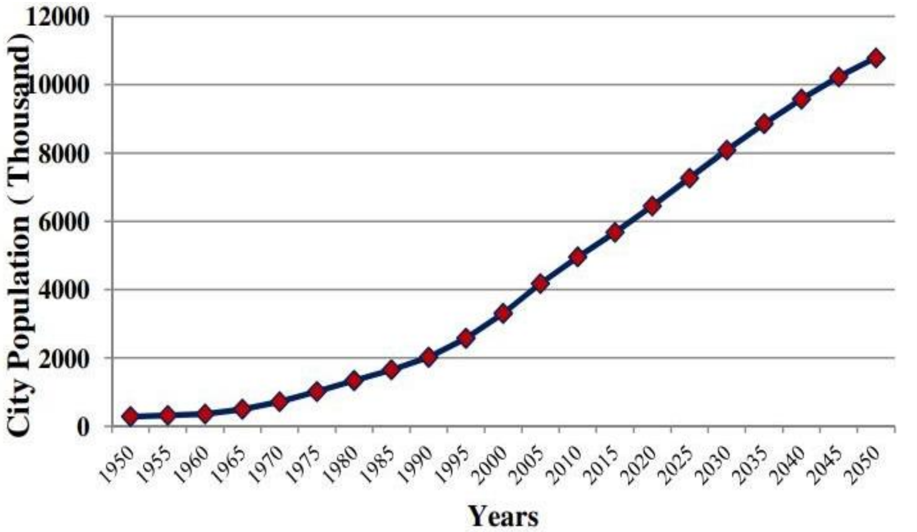


**Figure 2.8:** Population growth in Chattogram city

Chattogram, the port city, is a pivotal asset for both Bangladesh's economy and the advancement of regional economic cooperation and development. Its strategic location is instrumental in enhancing regional connectivity, placing Chattogram squarely at the crossroads of the Indian subcontinent and Southeast Asia, complemented by its breathtaking coastal landscape. The city is poised to become a major global financial centre and a crucial trans-shipment hub serving northeast India, Myanmar, Nepal, Bhutan, and southeastern China. In the face of current geopolitical shifts- such as the restructuring of the Chinese and Indian economies, the implications of Brexit in the European Union, and trade realignments following the U.S. presidential election- alongside Bangladesh's impressive macroeconomic achievements and its ambitious goals of achieving middle-income status by 2021 and evolving into a developed nation by 2041, it is imperative to engage in strategic planning for

Chattogram's development. By taking decisive action now, we can tap into the city's vast potential and propel sustainable growth forward.

### **2.6.3** Seismic Events of Chattogram City

Chattogram City, the second-largest urban area in Bangladesh, faces urgent challenges from rapid urbanization and unplanned development. The threat of earthquakes is particularly concerning, as many buildings are owner-constructed without proper engineering, making them vulnerable to seismic events. To tackle this issue head-on, we have selected Ward No. 29 (South Agrabad), the bustling Central Business District (CBD). Using a simple random sampling method, we identified 86 buildings with a confidence level of 90%. Our assessment employs the proven FEMA-RVS method for structural evaluation, complemented by the fire hazard framework from the Asian Disaster Preparedness Center (ADPC) and social vulnerability analysis from the World Bank's 2014 methodology. With this comprehensive understanding, we are ready to take decisive action to enhance Chattogram City's resilience and ensure a safer future for its residents.

**Table 2.3:** List of recent earthquakes and the extent of damage in Chattogram city

| Date of occurrence | Epicenter of Earthquake | Magnitude | Extent of Damage |
|---|---|---|---|
| December, 1830 | N/A | N/A | Most of the houses were severely cracked |
| October, 1842 | N/A | N/A | Minor losses of resources |
| 1865 | N/A | N/A | Most of the houses were severely cracked |
| November 21, 1997 | Bandarban-Myanmar | 6.1 | The sinking of two underground floors of a five-storied building and 32 people were dead. |
| July 22, 1999 | Maheshkhali Island, Cox Bazar | 5.2 | 6 people were killed, over 200 were injured and about 700 homes were damaged or destroyed on Maheshkhali Island, Cox Bazar, Bangladesh |
| December 19, 2011 | Manikganj, Dhaka | 4.2 | 20 people were injured |
| July 22, 2005 | Rangamati, Chattogram | 5.5 | 2 people died |
| May 3, 2011 | Comilla | 4.6 | N/A |

## 2.7 Building Inventory Survey by Rapid Visual Screening Approach

Building earthquake inventory surveys are essential for assessing the vulnerability of buildings to earthquake damage. The survey approach involves collecting information about the building's age, construction type, materials used, and other factors that can affect its seismic vulnerability. Here are some steps that can be followed to conduct a building earthquake inventory survey:

a. Develop a survey plan: Before starting the survey, develop a plan that includes the objectives, scope, and methodology of the survey. Identify the target buildings and the criteria for selecting them, such as their age, height, and location.
b. Collect data: Collect data about the buildings using a variety of sources, such as building permit records, property records, and visual inspections. Record the building's location, age, height, construction type, and materials used. You may also want to collect data on occupancy, number of stories, and any previous seismic retrofits.
c. Conduct visual inspections: Conduct visual inspections of the buildings to assess their condition and identify any potential seismic vulnerabilities. Inspect the foundation, walls, roofs, and other structural components. Look for signs of cracking, settling, and other damage.
d. Assess seismic vulnerability: Assess the seismic vulnerability of the buildings based on the data collected and the visual inspections conducted. Use a rating system or other method to evaluate the level of seismic risk for each building.
e. Develop recommendations: Develop recommendations for seismic retrofits or other measures to reduce the seismic vulnerability of the buildings. Prioritize the recommendations based on the level of risk and the feasibility of implementation.
f. Compile the results: Compile the results of the survey into a report that includes a summary of the findings, a list of the buildings surveyed, and the recommendations for reducing seismic vulnerability.

By conducting a building earthquake inventory survey, experts can identify vulnerable buildings and the expected level of damage of a building falling in a particular level/degree of vulnerability typically assessed by an RVS method, prioritize the need for detailed engineering assessment or retrofitting efforts, and develop strategies to reduce the risk of earthquake damage to buildings and occupants.

### 2.7.1 Common RVS Methods

#### 2.7.1.1 FEMA 154

FEMA 154 offers an efficient and affordable way to evaluate the seismic safety of buildings, ensuring that structures can withstand potential earthquakes. Developed by the Applied Technology Council (ATC) for FEMA in 1988, this method has been refined over the years, with its third edition released in 2015. Investing in FEMA 154 can help protect lives and properties by identifying vulnerabilities before they become critical issues.

**Table 2.4:** Details of FEMA 154, from Alam (2011)

| Topic | Description |
|---|---|
| General description | Mainly based on a probabilistic approach to vulnerability assessment via rapid visual inspections. |
| Main applications | Rapid Visual Screening (RVS) sidewalk survey to short-list the buildings to which simplified vulnerability assessment procedure should be applied. |
| Sources/ data set | **S**tudies of the existing U.S. inventory during the development of ATC 14. Evaluating the Seismic Evaluation of Existing Buildings (ASCE: 1987) |
| Main features | • First-level categorization of a building into a FEMA model building type and a second-level identification of risk characteristics e.g. (age, Height configuration irregularities and site soil type).<br>• The final result is a numerical score intended to be used to Rank buildings by relative risk. |
| Limitations | Not applicable for detailed assessment of the building Whereas even the most basic structural characteristics of buildings can seldom Be identified without a level of effort approaching evaluation. |

This document features an essential data collection form that effectively gathers critical information for each building under assessment. Using this form, we can ensure accurate verification and update of building identification details, assess the size and shape, create detailed sketches of both the plan and elevation views and document occupancy accurately. The RVS procedure follows a proven methodology based on sidewalk surveys, utilizing this form to guide the process. The surveyor completes the form with keen visual observations of both the exterior and, when possible, the interior, ensuring a thorough and accurate assessment of each building.

**2.7.1.2** FEMA 310

FEMA 310, a vital 1998 handbook, presents a three-tiered approach for assessing the seismic resistance of existing buildings. Based on the NEHRP Handbook for Seismic Evaluation, it is essential for enhancing safety and resilience in vulnerable areas.

**Table 2.5:** Details of FEMA 310, from Alam (2011)

| **Topic** | **Description** |
|---|---|
| General description | Mainly based on a probabilistic approach to vulnerability. Assessment which is a three-tiered process for seismic Evaluation of existing buildings in any region of seismicity. |
| Main applications | Buildings are evaluated to either the Life Safety or Immediate Occupancy Performance Level. |
| Sources/ data set | This method is based on the NEHRP Handbook for Seismic Evaluation of Existing Buildings (FEMA 178) |
| Main features | • The groups of "building types" defined in ATC-14 are Considered in this method.<br>• Three-tiered approach with increasing complexity and decreasing conservatism, very thorough and detailed Method. |
| Limitations | Model building codes typically exempt certain classes of Buildings form seismic requirements on new construction. The set of FEMA Model Building Types is not particularly useful for older concrete buildings without well defined (or designed) lateral system. |

FEMA 310 uses a thorough evaluation procedure to assess a building's structural condition, addressing structural, non-structural, and geological hazard concerns. A design professional estimates the expected structural damage during an earthquake, known as the Performance Level, which highlights the building's importance and potential consequences of damage. This assessment is crucial for ensuring safety and protecting lives and property during disasters.

**2.7.1.3** ASCE 41-13

ASCE 41-13. Seismic Evaluation and Retrofit of Existing Buildings is a 2013 publication by the American Society of Civil Engineers (ASCE) that describes procedures for evaluating and retrofitting buildings to withstand earthquakes. The Standard is written in code language and is intended to be used in an enforceable way. The standard’s three-tiered process for seismic evaluation and retrofit includes:

- Tier 1 screening procedure: Usually performed first to identify potential structural deficiencies.
- Tier 2 deficiency-based evaluation procedure: Focuses on the deficiencies identified in the Tier 1 screening.
- Tier 3 systematic evaluation procedure: The final tier of the process.

The standard's procedures are grounded in performance-based principles, making them streamlined and specifically suited for various building types. Rather than imposing rigid timelines, performance objectives, or specific projects for evaluation, this standard offers flexibility. It presents a thoughtful selection of options for enhancing building performance during seismic events. Ultimately, it empowers building codes to define precise requirements that ensure safety and resilience in our structures.

## 2.8 Post-seismic Vulnerability Parameters (not included in FEMA and ASCE guidelines)

The category "others" (based on BNBC) likely includes methods or standards not explicitly mentioned but still considered in the analysis. This could be a mix of various guidelines, research papers, or methods from different organizations or researchers.

FEMA 310 and ASCE 41-13 are two widely used guidelines for the seismic evaluation and retrofitting of existing buildings. While they share some similarities, there are also notable differences between the two. Here's a comparison of FEMA 310 and ASCE 41-13.

## 2.9 General Factors of Vulnerability Assessed in RVS Methods

The vulnerability factors fulfilling Building Survey for this study following FEMA 154, FEMA 310 and ASCE 41-13 Guidelines based on BNBC are:

### **2.9.1** Soft Story

The lateral-force-resisting system's stiffness within each story must not fall below 70% of the stiffness in an adjacent story above or below, nor should it be less than 80% of the average stiffness of the three adjacent stories for both Life-Safety and Immediate Occupancy considerations. Geometric irregularities are typically identified by scrutinizing variations in the dimensions of the lateral-force-resisting system from one story to another. Another example is a story in a high-rise that is set back for architectural reasons. (FEMA, 1985)

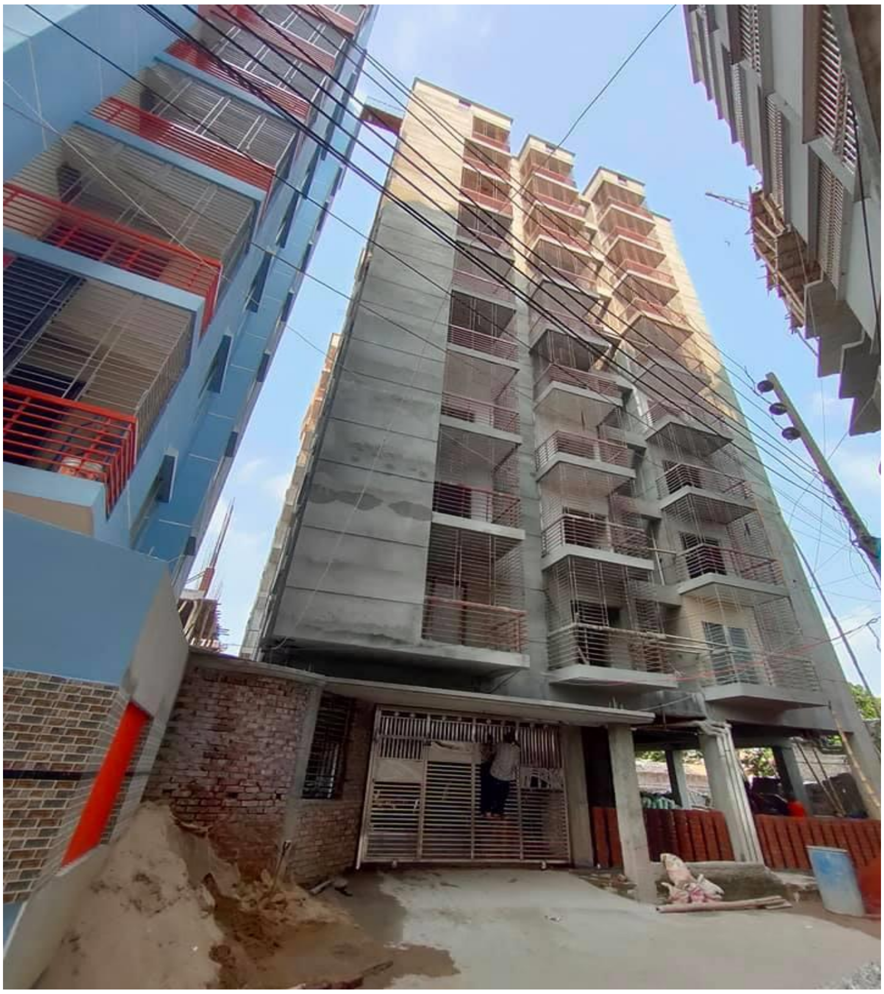

**Figure 2.9:** Soft story building

### **2.9.2** Adjacent Buildings

To ensure safety and resilience, it is crucial that no adjacent building is positioned closer than 4% of the height of the evaluated structure for Life Safety and Immediate Occupancy. In the pursuit of maximizing space, buildings are frequently constructed right up to property lines, often ignoring the impact of neighbouring structures. This oversight can lead to dangerous "pounding" effects during an earthquake (FEMA 310). To mitigate these risks, building codes and regulations are in place, outlining essential standards and guidelines for the construction and maintenance of adjacent buildings. Adhering to these regulations not only protects the integrity of the structures but also prioritizes the safety of all occupants (ASCE 41-06, 2000).


**Figure 2.10:** An adjacent building view of Chattogram city

### **2.9.3** Building Vertical Discontinuities

Vertical elements in the lateral-force-resisting system must maintain a continuous connection to the foundation, with common instances of discontinuity, such as in shear walls or braced frames, detected through visual observation. Concerns arise in buildings with significant torsion, as it leads to added seismic demands and lateral drifts on vertical elements due to diaphragm rotation. It is recommended to design structures with a balanced system initially, as intentionally introducing torsion can compromise earthquake performance.

Vertical discontinuities can occur within a single building or across a group of buildings in a particular area. They can be intentional, such as when designers use contrasting materials or colours to create a visual break between different sections of a building. Alternatively, vertical discontinuities can be accidental or a result of changes made over time without considering the overall design impact. (FEMA, 1985)


**Figure 2.11:** Building vertical discontinuities

### **2.9.4** Masonry Units

Masonry units are individual blocks or bricks employed in construction to construct masonry walls, formed by stacking and bonding the units with mortar. These units may be crafted from diverse materials like clay, concrete, stone, or even glass. Typically, rectangular, their size, shape, and texture can vary based on the intended use and architectural style. For instance, certain units are intentionally rough-textured to enhance grip and slip resistance, while others may feature a smooth, polished surface for a more sophisticated aesthetic.

**Figure 2.12:** A view of masonry units in a building

Masonry units are frequently chosen due to their enduring nature, robustness, and ability to withstand fire. They find application in the construction of load-bearing walls, ornamental facades, chimneys, and various other structural components. The size and weight of masonry units can vary depending on the material and intended use, and they are typically installed using mortar to bond the units together and create a solid, durable wall (FEMA, 1985).

### **2.9.5** Masonry Joints

Masonry joints play a crucial role in the construction of masonry structures, providing both structural support and aesthetic cohesion. Different types of joints serve specific purposes, contributing to the overall stability and appearance of the construction. Here are some common types of masonry joints:

i. Concave Joint (or Recessed Joint): This type of joint features a curved indentation, creating a concave profile. It is often used for decorative purposes and can enhance the visual appeal of the masonry work.
ii. Vee Joint: The Vee joint is characterized by a V-shaped groove between adjacent masonry units. It is commonly employed in brickwork and adds a distinctive pattern to the overall design.

iii. Weather Struck Joint: In a weather struck joint, excess mortar is scraped off from the face of the masonry units, leaving a slightly angled, weathered appearance. This joint helps shed water away from the wall surface.

iv. Flush Joint: A flush joint is achieved when the mortar is neatly levelled with the face of the masonry units, creating a smooth, even surface. This joint type is often chosen for a contemporary and clean aesthetic.

v. Raked Joint: Raked joints have an indented profile, with the mortar recessed slightly below the face of the masonry units. This style is frequently used for rustic or textured looks.

vi. Struck Joint: Struck joints have a finished appearance where excess mortar is struck off the face of the masonry units, leaving a flat, clean surface.

**Figure 2.13:** A view of masonry joints in a building

vii. Bucket Handle Joint: This joint resembles an inverted U or a bucket handle and is created by forming a semicircular groove between the bricks or blocks. It adds a decorative touch to the masonry.

viii. Beaded Joint: A beaded joint involves the use of a small, rounded molding or bead to create a raised profile along the mortar joint. This can enhance the visual interest of the masonry.

ix. Keyed Joint: Keyed joints incorporate small grooves or channels into the mortar, improving the bond between the mortar and masonry units. This type of joint enhances the overall stability of the structure.

x. Reticulated Joint: Reticulated joints are characterized by a net-like pattern created by small channels or grooves in the mortar. This adds a unique texture to the masonry.

### **2.9.6** Redundancy

Redundancy is a vital component of lateral force-resisting systems, greatly enhancing their seismic performance. When a structure incorporates redundancy, it guarantees that if one section of the lateral force-resisting system fails, another section can immediately step in to provide essential resistance. This built-in redundancy allows for multiple regions where yielding can occur, effectively spreading inelastic activity across the structure. As a result, the structure's ductility and energy dissipation capacity are significantly improved. Additionally, having redundant load paths not only strengthens the structure but also plays a critical role in preventing catastrophic failures during unexpected loads or damage from natural disasters, fire, or other hazards. Emphasizing redundancy in design is not just smart; it is essential for safety and resilience.

**Figure 2.14**: Redundancy of a building

Buildings often incorporate multiple columns or beams to support loads, instead of depending on just one. This design allows for load redistribution to the remaining columns or beams if one fails, thereby maintaining the overall stability of the structure. Similarly, bridges can be designed with redundant load paths by using multiple trusses or cables, which helps distribute loads and prevents catastrophic failure in case of damage to one or more components. (FEMA, 1998)

### **2.9.7** Flat Slabs and Frame

Flat slabs, a type of reinforced concrete structure, simplify building construction by eliminating beams and drops, offering a cost-effective design. For life safety, continuous bottom steel through column joints is mandated for flat slabs classified as secondary components. Notably, flat slabs are restricted for use in structures aiming for the Immediate Occupancy Performance Level.

**Figure 2.15:** Flat slabs of a building

In a flat slab configuration, the slab receives direct support from columns or walls, bypassing the need for intermediary beams or girders. This is accomplished by reinforcing the slab at column points, enhancing its strength and support. Additionally, steel bars or mesh can be incorporated into the flat slab to bolster tensile strength and mitigate the risk of cracking.

Flat slabs present multiple benefits compared to conventional slab structures. Initially, their construction is quicker and more straightforward, as they eliminate the complexity and time-consuming installation of beams and drops. Additionally, flat slabs offer enhanced flexibility in floor height and layout, as there are no constraints on beam depth or spacing. Finally, flat slabs can offer better performance in seismic areas, since they can provide a more ductile and resilient structural system. (FEMA, 1985)

### **2.9.8** Diaphragm Continuity

The diaphragm, composed of concrete, steel, or wood, spans horizontally between building floors and roofs, functioning as the primary horizontal load-bearing element. It transfers lateral forces, such as those from wind or seismic activity, to the vertical elements resisting them. The diaphragm's rigidity, especially in seismic design, is crucial, considering relative flexibility or rigidity compared to vertical elements and restrictions on split-level floors and expansion joints in wood buildings.

### **2.9.9** Plan Irregularities

Plan irregularities involve variations from a standard geometric shape in the horizontal layout of a building. These variations can result in intricate or asymmetrical floor plans, significantly affecting the structural behaviour, stability, and overall performance of the building.

Some examples of plan irregularities in building design include:

i. Zigzag or L-shaped floor plans, which can create load transfer problems and non-uniform distribution of lateral forces.
ii. Projections, such as bay windows or balconies, can create localized concentrations of stresses and impact the structural performance of the building.
iii. T-shaped or offset core layouts, which can create torsion and twisting forces that affect the stability and seismic performance of the building.
iv. Changes in floor height, can create vertical irregularities and affect the load transfer and lateral force resistance of the building.
v. Openings or large cutouts in the floor plan, which can reduce the effective diaphragm stiffness and create localized concentration of stresses.

Plan irregularities in a building's layout necessitate extra analysis and design considerations for structural stability. To address these, proper detailing, material selection, and construction techniques are essential, with building codes guiding requirements, particularly concerning tensile capacity at re-entrant corners for Immediate Occupancy performance levels.


**Figure 2.16:** Typical plan irregularities of buildings in Chattogram city

### **2.9.10** Attached Equipment

Building attached equipment usually involves the construction or installation of equipment directly connected to a building or structure. This equipment is intended to improve the building's functionality, efficiency, or safety. Bracing is required for equipment weighing more than 20 pounds attached to the ceiling, wall, or other support at a height exceeding 4 feet above the floor. Some common examples of attached equipment include:

i. Material handling equipment: Forklifts, cranes, conveyors, and hoists are examples of machinery used for moving and transporting heavy materials within a building or facility

ii. Industrial generators and power systems: In some cases, large generators or power systems are attached to buildings to provide backup power during outages or to supplement the electrical grid. (BNBC, 2022)

iii. Elevators and escalators: These are vertical transportation systems that enable people to move between different levels of a building easily and efficiently.
iv. Fire suppression systems: Fire sprinkler systems, fire alarms, and other firefighting equipment are attached to buildings to detect and suppress fires, helping to protect occupants and minimize property damage.
v. Industrial compressors: Compressed air systems are used in various applications, including powering pneumatic tools, operating machinery, and providing air for ventilation and process control. (BNBC, 2022)

**2.9.11** Building Load Path

The load path in a building ensures the safe transfer of forces from applied loads to the foundation, maintaining structural integrity. It is crucial for supporting dead loads, live loads, and seismic forces, requiring a complete load path for transferring inertial forces to the foundation in any horizontal direction.

Roof/Upper Floors: Loads from the roof and upper floors are transmitted downward through the roof framing or floor system. These loads are then transferred to the supporting walls, columns, or beams.

Walls/Columns/Beams*:* The walls, columns, or beams carry the vertical loads from the upper floors and transfer them to the lower levels or the foundation. These elements are designed to resist compression forces.

Foundation: The foundation, typically consisting of footings and a slab or a system of piers, receives the loads from the walls, columns, or beams and transfers them to the ground. The foundation is designed to distribute the loads and prevent excessive settlement or movement. (BNBC, 2022)

**2.9.12** Building Support Systems

Integral to structures, building support systems are vital elements that ensure stability, load-bearing capability, and safety. Their design revolves around efficiently distributing the weight and forces acting on a building to the ground or other supportive structures. Here are some common types of building support systems:

i. Foundation Systems: Foundations are typically made of concrete and provide a stable base for the entire structure. They transfer the weight of the building to the ground, ensuring stability and preventing settlement.
ii. Structural Framing Systems: These systems consist of columns, beams, and load-bearing walls that support the weight of the floors, walls, and roof. They distribute the loads down to the foundation.
iii. Floor and Roof Systems: These systems provide support for people, equipment, and various loads within the building. They are typically constructed using beams, girders, joists, and decking materials.
iv. Lateral Load Resisting Systems: These systems are designed to resist horizontal forces such as wind or seismic loads that can affect the stability of a building. Common lateral load-resisting systems include shear walls, braced frames, moment frames, and structural diaphragms.
v. Reinforcement Systems: Reinforcement, such as rebar (steel bars) embedded in concrete, is used to strengthen and increase the load-bearing capacity of structural elements like foundations, columns, and beams.

#### **2.9.13** Concrete Column

Building concrete columns involves several steps. Here's, Design, Formwork, Reinforcement, pouring concrete, Placement, Curing, Stripping the formwork, Finishing Etc.

#### **2.9.14** Complete Frames

Building complete frames, also termed structural frames or skeletons, involve constructing the primary load-bearing structure with elements like columns and beams. Secondary components, such as steel or concrete frames, must form a complete vertical load carrying system to avoid the need for walls to provide vertical support.

#### **2.9.15** Strong Column/ Weak Beam

Constructing building complete frames involves creating the primary load-bearing structure, incorporating design, foundation work, column and beam installation, and floor/roof systems. The process also includes addressing bracing, ensuring connections, conducting inspections, and integrating with other building components for a comprehensive construction approach.

### 2.9.16 Front Road Width

The width of the front road or street in front of a building plays a significant role in several aspects that can impact the functionality, safety, and overall value of the property. Here are some important reasons why the width of the building's front road is significant.

i. Access and Connectivity: A wider road enhances building access, facilitating smooth movement for vehicles, pedestrians, and emergency services, ensuring easy entry and exit without congestion or obstruction.
ii. Traffic Flow and Safety: Adequate Road width promotes smooth traffic flow, minimizing congestion and traffic jams, with proper lane separation to facilitate navigation and reduce accident risks. Additionally, a broader road may accommodate turning lanes and dedicated bicycle lanes, enhancing overall safety for road users.
iii. Parking Facilities: Road width influences parking availability; sufficient width allows on-street or dedicated parking, enhancing convenience for visitors, customers, or residents and boosting the building's appeal and functionality.

**Figure 2.17:** Front road width of a typical building in Chattogram city

### **2.9.17** Built Purpose

A building's purpose indicates its intended function, meeting the diverse needs of individuals, businesses, or communities, such as residential, commercial, industrial, and recreational uses. In our country, buildings are often constructed for one purpose but end up serving a different one.

### **2.9.18** Rescue Facility

A rescue facility is a purpose-built structure designed to support emergency response and rescue operations, serving as a central hub for personnel and equipment to ensure effective response during critical situations. Here are some key features and considerations for building a rescue facility:

i. Location: The rescue facility should be strategically located to ensure quick access to major roadways, emergency service areas, and areas prone to emergencies or disasters. Proximity to hospitals, fire stations, and other essential services may also be important.
ii. Space and Layout: The facility should have sufficient space to accommodate emergency vehicles, equipment, and personnel. It may include areas for vehicle maintenance, storage of specialized rescue equipment, training rooms, offices, and communication centres.
iii. Accessibility: The building should be designed to allow easy access for emergency vehicles and personnel. Adequate driveways, parking areas, and unobstructed entrances and exits are crucial.
iv. Safety and Security: Rescue facilities should incorporate safety features to protect personnel, equipment, and sensitive information. This may include security systems, controlled access points, emergency backup power, and fire suppression systems.
v. Specialized Facilities: Depending on the nature of rescue operations, specific areas may be required. These can include medical treatment rooms, decontamination areas, equipment maintenance workshops, and storage areas for specialized rescue tools and vehicles.

### **2.9.19** Pounding Possibility

Building near tall structures poses risks to foundation integrity, and structural considerations, and complicates emergency access routes, requiring careful attention to potential issues like differential settlement and ground vibration. Adequate planning and coordination are required to ensure proper access to emergency vehicles and evacuation procedures in case of emergencies. (ASCE,41-06,2000)

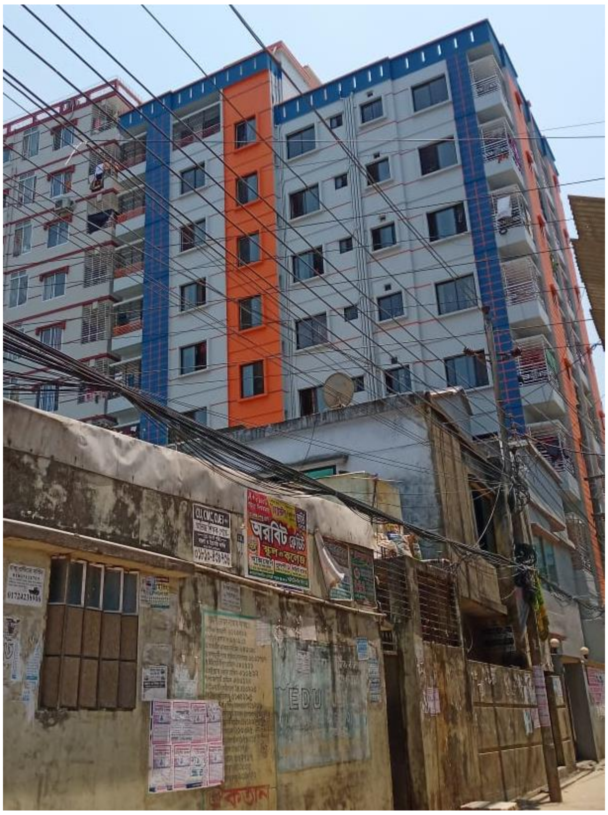

**Figure 2.18:** Pounding possibility due to adjacent building location

**2.9.20** Gas and Electric Line Distance

Building close to gas and electric lines poses certain risks that need to be considered and addressed during the planning and construction stages. Here are some potential risks associated with building near gas and electric lines:

i. Gas Leaks: Building near gas lines increases the risk of leaks, requiring careful identification and safety measures to prevent damage during construction.
ii. Electrical Hazards: Constructing near electric lines poses risks of electrical hazards like shocks or fires, emphasizing the need for careful clearance and avoiding contact with live wires during construction and maintenance.

# CHAPTER 3

## METHODOLOGY OF SEISMIC VULNERABILITY ASSESSMENT

### 3.1 General

The rebirth of interest in seismic vulnerability assessment methodologies (SVAM) has been triggered by historical catastrophic earthquakes worldwide. This renewed focus aims at conducting seismic risk analyses to anticipate potential damage scenarios. This chapter provides an overview of rapid visual screening (RVS) methods and analyses used for seismic vulnerability assessment and their applicability to the various types of RCC building structures existing in typical urban residential buildings of Chattogram city. The evaluation of expected losses from specific earthquake events or within a designated time frame is a primary objective which is often expressed through vulnerability scores to expected damage grades. The representation of these assessment results within a Gaussian Distribution Curve becomes a valuable tool to verify the uniformity of distribution of data and standard deviation from the mean value of the data population. Such representations of visual screening methods of vulnerability assessment not only aid in comprehending potential losses but also serve as instrumental tools for decision-making for policy interventions for risk mitigation. One of the main focuses of this study is to analyze post-seismic vulnerability features that are not typically considered in common RVS methods of assessment. In the pursuit of a degree of understanding, this study depends on various essential features of commonly used RVS methods that should essentially be considered for Tier-1 seismic vulnerability assessment of buildings. Special priority is placed on anticipating the applicability of these methods within the vulnerability assessment process which are relevant considerations for choosing a particular method depending on typical conditions of Bangladesh.

A vulnerability assessment entails a meticulous evaluation of a structure's susceptibility to a particular hazard, estimating its potential impact and delineating the repercussions on a community. Vulnerability, in this context, is characterized as the expected extent of loss incurred by a specific element at risk or a collection of such elements when confronted with a hazard. It serves as a crucial metric in understanding the potential consequences of hazardous events and is pivotal in shaping effective risk management strategies. Hugo (2002) asserts that the seismic vulnerability of buildings is greatly determined by their functional and aesthetic purposes. This understanding is essential for ensuring the safety and resilience of architectural designs. Vulnerability functions of an element at risk represent the probability that its response to earthquake excitation exceeds its various performance limit states. A seismic vulnerability assessment aims to obtain the probability of damage to a given building type due to an earthquake. To choose a suitable procedure for the assessment of buildings' seismic vulnerability, a review of the existing methods around the world is performed. Finally, suitable methods of Tier 1 RVS methods are chosen for the project which are commonly used in this region to assess the seismic vulnerability of existing buildings. Besides, building types or classifications of buildings of the study are also consistent for application of chosen RVS methods of assessment. Critical and common factors of vulnerability are short-listed that may affect building performance during an earthquake.

## 3.2 Research Methodology

The commonly used RVS methods to assess the seismic vulnerability of existing buildings worldwide are illustrated in Figure 3.1. Several methods for the earthquake vulnerability assessment have been developed and proposed in the last few decades such as FEMA 154, FEMA 310, ASCE 41-13, Modified Turkish Method, NRC Guideline, IITK-GSDMA Method and Japan Method have been selected from a wide range of published papers in the fields of seismology, structural vulnerability, and earthquake engineering. The RVS methods proposed by the Federal Emergency Management Agency (FEMA) of the USA are commonly used in the country. Among many different methods, the FEMA 154, FEMA 310 and ASCE 41-13 are commonly used in Bangladesh, and the parametric checklists of FEMA 310 and ASCE 41-13 include different factors that are closely linked with secondary or post-seismic vulnerability issues.

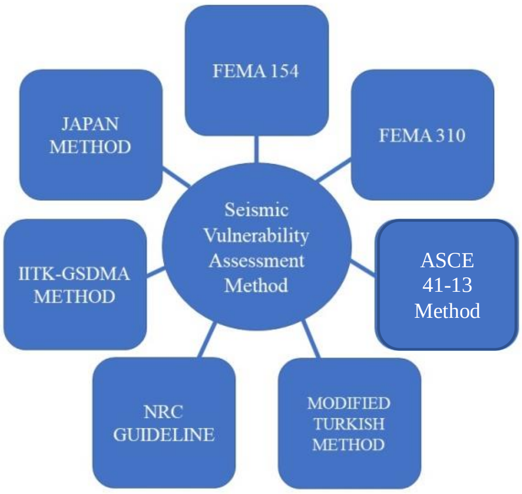


**Figure 3.1:** Commonly used RVS Methods for Seismic Vulnerability Assessment

### 3.3 Rapid Visual Screening (RVS)

The Federal Emergency Management Agency (FEMA) has developed essential pre-earthquake screening methods to assess seismic hazards in buildings using Rapid Visual Screening (RVS) techniques. These methods, created by the Applied Technology Council (ATC) in the late 1980s, help identify structures that may be vulnerable during an earthquake. Initiated with the FEMA 154 Report in 1988, the RVS approach allows for quick evaluation of a building's seismic vulnerability through visual inspections. This systematic procedure identifies documents, and prioritizes potentially hazardous buildings, as detailed in the 2002 FEMA 154 Report. The RVS methodology is summarized in a one-page form that includes key information such as building descriptions, layouts, occupancy, and structural assessments. Designed for building officials, inspectors, government agencies, and private owners, RVS empowers stakeholders to enhance safety and resilience against earthquakes. Although RVS applies to all buildings (FEMA-154, 2002), its principal purpose is to identify the following:

i. Buildings designed and constructed before the adoption of effective seismic design and detailing standards.
ii. Buildings situated on soft or weak soils.
iii. Buildings with performance characteristics that adversely affect their seismic response.

Once identified as potentially hazardous, these buildings should undergo further evaluation by a design professional experienced in seismic design to assess if they pose a seismic risk. In the FEMA 154, FEMA 310 and ASCE 41-13 assessment procedure, the generally influencing vulnerability parameters are soft story, plan irregularity, vertical irregularity, structural system, overhang, year/age of the building, pre-code, post-benchmark, soil condition, and apparent quality. A short list of parameters according to FEMA 310 and ASCE 41-13 has been prepared depending on the relevance of chosen parameters with the typical RCC building conditions of the study area of Chattogram city. As the chosen study area of Jalalabad ward is located within seismic hazard zone-2 of Bangladesh, an RVS data collection form of moderate seismicity is completed for buildings through the execution of the following steps:

i. Verifying and updating the building identification information
ii. Walking around the building to identify its size and shape, and sketching a plan and elevation view on the data collection form
iii. Determining and documenting occupancy
iv. Determining soil type, if not identified during the pre-planning process
v. Identifying potential nonstructural falling hazards, if any, and indicating them on the data collection form
vi. Identifying the seismic lateral-load resisting system (entering the building, if possible, to facilitate this process) and circling the related basic structural hazard score on the data collection form
vii. Identifying and circling the appropriate seismic performance attribute score modifiers (e.g., number of stories, design date, and soil type) on the data collection form
viii. Determining the final score, *S* (by adjusting the basic structural hazard score with the score modifiers identified in the previous step), and deciding if a detailed evaluation is required
ix. Photographing the building and attaching the photo to the form (if an instant camera is used) or indicating a photo reference number on the form (if a digital camera is used).

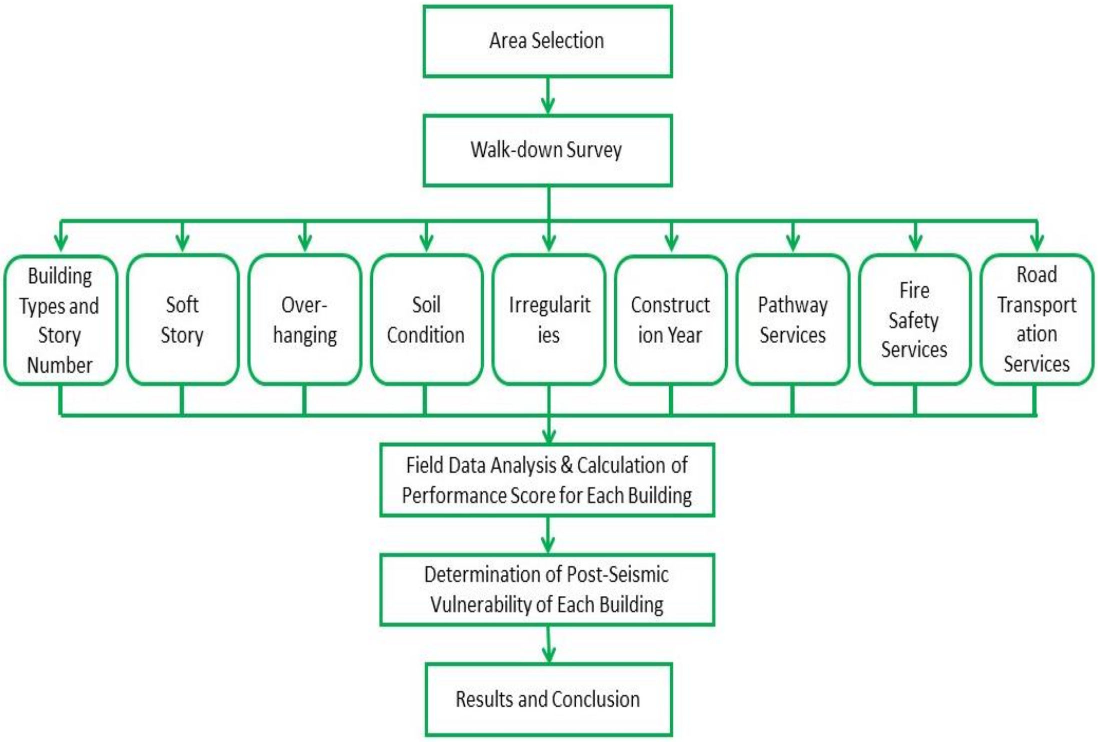


**Figure 3.2:** Flow chart of RVS works by walk-down survey process

## 3.4 Survey Process

A pre-field survey is an essential step in earthquake vulnerability assessments to ensure that fieldwork is conducted effectively and efficiently. The pre-field survey typically involves a desk review of available data to identify potential seismic hazards in the study area and to develop a preliminary understanding of the buildings' construction and occupancy characteristics. Here are some key steps involved in a pre-field survey of earthquake vulnerability assessments:

a. Review historical seismic activity: Review the historical seismic activity of the study area, including the magnitude, frequency, and location of past earthquakes. This information can help to identify potential seismic hazards and prioritize areas for fieldwork.

b. Review geological and geotechnical data: Review geological and geotechnical data to understand the soil conditions and other geological factors that can affect the buildings' seismic vulnerability

c. Review building inventories: Review existing building inventories to gain a preliminary understanding of the building stock in the study area, including the age, construction type, and occupancy of buildings.

d. Develop a fieldwork plan: Based on the results of the pre-field survey, develop a fieldwork plan that outlines the areas to be surveyed, the buildings to be inspected, and the data to be collected.

By conducting a pre-field survey, experts can develop a comprehensive understanding of the study area, identify potential vulnerabilities, and develop an effective fieldwork plan for earthquake vulnerability assessments.

### **3.4.1** Field survey

The study was decided to carry out in individual level due to limitation of time for field survey in context to the duration of master's thesis and large size of the study area. So, enumerators were used for collecting information about the building structure.

### 3.5 Seismic Vulnerability Assessment Methods

The seismic vulnerability of a built system refers to its proneness to a certain level of damage when exposed to an earthquake. The goal of a seismic vulnerability method is to gauge the likelihood of damage to individuals or groups of buildings following an earthquake. Operationally, the method establishes a connection between seismic hazard evaluation and physical damage, considering structural, geometric, and technological characteristics influencing the buildings' seismic behaviour. These methods typically evaluate damage data (local or global) using preliminary information or screening data at the Tier 1 screening level. No secondary or post-seismic hazards are assessed in these methods of screening.

#### **3.5.1** Overview of Common RVS Methods Used for Seismic Vulnerability Assessment

The FEMA 154, FEMA 310 and ASCE 41-13 methods have been chosen for the assessment of the seismic vulnerability of typical residential buildings of a ward of Chattogram City. These three methods are widely used in this region considering their suitability of application for typical building conditions in this area. At first, each of the methods will be briefly described followed by a comparative study of the methods.

##### **3.5.1.1** Chosen Parameters of Building Inventory Survey according to RVS Methods

Building earthquake inventory surveys are essential for assessing the vulnerability of buildings to earthquake damage. The survey approach involves collecting information about the building's age, construction type, materials used, and other factors that can affect its seismic vulnerability. Figure 3.3, Tables 3.1 and 3.2 are some of the chosen parameters from different RVS methods that are highly significant for possible seismic and post-seismic hazards and seismic vulnerability assessment in Bangladesh.

The topic of rapid visual screening of buildings for potential seismic hazards was explored in a series of papers included in *"Techniques for Rapid Assessment of Seismic Vulnerability" (Scawthorn, 1986).* Shortly thereafter, in 1988, the FEMA 154 methodology was introduced with the publication of the report titled *"Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook" (FEMA, 1988a)*.

*FEMA 154 (2002)* has been carefully developed to improve the Rapid Visual Screening (RVS) procedure, which is designed to identify and rank buildings vulnerable to seismic activity. This method has been effectively utilized in various studies, as highlighted by *Sadat* *et al. (2010), Srikanth et al. (2010), and Tesfamariam and Saatcioglu (2010),* to assess the seismic vulnerability of existing structures. One of the main advantages of this approach is its ability to quickly generate a list of at-risk buildings without requiring a detailed seismic vulnerability assessment. The RVS method is based on limited observational data and analytical findings, ultimately leading to the establishment of a cut-off score (S).

This score enables surveyors to categorize buildings into two distinct classes: those that possess acceptable seismic risk and those that may pose a significant seismic hazard. The assessment is carried out through a practical "sidewalk survey," where trained personnel evaluate the structures in their natural environment. In a more conservative approach, the Civil Engineering Research Laboratory (CERL) of the U.S. Army Corps of Engineers has adopted a cut-off score of 2.5. A higher score indicates that a building has adequate seismic resistance, providing confidence in its ability to withstand seismic events. Conversely, the 'cut-off' score signifies the threshold below which further evaluation is warranted.

The determination of the specific cut-off score is contingent upon the seismic zone in question. In the case of Chattogram, a region recognized for its moderate seismicity, FEMA 154 recommends utilizing a cut-off score of 2. Buildings that yield an S score below this threshold are urged to undergo a more extensive engineering assessment conducted by a qualified seismic design professional. If a structure achieves a final score exceeding the cut-off value, it suggests that the building is likely to perform satisfactorily during a seismic event. However, low-scoring buildings are identified as needing detailed scrutiny by a professional engineer to ensure their safety and integrity against potential seismic threats. The checklist for a moderate seismicity area has been depicted in Figure 3.3.

**Rapid Visual Screening of Buildings for Potential Seismic Hazards**

FEMA-154 Data Collection Form

**MODERATE Seismicity**

Scale:

**Address:** ____________________

____________________ **Zip** ______

**Other Identifiers** ____________________

**No. Stories** ______________ **Year Built** ______

**Screener** ______________ **Date** ______

**Total Floor Area (sq. ft.)** ____________________

**Building Name** ____________________

**Use** ____________________

**PHOTOGRAPH**

| **OCCUPANCY** | | | | **SOIL TYPE** | | | | | | **FALLING HAZARDS** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Assembly<br>Commercial<br>Emer. Services | Govt<br>Historic<br>Industrial | Office<br>Residential<br>School | Number of Persons<br>0 – 10 11 – 100<br>101-1000 1000+ | A<br>Hard Rock | B<br>Avg. Rock | C<br>Dense Soil | D<br>Stiff Soil | E<br>Soft Soil | F<br>Poor Soil | ☐ Unreinforced Chimneys | ☐ Parapets | ☐ Cladding | ☐ Other: ______ |

**BASIC SCORE, MODIFIERS, AND FINAL SCORE, *S***

| BUILDING TYPE | W1 | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Basic Score | **5.2** | **4.8** | **3.6** | **3.6** | **3.8** | **3.6** | **3.6** | **3.0** | **3.6** | **3.2** | **3.2** | **3.2** | **3.6** | **3.4** | **3.4** |
| Mid Rise (4 to 7 stories) | N/A | N/A | +0.4 | +0.4 | N/A | +0.4 | +0.4 | +0.2 | +0.4 | +0.2 | N/A | +0.4 | +0.4 | +0.4 | -0.4 |
| High Rise (>7 stories) | N/A | N/A | +1.4 | +1.4 | N/A | +1.4 | +0.8 | +0.5 | +0.8 | +0.4 | N/A | +0.6 | N/A | +0.6 | N/A |
| Vertical Irregularity | -3.5 | -3.0 | -2.0 | -2.0 | N/A | -2.0 | -2.0 | -2.0 | -2.0 | -2.0 | N/A | -1.5 | -2.0 | -1.5 | -1.5 |
| Plan Irregularity | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 |
| Pre-Code | 0.0 | -0.2 | -0.4 | -0.4 | -0.4 | -0.4 | -0.2 | -1.0 | -0.4 | -1.0 | -0.2 | -0.4 | -0.4 | -0.4 | -0.4 |
| Post-Benchmark | +1.6 | +1.6 | +1.4 | +1.4 | N/A | +1.2 | N/A | +1.2 | +1.6 | N/A | +1.8 | N/A | 2.0 | +1.8 | N/A |
| Soil Type C | -0.2 | -0.8 | -0.6 | -0.8 | -0.6 | -0.8 | -0.8 | -0.6 | -0.8 | -0.6 | -0.6 | -0.6 | -0.8 | -0.6 | -0.4 |
| Soil Type D | -0.6 | -1.2 | -1.0 | -1.2 | -1.0 | -1.2 | -1.2 | -1.0 | -1.2 | -1.0 | -1.0 | -1.2 | -1.2 | -1.2 | -0.8 |
| Soil Type E | -1.2 | -1.8 | -1.6 | -1.6 | -1.6 | -1.6 | -1.6 | -1.6 | -1.6 | -1.6 | -1.6 | -1.6 | -1.6 | -1.6 | -1.6 |

**FINAL SCORE *S***

**COMMENTS**

**Detailed Evaluation Required**

**YES NO**

* = Estimated, subjective, or unreliable data
DNK = Do Not Know

BR = Braced frame
FD = Flexible diaphragm
LM = Light metal

MRF = Moment-resisting frame
RC = Reinforced concrete
RD = Rigid diaphragm

SW = Shear wall
TU = Tilt up
URM INF = Unreinforced masonry infill

**Figure 3.3:** Checklist for a moderate seismicity area from FEMA 154 data form

**Table 3.1:** Building survey shortlisted data sheet (according to FEMA 310 guidelines)

| Basic structural checklists for building | | | | |
|---|---|---|---|---|
| i) Building system | | | | |
| 1. | Adjacent buildings | C | NC | N/A |
| 2. | Soft story | C | NC | N/A |
| 3. | Vertical discontinuities | C | NC | N/A |
| 4. | Masonry units | C | NC | N/A |
| 5. | Masonry joints | C | NC | N/A |
| ii) Lateral force resisting system | | | | |
| 6. | Redundancy | C | NC | N/A |
| 7. | Concrete columns | C | NC | N/A |
| 8. | Flat slabs | C | NC | N/A |
| iii) Diaphragms | | | | |
| 9. | Diaphragm continuity | C | NC | N/A |
| 10. | Plan irregularities | C | NC | N/A |
| iv) Mechanical and electrical equipment | | | | |
| 11. | Attached equipment | C | NC | N/A |
| v) Elevators | | | | |
| 12. | Support system | C | NC | N/A |
| ***** C- Complied, NC- Not Complied, N/A- Not Applicable | | | | |

**Table 3.2:** Building survey shortlisted data sheet (according to ASCE 41-13 guidelines)

| a) Basic structural checklist for building | | | | | Comments |
|---|---|---|---|---|---|
| i) Building system | | | | | |
| 1. | Load path | C | NC | N/A | |
| 2. | Adjacent buildings | C | NC | N/A | |
| 3. | Soft story | C | NC | N/A | |
| 4. | Vertical discontinuities | C | NC | N/A | |
| 5. | Masonry units | C | NC | N/A | |
| 6. | Masonry joints | C | NC | N/A | |
| 7. | Concrete wall cracks | C | NC | N/A | |
| 8. | Reinforced masonry wall cracks | C | NC | N/A | |
| 9. | Unreinforced masonry wall cracks | C | NC | N/A | |
| 10. | Plan Irregularity | C | NC | N/A | |
| ii) Lateral force resisting system | | | | | |
| 11. | Strong columns/ weak beams | C | NC | N/A | |
| 12. | Flat slab frames | C | NC | N/A | |
| 13. | Flat slabs | C | NC | N/A | |
| 14. | Overturning | C | NC | N/A | |
| iii) Diaphragm | | | | | |
| 15. | Diaphragm continuity | C | NC | N/A | |
| 16. | Plan irregularities | C | NC | N/A | |
| iv) Mechanical and electrical equipment | | | | | |
| 17. | Attached equipment | C | NC | N/A | |
| v) Elevators | | | | | |
| 18. | Support system | C | NC | N/A | |
| * C- Complied, NC- Not Complied, N/A- Not Applicable | | | | | |

**3.5.1.2** Important Requirements or Safety Guidelines for Buildings in BNBC 2020

Building codes and regulations may differ across countries and even within various regions or local jurisdictions. From our national standpoint, the BNBC guidelines specify important safety guidelines for residential and institutional buildings (BNBC, 2020). Buildings are subject to distinct building code stipulations to guarantee safety, accessibility, and operational efficiency. These requirements encompass diverse facets of construction, such as structural design, fire safety, accessibility for individuals with disabilities, and electrical and mechanical systems.

**Table 3.3:** Relevant checklist of parameters of post-seismic hazard and vulnerability according to BNBC 2020 (parameters not included in ASCE 41-13, FEMA 154 and FEMA 310 guidelines)

| No. | Parameters | Status | | | Comment |
|---|---|---|---|---|---|
| 01 | Front road width | C | NC | N/A | |
| 02 | Gas and electric line distance | C | NC | N/A | |
| 03 | Rescue facility | C | NC | N/A | |
| 04 | Beside tall building location | C | NC | N/A | |
| 05 | Built purpose | C | NC | N/A | |

### 3.6 Project Organization and Methodological Steps

A visual representation of the RVS steps and procedure followed for the study project is shown in Figure 3.4. The methodological steps are as follows.

a) Collect information about the building, such as its age, construction materials, And use.

b) Conduct a visual inspection of the building, looking for signs of seismic vulnerability such as cracks in the walls, uneven floors, or inadequate Foundation support.

c) Rate the building's seismic vulnerability based on the inspection findings, using A standardized RVS tool.

d) If the building is rated as high or very high vulnerability, conduct a more detailed assessment using a more advanced evaluation method.

e) Use the RVS results to prioritize buildings for seismic retrofitting or other risk reduction measures.

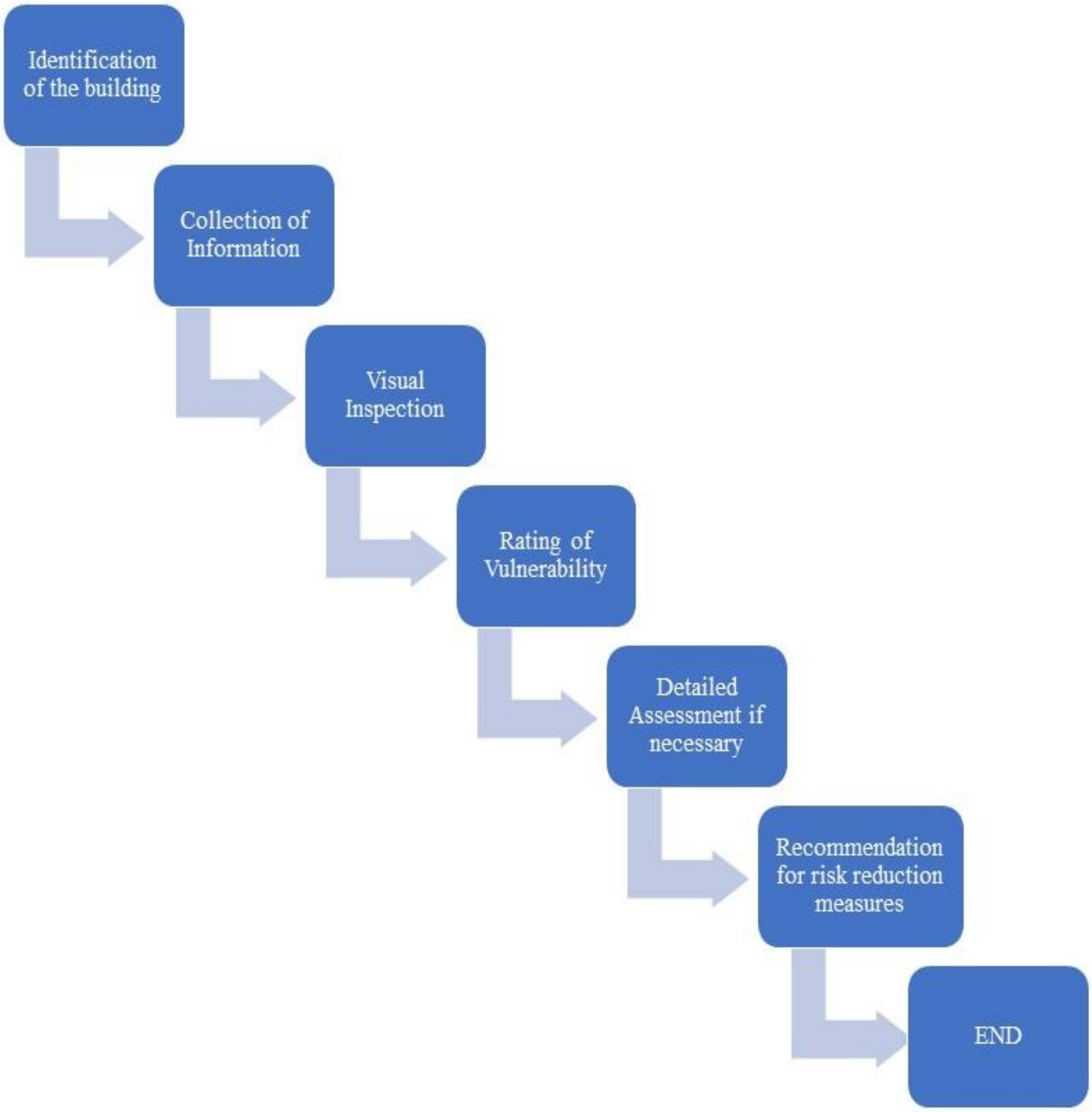


**Figure 3.4:** Project organization with strategic and methodological steps

### 3.7 Study Area in Chattogram City

This section presents a brief overview of Chattogram city and the rationale for selecting a ward of Chattogram City representing typical conditions of RCC residential buildings of the city. The history of Chattogram City (previously known as Chittagong City) dates back to ancient times, with its recognized natural harbour attracting attention from traders around the world. Referred to as Porto Grande by Portuguese and Venetian sailors, the city has a rich past that has contributed to its development as a major hub for trade and commerce. Despite changes in ownership and control, Chattogram has continued to thrive, becoming a significant centre for the Bangladesh Railway and the gateway for the country's foreign trade. Furthermore, the Chattogram Stock Exchange constitutes one of the nation’s two stock markets. Multiple companies headquartered in Chattogram are high-profile conglomerates and ventures within Bangladesh.


**Figure 3.5:** Map of Chattogram Metropolitan City

Chattogram has undergone deliberate urban development, resulting in the establishment of various industries. It serves as a pivotal communications centre, boasting connectivity by rail, road, and air to both domestic and international destinations. Furthermore, it is regarded as one of the most crucial industrial cities in Bangladesh, home to an export-processing zone and the branch offices of foreign corporations and financial institutions. Additionally, the city is equipped with hospitals, a museum, and esteemed higher education institutions. Notably, nearby, there is a cadet college and a merchant-marine academy, while the Zia Memorial Museum pays homage to the site of the late Bangladeshi leader Ziaur Rahman's passing.

Chattogram City stands as not only the major urban center of Chattogram District but also the heartbeat of Bangladesh as its second-largest city. Nestled between latitudes 22°14' and 22°24' N, and longitudes 91°46' and 91°53' E, it graces the banks of the historic Karnaphuli River.

The study area is a part of No. 2 Jalalabad Ward, in Chattogram City Corporation as shown in Figure 3.5, has 2580 buildings and is densely populated. This area is selected as this ward is one of the areas where most of the development of buildings is on the rise as well as developing in an unplanned way and the population rate is increasing abnormally. It is based on occupancy, it has different buildings e.g., residential, commercial, school, etc. They have different seismic lateral load-resisting systems such as reinforced concrete and steel frames, shear walls, etc. As the study area lies in zone 2 having a PGA of 0.28g, a major earthquake can affect existing buildings and harm people.

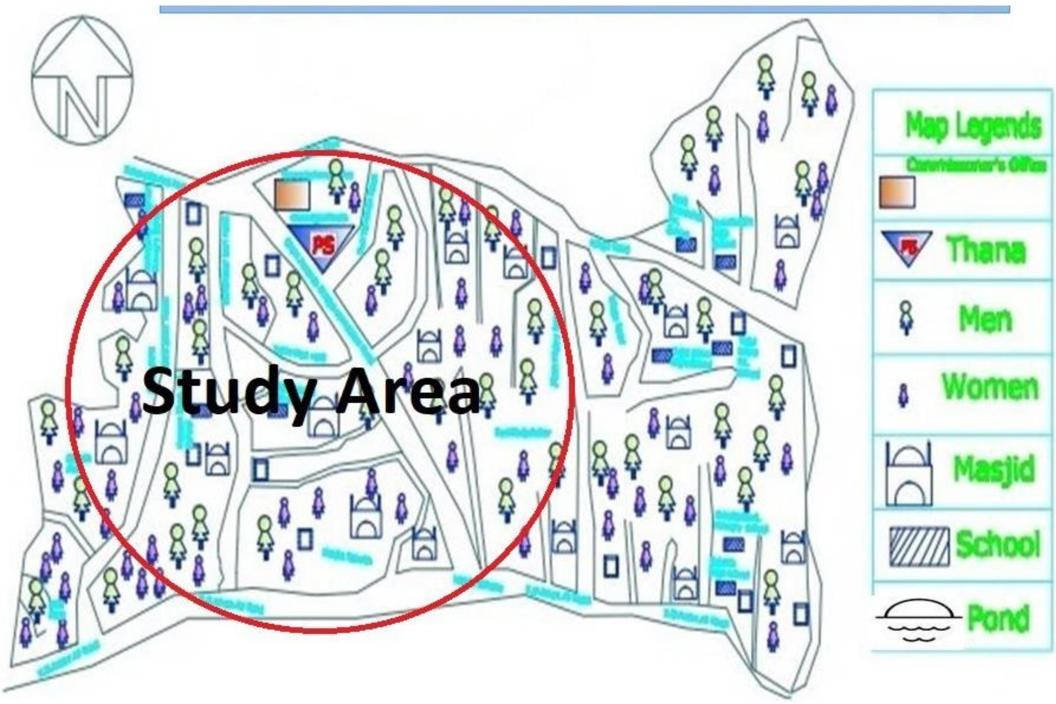


**Figure 3.6:** Map of No.2 Jalalabad Ward, in Chattogram City Corporation

### **3.7.1** General Conditions of Buildings of Chattogram City Corporation

The study location of the project was chosen after a preliminary field survey conducted on RCC residential buildings in a few wards of Chattogram city. A pre-field survey was conducted in Ward No. 3 Panchlaish, Ward No. 4 Chandgaon, Ward No. 6 East Sholoshahar, Ward No. 8 Sholokbahar, Ward No. 16 Chawkbazar, and Ward No. 31 Alkaran. An in-depth survey of 100 buildings was carried out using a reliable simple random sampling procedure. The conditions of the buildings were thoroughly evaluated through visual observations made during a walk-down survey. Detailed in Figures 3.6(a) to 3.6(f) are the typical conditions of residential buildings across various wards in Chattogram city. Photographs of some of the selected buildings are attached in Appendix B. Of all the 100 buildings (Summary of information provided in Appendix A), most of them are 4/5/6-storied buildings while a few of them are 2 to 3-storied buildings. The maximum story numbers of a building was found to be 10 storied, which are typical RCC buildings with RC moment-resisting frame structures. All of them are purpose-built, i.e., residential purposes and a few of them had ground parking lots. After the field survey, all six wards denote all are similar to 20 no Jalalabad ward of Chattogram city corporation according to building and area condition.

### **3.7.2** General Assessment of Soil Condition of the Study Area

The soil properties of Chattogram city have historically originated from agricultural and piscicultural lands, extending to certain hilly areas. The soil types found in the urban regions of Chattogram city include sandy loam, loamy sand, and silt loam, with sand content ranging from 53% to 83%. According to Brammer (1996), over 60% of the soils in the Chattogram region are primarily formed from moderately coarse to fine-textured, folded tertiary hill sediments. The soil profile at specific locations, such as No. 2 Jalalabad Ward in Chattogram city varies based on factors like geological composition, land use and environmental conditions. Typically, soil profiles consist of several layers or horizons, each with its distinct characteristics. Analyzing these profiles is essential, as they affect drainage, fertility, and overall suitability for various land uses. According to the soil report for the buildings in this area and also verified by visual observations, the soil types can be classified as dense soil, stiff soil or soft soil. For the study area, the average soil type is classified as stiff soil. The reports for the surveyed building sites indicate that the predominant soil type is stiff soil, referred to as soil type D according to the FEMA 154 checklist.

**(a):** Ward No-3 Panchlaish

**(b):** Ward No-4 Chandgaon

**(c):** Ward No-6 East Sholoshahar

**(d):** Ward No-8 Sholokbahar

**(e):** Ward No-16 Chawkbazar

**(f):** Ward No-31 Alkaran

**Figure 3.7:** Typical conditions of residential buildings in different wards of Chattogram city

# CHAPTER 4

## RESULTS AND DISCUSSION

### 4.1 General

In assessing the seismic vulnerability of Chattogram, the city's unique geographical location, situated near the convergence of the Indian and Burmese tectonic plates, emerges as a key factor contributing to its susceptibility to seismic activity. The examination of various components encompassing considerations such as geological attributes, building construction types and population density in the city becomes imperative in this assessment. The presence of soft soils amplifies seismic waves, intensifying ground shaking, while areas with steep slopes or unstable land pose additional risks. Therefore, an integral facet involves scrutinizing the soil type prevalent in Chattogram, a factor known to significantly influence the impact of earthquakes. Building construction types and adherence to seismic standards form another pivotal aspect of vulnerability assessment. Many old structures in Chattogram city, predating modern seismic design codes, may exhibit heightened vulnerability. The materials used in construction, including brick, concrete, and steel, contribute to a building's susceptibility. Considering the city's congested neighborhoods, population density emerges as a crucial factor in seismic vulnerability. High-density areas, characteristic of Chattogram, face increased risks of damage and loss of life during an earthquake.

### 4.2 Survey Processes

To complete an assessment which includes a multidimensional approach, incorporating geologic mapping, building inventory analysis and scenario modelling, two surveys are done which gives extra depth to the results obtained. They are pre-field surveys and field surveys. The pre-field survey is an essential step in earthquake vulnerability assessments to ensure that fieldwork is conducted effectively and efficiently. The pre-field survey typically involves a desk review of available data to identify potential seismic hazards in the study area and to develop a preliminary understanding of the buildings' construction and occupancy characteristics. By conducting a pre-field survey, experts can develop a comprehensive understanding of the study area, identify potential vulnerabilities, and develop an effective fieldwork plan for earthquake vulnerability assessments. Due to the limitation of time for conducting an extensive field survey considering the large size of the study area, the extent of the field survey was restricted to randomly selected locations and buildings of the study area. Data of historical seismic activity and geological data were collected from secondary sources, whereas a building inventory survey and walk-down survey for seismic vulnerability assessment were conducted on-site. So, enumerators were used for collecting information about the building structure.

## 4.3 Results and Analysis

### **4.3.1** Discussion on Pre-field Survey Data

The chosen study area for the project is part of 2 no. South Jalalabad ward of Chattogram City Corporation. Based on occupancy, it has different buildings e.g., residential, industrial, commercial, school, etc. The study area has 2580 buildings there are more than 80% (approximate) residential buildings. The buildings of the Jalalabad ward area have different lateral load-resisting systems such as reinforced concrete and steel frames, shear walls, etc. As the study area lies in seismic hazard zone 2 having a PGA of 0.28g, a major earthquake can affect existing buildings and harm people.

### **4.3.2** General Distribution of Vulnerability Results of FEMA 154 RVS Method

The normal Gaussian distribution of RVS scores and other relevant statistics of buildings of the study area as determined according to the FEMA 154 method of RVS assessment are shown in Figures 4.1, 4.2 and Table 4.1. The seismic vulnerability scores predominantly range between 0.5 and 4.8. There is also a small portion of structures that are in the range of less than 0.5. Based on visual observation of external features such as heavy overhang or vertical discontinuity, it is evident that many of the RCC residential structures of the study area may suffer from moderate to high degree of damage in the event of a moderate-intensity earthquake. However, the qualitative evaluation of many buildings from visual observations does not comply well with the mean vulnerability score of 2.89, as shown in the figure. Although the mean vulnerability score is above the general cut-off score (2~2.5), it cannot be taken as a standard or reliable average state of the vulnerability conditions of the structures of the study area. Many typical vulnerability parameters are not represented in the checklist of the FEMA 154 RVS method. The standard deviation score of 1.18 is also indicative wide dispersion of data which is not well representative of qualitative data as observed during the field survey. A relatively higher value of standard deviation is also indicative of the fact that a considerable percentage of buildings are falling in the range of vulnerability score below 2.0 (e.g., for ≤ μ-σ).

**Table 4.1:** Normal distribution (in %) of FEMA-154 results in different ranges of vulnerability scores

<u>RVS statistics (FEMA 154)</u>
City: Chattogram, Location: Ward 2
Types of construction - RC
Number of buildings - 100
Mean: 2.886, St. Dev.: 1.184,
Rang: Max - 4.8, Min - 0.5

| μ-3ð | μ-2ð | μ-ð | μ | μ+ð | μ+2ð | μ+3ð |
|---|---|---|---|---|---|---|
| -0.67 | 0.52 | 1.70 | 2.886 | 4.07 | 5.25 | 6.44 |

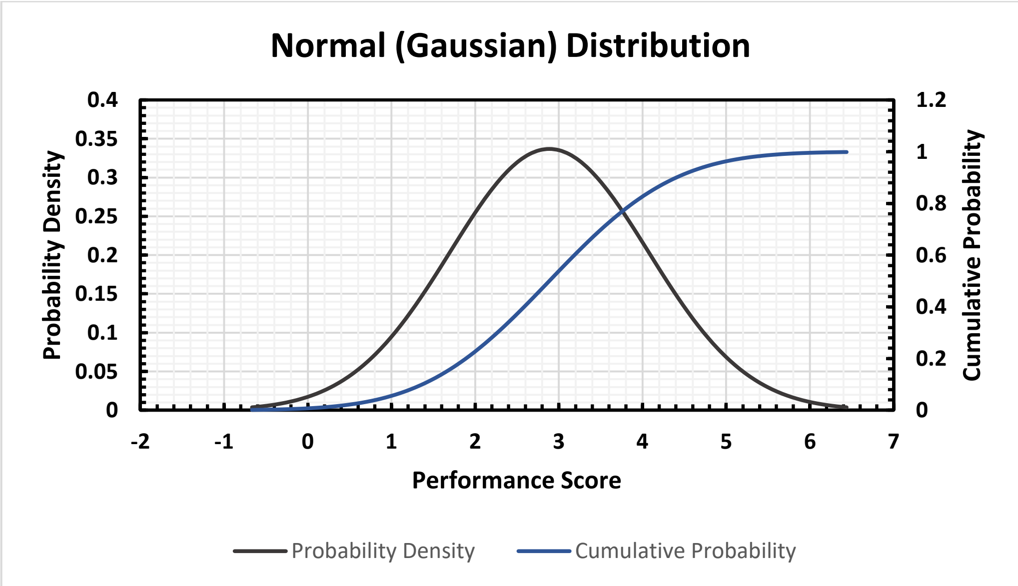


**Figure 4.1:** Gaussian distribution of vulnerability scores of buildings in the study area

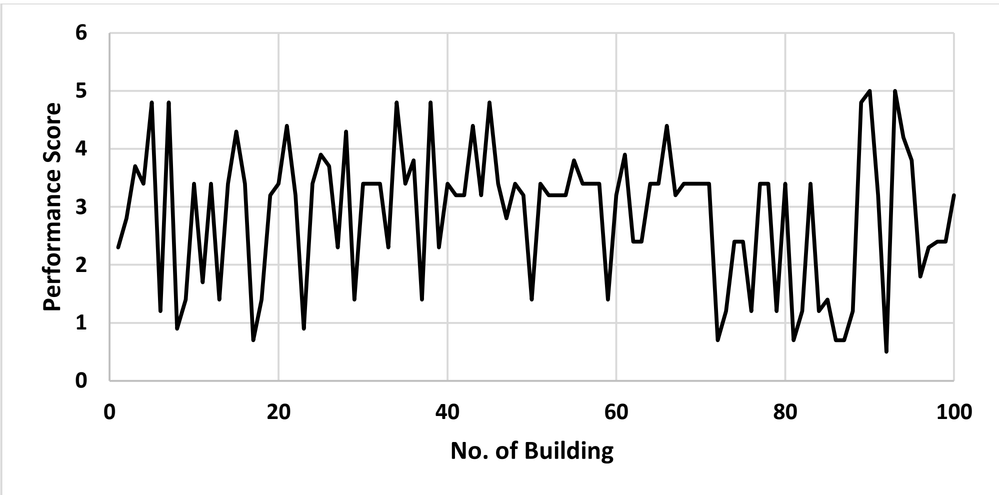


**Figure 4.2:** Performance score versus number of buildings

### 4.3.3 Overview of RVS Results of Selected Vulnerability Assessment Methods

A summary of the results of the seismic vulnerability assessment done by using selected methods of RVS is depicted in Figure 4.3 and Table 4.2. The pie chart in the figure presents the results of selected RVS assessment methods. The highest average value of 60% of non-compliance or vulnerability is found through the ASCE 41-13 method, which is calculated from the percentage of non-compliance parameters in a total of 100 buildings surveyed in the study area. The lowest average percentage of non-compliance (39%) is found for the short-listed parameters/checklist prepared according to BNBC guidelines that are considered important parameters affecting post-seismic hazards or vulnerability.

The percentage of buildings falling below the FEMA 154 vulnerability or cut-off score of 2 is 35% which are expected to suffer grade 2 to grade 3 damage under a seismic event of moderate intensity. There is an average 49% non-compliance of building vulnerability parameters obtained through using FEMA 310 RVS method while the percentage of non-compliance with ASCE 41-13 checklist of parameters is even higher, 60%.

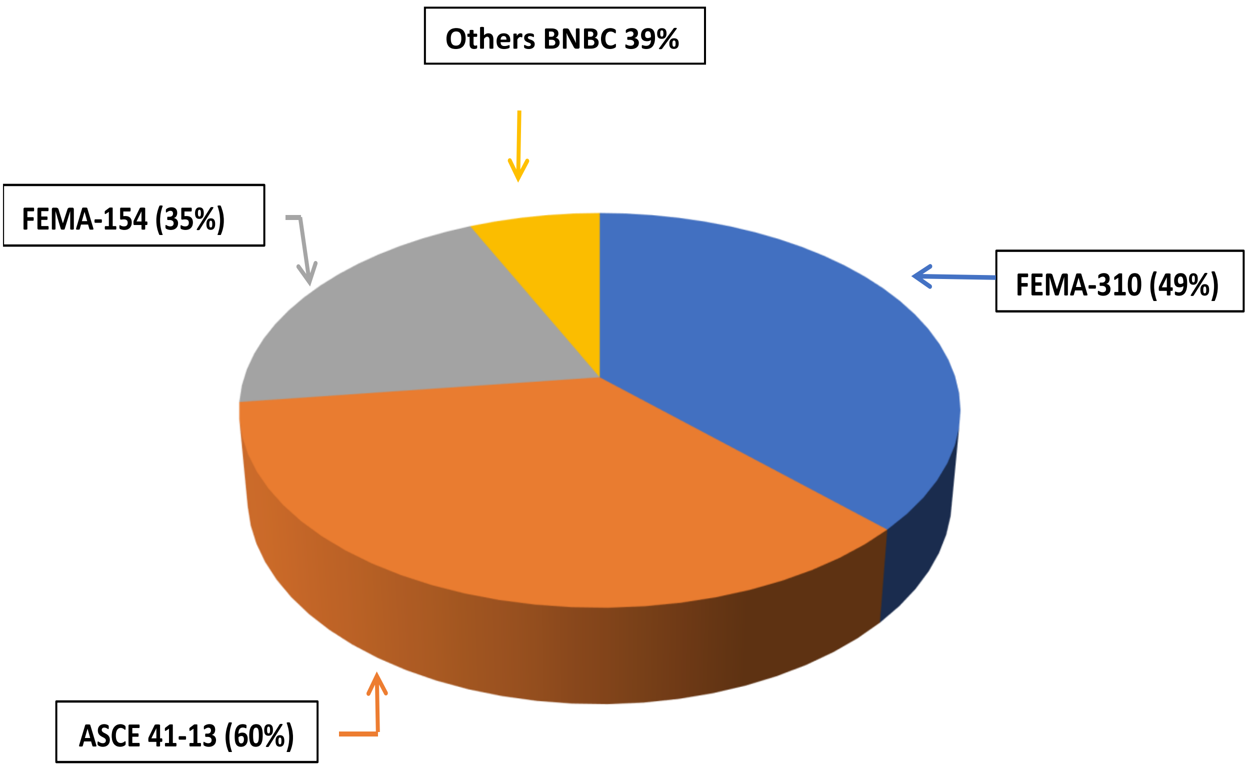


**Figure 4.3:** Pie chart of vulnerability assessment results in different RVS methods

**Table 4.2:** Non-compliance (%) of FEMA 310, ASCE 41-13 and BNBC 2020 safety factors

| Vulnerability/Safety assessment methods | Average % of factors non-compliant | Maximum/Minimum % of factors non-compliant |
|---|---|---|
| FEMA 310 | 49% | 75%/ 25% |
| ASCE 41-13 | 60% | 77.7%/ 33.3% |
| BNBC 2020 | 39% | 100%/ 0% |

If all vulneraility parameters are combined considered for assessment, the percentage of non-compliance for different parameters are found as shown in figure 4.4. Such a comparative chart may help decide prioratization of risk mitigation approaches addressing vulnerability features with higher percentage of non-compliance.

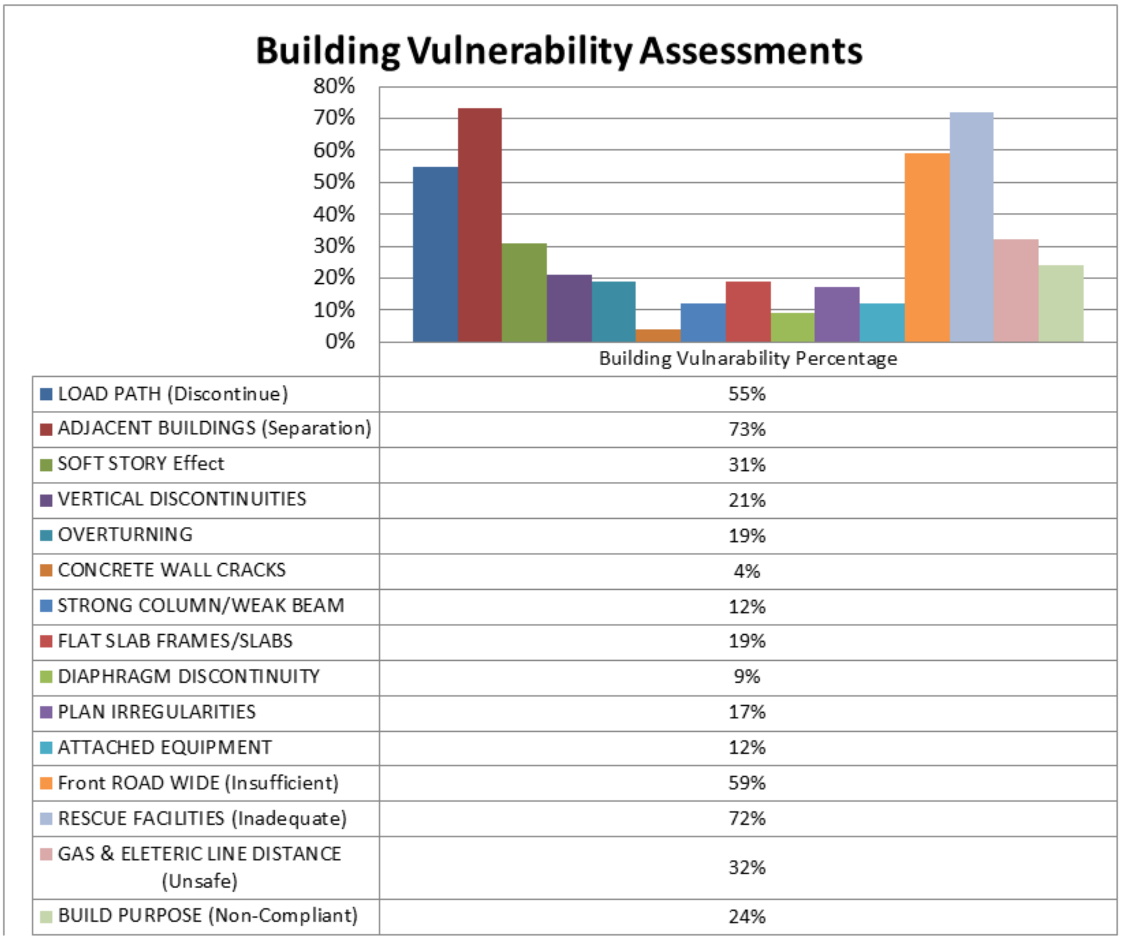


**Figure 4.4:** Building vulnerability (non-compliance %) in combined list of parameters

## 4.4 Discussion on Important Factors of Seismic Vulnerability of Residential Buildings of Jalalabad Area

A combined assessment using all the vulnerability factors selected in FEMA 154, FEMA 310 and ASCE 41-13 guidelines including as well a few safety factors of BNBC are summarized in Figure 4.4. It is obvious from the viewpoints of engineering judgement that non-compliance any one of the parameters of the combined list may be associated with a high degree seismic damage. There are also few parameters in the combined list that may be considered important post-seismic risk mitigation. Regardless of the percentage of non-compliance of any of the vulnerability factors, the following factors may be noted as important criteria for vulnerability assessment considering typical conditions of the buildings in the study area.

### **4.4.1** Soft Story

The lateral-force-resisting system's stiffness within each story must maintain at least 70% of the stiffness of an adjacent story above or below and not dip below 80% of the average stiffness of the three adjacent stories for both Life-Safety and Immediate Occupancy considerations, identifying geometric irregularities such as variations in system dimensions or setbacks for architectural purposes. In our study we find 31% of the buildings have soft story effects.

### **4.4.2** Adjacent Buildings

Adjacent buildings shall not be located closer to the structure being evaluated than 4% of its height for Life Safety and Immediate Occupancy, as outlined by FEMA 310 and ASCE standards, recognizing the potential impact of buildings on each other during earthquakes and necessitating specific construction and maintenance standards for safety. In our study we find 73% of the building are within close distance to each other.

### **4.4.3** Building Vertical Discontinuities

Vertical elements within the lateral-force-resisting system necessitate continuous connection to the foundation, with potential discontinuities, like in shear walls or braced frames, identified visually. Concerns emerge with torsion in buildings, amplifying seismic demands and lateral drifts due to diaphragm rotation, urging balanced system designs to avoid compromising earthquake performance. Vertical discontinuities, intentional or accidental, can occur within single buildings or across groups, impacting both structural integrity and aesthetic coherence. In our study we find 21% of the buildings have vertical discontinuities effect.

### **4.4.4** Flat Slabs and Frame

Flat slabs, a form of reinforced concrete structure, streamline construction by eliminating beams and drops, presenting a cost-efficient design. For life safety, continuous bottom steel through column joints is mandated, yet they're restricted in Immediate Occupancy structures. Supported directly by columns or walls, flat slabs enhance strength with reinforced points and can incorporate steel bars for added tensile strength. Offering swifter construction, layout flexibility, and potential seismic resilience, flat slabs stand as a versatile alternative to traditional slab systems. In our study we find 19% of the buildings have flat slabs and frame effect.

### **4.4.5** Diaphragm Continuity

The diaphragm is a vital component within building construction, serving as a primary horizontal load-bearing element composed of concrete, steel, or wood. It facilitates the transfer of lateral forces, such as those caused by wind or seismic activity, to the vertical elements that effectively counteract them. The diaphragm's rigidity is of utmost importance, particularly in seismic design, where its relative flexibility or rigidity in comparison to vertical elements, as well as restrictions on split-level floors and expansion joints in wood buildings, must be carefully considered. In our study we find 9% of the buildings are having diaphragm discontinuity effect.

### **4.4.6** Attached Equipment

It is found that 12% of the buildings of the study area have vertical attached equipment which may make it vulnerable due to seismic effect. Building attached equipment typically refers to the installation of equipment directly linked to a structure, aiming to enhance functionality, efficiency, or safety. For items exceeding 20 pounds and situated more than 4 feet above the floor, bracing is necessary to ensure stability and mitigate safety risks. Some common examples of attached equipment include:

i. Material handling equipment
ii. Industrial generators and power systems
iii. Elevators and escalators
iv. Fire suppression systems
v. Industrial compressors

#### **4.4.7** Plan Irregularities

Plan irregularities, deviations from standard geometric shapes in a building's horizontal layout, encompass intricate or asymmetrical floor plans, profoundly influencing structural behavior and stability. Extra analysis and design considerations are imperative to ensure stability, with attention to detailing, material selection, and construction techniques guided by building codes. Specific requirements, such as tensile capacity at re-entrant corners for Immediate Occupancy performance levels, underscore the critical need for meticulous planning and execution to mitigate structural risks associated with plan irregularities. In our study we find 17% building has plan irregularities effect.

#### **4.4.8** Building Load Path

A building's load path ensures forces transfer safely from applied loads to the foundation, supporting dead, live, and seismic loads in all directions. In our study we find 55% building has load path effect.

#### **4.4.9** Strong Column/Weak Beam

Constructing building complete frames entails creating the primary load-bearing structure composed on strong columns and weak beams encompassing necessary design, foundation work, column and beam installation, and floor/roof systems, while also addressing bracing, ensuring connections, conducting inspections, and integrating with other building components for a comprehensive construction approach. In our study we find 12% of the buildings apparently have song beam weak column effect.

#### **4.4.10** Front Road Width

The width of the front road or street in front of a building plays a significant role in several aspects that can impact the functionality, safety, and overall value of the property. Some of the important reasons why the width of the building's front road is significant are:

i. Access and connectivity
ii. Traffic flow and safety
iii. Parking facilities

In our study we find 59% of the buildings' front roads are having insufficient width.

#### **4.4.11** Built Purpose

A building's built purpose reflects its intended function, catering to various needs such as residential, commercial, industrial, or recreational uses. Yet, in our country, buildings often serve different purposes than initially planned. In our study we find 24% buildings built purpose are non-compliant.

#### **4.4.12** Rescue Facility

A rescue facility is a purpose-built structure designed to support emergency response and rescue operations, serving as a central hub for personnel and equipment to ensure effective response during critical situations. Here are some key features and considerations for building a rescue facility:

i. Location
ii. Space and layout
iii. Accessibility
iv. Safety and security
v. Specialized facilities

In our study, we find that 72% of buildings' rescue facilities are inadequate.

#### **4.4.13** Gas and Electric Line Distance

Building close to gas and electric lines poses certain risks that need to be considered and addressed during the planning and construction stages. Some potential risks associated with building near gas and electric lines are gas leaks and electrical hazards. In our study, we find that 32% of buildings' gas and electric line distances are unsafe.

### 4.5 Comparative Assessment of Vulnerability in Tier 1 Assessment Methods

The seismic vulnerability score derived from the engineering assessment of a specific building or building system has various implications for many different purposes. The Tier 1 assessment in FEMA 154, FEMA 310 and ASCE 41-13 generally helps engineers or assessors to decide whether a building needs to be assessed with Tier 2 or higher levels of detailed engineering assessment. However, the scoring system of Tier 1 assessment e.g., FEMA 154 may effectively help policymakers, municipal or other relevant authorities to decide about any immediate intervention to effectively consider seismic risk management for a particular community in a particular area. A parametric assessment of degree of seismic damage can be linked with vulnerability score of FEMA 154 (2002). Such a parametric assessment of vulnerability or a specific building is calculated for local conditions of buildings of the country using damage index calculation such as that done by SATREPS – TSUIB, 2009.

**Table 4.3:** Expected damage level based on RVS score. *Source: FEMA-154, 2002*

| RVS Score | Damage Potential |
|---|---|
| S<0.3 | High probability of Grade 5 damage<br>Very High probability of **G**rade 4 damage |
| 0.3< S<0.7 | High probability of Grade 4 damage<br>Very High probability of Grade 3 damage |
| 0.7<S<2.0 | High probability of Grade 3 damage<br>Very High probability of Grade 2 damage |
| 2.0<S<3.0 | High probability of Grade 2 damage<br>Very High probability of Grade 1 damage |
| S>3.0 | High probability of Grade 2 damage<br>Very High probability of Grade 1 damage |

Note-

- Grade 0: No Damage
- Grade 1: Slight damage, such as hairline cracks in a few wall

- Grade 2: moderate damage, such as large pieces of plaster falling, small cracks wall, roof tiles slipping etc.
- Grade 3: Heavy damage, such as extensive cracks in the wall
- Grade 4: Very heavy damage, such as serious failure of the wall
- Grade 5: Destruction, such as total collapse

However, the FEMA 154 method includes only general features feature and is not comparable to structural vulnerability features of FEMA 310 or ASCE 41-13 checklist. The Tier 1 assessment checklist of FEMA 154 considers much more generalized structural and non-structural parameters in the checklist whereas FEMA 310 and ASCE 41-13 have various structural assessment parameters in the checklist based on which an effective average score of vulnerability can be estimated.

The building buildings in the Jalalabad ward have been assessed by FEMA 154, FEMA 310, ASCE 41-13, and BNBC short-listed parameters. However, the vulnerability scores calculated by FEMA 154 seem to be an underestimate of the average conditions or damage index even under a moderate intensity of seismic event. The buildings of the Jalalabad area have at least one non-compliant vulnerability parameter of any of the selected assessment methods of FEMA 310 and ASCE 41-13. Failure or damage in any one of the aspects can lead to an unknown degree of seismic damage. Therefore, a further assessment based on a more detailed structural checklist of parameters of FEMA 310 and ASCE 41-13 is done assuming a random value vulnerability score of 2 for 50% of the non-compliance parameter of a building score, subsequently increasing or decreasing the score of vulnerability by 0.1 with respective decrease or increase of values of percentage of non-compliance in comparison to the reference value of 50%. Since a relative weightage value for the vulnerability score is assigned for buildings with a higher value of a non-compliance parameter, these results of the relative vulnerability score may be used as a suitable basis for comparison with the results of the RVS vulnerability score by FEMA 154. With an average of 49% per cent non-compliance with FEMA 310 parameters, a respective relative average score of vulnerability of 2.1 is calculated. It indicates that with an average state of building representative of the Jalalabad area, the building may suffer grade 1 to grade 2 damage with a moderate intensity earthquake. This is still an underestimate of the state of vulnerability when compared to the results of an average 60% non-compliance with a relative score of vulnerability of 1.9. The results of the assessment with the ASCE 41-13 method indicate that with an average state of building representative of the Jalalabad area, the building may suffer grade 2 to grade 3 damage with a moderate intensity earthquake.

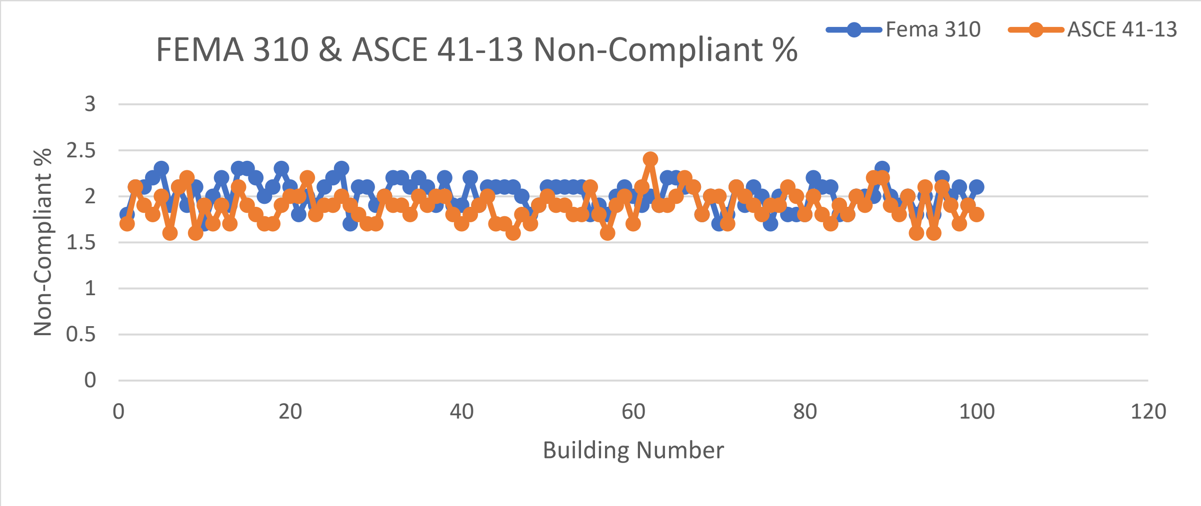


**Figure 4.5:** Graphical representation of (%) non-compliance parameters of FEMA 310 and ASCE 41-13

### 4.6 Building Road Network Vulnerability Assessment in the Study Area

Building road network vulnerability is one of the important parameters that is closely associated with post-seismic hazard mitigation as well as to development of overall urban seismic resilience. This has been taken as an important parameter for assessment in this study since BNBC 2020 has also specified adequate means of access to buildings through road network facilities. A further assessment is done based on this critical parameter stated in BNBC 2020, which may significantly increase the post-seismic hazard of vulnerability. As per the Chattogram city corporation map and census data, this ward is overpopulated. Though the presence of residential buildings is a high number, as per our survey findings, the roads are not wide enough (less than 3m). According to BNBC 2020, the minimum road width is 3m and for adequate turning radius for vehicles is 1:3. If the road facilities are less than 1, rescue facilities are restricted due to the narrow roads which leads to restrictions in fire rescue, post-seismic related activities, entry of firefighting trucks or personnel, etc., whereas, if the road facilities is more than 3, rescue facilities is not restricted due to wide roads. So, if an unfortunate event occurs in an affected area, such as a fire or earthquake-related disaster, carrying out rescue facilities will be hampered because of narrow roads in the study area.

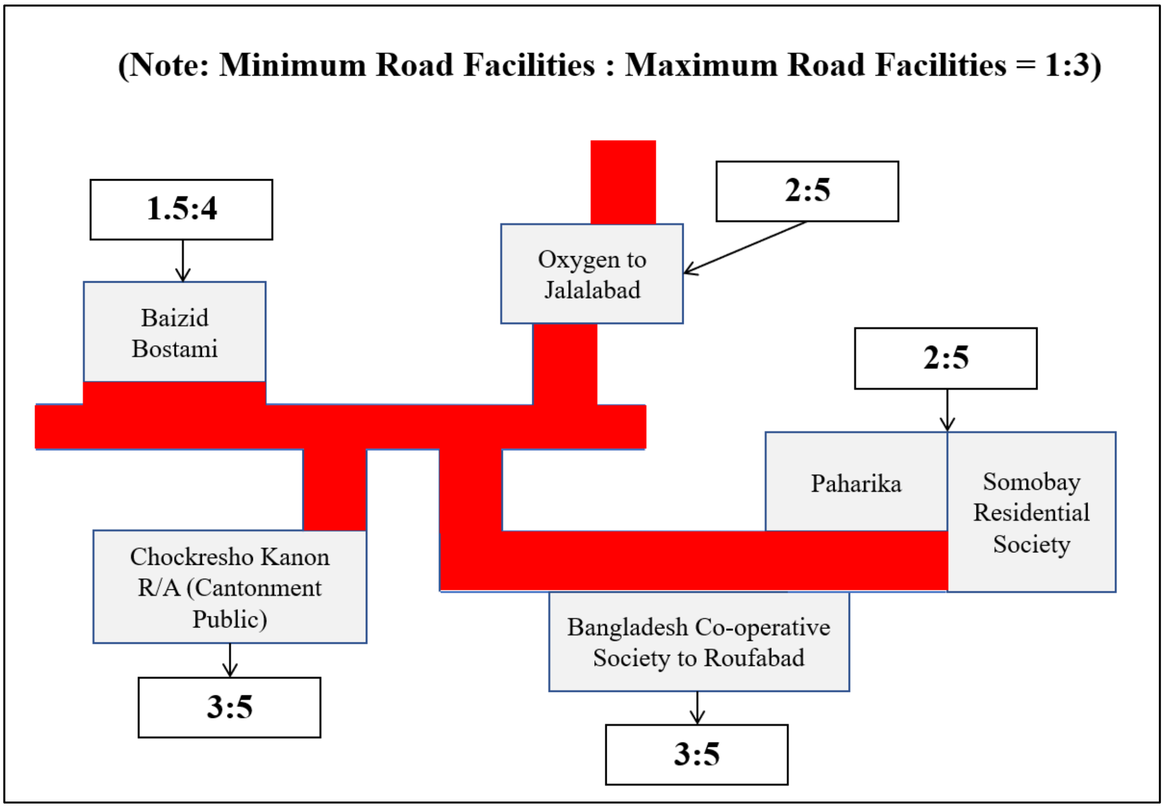


**Figure 4.6:** Maximum and minimum road width ratios for the road network of the study area

Table 4.4 and Figure 4.5 show the ratio of minimum and maximum road facilities for each area in different sections of road network of the study area. The maximum and minimum road widths for each sub area are mentioned on Table 4.4. A number of roads in the Oxygen to Jalalabad, Baizid Bostami and Roufabad area have too narrow road width to provide for adequate turning radius for a vehicle.

**Table 4.4:** Maximum and minimum road widths in the road network of the study area

| Sl. No. | Sub-area Name | Road Facilities | |
|---|---|---|---|
| | | Minimum (m) | Maximum (m) |
| 01 | Oxygen to Jalalabad | 2 | 5 |
| 02 | Bangladesh Co-operative Society to Roufabad | 2 | 5 |
| 03 | Paharika to Somobai Residential Society | 3 | 5 |
| 04 | Chockresho Kanon R/A (Cantonment Public) | 3 | 5 |
| 05 | Baizid Bostami | 1.5 | 4 |

According to the FEMA 154 RVS method of assessment, it is found that the building percentage of cut-off score ≤2 is high in Baizid Bostami, Roufabad and Oxygen to Jalalabad area (Table 4.5 and Figure 4.6) where width of front roads of buildings are generally narrow. According to the road assessment survey, the cut-off score being ≤2 is in high numbers of buildings constructed in narrow road-based areas.

**Table 4.5:** Building percentile according to FEMA 154 cut-off score ≤2

| Road Map | Area Name | No. of Building | Detailed Evaluation (Cut-off Score ≤2) | Percentile |
|---|---|---|---|---|
| 01 | Oxygen to Jalalabad | 23 | 9 | 39.13% |
| 02 | Bangladesh Co-operative Society to Roufabad | 22 | 5 | 22.72% |
| 03 | Paharika to Somobai Residential Area | 15 | 3 | 20% |
| 04 | Cantonment Public | 16 | 3 | 18.75% |
| 05 | Baizid Bostami | 24 | 15 | 62.50% |

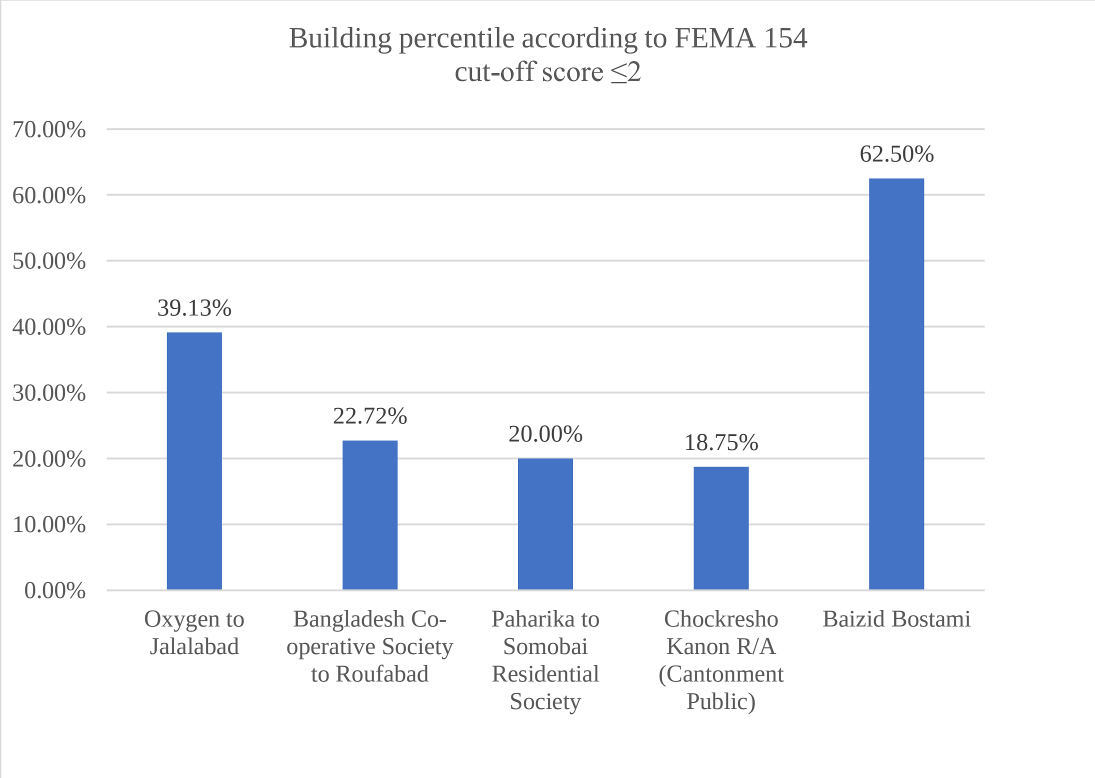


**Figure 4.7:** Building percentile (cut-off score ≤2) according to FEMA 154

The results of insufficient road width (according to BNBC standards) can thus be correlated with these higher scores of seismic vulnerabilities of buildings in these areas. Therefore, parametric assessment on features like building front road width, building separation distance, electric and gas line distance etc. should be integrally considered in seismic vulnerability assessment methods to mitigate risks of damage due to seismic and post-seismic secondary effects.

# CHAPTER 5

## CONCLUSION AND RECOMMENDATION

### 5.1 Conclusions

This study is based on rapid visual screening (RVS) for seismic vulnerability to assess conditions of vulnerability of typical reinforced concrete residential buildings of the Jalalabad area of Chattogram city. Jalalabad Residential Area is located within the city centre and the buildings of the area represent typical conditions of buildings of Chattogram city. The results of the FEMA 154 RVS method indicate that 35% of the buildings in the area fall below a cut-off vulnerability score of 2 which may be taken as a reference score of vulnerability considering local building conditions of Bangladesh. The Gaussian distribution curve using results of FEMA 154 data of preliminary assessment shows that only a smaller percentage of buildings (<15%) having scores lower than 1.0 are expected to suffer moderate to high degree of damage under a seismic event of moderate intensity. Since the assessment method relies on assessing only general features of structural geometry or soil conditions, the results of this method may become a conservative assessment of vulnerability. Although the scoring method is a suitable indicator for decision-making by policymakers or city authorities, the wide range of distribution of data with a high value of standard deviation makes the result an insufficient indicator of vulnerability based on local conditions in Bangladesh.

Visual observations of the conditions of the buildings of the study area suggest that the buildings with scores below 2.0 with FEMA 154 methods have high possibility of severe damage or even collapse in a moderate earthquake. The assessment of the buildings of the study area has also been done using FEMA 310 and ASCE 41-13 RVS methods. The results of these selected RVS assessment methods show a more reliable assessment of the average state of buildings' seismic vulnerability in the study area. With an average of 49% per cent non-compliance with FEMA 310 parameters, a respective relative score of vulnerability of 2.1 is calculated. It indicates that with an average state of building representative of the Jalalabad area, the building may suffer grade 1 to grade 2 damage due to a moderate-intensity earthquake. This may still be considered as an underestimate of the state of vulnerability when compared to the results of an average 60% non-compliance of vulnerability parameters of the ASCE 41-13 checklist. With a relative score of vulnerability of 1.9 determined according to ASCE 41-13 methods, the buildings of an average state in the study area may suffer grade 2 to grade 3 damage with a moderate intensity earthquake.

The study area is densely populated with a high number of residential buildings. However, field survey results are indicative that the roads are narrower than the minimum width required to comply with the BNBC 2020 standards. The insufficiency of road width within the residential area may restrict rescue operations during emergencies like earthquakes or other post-seismic or secondary hazards. The results of insufficient road widths in an area could be correlated with the higher percentage of buildings having a higher degree of seismic vulnerability. It is indicative of the fact that parametric assessment on features like building's front road width, building separation distance, electric and gas line distance etc. may be integrally considered in seismic vulnerability assessment methods especially considering post-seismic hazards.

## 5.2 Scope and Limitations of the Research

The following key points are succinctly addressed in outlining the limitations encountered during the study:

a) Any of the common RVS methods is not solely adequate to assess the actual scenario of seismic vulnerability of a building structure.

b) The exclusion of certain building types in the study area is attributed to a lack of specific data, and the arbitrary classification of buildings into occupancy classes may not capture the full spectrum of structures present.

c) It is difficult to get proper structural data of a building during field survey assessment and the primary assessment on data acquired is not a complete assessment.

d) The seismic vulnerability assessment employed in this study is based on a limited number of samples, utilizing a stratified sampling technique common in this research category.

Although there are some limitations of the work, this study may serve the purpose of providing baseline data for seismic vulnerability assessment especially considering issues of post-seismic vulnerability or hazards, fire hazards as well as for further detailed evaluation of buildings considering important aspects of road networks' vulnerability relation or something relatable for conducting tests for the structural integrity of buildings in this area or a neighbouring area. From this study, researchers may get useful information and insights into relevant observations and results in a reduced period of time.

### 5.3 Recommendation and Future Study

In our country's context, certain crucial parameters are necessary for ensuring the seismic and post-seismic safety of residential buildings. The rapid visual screening guidelines (FEMA or ASCE) lack clarity regarding specific parameters essential for conducting surveys on residential buildings. These include factors such as front road width, distances to electric and gas lines, built purpose, and rescue facility availability. These parameters are pivotal in safeguarding the current existing buildings and guiding the construction of future buildings, ultimately minimizing damage and casualties resulting from earthquakes and post-earthquake events.

The focal point of the case study revolves exclusively around tools for assessing vulnerability before seismic events. A forward-looking exploration could emphasize the need for comprehensive assessments that encompass both pre-seismic and post-seismic conditions, to craft a validated and standardized seismic vulnerability assessment tool. As there is some presence of limitations, the following recommendations are put forward for future research, with the goal achieving success towards a robust seismic vulnerability assessment:

a) Most of the buildings in the study area do not require detailed evaluation. Though, lack of awareness of occupants of buildings that require detailed evaluation may risk their lives during moderate earthquake. Furthermore, detailed evaluation of such buildings by an experienced design professional may need them to be retrofitted or demolished.

b) Buildings that were under construction were not considered in this research; their vulnerability should be assessed in future.

c) Urgent prioritized assessments of commercial and Residential building structures within Chattogram city should be done, recognizing them as critical areas necessitating immediate attention.

d) BNBC criteria such as front road wide, gas and electric line distance, rescue facility, adjacent building location, built purpose should be integrally considered in the checklist of vulnerable assessment parameter and this will provide RVS assessment as a suitable assessment both seismic and post seismic consideration.

e) The relevant local BNBC criteria may be included along with RVS assessment indicators especially considering post-seismic vulnerability assessment on evacuation and other emergency measures. Hence, an integrated method for seismic vulnerability assessment can help decision-makers or city authorities to decide about effective measures for seismic risk mitigation.

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# APPENDIX A

**Summary of Building Data**

| Building No. and Location | No. of Stories | Year of Construction | Soft stories | Visual Defects | Soil Type |
|---|---|---|---|---|---|
| 01/ Oxyzen Shitoljorna Road 1, Building 1 (on left) | C2/10 | PB,2008 | yes | no | D |
| 02/ Oxyzen Shitoljorna Road 1, Building 4 (on right) | C2/11 | PB,2006 | yes | no | D |
| 03/ Oxyzen Shitoljorna Road 1, Building 6 (on left) | C1/8 | PB,2005 | no | no | D |
| 04/ Oxyzen Shitoljorna Road 1, Building 9 (on right) | C1/5 | PB,2003 | yes | no | D |
| 05/ Oxyzen Shitoljorna Road 2, Building 3 (on left) | C2/8 | PB,2009 | yes | no | D |
| 06/ Oxyzen Shitoljorna Road 2, Building 5 (on right) | C1/4 | PC,1990 | no | Side wall crack | D |
| 07/ Oxyzen Shitoljorna Road 2, Building 7 (on left) | C1/8 | PB,2005 | yes | no | D |
| 07/ Oxyzen Shitoljorna Road 2, Building 10 (on right) | C1/6 | PB,2007 | yes | Outer wall Plaster crack | D |
| 09/ Oxyzen Shitoljorna Road 2, Building 13 (on left) | C1/7 | PB,2004 | no | no | D |
| 10/ Oxyzen Shitoljorna Road 2, Building 15 (on right) | C1/6 | PB,2002 | no | no | D |
| 11/ Oxyzen Shitoljorna Road 2, Building 18 (on left) | C2/8 | PB,2006 | yes | no | D |

| **Building No. and Location** | **No. of Stories** | **Year of Construction** | **Soft stories** | **Visual Defects** | **Soil Type** |
|---|---|---|---|---|---|
| 12/ Oxyzen Shitoljorna Road 3, Building 3 (on right) | C1/7 | PB,2008 | no | no | D |
| 13/ Oxyzen Shitoljorna Road 3, Building 6 (on left) | C1/7 | PB,1996 | no | yes | D |
| 14/ Oxyzen Shitoljorna Road 3, Building 9 (on right) | C1/5 | PB,2002 | yes | no | D |
| 15/ Oxyzen Star R/A Road 1, Building 1 (on right) | C1/8 | PB,2007 | no | no | D |
| 16/ Oxyzen Star R/A Road 1, Building 3 (on left) | C1/6 | PB,2005 | no | Outside plaster crack | D |
| 17/ Oxyzen Star R/A Road 1, Building 5 (on right) | C1/5 | PC,1989 | no | Plaster and wall crack | D |
| 18/Oxyzen Star R/A Road 1, Building 7 (on left) | C1/6 | PB,2001 | yes | Outside plaster crack | D |
| 19/ Baluchara R/A Main Road , Building 3 (on left) | C1/6 | PB,1998 | no | Ground floor and wall crack | D |
| 20/ Baluchara R/A Main Road , Building 6 (on right) | C1/5 | PB,2004 | no | no | D |
| 21/ Baluchara R/A Main Road , Building 9 (on left) | C1/7 | PB,2009 | yes | no | D |
| 22/ Baluchara Bazar Main Road , Building 3 (on left) | C1/3 | PB,2000 | no | no | D |
| 23/ Baluchara Bazar Main Road , Building 5 (on right) | C1/4 | PB,2009 | no | no | D |

| **Building No. and Location** | **No. of Stories** | **Year of Construction** | **Soft stories** | **Visual Defects** | **Soil Type** |
|---|---|---|---|---|---|
| 24/ Bangladesh Cooperative Road 1 , Building No 3 (on left) | C1/3 | PB,2002 | no | no | D |
| 25/ Bangladesh Cooperative Road 1 , Building No 5 (on right) | C1/6 | PB,2004 | yes | Outside wall crack | D |
| 26/ Bangladesh Cooperative Road 1 , Building No 7 (on left) | C1/7 | PB,2010 | yes | no | D |
| 27/ Bangladesh Cooperative Road 1 , Building No 9 (on right) | C1/3 | PB,2003 | no | Plaster crack | D |
| 28/ Bangladesh Cooperative Road 1 , Building No 11 (on left) | C1/5 | PB,2009 | no | no | D |
| 29/ Bangladesh Cooperative Road 1 , Building No 13 (on right) | C1/6 | PB,2011 | yes | no | D |
| 30/ Bangladesh Cooperative Road 1 , Building No 16 (on left) | C1/6 | PB,2010 | yes | no | D |
| 31/ Bangladesh Cooperative Road 2 , Building No 3 (on left) | C2/8 | PB,2007 | yes | Plaster crack | D |
| 32/ Bangladesh Cooperative Road 2, Building No 5 (on right) | C2/10 | PB,2012 | yes | no | D |
| 33/ Bangladesh Cooperative Road 2 , Building No 9 (on left) | C2/8 | PB,2016 | yes | no | D |
| 34/ Bangladesh Cooperative Road 2, Building No 11 (on right) | C1/5 | PB,2013 | no | no | D |

| Building No. and Location | No. of Stories | Year of Construction | Soft stories | Visual Defects | Soil Type |
|---|---|---|---|---|---|
| 35/ Bangladesh Cooperative Road 2 , Building No 13 (on left) | C1/7 | PB,2006 | yes | no | D |
| 36/ Bangladesh Cooperative Road 3, Building No 3 (on left) | C1/5 | PB,2003 | no | no | D |
| 37/ Bangladesh Cooperative Road 3 , Building No 6 (on right) | C1/6 | PB,2005 | yes | no | D |
| 38/ Bangladesh Cooperative Road 3 , Building No 7 (on left) | C1/6 | PB,2010 | yes | no | D |
| 39/ Bangladesh Cooperative Road 3, Building No 9 (on right) | C2/9 | PB,2017 | yes | no | D |
| 40/ Bangladesh Cooperative Road 4, Building No 3 (on right) | C2/9 | PB,2016 | yes | no | D |
| 41/ Bangladesh Cooperative Road 4, Building No 7 (on left) | C1/5 | PB,2014 | yes | no | D |
| 42/ Bangladesh Cooperative Road 3, Building No 9 (on right) | C2/9 | PB,2018 | no | no | D |
| 43/ Bangladesh Cooperative Road 3, Building No 3 (on left) | C1/5 | PB,2007 | yes | no | D |
| 44/ Bangladesh Cooperative Road 3 , Building No 7 (on right) | C2/9 | PB,2020 | yes | no | D |
| 45/ Bangladesh Cooperative Road 3, Building No 9 (on left) | C2/9 | PB,2016 | yes | Outside wall crack | D |

| **Building No. and Location** | **No. of Stories** | **Year of Construction** | **Soft stories** | **Visual Defects** | **Soil Type** |
|---|---|---|---|---|---|
| 46/Paharika R/A, Road No 1, Building No 3 (on left) | C1/5 | PB,2010 | yes | no | D |
| 47/Paharika R/A, Road No 1, Building No 6 (on right) | C1/6 | PB,2019 | no | no | D |
| 48/Paharika R/A, Road No 2, Building No 3 (on left) | C1/7 | PB,2001 | no | yes | D |
| 49/Paharika R/A, Road No 2, Building No 6 (on right) | C1/5 | PB,2004 | yes | no | D |
| 50/Paharika R/A, Road No 3, Building No 3 (on left) | C1/4 | PB,2018 | no | no | D |
| 51/Paharika R/A, Road No 3, Building No 6 (on right) | C1/2 | PB,2010 | no | no | D |
| 52/Paharika R/A, Road No 3, Building No 9 (on left) | C1/3 | PB,2014 | no | no | D |
| 53/Paharika R/A, Road No 5, Building No 5 (on right) | C1/5 | PB,2010 | no | Outside wall crack | D |
| 54/Somobai R/A, Road No 1, Building No 5 (on left) | C1/3 | PB,2017 | no | no | D |
| 55/Somobai R/A, Road No 1, Building No 7 (on right) | C2/8 | PB,2010 | yes | no | D |
| 56/Somobai R/A, Road No 1, Building No (on left) | C1/7 | PB,2009 | yes | no | D |

| Building No. and Location | No. of Stories | Year of Construction | Soft stories | Visual Defects | Soil Type |
|---|---|---|---|---|---|
| 57/Somobai R/A, Road No 3, Building No 3 (on left) | C1/8 | PB,2008 | yes | no | D |
| 58/Somobai R/A, Road No 3, Building No 6 (on right) | C1/6 | PB,2009 | no | no | D |
| 59/Somobai R/A, Road No 3, Building No 9 (on left) | C1/2 | PB,2005 | no | Outside wall crack | D |
| 60/Somobai R/A, Road No 3, Building No 11 (on right) | C1/5 | PB,2010 | no | no | D |
| 61/Chockresho R/A, Road No 1, Building No 3 (on left) | C1/4 | PB,2010 | no | no | D |
| 62/Chockresho R/A, Road No 1, Building No 5 (on right) | C1/6 | PB,2009 | no | Ground floor wall crack | D |
| 63/Chockresho R/A, Road No 1, Building No 7 (on left) | C1/5 | PB,2007 | no | no | D |
| 64/Chockresho R/A, Road No 1, Building No 9 (on right) | C1/7 | PB,2008 | yes | no | D |
| 65/Chockresho R/A, Road No 2, Building No 3 (on left) | C1/2 | PB,2002 | yes | no | D |
| 67/Chockresho R/A, Road No 1, Building No 5 (on right) | C1/6 | PB,2005 | yes | no | D |
| 68/Chockresho R/A, Road No 2, Building No 7 (on left) | C1/7 | PB,2014 | yes | no | D |
| 69/Chockresho R/A, Road No 2, Building No 9 (on right) | C1/7 | PB,2016 | no | no | D |

| **Building No. and Location** | **No. of Stories** | **Year of Construction** | **Soft stories** | **Visual Defects** | **Soil Type** |
|---|---|---|---|---|---|
| 70/Chockresho R/A, Road No 3, Building No 3 (on left) | C1/6 | PB,2018 | no | no | D |
| 71/Chockresho R/A, Road No 3, Building No 6 (on right) | C1/6 | PB,2009 | yes | no | D |
| 72/Chockresho R/A, Road No 3, Building No 9 (on left) | C1/6 | PB,2006 | yes | Outside plaster slides crack | D |
| 73/Chockresho R/A, Road No 3, Building No 11 (on right) | C1/4 | PB,2005 | yes | no | D |
| 74/Chockresho R/A, Road No 4, Building No 3 (on left) | C1/7 | PB,2004 | no | no | D |
| 75/Chockresho R/A, Road No 4, Building No 6 (on right) | C1/6 | PB,2003 | no | no | D |
| 76/Baizid Bostami R/A, Road No 1, Building No 3 (on left) | C1/5 | PB,2006 | no | no | D |
| 77/Baizid Bostami R/A, Road No 1, Building No 5 (on right) | C1/4 | PC,1990 | no | Ground floor wall crack | D |
| 78/Baizid Bostami R/A, Road No 1, Building No 8 (on left) | C1/4 | PC,1991 | no | Outside wall crack | D |
| 79/Baizid Bostami R/A, Road No 1, Building No 11 (on left) | C1/6 | PB,1999 | no | no | D |
| 80/Baizid Bostami R/A, Road No 2, Building No 3 (on right) | C1/7 | PB,2008 | no | no | D |
| 81/Baizid Bostami R/A, Road No 2, Building No 5 (on left) | C1/5 | PC,1988 | no | Outside wall crack | D |

| Building No. and Location | No. of Stories | Year of Construction | Soft stories | Visual Defects | Soil Type |
|---|---|---|---|---|---|
| 82/Baizid Bostami R/A, Road No 2, Building No 7 (on right) | C1/5 | PB,2001 | no | no | D |
| 83/Baizid Bostami R/A, Road No 2, Building No 9 (on left) | C1/5 | PB,2009 | no | no | D |
| 84/Baizid Bostami R/A, Road No 2, Building No 11 (on right) | C1/5 | PC,1987 | no | Outside and stair wall crack | D |
| 85/Baizid Bostami R/A, Road No 3, Building No 3 (on left) | C1/6 | PB,2006 | yes | no | D |
| 86/Baizid Bostami R/A, Road No 3, Building No 5 (on right) | C1/4 | PC,1989 | no | Outside wall crack | D |
| 87/Baizid Bostami R/A, Road No 3, Building No 7 (on left) | C1/6 | PB,1998 | yes | no | D |
| 88/Baizid Bostami R/A, Road No 3, Building No 9 (on right) | C1/4 | PB,2009 | yes | no | D |
| 89/Baizid Bostami R/A, Road No 3, Building No 11 (on left) | C1/3 | PC,1990 | no | Outside wall crack | |
| 90/Baizid Bostami R/A, Road No 4, Building No 3 (on right) | C1/5 | PB,2004 | no | Ground floor wall crack | D |
| 91/Baizid Bostami R/A, Road No 4, Building No 5 (on left) | C1/4 | PC,1985 | no | Outside plaster crack | D |
| 92/Baizid Bostami R/A, Road No 4, Building No 7 (on right) | C1/5 | PC,1990 | yes | Outside plaster crack | D |

| Building No. and Location | No. of Stories | Year of Construction | Soft stories | Visual Defects | Soil Type |
|---|---|---|---|---|---|
| 93/Baizid Bostami R/A, Road No 5, Building No 3 (on left) | C1/4 | PC,1986 | yes | Outside wall and plaster crack | D |
| 94/Baizid Bostami R/A, Road No 5, Building No 5 (on right) | C1/6 | PB2001 | no | no | D |
| 95/Baizid Bostami R/A, Road No 5, Building No 9 (on left) | C1/3 | PB,2000 | no | no | D |
| 96/Baizid Bostami R/A, Road No 6, Building No 3 (on right) | C1/5 | PB,2003 | no | no | D |
| 97/Baizid Bostami R/A, Road No 6, Building No 6 (on left) | C1/7 | PB,2005 | no | no | D |
| 98/Baizid Bostami R/A, Road No 6, Building No 9 (on right) | C1/6 | PB,2008 | yes | no | D |
| 99/Baizid Bostami R/A, Road No 7, Building No 3 (on left) | C1/4 | PB,1995 | no | Outside wall crack | D |
| 100/Baizid Bostami R/A, Road No 7, Building No 7 (on right) | C1/2 | PB,1999 | no | no | D |
| *Note:*<br>PC- Pre-Code (Before 1993)<br>PB- Post Bench Mark<br>C1- Reinforced Masonry Building<br>C2 – Shear wall based residential Building<br>Soil Type D- Stiff Soil | | | | | |

# APPENDIX B

**Selected Building Photographs**

Oxygen to Jalalabad: Selected Building Photographs

## Oxygen to Jalalabad




Bangladesh Co-operative Society to Roufabad: Selected Building Photographs

## Bangladesh Co-operative Society to Roufabad

Paharika to Somobai Residential Area: Selected Building Photographs

## Paharika to Somobai Residential Area

Cantonment Public Chockresho Kanon: Selected Building Photographs

# Cantonment Public Chockresho Kanon

Baizid Bostami: Selected Building Photographs

# Bayzid Bostami