Assessment of Seismic Vulnerability of Typical RC Garments Building of Chattogram City Corporation

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Assessment of Seismic Vulnerability of Typical RC Garments Building of Chattogram City Corporation

A Thesis/Project

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A Project

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CERTIFICATION

The thesis/project report titled "**Assessment of Seismic Vulnerability of Typical RC Garments Building of Chattogram City Corporation**" submitted by **Md. Hedayet Ullah**, Student ID: **19MDEM001P**, 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 28th March 2024.

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This is to certify that **Md. Hedayet Ullah** has carried out this project work under my supervision, and he has fulfilled the relevant Academic Ordinance of the Chittagong University of Engineering and Technology, so he is qualified to submit the following project report in the application for the degree of MASTER OF ENGINEERING. Furthermore, the project work complies with the PLAGIARISM and ACADEMIC INTEGRITY regulations of CUET.

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Dedication

I would like to dedicate this work to my lovely mom **MRS ROUSAN ARA** who is my source of inspiration and encouragement.

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ATC	Applied Technology Council
BSH	Basic Structural Hazard Score
BNBC	Bangladesh National Building Code
CRR	Cyclic Resistance Ratio
CSR	Cyclic Stress Ratio
EQ	Earthquake
FS	Factor of Safety
FEMA	Federal Emergency Management Agency
ASCE	American Society of Civil Engineers
GIS	Geographic Information System
HAZUS	Hazards US
HYDE	Hysteretic Device
MSF	Magnitude Scaling Factor
NRC	National Research Council
PGA	Peak Ground Acceleration
RVS	Rapid Visual Screening
RC	Reinforced Concrete
SPT	Standard Penetration Test
VAM	Vulnerability Assessment Methods

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Abstract

Many industrial infrastructures of urban areas of Bangladesh are highly vulnerable to natural disasters like earthquake. The ready-made garments industries of Chattogram are not generally built as earthquake resilient following guidelines of Bangladesh National Building Code (BNBC). In this project, a field survey was conducted on typical reinforced concrete (RC) garments buildings of a few wards of Chattogram City Corporation. Data collected by Rapid Visual Screening (RVS) of selected buildings of a ward are analyzed to assess seismic vulnerability of typical RC garments buildings of Chattogram city. Methods of widely used RVS for seismic vulnerability assessment such as FEMA 154, FEMA 310, ASCE 41-13 etc. are used. Significant problems related to seismic vulnerability parameters are found to exist in load path, soft stories, weak brick joints, vibration of equipment etc. Horizontal and vertical plan irregularities of building construction, strong beams/weak columns, diaphragm discontinuity, etc. are also observed in many surveyed buildings of the study area. According to FEMA 154 method, 29% of the buildings are assessed to be vulnerable to earthquake hazards. On an average, the selected buildings do not satisfy 54% and 79% of the respective vulnerability criteria according to FEMA 310 and ASCE 41-13 methods of Tier-1 assessment. The probability of collapse due to a high intensity earthquake is moderate in 70% of the surveyed buildings whereas the probability due to seismic vulnerability is high for 6% of the RC buildings according to a vulnerability rating index method of visual assessment. The RC industrial buildings were also assessed in terms of a few additional guidelines of BNBC regarding front road width, utility line distance, assembly area or rescue facilities etc. The seismic vulnerability is found to be increased when the RVS assessment is done including these important criteria of urban seismic resilience.

বিমূর্ত

বাংলাদেশের নগর অঞ্চলের অনেক শিল্প প্রতিষ্ঠানের অবকাঠামো বিভিন্ন প্রাকৃতিক দুর্যোগ যেমন ভূমিকম্পের উচ্চ ঝুঁকিতে রয়েছে। চট্টগ্রামের রেডিমেড গার্মেন্টস তথা তৈরি পোশাক শিল্প প্রতিষ্ঠানের ভবনগুলো সাধারণভাবে বাংলাদেশ ন্যাশনাল বিল্ডিং কোড (বি.এন.বি.সি) অনুসরণপূর্বক ভূমিকম্প সহনীয় স্থাপনা হিসেবে নির্মিত হয়নি। এই প্রকল্পে চট্টগ্রাম নগরের কয়েকটি ওয়ার্ডে জরিপ চালানোর মাধ্যমে আর.সি কংক্রিটের তৈরি গার্মেন্টস ভবনের তথ্য সংগ্রহ করা হয়। নগরের একটি গুরুত্বপূর্ণ শিল্প এলাকার নির্বাচিত কিছু সংখ্যক ভবনের উপর দ্রুত ভিজ্যুয়াল স্ক্রীনিংয়ের পদ্ধতি প্রয়োগে সংগৃহীত তথ্যের উপর বিশ্লেষনাত্তক অনুসন্ধান পদ্ধতি প্রয়োগের মাধ্যমে আর.সি কংক্রিটের তৈরি গার্মেন্টস ভবনের ভুমিকম্পে ক্ষতিগ্রস্থ হওয়ার ঝুঁকি নির্ণয় করা হয়। মাঠ জরিপের সময় বহুল ব্যবহৃত দ্রুত ভিজ্যুয়াল স্ক্রীনিংয়ের পদ্ধতি যেমনঃ এফ.ই.এম.এ. ১৫৪, এফ.ই.এম.এ. ৩১০, এ.এস.সি.ই ৪১-১৩ ইত্যাদি বেছে নেওয়া হয়। জরিপে লক্ষণীয় ভবনগুলোর উল্লেখযোগ্য সমস্যা ছিল অসম্পূর্ণ লোড পাথ, সফট স্টোরি, ইটের দুর্বল জয়েন্ট, সরঞ্জামের কম্পন ইত্যাদি। এছাড়াও এই প্রকল্পে জরিপকৃত অনেক ভবনের ক্ষেত্রে আনুভূমিক ও উলম্ব সম্প্রসারণে অনিয়ম, শক্তিশালী বিম- দুর্বল কলাম ডিজাইন, ডায়াফ্রাম অধারাবাহিকতা ইত্যাদি সমস্যা পরিলক্ষিত হয়। এফ.ই.এম.এ. ১৫৪ পদ্ধতির ভিজ্যুয়াল রেটিং সূচকে ভবনগুলোর শতকরা ২৯ ভাগের ভূমিকম্পে ক্ষতিগ্রস্থ হওয়ার ঝুঁকি বিদ্যমান। গড় হিসাবে, এফ.ই.এম.এ. ৩১০ এবং এ.এস.সি.ই ৪১-১৩ পদ্ধতির প্রথম ধাপের স্ক্রীনিং তালিকার যথাক্রমে শতকরা ৫৪ ভাগ এবং শতকরা ৭৯ ভাগ নির্ণায়ক প্যারামিটার নির্বাচিত ভবনগুলোর ক্ষেত্রে মানোত্তীর্ণ নয়। ভিজ্যুয়াল স্ক্রীনিংয়ের পদ্ধতি প্রয়োগে নির্ণীত একটি ঝুঁকি ইন্ডেক্স সূচকে জরিপকৃত এলাকার ৭০% আর.সি কংক্রিট গার্মেন্টস ভবনের শক্তিশালী ভূমিকম্পে ধ্বসে পড়ার "মধ্যম মানের" ঝুঁকি বিদ্যমান এবং ৬% ভবন ধ্বসে পড়ার ঝুঁকি "উচ্চ মানের"। মাঠ জরিপের সময় ভবনগুলোকে দ্রুত ভিজ্যুয়াল স্ক্রীনিং নির্দেশিকার বাইরেও বি.এন.বি.সি অনুযায়ী অনুসরণীয় অতিরিক্ত কিছু প্যারামিটার যেমন, সামনের রাস্তার প্রশস্থতা, ইউটিলিটি লাইনের দূরত্ব, এসেম্বলি স্থান ও উদ্ধার সুবিধার পর্যাপ্ততা ইত্যাদির ভিত্তিতে মূল্যায়ন করা হয়। নগরের ভুমিকম্প সহনশীলতা নিশ্চিত করার জন্য গুরুত্বপূর্ণ এসব প্যারামিটার দ্রুত ভিজ্যুয়াল স্ক্রীনিং পদ্ধতিতে অন্তর্ভুক্ত করা হলে ভবনগুলোর ভূমিকম্পে ক্ষতিগ্রস্থ হওয়ার ঝুঁকি বেড়ে যায়।

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Chapter 1

Introduction

1.1 Background and Rationale of the Project

The Economy of Bangladesh has become a major economy in South Asia. The emerging market economy of the country has been ranked as the 41st largest economy in the world by nominal GDP growth [1]. Bangladesh is anticipated to have the 24th largest economy in the world by 2030 [2]. Rapid industrialization has been promoted as an essential prerequisite for achieving sustainable economic development in the country. The infrastructural and industrial development of Chattogram City has played a vital role in the overall economic development of the country. Chattogram is the major port city as well as the commercial capital of Bangladesh. Various types of industries have been established in Chattogram due to the ease of export through this gateway to Bangladesh. More than 92% of exported and imported goods are transported through the Chattogram port [3-5].

The major contributing sector to the economic development of the country is the Ready Made Garments (RMG) sector. The RMG industrial sector has gone through rapid but unplanned growth throughout the major urban centers of Bangladesh, especially in Dhaka and Chattogram city areas. Chattogram RMG industries contribute significantly to the national economy [6-7]. However, the infrastructures of RMG industries are vulnerable to several natural and anthropogenic hazards. There are major issues of vulnerability of these industrial facilities and infrastructures due to anthropogenic and natural hazards such as seismic events or earthquakes, accidental fire hazards, cyclones, floods, etc. [8-11].

Following the Rana Plaza disaster, numerous national and international measures were implemented to enhance structural safety. These initiatives aim to reform and restructure Bangladesh's ready-made garment (RMG) sector, to minimize the risk of structural failures and improve workplace safety. However, the seismic vulnerability is still very high in garment buildings [12]. The Government of Bangladesh has taken different initiatives to reduce the damage caused by natural disasters to industrial buildings [4,7,13]. Bangladesh National Building Code (BNBC, 2020), mandated to ensure the safety of the constructed industrial buildings, has detailed guidelines to be followed for planning and construction of this type of buildings. Even though many government agencies have inspected garment buildings after the Rana Plaza incident, safe working conditions are yet to be ensured in the garment buildings. Any accidental hazards in this type of industrial building due to major seismic events such as earthquakes are more worrisome than other buildings. Since thousands of workers work in the RMG industrial buildings, the casualties of people and property will be very high if an accidental event of earthquake occurs especially during the daytime [14-15].

Historical data indicates that several significant earthquakes have occurred in or near Bangladesh. Due to its location near the expected collision boundaries of the northeast Indian Plate and the Eurasian Plate, Bangladesh faces a substantial risk of moderate to severe earthquakes in the future. Even a medium-magnitude earthquake on the Richter scale could result in massive casualties in major cities like Dhaka, Sylhet, and Chittagong [6, 12, 16]. According to the Global Hazard Assessment Program (GSHAP), the most hazardous division in Bangladesh is the Port City Chittagong. The hilly terrain of this city corporation area may also induce huge landslides during a heavy earthquake [12].

Among many of the RMG industrial buildings in Chattogram, most of the buildings are reinforced concrete (RC) structures. Many of the RC buildings being used as RMG industrial facilities in Chattogram are not even purpose-built for industrial use [2, 18]. Therefore, many of these RC buildings are vulnerable to major loss or damage due to disasters like earthquakes. There exist many design and functional problems that do not conform to design, construction, or functional standards for developing seismic resilience according to national or international standards. Among many of the technical deficiencies in the design or functional problems, major problems that are commonly observed in RC buildings of RMG industries of Chattogram city are plan irregularities in various aspects, soft stories, heavy overhang with unreinforced masonry works, post-seismic hazards from utility connection, effects of vibrating machinery or attached heavy equipment, etc. [12, 14].

In these backdrops, this project is aimed at assessing the vulnerability of typical RC garment buildings of Chattogram City. Since many of the garment buildings of the city are RC frame structure buildings, several randomly selected RC garment buildings of a typical industrial zone of Chattogram are chosen for seismic vulnerability assessment. Seismic vulnerability assessment is done through several rapid visual screening methods by walk-down surveys done in the study area. Vulnerability parameters are chosen based on major design and functional parameters that are generally considered important for the seismic resilience of buildings. Emphasis is also given on safety and vulnerability considerations aftermath of an earthquake such as emergency rescue or evacuation routes, sufficient road width in front of the building premise, fire safety measures with relevance to earthquake hazards, electrical and gas line safety measures, post-earthquake rescue planning or execution, etc. that are considered very important in the planning hierarchy of urban seismic resilience [12, 14-15].

1.2 Objectives with Specific Aims

This project is aimed at conducting a seismic vulnerability assessment of typical RC garment buildings of Chattogram City using a preliminary assessment tool commonly known as Rapid Visual Screening (RVS) [20]. As the assessment in RVS is done from the outside of a building, the interior of buildings cannot be inspected in the conventional RVS methods of assessment. Consequently, invisible risks may lead to improper evaluation of the overall seismic performance or resilience of a building. While a building has many internal and external features that collectively influence the seismic resilience of the building itself as well as the overall urban seismic resilience, the RVS methods should include many factors in addition to those used in common RVS methods [20, 22]. In this regard, one of the major objectives of this study is to address some additional features of vulnerability assessment in the RVS methods that are not covered in the conventional RVS methods. The specific objectives of the project work are as follows.

- To assess current conditions or vulnerability of typical RC garments building of Chattogram city as compared to the benchmarks set in BNBC.
- To compare the seismic vulnerability of the buildings using different methods of vulnerability assessment.
- To recommend additional features that need to be integrally considered in seismic vulnerability assessment considering specific hazard states relevant to our country.
- To evaluate possible incorporation in seismic vulnerability assessment aspects using an analytical hierarchy of urban planning aspects of Bangladesh.

1.3 Organization of the Report

The findings of the project work including the scope of the work, objectives and methodology, and seismic vulnerability assessment methods are reported in several chapters of this project report. The first chapter provides a brief introduction to the background and rationale of the project work including the specific objectives of the project. The second chapter is written about a literature review done on relevant topics. The third chapter is about the methodology of the work including a brief description of RVS methods of seismic vulnerability assessment that are used in this project work. Chapter 4 of this report is written on findings of an analysis of results of seismic vulnerability assessment by different RVS methods, comparative analysis, and discussions. The fifth and last chapter of this report is about conclusive findings and recommendations of the study [20, 22].

Chapter 2

Literature Review

2.1 General

Earthquake is one of the most deadly natural disasters that may affect the human environment which sometimes may lead to a large number of deaths and huge damage to infrastructure and property as well. Building earthquake vulnerability assessments are, therefore, crucial for identifying potential weaknesses and risks associated with earthquakes. Earthquakes can cause extensive damage to the environment as well. It can have significant environmental impacts, including landslides, liquefaction, and tsunamis. However, there are still several unresolved issues related to earthquakes despite significant advances in seismology. [25-26].

Over the past few centuries, Bangladesh has experienced several large, catastrophic earthquakes. However, in recent times, no significant earthquakes have caused damage in the region. Historical records show that major earthquakes have typically occurred away from major cities, impacting sparsely populated areas. Consequently, human casualties and economic losses have been limited. Despite being rare and lasting only a few seconds, earthquakes can cause extensive damage and have severe long-term consequences, as evidenced by the 2010 Haiti earthquake [27-28].

South and Southeast Asian countries, particularly Bangladesh, India, Nepal, and Myanmar, have significantly failed to ensure earthquake-resistant construction in high seismic zones, despite the rapidly increasing seismic risk in the region in recent years. An assessment of this risk was conducted through Rapid Visual Screening (RVS) of 16,000 buildings in the cities of Gandhidham and Adipur [29]. The study's findings indicate a wide range of construction practices in the region, with RC and masonry structures being the most common. The RVS scores for these buildings suggest that they are generally of low quality. Therefore, further evaluation and strengthening of these buildings are recommended [29, 51].

In the assessment of seismic vulnerability, it is sometimes useful to investigate risks or vulnerability by determining the damage index of existing buildings. An analytical seismic vulnerability assessment of an industrial building in Peninsular Malaysia was carried out to develop analytical vulnerability curves and damage index using the correlation of the building's response to seismic effects [30]. An analytical seismic vulnerability assessment was conducted to evaluate the capacity of industrial buildings in Peninsular Malaysia, where sufficient damage data is lacking. A case study involving an industrial building, specifically an irradiation plant in

Peninsular Malaysia, was used to demonstrate the approach [30] developed for this analytical vulnerability assessment of industrial buildings.

Although South and Southeast Asian countries including Bangladesh are located in a region of significant seismic activity, most people and policy makers are not aware of the potential seismic risks in this region. Understanding the mechanisms of potential future earthquakes in Bangladesh and their effects on the environment is crucial for predicting and mitigating the impact of future earthquakes [26]. Understanding the environmental effects of earthquakes is also very essential for minimizing their impact on the environment and ecosystems [23, 27].

2.2 Chattogram- A Seismic Hazard Zone of Bangladesh

Chittagong City, located in southeastern Bangladesh, is highly vulnerable to earthquakes due to its location near the intersection of several active tectonic plates. Despite this high level of seismic risk, the city's infrastructure is largely unprepared for a major earthquake, putting the lives and livelihoods of its residents at risk [27]. One of the key issues facing Chittagong City is the lack of earthquake-resistant infrastructure. Many buildings, including residential and commercial structures, are constructed using low-quality materials and inadequate building codes. This makes them highly vulnerable to damage or collapse in the event of an earthquake, putting occupants at risk of injury or death [25].

One of the key problems facing Chittagong City is the lack of earthquake preparedness and resilience in the face of a major seismic event. Many residents of Chittagong City are not familiar with the appropriate safety measures to take during an earthquake, such as taking cover under a sturdy desk or table or evacuating buildings quickly and safely. There is a lack of coordinated emergency response planning and resources in the event of a major earthquake. Hospitals, emergency services, and other critical infrastructure may not be adequately equipped to handle the high volume of casualties and damage resulting from a major earthquake [14]. Addressing this problem would require a multi-pronged approach, including improved building codes and regulations, public education and awareness campaigns, and investment in critical infrastructure and emergency response planning [31].

2.3 Preliminary Assessment of Seismic Vulnerability

2.3.1 Tectonics

Bangladesh is situated at the intersection of three tectonic plates: the Indian Plate, the Eurasian Plate, and the Burma Plate, as illustrated in Figure 2-1. To the north of Bangladesh, the Indian Plate converges with the Eurasian Plate, while in the east, the Burma Plate intersects with the Indian Plate. The Indian Plate is moving northeast, and the Burma Plate is moving northwest. Additionally, the Shillong Plateau fault lies to the north of Bangladesh, with the east-west trending Dauki Fault running along the southern edge of the Shillong Plateau, as shown in Figure 2-1. The Dauki Fault may extend to the northern part of the subduction fault in Sylhet [23, 27].

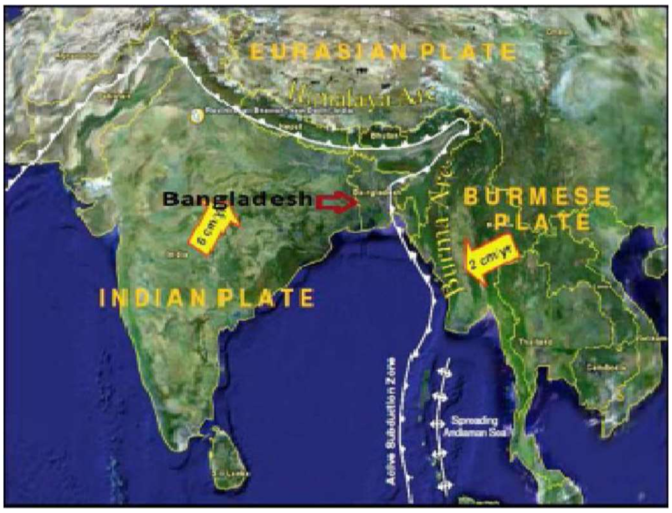


Figure 2-1: Plate Boundary between Indian and Eurasian plate,
(Background: Google Earth)

Plate Boundary Fault 1 (PBF1)

According to Shishikura et al. (2007), the latest event along PBF occurred during the 1762 earthquake, and the recurrence period is 900 years. The 50-year probability of future earthquake occurrence is 1.1 %, which is small because the elapsed time since the latest event is 246 years and the recurrence period is 900 years [28].

Plate Boundary Faults 2 and 3 (PBF2 and PBF3)

The latest event and the recurrence period along the PBF2 and PBF3 are unknown. If the 900 years by analogy with PBF1 and the latest event are before the 16th century, the 50-year probability is over 6.7% [31].

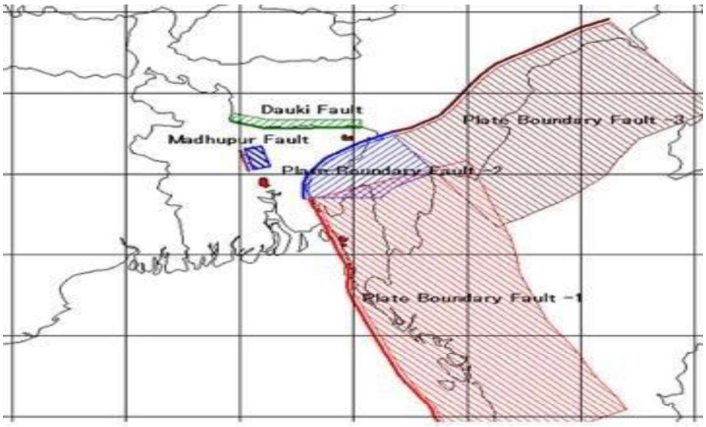


Figure 2-2: Scenario Earthquake Fault Model, Adapted from [11]

Dauki Fault (DF)

The latest event corresponds with the 1897 Great Assam Earthquake. The time of the penultimate event is inferred to correspond with the 1548 earthquake. Since the recurrence period is 349 years and the elapsed time is 111 years, the 50-year probability is 7.0% [31].

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% [31].

2.3.2 Historical Earthquake, Seismic Sources and Magnitude

There are a few sources that documented data on historical earthquakes in and around Bangladesh. The following table is a summary of data collected from several earthquake catalogs, such as website information at "Banglapedia Earthquake" [12]. Figures 2-3 and 2-4, also show data of historical earthquakes in and around Bangladesh. Significant information on earthquakes in and around Bangladesh has been available for the last 100 years in other important documents [28]

Table 2-1: Major Earthquake in Bangladesh in the last 100 years [12].

Date	Name of earthquake	Magnitude	Epicenter
8 July, 1918	Srimangal earthquake	7.3	Bangladesh-Tripura border
9 September, 1923	Meghalaya earthquake	7.1	Bangladesh-India border (Meghalaya)
2 September, 1930	Dubri earthquake	7.1	Dubgiri
6 March, 1933	India Bangladesh earthquake	7.6	Bangladesh-India border
15 January, 1934	Bihar Nepal earthquake	8.3	Bihar Nepal border
11 February 1936	Bihar earthquake	7.5	North Bihar
16 August, 1938	Manipur Earthquake	7.2	Monipur-Maynmar earthquake
23 October, 1943	Assam earthquake	7.2	Hojai Assam
21 March, 1954	Monipur-Maynmar earthquake	7.4	Monipur-Maynmar border
21 November, 1997	Bandarban earthquake	7.1	Mizoram-Maynmar border
26 December, 2004	Cox's Bazar earthquake	7.0	Bodda Ace, Indonesia
12 September, 2007	Tsunami due to earthquake (Cox's Bazar)	8.5	Bengkula, Sumatra

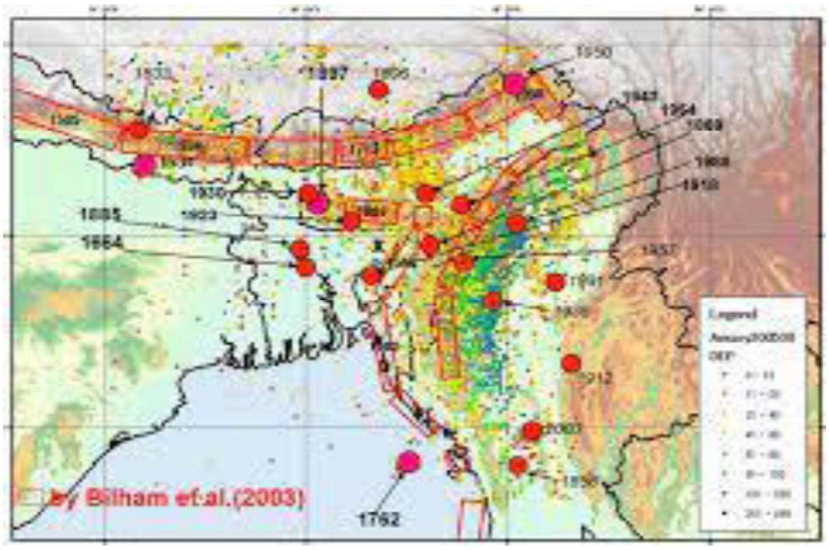
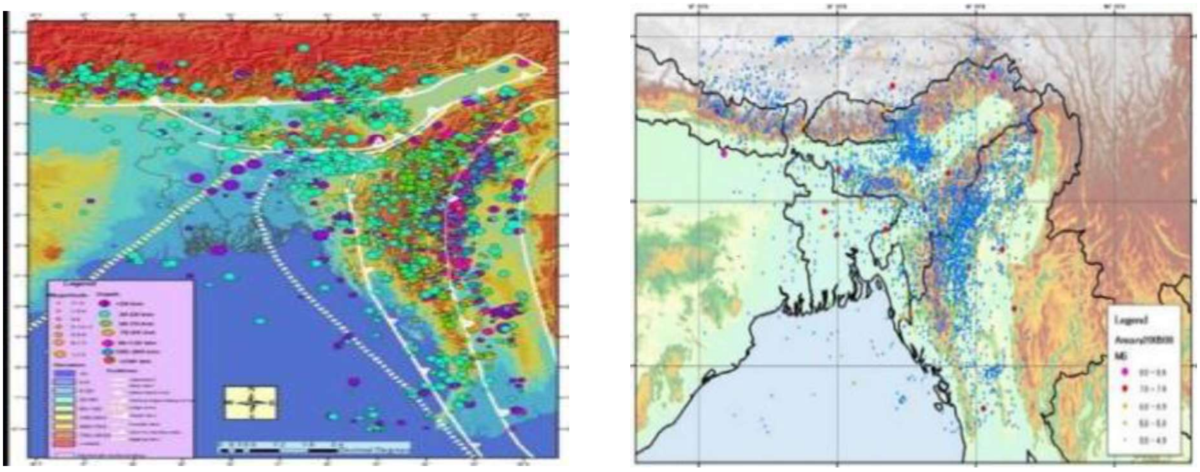


Figure 2-3: Epicenter of Historical Earthquakes from 1664 to 2007 [11].



(a) Earthquake Magnitude in and Around Bangladesh

(b) Depth and Source Region of Historical Earthquakes

Figure 2-4: Seismicity in Bangladesh, from [11]

Figure 2-4 shows that seismic activity in Bangladesh is high along the boundary between the Indian and Eurasian Plates and near the Dauki Fault. Bolt (1987) analyzed various seismic sources in and around Bangladesh and concluded the maximum likely earthquake magnitude for the region [13]. He also took into account fault length, fault characteristics, earthquake records, and the maximum magnitude of earthquakes that can occur in different tectonic blocks, as detailed in Table 2-2 [28].

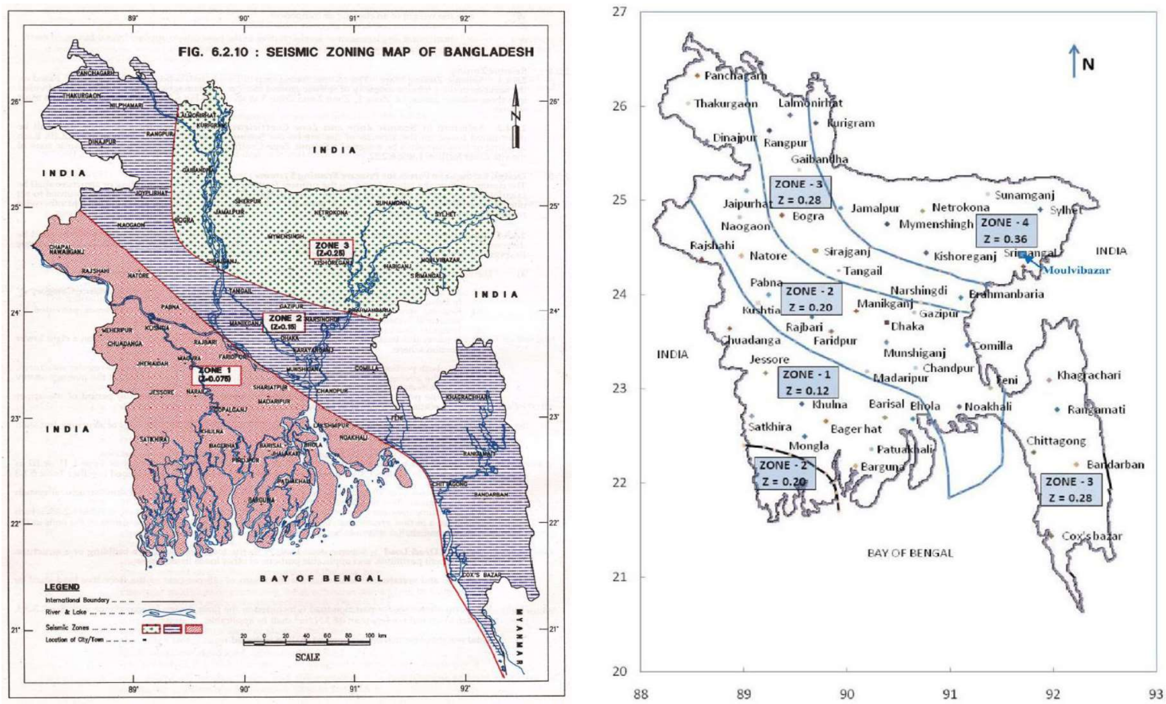
Table 2-2: Significant Seismic Sources for Bangladesh, [13]

Location	Maximum likely 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

Table 2-2 indicates that the Assam and Tripura fault zones have major faults that could potentially generate earthquakes of magnitude 8.6 and 8.0, respectively, in the future. Similarly, earthquakes with a maximum magnitude of 7.5 in the Sub-Dauki and Bogra fault zones are also possible [27].

2.4 Seismic Zoning Maps

According to the seismic zoning map of Bangladesh, the country is divided into several seismic zones based on maximum expected ground motions (forces) for earthquakes likely to occur in a specific zone or area. The country was divided into three generalized seismic zones according to BNBC 1993 as shown in Figure 2-5.a, with zone coefficient Z equal to 0.25 (zone-I), 0.15 (zone-II), and 0.075 (zone-III). According to a study by Bolt [13], it appears that the seismic zoning and zone co-efficient of BNBC 1993 are not consistent with those of the neighboring country India and it is felt that the seismic zoning of BNBC is required to be upgraded. With this in line, again the basis of the Maximum Credible Earthquake (MCE) with a return period of 2475 years has been introduced in the building code BNBC 2020. As depicted in Figure 2-5.b, Bangladesh's seismic zoning map is divided into four seismic zones, each with a corresponding zone coefficient: Zone 1 has a coefficient of 0.12, Zone 2 has 0.2, Zone 3 has 0.28, and Zone 4 has 0.36. This coefficient signifies the Peak Ground Acceleration (PGA) value on rock or very stiff soil sites [22, 28, 35].

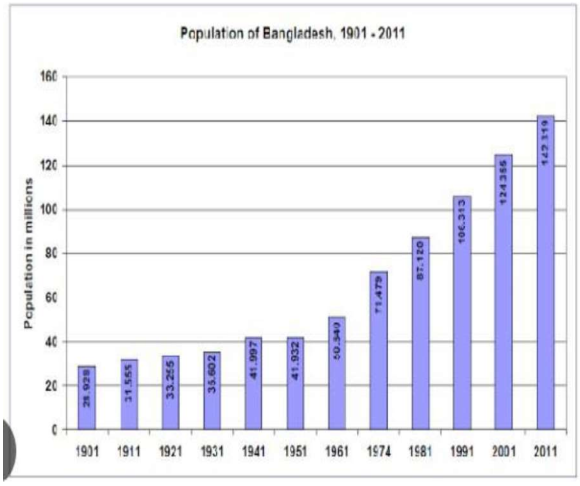


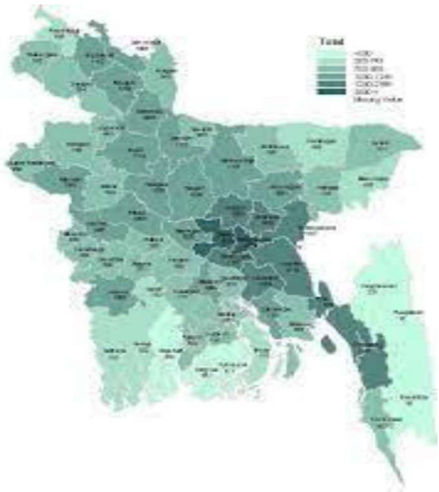
a) Seismic Zoning Map in BNBC 1993 b) Seismic Zoning Map in BNBC 2020

Figure 2-5: Seismic Zoning Map of Bangladesh, Adapted [15]

2.5 Population and Construction Trends of Bangladesh

There have been several human censuses in Bangladesh after its independence in 1971. The figures below show 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 according to the 2011 Census Preliminary Results shown in Figure 2-6.a and 2-6.b, the highest density (inhabitants/km^2) at the district level is 8,111 in Dhaka and in Narayanganj district it is 4,139; and the lowest is in Bandarban district (86) [23, 27]. According to the population & housing census, the sudden increase in the population and the necessity for commercial and office space as well as residential space in the city have resulted in the increasing number of constructions of tall buildings in the city [14].





a) Population Trend of Bangladesh, since 1901 b) Population Density in 2011

Figure 2-6: Population trend in Bangladesh, from Population & Housing Census (2011)

2.5.1 Population and Economic Growth in Chattogram City

An increased proportion of people are being concentrated in limited urban spaces of major cities of the country like Dhaka of Chattogram city areas where the services of public utilities have not proportionately grown over the last few years [21]. This is a general tendency in all major cities around the world which happens mainly due to uncontrolled growth of population. According to the recent census, more than 300 urban regions in the world are accommodating on average more than one million people. This is an indication of the large future growth of the urban population of the world as well as the growing challenges of urban authorities to provide public utility services. The problems and challenges will be enormous in developing countries where the concerned city authorities are already suffering to provide necessary urban services to their present population with scarce resources [17, 26].

The strategic importance of Chattogram City has been established mainly as being the main port city of Bangladesh. It has strategic importance not only for contributing to the economic growth of the country but also for serving as an economic hub in the South Asian countries' cooperation for commerce, trade, and development. It plays a pivotal role in promoting global and regional connectivity and has every potential to transform itself as one of the global financial centers and regional transshipment hubs across South and Southeast Asian countries. Considering a favorable geopolitical and economic alignment with the Chinese and Indian economies, the government of the country has reasonably set goals to become a middle-income country by the year 2021 and a developed country by 2041. It is, therefore, very important to set a proper strategic plan to control and guide urban growth in the Chattogram region in a planned way [16, 19, 23, 25].

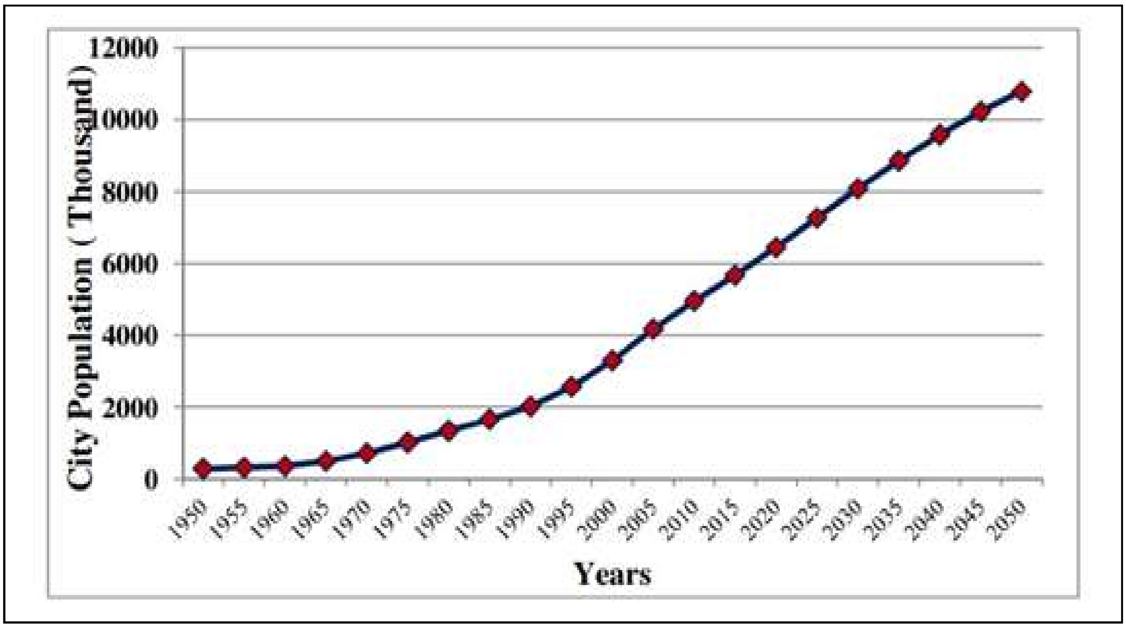


Figure 2-7: Current and Future Trends of Population Growth in Chattogram City

2.5.2 Seismic Events of Chattogram City

Disasters like earthquakes may turn out to be highly unfavorable events causing irrecoverable losses, especially in Dhaka, Chattogram, and Sylhet regions of the country. This may happen mainly because of the uncontrolled growth of the population in these urban areas that occurred during the last few decades. Most of the structures are non-engineered in nature and have multiple issues of vulnerability due to earthquakes as well as their secondary effects or associated post-seismic hazards. Although major earthquake events in this region have been rare in the past centuries (Table 2.3), the probabilities of future major earthquakes and the vulnerability of the urban area of Chattogram even due to moderate earthquakes cannot be neglected. Some of the urban structures in Chattogram are very old and constructed before BNBC regulations and control of municipal authorities came into action.

In these backdrops, Rahman et al. (2015) conducted a composite vulnerability assessment in selected urban areas of Bangladesh where the assessment of structural vulnerability was analyzed by a FEMA-RVS method, fire hazards vulnerability assessment was done according to ADPC (2004), and social vulnerability assessment was done by a method developed by World Bank (2014) [22,27]. The findings of the assessment suggest that urban structures are highly vulnerable to earthquakes and associated post-seismic hazards and there exists a very low level of awareness against possible hazards of earthquakes. The findings of this type of research could be useful for policy and decision-makers to prioritize risk mitigation investments, and measures to strengthen the emergency preparedness and response mechanisms against future earthquake events [22, 30].

Table 2-3: Earthquake in Around Chattogram, [18]

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 buildings were severely cracked
21-11-1997	Bandarban,Myanmar	6.1	The sinking of two underground floors of a storied building and 32 people dead.
22-12-1999	Moheskhali	5.1	7 persons died and 24 persons were injured, 1292 houses were fully damaged with 5662 partially, and 10 cyclone centers and other structures were damaged.
22-07-2005	Dhaka(Manikganj)	4.2	20 people were injured
22-07-2011	Rangamati	5.5	Two people died
03-05-2011	Comilla	4.6	N/A

2.6 Characteristics of Earthquake Resistant Buildings

2.6.1 Structural Simplicity, Uniformity and Symmetry

Structural simplicity, uniformity, and plan symmetry are characterized by an even distribution of mass, structural elements, and its lateral force-resisting system. The modeling, analysis, detailing and construction of simple and regular structures are subject to much less uncertainty and engineers can assess its desired or reliable seismic behavior [33]. Any concentrations of stress or large ductility due to non-uniformity along the height of the structure may induce premature collapse of a structure in sensitive zones [34]. Based on these considerations, both the lateral stiffness and the mass of different story levels should remain nearly constant. Any required reduction or increase of mass and stiffness in any story level should be introduced gradually. An irregular building may be subdivided into dynamically independent regular units well separated against the pounding of the individual units to achieve uniformity [38]. The length-to-breadth ratio ($\lambda = L_{max}/L_{min}$) of the building in plan shall not be higher than 4, where L_{max} and L_{min} are respectively the larger and smaller in plan dimension of the building, measured in orthogonal directions [34].

2.6.2 Earthquake Resistant Design in BNBC Code

The ground movement experienced at a specific location during an earthquake is influenced by various factors including the earthquake's magnitude, its source characteristics such as focal depth, the distance from the earthquake epicenter, and the local soil conditions. The seismic zoning map categorizes the country into four zones based on the anticipated levels of ground motion intensity [38]. In each seismic zone, there exists a zone coefficient that offers anticipated peak ground acceleration values on rock or firm soil, aligning with the maximum credible earthquake [33-34].

Designing and constructing buildings to withstand major earthquake events without sustaining any damage is not economically viable. Instead, it is preferable to enhance the anticipated performance and resilience of structures with higher occupancy or those deemed essential. In this context, a designer might opt to create a structure that permits inelastic deformation and concentrates structural damage at designated locations within the structure, all while maintaining its integrity against a major earthquake [38].

To mitigate the earthquake forces exerted on a structure, the response modification or reduction factor, denoted as R, is utilized. This factor leverages the inherent ductility, redundancy, and material over-strength of the structure to dissipate inelastic energy. Additionally, the importance factor, denoted as I augments design forces for crucial structures. By incorporating suitable lateral force-resisting systems with sufficient ductility, detailing, and high-quality construction, buildings can be engineered to achieve a response reduction factor, R, ranging from 5 to 8. Consequently, the provisions outlined in this Code about ductility and detailing must be met, even for structures and components where load combinations excluding earthquake effects yield higher demands compared to combinations incorporating earthquake effects. Elastic deformations calculated under these reduced design forces are then adjusted by the deflection amplification factor, denoted as C_d, to estimate the deformations expected from the design earthquake [41-42].

Seismic design guidelines typically presume the soil beneath a structure will maintain its strength during earthquakes, while careful design of reinforced and prestressed concrete elements is necessary to prevent premature failure. Ductile detailing is crucial for reinforced concrete, and steel structures should be proportioned for high ductility to avoid buckling. Buildings must have complete lateral and vertical force-resisting systems capable of withstanding design ground motions, ensuring sufficient strength, stiffness, and energy dissipation capacity within specified limits of deformation and strength demand. Structural adequacy is demonstrated through mathematical modeling and evaluation for the effects of design ground motions, with seismic forces and their distribution determined according to applicable procedures. Internal forces and deformations are then assessed, ensuring deformation under seismic forces remains within prescribed limits [41-43].

2.6.3 Supplementary Requirements in BNBC for Occupancy C- Institutional Buildings

Construction, Height, and Allowable Area

Construction, height, and allowable area regulations vary depending on the specific location and the building codes and zoning ordinances in place. It is essential to consult the local building department or planning authority to obtain accurate and up-to-date information [34, 38].

Location on Property

The location of a building on a property is typically governed by zoning regulations and setback requirements set by local authorities. These regulations are in place to ensure proper land use, maintain a balance between neighboring properties, and promote safety and aesthetics [39].

Access and Exit Facilities and Egress System

Building access and exit facilities, as well as the egress system, are crucial components of building design and safety. They ensure that occupants can safely enter and exit the building during normal operations and in the event of an emergency [40].

Lighting, Ventilation and Sanitation

Building lighting, ventilation, and sanitation are essential aspects of creating a comfortable, healthy, and functional indoor environment. Adequate lighting is important for occupant comfort, productivity, and safety. Good lighting design should consider natural light sources, artificial lighting fixtures, and control systems. Proper ventilation is crucial for maintaining good indoor air quality and ensuring a healthy environment. Ventilation systems provide a constant supply of fresh air while removing pollutants, odors, and excess humidity. Sanitation refers to the cleanliness and hygiene of a building. It includes various factors such as waste management, water supply, plumbing systems, and facilities for personal hygiene (such as restrooms and hand washing stations) [39-40].

Shaft and Enclosure

Building shafts and enclosures are integral components of a building's infrastructure and play crucial roles in various aspects such as utilities, safety, and functionality. Shafts: Building shafts are vertical or inclined openings within a building that provide passage, access, or containment for various systems, utilities, or services. Building enclosures refer to the exterior envelope or shell of a building that separates the interior spaces from the external environment. The enclosure includes walls, roofs, windows, doors, and other structural components. [40].

Fire Detection, Alarm, Evacuation and Extinguishment System

Fire detection, alarm, evacuation, and extinguishment systems are crucial components of building safety measures. These systems help detect fires, alert occupants, facilitate safe evacuation, and provide means to extinguish or control the fire [38-40].

2.7 Building Inventory Survey 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. By conducting a building earthquake inventory survey, experts can identify vulnerable buildings, prioritize retrofitting efforts, and develop strategies to reduce the risk of earthquake damage to buildings and occupants [37, 40]. Some of the steps that are generally followed to conduct a building earthquake inventory survey are as follows:

Develop a survey plan: Before starting the survey, a plan is developed that includes the objectives, scope, and methodology of the survey. Identification of the target buildings and the criteria for selecting them, such as their age, height, and location are also done in this step.

Collect data: Data is collected about some necessary features of buildings using a variety of sources, such as building permit records, property records, and visual inspections. The building's location, age, height, construction type, materials used, etc. are also recorded. Additional data on occupancy, number of stories, and any previous seismic retrofits are also collected in this step.

Conduct visual inspections: Visual inspections of the buildings are conducted to assess their condition and identify any potential seismic vulnerabilities. Inspection of the foundation, walls, roofs, and other structural components, signs of cracking, settling, and other damage is also done at this step [36].

Assess seismic vulnerability: Assessment of the seismic vulnerability is done based on collected data of the buildings and the visual inspection records. Sometimes a rating system or other method is used to evaluate the level of seismic risk for each building.

Develop recommendations: Recommendations are made for seismic retrofits or other measures to reduce the seismic vulnerability of the buildings. The recommendations are prioritized based on the level of risk and the feasibility of implementation.

Compile the results: A report is made compiling the results of the survey that includes a summary of the findings, a list of the buildings surveyed, and recommendations for reducing seismic vulnerability. [44-45].

2.8 Building Vulnerability Factors

2.8.1 Adjacent Buildings

Adjacent buildings refer to two or more buildings that are next to each other or nearby, typically sharing a common boundary or wall. These buildings can be residential, commercial, or industrial structures and may be owned by the same person or by different parties. Adjacent buildings can have a significant impact on each other's structural integrity, insulation, and overall safety. Therefore, building codes and regulations often require specific standards and guidelines for the construction and maintenance of adjacent buildings to ensure their safety and the safety of those who use them [32-34].

Figure 2-8: View of Typical Adjacent Buildings in a Residential Area Chattogram City

2.8.2 Soft Story

Building a soft story refers to constructing a structure with a ground floor that is designed to be more flexible than the upper floors. This approach is typically used in buildings with a large open ground floor, such as retail stores, parking garages, and other commercial properties [46-47].

Figure 2-9: Soft Story in a Building

2.8.3 Building Vertical Discontinuities

Building vertical discontinuities refer to breaks or changes in the vertical plane or elevation of a building's structure, facade, or interior design. These changes may include alterations in the height or width of a building, variations in the materials used in construction, changes in the architectural style or design elements, or transitions between different uses or functions of a building. 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 colors 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 [46-47].

Figure 2-10: Building Vertical Discontinuities

2.8.4 Masonry Units

Masonry units refer to individual blocks or bricks used in construction to create masonry walls, which are walls made by stacking individual units together and bonding them with mortar. Masonry units can be made of various materials such as clay, concrete, stone, or even glass. These units are typically rectangular in shape, and their size, shape, and texture can vary depending on the intended use and architectural style. For example, some masonry units are designed with a rough surface for added grip and slip resistance, while others may be smooth and polished for a more refined appearance.

Masonry units are often preferred for their durability, strength, and fire resistance. They can be used to construct load-bearing walls, decorative facades, chimneys, and other structural elements. 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 [46-47].

Figure 2-11: Masonry Units in a Typical Building of Chattogram City

2.8.5 Masonry Joints

Masonry joints are an essential part of any building made of masonry materials such as brick, concrete blocks, or stone. These joints are used to connect individual masonry units to form a cohesive and stable structure. There are several types of masonry joints commonly used in building construction:

Concave Joint: This type of joint has a concave shape and is commonly used for aesthetic purposes. It is formed by using a jointer tool to create a curved depression in the mortar.

V-Joint: This joint has a V-shaped profile and is commonly used for decorative purposes. It is formed by using a trowel to cut a V-shaped groove into the mortar.

Raked Joint: This joint has a rough, textured appearance and is commonly used for a rustic or informal look. It is formed by using a trowel to rake the surface of the mortar.

Flush Joint: This joint has a flat, smooth surface and is commonly used for a clean, modern look. It is formed by using a trowel to smooth the surface of the mortar flush with the surface of the masonry units.

Weathered Joint: This joint has a sloping profile and is commonly used for drainage purposes. It is formed by sloping the surface of the mortar away from the masonry units to allow water to run off [45-47].

These joints sometimes are weak zones in a building unless the joints are properly done according to design or construction guidelines.

2.8.6 Redundancy

In the context of building structures, redundancy refers to the existence of extra or redundant load paths within a structure that can provide backup support in case of failure or damage to one or more load-bearing elements. Structural redundancy is an important concept in building design, particularly in high-rise buildings, bridges, and other critical infrastructure. The presence of redundant load paths can help to prevent catastrophic failure in the event of an unexpected load or structural damage due to natural disasters, fire, or other hazards [46-47].

For example, a building may have multiple columns or beams supporting a load, rather than relying on a single column or beam. In this way, if one column or beam fails, the load can be redistributed to the remaining columns or beams without compromising the overall stability of the structure. Similarly, in bridges, redundant load paths can be provided through the use of multiple trusses or cables, which can help to distribute loads and prevent catastrophic failure in the event of damage to one or more elements [46].

2.8.7 Flat Slabs and Frames

Flat slabs are a type of reinforced concrete slab structure used in building construction. Unlike traditional slab structures that use beams or girders to support the slab, flat slabs use a simpler and more economical design that eliminates beams and drops.

In a flat slab structure, the slab is directly supported by columns or walls, without any intermediary beams or girders. This is achieved by thickening the slab at the column locations to provide additional strength and support. The flat slab can also be reinforced with steel bars or mesh to provide additional tensile strength and prevent cracking.

Flat slabs offer several advantages over traditional slab structures. First, they are easier and faster to construct, since they eliminate the need for beams and drops, which are complex and time-consuming to install. Second, flat slabs can provide more flexibility in terms of floor height and layout since there are no restrictions 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 [46, 49].

Figure 2-12: Flat Slabs

2.8.8 Diaphragm Continuity

The diaphragm is the structural component that spans between the vertical elements, such as the floors and roof of a building. The diaphragm can be made of various materials such as concrete, steel, or wood, and serves as the horizontal load-bearing element of the building. When a building is subjected to lateral forces, such as wind or seismic forces, the diaphragm is responsible for transferring those forces to the vertical elements of the building that resist them

To ensure the proper transfer of lateral forces, the diaphragm must be continuous throughout the building. This means that there should be no interruptions or discontinuities in the diaphragm that would prevent the lateral forces from being properly transferred to the vertical elements. Discontinuities in the diaphragm can occur due to changes in floor or roof height, openings for stairs or elevators, or other design features. [45- 46]

2.8.9 Plan Irregularities

Plan irregularities refer to deviations from a regular geometric shape in the horizontal plane of a building's layout. These deviations can create complex or asymmetrical floor plans, which can have a significant impact on the building's structural behavior, stability, and performance.

Some examples of plan irregularities in building design include:

Zigzag or L-shaped floor plans, can create load transfer problems and non-uniform distribution of lateral forces.

Projections, such as bay windows or balconies, can create localized concentrations of stresses and impact the structural performance of the building.

T-shaped or offset core layouts, can create torsion and twisting forces that affect the stability and seismic performance of the building.

Changes in floor height, can create vertical irregularities and affect the load transfer and lateral force resistance of the building. Openings or large cutouts in the floor plan, can reduce the effective diaphragm stiffness and create a localized concentration of stresses.

Plan irregularities can have a significant impact on the structural design of a building and may require additional analysis and design considerations to ensure the building's stability and performance. Proper detailing, material selection, and construction techniques may be required to mitigate the effects of plan irregularities and ensure the safety and durability of the building. Building codes and standards often provide guidance and requirements for addressing plan irregularities in building design [46-47].

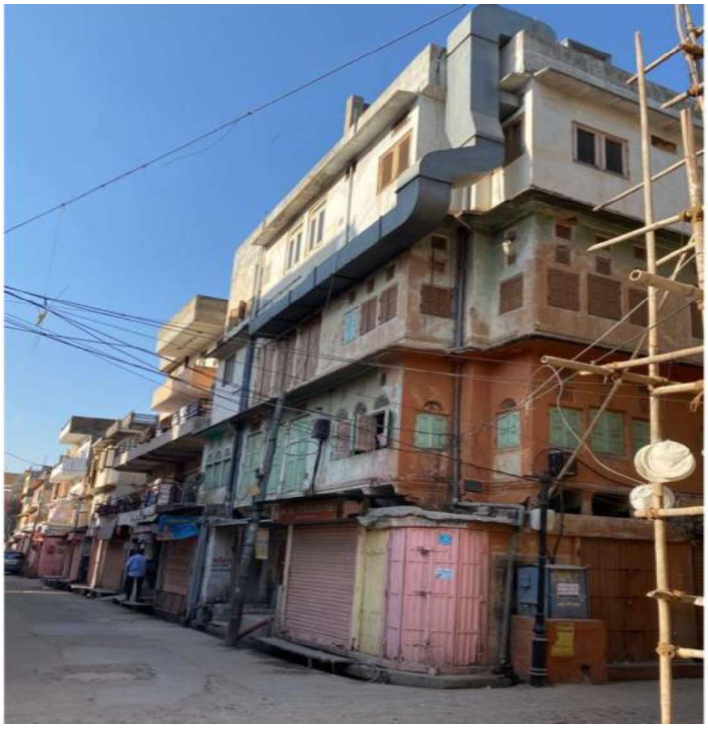


Figure 2-13: Typical Plan Irregularities in Buildings

2.8.10 Attached Equipment

Building attached equipment typically refers to constructing or installing equipment that is directly connected or integrated with a building or structure. This equipment is designed to enhance the functionality, efficiency, or safety of the building. Some common examples of attached equipment include

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

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 [38].

Elevators and Escalators: These are vertical transportation systems that enable people to move between different levels of a building easily and efficiently.

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.

Industrial Compressors: Compressed air systems are used in various applications, including powering pneumatic tools, operating machinery, and providing air for ventilation and process control [32-34].

2.8.11 Building Load Path

The load path in a building refers to the transfer of forces from the various applied loads to the foundation or the ground. It ensures that the structure can safely support the loads it experiences, such as dead loads (weight of the building itself) and live loads (occupant and furniture loads, snow, wind, etc.). The load path is critical for maintaining structural integrity and ensuring the safety of the building [44, 46, 48].

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 walls, columns, or beams and transfers them to the ground. The foundation is designed to distribute the loads and prevent excessive settlement or movement [47].

2.8.12 Building Support Systems

These are essential components of structures that provide stability, load-bearing capacity, and safety. These systems are designed to distribute the weight and forces acting on a building to the ground or other supporting structures.

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.

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.

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.

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.

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 [43-44, 46, 48].

2.8.13 Concrete Columns

A basic guideline for earthquake-resistant buildings is to follow the design guidelines of strong columns and weak beams. Construction of a strong column as per design involves several steps such as design, formwork, reinforcement detailing, pouring concrete, placement, concrete cover to reinforcement, curing, stripping the formwork, finishing, etc.

2.8.14 Complete Frames

Building complete frames, also known as structural frames or building skeletons, involves constructing the primary load-bearing structure of a building. This typically includes columns, beams, and other structural elements that support the floors, walls, and roof. A general chronological order of process to be followed in a complete frame is design, foundation, columns, beams, floor and roof systems, bracing and stability, connections, inspections, and quality control integration with other building components [49].

2.8.15 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 important reasons why the width of the building's front road is significant are outlined below.

Figure 2-14: Typical Condition of Front Road Width of a Garments Building of Chattogram

Access and connectivity: A wider road allows for better access to the building, facilitating the movement of vehicles, pedestrians, and emergency services. It ensures that vehicles can easily enter and exit the property without congestion or obstruction.

Traffic flow and safety: Sufficient road width helps maintain smooth traffic flow, reducing the chances of congestion and traffic jams. It allows for proper lane separation, making it easier for vehicles to navigate and reducing the risk of accidents. Additionally, a wider road may provide space for turning lanes or dedicated bicycle lanes, enhancing safety for all road users.

Parking facilities: The width of the road can impact the availability and configuration of parking spaces. Sufficient road width allows for on-street parking or dedicated parking lanes, providing convenient parking options for visitors, customers, or residents. Adequate parking facilities can increase the attractiveness and functionality of the building [32-34].

2.8.16 Built Purpose

The purpose of a building refers to its intended use or function. Buildings are constructed to serve various purposes based on the needs of individuals, businesses, or communities. Some common purposes for which buildings are built are for residential, commercial, industrial, and recreational use. There are specific design guidelines for different types of buildings, a violation of which may significantly increase vulnerability in many different design and functional aspects. [32-34].

2.8.17 Rescue Facility

A rescue facility is a specialized building designed to support and facilitate emergency response and rescue operations. These facilities are typically constructed to provide a central location for emergency personnel and equipment, ensuring effective and efficient response during critical situations. Here are some key features and considerations for building a rescue facility:

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.

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 centers. [32-34].

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.

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.

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 [38].

2.8.18 Pounding Possibility

Building near tall buildings can pose certain risks and considerations. The Structural considerations of foundations and the structural integrity of a building may be influenced by the presence of adjacent buildings. Potential concerns include differential settlement, ground vibration, and the impact of neighboring construction activities. The Emergency access and egress presence of tall buildings near a new structure can potentially complicate emergency access and egress routes. Adequate planning and coordination are required to ensure proper access to emergency vehicles and evacuation procedures in case of emergencies [46-47].

Figure 2-15: Pounding Possibility due to Closely Adjacent Building Location

2.8.19 Gas and Electricity Line Distance

Building near 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:

Gas Leaks: Building near gas lines increases the risk of gas leaks, which can be hazardous and potentially lead to explosions or fires. It is important to identify the location and depth of gas lines and implement proper safety measures to prevent damage or accidental puncturing during construction.

Electrical Hazards: Building near electric lines introduces the risk of electrical hazards, such as electric shock or fire. Care must be taken to ensure proper clearance from power lines and to avoid any contact with live wires during construction or future maintenance activities [32, 35].

2.9 Rapid Visual Screening for Building Inventory Survey

The huge loss and damage incurred due to catastrophic earthquakes around the world has sparked interest among engineers and scientists to use seismic vulnerability assessment as a primary diagnosis tool for seismic risk analysis of built infrastructure. It provides outputs of vulnerability index parameters which are indicative of expected damage or losses of a specific earthquake event in an area. The representations of the results of vulnerability assessment are often used as helpful tools to support decision-making and implementing alternative seismic risk mitigation strategies.

A vulnerability assessment involves evaluating how susceptible structures are to a particular hazard, estimating the impact, and describing its effects on a community. Vulnerability refers to the extent of loss experienced by a specific element at risk or a group of such elements as a result of the hazard. According to Hugo (1998), the seismic vulnerability of buildings varies significantly depending on their functional and aesthetic purposes. Vulnerability functions of at-risk elements indicate the likelihood that their response to earthquake activity will exceed various performance limit states. The objective of a seismic vulnerability assessment is to determine the probability of damage to a particular type of building caused by an earthquake [36].

Seismic Vulnerability Assessment Methods (VAM) for existing buildings were developed over the last few decades, considering different approaches for the collection of data. Thus, there are different approaches available from the literature. To choose a suitable procedure for the assessment of buildings' seismic vulnerability, a review of the existing methods around the world should be done and comparative assessments can be done on how the different methods vary depending on variations of design practices, and functional and aesthetic aspects in different local and environmental contexts. Thus, a suitable method of seismic vulnerability assessment should be chosen that includes all visible parameters of concern for seismic vulnerability.

The practice of Rapid Visual Screening (RVS) for identifying seismic risks in buildings began in 1988 with the release of the FEMA 154 Report titled "Rapid Visual Screening of Buildings for Potential Seismic Hazards" [45]. Later, many different RVS methodologies have been developed in the past three decades which are being used for a broad audience including building officials and inspectors, government agencies, and private sector building owners. The following sections describe some of the commonly used walk-down survey methods of vulnerability assessments and checklists of parameters used for assessing the seismic vulnerability of a building [36, 46-49].

2.9.1 General Conditions of RVS Assessment Methods

The seismic vulnerability of a constructed system refers to its likelihood of experiencing a specific level of damage when exposed to an earthquake. Accordingly, the objective of a seismic vulnerability method is to quantify the likelihood of a building or a group of buildings being damaged in the event of an earthquake. In practical terms, a vulnerability method should link the assessment of seismic hazards to the actual physical damage sustained by the constructed system, considering structural, geometric, and technological factors that influence the behavior of buildings during seismic events [25, 27, 29].

2.9.2 Common RVS Methods

Various earthquake vulnerability assessment techniques have been developed over recent decades, with several widely utilized methods across the globe. These include FEMA 154 (1988), FEMA 310 (2002), ASCE 41-13 (2013), Modified Turkish method (MTM), Japan RVS Method (2001), Greek Method (2011), GNDT II Level approach (2016), and NRC guidelines (1993). Numerous studies in seismology, structural vulnerability, and earthquake engineering have reviewed these methods. Below, we provide a brief overview of some commonly used RVS methods worldwide [36, 46-48,49]

FEMA 154

FEMA 154 is one of the most used seismic vulnerability assessment methods that focuses on the evaluation of structures subjected to flood, wind, and earthquake hazards by simple walk-down survey method. FEMA154 primarily addresses buildings. It may not provide detailed guidance for the seismic evaluation and retrofitting of building structures, such as bridges, dams, or industrial facilities. Engineers working on such projects may need to consult additional resources [36, 47].

FEMA 154 (1998) was developed utilizing the Rapid Visual Screening (RVS) technique for identifying and prioritizing buildings susceptible to seismic events. Previous studies have applied this method to evaluate the seismic vulnerability of existing structures. The approach condenses screening procedures into a concise one-page form, integrating building descriptions, layouts, occupancy details, and a rapid structural assessment concerning seismic risks (See FEMA 154 form in Appendix 1). Its primary focus is on swiftly identifying potentially hazardous buildings without conducting exhaustive vulnerability assessments. By combining observed data and analytical insights, a threshold score (S) has been established to aid surveyors in classifying buildings into two categories: those with an acceptable seismic risk level and those presenting potential hazards. The Civil Engineering Research Laboratory (CERL) of the U.S. Army Corps of Engineers has adopted a threshold score of 2.5, emphasizing a cautious approach, as outlined in FEMA 1998. A "sidewalk survey" method is employed for assessment in accordance with this approach [44].

FEMA 310

Many of the drawbacks associated with ATC-13 and FEMA 154 have been addressed by FEMA 310 (1998), making it recognized as an advanced seismic assessment method for existing buildings in the literature (Yakut 2004, Srikanth et al. 2010, UNDP/ERRRP 2009). FEMA 310 outlines a three-tiered approach of increasing detail for evaluating the seismic performance of existing buildings. A summary of the FEMA 310 method is provided in Figure 3-1 of Chapter 3, with further elaboration on the method's specifics and limitations available in Table 3-2.

The method FEMA 310 describes a three-tiered procedure of increasing detail for the seismic evaluation of existing buildings. Conducting a seismic evaluation, even with the guidance of FEMA-310, requires specialized knowledge in structural engineering and seismic analysis. It is essential to involve experienced professionals who are familiar with seismic engineering principles [46].

ASCE 41-13

ASCE 41-13 [48] generally provides a methodology for the seismic evaluation and retrofit of existing buildings. The assessment method outlines a step-by-step process for assessing the deficiency and seismic capacity of buildings and determining the necessary retrofit measures. Different important building parameters of vulnerability in this method may be categorized as follows:

Building characterization: The first step is to gather information about the building, including its architectural, structural, and geotechnical characteristics. This involves collecting plans, specifications, and any available historical records. Site-specific information, such as soil conditions and seismicity, should also be considered.

Seismic hazard analysis: The next step is to conduct a seismic hazard analysis for the site. This involves evaluating the seismicity of the region and determining the ground motion parameters, such as the spectral acceleration values.

Performance objectives: The performance objectives for the building are then established based on its importance, occupancy, desired level of seismic performance, and the acceptable level of damage and risk during an earthquake is also defined.

Seismic evaluation: A seismic evaluation of the building is performed to assess its current seismic capacity. This involves evaluating the structural system, components, and connections. The evaluation may include analytical modeling, structural analysis, and/or field investigations.

Capacity and demand assessment: The seismic demand on the building is defined by applying appropriate ground motions to the structural model. The demand is compared with the capacity of the building's structural elements to assess their adequacy.

Implementation and construction: The retrofit design is implemented by following proper construction practices and guidelines. It is ensured that the retrofit measures are executed correctly and inspected for quality assurance [20].

It is essential to consult the complete ASCE 41-13 document for detailed instructions and specific requirements for each step of the methodology. Additionally, it is recommended to consult with qualified professionals experienced in seismic evaluation and retrofit to ensure compliance with the code and to address site-specific conditions and challenges [48].

Additional Safety Requirements of BNBC for Institutional and Industrial Buildings

Building codes and regulations can vary by country and even within different regions or local jurisdictions. In Bangladesh, there are no definite guidelines in BNBC for seismic evaluation of existing buildings. However, some important safety guidelines for institutional and industrial buildings are specified in BNBC which may be closely linked to guidelines for mitigating secondary hazards of earthquakes, and hence, increasing seismic resilience of existing buildings. Such safety guidelines of BNBC also conform to seismic evaluation criteria as outlined in the checklists of RVS methods such as FEMA 310, ASCE 41-13, etc. Some of such additional features are well related to specific building code requirements to ensure the safety, accessibility, emergency evacuation, and functionality of buildings during emergencies. These requirements may cover various aspects of construction, including structural design, fire safety, and accessibility for persons with disabilities, electrical and mechanical systems [34,32,48].

Chapter 3

Methodology of Seismic Vulnerability Assessment

3.1 General

This chapter presents an overview of methods and analyses used for seismic vulnerability assessment of typical RC garments building of Chattogram. Preliminary assessment methods of seismic vulnerability of buildings or structures that are widely used in different countries around the world are mainly focused on in this work. The vulnerability parameters mentioned in commonly used methods such as FEMA 154, FEMA 310, and ASCE 41-13 are reviewed in accordance with relevant parameters mentioned in the BNBC guidelines as well as in the recently published documents outlining guidelines for urban seismic resilience of Bangladesh [20, 24].

3.2 Preliminary Field Survey

Preliminary field (pre-field) survey is an essential step in seismic vulnerability assessments to ensure that fieldwork is conducted in an organized fashion. The 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. Some of the key steps involved in a pre-field survey of seismic vulnerability assessment are

- 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.
- review geological and geotechnical data to understand the soil conditions and other geological factors that can affect the buildings' seismic vulnerability.
- 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.
- conduct remote sensing analysis of the study area using satellite imagery and other remote sensing data to identify potential vulnerabilities, such as the presence of soft soils or steep slopes.
- develop a fieldwork plan based on the results of the pre-field survey that outlines the areas to be surveyed, the buildings to be inspected and the data to be collected.

The location of the field survey and randomly selected RC garments building to be surveyed were chosen after a careful review of the above considerations of the pre-field survey [26-28].

3.3 Study Area in Chattogram City

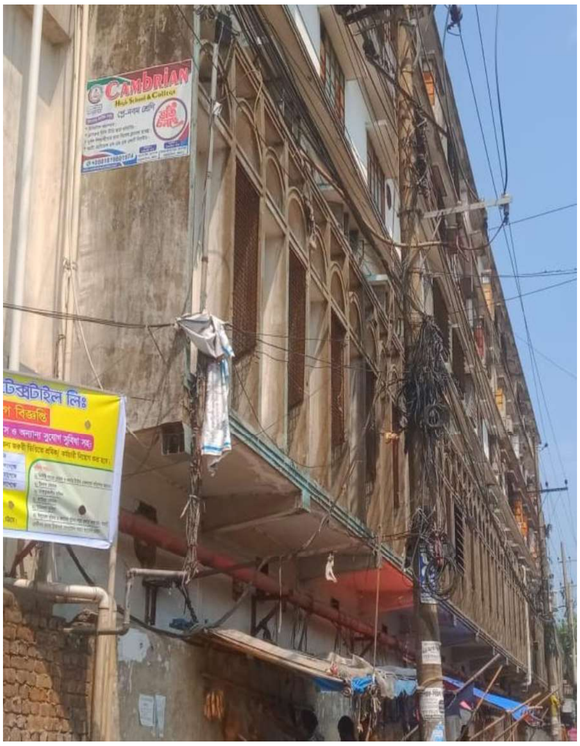
This section provides a summary of the selected study area within Chattogram City. The Port of Chittagong, recognized as one of the world's earliest ports and featured on Ptolemy's world map, serves as the primary maritime entry point for the nation [12]. The port stands as the most active international seaport in the Bay of Bengal and ranks as the third busiest across South Asia. Additionally, the Chittagong Stock Exchange represents one of the nation's two stock markets. Numerous companies headquartered in Chittagong are prominent industrial conglomerates and enterprises within Bangladesh.

Figure 3-1: Map of Chattogram Metropolitan Area

The area to be surveyed for seismic vulnerability assessment of typical RC garments buildings of Chattogram city was selected after a pre-field survey conducted in Ward No-3, Ward No-4, Ward No-7, Ward No-24, and Ward No-2 of Chattogram area. A total of 86 buildings were surveyed by simple random sampling procedure and typical conditions of buildings were assessed by visual observations done by walk-down survey. Figures 3-2(a) to 3-2(d) show typical conditions of garment buildings of different wards in Chattogram city. Most of the buildings are typical RC moment-resisting frame structures not exceeding 5 stories in height. Some of them are not even purpose-built for industrial use. Underground levels of most of the buildings are constructed as soft story levels with designated use reserved for parking, loading-unloading areas, etc. Unreinforced heady masonry works are built on cantilever parts in many of the buildings at the upper story level.

3-2(a): An RMG Building at Panchlaish Ward no. 3

3-2(b): An RMG Building at Chandgaon Ward no. 4



3-2(c): An RMG Building, West.Sholoshahar Ward no. 7

3-2(d): An RMG Building, North Agrabad Ward no. 24

Figure 3-2: Typical Conditions of RMG Industrial Buildings in Chattogram City Corporation

After assessment of the observed common conditions of RC industrial buildings in that area, the area selected for survey of RC garments buildings is Akbarshah (Jalalabad) Ward No-2 located near the Oxygen circle of Chattogram (Figure 3-3). The garments buildings located in this are mostly RC buildings which nearly represent the typical conditions of RC garments buildings in the Chattogram city area. A total of 16 garment buildings in the study area were surveyed considering the RVS methods and parameters mentioned below [6,12,18].

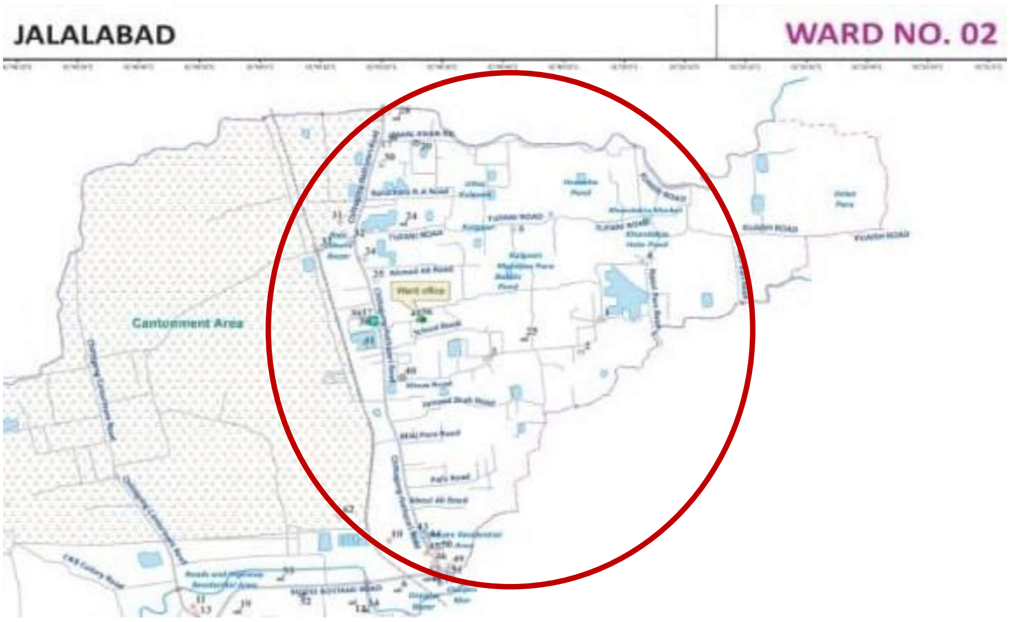


Figure 3-3: Location of Study Area in the Map of Chattogram City near Oxygen Circle

3.3.1 Soil Conditions in Study Area

The properties of urban soils differ greatly from agricultural lands to the particular area of hills. The soil types in urban areas of Chittagong City are sandy loam, loamy sand, and silt loam with 53%-83% sand. According to Brammer (1996), More than 60% of the Chittagong region's soils are formed in moderately coarse to fine-textured, folded tertiary hill sediments [41-43].

3.4 Methodological Steps of Visual Assessment Survey of Seismic Vulnerability

Rapid Visual Screening (RVS), a process to assess the seismic vulnerability of buildings, was used as the methodology of seismic vulnerability assessment. A comparative analysis of findings up to the Tier 1 level of assessment in different methods is also done. The RVS method of preliminary engineering assessment was chosen because of the limitation of time and scope of work.

Methodological steps of the RVS methods are as follows which is also shown in the schematic diagram of Figure 3.3.

- Identify the building to be assessed (randomly selected based on a pre-field survey).
- Collect information about the building such as its age, construction materials, soil type, use, and other general information.
- Conduct a visual inspection of the building, looking for signs of seismic vulnerability such as plan irregularity, cracks in the walls, soft story, or inadequate foundation support.
- Rate the building's seismic vulnerability based on the inspection findings, using a standardized RVS tool.
- If the building is rated as high or very high vulnerability, conduct a more detailed assessment using a more advanced evaluation method (in tier 2 or tier 3 level, if necessary).
- Assess RVS results to prioritize buildings for seismic retrofitting or risk reduction measures [29, 42-45].

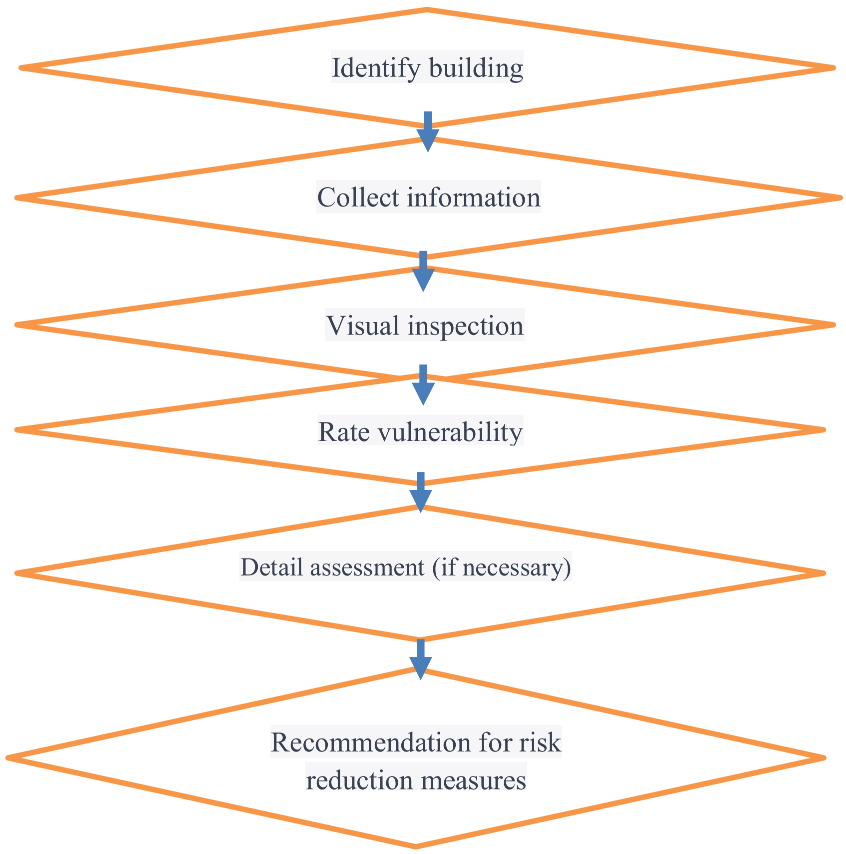


Figure 3-4: Schematic Diagram of Workflow Chart of RVS for Seismic Vulnerability Assessment

3.5 List of Vulnerability Parameters of Assessment

The assessment has been done based on the short list of major vulnerability factors of RC buildings that are relevant to construction practices or construction faults commonly observed in our country. The following sections provide a shortlist of the parameters of different methods used for the assessment. Different methods of seismic vulnerability assessment used in this work are based on vulnerability parameters categorized into several major structural and non-structural factors that can potentially contribute to seismic vulnerability. The vulnerability parameters of different methods are presented in the following shortlists which also have supplementary parameters included in the list according to the guidelines of BNBC [27-32].

3.5.1 FEMA 154

Although FEMA 154 [36, 47] may not provide detailed guidance for seismic evaluation and retrofitting of building structures; engineers, scientists, and decision-makers often use the results of this assessment method as a primary indicator of building vulnerability. Based on limited observed and analytical data and the probability of collapse, a cut-off score (S) has been developed which helps the surveyor to classify the buildings into two classes, e.g. buildings with acceptable seismic risk or buildings that may be seismically hazardous.

Civil Engineering Research Laboratory (CERL) of the U.S. Army Corps of Engineers has utilized a cut-off score of 2.5, with the particular intent of a more conservative approach (FEMA 2002). However, this cut-off score may vary depending on different local contexts and other associated conditions. A high score (i.e. above the cut-off score) indicates the adequate seismic resistance of a building, whereas if a building receives a low score, it should be assessed in detail by a professional engineer. Details of the FEMA 154 method are provided in Table 3-1 [36, 47, 49].

3.5.2 FEMA 310

The method FEMA 310 [46] describes a three-tiered procedure of increasing detail for the seismic evaluation of existing buildings. Conducting a seismic evaluation with the guidance of FEMA 310 requires specialized knowledge in structural engineering and seismic analysis. It is essential to involve experienced professionals who are familiar with seismic engineering principles. However, Tier-1 assessment parameters of this method can be used for comparative assessment of FEMA 154 assessment methods [36, 47, 49].

In addition to the listed parameters in Table 3-1 and Table 3-2, some additional factors are assessed as vulnerability criteria which are included in the checklist of Table 3-3. These building vulnerability criteria may be directly or indirectly linked to secondary hazards or effects of earthquakes on existing buildings during or after an earthquake. Criteria of Table 3-3 are assessed in conformity with relevant BNBC safety criteria or guidelines for institutional and industrial buildings. [29, 34].

Table 3-1: General Vulnerability Criteria of FEMA 154 Assessment Form

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

MODERATE Seismicity

Address: ____________________
____________________ **Zip** ________
Other Identifiers ____________________
No. Stories ____________ **Year Built** ________
Screener ____________ **Date** ________
Total Floor Area (sq. ft.) ____________________
Building Name ____________________
Use ____________________

Scale:

PHOTOGRAPH

OCCUPANCY

Assembly	Govt	Office	Number of Persons
Commercial	Historic	Residential	0 – 10 11 – 100
Emer. Services	Industrial	School	101-1000 1000+

SOIL TYPE

A	B	C	D	E	F
Hard Rock	Avg. Rock	Dense Soil	Stiff Soil	Soft Soil	Poor Soil

FALLING HAZARDS

☐ 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

Table 3-2: Selected Vulnerability Criteria as per FEMA 310 Assessment

a) Basic structural checklists for building					**Comments**
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-fore-resisting System					
7.	Redundancy	C	NC	N/A	
8.	Concrete columns	C	NC	N/A	
9.	Flat slabs	C	NC	N/A	
iii) Diaphragms					
10.	Diaphragm continuity	C	NC	N/A	
11.	Plan irregularities	C	NC	N/A	
iv) Mechanical and Electrical Equipment					
12.	Attached equipment	C	NC	N/A	
iv) Elevators					
13.	Support system	C	NC	N/A	

Table 3-3: Selected Criteria of BNBC Safety Guidelines for Institutional or Industrial Building

i) Extra Inspection (out of FEMA Guideline)					
1.	Front road width	C	NC	N/A	
2.	Gas and electric line distance	C	NC	N/A	
3.	Rescue facility	C	NC	N/A	
4.	Besides the tall building location	C	NC	N/A	
5.	Built purpose	C	NC	N/A	
* C- Complied, NC- Not Complied, N/A- Not Applicable					

3.5.3 ASCE 41-13

The shortlist of vulnerability parameters from the ASCE 41-13 [48] checklist is chosen (as shown in Table 3-4) to compare the results of Tier 1 assessment done in FEMA 154 and FEMA 310 methods of assessment.

Table 3-4: Selected Vulnerability Criteria as per ASCE 41-13 Guideline

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.	Complete frames	C	NC	N/A	
12.	Strong columns/ weak beams	C	NC	N/A	
13.	Flat slab frames	C	NC	N/A	
14.	Flat slabs	C	NC	N/A	
15.	Overturning	C	NC	N/A	
16	Torsion	C	NC	N/A	
iii) Diaphragm					
17.	Diaphragm continuity	C	NC	N/A	
18.	Plan irregularities	C	NC	N/A	
iv) Mechanical and Electrical Equipment					
19.	Attached equipment	C	NC	N/A	
v) Elevators					
20.	Support system	C	NC	N/A	
vi) Geologic site hazards					
21.	Liquefaction	C	NC	N/A	
22.	Slope failure	C	NC	N/A	
* C- Complied, NC- Not Complied, N/A- Not Applicable					

Chapter 4

Results and Discussion

4.1 General

Bangladesh may be affected by moderate to severe earthquakes in the future due to its proximity to the anticipated collision boundaries of the northeast Indian Plate and Eurasian Plate. According to the Global Hazard Assessment Program (GSHAP), one of the most hazardous divisions in Bangladesh could be the port city of Chittagong since this area is located very close to the anticipated collision boundaries of the Indian and Burmese tectonic plates. This area is also the second most highly populated division of the country [50].

Among many different types of structures in Chattogram City, RMG industrial buildings may be considered as one of the serious concerns of seismic vulnerability. The RMG buildings remain highly populated with workers, especially during the daytime. Most of the RMG industrial buildings in Chattogram are made of RC frame structures. Since many of these RC buildings being used as RMG industrial facilities in Chattogram are not even purpose-built for industrial use, they are highly vulnerable to major loss or damage due to disasters due to earthquakes. There exist many design and functional problems that do not conform to design, construction, or functional standards for developing seismic resilience according to national or international standards. Among many of the technical deficiencies in the design or functional problems, major problems that are commonly observed in RC buildings of RMG industries of Chattogram city are plan irregularities in various aspects, soft stories, heavy overhang with unreinforced masonry works, post-seismic hazards from utility connection, effects of vibrating machinery or attached heavy equipment, etc. The hilly terrain of this city corporation area may also induce huge landslides during a heavy earthquake [2,16].

This project is aimed at assessing the vulnerability of typical RC garment buildings of Chattogram City. A total of 16 randomly selected RC garment buildings of a typical industrial zone of Chattogram are chosen for seismic vulnerability assessment. Seismic vulnerability assessment is done through several RVS methods by walk-down surveys done in the study area. Building information is provided in Table 4-1. Seismic vulnerability assessment parameters are chosen based on major design and functional parameters that are generally considered important for the seismic resilience of buildings. Emphasis is also given on safety and vulnerability considerations aftermath of an earthquake such as emergency rescue or evacuation routes, sufficient road width in front of the building premise, fire safety measures with relevance to earthquake hazards, electrical and gas line safety measures, post-earthquake rescue planning or execution, etc. that are considered very important in the planning hierarchy of urban seismic resilience. Several other associated factors are also considered, including the city's geology, building construction types, and population density. Building construction types and standards in the pre-code and post-code buildings are also considered in the assessment [27, 29].

Table 4-1: Preliminary Building Information Selected Buildings

S.L	Building No	Years of construction (Approximate)	Numbers of story	Pre/Post Code
1	01	2003	G+4	Post Code
2	02	2007	G+4	Post Code
3	03	2008	G+4	Post Code
4	04	2005	G+4	Post Code
5	05	2006	G+4	Post Code
6	06	1996	G+1	Post Code
7	07	2003	G+3	Post Code
8	08	------	G+3	------
9	09	2001	G+4	Post Code
10	10	2009	G+5	Post Code
11	11	-----	G+4	Post Code
12	12	-----	G+2	-------
13	13	2017	G+5	-------
14	14	-----	G+5	Post Code
15	15	2007	G+3	--------
16	16	2012	G+5	Post Code
* ------- no information provided				

4.2 Seismic Vulnerability Results in Different RVS Methods

The above-mentioned important factors including other associated factors are short-listed in the visual assessment survey sheets prepared according to FEMA 154, FEMA 310, and ASCE 41-13 guidelines for seismic vulnerability assessment. The shortlisted parameters of different RVS methods and selected BNBC guidelines are shown in Table 3-1 to Table 3-4.

Important findings of the survey are analyzed and a summary of the results of seismic vulnerability assessed according to different methods or criteria is presented in Figure 4.1. A cut-off score of 2.5 has been used for the FEMA 154 method of seismic vulnerability while non-compliance with one or more vulnerability parameters of FEMA 310 or ASCE 41-13 are considered as vulnerability conditions according to those RVS methods of assessment.

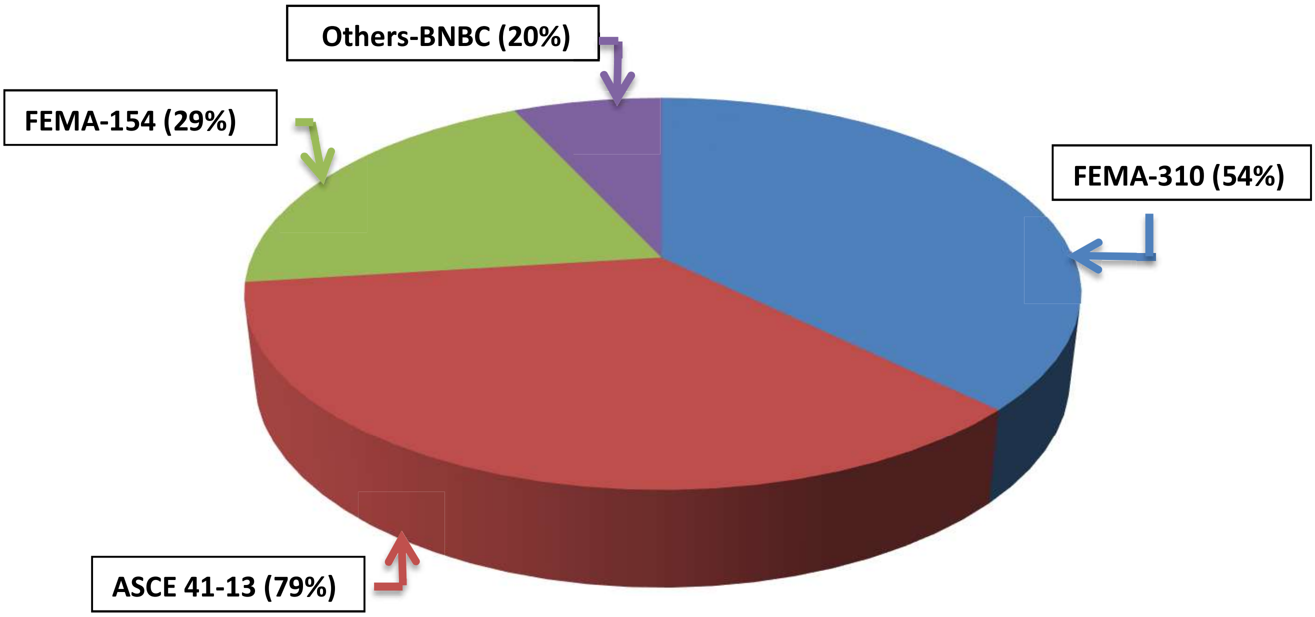
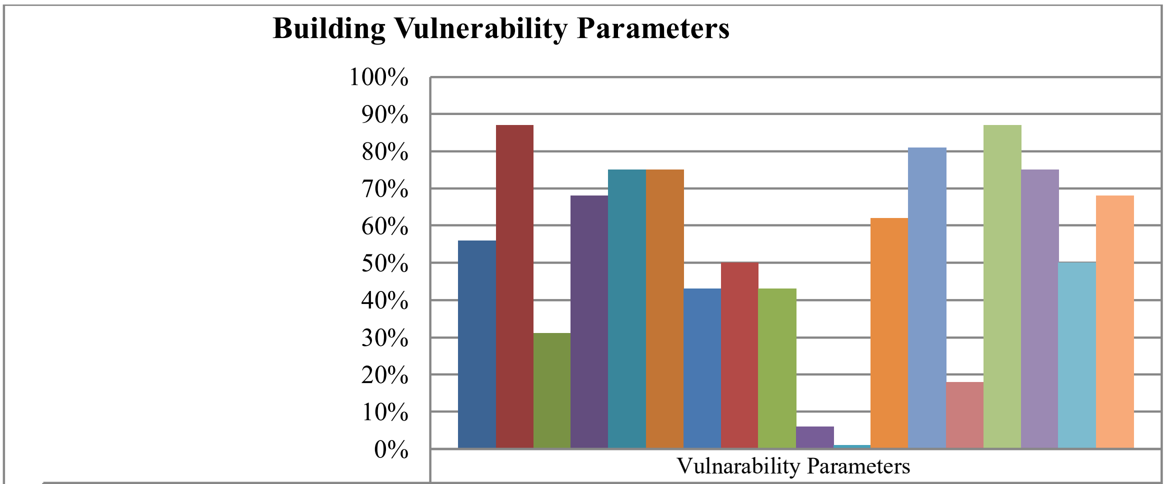


Figure 4-1: Seismic Vulnerability of Reinforced Concrete RMG Buildings in the Study Area

According to the FEMA-154 method, 29% of the selected buildings are assessed to score below the cut-off score. On average, the selected buildings do not satisfy 54% and 79% of the respective vulnerability criteria according to FEMA-310 and ASCE 41-13 methods of Tier-1 assessment. The selected buildings of the project area do not satisfy 20% of the selected criteria as per selected BNBC guidelines of Table 3-3.

Although there are many common parameters indicative of global vulnerability conditions of buildings in different RVS methods, there are some uncommon parameters that are indicative of likely damage conditions due to seismic vulnerability. These uncommon but important parameters can be included in general conditions of seismic vulnerability with extended considerations. For example, observed conditions with inadequate setback spaces, heavy overhang of masonry works on cantilevers, etc. are indicative of irregularities under certain general conditions of plan irregularities or load path, vertical discontinuity, etc. If all important vulnerability parameters are mutually considered in different methods, the results of the integrated assessment for seismic vulnerability of the RC buildings could become consistent regardless of the methods used for seismic vulnerability assessment. A summary of findings of analysis done in this connection including important parameters of seismic vulnerability is summarized as shown in Figure 4-2.



	Vulnarability Parameters
Load path (discontinued)	56%
Adjacent buildings (separation)	87%
Soft storey effect	31%
Vertical discontinuities	68%
Masonry units (unreinforced)	75%
Masonry joints	75%
Concrete wall cracks	43%
Complete frame structure	50%
Strong column/ weak beam	43%
Flat slab frames/ slabs	6%
Diaphragm discontinuity	1%
Plan irregularities	62%
Attached equipment	81%
Front road width (insufficient)	18%
Gas and electric line distance (unsafe)	87%
Pounding possibility	75%
Rescue facility (inadequate)	50%
Built purpose (Non-compliant)	68%

Figure 4-2: Building Vulnerability (%) due to Global or Local Vulnerability Parameters

4.3 Major Factors of Vulnerability of the RC Industrial Buildings of Study Area

4.3.1 Plan Irregularities

Most of the RC industrial buildings of the study area do not seem to have regular plan configuration which is ideal for developing seismic resilience of a building. They seem to be constructed with violations of BNBC regulations since many of the buildings do not even have the minimum required separation from the front road or minimum setback spaces left at the sides or rear of the building. Diaphragms with plan irregularities such as extending wings, plan insets, or E-, T-, X-, L-, or C-shaped configurations have re-entrant corners where large tensile and compressive forces can develop. The diaphragms to resist the seismic forces may not have sufficient strength at these re-entrant corners to resist these tensile forces, and hence, local damages may occur at those weak points.

The above external factors should, therefore, be noted as plan irregularities by a surveyor as these factors do not only cause vulnerability of a building itself but may also be serious contributors affecting urban seismic resilience. For example, falling hazards or debris from a building can cause road blockage and hamper urban rescue operations in a post-hazard situation.

4.3.2 Vertical Discontinuities

Many industrial buildings of the study have purposely built top stories as lift machinery other heavy machinery rooms or even as store rooms, extra storage water tanks, etc. Whenever there is significant torsion in a building due to seismic action, the concern is for additional seismic demands and lateral drifts imposed on the vertical elements by rotation of the diaphragm. Since these extra heavy installments in the buildings can cause pendulum action, the buildings with severe torsion are less likely to perform well in earthquakes, It is, therefore, desired to provide a balanced system in this regard.

4.3.3 Adjacent Buildings

Buildings often hug property lines tightly to maximize space, with many designed without considering neighboring structures. This poses challenges for maintenance and rescue efforts and increases the risk of building pounding during earthquakes. This phenomenon alters the buildings' dynamic responses, subjecting them to additional inertial loads. Similar-height buildings with matching floors exhibit similar behavior when pounding occurs, typically resulting in damage to nonstructural components. However, when floors are at different heights, they can damage adjacent building columns, leading to structural issues.

4.3.4 Attached Equipment

Most of the RMG industrial buildings in the study area are not designed for commercial purposes. Therefore, many of the heavy machinery rooms or lift machinery rooms are not purpose-built for accommodating those for an industrial building. The improperly attached equipment or machinery, therefore, may cause additional hazards in case of a seismic event. Equipment positioned higher than 4 feet from the ground presents a risk of falling if not securely anchored and braced. Suspended equipment is particularly vulnerable to damage compared to items mounted on the floor, roof or walls. During an earthquake, unbraced suspended equipment may sway and collide with nearby objects, resulting in damage. If bracing is lacking, measures must be taken to reduce the risk and achieve the desired level of performance.

4.3.5 Assembly Area

The assembly areas of the industrial buildings are not located in an ideal place as those should be as per BNBC regulations. Since the assembly areas are very important considerations in case of a seismic event it causes additional concern for seismic vulnerability. In picking an assembly area, its size, and distance from the emergency site must be considered as a sufficiently safe zone for assembly. The location of the venue should strike a balance, not being overly proximate to the emergency site but also not too distant for walking. It needs to be easily reachable and ideally situated near the perimeter of the evacuation zone. Additionally, the destination should be easily recognizable to the community to prevent evacuees from becoming disoriented and facilitate entry for emergency responders.

4.3.6 Built Purpose

Some of the buildings of the study area are seen to have spaces for commercial purposes like shops or other offices operating on the ground floor. It is generally indicative of the fact that the buildings serve multipurpose operations and are not safe for use for any single operation. A building designed with a specific purpose in mind is more likely to meet the functional needs of its users. Whether it is a home, office, school, or hospital, understanding and incorporating the intended use into the design ensures that the space serves its purpose effectively. The purpose-driven design promotes efficiency. It allows architects and builders to optimize the use of space, materials, and resources, reducing waste and improving overall efficiency. Different types of buildings are subject to specific safety codes and regulations. Designing with a clear purpose ensures that the structure complies with relevant building codes, safety standards, and legal requirements.

4.3.7 Load Path

Generally observed plan violations and other irregularities in construction such as heavy overhang of unreinforced masonry on cantilevers have made the likely situations of irregular load path in many of the buildings of the study area. There must be a complete lateral-force-resisting system that forms a continuous load path between the foundation, all diaphragm levels, and all portions of the building for proper seismic performance. The general load path is as follows.

Seismic forces generated within the building are transmitted via structural connections to horizontal diaphragms. These diaphragms then disperse the forces to vertical lateral-force-resisting elements like shear walls and frames. These vertical elements, in turn, transfer the forces to the foundation, which further transmits them into the underlying soil. Any interruption in this load path renders the building unable to withstand seismic forces, regardless of the strength of individual elements. To ensure the desired level of performance, it is essential to address these discontinuities with additional elements or connections to complete the load path. Design professionals need to remain vigilant for any gaps in this path, such as shear walls not extending to the foundation, missing shear transfer connections between diaphragms and vertical elements, discontinuous chords at diaphragm notches, or absent collectors.

4.4 Visual Rating Index

The results are also compared for consistency with the results obtained from simplified seismic capacity or Visual Rating Index (VRI) calculations of existing RC structures according to the SATREP– TSUIB manual developed by HBRI of Bangladesh for rating of RC buildings with potential seismic hazards in Bangladesh [22]. The seismic capacity of a building is measured through a visual rating index (I_{VR}) to be calculated according to the following equation.

$$I_{VR} = \frac{1}{n.w}\left[\pi_c\left(\frac{b_c^2}{l_S^2}\right) + \pi_{inf}\left(\frac{t_{inf}}{l_S}.R_{inf}\right) + \pi_{CW}\left(\frac{t_{CW}}{l_S}.R_{CW}\right)\right] F_{IV}.F_{IH}.F_D.F_Y \quad \text{..................... Eq. 4-1}$$

The notations of each parameter in the equation are as follows:
π_c= average shear strength of column = 1.0 MPa (assumed according to JBDPA 2001)
π_{CW}= average shear strength of concrete walls = 1.0 MPa (assumed according to JBDPA 2001)
τ_{inf}= average shear strength masonry infill = 0.20 MPa (ASCE/SEI 41-06 2007)
w= unit weight of buildings per floor area (assumed 11 kN/m^2, according to SATREPS 2015)
t_{inf}= thickness of masonry infill = 125mm
t_{CW}= the thickness of the concrete wall (typically no concrete wall)
Visual rating parameters:
n= number of stories of building

b_c= average column size (approximated= 500 mm)
ls =average span length (approximated= 5000 mm)
R_{inf}= masonry infill ratio, = 1/28, 1/24 (considering the minimum value, 1/28)
R_{CW}= concrete wall ratio, =0
The reduction factors are as follows:
F_{IV}=The modification factors for vertical irregularity (= 1.0, apparently no vertical irregularity)
F_{IH}= The modification factors for horizontal irregularity = 1.0 (assumed value)
F_D = The modification factors deterioration of concrete = 1.0 (assumed value)
F_y =The modification factors for the year of construction (assumed value 0.95)

According to the SATREP – TSUIB manual, the boundary values of V_{IR} for different levels of seismic capacity of existing RC buildings based on damage scenarios are presented in Table 4-2. The results of seismic capacity calculations are presented in Figure 4-3 and Table 4-3.

Table 4-2: Boundary Values of Visual Rating Index (I_{VR}) [22]

Range of each category	Categories	Description
$0.26 \leq I_{VR}$	A	No possibility of damage
$0.24 \leq I_{VR} < 0.26$	B	Light possibility of damage
$0.16 \leq I_{VR} < 0.24$	C	Less possibility of collapse to damage
$0.10 \leq I_{VR} < 0.16$	D	Moderate possibility of collapse
$I_{VR} < 0.10$	E	High possibility of collapse

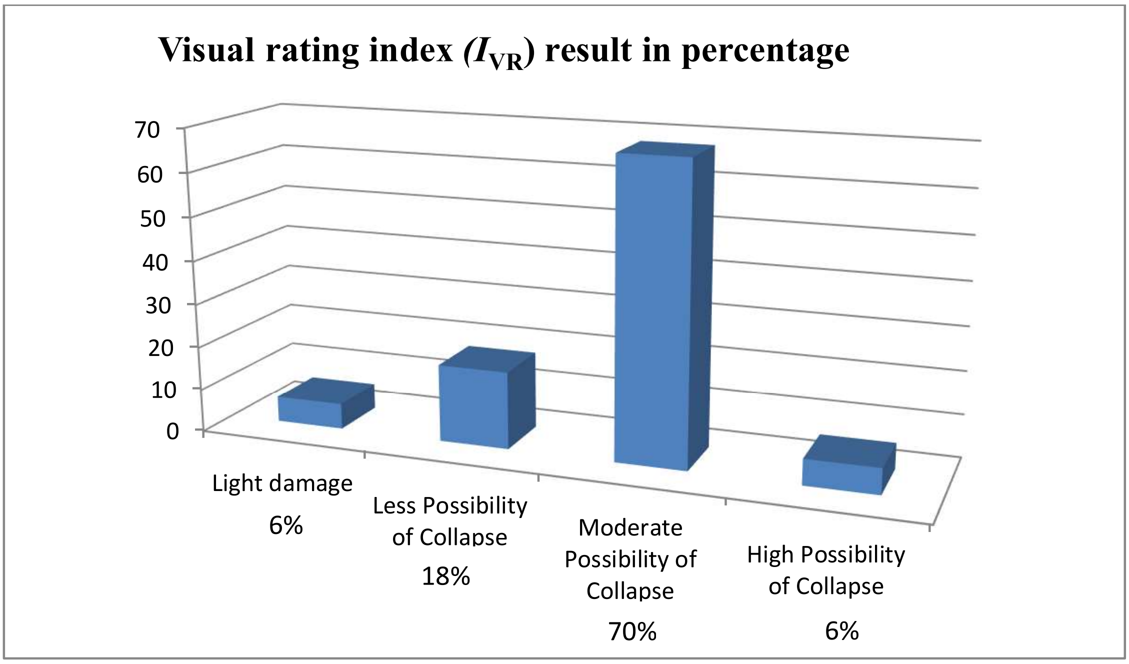


Figure 4-3: Seismic Capacity (I_{VR}, in %) of RC Garments Buildings of Study Area

Table 4-3: Seismic Capacity of RC Garments Buildings of Study Area (SATREP-TSUIB manual)

*Building No	Visual Rating Index (IVR)	Categories	Vulnerability condition of the building
B-1	0.143	D	Moderate Possibility of Collapse
B-2	0.170	C	Less Possibility of Collapse
B-3	0.141	D	Moderate Possibility of Collapse
B-4	0.137	D	Moderate Possibility of Collapse
B-5	0.137	D	Moderate Possibility of Collapse
B-6	0.238	B	Light damage
B-7	0.122	D	Moderate Possibility of Collapse
B-8	0.142	D	Moderate Possibility of Collapse
B-9	0.149	D	Moderate Possibility of Collapse
B-10	0.145	D	Moderate Possibility of Collapse
B-11	0.101	E	High Possibility of Collapse
B-12	0.146	D	Moderate Possibility of Collapse
B-13	0.164	C	Less Possibility of Collapse
B-14	0.138	D	Moderate Possibility of Collapse
B-15	0.150	D	Moderate Possibility of Collapse
B-16	0.162	C	Less Possibility of Collapse

* Visual images of the buildings are attached in Appendix A.

The parametric inputs for the seismic capacity calculation through index value (I_{VR}) calculation are determined from the approximations done based on visual observations of the buildings. The results in Figure 4-3 and Table 4-3 are conservative calculations of seismic vulnerabilities (or, capacities) as compared to ratings according to FEMA 154, FEMA 310 or ASCE 41-13 methods.

Although 69% of the buildings have a moderate possibility of collapse, the rating through the index (I_{VR}) can be considered as a conservative rating of vulnerability. There are many issues identified according to the FEMA 310 and ASCE 41-13 method that should be considered under the parametric assumptions for vertical or horizontal irregularities for the calculation of VRI. Therefore, the results of the VRI assessment are further indicative of the fact that if seismic vulnerability assessment is done with any alternative method with extended considerations of vulnerability factors, the results of seismic vulnerability assessment of the selected garments building could become consistent with the results of seismic capacity index. If any alternative method is implemented with all possible extended considerations in the basic checklist of parameters of FEMA 154, it can be conveniently used by policy or decision-makers since this method uses a cut-off score of seismic vulnerability ratings of buildings. Commonly observed but unconventional construction problems of horizontal, vertical and overall plan irregularity may be considered with extended consideration or with refined index parameters included in the equation of capacity calculation. Parameters such as adjacent buildings, diaphragm discontinuity, inadequate front road width, and other similar factors can be included under the category of plan irregularities instead of the conventional consideration of only the desired symmetric configuration of the building as plan irregularity.

Chapter 5
Conclusion and Recommendation

5.1 Conclusions

Seismic vulnerability assessment of typical RC garment buildings of Chattogram city was done using a preliminary assessment tool commonly known as Rapid Visual Screening (RVS). An assessment of current conditions or vulnerability of 16 randomly selected RC garments buildings of a ward of Chattogram city corporation area was done using three commonly used RVS methods for seismic vulnerability assessment. By analyzing different methods of seismic vulnerability assessment, no single method could be considered as a consistent indicator of seismic vulnerability of typical RC garment buildings in Chattogram. According to the FEMA-154 method, 29% of the selected buildings are assessed to score below a cut-off score of 2.5. On average, the selected buildings do not satisfy 54% and 79% of the respective vulnerability criteria according to FEMA-310 and ASCE 41-13 methods of Tier-1 assessment. The selected buildings of the project area do not satisfy 20% of the selected criteria chosen as per BNBC guidelines which may be considered important guidelines for achieving urban seismic resilience.

There exist many unconventional building construction practices or problems in Bangladesh that are not commonly addressed in the checklists of common RVS methods of seismic vulnerability assessment. It is also important to properly implement guidelines of building planning according to BNBC guidelines, since the guidelines are to be followed for the achievement of overall urban seismic resilience not only considering the vulnerability of a particular building depending on its structural conditions but also considering its relations or contributions to other external vulnerability factors of the country. In this context, the results of RVS methods are also compared for consistency with the results obtained from simplified seismic capacity calculations of existing RC structures according to the SATREP– TSUIB manual developed by HBRI of Bangladesh. If the commonly observed construction problems of horizontal, vertical and overall plan irregularity are considered with extended consideration or with refined index parameters included in the equation of capacity calculation, the seismic capacity results would also be consistent with the results of RVS methods of seismic vulnerability assessment.

5.2 Recommendations

A few extended criteria of assessment integrated into an alternative method of seismic vulnerability assessment could make the method suitable for the assessment of seismic vulnerability in typical RC garment buildings of Bangladesh. It is important to address some unconventional construction practices or problems in the vulnerability assessment criteria that could significantly increase the seismic vulnerability of typical RC buildings in Bangladesh. For example, parameters such as adjacent buildings, diaphragm discontinuity, inadequate front road width and other similar factors can be included under the category of plan irregularities instead of the conventional consideration of only the desired symmetric configuration of the building as plan irregularity. If the extended criteria suggested in this study are integrated into commonly used RVS screening methods, the preliminary assessment results of commonly used RVS methods could be taken as good indicative results of the seismic vulnerability of RC garment buildings of Bangladesh. If any alternative method is implemented with all possible extended considerations in the basic checklist of parameters of FEMA 154, it can be conveniently used by policy or decision-makers since this method uses a cut-off score of seismic vulnerability ratings of buildings.

One of the major drawbacks of the different methods of RVS for preliminary seismic vulnerability assessment is that no definite risk mitigation measures are suggested before a detail engineering assessment is done. However, there are some construction problems commonly observed in the RC garments buildings of Chattogram city which have a high possibility of causing damage conditions such as road blockage with falling hazards and other external or secondary hazards. It is, therefore, highly recommended that remedial or mitigation measures are immediately taken based on the results of some of these specific vulnerability conditions that might hinder other development efforts of urban seismic resilience.

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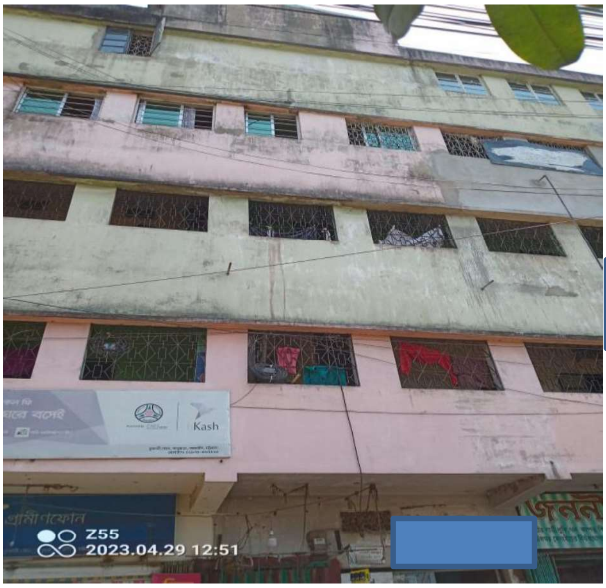
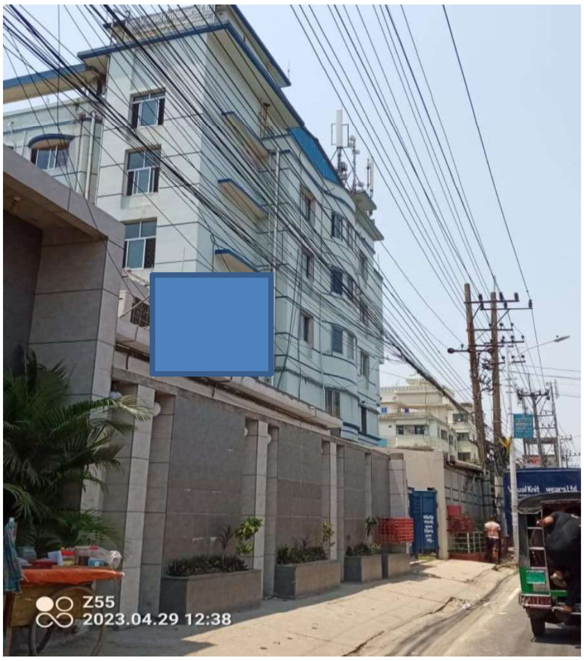
Appendix A

Building -01



Building -02



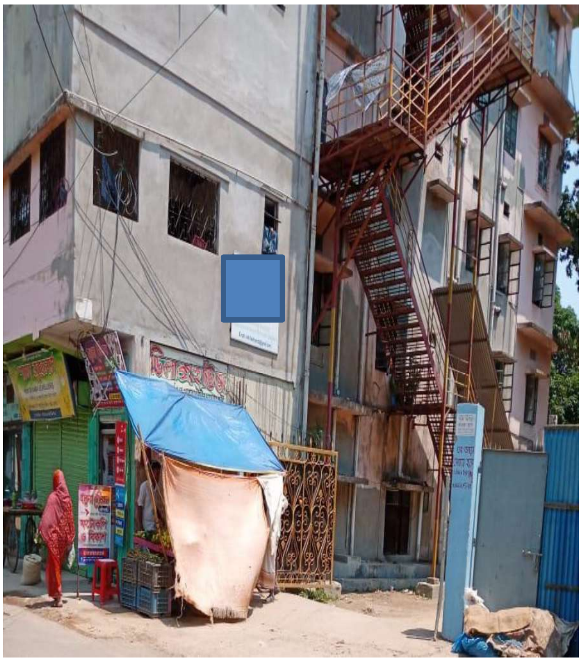
Building -03

Building -04

Building -05

Building -06

Building -07



Building -08

Building -09

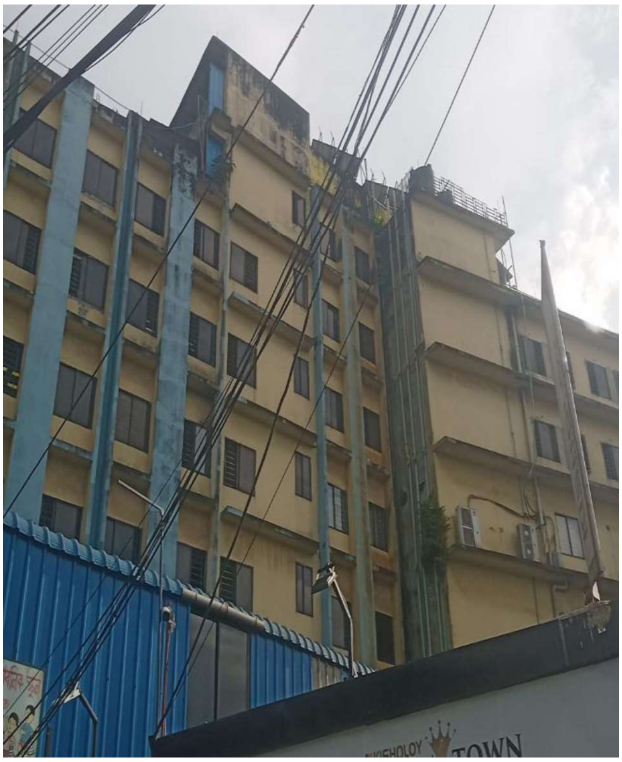
Building -10

Building -11

Building -12

Building -13

Building -14



Building -15

Building -16