SEISMIC ANALYSIS OF MULTISTORIED RESIDENTIAL BUILDING USING REINFORCED CONCRETE JACKETING

By

Md. Hasibur Rahman

Md. Muntasir Mahmud Sarker

Md. Abu Saleh Mollik

Md. Sohel Akon

A thesis submitted to the Department of Civil Engineering in partial fulfillment for the degree of Bachelor of Science in Civil Engineering

Department of Civil Engineering

Sonargaon University

147/I, Green Road, Dhaka-1215, Bangladesh

Section: 13C

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By

Md. Hasibur Rahman (BCE1801013016)

Md. Muntasir Mahmud Sarker (BCE1801013186)

Md. Abu Saleh Mollik (BCE1801013031)

Md. Sohel Akon (BCE1801013173)

Supervisor

Shanjida Ahmed Shohana
Lecturer
Department of Civil Engineering
Sonargaon University
Dhaka, Bangladesh

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……………………………………… Chairman

1. Shanjida Ahmed Shohana
   Lecturer
   Department of Civil Engineering
   Sonargaon University (SU)

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2. External Member — Member

………………………………………

3. External Member — Member

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STUDENT NAME	**STUDENT ID.**	**SIGNATURE**
MD. HASIBUR RAHMAN	BCE1801013016	
MD. MUNTASIR MAHMUD SARKER	BCE1801013186	
MD. ABU SALEH MOLLIK	BCE1801013031	
MD. SOHEL AKON	BCE1801013173	

Dedicated

to

"Our parents for their unyielding love and support"

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ABSTRACT

Bangladesh is surrounded by seismically active areas. Dhaka, Chittagong, Sylhet, Mymensingh, and Rangpur are among the most vulnerable cities in Bangladesh. Due to inadequacies in the design and construction of structures, Dhaka and Rangpur are the pivotal points to attract attention to. Many multistory structures have previously been constructed to meet the ever-increasing need of the urban population, but they are susceptible because earthquake forces were not considered in the design or because quality construction was not maintained. Retrofitting and reconstruction are the means and ways of protecting vulnerable structures. Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure caused by earthquakes. In Bangladesh, it's a new concept. This type of intervention minimizes significant cost and bad environmental impact when compared to new building construction.

The objective of this research is to demonstrate the impact of retrofitting on the vulnerability of structures. To test this idea, (G+6) & (G+10) story building with and without retrofitting was evaluated in soil type SC & SD in seismic zone 2 & zone 3. FEM-based software (ETABS 18.1.1) was used for modeling and analysis of this model. For applying earthquake load, Equivalent Static Force Method is used according to BNBC 2020. Concrete jacketing retrofitting method is applied for the beam and column. After conducting research, it is found that several beams and columns failed when seismic load is applied to the structure with the increment of building height with variable soil type. We concluded that Dhaka zone or zone 2 is more ideal for high-rise structures than Rangpur zone or zone 3.

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CHAPTER 1
INTRODUCTION

1.1 Background and Motivations

Bangladesh is at risk of moderate to high earthquakes, which could cause extensive damage and result in the deaths of thousands of people. In recent years Bangladesh has been hit by several deadly and minor earthquakes. These mild tremors indicate that larger earthquakes may strike shortly. Dhaka belongs among the world's 20 high-risk cities on the Earthquake Disaster Risk Index. Recent tale-seismic (remote) and local earthquakes have shaken Dhaka, however, there is limited documentation of prior mega thrust earthquakes. As a result, it's impossible to predict how frequently such earthquakes will occur, how big they'll be, or how much shaking they'll generate. Except for the incidence and damage that were done by certain frequent earthquakes of magnitude between 4 and 6 inside the country or near the country's territory, Bangladesh's new generation has not witnessed a major earthquake.

Bangladesh had not written any building code until 1993. The Bangladesh National Building Code (BNBC) was initially issued in 1993 to regulate building development and uphold specific standards. Most existing reinforced concrete structures in Bangladesh are prone to earthquakes of moderate magnitude since they were designed and built before the implementation of new earthquake-resistant design guidelines. As a result, the residents are at risk of being injured or killed if the building collapses during a big earthquake. Besides these reinforced concrete structures must need some repairs and improvements during their service life for several reasons such as design errors, severe atmospheric conditions, poor structural care, or an accident like fire, collision, etc. In this case, there are two options in this situation: replacement or retrofitting. Whole-structure replacement has downsides, such as high labor and material costs. So, rather than rebuilding the entire structure, if practicable and practical, it is preferable to repair or upgrade it through retrofitting.

Retrofitting is strengthening of existing structures or structural elements to enhance their performance with new technology, features, and components [1]. When compared to the construction of new buildings, this type of intervention uses less land energy and can be applied to the large building stock.

There are several approaches to retrofitting, each with its own set of benefits and drawbacks. Among them, RC Jacketing has been regarded as one of the most essential and commonly utilized ways in Bangladesh for reinforcing and restoring the vulnerable RC beams and columns. The method entails adding a layer of reinforced concrete in the shape of a jacket outside the perimeter of the existing member, utilizing longitudinal steel reinforcement and transverse steel ties. It improves the column's axial and shear strength, allowing extensive foundation strengthening to be avoided.

However, there is a limitation of information about code guidelines. In truth, most repair and strengthening designs are based entirely on engineering evaluations, and empirical information and existing practice frequently play a key part in making judgments. As a result, additional retrofit research is needed. Retrofitting is quite a new concept in Bangladesh. Now a day’s many researchers in our country have proposed many materials, methods, and techniques for strengthening RC beams and columns. The studies performed on an existing vulnerable RC building’s beams and columns using traditional methods like Reinforced Concrete Jacketing and try to evaluate the performance after retrofitting is done for seismic load, which is frequently overlooked during structure and construction design.

1.2 Research Objectives

The major goal of this research is to improve knowledge and skills in earthquake-resistant design and seismic rehabilitation of existing structures using Reinforce Concrete Jacketing, as well as to gain experience modeling and analyzing buildings against seismic loads using ETABS. The following are the study's goals:

- To observe how comparatively vulnerable the structures are in different earthquake zone (zone II and zone III). Also, we investigate how the structure performs after Reinforce Concrete Retrofitting.
- To evaluate the potential of base shear, displacement, and drift of buildings and the benefits of implementing the retrofit solutions recommended for building strengthening.

- To model a real building with ETABS and investigate the earthquake effects with Equivalent Static Method according to BNBC 2020, as well as to provide acceptable rehabilitation approaches in terms of performance.

1.3 Organization of the thesis

This section should have a brief description of the thesis outline of the thesis. It should contain chapter no. with a title and brief descriptions of the content of each chapter. An example guide is provided below.

Chapter 1: Introduction and Objective. This chapter provides the background and motivations of the research. The overall objectives and expected outcomes are also described in this chapter.

Chapter 2: Literature Review. This chapter reviews the related works in the retrofitting field with a special focus on Reinforce Concrete Jacketing.

Chapter 3: Methodology. This chapter describes the methodology adopted to carry out the research.

Chapter 4: Results and Discussion. This chapter provides structural design of a typical residential building and retrofit design for failure members.

Chapter 5: Conclusions and Future Work. This chapter summarizes the conclusions and major contributions of this study and provides recommendations for future studies.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to explore Reinforced Concrete Jacketing which is one of the most prevalent retrofitting techniques in Bangladesh. This approach is evaluated based on various aspects, and suggestions are provided to assist structural engineers in selecting the most appropriate solutions. These recommendations are based on published experimental research and real-world case studies. For this, an extensive literature review on this has been performed and some of them are summarized in this chapter. We also make an effort to cover some essential aspects of this research.

2.2 Available Studies on Retrofitting

Seismic design is an important aspect of building design however, many structures have been built without proper seismic detailing and reinforcement. Many studies have been undertaken on this topic all across the world. Technical guidelines for retrofitting have been published globally such as ASCE-SEI 41, NZSEE, and others. Here some of the available studies on retrofitting are summarized below:

E S Ju´lio, F Branco, and V D Silva studied the structural rehabilitation of columns using reinforced concrete jacketing and found that, unlike other procedures, the RC jacketing strengthening method results in a uniformly distributed increase in column strength and stiffness. Additionally, the original column's longevity is improved, in contrast to the corrosion and fire protection requirements of alternative procedures that expose steel or employ epoxy resins. Moreover, after removing the concrete from the damaged zone with hand chipping, jackhammering, electric hammering, or any other approach that induces micro-cracking of the substrate, sandblasting or water demolition techniques should be used.[2]

Gnanase karan, Kaliya perumal, and Amlan Kumar Sengupta investigated the impact of concrete jacketing on the flexural strength and performance of columns and found that self-compacting concrete was found to be suitable for use in the concrete jacket and that the retrofitted specimens did not show any visible delamination between the existing concrete and the concrete in the jacket. Moreover, the roughening of the existing concrete's surface with a motorized wire brush was found to be enough for the type of testing performed. By examining the corresponding sub-assembly specimens, this analysis can be extended to the exterior or corner columns.[3]

Hamidreza Nasersaeed stated that using a concrete jacket is an effective method for increasing structural frame strength and stiffness and that the RC jacketing technique is less expensive than other retrofitting techniques due to the availability of materials and the lack of specialized labor. In addition, the dense reinforcing design reduces the volume of excess concrete and longitudinal bar buckling in the repaired concrete column.[4]

Bhavar Dadasaheb studied the potential behavior of RCC structures and concluded that conventional reinforced concrete jacketing is preferable due to its feasibility and ease of implementation. Further, the building strengthening discussed in this study is an attempt to extend the life of the structure and to withstand catastrophic phenomena such as earthquakes, floods, and other natural disasters. It is suggested that old RCC structures be retrofitted with this adequate type of jacketing at the proper time so that it will be cost-effective and safe in the future.[5]

Sayed H. Sayed studies the impact of using concrete jackets made of various types of concrete to repair concrete columns after exposure to high temperatures, as well as the effect of using shear connectors on the bond between the column surface and the jacket, and concludes that there is a reduction in ultimate load of concrete columns exposure to high temperatures and a slight improvement from the use of shear connectors. Further, it is claimed that for such columns exposed to high temperatures, a self-compacting concrete jacket is the best option, however, recycled concrete should not be used to repair RC columns.[6]

Hazem Elbakry and Ahmed M. Tarabia investigate the effects of surface preparation, dowel contributions, and concrete jacket transverse reinforcement on the overall bond strength between new concrete jackets and old concrete. As a result, it was determined that hand-chiseling the substrate concrete to increase surface roughness is far more effective than grinding, and that using steel dowels to connect the new jacket concrete to the old concrete significantly improved the overall bond strength due to the developed shear friction.[7]

Shri. Pravin B. Waghmare state that materials and techniques can play a key role in structural repairs, seismic strengthening, and retrofitting of existing structures, whether they are damaged or not. The main goal of structural engineering is to quickly restore the structure to its original state. It's been difficult to choose the correct materials, techniques, and procedures to use for a certain structure's repair. The important criteria for a successful repair, strengthening, and restoration of damaged structures are the use of standard and new repair materials, technical assistance, manpower, and quality assurance during implementation. He also went through confinement, jacketing, fiber-reinforced polymer jacketing, steel jacketing, and beam jacketing in brief.[8]

Awang Taib, Mohd Zulham Affandi, Mohd Zahid, Ade Faisal, Saffuan Wan Ahmad investigated the impact of vertical ground motion on the irregular structure with setback. When considering vertical ground motion, the axial stress in the internal column might be up to 6 times larger than when considering horizontal ground motion.[9]

Anju Paul deals with the analysis and design of an existing old structure that was originally developed according to IS 1893-1984 for seismic zone II and then redesigned according to IS 1893-2002 for seismic zone III. The faulty member has been identified as the column, which will be modified to meet ductile performance. For the retrofitting of the columns, the most appropriate retrofitting approach, – i.e., usage of FRP wrapping, is recommended.[10]

Han-Seon Lee, Dong-Woo Ko observed that,

- The presence of a shear wall decreases shear deformation significantly at the lower frame but has almost negligible influence on the reduction of overturning deformation vase shear and OTM.
- Due to OTM, structures with symmetric plans suffered a shift in rotating axis (rocking behavior) as the earthquake intensity increased.
- The value of torsional stiffness varies depending on the governing of variation. Large torsional stiffness is caused by a higher mode of vibration.[11]

2.3 Finite Element Software (ETABS)

According to Civil Engineering sector, Finite element analysis (FEA) is a computerized method for predicting how a structure reacts to real-world natural or human-made forces, vibration, heat, fluid flow, and other physical effects. Finite element analysis shows whether a structure will break, wear out, or work the way it was designed. It is called analysis, but in the structure development process, it is used to predict what is going to happen when the structure is used. An actual structure is broken down into a large number (thousands to hundreds of thousands) of finite components, such as little cubes, via FEA. Each element's behavior can be predicted using mathematical equations. After that, a computer adds up all of the different behaviors to anticipate how the actual thing will behave.[12]

A wind spectrum of FEM software and tools is available for such analysis. In the present ETABS (version 18.1.1) has been used for this purpose. ETABS has been chosen for its user-friendly feature in building analysis. The features of ETABS are mentioned below:

- ETABS has Completely Customizable Graphical User Interface
- ETABS offers a single user interface to perform modeling, analysis, design and reporting.
- Based on various domestic and international norms, ETABS will automatically develop and apply seismic and wind loads.

- ETABS has a wide array of dynamic analysis tools available for both linear and nonlinear analysis.
- ETABS has powerful nonlinear elements to accurately represent the behavior of a structure.
- ETABS can automatically calculate members' self-weight and sectional properties.[13]

2.4 Provision of Plan Irregularities of Structure in BNBC Code

In the BNBC code, five types of plan irregularities of structures are mentioned and these are:

- Torsional Irregularity (to be considered when diaphragms are not flexible)
- Reentrant Corners
- Diaphragm Discontinuity
- Out-of-plane Offsets
- Nonparallel Systems

Torsional irregularity is defined as when the maximum story drift, including accidental torsion, at one of the structure's transverse axes, is greater than 1.2 times the average of the story at the structure's two ends.

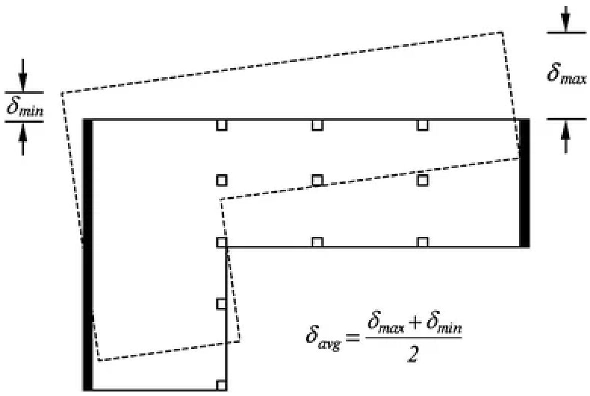


Figure 2.1. Torsional Irregularity co-efficient

Torsional irregularity co-efficient n_t is defined by

$$n_t = \frac{\delta_{max}}{\delta_{avg}}$$

Then

- Ifn_t≤ 1.2 then torsional irregularity does not exist.
- If 1.2 ≤n_t≤ 2 then torsional irregularity exits.[14]

2.5 Methods of Seismic Analysis

Seismic analysis is a branch of structural analysis which involves evaluating a building's seismic response. In earthquake-prone areas, it is a part of the structural design, earthquake engineering, or structural evaluation and retrofit process.

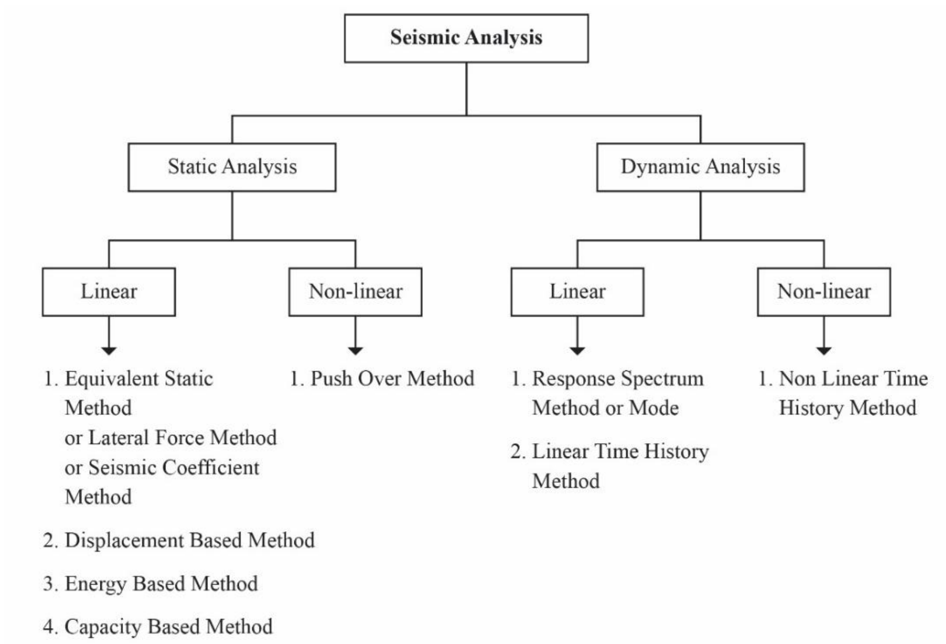


Figure 2.2. Methods of Seismic Analysis [15]

2.6 Equivalent Static Load Method

This approach specifies a series of forces acting on a structure to simulate the impact of earthquake ground motion, which is normally specified by a seismic design response spectrum. It is assumed that the structure responds in its basic mode. The building must be low-rise and not twist significantly as the ground changes for this to be true. Given the natural frequency of the building, the response is read from a design response spectrum. Many building standards enhance the usefulness of this concept by adding factors to account for higher buildings with certain higher modes, as well as low levels of twisting. Many codes use modification factors that reduce the design forces, such as force reduction factors, to account for effects caused by the building yielding. [16]

The total design lateral force or design base shear along any principal direction is given in terms of design horizontal Seismic coefficient and seismic weight of the structure. Design horizontal seismic coefficient depends on the zone factor of the site, importance of the structure, response reduction factor of the lateral load resisting elements, and the fundamental period of the structure.

The following procedure is generally used for the equivalent static analysis:

- Calculation of lumped weight.
- Calculation of fundamental natural period.

The fundamental natural period of vibration (Ta) in seconds of a moment-resisting frame building,

Ta = $0.075h^{0.75}$ (without brick infill panels) ………… (1)

Ta = 0.09 h/$\sqrt{d}$ (with brick infill panels) ………… (2)

where,

h = Height of the building

d = Base dimension of the building at the plinth level in m, along the considered direction of the lateral force.

- Determination of base shear (V_B) of the building.

V_B= A_h x W ………… (3)

where,

W= Seismic weight of the building

A_h= Horizontal seismic coefficient

As per BNBC 2020,

$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$ ………… (4)

Are the design horizontal seismic coefficient, which depends on the seismic zone factor (Z), importance factor (I), response reduction factor (R), and the average response acceleration coefficient (S_a/g). S_a/g, in turn, depends on the nature of foundation soil (rock, medium, or soft soil sites), natural period, and the damping of the structure.

The design base shear $V_B$thus obtained is then distributed along with the height of the building using a parabolic distribution expression:

$Q = V_B \frac{W_1 h_1}{\sum_{j=1}^{n} W_j h_{k^2}}$ ………… (5)

Where $Q_1$is the design lateral force, $W_1$is the seismic weight, h_1 is the height of the i^{th}floor measured from base and n is the number of stories in the building. [17]

2.7 Response Spectrum Method

A response-spectrum study determines a structure's maximum response to transient loads produced by a base vibration or shocks, such as displacement, velocity, or acceleration. In base vibration, a prescribed motion is applied to the base of the structure to be tested, causing the mass to shake. This system is most commonly used to analyze a structure's earthquake response. The resulting plot can then be used to isolate the response of any linear system based on its natural oscillation frequency. If there is no damping, the response will be infinite.

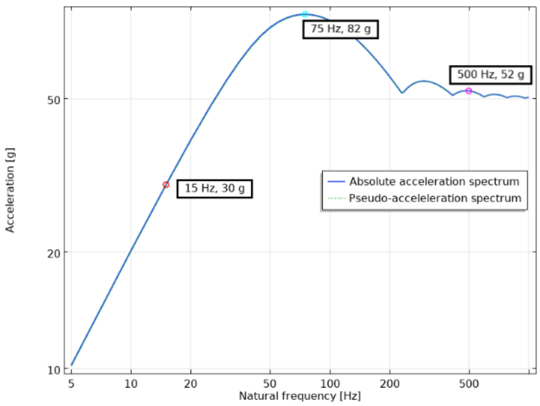


Figure 2.3. Response Spectrum Analysis [18]

The response spectrum method assists in the design of a building or structure for a maximal response from a sequence of ground motions from which design spectra were derived. It is a single force value. Time is not involved in it.

The response spectrum approach is no longer appropriate in the case of structures with major irregularities, are too tall, or are important to a community in disaster response, and where more complex analysis such as nonlinear static or dynamic analysis is frequently necessary.

2.8 Static Analysis Procedure

Although analysis of buildings subjected to dynamic earthquake loads should theoretically require dynamic analysis procedures, for a certain type of building structures subjected to earthquake shaking, simplified static analysis procedures may also provide reasonably good results. The equivalent static force method is such a procedure for determining the seismic lateral forces acting on the structure. This type of analysis may be applied to buildings whose seismic response is not significantly affected by contributions from modes higher than the fundamental mode in each direction. This requirement is deemed to be satisfied in buildings that fulfill the following two conditions:

I. The building period in the two main horizontal directions is smaller than both $4T_c$ and 2 seconds.
II. The building does not possess irregularity in elevation.

Spectral Acceleration:

$$S_a = \frac{2}{3}\frac{ZI}{R}C_s \qquad \text{………… (6)}$$

where,

S_a = Design spectral acceleration (in units of g which shall not be less than $0.67\beta ZIS$)

β = coefficient used to calculate lower bound for S_a. The recommended value for β is 0.11

Z = Seismic zone coefficient Table 2.1

I = Structure importance factor Table 2.2

R = Response reduction factor which depends on the type of structural system given in Table 2.10. The ratio $\frac{1}{R}$ cannot be greater than one.

C_s = Normalized acceleration response spectrum, which is a function of structure (building) period and soil type (site class) as defined by equation no. 12.

2.9 Design base shear

The seismic design base shear force in a given direction shall be determined from the following relation:

$$V=S_a W \qquad \text{………… (7)}$$

where,

S_a= Lateral seismic force coefficient calculated using equation no. 6. It is the design spectral acceleration (in units of g) corresponding to the building period T

W = Total seismic weight of the building defined

Alternatively, for buildings with a natural period less than or equal to 2.0 sec., the seismic design base shear can be calculated using ASCE 7-02 with seismic design parameters as given in Appendix C. However, the minimum values of S_a should be less than $0.044S_{DS}l$. The values of S_{DS} are provided in Table 2.11& Table 2.12

Vertical Distribution of base shear

$$S_a= V\frac{w_x {h_x}^k}{\sum_{i=1}^{n} w_i {h_i}^k} \qquad \text{………… (8)}$$

K = 1 for structure period ≤ 0.5

= 2 for structure period ≥ 2.5s

= linear interpolation between 1 and 2 for other periods.

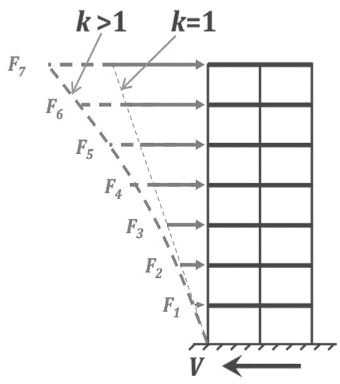


Figure 2.4. Vertical Distribution of base shear

Types of Common structural system

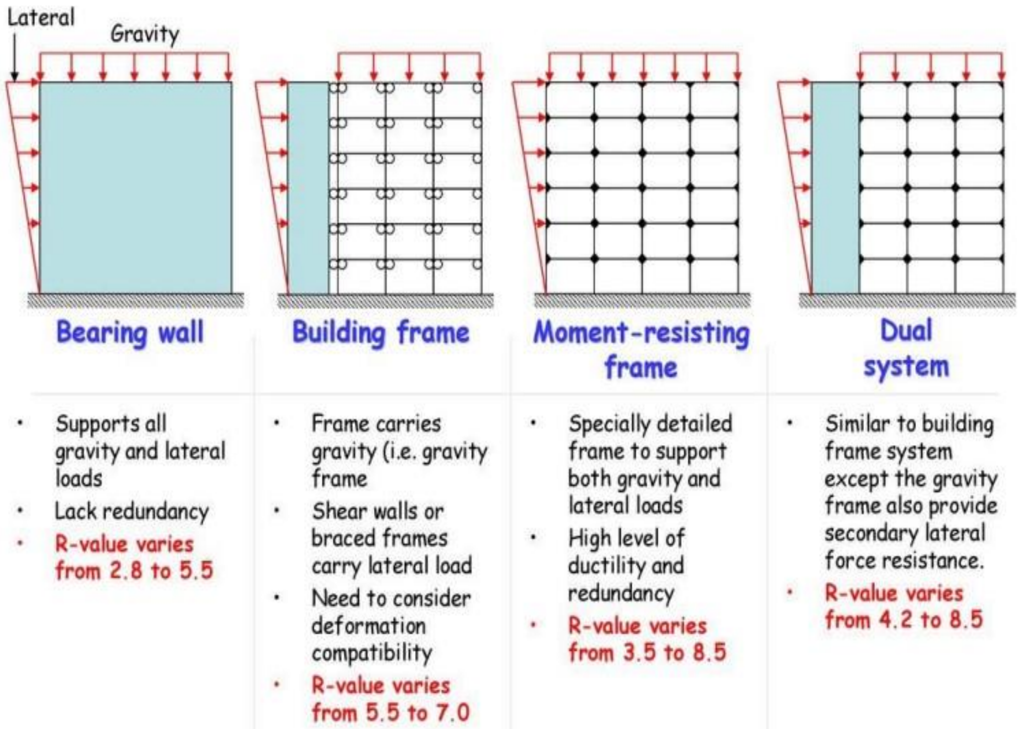


Figure 2.5. Common structural system

2.10 Seismic Zone of Bangladesh

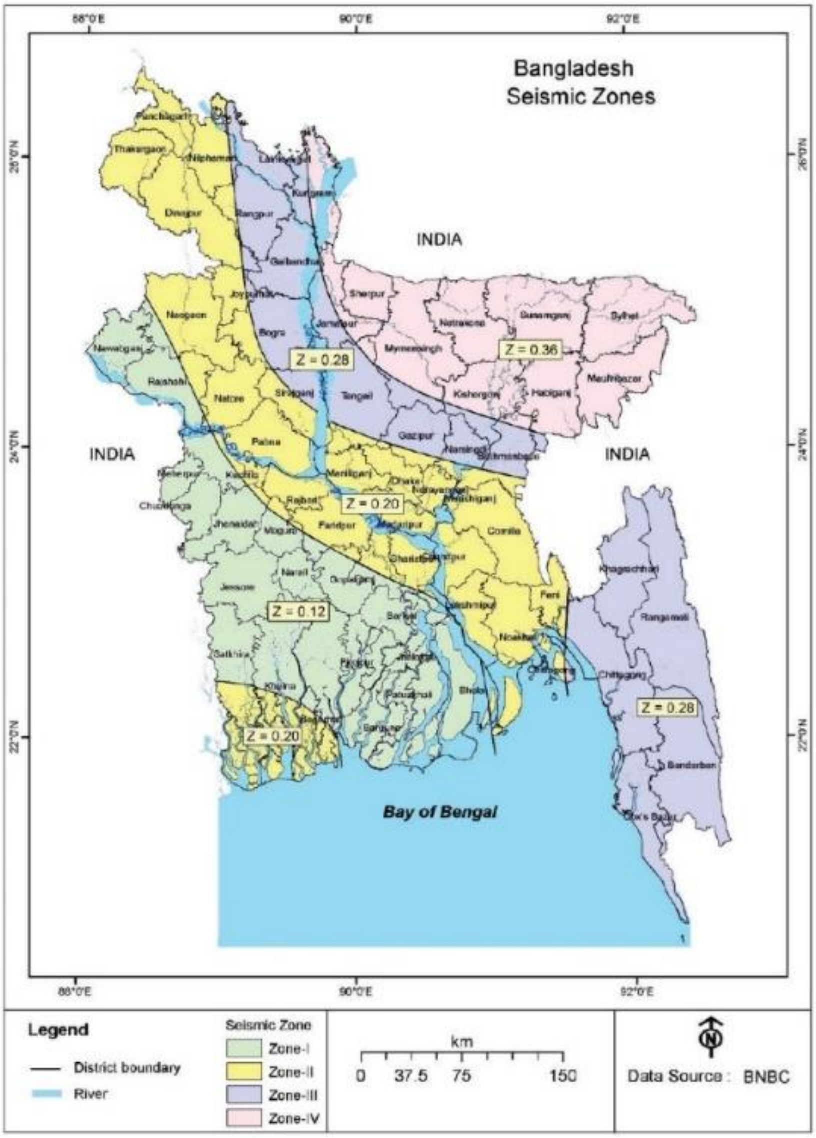


Figure 2.6. Seismic Zones of Bangladesh

Table 2.1. Description of Seismic Zones

Seismic Zone	Location	Seismic Intensity	Seismic Zone Coefficient, Z
1	Southwestern part including Barisal, Khulna, Jessore, Rajshahi	Low	0.12
2	Lower Central and Northwestern part including Noakhali, Dhaka, Pabna, Dinajpur, as well as Southwestern corner including Sundarbans	Moderate	0.20

3	Upper Central and Northwestern part including Brahmanbaria, Sirajganj, Rangpur	Severe	0.28
4	Northeastern part including Sylhet, Mymensingh, Kurigram	Very Severe	0.36

Table 2.2. Importance Factors for Buildings and Structures for Earthquake design

Occupancy Category	Importance factor
I, II	1.00
III	1.25
IV	1.50

Table 2.3. Occupancy Category of Buildings and Other Structures

Nature of Occupancy	Occupancy Category
Buildings and other structures that represent a low hazard to human life in the event of failure	I
All buildings and other structures except those listed in Occupancy Categories I, III, and IV	II
Buildings and other structures that represent a substantial hazard to human life in the event of failure, including, but not limited to: • Where more than 300 people congregate in one area • Daycare facilities with a capacity greater than 150 • School facilities with a capacity greater than 250 • Colleges or adult education facilities have more than 500 students. • Health care facilities with a capacity of 50 or more resident patients but not surgery facilities. • Jails and detention facilities	III
Buildings and other structures designated as essential facilities, including, but not limited to: • Hospitals and other health care facilities having surgery or emergency treatment facilities • Fire, rescue, ambulance, and police stations and emergency vehicle garages • Designated earthquake, hurricane, or other emergency shelters • Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response	IV

• Power generating stations and other public utility facilities are required in an emergency • Ancillary structures (including, but not limited to, communication towers, fuel storage tanks, cooling towers, electrical substation structures, fire water storage tanks or other structures housing or supporting water, or other fire-suppression material or equipment) required for the operation of Occupancy Category IV structures during an emergency	

Table 2.4. Seismic Design Category of Buildings

Site Class	Occupancy Category I, II, and III				Occupancy Category IV			
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
SA	B	C	C	D	C	D	D	D
SB	B	C	D	D	C	D	D	D
SC	B	C	D	D	C	D	D	D
SD	C	D	D	D	D	D	D	D
SE, $\boldsymbol{S_1}$, $\boldsymbol{S_2}$	D	D	D	D	D	D	D	D

Table 2.5. Physical Properties of Soil

Consistency	Very soft	soft	Medium	Stiff	Very stiff	Hard
N- Values	0 to 2	2 to 4	4 to 8	8 to 16	16 to 32	Over 32
Unconfined compressive	0-0.25	0.25-.50	0.50-1.00	1.00-2.00	2.00-4.00	Over 4.00
Unit weight (saturated in psf)	100	100-120	110-130	120-140	130*	130*

2.11 Basic Wind Speed of Bangladesh

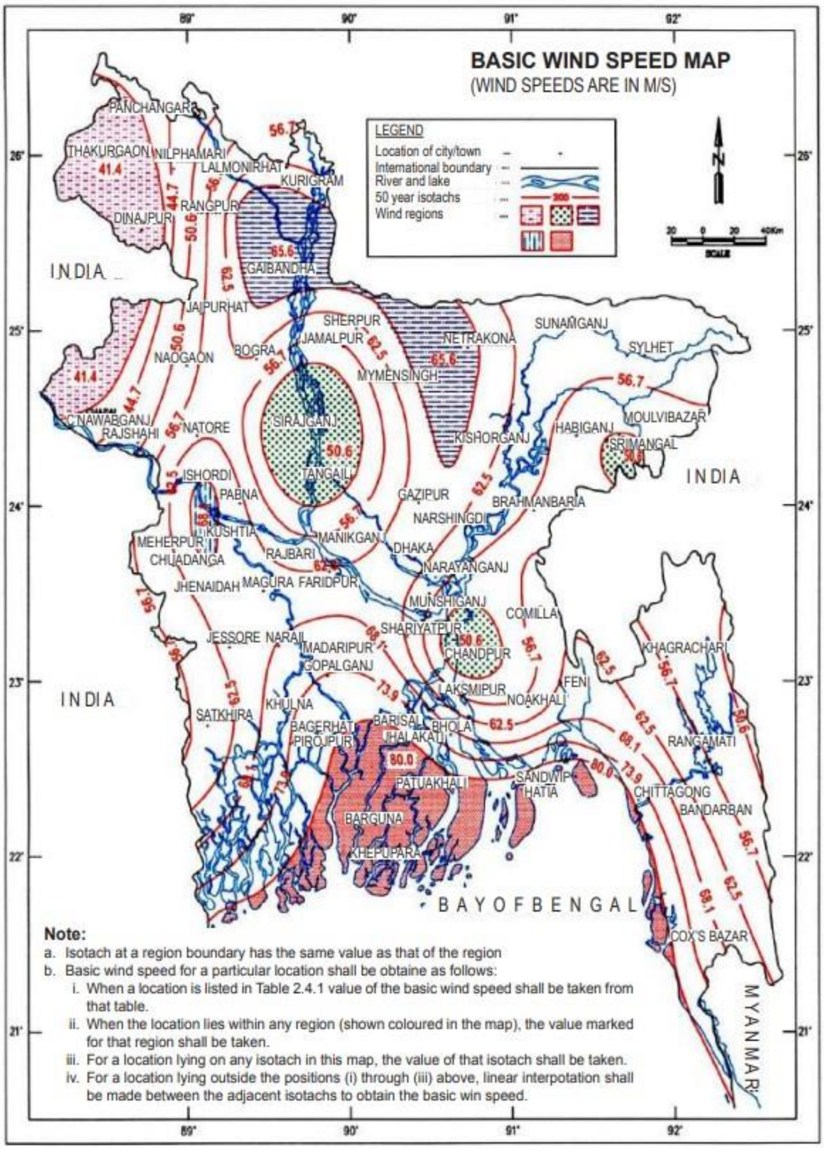


Figure 2.7. Wind Speed Map of Bangladesh

Table 2.6. Basic Wind Speeds, V, for Selected Locations in Bangladesh

Location	Basic Wind Speed (m/s)	Location	Basic Wind Speed (m/s)
Angarpota	47.8	Lalmonirhat	63.7
Bagerhat	77.5	Madaripur	68.1
Bandarban	62.5	Magura	65.0
Barguna	80.0	Manikganj	58.2
Barisal	78.7	Meherpur	58.2
Bhola	69.5	Maheshkhali	80.0

Bogra	61.9	Moulvibazar	53.0
Brahmanbaria	56.7	Munshiganj	57.1
Chandpur	50.6	Mymensingh	67.4
Chapai Nawabganj	41.4	Naogaon	55.2
Chittagong	80.0	Narail	68.6
Chuadanga	61.9	Narayanganj	61.1
Comilla	61.4	Narsinghdi	59.7
Cox's Bazar	80.0	Nator	61.9
Dahagram	47.8	Netrokona	65.6
Dhaka	65.7	Nilphamari	44.7
Dinajpur	41.4	Noakhali	57.1
Faridpur	63.1	Pabna	63.1
Feni	64.1	Panchagarh	41.4
Gaibandha	65.6	Patuakhali	80.0
Gazipur	66.5	Pirojpur	80.0
Gopalganj	74.5	Rajbari	59.1
Habiganj	54.2	Rajshahi	49.2
Hatiya	80.0	Rangamati	56.7
Ishurdi	69.5	Rangpur	65.3
Joypurhat	56.7	Satkhira	57.6
Jamalpur	56.7	Shariatpur	61.9
Jessore	64.1	Sherpur	62.5
Jhalakati	80.0	Sirajganj	50.6
Jhenaidah	65.0	Srimangal	50.6
Khagrachhari	56.7	St. Martin's Island	80.0
Khulna	73.3	Sunamganj	61.1
Kutubdia	80.0	Sylhet	61.1
Kishoreganj	64.7	Sandwip	80.0
Kurigram	65.6	Tangail	50.6
Kushtia	66.9	Teknaf	80.0
Lakshmipur	51.2	Thakurgaon	41.4

Table 2.7. Site classification based on soil properties

Site Class	Description of soil profile up to 30 meters depth	Average Soil Properties in top 30 meters		
		Shear wave velocity $\bar{V}_s$(m/s)	**Standard Penetration Value, $\bar{N}$ (blows/30cm)**	**Undrained shear strength, $\bar{S}_u$ (kPa)**
SA	Rock or other rock-like geological formations, including at most 5 m of weaker material at the surface.	> 800	---	---
SB	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, are characterized by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
SC	Deep deposits of dense or medium dense sand, gravel, or stiff clay with thickness from several tens to many hundreds of meters.	180 – 360	15 - 50	70 - 250
SD	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
SE	A soil profile consisting of a surface alluvium layer with Vs values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with Vs > 800 m/s.	---	---	---

2.12 Natural Period

a. Structural dynamics procedures (such as Rayleigh method or modal eigenvalue analysis), using structural properties and deformation characteristics of resisting elements, may be used to determine the fundamental period T of the building in the direction under consideration. This period shall not exceed the approximate fundamental period determined by equation 4 by more than 40 percent.

b. The building period T (in secs) may be approximated by the following formula:

$$T = C_t(h_n)^m \qquad \text{………… (9)}$$

where,

h_n= Height of building in meters from foundation or top of the rigid basement. This excludes the basement stories, where basement walls are connected with the ground floor deck or fitted between the building columns. But it includes the basement story when they are not so connected. C_t and m are obtained from Table 2.9

c. For masonry or concrete shear wall structures, the approximate fundamental period, T in sec may be determined as follows:

$$T = \frac{0.0062}{\sqrt{C_w}} h_n \qquad \text{………… (10)}$$

$$C_w = \frac{100}{A_B} \sum_{i=1}^{x} \left(\frac{h_n}{h_i}\right)^2 \frac{A_i}{[1+0.83(\frac{h_i}{D_i})^2]} \qquad \text{………… (11)}$$

where,

A_B = area of the base of the structure

A_i = web area of shear wall 'i'

D_i = length of shear wall 'i'

h_i = height of shear wall 'i'

x = number of shear walls in the building effective in resisting lateral forces in the direction under consideration.

Table 2.8. Site dependent soil factor and other parameters defining elastic response spectrum

Soil Type	S	T_b(s)	T_C(s)	T_D(s)
SA	1.0	0.15	0.40	2.0
SB	1.2	0.15	0.50	2.0
SC	1.15	0.20	0.60	2.0
SD	1.35	0.20	0.80	2.0
SE	1.4	0.15	0.50	2.0

$$C_s = S\left(1+\frac{T}{T_B}(2.5\eta-1)\right) \quad \text{for} \quad 0 \le T \le T_B$$
$$C_s = 2.5S\eta \quad \text{for} \quad T_B \le T \le T_C$$
$$C_s = 2.5S\eta\left(\frac{T_C}{T}\right) \quad \text{for} \quad T_C \le T \le T_D$$
$$C_s = 2.5S\eta\left(\frac{T_C T_D}{T^2}\right) \quad \text{for} \quad T_D \le T \le 4 \text{ sec}$$

………… (12)

Normalized acceleration response spectrum, C_s

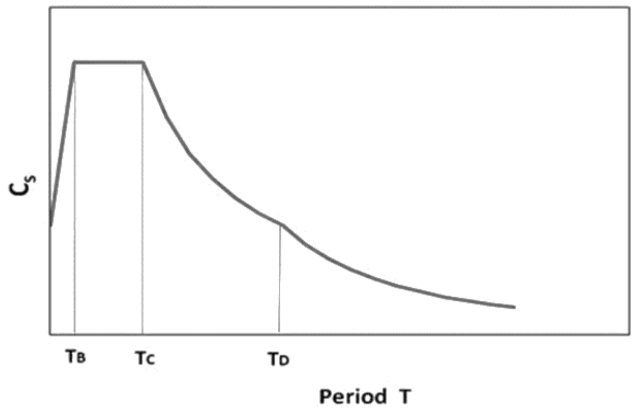


Figure 2.8. Normalized acceleration response spectrum

Here C_s is structural damping expressed as a percentage of critical damping.

$\eta=\sqrt{10/(5+\xi)} \ \geq 0.55$

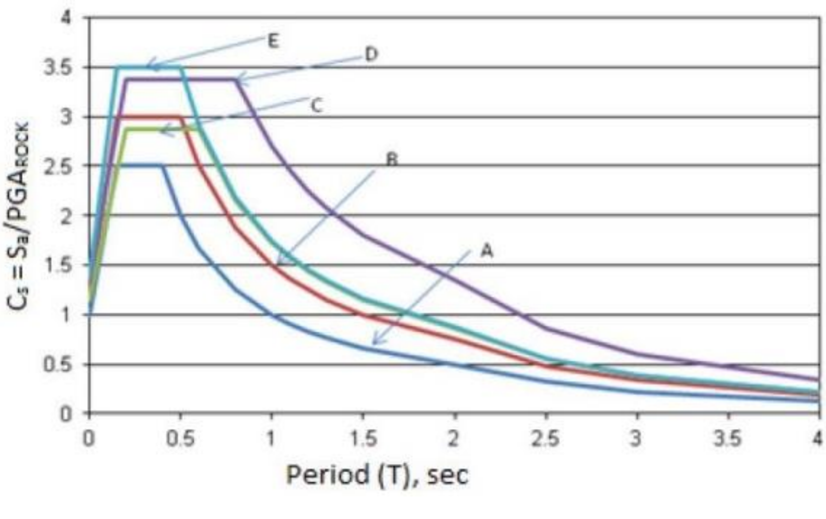


Figure 2.9. Normalized design acceleration response spectrum for different classes

Table 2.9. Values for Coefficients to Estimate Approximate Period

Structure type	C_t	m
Concrete moment-resisting frames	0.0466	0.9
Steel moment-resisting frames	0.0724	0.8
Eccentrically braced steel frame	0.0731	0.75
All other structural systems	0.0488	0.75
NOTE: Consider moment-resisting frames as frames that resist 100% of seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting under seismic forces.		

2.13 Seismic weight

Seismic weight, W, is the total dead load of a building or a structure, including partition walls, and applicable portions of other imposed loads listed below:

a. For live load up to and including 3 kN/m2, a minimum of 25 percent of the live load shall be applicable.
b. For a live load above 3 kN/m2, a minimum of 50 percent of the live load shall be applicable.
c. Total weight (100 percent) of permanent heavy equipment or retained liquid or any imposed load sustained in nature shall be included.

Where the probably imposed loads (mass) at the time of earthquake are more correctly assessed, the designer may go for a higher percentage of live load.

Table 2.10. Response Reduction Factor, Deflection Amplification Factor, and Height Limitations for Different Structural Systems

Seismic Force-Resisting System	Response Reduction Factor, R	System Overstrength Factor, Ω_0	Deflection Amplification Factor, C_d	Seismic Design Category B	Seismic Design Category C	Seismic Design Category D
				Height limit (m)		
C. MOMENT RESISTING FRAME SYSTEM (no shear wall)						
Special steel moment frames	8	3	5.5	NL	NL	NL

Intermediate steel moment frames	4.5	3	4	NL	NL	35
Ordinary steel moment frames	3.5	3	3	NL	NL	NP
Special reinforced concrete moment frames	8	3	5.5	NL	NL	NL
Intermediate reinforced concrete moment frames	5	3	4.5	NL	NL	NP
Ordinary reinforced concrete moment frames	3	3	2.5	NL	NP	NP

Seismic Force-Resisting System	Response Reduction Factor, R	System Overstrength Factor, Ω_0	Deflection Amplification Factor,C_d	Seismic Design Category B	Seismic Design Category C	Seismic Design Category D
				Height limit (m)		
E. DUAL SYSTEM: INTERMEDIATE MOMENT FRAMES CAPACLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES (with bracing or shear wall)						
Special steel concentrically braced frames	6	2.5	5	NL	NL	11
Special reinforced concrete shear walls	6.5	2.5	5	NL	NL	50
Ordinary reinforced masonry shear walls	3	3	3	NL	50	NP
Ordinary reinforced	5.5	2.5	4.5	NL	NL	NP

Table 2.11. Spectral Response Acceleration Parameter S_DS for Different Seismic Zone and Soil Type

Soil Type	Zone-1	Zone-2	Zone-3	Zone-4
SA	0.2	0.333	0.466	0.6
SB	0.24	0.4	0.56	0.72
SC	0.23	0.383	0.536	0.69
SD	0.27	0.45	0.63	0.81
SE	0.28	0.466	0.653	0.84

Table 2.12. Spectral Response Acceleration Parameter S_D1 for Different Seismic Zone and Soil Type

Soil Type	Zone-1	Zone-2	Zone-3	Zone-4
SA	0.08	0.133	0.186	0.24
SB	0.12	0.2	0.28	0.36
SC	0.138	0.23	0.322	0.414
SD	0.216	0.36	0.504	0.648
SE	0.14	0.233	0.326	0.42

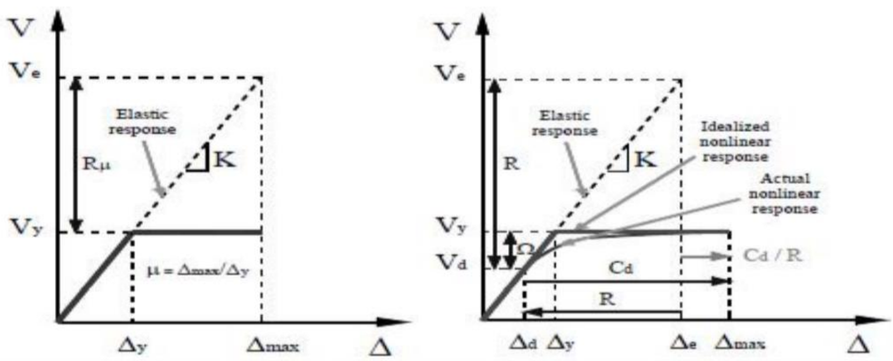


Figure 2.10. Structural response. (a) idealized (b) overall

2.14 Retrofit Strategies

Existing inadequate buildings must be retrofitted to prevent hazards in future earthquakes. The seismic evaluation of a building and the available resources are used to choose an appropriate retrofit strategy. A retrofit scheme for a building may include a combination of retrofit strategies. The following are recognized established retrofit strategies that have been in use successfully for many years:

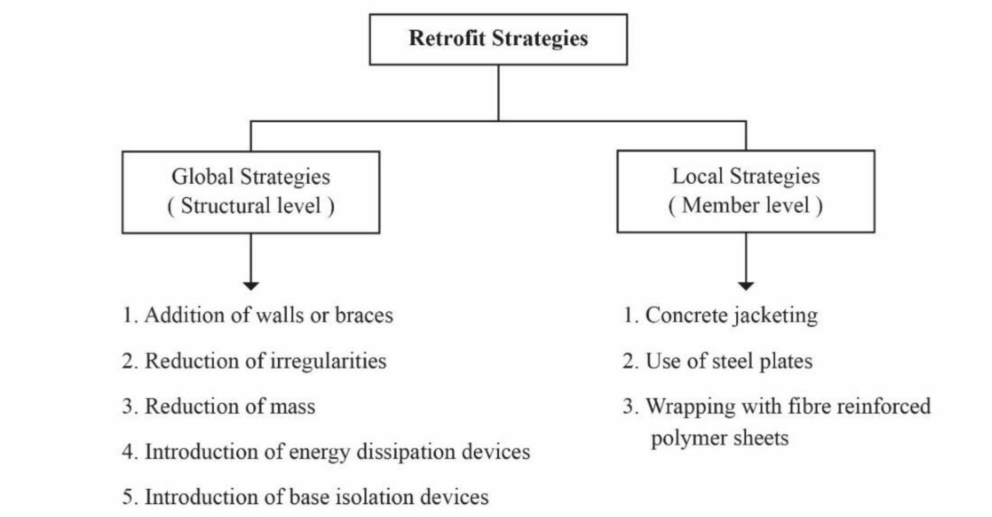


Figure 2.11. Type of Retrofit Strategies [3]

CHAPTER 3
METHODOLOGY

3.1 Introduction

The design provisions for the retrofitting are scattered in various chapters of the Bangladesh National Building Code (BNBC), ACI (American Concrete Institute) code, UBC (Uniform Building Code), and British Code of Practice and there is no straightforward design procedure in these codes. In this chapter, these code provisions have been studied, compared, and tried to suggest a straightforward guideline for the design of retrofitting for practicing engineers.

At first, an irregular plan of the ordinary moment-resisting frame structure is selected and designed by equivalent static load method for G+6 & G+10 story building using three-dimensional finite method. Three-dimensional analysis is done by ETABS. After analysis by ETABS, failure members will be designed for retrofitting according to Table 3.3.

3.2 Used Notation for this research

Ag = gross sectional area

Av = shear reinforcement area

d = distance between the extreme compression fiber and the tension reinforcement centroid

fe' = concrete's specified compressive strength

fy = reinforcement yield strength specified

h = overall member thickness

hw = total wall height from base to top

k = effective length factor

Ie = vertical distance between the supports.

Iw = horizontal length of the wall.

Mu = sectional factored moment

Nu = factored axial load normal to cross-section that occurs concurrently with Vu

Pnw = nominal axial load strength of the wall.

S1 = vertical reinforcement spacing in a wall

S2 = horizontal reinforcement spacing in a wall

Vs = shear reinforcement's shear strength

Vn = nominal shear strength.

Vu = shear force factored

Ve = nominal shear strength provided by concrete.

Ph = the ratio of horizontal shear reinforcement area to vertical section gross concrete area

Pv = the ratio of vertical shear reinforcement area to horizontal section gross concrete area.

3.3 Minimum Reinforcement and Spacing in Slab

I. Minimum ratio of vertical reinforcement area to the gross concrete area shall be:

   a. 0.0012 for deformed bars not larger than 16mm~ with a specified yield strength not less than 410 N/mm2, or

   b. 0.0015 for other bars.

II. Minimum ratio of horizontal reinforcement area to gross concrete area shall be:

   a. 0.0020 for deformed bars not larger than 16mm~ with a specified yield strength not less than 410 N/mm2, or

   b. 0.0025 for other deformed bars.

In addition to the minimum reinforcement, at least two 16mm~ bars shall be provided around all windows and doors opening. Such bars extended to develop the bar beyond the corners of the openings by at least 600 mm.

3.4 Minimum Thickness

There is no specific provision for minimum thickness. However, in the case of load-bearing walls thickness shall not be less than 1/25 of the supported height or length, whichever is shorter, nor less than 125 mm.

3.5 Design of Building

The building model under this study has(G+6) &(G+10) with a constant floor height of 10 feet. Four areas are used for analysis, and the equal length and width along the two horizontal directions are kept constant in each area for ease of use. Use different ZONE FACTOR values and explain their corresponding effects in the results. Other details are as follows:

Table 3.1. Zonal Parameter and Details

PARAMETERS	ZONE II (Dhaka)	ZONE III (Rangpur)
Seismic Zone factor, Z	0.20	0.28
Basic wind speed	146.97 mph	146.07 mph
Windward coefficient	0.80	0.80
Leeward coefficient	0.50	0.50
Importance factor, I	1	1
Exposure Condition	A	B
Importance co-efficient, R	8	8
Site co-efficient, S	1.15	1.35
Cd (classes of soil depend)	5.5	5.5
Ω (Nutrient availability Soil pH)	2.5	2.5
Sa (Spectral Acceleration)	0.0423	0.0592
Seismic Design Category	C	C
Site Class (Soil type)	SC (SPT value)	SD ((SPT value)
Soil condition (opinion)	Better	Good
Slab thickness	5 inches	5 inches
Floor finish	25 psf	25 psf
Partition wall	25psf	25psf
Super imposed dead load	100psf	100psf
Floor (Live Load)	45psf	45psf
Stair (Live Load)	60psf	60psf
All Steel fy	60000 psi	60000 psi
All Concrete f’c (Column)	4000 psi	4000 psi
All Concrete f’c (Beam)	4000 psi	4000 psi
All Concrete f’c (Slab)	4000 psi	4000 psi
Diaphragms	Rigid	Rigid
Poisson’s ratio of Concrete	0.15	0.15
Moment of inertia for Column	1	1
Torsional Constant Column	1	1
Moment of inertia for Beam	0.5	0.5
Torsional Constant Beam	0.5	0.5

The entire inquiry is based on a few criteria and specifications, as shown in Table 4.1.

Table 3.2. Summary of the design considerations and specification of the study

Items	Description
Design code	• Bangladesh National Building Code (BNBC), 2020.
Building Components	• Column type =Tied • Foundation type = Deep Foundation (Pilling) • Thickness of all partition walls = 5inch. • Thickness of Slab (All slabs) = 5 inches. • Thickness of stair slab = 7 inch
Material Properties	• Yield strength of reinforcing bars, fy= 60,000psi • Concrete compressive strength, fc' = 4,000 psi • Normal density concrete, unit weight = 150psf. • Unit weight of brick = 120psf. • Unit weight of water = 62.5psf.

Table 3.3. Floor Plan Details

Model 1: 7 story building	**Model 2: 10 story building**
• Height of building: **66**ft. • Length of building: **44**ft. • Width of building: **41.92**ft. • Total floors: 7 nos. (Typical Floors, 1^{st} to 6^{th})	• Height of building: **106**ft. • Length of building: **44**ft. • Width of building: **41.92**ft. • Total floors: **11** nos. (Typical Floors, 1^{st} to10^{th}

Plan View of Different Floors

Ground Floor:

- At street level, with one stair connecting it to the other floors
- The total floor area is 1844 ft^2
- The total floor height is 10'-0"

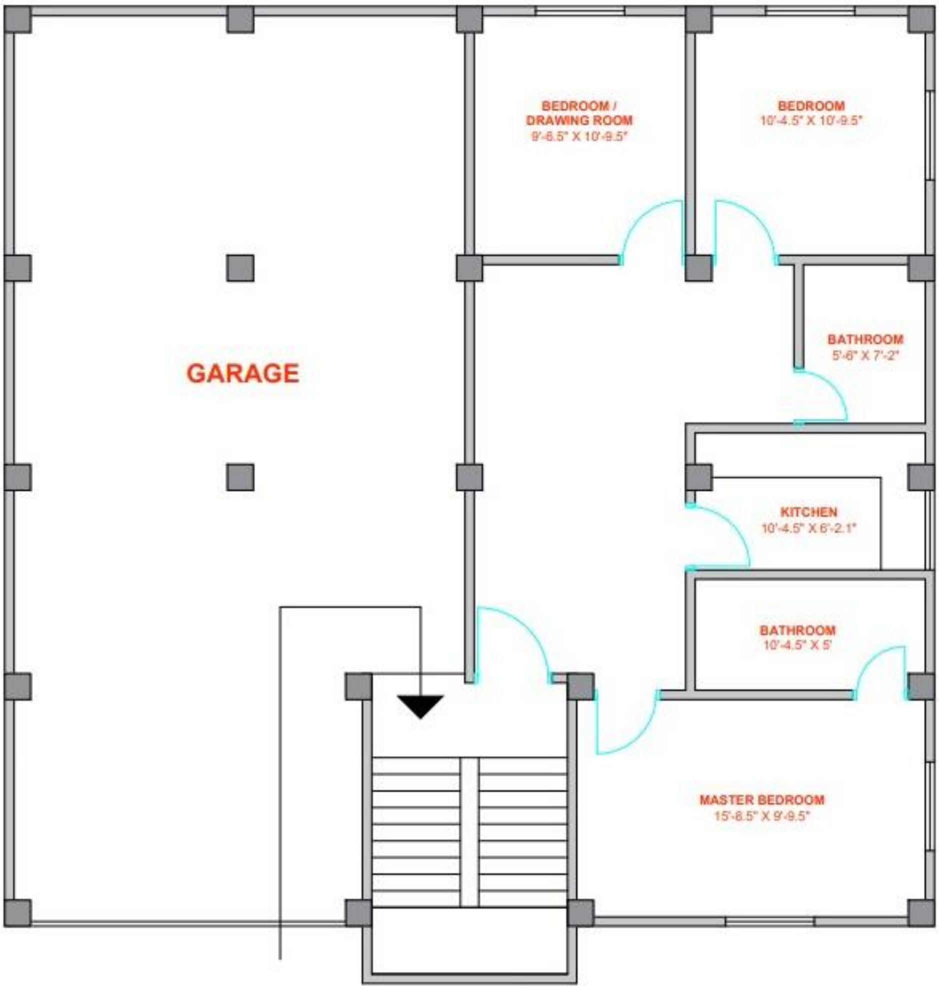


Figure 3.1. Ground Floor Plan

Typical Floor: (1st Floor - Roof)

- Connected to other floors via one stair
- The total floor area is 1844 ft^2
- The total floor height is 10'-0"

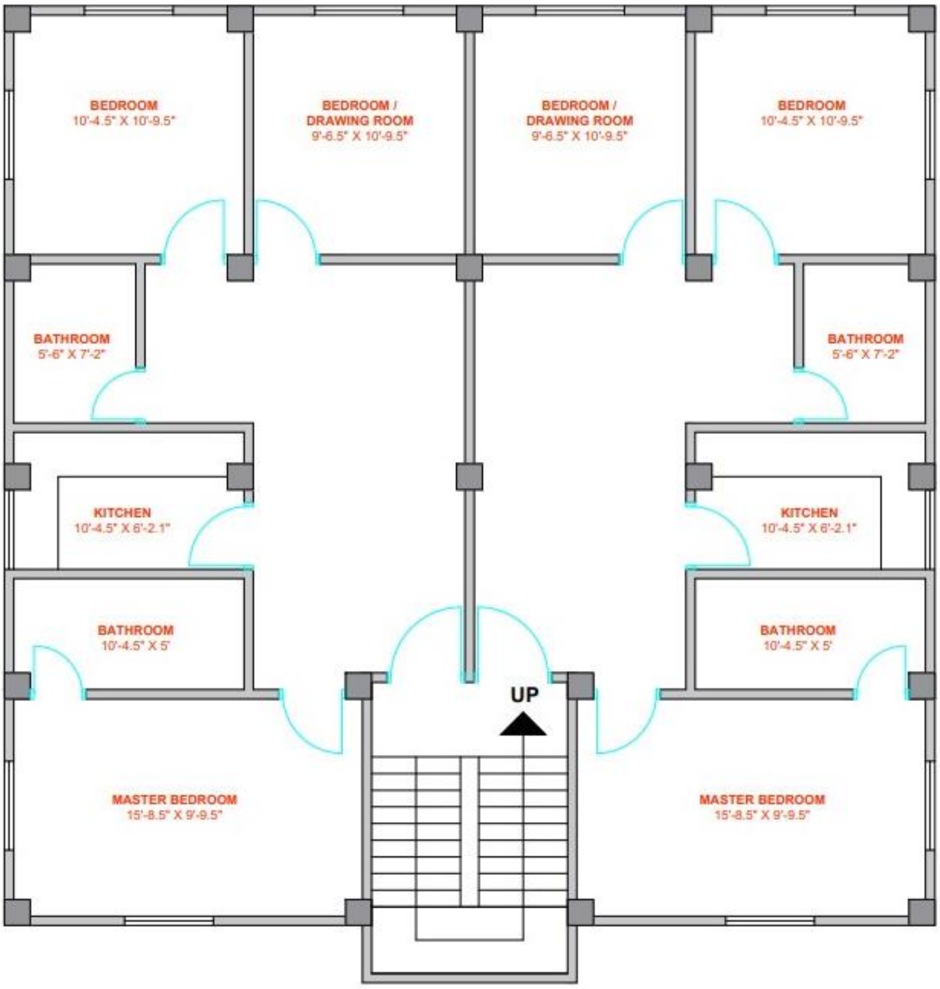


Figure 3.2. Typical Floor plan

Roof

- Total floor area = 1844 ft^2.
- One stair connects to other floors

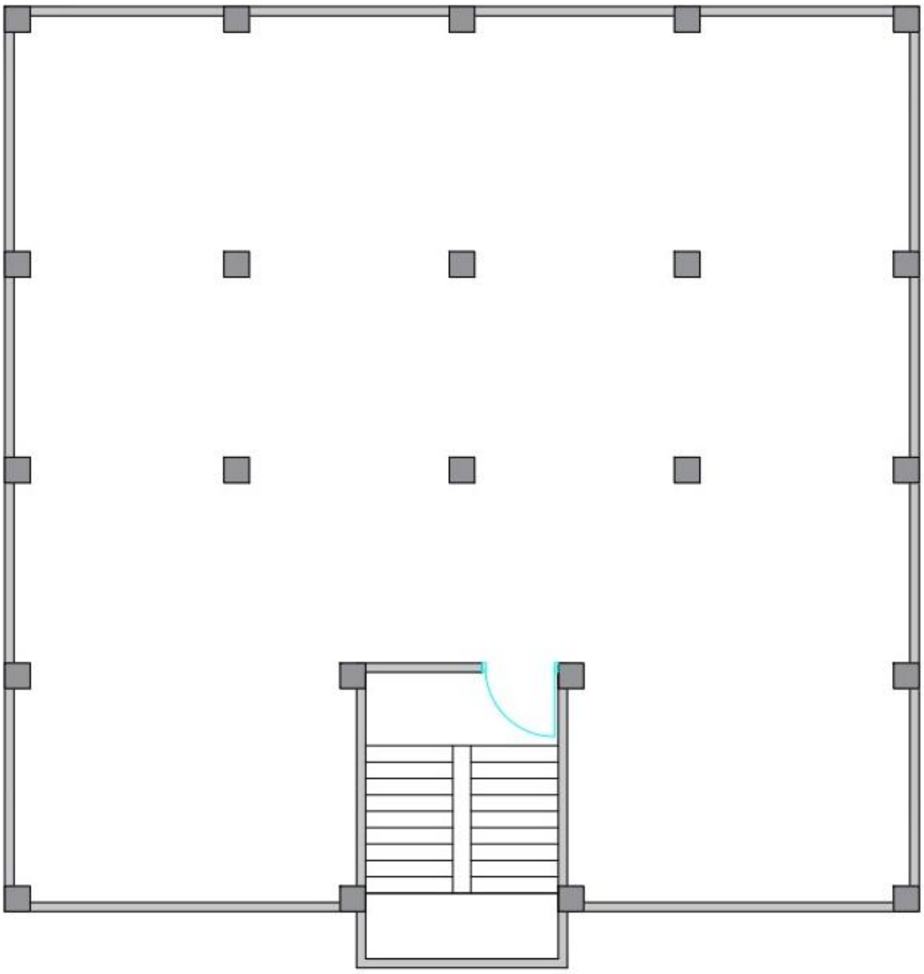


Figure 3.3. Rooftop Plan

Table 3.4. Legend of Building Columns and Beams

Column Name	Column Sizes	Beam Name	Beam Sizes
C1	14*14	Grade Beam (GB)	14*16
		Floor Beam (FB)	12*14

3.6 Types of Loads on Structures

The two most important factors to consider when building a structure are safety and cost. If the loads are adjudged and taken higher, the economy suffers; if the economy is considered and the loads are taken lower, the safety suffers. Loads acting on buildings and other structures are broadly classified as vertical loads, horizontal loads, and longitudinal loads. Vertical loads are made up of dead load, live load, and impact load. Wind and earthquake loads are examples of horizontal loads. In the design of bridges, gantry girders, and other structures, longitudinal loads, such as tractive and braking forces, are taken into account.

Table 3.5. Load combination according to BNBC2020

Expanded Combinations for ETABS (SDC B)		**Expanded Combinations for ETABS (SDC C & D)**	
Combination Case 1	1.4D	Combination Case 1	1.4D
Combination Case 2	1.2D + 1.6L	Combination Case 2	1.2D + 1.6L
Combination Case 3	1.2D + L	Combination Case 3	1.2D + L
Combination Case 4	1.2D + 0.8Wx	Combination Case 4	1.2D + 0.8Wx
Combination Case 5	1.2D – 0.8Wx	Combination Case 5	1.2D – 0.8Wx
Combination Case 6	1.2D + 0.8Wy	Combination Case 6	1.2D + 0.8Wy
Combination Case 7	1.2D – 0.8Wy	Combination Case 7	1.2D – 0.8Wy
Combination Case 8	1.2D + L + 1.6Wx	Combination Case 8	1.2D + L +1.6Wx
Combination Case 9	1.2D + L - 1.6Wx	Combination Case 9	1.2D + L + 1.6Wx
Combination Case 10	1.2D + L + 1.6Wy	Combination Case 10	1.2D + L + 1.6Wy
Combination Case 11	1.2D + L – 1.6Wy	Combination Case 11	1.2D + L – 1.6Wy
Combination Case 12	1.2D + L + Ex + D	Combination Case 12	1.2D + L + Ex + 0.3Ey + D
Combination Case 13	1.2D + L – Ex + D	Combination Case 13	1.2D + L + Ex – 0.3Ey + D
Combination Case 14	1.2D + L +Ey + D	Combination Case 14	1.2D + L – Ex + 0.3Ey + D
Combination Case 15	1.2D + L – Ey + D	Combination Case 15	1.2D + L – Ex – 0.3Ey + D
Combination Case 16	0.9D + 1.6Wx	Combination Case 16	1.2D + L + Ey + 0.3Ex + D
Combination Case 17	0.9D - 1.6Wx	Combination Case 17	1.2D + L + Ey - 0.3Ex + D
Combination Case 18	0.9D + 1.6Wy	Combination Case 18	1.2D + L - Ey + 0.3Ex + D
Combination Case 19	0.9D – 1.6Wy	Combination Case 19	1.2D + L - Ey - 0.3Ex + D
Combination Case 20	0.9D + Ex – D	Combination Case 20	0.9D + 1.6Wx
Combination Case 21	0.9D –Ex – D	Combination Case 21	0.9D – 1.6Wx
Combination Case 22	0.9D + Ey – D	Combination Case 22	0.9D + 1.6Wy
Combination Case 23	0.9D – Ey–D	Combination Case 23	0.9D – 1.6Wy
		Combination Case 24	0.9D + Ex + 0.3Ey – D
		Combination Case 25	0.9D + Ex - 0.3Ey – D
		Combination Case 26	0.9D - Ex + 0.3Ey – D
		Combination Case 27	0.9D - Ex - 0.3Ey – D
		Combination Case 28	0.9D + Ey + 0.3Ex – D
		Combination Case 29	0.9D + Ey- 0.3Ex – D
		Combination Case 30	0.9D - Ey + 0.3Ex – D
		Combination Case 31	0.9D - Ey - 0.3Ex – D

3.7 Details For Reinforced Concrete Jacketing

Concrete jacketing is perhaps the most used technique for reinforcing RC members. The technique here with a layer of reinforced concrete in the shape of a jacket outside the perimeter of the existing member, utilizing longitudinal steel reinforcement and transverse steel ties. The details for reinforced concrete jacketing are mentioned below.

Table 3.6. Details For Reinforced Concrete Jacketing [8]

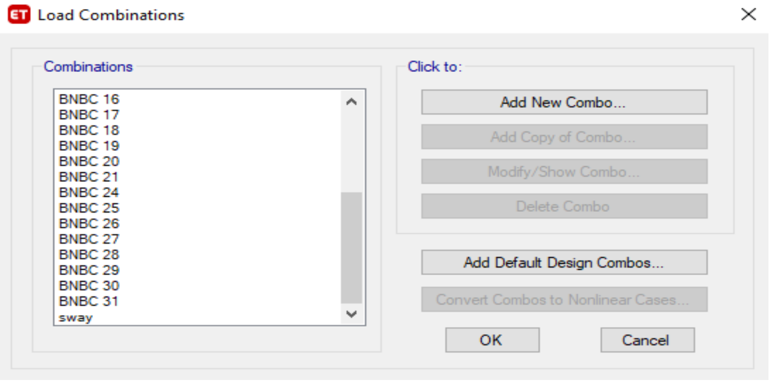
Properties of jackets	• Match with the concrete of the existing structure. • Compressive strength is greater than that of the existing structures by 5 N/mm^2 or at least equal to that of the existing structure.
Minimum width of jacket	• 10 cm for concrete cast-in-place and 4 cm for shotcrete. • If possible, a four-sided jacket should be used. • A monolithic behavior of the composite column should be assured. • A narrow gap should be provided to prevent any possible increase in flexural capacity.
Minimum area of longitudinal reinforcement	• $3Af_y$, where, A is the area of contact in cm^2 and f_y is in kg/cm^2 • Spacing should not exceed six times the width of the new elements (the jacket in the case) up to the limit of 60 cm. • Percentage of steel in the jacket with respect to the jacket area should be limited between 0.015and 0.04. • At least, 12 mm bar should be used at every corner for a four-sided jacket.
Minimum area of transverse reinforcement	• Designed and spaced as per earthquake design practice. • Minimum bar diameter used for ties is not less than 10 mm or 1/3 of the diameter of the biggest longitudinal bar. • The ties should have 135-degree hooks with 10bar diameter anchorage. • Due to the difficulty of manufacturing 135-degree hooks on the field, ties made up of multiple pieces can be used.
Shear stress in the interface	• Provide adequate shear transfer mechanism to assured monolithic behavior.

	• A relative movement between both concrete interfaces (between the jacket and the existing element) should be prevented. • Chipping the concrete cover of the original member and roughening its surface may improve the bond between the old and the new concrete. • For four-sided jacket, the ties should be used to confine and for shear reinforcement to the composite element.
Connectors	• Connectors should be anchored in both the concrete such that it may develop at least 80% of their yielding stress. • Distributed uniformly around the interface, avoiding concentration in specific locations. • It is better to use reinforced bars (rebar) anchored with epoxy resins of grouts.

Table 3.7. Special Frame section for retrofitting

Column	20*20
Beam	18*22

3.8 Load Combinations used for Reinforced Concrete Structures



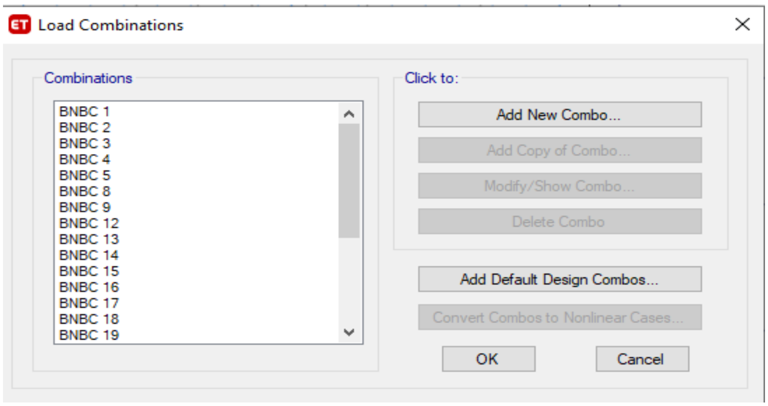


Figure 3.4. Load combination used on structure

3.9 Loading information as applied to the model

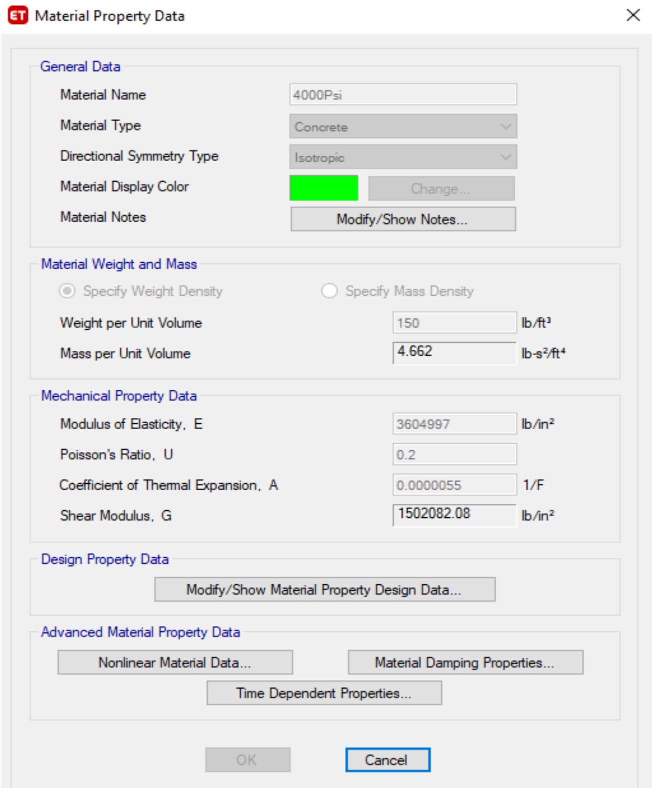
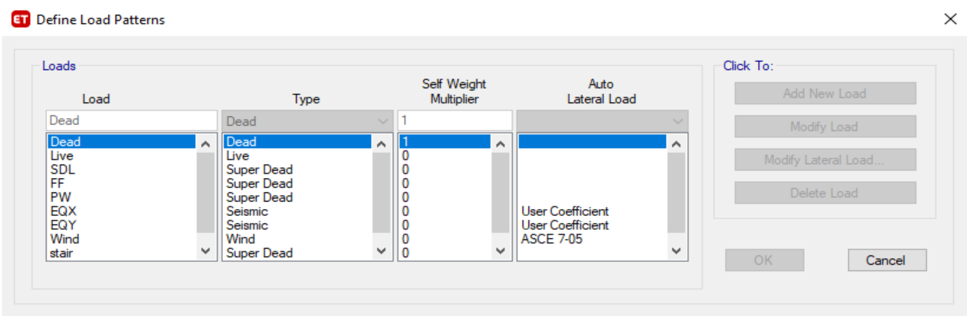


Figure 3.5. Material Properties Used on Structure

3.10 Load pattern



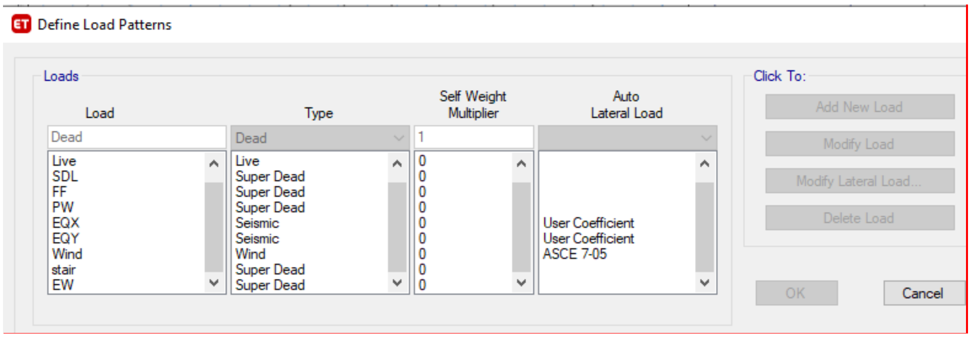


Figure 3.6. Load Pattern Used on Structure

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The purpose of this chapter is to describe the modeling and analysis procedure that has been employed to carry out the findings. Here we discuss the planned building's loads and material properties. Then at various heights, the plan has been analyzed and then we show the retrofitting design for the failure of column and beam.

4.2 Building Analysis Figures Using ETABS

<u>Model 1:</u>

(G+6) story Residential Building plan view and 3D view

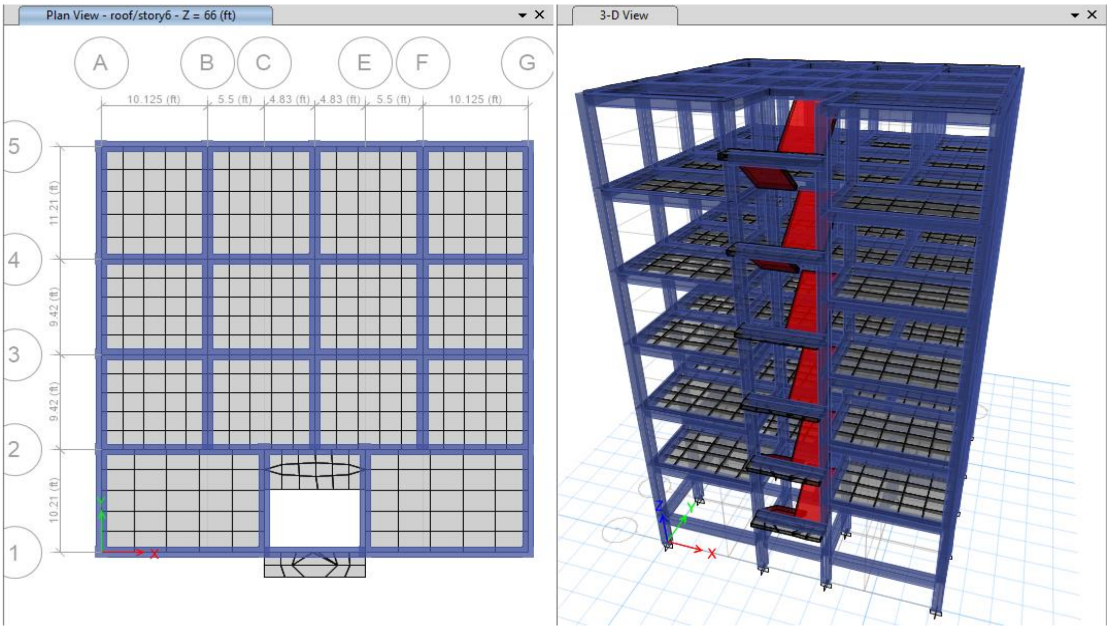


Figure 4.1. (G+6) story Residential Building plan view and 3D view

(G+6) story Residential Building with several beam failures in Dhaka district in zone 2

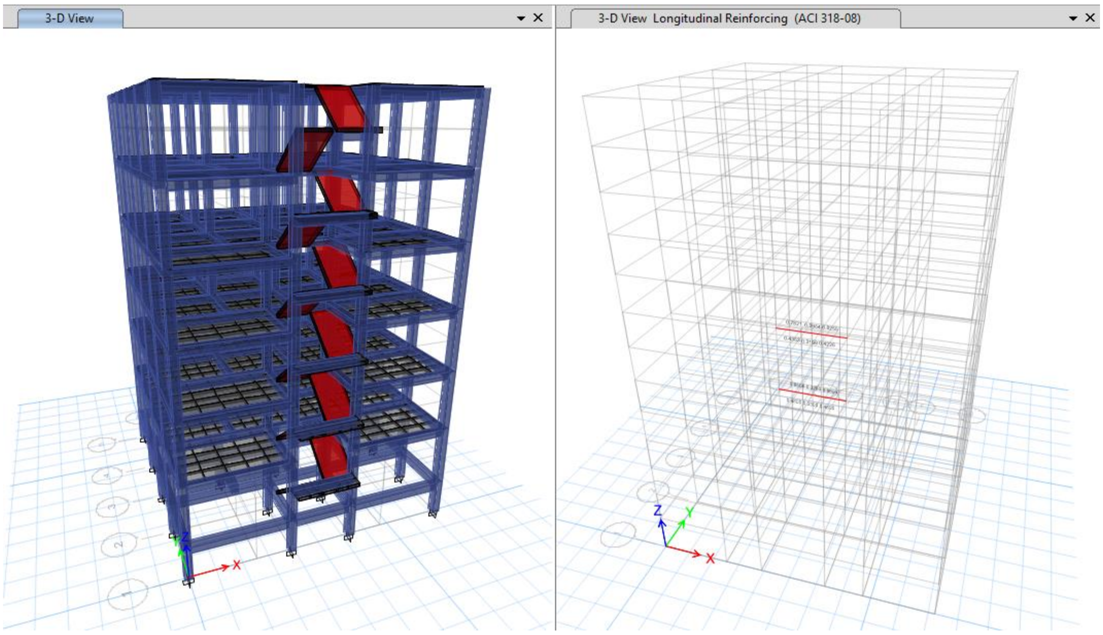


Figure 4.2. (G+6) story Residential Building with several beam failures in Dhaka district in zone 2

(G+10) story Residential Building with several beams and column failure in Rangpur district in zone 3

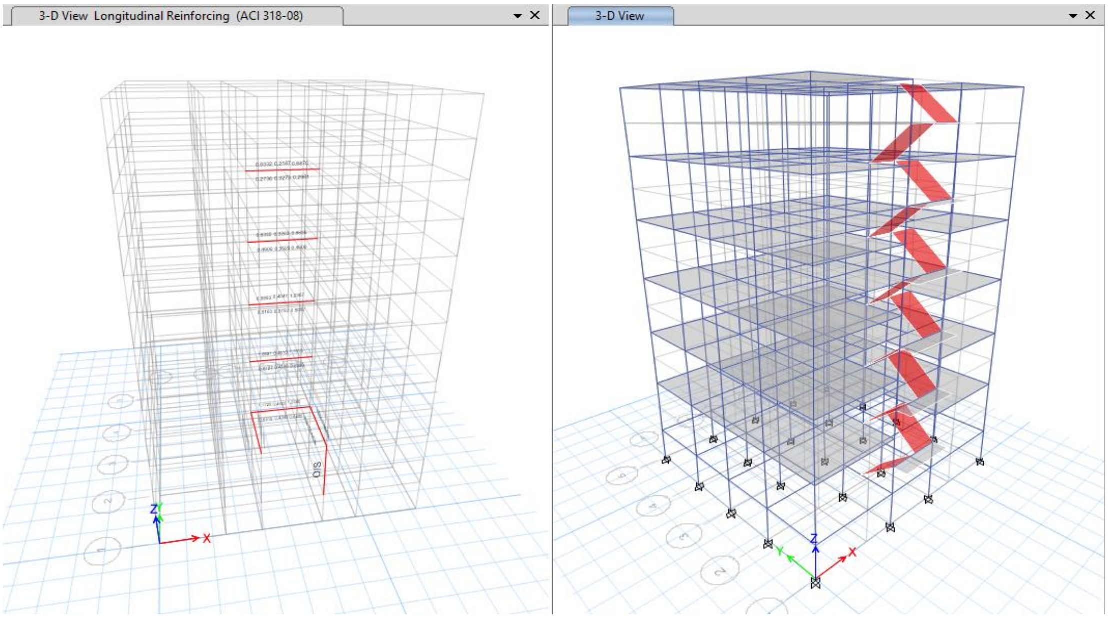


Figure 4.3. (G+10) story Residential Building with several beams and column failure in Rangpur district in zone 3

<u>Model 2:</u>

(G+10) story Residential Building plan view and 3D view

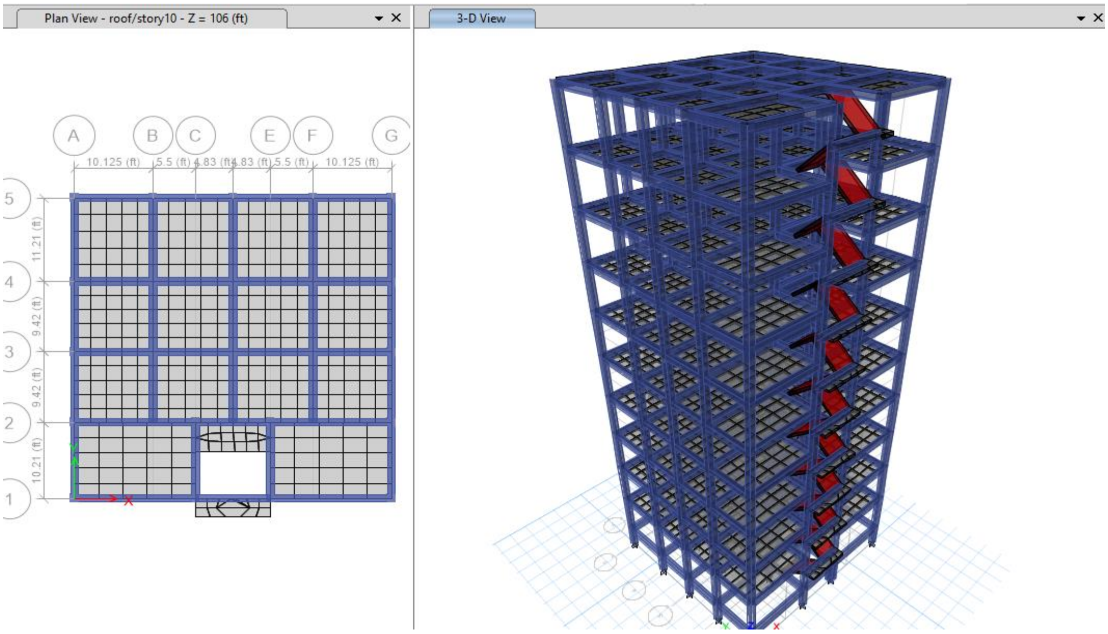


Figure 4.4. (G+10) story Residential Building plan view and 3D view

(G+10) story Residential Building several beam failures in Dhaka district in zone 2

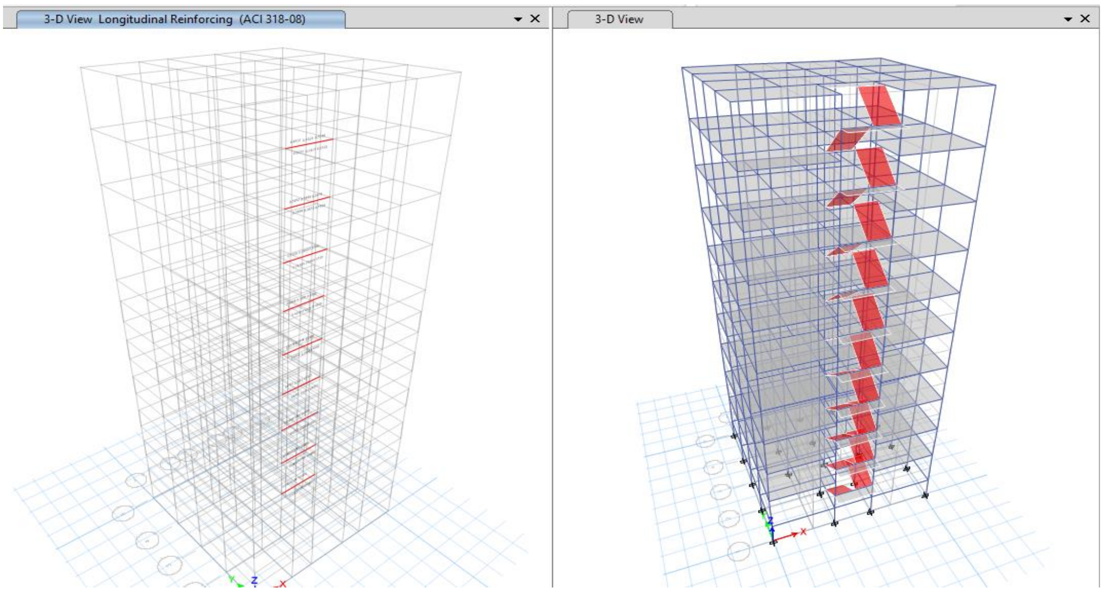


Figure 4.5. (G+10) story Residential Building several beam failures in Dhaka district in zone 2

(G+10) story Residential Building several beams and column failure in Rangpur district in zone 3

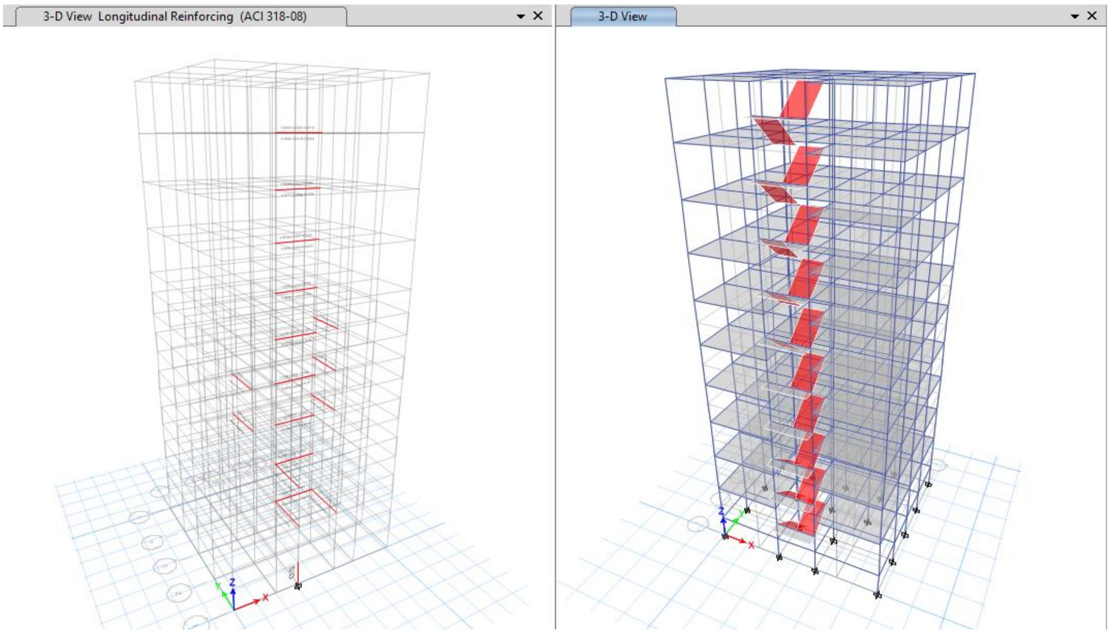


Figure 4.6. (G+10) story Residential Building several beams and column failure in Rangpur district in zone 3

4.3 Special section:

Special beam section used for retrofitting

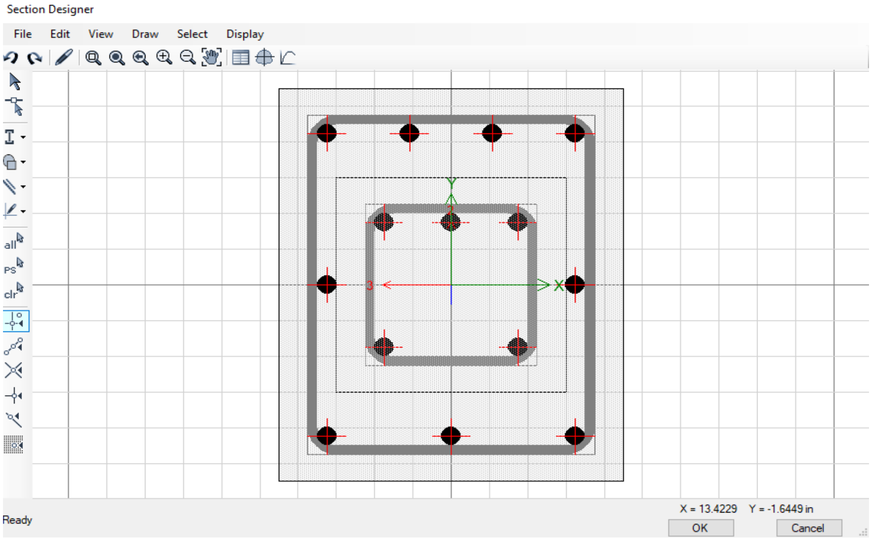


Figure 4.7. Special beam section used for retrofitting

Special Column section used for retrofitting

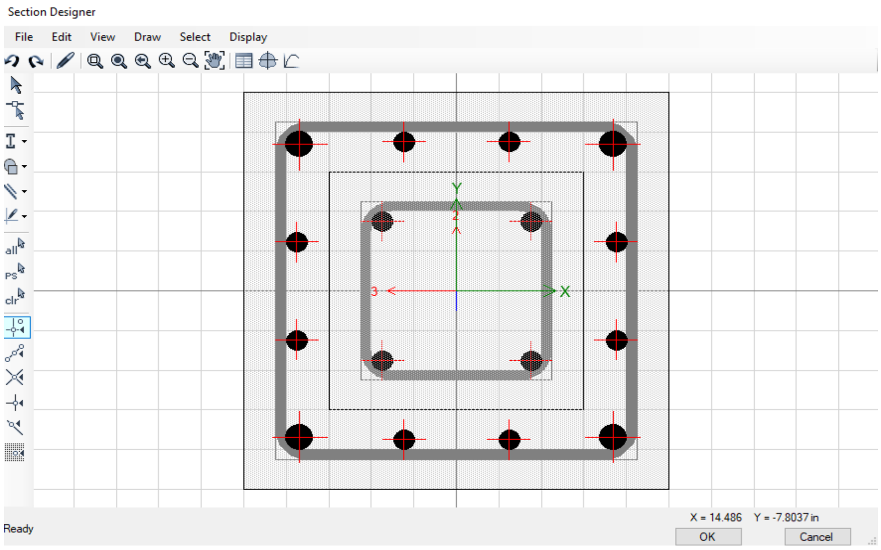


Figure 4.8. Special Column section used for retrofitting

4.4 (G+6) and (G+10) Storied Building Drift Details from ETABS

4.4.1 Dhaka District (Zone II)

<u>**(G+6) storied data table and Drift Graph with and without retrofitting in Dhaka District (Zone II)**</u>

<u>**Without retrofitting:**</u>

Table 4.1. (G+6) Storied Drift data table without retrofitting in Dhaka District (Zone II)

Story	Elevation (ft)	X-Direction	Y-Direction
Base	0	0	0
gf	6	0.00095	0.001127
Story1	16	0.002997	0.002633
Story2	26	0.003729	0.002998
Story3	36	0.003468	0.002808
Story4	46	0.002909	0.002412
Story5	56	0.002141	0.001849
Roof/story6	66	0.001256	0.001156

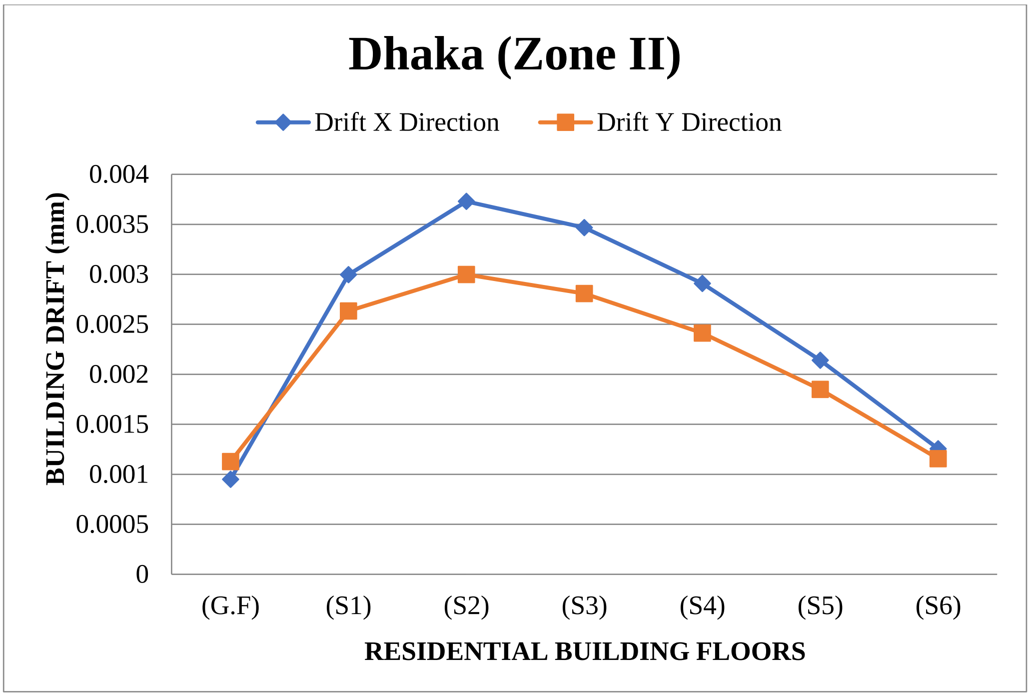


Figure 4.9. (G+6) Storied Drift Graph without retrofitting in Dhaka District (Zone II)

Observation:

- The highest drift on X-axis is 2nd Floor (0.003729mm) and the lowest drift is G. floor (0.00095mm)
- The highest drift on Y-axis is 2nd Floor (0.002998mm) and the lowest drift is G. floor (0.001127mm)

<u>With retrofitting:</u>

Table 4.2: (G+6) Storied Drift data table with retrofitting in Dhaka District (Zone II)

Story	Elevation (ft)	X-Direction	Y-Direction
Base	0	0	0
gf	6	0.00095	0.001128
Story1	16	0.002967	0.002627
Story2	26	0.003669	0.002984
Story3	36	0.003411	0.002791
Story4	46	0.002877	0.002399
Story5	56	0.002133	0.001842
story6	66	0.001262	0.00115

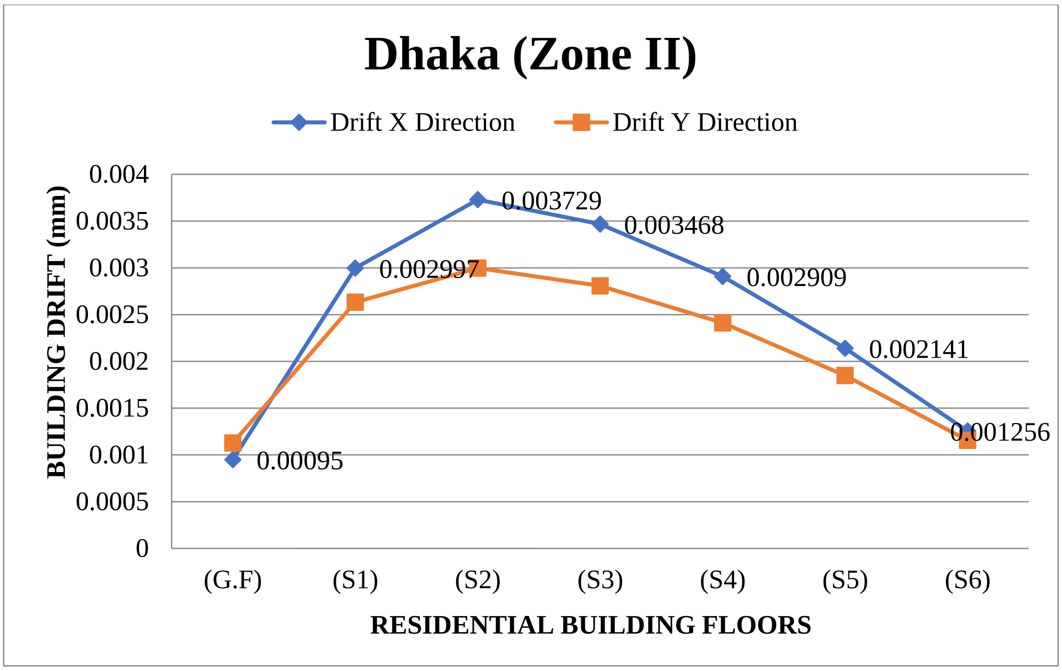


Figure 4.10. (G+6) Storied Drift Graph with retrofitting in Dhaka District

Observation:

- The highest drift on X-axis is 2nd Floor (0.003669mm) and the lowest drift is G. floor (0.00095mm)
- The highest drift on Y-axis is 2nd Floor (0.002984mm) and the lowest drift is G. floor (0.001128mm)

<u>(G+10) Storied Drift Graph with and without retrofitting in Dhaka District (Zone II)</u>

<u>Without retrofitting:</u>

Table 4.3: (G+10) Storied Drift data table without retrofitting in Dhaka District (Zone II)

Story	Elevation (ft)	X-Direction	Y-Direction
Base	0	0	0
gf	6	0.001037	0.001161
Story1	16	0.003323	0.002907
Story2	26	0.004342	0.003535
Story3	36	0.004424	0.003676
Story4	46	0.004284	0.003582
Story5	56	0.004031	0.003436

Story	Elevation (ft)	X-Direction	Y-Direction
Story6	66	0.003676	0.003207
Story7	76	0.003206	0.002872
Story8	86	0.002631	0.002443
Story9	96	0.002092	0.001931
Roof/story10	106	0.001697	0.00135

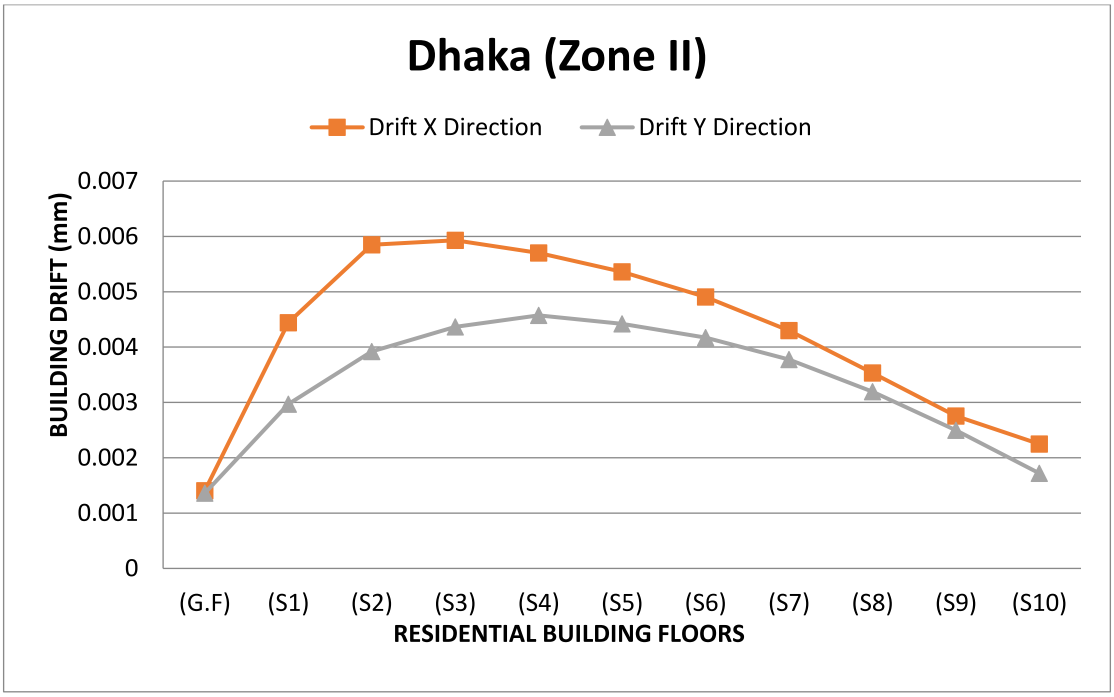


Figure 4.11. (G+10) Storied Drift Graph without retrofitting in Dhaka District (Zone II)

Observation:

- The highest drift on X-axis is 3rd Floor (0.004424mm) and the lowest drift is G. floor (0.001037mm)
- The highest drift on Y-axis is 3rd Floor (0.003676mm) and the lowest drift is G. floor (0.001161mm)

With retrofitting:

Table 4.4: (G+10) Storied Drift data table with retrofitting in Dhaka District (Zone II)

Story	Elevation (ft)	X-Direction	Y-Direction
Base	0	0	0
gf	6	0.001036	0.001163
Story1	16	0.003291	0.0029
Story2	26	0.004276	0.003514
Story3	36	0.004353	0.003645
Story4	46	0.004216	0.003546
Story5	56	0.003969	0.003395
Story6	66	0.003622	0.003163
Story7	76	0.003163	0.002827
Story8	86	0.0026	0.002397
Story9	96	0.002101	0.001886
roof/story10	106	0.001729	0.001312

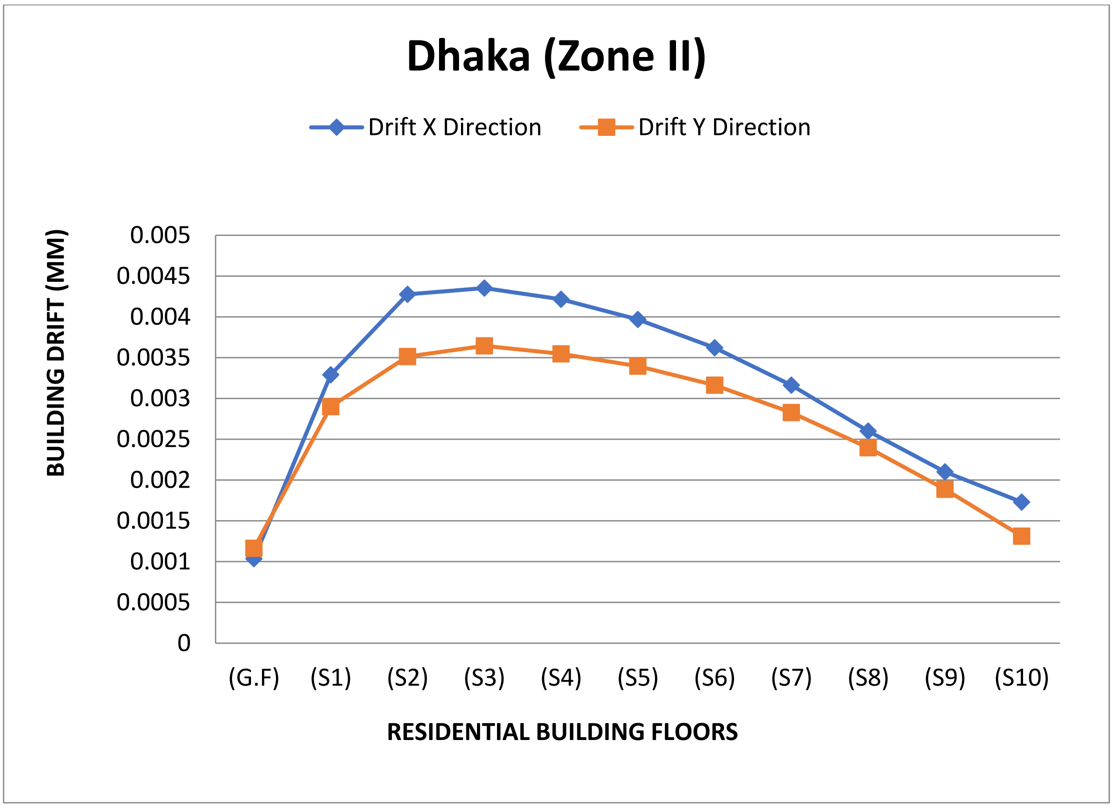


Figure 4.12. (G+10) Storied Drift Graph with retrofitting in Dhaka District

Observation:

- The highest drift on X-axis is 3rd Floor (0.004353mm) and the lowest drift is G. floor (0.001036mm)
- The highest drift on Y-axis is 3rd Floor (0.003645mm) and the lowest drift is G. floor (0.001163mm)

4.4.2 Rangpur District (Zone III)

(G+6) Storied Drift Graph with and without retrofitting in Rangpur District (Zone III)

Without retrofitting:

Table 4.5: (G+6) Storied Drift data table with and without retrofitting in Rangpur District (Zone III)

Story	Elevation (ft)	X-Direction	Y-Direction
Base	0	0	0
gf	6	0.001331	0.001578
Story1	16	0.004197	0.003687
Story2	26	0.005222	0.004198
Story3	36	0.004856	0.003933
Story4	46	0.004073	0.003378
Story5	56	0.002999	0.002589
roof/story6	66	0.001759	0.001619

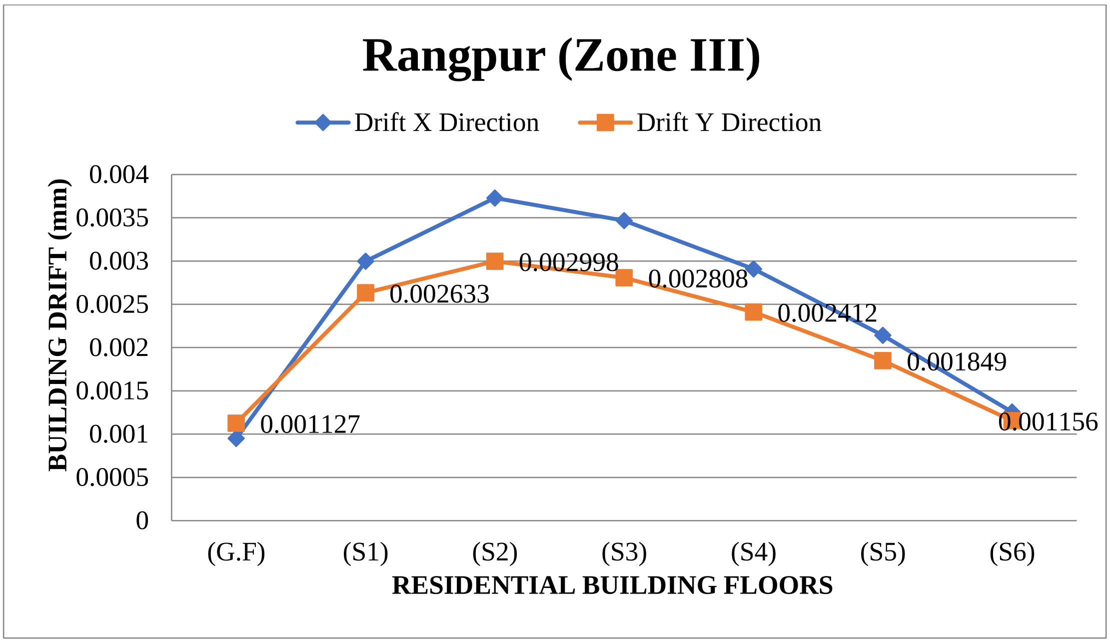


Figure 4.13. (G+6) Storied Drift Graph without retrofitting in Rangpur District (Zone III)

Observation:

- The highest drift on X-axis is 2nd Floor (0.005222mm) and the lowest drift is G. floor (0.001331mm)
- The highest drift on Y-axis is 2nd Floor (0.004198mm) and the lowest drift is G. floor (0.001578mm)

With retrofitting:

Table 4.6: (G+6) Storied Drift data table with retrofitting in Rangpur District (Zone III)

Story	Elevation (ft)	X-Direction	Y-Direction
Base	0	0	0
gf	6	0.001335	0.001534
Story1	16	0.004173	0.003168
Story2	26	0.005149	0.003804
Story3	36	0.004766	0.003893
Story4	46	0.003992	0.003373
Story5	56	0.002937	0.002579
roof/story6	66	0.001711	0.001611

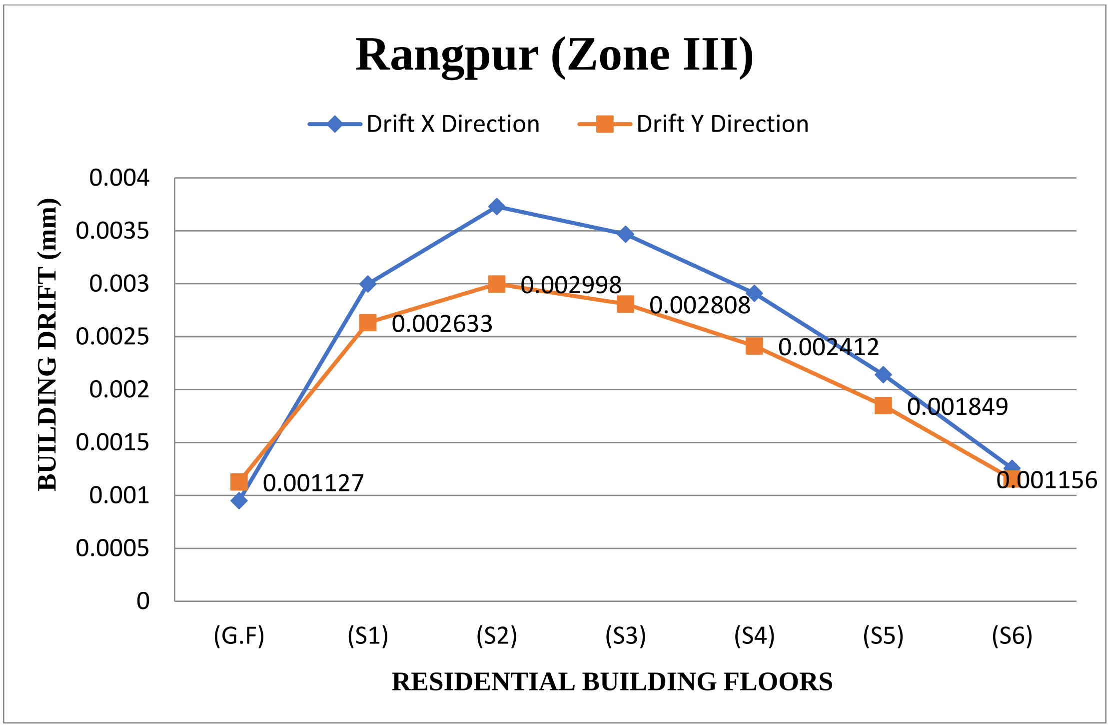


Figure 4.14. (G+6) Storied Drift Graph with retrofitting in Rangpur District

Observation:

- The highest drift on X-axis is 2nd Floor (0.005149mm) and the lowest drift is G. floor (0.001335mm)
- The highest drift in Y-axis is 3rd Floor (0.003893mm) and the lowest drift is G. floor (0.001534mm)

(G+10) Storied Drift Graph with and without retrofitting in Rangpur District (Zone III)

Without retrofitting:

Table 4.7: (G+10) Storied Drift data table with and without retrofitting in Rangpur District (Zone III)

Story	Elevation (ft)	X-Direction	Y-Direction
Base	0	0	0
gf	6	0.00142	0.001601
Story1	16	0.004553	0.004007
Story2	26	0.005951	0.004874
Story3	36	0.006064	0.005067
Story4	46	0.005873	0.004938
Story5	56	0.005527	0.004737
Story6	66	0.005041	0.00442
Story7	76	0.004398	0.003959
Story8	86	0.003609	0.003366
Story9	96	0.002894	0.002661
roof/story10	106	0.002347	0.00186

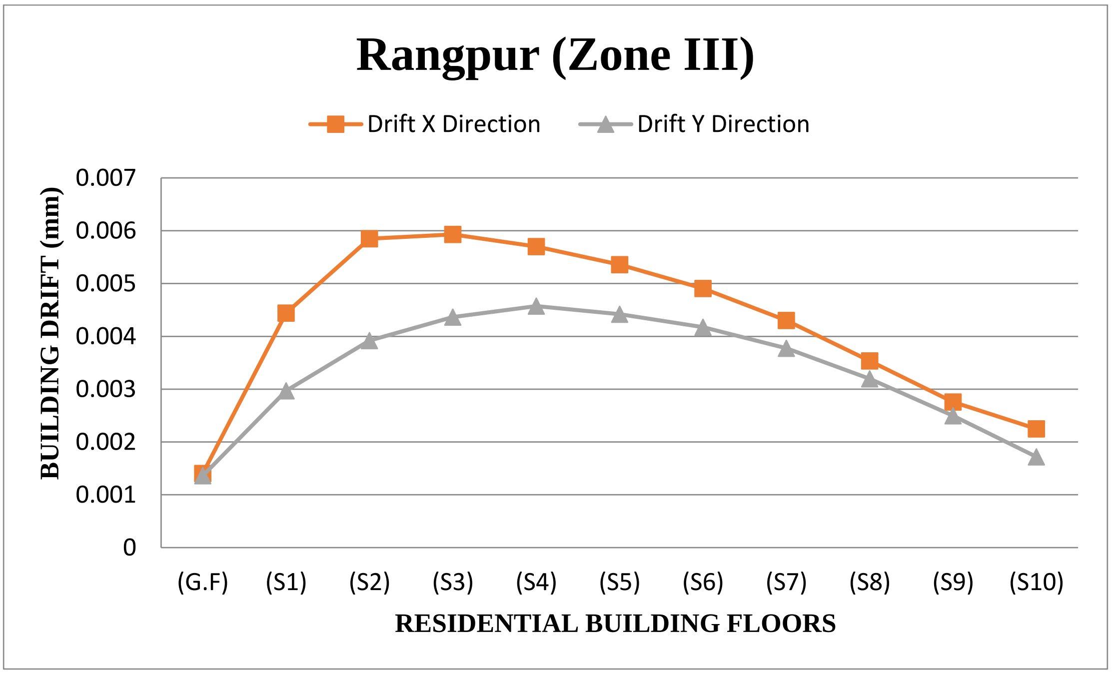


Figure 4.15. (G+10) Storied Drift Graph without retrofitting in Rangpur District (Zone III)

Observation:

- The highest drift on X-axis is 3rd Floor (0.006064mm) and the lowest drift is G. floor (0.00142mm)
- The highest drift in Y-axis is 3rd Floor (0.005067mm) and the lowest drift is G. floor (0.001601mm)

With retrofitting:

Table 4.8: (G+10) Storied Drift data table with retrofitting in Rangpur District (Zone III)

Story	Elevation (ft)	X-Direction	Y-Direction
Base	0	0	0
gf	6	0.001405	0.00136
Story1	16	0.004442	0.002969
Story2	26	0.005849	0.003921
Story3	36	0.00593	0.004366
Story4	46	0.005701	0.004573
Story5	56	0.005359	0.004419
Story6	66	0.004906	0.004173
Story7	76	0.0043	0.003776
Story8	86	0.003534	0.003195
Story9	96	0.002756	0.002496
roof/story10	106	0.002248	0.00172

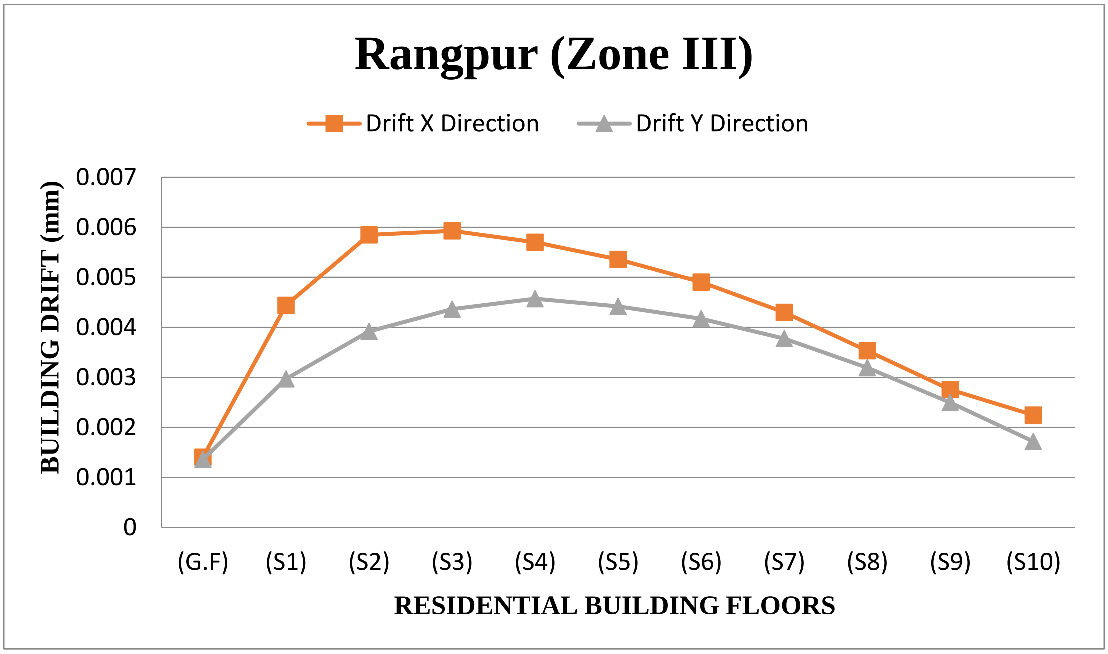


Figure 4.16. (G+10) Storied Drift Graph with retrofitting in Rangpur District

Observation:

- The highest drift on X-axis is 3rd Floor (0.00593mm) and the lowest drift is G. floor (0.001405mm)
- The highest drift in Y-axis is 4th Floor (0.004573mm) and the lowest drift is G. floor (0.00136mm)

4.5 Overall Drift Graph

4.5.1 Overall Drift Graph for all (G+6) Storied buildings with and without retrofitting in zone 2 and zone 3

Without retrofitting:

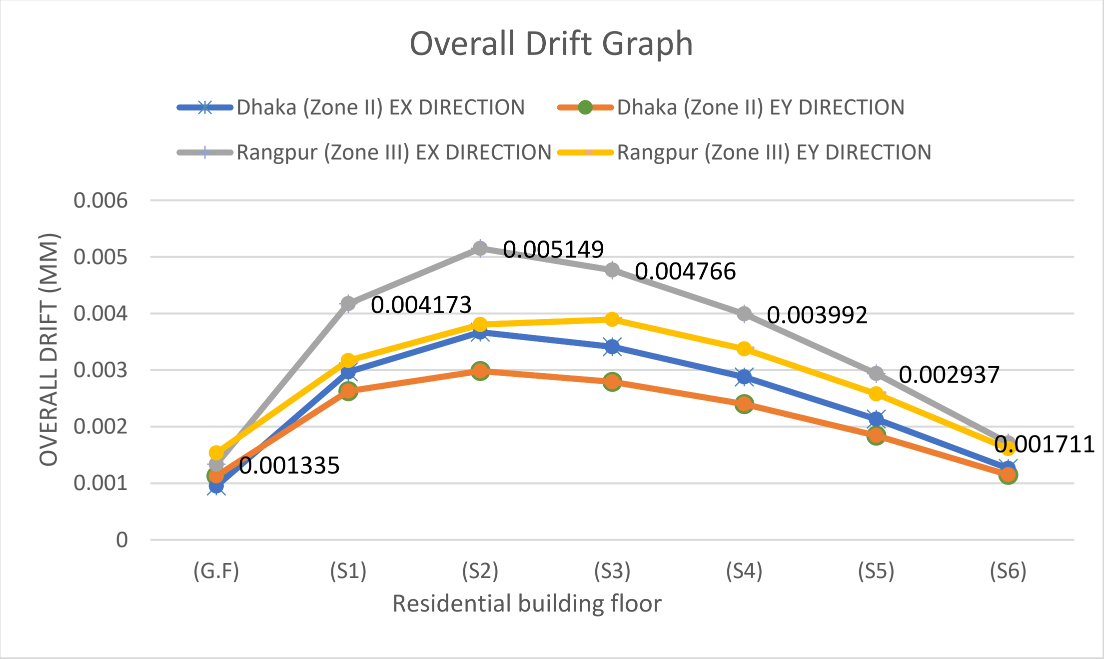


Figure 4.17. Overall Drift Graph for all (G+6) storied buildings without retrofitting in zone 2 and zone 3

With retrofitting:

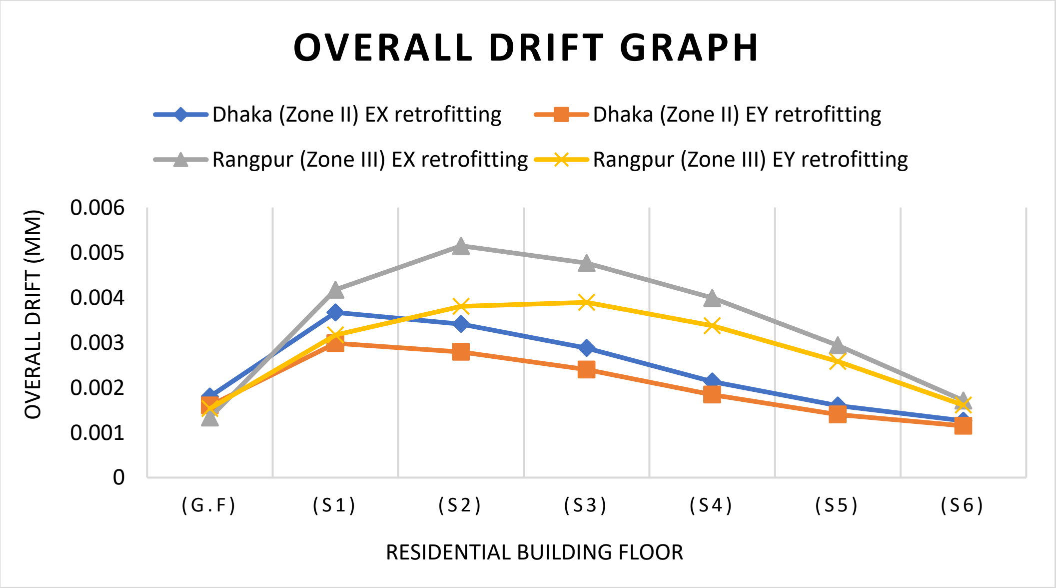


Figure 4.18. Overall Drift Graph for all (G+6) storied buildings with retrofitting in zone 2 and zone 3

Observation: Rangpur zone has highest drift than Dhaka zone for (G+6) storied buildings before and after retrofitting.

Table 4.9: Overall highest and lowest drift after retrofitting in zone 2 and 3

Overall Highest Drift		**Overall Lowest Drift**	
EX direction	**EY direction**	**EX direction**	**YY direction**
Rangpur (Zone III)	Rangpur (Zone III)	Dhaka (Zone II)	Dhaka (Zone II)
2^{rd} Floor (0.005149mm)	3^{rd} Floor (0.003893mm)	G. Floor (0.00095mm)	G. Floor (0.001128mm)

4.5.2 Overall Drift Graph for all (G+10) storied buildings with and without retrofitting in zone 2 and zone 3

Without retrofitting:

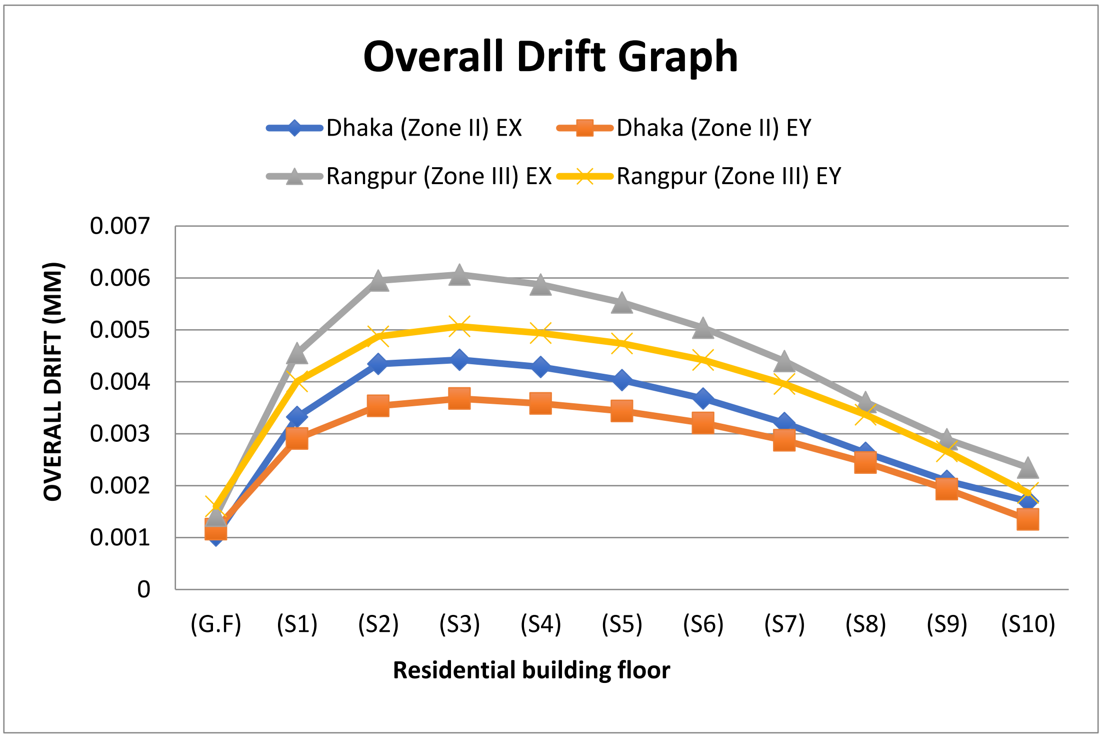


Figure 4.19. Overall Drift Graph for all (G+10) storied buildings without retrofitting in zone 2 and zone 3

With retrofitting:

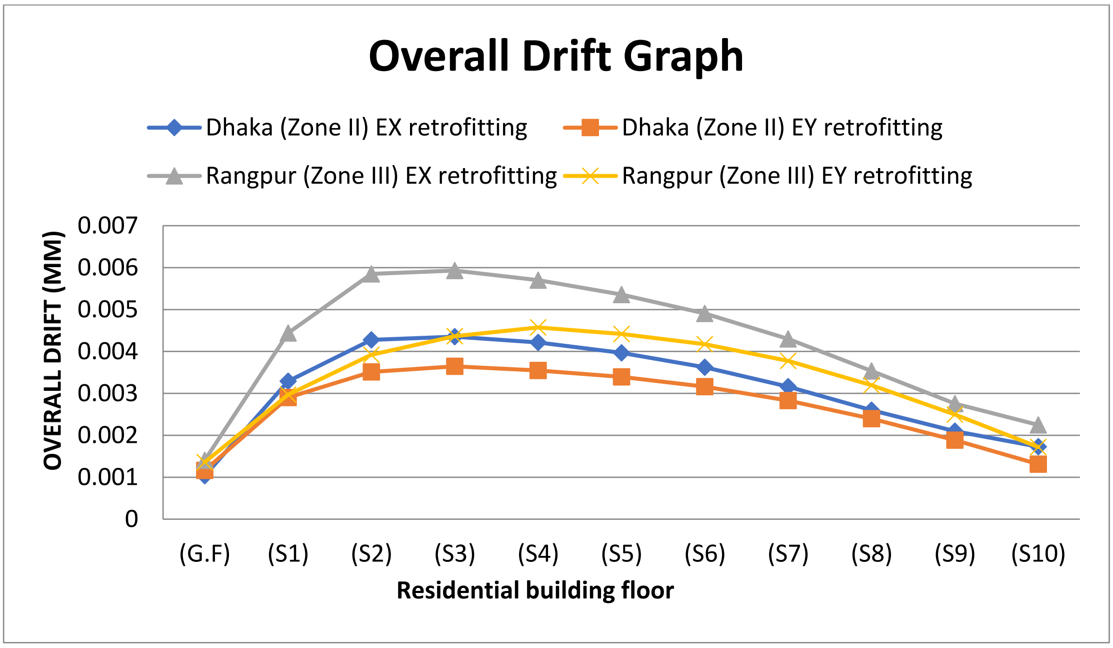


Figure 4.20. Overall Drift Graph for all (G+10) storied buildings with retrofitting in zone 2 and zone 3

Observation: Rangpur zone has highest drift than Dhaka zone for (G+10) storied buildings before and after retrofitting.

Table 4.10: Overall highest and lowest drift after retrofitting in zone 2 and 3

Overall Highest Drift		Overall Lowest Drift	
EX direction	**EY direction**	**EX direction**	**YY direction**
Rangpur (Zone III)	Rangpur (Zone III)	Dhaka (Zone II)	Dhaka (Zone II)
3^{rd} Floor (0.00593mm)	4^{rd} Floor (0.004573mm)	G. Floor (0.001036mm)	G. Floor (0.001163mm)

4.6 Building Displacement

4.6.1 (G+6) Storied displacement Graph with and without retrofitting in Dhaka District (Zone II)

<u>Without retrofitting:</u>

Table 4.11: Building Displacement of (G+6) storied building without retrofitting Using ETABS

Floors	Displacement X Direction	Displacement Y Direction
GF	0.11948	0.09965
Story1	0.4281	0.403887
Story2	0.875619	0.762095
Story3	1.291788	1.096116
Story4	1.640825	1.381606
Story5	1.8978	1.601598
Story6	2.047591	1.740305

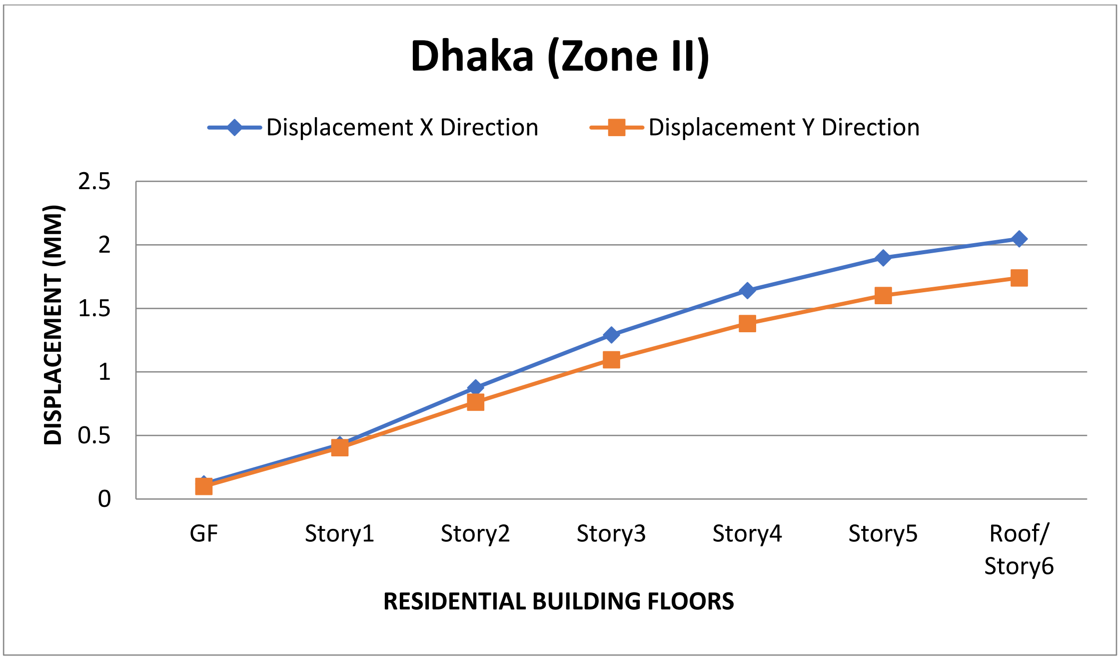


Figure 4.21. Building Displacement of (G+6) storied building without retrofitting Using ETABS

Observation:

- The Highest Displacement in EX direction is Roof floor (2.047591) and the lowest on the G. floor (0.11948)
- The Highest Displacement in the EY direction is Roof floor (1.740305) and the lowest on the G. floor (0.09965)

With retrofitting:

Table 4.12: Building Displacement of (G+6) storied building with retrofitting Using ETABS

Floors	Displacement X Direction	Displacement Y Direction
GF	0.1182	0.099667
Story1	0.424437	0.403233
Story2	0.864695	0.759718
Story3	1.273985	1.091779
Story4	1.619278	1.375805
Story5	1.875279	1.594997
Story6	2.024574	1.732964

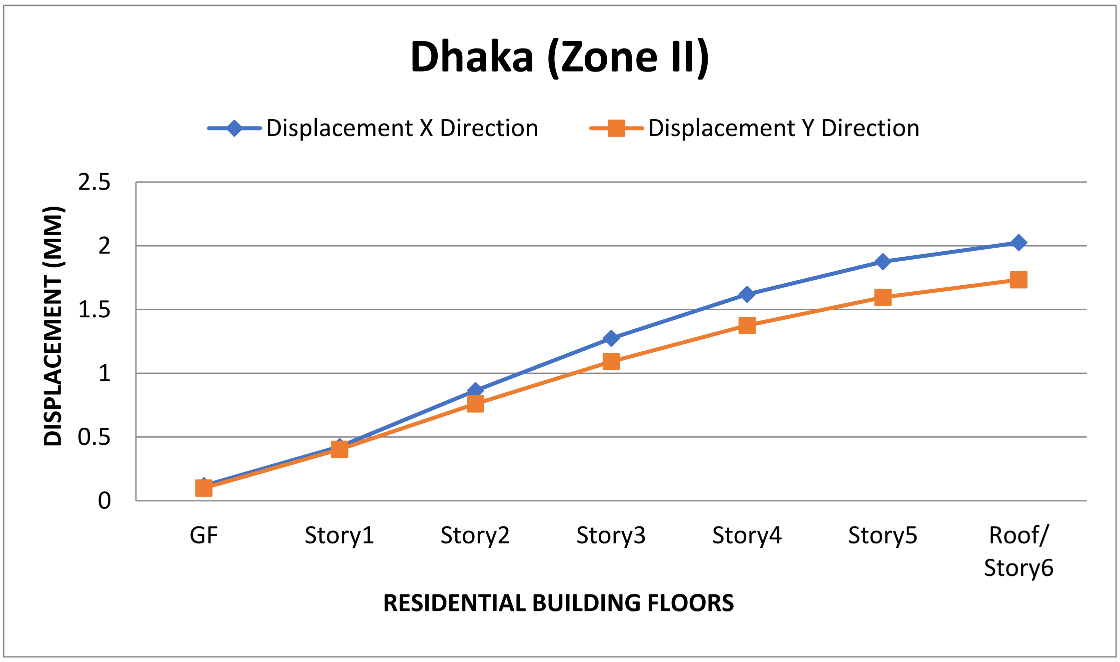


Figure 4.22. Building Displacement of (G+6) storied building with retrofitting Using ETABS

Observation:

- The Highest Displacement in EX direction is Roof floor (2.024574) and the lowest on the G. floor (0.1182)
- The Highest Displacement in the EY direction is Roof floor (1.732964) and the lowest on the G. floor (0.099667)

4.6.2 (G+6) Storied Displacement Graph with and without retrofitting in Rangpur District (Zone III)

<u>Without retrofitting:</u>

Table 4.13. Building Displacement of (G+6) storied building without retrofitting Using ETABS

Floors	Displacement X Direction	Displacement Y Direction
GF	0.167308	0.13954
Story1	0.599469	0.565563
Story2	1.226132	1.067163
Story3	1.808893	1.534894
Story4	2.297651	1.934666
Story5	2.657493	2.242721
Story6	2.867246	2.436953

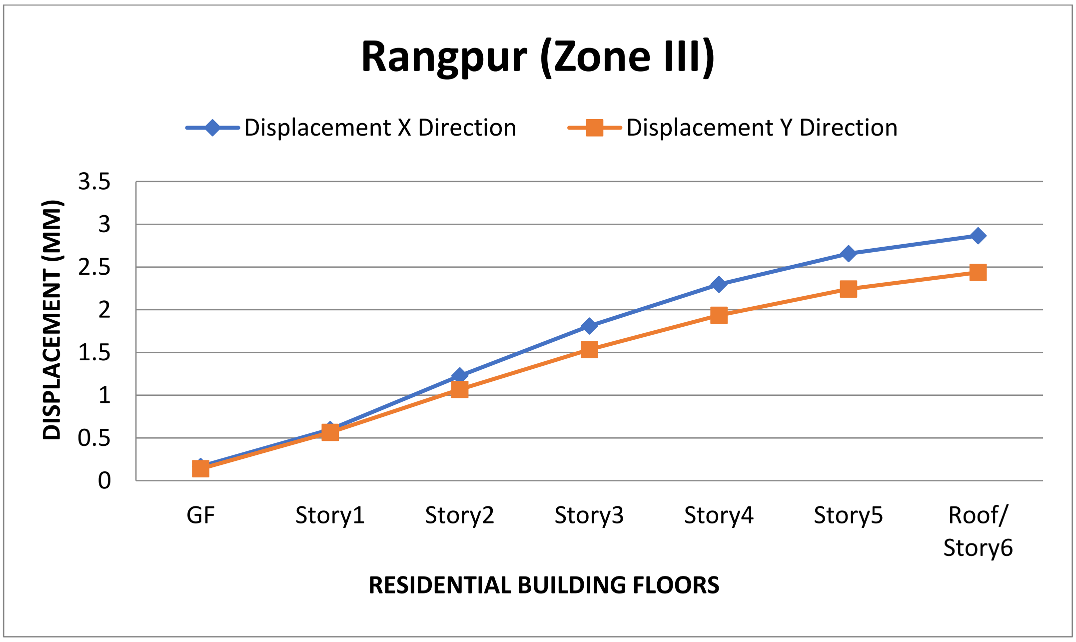


Figure 4.23. Building Displacement of (G+6) storied building without retrofitting Using ETABS

Observation:

- The Highest Displacement in EX direction is Roof floor (2.867246) and the lowest on the G. floor (0.167308)
- The Highest Displacement in the EY direction is Roof floor (2.436953) and the lowest on the G. floor (0.13954)

With retrofitting:

Table 4.14. Building Displacement of (G+6) storied building with retrofitting Using ETABS

Floors	Displacement X Direction	Displacement Y Direction
GF	0.164558	0.135337
Story1	0.596937	0.49614
Story2	1.214839	0.946421
Story3	1.786732	1.407167
Story4	2.265809	1.804041
Story5	2.618209	2.11289
Story6	2.823513	2.306211

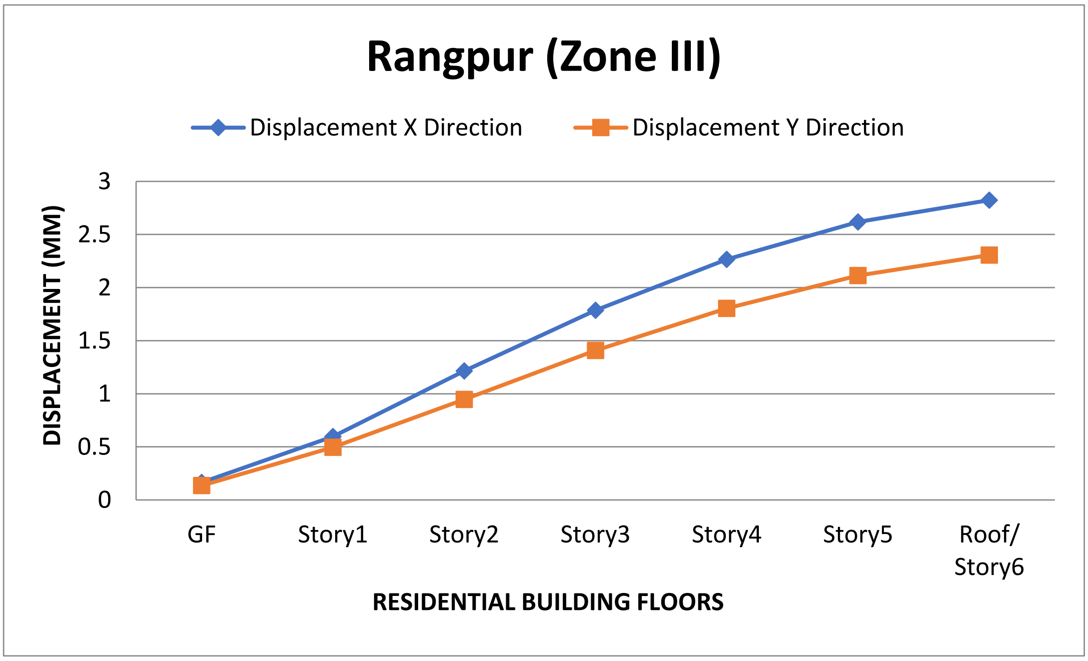


Figure 4.24. Building Displacement of (G+6) storied building with retrofitting Using ETABS

Observation:

- The Highest Displacement in EX direction is Roof floor (2.823513) and the lowest on the G. floor (0.164558)
- The Highest Displacement in the EY direction is Roof floor (2.306211) and the lowest on the G. floor (0.135337)

4.6.3 (G+10) Storied displacement Graph with and without retrofitting in Dhaka District (Zone II)

Without retrofitting:

Table 4.15. Building Displacement of (G+10) storied building without retrofitting Using ETABS

Floors	Displacement X Direction	Displacement Y Direction
GF	0.122056	0.103041
Story1	0.473369	0.441139
Story2	0.994414	0.863503
Story3	1.525263	1.298542
Story4	2.039296	1.726048
Story5	2.523039	2.138414
Story6	2.96415	2.523207
Story7	3.348641	2.867579
Story8	3.663995	3.160387
Story9	3.898712	3.391791
roof/story10	4.046754	3.553467

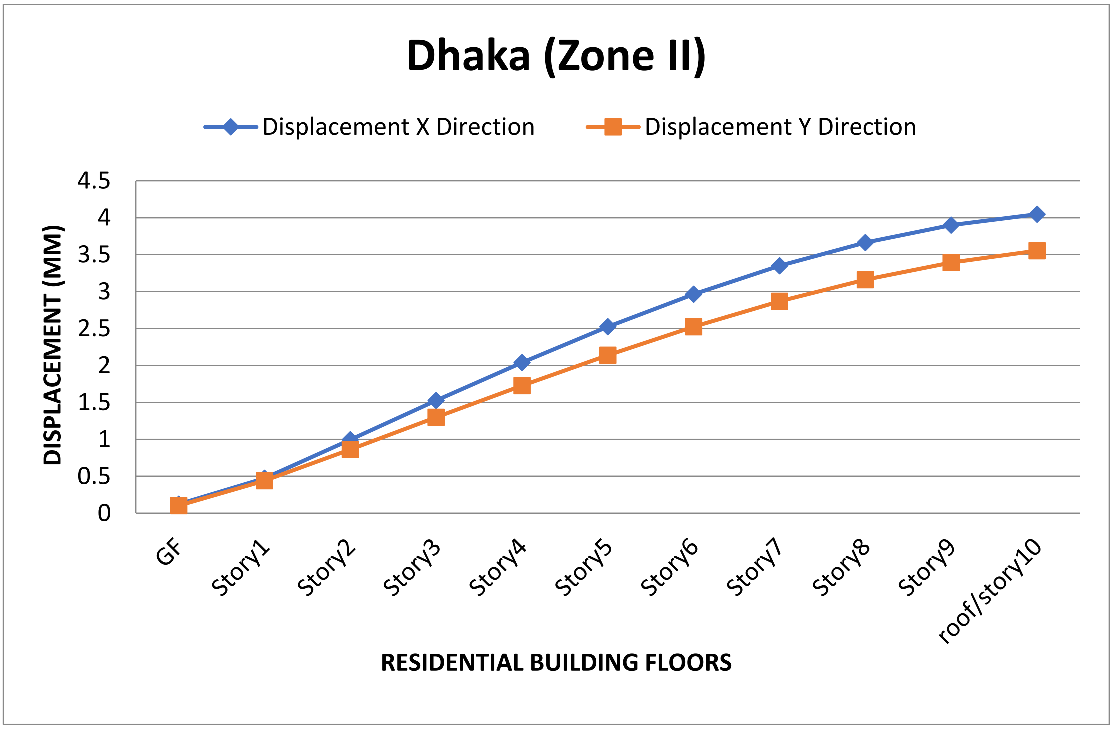


Figure 4.25. Building Displacement of (G+10) storied building without retrofitting Using ETABS

Observation:

- The Highest Displacement in EX direction is Roof floor (4.046754) and the lowest on the G. floor (0.122056)
- The Highest Displacement in the EY direction is Roof floor (3.553467) and the lowest on the G. floor (0.103041)

With retrofitting:

Table 4.16. Building Displacement of (G+10) storied building with retrofitting Using ETABS

Floors	Displacement X Direction	Displacement Y Direction
GF	0.120986	0.103202
Story1	0.46954	0.440394
Story2	0.982625	0.860297
Story3	1.504952	1.291695
Story4	2.010836	1.714763
Story5	2.487172	2.12221
Story6	2.921806	2.501717
Story7	3.30114	2.840674

Story8	3.612819	3.128046
Story9	3.845429	3.354122
roof/story10	3.992579	3.511239

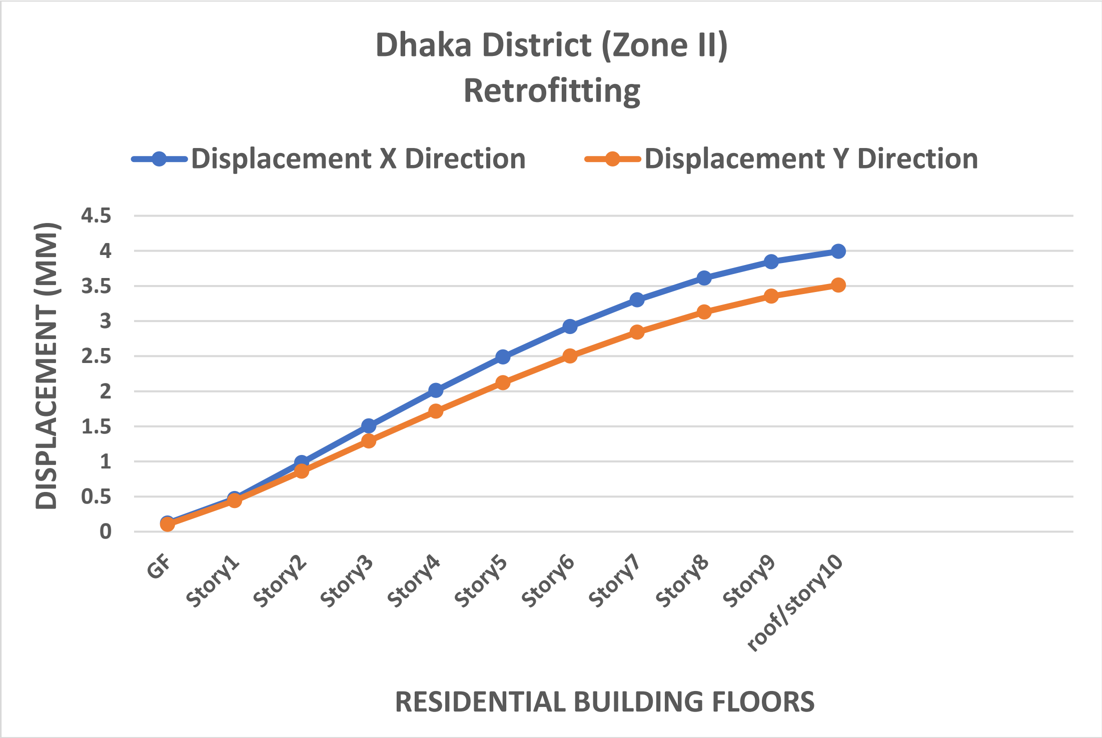


Figure 4.26. Building Displacement of (G+10) storied building with retrofitting Using ETABS

Observation:

- The Highest Displacement in EX direction is Roof floor (3.992579) and the lowest on the G. floor (0.120986)
- The Highest Displacement in the EY direction is Roof floor (3.511239) and the lowest on the G. floor (0.103202)

4.6.4 (G+10) Storied Displacement Graph with and without retrofitting in Rangpur District (Zone III)

Without retrofitting:

Table 4.17. Building Displacement of (G+10) storied building without retrofitting Using ETABS

Floors	Displacement X Direction	Displacement Y Direction
GF	0.168991	0.142059
Story1	0.648666	0.608175
Story2	1.362774	1.19046
Story3	2.090419	1.790208
Story4	2.795144	2.379556
Story5	3.458439	2.948013
Story6	4.063374	3.478428
Story7	4.59075	3.953103
Story8	5.023408	4.35666
Story9	5.345592	4.675535
roof/story10	5.548998	4.898287

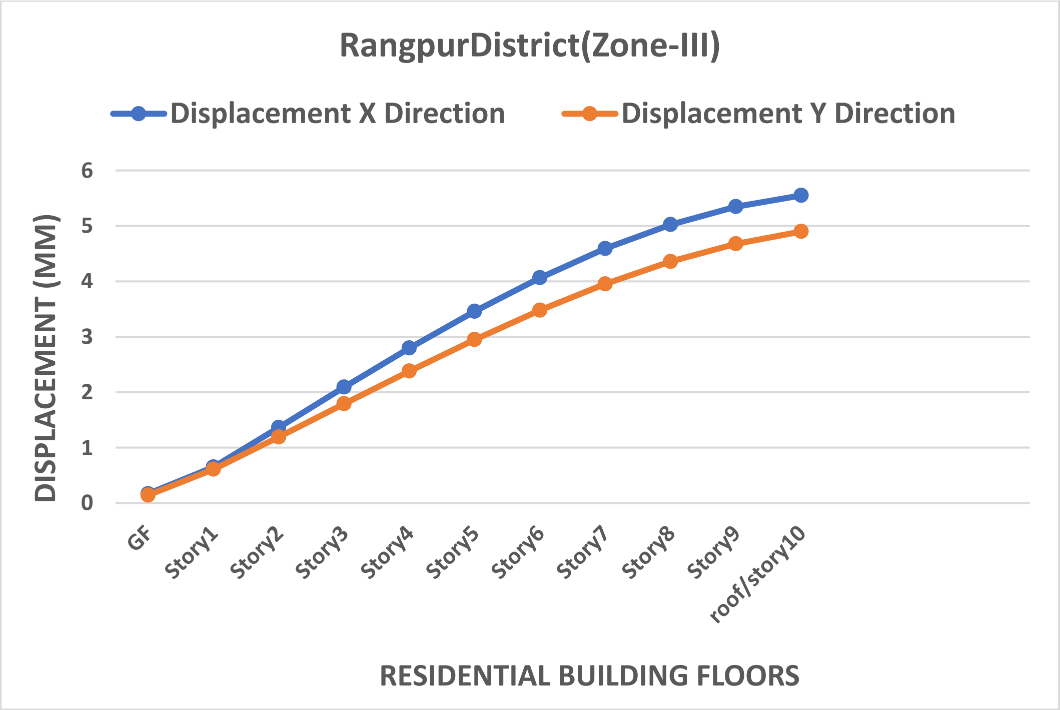


Figure 4.27. Building Displacement of (G+10) storied building without retrofitting Using ETABS

Observation:

- The Highest Displacement in EX direction is Roof floor (5.548998) and the lowest on the G. floor (0.168991)
- The Highest Displacement in the EY direction is Roof floor (4.898287) and the lowest on the G. floor (0.142059)

With retrofitting:

Table 4.18. Building Displacement of (G+10) storied building with retrofitting Using ETABS

Floors	Displacement X Direction	Displacement Y Direction
GF	0.10803	0.118484
Story1	0.634274	0.454216
Story2	1.336128	0.924789
Story3	2.047758	1.448682
Story4	2.731887	1.99158
Story5	3.374913	2.517733
Story6	3.963653	3.016005
Story7	4.479393	3.468466
Story8	4.90306	3.851524
Story9	5.218473	4.15066
roof/story10	5.417085	4.355289

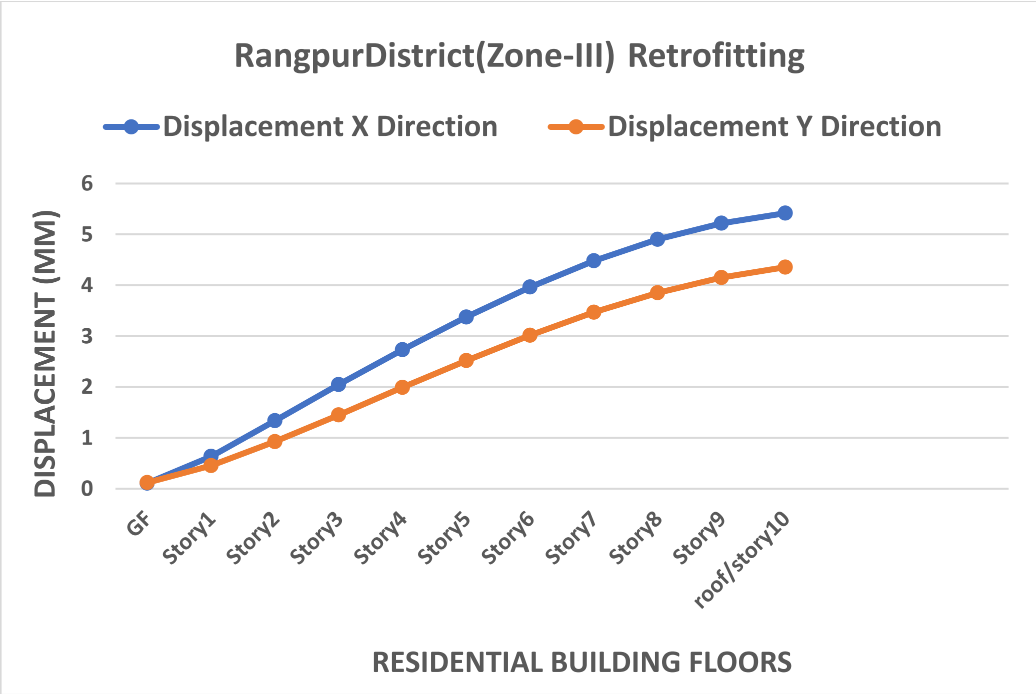


Figure 4.28. Building Displacement of (G+10) storied building with retrofitting Using ETABS

Observation:

- The Highest Displacement in EX direction is Roof floor (5.417085) and the lowest on the G. floor (0.10803)
- The Highest Displacement in the EY direction is Roof floor (4.355289) and the lowest on the G. floor (0.118484)

4.7 Overall Building Displacement

1. Overall building displacement for (G+6) storied building in zone 2 and zone 3.

Table 4.19: Overall highest and lowest displacement after retrofitting in zone 2 and 3

Zone name	X Direction (Max)	Y Direction (Max)
Zone 3	2.867246	2.436953
Zone 3 retrofitting	2.823513	2.306211
Zone 2	2.047591	1.740305
Zone 2 retrofitting	2.024574	1.732964

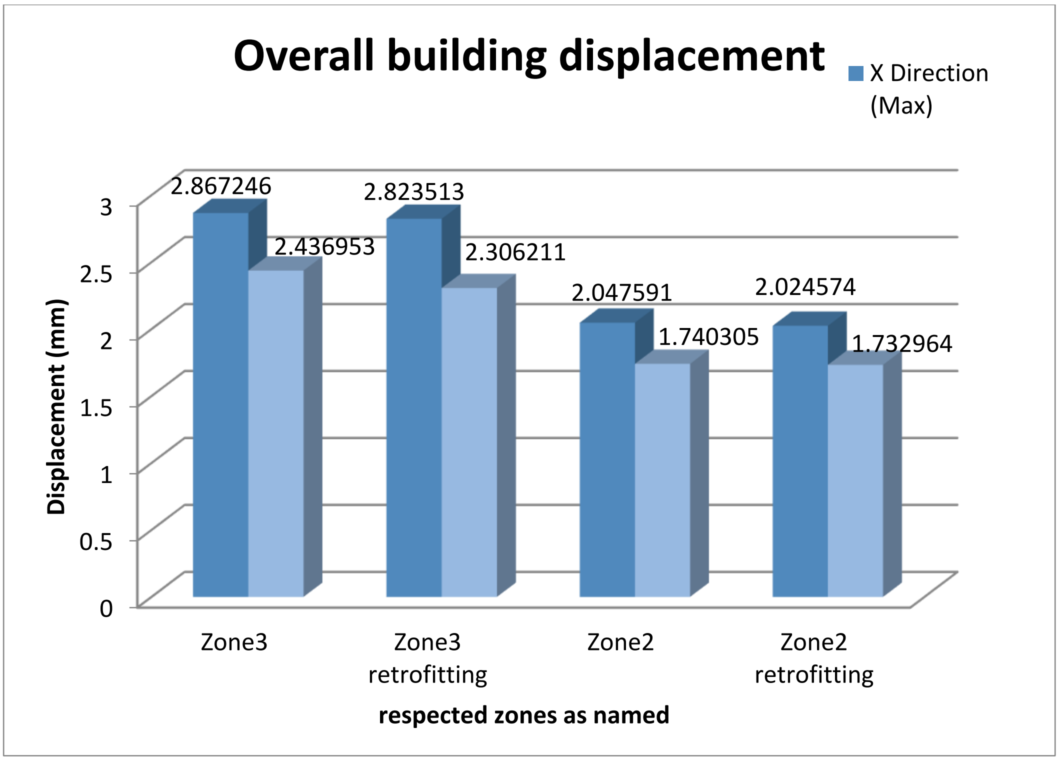


Figure 4.29. Overall (G+6) storied Building Displacement

Observation: Rangpur zone has highest displacement than Dhaka zone for (G+6) storied buildings before and after retrofitting.

2. Overall building displacement for (G+10) storied building in zone 2 and zone 3

Table 4.20. (G+10) Storied Building Displacement Overall Data in One Glance

Zone name	X Direction (Max)	Y Direction (Max)
Zone 3	5.548998	4.898287
Zone 3 retrofitting	5.417085	4.355289
Zone 2	4.046754	3.553467
Zone 2 retrofitting	3.992579	3.511239

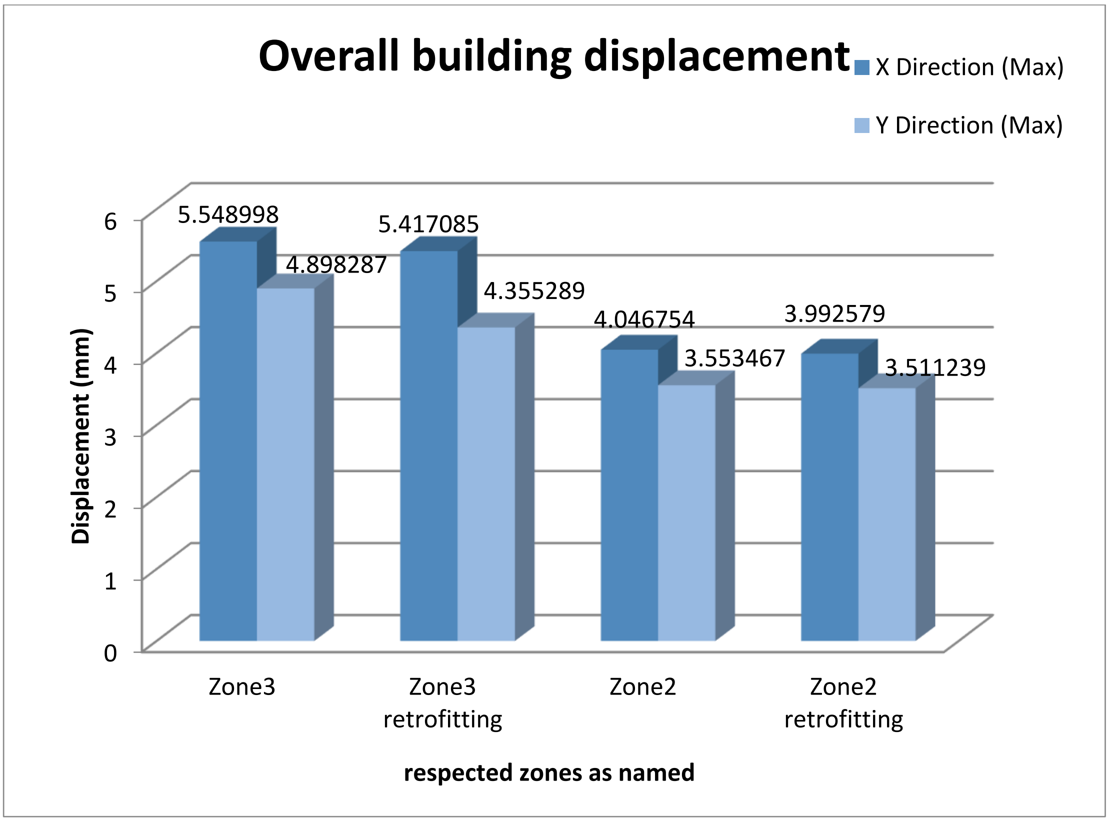


Figure 4.30. Overall (G+10) storied Building Displacement

Observation: Rangpur zone has highest displacement than Dhaka zone for (G+10) storied buildings before and after retrofitting.

4.8 Base Shear reaction Graph of Building

Model 1: (G+6) storied building

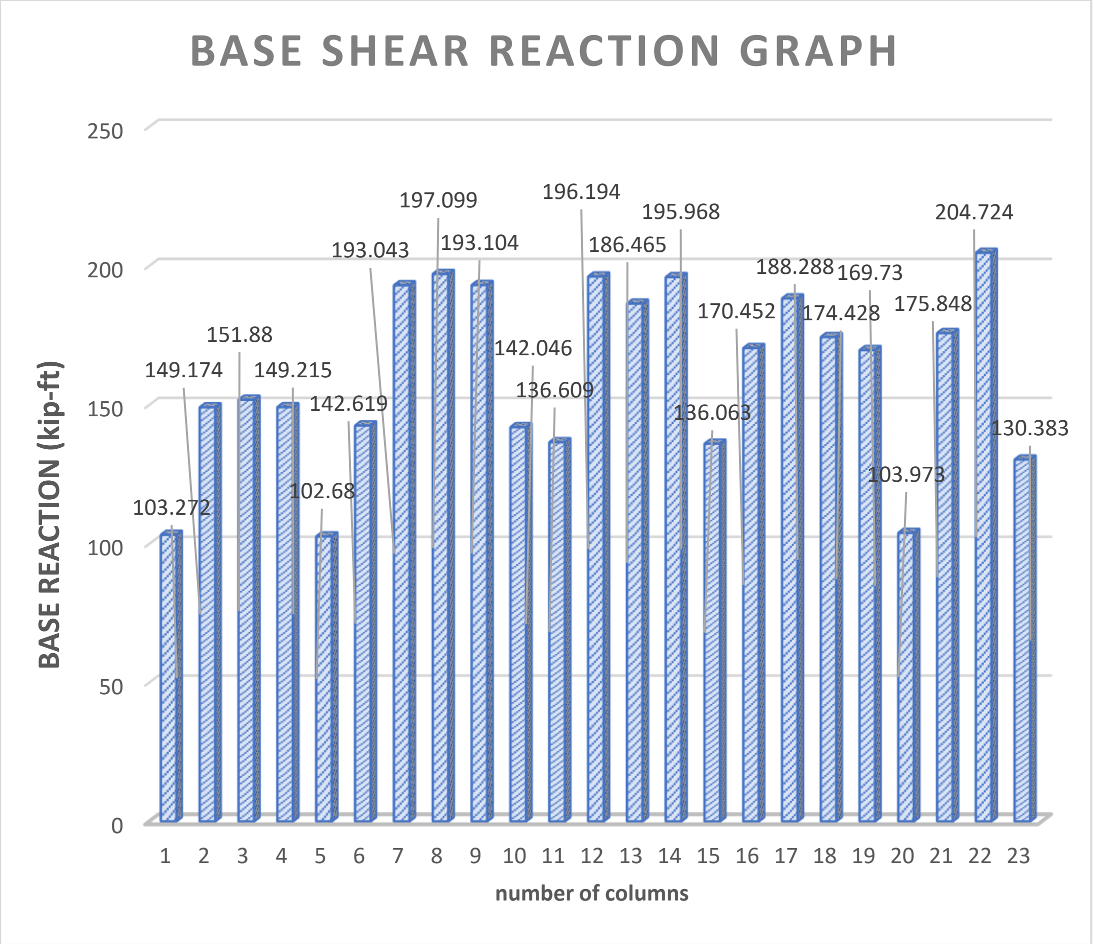


Figure 4.31: Base shear reaction of (G+6) storied building

Observation:

- The Highest Base Shear Reaction is seen in 22th Number column, value=204.724 Kip
- The Lowest Base Shear Reaction is seen in 5th Number column, value=102.68 Kip

Model 2: (G+10) storied building

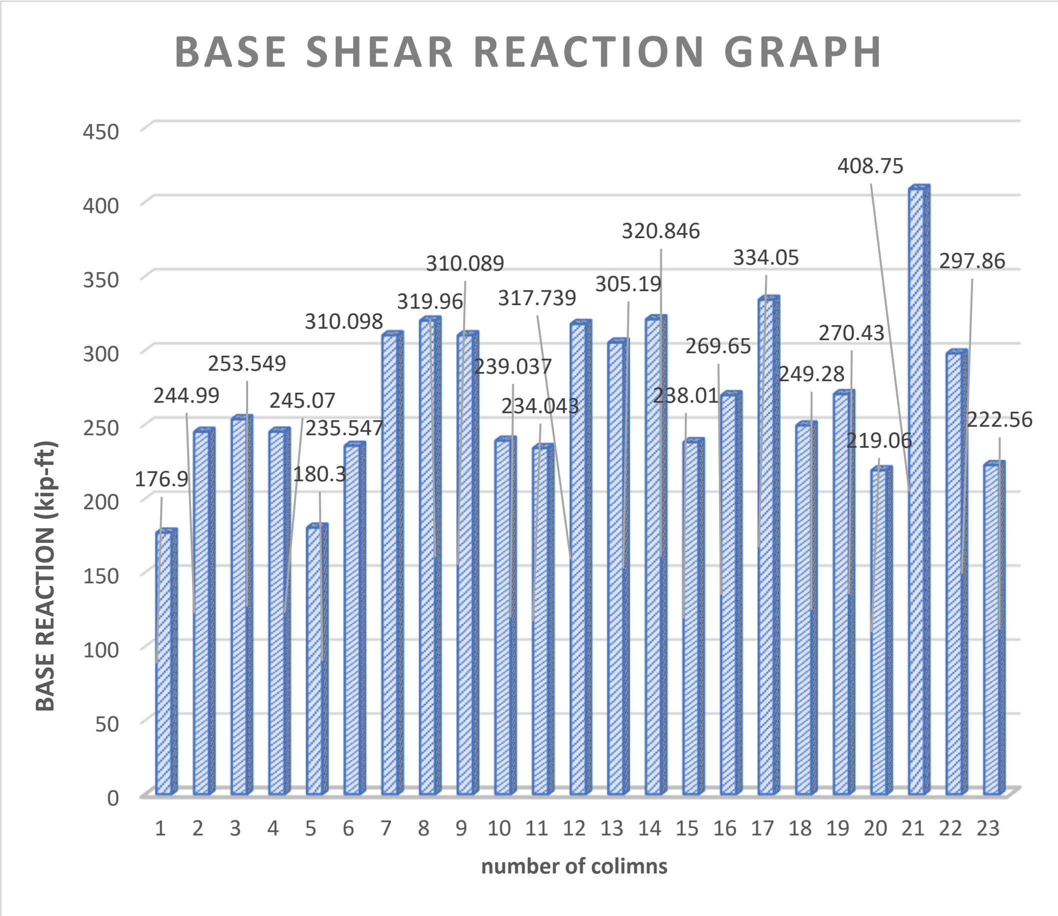


Figure 4.32. Base shear reaction of (G+10) storied building

Observation:

- The Highest Base Shear Reaction is seen in 21th Number column, value=408.75 Kip
- The Lowest Base Shear Reaction is seen in 5th Number column, value=176.9 Kip

4.9 Base shear Distribution Using ETABS 18.1.1

The maximum expected lateral stress on the base of the structure owing to seismic activity is called base shear. our base shear reaction is divided into a total of 23 main columns.

Model 1: (G+6) storied building

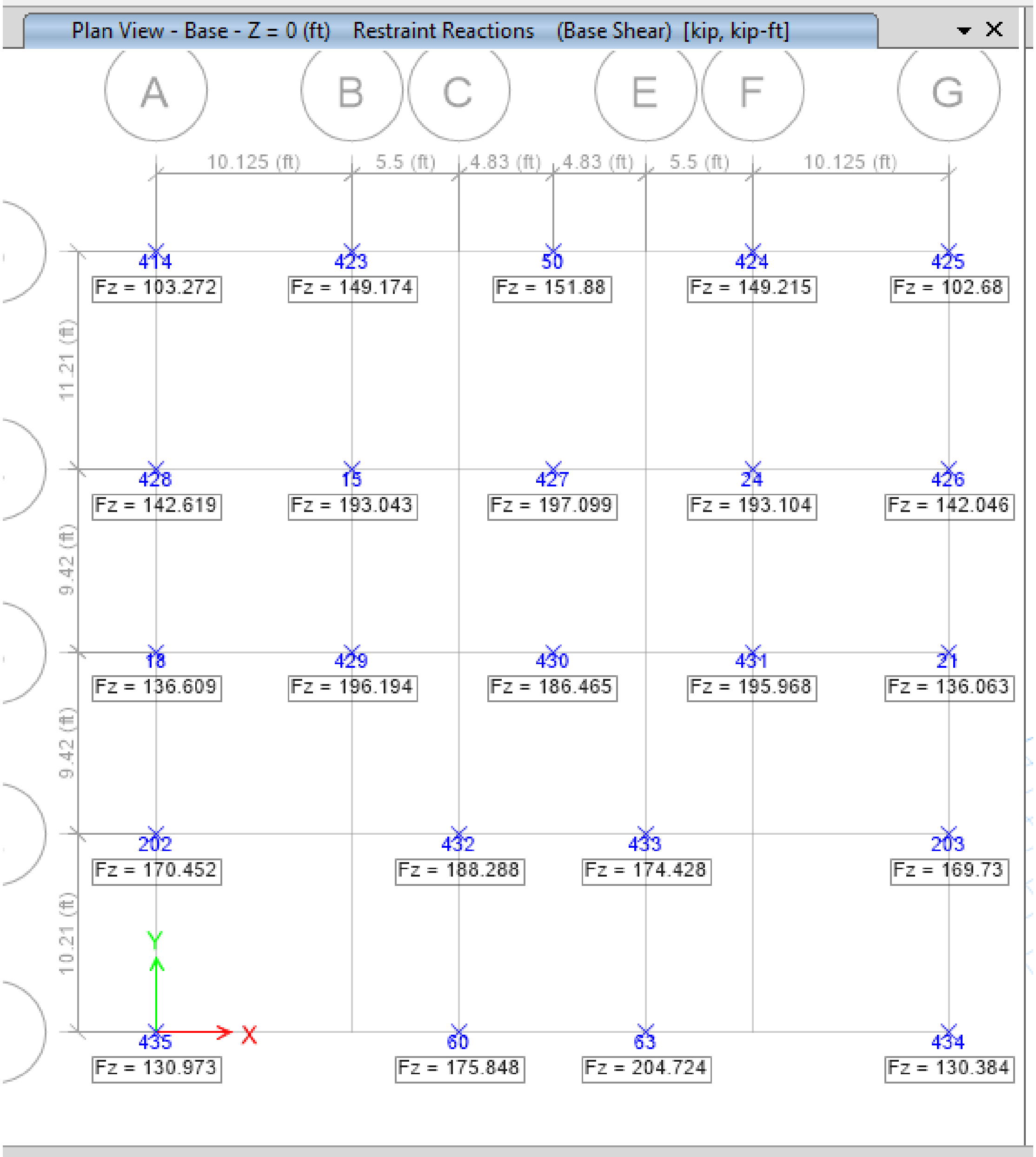


Figure 4.33. Base Shear Reaction of (G+6) storied Building using ETABS

The blue color records are numbered for the Fz values that ETABS provides by default. No. 63 has the highest **Fz=204.724 Kip** base shear reaction, while No. 425 has the lowest **Fz=102.68 Kip** base shear reaction.

Model 2: (G+10) storied building

Figure 4.34. Base Shear Reaction of (G+10) storied Building using ETABS

The blue color records are numbered for the Fz values that ETABS provides by default. No. 60 has the highest **Fz= 408.751 Kip** base shear reaction, while No. 414 has the lowest **Fz= 176.906 Kip** base shear reaction.

CHAPTER 5
CONCLUSION AND FUTURE WORKS

5.1 Conclusions

In Bangladesh, there are many different types of irregular structures, and the characteristics of these structures vary significantly. The findings of this study are summarized in this chapter, along with some recommendations for the research's future progress. The findings of this study are summarized below:

- Maximum columns in the lower bottom part of the structure have failed due to earthquakes.
- It was observed that when a beam was retrofitted with reinforced concrete jacketing, the load capacity of the section reaches from 414.84kips to 977 kips, which was much higher than the previous section. The increase in load capacity is 35.51%.
- On the other hand, when a column was retrofitted with reinforced concrete jacketing, the load capacity of the section reaches from 484 kips to 987.74kips, which was much higher than the previous section. The increase in load capacity is 4.08%.
- The number of beams and columns failure rate as well as the percentage of drift and displacement increases with the increase of height of a building.
- After retrofitting the percentage of drift and displacement reduces significantly.
- Same building structures act differently in various zones and soil types and the stability and failure rate of the structure is also different.
- After the research, we come to the point that between zone 2 and zone 3 or between Dhaka and Rangpur, Dhaka is more suitable for structure.

5.2 Limitations and Recommendations for Future Works

In this research of RC retrofitting, many aspects were not covered by the scope of this thesis due to limitations in time and resources. However, they might be considered to create more detailed research for future work. Here is an attempt to give direction to further studies:

- We found plenty of research papers on retrofitting globally. But in Bangladesh, till now this research topic does not take as seriously as it should be. We hope our paper contributes to this aspect.
- In this study, same layout plan for different heights was selected. In further research, it is highly recommended to use different layout plans with different heights.
- In this study, lift core and extra shear wall are not considered. In future work, it is also recommended to use extra shear wall and lift core in layout plan.
- Only a (G+6) & (G+10) story building was retrofitted in this study but it is recommended to use different height or story building in future research.
- There is no cost estimate in this study but in future research, cost estimates may be done for different layout plans.
- In this research, we use RC Jacketing for retrofitting. In further research, it is highly recommended to use different jacketing like steel jacketing and other retrofitting methods.

Finally, based on the study of this research, it is proposed, buildings that were not constructed with seismic load can be evaluated and retrofitted using the thesis approach outlined in this study.

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