STUDY OF TORSIONAL IRREGULARITY WITH SEISMIC LOADS OF RC BUILDING IN DIFFERENT FOUR ZONES OF BANGLADESH ACCORDING TO BNBC-2020

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-Authors

Declaration of Authentication

We certify that the research/project-based thesis titled "**STUDY OF TORSIONAL IRREGULARITY WITH SEISMIC LOADS OF RC BUILDING IN DIFFERENT FOUR ZONE OF BANGLADESH ACCORDING TO BNBC-2020"** is completely our group work. All information and sources used in this work that were discovered by other researchers are cited. Our supervisor has approved the use of the following types of work products in this paper: photos, figures, tables, and citations. We thus state that no earlier version of this thesis, in whole or in part, has been submitted for any other degree or publication.

ABSTRACT

This paper presents the results of a linear static analysis conducted on a (B+G+4) story building using the static Analysis approach in four different zones in Bangladesh. An analytical 3D model of the building, including irregularities, was created and analyzed using the ETABS structural analysis software. This comprehensive model encompasses all significant structural elements affecting key parameters like maximum displacement, maximum story drift, story stiffness, and maximum story displacement. The building chosen for this study is based on an architectural plan located in Faridpur city, and we analyzed it for 3 more different seismic zones of Bangladesh. It was meticulously recreated in a digital model, subjected to various loads, and then analyzed using static Analysis in accordance with the Bangladesh National Building Code (BNBC) of 2020.

This research aims to gain a profound understanding of how structures react to seismic forces and adopt a multidimensional approach to enhance their earthquake resistance capabilities in various zones.

our study underscores the pressing need for proactive measures to address seismic vulnerabilities in Bangladesh. By exploring torsional irregularities in RC buildings within the framework of BNBC-2020, we are taking a significant step towards enhancing the seismic resilience of structures, ultimately safeguarding lives and property with a safe design method for assessing and improving the earthquake resilience of structures.

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ABBREVIATIONS

2D- Two Dimensional

3D- Three Dimensional

3DAM - 3D Analytical Model

ACI-American Concrete Institute

ADRS- Acceleration Displacement Response Spectra

AISC-American Institute of Steel Construction

AISI-American Iron and Steel Institute;

ASCE-American Society of Civil Engineers

ATC- Applied Technology Council

BNBC- Bangladesh National Building Code

DE- Design Earthquake

EQ - Earthquake

ETABS - Extended Three-Dimensional Analysis of Building Systems

FEMA- Finite Element Method of Analysis

IBC- International Building Code

IMRF -Intermediate Moment Resisting Frame

IS-Indian Standard

LFD -Load Factor Design

LSA-Linear Static Analysis

LTHA-Linear Time History Analysis

MDI - Maximum Displacement

ME- Maximum Earthquake

MSD - Maximum Story Displacement

OMRF -Ordinary Moment Resisting Frame

RC - Reinforced Concrete

RCC- Reinforced Cement Concrete

RSA-Response Spectrum Analysis

SDM - Structural Design Method

SE- Serviceability Earthquake

SMRF -Special Moment Resisting Frame

SS - Story Stiffness

Chapter 1

1 INTRODUCTION

1.1 Background

Our world is facing a threat of natural disasters from time to time. earthquakes are one of the most unpredictable and devasting of all natural disasters. during an earthquake, failure of building maybe take place at a point of weakness occurred by irregularity of the structure. modern seismic design codes like draft BNBC 2020 distinguish this irregularity in two categories-plan irregularity and vertical irregularity. Torsion in buildings during earthquake is caused due to various reasons and the most common is unsymmetrical distribution of mass and stiffness along the height of building. Recent codes have given provision to counter these torsional effects by introducing accidental eccentricity which has to be considered at the time of analysis and design. A special care and attention must be taken, so that, torsional effects do not avert the ductile behavior of the structure. It is well known that the larger the eccentricity between the center of mass and center of stiffness, the larger will be the torsional effects, which leads to larger displacements and drifts in the buildings. Another important aspect in the configuration of building is the inelastic behavior of the asymmetric structures is the considerations of the degree of control over inelastic twist and our main design aim will be to restrict the inelastic twist. [1]

Therefore, it is important to research how RC-framed multistory buildings respond to varied seismic intensities in terms of lateral displacements and base shear, among other reactions. Understanding how structures with comparable layouts respond to earthquakes of varying intensity is crucial. It is required to conduct a seismic analysis of the structure using the many methodologies available in order to determine the seismic responses.

There are four types of analysis:

- Static,
- Nonlinear static,
- Linear dynamic,
- Nonlinear dynamic.

For regular structures with a limited height, linear static analysis or an equivalent static approach can be utilized. Response spectrum analysis can be used to do linear dynamic analysis. The magnitude of the forces and their distribution over the height of the structure are the primary distinctions between linear static and linear dynamic analysis.

1.2 Objective of Research

i. To investigate the impact of torsional irregularity on the seismic performance of RC building structures in four seismic zones of Bangladesh.
ii. To find out effective measurement to resist difficulties due to earthquake.
iii. To design a building structure on the basis of performance.
iv. To compare torsional irregularity of RC building in different seismic zone

1.3 Research Outcome

- We will get safe and economical building design.
- Evaluation and Assessment of seismic behavior of RC buildings with torsional irregularity: The study will provide insight into the behavior of RC buildings under torsional irregularity and seismic loads, including their response to earthquakes.
- Recommendations for improving seismic resistance: The study will provide recommendations for improving the seismic resistance of RC buildings with torsional irregularity, which can be used by engineers and builders to enhance the safety of building occupants during earthquakes.
- Advancement of knowledge in the field: The study will contribute to the existing body of knowledge on the seismic behavior of RC buildings with torsional irregularity, filling the gap in research in this area in Bangladesh.

However, the study will provide valuable information for improving the seismic resistance of RC buildings in Bangladesh and ensuring the safety of building occupants during earthquakes.

Chapter 2

2 LITERATURE REVIEW

2.1 Building

Building means any permanent or semi-permanent structure which is constructed or erected for human habitation or for any other purpose and includes but not limited to the foundation, plinth, walls, floors, roofs, stairs, chimneys, fixed platform, verandah, balcony, cornice, projections, extensions, annexes etc. The term building will also include the sanitary, plumbing, electrical, HVAC, appurtenances and all other building service installations which are constructed or erected as an integral part of a building. [2]

2.2 Linear Time History Analysis

Linear time history analysis calculates the solution to the dynamic equilibrium equation for the structural behavior (displacement, member force etc.) at an arbitrary time using the dynamic properties of the structure and applied loading when a dynamic load is applied. [2]

Linear Time History Analysis (LTHA) is a powerful numerical method used to analyze the dynamic behavior of structures subjected to earthquake ground motion. It is a widely accepted and reliable tool for evaluating the seismic response of buildings and other structures under different earthquake scenarios.

LTHA involves simulating the actual time history of ground motion recorded during past earthquakes or artificially generated seismic events. This time history is then used as input to the structural model of the building or structure being analyzed. The response of the structure to the input motion is calculated using a mathematical model that takes into account the structural properties of the building, including its mass, stiffness, and damping.

LTHA is based on the principle of linear superposition, which means that the response of a structure to a complex input motion can be calculated as the sum of its responses to simpler input motions. The method assumes that the structure being analyzed behaves linearly under earthquake loads, meaning that the deformations and stresses in the structure are proportional to the applied loads. This assumption allows for a simplified mathematical model that can be solved using numerical techniques.

LTHA can provide valuable information on the structural response of a building or structure to different types of earthquake ground motions. It can be used to evaluate the effectiveness of different seismic design and analysis methods, including those prescribed by building codes and standards.

The analysis results of LTHA can include information such as displacement, acceleration, and stress values of the structure at different points in time during the earthquake event. It can also provide insights into the distribution of internal forces and moments in the structure, which can be critical for evaluating its overall structural integrity.

LTHA is an essential tool for assessing the seismic performance of structures in earthquake-prone regions. It can be used to identify potential weaknesses in the structural design and suggest improvements to increase the seismic performance of the building or structure. For example, LTHA can help identify buildings with torsional irregularity, which is one of the critical factors that affect the seismic response of buildings.

2.3 Requirement for dynamic analysis

Dynamic analysis should be performed to obtain the design seismic force, and its distribution to different levels along the height of the building and to the various lateral load resisting elements, for the following buildings:

(a) Regular buildings with height greater than 40 m in Zones 2, 3, 4 and greater than 90 m in Zone 1.

(b) Irregular buildings (as defined in BNBC Sec 2.5.5.3) with height greater than 12 m in Zones 2, 3, 4 and greater than 40 m in Zone 1.

So, linear static analysis is required as per model structure.

2.4 Building low raised

Enclosed or partially enclosed buildings that comply with the following conditions.

1. Mean roof height h less than or equal to 18.3 m

2. Mean roof height h does not exceed least horizontal dimension.

2.5 Earthquake

An earthquake is the shaking of the surface of the Earth resulting from a sudden release of energy in the Earth's lithosphere that creates seismic waves. [3]

2.6 Earthquake ground motion

Ground motion is the movement of the earth's surface from earthquakes or explosions. Ground motion is produced by waves that are generated by sudden slip on a fault or sudden pressure at the explosive source and travel through the earth and along its surface

2.7 Richter scale

The Richter scale is a numerical measure of the magnitude of an earthquake, based on the amplitude of seismic waves recorded on a seismogram. It was developed by Charles Francis Richter in 1935 and is widely used to compare the size of earthquakes. The Richter scale is logarithmic, meaning that each increase of one unit represents a tenfold increase in wave amplitude and approximately a thirtyfold increase in energy release. Earthquakes with magnitudes of 2.0 or less are generally not felt, while those above 6.0 can cause significant damage.

2.8 Earthquake magnitude

Earthquake magnitude is a measure of the "size," or amplitude, of the seismic waves generated by an earthquake source and recorded by seismographs.

2.9 Base shear

Total design lateral force or shear due to earthquake at the base of a structure.

The total design base shear in a given direction has determined from the following relation

$$V = \frac{ZIC}{R}$$

Where,

Z = Seismic zone coefficient

I = Structure importance coefficient

R = Response modification coefficient

W = The total seismic dead load

C = Numerical coefficient [4]

2.10 Erect

To erect a new building or re-erect an existing building or to convert a building from one occupancy to another. Also known as CONSTRUCT.

2.11 Irregularity

Irregularity refers to any deviation from the expected or standard geometric or dimensional properties of a structure. Irregularities can take many forms, such as unevenness in the distribution of mass or load, non-uniformity in the cross-section or alignment of structural elements, or variations in the geometry or stiffness of a structure

2.12 Torsional irregularity

To be considered for rigid floor diaphragms, when the maximum storey drift (Δ_{max}) as shown in Figure (1) computed including accidental torsion, at one end of the structure is more than 1.2 times the average ¸$\Delta_{avg} = (\Delta_{max}+\Delta_{min})/2$ of the storey drifts at the two ends of the structure. If Δ_{max} > 1.4 Δ_{min} then the irregularity is termed as extreme torsional irregularity. [2]

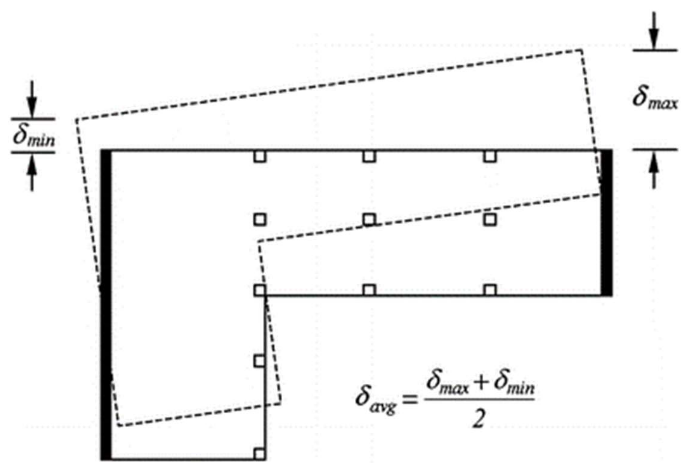


Figure 1..TORSIONAL IRREGULARITY

2.13 Seismic zone

A seismic zone is used to describe an area where earthquakes tend to focus [3]

2.14 Linear static analysis

Linear Static Analysis is a structural analysis method used to predict the response of a building or structure under the application of static loads. It assumes linear elastic behavior, meaning that material properties do not change with deformation, and the analysis considers the structure's response within the linear range of its behavior. The primary goal is to calculate the distribution of internal forces, stresses, and deformations within the structure to assess its safety and stability under applied loads. Linear Static Analysis is often used for preliminary design, load-carrying capacity assessment, and as a basis for more complex analyses in structural engineering and seismic design.

2.15 Deflection and storey drift

The deflections (∂x) of level x at the center of the mass shall be determined in

$$\partial x = \frac{c_d * \partial_{xe}}{I}$$

Where,

C_d = Deflection amplification factor

∂_{xe} = Deflection determined by an elastic analysis

I = Importance factor

2.16 Time period

The core structure time period is just the reverse of the recurrence of the structure at which it has to vibrate as a form of alarming effect in building architecture gets underway, typically a seismic potential depending on the mass and firmness characteristics of the system. As the code-based architecture spectrum shows greater rising speeds at shorter intervals, systems with shorter main periods draw in higher seismic forces. The fundamental period the building buildings the value of T may be approximated by the following relation-

$$T = C_t\ (hn)^m$$

Where,

h_n = Height in meters above the base to level n. [2]

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

2.17 Seismic zoning

The intent of the seismic zoning map is to give an indication of the Maximum Considered Earthquake (MCE) motion at different parts of the country. In probabilistic terms, the MCE motion may be considered to correspond to having a 2% probability of exceedance within a period of 50 years. The country has been divided into four seismic zones with different levels of ground motion. Table 6.2.14 includes a description of the four seismic zones. Figure 2 presents a map of Bangladesh showing the boundaries of the four zones. Each zone has a seismic zone coefficient (Z) which represents the maximum considered peak ground acceleration (PGA) on very stiff soil/rock (site class SA) in units of g (acceleration due to gravity). The zone coefficients (Z) of the four zones are: Z=0.12 (Zone 1), Z=0.20 (Zone 2), Z=0.28 (Zone 3) and Z=0.36 (Zone 4). The most severe earthquake prone zone, Zone 4 is in the northeast which includes Sylhet and has a maximum PGA value of 0.36g. Dhaka city falls in the moderate seismic intensity zone with Z=0.2, while Chittagong city falls in a severe intensity zone with Z=0.28. [4]

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

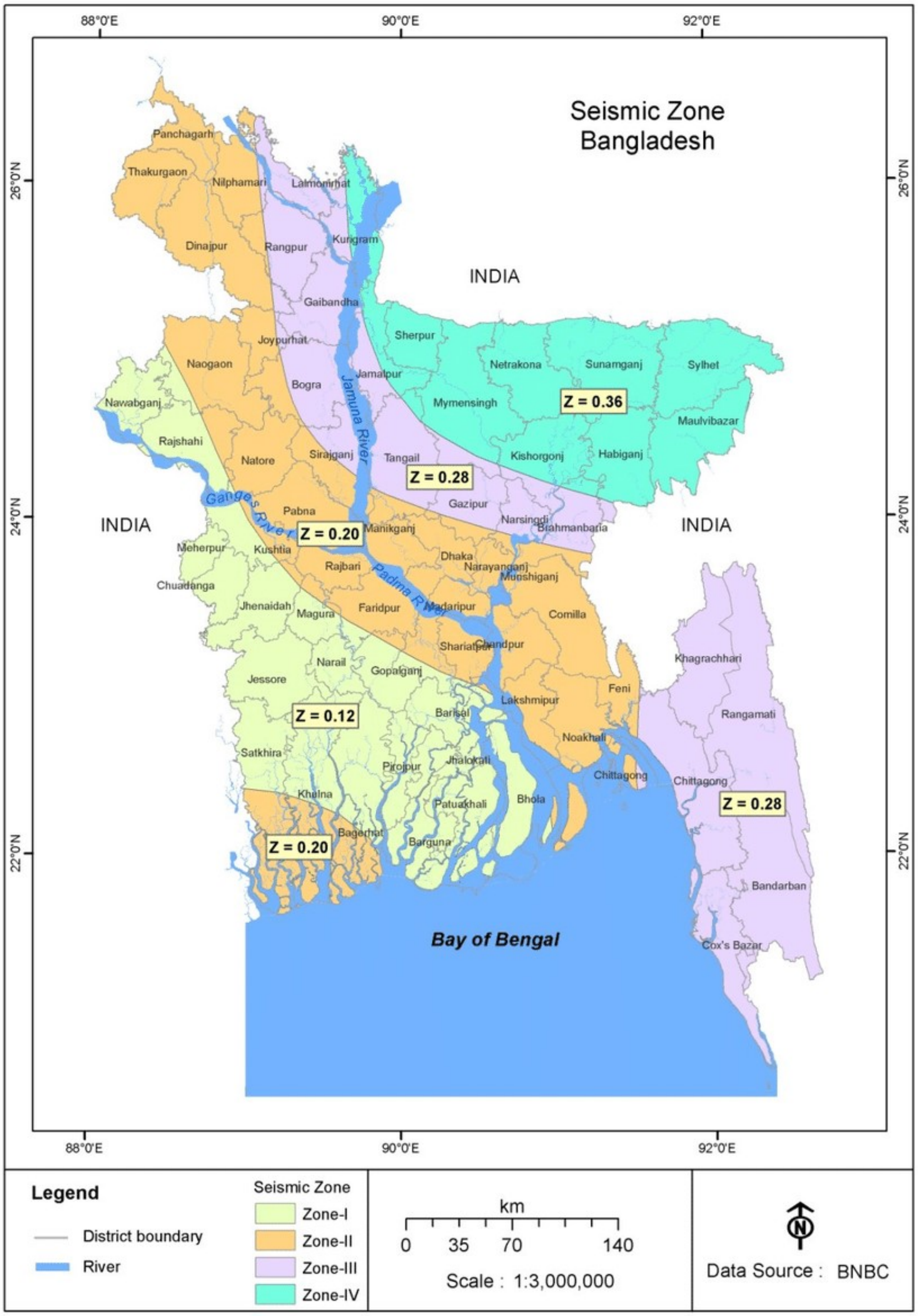


Figure 2 SEISMIC ZONE OF BANGLADESH

2.18 Torsional Irregularity criteria in different seismic codes

1. International Building Code (IBC):

The IBC is widely used in the United States and provides detailed guidance on assessing and mitigating torsional irregularities in structures. It outlines three main categories of torsional irregularities: regular, moderate, and severe. These categories are based on factors such as differences in lateral stiffness and mass distribution within a building. The IBC references ASCE 7 for more specific criteria related to torsional irregularities.

2. ASCE 7 (American Society of Civil Engineers Standard 7):

ASCE 7, a crucial document for seismic design in the United States, offers comprehensive guidelines for evaluating torsional irregularities. It classifies torsional irregularities into three types: mass irregularity, stiffness irregularity, and vertical geometric irregularity. The code provides limits on relative displacements between different levels of the structure to categorize the degree of torsional irregularity.

3. Eurocode 8 (EN 1998):

Eurocode 8, adopted by European countries, includes provisions for assessing torsional irregularities. It evaluates both mass and stiffness irregularities, imposing limits on torsional irregularity ratios. The code's objective is to ensure that torsional effects are properly considered in seismic design, leading to suitable structural detailing and strengthening where necessary.

4. National Building Code of Canada (NBCC):

The NBCC incorporates criteria for evaluating and mitigating torsional irregularities in seismic design. It examines mass and stiffness distribution to determine the level of torsional irregularity and provides specific requirements for structures falling into these categories. The code ensures that buildings with torsional irregularities receive specialized seismic design considerations

5. Bangladesh National Building Code (BNBC):

The BNBC addresses torsional irregularities in building design. It assesses irregularities based on mass and stiffness distribution, providing criteria for classification. For structures exhibiting torsional irregularities, the code prescribes specific seismic design measures and detailing requirements to enhance earthquake resilience.

6. New Zealand Standard for Structural Design Actions (NZS 1170):

NZS 1170 considers torsional irregularities by evaluating relative lateral displacements between different levels of a building. The standard ensures that torsional effects are appropriately accounted for in the seismic design process, potentially leading to adjustments in seismic design forces

7. Chinese Seismic Design Code (GB 50011):

China's seismic code, GB 50011, addresses torsional irregularities through assessments of mass and stiffness distribution. It classifies buildings based on their torsional behavior and may require specific seismic design provisions for structures with torsional irregularities. [Reference: Chinese Seismic Design Code (GB 50011)]

These references and details illustrate how various seismic design codes around the world tackle the critical issue of torsional irregularities, emphasizing the importance of proper evaluation and mitigation for earthquake-resilient structures.

2.19 Effect of Vertical Irregularity on RC buildings in previous earthquakes

The impact of torsional irregularity on reinforced concrete (RC) buildings during previous earthquakes has been a subject of extensive study and has provided valuable insights into the behavior of structures in seismic events. Torsional irregularities refer to variations in the distribution of mass or stiffness along different axes of a building, leading to twisting or torsional motion during an earthquake. Here, we explore the effects of torsional irregularity on RC buildings in notable seismic events:

1. Northridge Earthquake, USA (1994):

The Northridge earthquake in California, USA, demonstrated the detrimental effects of torsional irregularities. Some buildings with asymmetric configurations experienced significant torsional motion, leading to structural damage and, in some cases, collapse. This highlighted the importance of addressing torsional irregularities in seismic design.

2. Kobe Earthquake, Japan (1995):

The Kobe earthquake exposed the vulnerability of buildings with irregular shapes and

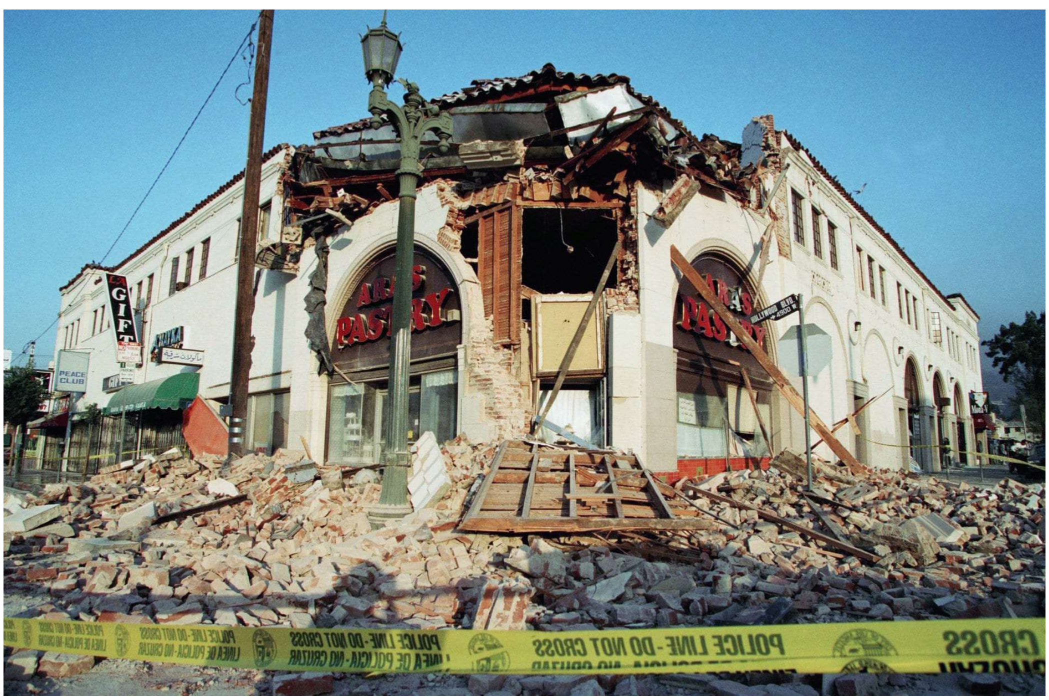


Figure 3:Northridge Earthquake, USA (1994)

mass distributions. Torsional effects were particularly evident in buildings with significant geometric irregularities. This earthquake prompted revisions in Japan's seismic design guidelines to account for torsional irregularities.

3. Mexico City Earthquake, Mexico (1985):

Figure 4:Kobe Earthquake, Japan (1995)

The Mexico City earthquake showcased the amplification of torsional effects in taller buildings with irregular mass distributions. Some structures exhibited significant torsional motion and suffered damage. Lessons from this event contributed to improvements in seismic design practices in Mexico.

4. Taiwan Earthquake (Various Events):

Taiwan, located in a seismically active region, has experienced several earthquakes that highlighted the impact of torsional irregularities. Buildings with asymmetric layouts or irregular shapes exhibited torsional motion and structural damage during seismic events. These occurrences informed updates to seismic design regulations in Taiwan.

5. Gujarat Earthquake, India (2001):

The Gujarat earthquake revealed the consequences of torsional irregularities in RC buildings. Some structures with irregular configurations experienced torsional motion, leading to non-uniform distribution of seismic forces and damage. This earthquake emphasized the importance of seismic-resistant design practices in India.

Figure 5:Gujarat Earthquake, India (2001)

6. Turkey Earthquakes (Various):

Turkey has encountered multiple destructive earthquakes that illustrated the effects of torsional irregularities. Buildings with irregular mass or stiffness distributions suffered from torsional motion and exhibited damage patterns associated with such irregularities. Subsequent revisions in seismic design codes in Turkey addressed these concerns.

Figure 6:Turkey-Syria Earthquake (2023)

In summary, torsional irregularity in RC buildings has been shown to have significant implications for their seismic performance during previous earthquakes. These effects can lead to non-uniform distribution of forces, structural damage, and, in severe cases, structural failure. As a result, seismic design guidelines in earthquake-prone regions have evolved to address torsional irregularities and enhance the earthquake resilience of RC structures. These lessons learned from past seismic events continue to inform and improve seismic design practices worldwide.

2.19.1 LINEAR STATIC ANALYSIS AS PER BNBC 2020

The Bangladesh National Building Code (BNBC) of 2020 provides guidelines and requirements for structural analysis and design, including linear static analysis. While the BNBC 2020 does not provide a comprehensive step-by-step procedure for linear static analysis, it does reference various standards and codes that engineers should follow when performing such analyses. Here's an overview of how linear static analysis is generally conducted in compliance with BNBC 2020:

1**. Load Combinations:**

The BNBC 2020 specifies load combinations that should be considered in linear static analysis. These combinations include dead loads, live loads, wind loads, and seismic loads. Engineers must follow these prescribed load combinations when performing the analysis.

2. **Design Loads:**

Determine the design loads for the structure based on the requirements outlined in BNBC 2020. This involves calculating the magnitude and distribution of loads, including dead loads (permanent loads), live loads (temporary loads), and other applicable loads such as wind and seismic forces.

3. **Material Properties:**

Define the material properties for the structural components of the building, including concrete, steel, masonry, and other materials. Ensure that the material properties comply with the specifications provided in the BNBC 2020.

4**. Geometry and Model Creation:**

Create a detailed structural model of the building using appropriate structural analysis software. This model should accurately represent the geometry, structural elements, connections, and support conditions of the building.

5. **Boundary Conditions:**

Apply appropriate boundary conditions to the model to simulate how the structure is connected to its supports or foundation. The BNBC 2020 may provide guidance on acceptable boundary conditions.

6. **Load Application:**

Apply the prescribed design loads and load combinations to the structural model in accordance with BNBC 2020 requirements.

7. **Analysis Settings:**

Configure the analysis settings in the structural analysis software. This includes specifying the analysis type (linear static analysis), convergence criteria, and other relevant parameters.

8. **Solve the Analysis:**

Run the linear static analysis using the analysis software. The software will calculate the structural response to the applied loads, including deflections, internal forces, and reactions.

9. **Review and Compliance:**

Review the analysis results to ensure that the structure complies with the safety and design criteria outlined in BNBC 2020. This includes checking for acceptable stress levels, deflection limits, and overall structural stability.

10. Documentation:

Document the analysis process, including the input parameters, analysis results, and any necessary design modifications. This documentation is essential for obtaining approvals and certifications in compliance with BNBC 2020.

It's crucial for engineers and structural designers to reference the specific provisions and requirements of the BNBC 2020 when conducting linear static analysis for building design in Bangladesh. Compliance with the code ensures that the structure meets the necessary safety standards and design criteria outlined in the national building code.

2.20 Alternative scales to measures earthquakes:

The Richter scale is an outdated method for measuring the magnitude of an earthquake, and modern seismology has developed more accurate and reliable alternatives. Some of the commonly used alternatives to the Richter scale are:

i. **Moment Magnitude Scale (Mw):** The Moment Magnitude Scale is a widely used method for measuring the magnitude of an earthquake, which is based on the total energy released by the earthquake. This method is considered more accurate than the Richter scale, especially for large earthquakes.

ii. **Moment Tensor (MT) Solutions:** Moment Tensor Solutions are a mathematical method for determining the source mechanism of an earthquake. This method provides information on the orientation of the fault, the direction of slip, and the amount of energy released in different directions.

iii. **Seismic Intensity Scale (SI):** The Seismic Intensity Scale measures the strength of shaking and the damage caused by an earthquake at a particular location. This method takes into account local geological conditions and the effects of the earthquake on human-made structures.

iv. **ShakeMap:** ShakeMap is a computer-generated map that shows the intensity of ground shaking and the potential damage caused by an earthquake. This method is based on data collected from seismographs and other sources, and provides a visual representation of the earthquake's impact on a region.

Overall, there are many alternative methods for measuring earthquakes that are more accurate and reliable than the Richter scale, and the choice of method depends on the specific needs of the seismological analysis.

2.21 BACKGROUND OF STUDY:

1. **Ahmed et al. (2021)** examined the seismic performance of RC buildings with torsional irregularities in different zones of Bangladesh, using linear time history analysis in accordance with BNBC 2020. They found that torsional irregularities significantly affected the seismic response of the buildings, and that the response was highly dependent on the location and severity of the torsional irregularities.
2. **Islam et al. (2020)** investigated the seismic performance of RC buildings with torsional irregularities in different zones of Bangladesh, as defined by BNBC 2017, using linear time history analysis. They found that the severity of torsional irregularities varied significantly across different zones, and that the seismic response of the buildings was highly dependent on the location and severity of the torsional irregularities
3. **Padol S. et al (2015)** [5] Studied A multistory RCC building with mass irregularity at various floor levels was analyzed, and a seismic study was conducted. This paper emphasizes the impact of different floor's mass irregularity in RCC analysis and construction using the time history method by the ETABS program. They found that any time structure contains several irregularities a result of an earthquake on structure can be reduced by adding a shear wall.
4. **K.G. Kostinakis, A.M. Athanatopoulou, V.S. Tsiggelis** Studied The efficiency of the percentage combination rules for determining any response parameter's maximum value under two horizontal seismic components is examined in the current research within the context of a linear response history analysis. We examine a number of reinforced concrete (R/C) buildings that were subjected to eight bi-directional seismic events. The maximum reaction over all incident angles provided by analytical formulas is compared to the maximum response values computed by the 30 percent and 40 percent rules. In these analyses, the recorded correlated accelerograms and the matching uncorrelated accelerograms serve as representations of the earthquake ground motion, respectively. Additionally, two separate sets of structural axes have been constructed, and analyses have been done using each of these sets. According to the findings, the percentage combination

5. **Sagar et al. (2015)** [6] analyzed the performance on various type of irregularity Considered i.e. (a) Horizontal Irregularity-plan irregularity (b) Vertical Irregularity -Mass Irregularity. To achieve objective of the project Time history Analysis & Response spectrum analysis method were carried out.
6. **S. Varadharajan et al. (2013)** reviewed existing works regarding plan irregularities and justified the preference of multistory building models over single storey building models. [7]
7. **Bansal, and Gagandeep (2014)** [8] studied ductility-based design is carried considering vertical irregular building and methods used are RSA and THA. Three types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered.
8. **Aijaj and Rahman (2013)** [9] tried to analyze the proportional distribution of lateral forces involved in earthquake for individual storey due to changes in stiffness of vertically irregular structure.

Overall, the literature on the study of torsional irregularity with seismic loads of RC buildings using linear time history analysis suggests that torsional irregularities significantly affect the seismic performance of buildings, and that the response is highly dependent on the location and severity of the irregularities. More research is needed to better understand the behavior of RC buildings with torsional irregularities under seismic loads and to develop effective strategies for promoting their seismic resilience in high-risk seismic regions like Bangladesh. The findings of these studies can be used to inform the development of more advanced seismic design guidelines for RC buildings in such regions.

Chapter 3

3 METHODOLOGY

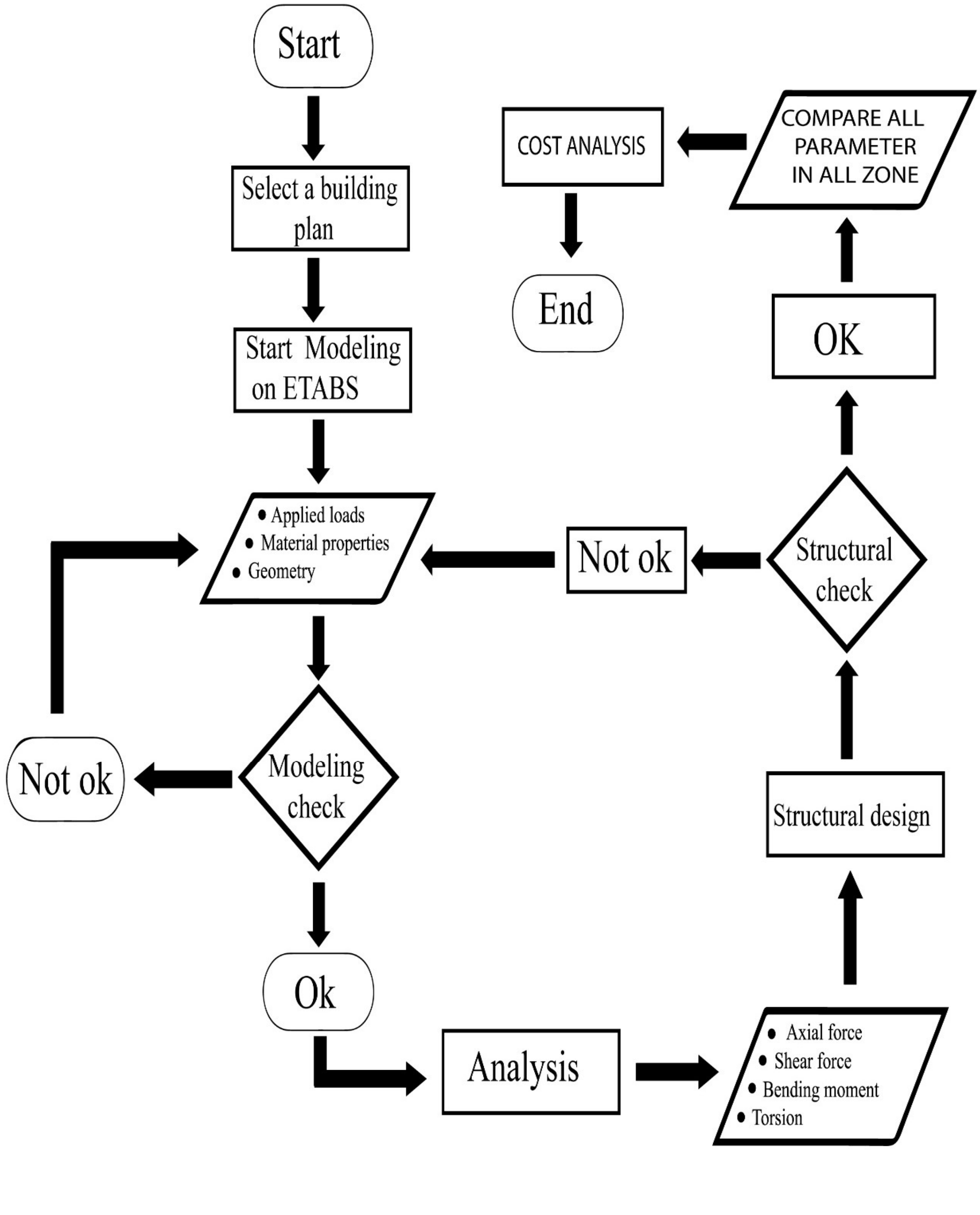
3.1 INTRODUCTION:

The seismic vulnerability of structures is a paramount concern for regions prone to seismic activity, such as Bangladesh. The ability of buildings to withstand seismic loads is influenced by various factors, including their design, construction, and geographical location. Torsional irregularity, a condition where the distribution of mass or stiffness in a building is not symmetrical about its vertical axis, is one of the critical parameters that can significantly affect the seismic response of reinforced concrete (RC) structures. Understanding and quantifying torsional irregularity are essential steps toward enhancing the seismic resilience of buildings.

In Bangladesh, seismic design and construction practices have seen continuous improvements guided by national building codes, the most recent being the Bangladesh National Building Code of 2020 (BNBC-2020). However, while these codes provide essential seismic design provisions, there is a need for a deeper investigation into the torsional irregularity behavior of RC buildings across different seismic zones within Bangladesh. This study aims to address this imperative by comprehensively examining torsional irregularity patterns and their implications on seismic performance.

The methodology employed in this research endeavors to elucidate the torsional irregularity phenomenon through rigorous analysis and assessment. It encompasses a multifaceted approach that encompasses data collection, structural modeling, analysis techniques, and the synthesis of findings. The steps within the methodology are meticulously designed to facilitate a holistic understanding of torsional irregularity in RC buildings in different seismic zones, thereby contributing to safer and more resilient construction practices.

This section outlines the structured methodology adopted for the study, detailing the steps involved in data collection, structural modeling, seismic analysis, and the assessment of results. The chosen methodology adheres to recognized engineering principles and standards and aims to generate reliable data and insights that can significantly impact seismic resilience in the built environment of Bangladesh. The methodology also addresses the specific goals and objectives set forth for this research, ensuring that each aspect of the study aligns with the overarching research questions.


Start
Select a building plan
Start Modeling on ETABS
Applied loads
Material properties
Geometry
Modeling check
Not ok
Ok
Analysis
Axial force
Shear force
Bending moment
Torsion
Structural design
Structural check
Not ok
OK
COMPARE ALL PARAMETER IN ALL ZONE
COST ANALYSIS
End

In our research, we chose to take LINEAR STATIC ANALYSIS method for full analysis procedure as per BNBC 2020. We took all load combination as per zone.

3.2 Steps of modeling of structure in Etabs :

Step	Description
1	Input grid lines (X-direction & Y- direction)
2	Define material & section properties
3	Define columns, beams and slabs
4	Input cantilever section of the structure
5	Input stair
6	Check modelling
7	Structural analysis and design
8	Structural check
9	If ok then find all parameter in a zone
10	Repeat step 1-9 for other seismic 3 zone
11	Compare and cost analysis

Chapter 4

4 DETAILS OF STRUCTURAL MODELING

4.1 Details of structure:

BUILDING INFORMATION :

SL	Building Parameters	Description
1	Types of frames	IMRF
2	Loading i. Dead loads ii. Live loads iii. Floor finish iv. Partition wall load	 Self-weight of structure 42 psf & 100 psf 45 psf 425 plf & 480 plf
3	Floor Height	10 ft
4	Specific weight of RCC	150 pcf
5	Compressive strength of concrete (Slab & Beam)	3000 psi
	Compressive strength of concrete (Column & SW)	3000 psi
6	Yield Strength of Steel	60000psi

Table 1:BUILDING INFORMATION

Member Description:

Member name	Member Dimensions
Column	22"X15", 18"X15", 12"x12"
Beam	10"X20", 12"X15"
Floor Slab	6 inch
Waist slab	8.5 inch
Partition Wall	5 inch

TABLE 2:MEMBER DETAILS

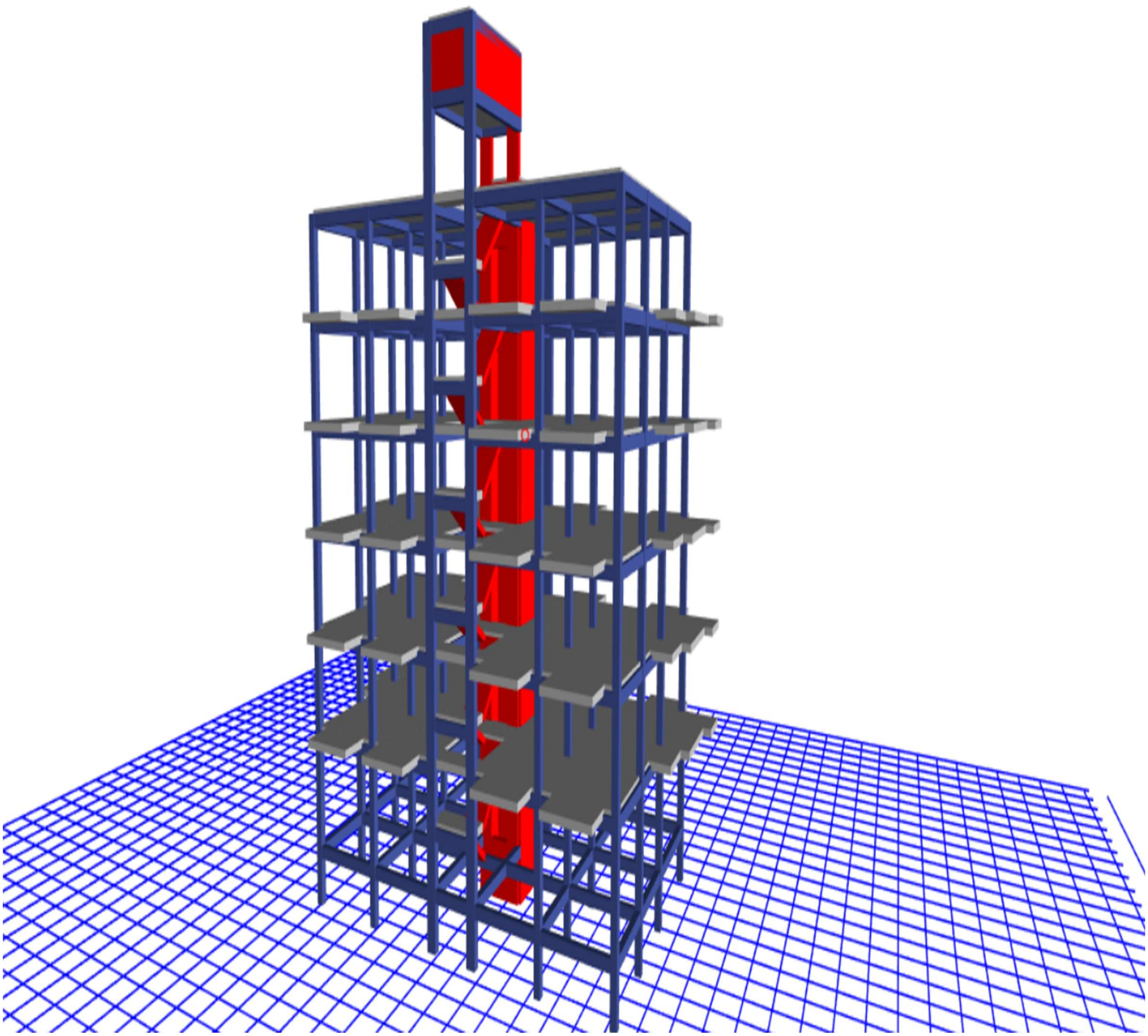


Figure 7: 3D VIEW OF BUILDING

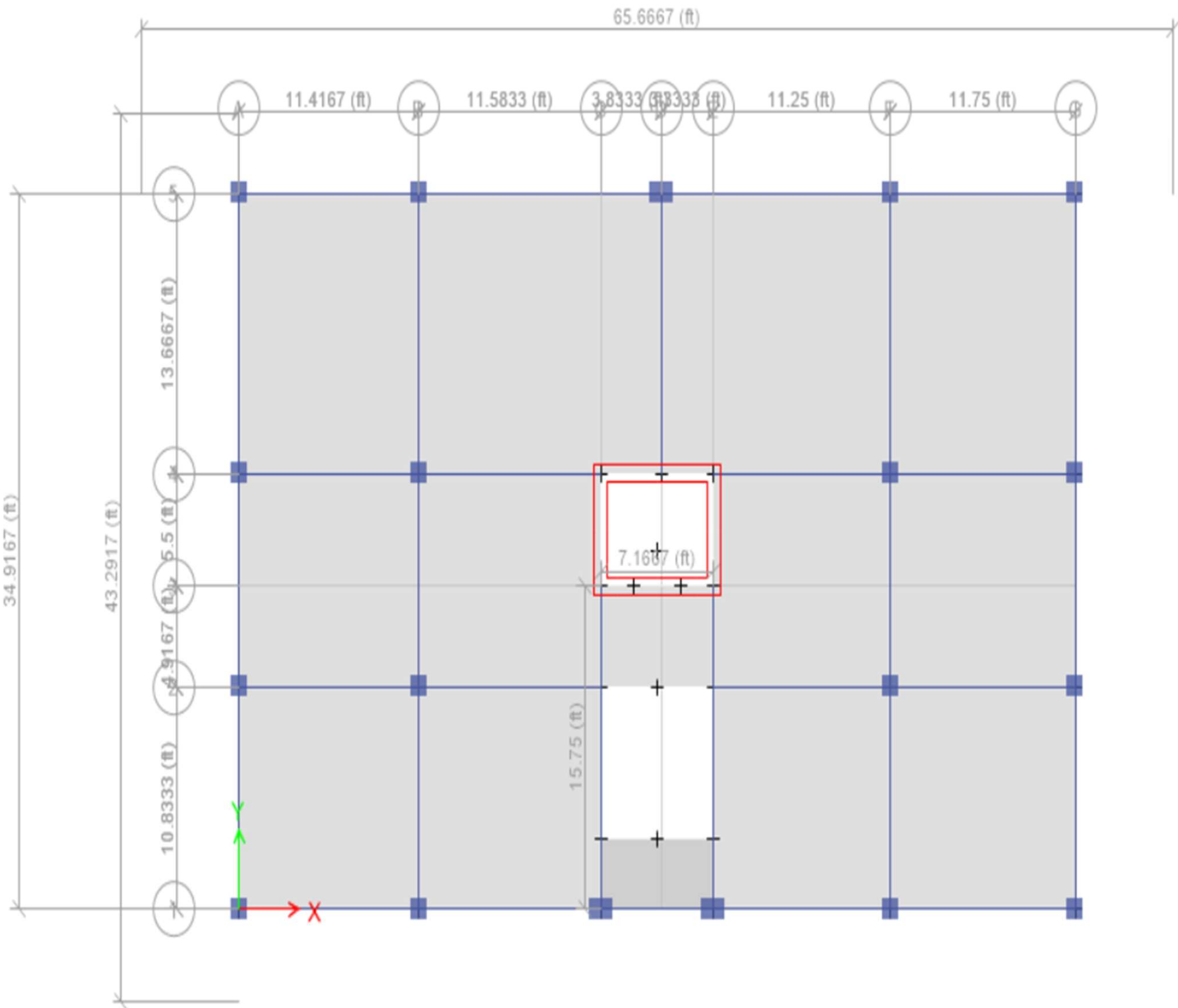


Figure 8: FLOOR PLAN (GROUND FLOOR & ROOF)

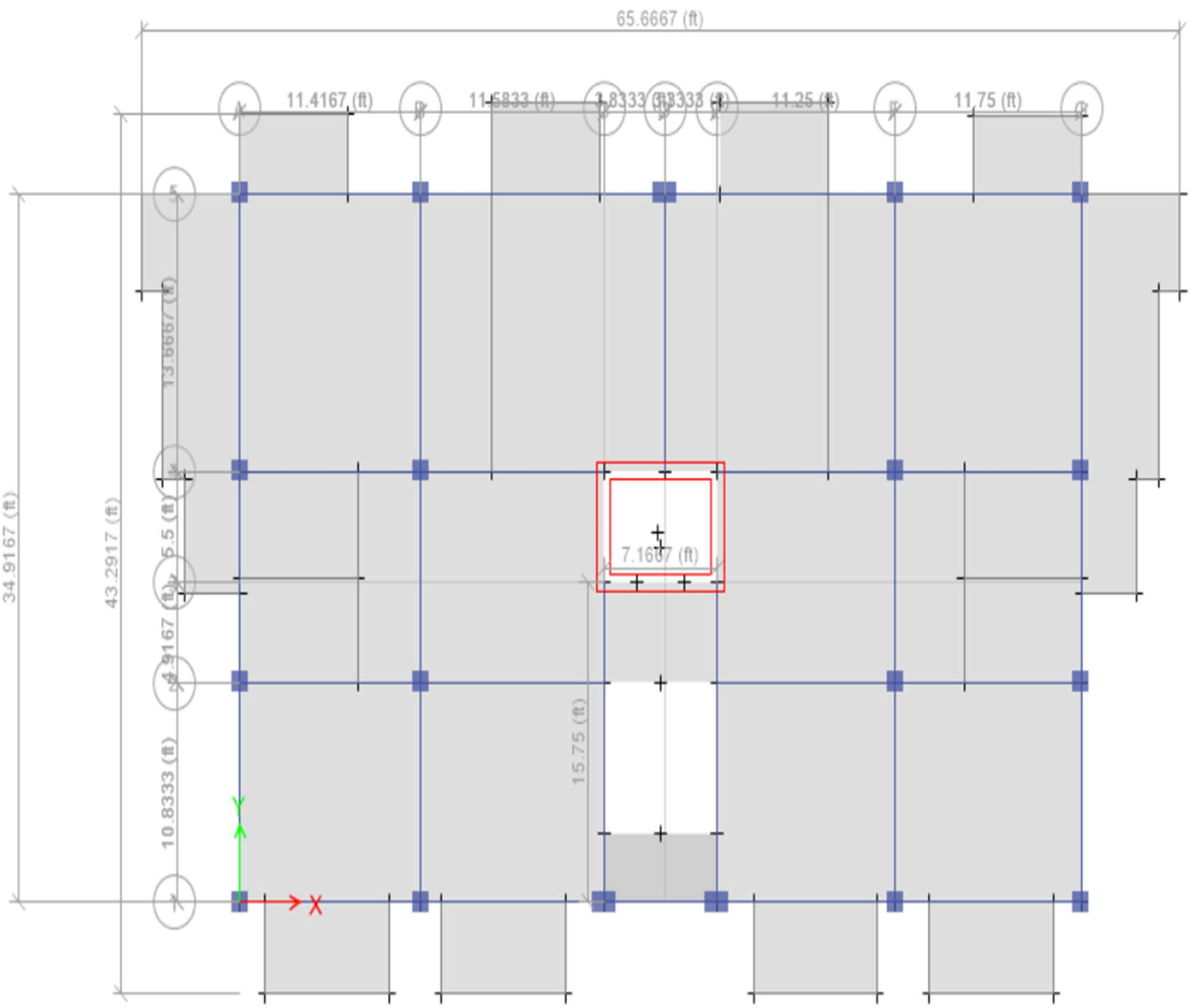


Figure 9: FLOOR PLAN (1ST FLOOR - 4TH FLOOR)

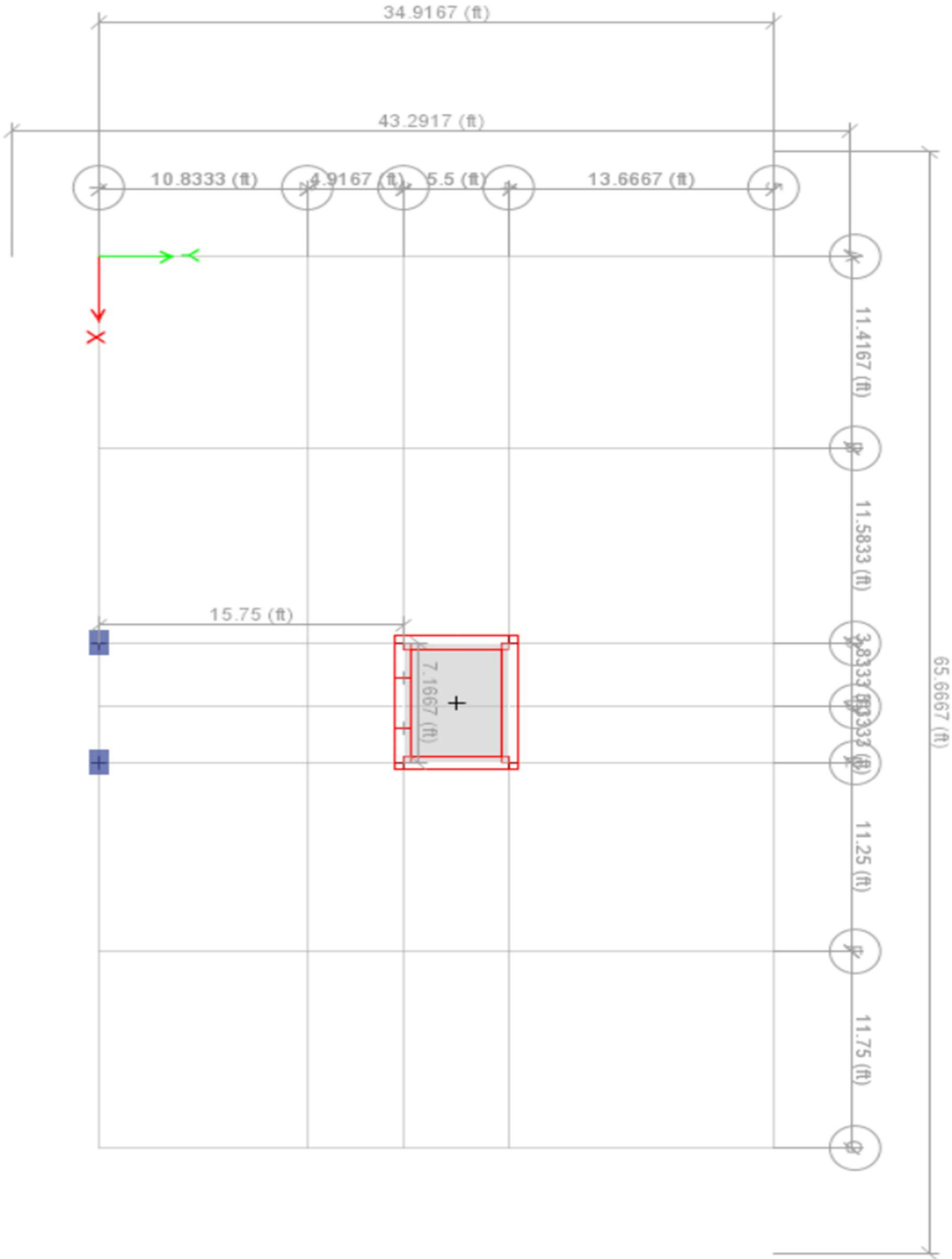


Figure 10:MACHINE ROOM (PLAN VIEW)

Figure 11:OWR (PLAN VIEW)

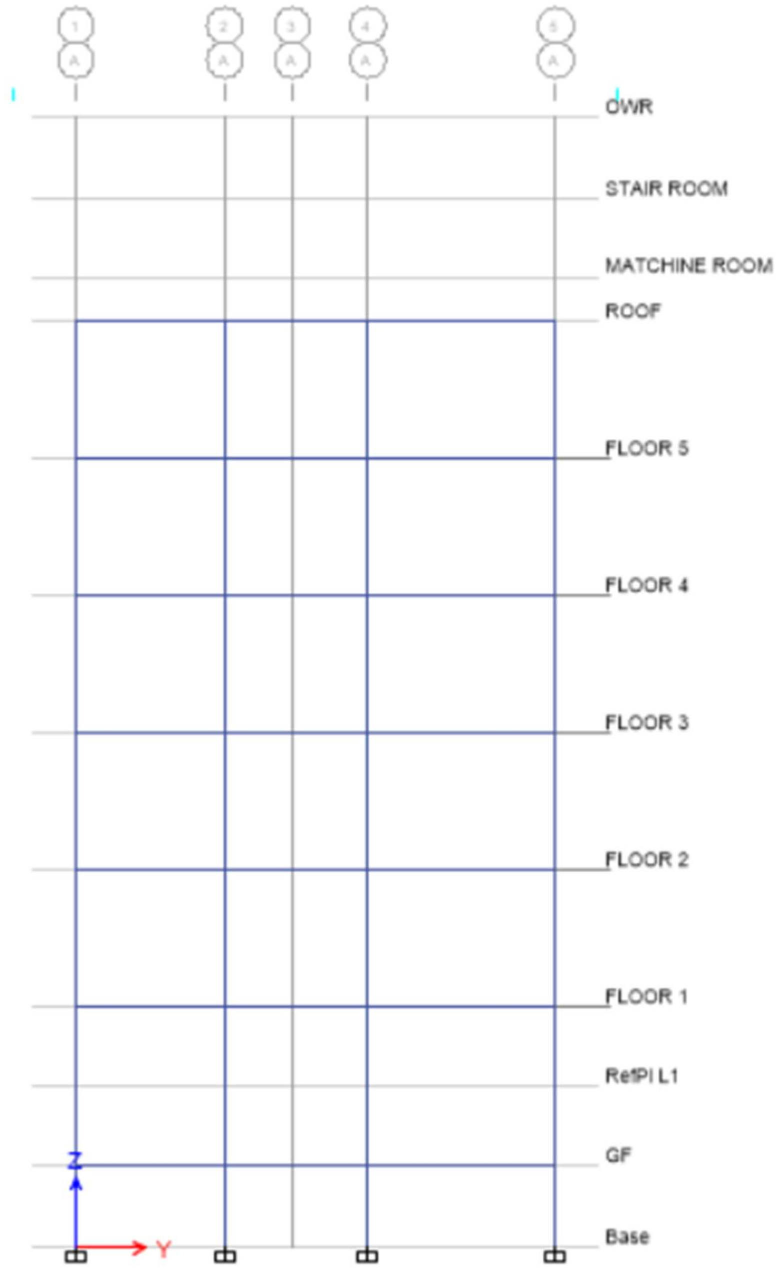


Figure 12:FRONT ELEVATION

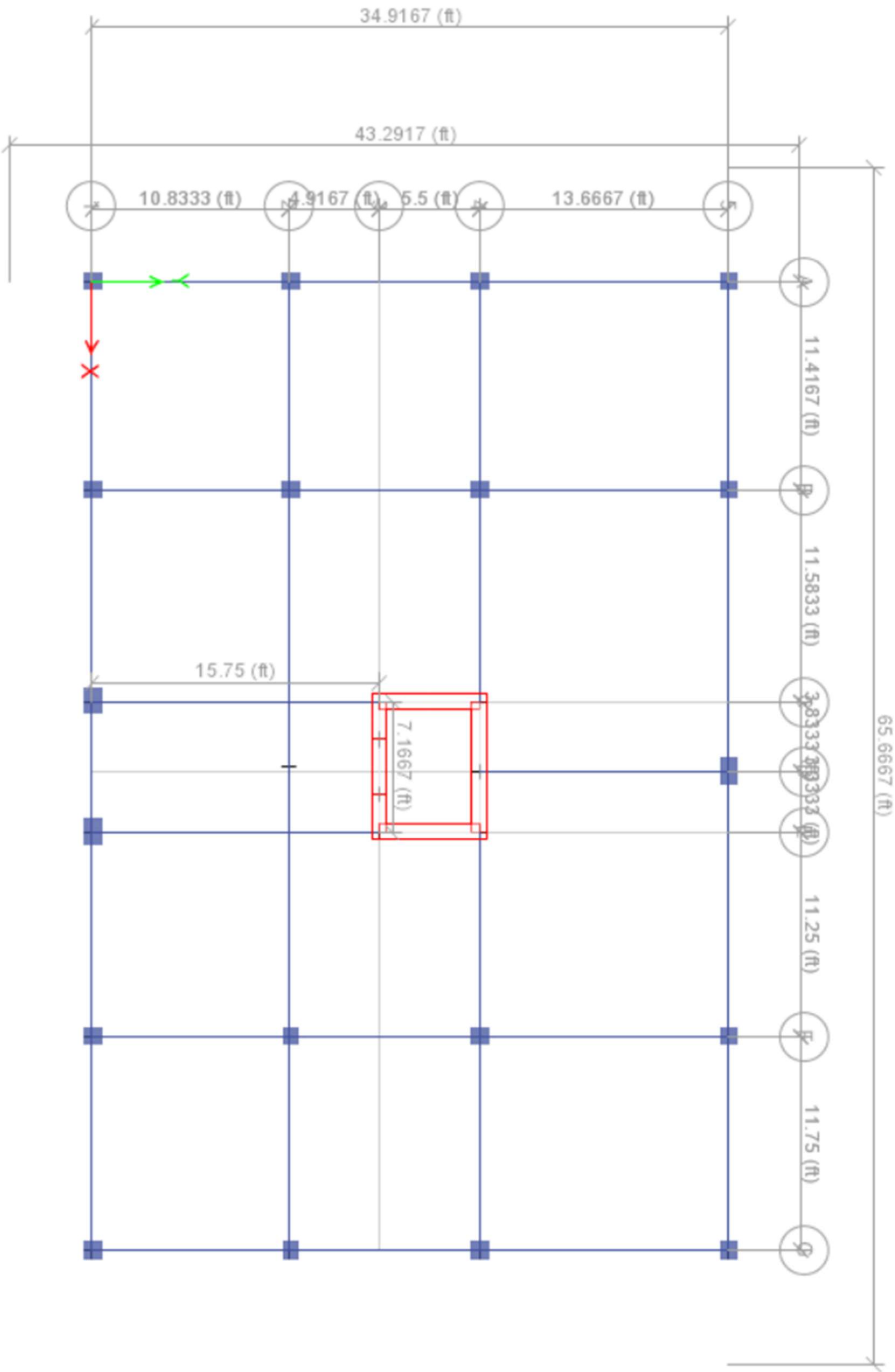


Figure 13:FLOOR PLAN VIEW (ROOF)

4.2 Loads on the building structures

For basic design and evaluation of the structures the various loading conditions have been

considered. Basic Load cases considered as Dead Load (DL), Live Load (LL), and

Earthquake Load (EQ). These load cases are combined according to draft BNBC 2020.

The basic loads are:

- Dead load (DL)
- Live load (LL)
- Earthquake load (EQ)

Dead load (DL): Dead load is the vertical load due to the weight of permanent structural

and non-structural components of a building. For the present study only self-weight of beams, columns, slabs, floor finish and masonry infill walls are considered as dead load case of the structure. All vertical dead loads except self-weight of beam, columns and slab are applied as superimposed dead load on the structure. Total vertical load for floor finish applied on the structure is 1.5 kN/m^2. Thicknesses of the slab and masonry infill partition wall is 0.15m and 0.125m respectively.

Live load (LL): The temporary load acting on structure as occupancy load is called live

load and considered as uniformly distributed surface load in gravity direction. In this study, live load applied on the floor levels is 2 kN/m^2

and on the roof is 1 kN/m^2

.

Earthquake load (EQ): Earthquake load (EQ) has been considered as per draft BNBC 2020. Equivalent static load method has been used with response reduction factor,

R=6 and associated other factors. In calculating seismic weight, a 25% of live load was considered. Other parameters used in seismic load calculation are

Z = 0.12 (For zone 1)

Z = 0.20 (For zone 2)

Z = 0.28 (For zone 3)

Z = 0.36 (For zone 4)

I = 1.00,

Sc = 1.15/1.35 as per draft BNBC 2020.

4.3 Load combinations

Ultimate Strength Design (USD) method was used to design the structural members.

Following load combinations were used in this study according to BNBC 2020:

1. 1.4D
2. 1.2D+1.6L
3. 1.2D+L
4. 1.2D+0.8W_x
5. 1.2D-0.8W_x
6. 1.2D+ 0.8W_y
7. 1.2D-0.8 W_y
8. 1.2D+L+1.6W_x
9. 1.2D+L-1.6 W_x
10. 1.2D+L+1.6 W_y
11. 1.2D+L-1.6 W_y
12. 1.2D+L+E_x+0.3E_y+ λD
13. 1.2D+L+E_x-0.3E_y+λD
14. 1.2D+L-E_x+0.3E_y+λD
15. 1.2D+L-E_x-0.3E_y+ λD
16. 1.2D+L+0.3E_x+E_y+ λD
17. 1.2D+L-0.3E_x+E_y+ λD
18. 1.2D+L+0.3E_x-E_y+ λD
19. 1.2D+L-0.3E_x-E_y+ λD
20. 0.9D+1.6W_x
21. 0.9d-1.6W_x
22. 0.9D+1.6W_y

23. $0.9D-1.6W_y$
24. $0.9D+E_x+0.3E_y-\lambda D$
25. $0.9D+E_x-0.3E_y-\lambda D$
26. $0.9D-E_x+0.3E_y-\lambda D$
27. $0.9D-E_x-0.3E_y-\lambda D$
28. $0.9D+E_y+0.3E_x-\lambda D$
29. $0.9D+E_y-0.3E_x-\lambda D$
30. $.0.9D-E_y+0.3E_x-\lambda D$
31. $0.9D-E_y-0.3E_x-\lambda D$

The maximum vertical ground acceleration shall be taken as 50 percent of the expected horizontal peak ground acceleration (PGA). The vertical seismic load effect E,, may be determined as:

$E_h = 0.5(a_h)\,D$

Where,

a_h = expected horizontal peak ground acceleration (in g) for design = $(\frac{2}{3})ZS$

D = effect of dead load,

S = site dependent soil factor.

W=Wind load

L= live load

E=seismic load

4.4 Various factor used in different zone to analyzed this structure is given below:

Factors	Zone 1	Zone 2	Zone 3	Zone 4
Z	0.12	0.20	0.28	0.36
S_s	0.3	0.5	0.7	0.9
S_1	0.12	0.20	0.28	0.36
F_a	1.35	1.2	1.35	1.15
F_v	2.7	1.75	2.7	1.725
Wind speed (mile /hr)	143.39	141.15	178.95	136.68

Chapter 5

5 ANALYSIS AND RESULT

The Linear static analysis simulation through ETABS software (v.2016), the values of the different parameters in different seismic zones of an RC building in given below in the table and graphs.

5.1 MAXIMUM STORY DISPLACEMENT (EARTHQUAKE LOAD IN X DIRECTION)

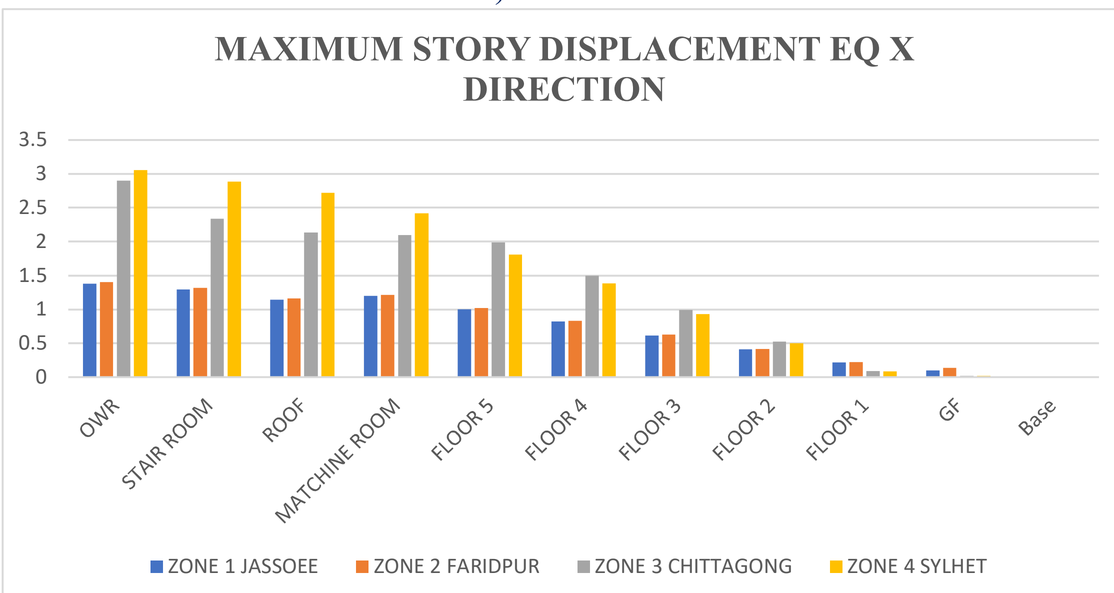


Figure 14:MAXIMUM STORY DISPLACEMENT EQX

This graph shows that, the highest value is observed in overhead water reservoir in zone 4 Sylhet. we found quite similar displacement in zone 1 and 2. For better understand of graph we showed the table format of that in below. In this graph, we also observed high displacement value in zone 4 & 3 comparatively than zone 1&2.

	ZONE 1 JASSOEE (in)	ZONE 2 FARIDPUR (in)	ZONE 3 CHITTAGONG (in)	ZONE 4 SYLHET (in)
OWR	1.3785	1.4025	2.89796	3.0587
Stair room	1.2946	1.3171	2.3384	2.8827
Roof	1.1433	1.1632	2.1351	2.7194
Machine room	1.1966	1.2174	2.0988	2.4200
Floor 5	1.003	1.020	1.9865	1.8090
Floor 4	0.8202	0.8345	1.4986	1.3827
Floor 3	0.6188	0.6295	0.9956	0.9339
Floor 2	0.4111	0.41829	0.5235	0.5029
Floor 1	0.2161	0.21992	0.0941	0.0859
Gf	0.1038	0.1395	0.0242	0.0218
Base	0	0	0	0

Table 3:MAXIMUM DISPLACEMENT EQX

5.2 MAXIMUM STORY DISPLACEMENT (EARTHQUAKE LOAD IN Y DIRECTION)

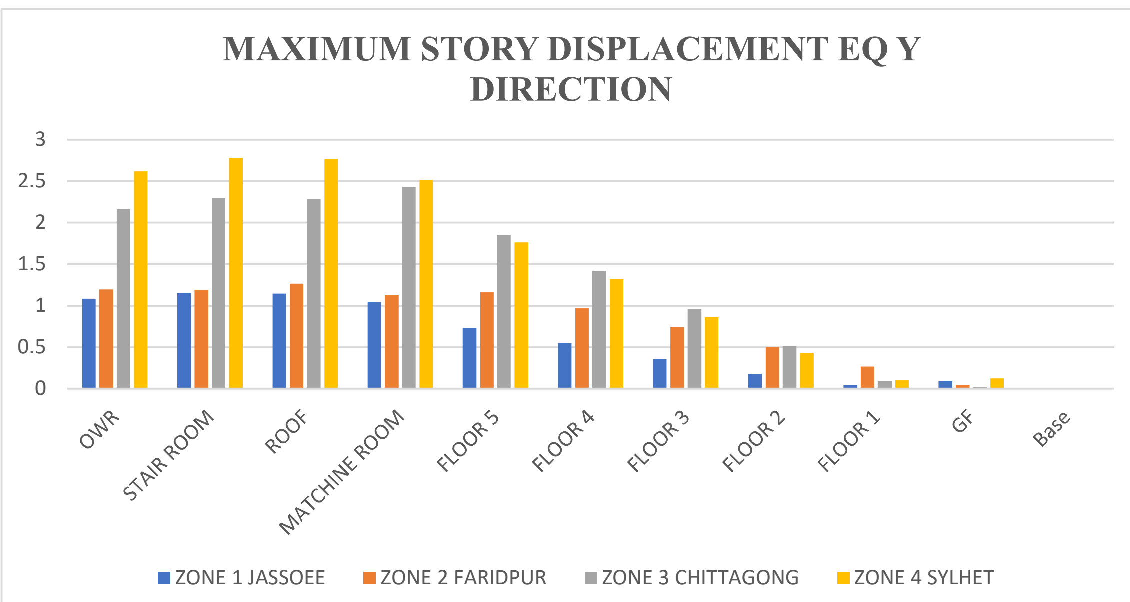


Figure 15:MAXIMUM STORY DISPLACEMENT EQY

This graph shows the maximum displacement in y direction for earthquake effect for the structure. The highest value is observed in overhead water reservoir in zone 4 Sylhet. we found that, the displacement is increasing floor by floor in that direction. For better understand of graph we showed the table format of that in below. In this graph, we also observed high displacement value in zone 4 comparatively than zone 1,2&3.

	ZONE 1 JASSOEE (in)	ZONE 2 FARIDPUR (in)	ZONE 3 CHITTAGONG (in)	ZONE 4 SYLHET (in)
OHR	1.0819	1.1967	2.1643	2.6202
Stair room	1.1479	1.1917	2.2937	2.7799
Roof	1.1430	1.2662	2.28426	2.7681
Machine room	1.0391	1.1292	2.4270	2.5165
Floor 5	0.7280	1.1580	1.8506	1.7631
Floor 4	0.5450	0.9655	1.4221	1.3199
Floor 3	0.3550	0.7420	0.9609	0.8599
Floor 2	0.1780	0.5013	0.5123	0.4311
Floor 1	0.0422	0.2673	0.0878	0.1022
Gf	0.0893	0.0458	0.0221	0.1216
Base	0	0	0	0

Table 4:MAXIMUM STORY DISPLACEMENT EQY

5.3 MAXIMUM STORY DRIFT (EARTHQUAKE LOAD X DIRECTION)

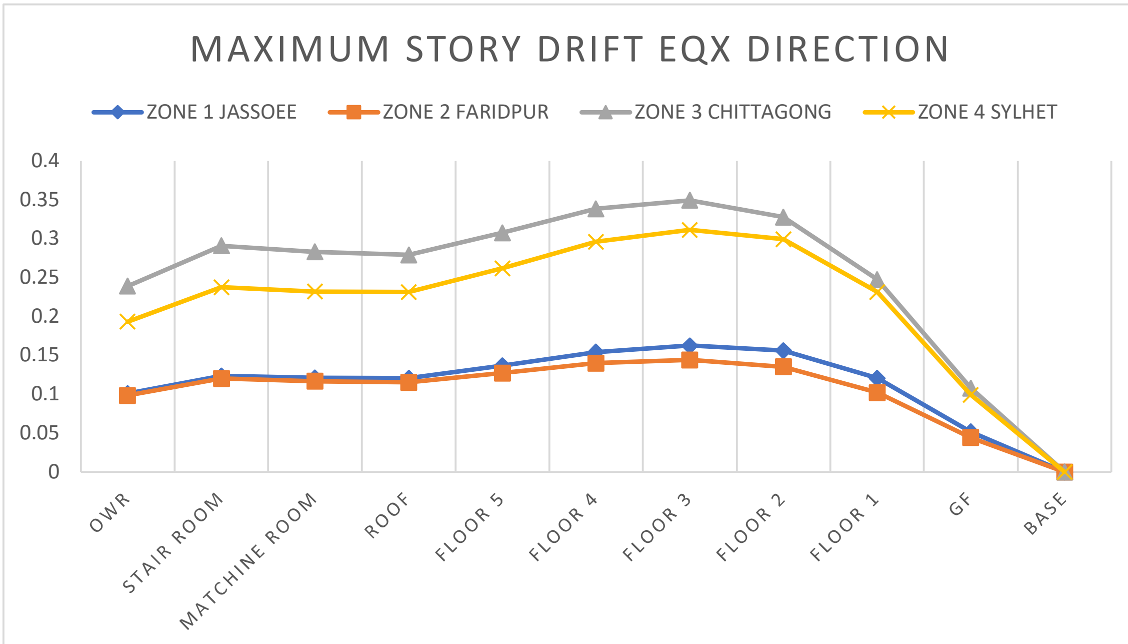


Figure 16:MAXIMUM STORY DRIFT EQX

This graph shows the maximum drift in x direction for earthquake load for the structure. The highest value is observed in floor 3 in zone 3 Chittagong. we found that, the drift is increasing floor by floor in that direction. For better understand of graph we showed the table format of that in below. In this graph, we also observed high displacement value in zone 3 comparatively than zone 1,2 and 4.

	ZONE 1 JASSOEE	ZONE 2 FARIDPUR	ZONE 3 CHITTAGONG	ZONE 4 SYLHET
OWR	0.1009	0.0987	0.2391	0.1933
STAIR ROOM	0.1239	0.1201	0.2909	0.2374
MATCHINE ROOM	0.1210	0.1169	0.2831	0.2321
ROOF	0.1206	0.1153	0.2793	0.2312
FLOOR 5	0.1367	0.1270	0.3077	0.2620
FLOOR 4	0.1544	0.1398	0.3387	0.2961
FLOOR 3	0.1625	0.1442	0.3492	0.3115
FLOOR 2	0.1561	0.1353	0.3278	0.2992
FLOOR 1	0.1206	0.1021	0.2474	0.2312
GF	0.0519	0.0445	0.1078	0.0995
Base	0	0	0	0

Table 5:MAXIMUM STORY DRIFT EQX

5.4 MAXIMUM STORY DRIFT (EARTHQUAKE LOAD Y DIRECTION)

	ZONE 1 JASSOEE (in)	ZONE 2 FARIDPUR (in)	ZONE 3 CHITTAGONG (in)	ZONE 4 SYLHET (in)
OWR	0.001008	0.001010	0.000163	0.000131716
Stair room	0.001003	0.000976	0.002364	0.001923361
Machine room	0.001381	0.001349	0.003267	0.002647309
Roof	0.001314	0.001229	0.002977	0.002518382
Floor 5	0.001604	0.00138	0.003343	0.003074924
Floor 4	0.001863	0.001525	0.003693	0.003570573
Floor 3	0.002005	0.001583	0.003833	0.003843237
Floor 2	0.00195	0.001475	0.003573	0.003738361
Floor 1	0.001509	0.001074	0.002602	0.002892221
Gf	0.000591	0.000462	0.001118	0.001132551
Base	0	0	0	0

Table 6: MAXIMUM STORY DRIFT EQY

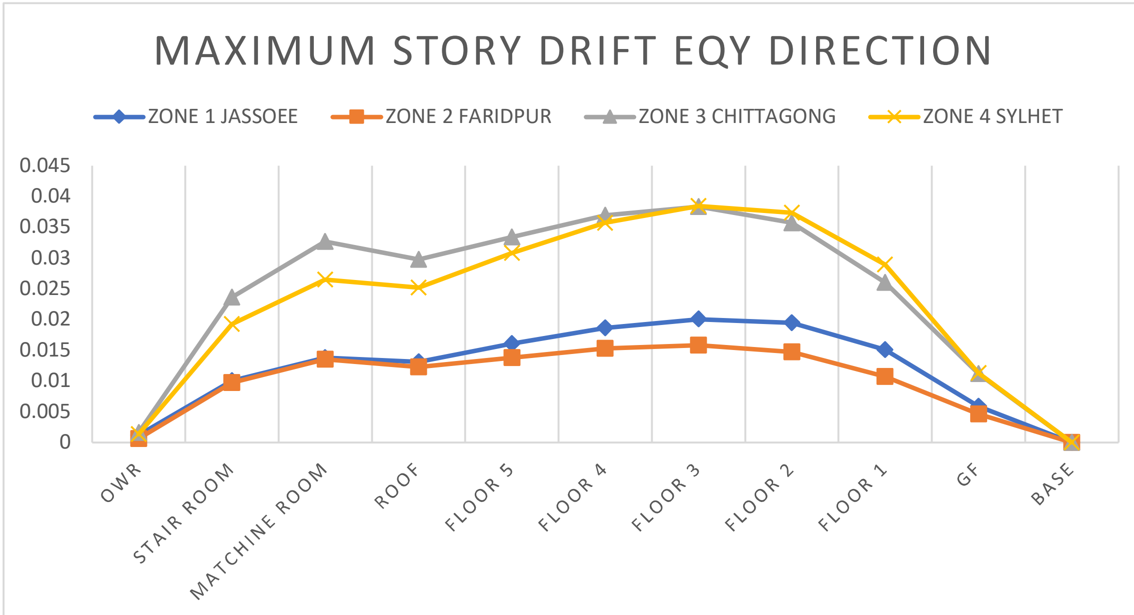


Figure 17:MAXIMUM STOREY DRIFT EQY

This graph shows how much a building faced drift value in different regions during an earthquake. The most movement occurs on the third floor of Sylhet (Zone 4), and the movement intensifies as we move up the floors. We've also included this data in a table below the graph. In addition, we see that Zone 3 has higher levels of mobility than Zones 1, 2, and 4.

5.5 MAXIMUM STORY DISPLACEMENT WIND LOAD IN X DIRECTION

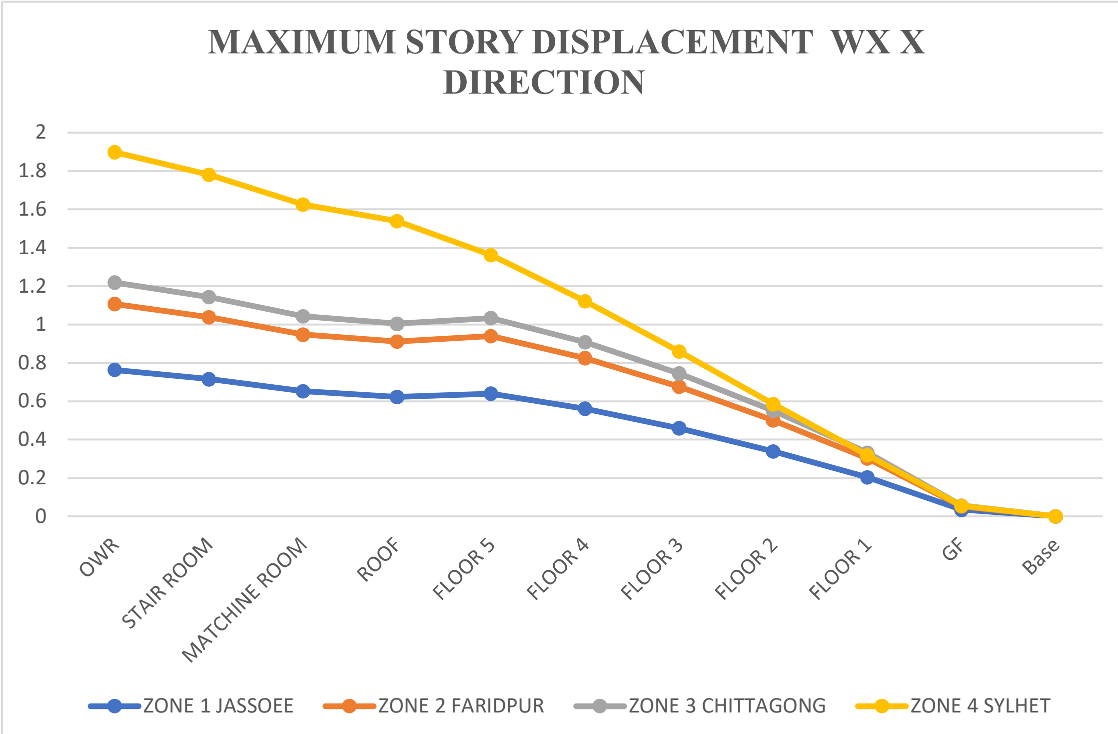


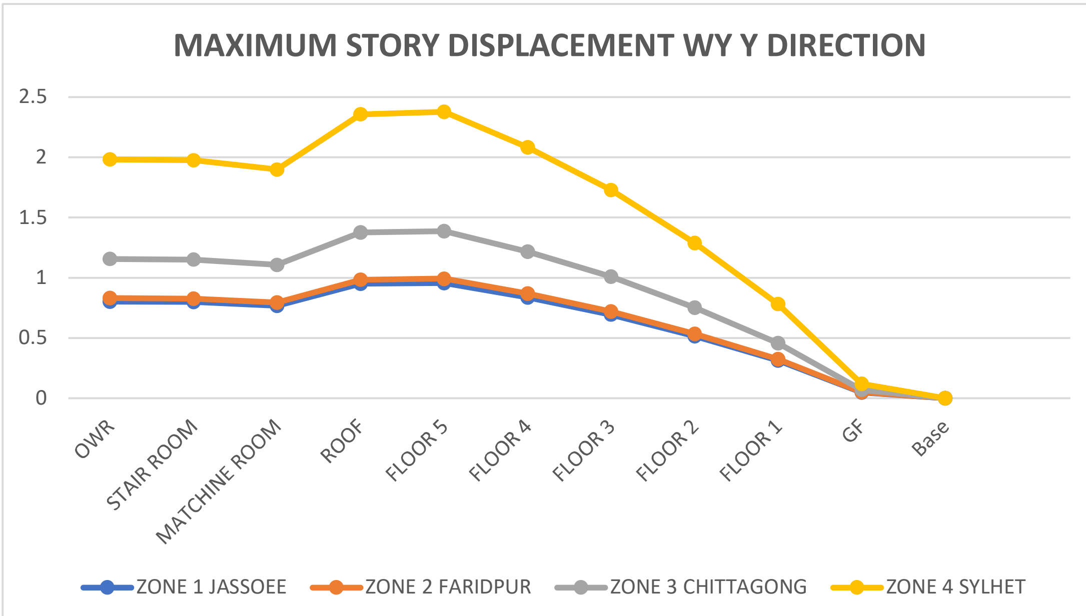
Figure 18:5.5 **MAXIMUM STORY DISPLACEMENT WY Y DIRECTION**

This graph shows how much a building make displacement in different regions during an earthquake. The most movement occurs on the third floor of Sylhet (Zone 4), and the movement intensifies as we move up the floors. We've also included this data in a table below the graph. In addition, we see that Zone 3 has higher levels of mobility than Zones 1, 2, and 4.

	ZONE 1 JASSOEE (in)	ZONE 2 FARIDPUR (in)	ZONE 3 CHITTAGONG (in)	ZONE 4 SYLHET (in)
OWR	0.76376	1.1073	1.218702	1.89811
Stair room	0.71647	1.03908	1.143612	1.78116
Machine room	0.65291	0.9480	1.04339	1.625079
Roof	0.62348	0.911979	1.0037	1.5398
Floor 5	0.64112	0.93970	1.03423	1.3627
Floor 4	0.561653	0.82505	0.90805	1.1220
Floor 3	0.45977	0.677341	0.745479	0.85974
Floor 2	0.3386	0.500626	0.550988	0.58549
Floor 1	0.20391	0.30244	0.332869	0.318274
Gf	0.03513	0.05216	0.057407	0.05492
Base	0	0	0	0

Table 7:5.6 MAXIMUM STORY DISPLACEMENT WX X DIRECTION

5.6 MAXIMUM STORY DISPLACEMENT WIND LOAD IN Y DIRECTION



This graph shows the maximum displacement against wind load in y direction. From this graph, we see the highest displacement in zone 4 . On the other hand almost the same type of displacement is seen in zones 1 and 2 . Among them, the highest value is on floor 5 at zone 4

	ZONE 1 JASSOEE (in)	ZONE 2 FARIDPUR (in)	ZONE 3 CHITTAGONG (in)	ZONE 4 SYLHET (in)
OWR	0.80168	0.8309	1.1569	1.9832
Stair room	0.7982	0.8274	1.1520	1.9747
Machine room	0.7665	0.7945	1.1066	1.8970
Roof	0.9503	0.9851	1.3755	2.3579
Floor 5	0.9573	0.9922	1.3872	2.3785
Floor 4	0.8373	0.8679	1.2151	2.0829
Floor 3	0.6935	0.7189	1.0083	1.7284
Floor 2	0.5154	0.5342	0.7512	1.2878
Floor 1	0.3123	0.3237	0.4564	0.7824
Gf	0.0481	0.0499	0.0704	0.1207
Base	0	0	0	0

Table 8:1.1 **MAXIMUM STORY DISPLACEMENT WY Y DIRECTION**

5.7 MAXIMUM STOREY SHEAR EARTHQUAKE LOAD IN X DIRECTION

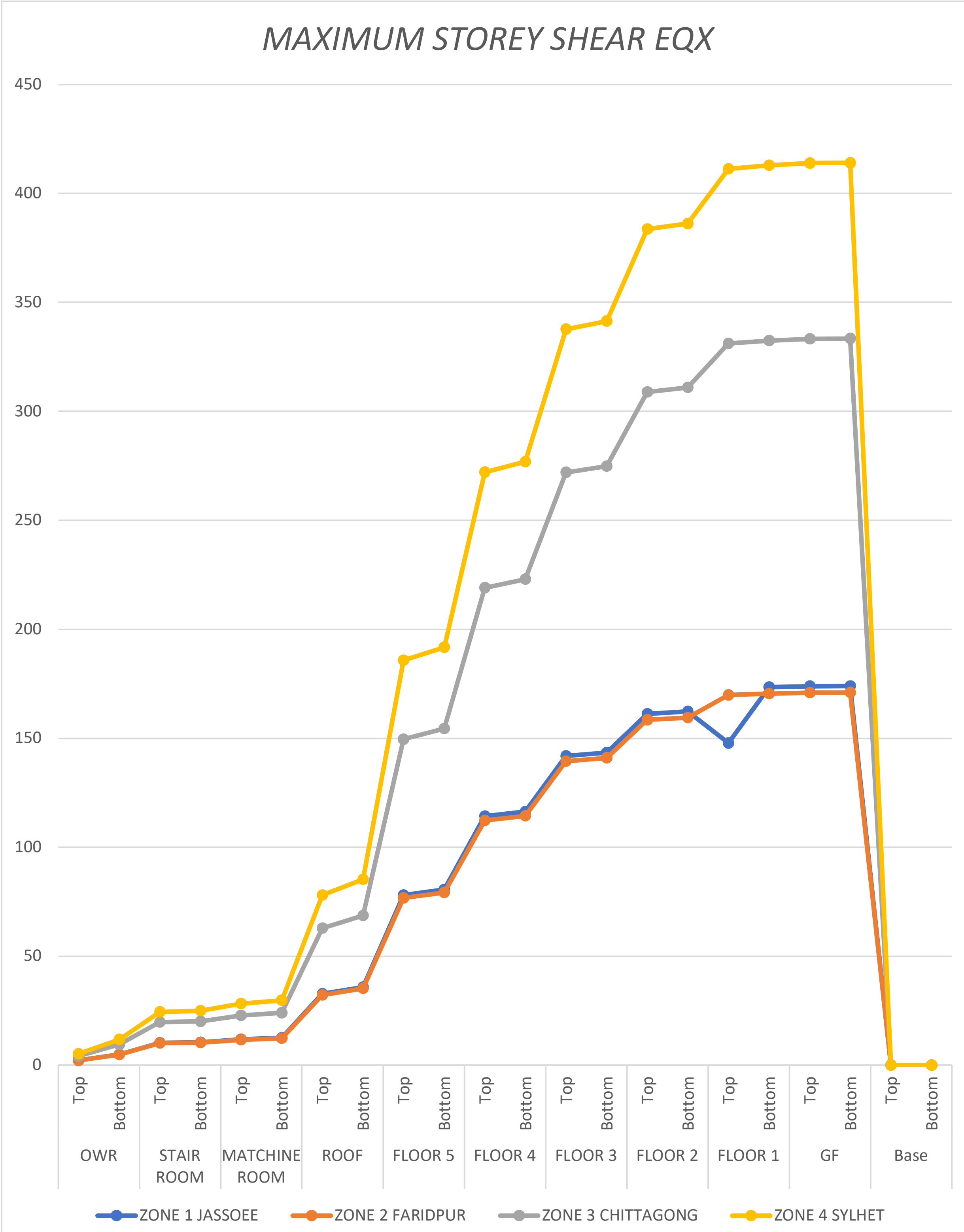


Figure 19:MAXIMUM STORY SHEAR EQX

Storey shear is an important parameter of a building structure .in our analysis we showed that shear in all zones in all floor from the graph we can see that, the maximum shear found in zone 4 point of ground floor bottom part. floor wise data is given below.

		ZONE 1 JASSOEE (in)	ZONE 2 FARIDPUR (in)	ZONE 3 CHITTAGONG (in)	ZONE 4 SYLHET (in)
OWR	Top	2.1753	2.1381	4.169	5.1778
	Bottom	4.938	4.853	9.464	11.754
STAIR ROOM	Top	10.2701	10.09452	19.68431	24.446
	Bottom	10.4871	10.30785	20.10031	24.9626
MATCHINE ROOM	Top	11.8882	11.68499	22.78572	28.2976
	Bottom	12.4944	12.28087	23.94769	29.7407
ROOF	Top	32.7771	32.21677	62.8227	78.0197
	Bottom	35.8022	35.19022	68.62093	85.22058
FLOOR 5	Top	78.0327	76.69876	149.5626	185.742
	Bottom	80.5539	79.17692	154.395	191.74369
FLOOR 4	Top	114.301	112.347	219.0767	272.0721
	Bottom	116.316	114.3274	222.9384	276.867
FLOOR 3	Top	141.886	139.4606	271.9481	337.73330
	Bottom	143.413	140.9611	274.8741	341.3671
FLOOR 2	Top	161.18	158.4251	308.929	383.6601
	Bottom	162.241	159.4678	310.9621	386.1850
FLOOR 1	Top	147.771	169.8173	331.1437	411.2486
	Bottom	173.481	170.516	332.5062	412.94062
GF	Top	173.877	170.9047	333.2641	413.8818
	Bottom	173.948	170.974	333.3994	414.0499
Base	Top	0	0	0	0
	Bottom	0	0	0	0

Table 9:5.7 MAXIMUM STORY SHEAR EQX

5.8 MAXIMUM STORY SHEAR (EARTHQUAKE LOAD IN Y DIRECTION)

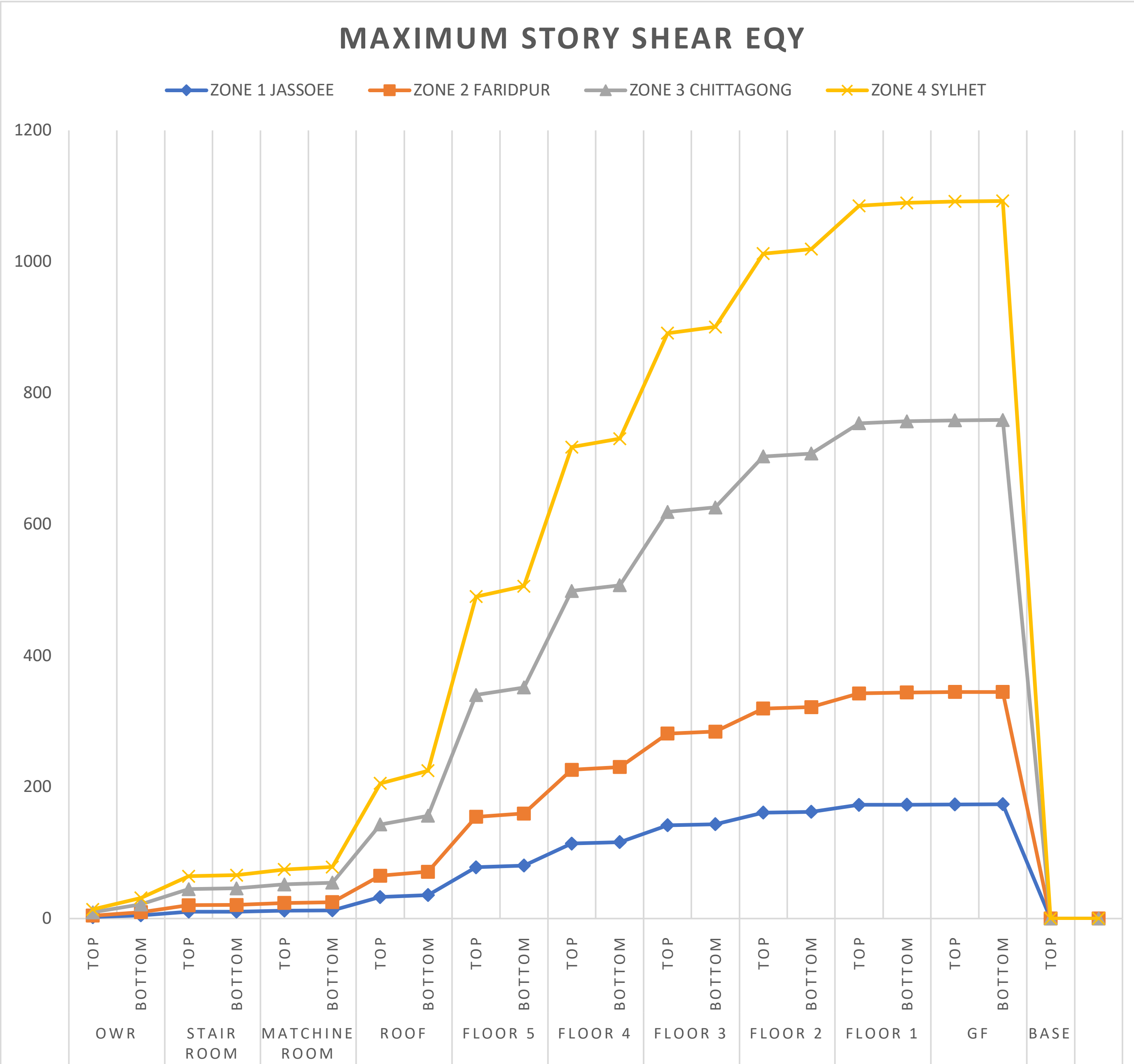


Figure 20:MAXIMUM STORY SHEAR EQY

In this graph we showed a vital component of a building's construction is storey shear. The largest shear was detected in zone 4 of the bottom of the ground level, as can be observed in the graph. In our research, we showed that shear occurs in all zones and all floors. Below are data divided down by floor.

		ZONE 1 JASSOEE (in)	ZONE 2 FARIDPUR (in)	ZONE 3 CHITTAGONG (in)	ZONE 4 SYLHET (in)
OWR	TOP	2.1753	2.138111	5.177889	4.1693
	BOTTOM	4.938	4.853592	11.754	9.46450
STAIR ROOM	TOP	10.2701	10.0945	24.44602	19.684
	BOTTOM	10.4871	10.3078	24.96265	20.100
MATCHINE ROOM	TOP	11.8882	11.6849	28.29767	22.7857
	BOTTOM	12.4944	12.2808	29.74073	23.94769
ROOF	TOP	32.7771	32.21677	78.01975	62.82275
	BOTTOM	35.8022	35.19023	85.2206	68.62094
FLOOR 5	TOP	78.0327	76.69877	185.7423	149.5625
	BOTTOM	80.5539	79.17692	191.7437	154.3950
FLOOR 4	TOP	114.301	112.3471	272.0722	219.0767
	BOTTOM	116.316	114.3274	276.868	222.93840
FLOOR 3	TOP	141.886	139.4606	337.7333	271.94810
	BOTTOM	143.413	140.9611	341.3671	274.8740
FLOOR 2	TOP	161.18	158.4251	383.6601	308.929
	BOTTOM	162.241	159.4678	386.185	310.9621
FLOOR 1	TOP	172.771	169.8173	411.2487	331.1437
	BOTTOM	173.482	170.516	412.9407	332.5062
GF	TOP	173.877	170.9047	413.8819	333.2641
	BOTTOM	173.948	170.9741	414.05	333.3994
Base	TOP	0	0	0	0
	BOTTOM	0	0	0	0

Table 10: MAXIMUM STOREY SHEAR EQY

5.9 MAXIMUM STORY STIFFNESS EARTHQUAKE LOAD IN X DIRECTION

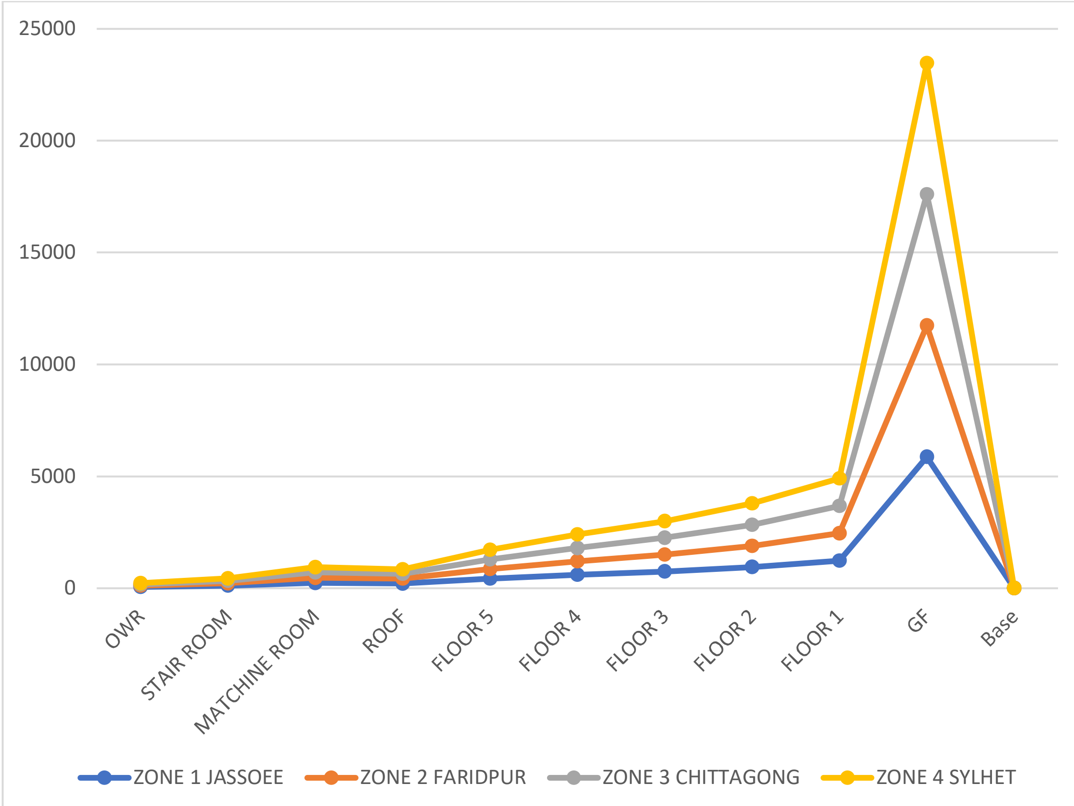


Figure 21:MAXIMUM STORY STIFNESS EQX

Maximum storey stiffness analysis is a mandatory step to design a structure. we determined that the maximum story stiffness is consistently observed on the ground floor within each zone. The highest recorded value stands at 5926.45 kip/inch in zone 4 for x direction. we observed that , stiffness is high in ground floor for each zone and then its showed a lower value and on the base it becomes zero (0) .

	ZONE 1 JASSOEE	ZONE 2 FARIDPUR	ZONE 3 CHITTAGONG	ZONE 4 SYLHET
OWR	55.75001	56.3500	56.8500	57.35000
Stair room	108.9013	108.9012	108.9012	108.901
Machine room	234.1267	234.1266	234.126	234.1266
Roof	210.4049	210.404	210.4042	210.4049
Floor 5	428.555	428.554	428.5549	428.5549
Floor 4	598.4845	598.4844	598.4844	598.4844
Floor 3	748.5925	748.5925	748.59254	748.59254
Floor 2	944.9706	944.9705	944.9705	944.9705
Floor 1	1225.932	1225.932	1225.9321	1225.93
Gf	5866.906	5866.9055	5866.9055	5866.9055
Base	0	0	0	0

Table 11:MAXIMUM STORY STIFNESS

5.10 MAXIMUM STORY STIFNESS EARTHQUAKE LOAD IN Y DIRECTION:

	ZONE 1 JASSOEE	ZONE 2 FARIDPU R	ZONE 3 CHITTAGON G	ZONE 4 SYLHET
OWR	1004.986	1004.285	1005.8855	1006.1855
Stair room	161.7261	161.7268	161.721	161.7260
Machine room	252.757	252.757	252.757	252.7576
Roof	232.2879	232.2879	232.287	232.287
Floor 5	464.8926	464.8925	464.8925	464.8925
Floor 4	625.2817	625.2819	625.2816	625.2816
Floor 3	759.6501	759.6500	759.650	759.6500
Floor 2	1034.08	1034.085	1034.0801	1034.080
Floor 1	1211.25	1211.24	1211.249	1211.24
Gf	5490.178	5490.17813	5490.1781	5490.178
Base	0	0	0	0

Table 12:MAXIMUM STIFNESS EQY

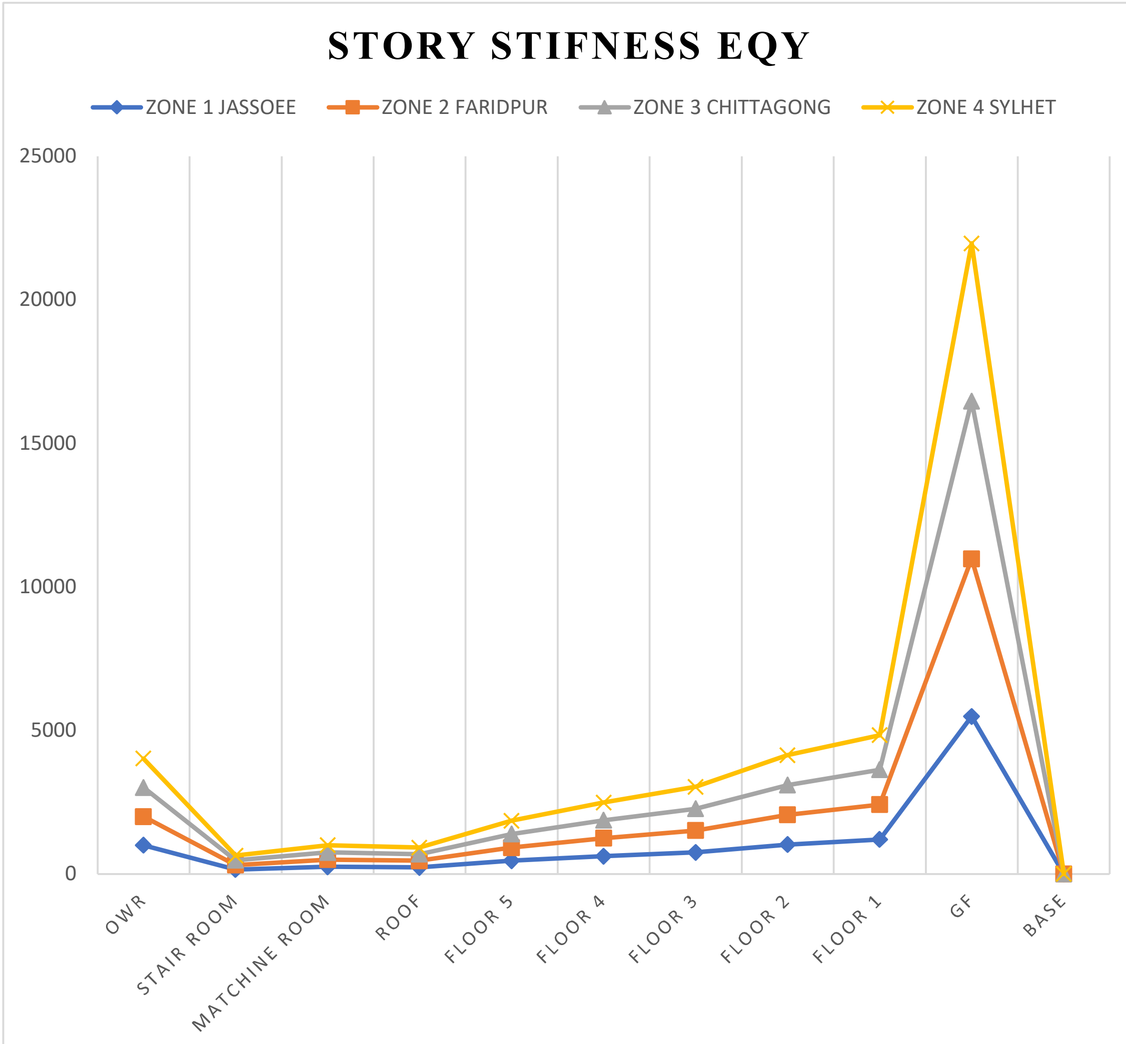


Figure 22::STORY STIFNESS EQY

We found that the highest stiffness is consistently on the ground floor in every zone for y direction. The highest stiffness value recorded is 5490.178 kip/inch in Zone 4 direction. We've noticed a pattern where stiffness is highest on the ground floor for each zone, then it gradually decreases and reaches zero at the base.

5.11 Result summary:

This table shown the summary of all parameter in X DIRECTION

Parameters	Zone 1	Zone 2	Zone 3	Zone 4
Maximum storey displacement (earthquake)	1.317	1.378	2.883	3.338
Maximum storey drift	0.002	0.002	0.003	0.003
Storey shear	-173.948	-170.974	-333.399	-414.05
Maximum storey displacement (wind)	1.218	0.763	1.898	1.107
Maximum stiffness	1225.932	1295.96	1310.65	1426.45

This table shown the summary of all parameter in Y DIRECTION :

Parameters	Zone 1	Zone 2	Zone 3	Zone 4
Maximum storey displacement (earthquake)	1.266	1.147	2.779	2.293
Maximum storey drift	0.001	0.001	0.002	0.002
Storey shear	-173.948	-170.974	-333.399	-414.05
Maximum storey displacement (wind)	0.992	0.957	1.378	2.378
Maximum stiffness	5490.178	5525.69	5790.178	5880.267

5.12 Change of dimension in various zone

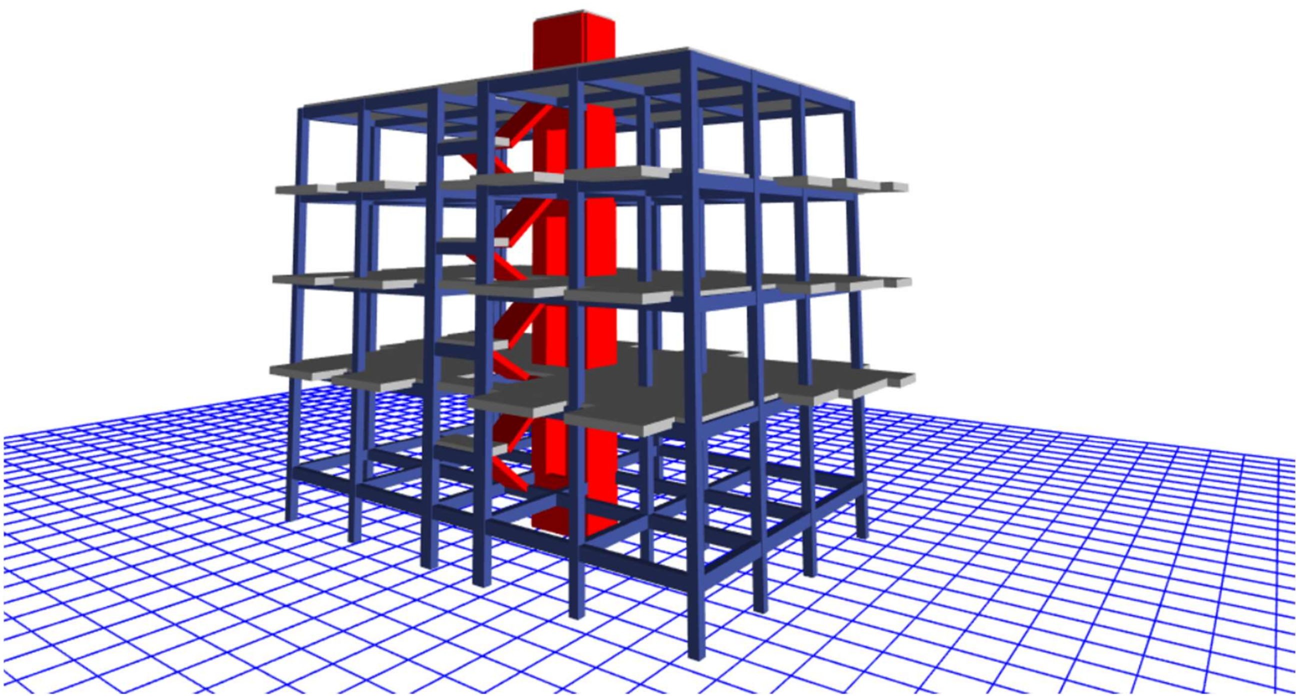
Parameters	Zone 1	Zone 2	Zone 3	Zone 4
Column	C1 10"X12" C2 12"X15" C3 12"X12"	C1 12"X12" C2 12"X15" C3 12"X18" C3 15"X12"	C1 10"X12" C1 12"X12" C2 12"X15" C3 12"X18"	C1 12"X12" C3 12"X18" C4 12"X20" C5 15"X20"
Beam	FB1 10"X12" FB2 10"X15“ FB3 12“X24" FB4 12“X15"	FB2 10"X15" FB3 10"X18“ FB4 12“X15"	FB1 10"X12" FB2 10"X15“ FB3 12“X20" FB4 12“X15"	FB1 10"X12" FB2 10"X15“ FB3 12“X24" FB4 15“X18"
Floor	Slab 5"	Slab 5"	Slab 5"	Slab 5"
Wall	Wall 10"	Wall 10"	Wall 10"	Wall 10"

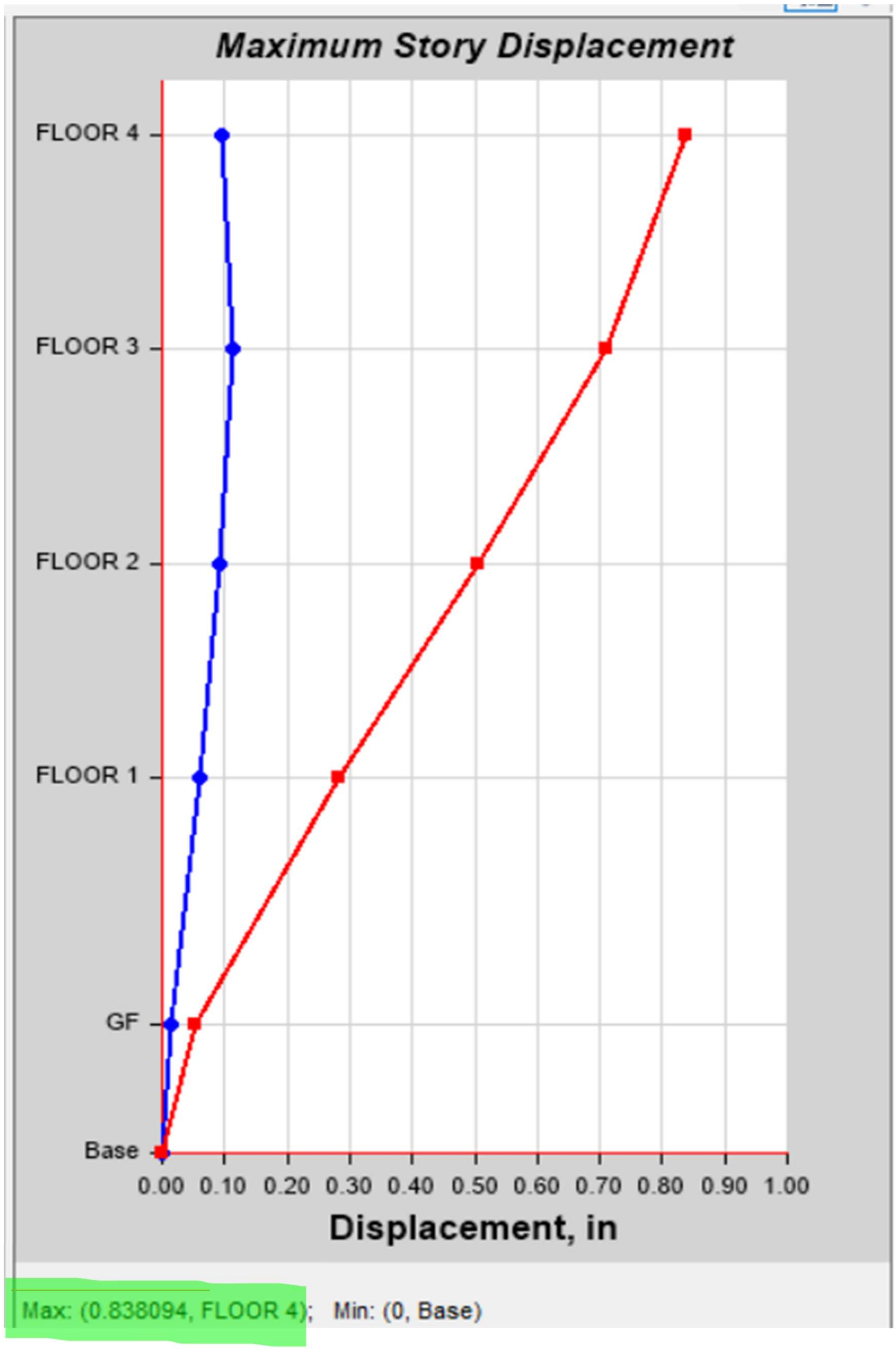
Chapter 6

6 CALCULATION

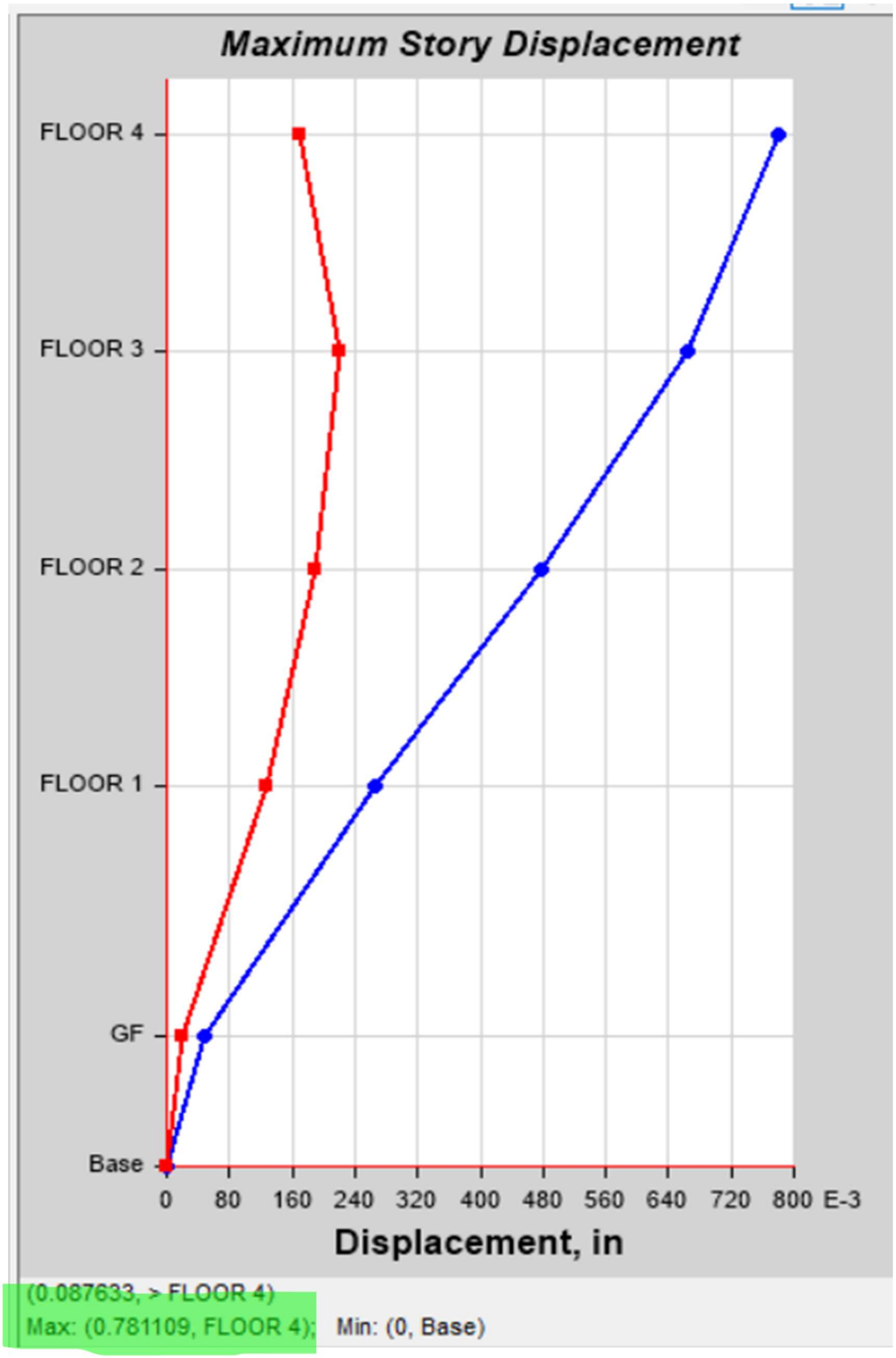
6.1 Small building 3d model & analysis :

We are examining a small structure to assess irregularities in comparison to a building that is approximately 84 feet in height.

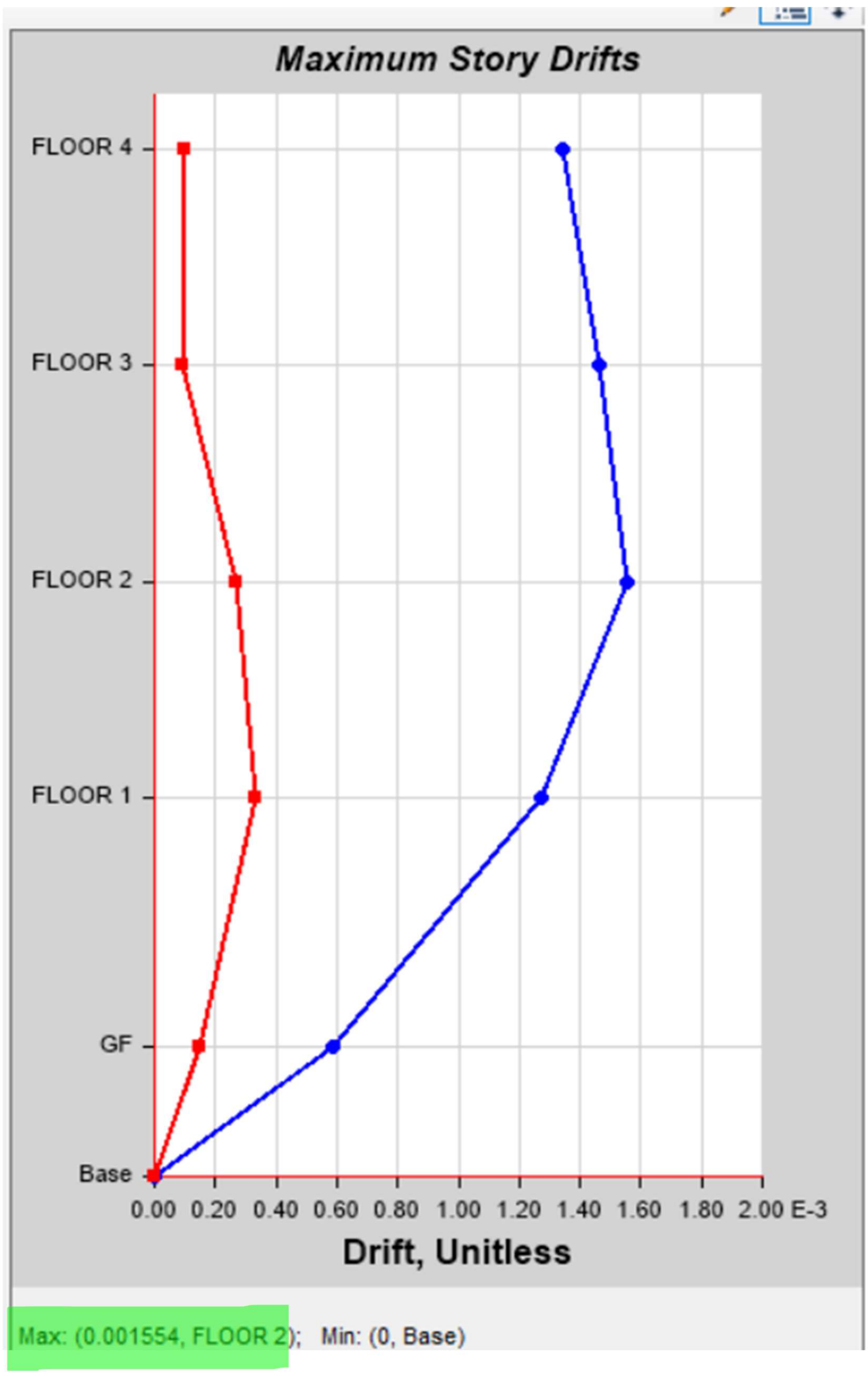


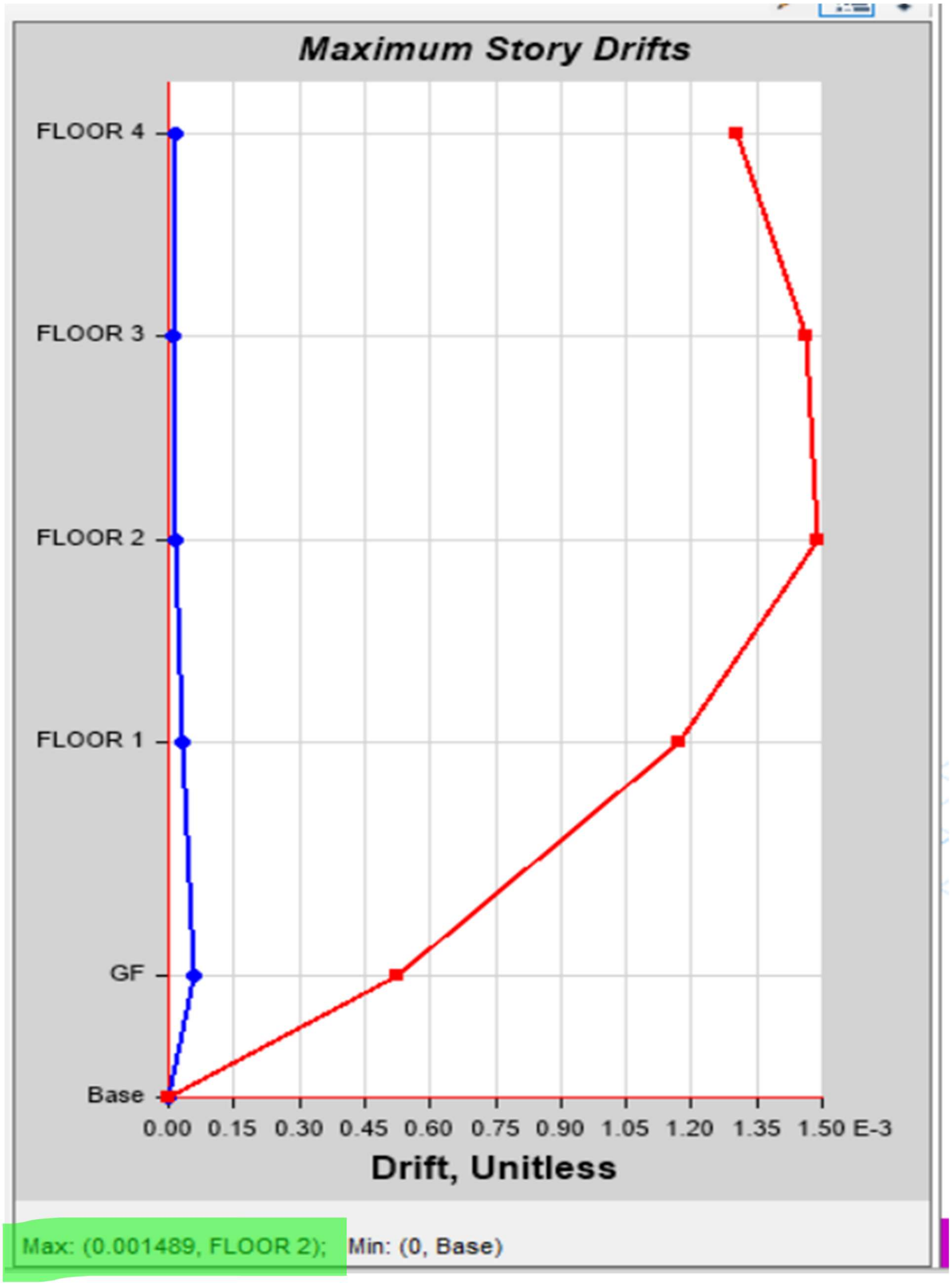


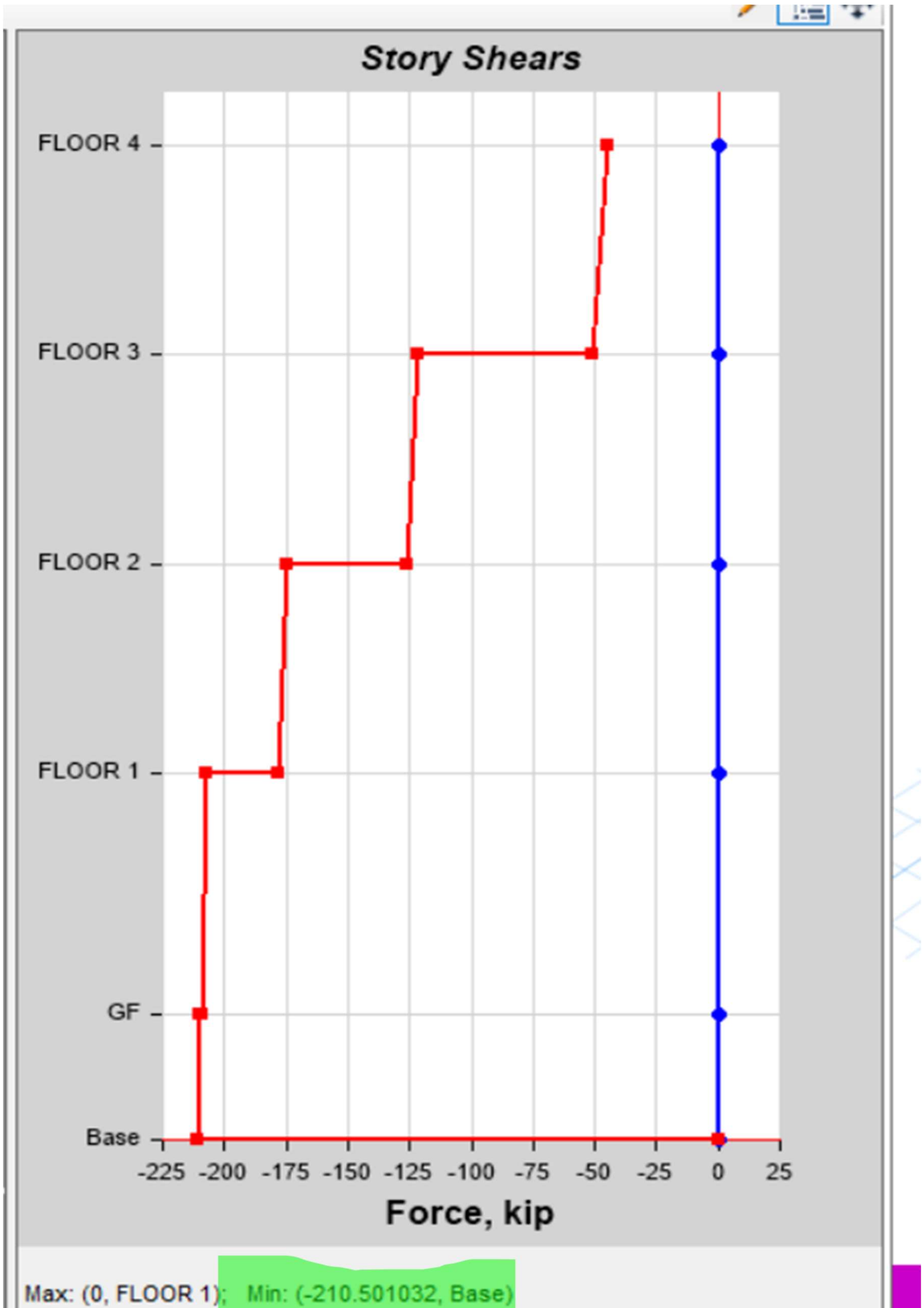
Maximum Story Displacement
FLOOR 4
FLOOR 3
FLOOR 2
FLOOR 1
GF
Base
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00
Displacement, in
Max: (0.838094, FLOOR 4); Min: (0, Base)

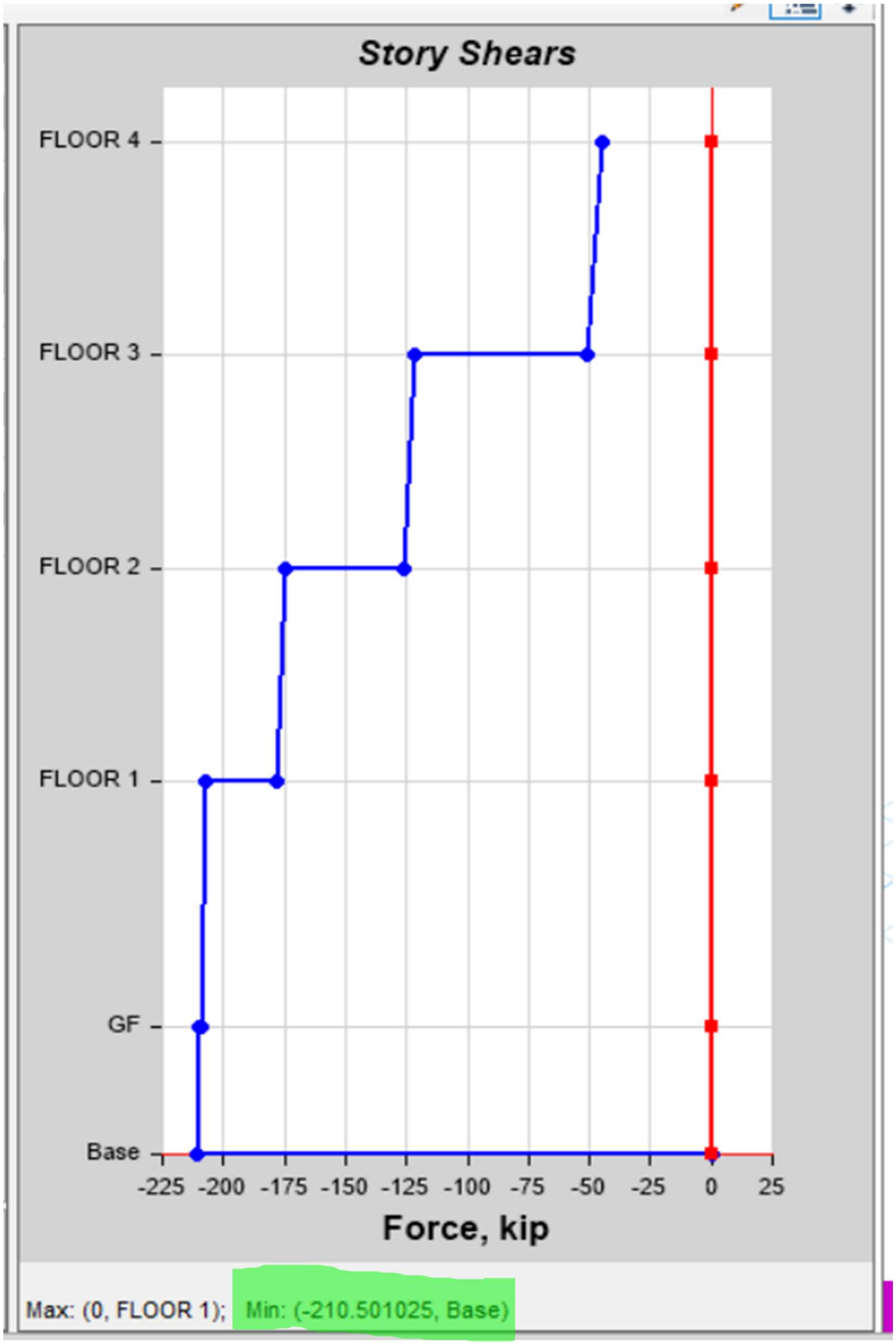


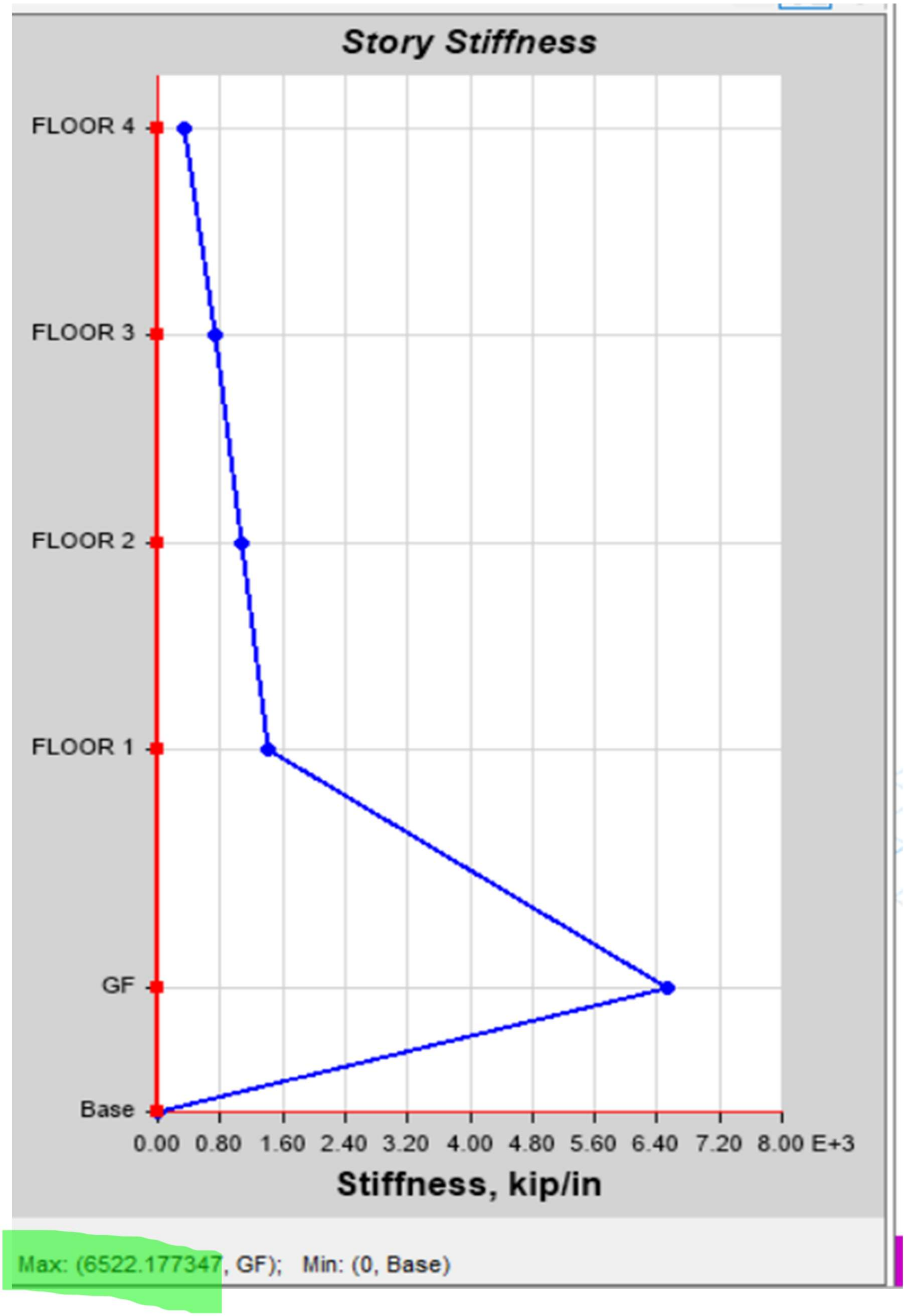
Maximum Story Displacement
FLOOR 4
FLOOR 3
FLOOR 2
FLOOR 1
GF
Base
0 80 160 240 320 400 480 560 640 720 800 E-3
Displacement, in
(0.087633, > FLOOR 4)
Max: (0.781109, FLOOR 4); Min: (0, Base)

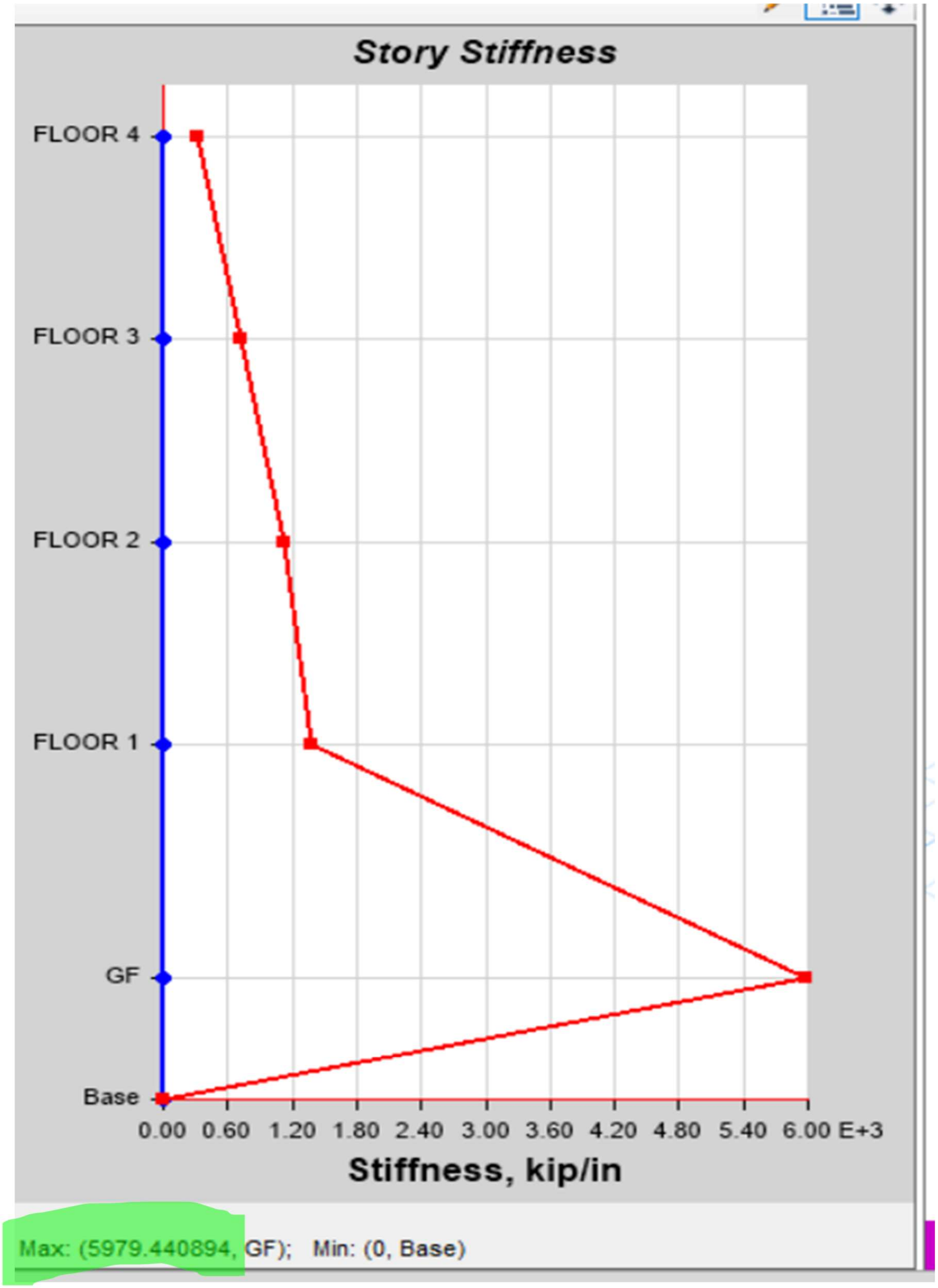

Maximum Story Drifts
FLOOR 4
FLOOR 3
FLOOR 2
FLOOR 1
GF
Base
0.00 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 2.00 E-3
Drift, Unitless
Max: (0.001554, FLOOR 2); Min: (0, Base)


Maximum Story Drifts
FLOOR 4
FLOOR 3
FLOOR 2
FLOOR 1
GF
Base
0.00 0.15 0.30 0.45 0.60 0.75 0.90 1.05 1.20 1.35 1.50 E-3
Drift, Unitless
Max: (0.001489, FLOOR 2); Min: (0, Base)


Story Shears
FLOOR 4
FLOOR 3
FLOOR 2
FLOOR 1
GF
Base
-225 -200 -175 -150 -125 -100 -75 -50 -25 0 25
Force, kip
Max: (0, FLOOR 1); Min: (-210.501032, Base)


Story Shears
FLOOR 4
FLOOR 3
FLOOR 2
FLOOR 1
GF
Base
-225 -200 -175 -150 -125 -100 -75 -50 -25 0 25
Force, kip
Max: (0, FLOOR 1); Min: (-210.501025, Base)


Story Stiffness
FLOOR 4
FLOOR 3
FLOOR 2
FLOOR 1
GF
Base
0.00 0.80 1.60 2.40 3.20 4.00 4.80 5.60 6.40 7.20 8.00 E+3
Stiffness, kip/in
Max: (6522.177347, GF); Min: (0, Base)


Story Stiffness
FLOOR 4
FLOOR 3
FLOOR 2
FLOOR 1
GF
Base
0.00 0.60 1.20 1.80 2.40 3.00 3.60 4.20 4.80 5.40 6.00 E+3
Stiffness, kip/in
Max: (5979.440894, GF); Min: (0, Base)

6.2 COST ESTIMATION FOR CONCRETE

Cost has been estimated for M25 grade concrete. At first, materials for 1 m^3

of concrete has been calculated. Then, the amount has been multiplied with the required volume of concrete. Volume of concrete has been found out from ETABS.

6.3 Material Calculation for M25 Grade Concrete

Let,

C: FA: CA = 1: 1: 2 (1+1+2 = 4)

Dry volume = Wet Volume *1.54

CEMENT

(1/4) x 1.54 = 0.385 m^3

Volume of cement in kg = 0.385 x 1440 kg/ m^3 = 403.2 kg

No. of bags needed = 403.2/50 = 8.064 bags (1 bag of cement = 50 kg)

FINE AGGREGATES

(1/4) x 1.54 = 0.385 m^3 = 14.82 cft (1 m = 3.28 ft)

COARSE AGGREGATES

(2/4) x 1.54 = 0.77 m^3 = 29.64 cft

WATER

Let, W/C =0.45

So, W = 0.45 x 403.2 = 181.44 kg = 181.44L

6.4 Volume Estimation from ETABS

For zone 1:

Section	Element type	Total weight of concrete		Unit per unit volume	Total volume of concrete	
		Kip	lb	pcf	ft^3	m^3
Column	Column	1670.616	1670616	150	11137.44	315.377
Ground column	Column					
Beam	Beam					
Ground beam	Beam					
Slab	Slab					

For zone 2:

Section	Element type	Total weight of concrete		Unit per unit volume	Total volume of concrete	
		Kip	lb	pcf	ft^3	m^3
Column	Column	1686.298	1686298	150	11241.987	318.338
Ground column	Column					
Beam	Beam					
Ground beam	Beam					
Slab	Slab					

For zone 3:

Section	**Element type**	**Total weight of concrete**		**Unit per unit volume**	**Total volume of concrete**	
		Kip	lb	pcf	ft^3	m^3
Column	Column	1815.753	1815753.2	150	12105.02	342.776
Ground column	Column					
Beam	Beam					
Ground beam	Beam					
Slab	Slab					

For zone 4:

Section	Element type	Total weight of concrete		Unit per unit volume	Total volume of concrete	
		Kip	Lb	Pcf	Ft^3	M^3
Column	Column	1916.573	1916573.2	150	12777.155	361.809
Ground column	Column					
Beam	Beam					
Ground beam	Beam					
Slab	Slab					

6.5 Material amount

Element	Zone 1	Zone 2	Zone 3	Zone 4
Cement (bags)	2538	2567	2765	2918
Fine aggregate (cft)	4664	4718	5080	5362
Coarse aggregate (cft)	9329	9436	10160	10724
Water (L)	57104	57760	62194	65647

6.6 Unit cost

Unit cost has been taken following the current market price for each material.

• CEMENT: BDT 500 per Bag

• FINE AGGREGATES: BDT 45 per cft

• COARSE AGGREGATES: BDT 80 per cft

• WATER: BDT 30 (100 L)

6.6.1 Total Cost

Zone	Cement (BDT)	Fine aggregate sand (BDT)	Coarse aggregate (BDT)	Water (BDT)	Total (BDT)
Zone 1	1269000	209880	746320	1713120	3938320
Zone 2	1283500	209880	754880	1732800	3981060
Zone 3	1382500	209880	812800	1865820	4271000
Zone 4	1459000	209880	857920	1969410	4496210

Chapter 7

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusion:

i. we analyze the results of Linear Static Analysis (LSA) in four seismic zones in Bangladesh, we note reduced values for Shear Force, Lateral Displacement, story stiffness, and Story Drift. As a result, our building is considered secure against potential earthquakes in zones 1 and 2.

ii. Conversely, we identify diminished values for Shear Force, Lateral Displacement, story stiffness, and Story Drift. To enhance resistance, we increased the size of columns and beams. Following these modifications, our building is now considered earthquake-resistant in zones 3 and 4 for future seismic events.

iii. We find the cost for construction of this structure & compare the cost in four zone. Based on the analysis of cost estimation, it can be concluded that the expense associated with concrete is greater in zones 3 and 4 compared to zones 1 and 2.

7.2 Recommendation:

Zone-Specific Design Guidelines: Develop and implement zone-specific seismic design guidelines that account for the varying seismic hazards in different regions of Bangladesh. These guidelines should provide clear provisions for addressing torsional irregularities in building design.

Seismic Retrofitting: Encourage the retrofitting of existing buildings, particularly those in high-seismic zones, to address torsional irregularities and enhance their seismic resilience. Incentive programs and financial support may be considered to promote retrofitting. Advanced Structural Analysis: Promote the use of advanced structural analysis software and tools that can accurately assess torsional effects in buildings during seismic events. This can help engineers make informed design decisions.

Innovative Construction Materials: Explore the use of innovative construction materials and technologies that can reduce torsional irregularities in building structures, such as the incorporation of seismic base isolators or tuned mass dampers.

Continuous Monitoring: Implement continuous structural health monitoring systems in critical buildings to assess their performance during seismic events and ensure timely maintenance and repairs.

Public Awareness: Continue public awareness campaigns to educate the general population about seismic risks and the importance of earthquake-resistant building design.

Regular Code Updates: Periodically review and update building codes and standards to incorporate the latest research findings and technological advancements in seismic engineering.

These recommendations aim to improve the seismic resilience of RC buildings in Bangladesh, particularly in the face of torsional irregularities, and contribute to the safety and well-being of the population in earthquake-prone areas.

7.3 Future Scopes

The cost of reinforcement has not been estimated in this study. It is recommended to estimate the cost of reinforcement so that the whole cost of the structure can be budgeted. The sizes of column and beam have been not kept the same in the whole model. Therefore, estimated cost might not be effective. It is also recommended to take same corner, peripheral and middle column and beam sizes as per necessity and keep same. Furthermore, plan irregularities can be included.

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