

SEISMIC EVALUATION OF ORDINARY & SPECIAL MOMENT RESISTING FRAMES AS PER BNBC 2020

By

MD. IMRAN HOSSEN

MD.ZAHID HASAN

MD. ISRAK KHAN MAHI

MD.TANZIL HOSSEN

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: 26A+27A

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By

MD. IMRAN HOSSEN CE2202026024

MD.ZAHID HASAN CE2202026034

MD. ISRAK KHAN MAHI CE2202026035

MD.TANZIL HOSSEN CE2202026068

Supervisor

Zeba Fariha

Lecturer

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Department of Civil Engineering

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BOARD OF EXAMINERS

The thesis titled “SEISMIC EVALUATION OF ORDINARY & SPECIAL MOMENT RESISTING FRAMES AS PER BNBC 2020” submitted by Md. Imran Hossen, ID: CE2202026024; Md.Zahid Hasan, ID: CE2202026034; Md. Israk Khan Mahi, ID: CE2202026035; Md.Tanzil Hossen; ID: CE2202026068 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Civil Engineering on 17/01/2026.

-
1. Zeba Fariha
Lecturer
Dept. of Civil Engineering
Sonargaon university
Chairman

-
2. Internal / External Member
Member

-
3. Internal / External Member
Member

DECLARATION

It is hereby declared that this thesis/project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

<u>STUDENT NAME</u>	<u>STUDENT ID.</u>	<u>SIGNATRE</u>
Md. Imran Hossen	CE2202026024	
Md.Zahid Hasan	CE2202026034	
Md. Israk Khan Mahi	CE2202026035	
Md.Tanzil Hossen	CE2202026068	

Dedicated

to

“In the name of Allah, the Most Gracious, the Most Merciful.

To my beloved family and cherished teachers, we dedicate this thesis to you with profound gratitude. Your unwavering support, encouragement, and wisdom have been my guiding lights throughout this academic journey. May Allah bless you abundantly for your kindness, patience, and dedication.

To our parents, who sacrificed so much to provide us with education and love, we are forever indebted. Your prayers and blessings have carried us through every challenge.

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May this work be a reflection of the knowledge imparted by our teachers; the love bestowed upon us by our family, and the divine wisdom granted by Allah.

Bismillah.

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ABSTRACT

Seismic safety of the RC structure is a crucial issue in Bangladesh, which falls within four different seismic zones as per BNBC 2020. The paper deals with the seismic performance of Special Moment Resisting Frames regarding drift, deflection, base shear, and story shift, leading to an overall structural resilience evaluation framework in line with BNBC 2020. Using analytical modeling and code-based design parameters, the research explores the response of SMRFs against seismic loading conditions for different hazard intensities. The analysis shows that SMRFs outperform in controlling drift, reducing story displacement, and enhancing stability among other framing systems; however, the advantage is not without added reinforcement and construction costs.

Beyond the technical findings, the results point to the larger relevance of BNBC 2020 to resilient urban infrastructure. The focus of the code on performance evaluation makes seismic safety a matter not only of compliance but also of long-term viability in earthquake-prone areas. By combining the aspects of drift, deflection, base shear, and story shift in one evaluation, this study offers a decision-making tool that designers, contractors, and regulators can use practically. The results have shown that SMRFs are quite indispensable in high-risk seismic zones, offering the most reliable protection against earthquake-induced damage, despite their economic demands. This dichotomy of structural performance and cost consideration reflects the realities of construction practices in Bangladesh, where resource limitations often drive design decisions. The contribution of this study lies in aligning the state of engineering practice with standards set by BNBC 2020 and further emphasizes the need to embrace the use of SMRFs as a way of balancing safety, efficiency, and sustainability in the rapidly growing urban infrastructure of Bangladesh.

TABLE OF CONTENT

ABSTRACT.....	vii
LIST OF FIGURES	ix
LIST OF TABLES	x
CHAPTER 1	1
1.1 Background and Motivations	1
1.2 Research Objectives and Overview	2
1.3 Organization of the thesis	3
CHAPTER 2	6
2.1 Introduction	6
2.2 Content	8
2.2.1 Seismic Behavior of OMRF & SMRF Buildings Under BNBC 2020	8
2.2.2 Story Drift and Story Shift Behavior in RC OMRFs & SMRFs	8
2.2.3 Base Shear and Deflection Response of OMRFs & SMRFs	9
2.3 Summary.....	10
CHAPTER 3	11
3.1 Introduction	11
3.2 Methodology Overview	11
3.2.1 Study Area	11
3.2.2 Data Collection	13
3.2.3 Material details	13
3.2.4 Buildings Structural Design and Details.....	14
3.2.5 Data Analyzing Method.....	16
3.3 Lateral Loads	18
3.4 Summary.....	19
CHAPTER 4	20
4.1 Introduction	20
4.2 Drift Results.....	20
4.2.1 Max Displacement	26
4.2.2 Base Reactions	31
4.2.3 Discussion of the Found Result	33
4.3 Summary.....	34
CHAPTER 5	35
5.1 Conclusions	35
5.2 Limitations and Recommendations for Future Works	35
REFERENCES	37

LIST OF FIGURES

Figure 3-1. Seismic zone of Bangladesh.....	12
Figure 3-2. Methodology of Data Collection.....	13
Figure 3-3. Column Details.....	14
Figure 3-4. Grade Beam and Floor Beam Details.....	15
Figure 3-5. Undeformed Shape of the Model.	15
Figure 3-6. Typical Floor Plan (Columns).....	16
Figure 3-7. Beam Layout Plan.	16
Figure 4-1. Story Drift OMRF Seismic Zone 1.	21
Figure 4-2. Story Drift OMRF Seismic Zone 2.	21
Figure 4-3. Story Drift OMRF Seismic Zone 3.	22
Figure 4-4. Story Drift OMRF Seismic Zone 4.	22
Figure 4-5. Story Drift SMRF Seismic Zone 1.....	23
Figure 4-6. Story Drift SMRF Seismic Zone 2.....	24
Figure 4-7. Story Drift SMRF Seismic Zone 3.....	24
Figure 4-8. Story Drift SMRF Seismic Zone 4.....	25
Figure 4-9. Maximum Drift of OMRF and SMRF system.	25
Figure 4-10. Maximum Displacement of OMRF and SMRF System.	30
Figure 4-11. Deformed Shape of Structure.....	31
Figure 4-12. Base Shear Differences Between OMRF & SMRF.	32

LIST OF TABLES

Table 3-1: Type of Concrete.	13
Table 3-2. Types of Rebar.	14
Table 3-3. Column Dimensions and reinforcements (Tie bars are 10mm bars).	14
Table 3-4. Load combination for Seismic Zone.	17
Table 3-5 Earthquake lateral load details.....	18
Table 4-1. Drift results for each story in each seismic category (OMRF).....	20
Table 4-2. Drift results for each story in each seismic category (SMRF)	23
Table 4-3. Displacement results for each story in each seismic category (OMRF)	26
Table 4-4. Displacement results for each story in each seismic category (SMRF)	26
Table 4-5. Base Shear & Reaction (OMRF).....	31
Table 4-6. Base Shear & Reaction (SMRF).....	32

CHAPTER 1

INTRODUCTION

1.1 Background and Motivations

Bangladesh is situated in a complex and seismically active area, shaped by the meeting of major tectonic systems like the northern Himalayan arc, the Dauki fault system, and the eastern Indo-Burman (Burma) arc. This makes the country particularly susceptible to earthquakes. Historical records and geological studies have shown that strong earthquakes can and do happen in this region, posing a significant threat, especially to densely populated urban areas. To address this risk, the latest update to the national building standard BNBC 2020 has made revisions to seismic design guidelines, promoting the use of more flexible and resilient structural systems, such as Special Moment Resisting Frames (SMRFs). Under the BNBC 2020 guidelines, reinforced concrete (RC) moment-resisting frames are categorized based on their ductility and detailing levels, such as ordinary, intermediate, and special. OMRFs are those frames which have minimal seismic detailing and limited ductility. As per BNBC 2020, they are usually allowed only in low seismic hazard zones or for structures with lower importance levels. High-ductility special moment-resisting frames (SMRFs) are assigned a greater “response reduction factor,” which indicates their ability to handle inelastic deformation and absorb seismic energy. On the other hand, OMRFs have a much lower response reduction factor to reflect their limited capability of dissipating seismic energy by inelastic behavior. This means that incorporating SMRFs can greatly boost the structural resilience of buildings in Bangladesh’s seismic zones, particularly in areas with high or moderate hazard levels, provided that proper detailing is used. However, it’s crucial to thoroughly evaluate how SMRFs and RC frames in general perform under seismic loads, especially when comparing the seismic vulnerability of commonly used gravity, designed OMRF buildings to code, compliant SMRF systems considering local soil conditions, site effects, and realistic dynamic demands, using up-to-date analysis tools.

In recent years, a number of studies have started to illuminate how reinforced concrete (RC) frames, including special moment-resisting frames (SMRFs), respond to earthquake loads, particularly in settings similar to Bangladesh. For example, a nonlinear time-history analysis focused on RC special moment frames in accordance with the Bangladesh National Building Code (BNBC) revealed that these frames can meet both serviceability and safety standards in high-hazard areas.

This cost increase is often the reason for the practice of OMRF systems still being in use, although their seismic vulnerabilities are known, mainly in developing urban regions like Bangladesh. The requirements for some members that are designed for Special Moment Resisting Frames (SMRF) can be made terribly complicated by the irregular building forms, such as re-entrant corners. These problems, if not handled cautiously, might greatly affect the anticipated performance. The global research supports the use of dampers or fiber-reinforced concrete, but there are still no local studies, especially regarding the specific seismic and soil conditions of Bangladesh.

With the rapid urban expansion happening in Bangladesh, the increasing number of mid-to high-rise reinforced concrete buildings, and the notable seismic risks in the region, it's evident that we need to thoroughly assess how Special Moment Resisting Frames (SMRF) perform under local conditions. This assessment should also critically compare SMRF behavior with the performance of existing OMRF buildings that dominate the current building stock. This assessment should include compliance with the BNBC 2020 code, realistic dynamic analyses, consideration of soil-structure interactions, addressing any plan irregularities, and a focus on practical construction details. This paper seeks to contribute to that evaluation by examining capacity-design principles, the demands for structural ductility, lateral response parameters, and practical constraints. Ultimately, it will assess how effectively SMRF can bolster the seismic resilience of urban infrastructure in Bangladesh when implemented correctly.

1.2 Research Objectives and Overview

The seismic performance of Ordinary Moment Resisting Frames (OMRFs) and Special Moment Resisting Frames (SMRFs), which are BNBC 2020, was analyzed in this research. The selection criterion was the capacity to resist lateral earthquake loads and the drifts demanded in the four seismic zones of Bangladesh. These zones are located in a tectonically very active region that is under the influence of the Himalayan arc, the Dauki Fault, and the Indo-Burman ranges. The study employs ETABS and performs advanced dynamic analysis that includes both response spectrum and nonlinear time-history methods to compare the essential parameters such as story drift, base shear, displacement patterns, and ductility capacity between OMRFs and SMRFs. The research discusses in detail how BNBC 2020's more rigorous seismic coefficients, detailing rules, and lower drift limits affect the relative performance between OMRFs and SMRFs, particularly in cases of irregularly shaped buildings

where re-entrant corners lead to increased torsional effects, bending moments, and energy dissipation demands. It is found that although OMRFs provide simplicity and low cost, the results indicate that the higher ductility of SMRFs, along with the strict detailing, makes them more capable of compliance with the demanding requirements of the updated code. Besides, the research investigates the possible impact of damping devices and advanced materials like HF-SHFRC on SMRF performance improvement in the context of Indonesian soil and seismic conditions, although local evidence is still scarce. The comparative analysis thus opens up the question of whether the latter offers a more resilient answer than the former when it comes to seismic safety under BNBC 2020.

According to our procedure of work and looking at previous studies our main goal of this study is,

- To compare the seismic performance of OMRFs and SMRFs designed according to BNBC 2020, focusing on drift limits, base shear, displacement patterns, and ductility capacity across Bangladesh's seismic zones.
- To compare the overall strength and stability of OMRFs and SMRFs when designed according to BNBC 2020.
- To check whether both frame types can safely resist earthquake forces within the seismic zones of Bangladesh.

1.3 Organization of the thesis

Chapter 1: Introduction and Objective

This paper presents a comparative study between OMRF and SMRF under BNBC 2020, for their earthquake-resistant capabilities in the seismic zones of Bangladesh. ETABS has been used for performing response spectrum and nonlinear time-history analysis. The main parameters studied are drift, base shear, displacement, and ductility. While it emerges that OMRFs are easier to design and economical, the SMRFs, which have higher ductility and more rigorous detailing, can perform well under the highly demanding requirements of BNBC 2020, in particular for irregular buildings, making them the resilient choice for seismic safety.

Chapter 2: Literature Review

It is stated in this study that seismically safe structural systems under the BNBC 2020 code, SMRFs offer better safety than OMRFs. The former class of systems, with stringent detailing and ductility, exhibits superior management of story drift, base shear, and deflection while the latter class remains cost-effective and simple but less resistant. As a whole, BNBC 2020's more stringent regulations crown SMRFs as the most trustworthy choice for earthquake resistance in Bangladesh's seismic zones.

Chapter 3: Methodology

The building was fully modeled in ETABS 22 after finalizing the architectural plan, with all structural elements defined using BNBC 2020-compliant materials and sections. Seismic loads were assigned following BNBC 2020 provisions based on modified ASCE 7-05 guidelines. Four models representing Bangladesh's seismic Zones I-IV were analyzed to evaluate story drift, base shear, modal behavior, and overall seismic performance.

Chapter 4: Results and Discussion

The results demonstrate that the drift and displacement increase from Zone 1 to Zone 4 for the given zones, with the most affected being Stories 1-2. SMRFs always perform better than OMRFs with lower drift, lower displacement, and better torsion control results, whereas the results for OMRFs are higher in all zones. The base shear for the two systems increases with the intensity of the seismic zones but within the limits of the BNBC 2020. SMRFs are advised for use in high-risk zones for critical projects and OMRFs for low seismic zones only.

Chapter 5: Conclusions and Future Work

The study concludes that the OMRF and SMRF systems both lie within the drift limits provided by BNBC 2020 and can be considered safe, but the SMRFs consistently yielded lower drift, displacement, and torsional effects along with more balanced base shear responses. Therefore, SMRFs have emerged as a more reliable system, particularly in Seismic Zones 3 and 4. Limitations include the need for advanced nonlinear time-history studies, considering the interaction of soil and structure, and including vertical seismic components in analyses. Future work should attempt retrofit techniques for OMRFs, perform comparative cost-benefit

studies, validate the results with experimental data, and provide recommendations toward updating BNBC to adopt performance-based design approaches for increased resilience.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Bangladesh is, to say the least, a very complicated place when it comes to its geological location. The country is located exactly at the point where the Himalayan arc, the Dauki fault, and the Indo-Burman subduction zone come together. However, buildings with soft-story designs or those that were only intended to support gravity loads struggled significantly when faced with strong seismic forces. The majority of these gravity, load, designed buildings are almost like OMRFs, which do not have the ductile detailing necessary to endure strong earthquake, induced deformations, thus leading to premature failure mechanisms[1]. For instance, a nonlinear time-history analysis study applied to RC special moment frames based on BNBC showed that such frames in high-hazard zones can meet serviceability and safety criteria, but buildings with soft-story configurations or designed only for gravity loads performed poorly under strong seismic demand[2]. An intriguing research project was undertaken to study the behavior of multi-story reinforced concrete buildings during earthquakes with a particular focus on the “re-entrant corners” type of architecture which poses more challenges to traditional design methods. The investigation centered on a new proposal that the seismic forces acting on the building could be reduced by selecting an appropriate design in addition to adherence to existing codes of practice. The methods of equivalent static analysis (ESA) and response spectrum analysis (RSA) were accordingly employed as per the BNBC 2020 specified procedure. The outcome of the study astonished the researchers: the beams and columns situated around the re-entrant corners showed to take the largest portion of bending moments, torsion, and axial forces. Such occurrences of force concentration are critical, especially in OMRF systems, where lack of confinement and joint detailing may result in brittle failure under combined axial and torsional demands[3]. This fact completely puts in the foreground the role of the architectural design and consequently the fate of the building as far as seismic safety is concerned[4]. Researchers have taken a close look at the seismic design guidelines of the BNBC, including its earlier versions, and compared them with various international codes. Their comparative study revealed that the BNBC sets different design forces and ductility expectations compared to codes used in other regions. This highlights both the strengths and limitations of using BNBC-based designs in areas that are prone to earthquakes[5]. Diving deeper into the seismic capacity of current RC frames, we find that

factors like ultimate concrete strain, ductility, and overstrength reveal a concerning truth: many of these frames have a limited ability to handle inelastic deformation and could be at risk during strong seismic events[6]. These limitations become especially significant in OMRFs, where the lack of capacity design principles and absence of special confinement reinforcement substantially lowers seismic reliability. The progress of SMRF systems is being substantially increased by continued research that is taking place worldwide. As an illustration, the work that was done on a 15-story reinforced concrete SMRF building fitted with wall dampers (VWDs) proved that these damping devices have a significant impact on energy dissipation and displacement control as compared to the conventional SMRF setups[7]. In addition, the new materials have had a great impact and boosting inelastic behavior and overall seismic performance of tall reinforced concrete special moment frame (RC SMRF) structures. One of the major examples is the highly flowable, strain-hardening fiber-reinforced concrete[8]. Such improvements are generally not possible for OMRF systems without fundamental changes in the detailing philosophy and the design approach.

The mentioned works give a common idea that if SMRF is properly planned, constructed, and perhaps even combined with materials or devices that enhance ductility and energy absorption, it could effectively be a scenario seismic-resilient in earthquake-prone areas. On the other hand, some challenges are still to be faced. The more stringent earthquake standards of the BNBC 2020 code drive up the base shear, increase the required lateral displacement, and reduce the drift limits, thus, in most cases, the increased material use or the costs for construction will be unavoidable[9]. Therefore, earthquakes are not only possible but also a genuine threat, and the small ones shouldn't be the only ones taken into account[10]. Recent research to indicate earthquakes that can be seen in history of the region also show that a lot of pressure is being built up on these active faults. This is a cautious signal and that means Bangladesh must have earthquake-resistant design standards that are very strict and cutting corners should be abolished. The urban population is increasing rapidly. You can find mid- and high-rise concrete buildings almost everywhere now. So, the question of whether all these new buildings can actually endure an earthquake of significant magnitude is not just an issue of another branch of engineering but the country's most significant problems of the present time.

The changes in local seismic rules in Bangladesh National Building Code (BNBC) over time show that there is a strong root awareness of the issue. BNBC 2020 has laid out the updated seismic zoning, higher base shear coefficients, more strict drift and reduction of the

changes in the ductile system especially SMRFs as well as the detailed requirements for changes in the ductile system. Comparative studies have indicated that these changes in BNBC 2020 make it more compatible with international standards such as ASCE 7-16, ACI 318-19, and Eurocode 8. Still, there are some differences in the reduction factors, load combinations, and detailing areas[11]. The role of SMRFs in the provision of a ductile seismic response is very important, however, they are based on capacity design principles and detailed instructions which ensure the support of inelastic deformation without failure[12]. The research of RC frames led to the conclusion that their behavior under seismic loading depends very much on the drift performance, force distribution inside the structure, and deflection demands which are easily solvable numerically by a tool such as ETABS. Investigations of local reinforced concrete buildings have disclosed that in the past there were common problems in the correctness of the detail, confinement and regularity of the frame and thus the performance under BNBC 2020 can only be properly evaluated by thorough analytical studies[13].

2.2 Content

2.2.1 Seismic Behavior of OMRF & SMRF Buildings Under BNBC 2020

Based on BNBC 2020, the main difference in the seismic response between Ordinary Moment Resisting Frames (OMRFs) and Special Moment Resisting Frames (SMRFs) lies in the significance given to ductility. BNBC 2020 strictly follows detailing requirements in the design of SMRFs to ensure that plastic hinge formation mainly occurs in beams, which should have enough overstrength in columns to avoid instability. As evidenced in recent research studies, the stable hysteretic curve and effective dissipation capacity of energy in generally better designs of SMRFs over OMRFs have always remained a critical advantage. But the more lenient design requirements in BNBC 2020, such as high detailing requirements in reinforcement and low drift limits, though improving safety, increase construction costs. In ETABS analysis, it has been observed that the design following BNBC 2020 allows better control in deformation, improved resilience, but the sensitivity in designs is a major setback for SMRFs. Whereas in OMRFs, the designs seem less complex but lacks sufficient ductility and energy, which are necessarily required to meet new seismic design requirements.

2.2.2 Story Drift and Story Shift Behavior in RC OMRFs & SMRFs

In seismic analysis, story drift ratio represents an important aspect because excessive lateral displacement might cause damages in non-structural elements and potentially result in structural failure. In fact, response spectrum and nonlinear static analysis reveal that RC frames

with low stiffness and/or low or no ductility capacity are likely to suffer severe top or bottom story drift. Story shift, which can be considered as the large difference in displacement between adjacent stories, can be clearly visible in OMRF or SMRF structures with irregular displacement patterns or fragmented column sizes. In order to minimize such problems, more rigid drift constraints are adopted by BNBC 2020, typically 0.02 for SMRFs, while solutions such as ETABS can quantify displacement and story drift in a more accurate manner in both static and dynamic conditions. Studies show that those that surpass drift values may suffer increased beam and column demands and be potentially susceptible to soft story failures. In fact, analytical results further reinforce that stiffer columns, regular bay spacing, and the strong-column-weak-beam concept are efficient designs that can reduce story drift and story shift, ultimately upgrading the seismic performance in OMRF and SMRF.

2.2.3 Base Shear and Deflection Response of OMRFs & SMRFs

Base shear is defined as the total lateral force a structure needs to resist during seismic ground shaking, and under BNBC 2020 the requirement is stricter than in BNBC 1993 or the 2006 draft because of the new hazard values. Studies with ETABS have shown that SMRF buildings according to BNBC 2020 usually have moderate to high base shear compared to such international codes as ASCE 7, though variations depend on the soil type and seismic zone factors. On the other hand, OMRF buildings are less concentrated on base shear and ductility owing to their simpler design and less reinforcement requirements, thus, they are more prone to exceed drift limits and to develop soft-story mechanisms as a result of strong earthquakes. In the investigation of deflection response roof displacement is considered as the main indicator of global flexibility. According to one of the studies, the SMRFs report the uniform deflection pattern to a greater extent, thus, when more mass and stiffness are evenly distributed, they are the ones that can show the least deflection, while on the contrary, the OMRFs are more vulnerable to irregular deflection behavior mainly through the buildings with re-entrant corners or having non-uniform stiffness distribution. The ETABS analyses through Equivalent Static Analysis (ESA), Response Spectrum Analysis (RSA), and nonlinear pushover methods have proven that the OMRFs often reach the higher displacement demand earlier, while SMRFs keep better control over lateral drift and deflection. These outcomes are very important in recognizing performance levels such as Immediate Occupancy (IO) and Life Safety (LS), hence SMRFs usually getting safer margins under BNBC 2020 when compared to OMRFs.

2.3 Summary

BNBC 2020 gives a lot of weight to ductile performance thus mandating stricter detailing for SMRFs so that plastic hinges develop in beams while columns get overstrength. Studies indicate that when SMRFs have the right detailing, they present stable hysteretic behavior and energy dissipation that is excellent compared to OMRFs, though at a cost of higher reinforcement and construction. Concerning story drift and story shift, SMRFs are favored by BNBC 2020's stricter drift limits (≈ 0.02 of story height), which not only help in controlling but also reducing soft-story mechanisms through the application of drift limits. OMRFs, due to their lower stiffness and lack of ductility, are more susceptible to drifting and displacement patterns that are non-uniform, especially in buildings with re-entrant corners or uneven stiffness distribution. The design base shear that BNBC 2020 requires is higher than that which was specified by previous codes as a consequence of which moderate to high values depending on soil and zone factors are realized. Under uniform mass and stiffness distribution, SMRFs typically yield uniform deflection patterns while opposite is the case for OMRFs who tend to have larger displacements and irregular drift making them less trustworthy in terms of strong seismic loads. To sum it up, the comparison analyses have been able to draw a line between an easier and cheaper solution on one hand that is represented by OMRFs and on the other hand a solution that is more robust and in tune with BNBC 2020's strict seismic safety requirements that is represented by SMRFs.

CHAPTER 3

METHODOLOGY

3.1 Introduction

A new-model reinforced concrete OMRF and SMRF system building was created and analyzed fully according to the seismic requirements of BNBC 2020 for this research. To make sure that the building truly reflected irregularities, the slabs were chosen to have non-uniform dimensions, the columns and beams were sized differently, and the grid layout was made irregular. Generally, regular buildings have uniform load transfer and exhibit more predictable seismic behavior; thus, the use of an irregular configuration enables the study to bring out possible irregularities and weak points of the structure that might recourse from the seismic event in the real world. This method makes it easier to see the concentration of drift, story shift, and stiffness variation, among other things, on which the structural elements depend. The structural analysis has been done through CSI ETABS 22, and BNBC 2020 requirements have been implemented for four seismic zones with soil type SC to understand the building's behavior at different hazard levels.

The key response parameters to which the attention of the researchers was principally drawn are story drift, story shift, base shear, and deflection which has been obtained through Response Spectrum Analysis based on the fundamental time period specified by the code. The performance evaluation that follows is based on the findings from these analyses.

3.2 Methodology Overview

3.2.1 Study Area

The building is 43ft (13.1m) tall with five stories (includes stair room roof as one story), each floor is 10ft (3.048m) tall and the foundation is 5ft (1.524m) from the foundation base. The soil type is SC.

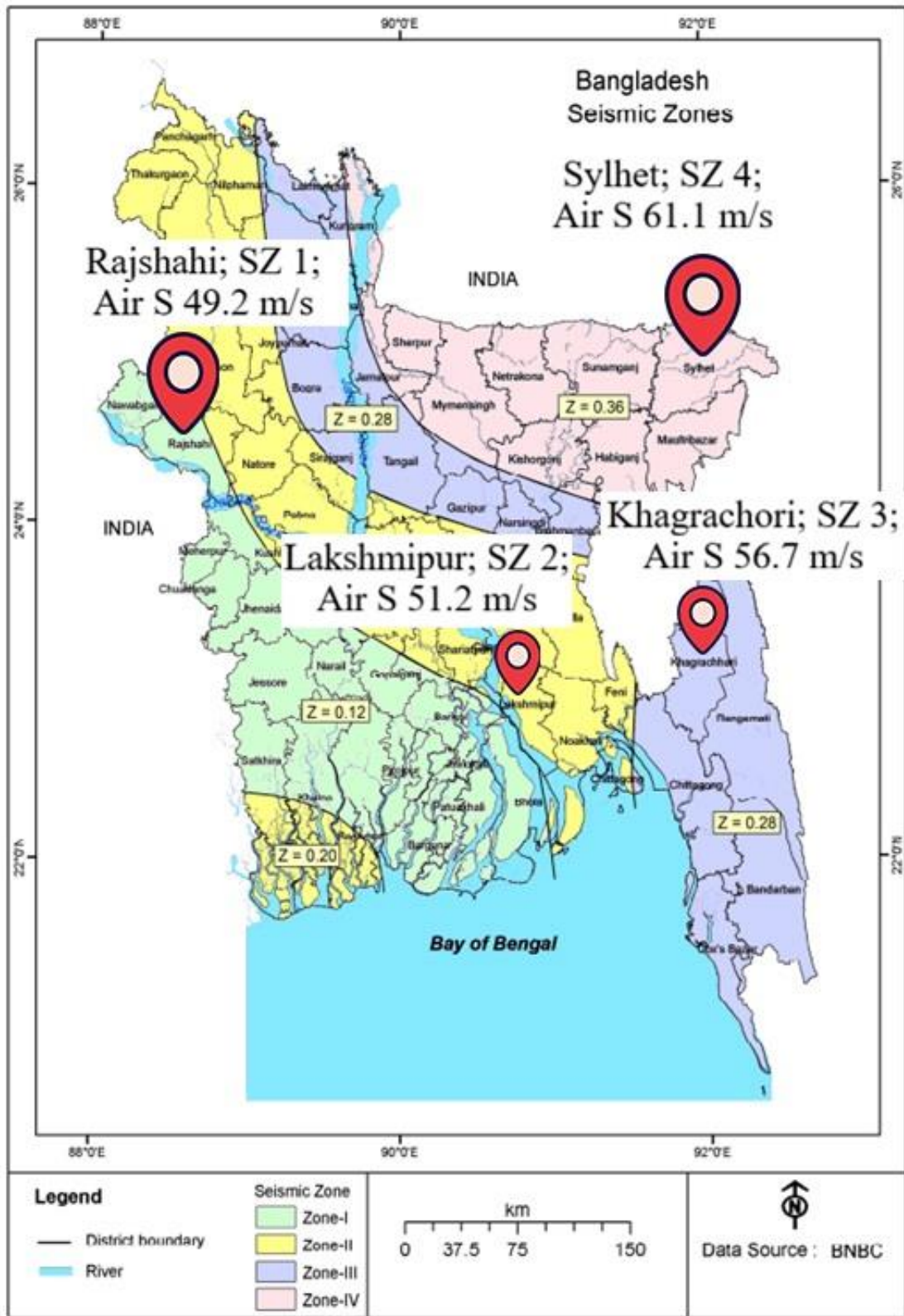


Figure 3-1. Seismic zone of Bangladesh

3.2.2 Data Collection

The data collection method consists of 5 steps work.

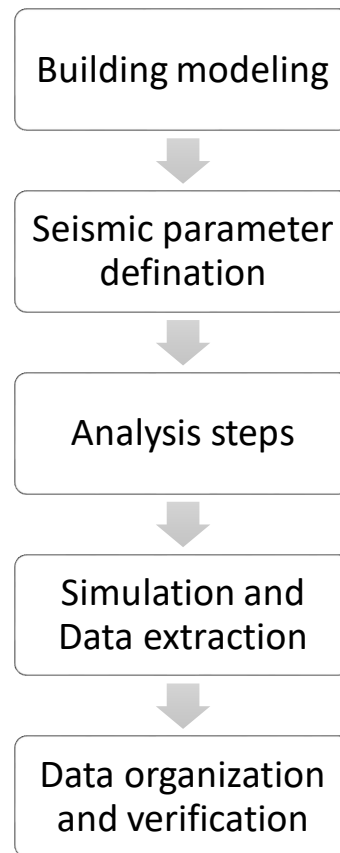


Figure 3-2. Methodology of Data Collection.

3.2.3 Material details

Materials used in this model was according to BNBC 2020. The material properties used in this building are,

Table 3-1: Type of Concrete.

Type of concrete	Compression Strength (psi)
Column Concrete	3500
Slab Concrete	2500
Beam Concrete	3500

- Weight density of all concrete is 150 lb./ft³

Table 3-2. Types of Rebar.

Type of Rebar	Tensile Strength (ksi)	Modules of elasticity (lb./in ²)	Minimum yield strength (ksi)	Minimum tensile strength (ksi)	Avg. yield strength (ksi)	Avg. tensile strength (ksi)
Main Rebar	72.5	29000000	60.000	90.000	66.000	99.000
Tie rebar	72.5	29000000	60.000	90.000	66.000	99.000
Rebar for stair	60	29000000	60.000	90.000	66.000	99.000

- Weight density of all rebar is 490 lb./ft³

3.2.4 Buildings Structural Design and Details

Table 3-3. Column Dimensions and reinforcements (Tie bars are 10mm bars).

Column Name	Column Dimensions and reinforcements	
	Base/Pile Column	G.F to 2 nd Floor Column
C1	14"x14" (6-16 MM)	12" X 12" (6-16 MM)
C2	14"x14" (8-16 MM)	12" X 12" (8-16 MM)

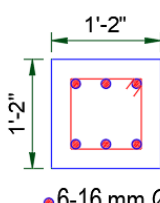
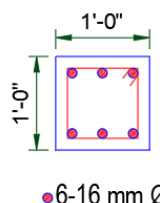
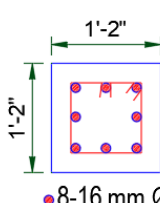
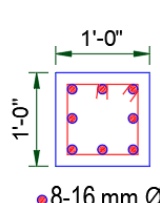
NAME OF COLUMN	UP TO PLINTH	PLINTH TO ABOVE	Tie Spacing
C1	 <p>1'-2" 1'-2" ● 6-16 mm Ø</p>	 <p>1'-0" 1'-0" ● 6-16 mm Ø</p>	<p>Lo=20" a=10mm@5" c/c b=10mm@8" c/c At Lapping Zone=10mm@5" c/c</p>
C2	 <p>1'-2" 1'-2" ● 8-16 mm Ø</p>	 <p>1'-0" 1'-0" ● 8-16 mm Ø</p>	<p>Lo=20" a=10mm@5" c/c b=10mm@8" c/c At Lapping Zone=10mm@5" c/c</p>

Figure 3-3. Column Details.

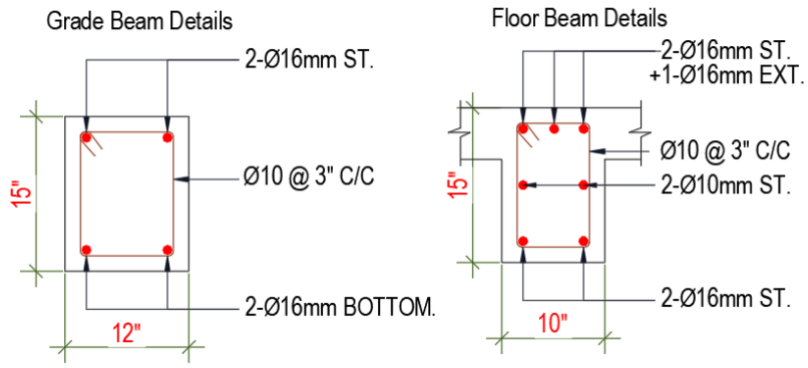


Figure 3-4. Grade Beam and Floor Beam Details.

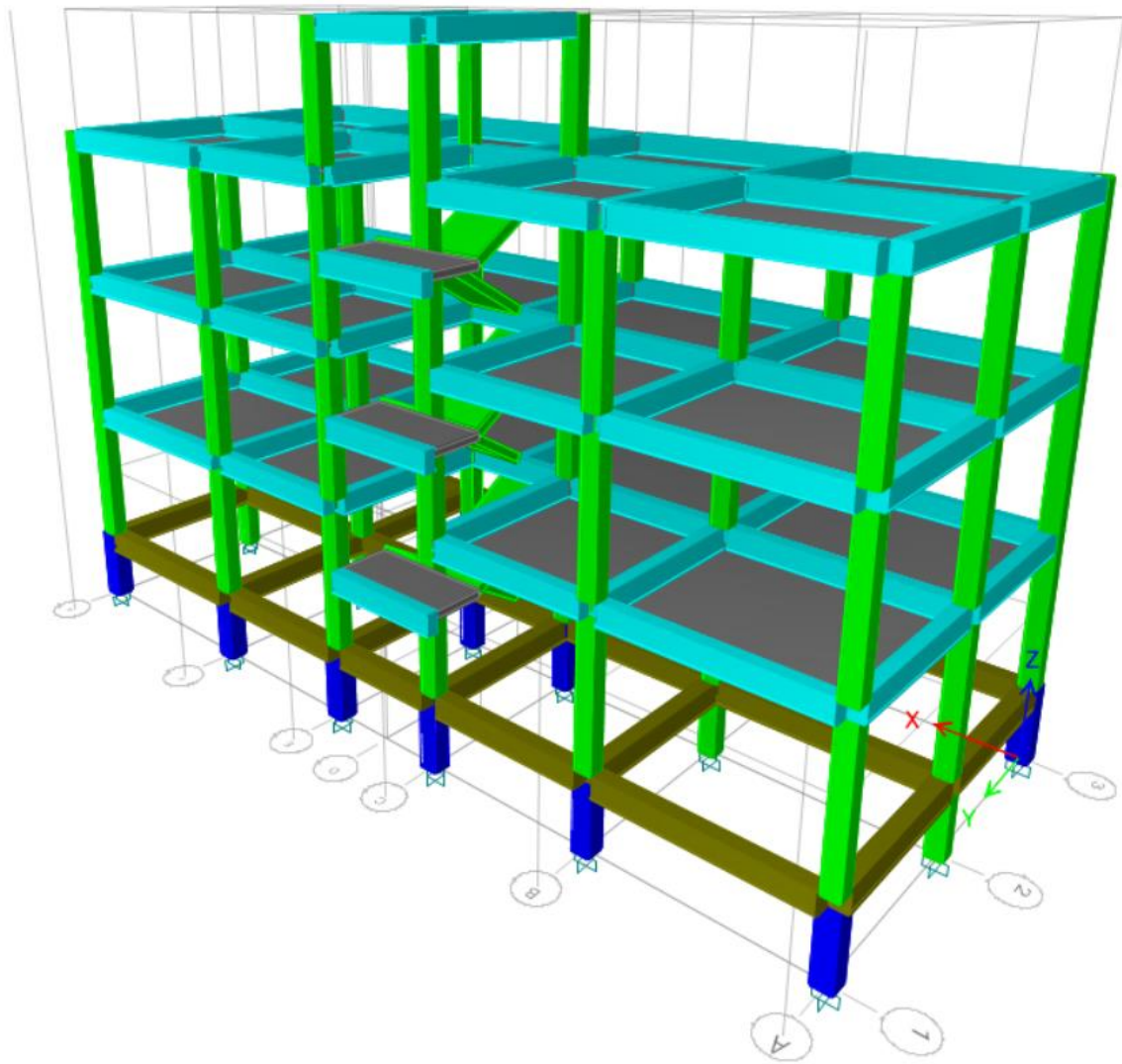


Figure 3-5. Undeformed Shape of the Model.

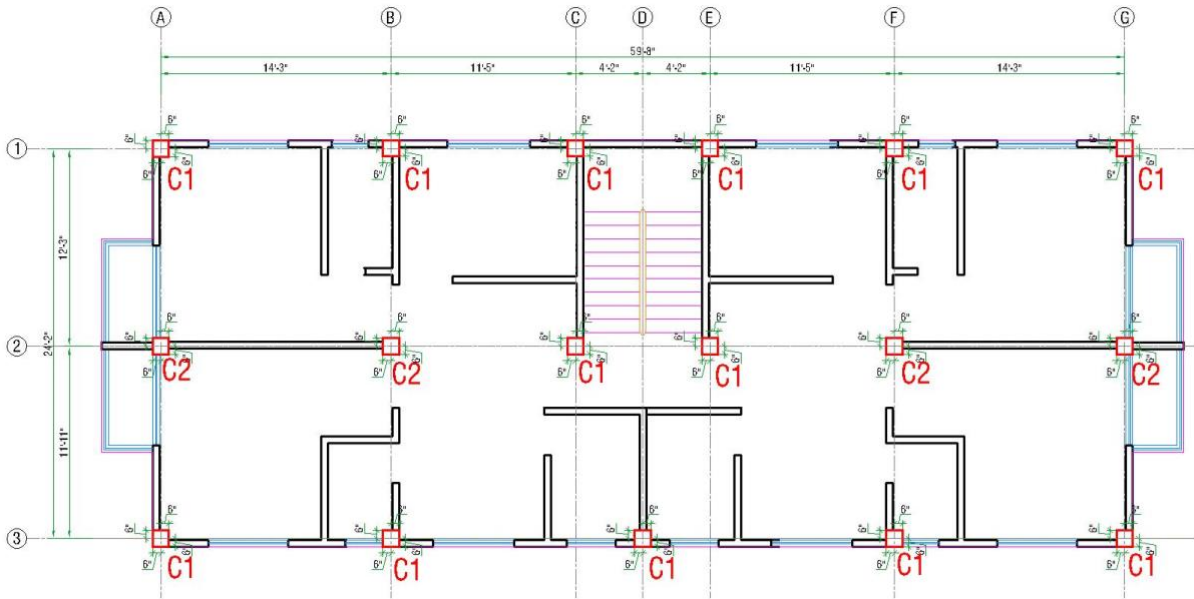


Figure 3-6. Typical Floor Plan (Columns).

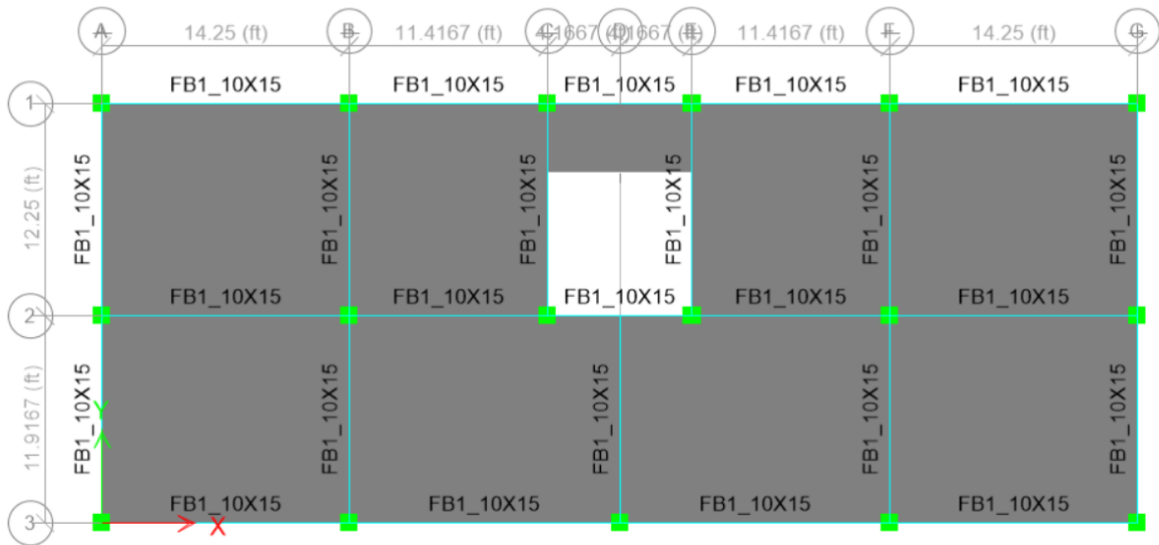


Figure 3-7. Beam Layout Plan.

3.2.5 Data Analyzing Method

Implementing all the data needed on ETABS-22 we analyzed the building according to BNBC 2020 load combinations. The soil type considered for this design was SC (Soil type C). We analyzed the building for all seismic zone 1, 2, 3, 4. All the load combinations are.

Table 3-4. Load combination for Seismic Zone.

Seismic Zone 1 (Rajshahi, Wind Speed= 49.2 m/s)			
(1) 1.4D	(7) 1.2D+1.6Lr 0.8Wy	(13) 1.2D - Ex + L	(19) 0.9D - 1.6Wy
(2) 1.2D+1.6L+0.5Lr	(8) 1.2D+1.6Wx+L+ 0.5Lr	(14) 1.2D + Ey +L	(20) 0.9D + Ex
(3) 1.2D+1.6Lr+L	(9) 1.2D -1.6Wx+L+ 0.5Lr	(15) 1.2D - Ey + L	(21) 0.9D - Ex
(4) 1.2D+1.6Lr+ 0.8Wx	(10) 1.2D+1.6Wy+L+ 0.5Lr	(16) 0.9D + 1.6Wx	(22) 0.9D + Ey
(5) 1.2D+1.6Lr- 0.8Wx	(11) 1.2D-1.6Wy+L+ 0.5Lr	(17) 0.9D - 1.6Wx	(23) 0.9D - Ey
(6) 1.2D+1.6Lr+ 0.8Wy	(12) 1.2D+Ex+L	(18) 0.9D + 1.6Wy	(24) Envelope
Seismic Zone 2 (Lakshmipur, Wind Speed= 51.2 m/s)			
(1) 1.4D	(7) 1.2D+1.6Lr-0.8Wy	(13) 1.2D - Ex + L	(19) 0.9D - 1.6Wy
(2) 1.2D+1.6L+0.5Lr	(8) 1.2D+1.6Wx+L+ 0.5Lr	(14) 1.2D + Ey +L	(20) 0.9D + Ex
(3) 1.2D+1.6Lr+L	(9) 1.2D -1.6Wx+L+ 0.5Lr	(15) 1.2D - Ey + L	(21) 0.9D - Ex
(4) 1.2D+1.6Lr+ 0.8Wx	(10) 1.2D+1.6Wy+L+ 0.5Lr	(16) 0.9D + 1.6Wx	(22) 0.9D + Ey
(5) 1.2D+1.6Lr- 0.8Wx	(11) 1.2D-1.6Wy+L+ 0.5Lr	(17) 0.9D - 1.6Wx	(23) 0.9D - Ey
(6) 1.2D+1.6Lr+ 0.8Wy	(12) 1.2D+Ex+L	(18) 0.9D + 1.6Wy	(24) Envelope
Seismic Zone 3 (Khagrachori, Wind Speed= 56.7 m/s)			
(1) 1.4D	(9) 1.2D- 1.6Wx+L+0.5Lr	(17) 1.3D + 0.3Ex - Ey + L	(25) 0.8D + Ex - 0.3Ey
(2) 1.2D+1.6L+0.5Lr	(10) 1.2D+1.6Wy+L+0.5Lr	(18) 1.3D - 0.3Ex + Ey + L	(26) 0.8D - Ex + 0.3Ey
(3) 1.2D+1.6Lr+L	(11) 1.2D- 1.6Wy+L+0.5Lr	(19) 1.3D - 0.3Ex - Ey + L	(27) 0.8D - Ex - 0.3Ey
(4) 1.2D+1.6Lr+0.8Wx	(12) 1.3D + Ex + 0.3Ey + L	(20) 0.9D+1.6Wx	(28) 0.8D + 0.3Ex + Ey
(5) 1.2D+1.6Lr- 0.8Wx	(13) 1.3D + Ex - 0.3Ey + L	(21) 0.9D-1.6Wx	(29) 0.8D + 0.3Ex - Ey
(6) 1.2D+1.6Lr+0.8Wy	(14) 1.3D - Ex + 0.3Ey + L	(22) 0.9D+1.6Wy	(30) 0.8D - 0.3Ex + Ey
(7) 1.2D+1.6Lr- 0.8Wy	(15) 1.3D - Ex - 0.3Ey + L	(23) 0.9D-1.6Wy	(31) 0.8D - 0.3Ex - Ey
(8) 1.2D+1.6Wx+L+0.5Lr	(16) 1.3D + 0.3Ex + Ey + L	(24) 0.8D + Ex + 0.3Ey	(32) Envelope

Seismic Zone 4 (Sylhet, Wind Speed= 61.1 m/s)			
(1) 1.4D	(9) 1.2D- 1.6W _x +L+0.5L _r	(17) 1.34D + 0.3Ex - Ey + L	(25) 0.85D + Ex - 0.3Ey
(2) 1.2D+1.6L+0.5L _r	(10) 1.2D+1.6W _y +L+0.5L _r	(18) 1.34D - 0.3Ex + Ey + L	(26) 0.85D - Ex + 0.3Ey
(3) 1.2D+1.6L _r +L	(11) 1.2D- 1.6W _y +L+0.5L _r	(19) 1.34D - 0.3Ex - Ey + L	(27) 0.85D - Ex - 0.3Ey
(4) 1.2D+1.6L _r +0.8W _x	(12) 1.34D + Ex + 0.3Ey + L	(20) 0.9D+1.6W _x	(28) 0.85D + 0.3Ex + Ey
(5) 1.2D+1.6L _r - 0.8W _x	(13) 1.34D + Ex - 0.3Ey + L	(21) 0.9D-1.6W _x	(29) 0.85D + 0.3Ex - Ey
(6) 1.2D+1.6L _r +0.8W _y	(14) 1.34D - Ex + 0.3Ey + L	(22) 0.9D+1.6W _y	(30) 0.85D - 0.3Ex + Ey
(7) 1.2D+1.6L _r - 0.8W _y	(15) 1.34D - Ex - 0.3Ey + L	(23) 0.9D-1.6W _y	(31) 0.85D - 0.3Ex - Ey
(8) 1.2D+1.6W _x +L+0.5L _r	(16) 1.34D + 0.3Ex + Ey + L	(24) 0.85D + Ex + 0.3Ey	(32) Envelope

- Note that envelope contains a sum of all the load combination of the specific seismic zone.

3.3 Lateral Loads

For lateral loads in ETABS ASCE 7-05 was used for wind loads and seismic loads. Which was defined by BNBC 2020 values.

Table 3-5 Earthquake lateral load details

	Seismic Zone 1	Seismic Zone 2	Seismic Zone 3	Seismic Zone 4
Time period, T	0.472	0.472	0.472	0.472
System Overstrength, Omega	3	3	3	3
Response Modification, R	8 For SMRF 3 For OMRF			
Deflection Amplification	5.5 For SMRF 2.5 For OMRF			
Occupancy Category	1	1	1	1
0.2s Spectral Accel S _s	0.3	0.5	0.7	0.9
1s Spectral Accel S ₁	0.12	0.20	0.28	0.36
Long transition period	2	2	2	2
F _a	1.15	1.15	1.15	1.15
F _v	1.725	1.725	1.725	1.725
SDS	0.23	0.3833	0.5367	0.69
SD1	0.138	0.23	0.322	0.414

3.4 Summary

After the architectural plan of the building was decided, the entire frame of the building the beams, the columns, the slabs, and the shear-resisting components were modeled and defined in ETABS 22, with the correct materials and section properties. The lateral load parameters were set according to the seismic provisions of BNBC 2020, which essentially adopts and modifies the ASCE 7-05 guidelines for the seismic load calculation. To cover the ground thoroughly, four different models were created to represent the four seismic zones of Bangladesh, each of them having the zone-specific seismic coefficients, response modification factors, importance factors, and soil profile conditions. After the gravity and lateral load cases had been defined in detail, the models were completed and taken through structural analysis to quantify story drift, base shear, mode shapes, and overall seismic performance as per BNBC 2020.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Comparative figures of the structural models developed depicted three essential seismic performance parameters-story drift, base shear, and member deflection-whose values were compared across zones. Their selection was mainly because they directly reflected the changes in structural response due to different seismic load factors. In the BNBC 2020 standard, four seismic zones of Bangladesh are assigned different seismic coefficients; hence, the number of lateral forces acting on the structure would vary in each zone. Comparing the said parameters in the four zones provides insight into how an increase in seismic intensity changes the building behavior in terms of lateral displacement patterns, internal force distribution, and deformation demand on structural members.

4.2 Drift Results

According to BNBC 2020 allowable drift is $0.005hx$ for wind and $0.025hx$ for earthquake. Taking the lowest value for safety which for this case is 0.095inch .

Table 4-1. Drift results for each story in each seismic category (OMRF).

	SEISMIC ZONE 1	SEISMIC ZONE 2	SEISMIC ZONE 3	SEISMIC ZONE 4
Story	Drift (in.)	Drift (in.)	Drift (in.)	Drift (in.)
Stair Room Roof	0.00238	0.002506	0.003025	0.00332
Typical Story 3	0.001644	0.001738	0.00235	0.00238
Typical Story 2	0.002104	0.002239	0.002997	0.003036
Typical Story 1	0.002453	0.002602	0.003462	0.003507
Plinth Level	0.000571	0.000661	0.000802	0.000813

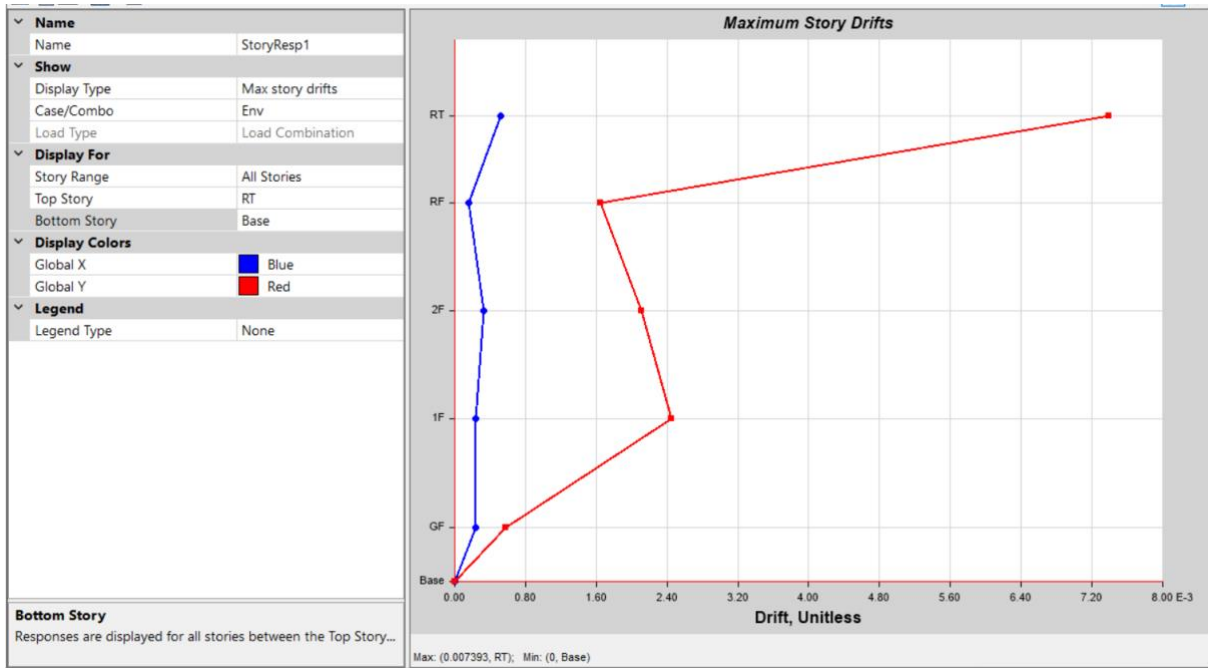


Figure 4-1. Story Drift OMRF Seismic Zone 1.

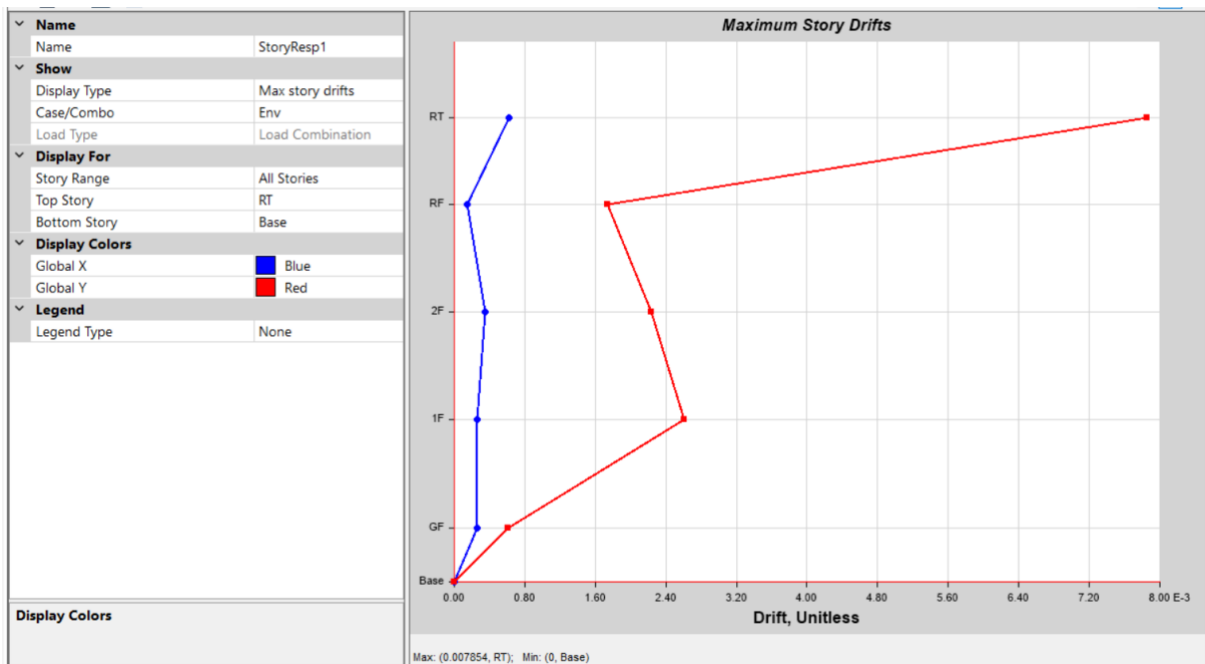


Figure 4-2. Story Drift OMRF Seismic Zone 2.

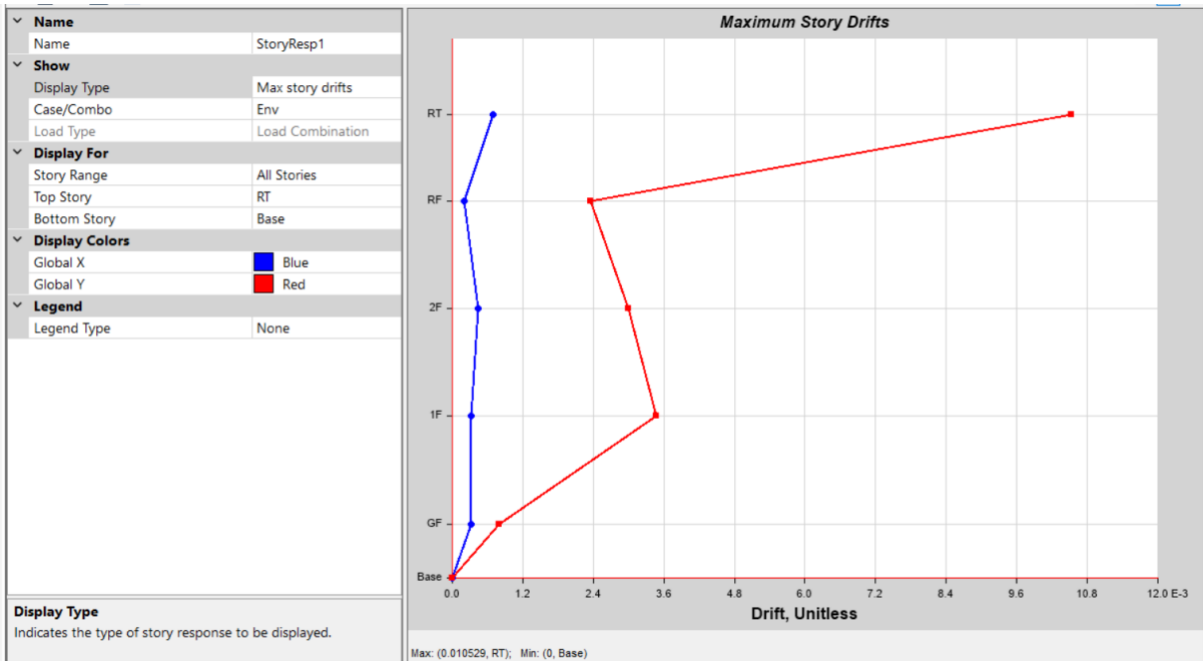


Figure 4-3. Story Drift OMRF Seismic Zone 3.

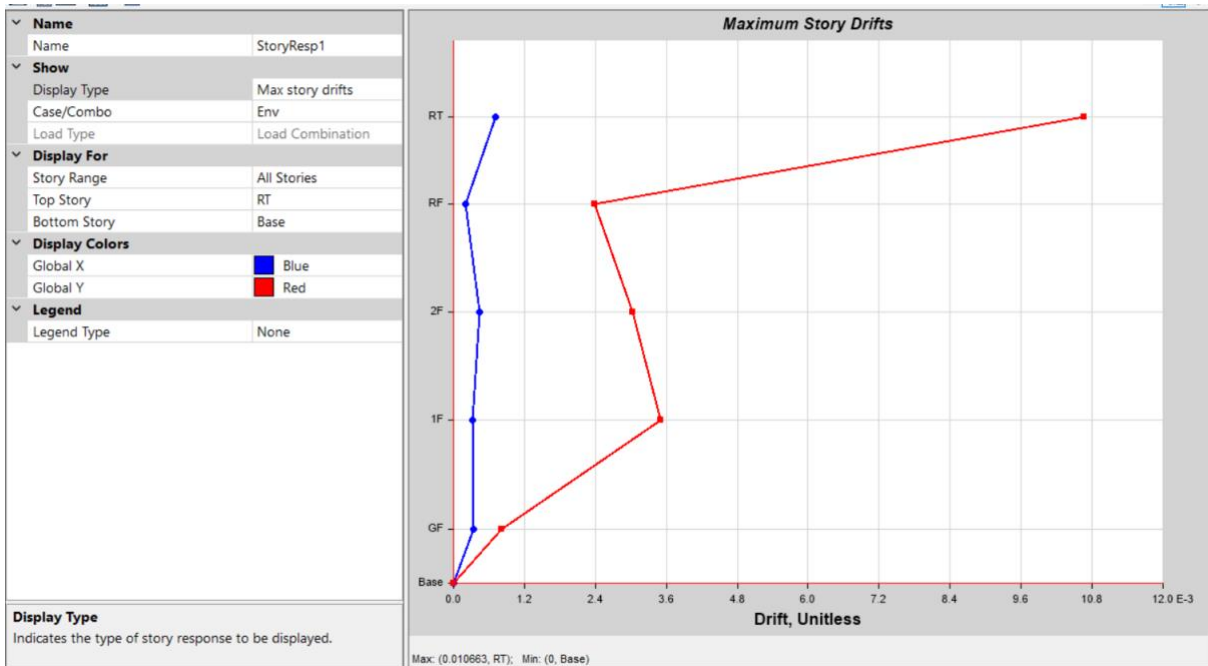


Figure 4-4. Story Drift OMRF Seismic Zone 4.

Table 4-2. Drift results for each story in each seismic category (SMRF)

	SEISMIC ZONE 1	SEISMIC ZONE 2	SEISMIC ZONE 3	SEISMIC ZONE 4
Story	Drift (in.)	Drift (in.)	Drift (in.)	Drift (in.)
Stair Room Roof	0.001942	0.002	0.002432	0.002522
Typical Story 3	0.001396	0.001486	0.001918	0.001942
Typical Story 2	0.001765	0.001886	0.002416	0.002247
Typical Story 1	0.002057	0.002195	0.002785	0.002821
Plinth Level	0.000486	0.000517	0.000658	0.000660

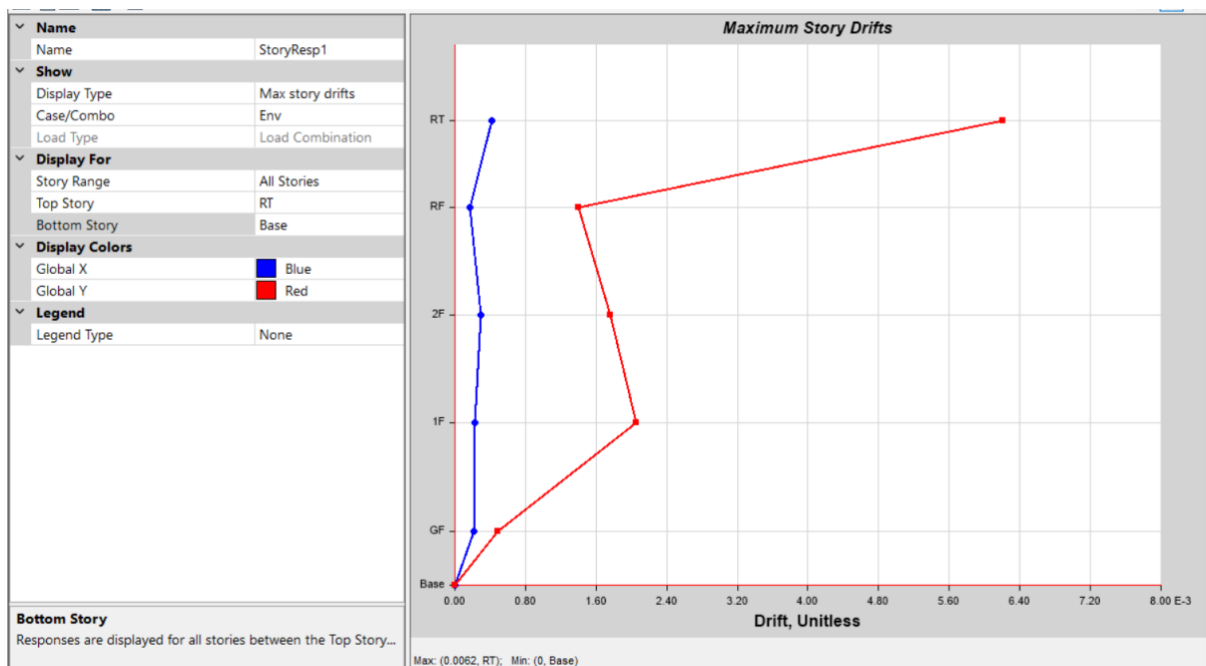


Figure 4-5. Story Drift SMRF Seismic Zone 1.

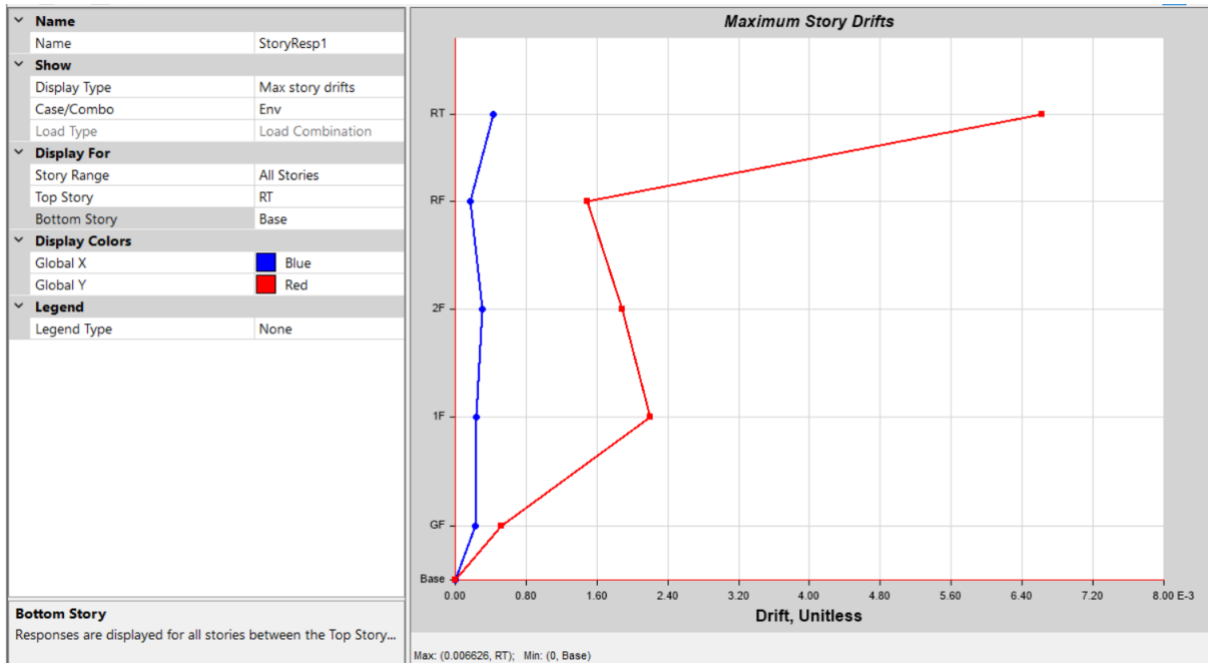


Figure 4-6. Story Drift SMRF Seismic Zone 2.

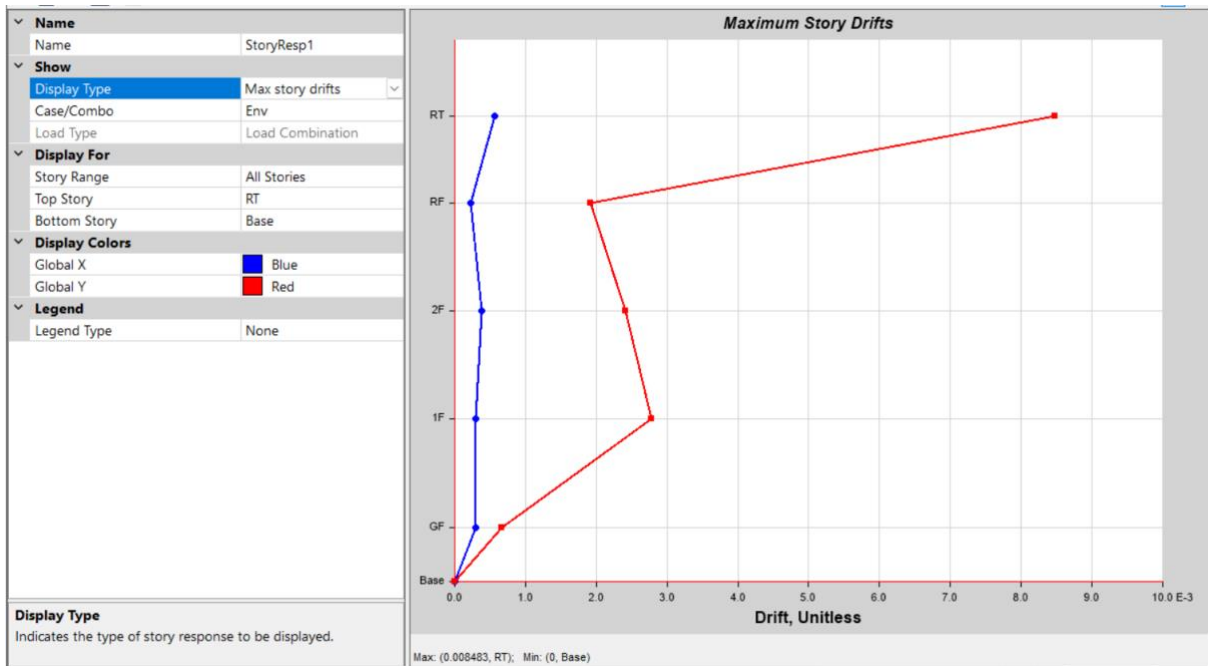


Figure 4-7. Story Drift SMRF Seismic Zone 3.

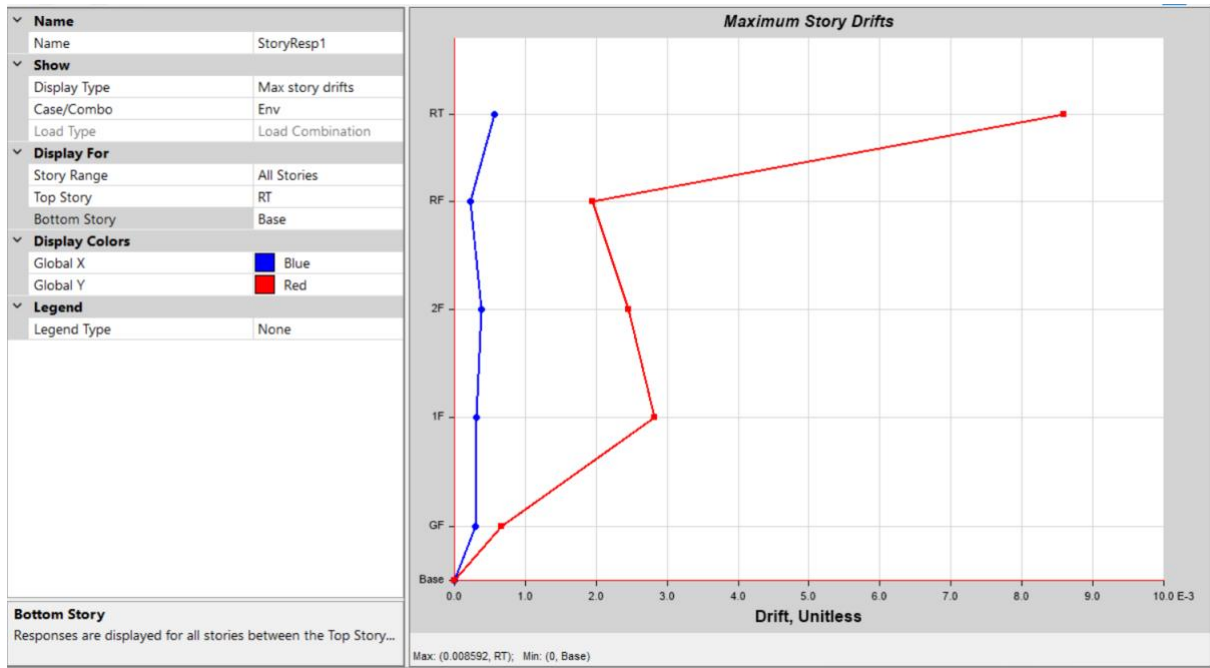


Figure 4-8. Story Drift SMRF Seismic Zone 4.

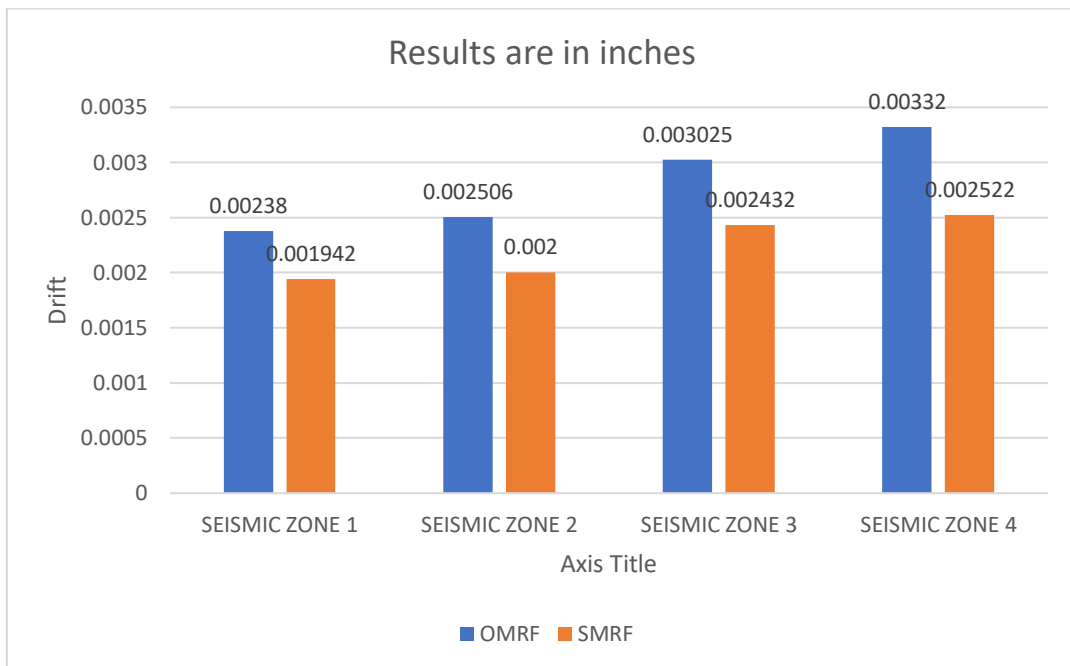


Figure 4-9. Maximum Drift of OMRF and SMRF system.

4.2.1 Max Displacement

According to BNBC max displacement value for a building is $0.02h_x$. According to that value allowable displacement of this building is 0.76inch.

Table 4-3. Displacement results for each story in each seismic category (OMRF)

	SEISMIC ZONE 1	SEISMIC ZONE 2	SEISMIC ZONE 3	SEISMIC ZONE 4
Story	Displacements (in.)	Displacements (in.)	Displacements (in.)	Displacements (in.)
Stair Room Roof	0.250863	0.267379	0.416369	0.466182
Typical Story 3	0.197334	0.208601	0.281999	0.28563
Typical Story 2	0.252535	0.268707	0.359649	0.364283
Typical Story 1	0.294386	0.312199	0.415429	0.420795
Plinth Level	0.034286	0.036685	0.048135	0.04876

Table 4-4. Displacement results for each story in each seismic category (SMRF)

	SEISMIC ZONE 1	SEISMIC ZONE 2	SEISMIC ZONE 3	SEISMIC ZONE 4
Story	Displacements (in.)	Displacements (in.)	Displacements (in.)	Displacements (in.)
Stair Room Roof	0.21815	0.250863	0.376157	0.376157
Typical Story 3	0.158007	0.167516	0.230108	0.233063
Typical Story 2	0.201172	0.211808	0.28991	0.293684
Typical Story 1	0.216530	0.246795	0.334208	0.338492
Plinth Level	0.029182	0.029182	0.039467	0.039985

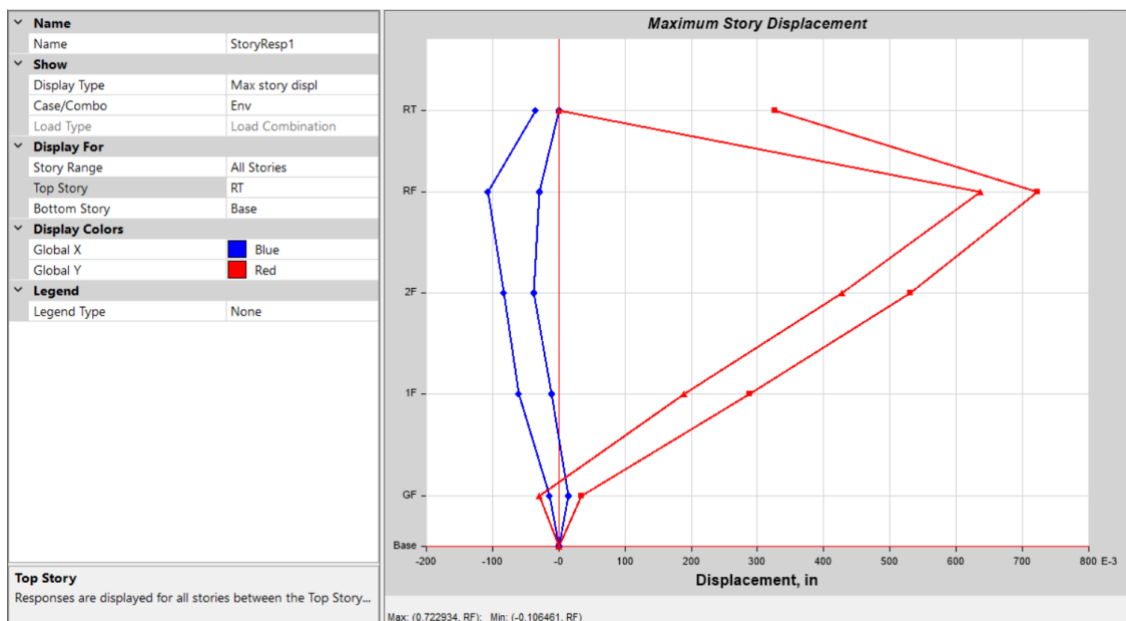


Figure 4-10. Story Displacement OMRF Seismic Zone 1.

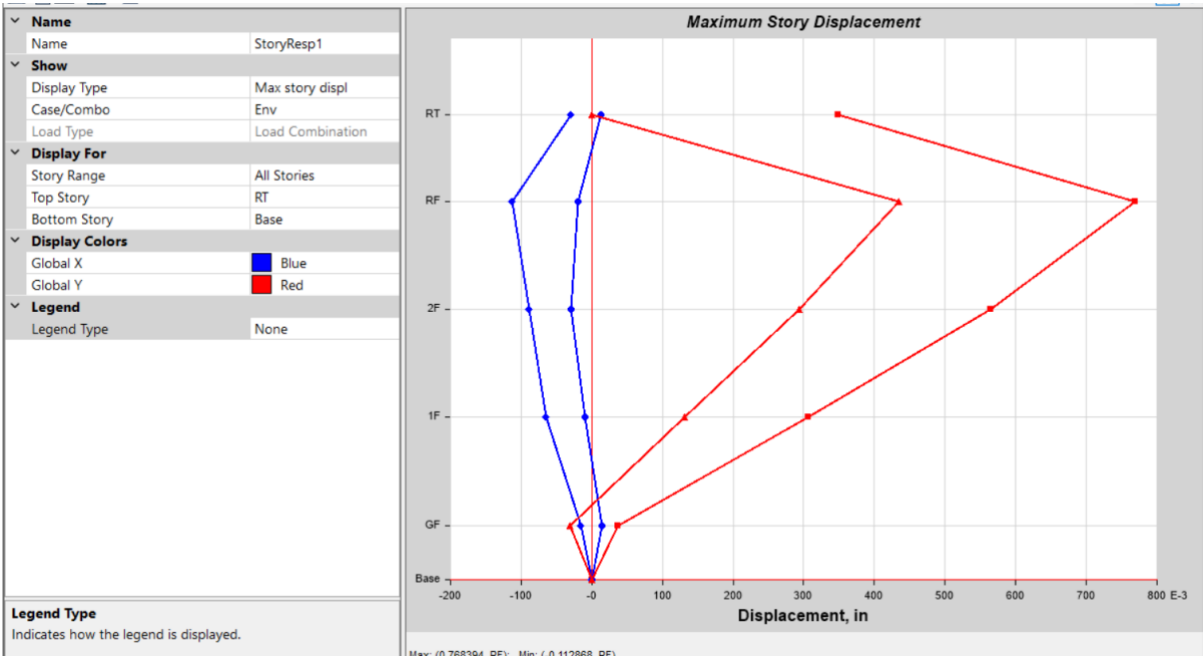


Figure 4-11. Story Displacement OMRF Seismic Zone 2.

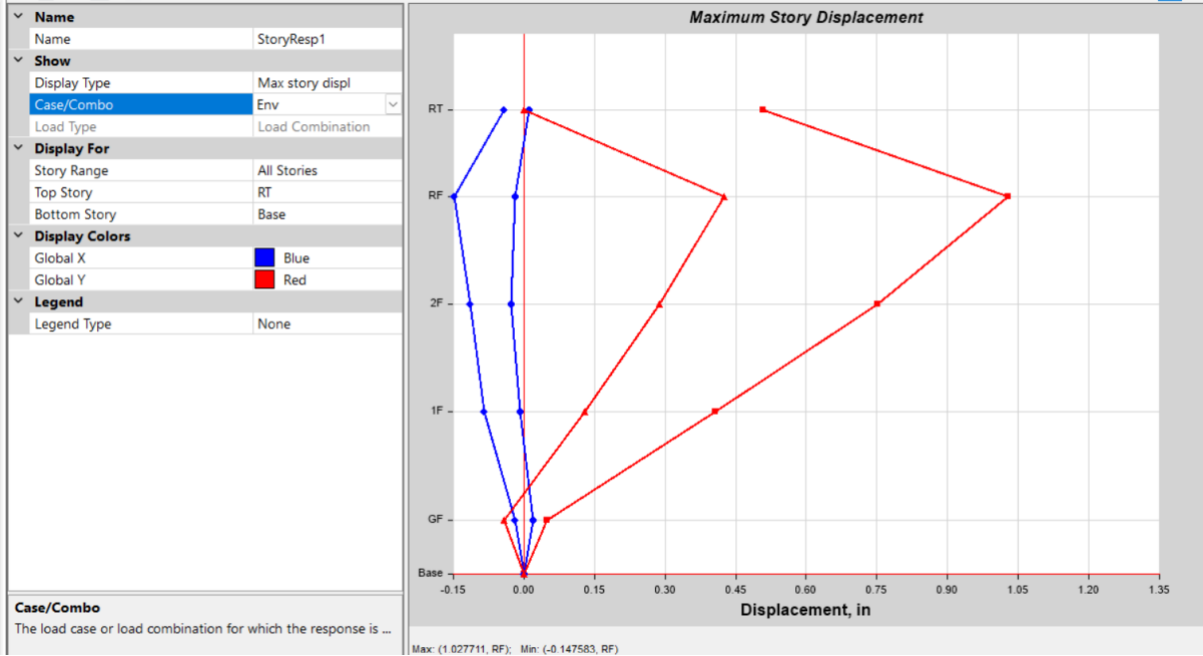


Figure 4-12. Story Displacement OMRF Seismic Zone 3.

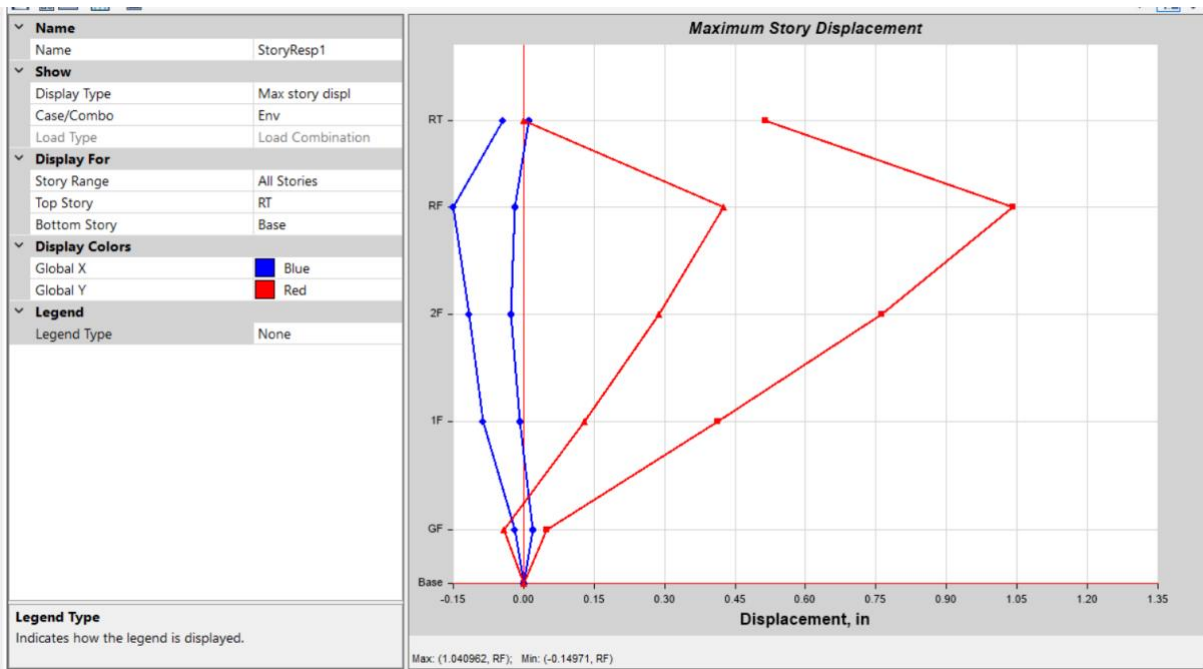


Figure 4-13. Story Displacement OMRF Seismic Zone 4.

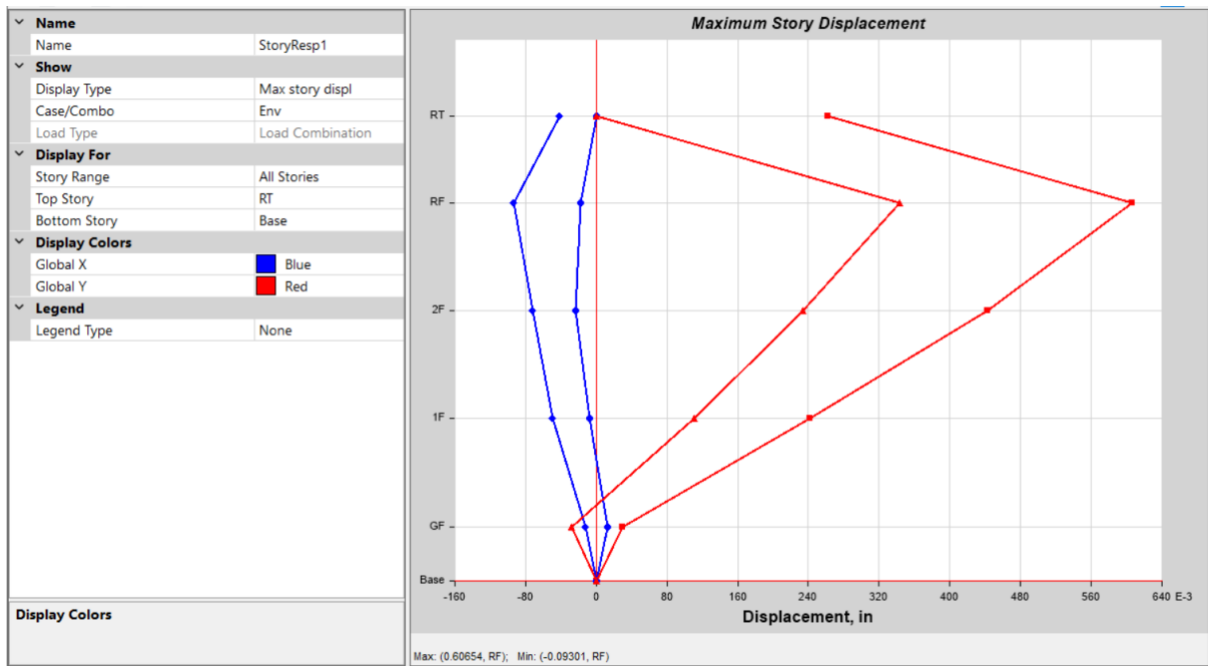


Figure 4-14. Story Displacements SMRF Seismic Zone 1.

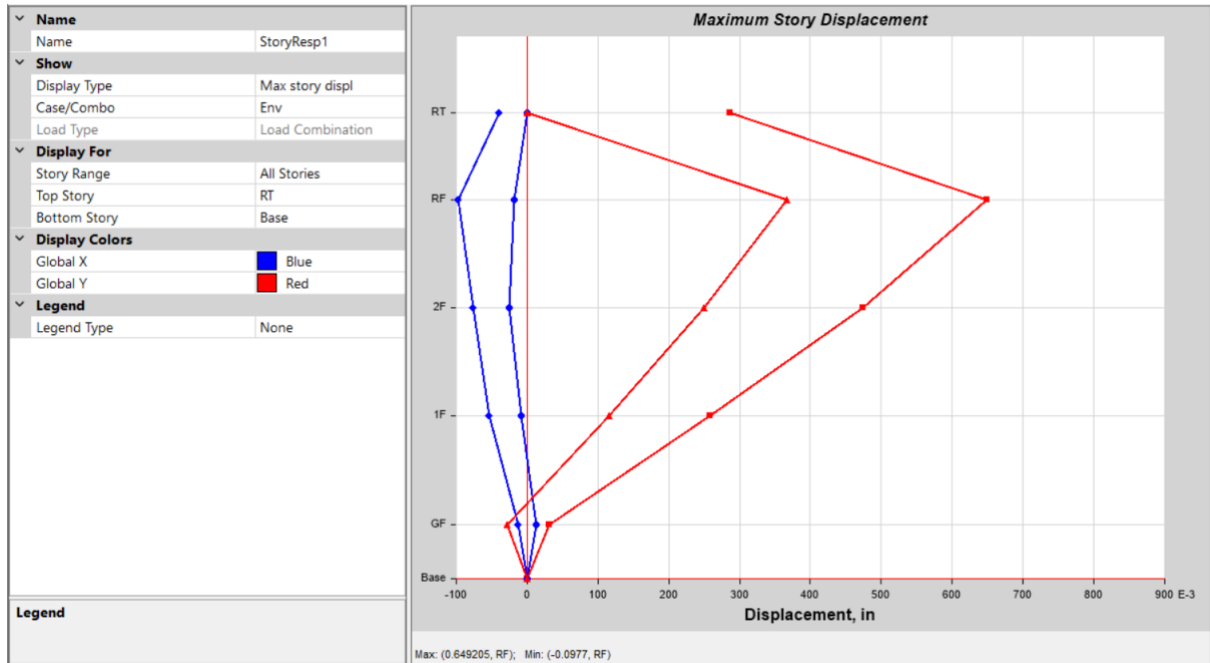


Figure 4-15. Story Displacements SMRF Seismic Zone 2.

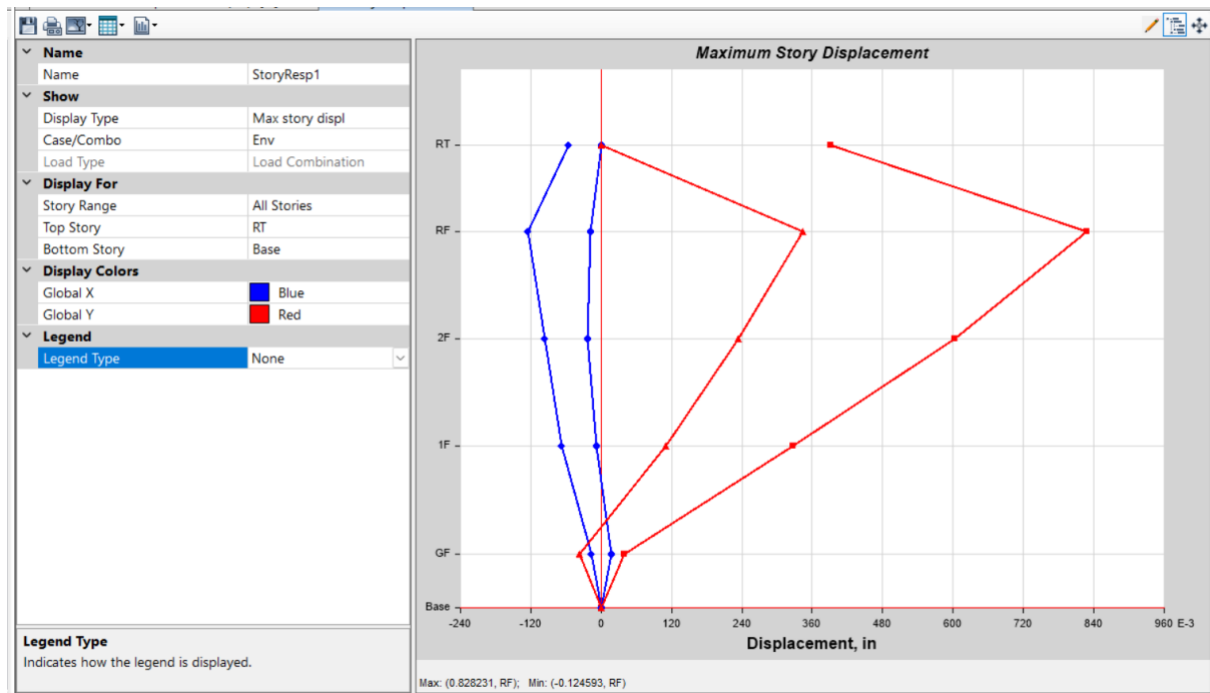


Figure 4-16. Story Displacements SMRF Seismic Zone 3.

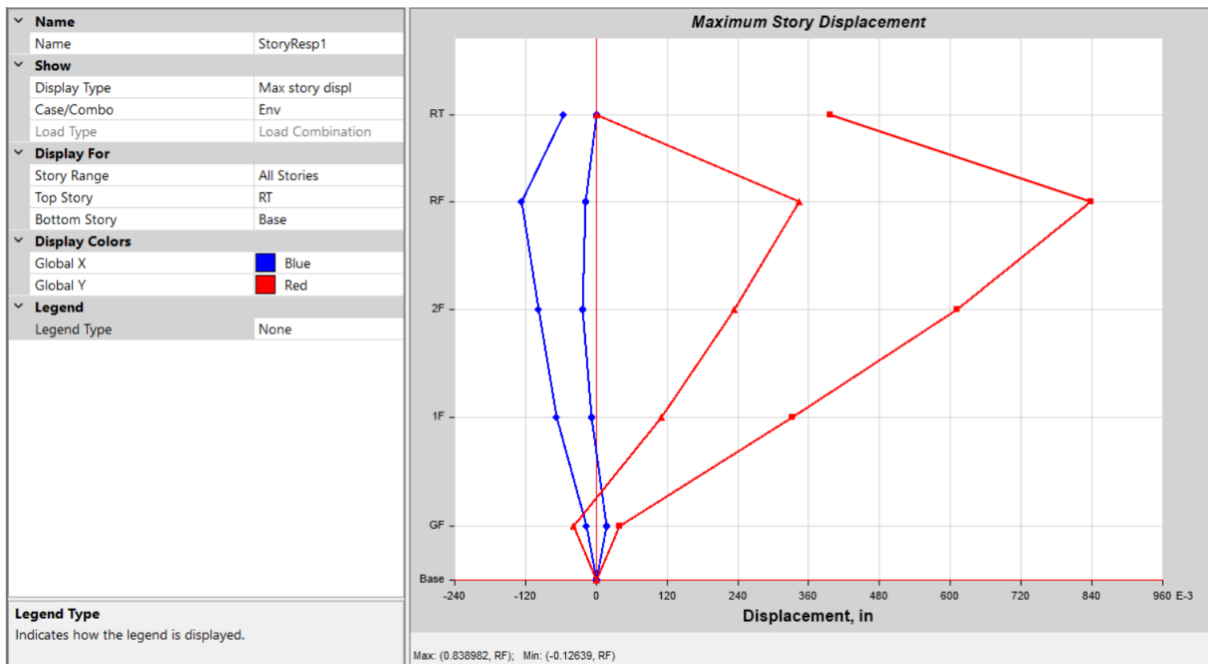


Figure 4-17. Story Displacements SMRF Seismic Zone 4.

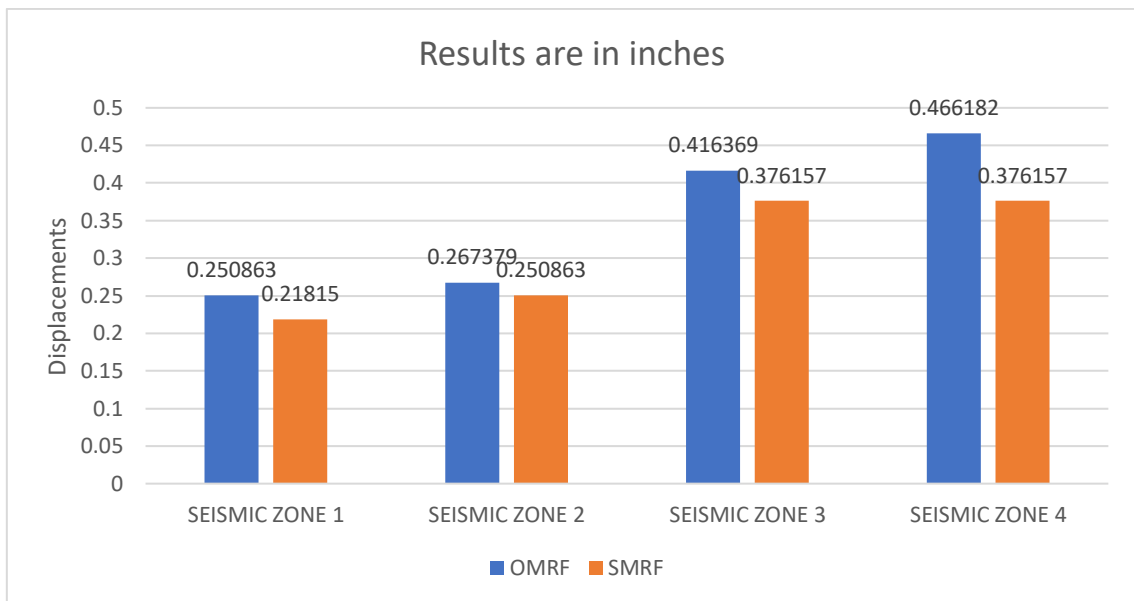


Figure 4-18. Maximum Displacement of OMRF and SMRF System.

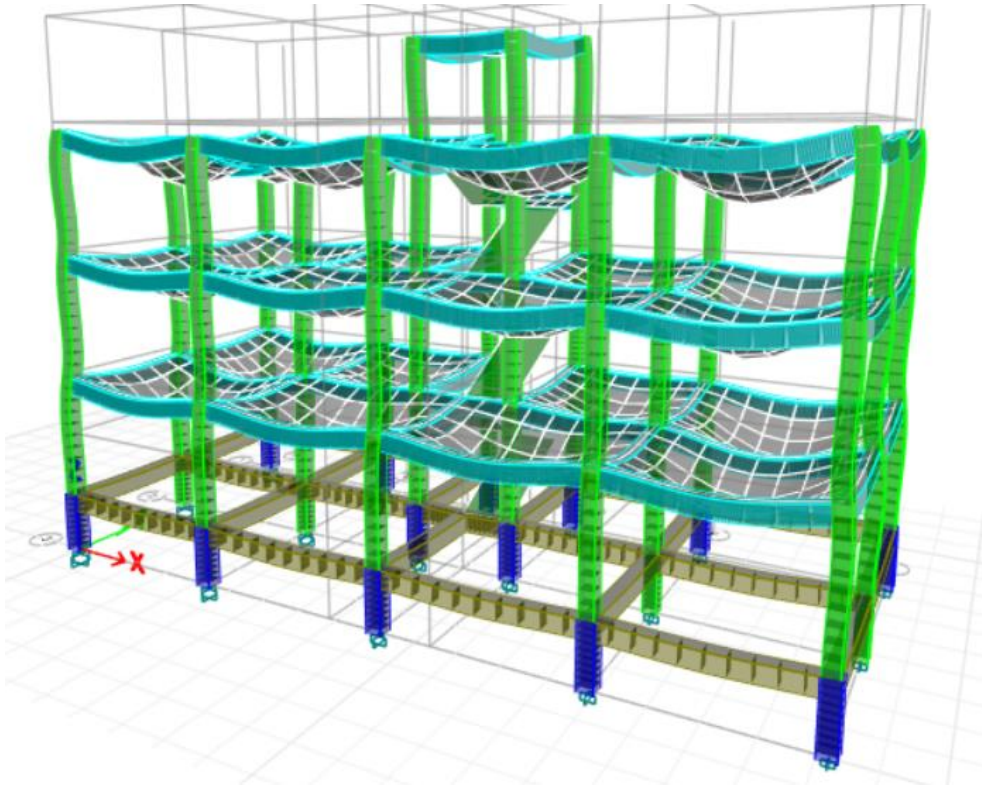


Figure 4-19. Deformed Shape of Structure.

4.2.2 Base Reactions

Table 4-5. Base Shear & Reaction (OMRF)

Zone	Load Combination	FZ kip	MX kip-ft	MY kip-ft	MZ kip-ft
Seismic Zone 1	Envelope load combo (Max)	19669.35	245148.9301	-402391.8588	6.404E-06
	Envelope load combo (Min)	13487.94	167676.7913	-586804.8199	3.454E-06
Seismic Zone 2	Envelope load combo (Max)	19757.776	247484.8516	-404157.4787	7.13E-07
	Envelope load combo (Min)	13547.123	169240.2033	-589442.8637	-2.606E-06
Seismic Zone 3	Envelope load combo (Max)	25850.76	322621.0689	-402391.8588	8.416E-06
	Envelope load combo (Min)	13487.94	167676.7913	-771217.7809	3.5E-06
Seismic Zone 4	Envelope load combo (Max)	26279.02	327969.0924	-402391.8588	1.667E-05
	Envelope load combo (Min)	13487.94	167676.7913	-783994.2525	7.293E-06

Table 4-6. Base Shear & Reaction (SMRF)

Zone	Load Combination	FZ kip	MX kip-ft	MY kip-ft	MZ kip-ft
Seismic Zone 1	Envelope load combo (Max)	19217.028	239435.2975	-393360.2679	-7.94E-06
	Envelope load combo (Min)	13185.205	163852.7065	-573310.5606	-1.184E-05
Seismic Zone 2	Envelope load combo (Max)	19217.028	239435.2975	-393360.2679	1.138E-05
	Envelope load combo (Min)	13185.205	163852.7065	-573310.5606	7.353E-06
Seismic Zone 3	Envelope load combo (Max)	25248.851	315017.8885	-393360.2679	-1.016E-05
	Envelope load combo (Min)	13185.205	163852.7065	-753260.8533	-2.038E-05
Seismic Zone 4	Envelope load combo (Max)	25664.29	320203.9508	-393360.2679	-9.483E-06
	Envelope load combo (Min)	13185.205	163852.7065	-765654.8104	-1.926E-05

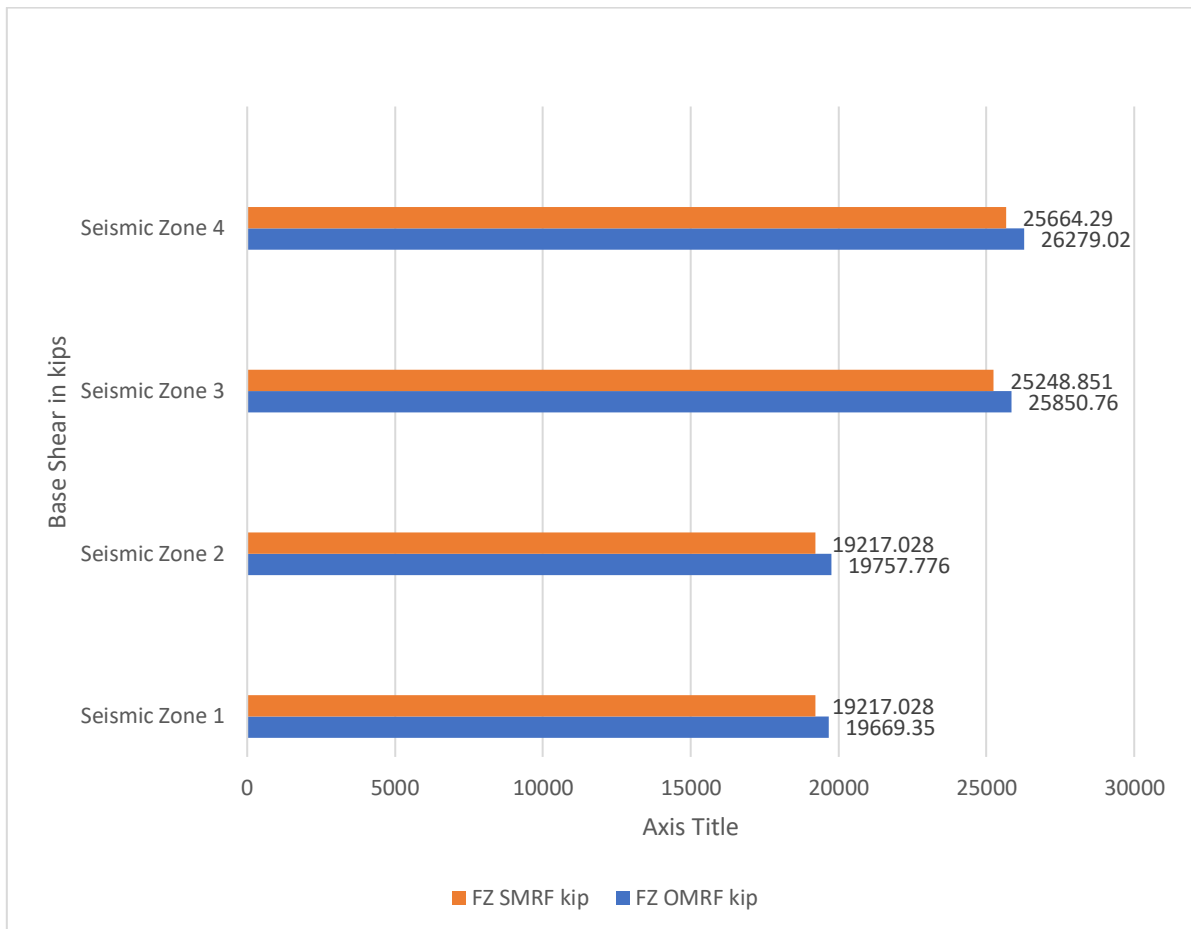


Figure 4-20. Base Shear Differences Between OMRF & SMRF.

4.2.3 Discussion of the Found Result

Observations

- Drift values increase progressively from Seismic Zone 1 to Zone 4, showing higher vulnerability in stronger zones.
- Plinth level consistently shows the least drift and displacement due to ground restraint.
- Typical Story 1 and 2 exhibit the highest drift and displacement, making them critical for seismic performance evaluation.
- SMRF frames consistently produce lower drift values compared to OMRF, confirming better lateral stiffness and ductility.
- Maximum displacement in OMRF is higher across all zones, especially Zone 4, while SMRF shows reduced displacement.
- Base shear values rise with seismic zone intensity for both systems, reflecting increased seismic demand.
- All drift values remain within BNBC 2020 allowable limits, confirming compliance and safety.

Comparison

- OMRF shows higher drift values across all stories and zones, while SMRF demonstrates reduced drift.
- OMRF experiences greater lateral displacement, especially in Zone 3 and 4, whereas SMRF maintains lower displacement.
- OMRF shows slightly higher torsional moments (MZ), while SMRF distributes forces more efficiently with reduced torsional effects.
- SMRF provides better control of structural deformation and improved serviceability compared to OMRF.

4.3 Summary

It is observed from the study that with the increase in seismic intensity from Zone 1 to Zone 4, structural movement and shifting increase, hence make those higher zones vulnerable. The plinth level remains steady due to ground restraint, while maximum drift and displacement appear at the first two stories consistently, hence are vital for seismic assessment. Throughout the zones, SMRFs outperformed OMRFs by providing lower drift, less displacement, and better torsional control, while OMRFs showed higher values, especially in Zones 3 and 4, due to weaker stiffness and ductility. With increased seismic intensity, base shear increases for both systems; however, drift values lie within the limit provided by BNBC 2020 for safety and compliance. In conclusion, SMRFs are suitable for high-risk zones and sensitive projects, whereas OMRFs can only be tried for lower seismic zones. Drift and displacement should be monitored as part of regular design models for their resilience and long-term safety.

CHAPTER 5

CONCLUSIONS AND FUTURE WORKS

5.1 Conclusions

- Both OMRF and SMRF systems satisfy BNBC 2020 drift limits, ensuring compliance and safety.
- Drift and displacement values increase with seismic zone severity, highlighting the importance of design adaptation in higher zones.
- SMRF consistently outperforms OMRF in controlling drift, displacement, and torsional effects, demonstrating superior seismic resilience.
- Base shear values rise with seismic intensity, but SMRF shows more balanced reactions, indicating better energy dissipation.
- For seismic zones 3 and 4, SMRF is the more reliable system for structural safety and serviceability.

5.2 Limitations and Recommendations for Future Works

➤ Limitations

- Extend analysis to include nonlinear dynamic time-history studies for more realistic seismic performance evaluation.
- Investigate retrofit techniques (e.g., CFRP jacketing, steel bracing) for improving OMRF performance in high seismic zones.
- Explore soil–structure interaction effects to assess foundation behavior under seismic loading.
- Conduct cost-benefit analysis comparing OMRF and SMRF systems to guide practical design decisions in Bangladesh.
- Validate numerical findings with experimental or field data to strengthen reliability of conclusions.
- Study performance under vertical seismic components and combined load cases for comprehensive safety assessment.
- Recommend future BNBC updates to incorporate advanced performance-based design approaches.

➤ Recommendations

- In Seismic Zone 1 and 2, OMRF systems should be considered best in case of economic conditions and safe system.
- For structures in Seismic Zones 3 and 4, SMRF systems should be prioritized due to superior drift and displacement control.
- OMRF may be acceptable in lower seismic zones but is less reliable under higher seismic demands.
- Designers should adopt SMRF for critical residential and commercial projects to ensure safety, serviceability, and compliance with BNBC 2020.
- Regular evaluation of drift and displacement in design models is essential to optimize structural resilience.

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APPENDIX

Appendix A

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Appendix B

Table 5-1. Story Drift OMRF Seismic Zone 1.

Story	Output Case	Step Type	Direction	Drift	X ft	Y ft	Z ft
RT	Env	Max	Y	0.007393	29.8333	0	43
RT	Env	Min	Y	0.007393	29.8333	0	43
RF	Env	Max	Y	0.001644	59.6667	0	35
RF	Env	Min	Y	0.001644	59.6667	0	35
2F	Env	Max	X	0.000331	0	24.1667	25
2F	Env	Max	Y	0.002104	59.6667	24.1667	25
2F	Env	Min	X	0.000331	0	24.1667	25
2F	Env	Min	Y	0.002104	59.6667	24.1667	25
1F	Env	Max	Y	0.002453	34	11.9167	15
1F	Env	Min	Y	0.002453	34	11.9167	15
GF	Env	Max	Y	0.000571	14.25	24.1667	5
GF	Env	Min	Y	0.000571	14.25	24.1667	5

Table 5-2. Story Displacements OMRF Seismic Zone 1.

Story	Output Case	Step Type	Direction	Max Displacements in	Avg Drift in	Ratio
RT	Env	Max	Y	0.709754	0.54438	1.304
RT	Env	Min	Y	0.709754	0.54438	1.304
RF	Env	Max	Y	0.197334	0.187051	1.055
RF	Env	Min	Y	0.197334	0.187051	1.055
2F	Env	Max	X	0.039681	0.032606	1.217
2F	Env	Max	Y	0.252535	0.241092	1.047
2F	Env	Min	X	0.039681	0.032606	1.217
2F	Env	Min	Y	0.252535	0.241092	1.047
1F	Env	Max	Y	0.294386	0.260961	1.128
1F	Env	Min	Y	0.294386	0.260961	1.128
GF	Env	Max	Y	0.034286	0.002133	16.076
GF	Env	Min	Y	0.034286	0.002133	16.076

Table 5-3. Story Drift OMRF Seismic Zone 2.

Story	Output Case	Step Type	Direction	Drift	X ft	Y ft	Z ft
RT	Env	Max	X	0.000625	34	11.9167	43
RT	Env	Max	Y	0.004958	29.8333	0	43
RT	Env	Min	Y	0.007854	29.8333	0	43
RF	Env	Max	Y	0.001738	59.6667	0	35
RF	Env	Min	Y	0.00108	59.6667	0	35
2F	Env	Max	Y	0.002239	59.6667	24.1667	25
2F	Env	Min	X	0.000351	0	24.1667	25
2F	Env	Min	Y	0.001414	59.6667	24.1667	25
1F	Env	Max	Y	0.002602	34	11.9167	15
1F	Env	Min	X	0.000255	59.6667	11.9167	15
1F	Env	Min	Y	0.00168	34	11.9167	15
GF	Env	Max	X	0.000244	59.6667	11.9167	5
GF	Env	Max	Y	0.000611	14.25	24.1667	5
GF	Env	Min	X	0.000254	0	24.1667	5
GF	Env	Min	Y	0.000501	34	11.9167	5

Table 5-4. Story Displacements OMRF Seismic Zone 2.

Story	Output Case	Step Type	Direction	Max Displacements in	Avg Drift in	Ratio
RT	Env	Max	X	0.059986	0.046568	1.288
RT	Env	Max	Y	0.47598	0.385834	1.234
RT	Env	Min	Y	0.753995	0.577171	1.306
RF	Env	Max	Y	0.208601	0.197847	1.054
RF	Env	Min	Y	0.129551	0.121255	1.068
2F	Env	Max	Y	0.268707	0.256661	1.047
2F	Env	Min	X	0.04214	0.034598	1.218
2F	Env	Min	Y	0.16965	0.161167	1.053
1F	Env	Max	Y	0.312199	0.277508	1.125
1F	Env	Min	X	0.030624	0.020132	1.521
1F	Env	Min	Y	0.201613	0.178796	1.128
GF	Env	Max	X	0.014665	0.002294	6.394
GF	Env	Max	Y	0.036685	0.008555	4.288
GF	Env	Min	X	0.015251	0.0028	5.446
GF	Env	Min	Y	0.030046	0.003147	9.548

Table 5-5. Story Drift OMRF Seismic Zone 3.

Story	Output Case	Step Type	Direction	Drift	X ft	Y ft	Z ft
RT	Env	Max	X	0.000701	34	11.9167	43
RT	Env	Max	Y	0.004856	29.8333	0	43
RT	Env	Min	Y	0.010529	29.8333	0	43
RF	Env	Max	Y	0.00235	59.6667	0	35
RF	Env	Min	Y	0.001059	59.6667	0	35
2F	Env	Max	Y	0.002997	59.6667	24.1667	25
2F	Env	Min	X	0.000435	0	24.1667	25
2F	Env	Min	Y	0.001383	59.6667	24.1667	25
1F	Env	Max	Y	0.003462	34	11.9167	15
1F	Env	Min	X	0.00032	59.6667	11.9167	15
1F	Env	Min	Y	0.001651	34	11.9167	15
GF	Env	Max	X	0.000323	59.6667	11.9167	5
GF	Env	Max	Y	0.000802	14.25	24.1667	5
GF	Env	Min	X	0.000326	0	24.1667	5
GF	Env	Min	Y	0.000688	34	11.9167	5

Table 5-6. Story Displacements OMRF Seismic Zone 3.

Story	Output Case	Step Type	Direction	Max Displacements in	Avg Drift in	Ratio
RT	Env	Max	X	0.067317	0.053274	1.264
RT	Env	Max	Y	0.466182	0.378148	1.233
RT	Env	Min	Y	1.01074	0.753842	1.341
RF	Env	Max	Y	0.281999	0.269105	1.048
RF	Env	Min	Y	0.127055	0.11896	1.068
2F	Env	Max	Y	0.359649	0.344567	1.044
2F	Env	Min	X	0.05219	0.043531	1.199
2F	Env	Min	Y	0.165912	0.157721	1.052
1F	Env	Max	Y	0.415429	0.369407	1.125
1F	Env	Min	X	0.038444	0.024833	1.548
1F	Env	Min	Y	0.198088	0.17554	1.128
GF	Env	Max	X	0.019382	0.004865	3.984
GF	Env	Max	Y	0.048135	0.014091	3.416
GF	Env	Min	X	0.019572	0.005035	3.887
GF	Env	Min	Y	0.041308	0.009135	4.522

Table 5-7. Story Drift OMRF Seismic Zone 4.

Story	Output Case	Step Type	Direction	Drift	X ft	Y ft	Z ft
RT	Env	Max	X	0.000708	34	11.9167	43
RT	Env	Max	Y	0.004856	29.8333	0	43
RT	Env	Min	Y	0.010663	29.8333	0	43
RF	Env	Max	Y	0.00238	59.6667	0	35
RF	Env	Min	Y	0.001059	59.6667	0	35
2F	Env	Max	Y	0.003036	59.6667	24.1667	25
2F	Env	Min	X	0.00044	0	24.1667	25
2F	Env	Min	Y	0.001383	59.6667	24.1667	25
1F	Env	Max	Y	0.003507	34	11.9167	15
1F	Env	Min	X	0.000325	59.6667	11.9167	15
1F	Env	Min	Y	0.001651	34	11.9167	15
GF	Env	Max	X	0.000328	59.6667	11.9167	5
GF	Env	Max	Y	0.000813	14.25	24.1667	5
GF	Env	Min	X	0.000331	0	24.1667	5
GF	Env	Min	Y	0.000697	34	11.9167	5

Table 5-8. Story Displacements OMRF Seismic Zone 4.

Story	Output Case	Step Type	Direction	Max Displacements in	Avg Drift in	Ratio
RT	Env	Max	X	0.068011	0.053883	1.262
RT	Env	Max	Y	0.466182	0.378148	1.233
RT	Env	Min	Y	1.023693	0.763217	1.341
RF	Env	Max	Y	0.28563	0.272565	1.048
RF	Env	Min	Y	0.127055	0.11896	1.068
2F	Env	Max	Y	0.364283	0.349006	1.044
2F	Env	Min	X	0.052774	0.044066	1.198
2F	Env	Min	Y	0.165912	0.157721	1.052
1F	Env	Max	Y	0.420795	0.374177	1.125
1F	Env	Min	X	0.038963	0.025158	1.549
1F	Env	Min	Y	0.198088	0.17554	1.128
GF	Env	Max	X	0.019651	0.004999	3.931
GF	Env	Max	Y	0.04876	0.014404	3.385
GF	Env	Min	X	0.019832	0.005165	3.84
GF	Env	Min	Y	0.041842	0.009402	4.45

Table 5-9. Story Drift SMRF Seismic Zone 1.

Story	Output Case	Step Type	Direction	Drift	X ft	Y ft	Z ft
RT	Env	Max	Y	0.003918	29.8333	0	43
RT	Env	Min	Y	0.0062	29.8333	0	43
RF	Env	Max	Y	0.001396	59.6667	0	35
RF	Env	Min	Y	0.000874	59.6667	0	35
2F	Env	Max	Y	0.001765	59.6667	24.1667	25
2F	Env	Min	X	0.000292	0	24.1667	25
2F	Env	Min	Y	0.001114	59.6667	24.1667	25
1F	Env	Max	Y	0.002057	29.8333	0	15
1F	Env	Min	X	0.000229	59.6667	11.9167	15
1F	Env	Min	Y	0.001328	29.8333	0	15
GF	Env	Max	X	0.000218	59.6667	11.9167	5
GF	Env	Max	Y	0.000486	14.25	24.1667	5
GF	Env	Min	X	0.000201	0	24.1667	5
GF	Env	Min	Y	0.000462	34	11.9167	5

Table 5-10. Story Displacements SMRF Seismic Zone 1.

Story	Output Case	Step Type	Direction	Max Displacements in	Avg Drift in	Ratio
RT	Env	Max	Y	0.376157	0.308135	1.221
RT	Env	Min	Y	0.59524	0.461714	1.289
RF	Env	Max	Y	0.167516	0.158007	1.06
RF	Env	Min	Y	0.104924	0.097526	1.076
2F	Env	Max	Y	0.211808	0.201172	1.053
2F	Env	Min	X	0.035099	0.028459	1.233
2F	Env	Min	Y	0.133706	0.126231	1.059
1F	Env	Max	Y	0.246795	0.21653	1.14
1F	Env	Min	X	0.027459	0.017986	1.527
1F	Env	Min	Y	0.159383	0.139398	1.143
GF	Env	Max	X	0.013094	0.002557	5.12
GF	Env	Max	Y	0.029182	0.005543	5.265
GF	Env	Min	X	0.012058	0.001711	7.047
GF	Env	Min	Y	0.027733	0.004418	6.277

Table 5-11. Story Drift SMRF Seismic Zone 2.

Story	Output Case	Step Type	Direction	Drift	X ft	Y ft	Z ft
RT	Env	Max	Y	0.004187	29.8333	0	43
RT	Env	Min	Y	0.006626	29.8333	0	43
RF	Env	Max	Y	0.001493	59.6667	0	35
RF	Env	Min	Y	0.000934	59.6667	0	35
2F	Env	Max	Y	0.001888	59.6667	24.1667	25
2F	Env	Min	X	0.000305	0	24.1667	25
2F	Env	Min	Y	0.001192	59.6667	24.1667	25
1F	Env	Max	Y	0.002195	29.8333	0	15
1F	Env	Min	X	0.000234	59.6667	11.9167	15
1F	Env	Min	Y	0.001418	29.8333	0	15
GF	Env	Max	X	0.000225	59.6667	11.9167	5
GF	Env	Max	Y	0.000517	14.25	24.1667	5
GF	Env	Min	X	0.000213	0	24.1667	5
GF	Env	Min	Y	0.000475	34	11.9167	5

Table 5-12. Story Displacements SMRF Seismic Zone 2.

Story	Output Case	Step Type	Direction	Max Displacements in	Avg Drift in	Ratio
RT	Env	Max	Y	0.40191	0.3273	1.228
RT	Env	Min	Y	0.636061	0.49037	1.297
RF	Env	Max	Y	0.179209	0.168965	1.061
RF	Env	Min	Y	0.112121	0.104197	1.076
2F	Env	Max	Y	0.226542	0.21561	1.051
2F	Env	Min	X	0.036577	0.029816	1.227
2F	Env	Min	Y	0.143046	0.135362	1.057
1F	Env	Max	Y	0.263417	0.232111	1.135
1F	Env	Min	X	0.028028	0.018341	1.528
1F	Env	Min	Y	0.17011	0.149464	1.138
GF	Env	Max	X	0.013491	0.002528	5.337
GF	Env	Max	Y	0.030992	0.006196	5.002
GF	Env	Min	X	0.012753	0.001931	6.604
GF	Env	Min	Y	0.028522	0.004227	6.747

Table 5-13. Story Drift SMRF Seismic Zone 3.

Story	Output Case	Step Type	Direction	Drift	X ft	Y ft	Z ft
RT	Env	Max	X	0.00056	29.8333	0	43
RT	Env	Max	Y	0.003918	29.8333	0	43
RT	Env	Min	Y	0.008483	29.8333	0	43
RF	Env	Max	Y	0.001918	59.6667	0	35
RF	Env	Min	Y	0.000874	59.6667	0	35
2F	Env	Max	Y	0.002416	59.6667	24.1667	25
2F	Env	Min	X	0.000374	0	24.1667	25
2F	Env	Min	Y	0.001114	59.6667	24.1667	25
1F	Env	Max	Y	0.002785	29.8333	0	15
1F	Env	Min	X	0.0003	59.6667	11.9167	15
1F	Env	Min	Y	0.001328	29.8333	0	15
GF	Env	Max	X	0.000293	59.6667	11.9167	5
GF	Env	Max	Y	0.000658	14.25	24.1667	5
GF	Env	Min	X	0.000269	0	24.1667	5
GF	Env	Min	Y	0.000623	34	11.9167	5

Table 5-14. Story Displacements SMRF Seismic Zone 3.

Story	Output Case	Step Type	Direction	Max Displacements in	Avg Drift in	Ratio
RT	Env	Max	X	0.053733	0.038103	1.41
RT	Env	Max	Y	0.376157	0.308135	1.221
RT	Env	Min	Y	0.814322	0.615294	1.323
RF	Env	Max	Y	0.230108	0.21833	1.054
RF	Env	Min	Y	0.104924	0.097526	1.076
2F	Env	Max	Y	0.28991	0.276112	1.05
2F	Env	Min	X	0.044897	0.03688	1.217
2F	Env	Min	Y	0.133706	0.126231	1.059
1F	Env	Max	Y	0.334208	0.293662	1.138
1F	Env	Min	X	0.036059	0.02351	1.534
1F	Env	Min	Y	0.159383	0.139398	1.143
GF	Env	Max	X	0.017553	0.004787	3.667
GF	Env	Max	Y	0.039467	0.010685	3.694
GF	Env	Min	X	0.016135	0.00375	4.303
GF	Env	Min	Y	0.03737	0.009236	4.046

Table 5-15. Story Drift SMRF Seismic Zone 4.

Story	Output Case	Step Type	Direction	Drift	X ft	Y ft	Z ft
RT	Env	Max	X	0.000569	29.8333	0	43
RT	Env	Max	Y	0.003918	29.8333	0	43
RT	Env	Min	Y	0.008592	29.8333	0	43
RF	Env	Max	Y	0.001942	59.6667	0	35
RF	Env	Min	Y	0.000874	59.6667	0	35
2F	Env	Max	Y	0.002447	59.6667	24.1667	25
2F	Env	Min	X	0.000378	0	24.1667	25
2F	Env	Min	Y	0.001114	59.6667	24.1667	25
1F	Env	Max	Y	0.002821	29.8333	0	15
1F	Env	Min	X	0.000305	59.6667	11.9167	15
1F	Env	Min	Y	0.001328	29.8333	0	15
GF	Env	Max	X	0.000297	59.6667	11.9167	5
GF	Env	Max	Y	0.000666	14.25	24.1667	5
GF	Env	Min	X	0.000273	0	24.1667	5
GF	Env	Min	Y	0.000631	34	11.9167	5

Table 5-16. Story Displacements SMRF Seismic Zone 4.

Story	Output Case	Step Type	Direction	Max Displacements in	Avg Drift in	Ratio
RT	Env	Max	X	0.054578	0.038686	1.411
RT	Env	Max	Y	0.376157	0.308135	1.221
RT	Env	Min	Y	0.824809	0.623026	1.324
RF	Env	Max	Y	0.233063	0.221122	1.054
RF	Env	Min	Y	0.104924	0.097526	1.076
2F	Env	Max	Y	0.293684	0.279705	1.05
2F	Env	Min	X	0.045404	0.037342	1.216
2F	Env	Min	Y	0.133706	0.126231	1.059
1F	Env	Max	Y	0.338492	0.297447	1.138
1F	Env	Min	X	0.036557	0.023853	1.533
1F	Env	Min	Y	0.159383	0.139398	1.143
GF	Env	Max	X	0.0178	0.00491	3.625
GF	Env	Max	Y	0.039985	0.010944	3.654
GF	Env	Min	X	0.01635	0.003857	4.239
GF	Env	Min	Y	0.03785	0.009477	3.994