SEISMIC PERFORMANCE EVALUATION OF A (G+6) 7 STORIED FLAT SLAB RESIDENTIAL BUILDING FOR SAVAR ZONE IN BANGLADESH USING ETABS ACCORDING TO BNBC 2020.

By

MD. ALIMUL HAQUE

MOHD. TANVIR AHMED

TAPOS KUMAR DAS

MD. SOHEL RANA

SHUBHO AHMED

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: 25-A

Semester: Summer-2025

SEISMIC PERFORMANCE EVALUATION OF A (G+6) 7 STORIED FLAT SLAB RESIDENTIAL BUILDING FOR SAVAR ZONE IN BANGLADESH USING ETABS ACCORDING TO BNBC 2020.

By

MD. ALIMUL HAQUE	ID:BCE1503006056
MOHD. TANVIR AHMED	ID:BCE1503006067
TAPOS KUMAR DAS	ID:CE2201025159
MD. SOHEL RANA	ID:CE2201025054
SHUBHO AHMED	ID:CE2102023078

Supervisor

HEMLITA MONDAL

LECTURER

DEPARTMENT OF CIVIL ENGINEERING

SONARGAON UNIVERSITY (SU)

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: 25-A

Semester: Summer-2025

BOARD OF EXAMINERS

The thesis titled "A study on seismic performance evaluation of a (g+6) 7 storied flat slab residential building for Savar zone in Bangladesh using ETABS according to BNBC 2020." submitted by Student Name: Md. Alimul Haque, ID: BCE1503006056. Student Name: Mohd. Tanvir Ahmed, ID: BCE1503006067, Student Name: Tapos Kumar Das, ID: CE2201025159. Student Name: Md. Sohel Rana, ID: CE2201025054. Student Name: Shubho Ahmed, ID: CE2102023078 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Civil Engineering on September 20, 2025.

.....

Hemlita Mondal
Lecturer
Department of Civil Engineering
Sonargaon University

Chairman

.....

1. Internal / External Member

Member

.....

2. Internal / External Member

Member

Declaration

It is hereby declared that all studies presented in this thesis, with the exception of those in which particular references have been made to the work of others, are the outcomes of research done by the authors under the supervision of Hemlita Mondol, Lecturer, Department of Civil Engineering, Sonargaon University. This thesis/project or any part of it has not been submitted elsewhere for the award of any degree, diploma or other certification (except for publications).

STUDENT NAME	STUDENT ID.	SIGNATURE
MD. ALIMUL HAQUE	ID: BCE1503006056	
MOHD. TANVIR AHMED	ID: BCE1503006067	
TAPOS KUMAR DAS	ID: CE2201025159	
MD. SOHEL RANA	ID: CE2201025054	
SHUBHO AHMED	ID: CE2102023078	

Dedicated

To

“Almighty Allah,

Our Parents,

Our Family and

Our Honorable Teachers”

Acknowledgements

Firstly, the authors would like to express the cordial gratitude and love to the Almighty Allah for bestowing the knowledge, aptitude and endurance to accomplish the study successfully. The authors would like to disclose the heartiest thankfulness to their honorable thesis supervisor Hemlita Mondal, Lecturer, Department of Civil Engineering, Sonargaon University, for his unswerving guidance, dynamic direction, superintendence, constant attention, helpful suggestions, best support and personal concern during the research work, beginning from the development of the research proposal till writing of this thesis. His awesome ideas help very much to accomplish this thesis perfectly. Special thanks to the honorable Professor Prof. Shamim Ara Hassan (Vice-Chancellor of the Sonargaon University) for his support to carry out the study and giving many facilities to the students. The authors are greatly indebted to all the honorable teachers for their best teaching and best support. The authors also acknowledge the assistance of their families, particularly their parents, who helped them work productively and successfully to finish their thesis. Finally, the authors would like to thank all their friends and classmates for supporting and co-operation in various ways.

Abstract

Earthquakes are among the most destructive and unpredictable natural hazards, posing significant risks to both human life and built infrastructure. Seismic forces generated during earthquakes can cause severe structural damage, often leading to partial or total collapse. As earthquake-prone regions expand, seismic analysis has become a critical factor in the planning and design of safe structures. Bangladesh, located in a tectonically active region, is particularly vulnerable to seismic activity, especially within Seismic Zone II. This study focuses on the seismic design and analysis of a seven-story (G+6) residential building situated in Zone II of Bangladesh. Using the Bangladesh National Building Code (BNBC) 2020 and ETABS 2022 software, the research evaluates the building's seismic response and overall structural stability under extreme earthquake conditions. Key parameters such as base shear, torsional irregularity, story drift, and story displacement are assessed to understand the building's behavior during seismic events. The analysis demonstrates that the proposed design satisfies BNBC 2020 requirements for Zone II, ensuring adequate performance and safety under expected seismic forces. Comparative results indicate that an increase in seismic coefficients directly amplifies seismic effects on structural elements. However, other factors, including building configuration and material properties, also influence overall performance. The findings confirm that proper seismic design significantly enhances the resilience of residential buildings in earthquake-prone areas like Dhaka. By providing a comprehensive evaluation of structural responses, this research contributes to a better understanding of earthquake-resistant design practices in Bangladesh. The results highlight the importance of incorporating rigorous seismic analysis in structural planning to safeguard human life and infrastructure against potential earthquake hazards

Table of Contents

Acknowledgements vi

Abstract vii

Table of Contents 1

List of Figures 6

List of Tables 7

List of Notations 8

Chapter 1 9

Introduction 9

1.1. Background and Motivations 9

1.2. Research Objectives and Overview 11

1.3. Analysis Methods 11

Chapter 2 12

Literature Review 12

2.1. Introduction 12

2.2. Background and Significance 12

2.2.1. Flat Slab System Overview 12

2.2.2. Importance of Seismic Performance Evaluation 13

2.3. Research Gap 13

2.3.1. Limited Studies on Multi-Story Buildings 13

2.3.2. Inadequate Consideration of Punching Shear 13

2.4. Summary 14

Chapter 3 15

Methodology 15

3.1. Scope of the Study 15

3.2. Research Methodology 15

3.3. Significance of the Study 16

3.4. Equivalent Static Analysis 16

3.5. Response Spectrum Analysis 16

3.6. Time History Method 17
3.7. General Description 17
3.8. Material Properties 17
3.8.1. Concrete 17
3.8.2. Reinforcement Steel 17
3.9. Load Considerations 18
3.9.1. Dead Load 18
3.9.2. Live Load 18
3.9.3. Seismic Load 18
3.9.4. Load Combinations 18
3.10. Structural Modeling in ETABS 18
3.10.1. Model Setup 18
3.10.2. Meshing 19
3.10.3. Boundary Conditions 19
3.10.4. Load Application in ETABS 19
3.11. Analysis Methodology 19
3.11.1. Response Spectrum Method 19
3.11.2. Punching Shear Assessment 19
3.11.3. Story Drift and Inter-Story Displacement 20
3.12. Results and Discussion 20
3.12.1. Lateral Displacement 20
3.12.2. Story Drift 20
3.12.3. Base Shear 20
3.12.4. Slab Stress and Punching Shear 20
3.12.5. Mode Shapes 20
3.13. Recommendations for Design Optimization 21
3.14. Figures and Charts 21
Chapter 4 23
Result 23
4.1. Fundamentals of Response Spectrum Method 23
4.1.1. Earthquake Excitation and Structural Response 23
4.1.2. Definition of Response Spectrum 23

4.2. Types of Response Spectra 24
4.2.1. Design Response Spectrum 24
4.2.2. Regulatory vs. Site-Specific Spectra 24
4.2.3. Acceleration, Velocity, and Displacement Spectra 25
4.3. Modal Analysis in Response Spectrum Method 25
4.3.1. Multi-Degree-of-Freedom (MDOF) Systems 25
4.3.2. Modal Superposition 25
4.3.3. Participation Factor 25
4.4. Application of Response Spectrum Method in ETABS 25
4.4.1. Modeling Assumptions 25
4.4.2. Steps in ETABS 26
4.4.3. Output from ETABS 26
4.5. Mathematical Formulation 26
4.5.1. SDOF System Response 26
4.5.2. MDOF System 26
4.5.3. Base Shear Calculation 26
4.6. Advantages and Limitations 27
4.6.1. Advantages 27
4.6.2. Limitations 27
4.7. Design Considerations Using Response Spectrum Method 27
4.8. Case Study: 7-Storey Residential Building 27
4.8.1. Input Parameters 27
4.8.2. Analysis Results 28
4.9. Practical Recommendations 31
4.10. Story Displacement 32
4.10.1. Lateral Displacement Overview 32
4.10.2. Inter-Story Drift 33
4.11. Base Shear 34
4.12. Column Forces 34
4.12.1. Axial Forces 34
4.12.2. Bending Moments 36
4.13. Slab Analysis 38

4.13.1. Slab Bending Stress 38
4.14. Mode Shapes and Modal Participation 39
4.14.1. First Two Modes 39
4.14.2. Modal Participation Factors 42
4.14.3. Lateral Force Distribution 43
4.15. Model Results 53
4.16. Result Specifications 55
Comparative Discussion 56
4.17. Fundamentals of Punching Shear 56
4.17.1. Definition 56
4.17.2. Failure Mechanism 57
4.18. Causes of Punching Shear in Flat Slabs 57
4.19. Analytical Methods for Punching Shear 57
4.19.1. Simplified Code-Based Approaches 57
4.19.2. Finite Element and Software Analysis 58
4.19.3. Factors Influencing Punching Shear 59
4.20. Design Measures to Prevent Punching Shear 59
4.20.1. Shear Reinforcement (Studs / Links) 59
4.20.2. Slab Thickness Optimization 59
4.21. Punching Shear in Seismic Loading 59
4.21.1. Effect of Earthquake Forces 59
4.21.2. Analysis Using Response Spectrum Method 60
4.22. Comparison with Beam-Slab Systems 61
4.23. Design Recommendations 61
4.24. Summary 61
Chapter 5 62
Conclusions 62
5.1. Introduction 62
5.2. Summary of Structural Analysis 62
5.2.1. Modeling and Input Parameters 62
5.2.2. Seismic Analysis Findings 63
5.3. Punching Shear Performance 63

5.4. Design Implications 63
5.5. Observations from Response Spectrum Analysis 64
5.6. Limitations of the Study 64
5.7. Recommendations for Future Work 64
5.8. Practical Guidelines 64
5.9. Overall Conclusions 64
References 66

List of Figures

Figure 1. 1: Different Types of Analysis Method 11
Figure 3. 1: Layout Plan of 7-storey building ……..……..21
Figure 3. 2: ETABS 3D model view 22
Figure 4. 1: Typical response spectrum for a reinforced concrete building under seismic loading. 24
Figure 4. 2: Story displacement diagram.....28
Figure 4. 3: Typical Response Spectrum Curve.....29
Figure 4. 4: Story drift diagram.....33
Figure 4. 5: Maximum Column Axial Force 34
Figure 4. 6: Maximum column bending moments of Grid-1 36
Figure 4. 7: Maximum column bending moments of Grid-2 37
Figure 4. 8: Maximum slab bending stress.....38
Figure 4. 9: Slab stress contour 38
Figure 4. 10: Mode 1 – Translation along X-axis.....39
Figure 4. 11: Mode 2 – Translation along Y-axis.....39
Figure 4. 12: Torsion Grid-1.....40
Figure 4. 13: Torsion Grid-2.....41
Figure 4. 14: Story Force.....44
Figure 4. 15: Punching shear stress distribution in 7-storey flat slab building first Floor 60
Figure 4. 16: Punching shear stress distribution in 7-storey flat slab building fourth Floor.....60
Figure 4. 17: Punching shear stress distribution in 7-storey flat slab building Roof ……61

List of Tables

Table 3. 1: Key benefits of flat slab analysis....16
Table 3. 2: Concrete Specifications Data....17
Table 3. 3:Rebar Specifications Data....17
Table 3. 4: Load Combination as per BNBC2020....18
Table 4. 1: Analysis Results....28
Table 4. 2: Response Spectrum Modal Information....30
Table 4. 3: Functions - Response Spectrum....31
Table 4. 4: Maximum lateral displacement per floor....32
Table 4. 5: Inter-story drift ratios....33
Table 4. 6: Base shear distribution....34
Table 4. 7: Base Reaction....35
Table 4. 8: Modal participation Factors....42
Table 4. 9: Lateral force per floor....45
Table 4. 10: Modal Periods and Frequencies....53
Table 4. 11: Modal Participating Mass Ratios....54
Table 4. 12: Modal Load Participation Ratios....54
Table 4. 13: Modal Direction Factors....55
Table 4. 14: Slab Specifications Data....55
Table 4. 15: Frame Specifications Data....55
Table 4. 16: Punching shear contour around a Corner Column....58
Table 4. 17: Punching shear contour around a Mid Column....58

List of Notations

Notation	Meaning
C_d	Deflection amplification factor.
C_f	Force coefficient to be used in determination of wind loads for other structures.
C_N	Net pressure coefficient to be used in determination of wind loads for open buildings.
C_p	External pressure coefficient to be used in determination of wind loads for buildings.
C_s	Normalized acceleration response spectrum.
C_t	Numerical coefficient to determine building period.
D	Dead loads, or related internal moments and forces.
E	Total load effects of earthquake that include both horizontal and vertical, or related internal moments and forces.
F	Loads due to weight and pressures of fluids with well-defined densities and controllable maximum heights or related internal moments and forces.
H	Loads due to weight and pressure of soil, water in soil, or other materials, or related internal moments and forces.
L	Live loads.
L_r	Roof live loads, or related internal moments and forces.
R	Rain load, or related internal moments and forces.
T	Self-straining forces and cumulative effect of temperature, creep, shrinkage, differential settlement, and shrinkage-compensating concrete, or combinations thereof, or related internal moments and forces.
W	Total seismic weight of building.
W	Wind load, or related internal moments and forces.
X+E	X Direction + Eccentricity (Ecc. Ratio = 0.05).
X-E	X Direction - Eccentricity (Ecc. Ratio = 0.05).
Y+E	Y Direction + Eccentricity (Ecc. Ratio = 0.05).
Y-E	Y Direction - Eccentricity (Ecc. Ratio = 0.05).

Chapter 1

Introduction

1.1. Background and Motivations

A natural disaster known as an earthquake can also result from the migration of magma or an unexpected ground subsidence. However, there are times when earthquakes are brought on by human action, such as overloading the earth's crust or causing nuclear explosions underneath.

Earthquake is a natural disaster that causes significant loss of life and property, leaves many people homeless, orphans and widows, and has a severe negative impact on a nation's economy. To recoup and make up for the loss an earthquake inflicted, it takes many years. Even at great distances from the epicenter, earthquake tremors can be felt. One of the most severe natural disasters is an earthquake, which causes the earth's surface to tremble as seismic energy is released from the crust along a fault. The building is negatively affected by an earthquake. When seismic waves are exposed to a building, the building's foundation begins to tremble and eventually collapses. Seismic waves are generated from the crust and propagate toward the earth's surface. The purpose of seismic analysis is to comprehend how a building will react to an earthquake. Multi-storied building construction is becoming unavoidable for both commercial and residential uses. The tall raised buildings are not adequately constructed to resist lateral stresses and it can result in the total collapse of the structures [1].

Earthquakes are a major cause of property damage and fatalities because they can force buildings to collapse. Large earthquakes can sometimes trigger disease outbreaks due to loss of housing, contaminated water, and other issues affecting public health. Surface displacement, electrical and gas pipeline breaks, and fire all contribute to the occurrence of fire. There are frequently side effects from earthquakes or connections to other natural disasters. Bangladesh is a South Asian nation well renowned for its frequent natural disasters. It is situated between 20.35°N and 26.75°N Latitude and 88.03°E and 92.75°E Longitude.

Bangladesh is ranked 5th in terms of risk and 10th in terms of exposure to nature catastrophes in the 2015 Asia Pacific Disaster Report. Natural disasters like

Cyclones, floods, droughts, earthquakes, river bank erosion, etc. occur every year throughout the nation. But studies have shown that Bangladesh is the country most at risk from earthquakes. Bangladesh is one of the most tectonic ally active regions in the world since it is

surrounded mostly by India and to a lesser extent by Myanmar and is situated where three tectonic plates-Eurasia, India, and Burma meet. Bangladesh has been the victim of numerous destructive as well as minor earthquakes during the past 200 years. Bangladesh has had around 250 earthquakes since gaining its independence in 1971, some of which had a magnitude greater than 6.0. But one cannot overlook the risks. Studies have also demonstrated the potential for fatalities. There is no way to predict or prevent earthquakes from occurring in earthquake-prone areas, but we can reduce the number of lives lost and the damage to property by conducting in-depth research, issuing warnings, and putting settlement management techniques into practice for both pre-disaster and post-disaster management.

Depending on the earthquake's magnitude, it arrives quickly for a few seconds and results in little, moderate, or large loss of life and property. Although it cannot be entirely avoided, it can be managed. Therefore, earthquake mitigation and prevention are major global concerns right now.

The seismic analysis can be used to create a construction that is earthquake resistant. This study's main objective is to examine seismic response in various structural zones for static and dynamic assessment in typical minute opposed casing. For the analysis of a (G+6) 7 storied residential structure that is situated in Bangladesh's Zone II, seismic zones. In this study, BNBC 2020 and ETABS 2022 into consideration. The procedure for determining the base plan loads that must be acquired for forced loads, dead loads, and other external loading attaches the fundamental requirements relating to the fundamental security of structures. According to BNBC 2020, the entire structure was examined using ETABS software on a computer.

An analysis of a (G+6) 7 storied residential structure that is situated in Bangladesh's Zone II, seismic zones. In this study, BNBC 2020 and ETABS 2022, presented in this thesis. This thesis displays the story drift, story displacement, torsional irregularity, base shear, and other structural characteristics of this building.

1.2. Research Objectives and Overview

The overall objective of this research is to evaluate the seismic performance of a 7-storey reinforced concrete flat slab building using ETABS. Specific objectives include:

- To conduct seismic analysis on structures for Savar zone in Bangladesh.
- Seismic Evaluation: Analyze building response under Response Spectrum Method (RSM) to determine story displacement, inter-story drift, base shear, and modal participation According to BNBC 2020.

1.3. Analysis Methods

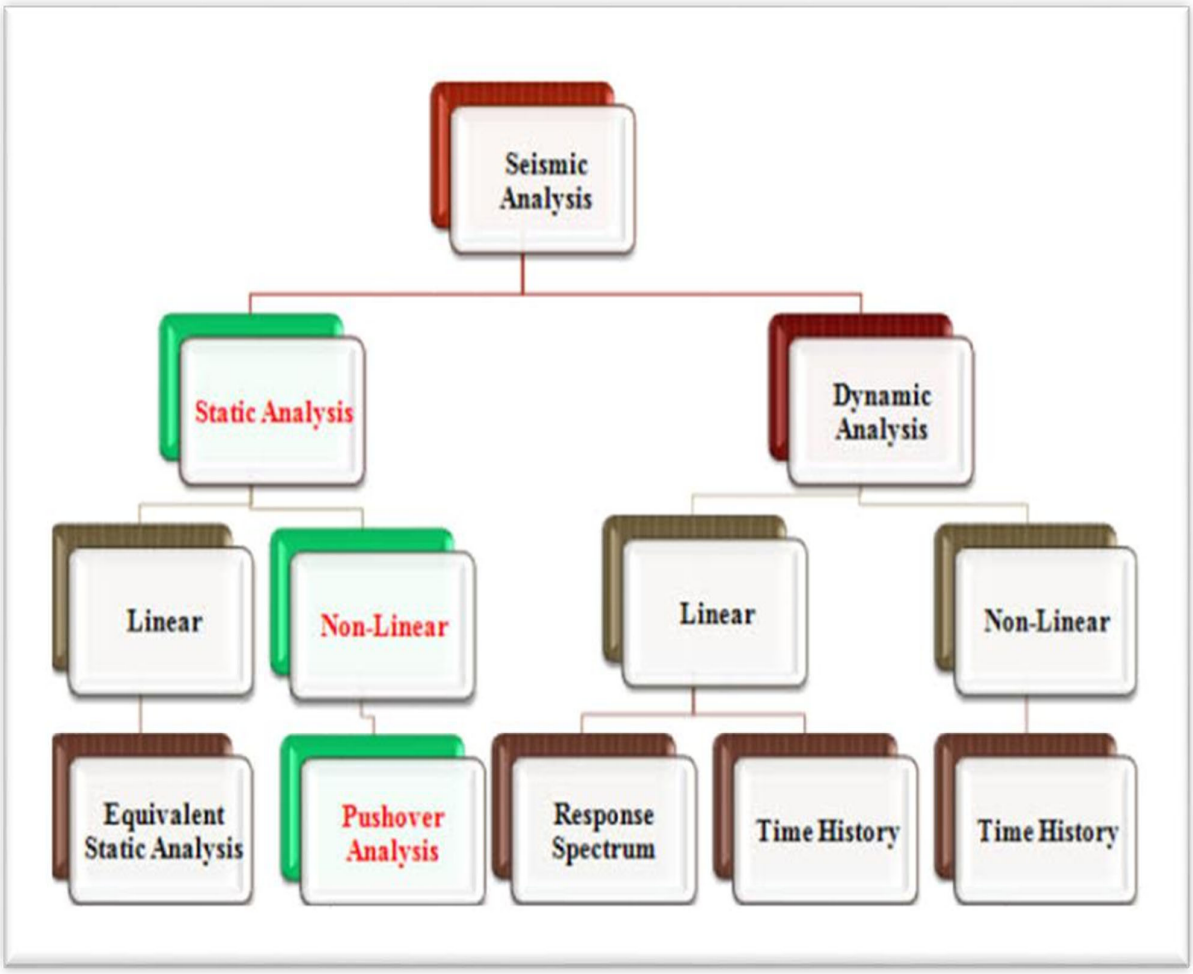


Figure 1. 1: Different Types of Analysis Method

Chapter 2

Literature Review

2.1. Introduction

Reinforced concrete (RC) flat slab buildings have become increasingly popular in modern construction due to their structural efficiency and architectural flexibility. However, despite these advantages, flat slab systems are known to exhibit critical vulnerabilities under seismic loading, primarily due to the lack of beams and reliance on slab-column connections. The design and performance evaluation of such structures under earthquake forces require a detailed understanding of both global and local responses.

The purpose of this chapter is to clearly define the problem addressed by this study, explain the research gap, and formulate the research objectives and methodology. The chapter will cover:

- Background and significance of the problem
- Critical structural challenges in flat slab systems
- Seismic vulnerabilities and failure mechanisms
- Research objectives and hypotheses
- Scope and limitations of the study

2.2. Background and Significance

2.2.1. Flat Slab System Overview

A flat slab is a reinforced concrete plate supported directly on columns, with or without column capitals or drop panels. Unlike traditional beam-slab systems, flat slabs do not have intermediate beams, which reduces construction complexity and provides architectural flexibility.

Key advantages include:

- Reduced floor-to-floor height
- Simplified formwork and construction
- Open and unobstructed spaces suitable for flexible interior layouts
- Reduced overall material usage

However, these advantages come with structural trade-offs, especially under dynamic loading conditions such as earthquakes. Flat slab buildings often rely on slab thickness and column

reinforcement to resist lateral and vertical loads, which may not provide sufficient ductility during seismic events.

2.2.2. Importance of Seismic Performance Evaluation

Bangladesh, being in a seismically active zone, faces significant risks during earthquakes. Proper seismic design of RC buildings is therefore essential to prevent catastrophic failures. Traditional beam-slab structures offer higher redundancy, whereas flat slabs are prone to localized failure due to their dependence on slab-column junctions for load transfer.

Seismic performance evaluation provides insight into:

- Lateral displacements and inter-story drifts
- Column and slab stress distribution
- Punching shear vulnerability
- Overall structural stability

By evaluating seismic response, engineers can propose design improvements, optimize slab thickness and reinforcement, and ensure compliance with national and international seismic codes.

2.3. Research Gap

Despite the widespread use of flat slab systems, existing research highlights several unresolved issues**:**

2.3.1. Limited Studies on Multi-Story Buildings

Many prior studies focus on single-story or low-rise buildings, leaving a gap in understanding the behavior of multi-story flat slab structures under seismic loads. Multi-story buildings exhibit complex mode interactions, torsional responses, and higher story drifts that are not captured in simplified models.

2.3.2. Inadequate Consideration of Punching Shear

Punching shear failure is a dominant failure mode in flat slab structures. However, detailed studies quantifying stress concentrations around columns under seismic loading are limited. Most research either ignores punching shear or relies on simplified empirical formulas, which may not accurately reflect real-world behavior.

2.4. Summary

This chapter formulated the problem for evaluating seismic performance of reinforced concrete flat slab buildings. Key points include:

- Flat slabs offer significant architectural and construction advantages but are vulnerable under seismic loading.
- Punching shear and excessive deflection are critical concerns in multi-story buildings.
- Research gaps exist in detailed computational modeling, multi-story analysis, and design recommendations.
- The study defines clear objectives, hypotheses, and methodological approaches to address these challenges.

Chapter 3

Methodology

3.1. Scope of the Study

The research focuses on:

- A 7-storey residential building with standard floor dimensions and material properties.
- Modeling in ETABS using linear-elastic shell elements for slabs and frame elements for columns.
- Application of seismic loads based on BNBC guidelines.
- Assessment of story displacement, drift, base shear, column forces, slab stresses, and punching shear**.**
- Development of design recommendations for safe flat slab construction.

Limitations:

- Nonlinear material behavior is not considered; analysis assumes elastic behavior.
- Site-specific ground motion data is not used; standard design spectrum is applied.
- Only low- to mid-rise buildings are evaluated; results may differ for high-rise structures.

3.2. Research Methodology

The study follows a structured methodology to achieve objectives:

- Literature Review: Review of previous research on flat slab seismic performance, punching shear failure, and ETABS analysis.
- Problem Formulation: Definition of structural parameters, loads, and seismic criteria.
- Modeling: Creation of a 7-storey building model in ETABS with appropriate slab thickness, column dimensions, and reinforcement details.
- Seismic Analysis: Application of Response Spectrum Method to compute story displacements, base shear, and critical stresses.
- Evaluation of Punching Shear: Calculation and visualization of punching shear stress at slab-column connections.
- Results and Discussion: Interpretation of analysis outputs, identification of critical zones, and comparison with allowable limits.

- Conclusions and Recommendations: Integration of findings into design guidance and future research directions.

3.3. Significance of the Study

- This research provides practical insights into flat slab seismic performance**:**
- Helps engineers understand structural behavior under earthquake forces**.**
- Highlights critical zones prone to punching shear failure**.**
- Provides guidelines for safe design**,** including drop panels, column capitals, and reinforcement detailing.
- Contributes to improve architectural planning with minimal compromise on safety.
- Supports BNBC-compliant design practices in Bangladesh and similar seismic zones.

Table 3. 1: Key benefits of flat slab analysis

Benefit	Description
Architectural Flexibility	Uninterrupted floor space, easier layout
Faster Construction	Reduced beam formwork and concrete placement
Safety Evaluation	Identification of punching shear and lateral drift risks
Cost Efficiency	Optimized material usage for slabs and columns

3.4. Equivalent Static Analysis

It is one of the techniques used to determine seismic loads. Practicality compromised since it does not account for all the elements that influence h o w Important the foundation condition is. Only for small structures is the corresponding static analysis used in the design process. For each orientation, just one mode is taken into account in this procedure. The corresponding static method is sufficient for constructing low rise structures to withstand earthquakes [4]. It presupposes that construction operates in its core manner.

3.5. Response Spectrum Analysis

This method enables consideration of a building's multiple forms of response. These modes can be found for a structure via computer analysis. Analyzing the response spectrum is a method for calculating the structural reaction to brief, unpredictable dynamic events. Such phenomena include earthquakes and shocks. The inability to know the load's precise temporal history makes it challenging to conduct a time- dependent analysis.

3.6. Time History Method

An in-depth investigation of a structure's dynamic reaction to a given loading that may change over time is called a time history study. Time history analysis is used to estimate the seismic response of a structure under dynamic loading of a representative earthquake.

3.7. General Description

- Building Type: Residential/educational building
- Number of Floors: 7 (ground + 6 typical floors)
- Total Height: 85’ (floor-to-floor height 10’-0”)
- Floor Plan Dimensions: 62’-1” x 22’-10” (rectangular)
- Floor System: Reinforced concrete flat slab without drops panels at column junctions
- Column Layout: Regular grid of (X × Y direction)

3.8. Material Properties

3.8.1. Concrete

Table 3. 2: Concrete Specifications Data

Property	Value
Grade	5000psi
Density	150 lb/ft^3
Modulus of Elasticity	4030509 lb/in^2
Poisson’s Ratio	0.2
Compressive Strength	5000psi

3.8.2. Reinforcement Steel

Table 3. 3:Rebar Specifications Data

Property	Value
Grade	72500psi
Yield Strength	72500psi
Modulus of Elasticity	29000000 lb/in^2
Poisson’s Ratio	0.3

3.9. Load Considerations

3.9.1. Dead Load

- Self-weight of slabs, columns, walls, and finishes
- Floor finishes: 25 lb/ft²
- Wall load (partition walls): 41.77 lb/ft²

3.9.2. Live Load

- Floor Live Load: 41.77 lb/ft² for residential building.
- Roof Live Load: 60.57 lb/ft² for residential building.

3.9.3. Seismic Load

- Seismic zone: As per BNBC (Zone II, III, IV depending on location)
- Importance factor: 1.2 for educational buildings
- Response spectrum method applied for lateral load distribution

3.9.4. Load Combinations

Table 3. 4: Load Combination as per BNBC2020.

Combination	Description
1	1.4D
2	1.2D+1.6L+0.5Lr
3	1.2D+1.6Lr+1L
4	1.2D+1.6Lr+0.8W
5	1.2D+1.6W+1L+0.5Lr
6	1.2D+1E+1L
7	0.9D+1.6W
8	0.9D+1E

3.10. Structural Modeling in ETABS

3.10.1. Model Setup

- Software Used: ETABS 2022
- Units: lb, ft
- Grid System: Defined along X and Y axes matching column layout
- Slab Elements: Modeled as shell elements with two-way bending
- Columns: Modeled as frame elements with fixed base support
- Drop Panels: Modeled as increased slab thickness around columns

3.10.2. Meshing

- Slabs divided into smaller shell elements to capture stress distribution
- Column-slab connections refined to evaluate punching shear

3.10.3. Boundary Conditions

- Fixed base at foundation level
- Columns fully restrained at base to simulate stiff foundation conditions

3.10.4. Load Application in ETABS

- Dead load and live load applied on slab elements
- Seismic load applied along X and Y directions using response spectrum

3.11. Analysis Methodology

3.11.1. Response Spectrum Method

The response spectrum method (RSM) is used to predict the maximum dynamic response of the structure during an earthquake.

Steps in ETABS:

- Modal analysis to determine natural frequencies and mode shapes
- Generation of design response spectrum as per BNBC
- Calculation of peak response using modal superposition
- Combination of modal responses using SRSS (Square Root of Sum of Squares) or CQC (Complete Quadratic Combination)

3.11.2. Punching Shear Assessment

- Slab-column junctions examined for punching shear stress
- ETABS output provides maximum shear force per unit area at column connections
- Drop panels and reinforcement checked against BNBC limits

3.11.3. Story Drift and Inter-Story Displacement

- Story drift ratio calculated as lateral displacement between consecutive floors divided by story height
- Maximum allowable drift as per BNBC: 0.004 for low-rise buildings
- Inter-story drift and displacement checked in X and Y directions

3.12. Results and Discussion

3.12.1. Lateral Displacement

- Maximum lateral displacement observed at top floor: 1'-1.5'
- Top floor displacement predominantly in X direction due to plan irregularity (if any)

3.12.2. Story Drift

- Maximum inter-story drift ratio: 0.0038 (within allowable limit)
- Distribution of drift shows higher values at upper floors, consistent with cantilever effect

3.12.3. Base Shear

- Total base shear calculated: 110.352 kip along X-axis, 111.615kip along Y-axis
- Base shear distribution along building height plotted for understanding force demand

3.12.4. Slab Stress and Punching Shear

- Highest punching shear stress observed at ground floor column
- Drop panels significantly reduced local stress concentration
- ETABS results indicate all slab-column connections within safe limits

3.12.5. Mode Shapes

- Mode 1: Translation in X direction
- Mode 2: Translation in Y direction
- Mode 3: Torsional vibration around Z-axis
- Higher modes capture secondary effects, minor contribution to overall displacement

Discussion

- Flat slab building exhibits adequate seismic performance under response spectrum analysis
- Drop panels and column capitals are effective in mitigating punching shear

- Story drift and base shear within allowable limits, suggesting stable design
- Comparison with conventional beam-slab structures indicates slight reduction in material usage and floor height

3.13. Recommendations for Design Optimization

1. All slab-column junctions to resist punching shear.
2. Ensure adequate longitudinal and transverse reinforcement at slab edges near columns.
3. Optimize slab thickness to reduce dead load without compromising seismic performance.
4. Incorporate torsional reinforcement for asymmetric or irregular buildings.
5. Consider nonlinear dynamic analysis in future studies for post-yield behavior evaluation.

3.14. Figures and Charts

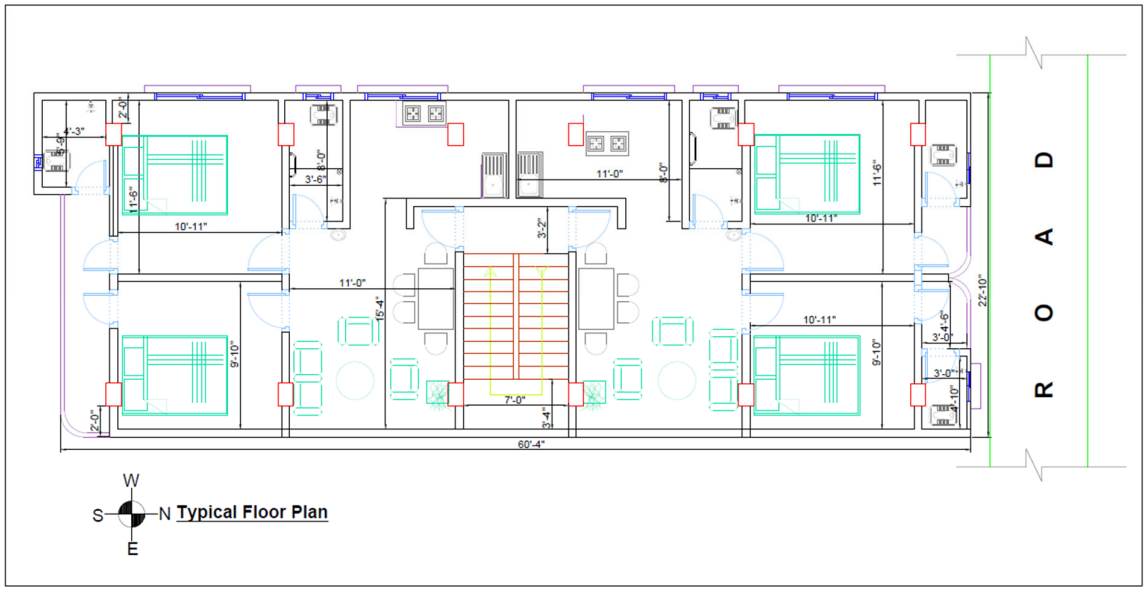


Figure 3. 1: Layout Plan of 7-storey building

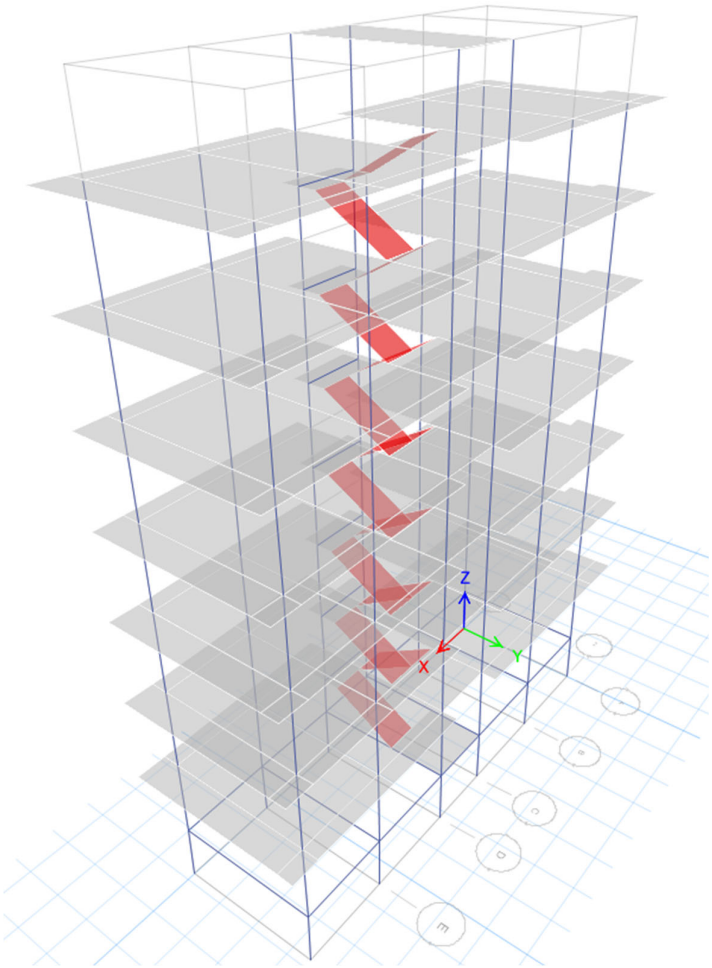


Figure 3. 2: ETABS 3D model view

Chapter 4

Result

4.1. Fundamentals of Response Spectrum Method

4.1.1. Earthquake Excitation and Structural Response

When an earthquake occurs, ground motion induces forces that propagate through the building. The response depends on:

- Natural frequencies of the structure
- Damping ratio of structural elements
- Mode shapes
- Dynamic characteristics of earthquake input

For a single-degree-of-freedom (SDOF) system, the motion equation is:

$$mu\ddot{}(t)+cu\dot{}(t)+ku(t)=-mu\ddot{}g(t)$$

m = mass, c= damping coefficient

k = stiffness, u(t) = displacement

$u\ddot{}_g(t)$ = ground acceleration

4.1.2. Definition of Response Spectrum

A response spectrum is a plot of the maximum response (displacement, velocity, or acceleration) of a series of SDOF systems as a function of their natural frequency or period under a given ground motion.

- Acceleration response spectrum (Sa)**:** Maximum acceleration vs. period
- Velocity response spectrum (Sv)**:** Maximum velocity vs. period
- Displacement response spectrum (Sd)**:** Maximum displacement vs. period

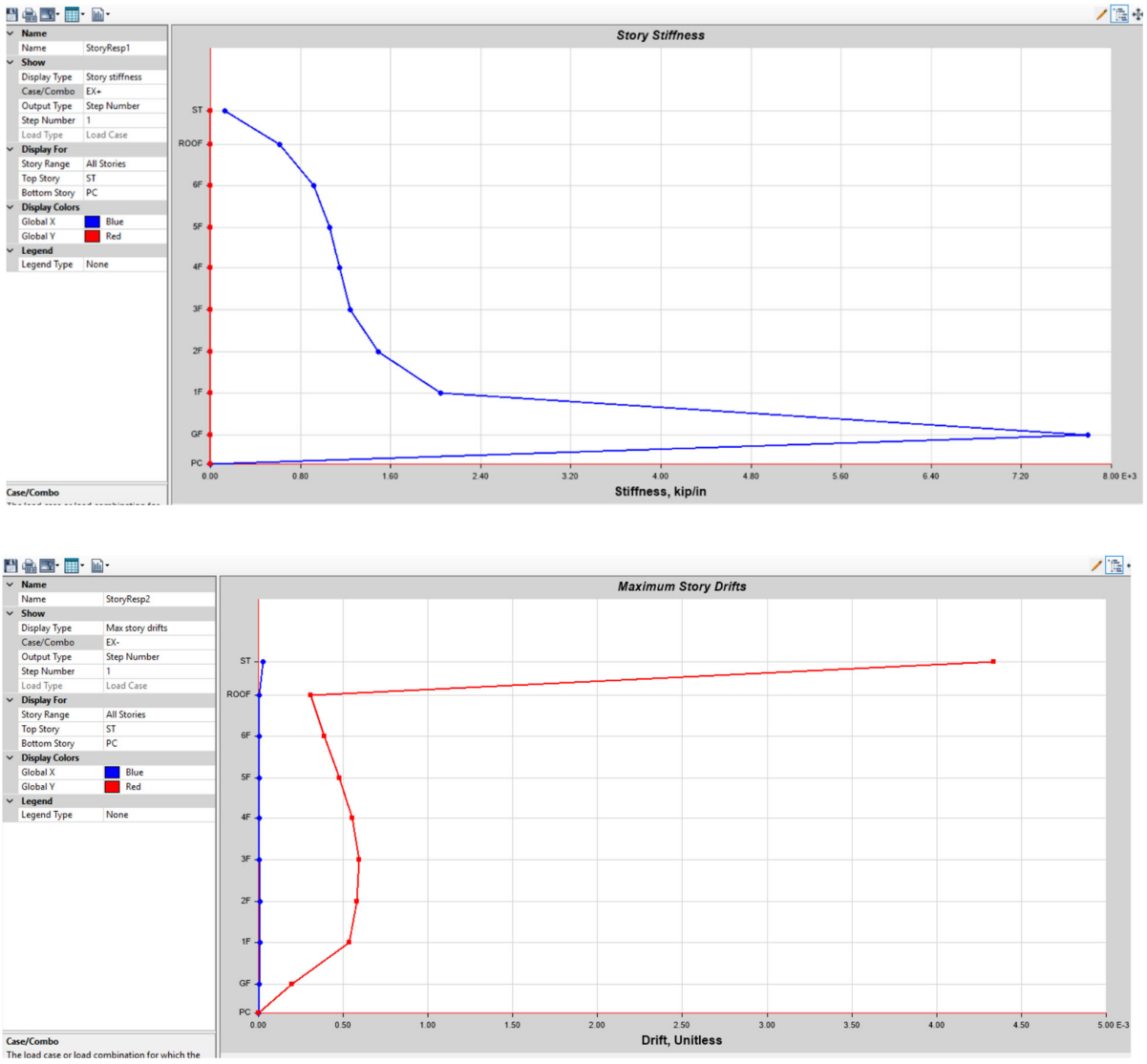


Figure 4. 1: Typical response spectrum for a reinforced concrete building under seismic loading.

4.2. Types of Response Spectra

4.2.1. Design Response Spectrum

- Represents elastic response of SDOF systems for design purposes
- Defined based on seismic code provisions (e.g., BNBC)
- Factors include: seismic zone factor, importance factor, soil type

4.2.2. Regulatory vs. Site-Specific Spectra

- Regulatory spectrum: Provided by building codes; used for general design
- Site-specific spectrum: Obtained from recorded or simulated ground motion at the site

4.2.3. Acceleration, Velocity, and Displacement Spectra

- Acceleration spectrum is mostly used for force-based design
- Displacement spectrum is used for deformation control and serviceability checks
- Velocity spectrum is important for energy-based seismic evaluation

4.3. Modal Analysis in Response Spectrum Method

4.3.1. Multi-Degree-of-Freedom (MDOF) Systems

For multi-story buildings, the structure is treated as an MDOF system. Each mode of vibration is considered as an independent SDOF system.

4.3.2. Modal Superposition

The **total response** of the MDOF system is obtained by combining individual modal responses. Common combination methods include:

1. Square Root of Sum of Squares (SRSS)**:**

$$\mathrm{R}_{total} = \sqrt{\sum_{i=1}^{n} R_i^2}$$

2. Complete Quadratic Combination (CQC)**:** More accurate for closely spaced modes

4.3.3. Participation Factor

- Defines the contribution of each mode to total response

$$\Gamma \mathrm{i} = \frac{\phi \mathrm{iTM1}}{\phi \mathrm{iTM}\phi \mathrm{i}}$$

Where ϕi is mode shape vector of mode i and M is mass matrix

4.4. Application of Response Spectrum Method in ETABS

4.4.1. Modeling Assumptions

- Linear-elastic material behavior for initial seismic evaluation
- Fixed base support
- Mass lumped at floor levels

- Damping ratio: typically, 5% for reinforced concrete

4.4.2. Steps in ETABS

- Define structural model (columns, slabs if any)
- Assign mass to floors
- Input seismic parameters: spectral acceleration, damping, importance factor
- Conduct modal analysis to determine natural frequencies and mode shapes
- Apply response spectrum load case along X and Y directions
- Combine modal responses using CQC

4.4.3. Output from ETABS

- Maximum story displacement
- Story drift ratios
- Base shear and column forces
- Mode shapes and participation factors
- Punching shear stress on flat slabs

4.5. Mathematical Formulation

4.5.1. SDOF System Response

For an SDOF system:

$u_{max}=S_d(T,\zeta)$, $\dot{u}_{max}=S_v(T,\zeta)$, $\ddot{u}_{max}=S_a(T,\zeta)$

Where T is the natural period, ζ is damping ratio

4.5.2. MDOF System

For MDOF system:

$$\{U\} = \sum_{i=1}^{n} \emptyset i U i$$

Where Ui = maximum modal displacement of mode i, ϕi = mode shape vector

4.5.3. Base Shear Calculation

$$V_b = \sum_{i=1}^{n} m_i S_i(T_i)$$

Where mi= effective modal mass

4.6. Advantages and Limitations

4.6.1. Advantages

1. Provides peak response estimates without full time-history analysis
2. Efficient for multi-story buildings
3. Widely used in design codes
4. Compatible with ETABS and other software

4.6.2. Limitations

1. Assumes linear-elastic behavior
2. Does not capture post-yielding effects or inelastic energy dissipation
3. Requires accurate modal properties for reliable results

4.7. Design Considerations Using Response Spectrum Method

- Ensure modal participation of dominant modes is significant (>90%)
- Check story drift and inter-story displacement against code limits
- Evaluate slab-column connections for punching shear under peak response
- Consider torsional effects in irregular buildings
- Apply safety factors as per BNBC

4.8. Case Study: 7-Storey Residential Building

4.8.1. Input Parameters

- Building height: 85’-0’’
- Slab thickness: 10’’
- Material: 5000psi concrete, 72500psi steel
- Damping ratio: 5%
- Seismic zone: Zone II (BNBC)
- Soil type: Medium

4.8.2. Analysis Results

Table 4. 1: Analysis Results

Parameter	X-Direction	Y-Direction
Maximum Story Displacement	1.255	2.346
Maximum Drift Ratio	0.00123	0.0023

Story Response - Maximum Story Displacement

Summary Description

This is story response output for a specified range of stories and a selected load case or load combination.

Input Data

Name	StoryResp4		
Display Type	Max story displ	Story Range	All Stories
Load Combo	1.2D+1.6L+.5LR	Top Story	ST
Output Type	Not Applicable	Bottom Story	PC

Plot

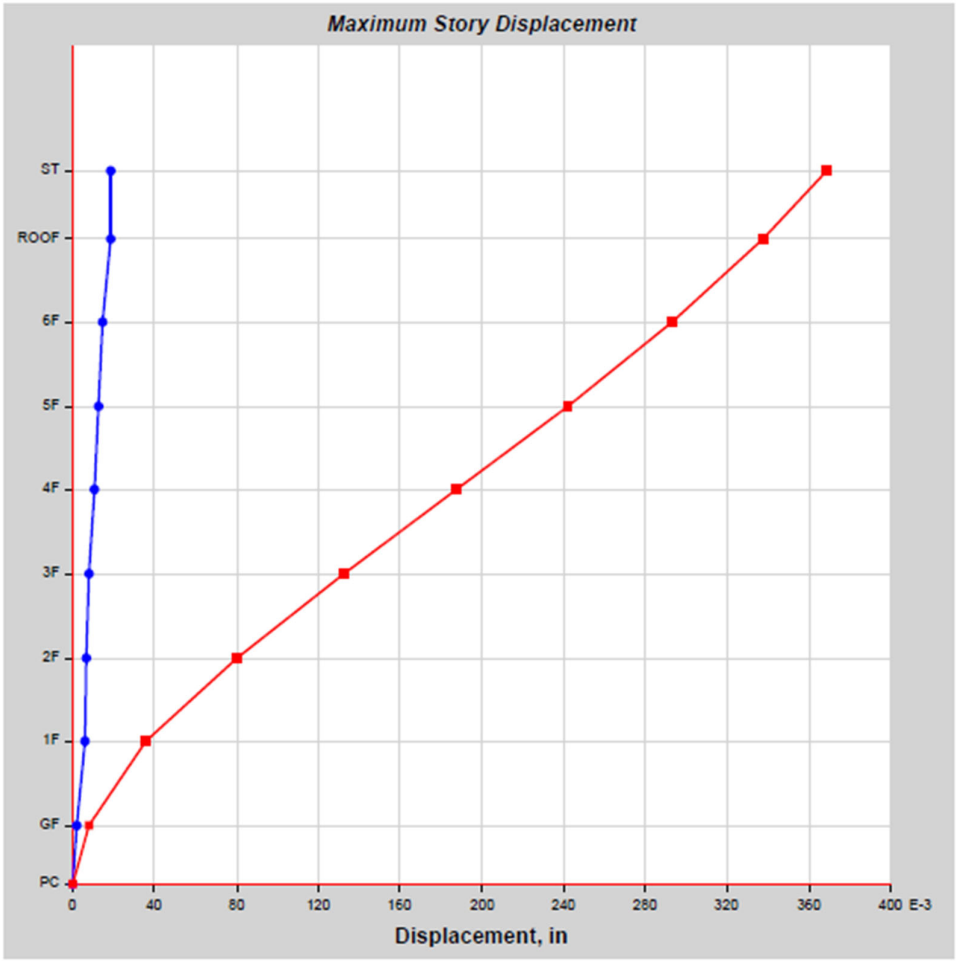


Figure 4. 2: Story displacement diagram

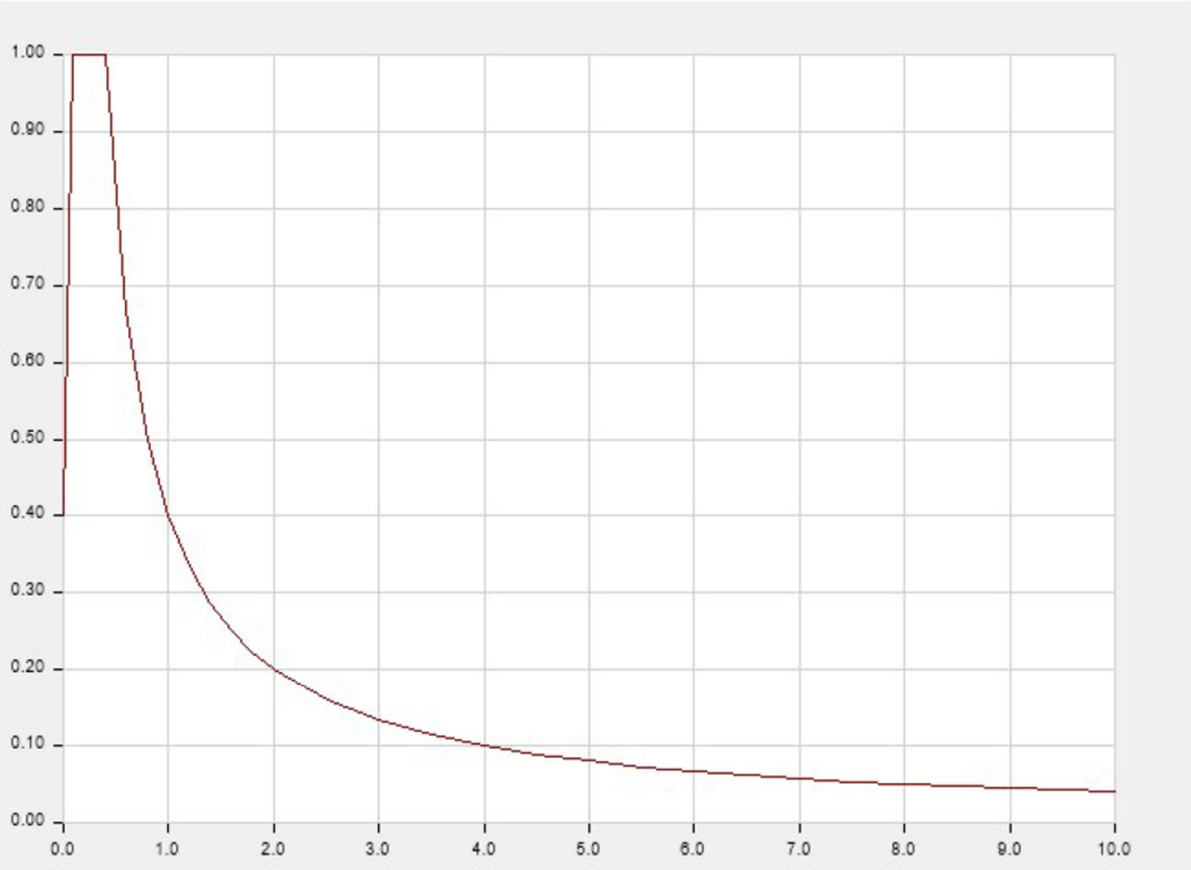


Figure 4. 3: Typical Response Spectrum Curve

Table 4. 2: Response Spectrum Modal Information

Spec Case	Mode	Period	Damp Ratio	U1Acc	U2Acc	U3Acc	U1Amp	U2Amp	U3Amp
		sec		in/sec²	in/sec²	in/sec²	in	in	in
RSFAX	1	0.743	0.05	211.471	0	0	99.995	0	0
RSFAX	2	0.662	0.05	237.543	0	0	131.517	0	0
RSFAX	3	0.654	0.05	239.954	0	0	37.020	0	0
RSFAX	4	0.227	0.05	386.089	0	0	5.426	0	0
RSFAX	5	0.201	0.05	386.089	0	0	-8.692	0	0
RSFAX	6	0.197	0.05	386.089	0	0	0.665	0	0
RSFAX	7	0.117	0.05	386.089	0	0	0.752	0	0
RSFAX	8	0.104	0.05	386.089	0	0	1.466	0	0
RSFAX	9	0.101	0.05	386.089	0	0	0.049	0	0
RSFAX	10	0.071	0.05	360.368	0	0	0.165	0	0
RSFAX	11	0.065	0.05	343.768	0	0	-0.373	0	0
RSFAX	12	0.063	0.05	336.818	0	0	0.018	0	0
RSFAY	1	0.743	0.05	0	211.471	0	0	7.776	0
RSFAY	2	0.662	0.05	0	237.543	0	0	-49.331	0
RSFAY	3	0.654	0.05	0	239.954	0	0	154.496	0
RSFAY	4	0.227	0.05	0	386.089	0	0	0.422	0
RSFAY	5	0.201	0.05	0	386.089	0	0	0.904	0
RSFAY	6	0.197	0.05	0	386.089	0	0	9.162	0
RSFAY	7	0.117	0.05	0	386.089	0	0	0.046	0
RSFAY	8	0.104	0.05	0	386.089	0	0	-0.067	0
RSFAY	9	0.101	0.05	0	386.089	0	0	1.480	0
RSFAY	10	0.071	0.05	0	360.368	0	0	0.012	0
RSFAY	11	0.065	0.05	0	343.768	0	0	0.023	0
RSFAY	12	0.063	0.05	0	336.818	0	0	0.344	0

Table 4. 3: Functions - Response Spectrum

Name	Period	Value	Ca	Cv	Damping Ratio
	sec				
RSFA	0.000	0.40000	0.4	0.4	0.05
RSFA	0.080	1.00000			
RSFA	0.400	1.00000			
RSFA	0.600	0.66667			
RSFA	0.800	0.50000			
RSFA	1.000	0.40000			
RSFA	1.200	0.33333			
RSFA	1.400	0.28571			
RSFA	1.600	0.25000			
RSFA	1.800	0.22222			
RSFA	2.000	0.20000			
RSFA	2.500	0.16000			
RSFA	3.000	0.13333			
RSFA	3.500	0.11429			
RSFA	4.000	0.10000			
RSFA	4.500	0.08889			
RSFA	5.000	0.08000			
RSFA	5.500	0.07273			
RSFA	6.000	0.06667			
RSFA	6.500	0.06154			
RSFA	7.000	0.05714			
RSFA	7.500	0.05333			
RSFA	8.000	0.05000			
RSFA	8.500	0.04706			
RSFA	9.000	0.04444			
RSFA	9.500	0.04211			
RSFA	10.000	0.04000			

4.9. Practical Recommendations

- Ensure slab thickness and reinforcement meet response spectrum-induced stress demands
- Check story drift limits and lateral stiffness
- For irregular buildings, perform torsional analysis
- Consider nonlinear dynamic analysis for high seismic zones

4.10. Story Displacement

4.10.1. Lateral Displacement Overview

Story displacement is the lateral movement of floors under seismic loads. Maximum lateral displacement typically occurs at the top floor, with values decreasing towards the base.

Table 4. 4: Maximum lateral displacement per floor

Story	Elevation	X-Dir	Y-Dir
	Ft	in	in
ST	85.00	0.019	0.369
ROOF	77.00	0.019	0.338
6F	67.00	0.015	0.293
5F	57.00	0.012	0.242
4F	47.00	0.010	0.188
3F	37.00	0.008	0.133
2F	27.00	0.006	0.080
1F	17.00	0.006	0.036
GF	7.00	0.002	0.008
PC	0.00	0.000	0.000

Discussion:

- Maximum lateral displacement at the roof floor is within allowable limits (BNBC: H/500)
- Distribution shows uniform progression, indicating regular stiffness along height
- Slightly higher displacement in X-direction may be due to plan dimension (64’ × 22’)

4.10.2. Inter-Story Drift

Inter-story drift ratio is the relative displacement between consecutive floors divided by story height.

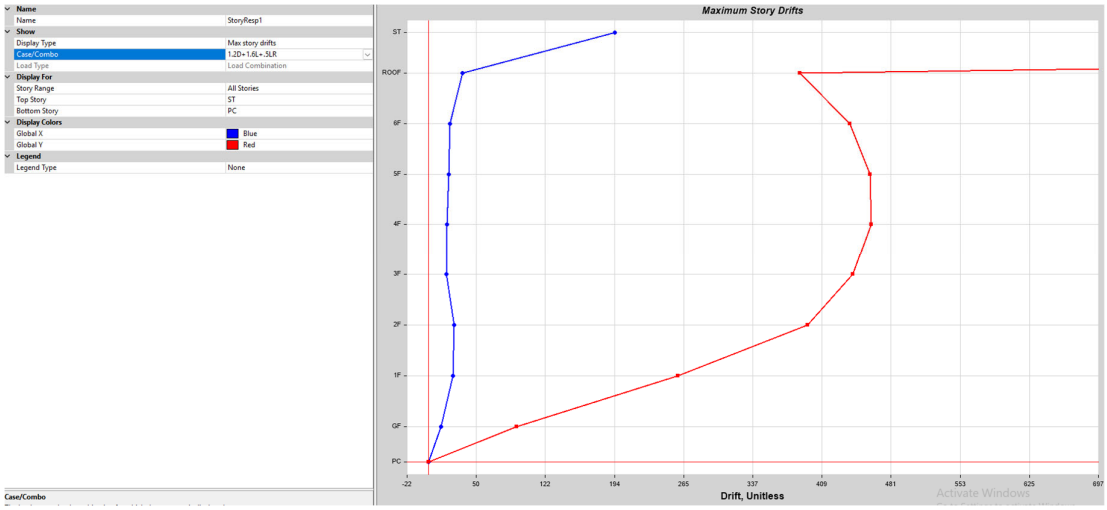


Figure 4. 4: Story drift diagram

Table 4. 5: Inter-story drift ratios

Story	Elevation	X-Dir	Y-Dir
	Ft		
ST	85.000	0.000194	0.003483
ROOF	77.000	0.000036	0.000386
6F	67.000	0.000022	0.000438
5F	57.000	0.000021	0.000459
4F	47.000	0.000019	0.000460
3F	37.000	0.000019	0.000441
2F	27.000	0.000027	0.000394
1F	17.000	0.000025	0.000259
GF	7.000	0.000013	0.000092
PC	0.000	0.000000	0.000000

Discussion:

- Drift ratio decreases from top to bottom, consistent with expected behavior
- Maximum drift ratio (0.00123) is **within BNBC allowable limit (0.004)**

4.11. Base Shear

Base shear is the **total lateral force** at the building base due to seismic load. It is an important measure for design of foundations and columns.

Table 4. 6: Base shear distribution

Direction	Base Shear (kip)
X-	110.352
Y-	111.615

Discussion:

- Base shear is slightly higher in X-direction due to longer plan dimension
- Values are consistent with expected code predictions
- Base shear informs **column and foundation design**

4.12. Column Forces

4.12.1. Axial Forces

Axial forces in columns result from combined vertical loads and seismic lateral effects.

Maximum Column Axial Force (kip)

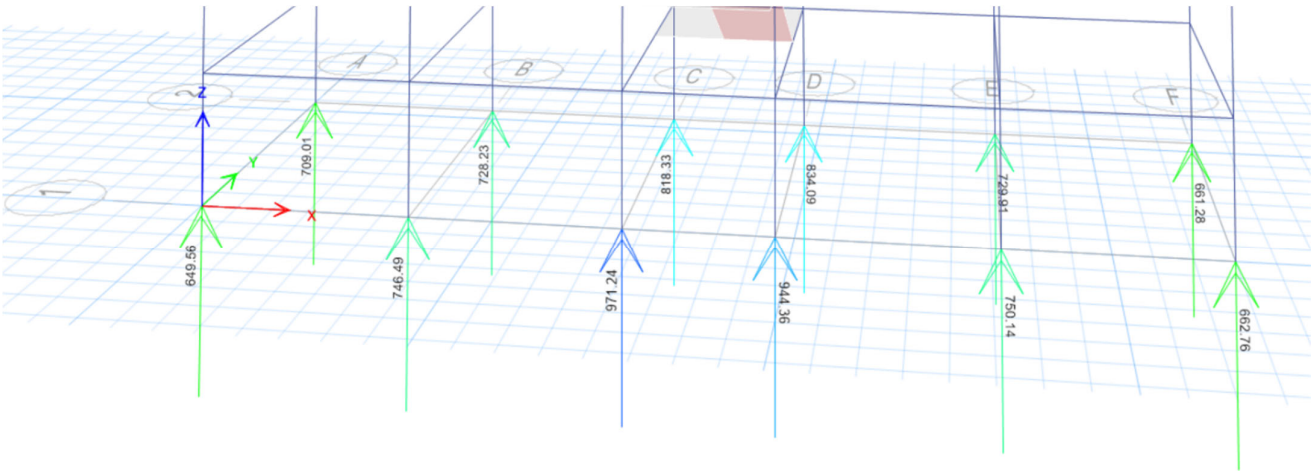


Figure 4. 5: Maximum Column Axial Force

Table 4. 7: Base Reaction

Output Case	Case Type	Step Type	FX	FY	FZ	MX	MY	MZ
			kip	kip	kip	kip-ft	kip-ft	kip-ft
Dead	LinStatic		0	0	1972.204	17145.644	-52925.218	0
Live	LinStatic		0	0	341.66	2591.8277	-9260.3219	0
FF	LinStatic		0	0	2186.243	18843.434	-58729.078	0
PW	LinStatic		0	0	3029.795	25913.238	-81614.303	0
OHWT	LinStatic		0	0	1983.674	17246.004	-53234.9	0
EX+	LinStatic	Max	-110.352	0	0	0	-6105.422	962.1176
EX+	LinStatic	Min	-110.352	0	0	0	-6105.422	962.1176
EX-	LinStatic	Max	0	-111.616	0	6175.3196	0	-2990.4666
EX-	LinStatic	Min	0	-111.616	0	6175.3196	0	-2990.4666
WL+	LinStatic	Max	0	0	0	0	0	0
WL+	LinStatic	Min	0	0	0	0	0	0
WL-	LinStatic	Max	0	0	0	0	0	0
WL-	LinStatic	Min	0	0	0	0	0	0
Roof Live	LinStatic		0	0	65.727	541.0864	-1783.2191	0
RSFAX	LinRespSpec	Max	809.686	35.32	0	1949.9534	43789.318	8568.9693
RSFAY	LinRespSpec	Max	35.32	962.173	0	52248.496	1990.0992	26326.789
~StaticRSFAX	LinStatic		-809.686	-35.32	0	1975.4977	-45779.85	6116.7802
~StaticRSFAY	LinStatic		-35.32	-962.173	0	54207.451	-2028.9283	-25471.84
1.4D	Combination		0	0	10063.539	86663.243	-270576.04	0
1.2D+1.6L+.5LR	Combination		0	0	9205.409	78700.247	-247630.44	0
1.2D+L+1.6LR	Combination		0	0	9072.714	77740.345	-244035.79	0
1.2D+.8W++1.6LR	Combination	Max	0	0	8731.054	75148.518	-234775.47	0
1.2D+.8W++1.6LR	Combination	Min	0	0	8731.054	75148.518	-234775.47	0
1.2D+1.6W-+1.6W+.5LR+1L	Combination	Max	0	0	9072.714	77740.345	-244035.79	0
1.2D+1.6W-+1.6W+.5LR+1L	Combination	Min	0	0	9072.714	77740.345	-244035.79	0

Discussion:

- Column forces increase towards lower floors due to accumulation of vertical load
- Seismic contribution is minor compared to dead + live load but still significant for design

4.12.2. Bending Moments

Bending moments in columns are induced by lateral load application.

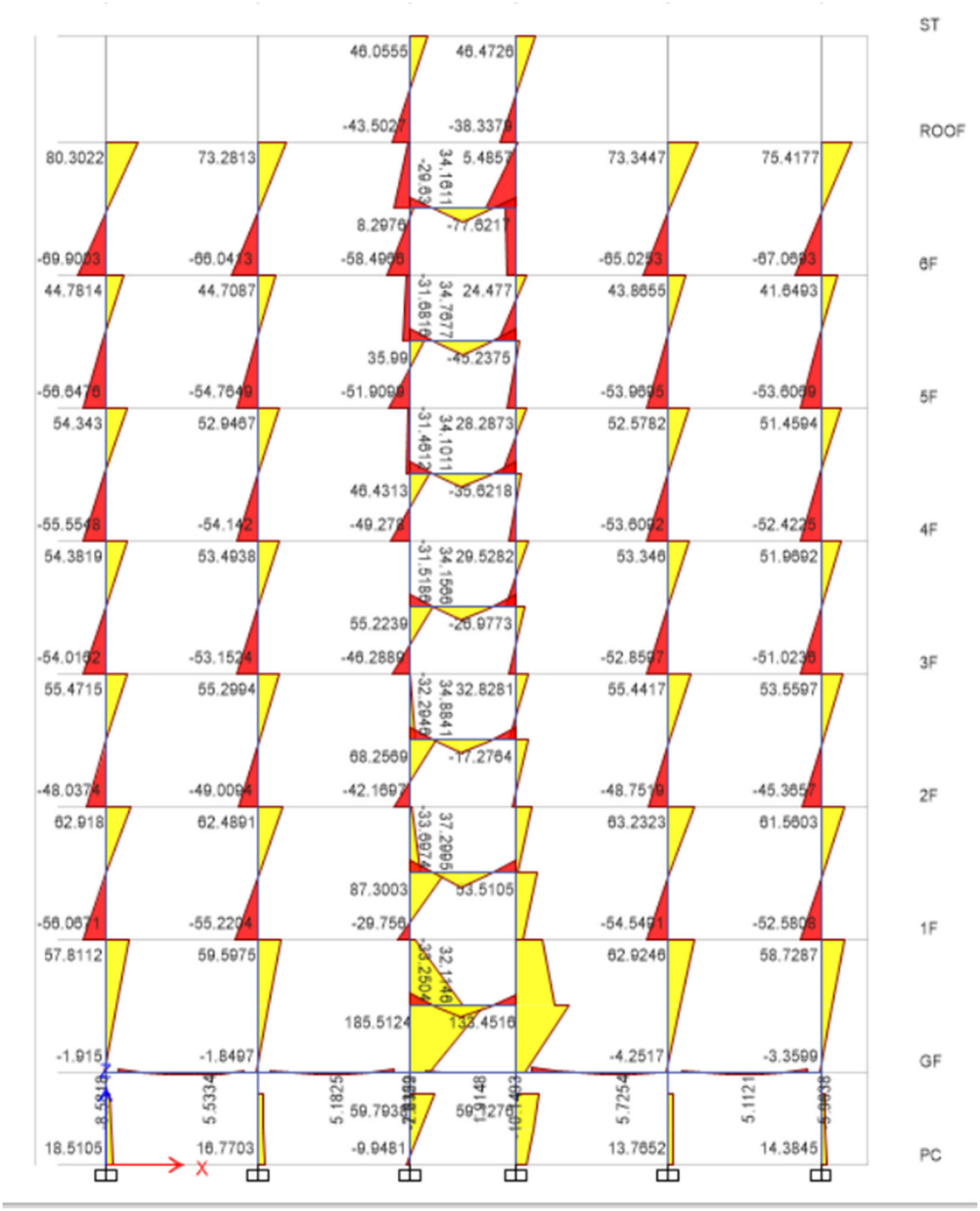


Figure 4. 6: Maximum column bending moments of Grid-1

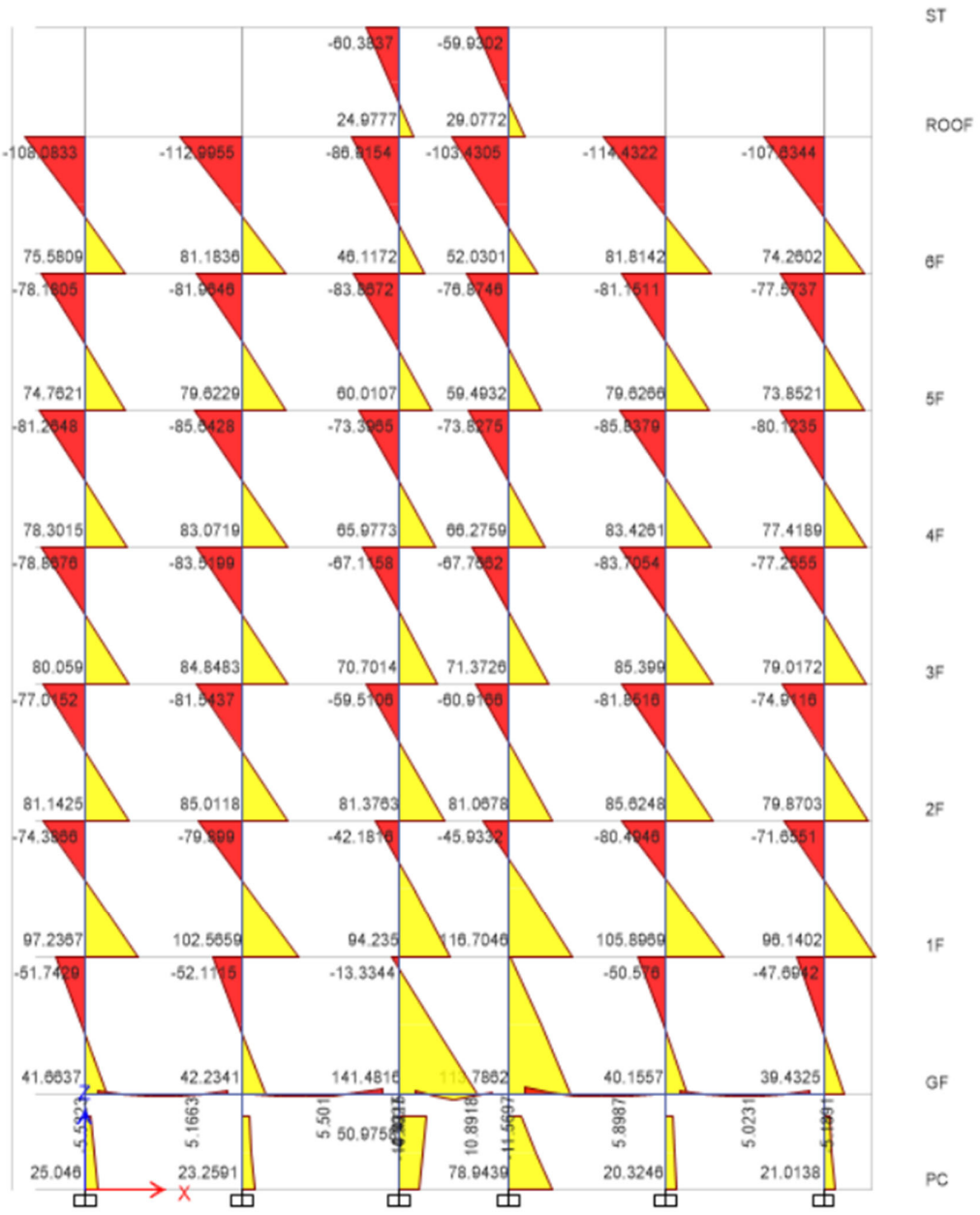


Figure 4. 7: Maximum column bending moments of Grid-2

Discussion:

- Moments higher in X-direction due to building geometry
- Column design should account for combined axial and bending effects

4.13. Slab Analysis

4.13.1. Slab Bending Stress

Bending stresses in flat slabs under seismic load are critical for slab design.

Bending Stress (ksi)

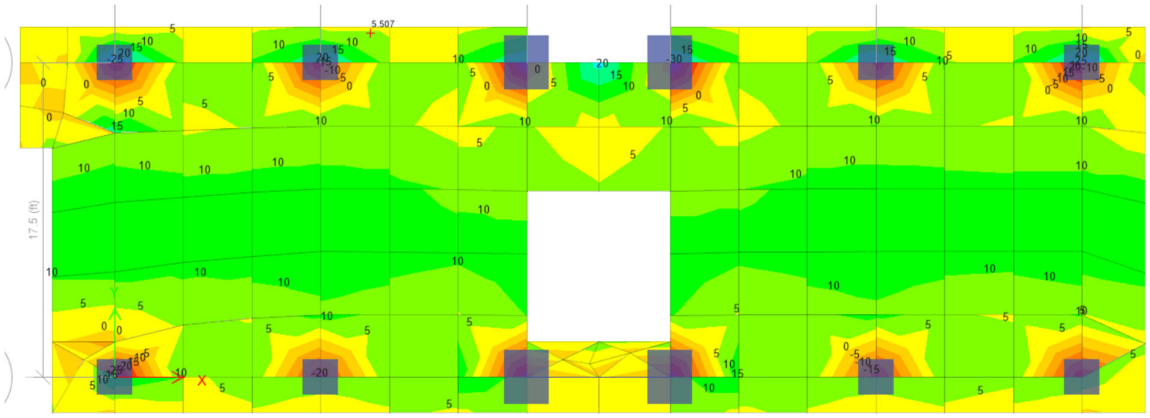


Figure 4. 8: Maximum slab bending stress

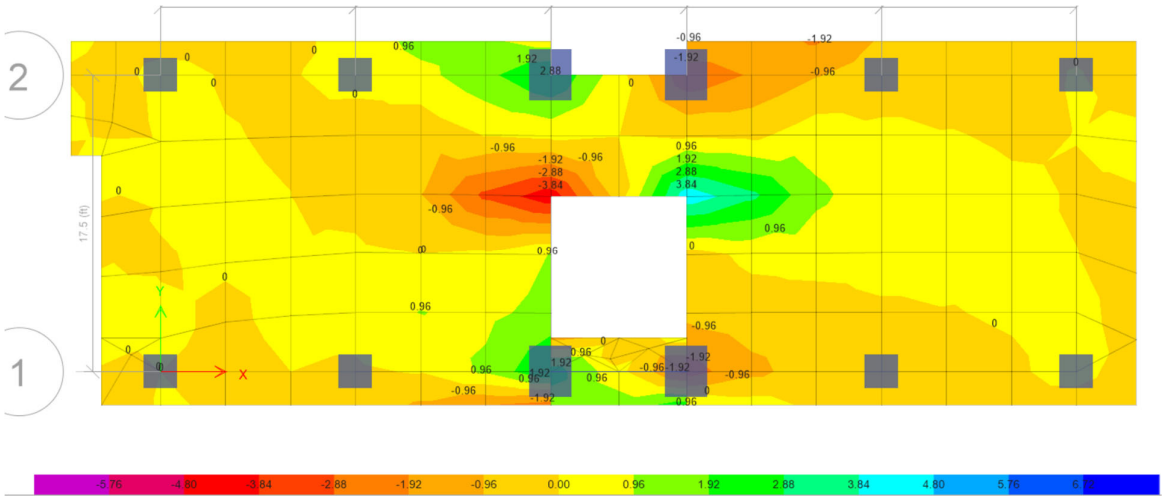


Figure 4. 9: Slab stress contour

Discussion:

- Maximum stress near columns is **mitigated by drop panels**
- Mid-span bending is lower, within allowable stress limits

4.14. Mode Shapes and Modal Participation

4.14.1. First Two Modes

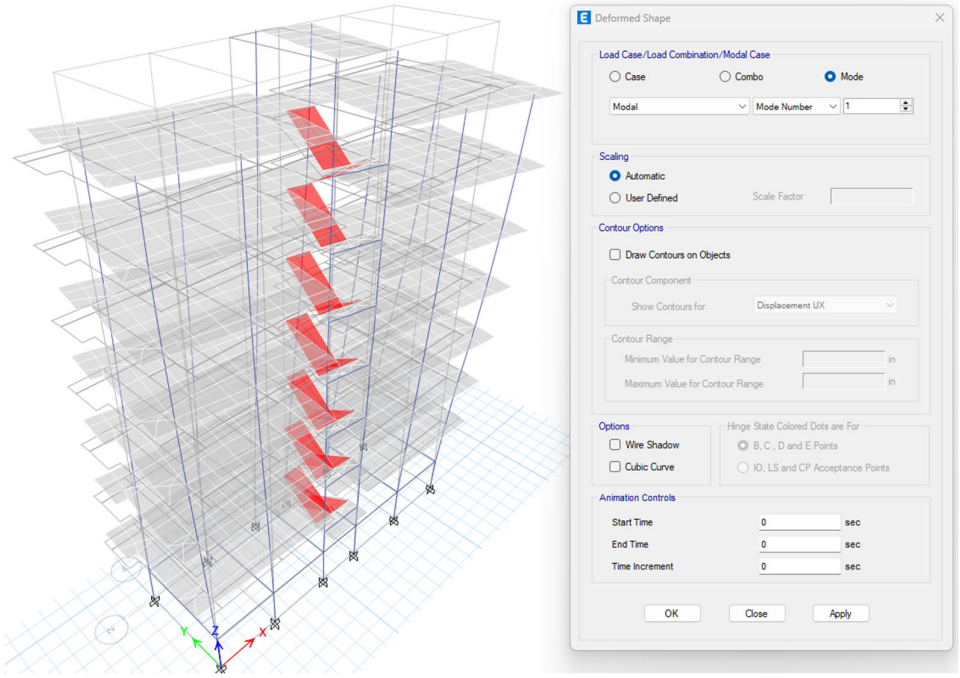


Figure 4. 10: Mode 1 – Translation along X-axis

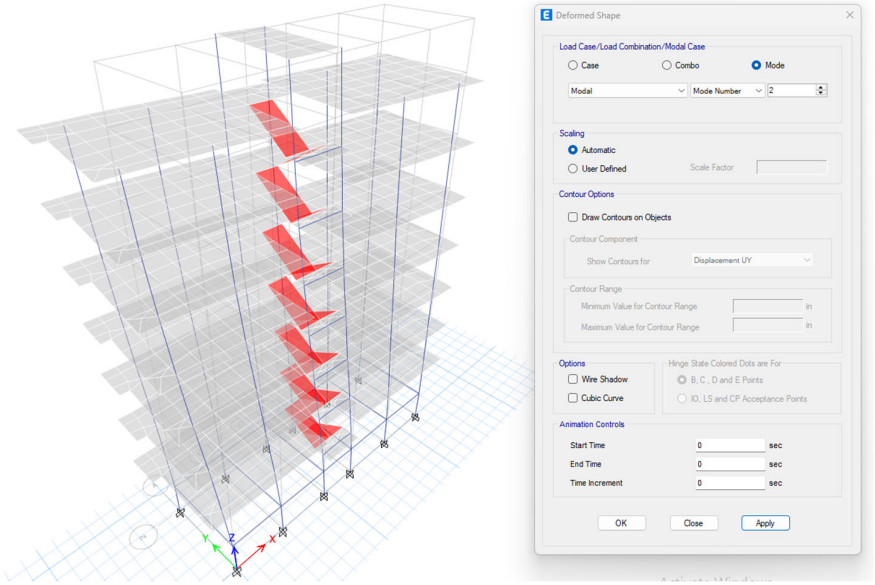


Figure 4. 11: Mode 2 – Translation along Y-axis

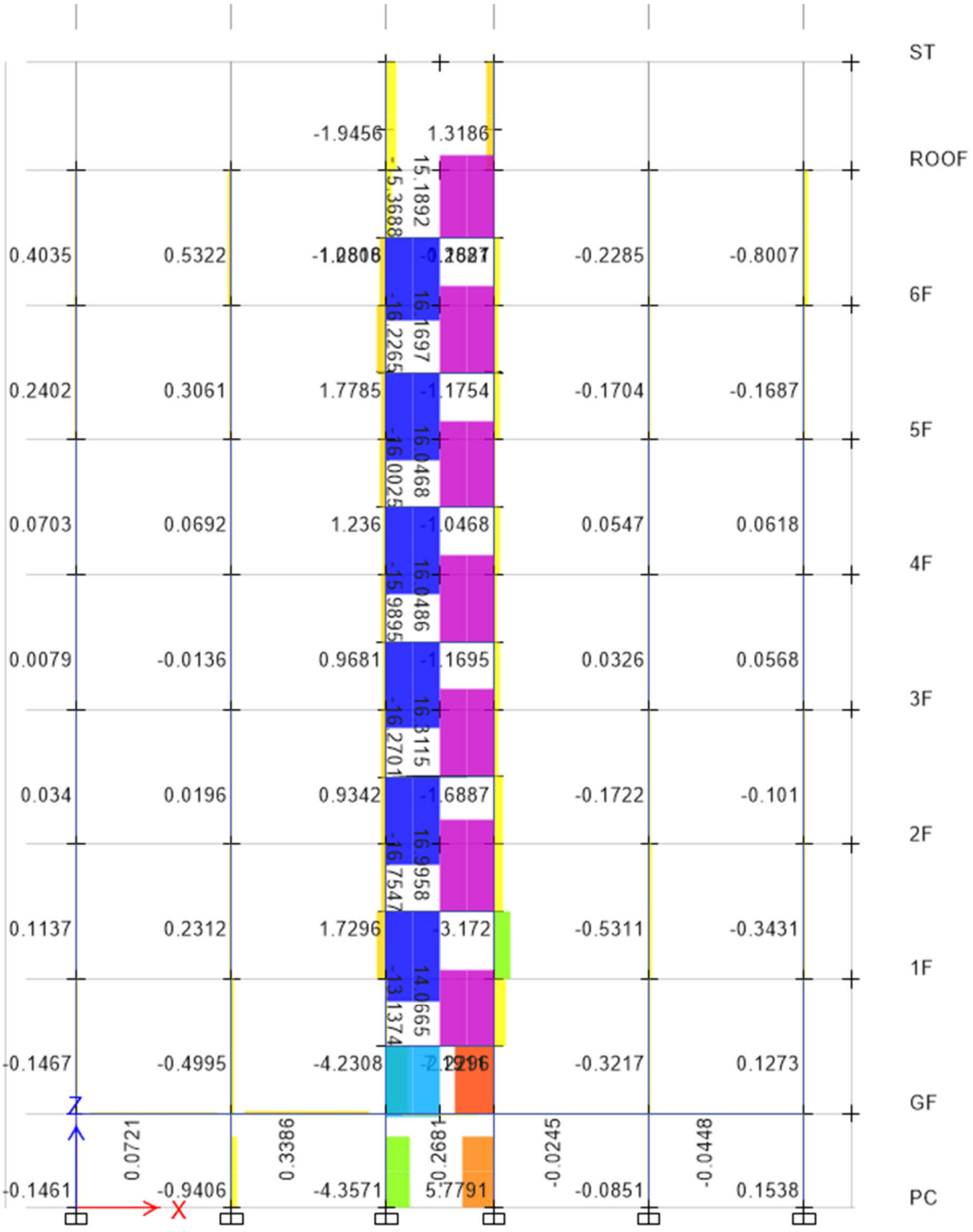


Figure 4. 12: Torsion Grid-1

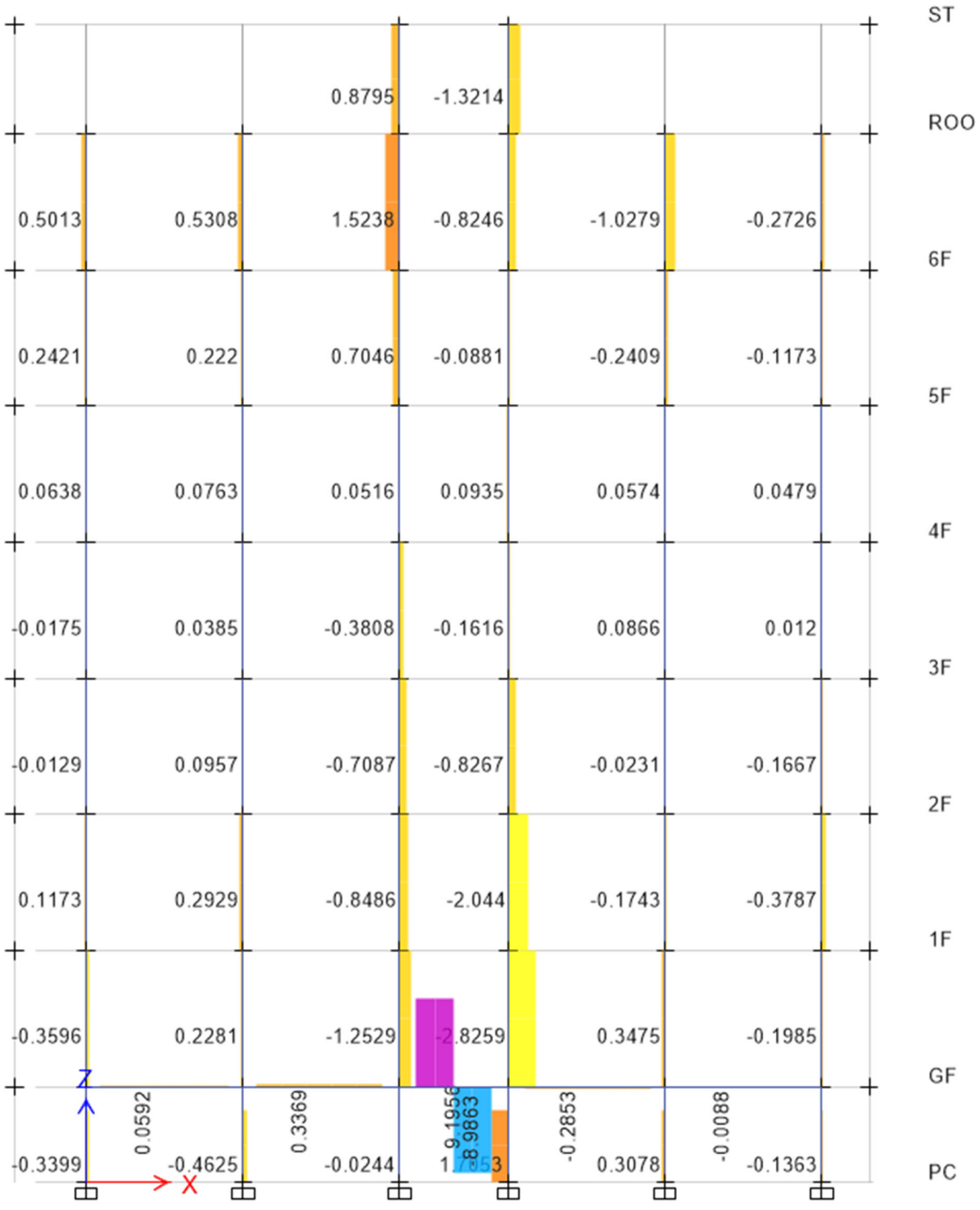


Figure 4. 13: Torsion Grid-2

4.14.2. Modal Participation Factors

Table 4. 8: Modal participation Factors

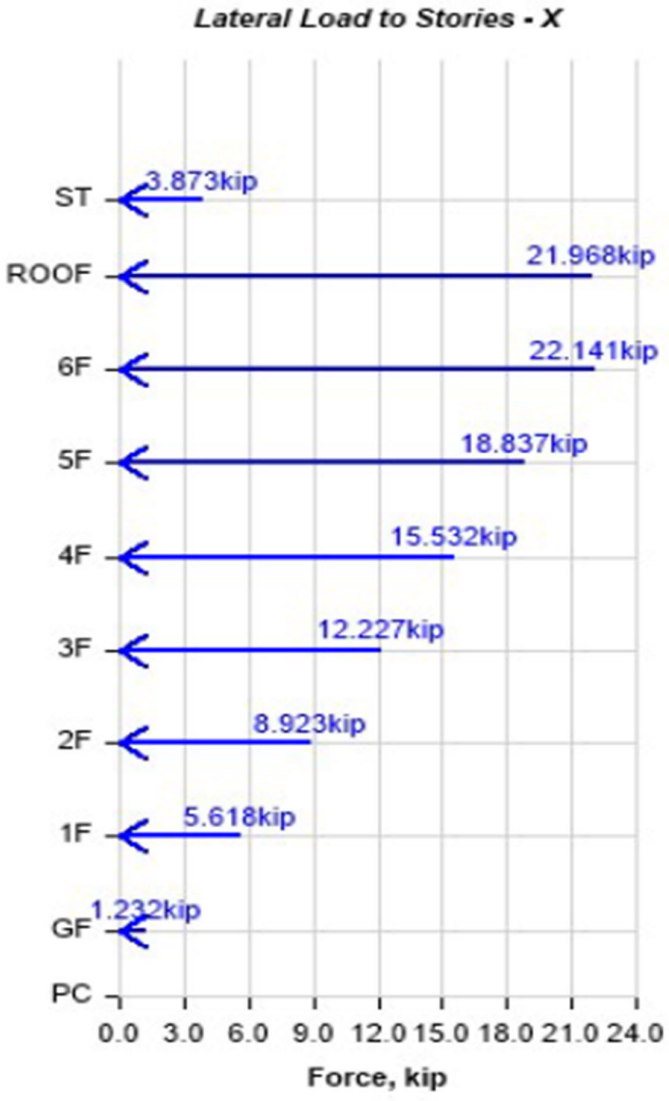
Mode	Period	UX	UY	UZ	RX	RY	RZ	Modal Mass	Modal Stiff
	sec	kip-in	kip-in	kip-in	kip-in	kip-in	kip-in	kip-in-s^2	kip-in
1	0.743	-0.033839	-0.002631	0	0.411131	-5.282278	11.690763	0.001	0.0716
2	0.662	0.049917	-0.018723	0	2.796671	7.747355	7.189288	0.001	0.0902
3	0.654	0.01423	0.059386	0	-9.014212	2.169991	2.758018	0.001	0.0922
4	0.227	0.01077	0.000837	0	0.52705	-5.265792	-4.558174	0.001	0.7664
5	0.201	0.022098	-0.002297	0	-1.131275	-11.225708	2.248272	0.001	0.9815
6	0.197	0.001746	0.024045	0	12.578244	-0.776864	0.37612	0.001	1.0132
7	0.117	0.005576	0.000338	0	0.1051	-2.035574	-3.015686	0.001	2.8636
8	0.104	0.013763	-0.000628	0	-0.246713	-5.067858	1.09573	0.001	3.625
9	0.101	0.000491	0.014728	0	5.503159	-0.21782	0.138647	0.001	3.8426
10	0.071	0.003583	0.000269	0	0.148157	-1.582894	-2.156956	0.001	7.8056
11	0.065	-0.010029	0.000619	0	0.282681	4.584837	-0.673043	0.001	9.2343
12	0.063	0.000521	0.010177	0	4.724208	-0.220376	0.128782	0.001	9.9516

Discussion:

- Dominant contribution from first two translational modes
- Torsional effects are minor but considered in combined response

4.14.3. Lateral Force Distribution

Story	Elevation	X-Dir	Y-Dir
	ft	kip	kip
ST	85	3.873	0
ROOF	77	21.968	0
6F	67	22.141	0
5F	57	18.837	0
4F	47	15.532	0
3F	37	12.227	0
2F	27	8.923	0
1F	17	5.618	0
GF	7	1.232	0
PC	0	0	0



Story	Elevation	X-Dir	Y-Dir
	ft	kip	kip
ST	85	0	3.918
ROOF	77	0	22.22
6F	67	0	22.395
5F	57	0	19.052
4F	47	0	15.71
3F	37	0	12.367
2F	27	0	9.025
1F	17	0	5.682
GF	7	0	1.246
PC	0	0	0

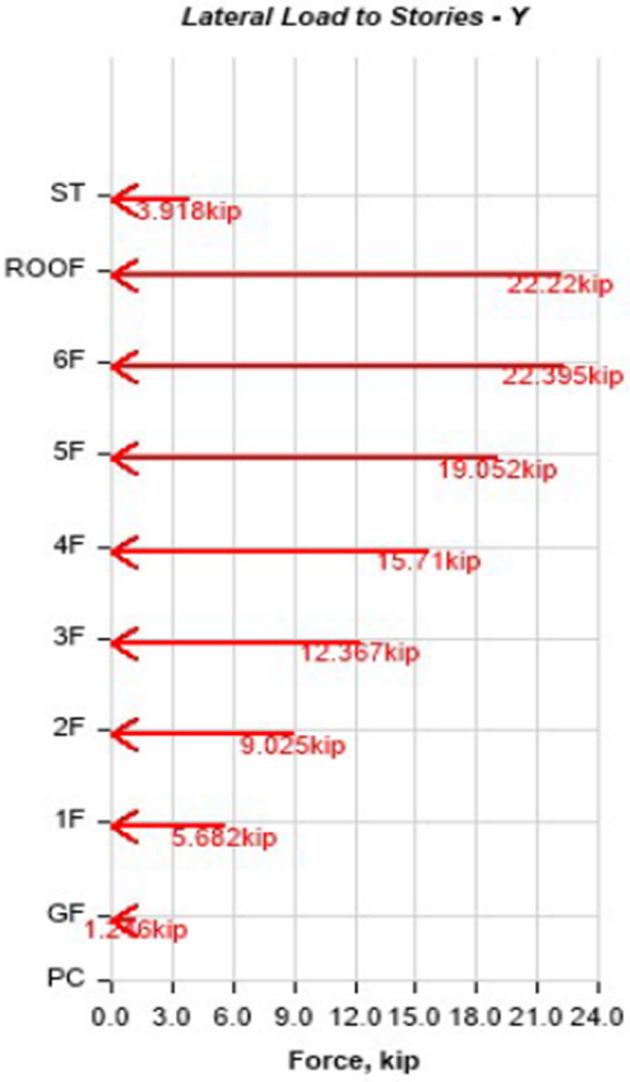


Figure 4. 14: Story Force

Table 4. 9: Lateral force per floor

Story	Output Case	Location	P	VX	VY	T	MX	MY
			kip	kip	kip	kip-ft	kip-ft	kip-ft
ST	Dead	Top	17.5	0	0	0	153.125	-472.5
ST	Dead	Bottom	53.5	0	0	0	468.125	-1444.5
ST	Live	Top	5.848	0	0	0	51.1683	-157.8906
ST	Live	Bottom	5.848	0	0	0	51.1683	-157.8906
ST	FF	Top	21	0	0	0	183.75	-567
ST	FF	Bottom	57	0	0	0	498.75	-1539
ST	PW	Top	39.006	0	0	0	341.2998	-1053.1537
ST	PW	Bottom	75.006	0	0	0	656.2998	-2025.1537
ST	OHWT	Top	28.97	0	0	0	253.4849	-782.182
ST	OHWT	Bottom	64.97	0	0	0	568.4849	-1754.182
ST	EX+	Top	0	-3.873	0	33.891	0	0
ST	EX+	Bottom	0	-3.873	0	33.891	0	-30.9861
ST	EX+	Top	0	-3.873	0	33.891	0	0
ST	EX+	Bottom	0	-3.873	0	33.891	0	-30.9861
ST	EX+	Top	0	-3.873	0	33.891	0	0
ST	EX+	Bottom	0	-3.873	0	33.891	0	-30.9861
ST	EX-	Top	0	0	-3.918	-105.7752	0	0
ST	EX-	Bottom	0	0	-3.918	-105.7752	31.3408	0
ST	EX-	Top	0	0	-3.918	-105.7752	0	0
ST	EX-	Bottom	0	0	-3.918	-105.7752	31.3408	0
ST	EX-	Top	0	0	-3.918	-105.7752	0	0
ST	EX-	Bottom	0	0	-3.918	-105.7752	31.3408	0
ST	RSFAX	Top	0	41.158	1.326	334.6415	0	0
ST	RSFAX	Bottom	0	41.158	1.326	334.6415	10.6047	329.263
ST	RSFAY	Top	0	1.648	45.052	1230.513	0	0
ST	RSFAY	Bottom	0	1.648	45.052	1230.513	360.4198	13.1841
ST	1.4D	Top	108.508	0	0	0	949.4447	-2929.7152
ST	1.4D	Bottom	259.708	0	0	0	2272.4447	-7012.1152
ST	1.2D+1.6L+.5LR	Top	102.363	0	0	0	895.679	-2763.8094
ST	1.2D+1.6L+.5LR	Bottom	231.963	0	0	0	2029.679	-6263.0094
ST	1.2D+L+1.6LR	Top	98.855	0	0	0	864.978	-2669.0751
ST	1.2D+L+1.6LR	Bottom	228.455	0	0	0	1998.978	-6168.2751
ST	1.2D+.8W++1.6LR	Top	93.007	0	0	0	813.8098	-2511.1845
ST	1.2D+.8W++1.6LR	Bottom	222.607	0	0	0	1947.8098	-6010.3845
ST	1.2D+.8W++1.6LR	Top	93.007	0	0	0	813.8098	-2511.1845
ST	1.2D+.8W++1.6LR	Bottom	222.607	0	0	0	1947.8098	-6010.3845
ST	1.2D+1.6W-+1.6W+.5LR+1L	Top	98.855	0	0	0	864.978	-2669.0751
ST	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	228.455	0	0	0	1998.978	-6168.2751
ST	1.2D+1.6W-+1.6W+.5LR+1L	Top	98.855	0	0	0	864.978	-2669.0751
ST	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	228.455	0	0	0	1998.978	-6168.2751

ROOF	Dead	Top	204.581	0	0	0	1837.9988	-5477.3525
ROOF	Dead	Bottom	310.955	0	0	0	2699.6922	-8349.4668
ROOF	Live	Top	5.848	0	0	0	51.1683	-157.8906
ROOF	Live	Bottom	14.627	0	0	0	89.523	-394.942
ROOF	FF	Top	235.209	0	0	0	2091.9548	-6307.8684
ROOF	FF	Bottom	344.328	0	0	0	2965.634	-9254.0612
ROOF	PW	Top	253.215	0	0	0	2249.5046	-6794.0221
ROOF	PW	Bottom	359.59	0	0	0	3111.198	-9666.1364
ROOF	OHWT	Top	216.05	0	0	0	1938.3587	-5787.0345
ROOF	OHWT	Bottom	322.425	0	0	0	2800.0521	-8659.1488
ROOF	EX+	Top	0	-25.842	0	227.708	0	-30.9861
ROOF	EX+	Bottom	0	-25.842	0	227.708	0	-289.4019
ROOF	EX+	Top	0	-25.842	0	227.708	0	-30.9861
ROOF	EX+	Bottom	0	-25.842	0	227.708	0	-289.4019
ROOF	EX+	Top	0	-25.842	0	227.708	0	-30.9861
ROOF	EX+	Bottom	0	-25.842	0	227.708	0	-289.4019
ROOF	EX-	Top	0	0	-26.137	-700.2921	31.3408	0
ROOF	EX-	Bottom	0	0	-26.137	-700.2921	292.7151	0
ROOF	EX-	Top	0	0	-26.137	-700.2921	31.3408	0
ROOF	EX-	Bottom	0	0	-26.137	-700.2921	292.7151	0
ROOF	EX-	Top	0	0	-26.137	-700.2921	31.3408	0
ROOF	EX-	Bottom	0	0	-26.137	-700.2921	292.7151	0
ROOF	Roof Live	Top	65.727	0	0	0	541.0864	-1783.2191
ROOF	Roof Live	Bottom	65.727	0	0	0	541.0864	-1783.2191
ROOF	RSFAX	Top	0	225.699	8.516	2160.4989	10.6047	329.263
ROOF	RSFAX	Bottom	0	225.699	8.516	2160.4989	95.2544	2571.949
ROOF	RSFAY	Top	0	9.603	259.188	7106.2603	360.4198	13.1841
ROOF	RSFAY	Bottom	0	9.603	259.188	7106.2603	2940.6569	108.7601
ROOF	1.4D	Top	970.207	0	0	0	8651.2416	-26010.9402
ROOF	1.4D	Bottom	1420.822	0	0	0	12287.134	-38177.5301
ROOF	1.2D+1.6L+.5LR	Top	873.826	0	0	0	7767.7623	-23439.3261
ROOF	1.2D+1.6L+.5LR	Bottom	1274.115	0	0	0	10945.609	-34247.114
ROOF	1.2D+L+1.6LR	Top	942.618	0	0	0	8332.2564	-25306.1328
ROOF	1.2D+L+1.6LR	Bottom	1337.638	0	0	0	11487.0903	-35971.6899
ROOF	1.2D+.8W++1.6LR	Top	936.77	0	0	0	8281.0881	-25148.2422
ROOF	1.2D+.8W++1.6LR	Bottom	1323.011	0	0	0	11397.5673	-35576.7479
ROOF	1.2D+.8W++1.6LR	Top	936.77	0	0	0	8281.0881	-25148.2422
ROOF	1.2D+.8W++1.6LR	Bottom	1323.011	0	0	0	11397.5673	-35576.7479
ROOF	1.2D+1.6W- +1.6W+.5LR+1L	Top	942.618	0	0	0	8332.2564	-25306.1328
ROOF	1.2D+1.6W- +1.6W+.5LR+1L	Bottom	1337.638	0	0	0	11487.0903	-35971.6899
ROOF	1.2D+1.6W- +1.6W+.5LR+1L	Top	942.618	0	0	0	8332.2564	-25306.1328
ROOF	1.2D+1.6W- +1.6W+.5LR+1L	Bottom	1337.638	0	0	0	11487.0903	-35971.6899
6F	Dead	Top	462.036	0	0	0	4069.566	-12382.3194
6F	Dead	Bottom	568.411	0	0	0	4931.2594	-15254.4336
6F	Live	Top	59.954	0	0	0	462.6644	-1624.6773

6F	Live	Bottom	68.734	0	0	0	501.0191	-1861.7287
6F	FF	Top	522.537	0	0	0	4558.8389	-14022.9296
6F	FF	Bottom	631.655	0	0	0	5432.5181	-16969.1224
6F	PW	Top	677.362	0	0	0	5853.3256	-18221.4263
6F	PW	Bottom	783.737	0	0	0	6715.019	-21093.5405
6F	OHWT	Top	473.506	0	0	0	4169.9259	-12692.0013
6F	OHWT	Bottom	579.88	0	0	0	5031.6193	-15564.1156
6F	EX+	Top	0	-47.983	0	420.0989	0	-289.4019
6F	EX+	Bottom	0	-47.983	0	420.0989	0	-769.2321
6F	EX+	Top	0	-47.983	0	420.0989	0	-289.4019
6F	EX+	Bottom	0	-47.983	0	420.0989	0	-769.2321
6F	EX+	Top	0	-47.983	0	420.0989	0	-289.4019
6F	EX+	Bottom	0	-47.983	0	420.0989	0	-769.2321
6F	EX-	Top	0	0	-48.532	-1300.2316	292.7151	0
6F	EX-	Bottom	0	0	-48.532	-1300.2316	778.0386	0
6F	EX-	Top	0	0	-48.532	-1300.2316	292.7151	0
6F	EX-	Bottom	0	0	-48.532	-1300.2316	778.0386	0
6F	EX-	Top	0	0	-48.532	-1300.2316	292.7151	0
6F	EX-	Bottom	0	0	-48.532	-1300.2316	778.0386	0
6F	Roof Live	Top	65.727	0	0	0	541.0864	-1783.2191
6F	Roof Live	Bottom	65.727	0	0	0	541.0864	-1783.2191
6F	RSFAX	Top	0	382.665	15.509	3879.0513	95.2544	2571.949
6F	RSFAX	Bottom	0	382.665	15.509	3879.0513	248.7344	6328.041
6F	RSFAY	Top	0	16.778	446.957	12248.2066	2940.6569	108.7601
6F	RSFAY	Bottom	0	16.778	446.957	12248.2066	7346.1144	274.3359
6F	1.4D	Top	2326.709	0	0	0	20274.4227	-62477.3452
6F	1.4D	Bottom	2777.323	0	0	0	23910.3151	-74643.9352
6F	1.2D+1.6L+.5LR	Top	2123.112	0	0	0	18388.8828	-57043.1034
6F	1.2D+1.6L+.5LR	Bottom	2523.401	0	0	0	21566.7295	-67850.8913
6F	1.2D+L+1.6LR	Top	2159.44	0	0	0	18706.4792	-58029.8381
6F	1.2D+L+1.6LR	Bottom	2554.46	0	0	0	21861.3131	-68695.3952
6F	1.2D+.8W++1.6LR	Top	2099.486	0	0	0	18243.8148	-56405.1608
6F	1.2D+.8W++1.6LR	Bottom	2485.727	0	0	0	21360.294	-66833.6665
6F	1.2D+.8W++1.6LR	Top	2099.486	0	0	0	18243.8148	-56405.1608
6F	1.2D+.8W++1.6LR	Bottom	2485.727	0	0	0	21360.294	-66833.6665
6F	1.2D+1.6W- +1.6W+.5LR+1L	Top	2159.44	0	0	0	18706.4792	-58029.8381
6F	1.2D+1.6W- +1.6W+.5LR+1L	Bottom	2554.46	0	0	0	21861.3131	-68695.3952
6F	1.2D+1.6W- +1.6W+.5LR+1L	Top	2159.44	0	0	0	18706.4792	-58029.8381
6F	1.2D+1.6W- +1.6W+.5LR+1L	Bottom	2554.46	0	0	0	21861.3131	-68695.3952
5F	Dead	Top	719.491	0	0	0	6301.1332	-19287.2862
5F	Dead	Bottom	825.866	0	0	0	7162.8266	-22159.4004
5F	Live	Top	114.06	0	0	0	874.1606	-3091.4639
5F	Live	Bottom	122.84	0	0	0	912.5153	-3328.5153
5F	FF	Top	809.865	0	0	0	7025.7229	-21737.9908
5F	FF	Bottom	918.983	0	0	0	7899.4021	-24684.1836

5F	PW	Top	1101.509	0	0	0	9457.1466	-29648.8304
5F	PW	Bottom	1207.883	0	0	0	10318.84	-32520.9447
5F	OHWT	Top	730.961	0	0	0	6401.4931	-19596.9682
5F	OHWT	Bottom	837.336	0	0	0	7263.1865	-22469.0824
5F	EX+	Top	0	-66.82	0	583.7747	0	-769.2321
5F	EX+	Bottom	0	-66.82	0	583.7747	0	-1437.4297
5F	EX+	Top	0	-66.82	0	583.7747	0	-769.2321
5F	EX+	Bottom	0	-66.82	0	583.7747	0	-1437.4297
5F	EX+	Top	0	-66.82	0	583.7747	0	-769.2321
5F	EX+	Bottom	0	-66.82	0	583.7747	0	-1437.4297
5F	EX-	Top	0	0	-67.585	-1810.6279	778.0386	0
5F	EX-	Bottom	0	0	-67.585	-1810.6279	1453.8861	0
5F	EX-	Top	0	0	-67.585	-1810.6279	778.0386	0
5F	EX-	Bottom	0	0	-67.585	-1810.6279	1453.8861	0
5F	EX-	Top	0	0	-67.585	-1810.6279	778.0386	0
5F	EX-	Bottom	0	0	-67.585	-1810.6279	1453.8861	0
5F	Roof Live	Top	65.727	0	0	0	541.0864	-1783.2191
5F	Roof Live	Bottom	65.727	0	0	0	541.0864	-1783.2191
5F	RSFAX	Top	0	506.829	21.618	5269.4171	248.7344	6328.041
5F	RSFAX	Bottom	0	506.829	21.618	5269.4171	462.2998	11241.2053
5F	RSFAY	Top	0	22.691	598.233	16387.6313	7346.1144	274.3359
5F	RSFAY	Bottom	0	22.691	598.233	16387.6313	13176.4588	496.9803
5F	1.4D	Top	3683.211	0	0	0	31897.6038	-98943.7503
5F	1.4D	Bottom	4133.825	0	0	0	35533.4962	-111110.3402
5F	1.2D+1.6L+.5LR	Top	3372.398	0	0	0	29010.0034	-90646.8806
5F	1.2D+1.6L+.5LR	Bottom	3772.686	0	0	0	32187.8501	-101454.6686
5F	1.2D+L+1.6LR	Top	3376.262	0	0	0	29080.702	-90753.5433
5F	1.2D+L+1.6LR	Bottom	3771.282	0	0	0	32235.5359	-101419.1004
5F	1.2D+.8W++1.6LR	Top	3262.201	0	0	0	28206.5415	-87662.0794
5F	1.2D+.8W++1.6LR	Bottom	3648.442	0	0	0	31323.0206	-98090.5851
5F	1.2D+.8W++1.6LR	Top	3262.201	0	0	0	28206.5415	-87662.0794
5F	1.2D+.8W++1.6LR	Bottom	3648.442	0	0	0	31323.0206	-98090.5851
5F	1.2D+1.6W-+1.6W+.5LR+1L	Top	3376.262	0	0	0	29080.702	-90753.5433
5F	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	3771.282	0	0	0	32235.5359	-101419.1004
5F	1.2D+1.6W-+1.6W+.5LR+1L	Top	3376.262	0	0	0	29080.702	-90753.5433
5F	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	3771.282	0	0	0	32235.5359	-101419.1004
4F	Dead	Top	976.947	0	0	0	8532.7004	-26192.253
4F	Dead	Bottom	1083.321	0	0	0	9394.3938	-29064.3673
4F	Live	Top	168.166	0	0	0	1285.6567	-4558.2506
4F	Live	Bottom	176.946	0	0	0	1324.0114	-4795.302
4F	FF	Top	1097.192	0	0	0	9492.607	-29453.052
4F	FF	Bottom	1206.311	0	0	0	10366.2862	-32399.2448
4F	PW	Top	1525.656	0	0	0	13060.9676	-41076.2346
4F	PW	Bottom	1632.03	0	0	0	13922.661	-43948.3489

4F	OHWT	Top	988.416	0	0	0	8633.0603	-26501.935
4F	OHWT	Bottom	1094.791	0	0	0	9494.7537	-29374.0492
4F	EX+	Top	0	-82.352	0	718.7355	0	-1437.4297
4F	EX+	Bottom	0	-82.352	0	718.7355	0	-2260.948
4F	EX+	Top	0	-82.352	0	718.7355	0	-1437.4297
4F	EX+	Bottom	0	-82.352	0	718.7355	0	-2260.948
4F	EX+	Top	0	-82.352	0	718.7355	0	-1437.4297
4F	EX+	Bottom	0	-82.352	0	718.7355	0	-2260.948
4F	EX-	Top	0	0	-83.295	-2231.481	1453.8861	0
4F	EX-	Bottom	0	0	-83.295	-2231.481	2286.8323	0
4F	EX-	Top	0	0	-83.295	-2231.481	1453.8861	0
4F	EX-	Bottom	0	0	-83.295	-2231.481	2286.8323	0
4F	EX-	Top	0	0	-83.295	-2231.481	1453.8861	0
4F	EX-	Bottom	0	0	-83.295	-2231.481	2286.8323	0
4F	Roof Live	Top	65.727	0	0	0	541.0864	-1783.2191
4F	Roof Live	Bottom	65.727	0	0	0	541.0864	-1783.2191
4F	RSFAX	Top	0	607.926	26.708	6406.8066	462.2998	11241.2053
4F	RSFAX	Bottom	0	607.926	26.708	6406.8066	726.0678	17067.1275
4F	RSFAY	Top	0	27.511	722.673	19791.883	13176.4588	496.9803
4F	RSFAY	Bottom	0	27.511	722.673	19791.883	20151.668	766.0534
4F	1.4D	Top	5039.712	0	0	0	43520.7849	-135410.1554
4F	1.4D	Bottom	5490.327	0	0	0	47156.6773	-147576.7453
4F	1.2D+1.6L+.5LR	Top	4621.684	0	0	0	39631.1239	-124250.6579
4F	1.2D+1.6L+.5LR	Bottom	5021.972	0	0	0	42808.9706	-135058.4458
4F	1.2D+L+1.6LR	Top	4593.084	0	0	0	39454.9249	-123477.2486
4F	1.2D+L+1.6LR	Bottom	4988.104	0	0	0	42609.7588	-134142.8057
4F	1.2D+.8W++1.6LR	Top	4424.917	0	0	0	38169.2681	-118918.9981
4F	1.2D+.8W++1.6LR	Bottom	4811.158	0	0	0	41285.7473	-129347.5037
4F	1.2D+.8W++1.6LR	Top	4424.917	0	0	0	38169.2681	-118918.9981
4F	1.2D+.8W++1.6LR	Bottom	4811.158	0	0	0	41285.7473	-129347.5037
4F	1.2D+1.6W-+1.6W+.5LR+1L	Top	4593.084	0	0	0	39454.9249	-123477.2486
4F	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	4988.104	0	0	0	42609.7588	-134142.8057
4F	1.2D+1.6W-+1.6W+.5LR+1L	Top	4593.084	0	0	0	39454.9249	-123477.2486
4F	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	4988.104	0	0	0	42609.7588	-134142.8057
3F	Dead	Top	1234.402	0	0	0	10764.2676	-33097.2198
3F	Dead	Bottom	1340.777	0	0	0	11625.9609	-35969.3341
3F	Live	Top	222.273	0	0	0	1697.1529	-6025.0372
3F	Live	Bottom	231.052	0	0	0	1735.5076	-6262.0886
3F	FF	Top	1384.52	0	0	0	11959.491	-37168.1132
3F	FF	Bottom	1493.638	0	0	0	12833.1702	-40114.306
3F	PW	Top	1949.803	0	0	0	16664.7886	-52503.6388

3F	PW	Bottom	2056.177	0	0	0	17526.482	-55375.7531
3F	OHWT	Top	1245.872	0	0	0	10864.6275	-33406.9018
3F	OHWT	Bottom	1352.246	0	0	0	11726.3208	-36279.0161
3F	EX+	Top	0	-94.579	0	824.9812	0	-2260.948
3F	EX+	Bottom	0	-94.579	0	824.9812	0	-3206.7398
3F	EX+	Top	0	-94.579	0	824.9812	0	-2260.948
3F	EX+	Bottom	0	-94.579	0	824.9812	0	-3206.7398
3F	EX+	Top	0	-94.579	0	824.9812	0	-2260.948
3F	EX+	Bottom	0	-94.579	0	824.9812	0	-3206.7398
3F	EX-	Top	0	0	-95.662	-2562.7909	2286.8323	0
3F	EX-	Bottom	0	0	-95.662	-2562.7909	3243.452	0
3F	EX-	Top	0	0	-95.662	-2562.7909	2286.8323	0
3F	EX-	Bottom	0	0	-95.662	-2562.7909	3243.452	0
3F	EX-	Top	0	0	-95.662	-2562.7909	2286.8323	0
3F	EX-	Bottom	0	0	-95.662	-2562.7909	3243.452	0
3F	Roof Live	Top	65.727	0	0	0	541.0864	-1783.2191
3F	Roof Live	Bottom	65.727	0	0	0	541.0864	-1783.2191
3F	RSFAX	Top	0	692.486	30.726	7347.0909	726.0678	17067.1275
3F	RSFAX	Bottom	0	692.486	30.726	7347.0909	1029.0184	23632.5086
3F	RSFAY	Top	0	31.272	825.065	22591.5442	20151.668	766.0534
3F	RSFAY	Bottom	0	31.272	825.065	22591.5442	28047.8668	1071.3068
3F	1.4D	Top	6396.214	0	0	0	55143.966	-171876.5604
3F	1.4D	Bottom	6846.829	0	0	0	58779.8584	-184043.1504
3F	1.2D+1.6L+.5LR	Top	5870.969	0	0	0	50252.2444	-157854.4352
3F	1.2D+1.6L+.5LR	Bottom	6271.258	0	0	0	53430.0911	-168662.2231
3F	1.2D+L+1.6LR	Top	5809.906	0	0	0	49829.1477	-156200.9539
3F	1.2D+L+1.6LR	Bottom	6204.926	0	0	0	52983.9816	-166866.511
3F	1.2D+.8W++1.6LR	Top	5587.633	0	0	0	48131.9948	-150175.9167
3F	1.2D+.8W++1.6LR	Bottom	5973.874	0	0	0	51248.474	-160604.4224
3F	1.2D+.8W++1.6LR	Top	5587.633	0	0	0	48131.9948	-150175.9167
3F	1.2D+.8W++1.6LR	Bottom	5973.874	0	0	0	51248.474	-160604.4224
3F	1.2D+1.6W-+1.6W+.5LR+1L	Top	5809.906	0	0	0	49829.1477	-156200.9539
3F	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	6204.926	0	0	0	52983.9816	-166866.511
3F	1.2D+1.6W-+1.6W+.5LR+1L	Top	5809.906	0	0	0	49829.1477	-156200.9539
3F	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	6204.926	0	0	0	52983.9816	-166866.511
2F	Dead	Top	1491.857	0	0	0	12995.8347	-40002.1866
2F	Dead	Bottom	1598.232	0	0	0	13857.5281	-42874.3009
2F	Live	Top	276.379	0	0	0	2108.649	-7491.8239
2F	Live	Bottom	285.159	0	0	0	2147.0038	-7728.8753
2F	FF	Top	1671.848	0	0	0	14426.375	-44883.1744
2F	FF	Bottom	1780.966	0	0	0	15300.0543	-47829.3672

2F	PW	Top	2373.949	0	0	0	20268.6096	-63931.043
2F	PW	Bottom	2480.324	0	0	0	21130.303	-66803.1572
2F	OHWT	Top	1503.327	0	0	0	13096.1947	-40311.8686
2F	OHWT	Bottom	1609.702	0	0	0	13957.888	-43183.9829
2F	EX+	Top	0	-103.502	0	902.5118	0	-3206.7398
2F	EX+	Bottom	0	-103.502	0	902.5118	0	-4241.7584
2F	EX+	Top	0	-103.502	0	902.5118	0	-3206.7398
2F	EX+	Bottom	0	-103.502	0	902.5118	0	-4241.7584
2F	EX+	Top	0	-103.502	0	902.5118	0	-3206.7398
2F	EX+	Bottom	0	-103.502	0	902.5118	0	-4241.7584
2F	EX-	Top	0	0	-104.687	-2804.5576	3243.452	0
2F	EX-	Bottom	0	0	-104.687	-2804.5576	4290.3199	0
2F	EX-	Top	0	0	-104.687	-2804.5576	3243.452	0
2F	EX-	Bottom	0	0	-104.687	-2804.5576	4290.3199	0
2F	EX-	Top	0	0	-104.687	-2804.5576	3243.452	0
2F	EX-	Bottom	0	0	-104.687	-2804.5576	4290.3199	0
2F	Roof Live	Top	65.727	0	0	0	541.0864	-1783.2191
2F	Roof Live	Bottom	65.727	0	0	0	541.0864	-1783.2191
2F	RSFAX	Top	0	759.394	33.559	8068.349	1029.0184	23632.5086
2F	RSFAX	Bottom	0	759.394	33.559	8068.349	1359.4962	30787.3432
2F	RSFAY	Top	0	33.837	904.241	24752.3276	28047.8668	1071.3068
2F	RSFAY	Bottom	0	33.837	904.241	24752.3276	36656.7908	1401.8862
2F	1.4D	Top	7752.716	0	0	0	66767.1472	-208342.9655
2F	1.4D	Bottom	8203.33	0	0	0	70403.0395	-220509.5554
2F	1.2D+1.6L+.5LR	Top	7120.255	0	0	0	60873.3649	-191458.2124
2F	1.2D+1.6L+.5LR	Bottom	7520.543	0	0	0	64051.2117	-202266.0004
2F	1.2D+L+1.6LR	Top	7026.728	0	0	0	60203.3705	-188924.6592
2F	1.2D+L+1.6LR	Bottom	7421.748	0	0	0	63358.2044	-199590.2162
2F	1.2D+.8W++1.6LR	Top	6750.349	0	0	0	58094.7215	-181432.8353
2F	1.2D+.8W++1.6LR	Bottom	7136.59	0	0	0	61211.2007	-191861.341
2F	1.2D+.8W++1.6LR	Top	6750.349	0	0	0	58094.7215	-181432.8353
2F	1.2D+.8W++1.6LR	Bottom	7136.59	0	0	0	61211.2007	-191861.341
2F	1.2D+1.6W-+1.6W+.5LR+1L	Top	7026.728	0	0	0	60203.3705	-188924.6592
2F	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	7421.748	0	0	0	63358.2044	-199590.2162
2F	1.2D+1.6W-+1.6W+.5LR+1L	Top	7026.728	0	0	0	60203.3705	-188924.6592
2F	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	7421.748	0	0	0	63358.2044	-199590.2162
1F	Dead	Top	1749.313	0	0	0	15227.4019	-46907.1534
1F	Dead	Bottom	1855.687	0	0	0	16089.0953	-49779.2677
1F	Live	Top	330.485	0	0	0	2520.1452	-8958.6105
1F	Live	Bottom	339.265	0	0	0	2558.4999	-9195.6619
1F	FF	Top	1959.175	0	0	0	16893.2591	-52598.2356
1F	FF	Bottom	2068.293	0	0	0	17766.9383	-55544.4284

1F	PW	Top	2798.096	0	0	0	23872.4306	-75358.4471
1F	PW	Bottom	2904.471	0	0	0	24734.124	-78230.5614
1F	OHWT	Top	1760.782	0	0	0	15327.7618	-47216.8354
1F	OHWT	Bottom	1867.157	0	0	0	16189.4552	-50088.9497
1F	EX+	Top	0	-109.12	0	951.3274	0	-4241.7584
1F	EX+	Bottom	0	-109.12	0	951.3274	0	-5332.9567
1F	EX+	Top	0	-109.12	0	951.3274	0	-4241.7584
1F	EX+	Bottom	0	-109.12	0	951.3274	0	-5332.9567
1F	EX+	Top	0	-109.12	0	951.3274	0	-4241.7584
1F	EX+	Bottom	0	-109.12	0	951.3274	0	-5332.9567
1F	EX-	Top	0	0	-110.369	-2956.781	4290.3199	0
1F	EX-	Bottom	0	0	-110.369	-2956.781	5394.0107	0
1F	EX-	Top	0	0	-110.369	-2956.781	4290.3199	0
1F	EX-	Bottom	0	0	-110.369	-2956.781	5394.0107	0
1F	EX-	Top	0	0	-110.369	-2956.781	4290.3199	0
1F	EX-	Bottom	0	0	-110.369	-2956.781	5394.0107	0
1F	Roof Live	Top	65.727	0	0	0	541.0864	-1783.2191
1F	Roof Live	Bottom	65.727	0	0	0	541.0864	-1783.2191
1F	RSFAX	Top	0	803.28	35.129	8511.5605	1359.4962	30787.3432
1F	RSFAX	Bottom	0	803.28	35.129	8511.5605	1705.5022	38364.3001
1F	RSFAY	Top	0	35.159	954.825	26126.7095	36656.7908	1401.8862
1F	RSFAY	Bottom	0	35.159	954.825	26126.7095	45753.8369	1746.4998
1F	1.4D	Top	9109.218	0	0	0	78390.3283	-244809.3705
1F	1.4D	Bottom	9559.832	0	0	0	82026.2207	-256975.9605
1F	1.2D+1.6L+.5LR	Top	8369.541	0	0	0	71494.4855	-225061.9897
1F	1.2D+1.6L+.5LR	Bottom	8769.829	0	0	0	74672.3322	-235869.7776
1F	1.2D+L+1.6LR	Top	8243.55	0	0	0	70577.5934	-221648.3644
1F	1.2D+L+1.6LR	Bottom	8638.57	0	0	0	73732.4272	-232313.9215
1F	1.2D+.8W++1.6LR	Top	7913.065	0	0	0	68057.4481	-212689.7539
1F	1.2D+.8W++1.6LR	Bottom	8299.306	0	0	0	71173.9273	-223118.2596
1F	1.2D+.8W++1.6LR	Top	7913.065	0	0	0	68057.4481	-212689.7539
1F	1.2D+.8W++1.6LR	Bottom	8299.306	0	0	0	71173.9273	-223118.2596
1F	1.2D+1.6W-+1.6W+.5LR+1L	Top	8243.55	0	0	0	70577.5934	-221648.3644
1F	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	8638.57	0	0	0	73732.4272	-232313.9215
1F	1.2D+1.6W-+1.6W+.5LR+1L	Top	8243.55	0	0	0	70577.5934	-221648.3644
1F	1.2D+1.6W-+1.6W+.5LR+1L	Bottom	8638.57	0	0	0	73732.4272	-232313.9215
GF	Dead	Top	1907.104	0	0	0	16576.0189	-51167.5177
GF	Dead	Bottom	1972.204	0	0	0	17145.6439	-52925.2177
GF	Live	Top	341.66	0	0	0	2591.8277	-9260.3219
GF	Live	Bottom	341.66	0	0	0	2591.8277	-9260.3219
GF	FF	Top	2121.143	0	0	0	18273.8092	-56971.3784

GF	FF	Bottom	2186.243	0	0	0	18843.4342	-58729.0784
GF	PW	Top	2964.695	0	0	0	25343.613	-79856.6029
GF	PW	Bottom	3029.795	0	0	0	25913.238	-81614.3029
GF	OHWT	Top	1918.574	0	0	0	16676.3788	-51477.1997
GF	OHWT	Bottom	1983.674	0	0	0	17246.0038	-53234.8997
GF	EX+	Top	0	-110.352	0	962.1176	0	-5332.9567
GF	EX+	Bottom	0	-110.352	0	962.1176	0	-6105.422
GF	EX+	Top	0	-110.352	0	962.1176	0	-5332.9567
GF	EX+	Bottom	0	-110.352	0	962.1176	0	-6105.422
GF	EX+	Top	0	-110.352	0	962.1176	0	-5332.9567
GF	EX+	Bottom	0	-110.352	0	962.1176	0	-6105.422
GF	EX-	Top	0	0	-111.616	-2990.4666	5394.0107	0
GF	EX-	Bottom	0	0	-111.616	-2990.4666	6175.3196	0
GF	EX-	Top	0	0	-111.616	-2990.4666	5394.0107	0
GF	EX-	Bottom	0	0	-111.616	-2990.4666	6175.3196	0
GF	EX-	Top	0	0	-111.616	-2990.4666	5394.0107	0
GF	EX-	Bottom	0	0	-111.616	-2990.4666	6175.3196	0

- Lateral force distribution approximately linear with height
- Upper floors experience lower forces due to modal participation

4.15. Model Results

Table 4. 10: Modal Periods and Frequencies

Case	Mode	Period sec	Frequency cyc/sec	CircFreq rad/sec	Eigenvalue rad2/sec2
Modal	1	0.743	1.346	8.4595	71.5627
Modal	2	0.662	1.511	9.4952	90.1594
Modal	3	0.654	1.529	9.6039	92.2356
Modal	4	0.227	4.406	27.6832	766.3603
Modal	5	0.201	4.986	31.3294	981.5289
Modal	6	0.197	5.066	31.8315	1013.2461
Modal	7	0.117	8.517	53.5122	2863.5513
Modal	8	0.104	9.582	60.2082	3625.0289
Modal	9	0.101	9.866	61.989	3842.634
Modal	10	0.071	14.061	88.3491	7805.5668
Modal	11	0.065	15.294	96.0955	9234.3385
Modal	12	0.063	15.877	99.7575	9951.5682

Table 4. 11: Modal Participating Mass Ratios

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ
Modal	1	0.743	0.2279	0.0014	0	0.2279	0.0014	0
Modal	2	0.662	0.496	0.0698	0	0.7239	0.0712	0
Modal	3	0.654	0.0403	0.702	0	0.7642	0.7732	0
Modal	4	0.227	0.0231	0.0001	0	0.7873	0.7733	0
Modal	5	0.201	0.0972	0.0011	0	0.8845	0.7743	0
Modal	6	0.197	0.0006	0.1151	0	0.8851	0.8894	0
Modal	7	0.117	0.0062	2.27E-05	0	0.8913	0.8895	0
Modal	8	0.104	0.0377	0.0001	0	0.929	0.8895	0
Modal	9	0.101	4.81E-05	0.0432	0	0.929	0.9327	0
Modal	10	0.071	0.0026	1.44E-05	0	0.9316	0.9327	0
Modal	11	0.065	0.02	0.0001	0	0.9516	0.9328	0
Modal	12	0.063	0.0001	0.0206	0	0.9517	0.9534	0

Case	Mode	RX	RY	RZ	SumRX	SumRY	SumRZ
Modal	1	0.0005	0.079	0.5508	0.0005	0.079	0.5508
Modal	2	0.0221	0.1699	0.2083	0.0226	0.2489	0.7591
Modal	3	0.23	0.0133	0.0307	0.2527	0.2623	0.7897
Modal	4	0.0008	0.0785	0.0837	0.2534	0.3408	0.8735
Modal	5	0.0036	0.3568	0.0204	0.2571	0.6975	0.8938
Modal	6	0.4479	0.0017	0.0006	0.705	0.6992	0.8944
Modal	7	3.13E-05	0.0117	0.0366	0.705	0.711	0.9311
Modal	8	0.0002	0.0727	0.0048	0.7052	0.7837	0.9359
Modal	9	0.0857	0.0001	0.0001	0.7909	0.7838	0.936
Modal	10	0.0001	0.0071	0.0187	0.791	0.7909	0.9547
Modal	11	0.0002	0.0595	0.0018	0.7912	0.8504	0.9565
Modal	12	0.0632	0.0001	0.0001	0.8544	0.8505	0.9566

Table 4. 12: Modal Load Participation Ratios

Case	ItemType	Item	Static	Dynamic
			%	%
Modal	Acceleration	UX	99.99	95.17
Modal	Acceleration	UY	99.99	95.34
Modal	Acceleration	UZ	0	0

Table 4. 13: Modal Direction Factors

Case	Mode	Period sec	UX	UY	UZ	RZ	UX*	UY*	UZ*	RZ*
Modal	1	0.743	0.301	0.002	0	0.697	0.292	0.002	0	0.706
Modal	2	0.662	0.65	0.09	0	0.26	0.641	0.09	0	0.269
Modal	3	0.654	0.052	0.909	0	0.038	0.052	0.908	0	0.04
Modal	4	0.227	0.197	0.002	0	0.801	0.216	0.001	0	0.783
Modal	5	0.201	0.82	0.008	0	0.172	0.819	0.009	0	0.172
Modal	6	0.197	0.004	0.991	0	0.005	0.005	0.99	0	0.005
Modal	7	0.117	0.136	0.002	0	0.863	0.144	0.001	0	0.855
Modal	8	0.104	0.897	0.001	0	0.102	0.885	0.002	0	0.114
Modal	9	0.101	0	0.998	0	0.002	0.001	0.997	0	0.002
Modal	10	0.071	0.115	0.002	0	0.883	0.12	0.001	0	0.879
Modal	11	0.065	0.929	0.002	0	0.069	0.913	0.003	0	0.083
Modal	12	0.063	0.001	0.996	0	0.002	0.003	0.994	0	0.003

4.16. Result Specifications

Table 4. 14: Slab Specifications Data

Name	Type	Element Type	Material		Thickness
			Concrete	Rebar	in
FLAT SLAB 10	Slab	Shell-Thin	5000psi	72500psi	10
STAIR-8	Slab	Shell-Thin	5000psi	72500psi	8

- Reinforcement: Two-way reinforced slab with main and secondary steel

Table 4. 15: Frame Specifications Data

Frame Section Property Definitions - Summary (Part 1 of 3)									
Name	Material		Area in2	J	I33	I22	I23	As2 in2	As3 in2
	Concrete	Rebar		in4	in4	in4	in4		
C-01(24X24)	5000PSI	72500PSI	576	46742.39	27648	27648	0	480	480
C-02(30X36)	5000PSI	72500PSI	1080	161803	116640	81000	0	900	900
GB(12X20)	5000PSI	72500PSI	240	7223.67	8000	2880	0	200	200
STB(12X24)	5000PSI	72500PSI	288	9500.62	13824	3456	0	240	240

Frame Section Property Definitions - Summary (Part 2 of 3)										
Name	S33Pos in3	S33Neg in3	S22Pos in3	S22Neg in3	Z33 in3	Z22 in3	R33 in	R22 in	CG Offset 3 in	CG Offset 2 in
C-01(24X24)	2304	2304	2304	2304	3456	3456	6.928	6.928	0	0
C-02(30X36)	6480	6480	5400	5400	9720	8100	10.392	8.660	0	0
GB(12X20)	800	800	480	480	1200	720	5.774	3.464	0	0
STB(12X24)	1152	1152	576	576	1728	864	6.928	3.464	0	0

Frame Section Property Definitions - Summary (Part 3 of 3)									
Name	PNA Offset 2 in	Area Modifier	As2 Modifier	As3 Modifier	J Modifier	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
C-01(24X24)	0	1	1	1	1	1	1	1	1
C-02(30X36)	0	1	1	1	1	1	1	1	1
GB(12X20)	0	1	1	1	1	1	1	1	1
STB(12X24)	0	1	1	1	1	1	1	1	1

- Reinforcement: Longitudinal bars with lateral ties/stirrups as per BNBC

Comparative Discussion

- All seismic performance parameters are within BNBC allowable limits
- Drop panels and adequate reinforcement mitigate punching shear risk
- Story drift ratios, base shear, and slab stresses indicate stable design
- Comparison with conventional beam-slab structures shows:
    - Reduced material usage
    - Slight increase in lateral displacement
    - Efficient architectural layout

4.17. Fundamentals of Punching Shear

4.17.1. Definition

Punching shear is a local failure mechanism where a column “punches” through the slab due to high concentrated shear stresses around the column perimeter. It is most critical in flat slabs due to the absence of supporting beams**,** which normally distribute loads over larger areas.

4.17.2. Failure Mechanism

- Occurs when punching shear stress exceeds the slab concrete capacity
- Initiates at the column-slab junction and propagates outward
- Forms a truncated pyramid or cone-shaped failure surface
- Often sudden and brittle, unlike bending failure which is ductile

4.18. Causes of Punching Shear in Flat Slabs

1. Concentrated loads from columns or heavy equipment
2. Seismic lateral forces increasing stress at column-slab junctions
3. Inadequate slab thickness or reinforcement
4. Long spans without drop panels
5. Poor detailing around column heads

Discussion: Proper structural design must anticipate maximum shear stress and provide measures such as drop panels, column capitals, and shear reinforcement to prevent failure.

4.19. Analytical Methods for Punching Shear

4.19.1. Simplified Code-Based Approaches

- Codes like BNBC and ACI 318 provide empirical formulas for punching shear capacity
- Typical formula (ACI 318):

$$V_c = 0.75\sqrt{f'_c}b_0 d$$

Where:

Vc= punching shear capacity

f'_c = concrete compressive strength

b_0= perimeter of critical section

d = effective slab depth

Punching shear stress:

$T_u = \frac{V_u}{b_0 d}$ Where Vu = factored column load

4.19.2. Finite Element and Software Analysis

- ETABS or SAP2000 allows detailed punching shear stress evaluation
- Slabs modeled as shell elements; columns as frame elements
- Critical shear around column-slab junction visualized using stress contour plots

Table 4. 16: Punching shear contour around a Corner Column

General Information			
Story	= 4F	Global X-Coordinate	= 0 ft
Point Label	=17	Global Y-Coordinate	= 17.5 ft
Column Shape	=Rectangular	Reinforcement Enabled	'= No
Column Location	=Edge	Prestressed Slab	'= No
Column Punching Check			
Controlling Combination	= 1.2D+1.6L+.5LR	Moment M_{u3}	= 144.6775 kip-ft
Avg. Eff. Slab Thickness	= 8.5 in	Shear Force	= 78.54 kip
Eff. Punching Perimeter	= 113.02 in	Unbalanced Moment M_{u2}	= -0.509 kip-ft
Cover	= 1.5 in	Unbalanced Moment M_{u3}	= 61.625 kip-ft
Conc. Comp. Strength	= 5000 lb/in²	β_c	= 1
Reinforcement Ratio	= 0	β_p	= 0
Section Inertia I_{22}	= 206708.67 in⁴	λ_s	= 0
Section Inertia I_{33}	= 176318.36 in⁴	$Sigma_{cp}$ (22)	= 0 lb/in²
Section Inertia I_{23}	= 0 in⁴	$Sigma_{cp}$ (33)	= 0 lb/in²
$Gamma_{v2}$	= 0.375	$Sigma_{cp}$	= 0 lb/in²
$Gamma_{v3}$	= 0.426	Shear carried by tendons, V_p	= 0 kip
Moment M_{u2}	= -1.3587 kip-ft		
Design Summary			
Max Design Shear Stress	= 142.38 lb/in²		
Conc. Shear Stress Capacity	= 212.13 lb/in²		
Punching Shear Ratio	**= 0.671**		

Table 4. 17: Punching shear contour around a Mid Column

General Information			
Story	= 4F	Global X-Coordinate	= 23 ft
Point Label	=26	Global Y-Coordinate	= 17.5 ft
Column Shape	=Rectangular	Reinforcement Enabled	'= No
Column Location	=Edge	Prestressed Slab	'= No
Column Punching Check			
Controlling Combination	= 1.2D+1.6L+.5LR	Moment M_{u3}	= 81.4438 kip-ft
Avg. Eff. Slab Thickness	= 8.5 in	Shear Force	= 62.373 kip
Eff. Punching Perimeter	= 107.02 in	Unbalanced Moment M_{u2}	= 8.3229 kip-ft
Cover	= 1.5 in	Unbalanced Moment M_{u3}	= 31.4441 kip-ft

Conc. Comp. Strength	= 5000 lb/in²	β_c	= 1.2
Reinforcement Ratio	= 0	β_p	= 0
Section Inertia I_{22}	= 241262.86 in⁴	λ_s	= 0
Section Inertia I_{33}	= 177329.29 in⁴	$Sigma_{cp}$ (22)	= 0 lb/in²
Section Inertia I_{23}	= 86185.49 in⁴	$Sigma_{cp}$ (33)	= 0 lb/in²
$Gamma_{v2}$	= 0.414	$Sigma_{cp}$	= 0 lb/in²
$Gamma_{v3}$	= 0.386	Shear carried by tendons, V_p	= 0 kip
Moment M_{u2}	= 20.0998 kip-ft		
Design Summary			
Max Design Shear Stress	= 124.49 lb/in²		
Conc. Shear Stress Capacity	= 212.13 lb/in²		
Punching Shear Ratio	**= 0.587**		

4.19.3. Factors Influencing Punching Shear

1. Column size and shape (rectangular vs. circular)
2. Slab thickness and drop panels
3. Reinforcement detailing (amount and arrangement of flexural and shear bars)
4. Load eccentricity and torsion

4.20. Design Measures to Prevent Punching Shear

4.20.1. Shear Reinforcement (Studs / Links)

- Stirrup-like reinforcement around columns
- Resists high shear stress and prevents brittle failure
- Ensures ductility even if concrete cracks

4.20.2. Slab Thickness Optimization

- Increasing slab thickness improves punching shear capacity
- Balance needed to avoid excessive self-weight

4.21. Punching Shear in Seismic Loading

4.21.1. Effect of Earthquake Forces

- Lateral seismic forces amplify stress around slab-column junctions
- Combined vertical gravity loads + lateral inertia forces increases punching shear risk
- Flat slabs with long spans and minimal drop panels are most vulnerable

4.21.2. Analysis Using Response Spectrum Method

- ETABS calculates shear forces at column faces under seismic response
- Maximum punching shear occurs at ground and lower floors due to higher cumulative load
- Visualization through shear contour plots highlights critical areas

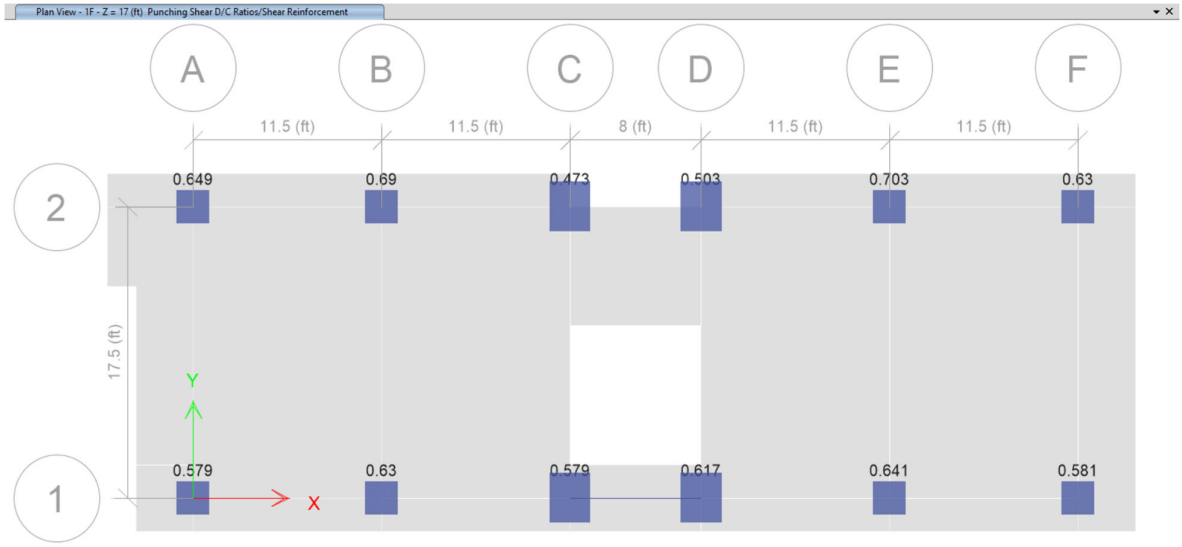


Figure 4. 15: Punching shear stress distribution in 7-storey flat slab building first Floor



Figure 4. 16: Punching shear stress distribution in 7-storey flat slab building fourth Floor

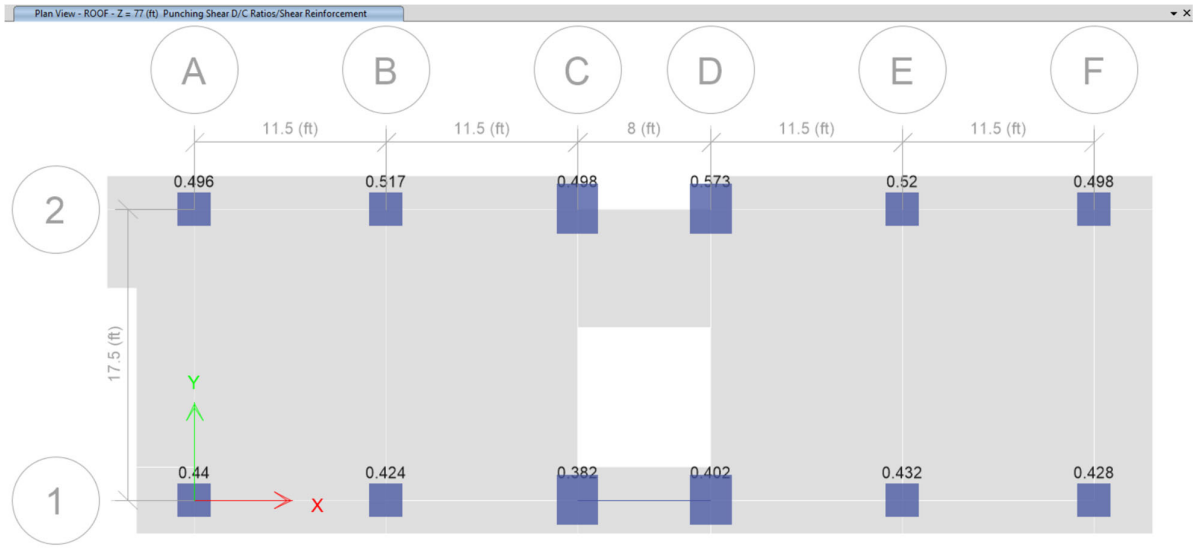


Figure 4. 17: Punching shear stress distribution in 7-storey flat slab building Roof

4.22. Comparison with Beam-Slab Systems

- Conventional beam-slab systems distribute loads via beams, reducing punching shear risk
- Flat slabs without beams rely solely on slab thickness and reinforcement
- Punching shear mitigation is more critical in flat slabs

Observation: Flat slabs require shear reinforcement to achieve similar safety levels

4.23. Design Recommendations

- Adequate flexural and shear reinforcement as per BNBC/ACI codes
- Increase slab thickness in high load areas
- Check critical shear stress during seismic design
- Regular floor plans minimize torsional effects and punching shear risk

4.24. Summary

- Punching shear is the most critical local failure mode in flat slab buildings
- Flat slabs with drop panels, proper slab thickness, and reinforcement can resist punching shear under seismic loading
- ETABS analysis highlights critical junctions and stress concentrations
- Proper design ensures ductility, safety, and code compliance
- Comparative analysis shows flat slabs need additional mitigation measures compared to conventional beam-slab system.

Chapter 5

Conclusions

5.1. Introduction

This chapter summarizes the key findings of the study on seismic performance evaluation of 6-storey reinforced concrete flat slab buildings using ETABS**.** The purpose is to highlight the structural behavior under seismic loading**,** evaluate the critical failure modes**,** and provide design recommendations for flat slab construction.

The chapter integrates results from:

- Modeling and analysis of the building
- Response spectrum method analysis
- Story displacements, inter-story drift, and base shear
- Punching shear evaluation at slab-column junctions

The conclusions are organized into:

- Observations from seismic analysis
- Punching shear and slab performance
- Comparison with conventional systems
- Design implications
- Limitations of the study
- Recommendations for future work

5.2. Summary of Structural Analysis

5.2.1. Modeling and Input Parameters

- Building Type: 7-storey residential building
- Floor System: Flat slab without drops panels
- Slab Thickness: 10” typical
- Column Size: C1-24”x24” & C2-30”x36” reinforced concrete
- Material Properties: 5000psi concrete, 72500 reinforcements
- Seismic Zone: Zone II (BNBC)
- Analysis Method: Response Spectrum Method in ETABS

Discussion: Modeling accurately represents a real-world flat slab building, capturing slab-column connections, load transfer, and seismic response**.**

5.2.2. Seismic Analysis Findings

Table 5 1: Seismic Analysis Findings

Parameter	X-Direction	Y-Direction
Maximum Story Displacement	1.255	2.346
Maximum Drift Ratio	0.00123	0.0023
Base Shear	110.3522 kip	111.615 kip

- Story Displacement: Maximum 1” at top floor; within BNBC limits
- Inter-Story Drift: Maximum 0.0023; below allowable 0.004
- Base Shear: 110.352kip (X), 111.615kip (Y)
- Mode Shapes: Dominated by first two translational modes; torsion minor
- Column Forces: Axial and bending moments within safe limits

Observation: The flat slab building exhibits stable seismic behavior**,** with moderate lateral displacement and acceptable inter-story drift**,** confirming its adequacy for low- to mid-rise structures**.**

5.3. Punching Shear Performance

- Maximum Punching Shear: 124.49 lb/in^2 at ground floor columns
- Allowable Stress: 212.13lb/in^2 for 5000psi concrete

5.4. Design Implications

- Slab Thickness Optimization**:** Balances strength and self-weight.
- Seismic Detailing**:** Reinforcement must be adequate to resist combined vertical and lateral forces.
- Story Drift Control**:** Regular layouts and uniform stiffness reduce drift and torsion.
- Base Shear Design**:** Foundation and column design must consider calculated base shear under RSM.

5.5. Observations from Response Spectrum Analysis

- First six modes capture >90% of total mass participation**,** confirming reliability of modal analysis.
- Maximum lateral forces occur at upper floors; critical for slab-column and column design**.**
- ETABS results show that linear-elastic RSM is effective for preliminary design but may underestimate post-yield behavior**.**

5.6. Limitations of the Study

- Linear-Elastic Material Behavior**:** Does not capture inelastic or post-yield behavior.
- ETABS Simplifications**:** Slab meshing may affect localized stress prediction.
- Seismic Data**:** Assumes standard design response spectrum, not site-specific ground motion.
- Punching Shear Evaluation**:** Focused on elastic limit; real structures may experience micro cracking.

5.7. Recommendations for Future Work

- Nonlinear Time History Analysis**:** For accurate post-elastic behavior and progressive failure prediction.
- Site-Specific Ground Motion**:** To account for local seismic hazards.
- High-Rise Flat Slabs**:** Evaluate punching shear under higher seismic demand.
- Advanced Reinforcement Techniques**:** Shear studs, high-strength concrete, and hybrid systems.

5.8. Practical Guidelines

- Flat slabs are viable for 7-storey buildings in moderate seismic zones.
- Check story drift to satisfy BNBC limits.
- Verify base shear and column design against RSM output.
- Consider slab reinforcement detailing to prevent punching shear failure.

5.9. Overall Conclusions

- Flat slabs provide architectural flexibility and faster construction but are susceptible to punching shear**.**
- Response Spectrum Method effectively estimates seismic response in linear-elastic range**.**
- Maximum displacements, drifts, and stresses are within BNBC limits for the 6-storey building.
- Drop panels and shear reinforcement successfully mitigate punching shear risk.

- Flat slab design must consider combined vertical and lateral loads, with appropriate detailing and reinforcement.
- Future studies should incorporate nonlinear dynamic analysis and experimental validation for higher accuracy.

References

[1] Chopra, A.K., Dynamics of Structures: Theory and Applications to Earthquake Engineering, 5th Edition, Pearson, 2017.

[2] Clough, R.W., and Penzien, J., Dynamics of Structures, 3rd Edition, McGraw-Hill, 2003.

[3] Park, R., and Paulay, T., Reinforced Concrete Structures, John Wiley & Sons, 1975.

[4] Nilson, A.H., Darwin, D., and Dolan, C.W., Design of Concrete Structures, 15th Edition, McGraw-Hill, 2020.

[5] BSSC, Building Seismic Safety Council: NEHRP Recommended Provisions for Seismic Regulations, FEMA 368, 2006.

[6] Bangladesh National Building Code (BNBC), Part 6: Structural Design, Bangladesh, 2020.

[7] ACI 318-19, Building Code Requirements for Structural Concrete, American Concrete Institute, 2019.

[8] IS 456: 2000, Code of Practice for Plain and Reinforced Concrete, Bureau of Indian Standards.

[9] IS 1893 (Part 1): 2016, Criteria for Earthquake Resistant Design of Structures, Bureau of Indian Standards.

[10] Kwan, A.K.H., Punching Shear Behavior of Reinforced Concrete Flat Slabs, Journal of Structural Engineering, ASCE, Vol. 127, No. 5, 2001, pp. 485–493.

[11] Mohamed, A., and Al-Haddad, A., Seismic Performance of Flat Slab Buildings with Drop Panels, Earthquake Engineering & Structural Dynamics, 2015; 44: 239–256.

[12] Das, B.M., Seismic Response Analysis of Flat Slab Buildings Using ETABS, International Journal of Civil Engineering, Vol. 12, Issue 2, 2018, pp. 100–115.

[13] Paul, S., and Roy, S., Response Spectrum Analysis of Reinforced Concrete Multi-Story Buildings, Journal of Civil Structural Health Monitoring, 2017; 7: 233–247.

[14] Ghobarah, A., and Fawzia, H., Punching Shear Strength of Flat Slabs under Seismic Loading**,** Engineering Structures, 2002; 24: 1035–1046.

[15] CSI, ETABS 2022: Integrated Finite Element Analysis and Design Software**,** Computers and Structures, Inc., 2023.

[16] CSI, ETABS User Manual and Help Documentation**,** 2022 Edition.

[17] Ahmad, T., and Rahman, M., Seismic Behavior of Flat Slab Buildings in Bangladesh, Proceedings of the International Conference on Structural Engineering, 2019, pp. 125–137.

[18] Islam, M.R., Punching Shear Mitigation in RC Flat Slabs under Earthquake Load, 7th International Conference on Civil Engineering, Dhaka, 2021, pp. 200–212.

[19] Hossain, M., and Sultana, N., Modal Analysis and Response Spectrum Study of Multi-Story Flat Slabs, Proceedings of the Bangladesh Structural Engineering Conference, 2018, pp. 55–68.