Seismic and Structural Performance of Multi-Storied Buildings: A Study on Plan Configurations Using ETABS

A Thesis Submitted by

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DAFFODIL INTERNATIONAL UNIVERSITY
DHAKA, BANGLADESH

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I would also like to acknowledge the Department of Civil Engineering at Daffodil International University for providing the necessary facilities and resources that enabled us to conduct my research effectively.

My appreciation extends to the authors of previous studies in the realm of seismic load analysis specially in ETABS. The works of Murty, C.V.R. (2005) and Ahmed, S., & Rahman, M. (2021). have been particularly enlightening and have laid the groundwork for our own inquiry.

Special thanks are due to our peers and faculty members who have offered their critical reviews and constructive criticisms during the various stages of this research. Their feedback has been invaluable in enhancing the academic rigor of this study.

Lastly, I acknowledge the role of this research in contributing to the broader discourse on sustainable construction practices. We hope that our findings will serve as a catalyst for further scholarly investigations and practical implementations aimed at reducing the environmental impact of the construction industry.

ABSTRACT

The growing demand for high-rise buildings in urban areas, particularly in seismically active zones, has intensified the need for efficient structural design and seismic safety. Building configuration, especially the plan shape, plays a vital role in determining the structural response to seismic forces. This study investigates the seismic and structural performance of multi-storied reinforced concrete (RC) buildings with three different plan configurations—Rectangular, Hollow Rectangular, and Z-shaped—using ETABS 2018 software. A G+10 store RC frame structure was modeled for each configuration, and analyzed under static and seismic loading conditions as per BNBC 2020 guidelines. Key structural parameters including base shear, axial force, shear force, bending moment, and torsion were evaluated and compared across the different configurations. The results indicate that the rectangular plan exhibited the most favorable seismic response with uniform stress distribution and minimal torsional effects. The hollow rectangular configuration, while providing some spatial advantages, showed increased torsion and shear concentration at re-entrant corners. The Z-shaped configuration demonstrated the poorest seismic performance due to irregular geometry, leading to higher stress concentrations and torsional instability. This research highlights the importance of plan regularity in seismic design and underscores the need for careful consideration of geometrical configuration during the design phase. The findings aim to guide structural engineers and architects in optimizing both the functional and seismic aspects of multi-storied buildings for improved safety and performance.

LIST OF SYMBOLS

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ETABS	Three-Dimensional Analysis of Building System	13
BNBC	Bangladesh National Building Code	14
EQ	Earthquake	15
ASCE	American Society of Civil Engineers	18
ACI	American Concrete Institute	18
DL	Dead Load	19
LL	Live Load	19

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The rapid growth of urbanization and population expansion has led to an increased demand for multi-storied buildings, especially in seismically active regions. Modern cities are continuously evolving, requiring taller structures to accommodate residential, commercial, and institutional needs. However, with the increase in building height and complexity, structural stability becomes a critical concern, particularly in earthquake-prone areas where seismic forces impose significant challenges on the integrity of buildings.

Plan configurations of buildings significantly influence their ability to withstand lateral loads such as those caused by earthquakes and wind forces. Structural engineers have long emphasized the importance of regularity and symmetry in building plans to ensure uniform distribution of forces and minimize stress concentrations. Buildings with irregular plan shapes, such as L-shaped, T-shaped, and C-shaped configurations, often experience higher torsional effects, leading to greater vulnerability to seismic forces compared to conventional rectangular buildings.

Seismic forces act dynamically on structures, and irregular configurations can lead to differential movements across different parts of the building. This can result in excessive displacement, story drift, and torsional effects, which can compromise the overall stability of the structure. Irregular buildings tend to have weak points, particularly at reentrant corners, where stress concentrations are higher. These factors necessitate a detailed study on the effect of various plan configurations to understand their impact on seismic performance and structural integrity.

Advancements in structural analysis software, such as ETABS, provide a powerful tool for evaluating the seismic response of multi-story buildings with different configurations. ETABS allows engineers to simulate real-world loading conditions and assess key parameters such as base shear, story drift, displacement, and natural time period. By using ETABS, this study aims to compare the seismic performance of different plan configurations to determine the most efficient and stable design for high-rise structures.

Several building codes, including BNBC (Bangladesh National Building Code), emphasize the importance of plan regularity and recommend measures to minimize the effects of irregularities. Despite these guidelines, architects and engineers often design irregular buildings due to aesthetic, functional, or space-related considerations. This raises the need for an in-depth structural analysis to identify optimal configurations that balance aesthetics with seismic safety.

The significance of this study lies in its potential to contribute to safer and more efficient building designs, particularly in regions susceptible to earthquakes. Understanding how different plan configurations behave under seismic conditions can help engineers and designers make informed decisions that enhance structural resilience. Furthermore, the findings of this research can be beneficial for updating building codes, improving construction practices, and reducing the risk of structural failures during earthquakes.

1.2 STATEMENT OF PROBLEMS

With rapid urbanization and increasing population density, the demand for multi-story buildings has risen significantly. However, the selection of an appropriate plan configuration is often driven by architectural aesthetics and functional requirements rather than structural efficiency and seismic resilience. Buildings with irregular plan configurations, such as L-shaped, T-shaped, and Z-shaped, may suffer from structural deficiencies, including increased torsional effects, uneven load distribution, and higher susceptibility to seismic forces.

Despite the availability of advanced structural analysis tools like ETABS, there remains a lack of comprehensive studies comparing the seismic performance of different plan configurations under various loading conditions. The key problems addressed in this research are:

- How do different plan configurations affect the seismic behavior of multi-storied buildings?
- Which configuration provides the most stable and structurally efficient response under seismic loads?

- What are the critical parameters influencing story base shear, bending moment, axial force in different plan configurations?

This study seeks to bridge the gap in existing research by providing a detailed comparison of different plan configurations using ETABS, helping engineers and architects make informed decisions to ensure the safety and sustainability of high-rise structures.

1.3 OBJECTIVES

- To analyze the effect of different plan configurations on structural stability and seismic response.
- To compare story base shear, bending moment, torsion and shear force among various configurations.
- To evaluate the seismic performance of different configurations using ETABS.
- To determine the most efficient plan configuration in terms of structural integrity and safety.
- To provide design recommendations for optimized seismic performance in multi-storied buildings.

1.4 SCOPES OF THE STUDY

This study focuses on the seismic and structural performance of multi-storied buildings with different plan configurations. The scope is defined by the following limitations:

- Building Type: The study is limited to G+10 RC framed structures commonly used in urban construction.
- Plan Configurations: Only four configurations—Rectangular, Z-shaped and Hollow rectangular shape—are considered.
- Analysis Tool: ETABS software is used for modeling and analysis.
- Loading Conditions: The study incorporates static with seismic loads applied according to BNBC 2020.

- Material Specifications: 4000psi grade concrete and 60ksi steel are used for structural elements.
- Soil Type: The analysis is based on medium soil conditions as per BNBC 2020 classification.
- Exclusions: The study does not consider construction techniques, non-structural elements, or variations in material properties beyond the defined parameters.

CHAPTER 2

LITERATURE REVIEW

2.1 ETABS (EXTENDED THREE-DIMENSIONAL ANALYSIS OF BUILDING SYSTEMS)

ETABS (Extended Three-Dimensional Analysis of Building Systems) is a widely used structural analysis and design software developed by Computers and Structures, Inc. (CSI). It is specifically designed for modeling, analyzing, and designing buildings, especially multi-storied structures, under various loading conditions, including static, dynamic, and seismic loads. It has advanced modeling capabilities like a user-friendly graphical interface for creating complex building structures, support for different structural elements like beams, columns, slabs, shear walls, and bracings and automatic meshing and model generation. Seismic and wind load analysis, design and optimization, visualization and reporting are done by ETABS. The structural design of high-rise buildings is greatly influenced by their geometry and load-bearing behavior. Plan configurations play a crucial role in determining the seismic and wind performance of buildings. In this study, ETABS is used to model and analyze four different plan configurations to evaluate their structural responses. The objective is to compare the impact of different configurations on parameters such as base shear, store drift, and displacement under various loading conditions.

2.2 LITERATURE REVIEW

Numerous researchers have investigated the influence of building geometry and plan configuration on the seismic performance of structures. A study by Chopra (2012) emphasized the role of dynamic analysis in assessing building responses during earthquakes, highlighting the importance of irregularity in mass and stiffness distribution. Regular buildings tend to perform better under seismic loading due to uniform lateral force distribution.

Murty (2005) discussed how plan irregularities such as L, T, and C shapes cause torsional effects, which amplify seismic responses, especially in high-rise buildings. The Indian Standard IS 1893:2016 has recognized these configurations as irregular and recommends special design considerations.

In their research, Shinde and Kumbhar (2017) analyzed the seismic performance of G+10 RC buildings with different plan configurations using ETABS. Their results indicated that buildings with a rectangular plan showed lower store drifts and base shear compared to L-shaped and T-shaped buildings. This aligns with the concept that regularity improves structural behavior.

Jain and Nigam (2000) explored the seismic vulnerability of plan-irregular buildings and found that asymmetry in the building plan leads to stress concentrations and increased displacement in certain areas. These vulnerabilities can compromise the overall structural integrity during seismic events.

A more recent study by Shah and Gore (2020) modeled various high-rise buildings with different geometries in ETABS, using both static and dynamic loadings. Their findings demonstrated that torsional effects and non-uniform drift distribution were more prominent in C and T-shaped buildings, validating the need for additional design checks.

Ghosh and Fanella (2003) highlighted the benefits of response spectrum analysis in evaluating the time period and drift parameters, which are critical for seismic design. Their work also supports the use of ETABS as a comprehensive tool for performance-based seismic design.

Another significant study by Bhagat and Pawar (2018) evaluated buildings with re-entrant corners and concluded that such buildings are more prone to failure at the junctions due to stress concentration. Their recommendations include structural modifications like the addition of shear walls or bracings to mitigate these effects.

In Bangladesh, the implementation of BNBC 2020 has emphasized the need for response spectrum analysis and consideration of plan irregularities. Engineers now frequently use ETABS to comply with the updated seismic zoning and design guidelines. Ahmed and Rahman (2021) analyzed typical G+10 buildings in Dhaka and observed that plan regularity significantly reduces base shear and drift, which can be accurately assessed using ETABS.

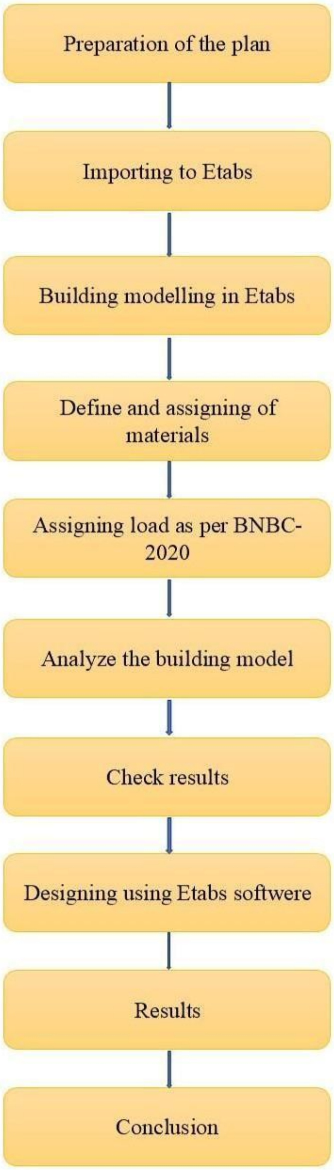
Overall, the literature indicates a clear consensus that regular building plans—especially rectangular—offer better seismic performance. However, due to architectural requirements, irregular configurations are still used and thus must be carefully analyzed. ETABS stands out as a reliable and efficient tool for modeling such configurations and conducting in-depth seismic performance evaluations.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Here we will discuss our entire work process. A flow chart is provided for better understanding.



3.2 SOFTWARE USED FOR ANALYSIS

ETABS is an engineering software product that caters to multi story building analysis and design. Modeling tools and details, and cross-sections may be generated for concrete and steel structures. ETABS provides an unequaled suite of tools for structural engineers designing buildings, whether they are working on one-story industrial structures or the tallest commercial high-rises. Immensely capable, yet easy-to-use, has been the hallmark of ETABS since its introduction decades ago, and this latest release continues that tradition by providing engineers with the technologically-advanced, yet intuitive, software they require to be their most productive

3.3 ASSUMPTIONS FOR MODELLING SIMPLIFICATION

We assumed a linearly elastic homogeneous material for the RC frame, which is always steel reinforced in reality. According to the ACI recommendation, the analysis results for the RC frame are accurate enough for this simplification only if appropriate properties of concrete are considered.

An RCC framed structure is basically an assembly of slabs, beams, columns and foundation interconnected to each other as a unit. The load transfer mechanism in these structures is from slabs to beams, from beams to columns, and then ultimately from columns to the foundation, which in turn passes the load to the soil. In this structural analysis study, we have adopted three cases by assuming different shapes for the same structure, as explained below.

1. Rectangular Plan
2. Hollo Rectangular Shape Plan
3. Z shape Plan

3.4 PROPERTIES FOR RECTANGLE SHAPE BUILDING

This portion provides property information for the material frame section, shell section and others.

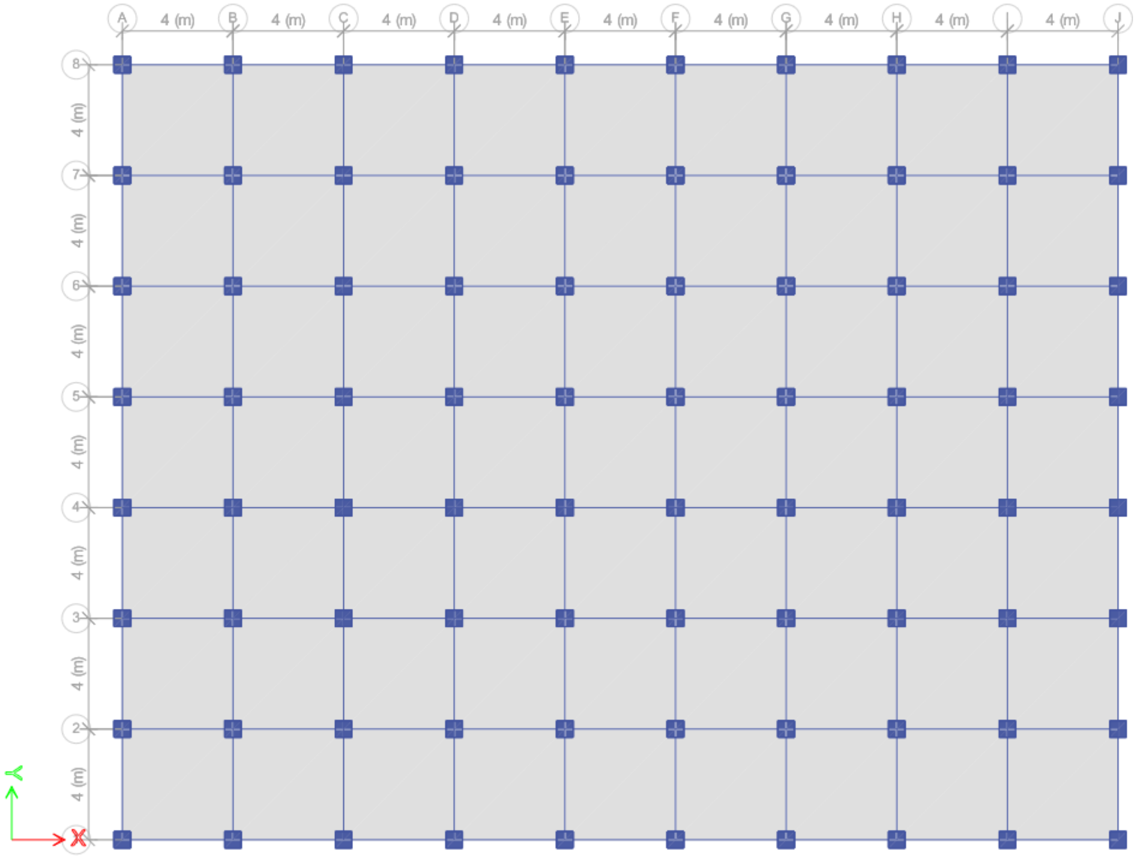


Figure 3.1 Plan view of a rectangular Building

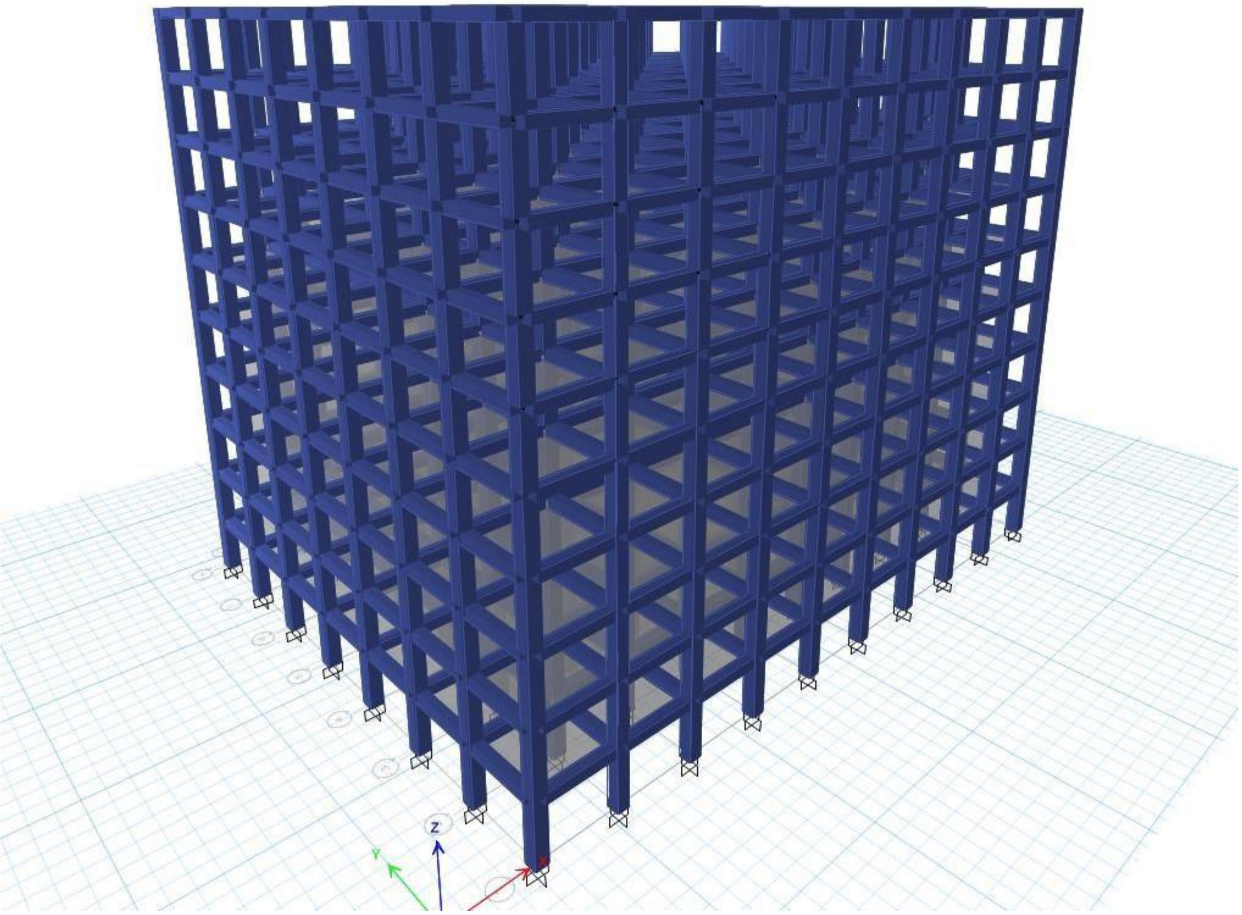
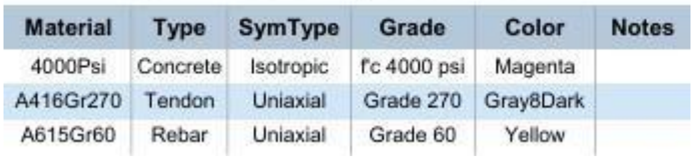


Figure 3.2 3D View

3.4.1 MATERIALS

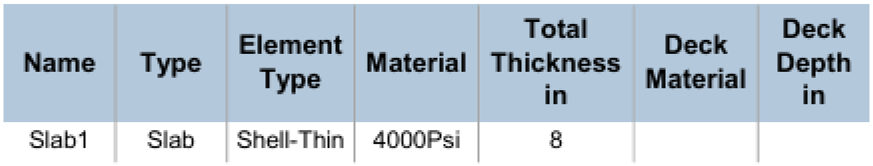


Material	Type	SymType	Grade	Color	Notes
4000Psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

3.4.2 FRAME SECTION

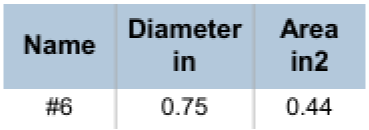
Name	Material	Shape	Color	Area in2	J in4	I33 in4	I22 in4	I23 in4	As2 in2
B 450mmX 450mm	4000Psi	Concrete Rectangular	Magenta	313.88	13879.73	8209.83	8209.83	0	261.56
C 500mmX500mm	4000Psi	Concrete Rectangular	Red	558	43866.81	25947.1	25947.1	0	465
C 600mmX600mm	4000Psi	Concrete Rectangular	Cyan	558	43866.81	25947.1	25947.1	0	465

3.4.3 SHELL SECTION



Name	Type	Element Type	Material	Total Thickness in	Deck Material	Deck Depth in
Slab1	Slab	Shell-Thin	4000Psi	8		

3.4.4 REINFORCEMENT SIZE



Name	Diameter in	Area in2
#6	0.75	0.44

3.5 PROPERTIES FOR HOLLOW RECTANGLE SHAPE BUILDING

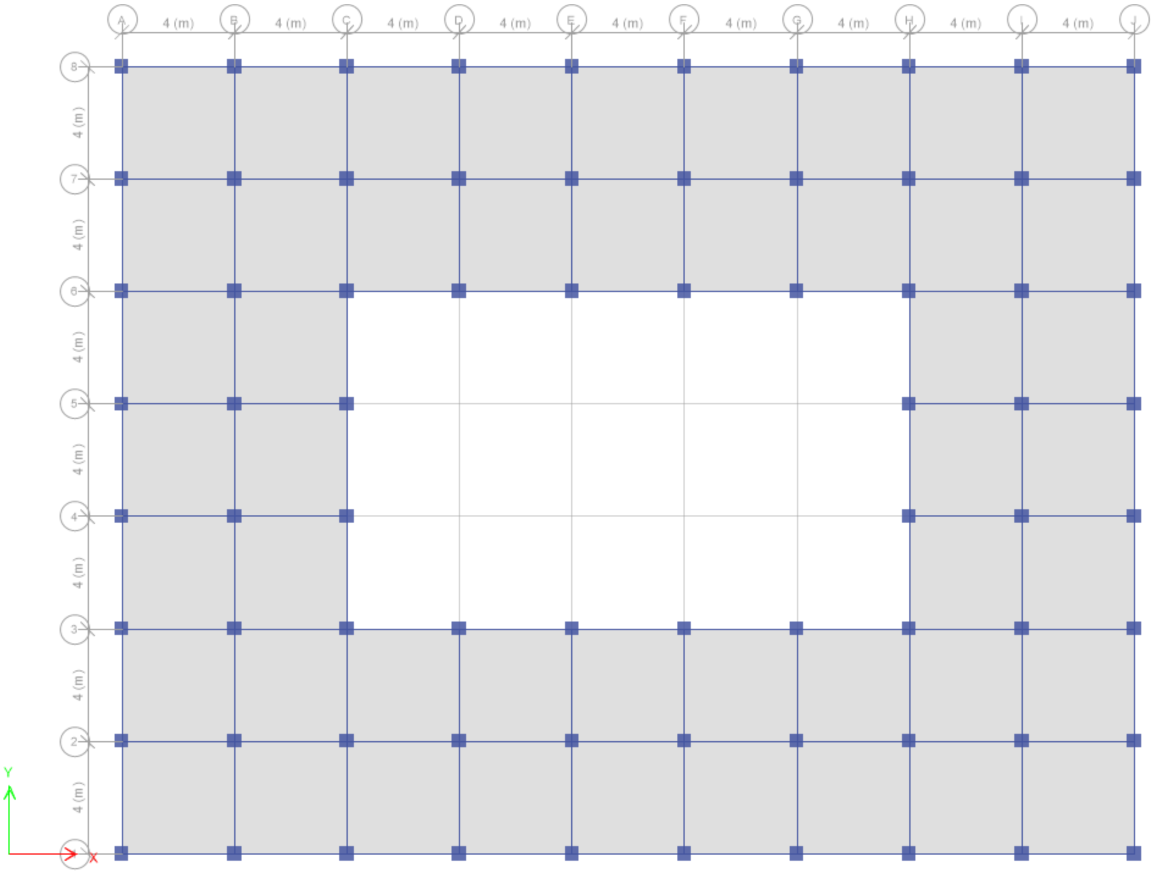


Figure 3.3 Plan view

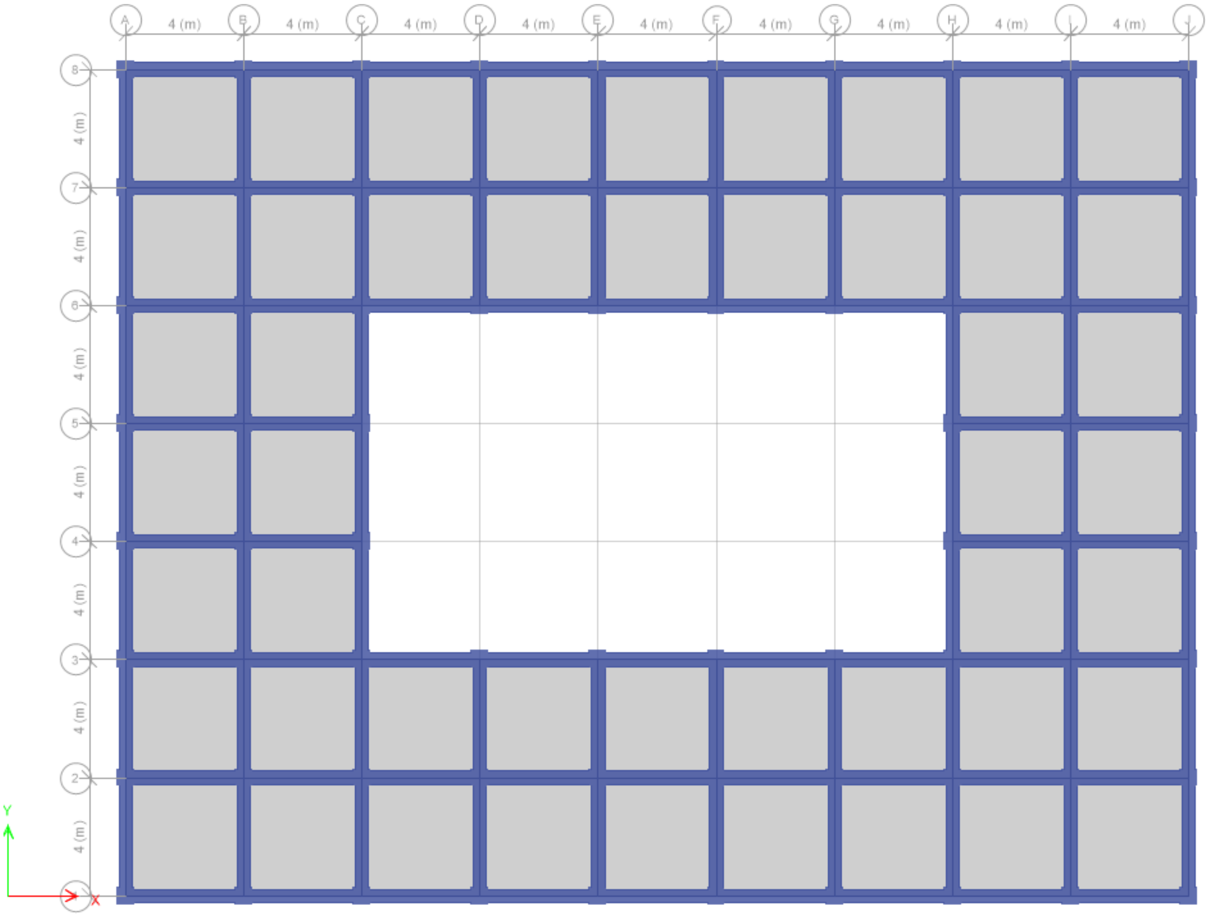


Figure 3.4 3D plan view

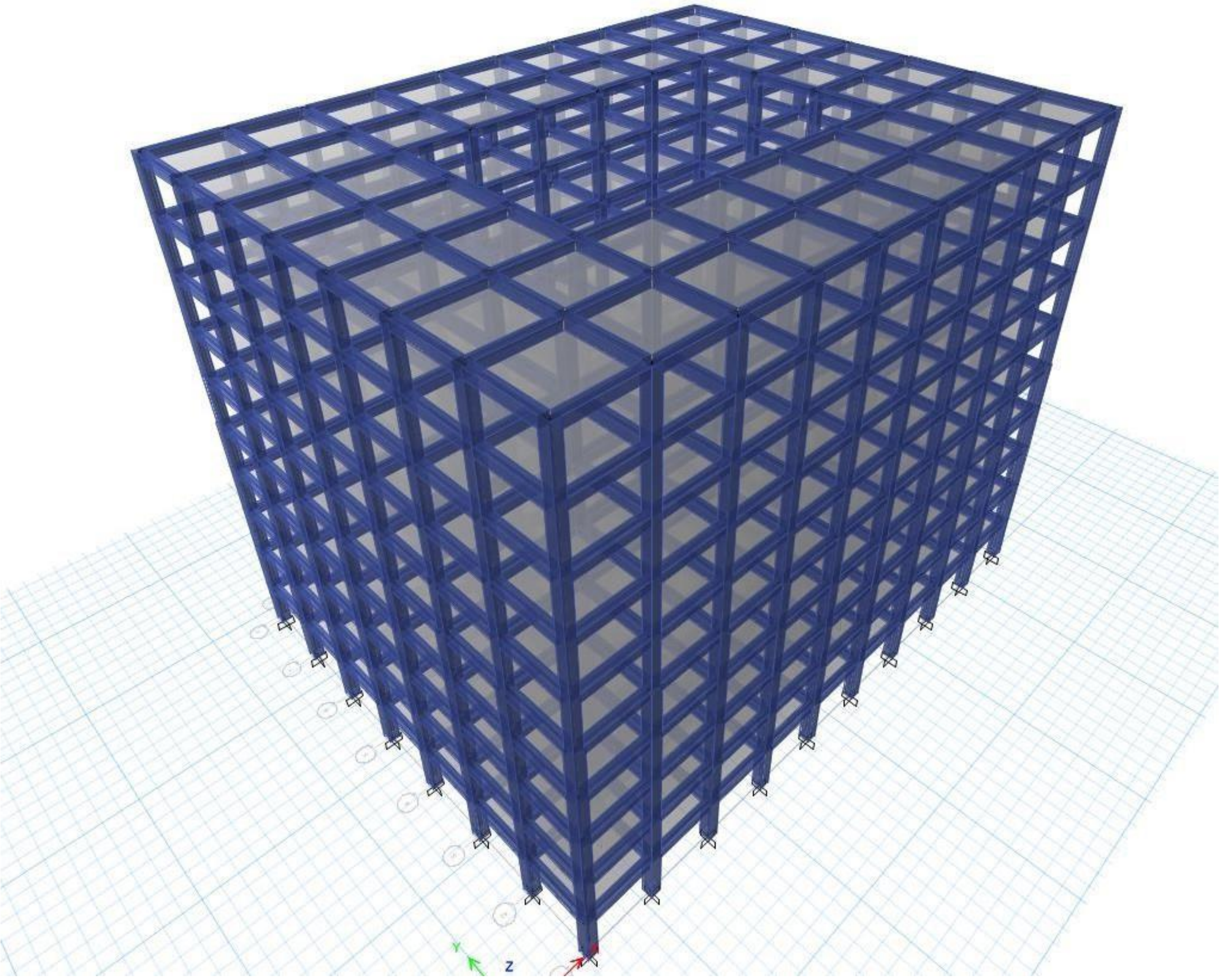
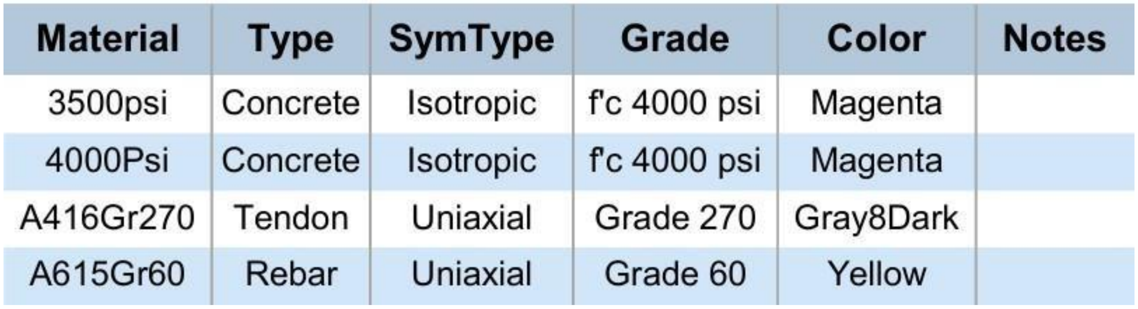


Figure 3.5 3D view

3.5.1 MATERIALS



Material	Type	SymType	Grade	Color	Notes
3500psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
4000Psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

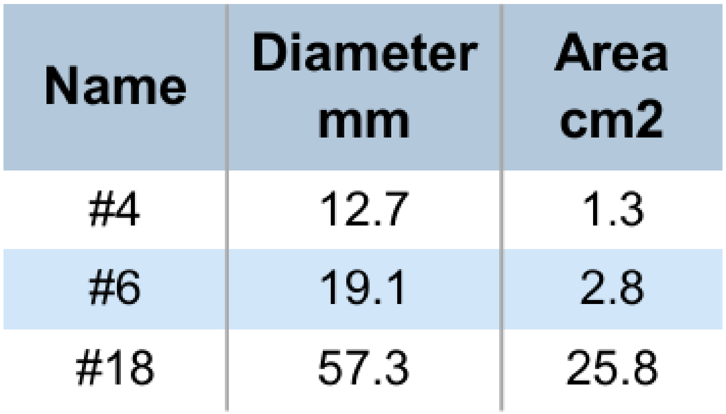
3.5.2 FRAME SECTION

Name	Material	Shape	Color	Area cm2	J cm4	I33 cm4	I22 cm4	I23 cm4	As2 cm2
B 450mmX 450mm	4000Psi	Concrete Rectangular	Magenta	2025	577718.1	341718.8	341718.8	0	1687.5
C 500mmX500mm	4000Psi	Concrete Rectangular	Red	2500	880533.7	520833.3	520833.3	0	2083.3
C 600mmX600mm	4000Psi	Concrete Rectangular	Cyan	3600	1825874.6	1080000	1080000	0	3000

3.5.3 SHELL SECTIONS

Name	Type	Element Type	Material	Total Thickness mm	Deck Material	Deck Depth mm
Slab 125mm	Slab	Shell-Thin	3500psi	125		

3.5.4 REINFORCEMENT SIZES



Name	Diameter mm	Area cm2
#4	12.7	1.3
#6	19.1	2.8
#18	57.3	25.8

3.6 PROPERTIES OF “Z” SHAPE BUILDING

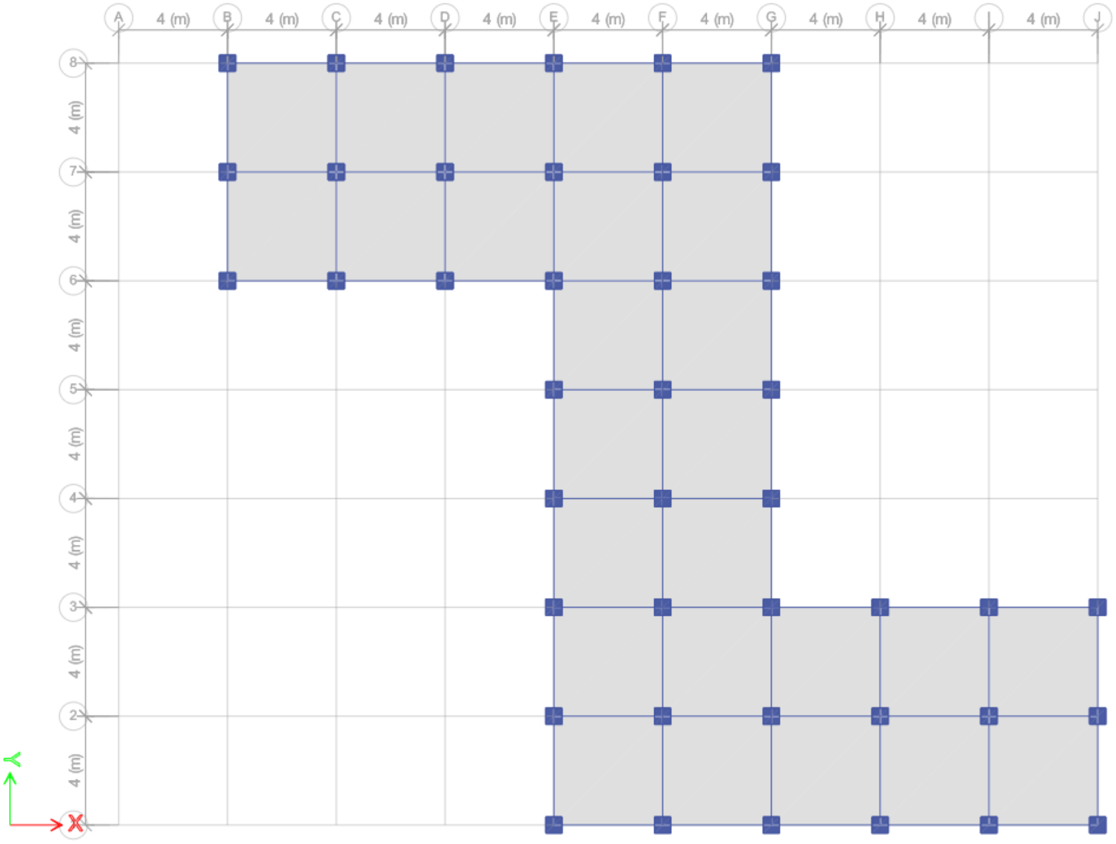


Figure 3.6 Plan view

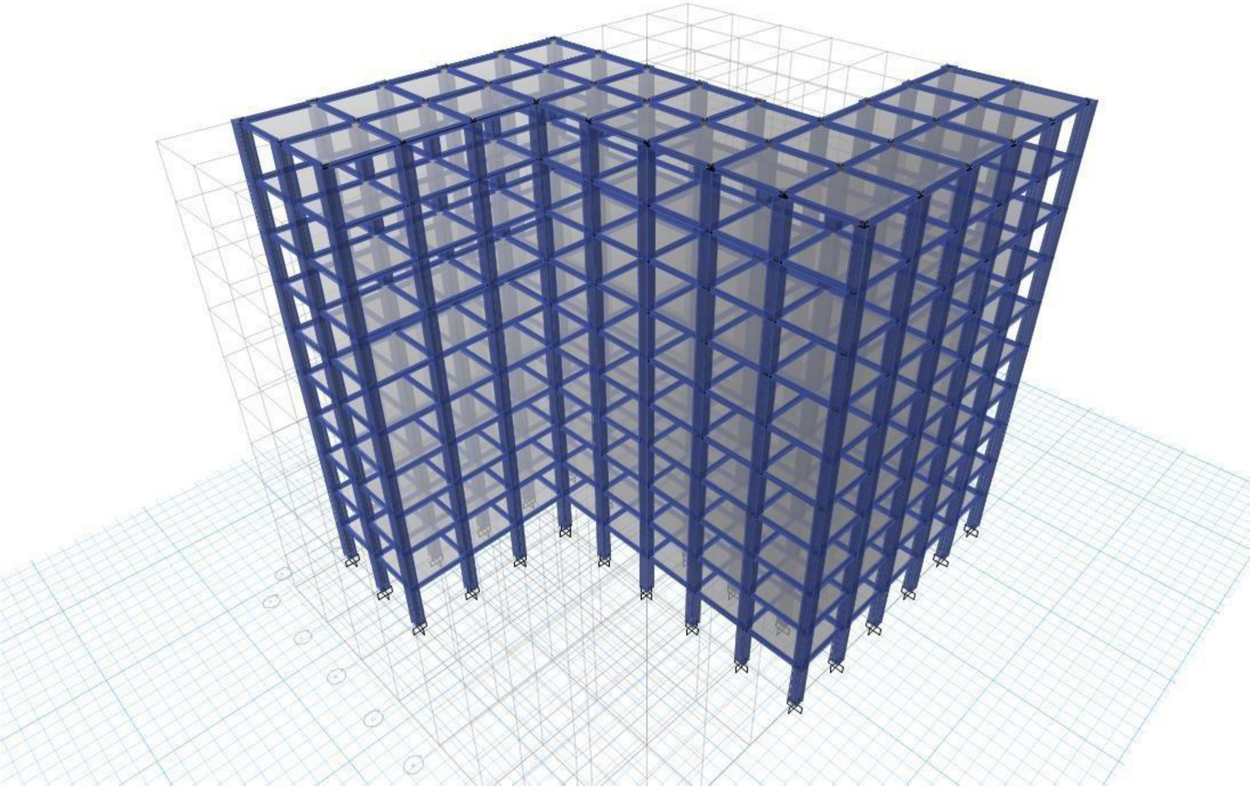
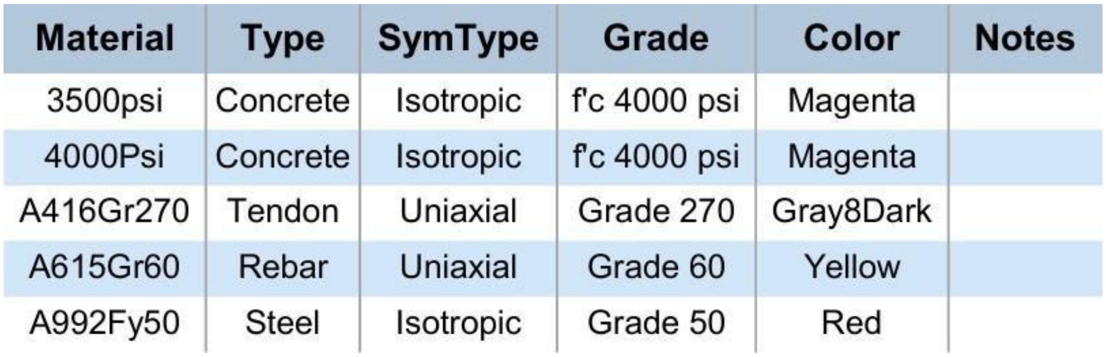


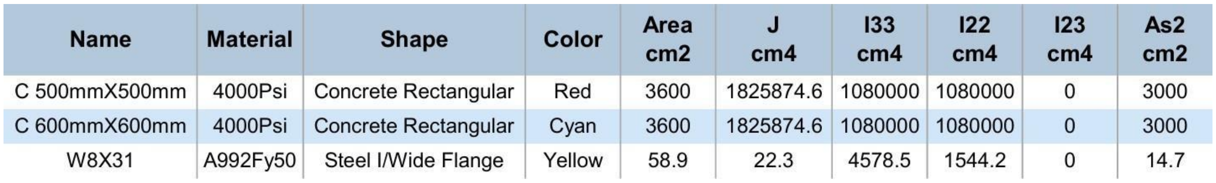
Figure 3.7: 3D view

3.6.1 MATERIALS



Material	Type	SymType	Grade	Color	Notes
3500psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
4000Psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	
A992Fy50	Steel	Isotropic	Grade 50	Red	

3.6.2 FRAME SECTION

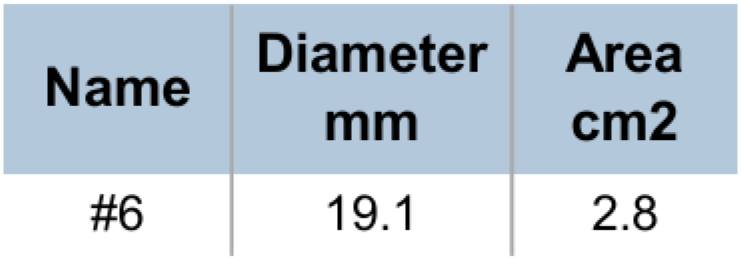


Name	Material	Shape	Color	Area cm2	J cm4	I33 cm4	I22 cm4	I23 cm4	As2 cm2
C 500mmX500mm	4000Psi	Concrete Rectangular	Red	3600	1825874.6	1080000	1080000	0	3000
C 600mmX600mm	4000Psi	Concrete Rectangular	Cyan	3600	1825874.6	1080000	1080000	0	3000
W8X31	A992Fy50	Steel I/Wide Flange	Yellow	58.9	22.3	4578.5	1544.2	0	14.7

3.6.3 SHELL SECTIONS

Name	Type	Element Type	Material	Total Thickness mm	Deck Material	Deck Depth mm
Slab 125mm	Slab	Shell-Thin	3500psi	125		
Slab1	Slab	Shell-Thin	4000Psi	203.2		

3.6.4 REINFORCEMENT SIZE



Name	Diameter mm	Area cm2
#6	19.1	2.8

3.7 LOADING

Loads acting on the structure are dead load (DL), live load (LL), and Earthquake load (EL). For earthquake load, the seismic zone is considered zone iv where Z=0.36, Soil type SC, Impact factor 1 Response reduction factor: 5, Damping: 5% according to BNBC 2020. Here Seismic load is considered along two directions EQ length and EQ width.

3.8 LOAD COMBINATION

The structure has been analyzed for load combinations considering all the previous loads in proper ratio. A combination of self-weight, dead load, live load and seismic load was taken into consideration according to BNBC 2020.

Table 1: Load Combination

Serial No.	Combination
1	1.4D
2	1.2D + 1.6L + 0.5Lr
3	1.2D + 1.6Lr + 1L
4	1.2D + 1.6L + 0.8Wx
5	1.2D + 1.6Lr + 0.8Wx
6	1.2D + 1.6L + 0.8Wy
7	1.2D + 1.6Lr + 0.8Wy
8	1.2D + 1.6Wx + 1L + 0.5Lr
9	1.2D + 1.6Wx + 1L
10	1.2D + 1.6Wy + 1L + 0.5Lr
11	1.2D + 1.6Wy + 1L
12	0.9D + 1.6Wx
13	0.9D + 1.6Wx+
14	0.9D + 1.6Wy+
15	0.9D + 1.6Wy-
16	1.338D + 1Ex + 0.3Ey+ + 1L
17	1.338D + 1Ex + 0.3Ey- + 1L
18	1.338D + 1Ex- + 0.3Ey+ + 1L
19	1.338D + 1Ex- + 0.3Ey- + 1L
20	1.338D + 0.3Ex + 1Ey+ + 1L
21	1.338D + 0.3Ex + 1Ey- + 1L
22	1.338D + 0.3Ex- + 1Ey+ + 1L
23	1.338D + 0.3Ex- + 1Ey- + 1L

24	0.762D + 1Ex + 0.3Ey+
25	0.762D + 1Ex + 0.3Ey-
26	0.762D + 1Ex- + 0.3Ey+
27	0.762D + 1Ex- + 0.3Ey-
28	0.762D + 0.3Ex + 1Ey+
29	0.762D + 0.3Ex + 1Ey-
30	0.762D + 0.3Ex- + 1Ey+
31	0.762D + 0.3Ex- + 1Ey-

CHAPTER 4

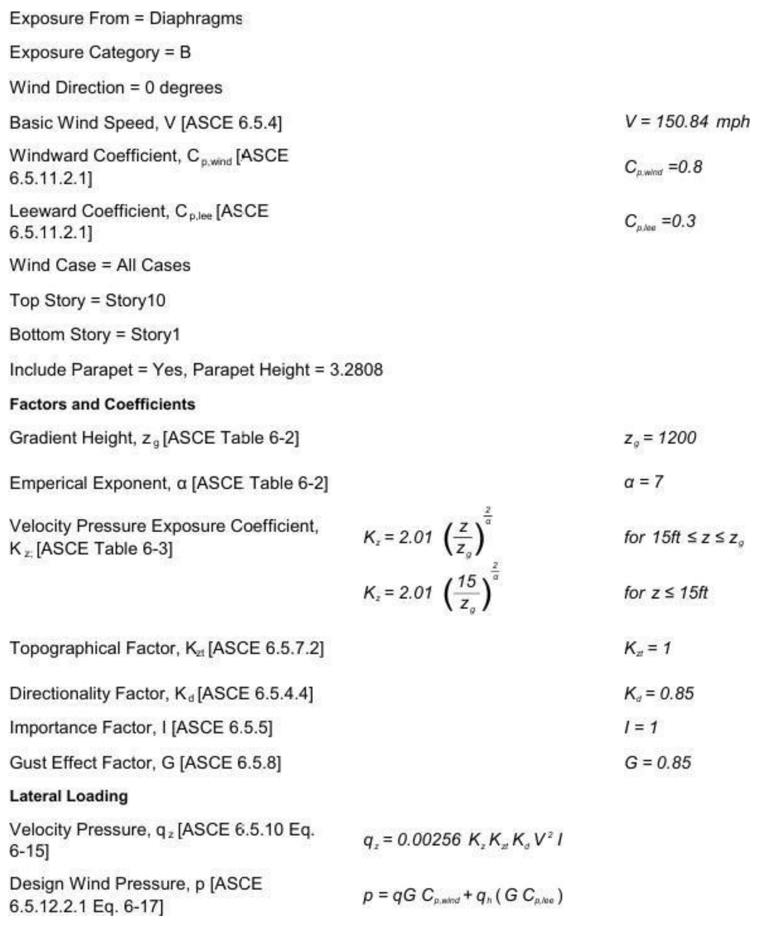
RESULT AND DISCUSSION

4.1 ANALYSIS OF RECTANGLE SHAPE BUILDING

4.1.1 WIND LOAD CALCULATION

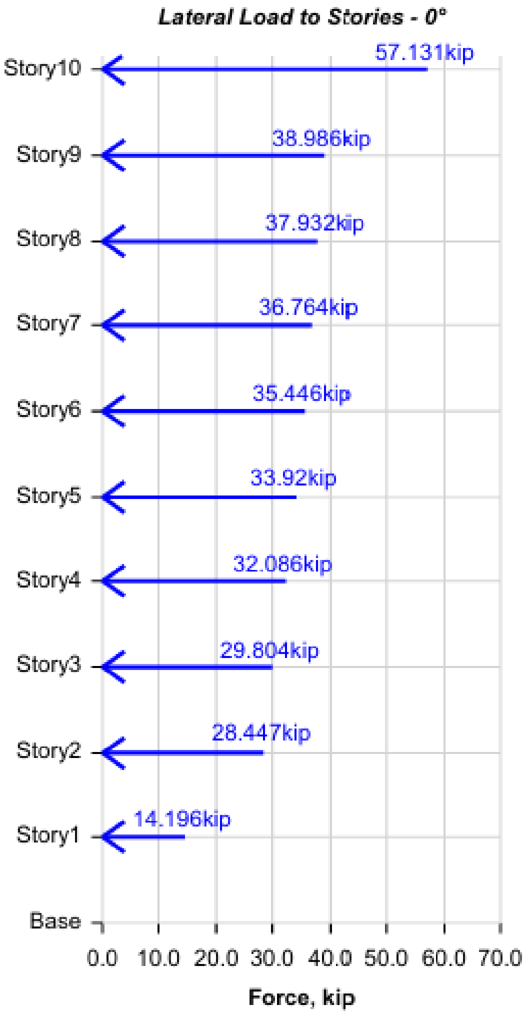
This calculation presents the automatically generated lateral wind loads for load pattern WX according to ASCE 7-05, as calculated by ETABS.

4.1.1.1 EXPOSURE PARAMETERS

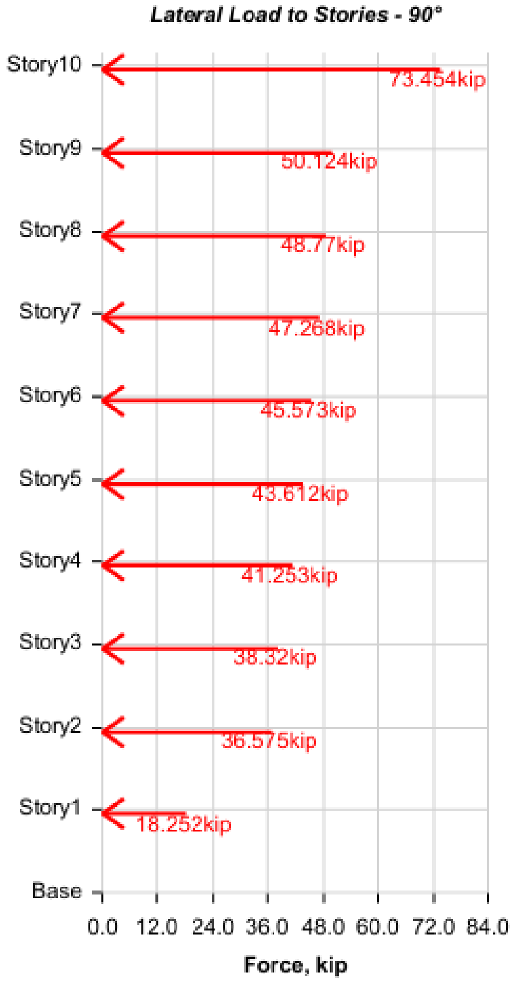


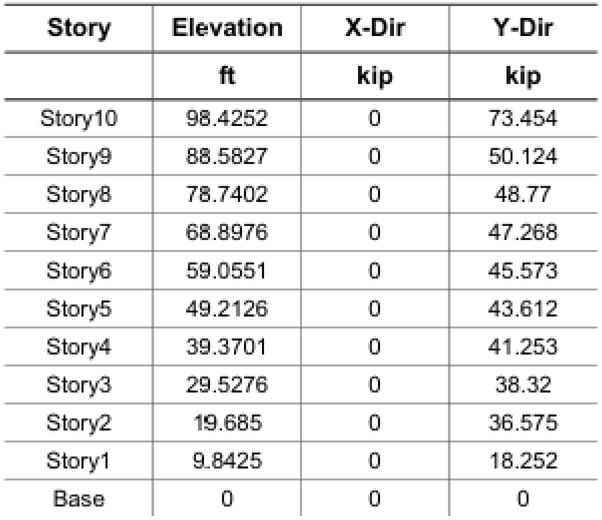
Exposure From = Diaphragms		
Exposure Category = B		
Wind Direction = 0 degrees		
Basic Wind Speed, V [ASCE 6.5.4]		$V = 150.84$ mph
Windward Coefficient, $C_{p,wind}$ [ASCE 6.5.11.2.1]		$C_{p,wind} = 0.8$
Leeward Coefficient, $C_{p,lee}$ [ASCE 6.5.11.2.1]		$C_{p,lee} = 0.3$
Wind Case = All Cases		
Top Story = Story10		
Bottom Story = Story1		
Include Parapet = Yes, Parapet Height = 3.2808		
Factors and Coefficients		
Gradient Height, z_g [ASCE Table 6-2]		$z_g = 1200$
Emperical Exponent, α [ASCE Table 6-2]		$\alpha = 7$
Velocity Pressure Exposure Coefficient, K_z [ASCE Table 6-3]	$K_z = 2.01 \left(\frac{z}{z_g}\right)^{\frac{2}{\alpha}}$	for $15ft \le z \le z_g$
	$K_z = 2.01 \left(\frac{15}{z_g}\right)^{\frac{2}{\alpha}}$	for $z \le 15ft$
Topographical Factor, K_{zt} [ASCE 6.5.7.2]		$K_{zt} = 1$
Directionality Factor, K_d [ASCE 6.5.4.4]		$K_d = 0.85$
Importance Factor, I [ASCE 6.5.5]		$I = 1$
Gust Effect Factor, G [ASCE 6.5.8]		$G = 0.85$
Lateral Loading		
Velocity Pressure, q_z [ASCE 6.5.10 Eq. 6-15]	$q_z = 0.00256\ K_z K_{zt} K_d V^2 I$	
Design Wind Pressure, p [ASCE 6.5.12.2.1 Eq. 6-17]	$p = qG\ C_{p,wind} + q_h\ (G\ C_{p,lee})$	

4.1.1.2 APPLIED STORY FORCES



Story	Elevation	X-Dir	Y-Dir
	ft	kip	kip
Story10	98.4252	57.131	0
Story9	88.5827	33.986	0
Story8	78.7402	37.932	0
Story7	68.8976	36.764	0
Story6	59.0551	35.446	0
Story5	49.2126	33.92	0
Story4	39.3701	32.086	0
Story3	29.5276	29.804	0
Story2	19.685	23.447	0
Story1	9.8425	14.196	0
Base	0	0	0



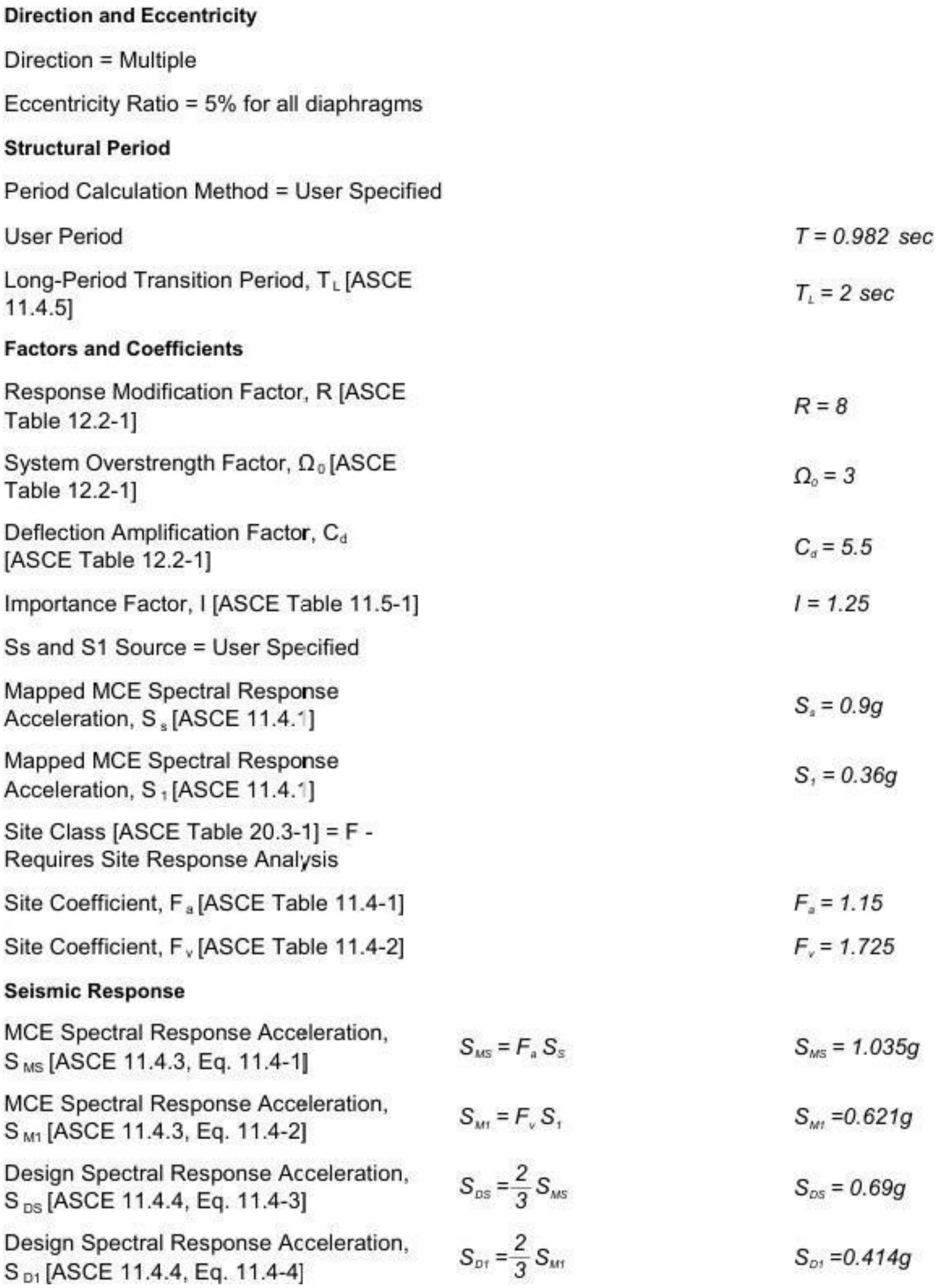


Story	Elevation	X-Dir	Y-Dir
	ft	kip	kip
Story10	98.4252	0	73.454
Story9	88.5827	0	50.124
Story8	78.7402	0	48.77
Story7	68.8976	0	47.268
Story6	59.0551	0	45.573
Story5	49.2126	0	43.612
Story4	39.3701	0	41.253
Story3	29.5276	0	38.32
Story2	19.685	0	36.575
Story1	9.8425	0	18.252
Base	0	0	0

4.1.2 SEISMIC LOAD CALCULATION

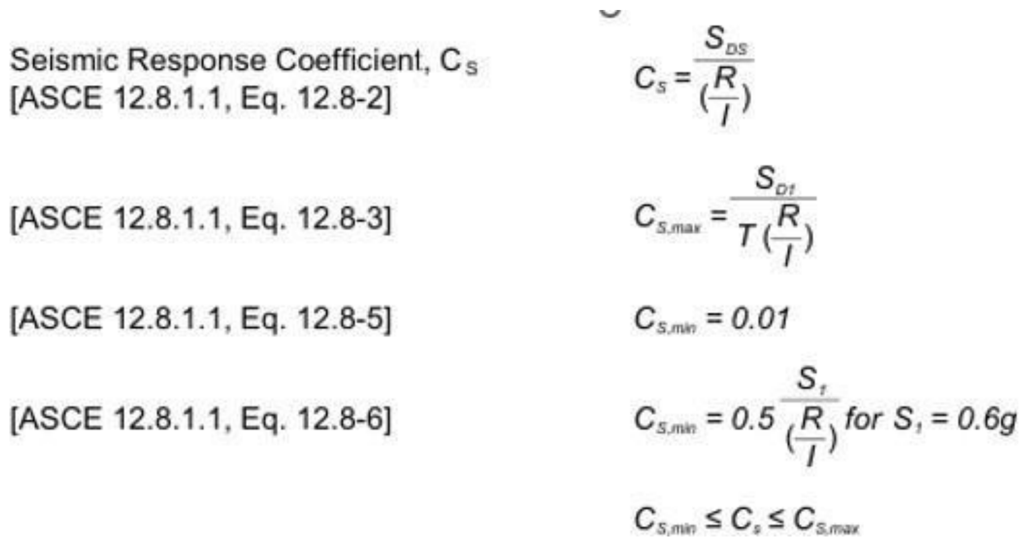
This calculation presents the automatically generated lateral seismic loads for load pattern EX according to ASCE 7-05, as calculated by ETABS.

4.1.2.1 EXPOSER PARAMETERS



Direction and Eccentricity		
Direction = Multiple		
Eccentricity Ratio = 5% for all diaphragms		
Structural Period		
Period Calculation Method = User Specified		
User Period		$T = 0.982$ sec
Long-Period Transition Period, T_L [ASCE 11.4.5]		$T_L = 2$ sec
Factors and Coefficients		
Response Modification Factor, R [ASCE Table 12.2-1]		$R = 8$
System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]		$\Omega_o = 3$
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]		$C_d = 5.5$
Importance Factor, I [ASCE Table 11.5-1]		$I = 1.25$
Ss and S1 Source = User Specified		
Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.1]		$S_s = 0.9g$
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.1]		$S_1 = 0.36g$
Site Class [ASCE Table 20.3-1] = F - Requires Site Response Analysis		
Site Coefficient, F_a [ASCE Table 11.4-1]		$F_a = 1.15$
Site Coefficient, F_v [ASCE Table 11.4-2]		$F_v = 1.725$
Seismic Response		
MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.3, Eq. 11.4-1]	$S_{MS} = F_a S_S$	$S_{MS} = 1.035g$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.3, Eq. 11.4-2]	$S_{M1} = F_v S_1$	$S_{M1} = 0.621g$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.4, Eq. 11.4-3]	$S_{DS} = \frac{2}{3} S_{MS}$	$S_{DS} = 0.69g$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.4, Eq. 11.4-4]	$S_{D1} = \frac{2}{3} S_{M1}$	$S_{D1} = 0.414g$

4.1.2.2 STOREY SHEAR



Seismic Response Coefficient, C_S
[ASCE 12.8.1.1, Eq. 12.8-2]

$$C_s = \frac{S_{DS}}{(\frac{R}{I})}$$

[ASCE 12.8.1.1, Eq. 12.8-3]

$$C_{S,max} = \frac{S_{D1}}{T(\frac{R}{I})}$$

[ASCE 12.8.1.1, Eq. 12.8-5]

$$C_{S,min} = 0.01$$

[ASCE 12.8.1.1, Eq. 12.8-6]

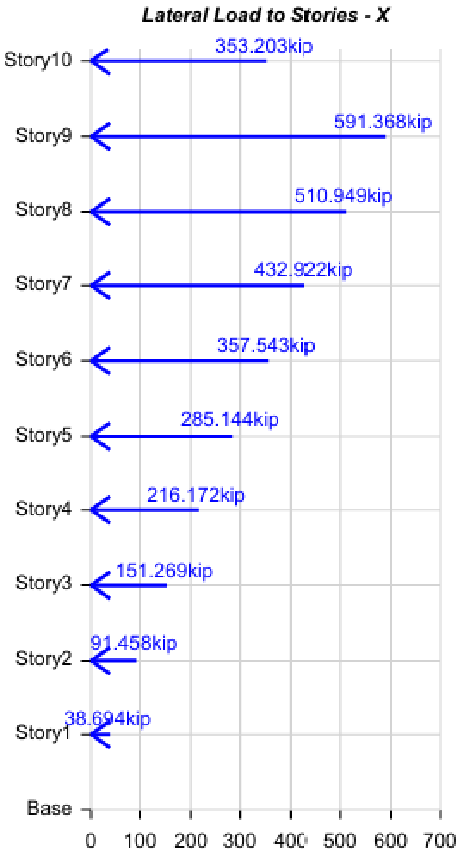
$$C_{S,min} = 0.5\frac{S_1}{(\frac{R}{I})} \text{ for } S_1 = 0.6g$$

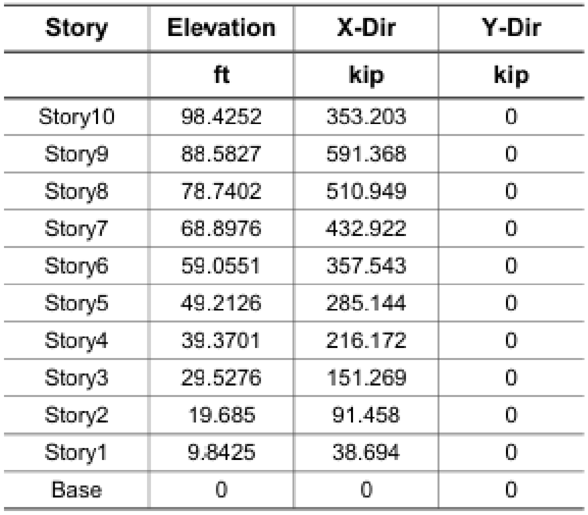
$$C_{S,min} \leq C_s \leq C_{S,max}$$

Table 2: Storey shear

Storey level	Storey shear (kip)
1	30.56
2	21.70
3	19.70
4	18.09
5	16.43
6	14.34
7	11.84
8	8.77
9	5.47
10	0.56

4.1.2.3 APPLIED STORY FORCES





Story	Elevation	X-Dir	Y-Dir
	ft	kip	kip
Story10	98.4252	353.203	0
Story9	88.5827	591.368	0
Story8	78.7402	510.949	0
Story7	68.8976	432.922	0
Story6	59.0551	357.543	0
Story5	49.2126	285.144	0
Story4	39.3701	216.172	0
Story3	29.5276	151.269	0
Story2	19.685	91.458	0
Story1	9.8425	38.694	0
Base	0	0	0

4.1.3 AXIAL FORCE

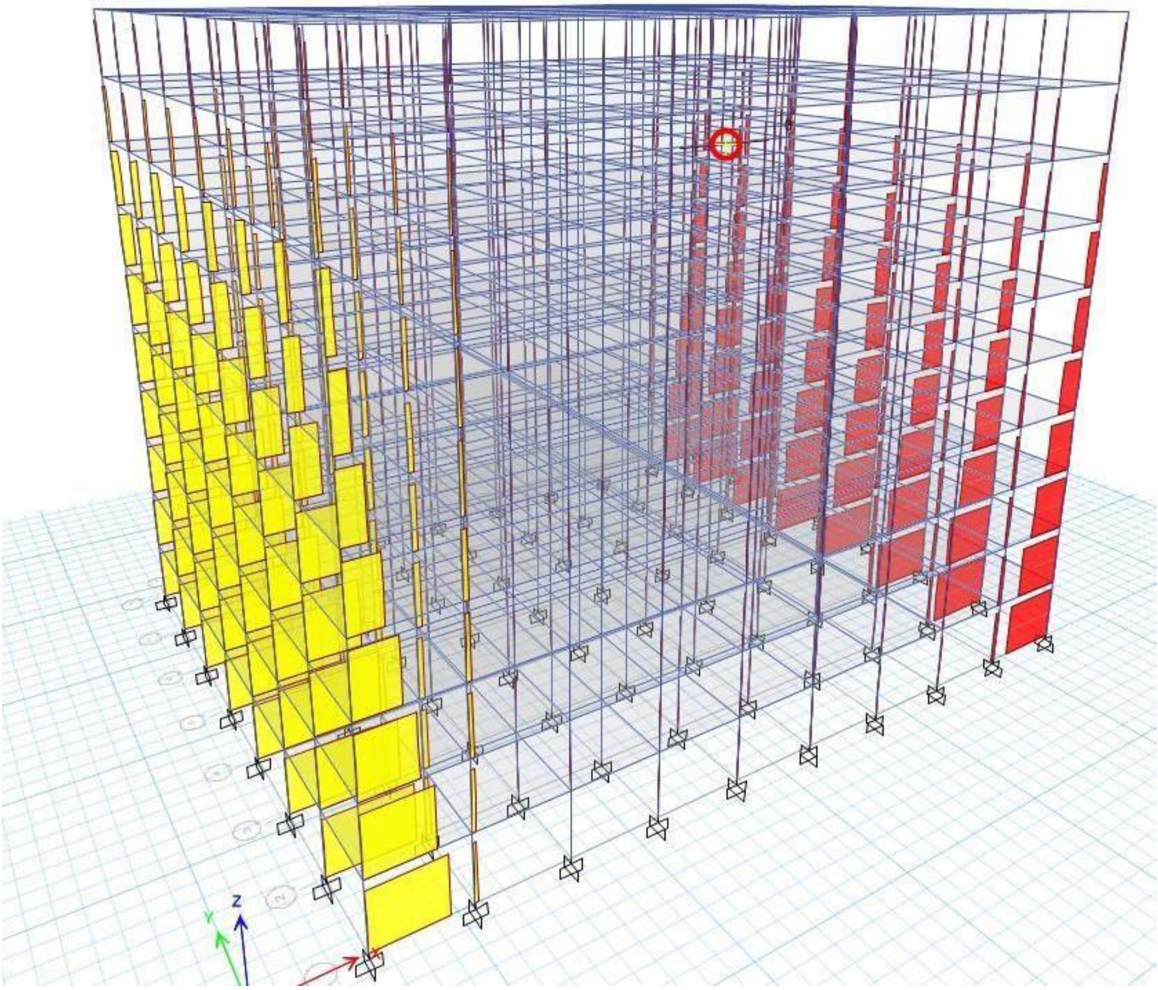


Figure 4.1 3d view of axial force

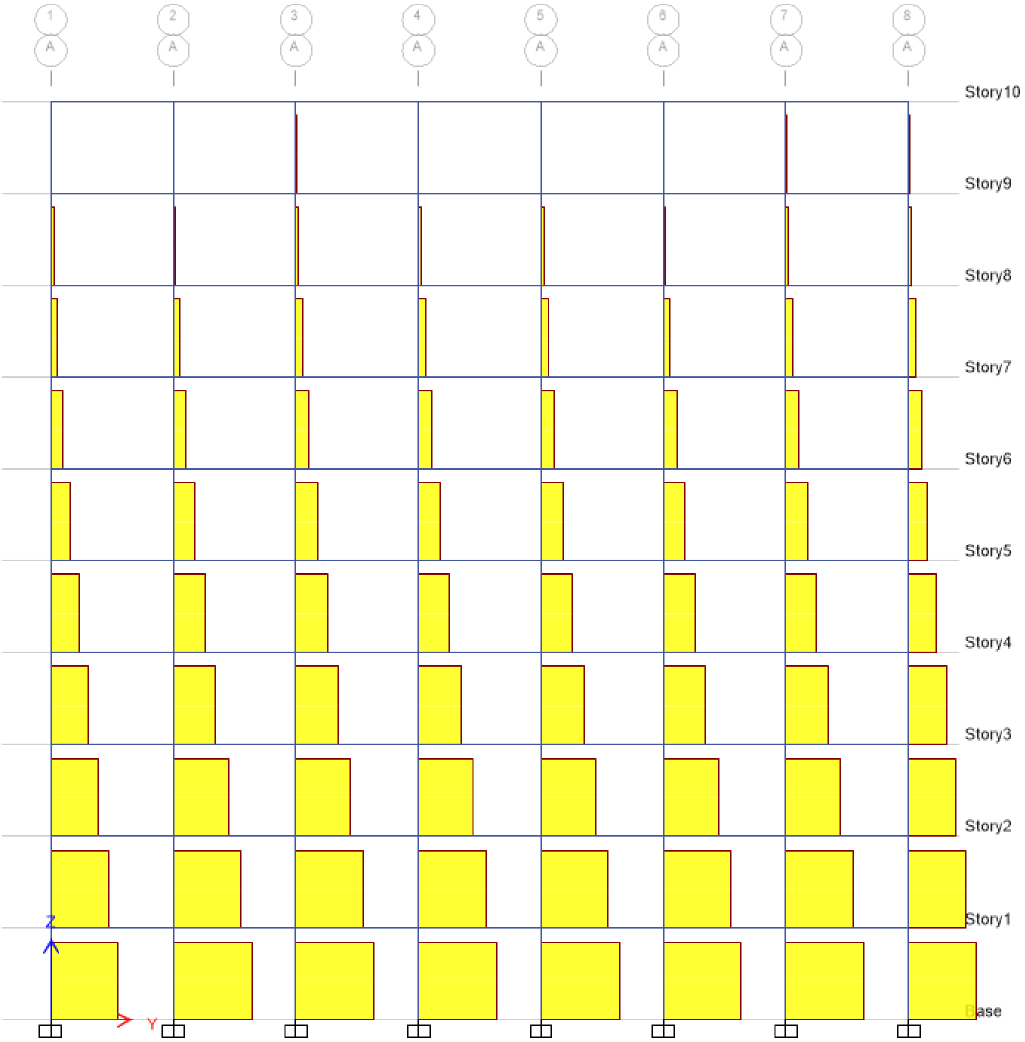


Figure 4.2 Elevation view

4.1.4 SHEAR FORCE

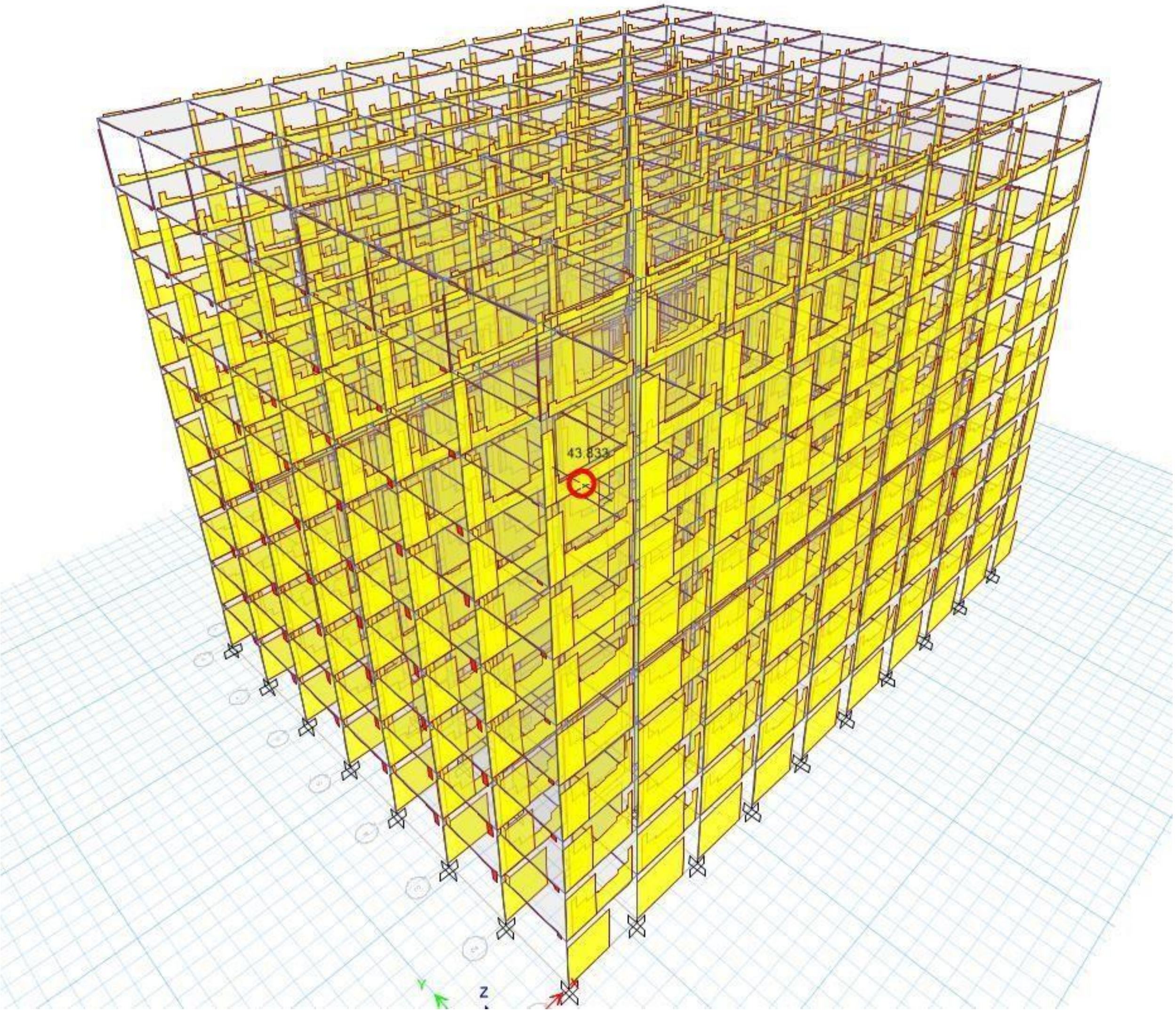


Figure 4.3 3d view of Shear force

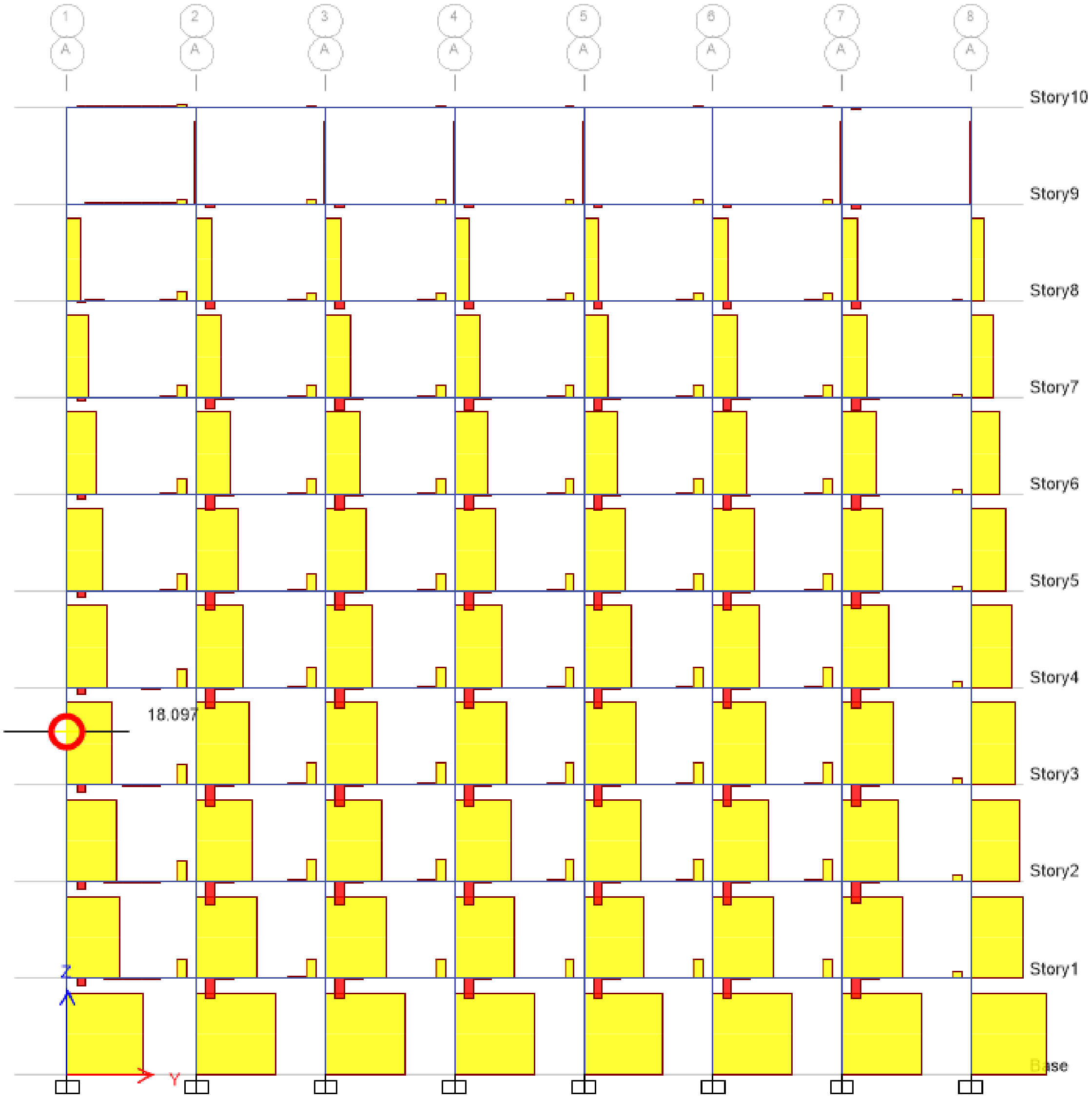


Figure 4.4 Elevation view of shear force

4.1.5 BENDING MOMENT

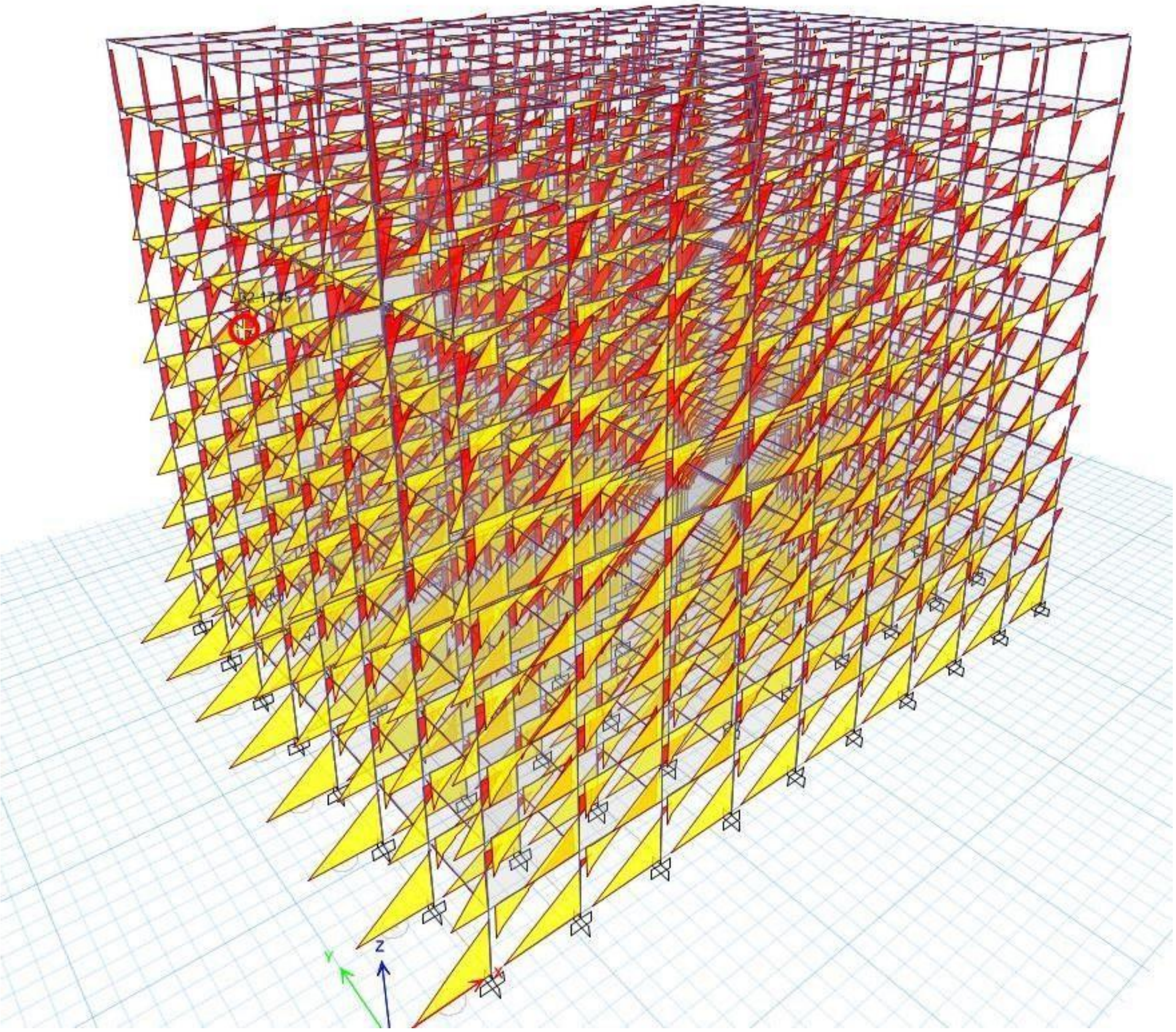


Figure 4.5 3d view of bending moment

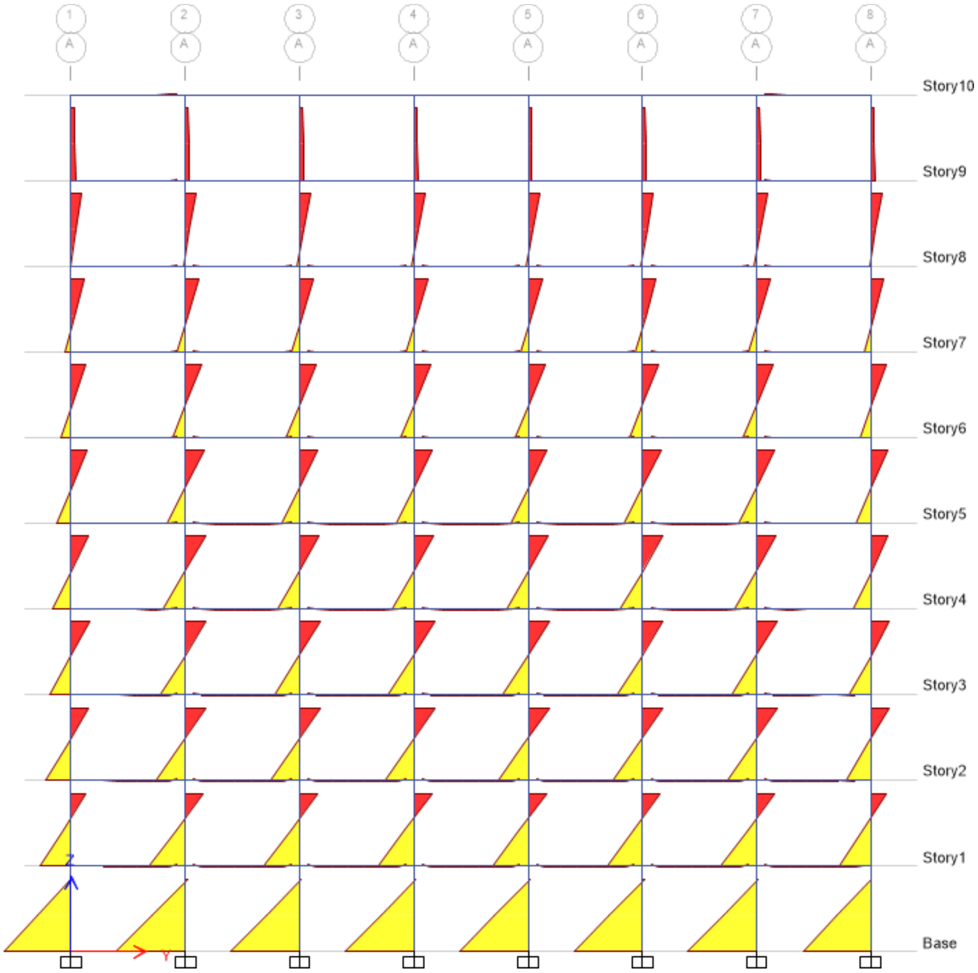


Figure 4.6 Elevation of Bending moment

Table 3: Bending moment.

Storey level	Bending Moment (kip-ft)
1	257.51
2	119.72
3	96.10
4	82.08
5	70.45
6	57.08
7	41.53
8	23.65
9	4.82
10	1.28

4.1.6 TORSION

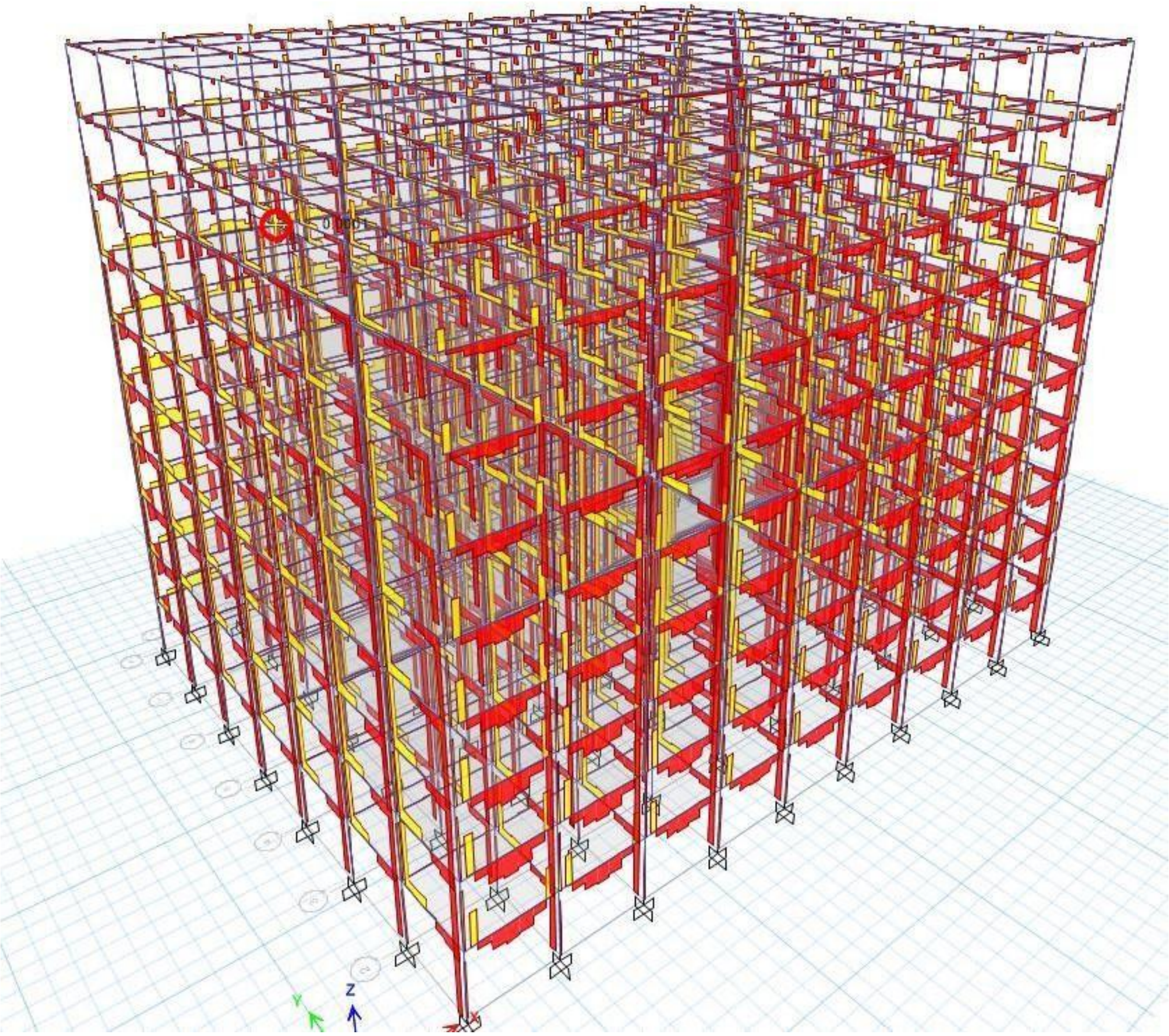


Figure 4.7 3d view of torsion

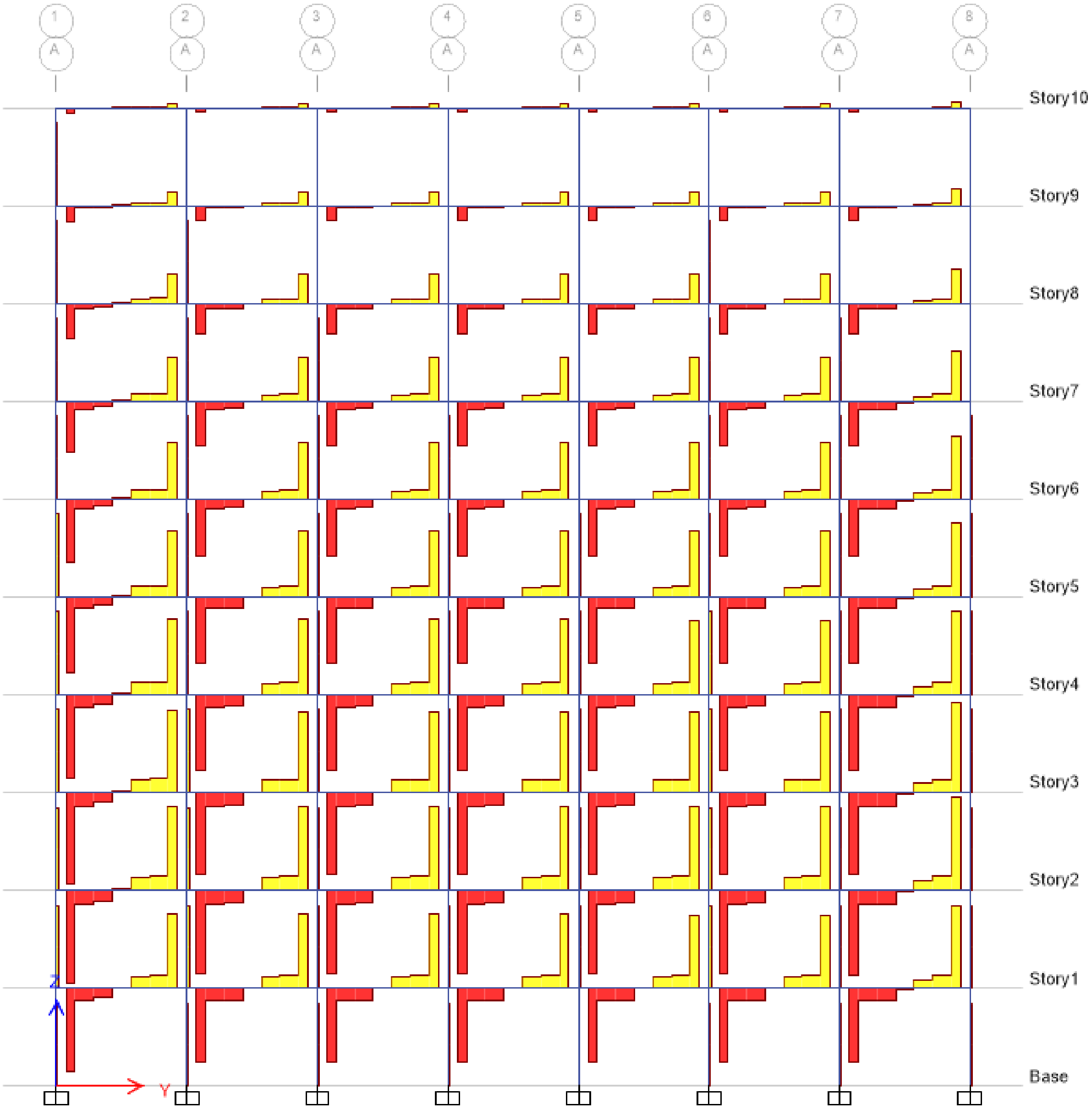


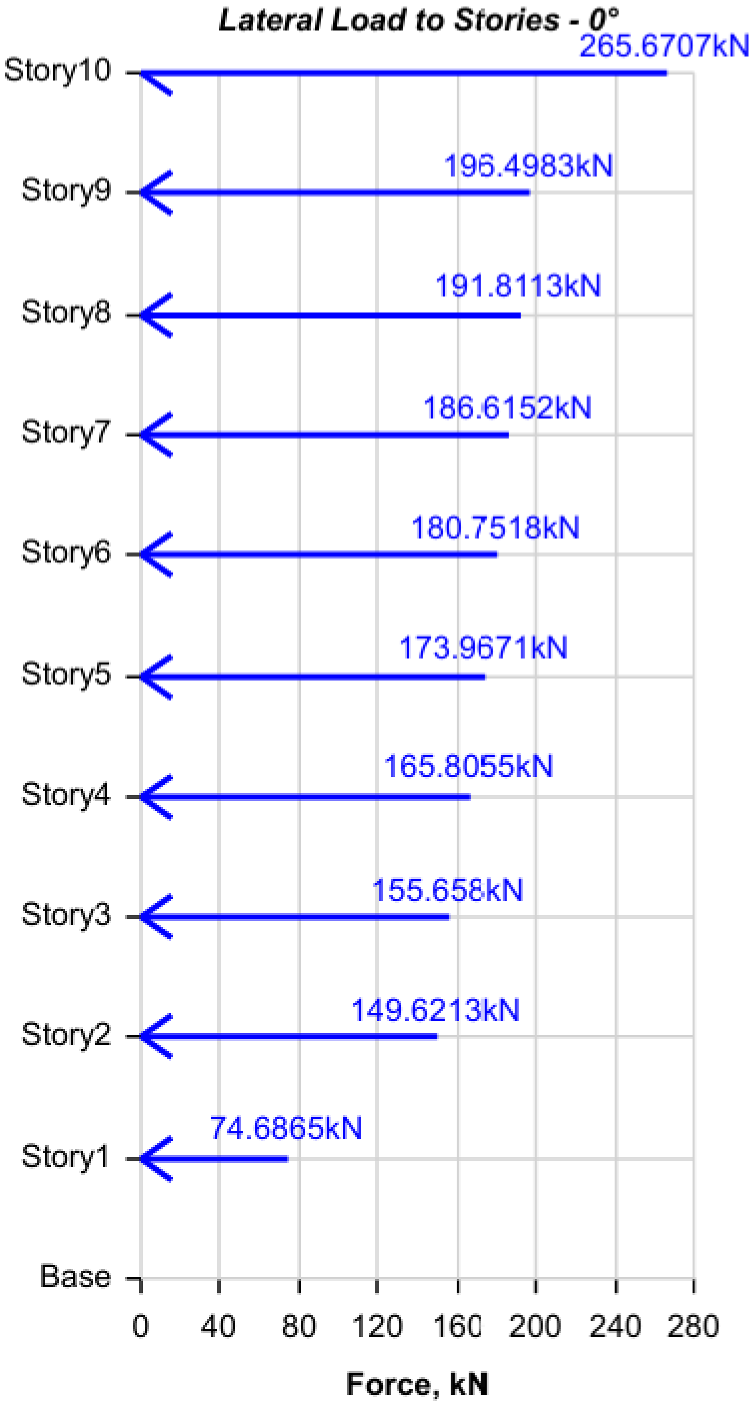
Figure 4.8 Elevation view of torsion

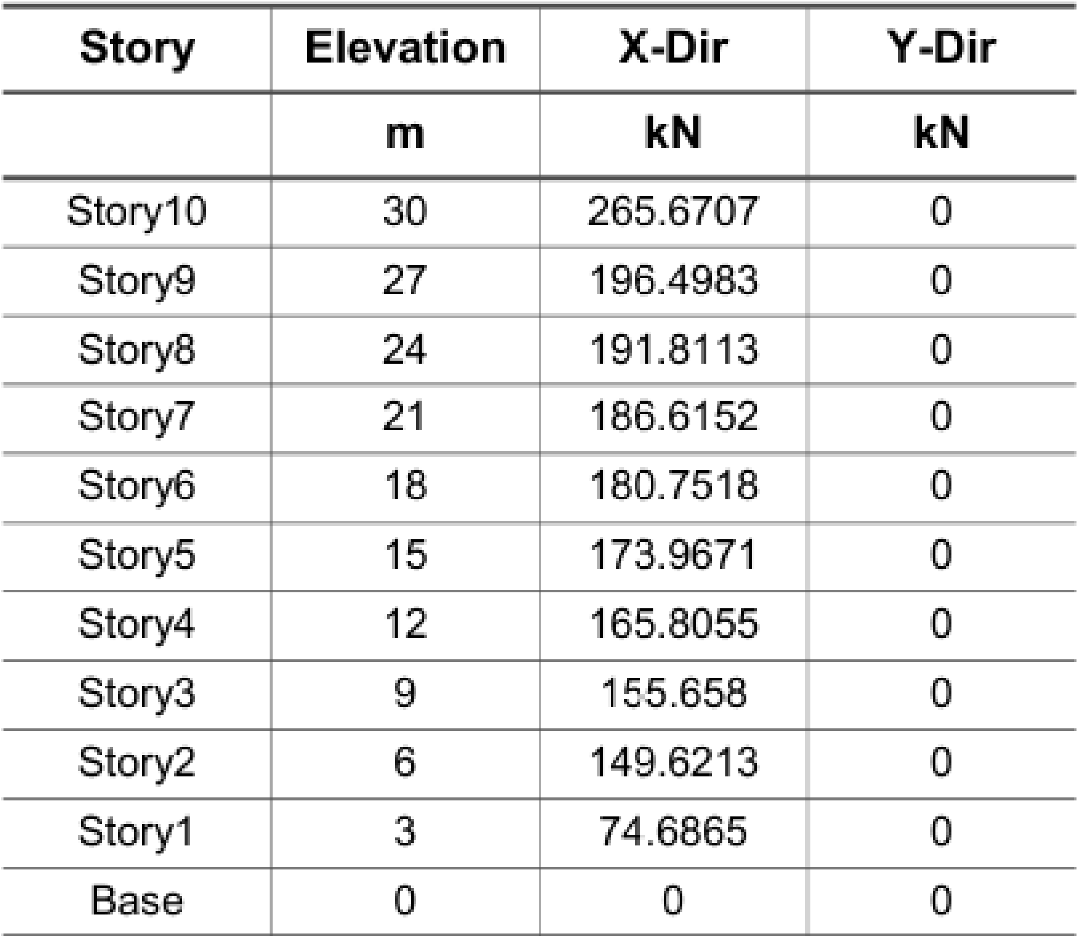
4.2 ANALYSIS OF HOLLOW RECTANGULAR SHAPE BUILDING

4.2.1 WIND LOAD CALCULATION

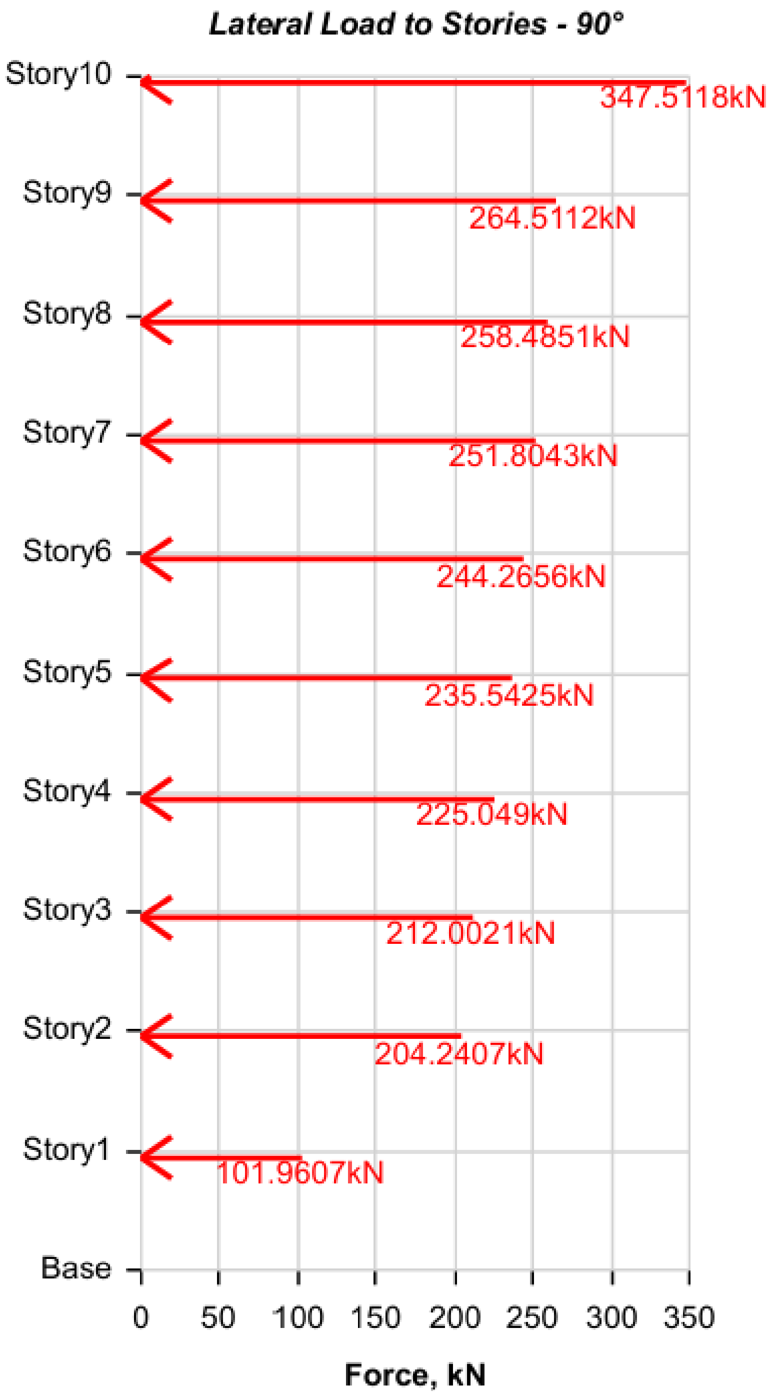
This calculation presents the automatically generated lateral wind loads for load pattern WX according to ASCE 7-05, as calculated by ETABS.

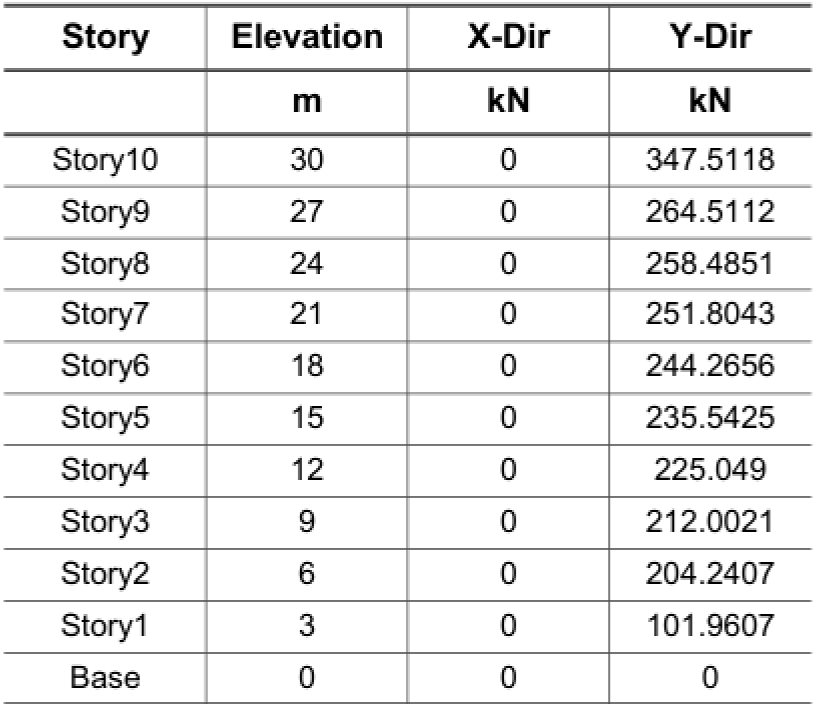
4.2.1.1 APPLIED STORY FORCES





Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
Story10	30	265.6707	0
Story9	27	196.4983	0
Story8	24	191.8113	0
Story7	21	186.6152	0
Story6	18	180.7518	0
Story5	15	173.9671	0
Story4	12	165.8055	0
Story3	9	155.658	0
Story2	6	149.6213	0
Story1	3	74.6865	0
Base	0	0	0


Lateral Load to Stories - 90°
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base
347.5118kN
264.5112kN
258.4851kN
251.8043kN
244.2656kN
235.5425kN
225.049kN
212.0021kN
204.2407kN
101.9607kN
0
50
100
150
200
250
300
350
Force, kN



Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
Story10	30	0	347.5118
Story9	27	0	264.5112
Story8	24	0	258.4851
Story7	21	0	251.8043
Story6	18	0	244.2656
Story5	15	0	235.5425
Story4	12	0	225.049
Story3	9	0	212.0021
Story2	6	0	204.2407
Story1	3	0	101.9607
Base	0	0	0

4.2.2 SEISMIC LOAD ANALYSIS

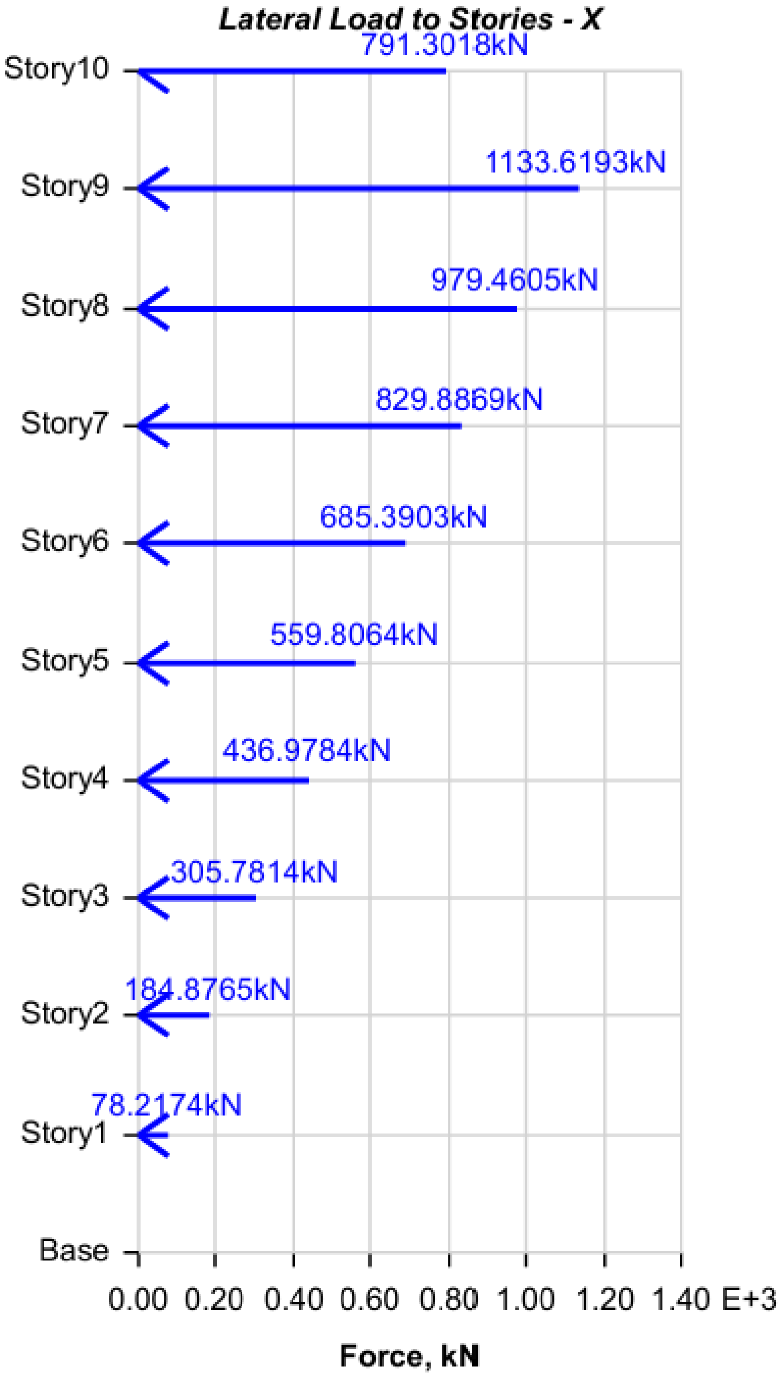
This calculation presents the automatically generated lateral seismic loads for load pattern EX according to ASCE 7-05, as calculated by ETABS.

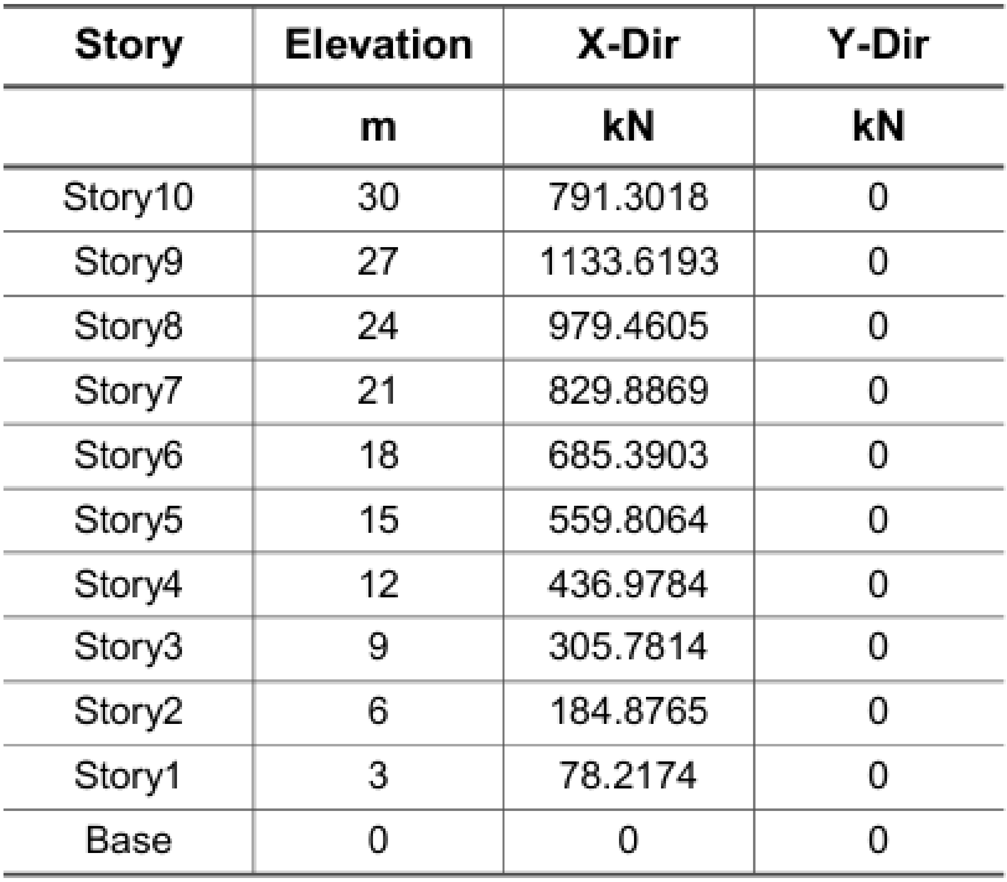
4.2.2.1 STOREY SHEAR

Table 4

Storey level	Storey shear (kip)
1	71.76
2	54.24
3	48.41
4	45.02
5	35.61
6	39.40
7	29.48
8	23.19
9	15.11
10	1.94

4.2.2.2 APPLIED STORY FORCE





Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
Story10	30	791.3018	0
Story9	27	1133.6193	0
Story8	24	979.4605	0
Story7	21	829.8869	0
Story6	18	685.3903	0
Story5	15	559.8064	0
Story4	12	436.9784	0
Story3	9	305.7814	0
Story2	6	184.8765	0
Story1	3	78.2174	0
Base	0	0	0

AXIAL FORCE

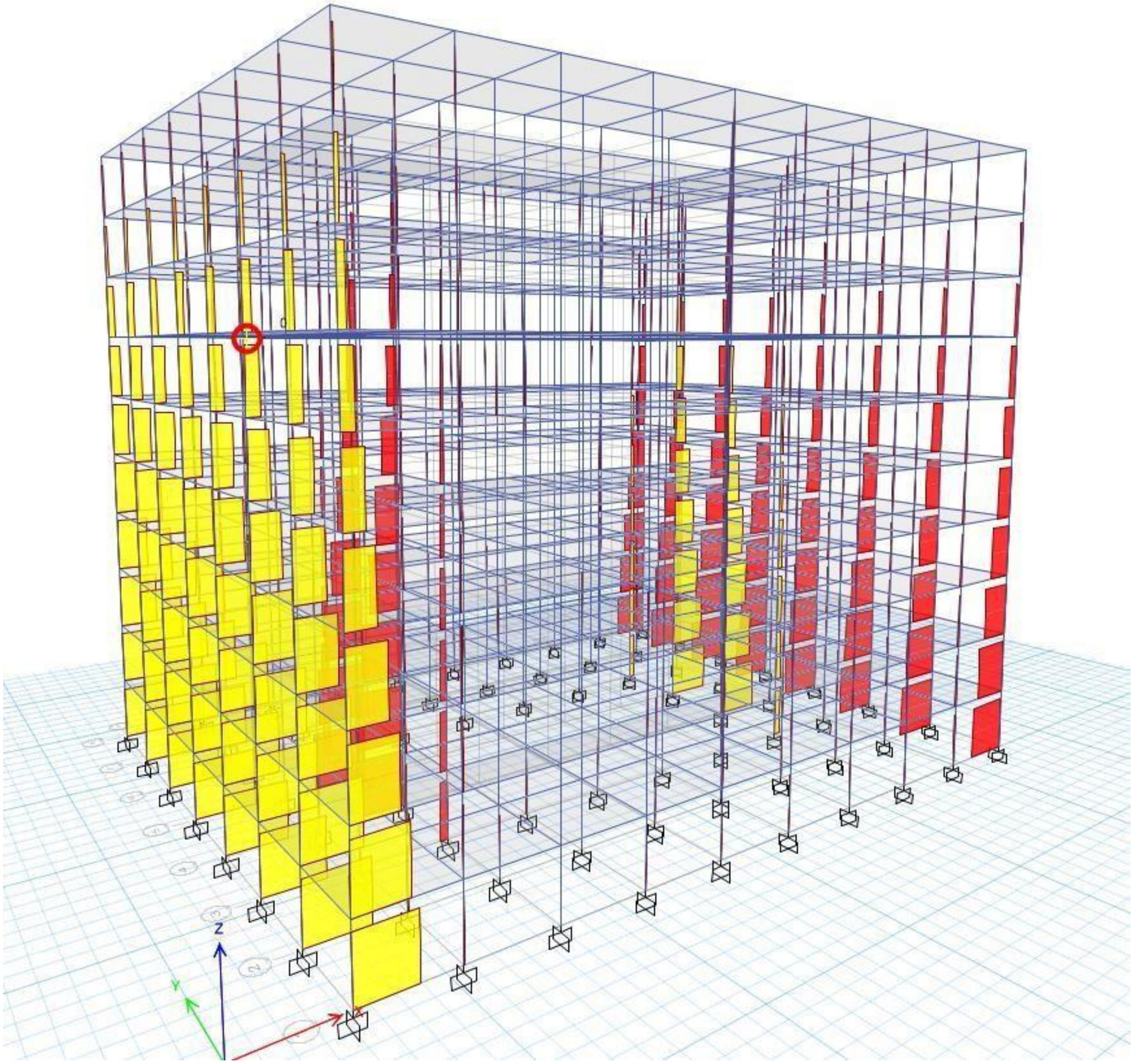


Figure 4.9 3d view of axial force

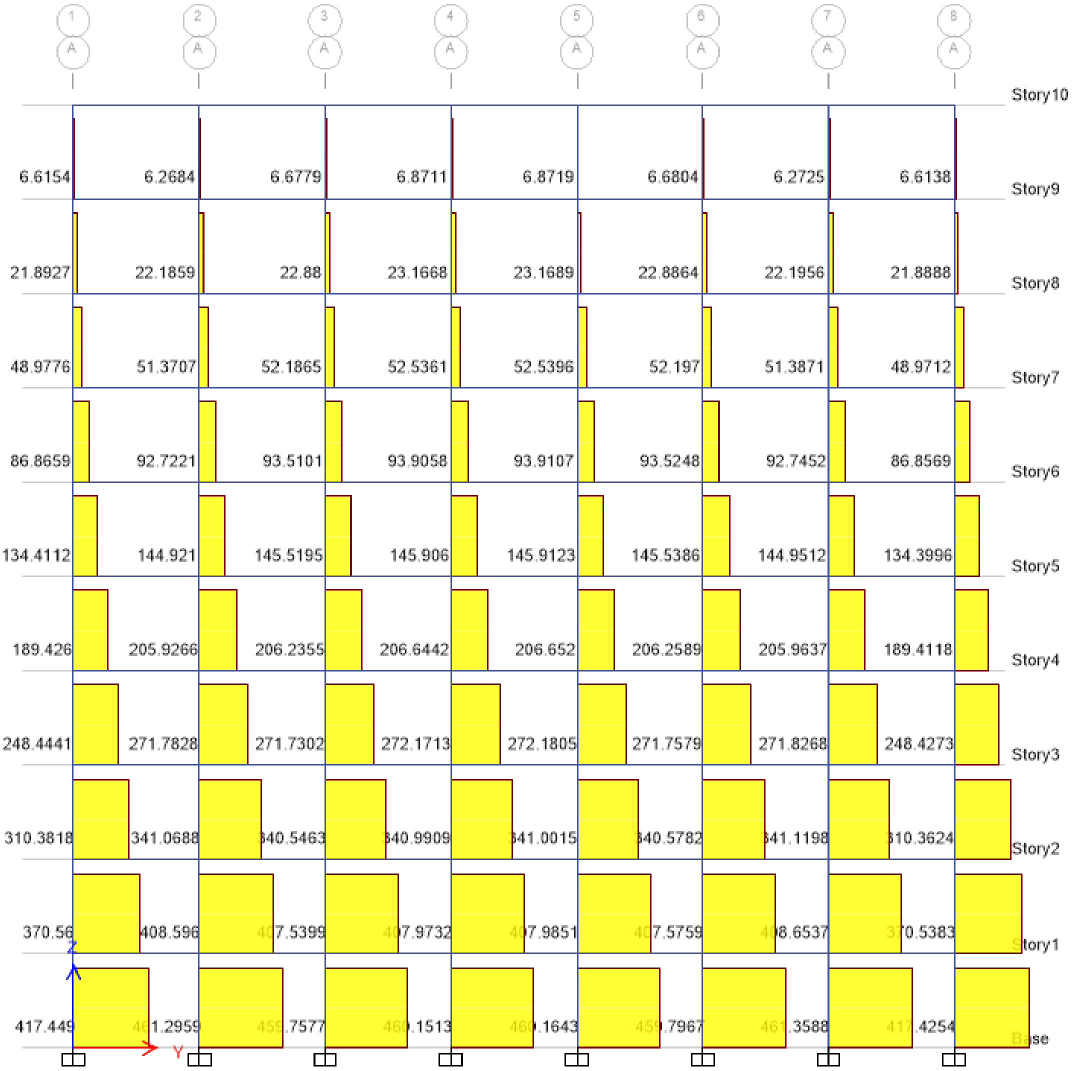


Figure 4.10 Elevation view of axial force diagram

4.2.3 SHEAR FORCE

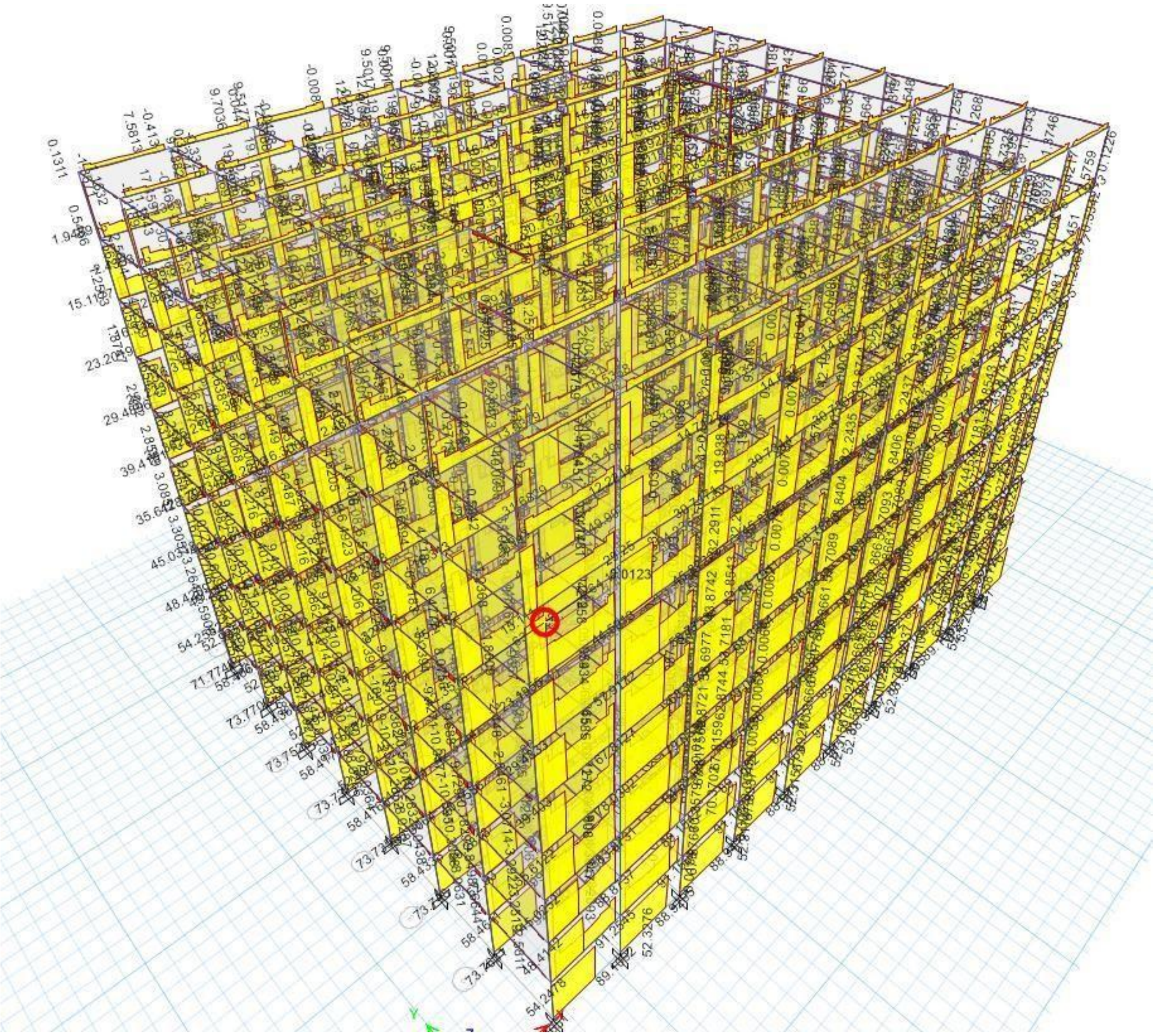


Figure 4.11 3d diagram of shear force

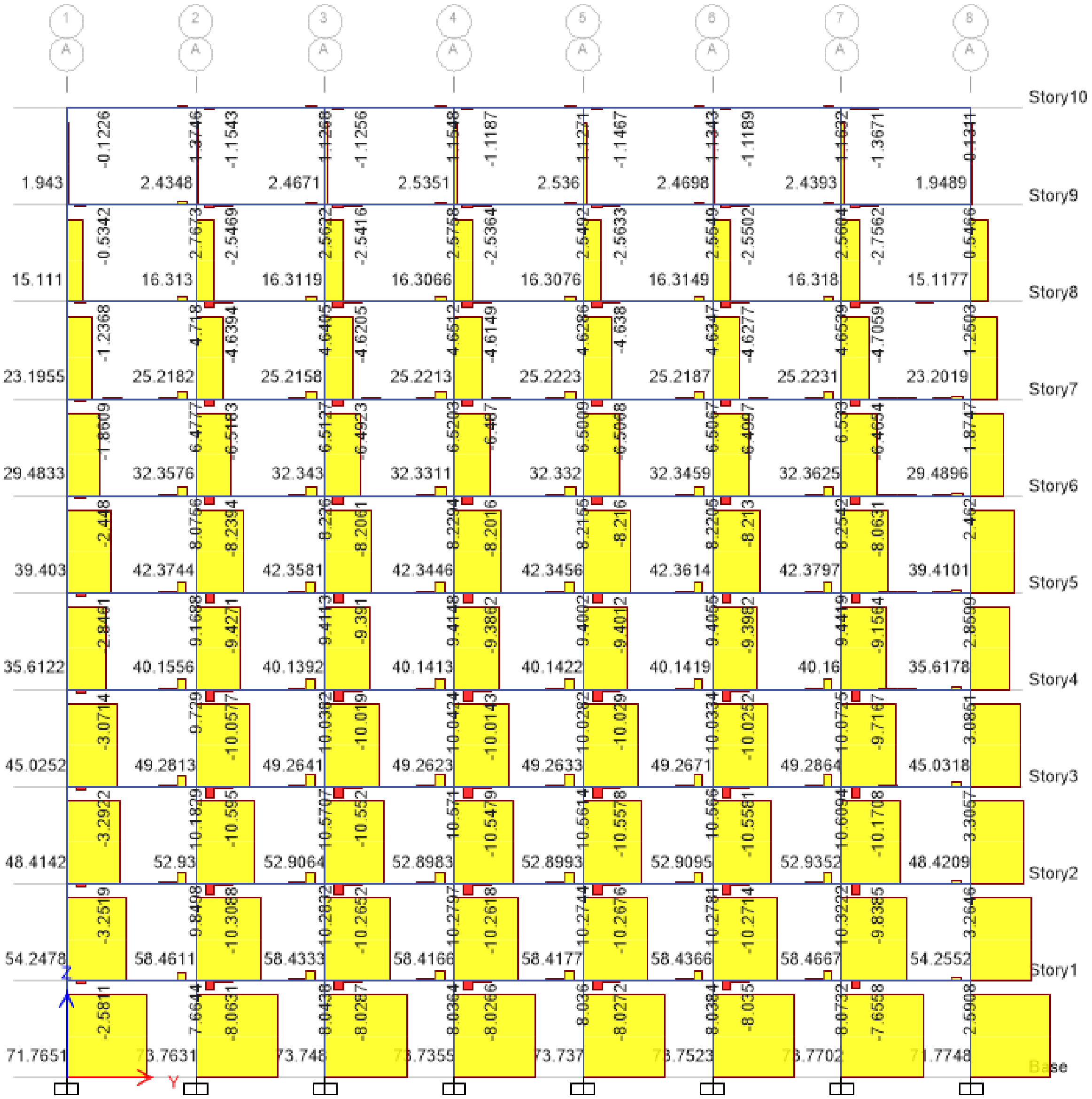


Figure 4.12 Elevation view of shear force diagram

4.2.4 BENDING MOMENT

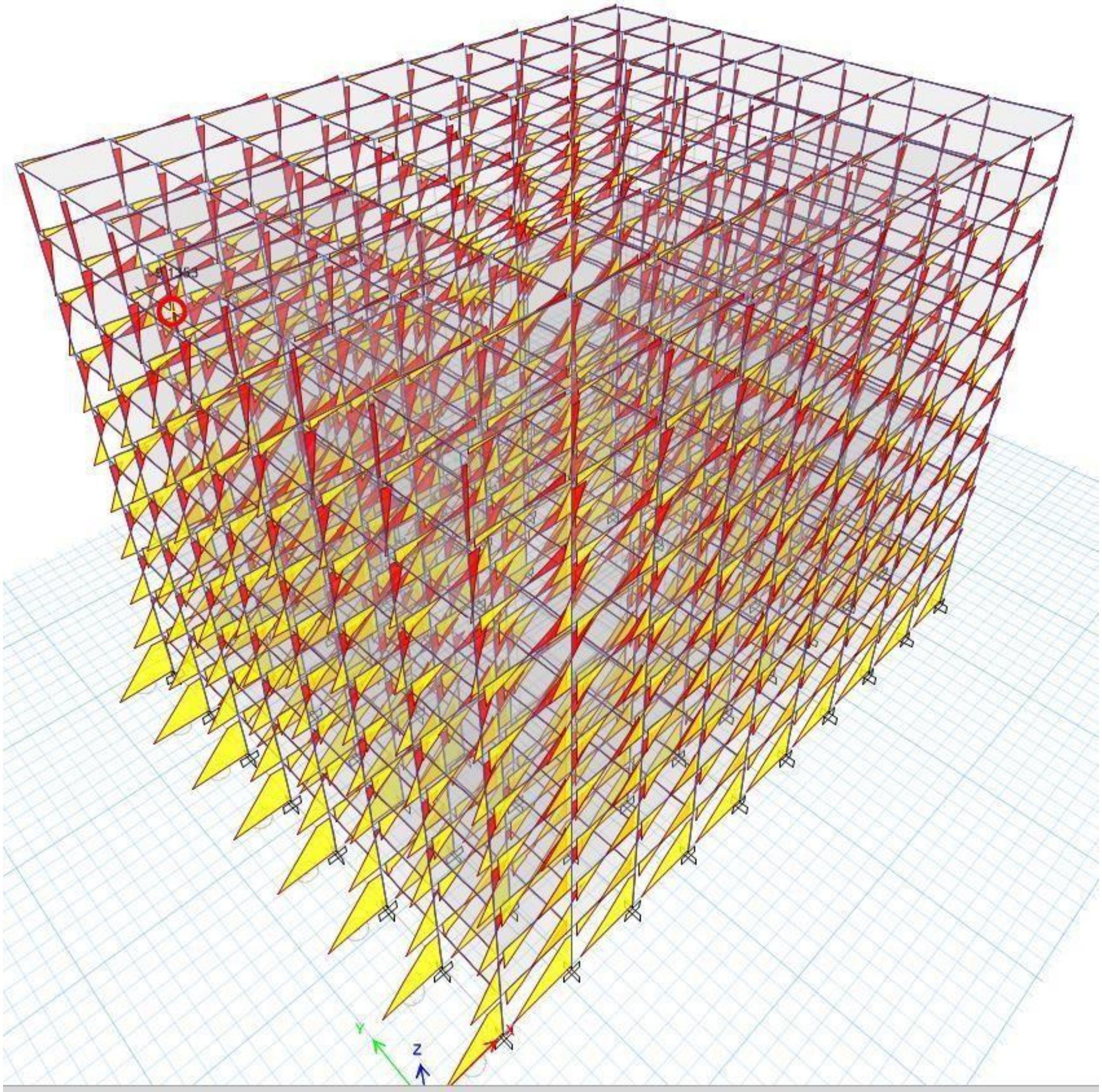


Figure 4.13 3d diagram of bending moment

Table 5: Bensing Moment

Storey level	Bending Moment (kip-ft)
1	238.14
2	118.85
3	79.03
4	60.25
5	45.43
6	51.18
7	31.05
8	20.48
9	6.48
10	0.43

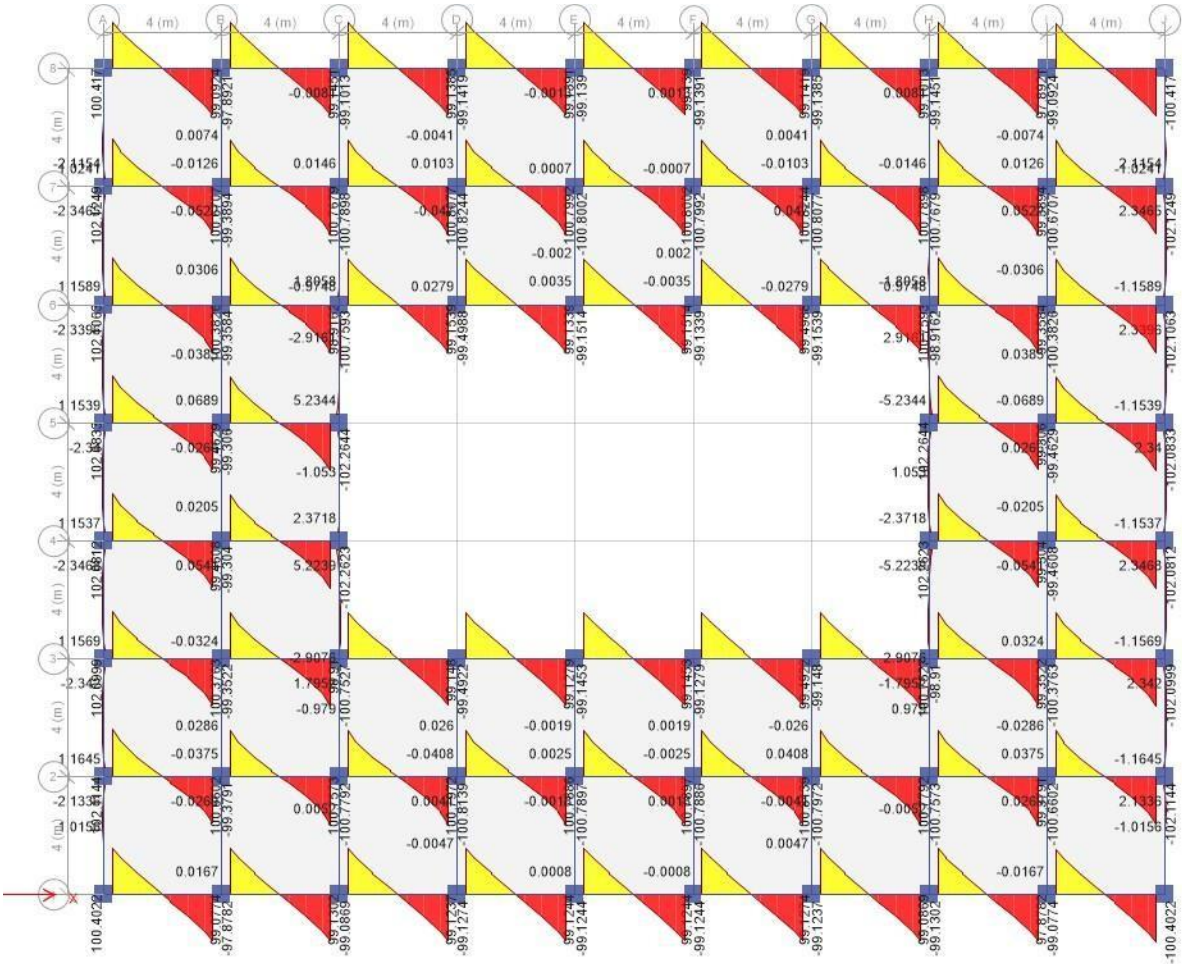


Figure 4.14 Plan view of bending moment

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4.2.5 TORSION

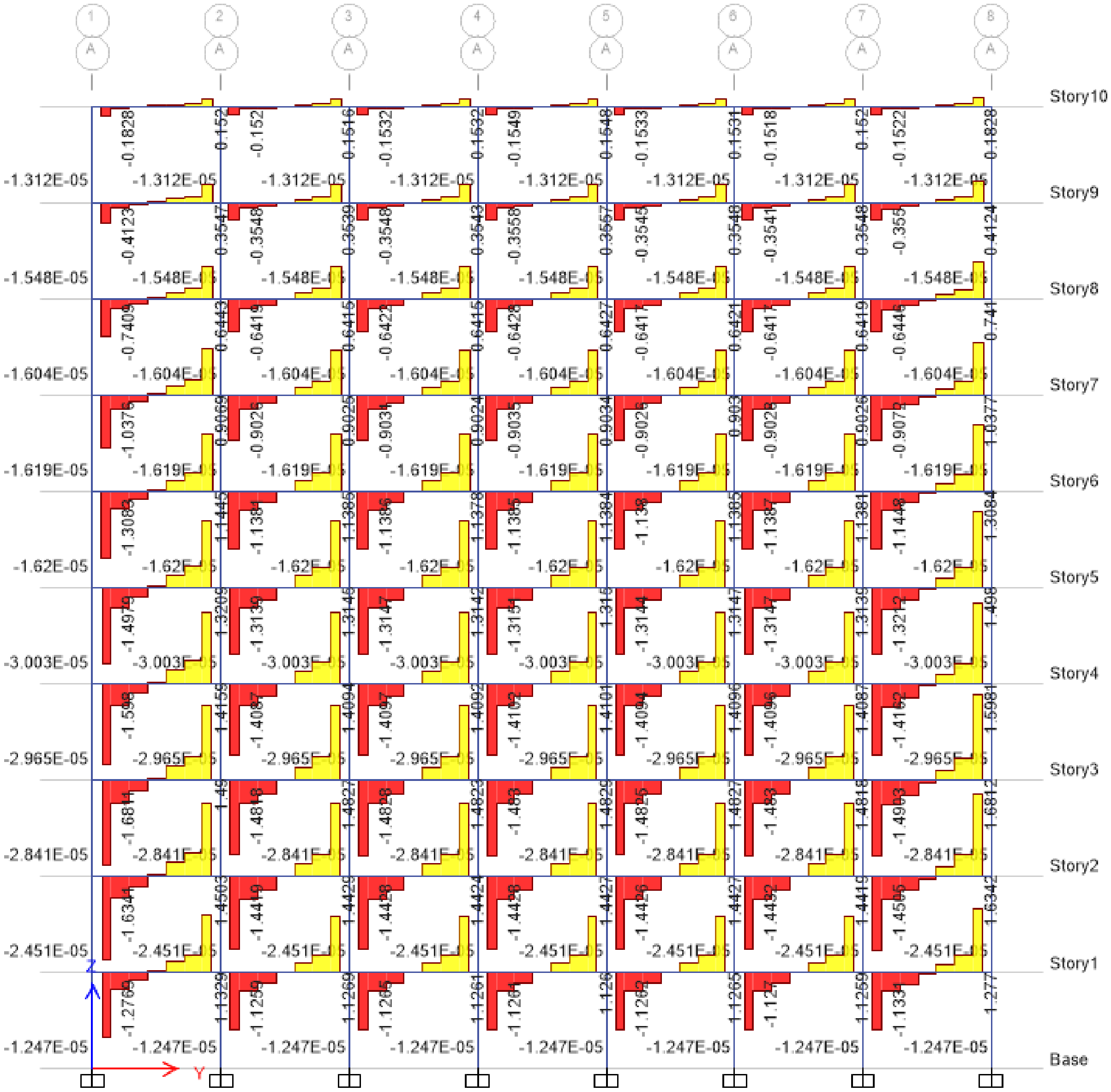


Figure 4.15 elevation of torsional diagram

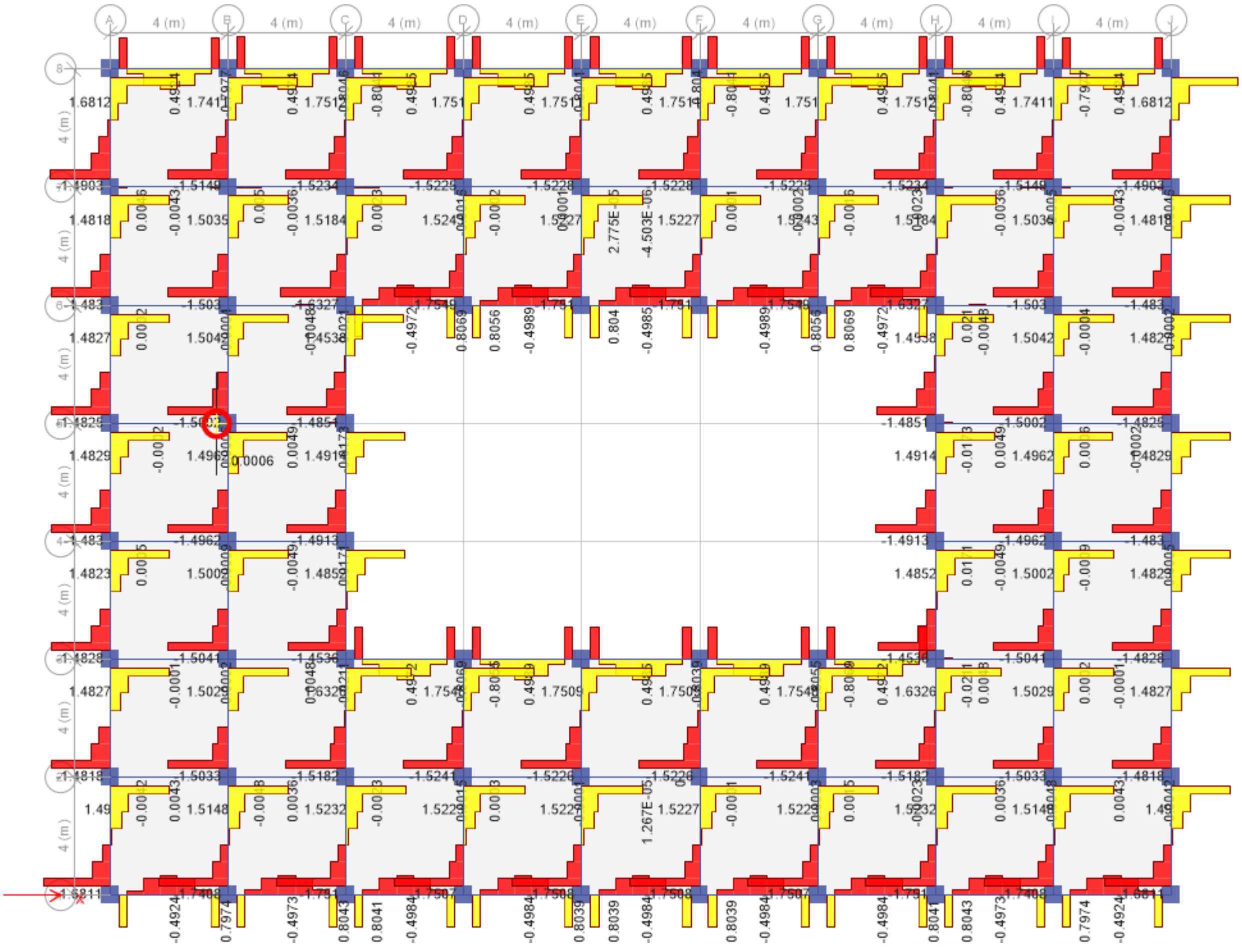


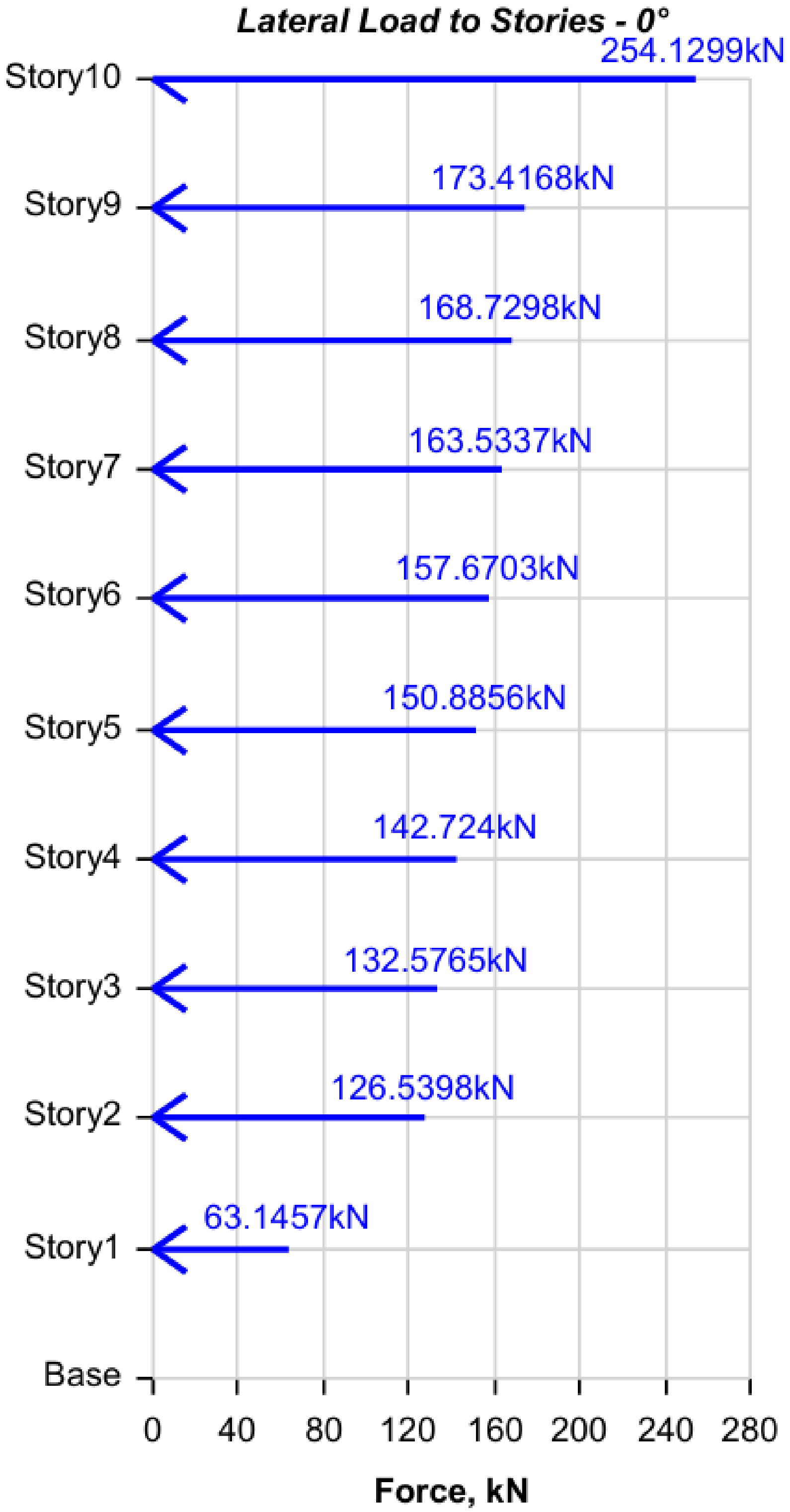
Figure 4.16 Plan view of torsional diagram

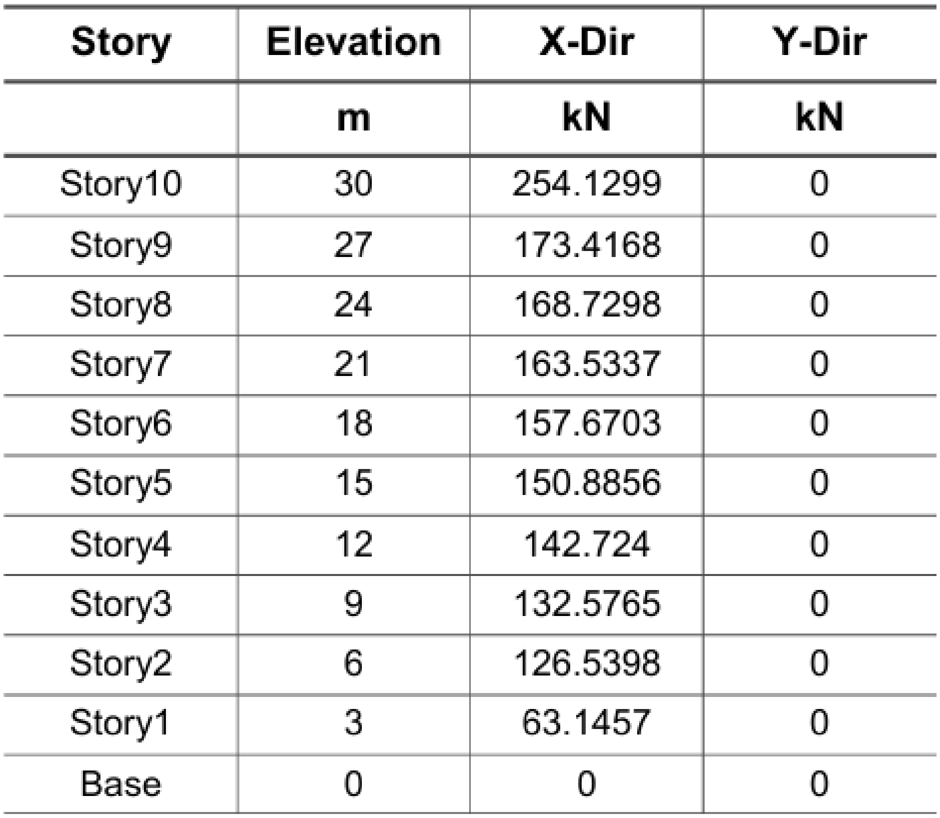
4.3 ANALYSIS OF “Z” SHAPE BUILDING

4.3.1 WIND LOAD ANALYSIS

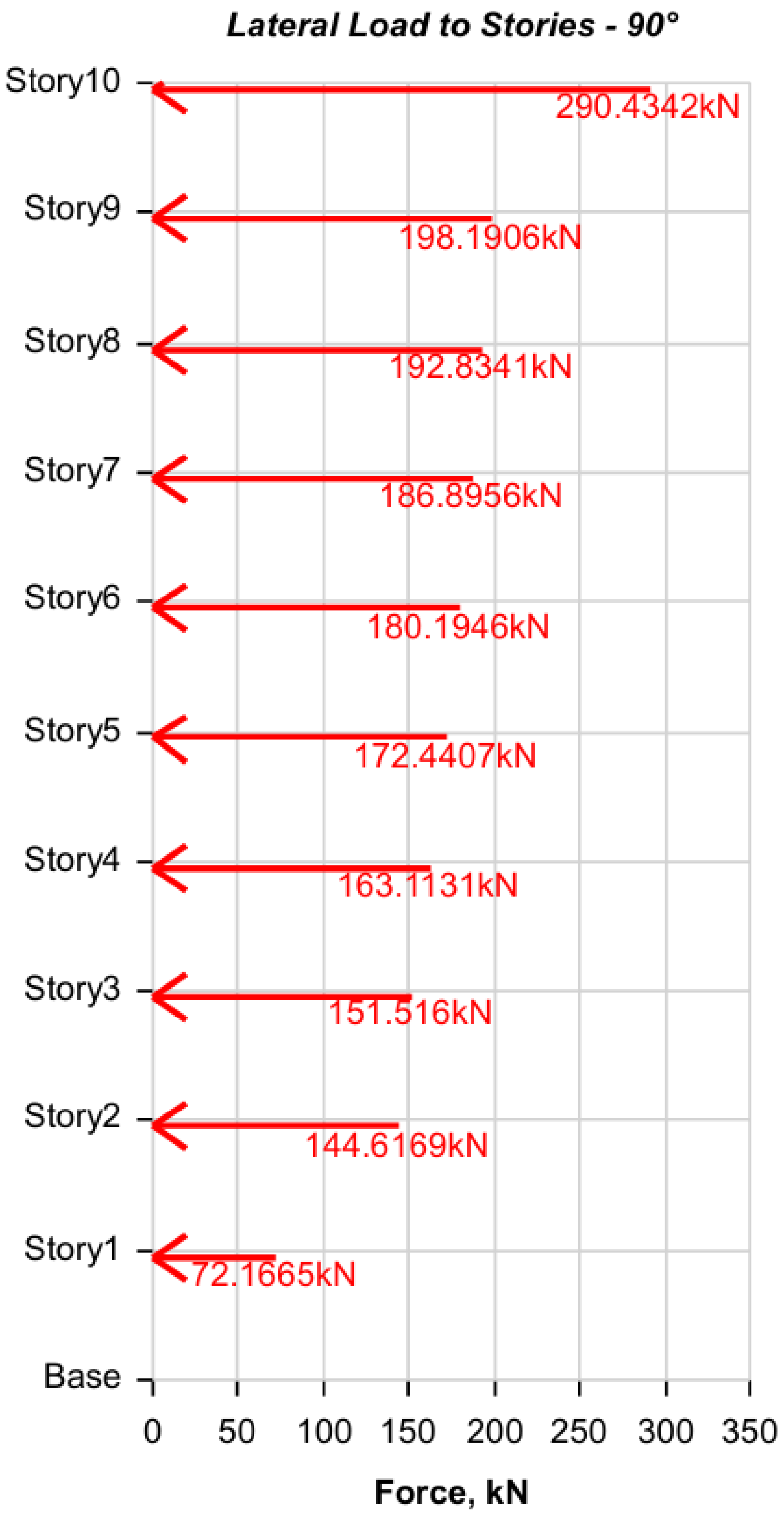
This calculation presents the automatically generated lateral wind loads for load pattern WX according to ASCE 7-05, as calculated by ETABS.

4.3.1.1 APPLIED STORY FORCES

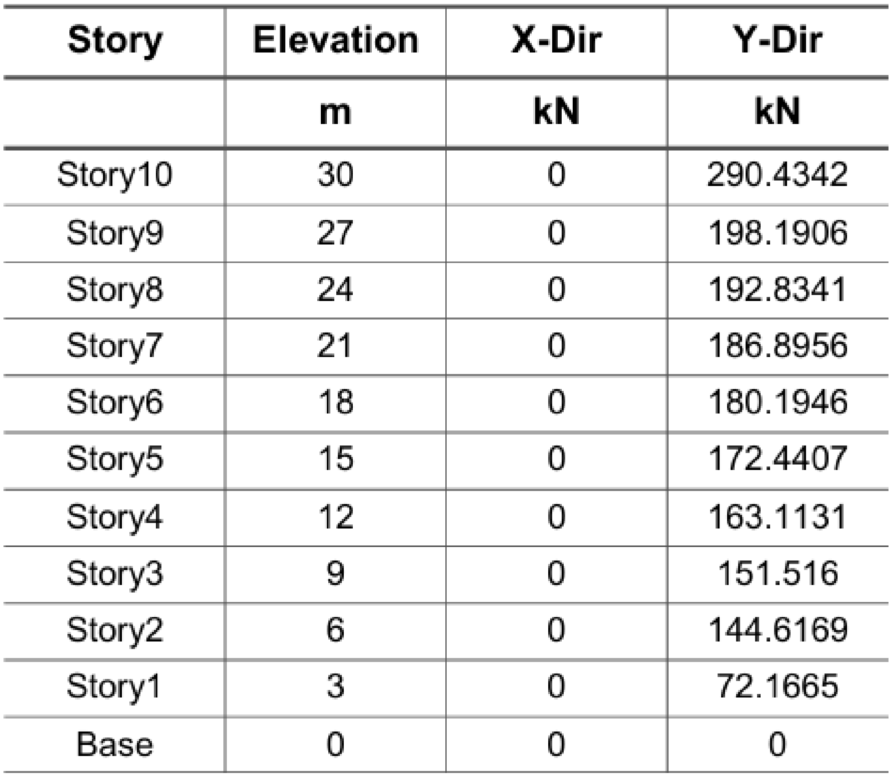




Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
Story10	30	254.1299	0
Story9	27	173.4168	0
Story8	24	168.7298	0
Story7	21	163.5337	0
Story6	18	157.6703	0
Story5	15	150.8856	0
Story4	12	142.724	0
Story3	9	132.5765	0
Story2	6	126.5398	0
Story1	3	63.1457	0
Base	0	0	0



Lateral Load to Stories - 90°
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base
290.4342kN
198.1906kN
192.8341kN
186.8956kN
180.1946kN
172.4407kN
163.1131kN
151.516kN
144.6169kN
72.1665kN
0
50
100
150
200
250
300
350
Force, kN



Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
Story10	30	0	290.4342
Story9	27	0	198.1906
Story8	24	0	192.8341
Story7	21	0	186.8956
Story6	18	0	180.1946
Story5	15	0	172.4407
Story4	12	0	163.1131
Story3	9	0	151.516
Story2	6	0	144.6169
Story1	3	0	72.1665
Base	0	0	0

4.3.2 SEISMIC LOAD ANALYSIS

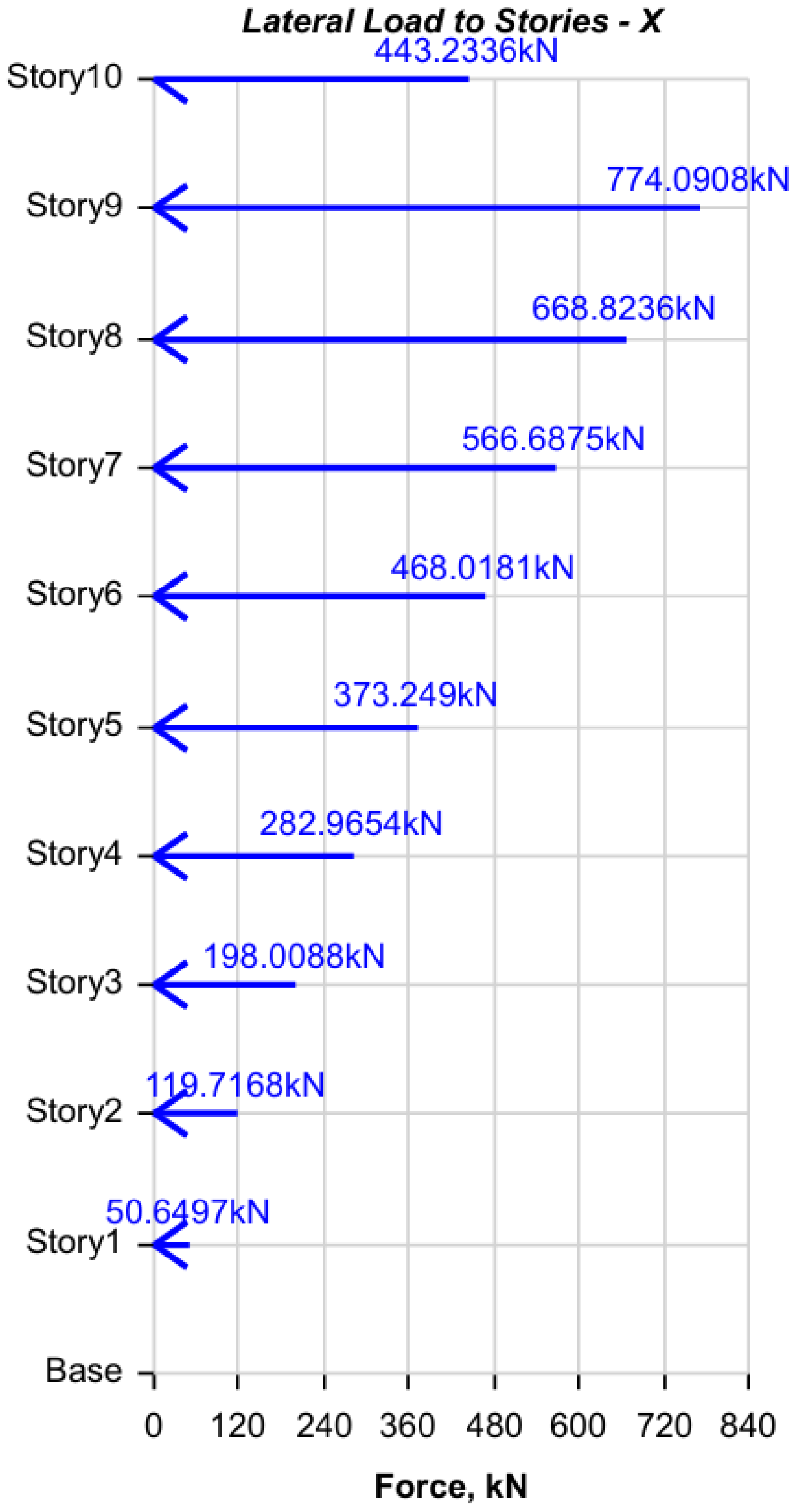
This calculation presents the automatically generated lateral seismic loads for load pattern EX according to ASCE 7-05, as calculated by ETABS.

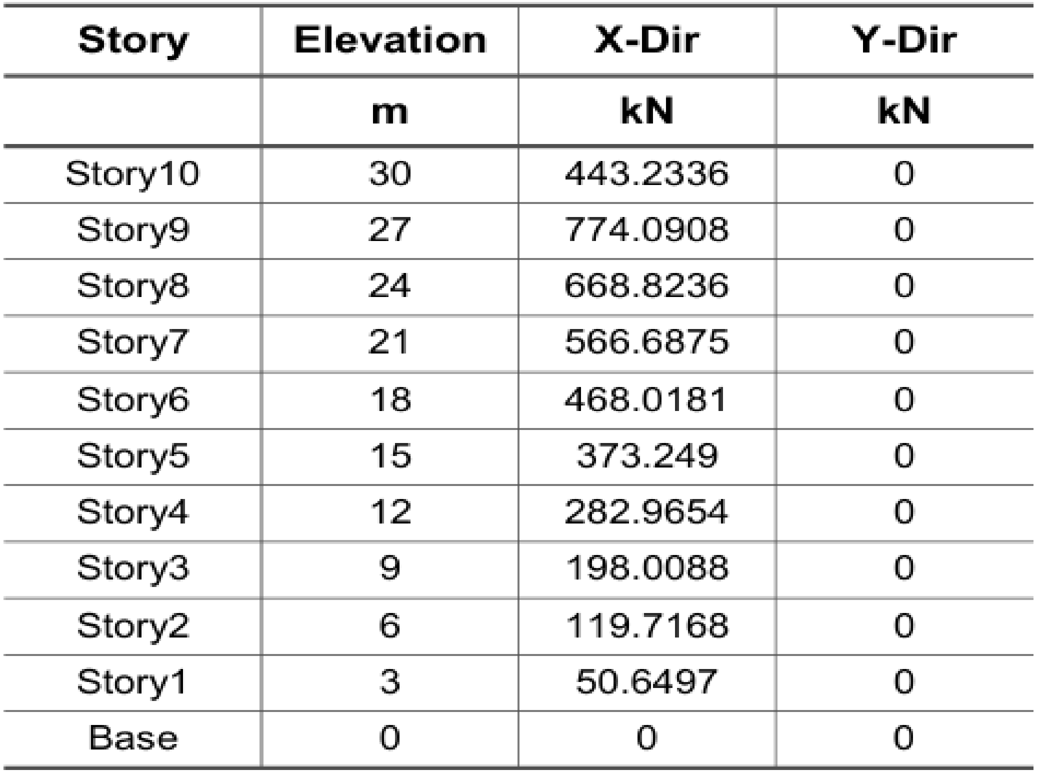
4.3.2.1 STOREY SHEAR

Table 6

Storey level	Storey Shear (kip)
1	88.86
2	67.78
3	58.99
4	52.72
5	47.27
6	41.29
7	34.35
8	25.51
9	16.21
10	3.68

4.3.2.2 APPLIED STORY FORCES





Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
Story10	30	443.2336	0
Story9	27	774.0908	0
Story8	24	668.8236	0
Story7	21	566.6875	0
Story6	18	468.0181	0
Story5	15	373.249	0
Story4	12	282.9654	0
Story3	9	198.0088	0
Story2	6	119.7168	0
Story1	3	50.6497	0
Base	0	0	0

4.3.3 AXIAL FORCE

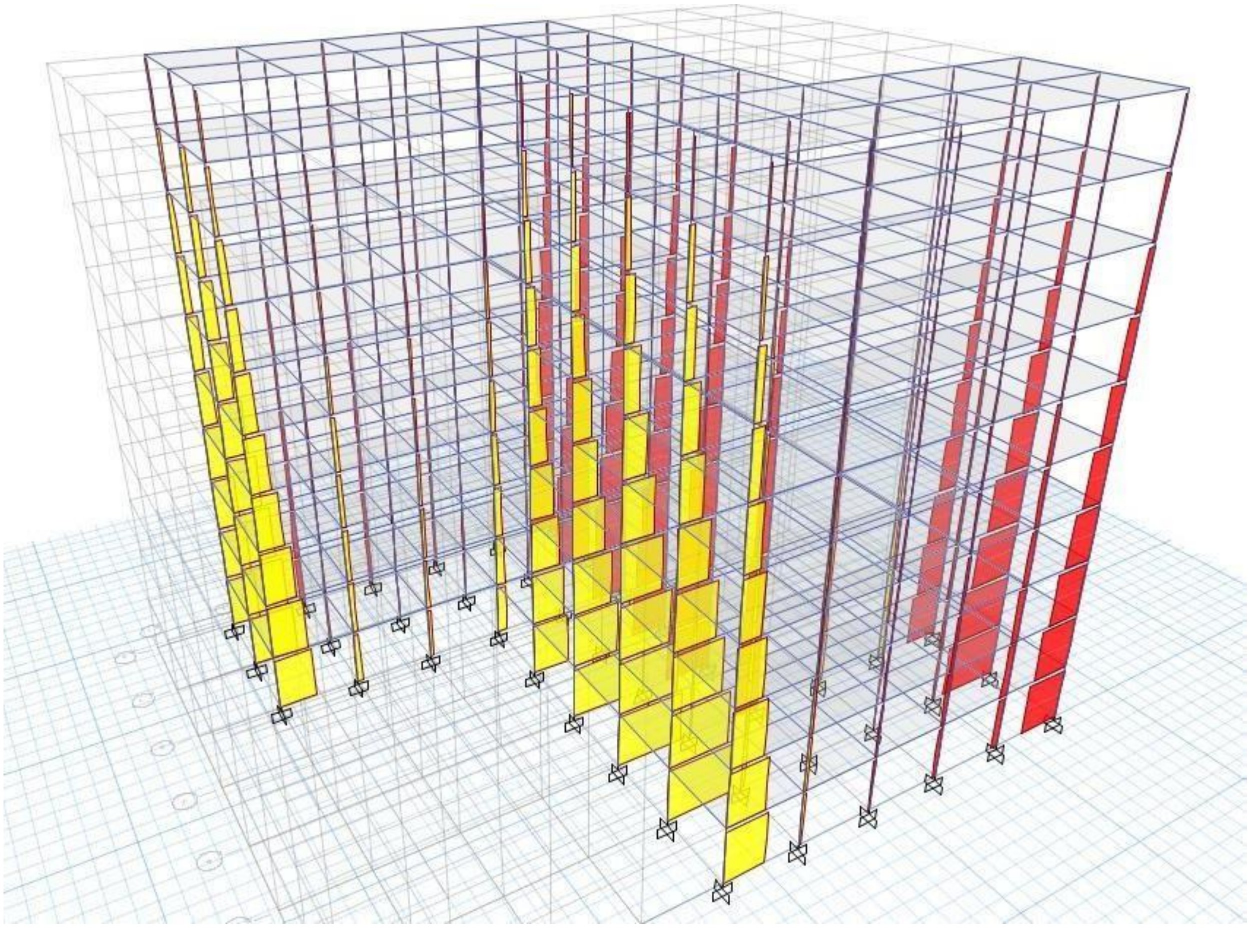


Figure 4.17 3d view of axial force diagram

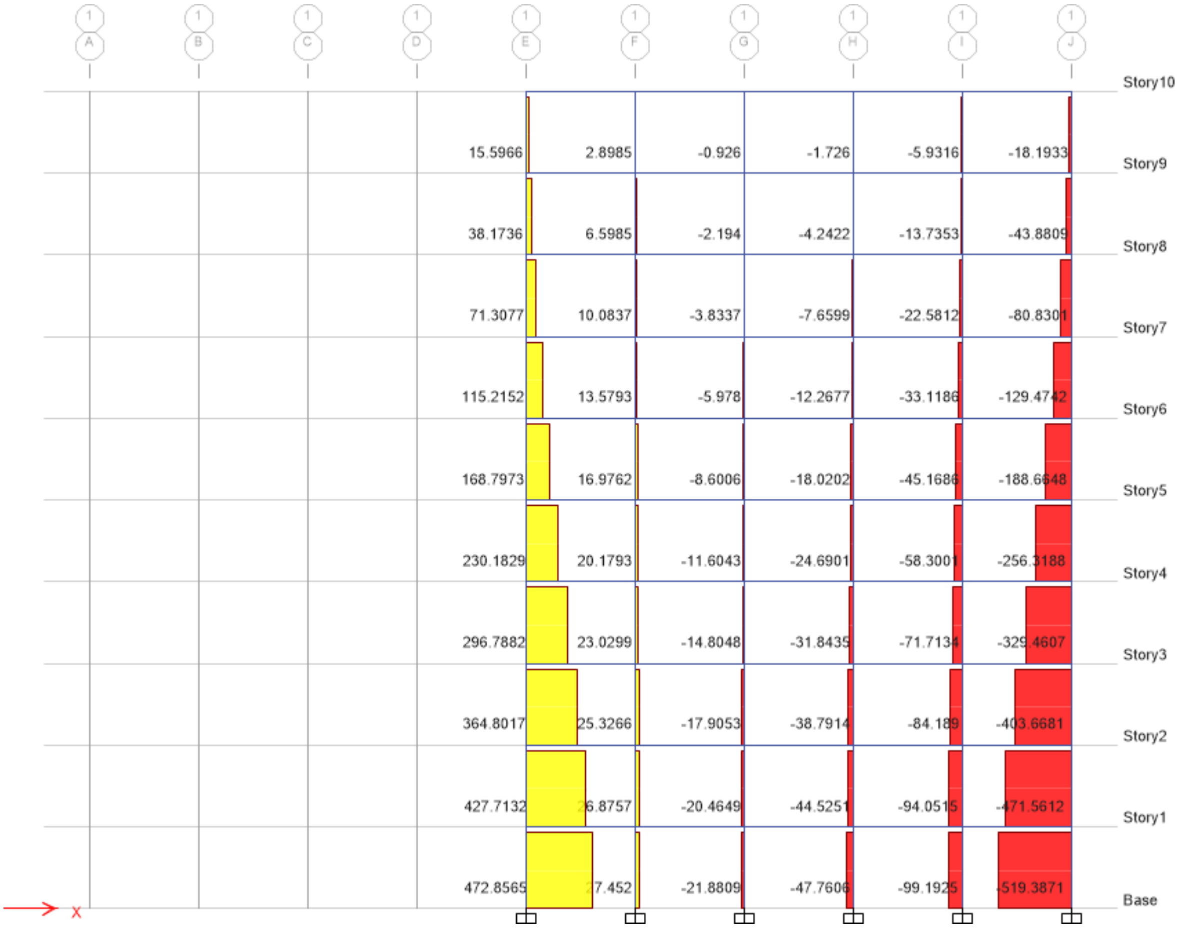


Figure 4.18: Elevation of axial force diagram

4.3.4 SHEAR FORCE

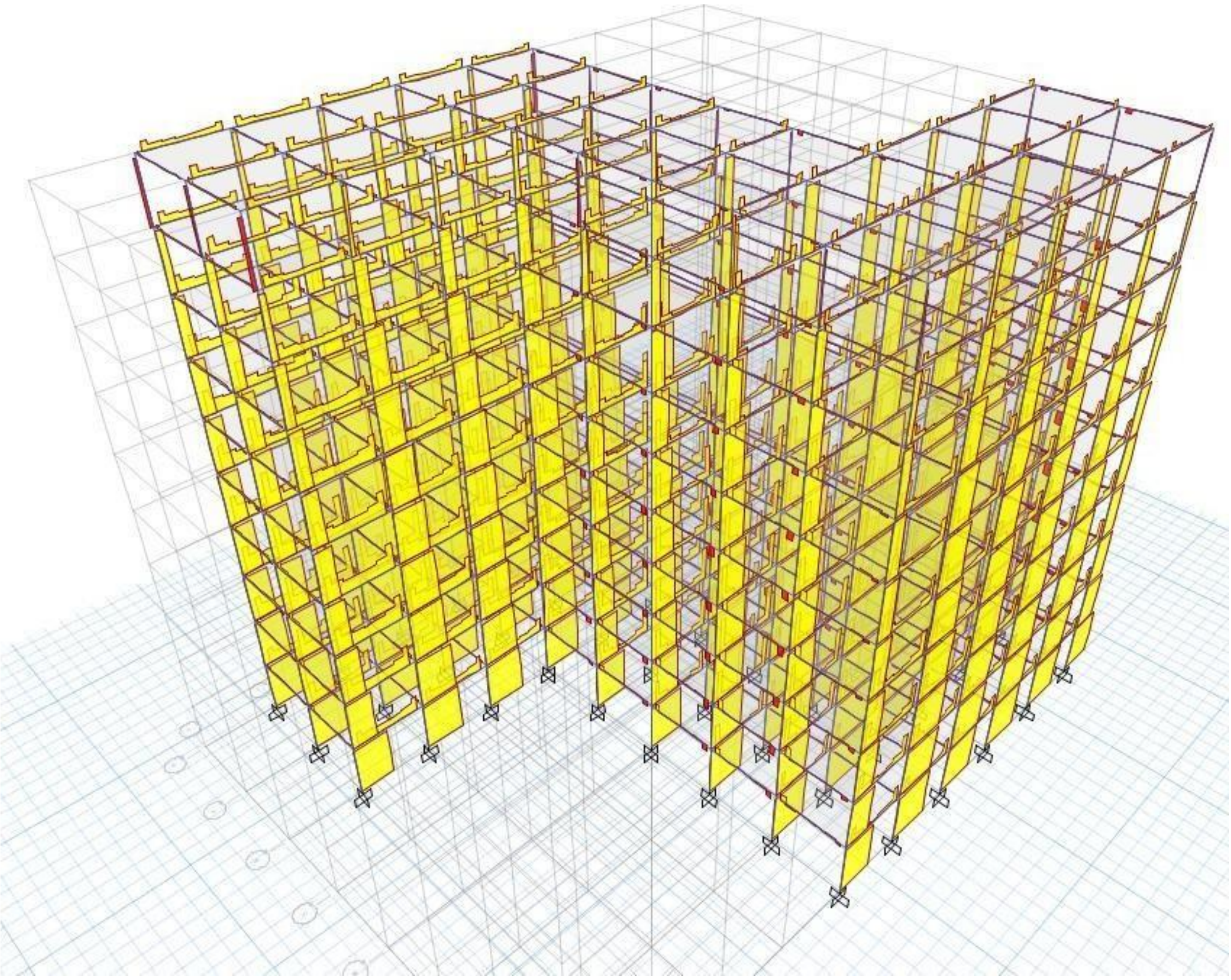


Figure 4.19 3d view shear force

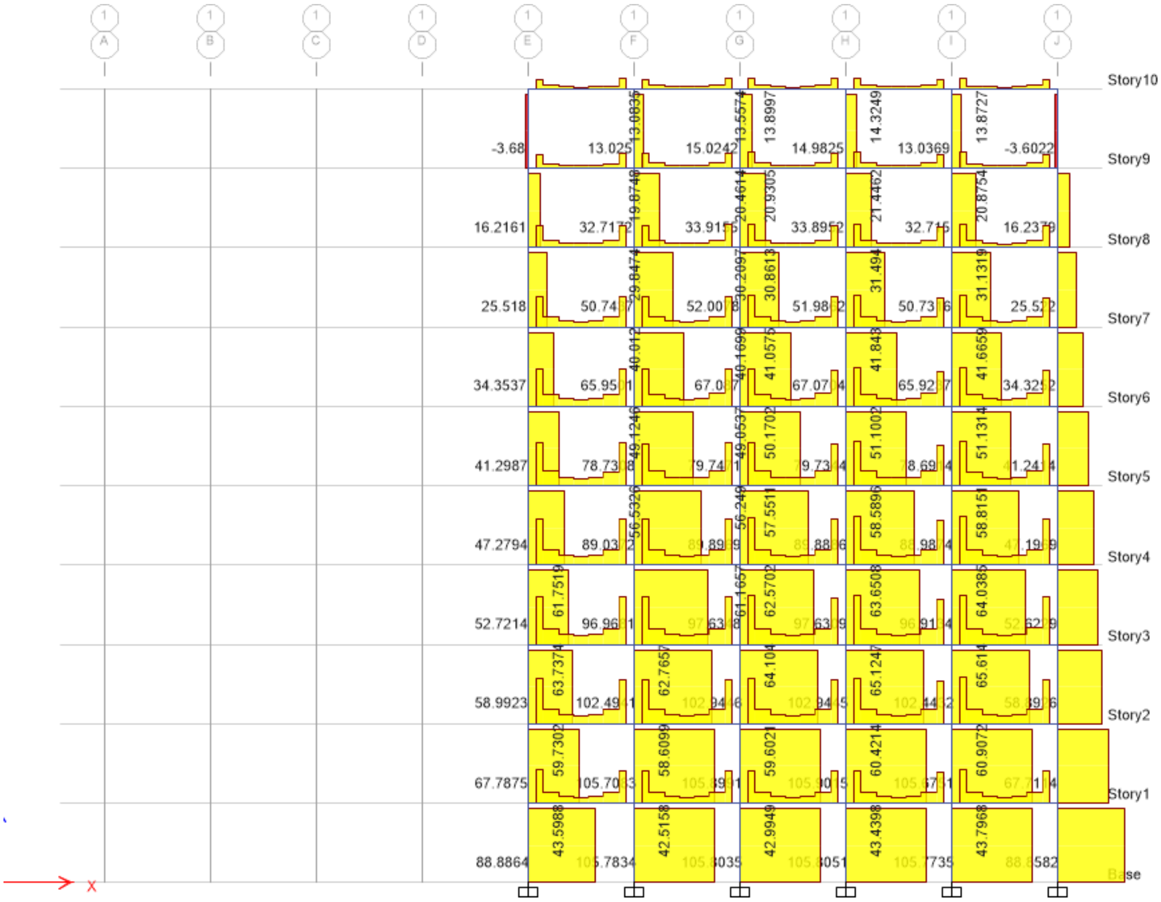


Figure 4.20 Elevation view of shear force diagram

4.3.5 BENDING MOMENT

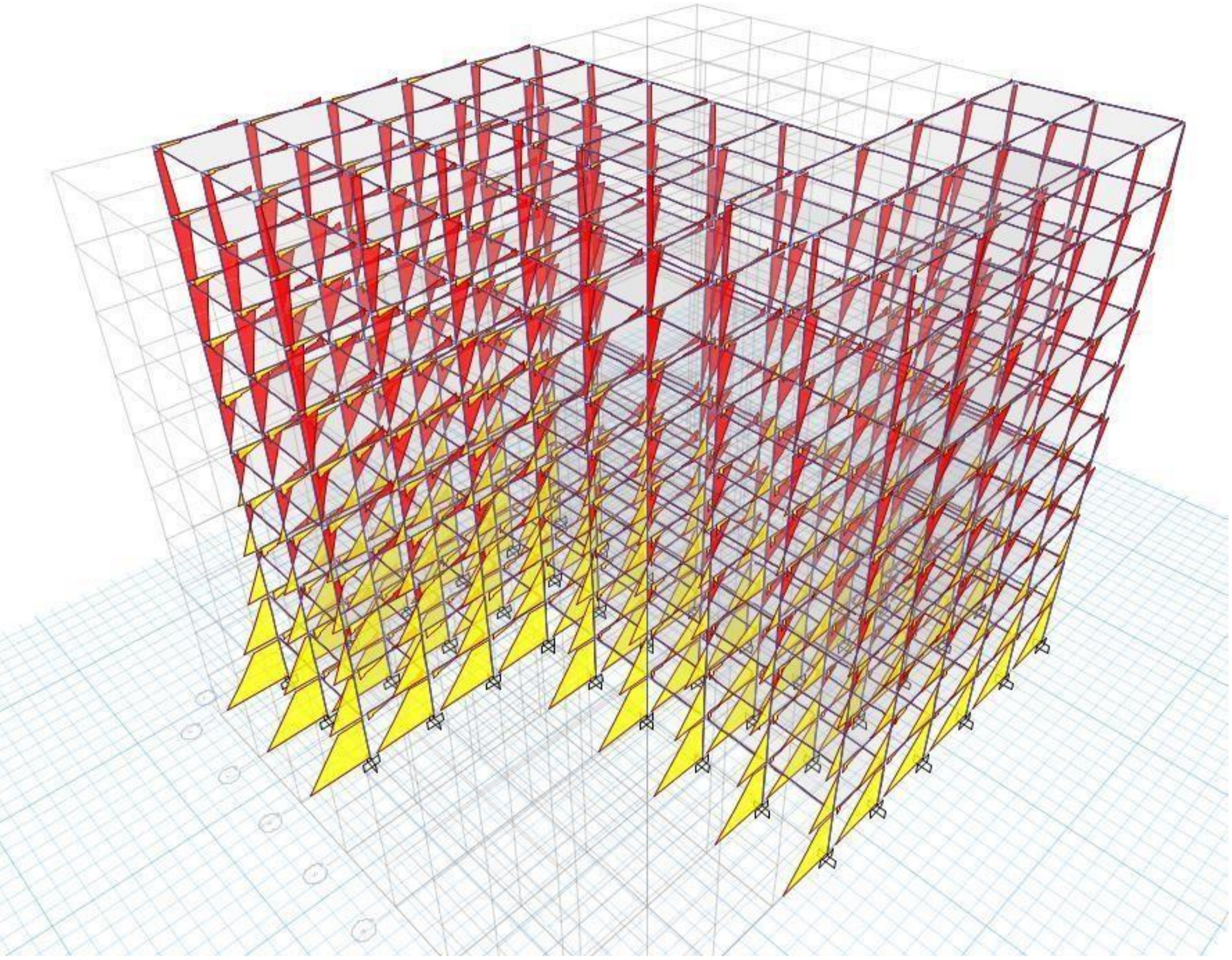


Figure 4.21 3d view of bending moment

Figure 4.22 elevation view of bending moment

Table 7: Bending Moment

Storey level	Bending Moment (kip-ft)
1	362.20
2	188.13
3	111.89
4	70.79
5	44.47
6	23.14
7	3.15
8	2.50
9	1.08
10	0.56

4.3.6 TORSION

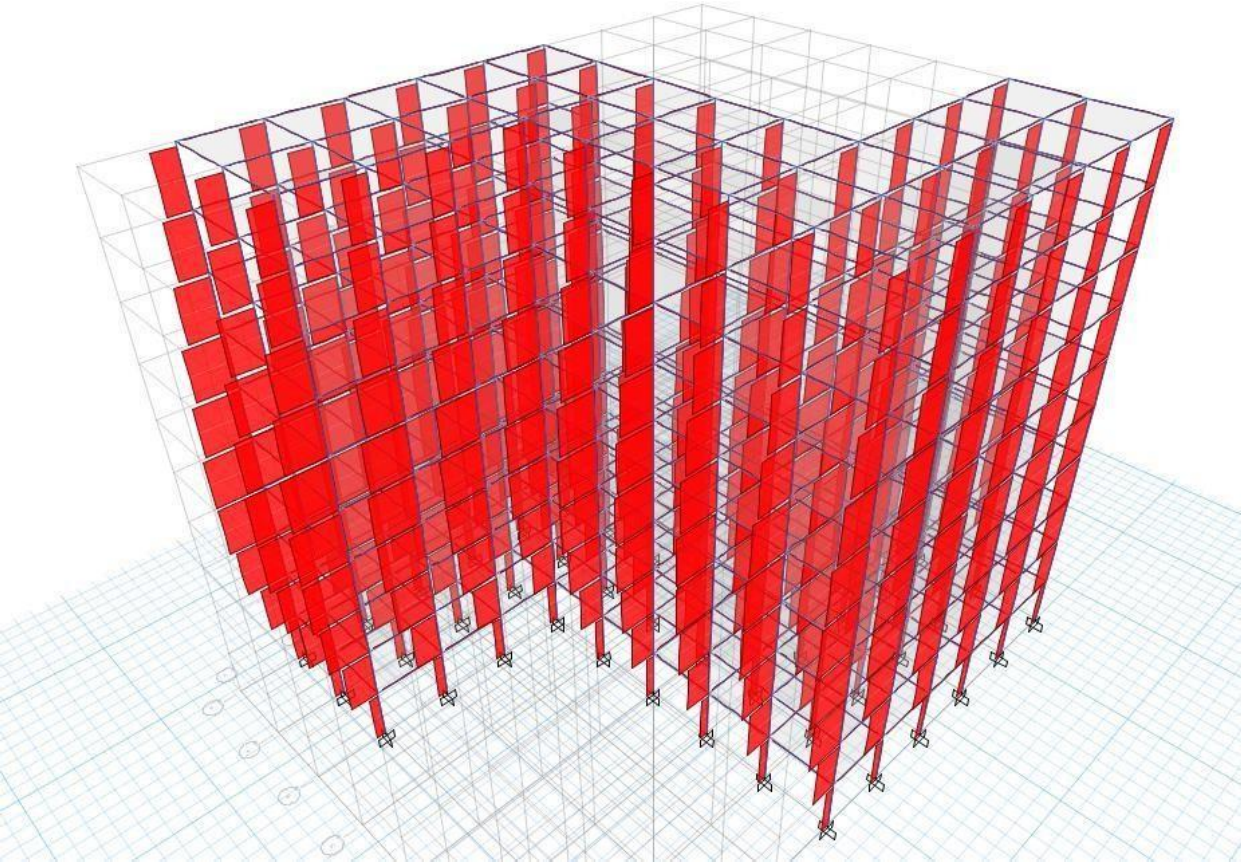


Figure 4.23 3d view of torsion

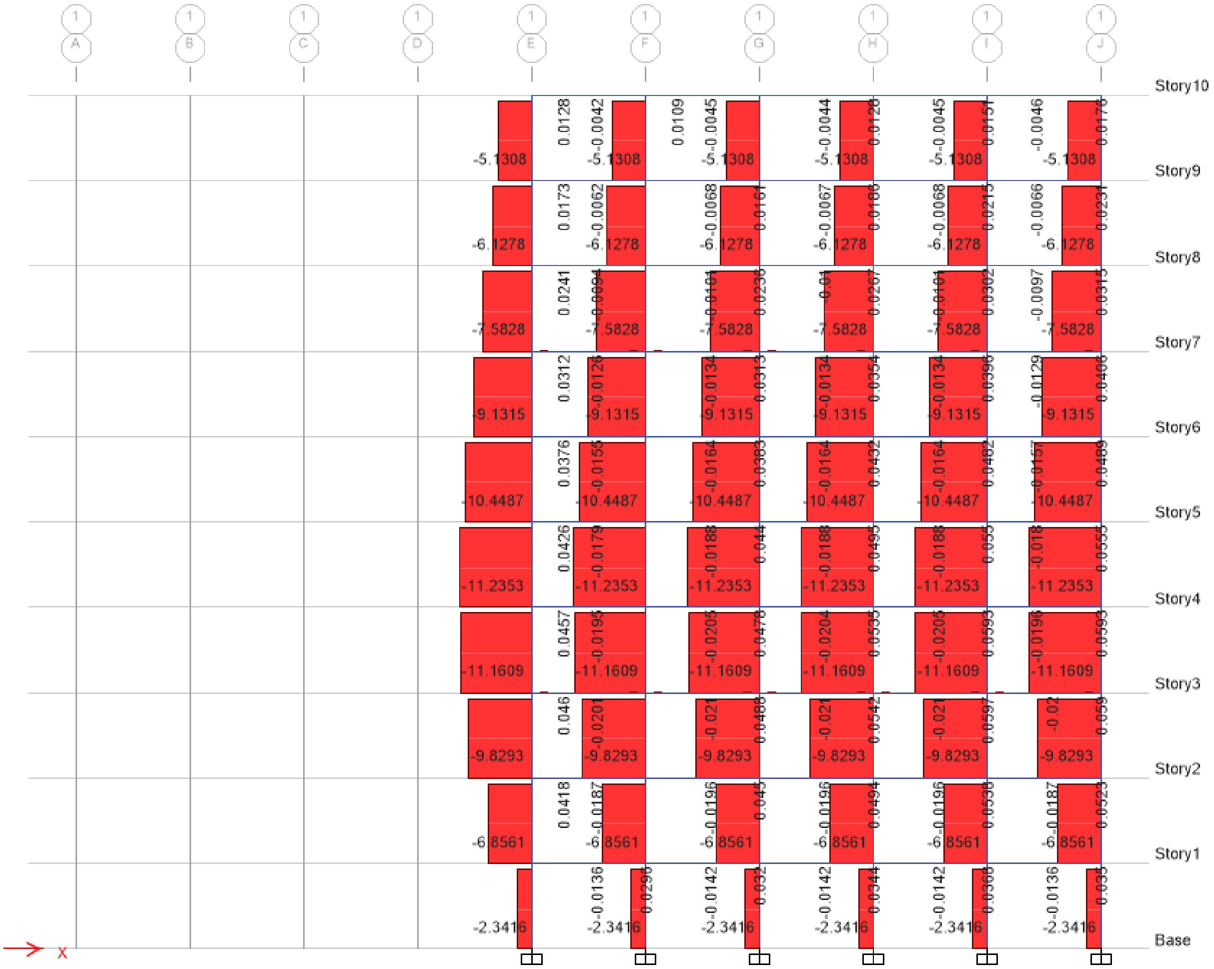


Figure 4.24: Elevation of torsional diagram

The analysis conducted in this study using ETABS focused on the seismic performance of three different plan configurations: Rectangular, Hollow Rectangular, and Z-shaped buildings. The discussion below interprets the key structural parameters obtained and their implications on seismic response.

From the seismic load analysis, the rectangular-shaped building consistently demonstrated lower base shear values compared to the other configurations. This is indicative of a more uniform distribution of lateral forces, which is essential for minimizing stress concentrations. The hollow rectangular and Z-shaped buildings exhibited higher base shear due to geometric discontinuities and the presence of re-entrant corners, which act as stress risers during seismic events.

Axial forces were more evenly distributed in the rectangular configuration. In contrast, the Z-shaped configuration showed significant axial force concentration in certain columns, especially near the re-entrant corners, potentially leading to localized failure during an earthquake. Hollow rectangular plans also exhibited some concentration of forces, although less than the Z-shaped model.

Shear force diagrams revealed that irregular configurations (Z-shaped and hollow rectangular) are subjected to higher shear forces in select columns and beams due to torsional effects. Similarly, bending moment diagrams illustrated that these configurations experience greater moment variations, particularly at geometrical irregularities, which compromises structural integrity.

The torsional response was notably higher in the Z-shaped building. This confirms findings in previous literature that irregular geometries result in larger torsional moments. Increased torsional effects can lead to story drift imbalances, resulting in structural damage. The rectangular building had the lowest torsional response, suggesting better torsional stability and resistance to lateral displacements.

Overall, the rectangular configuration proved to be the most efficient in distributing seismic loads, minimizing torsion, and maintaining structural balance. While the hollow rectangular configuration provides some structural benefits and functional space efficiency, it requires additional reinforcements or shear walls to mitigate stress concentrations. The Z-shaped configuration, while architecturally unique, performed the poorest in terms of seismic resistance and would require significant structural modifications for safe implementation.

CHAPTER 5

CONCLUSION

This study aimed to evaluate and compare the seismic performance of multi-storied buildings with different plan configurations using ETABS. Based on the analysis and results, the following conclusions can be drawn:

1. Rectangular plan configurations provide the most stable and efficient seismic performance among the three studied shapes. They exhibit lower base shear, minimal torsional effects, and uniform stress distribution, making them ideal for high-rise buildings in seismic zones.
2. Hollow rectangular plans perform moderately well but exhibit localized stress concentrations that require additional design considerations, such as the use of shear walls or bracing systems to improve overall performance.
3. Z-shaped configurations are the least favorable under seismic loads due to high torsion, non-uniform force distribution, and vulnerability at re-entrant corners. Their use should be limited or supplemented with enhanced seismic design strategies.
4. The use of ETABS proved effective in modeling and analyzing complex geometries under realistic seismic loading conditions, providing valuable insights into structural behavior.
5. Structural engineers should prioritize plan regularity and symmetry during the design phase to enhance earthquake resistance. Where architectural irregularities are necessary, appropriate seismic detailing and reinforcement strategies must be implemented.

Table 8

Buildings	**Findings**
Rectangle	lower base shear, minimal torsional effects, and uniform stress distribution
Hollo- rectangle	exhibit localized stress concentrations that require additional design considerations, such as the use of shear walls or bracing systems to improve overall performance.
Z shape	least favorable under seismic loads due to high torsion, non-uniform force distribution, and vulnerability at re-entrant corners.

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