STAMFORD UNIVERSITY BANGLADESH
DEPARTMENT OF CIVIL ENGINEERING

A COMPARATIVE STUDY BETWEEN BRACED AND NON-BRACED HIGH-RISE STRUCTURES

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A Project and Thesis

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In partial fulfillment of the requirement for the Degree of Bachelor of Science (B.Sc.) in Civil Engineering.

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The project and thesis titled '**A Comparative Study between Braced and Non-Braced High-Rise Structures'** submitted by Md. Rshedul Haq, ID No. CEN-06009234, Batch No. 60(B); Ziaur Rahman, ID No. CEN-06009236, Batch No.60(B) and Dil Afrose Konok, ID No.CEN-06009271, Batch No.60(B), students of the Department of Civil Engineering have been examined thoroughly and accepted in partial fulfillment of the requirements for the degree of Bachelor of Science in Civil Engineering on 12th September, 2020.

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DECLARATION

We, Md. Rshedul Haq, Ziaur Rahman, and Dil Afrose Konok are the students of B.Sc. in Civil Engineering, hereby solemnly declare that the works presented in this project & thesis has been carried out by us and has not previously been submitted to any other University / College / Organization for any academic qualification / certificate degree.

We warrant that the present work does not breach any copyright.

We further undertake to indemnify the University against any loss or damage arising from breach of the fore going obligations.

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ABSTRACT

This study was carried out in the Department of Civil Engineering of Stamford University Bangladesh with the objectives of comparison of lateral loadings effects on different structural system of high rise building.

The building system is one of the most important considerations in the conceptual stage of building design. Since the building shape determines the size and the orientation of the exterior envelope exposed to the outdoor environment, it can affect building performance in many aspects: energy efficiency, cost and aesthetics. Too often, however, decisions on the building shape are based on aesthetics only, which has the evident disadvantage of limiting the potential of performance improvement. Shape optimization can help overcome this disadvantage by exploring more design alternatives at the conceptual design stage for specific criteria such as environmental and economic performance.

The shape and exterior structure of a house play major roles in determining its energy efficiency and the comfort of residents. The shape is comprised of the building's height, width, and depth—also known as the footprint. The exterior structure—also known as the building envelope—includes the walls, roof, windows, doors, and cladding. The footprint and envelope of the home can either enhance efficiency or contribute to more energy consumption. Homes that have simple or uncomplicated shapes are typically more efficient to heat and cool than homes with complex or irregular shapes.

The determination of the structural shape of a high-rise building would preferably involve only the selection and arrangement of the major structural element to resist most efficiently the various combinations of gravity & horizontal loading. In reality, however the choice of structural shape is usually strongly influenced by other than structural consideration like: internal planning, the material, method of construction, the external architectural treatment, the planned location, routing of service systems, the nature & magnitude of the horizontal loading & the height and proportions of the building.

Based on the above considerations, this study focuses on the responses by analyzing the effects of the lateral loads on two 20 storied high-rise structures having Edge Supported floor systems each of which one with braced frame and another with non-braced frame and finally, presents a comparative result.

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CHAPTER 1

INTRODUCTION

1.1 General

High-rise buildings, which are developed as a response to population growth, rapid urbanization and economic cycles, are indispensable for a metropolitan city development. This statement holds true for today; however, the relationship between cost and benefit is more complex in today's global marketplace. The political ideology of the city plays an important role in the globalization process (Newman and Thornily, 2005; Abu-Ghazalah, 2007). The current trend for constructing buildings is to build higher and higher, and developers tend to compete with one another on heights. Tenants also appreciate a landmark address and politicians are conscious of the symbolic role of high-rise buildings. The international and high technology styles have accompanied nearly all new tall buildings and became landmark of our cities (McNeill and Tewdwr-Jones, 2003). Nonetheless high-rise buildings are more expensive to construct per square meter, they produce less usable space and their operation costs are more expensive than conventional office buildings. The space efficiency, as well as the shape and geometry of the high-rise building need to satisfy the value and cost of the development equation.

1.2 Background of study

The building structure is one of the most important considerations in the conceptual stage of building design. Since the building shape determines the size and the orientation of the exterior envelope exposed to the outdoor environment, it can affect building performance in many aspects: energy efficiency, cost and aesthetics. Too often, however, decisions on the building shape are based on aesthetics only, which has the evident disadvantage of limiting the potential of performance improvement. Shape optimization can help overcome this disadvantage by exploring more design alternatives at the conceptual design stage for specific criteria such as environmental and economic performance.

The determination of the structural shape of a high-rise building would preferably involve only the selection and arrangement of the major structural element to resist most efficiently the various combinations of gravity & horizontal loading. In reality, however the choice of structural shape is usually strongly influenced by other than structural consideration like: internal planning, the material, method of construction, the external architectural treatment, the planned location, routing of service systems, the nature & magnitude of the horizontal loading & the height and proportions of the building.

In the recent years, Bangladesh has growing trends towards the construction of multi-storied buildings. Almost of these skyscrapers are being constructed in Dhaka city. For this reason, these types of skyscrapers are being affected by lateral loading. The structural systems of tall buildings must carry vertical gravity loads, but lateral loads are also a major consideration. Lateral loads are always applied horizontally. Wind loads and earthquakes are mainly considered as lateral loads. Wind loads are particularly important in the design of large structures, such as tall buildings, that have large open interiors and walls in which large openings may occur. Wind load acts directly on the structure. Variation of wind velocity with height must be considered in the design of tall structures. If the wind effects are not properly considered in the design, then the structure will produce lateral deflection, i.e. sway and the resident of the structure will feel dizziness, headache and other uncomfortable feelings.

Based on the above considerations, this study focuses on the responses by analyzing the effects of the lateral loads on two 20 storied high-rise structures having edge supported floor systems each of which one with braced structure and another with non-braced structure and finally, presents a comparative result.

1.3 Objectives of the study

- To review the overall aspects of lateral loads consideration in the analysis of RCC structures.
- To observe the effects of lateral loads on different structural systems of high rise building especially braced & non-braced structural system in terms of auto lateral load to Stories, maximum Story displacement, maximum story drift, story shear, overturning moment, story stiffness etc. of different building elements.
- To find out the best structural system between braced & non-braced under same regular loading.

1.4 Organization of the Thesis Works

The thesis has been arranged in the following order also including references as well as appendices used for the study.

Chapter I: This includes the introduction, the objectives and the scope of the study.

Chapter II: Includes Literature Review.

Chapter III: Includes the methodology of the study.

Chapter IV: Provides comparative analyses between both structures and discussions.

Chapter V: Includes conclusions and recommendations for further study.

References

1.5 Scopes/limitations of the study

1. The study does not cover the design of the high-rise structure.
2. Plumbing, electrification, brick works etcetera were not considered.
3. Estimation & Cost analysis of the structure were not done.
4. Static analysis of the structure by ETABS 2016 was performed.

CHAPTER 2

BNBC CODE: STANDARD DATA & SPECIFICATIONS

2.1 Wind Load

The actual intensity wind pressure depends on a number of factors like angle of incidence of the wind, roughness of surrounding area, effects of architectural features, i.e. shape of the structure etc. and lateral resistance of the structure. Apart from these, the maximum design wind load pressure depends on the duration and amplitude of the gusts and the probability of occurrence of an exceptional wind in the lifetime of building. It is possible to take into account the above factors in determining the wind pressure.

The lateral load due to wind is the major factor that causes the design of high rise buildings to differ from those of low rise to medium rise buildings. For buildings of up to about 10 storied and of typical properties and the design is rarely affected by the wind loads. Above this height, however, the increase in size of the structural members, and the possible rearrangement of the structure to account for wind load, incurs a cost premium that increases progressively with height. Innovations in architectural treatment increase in the strengths of materials, and advances in method of analysis-tall building structures become more efficient and lighter and, consequently, more prone to deflect and even to sway under wind load.

Code Provisions for Wind Load

The minimum design wind load on buildings and components is determined based on the velocity of the wind, the shape and size of the building and the terrain exposure condition of the site. Provisions to the calculation of design wind loads for the primary framing system and for the individual structural components of the buildings. Provisions are included for forces due to along-wind response of regular shaped building, caused by the common wind-storms including cyclones, thunderstorms and nonwestern.

a. Basic Wind Speed

The basic wind speed for the design is taken from basic wind speed map of Bangladesh (BNBC, 1993), where it is in km/h for any location in Bangladesh, having isobaths representing the fastest-mile wind speed at 10 meters above the ground with terrain exposure B for a 50 years’ recurrence interval. The minimum value of the basic wind speed set in the map is 130 km / h and maximum is 260 km/h. The basic wind speed for selected locations in Bangladesh are given in Table 2.1

Table 2.1: Basic Wind Speeds for Selected Locations in Bangladesh

Location	Basic Wind Speed (km/h)	Location	Basic Wind Speed (km/h)
Angarpota	150	Lalmonirhat	204
Bagerhat	252	Madaripur	220
Bandarban	200	Magura	208
Barguna	260	Manikganj	185
Barisal	256	Meherpur	185
Bhola	225	Maheshkhali	260
Bogra	198	Moulvibazar	168
Brahmanbaria	180	Munshiganj	184
Chandpur	160	Mymensingh	217
Chapai		Naogaon	175
Nawabganj	130	Narail	222
Chittagong	260	Narayanganj	195
Chuadanga	198	Narsinghdi	190
Comilla	196	Natore	198
Cox’s Bazar	260	Netrokona	210
Dahagram	150	Nilphamari	140
Dhaka	210	Noakhali	184
Dinajpur	130	Pabna	202
Faridpur	202	Panchagarh	130
Feni	205	Patuakhali	260
Gaibandha	210	Pirojpur	260
Gazipur	215	Rajbari	188
Gopalganj	242	Rajshahi	155
Habiganj	172	Rangamati	180
Hatiya	260	Rangpur	209
Ishurdi	225	Satkhira	183
Joypurhat	180	Shariatpur	198
Jamalpur	180	Sherpur	200
Jessore	205	Sirajganj	160
Jhalakati	260	Srimangal	160
Jhenaidah	208	St. Martin’s Island	260
Khagrachhari	180	Sunamganj	195
Khulna	238	Sylhet	195
Kutubdia	260	Sandwip	260
Kishoreganj	207	Tangail	160
Kurigram	210	Teknaf	260
Kushtia	215	Thakurgaon	130
Lakshmipur	162		

b. Exposure Category

Exposure A: Urban and sub-urban areas, industrial areas, wooded areas, hilly or other terrain covering at least 20 percent of the area with obstructions of 6 meters or more in height and extending from the site at least 500 meters or 10 times the height of the structure, whichever is greater.

Exposure B: Open terrain with scattered obstruction having heights generally less than 10m extending 800m or more from the site in any full quadrant. This category includes airfields, open park land, sparely built up out skirts of towns, flat open country and grass land.

Exposure C: Flat and unobstructed open terrain, coastal areas and riversides facing large bodies of water, over 1.5 km or more in width. Exposure C extends inland from the shoreline 400m or 10 times the height of structure, whichever greater.

Variables affecting wind pressure distributions

a. Building shape:

Pressure on certain parts of a structure is rather sensitive to changes in the shape of the building. The suctions on the windward roof slope, for instance, very considerably with the slope of the roof, the ratio of height to width, and the ratio of width to length of the building. Suctions on the leeward wall, on the other hand, are not greatly affected by such variables. Sometimes shape details have an unexpectedly large effect on the wind pressure distribution. Parapet walls, large chimneys, silos and spires may have considerable influence and often the only way to assess such effects is to test a scale model in a wind tunnel.

b. Openings:

The size and location of opening such as windows and doors determine the internal pressure that must be considered in the calculation of net forces of walls and roofs. Internal pressure tends to take on the values appropriate to the exterior of the wall in which the opening predominate. If they are small and uniformly distributed, values of ± 2 are recommended, the more unfavorable of the two to be considered in each case.

c. Wind direction:

The orientation of a building to the wind has a market effect on pressure distribution, particularly on suction maxima, which occur over a small area near the leading edges of roofs.

d. Increase of wind speed with height:

Since the wind speed and consequently the velocity pressure increases with height above the ground, a height factor is applied to the basic pressure in the design of building.

2.2 Earthquake Load

Structural System for EQ

a) **Bearing Wall System**: A structural system having bearing walls or bracing systems without a complete vertical load carrying frame to support gravity loads. Resistance to lateral loads is provided by shear walls or braced frames.

b) **Building Frame System**: A structural system with an essentially complete space frame providing support for gravity loads. Resistance to lateral loads is provided by shear walls or braced frames separately.

c) **Moment Resisting Frame System**: A structural system with an essentially complete space frame providing support for gravity loads. Moment resisting frames also provide resistance to lateral load primarily by flexural action of members, and may be classified as one of the following types:

i) Special Moment Resisting Frames (SMRF)
ii) Intermediate Moment Resisting Frames (IMRF)
iii) Ordinary Moment Resisting Frames (OMRF).

The framing system, IMRF and SMRF shall have special detailing to provide ductile behavior for concrete and steel structures respectively. OMRF need not conform to the ductility requirements.

d) **Dual System**: A structural system having a combination of the following framing systems:

i) Moment resisting frames (SMRF, IMRF or steel OMRF), and
ii) Shear walls or braced frames.

The moment resisting frames shall be capable of resisting at least 25% of the applicable total seismic lateral force, even when wind or any other lateral force governs the design.

e) **Special Structural System**: A structural system not defined above nor listed in Table 2.2 and specially designed to carry the lateral loads, such as tube-in-tube, bundled tube, etc.

f) **Non-building Structural System**: A structural system used for purposes other than in buildings.

Table 2.2: Basic Structural Systems and Height Limits for Seismic Zone 3 *

Basic Structural System (1)	**Lateral Force Resisting System - Description**	***H* (2) (metres)**
a. Bearing Wall System	1. Light framed walls with shear panels	
	i) Plywood walls for structures, 3 - storeys or less	---
	ii) All other light framed walls	20
	2. Shear walls	
	i) Concrete	50
	ii) Masonry	40
	3. Light steel-framed bearing walls with tension only bracings	20
	4. Braced frames where bracing carries gravity loads	
	i) Steel	50
	ii) Concrete (3)	---
	iii) Heavy timber	20
b. Building Frame System	1. Steel eccentric braced frame (EBF)	75
	2. Light framed walls with shear panels	
	i) Plywood walls for structures 3-storeys or less	20
	ii) All other light framed walls	20
	3. Shear walls	
	i) Concrete	75
	ii) Masonry	50
	4. Concentric braced frames (CBF)	
	i) Steel	50
	ii) Concrete (3)	---
	iii) Heavy timber	20
c. Moment Resisting Frame System	1. Special moment resisting frames (SMRF)	
	i) Steel	N.L.
	ii) Concrete	N.L.
	2.Intermediate moment resisting frames (IMRF), concrete (4)	---
	3. Ordinary moment resisting frames (OMRF)	
	i) Steel	50
	ii) Concrete (5)	---
d. Dual System	1. Shear walls	
	i) Concrete with SMRF	N.L.
	ii) Concrete with steel OMRF	50
	iii) Concrete with concrete IMRF (4)	50
	iv) Masonry with SMRF	50
	v) Masonry with steel OMRF	50
	vi) Masonry with concrete IMRF (3)	---
	2. Steel Eccentric Braced Frame (EBF)	
	i) With Steel SMRF	N.L.
	ii) With Steel OMRF	N.L.
	3. Concentric braced frame (CBF)	50
	i) Steel with steel SMRF	N.L
	ii) Steel with steel OMRF	50
	iii) Concrete with concrete SMRF (3)	---
	iv) Concrete with concrete IMRF (3)	---

e. Special Structural Systems	Structural systems not listed above	---

Notes :(1) Basic structural systems
(2) *H*=Height limit applicable to structures in Seismic Zone 3
(3) Prohibited in Seismic Zone 3
(4) Prohibited in Seismic Zone 3
(5) Prohibited in Seismic Zones 2 and 3
N.L. No Limit
--- Not applicable
* For Seismic Zones

Structural Configurations

Based on the structural configuration, each structure shall be designated as a regular, or irregular structure as defined below:

a) **Regular Structures**: Regular structures have no significant physical discontinuities in plan or vertical configuration or in their lateral force resisting systems.

b) **Irregular Structures**: Irregular structures have significant physical discontinuities in configuration or in their lateral force resisting systems. Irregular structures have either vertical irregularity or plan irregularity or both in their structural configurations.

Table 2.3: Vertical Irregularities of Structures

Vertical Irregularity	
Type	**Definition**
I	**Stiffness Irregularity (Soft Storey):** A soft storey is one in which the lateral stiffness is less than 70 per cent of that in the storey above or less than 80 per cent of the average stiffness of the three store’s above.
II	**Mass Irregularity:** Mass irregularity shall be considered to exist where the effective mass of any storey is more than 150 per cent of the effective mass of an adjacent storey. A roof which is lighter than the floor below need not be considered.
III	**Vertical Geometric Irregularity:** Vertical geometric irregularity shall be considered to exist where horizontal dimension of the lateral force-resisting system in any storey is more than 130 per cent of that in an adjacent storey, one-storey penthouses need not be considered.
IV	**In-Plane Discontinuity in Vertical Lateral Force-Resisting Element:** An in-plane offset of the lateral load-resisting elements greater than the length of those elements.
V	**Discontinuity in Capacity (Weak Storey):** A weak storey is one in which the storey strength is less than 80 per cent of that in the storey above. The storey strength is the total strength of all seismic-resisting elements sharing the storey shear for the direction under consideration.

Structures with vertical irregularity Type V as defined in Table 2.3 shall not be over 9.0 metres in height where the weak storey has a calculated strength of less than 65% of the storey above. However, for structures, where a weak storey is capable of resisting a total seismic force of 0.375*R* times the design force, the above limitation shall not be applied.

Table 2.4: Plan Irregularities of Structures

Plan Irregularity	
Type	**Definition**
I	**Torsional Irregularity (to be considered when diaphragms are not flexible):** Torsional irregularity shall be considered to exist when the maximum storey drift, computed including accidental torsion, at one end of the structure transverse to an axis is more than 1.2 times the average of the storey drifts of the two ends of the structure.
II	**Reentrant Corners:** Plan configurations of a structure and its lateral force-resisting system contain reentrant corners, where both projections of the structure beyond a reentrant corner are greater than 1.5 per cent of the plan dimension of the structure in the given direction.
III	**Diaphragm Discontinuity:** Diaphragms with abrupt discontinuities or variations in stiffness, including those having cutout or open areas greater than 50 per cent of the gross enclosed area of the diaphragm, or changes in effective diaphragm stiffness of more than 50 per cent from one storey to the next.
IV	**Out-of-plane Offsets:** Discontinuities in a lateral force path, such as out-of-plane offsets of the vertical elements.
V	**Nonparallel Systems:** The vertical lateral load-resisting elements are not parallel to or symmetric about the major orthogonal axes of the lateral force-resisting system.

Selection of Lateral Force Method

Seismic lateral forces on primary framing systems shall be determined by using either the Equivalent Static Force Method or the Dynamic Response Method complying with the restrictions given below:

a) The Equivalent Static Force Method may be used for the following structures:

i) All structures, regular or irregular, in Seismic Zone 1 and in Structure Importance Category IV in Seismic Zone 2, except case b(iv) below.

ii) Regular structures under 75 metres in height with lateral force resistance provided by structural systems except case b(iv) below.

iii) Irregular structures not more than 20 metres in height.

iv) A tower like building or structure having a flexible upper portion supported on a rigid lower portion where:

1) both portions of the structure considered separately can be classified as regular structures,

2) the average storey stiffness of the lower portion is at least ten times the average storey stiffness of the upper portion, and

3) the period of the entire structure is not greater than 1.1 times the period of the upper portion considered as a separate structure fixed at the base.

b) The Dynamic Response Method may be used for all classes of structure, but shall be used for structures of the following types:

i) Structures 75 metres or more in height except as permitted by case a(i) above.

ii) Structures having a stiffness, weight or geometric vertical irregularity of Type I, II, or III or structures having irregular features.

iii) Structures over 20 metres in height in Seismic Zone 3 not having the same structural system throughout their height.

iv) Structures, regular or irregular, located on Soil Profile Type S_4, which have a period greater than 0.7 second.

A. Equivalent Static Force Method

This method may be used for calculation of seismic lateral forces for all structures.

Design Base Shear: The total design base shear in a given direction shall be determined from the following relation:

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

where, Z = Seismic zone coefficient given in Table 2.5

I = Structure importance coefficient given in Table 2.6

R = Response modification coefficient for structural systems given in Table 2.8.

W = The total seismic dead load

C = Numerical coefficient given by the relation:

$$= \frac{1.25S}{T^{2/3}}$$

S = Site coefficient for soil characteristics as provided in Table 2.9

T = Fundamental period of vibration in seconds, of the structure for the direction under consideration.

Table 2.5:

Seismic Zone Coefficients, *Z*

Seismic Zone	Zone Coefficient
1	0.075
2	0.150
3	0.250

Table 2.6:

Structure Importance Coefficients *I, I′*

Structure Importance Category	Structure Importance Coefficient	
	I	I'
I Essential facilities	1.25	1.50
II Hazardous facilities	1.25	1.50
III Special occupancy structures	1.00	1.00
IV Standard occupancy structures	1.00	1.00
V Low-risk Structures	1.00	1.00

The value of C need not exceed 2.75 and this value may be used for any structure without regard to soil type or structure period. Except for those requirements where Code prescribed forces are scaled up by 0.375R, the minimum value of the ratio C/R shall be 0.075.

Definition of different facilities as mentioned in Table 2.6 is summarized in Table 2.7.

Structure Period: For all buildings the value of T may be approximated by the following formula:

$$T = C_t\, (h_n)^{3/4}$$

where, C_t = 0.083 for steel moment resisting frames

= 0.073 for reinforced concrete moment resisting frames, and eccentric braced steel frames

= 0.049 for all other structural systems

h_n = Height in metres above the base to level n.

Table 2.7: Structure Importance Categories

Structure Importance Category	Occupancy Type or Functions of Structure	
	General	**Particular**
I	Essential Facilities	1. Hospital and other medical facilities having surgery and emergency treatment area. 2. Fire and police stations. 3. Tanks or other structures containing, housing or supporting water or other fire-suppression materials or equipment required for the protection of essential or hazardous facilities, or special occupancy structures. 4. Emergency vehicle shelters and garages. 5. Structures and equipment in emergency-preparedness centers, including cyclone and flood shelters. 6. Standby power-generating equipment for essential facilities. 7. Structures and equipment in government communication centers and other facilities required for emergency response.
II	Hazardous Facilities	Structures housing, supporting or containing sufficient quantities of toxic or explosive substances to be dangerous to the safety of the general public if released.
III	Special Occupancy Structures	1. Covered structures whose primary occupancy is public assembly with capacity > 300 persons. 2. Buildings for schools through secondary or day-care centre with capacity > 250 students. 3. Buildings for colleges or adult education schools with capacity > 500 students. 4. Medical facilities with 50 or more resident incapacitated patients not included above. 5. Jails and detention facilities. 6. All structures with occupancy > 5,000 persons. 7. Structures and equipment in power-generating stations and other public utility facilities not included above and required for continued operation.
IV	Standard Occupancy Structures	All structures having occupancies or functions not listed above.
V	Low Risk Structures	Buildings and Structures that exhibit a low risk to human life and property in the event of failure, such as agricultural buildings, minor storage facilities, temporary facilities, construction facilities, and boundary walls.

Table 2.8: Response Modification Coefficient for Structural Systems, *R*

Basic Structural System(1)	Description of Lateral Force Resisting System	*R*
a. Bearing Wall System	1. Light framed walls with shear panels	
	i) Plywood walls for structures, 3 story's or less	8
	ii) All other light framed walls	6
	2. Shear walls	
	i) Concrete	6
	ii) Masonry	6
	3. Light steel framed bearing walls with tension only bracing	4
	4. Braced frames where bracing carries gravity loads	
	i) Steel	6
	ii) Concrete (2)	4
	iii) Heavy timber	4
b. Building Frame System	1. Steel eccentric braced frame (EBF)	10
	2. Light framed walls with shear panels	
	i) Plywood walls for structures 3-storeys or less	9
	ii) All other light framed walls	7
	3. Shear walls	
	i) Concrete	8
	ii) Masonry	8
	4. Concentric braced frames (CBF)	
	i) Steel	8
	ii) Concrete (2)	8
	iii) Heavy timber	8
c. Moment Resisting Frame System	1. Special moment resisting frames (SMRF)	
	i) Steel	12
	ii) Concrete	12
	2. Intermediate moment resisting frames (IMRF), concrete (3)	8
	3. Ordinary moment resisting frames (OMRF)	
	i) Steel	6
	ii) Concrete (4)	5
d. Dual System	1. Shear walls	
	i) Concrete with steel or concrete SMRF	12
	ii) Concrete with steel OMRF	6
	iii) Concrete with concrete IMRF (3)	9
	iv) Masonry with steel or concrete SMRF	8
	v) Masonry with steel OMRF	6
	vi) Masonry with concrete IMRF (2)	7
	2. Steel EBF	
	i) With steel SMRF	12
	ii) With steel OMRF	6
	3. Concentric braced frame (CBF)	
	i) Steel with steel SMRF	10
	ii) Steel with steel OMRF	6
	iii) Concrete with concrete SMRF (2)	9
	iv) Concrete with concrete IMRF (2)	6

Note:	
(1)	Basic Structural Systems.
(2)	Prohibited in Seismic Zone 3.
(3)	Prohibited in Seismic Zone 3
(4)	Prohibited in Seismic Zones 2 and 3.

Table 2.9: Site Coefficient, *S* for Seismic Lateral Forces (1)

Site Soil Characteristics		Coefficient, *S*
Type	**Description**	
S_1	A soil profile with either : a) A rock-like material characterized by a shear-wave velocity greater than 762 m/s or by other suitable means of classification, or b) Stiff or dense soil condition where the soil depth is less than 61 metres	1.0
S_2	A soil profile with dense or stiff soil conditions, where the soil depth exceeds 61 metres	1.2
S_3	A soil profile 21 metres or more in depth and containing more than 6 metres of soft to medium stiff clay but not more than 12 metres of soft clay	1.5
S_4	A soil profile containing more than 12 metres of soft clay characterized by a shear wave velocity less than 152 m/s	2.0
Note : (1) The site coefficient shall be established from properly substantiated geotechnical data. In locations where the soil properties are not known in sufficient detail to determine the soil profile type, soil profile S_3 shall be used. Soil profile S_4 need not be assumed unless the building official determines that soil profile S_4 may be present at the site, or in the event that soil profile S_4 is established by geotechnical data.		

Vertical Distribution of Lateral Forces: In the absence of a more rigorous procedure, the total lateral force, which is the base shear *V*, shall be distributed along the height of the structure:

$$V = F_t + \sum_{i=1}^{n} F_i$$

where, F_i = Lateral force applied at storey level -*i* and

F_t = Concentrated lateral force considered at the top of the building in addition to the force F_n.

The concentrated force, F_t acting at the top of the building shall be determined as follows:

F_t = 0.07 $TV \leq 0.25\ V$ when $T > 0.7$ second

F_t = 0.0 when $T \leq$ 0.7 second

The remaining portion of the base shear (V-F_t), shall be distributed over the height of the building, including level-n, according to the relation:

$$F_x = \frac{(V - F_t) w_x h_x}{\sum_{i=1}^{n} w_i h_i}$$

At each storey level-x, the force F_x shall be applied over the area of the building in proportion to the mass distribution at that level.

Any combination of Building Frame Systems, Dual Systems, or Moment Resisting Frame Systems may be used to resist design seismic forces in structures less than 50 m in height. Only combinations of Dual Systems and Special Moment Resisting Frames (SMRF) can be used to resist the design seismic forces in structures exceeding 50 m in height in Seismic Zone 3.

Overturning Requirements:

Every structure shall be designed to resist the overturning effects caused by wind or earthquake forces.

The overturning moment Mx at any storey level-x of a building shall be determined as :

$$M_x = F_t\left(h_n - h_x + \sum_{i=1}^{n} F_i\right)(h_i - h_x)$$

where,

h_i, h_x, h_n = Height in metres at level- i, -x or -n respectively.

F_i = Lateral force applied at level-i, i=1 *to n.*

F_t = Concentrated lateral force applied at level-n in addition to F_n applicable for earthquake only. For all other lateral load cases, F_t = 0.

At foundation level, the base overturning moment for the entire structure or for any one of its lateral load-resisting elements, shall not exceed two-thirds of the dead load resisting moment. The weight of the earth superimposed over footings may be used to calculate the dead load resisting moment.

B. Dynamic Response Method

Ground Motion: The ground motion representation as set out in this section shall, as a minimum, be one having 20% probability of being exceeded in 50 years and may be one of the following:

a) *Response Spectrum*: The response spectrum to be used in the dynamic analysis shall be any one of the following:

   i) Site Specific Design Spectra**:** A site specific response spectra shall be developed based on the geologic, tectonic, seismologic, and soil characteristics associated with the specific site. The spectra shall be developed for a damping ratio of 0.05 unless a different value is found to be consistent with the expected structural behavior at the intensity of vibration established for the site.

   ii) Normalized Response Spectra: In absence of a site-specific response spectrum, the normalized response spectra shall be used in the dynamic analysis procedure.

b) *Time History*: Ground motion time history developed for the specific site shall be representative of actual earthquake motions for the directions under consideration. Response spectra from time history, either individually or in combination, shall approximate the site-specific design spectra conforming to paragraph a (i) above.

Response Spectrum Analysis: The analysis shall include the peak dynamic response of all modes having a significant contribution to total structural response. Peak modal response shall be calculated using the ordinates of the appropriate response spectrum curve which correspond to the modal periods. Maximum modal contributions shall be combined in a statistical manner to obtain an approximate total structural response.

a) *Number of Modes*: The requirement that all significant modes be included may be satisfied by demonstrating that, for the modes considered, at least 90 per cent of the participating mass of the structure is included in the calculation of response for each principal horizontal direction.

b) *Combination of Modes*: The peak member forces, displacements, storey forces, storey shears, and base reactions for each mode shall be combined using established procedures in order to estimate resultant maximum values of these response parameters. When three dimensional models are used for analysis, modal interaction effects shall be considered when combining modal maximum.

Time History Analysis: When this procedure is followed, an elastic or inelastic dynamic analysis of a structure shall be made using a mathematical model of the structure and applying at its base or any other appropriate level, a ground motion time history. The time-dependent dynamic response of the structure shall be obtained through numerical integration of its equations of motion.

Drift of the Storey

Storey drift is the displacement of one level relative to the level above or below due to the design lateral forces. Calculated storey drift shall include both translational and torsional deflections and conform to the following requirements:

a) Storey drift, Δ, shall be limited as follows:

i) $\Delta \leq 0.04h/R \leq 0.005h$ for T < 0.7 second.

ii) $\Delta \leq 0.03h/R \leq 0.004h$ for $T \geq$ 0.7 second.

iii) $\Delta \leq 0.0025h$ for unreinforced masonry structures.

where, h = height of the building or structure.

The period T used in this calculation shall be the same as that used for determining the base shear. The limits involving R in (i) and (ii) above shall be applicable only when earthquake forces are present.

b) The drift limits set out in (a) above may be exceeded where it can be demonstrated that greater drift can be tolerated by both structural and nonstructural elements without affecting life safety.

P-Delta Effects

The resulting member forces and moments and the storey drifts induced by P-Delta effects need not be considered when the ratio of secondary moment to primary moment remains within 0.10. The ratio may be evaluated for any storey as the product of the total dead and live loads above the storey and the lateral drift in that storey divided by the product of the storey shear in that storey and the height of that storey.

In Seismic Zone 3, P-Delta effects need not be considered where the storey drift ratio does not exceed *0.02/R.*

EQ Magnitude

According to the depth of focus, tectonic earthquake is classified as:

Shallow: depth of focus is "less than 60 km.
Intermediate: depth of focus between 60 to 70' km.
Deep: depth of focus above 70 km.

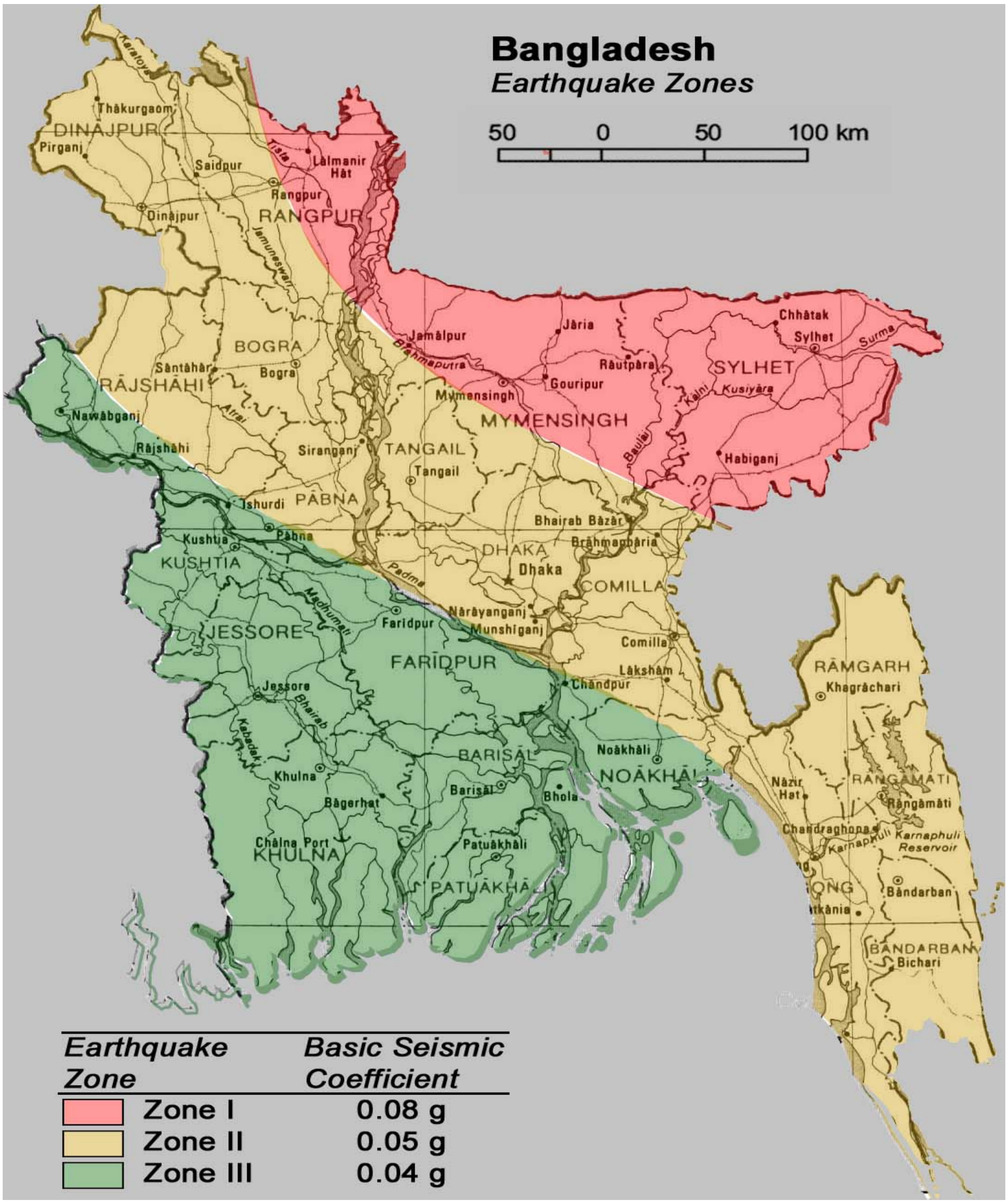
***Scale*:** The scale of earthquake intensities was conveniently classified into 12 categories, till 1935, when C.F. Richter devised a scale indicating numerical J5; magnitude of the intensity of earthquake, 10 is the highest on this scale. The greater the number more is the damaging power.

The intensity of earthquake in terms of Richter scale is expressed as:
1) *Instrumental*: detected by seismograph, magnitude 1-3;
2) *Feeble*: noticed only by sensitive people
3) *Slight*: is like vibration of passing lorry, felt on upper floors, magnitude'. 3.5 to 4.2;
4) *Moderate*: felt while walking, magnitude 4.3;
5) *Rather Strong*: most sleeper awakened, magnitude 4.8;
6) *Strong*: trees sway, suspended objects swing, falling loose, objects, magnitude 4.9- 5.4;
7) *Very Strong*: walls crack, plaster falls, magnitude 5.5-6;
8) *Destructive*: chimneys fall; buildings damaged, magnitude 6.8;
9) *Ruinous*: houses collapse, ground cracks, pipes break open, magnitude 6.9;
10) *Disastrous*: ground cracks badly budges. Destroyed, rail lines bent, magnitude 7-7.3;
11) *Very Disastrous*: few buildings remain standing; bridges destroyed, great landslide and flood, magnitude 7.4-8.7;
12) *Catastrophic*: total destruction. Objects thrown into air, ground rises and falls in waves, magnitude 8.2 and above.

There are three zones namely zone 1, being most active, zone II, less active and zone III, being the minimum possible intensity of earthquake. Seismic probable magnitudes are:

Zone	(Richter scale)
I	>7.0
II	6.5-7.0
III	6.0-6.5

2.1 Earthquake Zoning Map of Bangladesh



CHAPTER 3
METHODOLOGY OF THE STUDY

3.1 General

This chapter gives the outlines of the procedures that were followed to complete this study.

3.2 Study procedures

Step-I: Selection and planning of the structure

Two 20 storied braced and non-braced structures having same plinth areas with Edge supported floor system had been selected. The both structures have commercial cum residential floors.

Type-I building- Edge supported floor system Braced Structure as shown in Figure 3.1.
Type-II building- Edge supported floor system Non-Braced Structure as shown in Figure 3.2.
The both structures have all the facilities and amenities such as passenger lifts, stairs, ramps, car parking etc.

Step-II: Selection of the material properties & loadings

As per discussions made in *Chapter 2* and based on design code/specifications of *ACI/BNBC*, material properties (compressive strength of concrete, yield stress of steel, unit weight of concrete, soil, brick etc.) and loadings (standard live load, floor finish, etc.) were selected. Wind and earthquake loads were also considered.

Step-III: Analysis & findings of the study

Both types of structure; one is braced and another is non-braced structure, were analyzed by using ETABS 2016. *Chapter 4* provides detailed analysis and findings of the study.

Step-IV: Conclusions & Recommendations

Based on study, few concluding remarks were drawn. To carry out further study on this topic, recommendations were proposed in the *Chapter 5*.

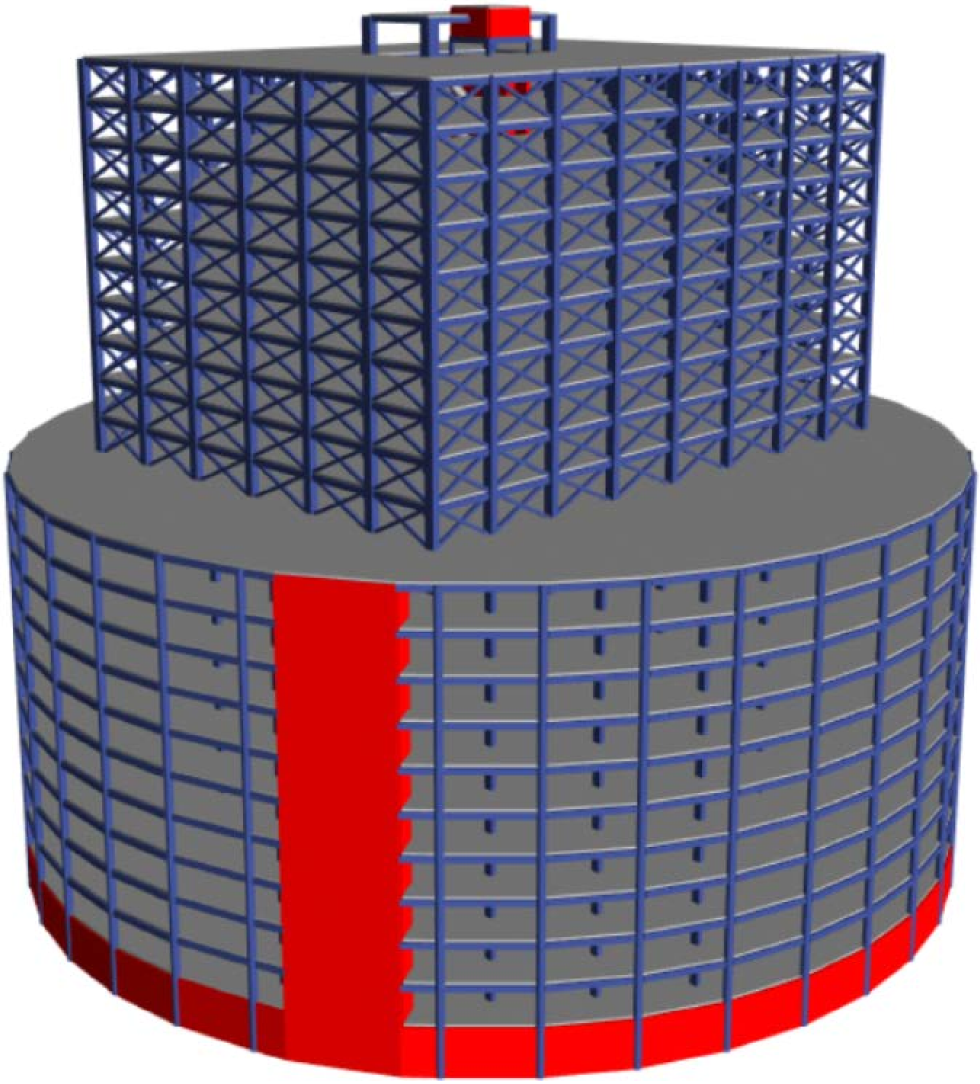


Figure 3.1: 3-D view of the Type-I structure (Braced)

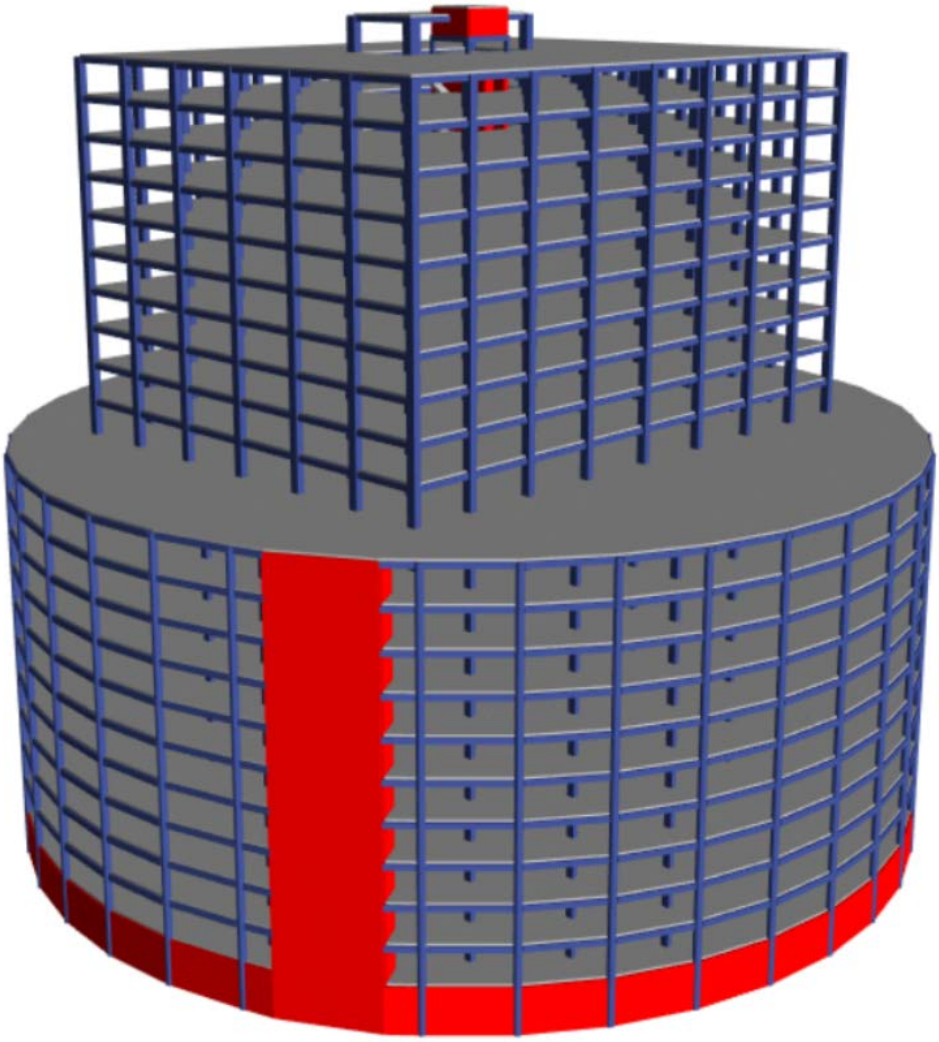


Figure 3.2: 3-D view of the Type-II structure (Non-Braced)

3.3 Design data and specifications considered in this study

The whole study was carried out based on few considerations and specifications which are summarized in Table 3.1 below.

Table 3.1: Summary of the design considerations and specification of the study

Items	Description
Design code	• American Concrete Institute (*ACI*) Building design code, 2014. • Bangladesh National Building Code (*BNBC*), 2006.
Loadings	• Floor finish for commercial floors =30 *psf*. • Floor finish for residential floors =25 *psf*. • Floor finish for stair =30 *psf*. • Floor finish for water tank, ramp, basement =10 *psf*. • Live load for all residential floors=40 *psf*. • Live load for all stair = 150 *psf*. • Live load for all commercial floors = 150 *psf*. • Live load for ramp, basement floor & water tank=10 *psf*. • P.W. load for residential and commercial floors=*30psf*. • Earthquake and wind load are considered.
Building components	• Column type = Circular & Tied • Footing type = Pile foundation. • Thickness of all partition walls = 5 *inch*. • Thickness of shear-wall=14 *inch*. • Thickness of Slab=6 *inch*. • Thickness of ramp= *8 inch*.
Material properties	• Yield strength of reinforcing bars, f_y= 60,000 *psi*. • Concrete compressive strength, $f'_{c=}$ 4,000 *psi* for column, grade beam, ramp retaining all and shear-wall. And 3000 psi for slab, stair. • Normal density concrete having w_c = 150 *pcf*. • Unit weight of brick, w_b = 120 *pcf*. • Unit weight of water =62.5 *pcf*.

3.4 Load Calculation

3.4.1 Load case according to the *BNBC* code

1. 1.00×DL+1.00LL
2. 1.40×DL+1.70×LL
3. 1.05×DL+1.275×LL +1.275WLX
4. 1.05×DL+1.275×LL +1.275**(**-WLX)
5. 1.05×DL+1.275×LL +1.275WLZ
6. 1.05×DL+1.275×LL +1.275(-WLZ)
7. 1.05×DL+1.275×LL +1.4025EQX
8. 1.05×DL+1.275×LL +1.4025(-EQX)
9. 1.05×DL+1.275×LL +1.4025(EQZ)
10. 1.05×DL+1.275×LL +1.4025(-EQZ)

3.4.2 Dead load calculation for Floor space

Self-weight of slab = 6/12 *150=75 *psf.*

Floor finish Commercial= 30 *psf.*
Floor finish residential=25psf.
5″ Partition wall Load calculation = 30 *psf.* *(residential)*

5” partition wall load calculation = 30 psf (commercial)

Total dead load for 6.0″ thickness slab, for Commercial,

= self-weight of slab + Floor finish load + partition wall load = 75+ 30 + 30 = 135 *psf*

Total dead load for 6.0″ thickness slab, for Residential,

= self-weight of slab + Floor finish load + partition wall load = 75 + 25 + 30 = 130 *psf*

3.4.3 Dead load calculation for ramp slab

Self-weight of ramp slab = $\frac{8.0}{12} \times 150 = 100\, psf.$

Floor finish = 10 *psf*

Total dead load for 8.0″ thickness slab = 100+ 10 = 110 *psf.*

3.4.4 Live load calculation

Live load for all residential floor space	= 40*psf.*
Live load for all stair	= 150*psf.*
Live load for ramp & water tank slab	=10 *psf.*
Live load for all commercial floor space	=150 *psf.*
Water pressure for water tank	=437.5 *psf.*

3.4.5 Seismic load calculation

Height of building	= 212 *ft* = 64.614*m*
Seismic zone Coefficient (Dhaka zone)	= 0.150
Special moment resisting frame, *R*	= 9
Importance Coefficient for residential building, *I*	= 1.0
Vibration time period, *T*	$= C_t \times h^{\frac{3}{4}}{}_n = 0.049 \times 64.614^{\frac{3}{4}}$
	= 1.1167 *second*
Soil profile, S	= 1.5

3.4.6 Wind load calculation

Both Braced and Non-Braced Structures-

Diameter of building, D	=253 ft
Height of building, H	= 212 *ft*
Wind pressure in Dhaka city, V_b	= 210 *Km/h*
Importance coefficient, *I*	= 1.0

CHAPTER 4

ANALYSIS & FINDINGS OF THE STUDY

4.1 Introduction

This chapter provides findings of the study and discussion of the obtained results as per references used. This study focuses on the responses by analyzing the effects of the lateral loads on two 20 storied high-rise structures having Braced Structure and Non-Braced Structure. All results are summarized in several tabular forms and presented in graphical forms in order to make comparative analyses. Also, few explanations were made based on data from ETABS. Finally, presents a comparative result to identify best structural system for a high-rise structure against lateral loadings.

4.2 Comparative discussions

According to the main objective of this study, it is required to find out the effects of lateral loadings in the analysis of two 20 storied high-rise structures, one with Braced Structure and another with Non-Braced Structure, having similar commercial floor plan and areas also similar residential floor plan and areas which make a comparison among these structural responses. To obtain this goal, the whole comparative study is divided into several sub topics so that a clear picture can be obtained and complete discussions are possible. Also following points are considered:

1. The both structures are divided into several grids in ETABS plan: **1~19 in horizontal grids and A~S in vertical grids.**
2. Analyses data are taken for Lateral loads to Stories; Maximum stories Displacement; Maximum stories Drifts; stories Shear, stories Overturning Moments and stories Stiffness in case of both structures.

Figures 4.1(a) and 4.1(d) show the 3-D ETABS model view of Braced Structure and Non-Braced Structure respectively. Also Figures 4.1(b) ~ 4.1(c) and 4.1(e) ~ 4.1(f) present plan views at 1st floor and 11th floor of both structures respectively which give clear picture on the presence of columns, peripheral floor beams and shear walls that considered in this study.

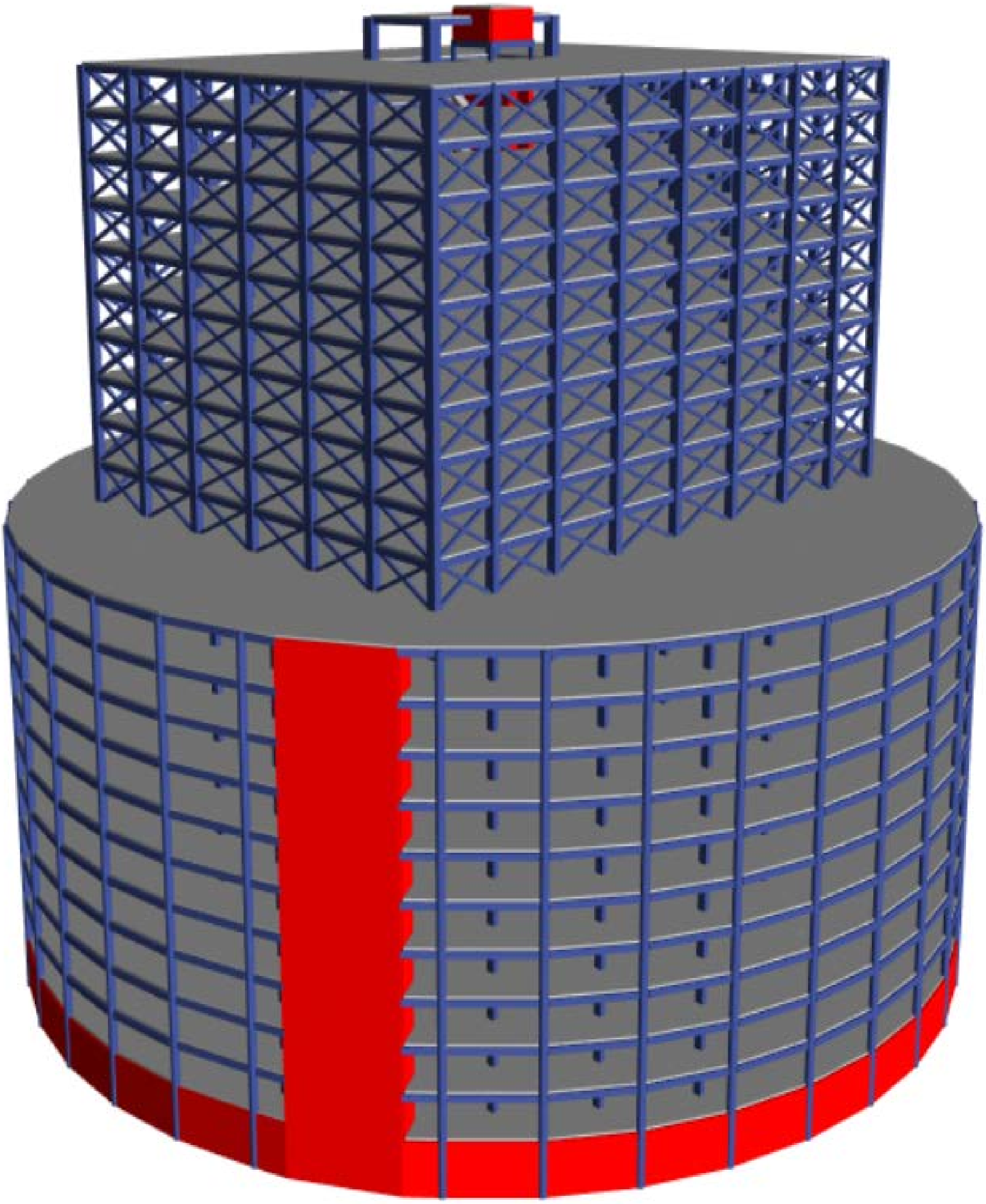


Figure 4.1(a): 3-D Model View of Braced Structure

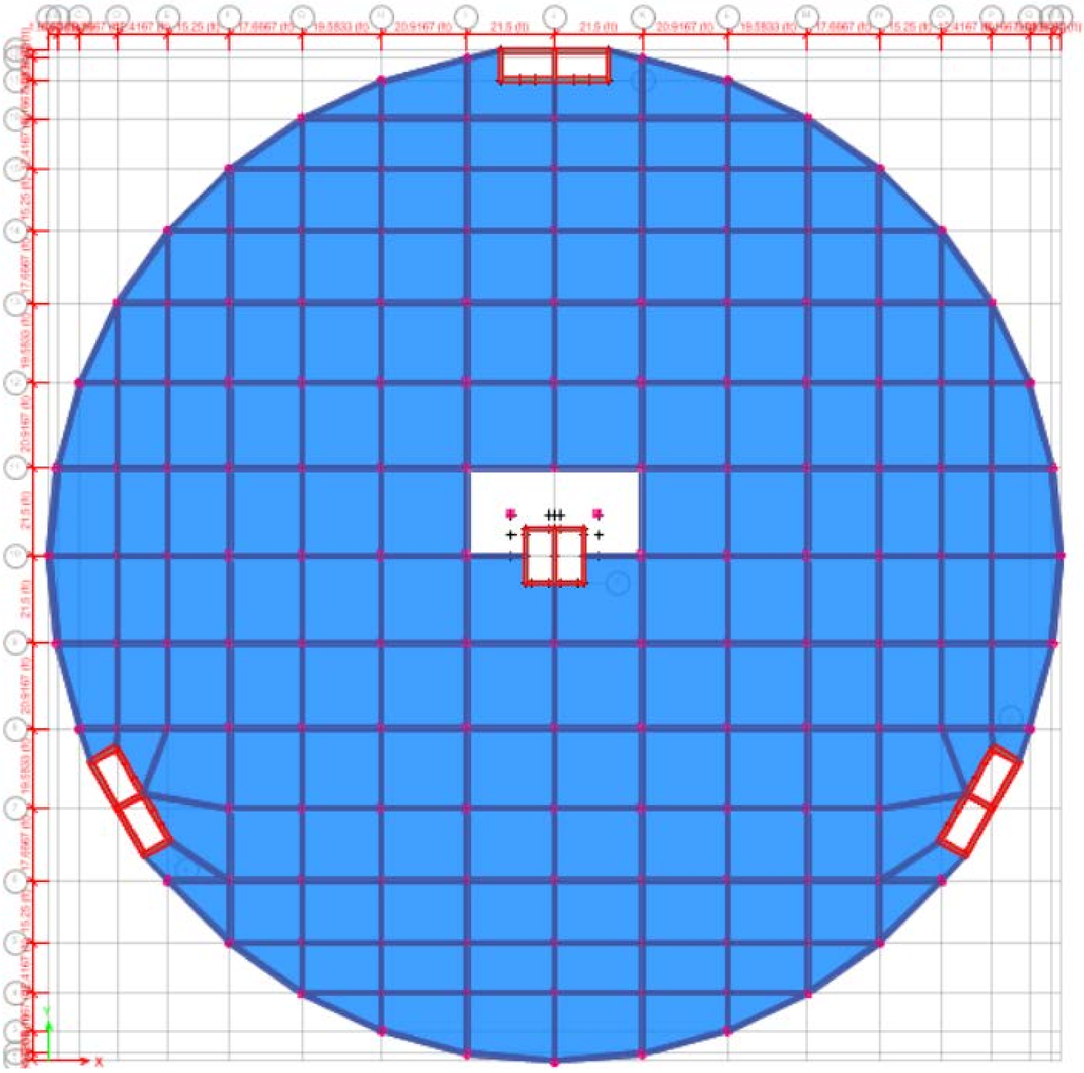


Figure 4.1(b): 1st Floor Plan View of Braced Structure

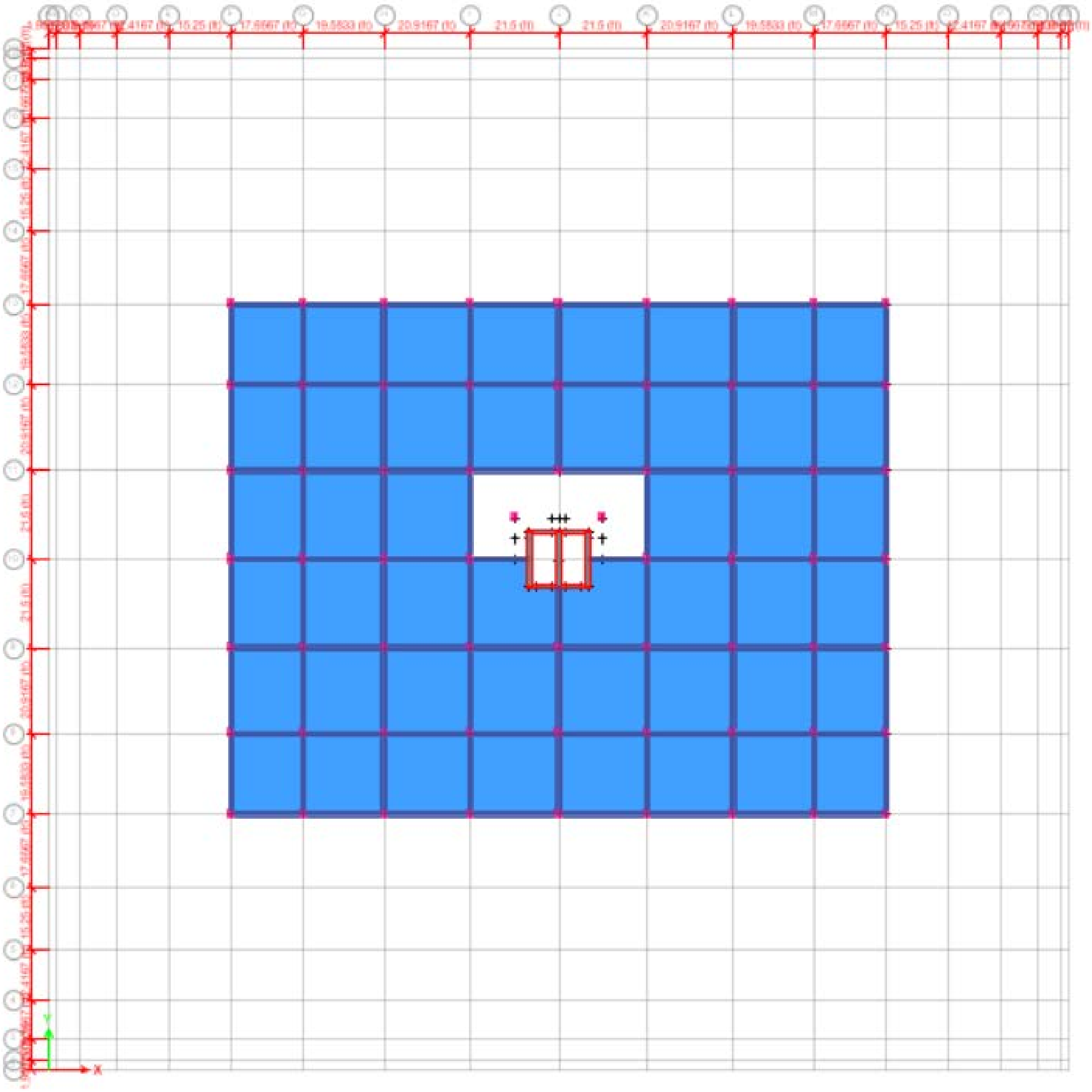


Figure 4.1(c): 11th Floor Plan View of Braced Structure

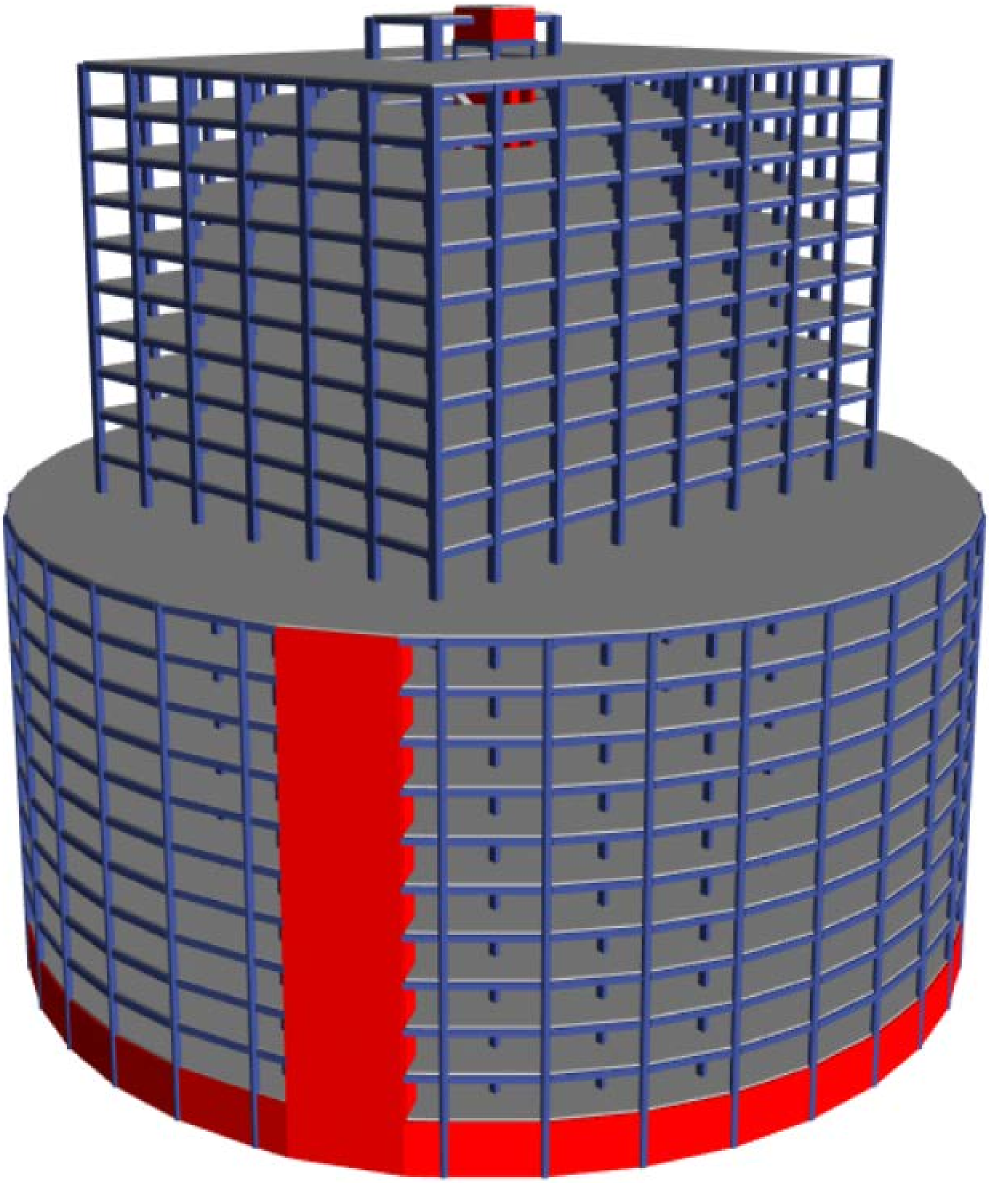


Figure 4.1(d): 3-D Model View of Non-Braced Structure

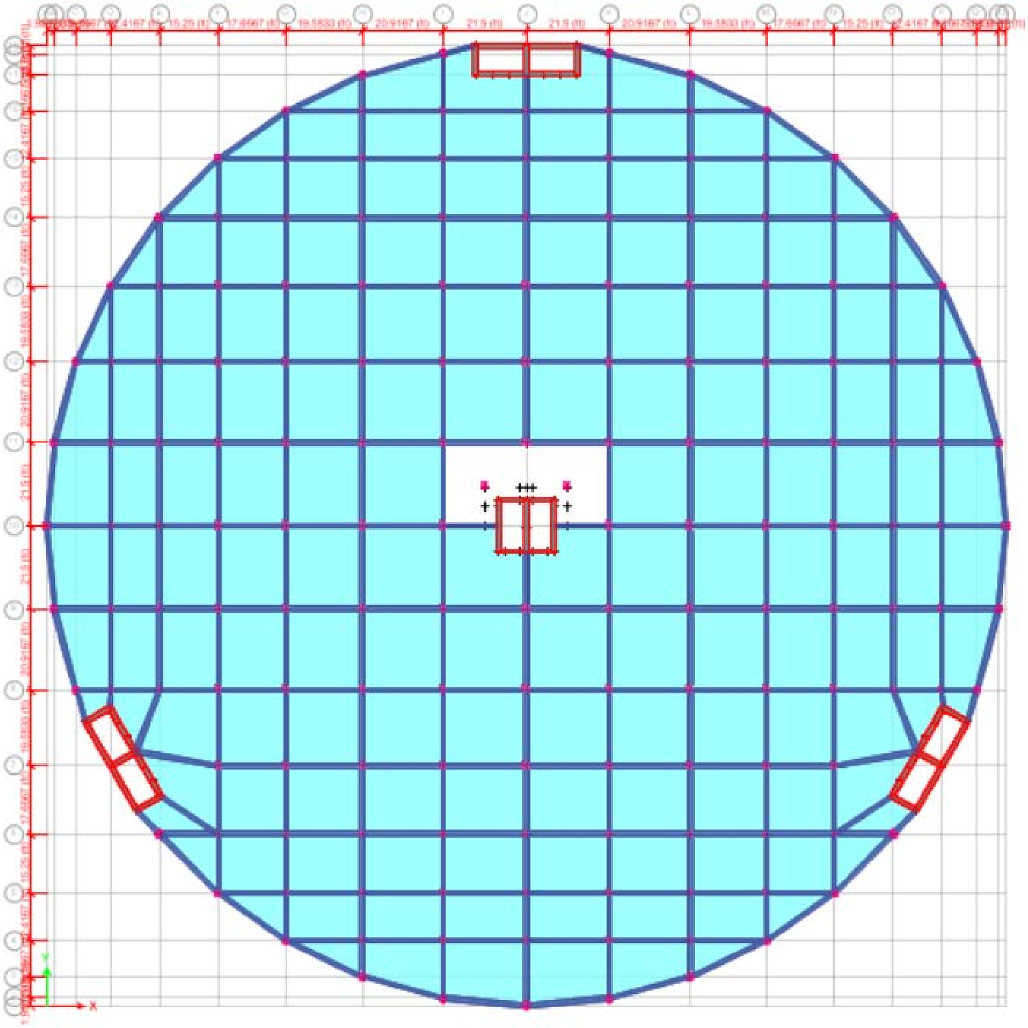


Figure 4.1(e): 1st Floor Plan View of Non-Braced Structure

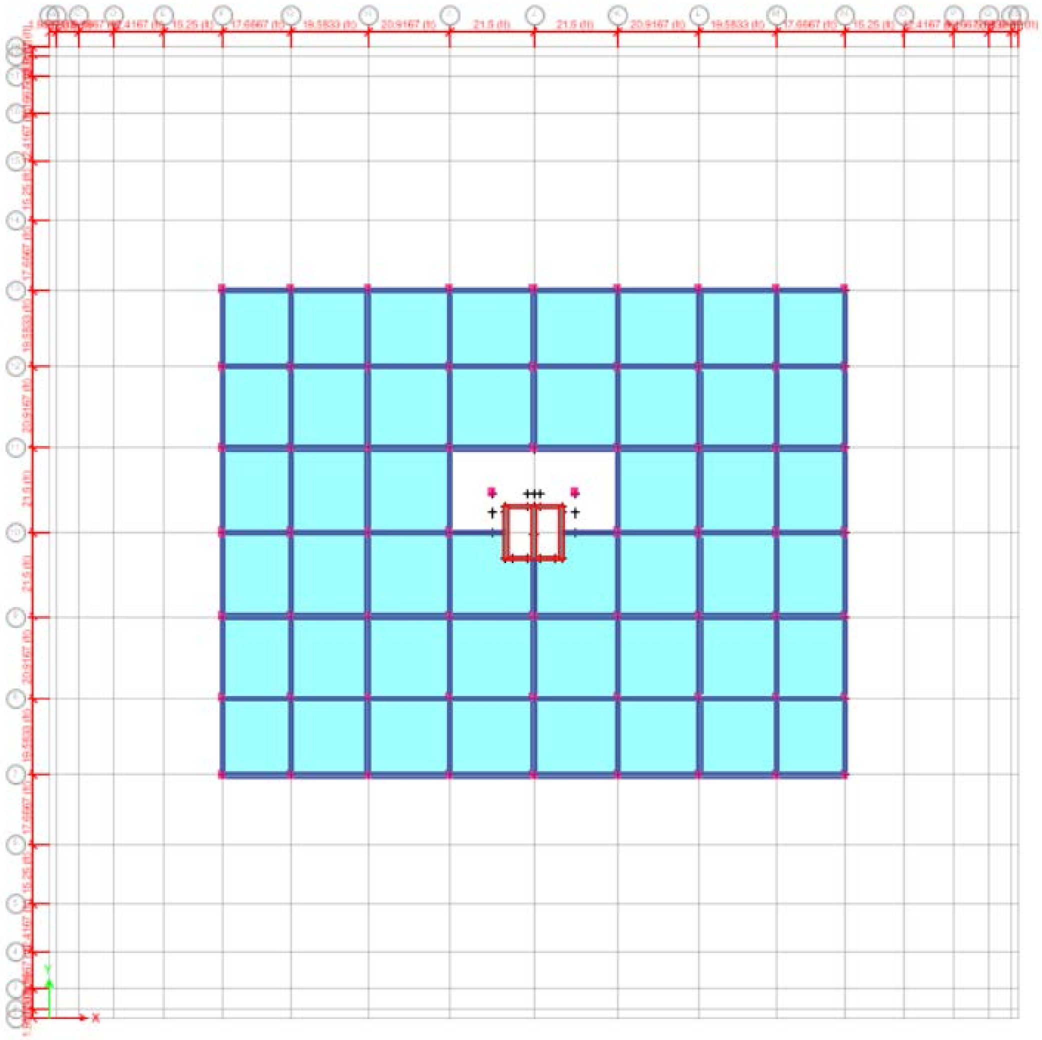


Figure 4.1(f): 11th Floor Plan View of Non-Braced Structure

4.2.1 Comparison based on Different Influencing Factors

This section will present the differences among the responses of Braced and Non-Braced Structure towards lateral loadings in terms of the following factors:

- Auto Lateral Loads to Stories
- Maximum Story Displacement
- Maximum Story Drifts
- Story Shears
- Story Overturning Moments
- Story Stiffness

Comparative analysis was done by ETABS. The global X-axis and Y-axis of the model are similar of the building. The global X-axis and Y-axis of the two models are shown in Figure 4.2(a ~b).

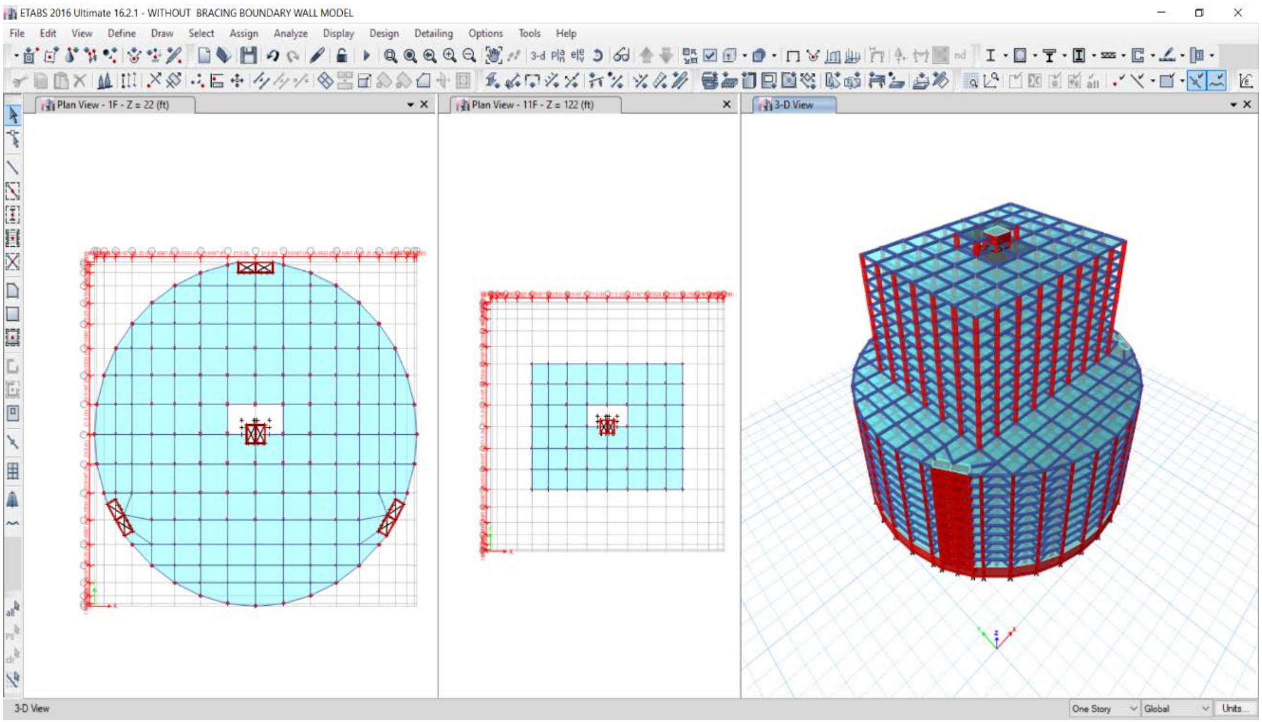


Figure 4.2(a): Global X & Y Direction of ETABS Model (Non-Braced)

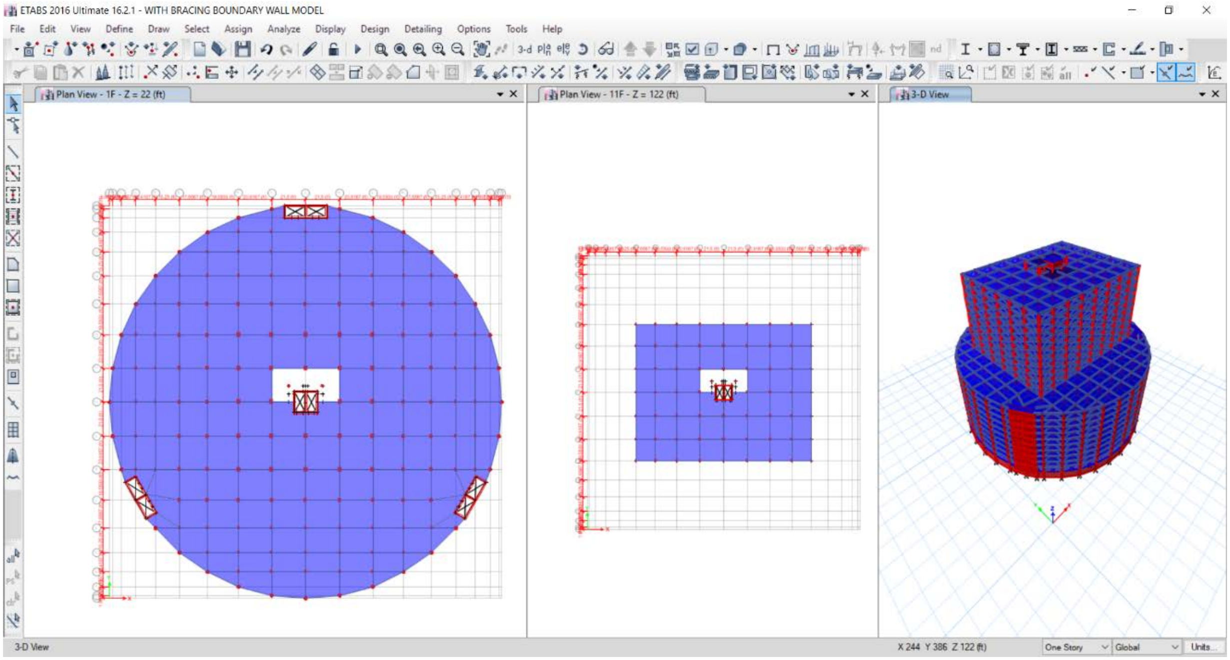


Figure 4.2(b): Global X & Y Direction of ETABS Model (Braced)

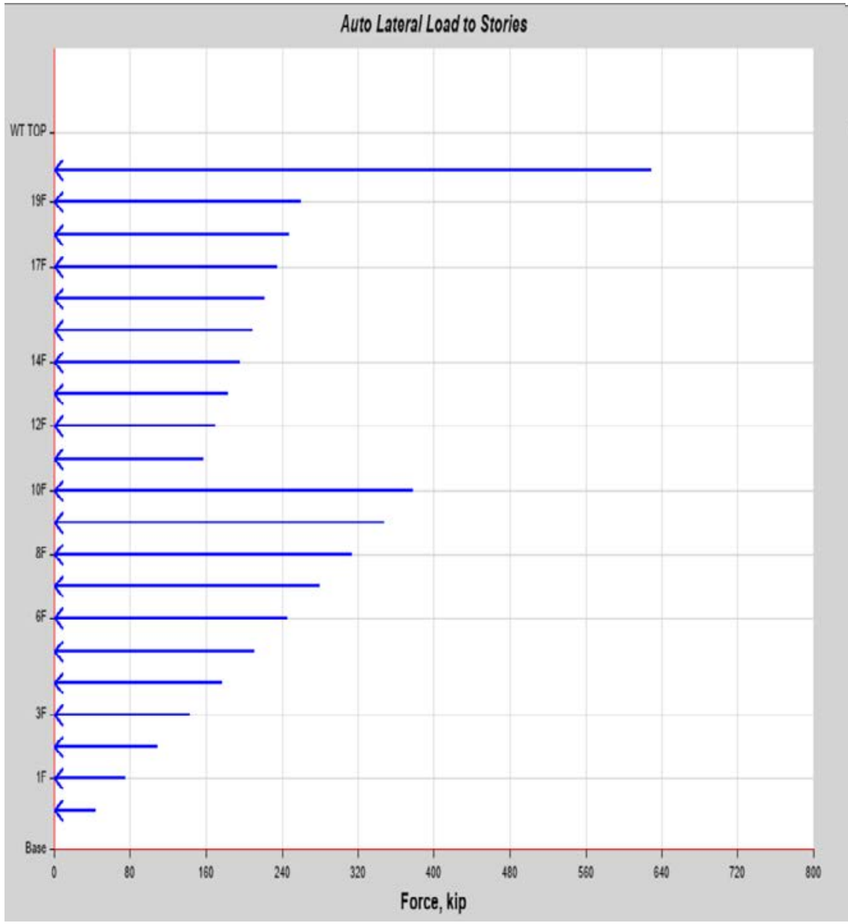
To illustrate the different phase of response curves due to lateral loadings in both X & Y direction, and to set comparison these responses, the whole discussion is going to focus on the effects of wind and earthquake separately.

4.2.2 Response due to Earthquake Loads in Global +ve directions

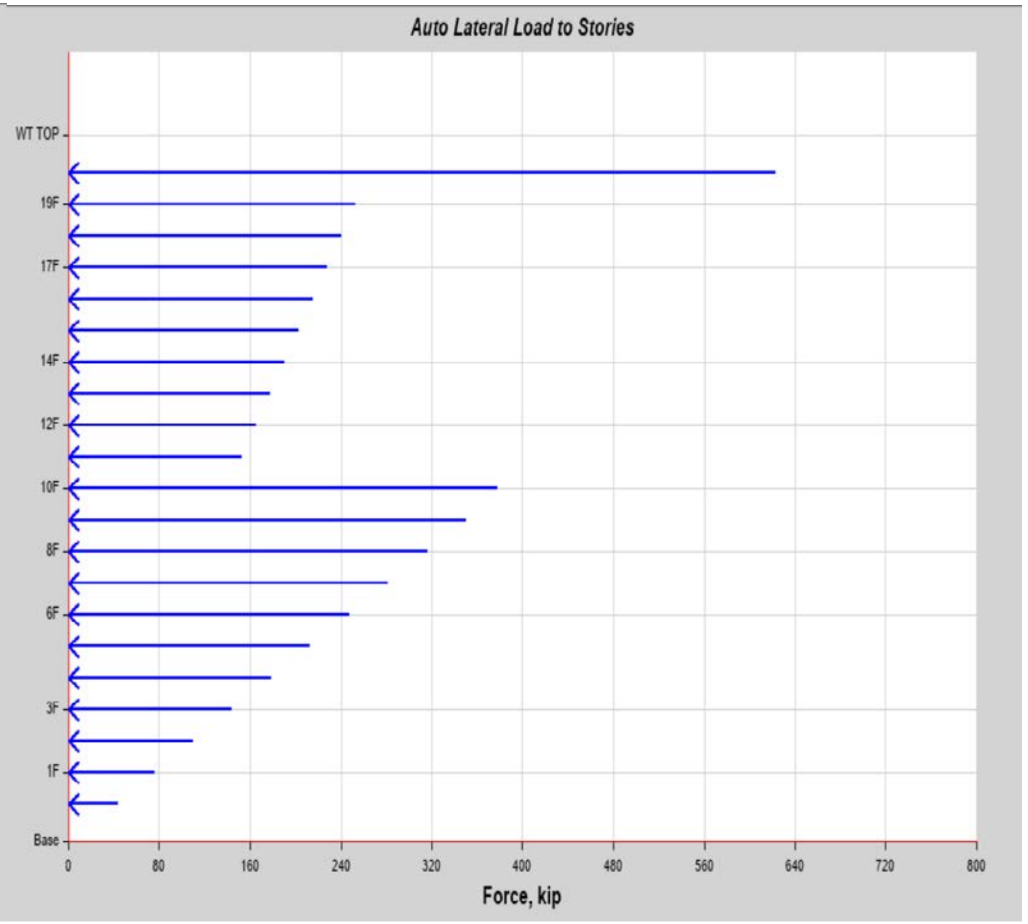
1] Lateral loads resisted by the Stories:

Figures 4.3 (a ~b) illustrated below provide information about the response for lateral loads to stories. Here the horizontal axis represents lateral loads in kips and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between lateral loads resisting capacities of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.1 (a ~b) respectively.

From figure it is clearly seen that, response curves are near about symmetric in both Braced Structure and Non-Braced Structure while the value changes gradually in each story. It shows that the value of EQ force increases gradually from Ground Floor to 10th floor. But sudden decreases at 11th floor (due to lower floor areas) & again increases gradually to Roof Top.

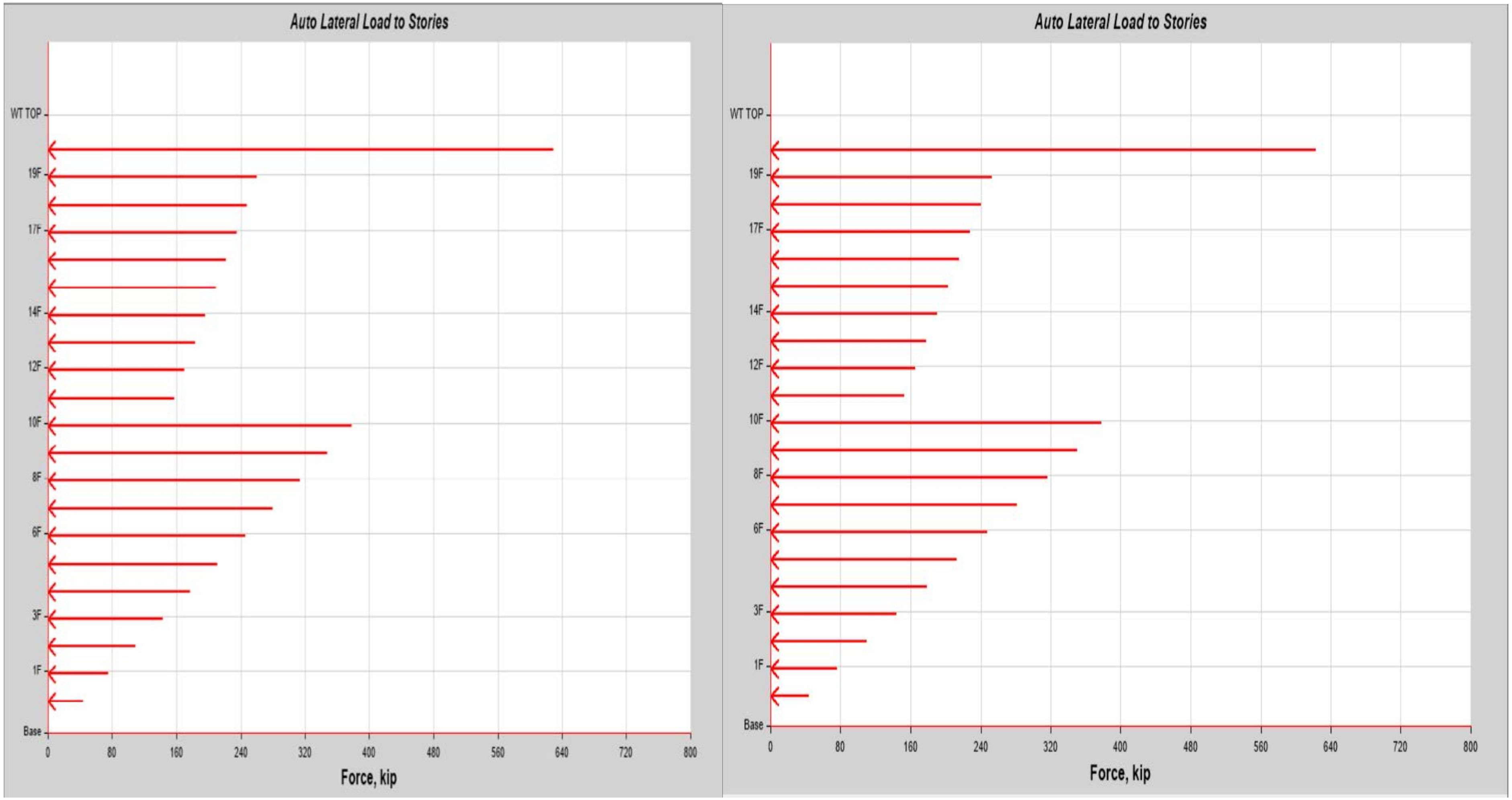


Braced Structure



Non-Braced Structure

Figure 4.3a: Resisting Earthquake loads at stories in +X direction.



Braced Structure

Non-Braced Structure

Figure 4.3b: Resisting Earthquake loads at stories in +Y direction.

Table 4.1a: Resisting EQ loads in stories in +X direction

Story	Braced	Non-Braced
	Resisting EQ loads kip	Resisting EQ loads kip
WT	0	0
Roof top	629.64	622.92
19th Floor	260.53	252.82
18th Floor	247.63	240.31
17th Floor	234.74	227.79
16th Floor	221.84	215.27
15th Floor	208.94	202.76
14th Floor	196.04	190.24
13th Floor	183.14	177.73
12th Floor	170.25	165.21
11th Floor	157.35	152.69
10th Floor	378.03	378.38
9th Floor	347.72	350.54
8th Floor	313.62	316.17
7th Floor	279.53	281.80
6th Floor	245.44	247.44
5th Floor	211.35	213.07
4th Floor	177.26	178.70
3rd Floor	143.17	144.34
2nd Floor	109.08	109.97
1st Floor	74.99	75.60
GF	43.75	44.10
Base	0	0

Table 4.1b: Resisting EQ in stories in +Y direction.

Story	Braced	Non-Braced
	Resisting EQ loads kip	Resisting EQ loads kip
WT	0	0
Roof top	629.64	622.92
19th Floor	260.53	252.82
18th Floor	247.63	240.31
17th Floor	234.74	227.79
16th Floor	221.84	215.27
15th Floor	208.94	202.76
14th Floor	196.04	190.24
13th Floor	183.14	177.73
12th Floor	170.25	165.21
11th Floor	157.35	152.69
10th Floor	378.03	378.38
9th Floor	347.72	350.54
8th Floor	313.62	316.17
7th Floor	279.53	281.80
6th Floor	245.44	247.44
5th Floor	211.35	213.07
4th Floor	177.26	178.70
3rd Floor	143.17	144.34
2nd Floor	109.08	109.97
1st Floor	74.99	75.60
GF	43.75	44.10
Base	0	0

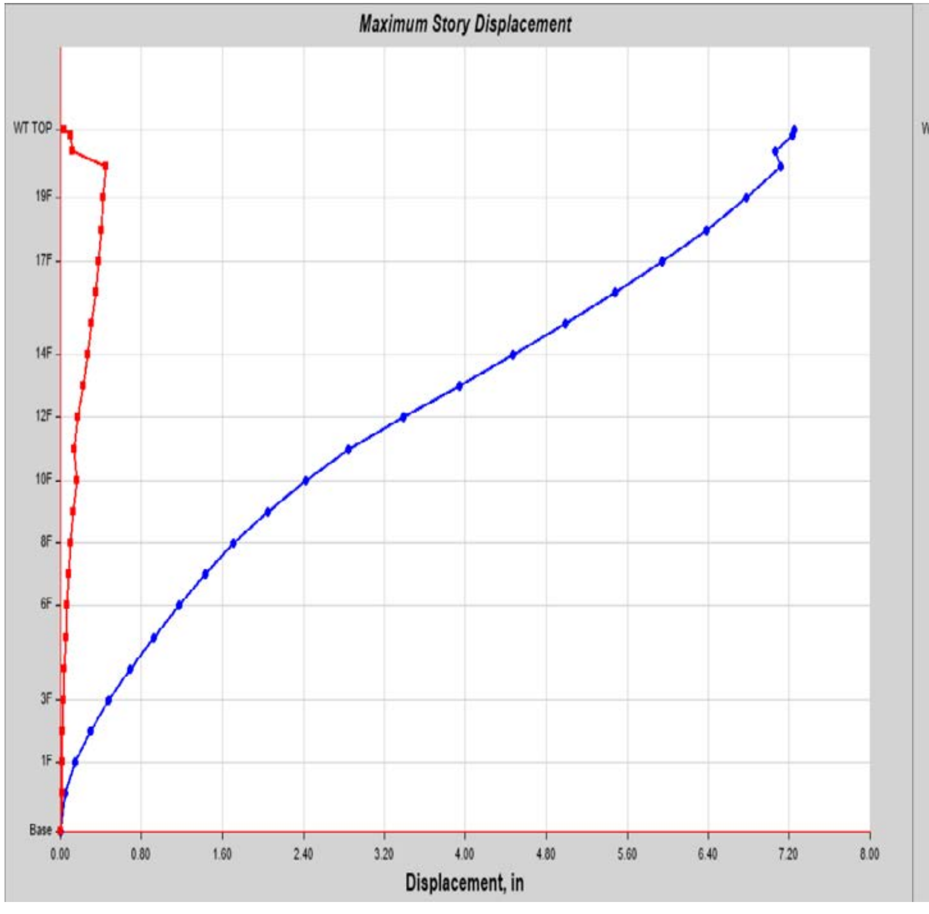
Findings: From all figures and tables, it is observed that Braced Structure can resist higher lateral loads compared to that of the Non-Braced Structure.

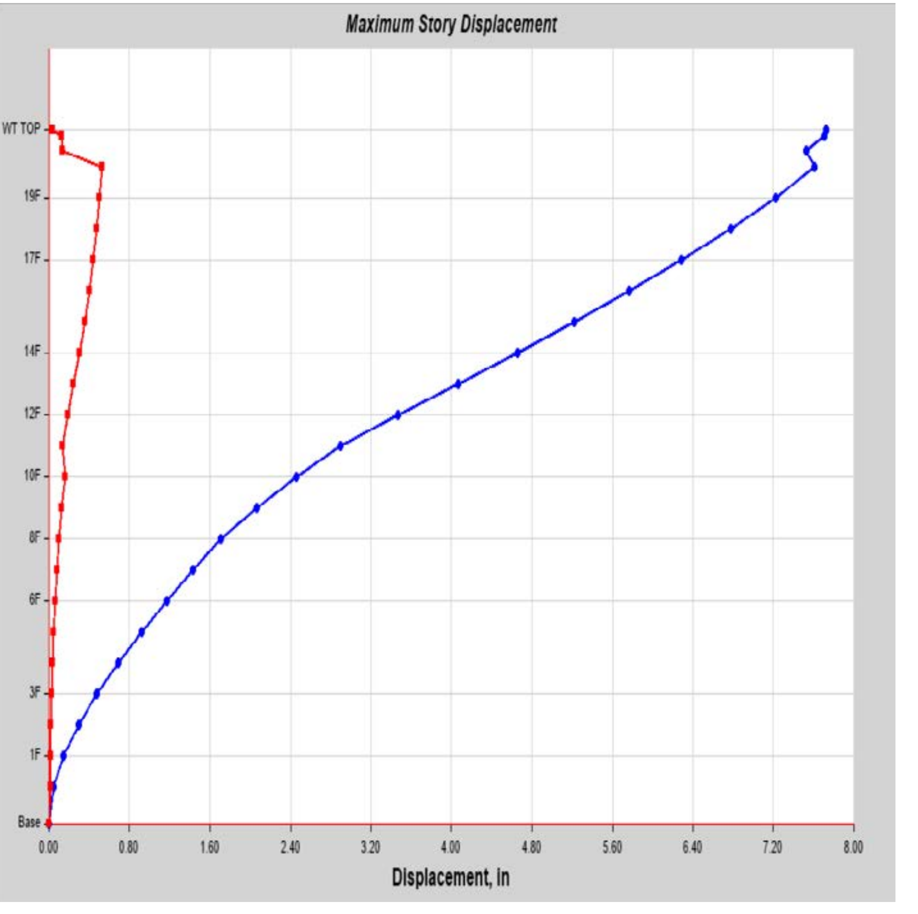
2] Maximum Story Displacement:

Figures 4.4(a ~b) illustrated below provide information about the response for maximum story displacement. Here the horizontal axis represents displacement in inch and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between displacements of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.2 (a ~b) respectively.

From figure it is clearly seen that curve starts from base and sharply goes on Roof Top. The displacement curve of Braced Structure & Non-Braced Structure fluctuates similarly in X & Y directions.

It shows that the story displacement starts from base with zero value. From curve, the value of story displacement increases from bottom to top (due to impact of Lateral load)

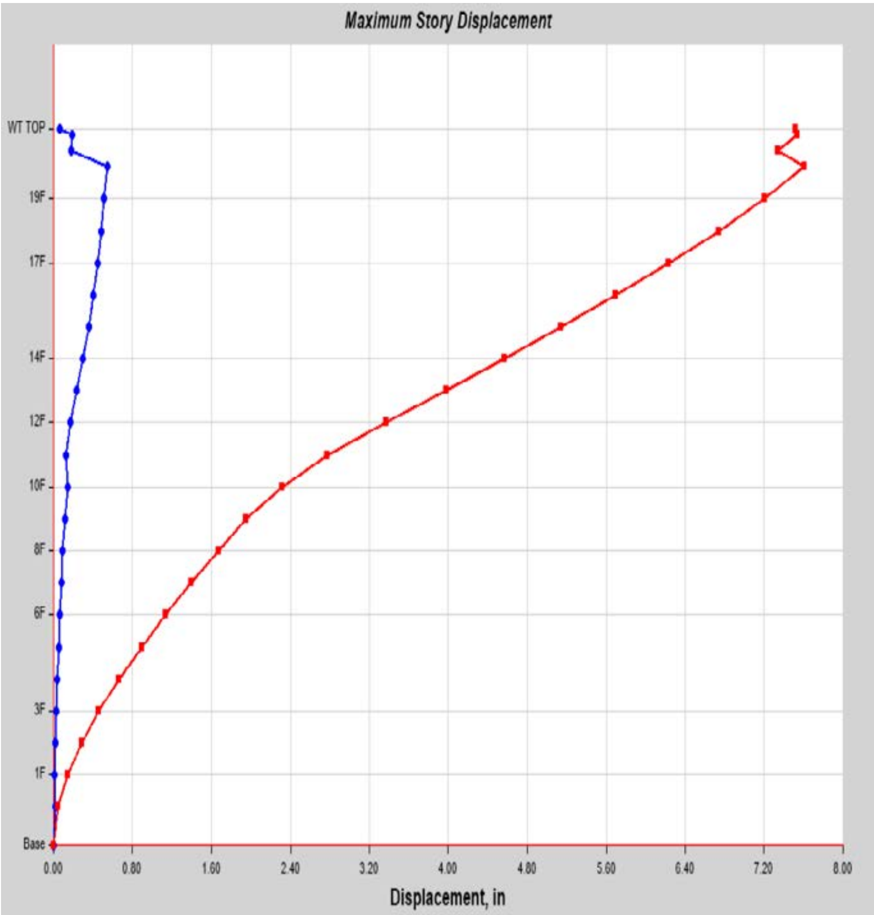




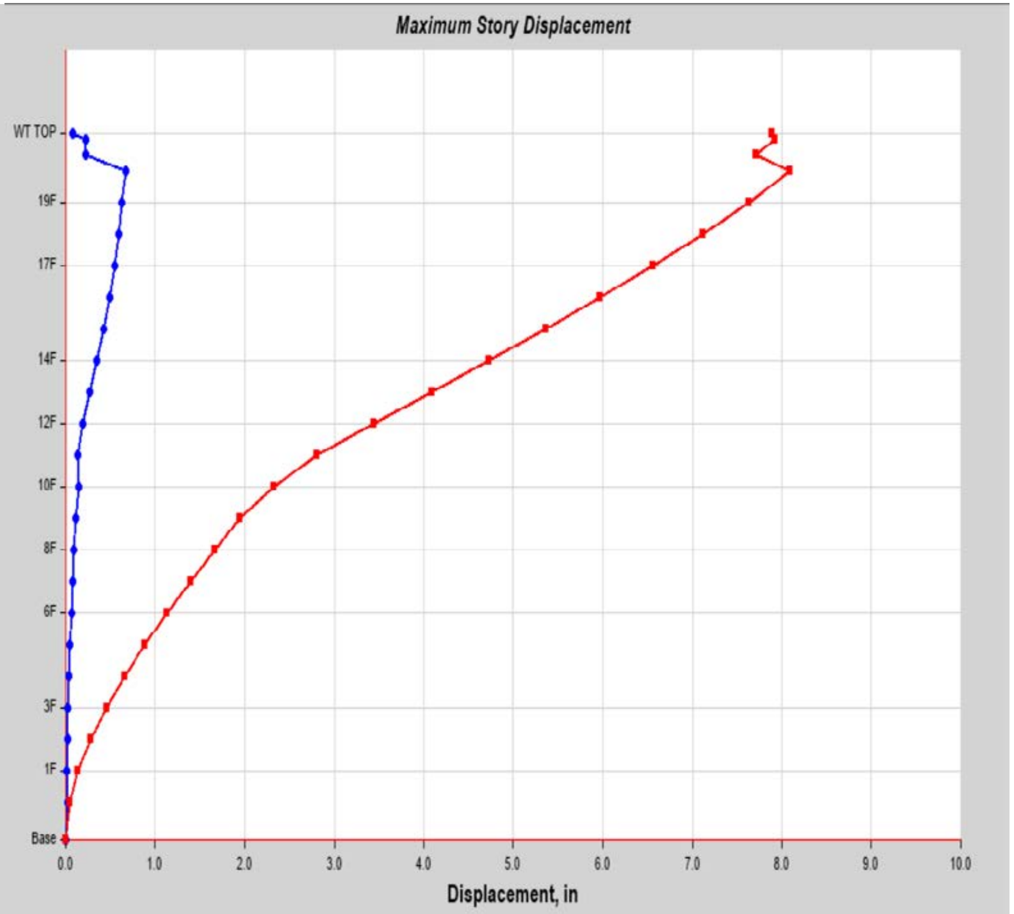
Braced Structure

Non-Braced Structure

Figure 4.4a: Maximum Story Displacement due to Earthquake loads in +X direction.



Braced Structure



Non-Braced Structure

Figure 4.4b: Maximum Story Displacement due to Earthquake loads in +Y direction.

Table 4.2a: Story Displacement due to EQ loads in +X direction.

Story	Braced	Non-Braced
	Displacement inch	Displacement inch
WT	7.25	7.73
Roof top	7.11	7.60
19th Floor	6.77	7.22
18th Floor	6.38	6.77
17th Floor	5.94	6.28
16th Floor	5.47	5.76
15th Floor	4.98	5.22
14th Floor	4.47	4.65
13th Floor	3.93	4.07
12th Floor	3.38	3.46
11th Floor	2.84	2.89
10th Floor	2.42	2.46
9th Floor	2.04	2.06
8th Floor	1.70	1.70
7th Floor	1.43	1.43
6th Floor	1.17	1.17
5th Floor	0.91	0.91
4th Floor	0.68	0.68
3rd Floor	0.47	0.47
2nd Floor	0.29	0.29
1st Floor	0.14	0.14
GF	0.04	0.04
Base	0	0

Table 4.2b: Story Displacement due to EQ loads in +Y direction

Story	Braced	Non-Braced
	Displacement inch	**Displacement inch**
WT	7.48	7.89
Roof top	7.60	8.08
19th Floor	7.20	7.63
18th Floor	6.73	7.11
17th Floor	6.23	6.55
16th Floor	5.69	5.96
15th Floor	5.13	5.35
14th Floor	4.56	4.73
13th Floor	3.97	4.09
12th Floor	3.37	3.44
11th Floor	2.77	2.79
10th Floor	2.31	2.33
9th Floor	1.95	1.95
8th Floor	1.66	1.66
7th Floor	1.39	1.39
6th Floor	1.13	1.13
5th Floor	0.89	0.89
4th Floor	0.66	0.66
3rd Floor	0.45	0.45
2nd Floor	0.28	0.28
1st Floor	0.13	0.13
GF	0.04	0.04
Base	0	0

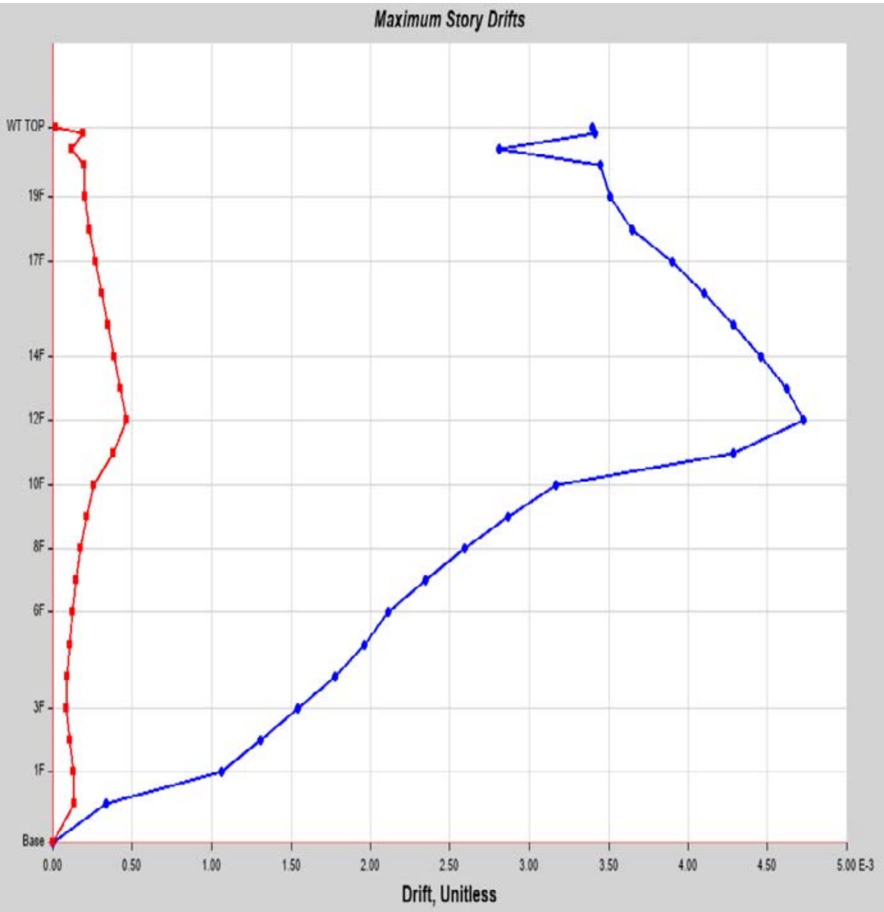
Findings: From all figures and tables, it is observed that Braced can resist higher displacements compared to that of the Non-Braced Structure.

3] Maximum Story Drifts:

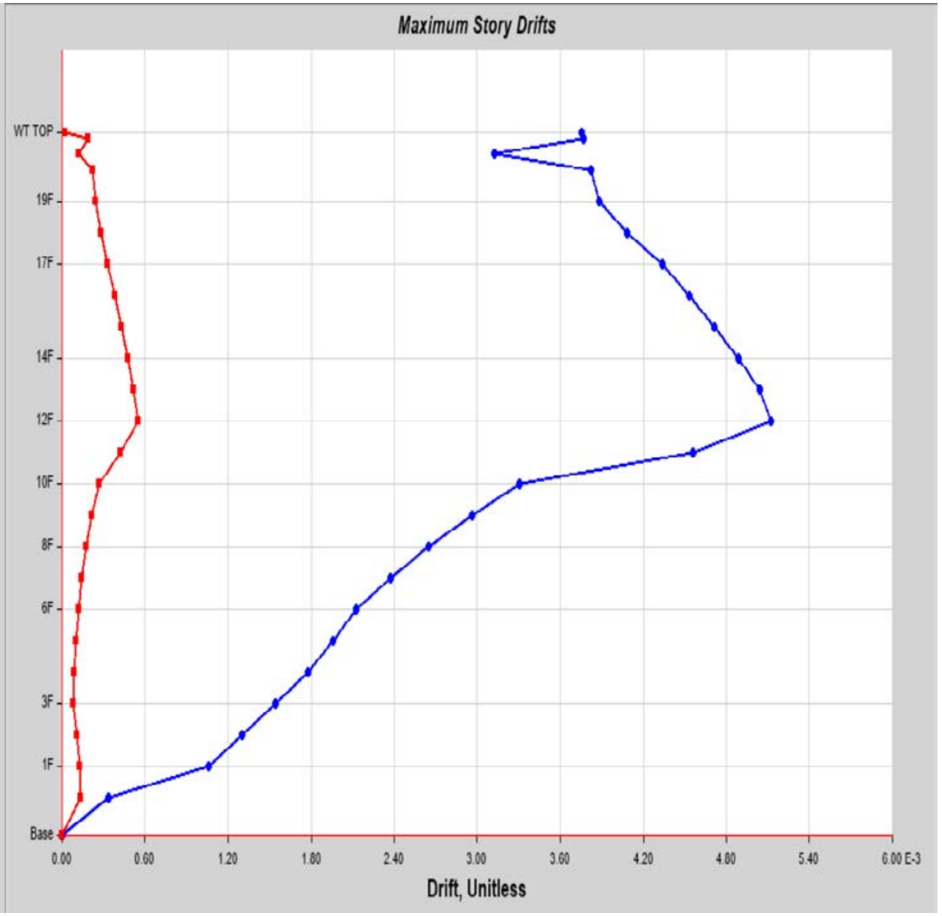
Figures 4.5(a ~b) illustrated below provide information about the response maximum story drifts. Here the horizontal axis represents drifts and the vertical axis represents the number of the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story drifts of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.3 (a ~b) respectively.

From figure it is clearly seen that, the story drift forms a parabolic shape with zero drift at bottom, increases toward mid and finally decreases again at top. Curve starts from base with zero value and sharply rises to 13th story and then gradually decreases to 20th story in EQX and rapidly goes to 13th story and then gradually decreases to 20th story in EQY.

The story drifts value increases due to increase displacement and suddenly decreases due to lower floor areas.

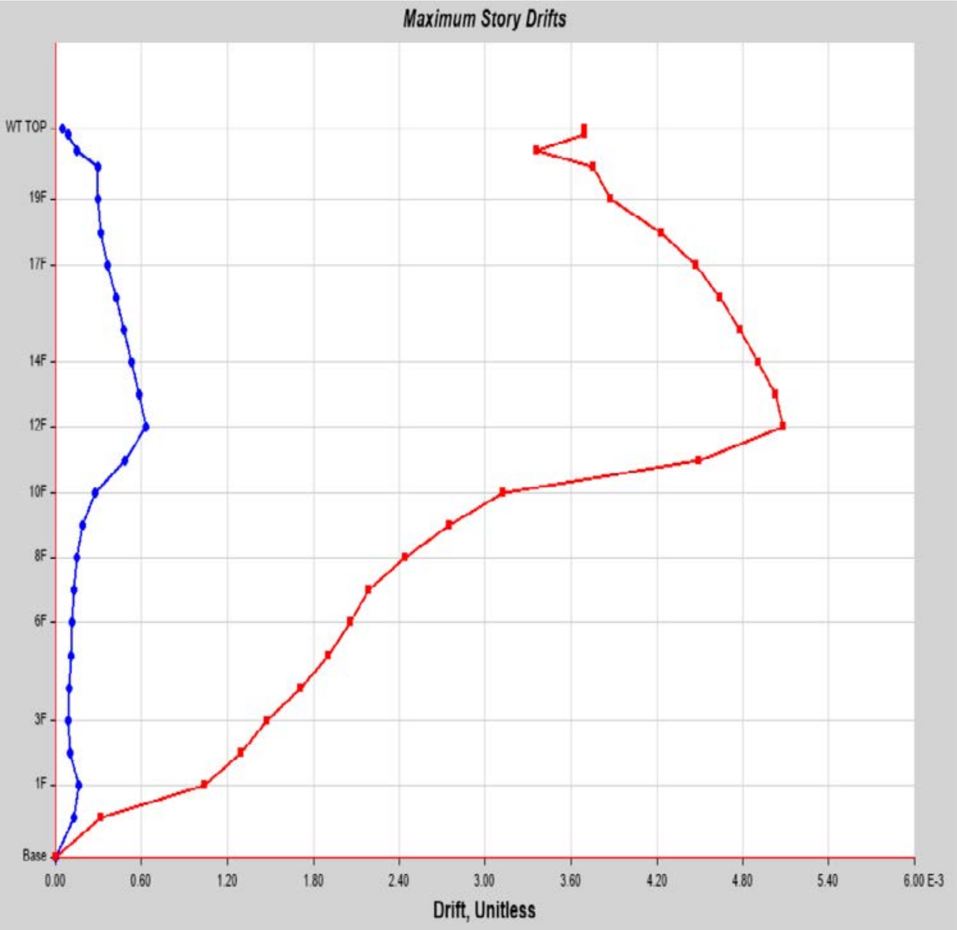


Braced Structure

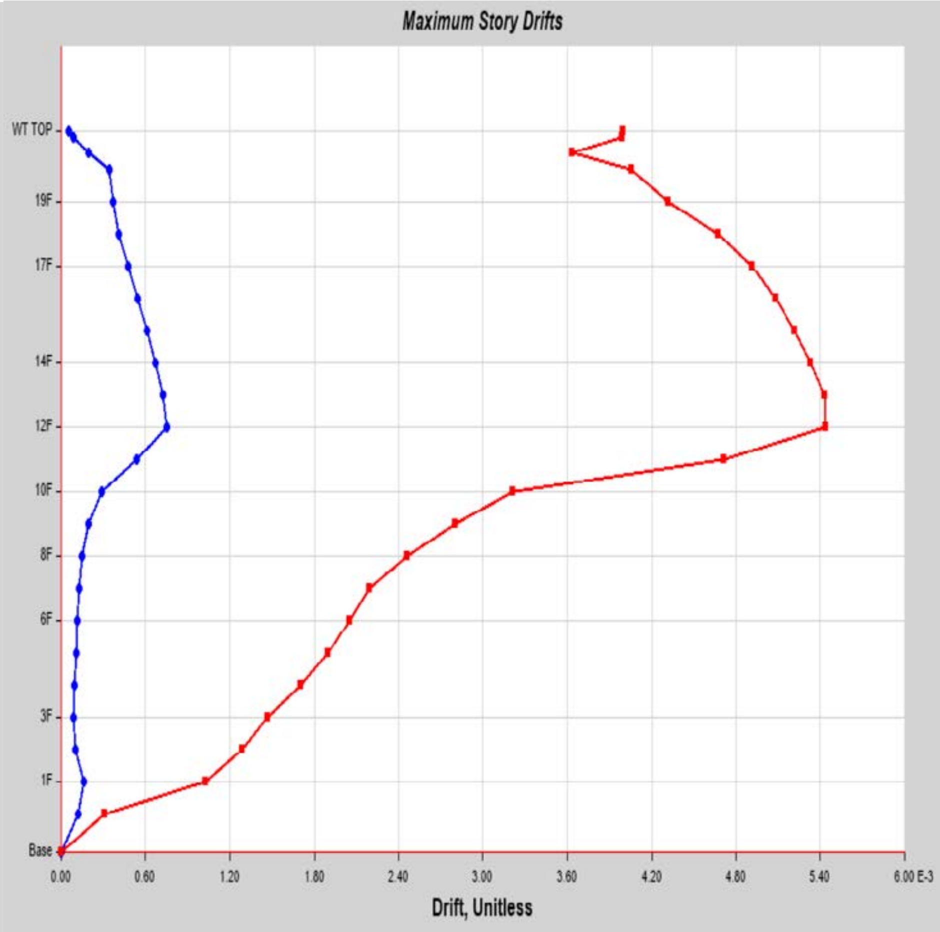


Non-Braced Structure

Figure 4.5a: Maximum Story Drifts due to Earthquake loads in +X direction



Braced Structure



Non-Braced Structure

Figure 4.5b: Maximum Story Drifts due to Earthquake loads in +Y direction

Table 4.3a: Maximum Story Drifts in +X direction.

Story	Braced	Non-Braced
	Story drift	**Story drift**
WT	0.0032	0.0036
Roof top	0.0034	0.0038
19th Floor	0.0035	0.0038
18th Floor	0.0036	0.0040
17th Floor	0.0039	0.0043
16th Floor	0.0041	0.0045
15th Floor	0.0042	0.0047
14th Floor	0.0044	0.0048
13th Floor	0.0046	0.0050
12th Floor	0.0047	0.0051
11th Floor	0.0042	0.0045
10th Floor	0.0031	0.0033
9th Floor	0.0028	0.0029
8th Floor	0.0025	0.0026
7th Floor	0.0023	0.0023
6th Floor	0.0021	0.0021
5th Floor	0.0019	0.0019
4th Floor	0.0017	0.0017
3rd Floor	0.0015	0.0015
2nd Floor	0.0013	0.0013
1st Floor	0.0010	0.0010
GF	0.0003	0.0003
Base	0	0

Table 4.3b: Maximum Story Drifts in +Y direction

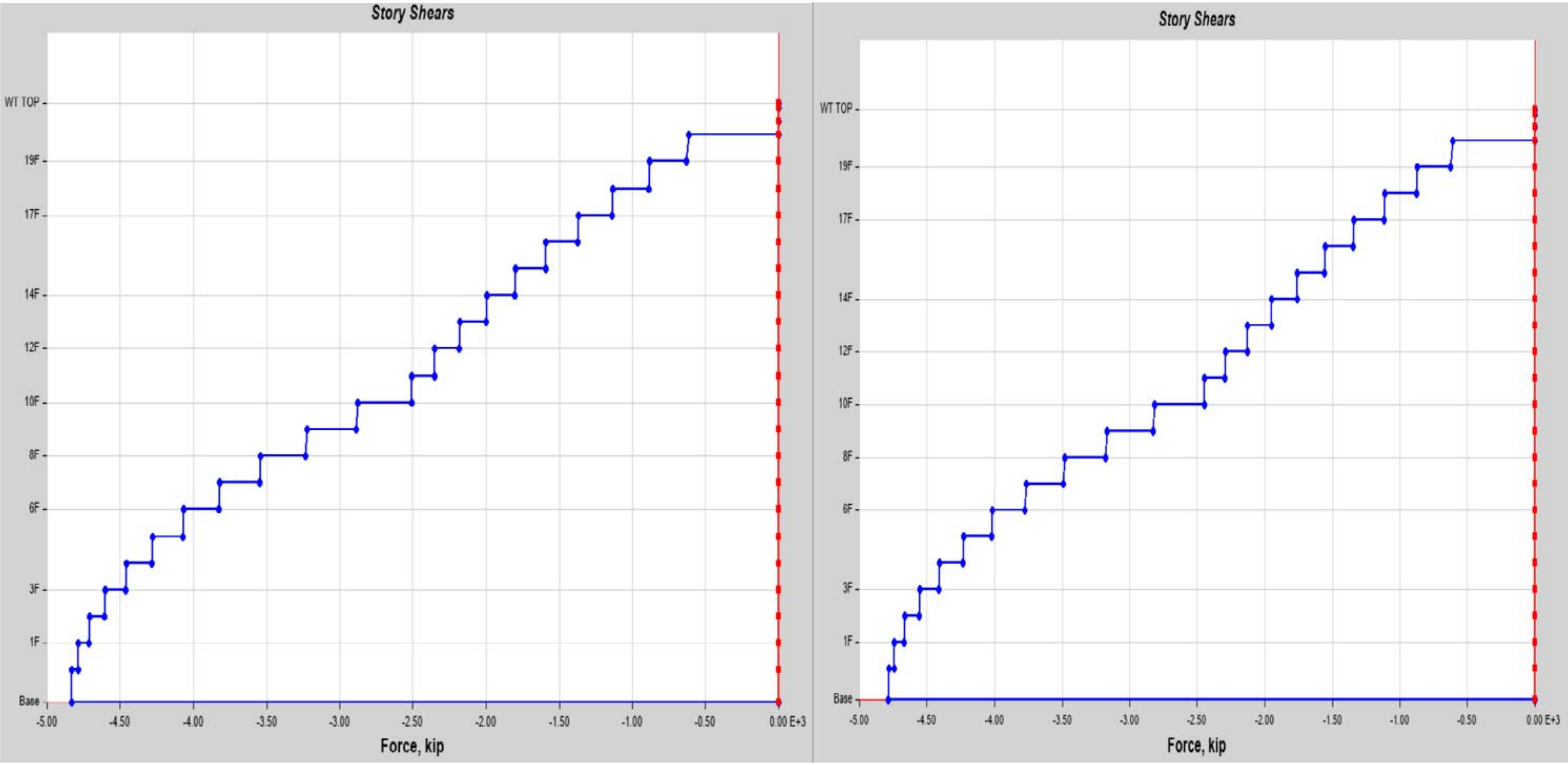
Story	Braced	Non-Braced
	Story drift	Story drift
WT	0.0035	0.0039
Roof top	0.0037	0.0040
19th Floor	0.0038	0.0043
18th Floor	0.0042	0.0046
17th Floor	0.0044	0.0049
16th Floor	0.0046	0.0050
15th Floor	0.0047	0.0052
14th Floor	0.0049	0.0053
13th Floor	0.0050	0.0054
12th Floor	0.0050	0.0054
11th Floor	0.0044	0.0047
10th Floor	0.0031	0.0032
9th Floor	0.0027	0.0028
8th Floor	0.0024	0.0024
7th Floor	0.0021	0.0021
6th Floor	0.0020	0.0020
5th Floor	0.0019	0.0018
4th Floor	0.0017	0.0017
3rd Floor	0.0014	0.0014
2nd Floor	0.0012	0.0012
1st Floor	0.0010	0.0010
GF	0.0003	0.0003
Base	0	0

4] Story Shears:

Figures 4.6(a ~b) illustrated below provide information about the response for story shears. Here the horizontal axis represents story shear in kips and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story shears of Braced and Non-Braced Structure in X and Y direction are clearly shown in Tables 4.4 (a ~b) respectively.

From figure it is clearly seen that, response curves are symmetric in both Braced Structure and Non-Braced Structure in EQY and in EQX. It is also shown that Braced structure can withstand greater story shear force compared to Non-Braced structure.

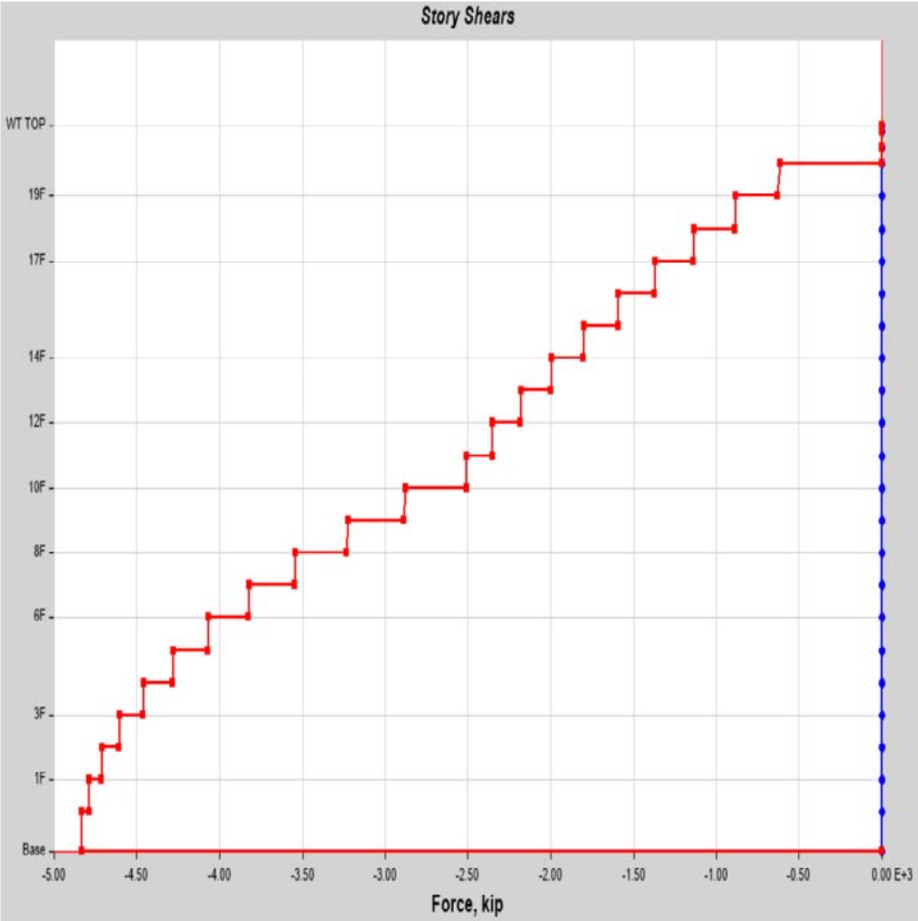
It shows that the story shear resisting capacity is higher at base due to strong basement. Shear resisting capacity is decreasing from bottom to top (due to lateral load impact) and its value negative against given load.

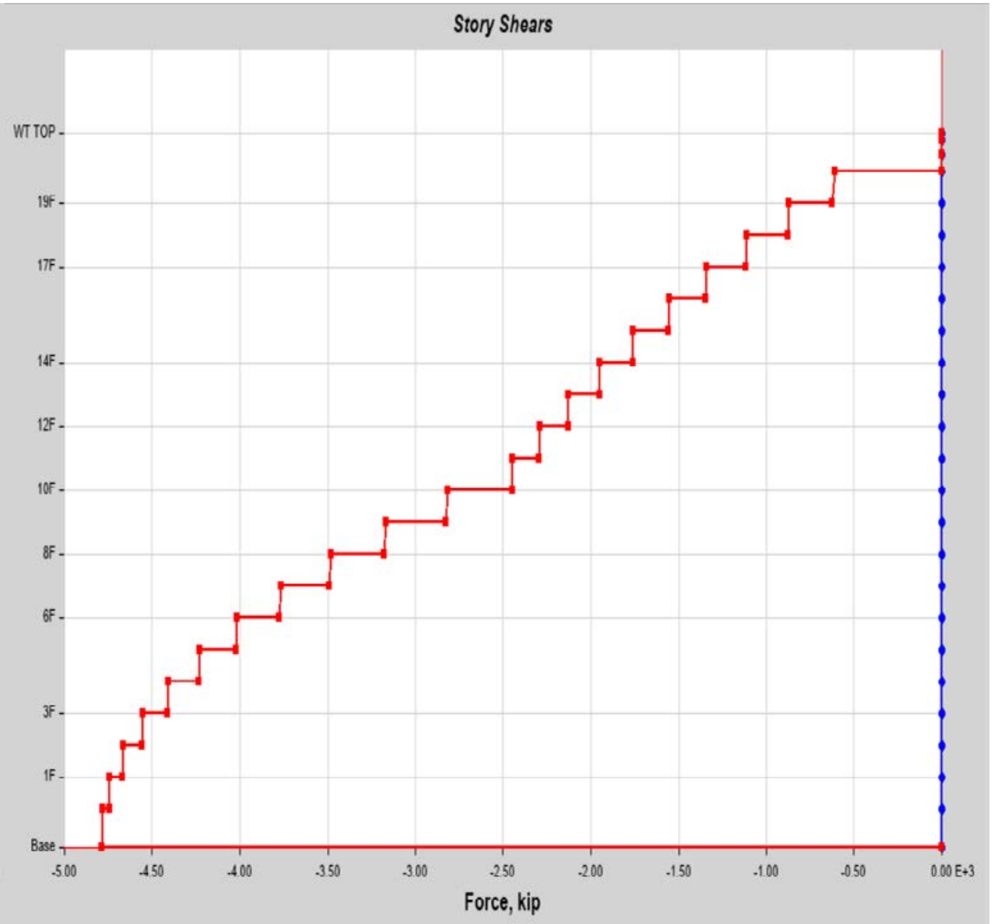


Braced Structure

Non-Braced Structure

Figure 4.6a: Story Shears due to Earthquake loads in +X direction.





Braced Structure

Non-Braced Structure

Figure 4.6b: Story Shears due to Earthquake loads in +Y direction

Table 4.4a: Story Shears in +X direction.

Story	Braced	Non-Braced
	Shear resisted at each story kip	Shear resisted at each story kip
WT	0	0
Roof top	-629.64	-622.92
19th Floor	-890.17	-875.75
18th Floor	-1137.81	-1116.06
17th Floor	-1372.55	-1343.85
16th Floor	-1594.39	-1559.13
15th Floor	-1803.34	-1761.90
14th Floor	-1999.38	-1952.14
13th Floor	-2182.53	-2129.87
12th Floor	-2352.78	-2295.09
11th Floor	-2510.13	-2447.78
10th Floor	-2888.17	-2826.17
9th Floor	-3235.89	-3176.71
8th Floor	-3549.51	-3492.88
7th Floor	-3829.04	-3774.69
6th Floor	-4074.49	-4022.13
5th Floor	-4285.84	-4235.20
4th Floor	-4463.11	-4413.91
3rd Floor	-4606.29	-4558.25
2nd Floor	-4715.37	-4668.22
1st Floor	-4790.37	-4743.83
GF	-4834.12	-4787.94
Base	0	0

Table 4.4b: Story Shears in +Y direction

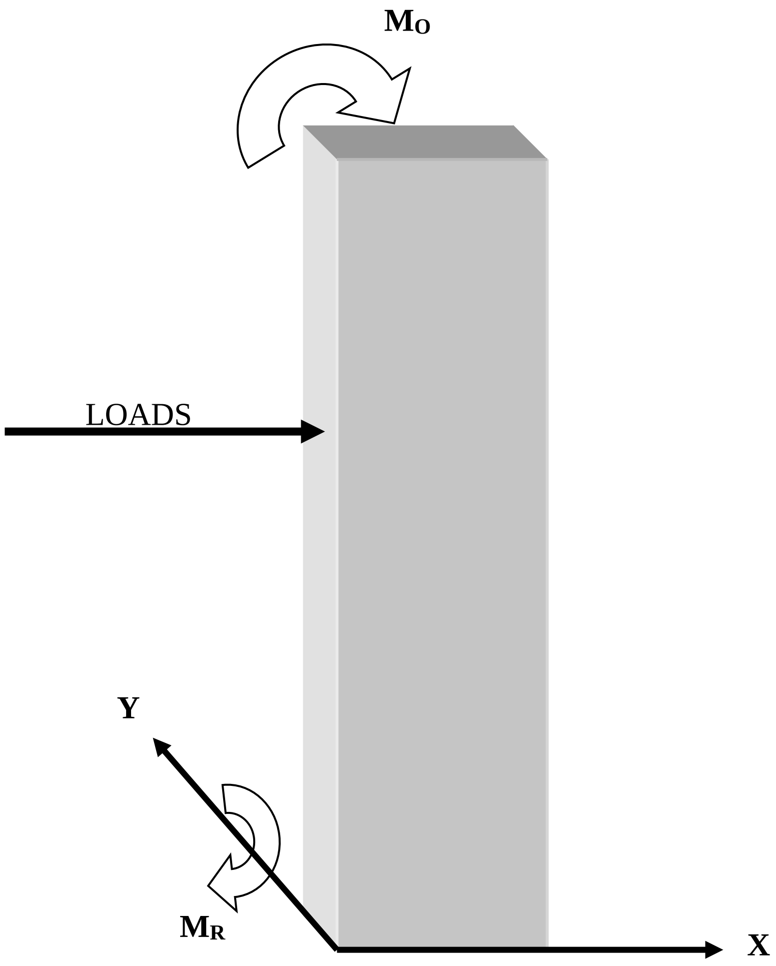
Story	Braced	Non-Braced
	Shear resisted at each story kip	**Shear resisted at each story kip**
WT	0	0
Roof top	-629.64	-622.92
19th Floor	-890.17	-875.75
18th Floor	-1137.81	-1116.06
17th Floor	-1372.55	-1343.85
16th Floor	-1594.39	-1559.13
15th Floor	-1803.34	-1761.90
14th Floor	-1999.38	-1952.14
13th Floor	-2182.53	-2129.87
12th Floor	-2352.78	-2295.09
11th Floor	-2510.13	-2447.78
10th Floor	-2888.17	-2826.17
9th Floor	-3235.89	-3176.71
8th Floor	-3549.51	-3492.88
7th Floor	-3829.04	-3774.69
6th Floor	-4074.49	-4022.13
5th Floor	-4285.84	-4235.20
4th Floor	-4463.11	-4413.91
3rd Floor	-4606.29	-4558.25
2nd Floor	-4715.37	-4668.22
1st Floor	-4790.37	-4743.83
GF	-4834.12	-4787.94
Base	0	0

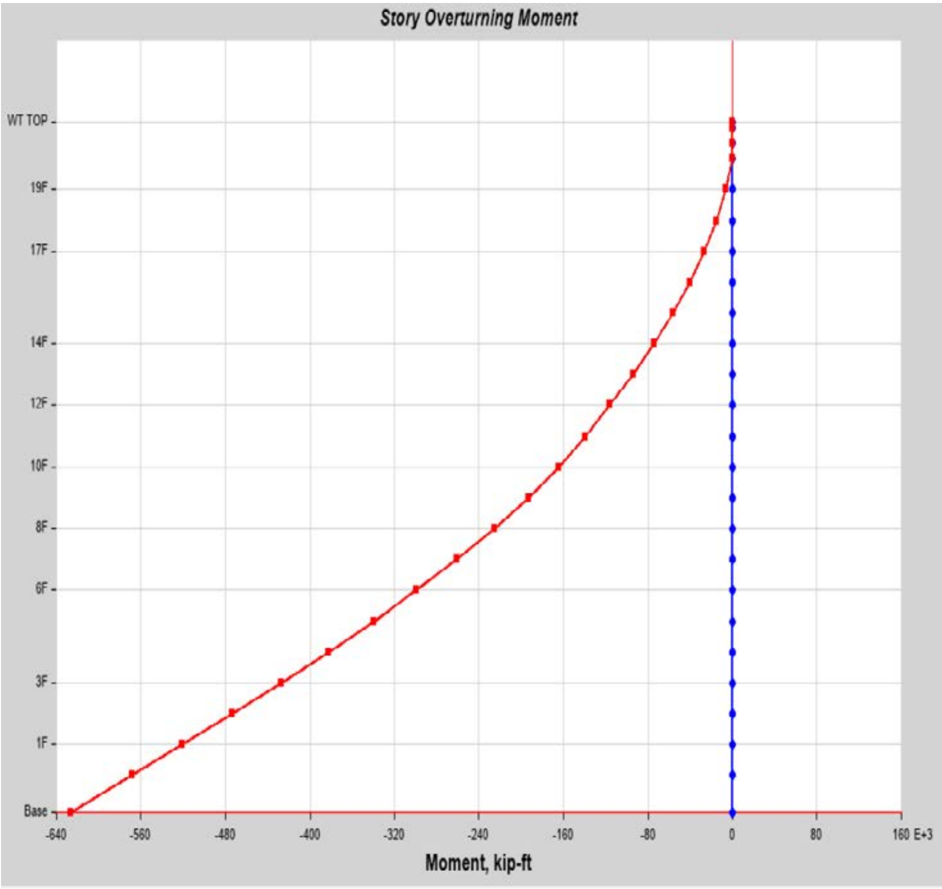
Findings: From all figures and tables, it is observed that Braced Structure can resist higher story shears compared to that of the Non-Braced Structure.

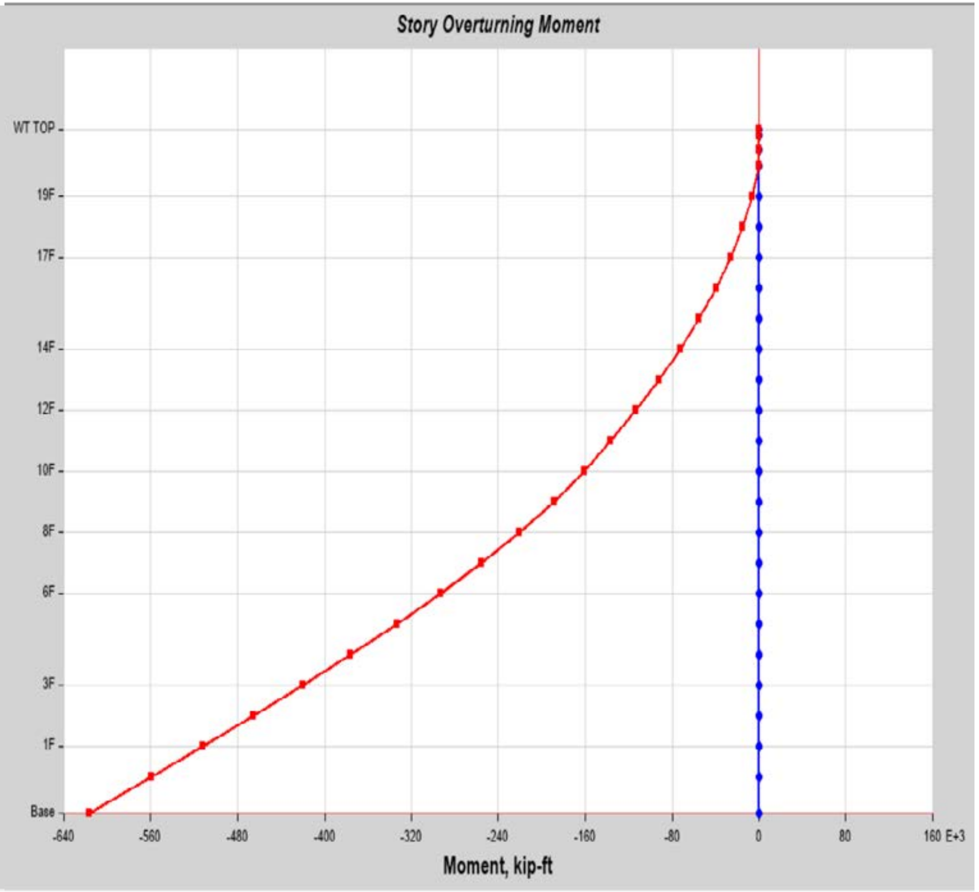
5] Resisting Story Overturning Moments [M_R]:

Figures 4.7(a ~b) illustrated below provide information about the response for story overturning moments. Here the horizontal axis represents overturning moments in kip-inch and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story overturning moments of Braced and Non-Braced Structure in X and Y direction are clearly shown in Tables 4.5 (a~ b) respectively.

From figure it is clearly seen that, curve starts from base with its peak value and sharply goes down to 20th story in both EQX and EQY. It is noted here that due to lateral loads in X-direction, the whole structure will resist its overturn with respect to Y-axis and creates a resisting overturning moment M_R with respect to Y-axis as shown in figure below. Similar case can be explained for loads in Y-direction. However, it is shown that Braced structure can withstand greater story overturning compared to Non-Braced structure.



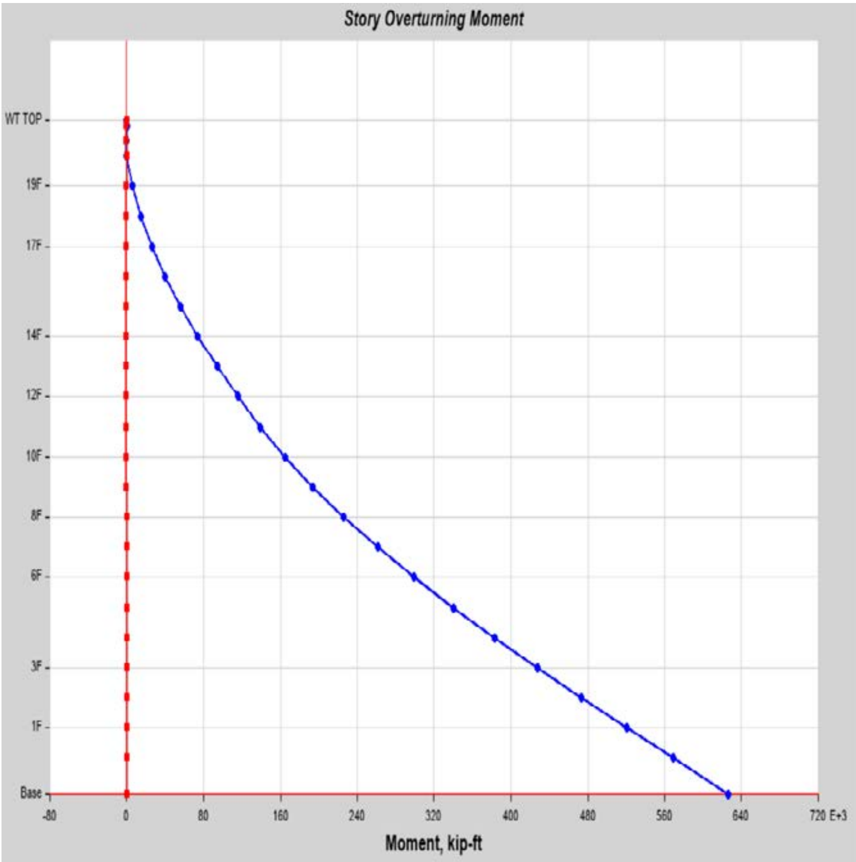


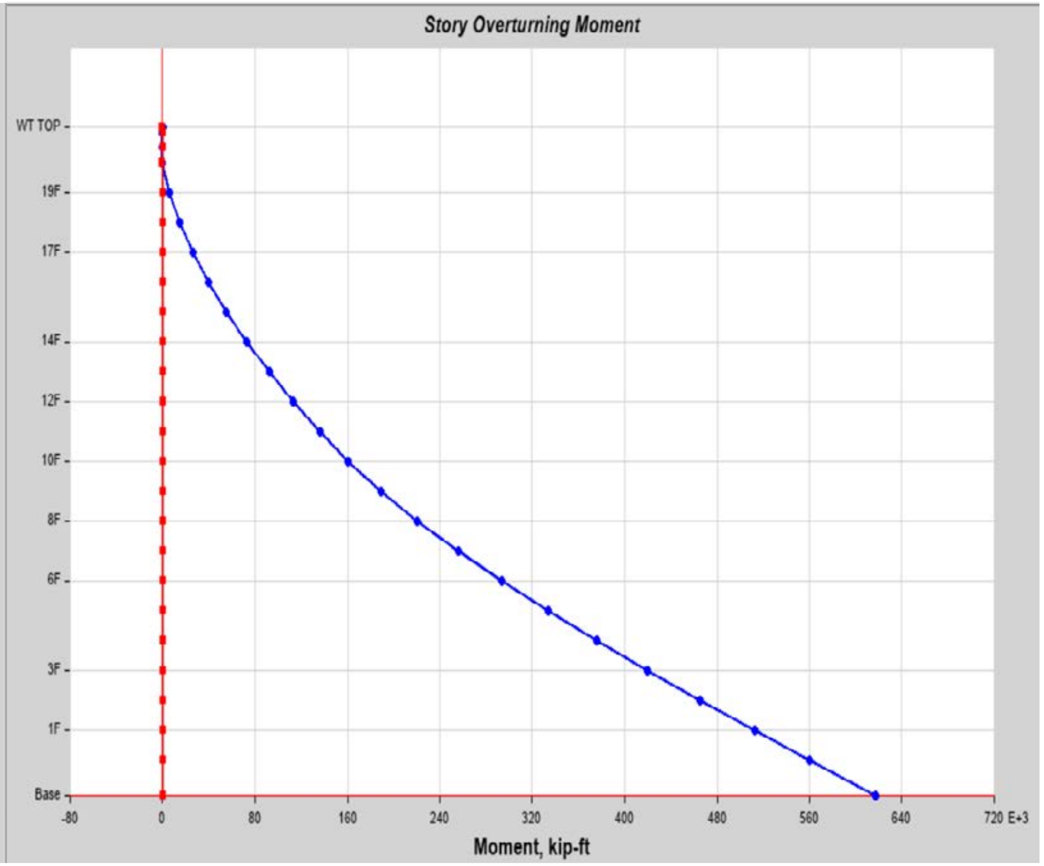


Braced Structure

Non-Braced Structure

Figure 4.7a: Overturning Moments due to Earthquake loads Story in +X direction.





Braced Structure

Non-Braced Structure

Figure 4.7b: Overturning Moments due to Earthquake loads Story in +Y direction.

Table 4.5a: Overturning Moments in +X direction.

Story	Braced	Non-Braced
	Resisting overturning moment kip-feet	**Resisting overturning moment kip-feet**
WT	0	0
Roof top	0	0
19th Floor	-6240.40	-6172.70
18th Floor	-15120.81	-14908.70
17th Floor	-26478.66	-26048.87
16th Floor	-40184.95	-39468.06
15th Floor	-56110.73	-55041.10
14th Floor	-74127.00	-72642.83
13th Floor	-94104.79	-92148.08
12th Floor	-115915.12	-113431.71
11th Floor	-139429.02	-136368.53
10th Floor	-164517.51	-160833.40
9th Floor	-193348.36	-189043.83
8th Floor	-225660.96	-220764.25
7th Floor	-261114.34	-255650.98
6th Floor	-299367.60	-293360.37
5th Floor	-340079.84	-333548.73
4th Floor	-382910.18	-375872.42
3rd Floor	-427517.71	-419987.75
2nd Floor	-473561.54	-465551.06
1st Floor	-520700.77	-512218.68
GF	-568594.52	-559646.95
Base	-626579.31	-617077.34

Table 4.5b: Overturning Moments in +Y direction.

Story	Braced	Non-Braced
	Resisting overturning moment kip-feet	**Resisting overturning moment kip-feet**
WT	0	0
Roof top	0	0
19th Floor	6240.40	6172.70
18th Floor	15120.81	14908.70
17th Floor	26478.66	26048.87
16th Floor	40184.95	39468.06
15th Floor	56110.73	55041.10
14th Floor	74127.00	72642.83
13th Floor	94104.79	92148.08
12th Floor	115915.12	113431.70
11th Floor	139429.02	136368.53
10th Floor	164517.51	160833.40
9th Floor	193348.36	189043.83
8th Floor	225660.96	220764.24
7th Floor	261114.34	255650.98
6th Floor	299367.60	293360.36
5th Floor	340079.84	333548.73
4th Floor	382910.18	375872.41
3rd Floor	427517.71	419987.74
2nd Floor	473561.54	465551.05
1st Floor	520700.77	512218.68
GF	568594.52	559646.95
Base	626579.30	617077.33

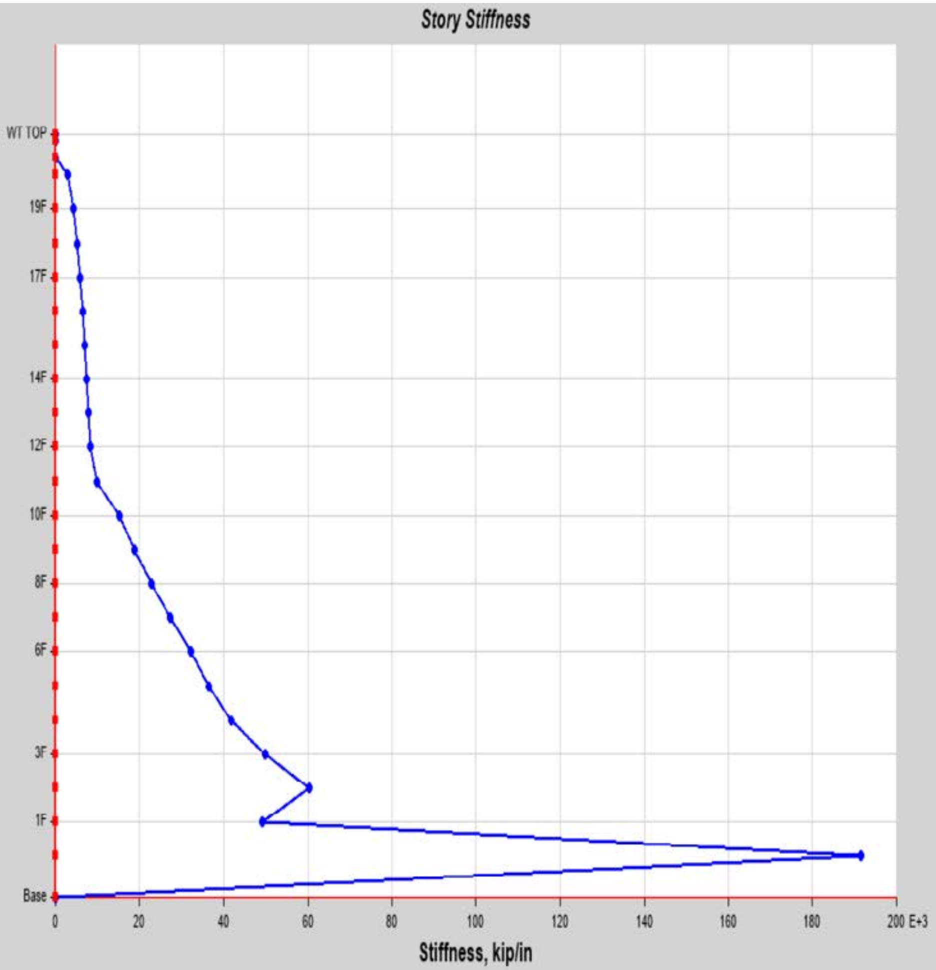
Findings: From all figures and tables, it is observed that Braced Structure can resist higher overturning moments compared to that of the Non-Braced Structure.

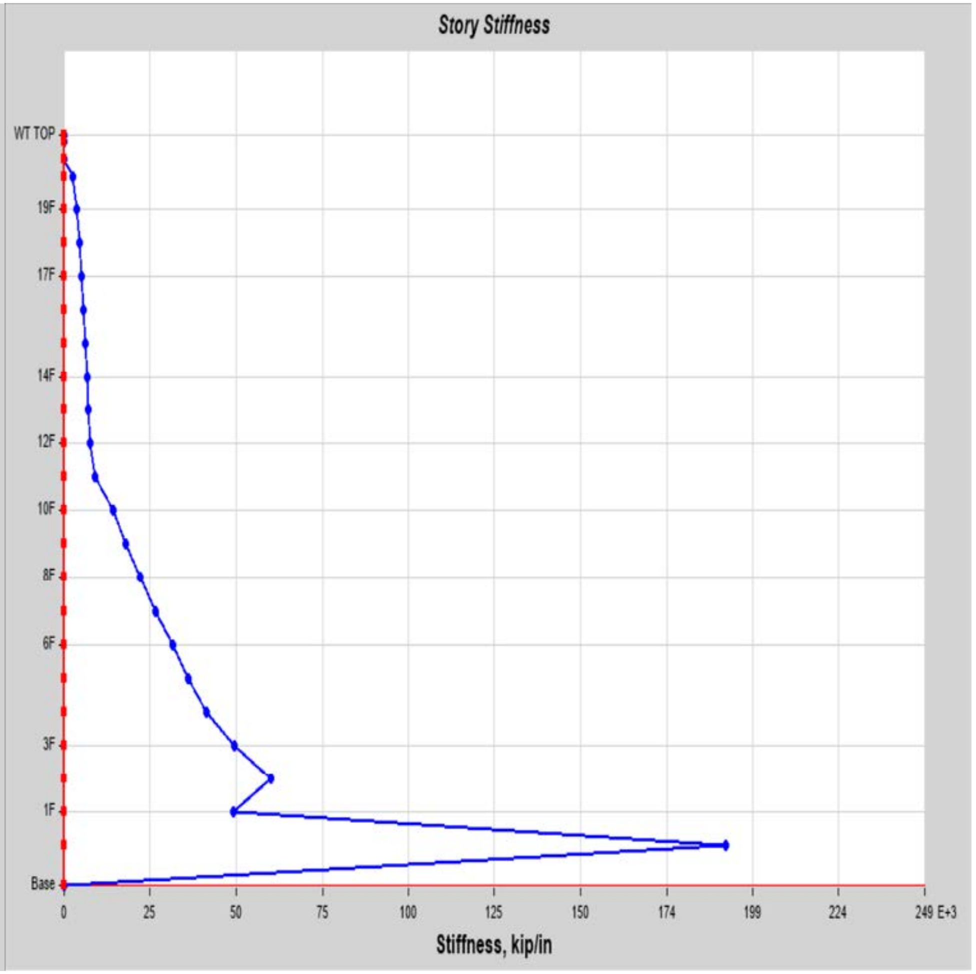
6] Story Stiffness:

Figures 4.8 (a ~b) illustrated below provide information about the response for story stiffness. Here the horizontal axis represents story stiffness in kip-inch and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story stiffness of Braced and Non-Braced Structure in X and Y direction are clearly shown in Tables 4.6 (a ~b) respectively.

From figure it is clearly seen that, Non-Braced structure has lower stiffness compared to Braced structure.

It shows that story stiffness value is maximum at ground floor. Stiffness value decreases at first floor because of sudden shock and increase again 2nd floor then gradually stiffness value decreases from 2nd floor to Roof top (due to lateral impact load)

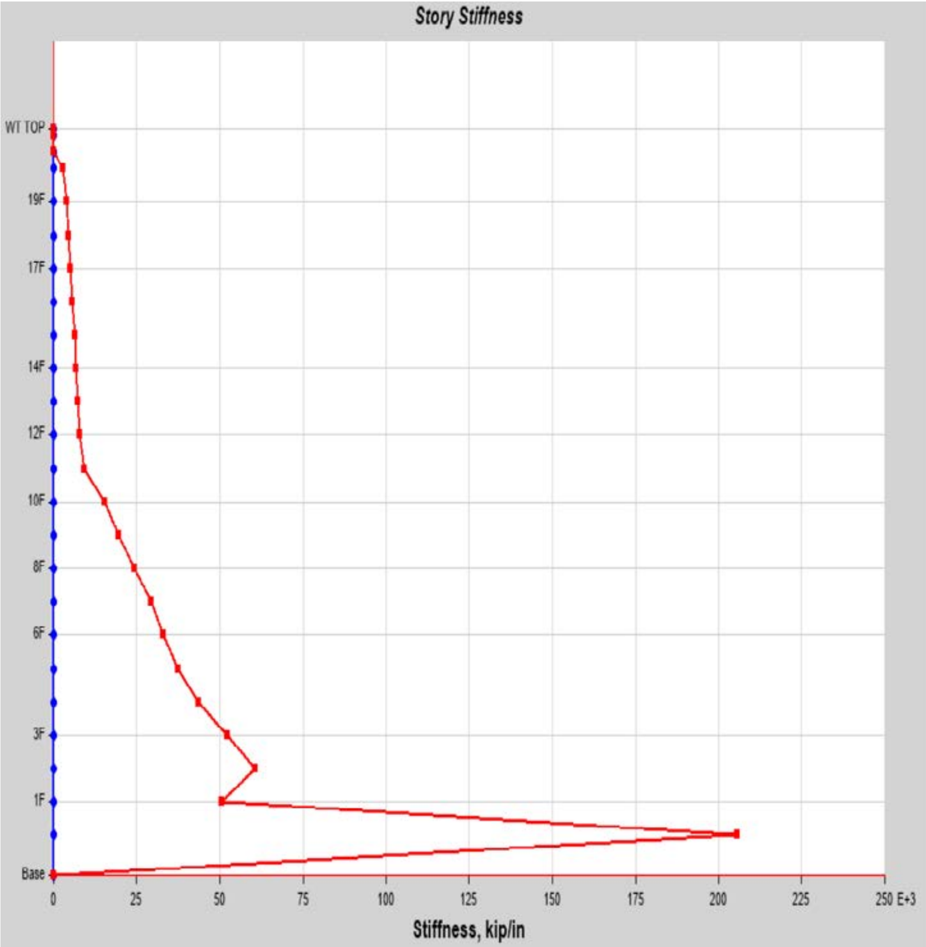


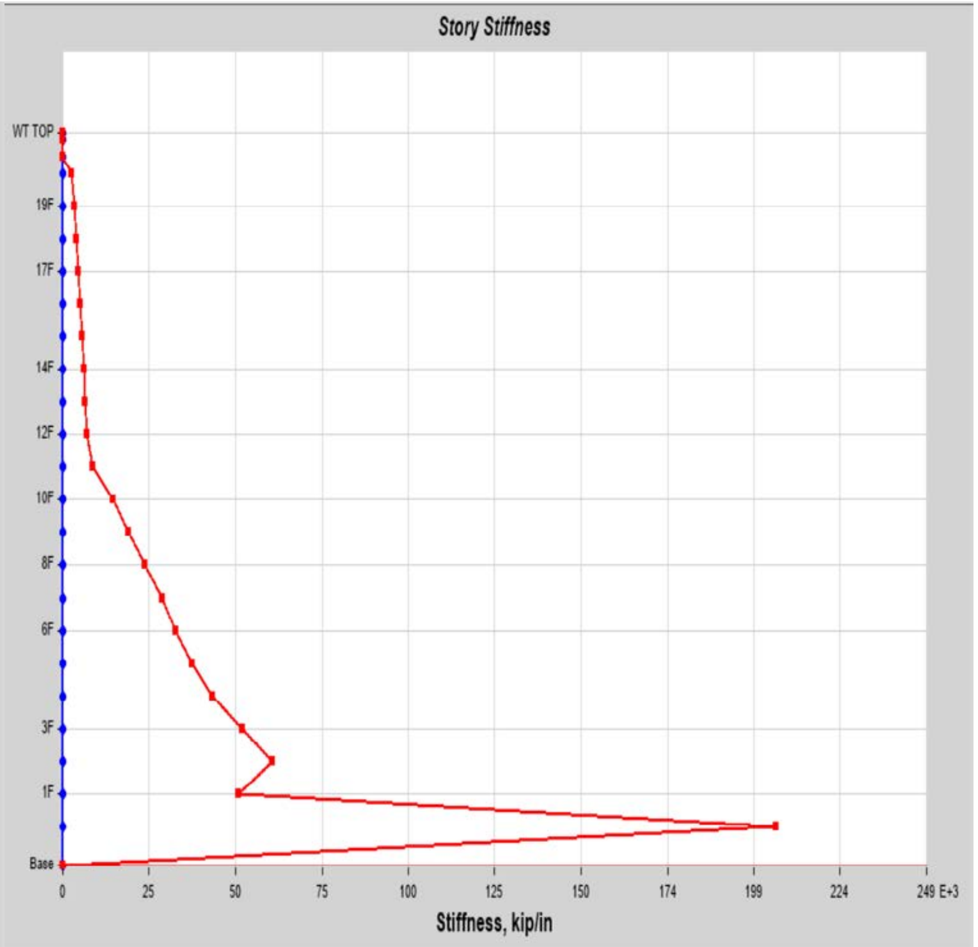


Braced Structure

Non-Braced Structure

Figure 4.8a: Story Stiffness due to Earthquake loads in +X direction.





Braced Structure

Non-Braced Structure

Figure 4.8b: Story Stiffness due to Earthquake loads in +Y direction.

Table 4.6a: Story Stiffness in +X direction

Story	Braced	Non-Braced
	Stiffness of each story kip/in	**Stiffness of each story kip/in**
WT	0	0
Roof top	3014.19	2693.27
19th Floor	4158.97	3702.60
18th Floor	5157.16	4557.23
17th Floor	5866.11	5167.65
16th Floor	6476.70	5731.13
15th Floor	7016.02	6232.06
14th Floor	7471.96	6659.36
13th Floor	7870.53	7039.90
12th Floor	8298.26	7473.13
11th Floor	9762.87	8953.95
10th Floor	15196.98	14241.85
9th Floor	18813.16	17885.23
8th Floor	22832.35	21981.66
7th Floor	27229.95	26492.26
6th Floor	32127.14	31524.04
5th Floor	36454.40	36046.13
4th Floor	41818.39	41404.79
3rd Floor	49739.56	49304.45
2nd Floor	60238.91	59853.07
1st Floor	49158.26	49142.08
GF	191580.71	191693.07
Base	0	0

Findings: From all figures and tables, it is observed that Braced Structure can resist higher overturning moments compared to that of the Non-Braced Structure.

Table 4.6b: Story Stiffness in +Y direction.

Story	Braced	Non-Braced
	Stiffness of each story kip/in	Stiffness of each story kip/in
WT	0	0
Roof top	2778.21	2541.13
19th Floor	3829.17	3382.77
18th Floor	4482.66	3980.69
17th Floor	5117.12	4558.17
16th Floor	5724.27	5111.78
15th Floor	6286.68	5629.95
14th Floor	6788.78	6101.37
13th Floor	7237.32	6536.88
12th Floor	7714.43	7032.18
11th Floor	9319.52	8657.45
10th Floor	15399.09	14653.25
9th Floor	19598.14	18897.39
8th Floor	24262.46	23663.65
7th Floor	29201.40	28736.91
6th Floor	33044.69	32683.71
5th Floor	37560.59	37232.97
4th Floor	43596.36	43283.92
3rd Floor	52133.75	51840.95
2nd Floor	60690.11	60519.61
1st Floor	50583.66	50593.58
GF	205659.07	205880.11
Base	0	0

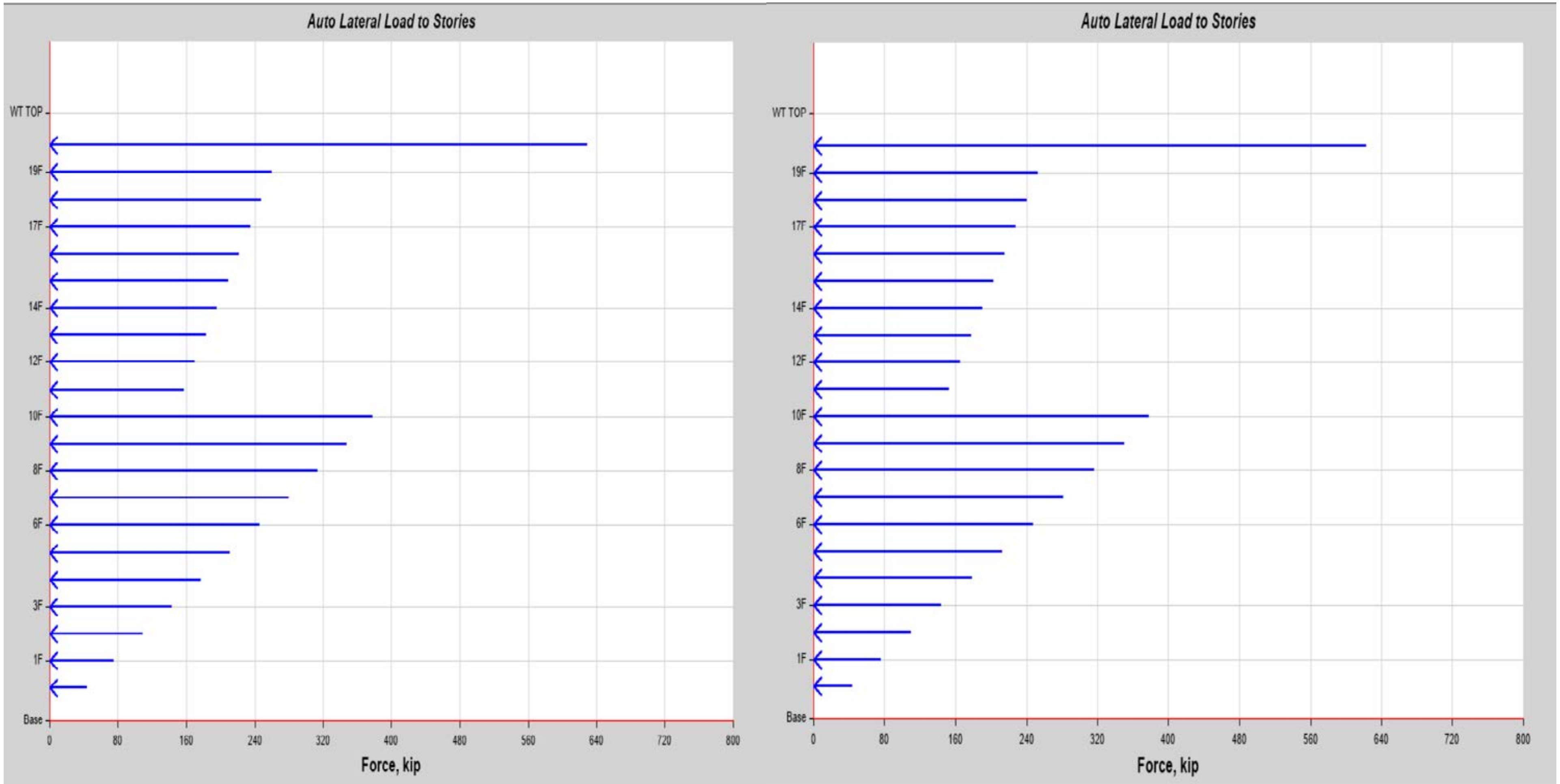
4.2.3 <u>Response due to Earthquake Loads in Global -ve directions</u>

1] Lateral loads resisted by the Stories:

Figures 4.9 (a ~b) illustrated below provide information about the response for lateral loads to stories. Here the horizontal axis represents lateral loads in kips and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between lateral loads resisting capacities of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.7 (a ~b) respectively.

From figure it is clearly seen that, response curves are near about symmetric in both Braced Structure and Non-Braced Structure while the value changes gradually in each story.

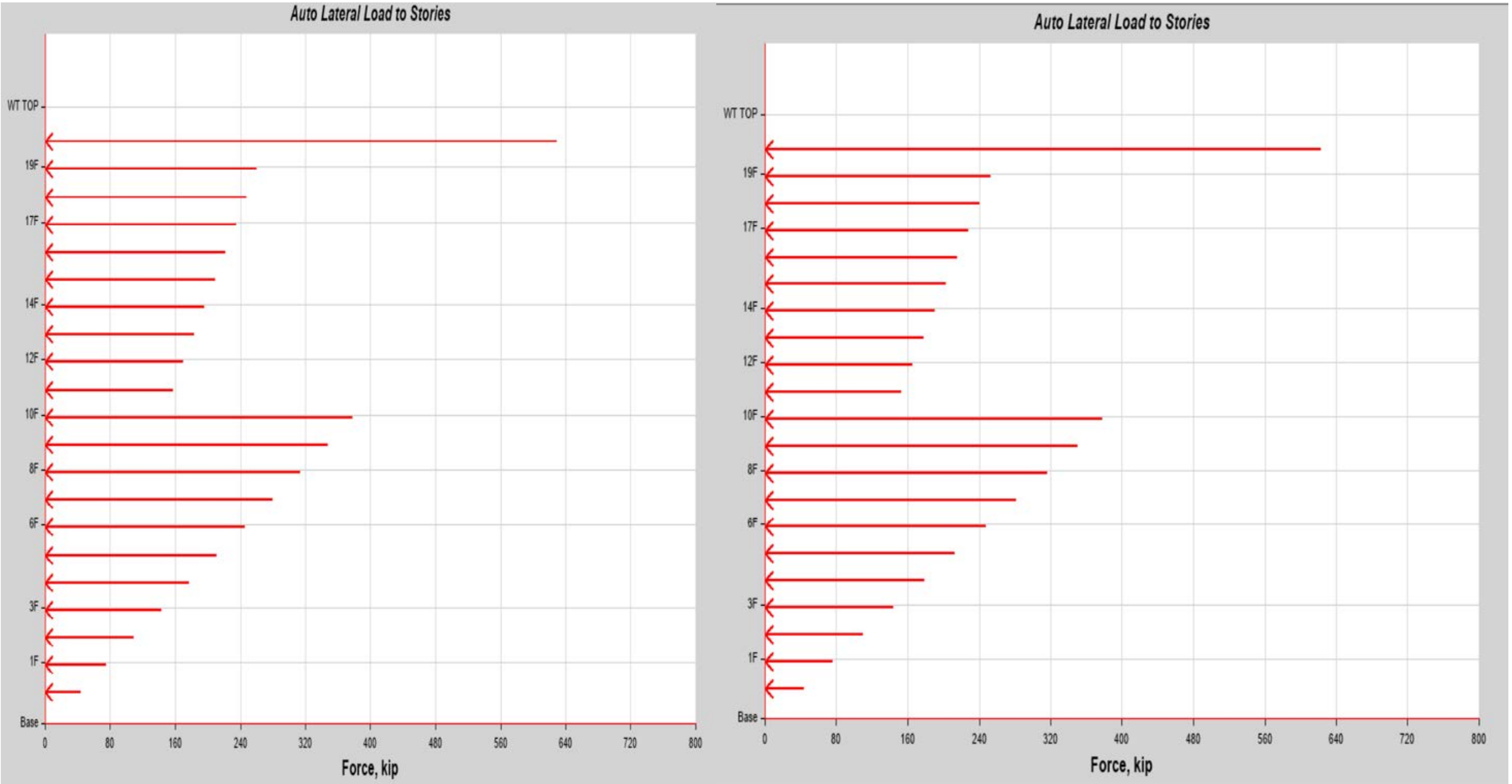
It shows that the value of lateral load due to both EQ-X and EQ-Y increases gradually from Ground Floor to 10^{th} floor & decreases at 11^{th} floor (due to lower floor area) & again, increases gradually to Roof Top.



Braced Structure

Non-Braced Structure

Figure 4.9a: Resisting loads by each story due to Earthquake in -X direction.



Braced Structure

Non-Braced Structure

Figure 4.9b: Resisting loads by each story due to Earthquake in -Y direction.

Table 4.7a: Resisting Lateral Loads in-X direction.

Story	Braced	Non-Braced
	Resisting Lateral Loads kip	**Resisting Lateral Loads kip**
WT	0	0
Roof top	629.64	622.92
19th Floor	260.53	252.82
18th Floor	247.63	240.31
17th Floor	234.74	227.79
16th Floor	221.84	215.27
15th Floor	208.94	202.76
14th Floor	196.04	190.24
13th Floor	183.14	177.73
12th Floor	170.25	165.21
11th Floor	157.35	152.69
10th Floor	378.03	378.38
9th Floor	347.72	350.54
8th Floor	313.62	316.17
7th Floor	279.53	281.80
6th Floor	245.44	247.44
5th Floor	211.35	213.07
4th Floor	177.26	178.70
3rd Floor	143.17	144.34
2nd Floor	109.08	109.97
1st Floor	74.99	75.60
GF	43.75	44.10
Base	0	0

Table 4.7b: Resisting Lateral Loads in-Y direction

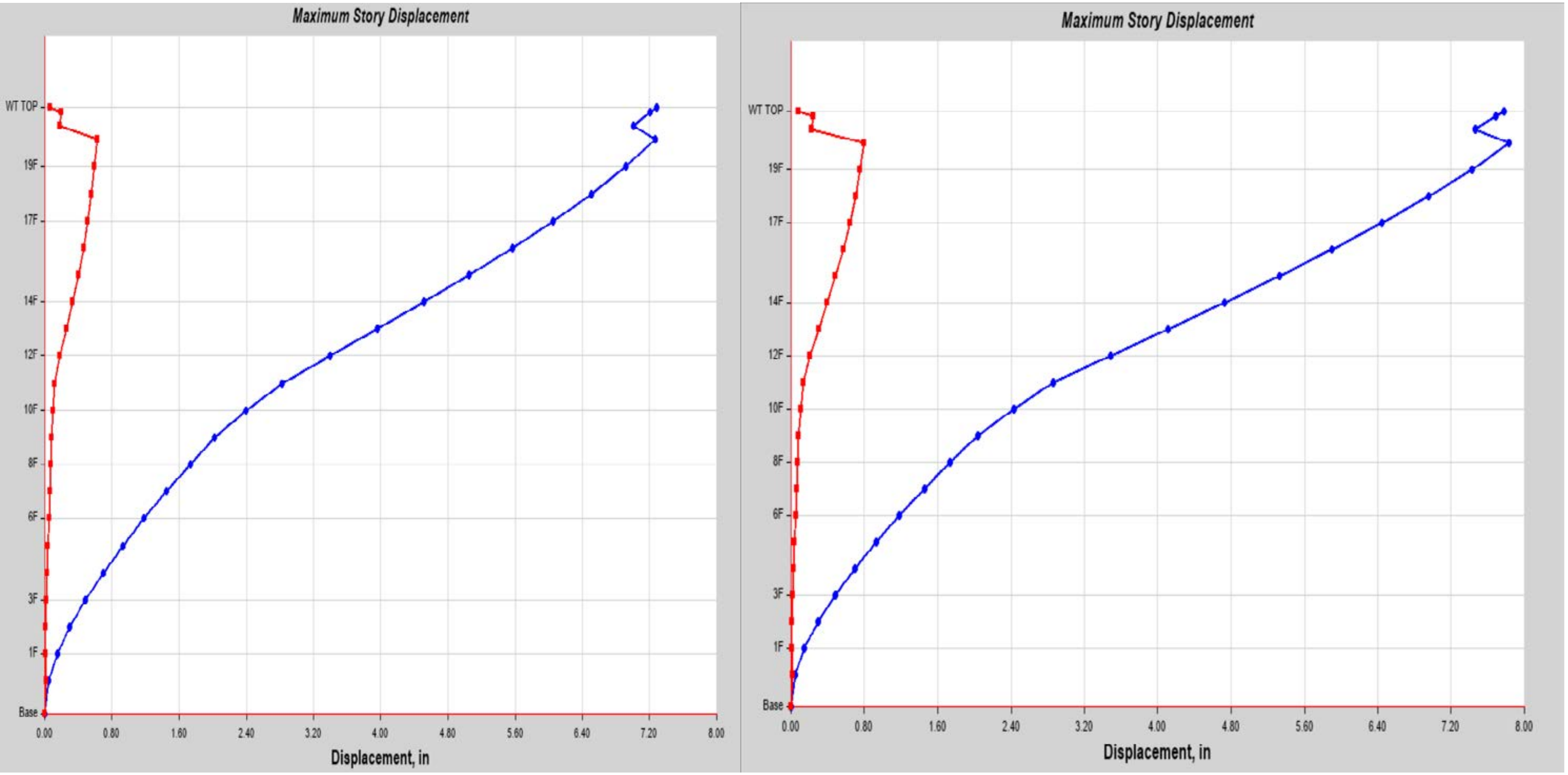
Story	Braced	Non-Braced
	Resisting Lateral Loads kip	Resisting Lateral Loads kip
WT	0	0
Roof top	629.64	622.92
19th Floor	260.53	252.82
18th Floor	247.63	240.31
17th Floor	234.74	227.79
16th Floor	221.84	215.27
15th Floor	208.94	202.76
14th Floor	196.04	190.24
13th Floor	183.14	177.73
12th Floor	170.25	165.21
11th Floor	157.35	152.69
10th Floor	378.03	378.38
9th Floor	347.72	350.54
8th Floor	313.62	316.17
7th Floor	279.53	281.80
6th Floor	245.44	247.44
5th Floor	211.35	213.07
4th Floor	177.26	178.70
3rd Floor	143.17	144.34
2nd Floor	109.08	109.97
1st Floor	74.99	75.60
GF	43.75	44.10
Base	0	0

2] Maximum Story Displacement:

Figures 4.10(a ~b) illustrated below provide information about the response for maximum story displacement. Here the horizontal axis represents displacement in inch and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between displacements of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.8 (a ~b) respectively.

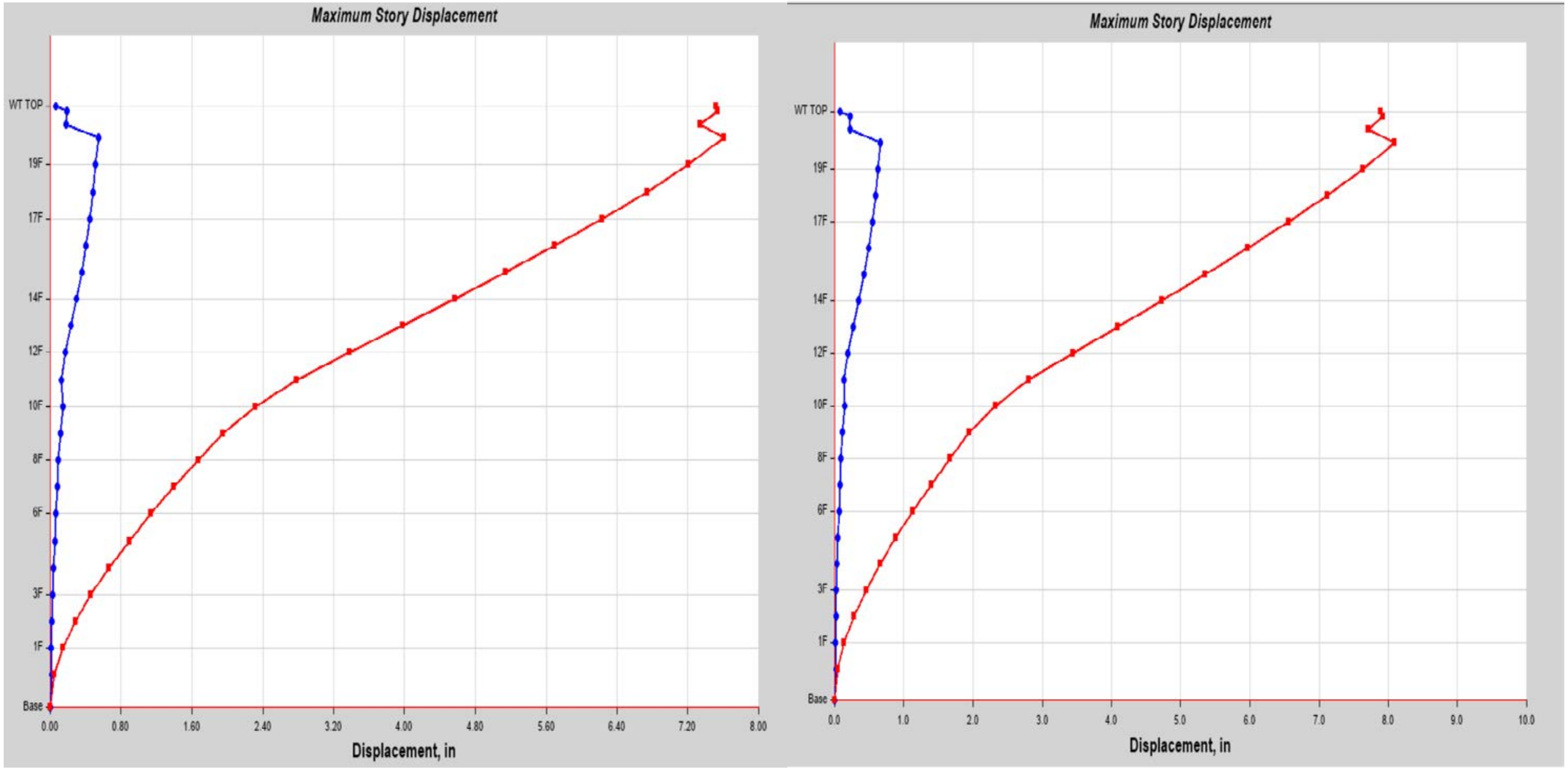
From figure it is clearly seen that curve starts from base and sharply goes on Roof Top in both EQ-X and EQ-Y. The displacement curve of Braced Structure & Non-Braced Structure fluctuates similarly in EQ-X & EQ-Y.

It shows that the story displacement starts from base with zero value. From curve, the value of story displacement increases from bottom to top (due to impact of Lateral load).



Braced Structure | Non-Braced Structure

Figure 4.10a: Maximum Story Displacement due to Earthquake loads in -X direction



Braced Structure Non-Braced Structure

Figure 4.10b: Maximum Story Displacement due to Earthquake loads in -Y direction.

Table 4.8a: Maximum Story Displacement in-X direction.

Story	Braced	Non-Braced
	displacement inch	**displacement inch**
WT	7.31	7.69
Roof top	7.26	7.83
19th Floor	6.91	7.42
18th Floor	6.50	6.95
17th Floor	6.050	6.44
16th Floor	5.56	5.89
15th Floor	5.05	5.32
14th Floor	4.51	4.72
13th Floor	3.96	4.11
12th Floor	3.39	3.48
11th Floor	2.82	2.86
10th Floor	2.39	2.42
9th Floor	2.02	2.03
8th Floor	1.73	1.73
7th Floor	1.45	1.45
6th Floor	1.18	1.18
5th Floor	0.92	0.92
4th Floor	0.69	0.69
3rd Floor	0.48	0.48
2nd Floor	0.29	0.29
1st Floor	0.14	0.14
GF	0.04	0.04
Base	0	0

Table 4.8b: Maximum Story Displacement in-Y direction.

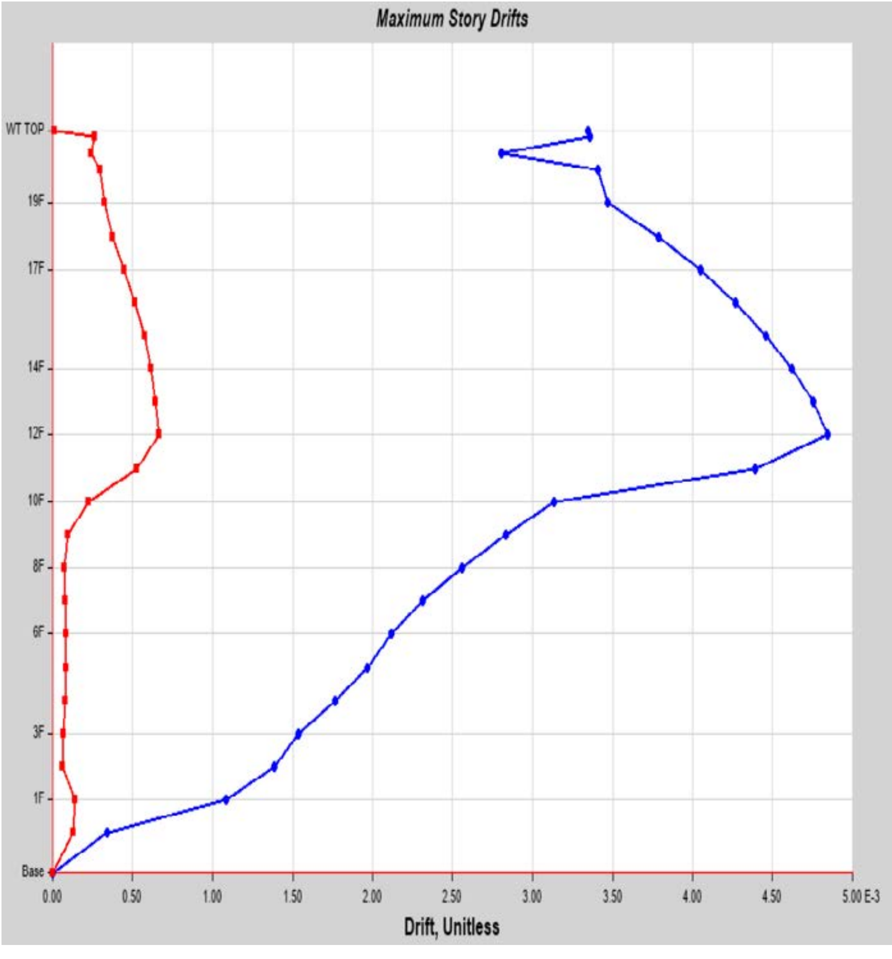
Story	Braced	Non-Braced
	displacement inch	**displacement inch**
WT	7.48	7.96
Roof top	7.60	8.08
19th Floor	7.20	7.63
18th Floor	6.74	7.11
17th Floor	6.23	6.55
16th Floor	5.69	5.96
15th Floor	5.13	5.35
14th Floor	4.56	4.73
13th Floor	3.97	4.09
12th Floor	3.37	3.44
11th Floor	2.77	2.79
10th Floor	2.31	2.32
9th Floor	1.95	1.95
8th Floor	1.66	1.66
7th Floor	1.39	1.39
6th Floor	1.13	1.13
5th Floor	0.89	0.89
4th Floor	0.66	0.66
3rd Floor	0.45	0.45
2nd Floor	0.28	0.28
1st Floor	0.13	0.13
GF	0.04	0.04
Base	0	0

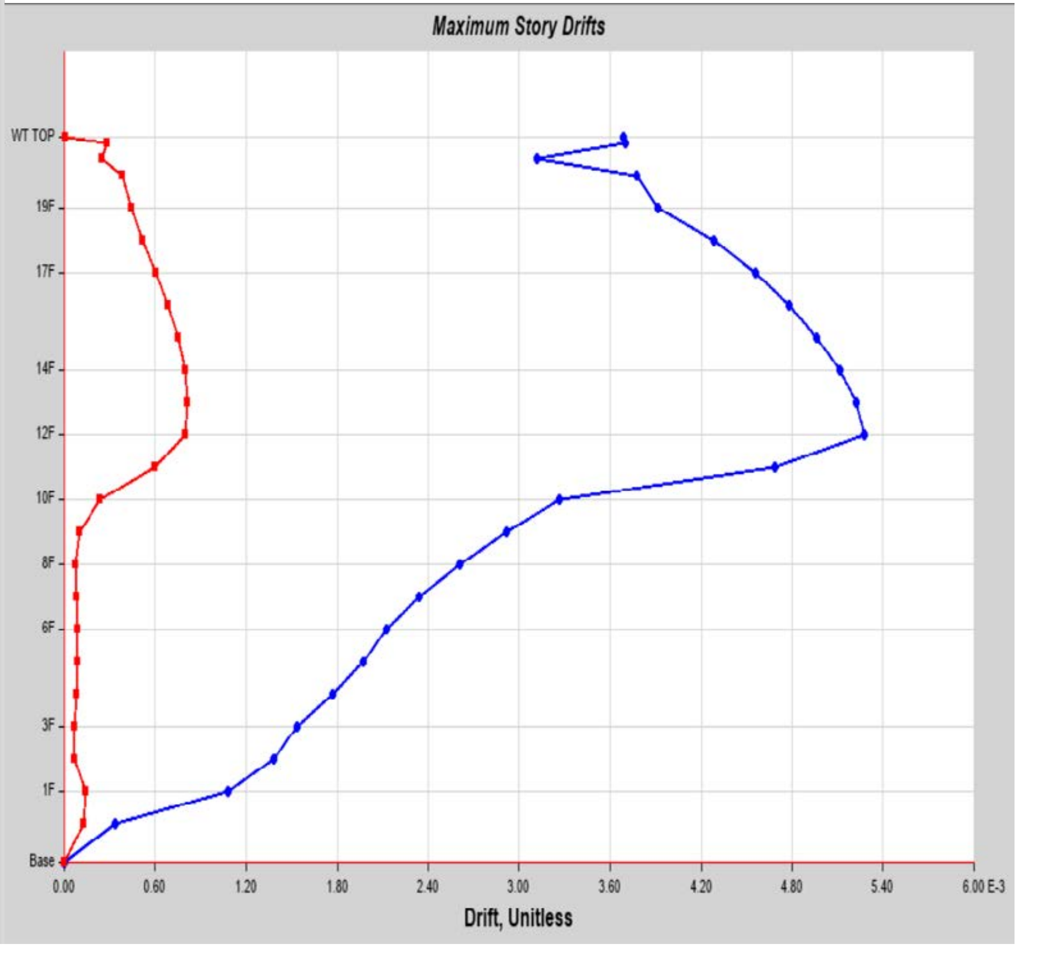
3] Maximum Story Drifts:

Figures 4.11(a ~b) illustrated below provide information about the response maximum story drifts. Here the horizontal axis represents drifts and the vertical axis represents the number of the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story drifts of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.9 (a ~b) respectively.

From figure it is clearly seen that, the story drift forms a parabolic shape with zero drift at bottom, increases toward mid and finally decreases again at top. Curve starts from base with zero value and sharply rises to 13^{th} story and then gradually decreases to 20^{th} story in EQ-X and rapidly goes to 13^{th} story and then gradually decreases to 20^{th} story in EQ-Y.

Story drifts value increases due to increase of displacement and suddenly decreases due to lower floor areas.

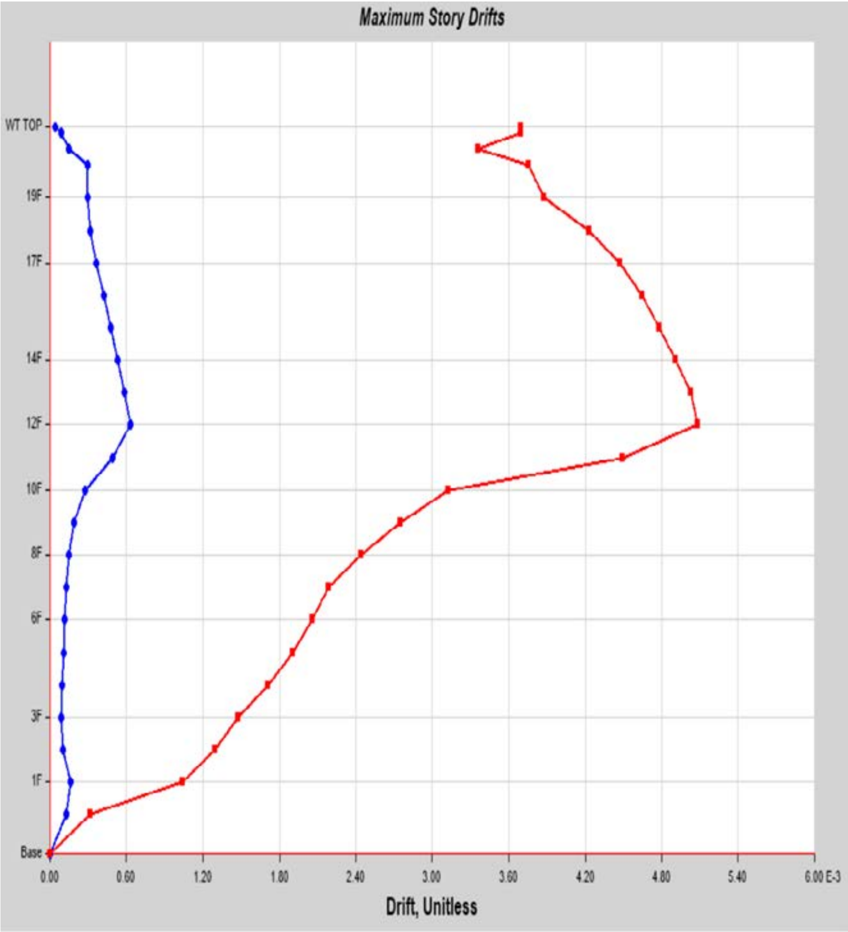




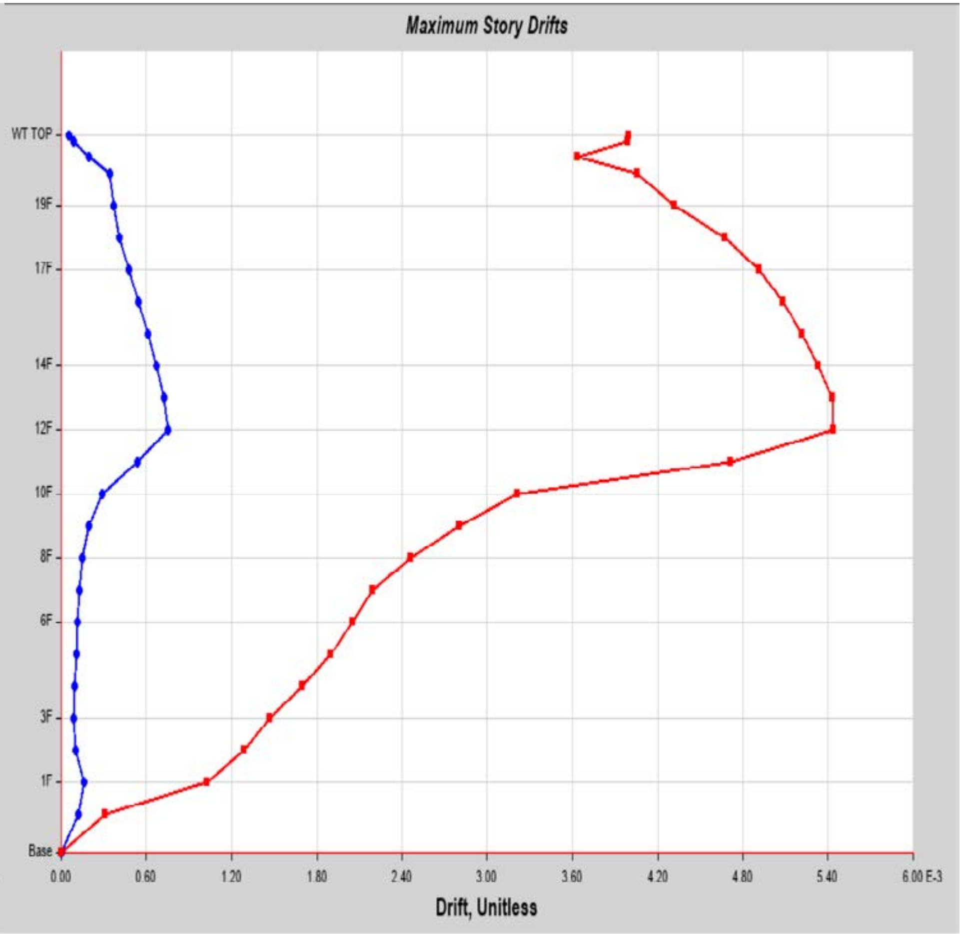
Braced Structure

Non-Braced Structure

Figure 4.11a: Maximum Story Drifts due to Earthquake loads in -X direction.



Braced Structure



Non-Braced Structure

Figure 4.11 b: Maximum Story Drifts due to Earthquake loads in-Y direction.

Table 4.9a: Maximum Story Drifts in-X direction.

Story	Braced	Non-Braced
	Story drift	Story drift
WT	0.0033	0.0035
Roof top	0.0034	0.0037
19th Floor	0.0034	0.0039
18th Floor	0.0037	0.0042
17th Floor	0.0040	0.0045
16th Floor	0.0042	0.0047
15th Floor	0.0044	0.0049
14th Floor	0.0046	0.0051
13th Floor	0.0047	0.0052
12th Floor	0.0048	0.0052
11th Floor	0.0043	0.0046
10th Floor	0.0031	0.0032
9th Floor	0.0028	0.0029
8th Floor	0.0025	0.0026
7th Floor	0.0023	0.0023
6th Floor	0.0021	0.0021
5th Floor	0.0019	0.0019
4th Floor	0.0017	0.0017
3rd Floor	0.0015	0.0015
2nd Floor	0.0013	0.0013
1st Floor	0.0010	0.0010
GF	0.0003	0.0003
Base	0	0

Table 4.9b: Maximum Story Drifts in-Y direction.

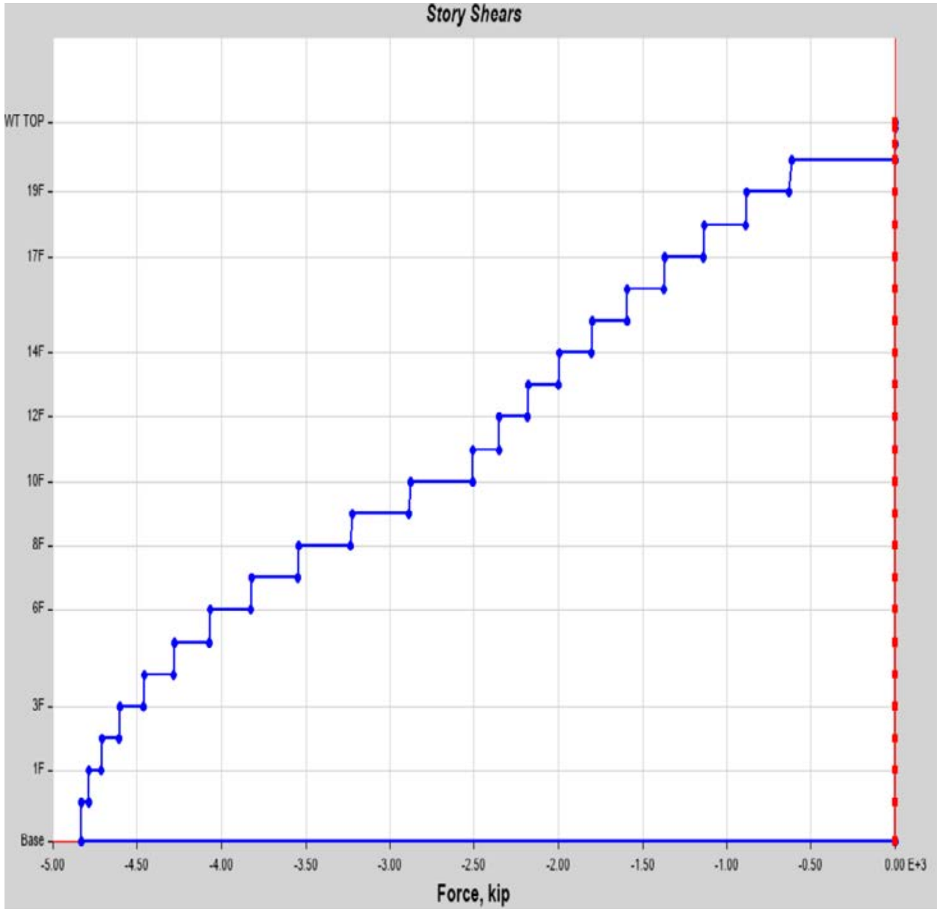
Story	Braced	Non-Braced
	Story drift	Story drift
WT	0.0036	0.0039
Roof top	0.0037	0.0040
19th Floor	0.0038	0.0043
18th Floor	0.0042	0.0046
17th Floor	0.0044	0.0049
16th Floor	0.0046	0.0050
15th Floor	0.0047	0.0052
14th Floor	0.0049	0.0053
13th Floor	0.0050	0.0054
12th Floor	0.0050	0.0054
11th Floor	0.0044	0.0047
10th Floor	0.0031	0.0032
9th Floor	0.0027	0.0028
8th Floor	0.0024	0.0024
7th Floor	0.0021	0.0021
6th Floor	0.0020	0.0020
5th Floor	0.0019	0.0018
4th Floor	0.0017	0.0016
3rd Floor	0.0014	0.0014
2nd Floor	0.0012	0.0012
1st Floor	0.0010	0.0010
GF	0.0003	0.0003
Base	0	0

4] Story Shears:

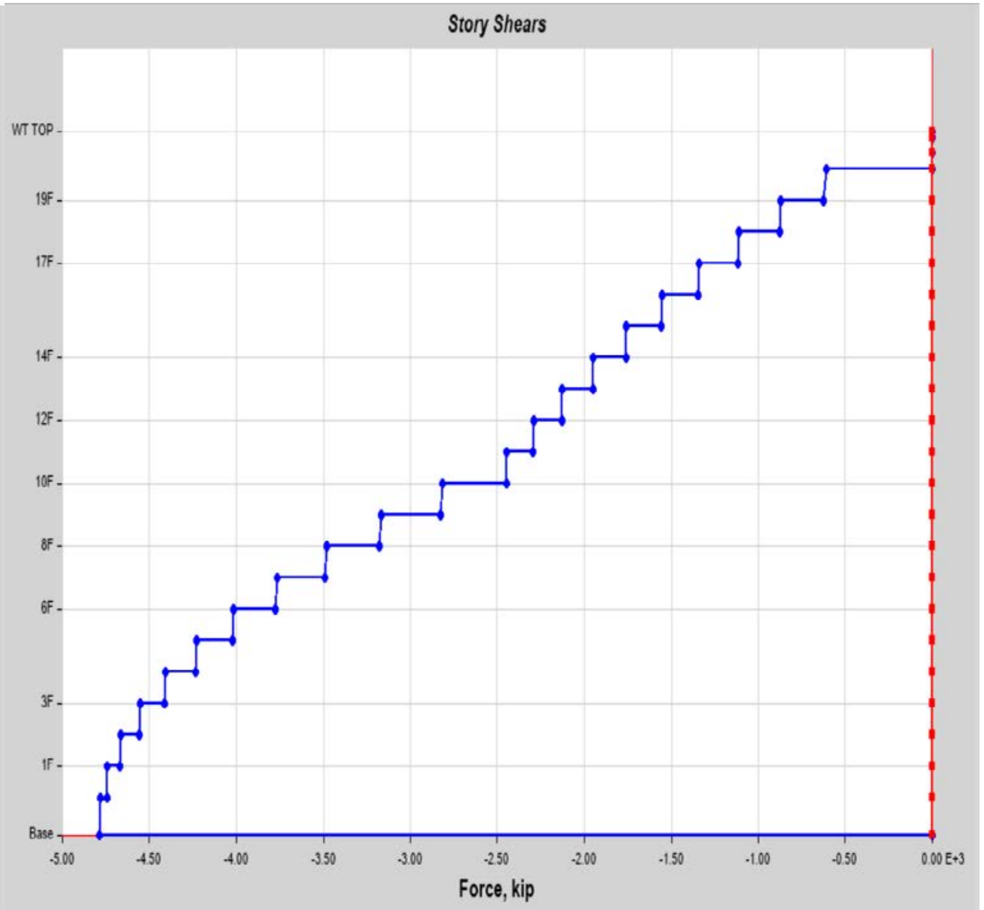
Figures 4.12(a ~b) illustrated below provide information about the response for story shears. Here the horizontal axis represents story shear in kips and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story shears of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.10 (a ~b) respectively.

From figure it is clearly seen that, response curves are symmetric in both Braced Structure and Non-Braced Structure in EQ-Y and in EQ-X. It is also shown that Braced structure can withstand greater story shear force compared to Non-Braced structure.

It shows that the story shear resisting capacity is higher at base due to strong basement. Shear resisting capacity decreases from bottom to top (due to lateral load impact) and its value negative against given load.

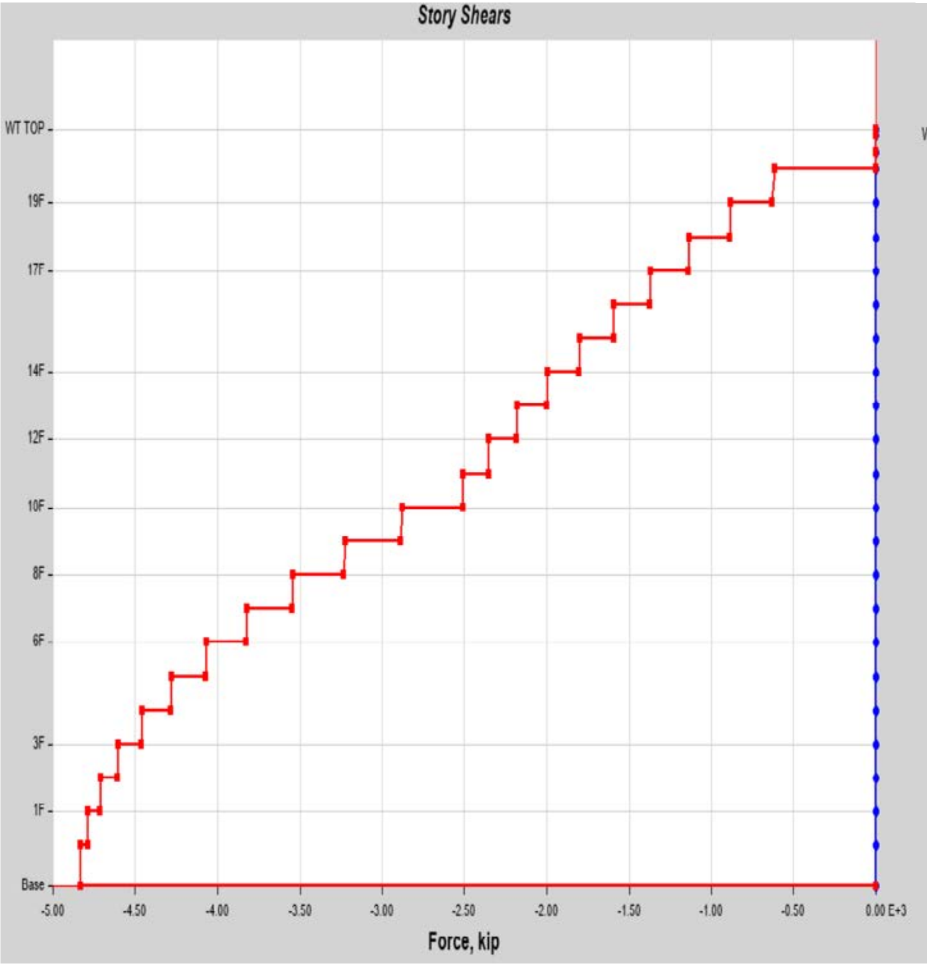


Braced Structure

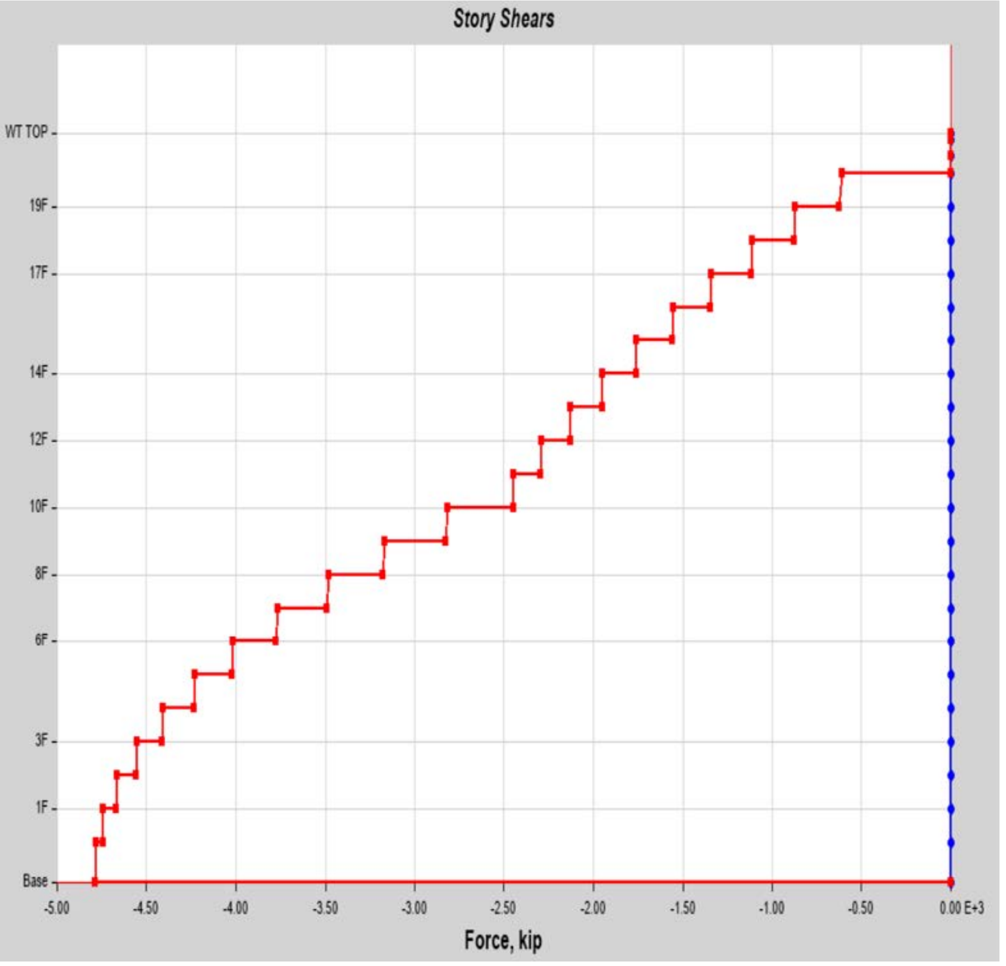


Non-Braced Structure

Figure 4.12a: Story Shears due to Earthquake loads in-X direction



Braced Structure



Non-Braced Structure

Figure 4.12b: Story Shears due to Earthquake loads in -Y direction

Table 4.10a: Story Shears in-X direction.

Story	Braced	Non-Braced
	Shear resisted at each story Kip	Shear resisted at each story kip
WT	0	0
Roof top	-629.64	-622.92
19th Floor	-890.17	-875.75
18th Floor	-1137.81	-1116.06
17th Floor	-1372.55	-1343.85
16th Floor	-1594.39	-1559.13
15th Floor	-1803.34	-1761.90
14th Floor	-1999.38	-1952.14
13th Floor	-2182.53	-2129.87
12th Floor	-2352.78	-2295.09
11th Floor	-2510.13	-2447.78
10th Floor	-2888.17	-2826.17
9th Floor	-3235.89	-3176.71
8th Floor	-3549.51	-3492.88
7th Floor	-3829.04	-3774.69
6th Floor	-4074.49	-4022.13
5th Floor	-4285.84	-4235.20
4th Floor	-4463.11	-4413.91
3rd Floor	-4606.29	-4558.25
2nd Floor	-4715.37	-4668.22
1st Floor	-4790.37	-4743.83
GF	-4834.12	-4787.94
Base	0	0

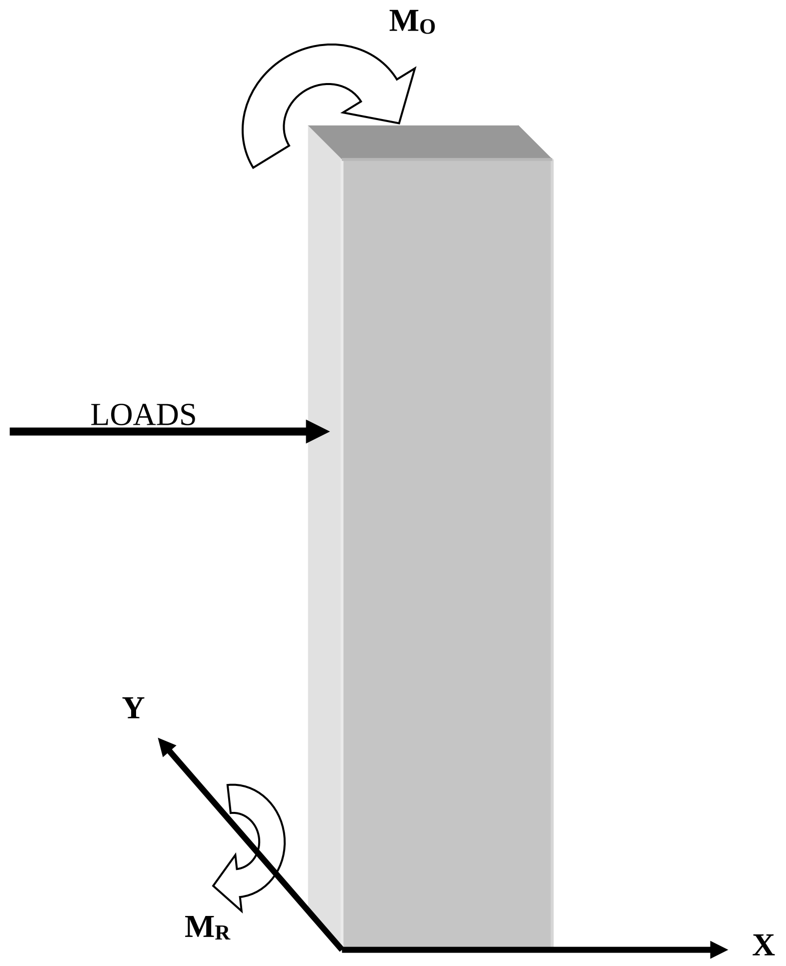
Table 4.10b: Story Shears in-Y direction.

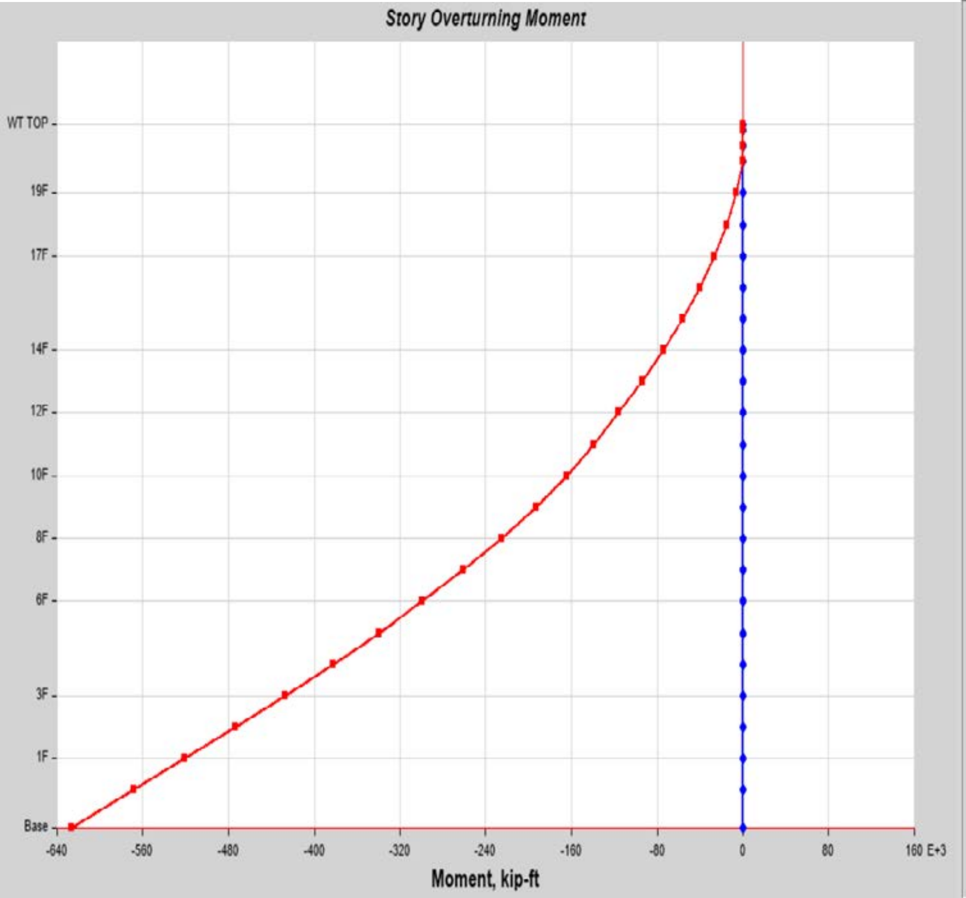
Story	Braced	Non-Braced
	Shear resisted at each story Kip	Shear resisted at each story kip
WT	0	0
Roof top	-629.64	-622.92
19th Floor	-890.17	-875.75
18th Floor	-1137.81	-1116.06
17th Floor	-1372.55	-1343.85
16th Floor	-1594.39	-1559.13
15th Floor	-1803.34	-1761.90
14th Floor	-1999.38	-1952.14
13th Floor	-2182.53	-2129.87
12th Floor	-2352.78	-2295.09
11th Floor	-2510.13	-2447.78
10th Floor	-2888.17	-2826.17
9th Floor	-3235.89	-3176.71
8th Floor	-3549.51	-3492.88
7th Floor	-3829.04	-3774.69
6th Floor	-4074.49	-4022.13
5th Floor	-4285.84	-4235.20
4th Floor	-4463.11	-4413.91
3rd Floor	-4606.29	-4558.25
2nd Floor	-4715.37	-4668.22
1st Floor	-4790.37	-4743.83
GF	-4834.12	-4787.94
Base	0	0

5] Resisting Story Overturning Moments [M_R]:

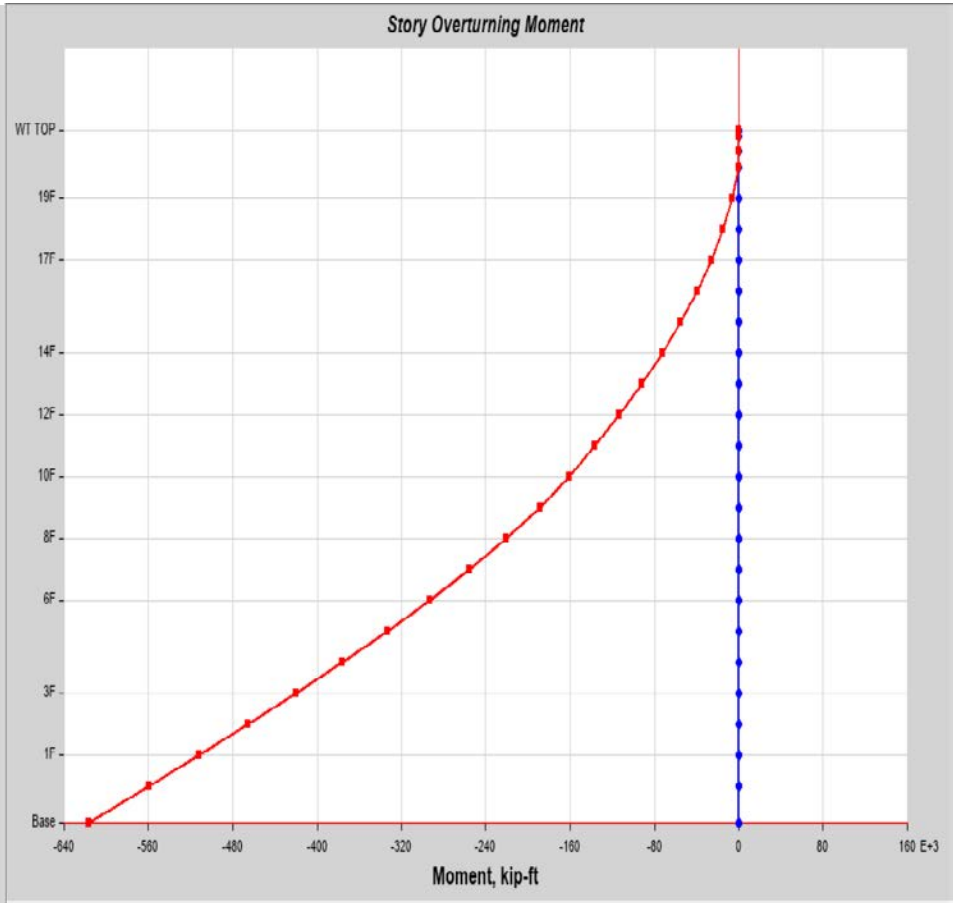
Figures 4.13(a ~b) illustrated below provide information about the response for story overturning moments. Here the horizontal axis represents overturning moments in kip-inch and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story overturning moments of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.11(a ~b) respectively.

From figure it is clearly seen that, curve starts from base with its peak value and sharply goes down to 20th story in both EQ-X and EQ-Y. It is noted here that due to lateral loads in X-direction, the whole structure will resist its overturn with respect to Y-axis and creates a resisting overturning moment M_R with respect to Y-axis as shown in figure below. Similar case can be explained for loads in Y-direction. However, it is shown that circular shape structure can withstand greater story overturning compared to square shape structure.



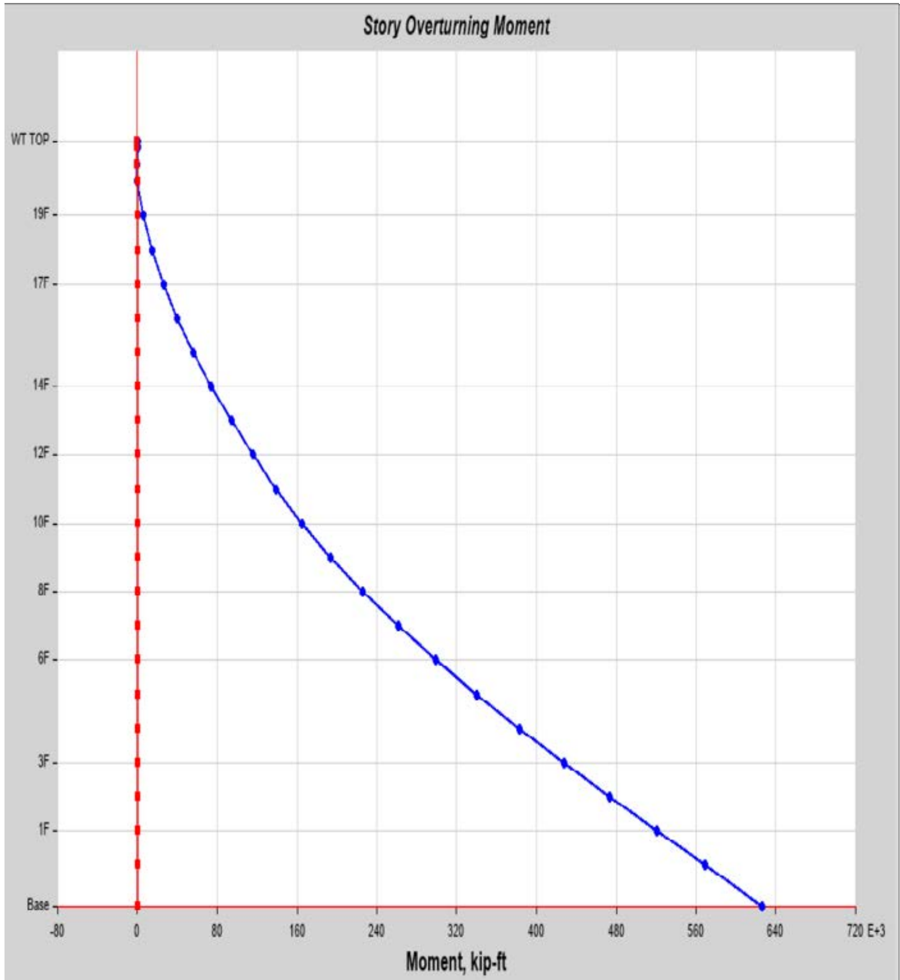


Braced Structure

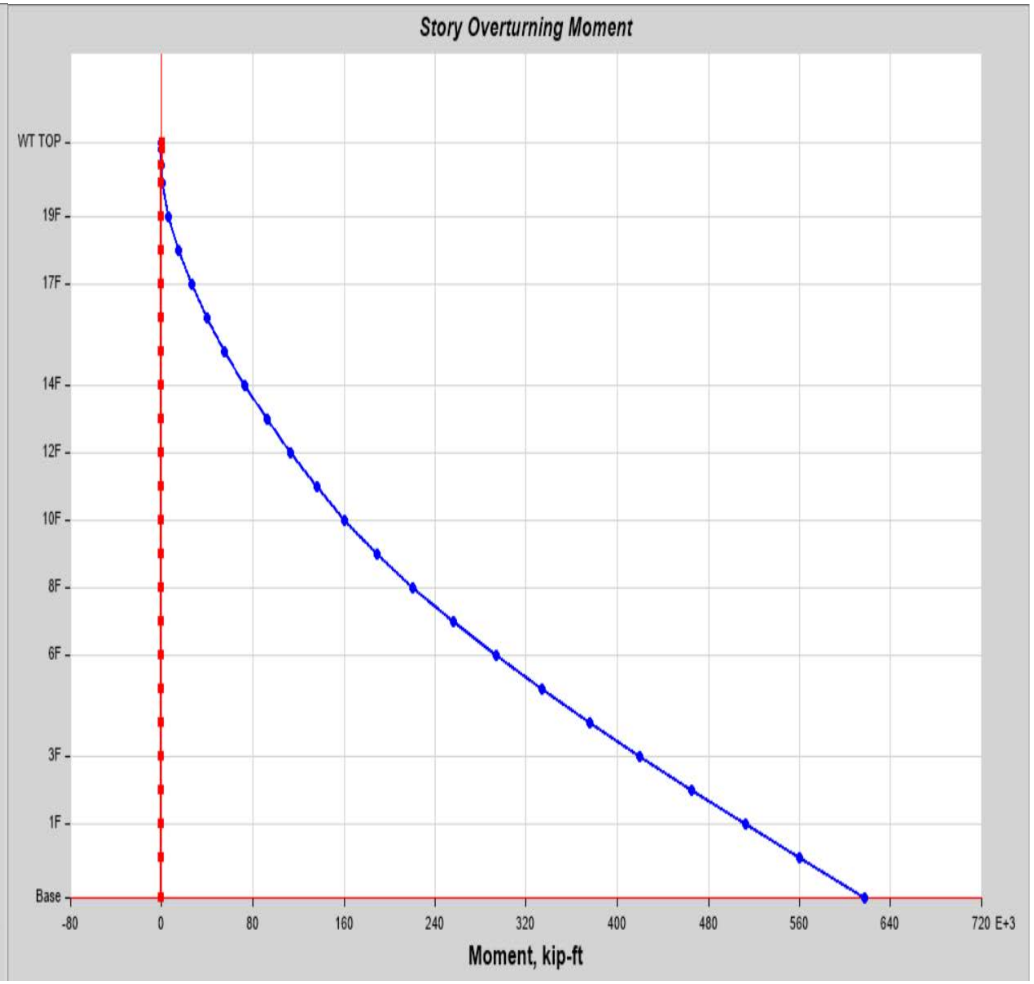


Non-Braced Structure

Figure 4.13a: Story Overturning Moments due to Earthquake loads in-X direction



Braced Structure



Non-Braced Structure

Figure 4.13b: Story Overturning Moments due to Earthquake loads in-Y direction

Table 4.11a: Story Overturning Moments in-X direction.

Story	Braced	Non-Braced
	Resisting Overturning Moment kip-feet	**Resisting Overturning Moment kip-feet**
WT	0	0
Roof top	0	0
19th Floor	-6240.40	-6172.70
18th Floor	-15120.81	-14908.70
17th Floor	-26478.66	-26048.87
16th Floor	-40184.95	-39468.06
15th Floor	-56110.73	-55041.10
14th Floor	-74127.00	-72642.83
13th Floor	-94104.79	-92148.08
12th Floor	-115915.12	-113431.71
11th Floor	-139429.02	-136368.53
10th Floor	-164517.51	-160833.40
9th Floor	-193348.36	-189043.83
8th Floor	-225660.96	-220764.25
7th Floor	-261114.34	-255650.98
6th Floor	-299367.60	-293360.37
5th Floor	-340079.84	-333548.73
4th Floor	-382910.18	-375872.42
3rd Floor	-427517.71	-419987.75
2nd Floor	-473561.54	-465551.06
1st Floor	-520700.77	-512218.68
GF	-568594.52	-559646.95
Base	-626579.31	-617077.34

Table 4.11b: Story Overturning Moments in-Y direction

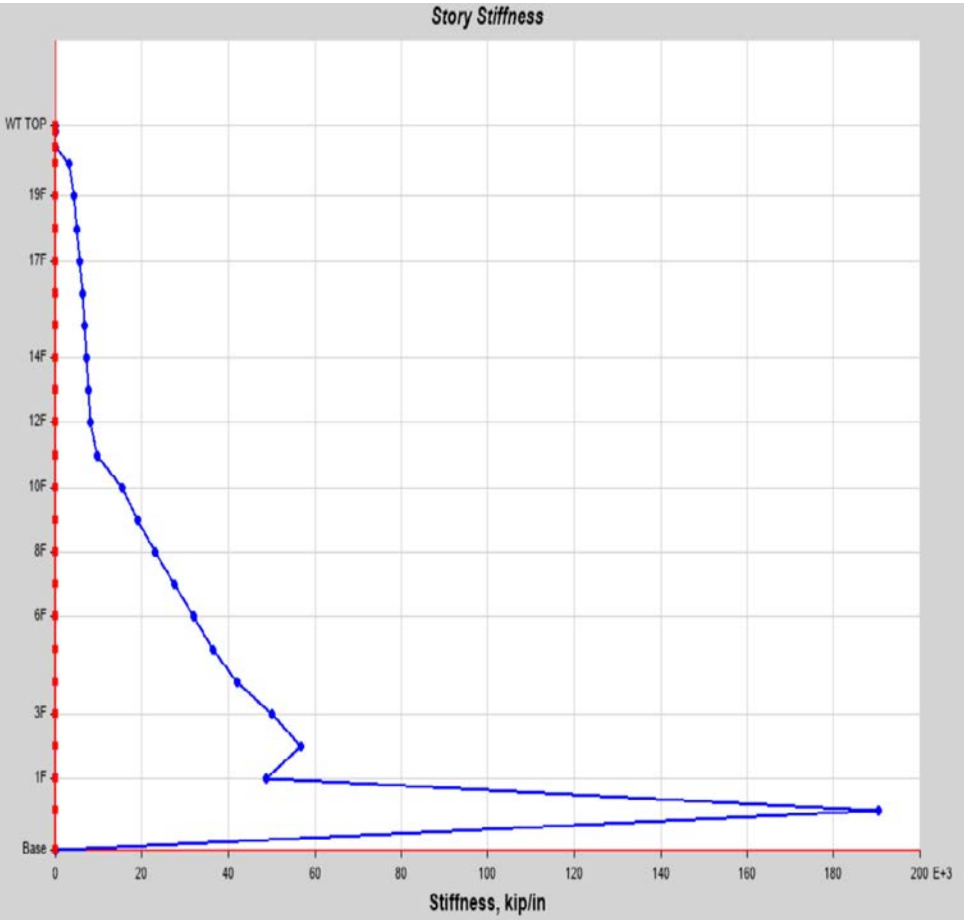
Story	Braced	Non-Braced
	Resisting Overturning Moment kip-feet	**Resisting Overturning Moment kip-feet**
WT	0	0
Roof top	0	0
19th Floor	6240.40	6172.70
18th Floor	15120.81	14908.70
17th Floor	26478.66	26048.87
16th Floor	40184.95	39468.06
15th Floor	56110.73	55041.10
14th Floor	74127.00	72642.83
13th Floor	94104.79	92148.08
12th Floor	115915.12	113431.70
11th Floor	139429.02	136368.53
10th Floor	164517.51	160833.40
9th Floor	193348.36	189043.83
8th Floor	225660.96	220764.24
7th Floor	261114.34	255650.98
6th Floor	299367.60	293360.36
5th Floor	340079.84	333548.73
4th Floor	382910.18	375872.41
3rd Floor	427517.71	419987.74
2nd Floor	473561.54	465551.05
1st Floor	520700.77	512218.68
GF	568594.52	559646.95
Base	626579.30	617077.33

6] Story Stiffness:

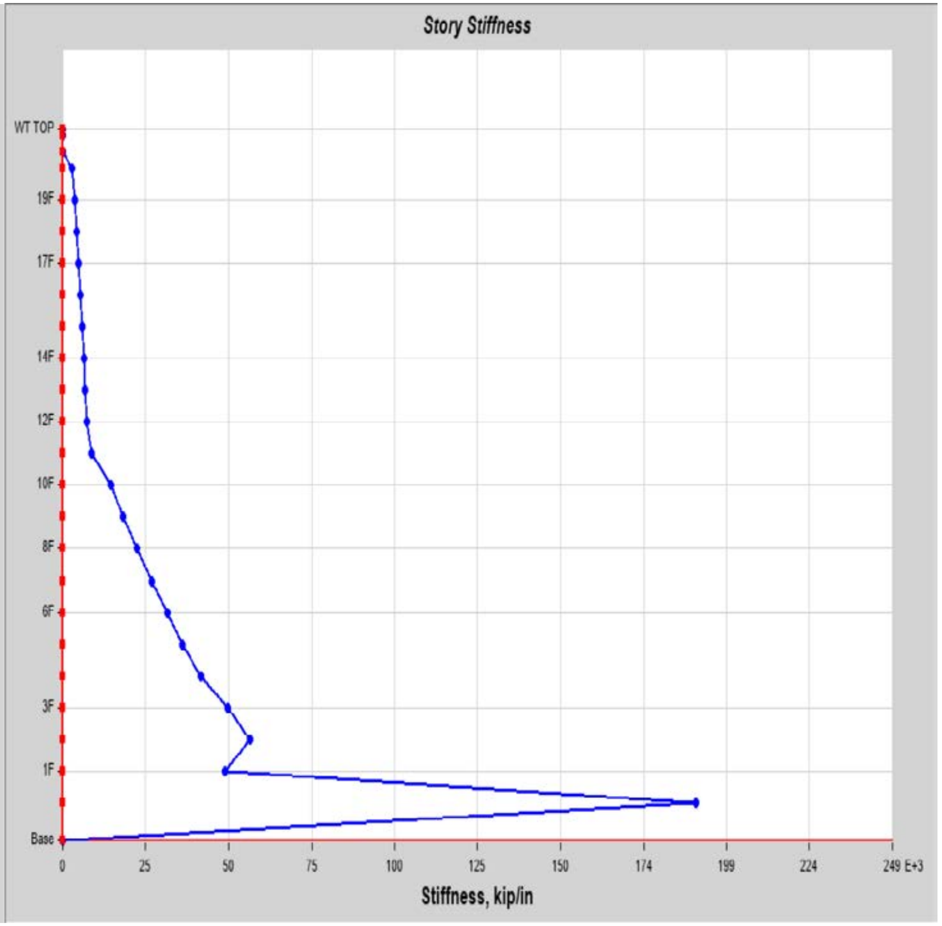
Figures 4.14(a ~b) illustrated below provide information about the response for story stiffness. Here the horizontal axis represents story stiffness in kip-inch and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story stiffness of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.12 (a ~b) respectively.

From figure it is clearly seen that, Non-Braced structure has lower stiffness compared to Braced structure.

It shows that story stiffness value is maximum at ground floor. Stiffness value decreases at first floor because of sudden shock and increase again 2nd floor then gradually stiffness value decreases from 2nd floor to Roof top (due to lateral impact load).

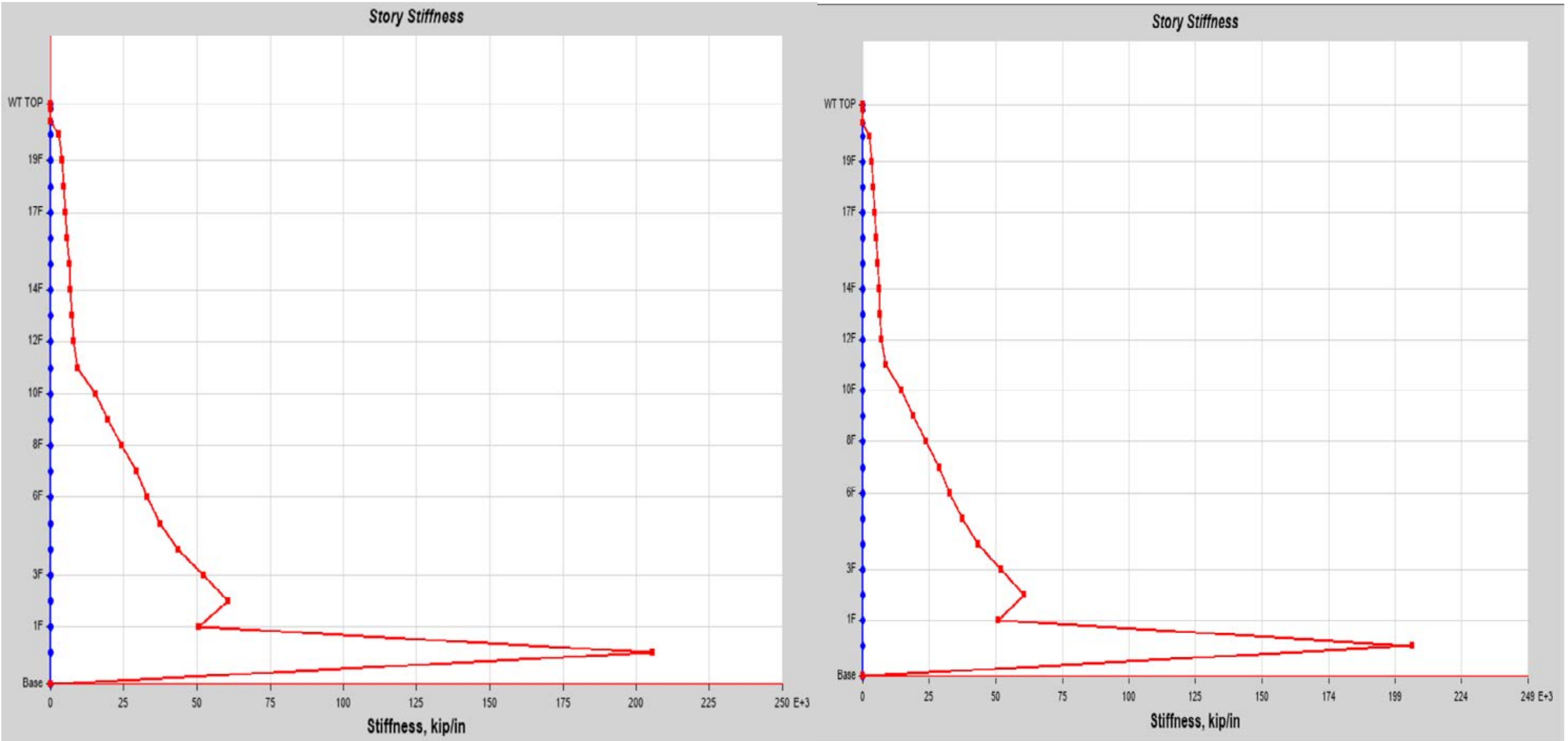


Braced Structure



Non-Braced Structure

Figure 4.14a: Story Stiffness due to Earthquake loads in-X direction



Braced Structure

Non-Braced Structure

Figure 4.14b: Story Stiffness due to Earthquake loads in -Y direction

Table 4.12a: Story Stiffness in-X direction.

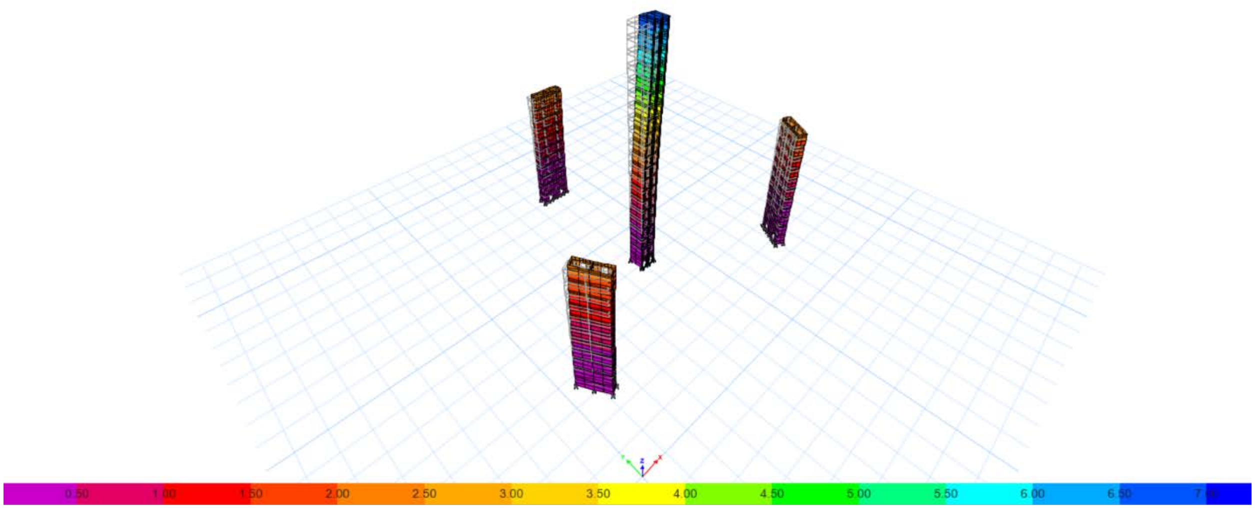
Story	Braced	Non-Braced
	Story Stiffness kip/in	Story Stiffness kip/in
WT	0	0
Roof top	3047.83	2726.07
19th Floor	4202.70	3725.47
18th Floor	5009.78	4341.50
17th Floor	5651.09	4916.55
16th Floor	6226.49	5438.75
15th Floor	6741.88	5915.47
14th Floor	7210.11	6359.30
13th Floor	7654.46	6794.32
12th Floor	8095.62	7249.69
11th Floor	9531.31	8702.18
10th Floor	15368.94	14423.97
9th Floor	19048.14	18139.96
8th Floor	23127.91	22305.97
7th Floor	27573.69	26874.27
6th Floor	32055.01	31559.91
5th Floor	36333.51	35854.49
4th Floor	42107.53	41636.31
3rd Floor	50061.95	49591.96
2nd Floor	56681.40	56262.94
1st Floor	48740.36	48708.73
GF	190493.34	190181.96
Base	0	0

Table 4.12b: Story Stiffness in-Y direction.

Story	Braced	Non-Braced
	Story Stiffness kip/in	**Story Stiffness kip/in**
WT	0	0
Roof top	2764.56	2528.81
19th Floor	3812.74	3382.75
18th Floor	4482.23	3980.60
17th Floor	5116.46	4557.99
16th Floor	5723.36	5111.49
15th Floor	6285.52	5629.57
14th Floor	6787.43	6100.94
13th Floor	7235.88	6536.47
12th Floor	7713.12	7031.95
11th Floor	9318.46	8657.66
10th Floor	15401.19	14655.76
9th Floor	19600.31	18900.22
8th Floor	24263.46	23665.50
7th Floor	29200.85	28737.32
6th Floor	33041.79	32690.93
5th Floor	37556.56	37240.69
4th Floor	43590.91	43290.05
3rd Floor	52125.50	51847.44
2nd Floor	60679.98	60529.07
1st Floor	50588.45	50608.34
GF	205643.36	205867.13
Base	0	0

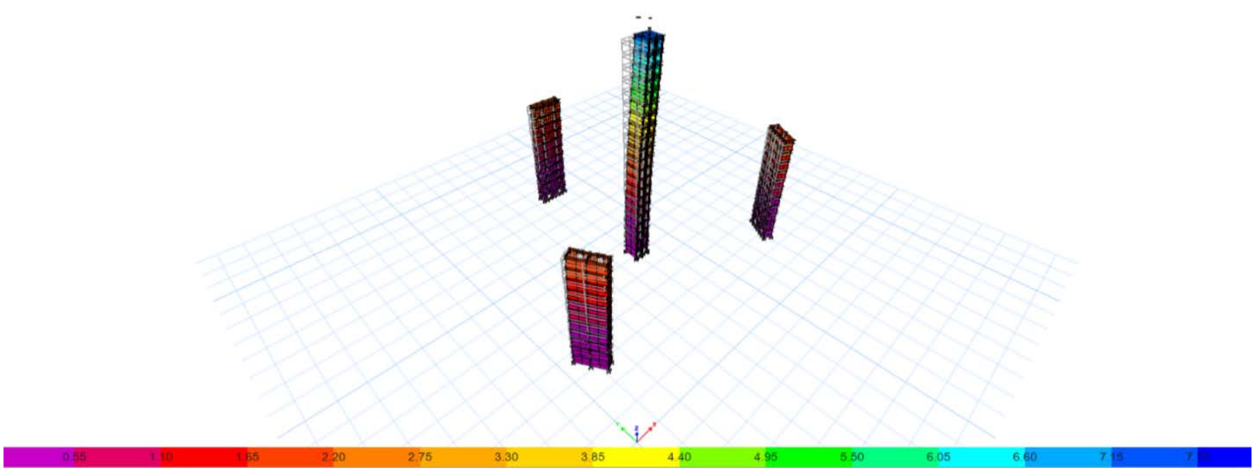
4.2.4 Deformed Shape of Lift Core due to EQ Loads

7.25 inch



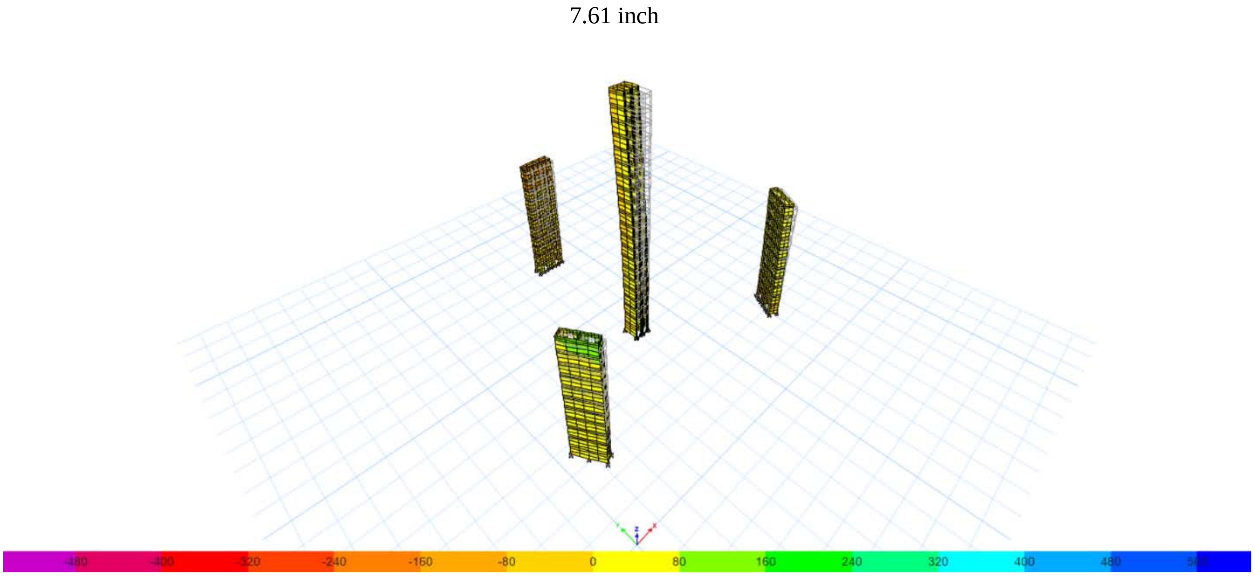
Braced Structure

7.72 inch

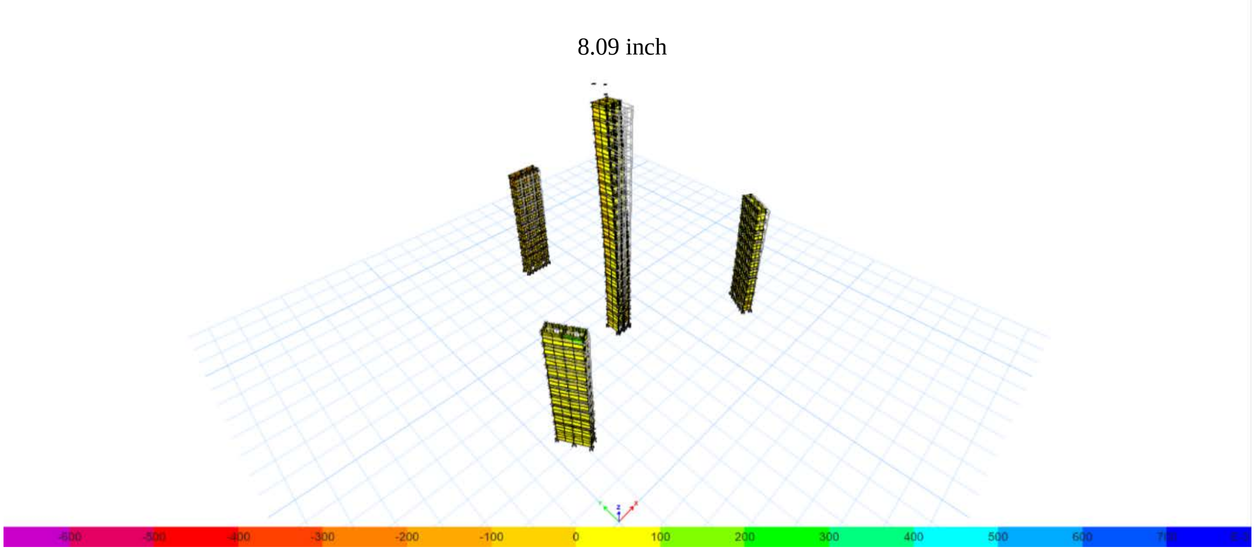


Non-Braced Structure

Figure 4.15a: Deformed shape of lift core due to EQ in +X direction



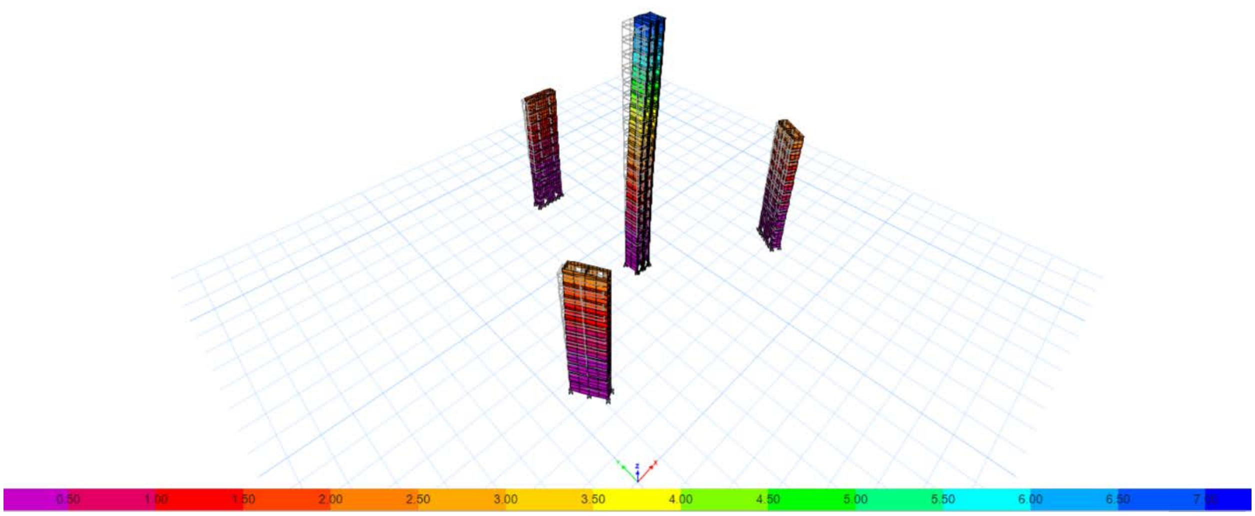
Braced Structure



Non-Braced Structure

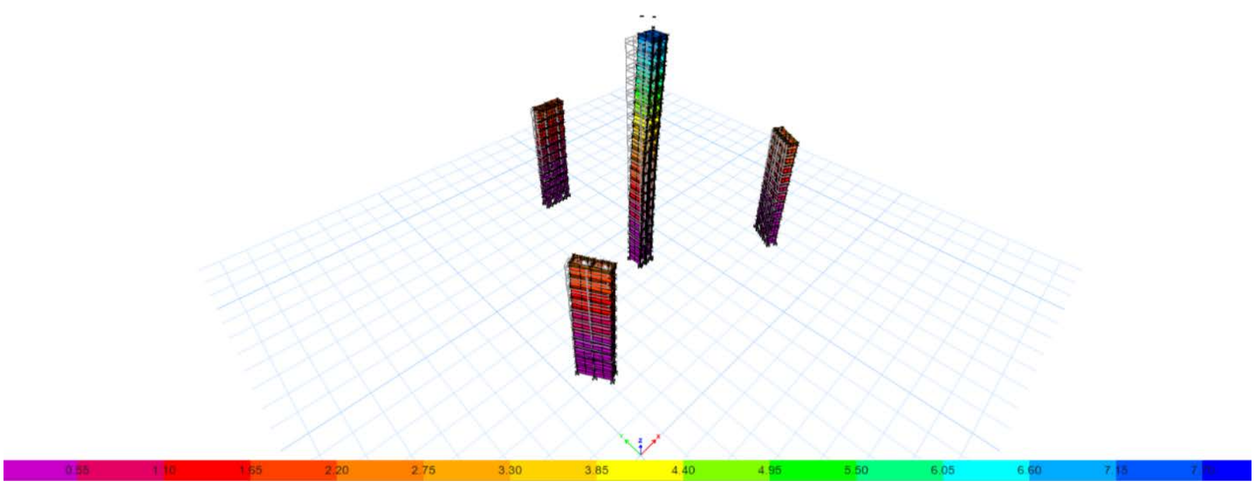
Figure 4.15b: Deformed shape of lift core due to EQ in +Y direction

7.29 inch



Braced Structure

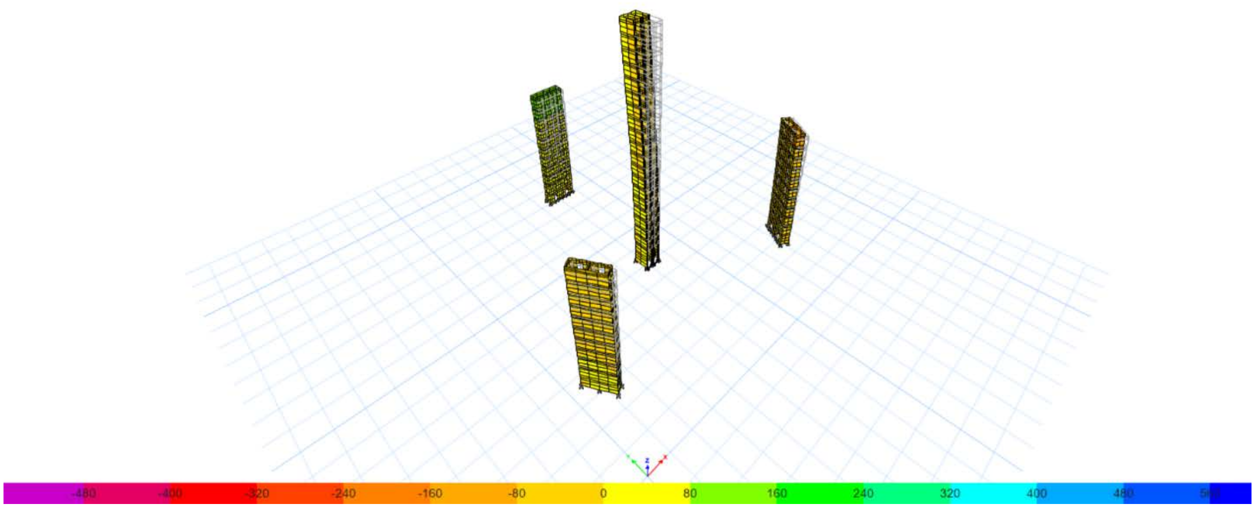
7.83 inch



Non-Braced Structure

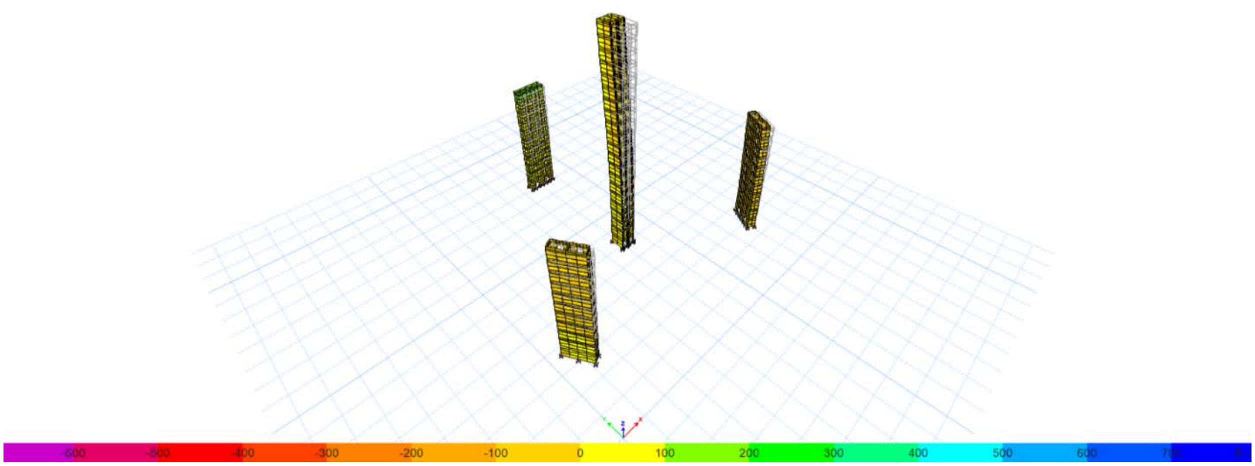
Figure 4.15c: Deformed shape of lift core due to EQ in -X direction

7.61 inch



Braced Structure

8.09 inch



Non-Braced Structure

Figure 4.15d: Deformed shape of lift core due to EQ in -Y direction

4.13a: Base Reaction, Forces

Load Case	FX kip		FY kip		FZ kip	
	Braced	**Non-Braced**	**Braced**	**Non-Braced**	**Braced**	**Non-Braced**
Dead	0	0	0	0	105577.38	103987.11
Live	0	0	0	0	84104.43	84104.43
EQ+X	-4834.12	-4787.93	0	0	0	0
EQ-X	-4834.12	-4787.93	0	0	0	0
EQ+Y	0	0	-4834.12	-4787.93	0	0
EQ-Y	0	0	-4834.12	-4787.93	0	0

From this Table 4.13a, it is observed that Braced Structure can resist more base reactions due to dead, live, EQ and wind loadings compared to Non-Braced Structure.

Table 4.13b: Base Reaction, Moments

Load Case	MX kip-feet		MY kip-feet		MZ kip-feet	
	Braced	**Non-Braced**	**Braced**	**Non-Braced**	**Braced**	**Non-Braced**
Dead	13081467	12884274	-13091373	-12894381	0	0
Live	10409375	10409375	-10428949	-10428949	0	0
EQ+X	0	0	-626579.31	-617076.79	641292.06	635357.46
EQ-X	0	0	-626579.31	-617076.79	555414.00	549875.42
EQ+Y	626579.30	617076.79	0	0	-646693.8	-640668.23
EQ-Y	626579.30	617076.7	0	0	-552145.9	-546738.32

From this Table 4.13b, it is observed that Braced Structure can resist more base overturning moments due to dead, live, EQ and wind loadings compared to Non-Braced Structure.

Table 4.14: Comparison Table

Topic	Story Level	Braced Structure				Non-Braced Structure			
		EQ+X	EQ+Y	EQ-X	EQ-Y	EQ+X	EQ+Y	EQ-X	EQ-Y
Lateral Loads to Stories (kip)	GF	43.75	43.75	43.75	43.75	44.10	44.10	44.10	44.10
	Top Floor	629.64	629.64	629.64	629.64	622.92	622.92	622.92	622.92
Maximum Story Displacement (inch)	GF	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	Top Floor	7.1	7.6	7.2	7.6	7.6	8.1	7.8	8.1
Maximum Story Drifts	GF	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
	Top Floor	0.0034	0.0037	0.0034	0.0037	0.0038	0.0041	0.0038	0.0041
Story Shears (kip)	GF	-4834.12	-4834.12	-4834.12	-4834.12	-4787.94	-4787.94	-4787.94	-4787.94
	Top Floor	-629.64	-629.64	-629.64	-629.64	-622.92	-622.92	-622.92	-622.92
Story Overturning Moment (k-in)	Basement	-626579.3	626579.3	-626579.3	626579.3	-617077.3	617077.3	-617077.3	617077.3
Story Stiffness (kip/in)	GF	191580.71	205659.07	190493.3	205643.3	191693.07	205880.11	190181.9	205867.13
	Top Floor	3014.19	2778.21	3047.83	2764.56	2693.27	2541.13	2726.07	2528.81

From summary Table 4.14, it can be justified that Braced structure is the best one against lateral loadings with compared to Non-Braced structure.

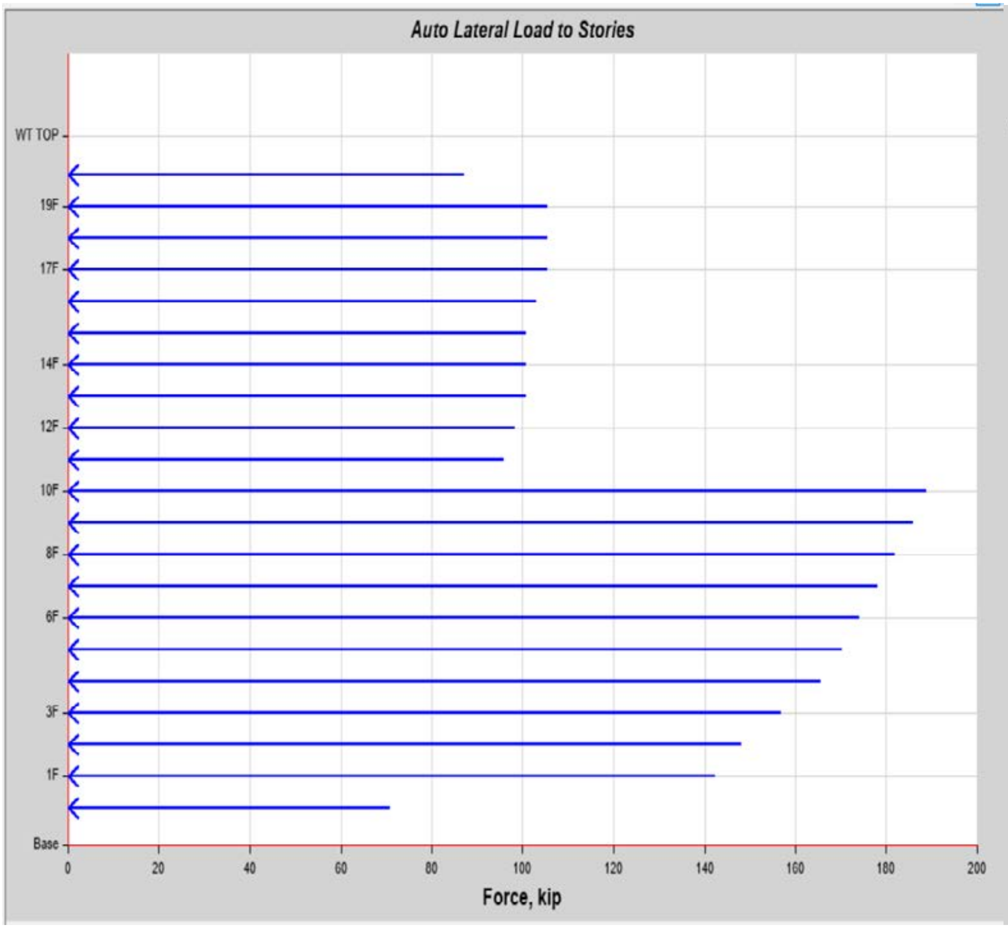
4.2.5 <u>Response due to Wind Loads in Global Positive Directions</u>

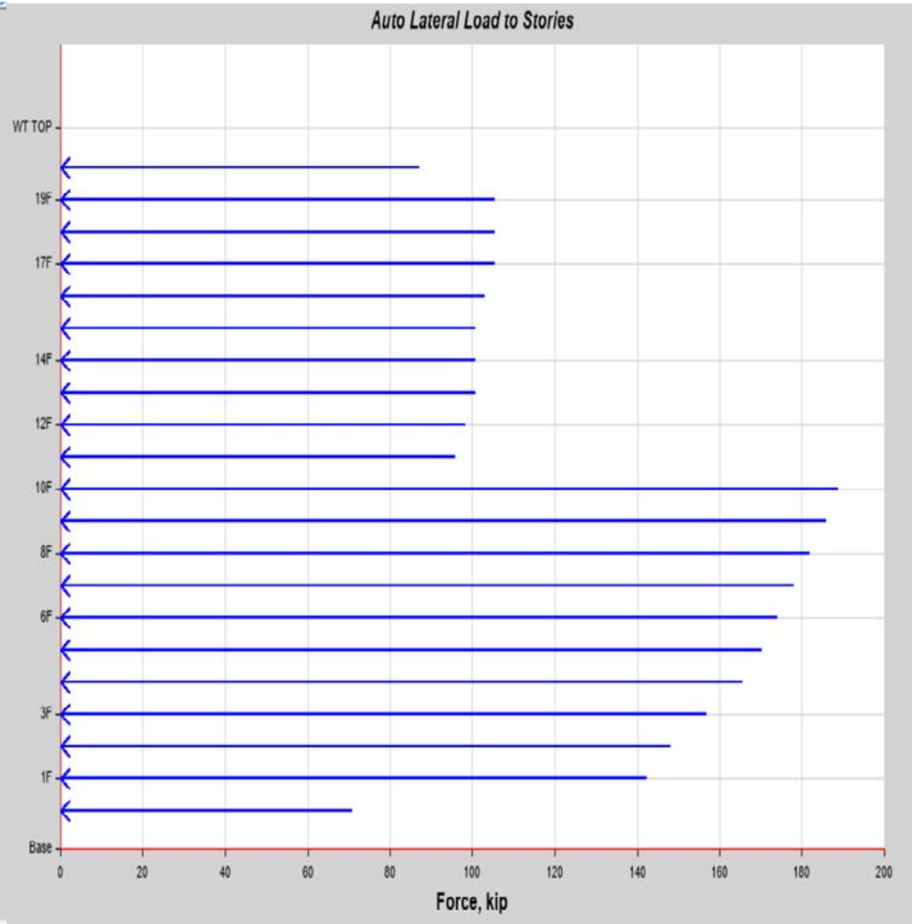
1] Lateral loads resisted by the Stories:

Figures 4.15(a ~b) illustrated below provide information about the response for lateral loads to stories. Here the horizontal axis represents lateral loads in kips and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between lateral loads resisting capacities of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.15 (a ~b) respectively.

From figure it is clearly seen that, response curves are near about symmetric in both Braced Structure and Non-Braced Structure while the value changes gradually in each story (Due to wind load impact).

It shows that the value of lateral load due to both WX and WY increases gradually from Ground Floor to 10^{th} floor & decreases at 11^{th} floor (Due to lower floor space) & again increases gradually to 20^{th} story suddenly decreases at roof top.

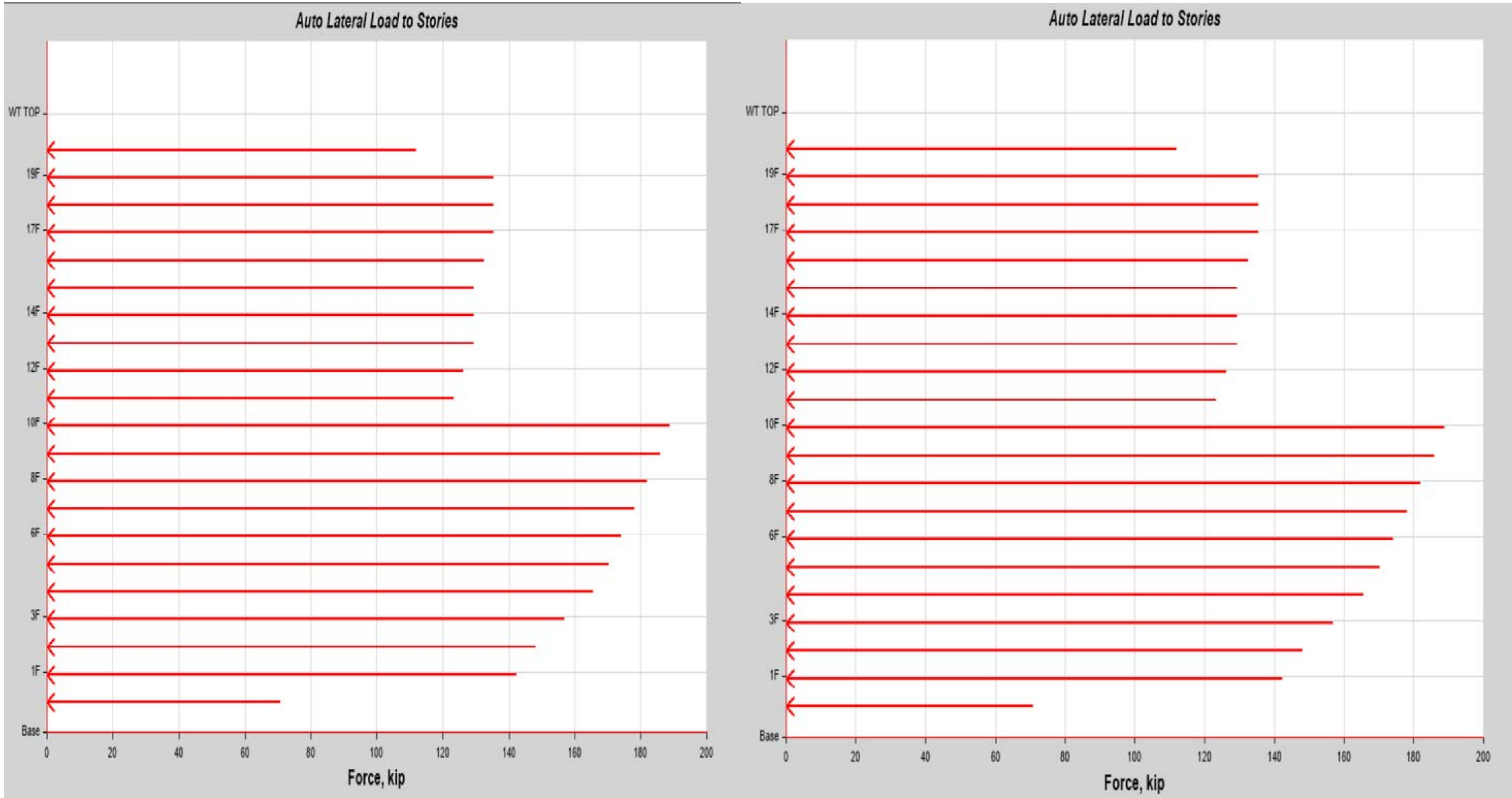




Braced Structure

Non-Braced Structure

Figure 4.15a: Resisting Wind loads at stories in +X direction



Braced Structure

Non-Braced Structure

Figure 4.15b: Resisting Wind loads at stories in +Y direction.

Table 4.15a: Resisting Wind loads in stories in +X direction

Story	Braced	Non-Braced
	Resisting EQ loads kip	**Resisting EQ loads kip**
WT	0	0
Roof top	87.10	87.10
19th Floor	105.47	105.47
18th Floor	105.47	105.47
17th Floor	105.47	105.47
16th Floor	103.09	103.09
15th Floor	100.71	100.71
14th Floor	100.71	100.71
13th Floor	100.71	100.71
12th Floor	98.33	98.33
11th Floor	95.95	95.95
10th Floor	188.88	188.88
9th Floor	185.86	185.86
8th Floor	181.96	181.96
7th Floor	178.07	178.07
6th Floor	174.18	174.18
5th Floor	170.29	170.29
4th Floor	165.53	165.53
3rd Floor	156.88	156.88
2nd Floor	148.12	148.12
1st Floor	142.28	142.28
GF	70.87	70.87
Base	0	0

Table 4.15b: Resisting Wind Loads in stories in +Y direction.

Story	Braced	Non-Braced
	Resisting EQ loads kip	**Resisting EQ loads kip**
WT	0	0
Roof top	111.92	111.92
19th Floor	135.52	135.52
18th Floor	135.52	135.52
17th Floor	135.52	135.52
16th Floor	132.47	132.47
15th Floor	129.41	129.41
14th Floor	129.41	129.41
13th Floor	129.41	129.41
12th Floor	126.35	126.35
11th Floor	123.30	123.30
10th Floor	188.88	188.88
9th Floor	185.86	185.86
8th Floor	181.96	181.96
7th Floor	178.07	178.07
6th Floor	174.18	174.18
5th Floor	170.29	170.29
4th Floor	165.53	165.53
3rd Floor	156.88	156.88
2nd Floor	148.12	148.12
1st Floor	142.28	142.28
GF	70.87	70.87
Base	0	0

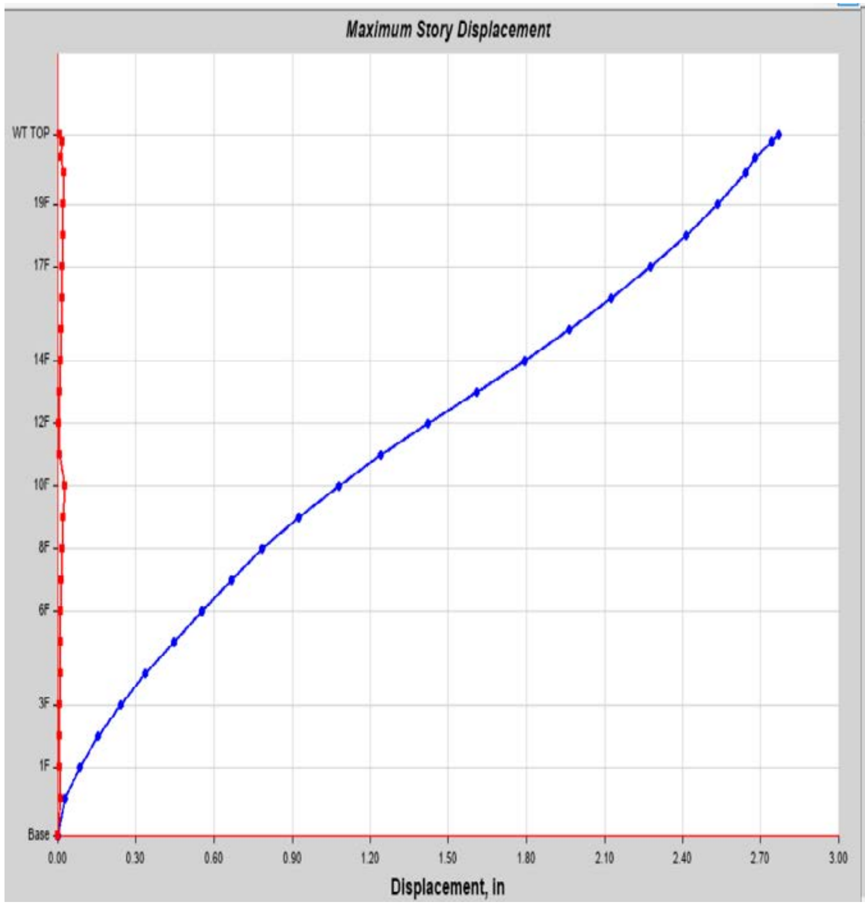
Findings: From Tables 4.15a and 4.15b, it is observed that Braced Structure can resist higher lateral loads compared to that of the Non-Braced Structure.

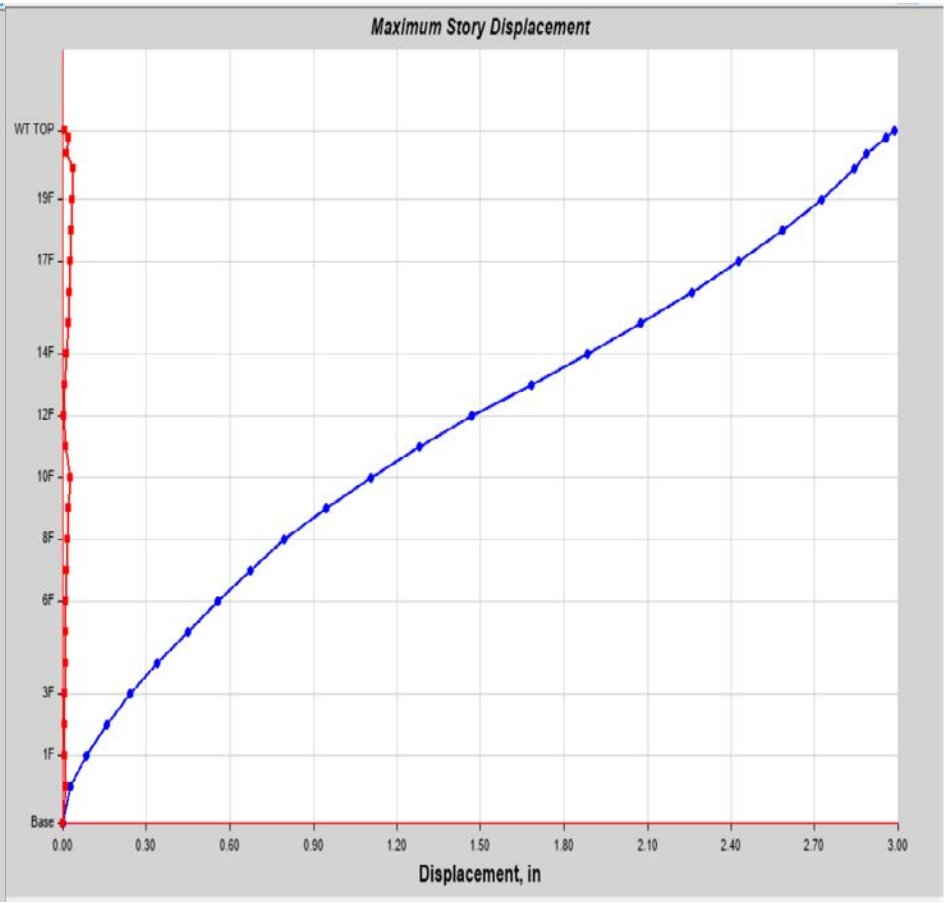
2] Maximum Story Displacement:

Figures 4.16(a ~b) illustrated below provide information about the response for maximum story displacement. Here the horizontal axis represents displacement in inch and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between displacements of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.16 (a ~b) respectively.

From figure it is clearly seen that curve starts from base and sharply goes on Roof Top in both WX and WY. The displacement curve of Braced Structure & Non-Braced Structure fluctuates similarly in WX & WY.

It shows that the story displacement starts from base with zero displacement. The value of story displacement increases from bottom to WT top (Due to wind load impact and increase of building height).

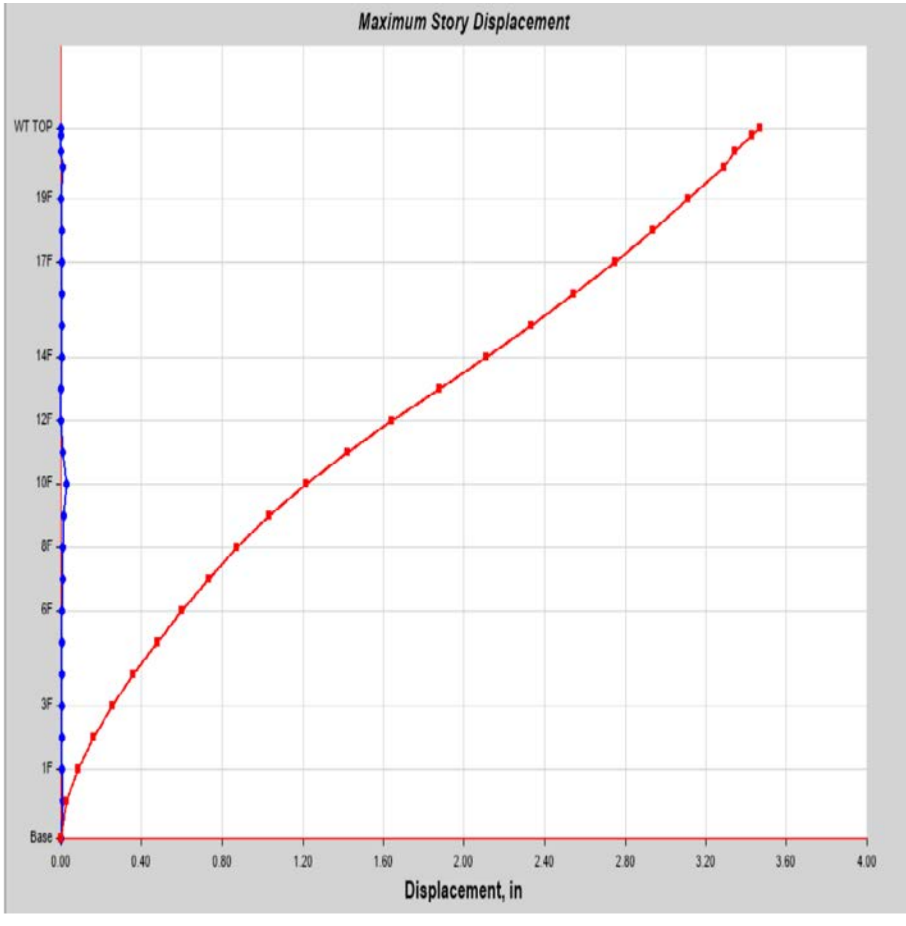




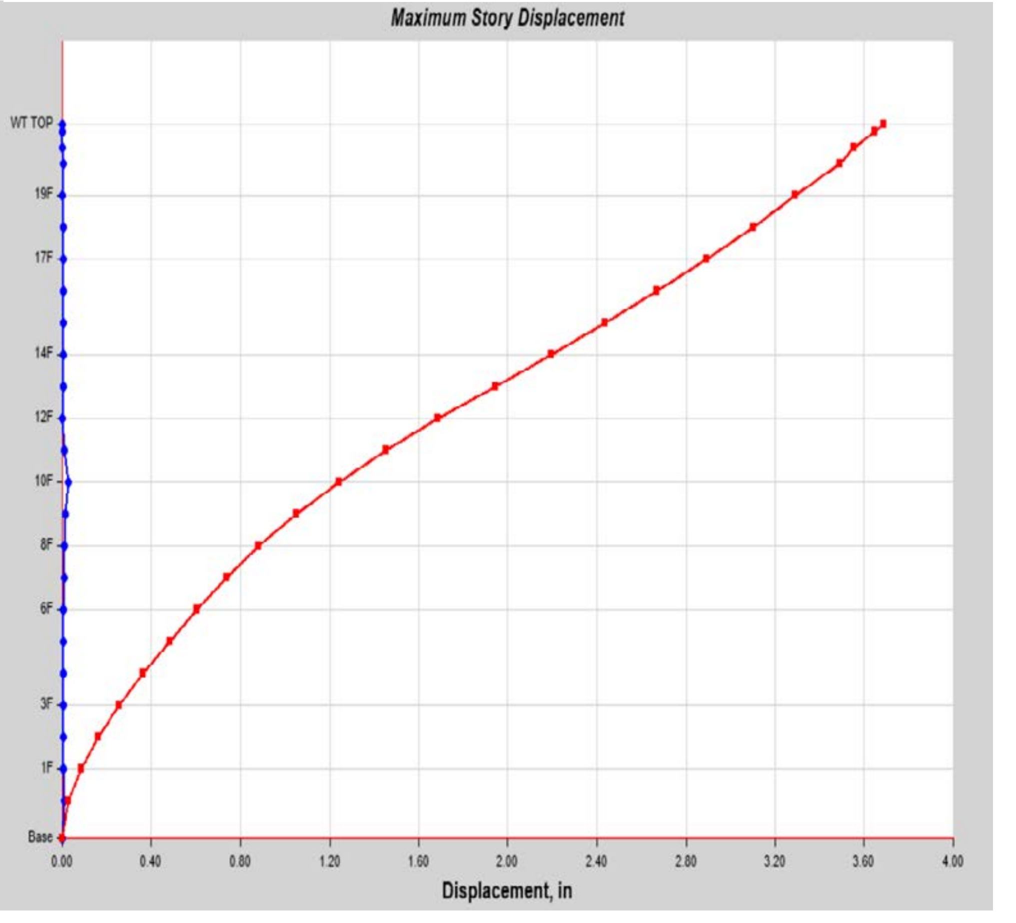
Braced Structure

Non-Braced Structure

Figure 4.16a: Maximum Story Displacement due to Wind loads in +X direction



Braced Structure



Non-Braced Structure

Figure 4.16b: Maximum Story Displacement due to Wind loads in +Y direction

Table 4.16a: Story Displacement due to Wind loads in +X direction.

Story	Braced	Non-Braced
	Displacement inch	**Displacement inch**
WT	2.78	2.98
Roof top	2.64	2.84
19th Floor	2.53	2.72
18th Floor	2.41	2.58
17th Floor	2.27	2.42
16th Floor	2.12	2.25
15th Floor	1.96	2.07
14th Floor	1.79	1.88
13th Floor	1.61	1.68
12th Floor	1.42	1.46
11th Floor	1.24	1.28
10th Floor	1.07	1.10
9th Floor	0.92	0.94
8th Floor	0.78	0.79
7th Floor	0.66	0.67
6th Floor	0.55	0.55
5th Floor	0.44	0.44
4th Floor	0.33	0.33
3rd Floor	0.24	0.24
2nd Floor	0.15	0.15
1st Floor	0.08	0.08
GF	0.02	0.02
Base	0	0

Table 4.16b: Story Displacement due to Wind loads in +Y direction

Story	Braced	Non-Braced
	Displacement inch	Displacement inch
WT	3.47	3.68
Roof top	3.29	3.49
19th Floor	3.10	3.29
18th Floor	2.93	3.10
17th Floor	2.74	2.89
16th Floor	2.54	2.66
15th Floor	2.33	2.43
14th Floor	2.10	2.19
13th Floor	1.87	1.94
12th Floor	1.63	1.68
11th Floor	1.41	1.45
10th Floor	1.21	1.24
9th Floor	1.03	1.04
8th Floor	0.87	0.88
7th Floor	0.73	0.73
6th Floor	0.59	0.60
5th Floor	0.47	0.48
4th Floor	0.35	0.36
3rd Floor	0.25	0.25
2nd Floor	0.16	0.16
1st Floor	0.08	0.08
GF	0.02	0.02
Base	0	0

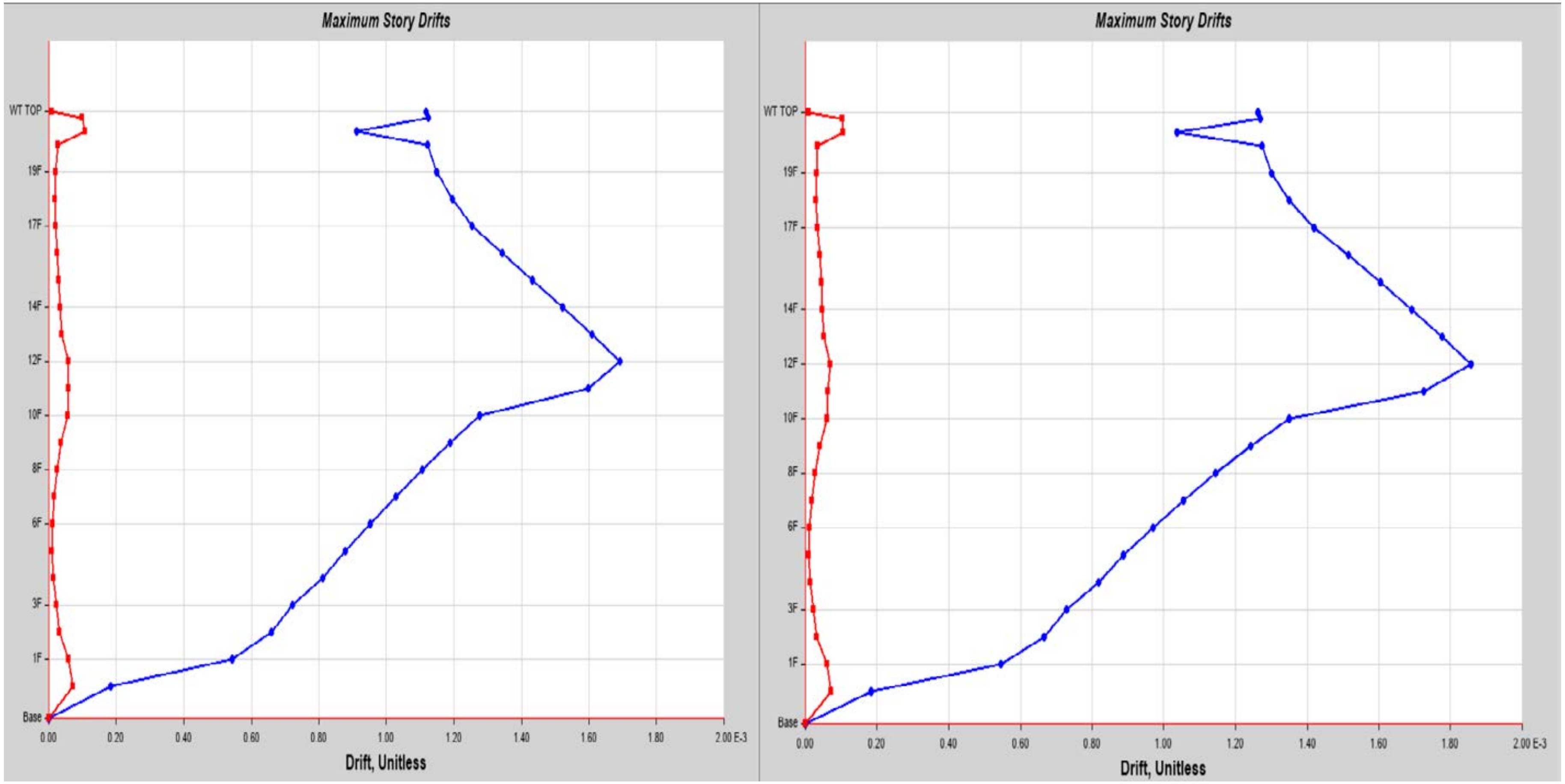
Findings: From Tables 4.16a and 4.16b, it is observed that Braced can resist higher displacements compared to that of the Non-Braced Structure.

3] Maximum Story Drifts:

Figures 4.17(a ~b) illustrated below provide information about the response maximum story drifts. Here the horizontal axis represents drifts and the vertical axis represents the number of the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story drifts of Braced and Non-Braced in X and Y direction are clearly shown in Tables 4.17(a ~b) respectively.

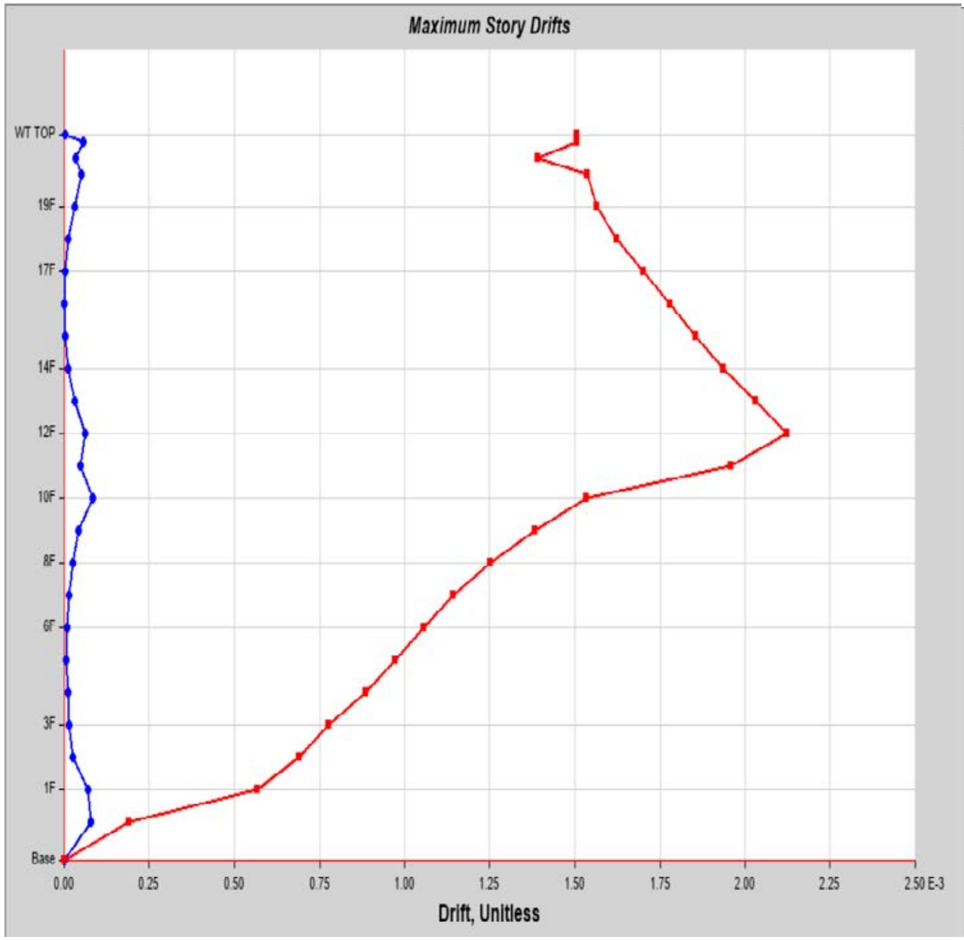
From figure it is clearly seen that, the story drift forms a parabolic shape with zero drift at bottom, increases toward mid and finally decreases again at top. Maximum story drifts are the ratio of displacement between two consecutive floors. Curve starts from base with zero value and sharply rises to 13^{th}story and then gradually decreases to 20^{th} story in WX and rapidly goes to 13^{th} story and then gradually decreases to 20^{th} story in WY.

Story drifts value increases due to increase of displacement and suddenly decreases due to decrease of lower floor area.

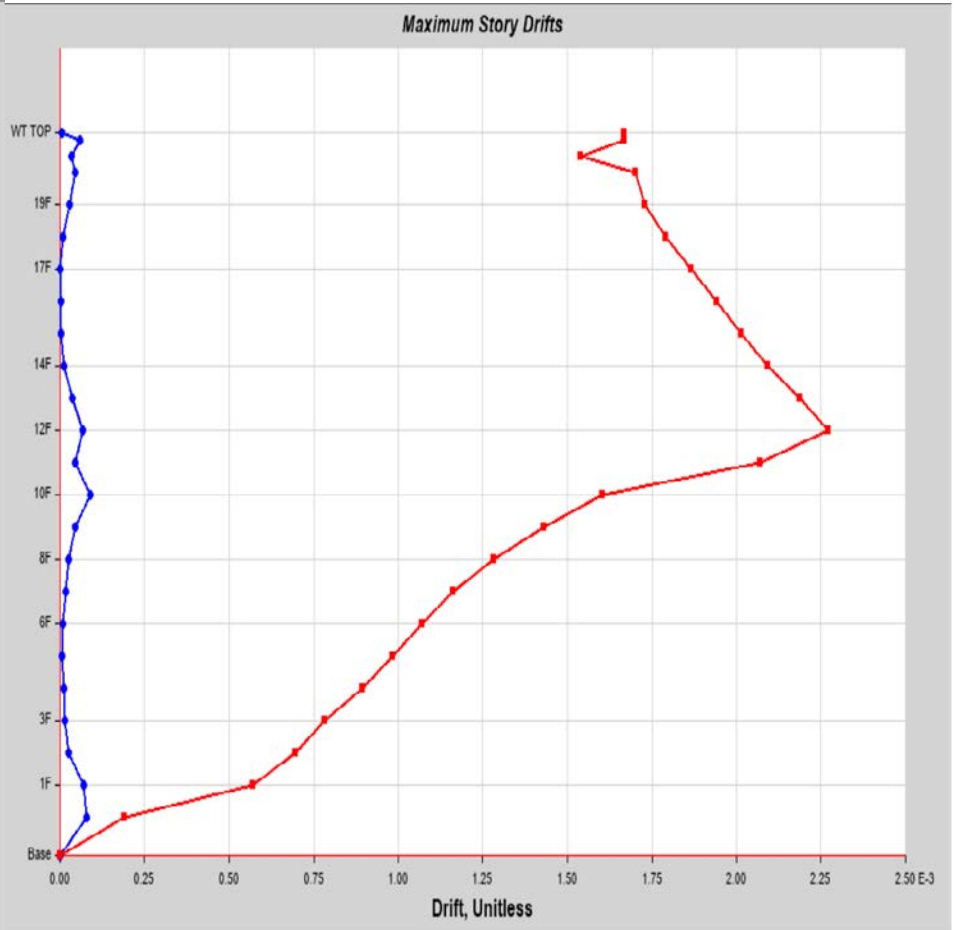


Braced Structure Non-Braced Structure

Figure 4.17a: Maximum Story Drifts due to Wind loads in +X direction



Braced Structure



Non-Braced Structure

Figure 4.17b: Maximum Story Drifts due to Wind loads in +Y direction

Table 4.17a: Maximum Story Drifts in +X direction.

Story	**Braced**	**Non-Braced**
	Story drift	**Story drift**
WT	0.0011	0.0012
Roof top	0.0011	0.0012
19th Floor	0.0011	0.0013
18th Floor	0.0011	0.0013
17th Floor	0.0012	0.0014
16th Floor	0.0013	0.0015
15th Floor	0.0014	0.0016
14th Floor	0.0015	0.0016
13th Floor	0.0016	0.0017
12th Floor	0.0016	0.0018
11th Floor	0.0015	0.0017
10th Floor	0.0012	0.0013
9th Floor	0.0011	0.0012
8th Floor	0.0011	0.0011
7th Floor	0.0010	0.0010
6th Floor	0.0009	0.0009
5th Floor	0.0008	0.0008
4th Floor	0.0008	0.0008
3rd Floor	0.0007	0.0007
2nd Floor	0.0006	0.0006
1st Floor	0.0005	0.0005
GF	0.0001	0.0001
Base	0	0

Table 4.17b: Maximum Story Drifts in +Y direction

Story	Braced	Non-Braced
	Story drift	Story drift
WT	0.0015	0.0016
Roof top	0.0015	0.0017
19th Floor	0.0015	0.0017
18th Floor	0.0016	0.0017
17th Floor	0.0017	0.0018
16th Floor	0.0017	0.0019
15th Floor	0.0018	0.0020
14th Floor	0.0019	0.0020
13th Floor	0.0020	0.0021
12th Floor	0.0021	0.0022
11th Floor	0.0019	0.0020
10th Floor	0.0015	0.0016
9th Floor	0.0013	0.0014
8th Floor	0.0012	0.0012
7th Floor	0.0011	0.0011
6th Floor	0.0010	0.0010
5th Floor	0.0009	0.0009
4th Floor	0.0008	0.0008
3rd Floor	0.0007	0.0007
2nd Floor	0.0006	0.0006
1st Floor	0.0005	0.0005
GF	0.0001	0.0001
Base	0	0

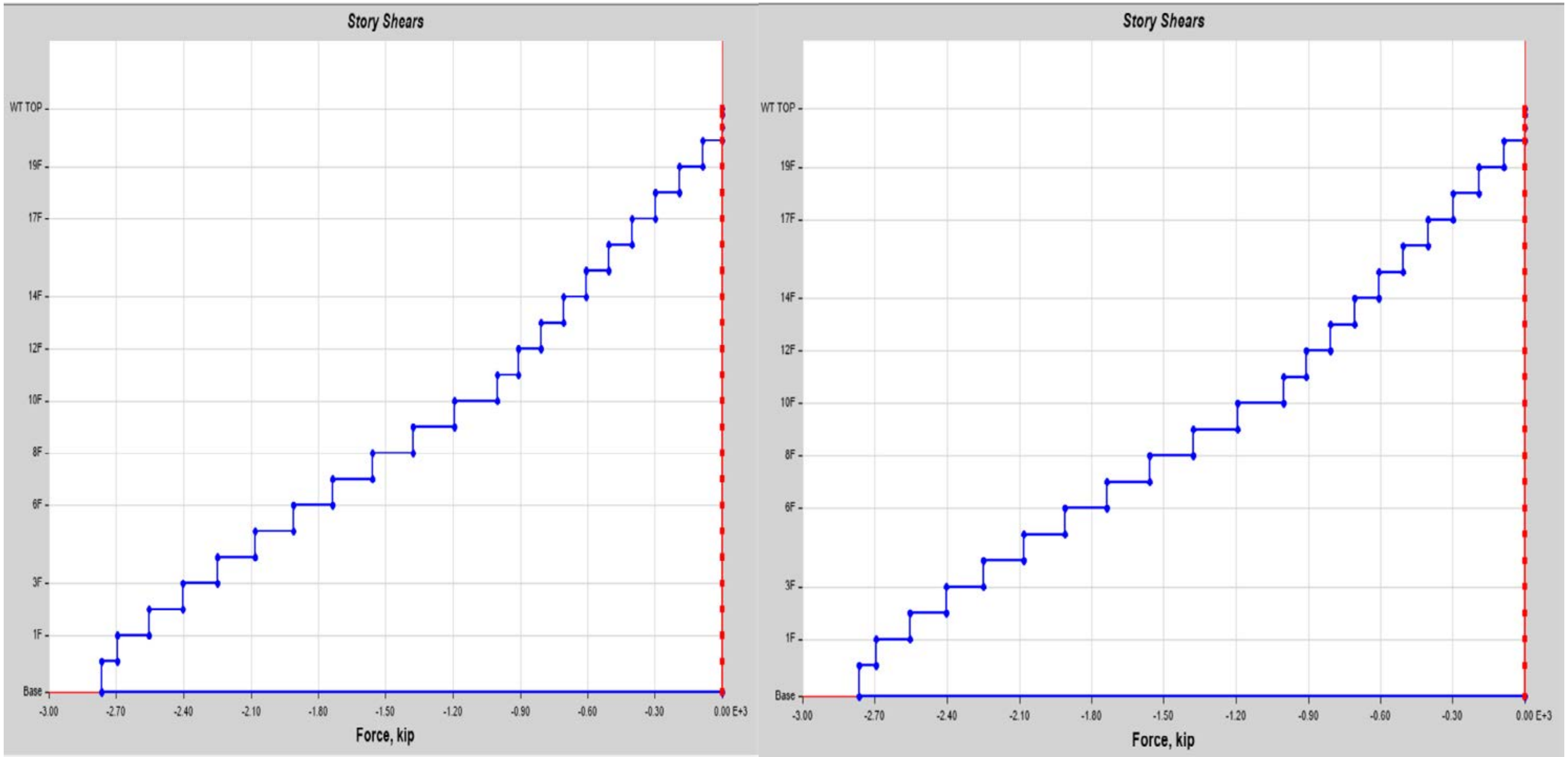
Findings: From Tables 4.17a and 4.17b, it is observed that Braced can resist higher displacements compared to that of the Non-Braced Structure.

4] Story Shears:

Figures 4.18(a ~b) illustrated below provide information about the response for story shears. Here the horizontal axis represents story shear in kips and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story shears of Braced and Non-Braced Structure in X and Y direction are clearly shown in Tables 4.18(a ~b) respectively.

From figure it is clearly seen that, response curves are symmetric in both Braced Structure and Non-Braced Structure in WY and in WX. It is also shown that Non-Braced structure can withstand greater story shear force compared to Braced structure.

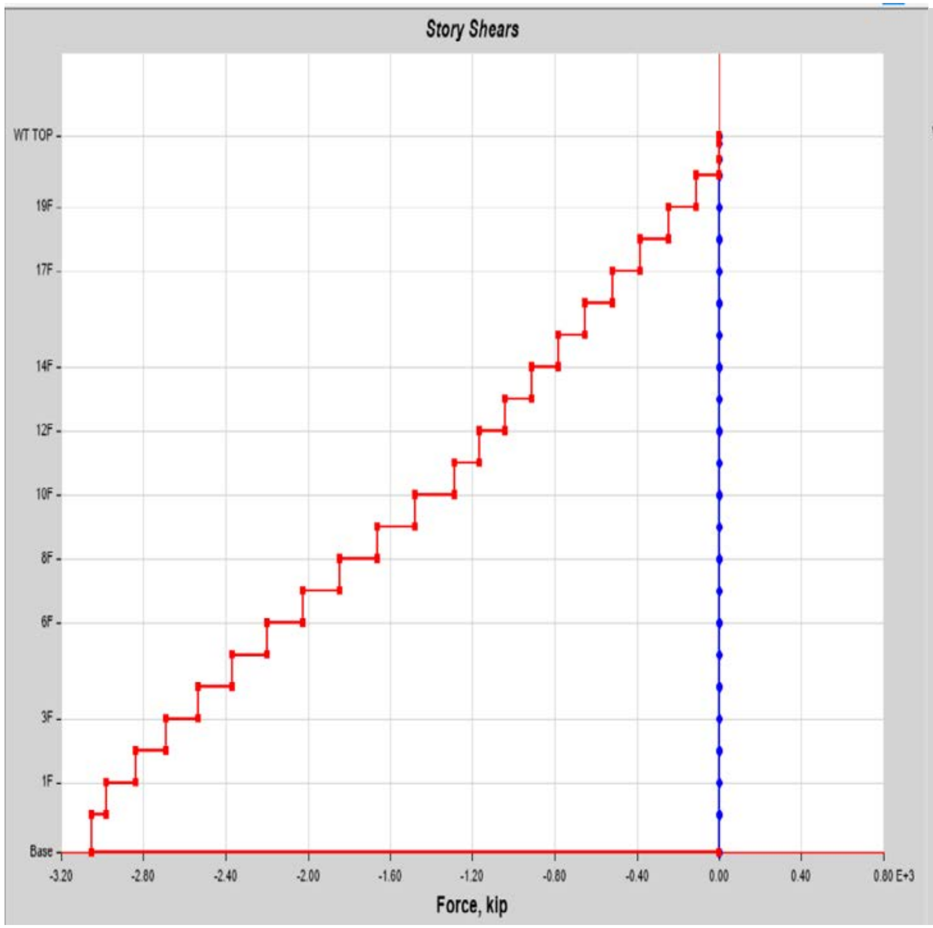
It shows that the story shear resisting capacity is higher at base due to strong basement. Shear resisting capacity is decreasing from bottom to top (Due to wind load impact) And its value is negative against given load.



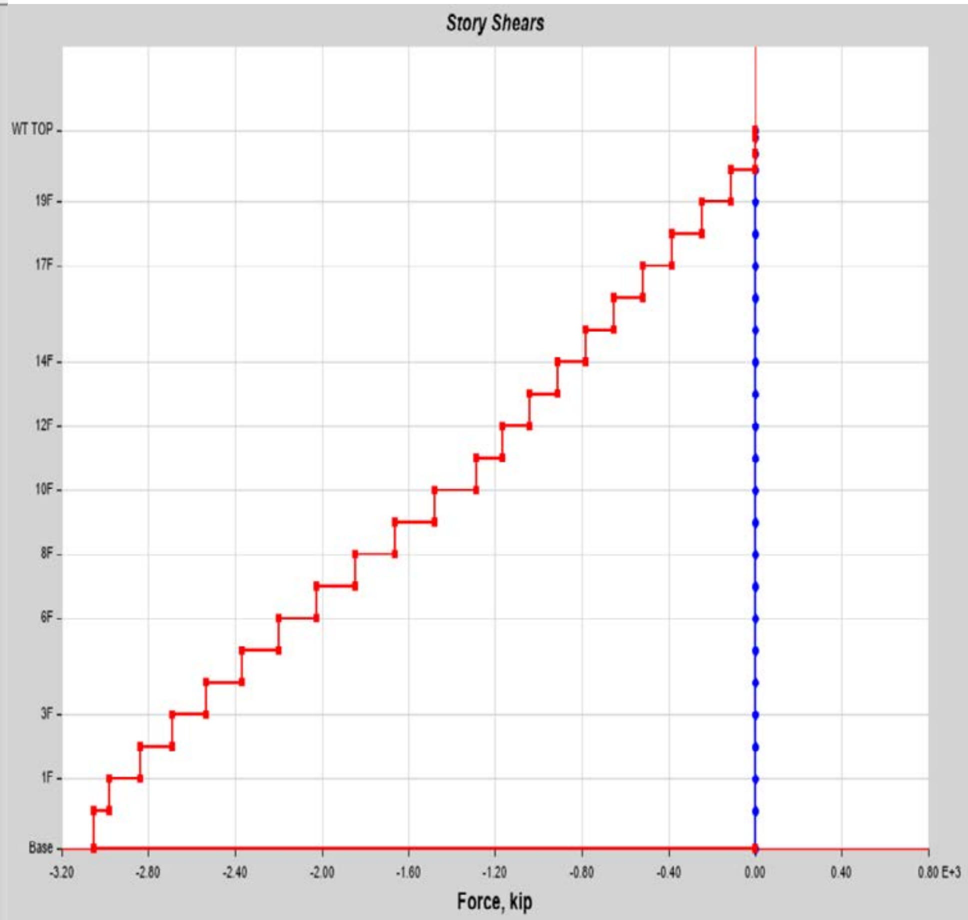
Braced Structure

Non-Braced Structure

Figure 4.18a: Story Shears due to Wind loads in +X direction.



Braced Structure



Non-Braced Structure

Figure 4.18b: Story Shears due to Wind loads in +Y direction

Table 4.18a: Story Shears in +X direction.

Story	Braced	Non-Braced
	Shear resisted at each story kip	Shear resisted at each story kip
WT	0	0
Roof top	-87.10	-87.10
19th Floor	-192.57	-192.57
18th Floor	-298.04	-298.04
17th Floor	-403.52	-403.52
16th Floor	-506.61	-506.61
15th Floor	-607.33	-607.33
14th Floor	-708.04	-708.04
13th Floor	-808.76	-808.76
12th Floor	-907.09	-907.09
11th Floor	-1003.06	-1003.06
10th Floor	-1191.94	-1191.94
9th Floor	-1377.81	-1377.81
8th Floor	-1559.77	-1559.77
7th Floor	-1737.85	-1737.85
6th Floor	-1912.03	-1912.03
5th Floor	-2082.33	-2082.33
4th Floor	-2247.86	-2247.86
3rd Floor	-2404.74	-2404.74
2nd Floor	-2552.87	-2552.87
1st Floor	-2695.16	-2695.16
GF	-2766.03	-2766.03
Base	0	0

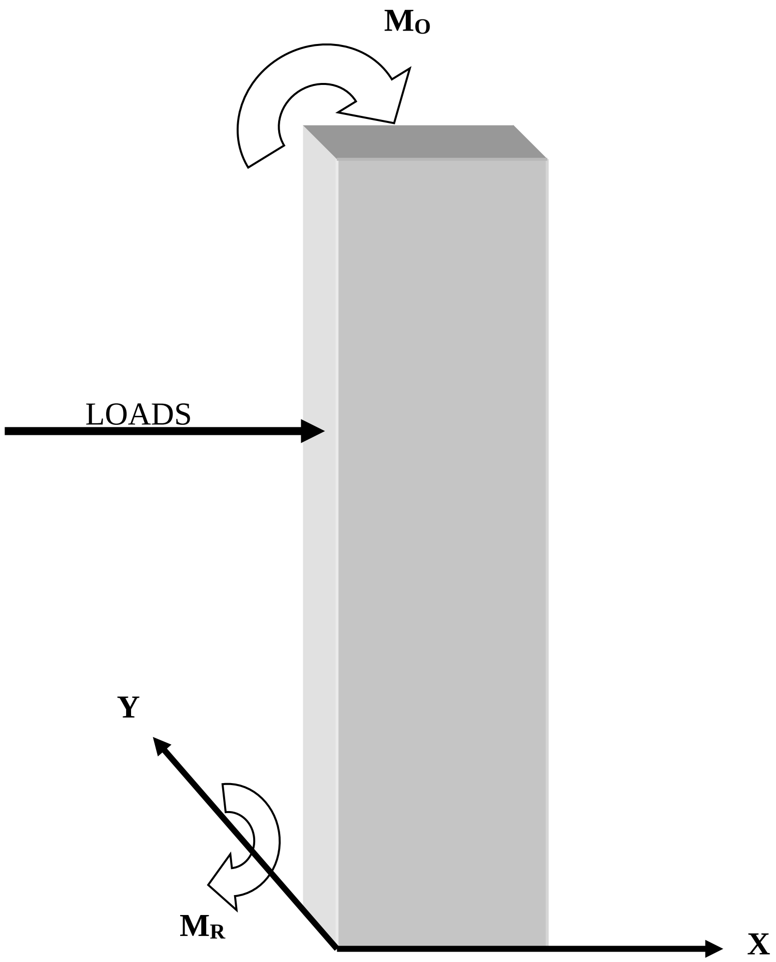
Table 4.18b: Story Shears in +Y direction

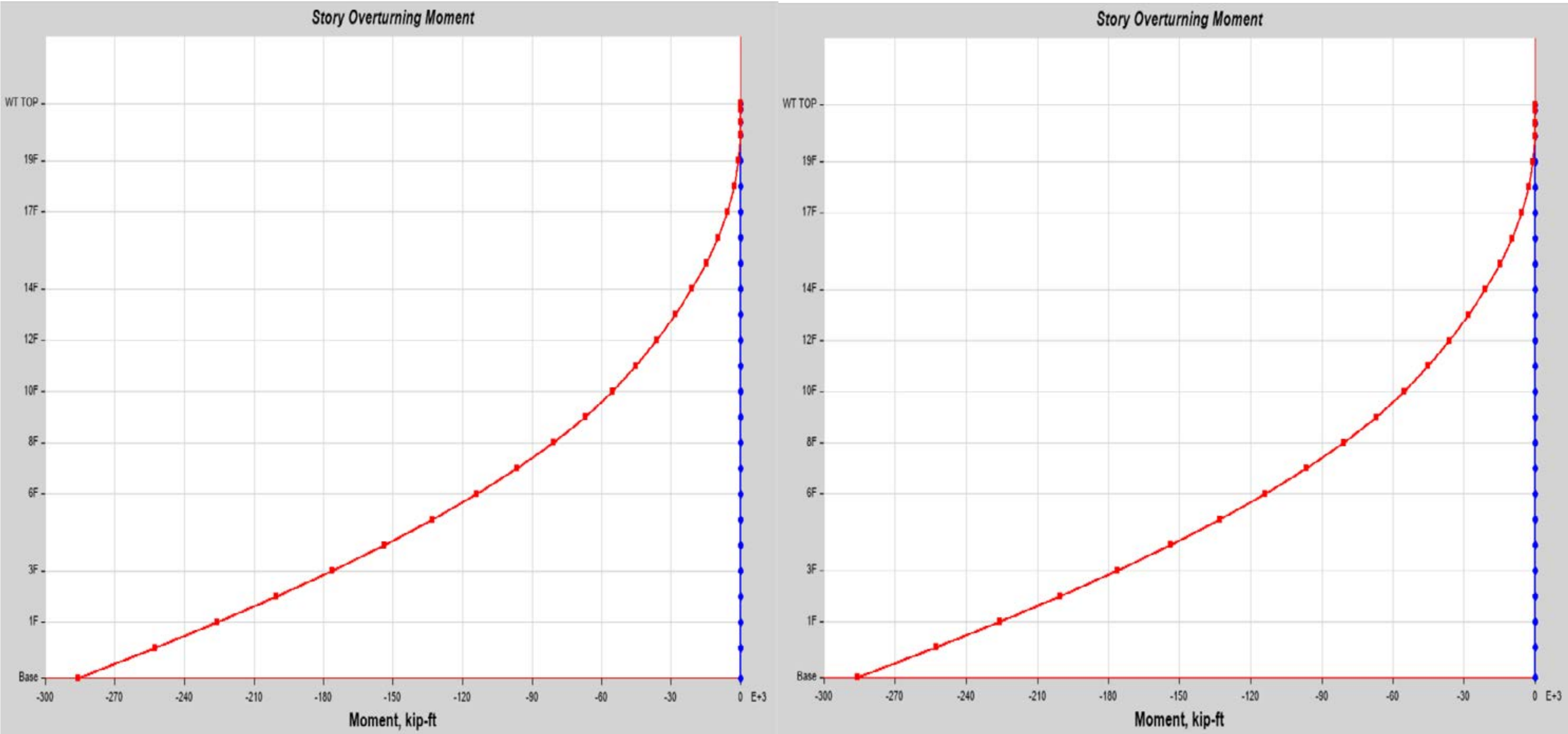
Story	**Braced**	**Non-Braced**
	Shear resisted at each story kip	**Shear resisted at each story kip**
WT	0	0
Roof top	-111.92	-111.92
19th Floor	-247.44	-247.44
18th Floor	-382.97	-382.97
17th Floor	-518.50	-518.50
16th Floor	-650.97	-650.97
15th Floor	-780.38	-780.38
14th Floor	-909.8	-909.8
13th Floor	-1039.21	-1039.21
12th Floor	-1165.57	-1165.57
11th Floor	-1288.87	-1288.87
10th Floor	-1477.76	-1477.76
9th Floor	-1663.62	-1663.62
8th Floor	-1845.59	-1845.59
7th Floor	-2023.67	-2023.67
6th Floor	-2197.85	-2197.85
5th Floor	-2368.14	-2368.14
4th Floor	-2533.68	-2533.68
3rd Floor	-2690.56	-2690.56
2nd Floor	-2838.69	-2838.69
1st Floor	-2980.98	-2980.98
GF	-3051.85	-3051.85
Base	0	0

5] Resisting Story Overturning Moments [M_R]:

Figures 4.19(a ~b) illustrated below provide information about the response for story overturning moments. Here the horizontal axis represents overturning moments in kip-inch and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story overturning moments of Braced and Non-Braced Structure in X and Y direction are clearly shown in Tables 4.19 (a ~b) respectively.

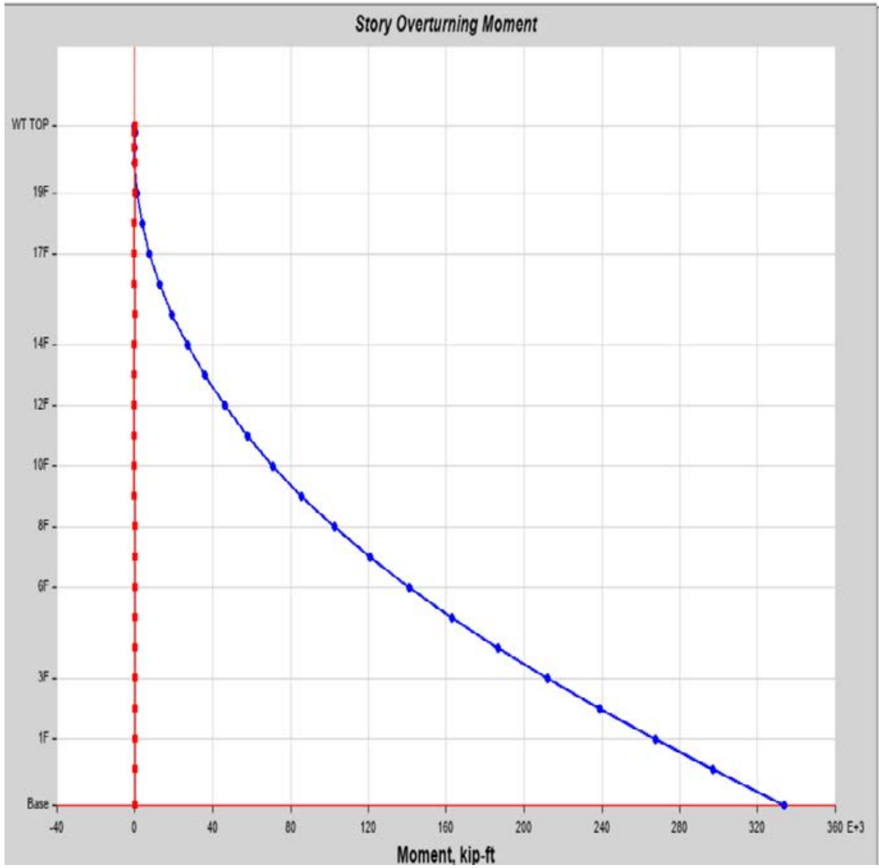
From figure it is clearly seen that, curve starts from base with its peak value and sharply goes down to 20th story in both WX and WY. It is noted here that due to lateral loads in X-direction, the whole structure will resist its overturn with respect to Y-axis and creates a resisting overturning moment M_R with respect to Y-axis as shown in figure below. Similar case can be explained for loads in Y-direction. However, it is shown that Braced structure can withstand greater story overturning compared to Non-Braced structure.

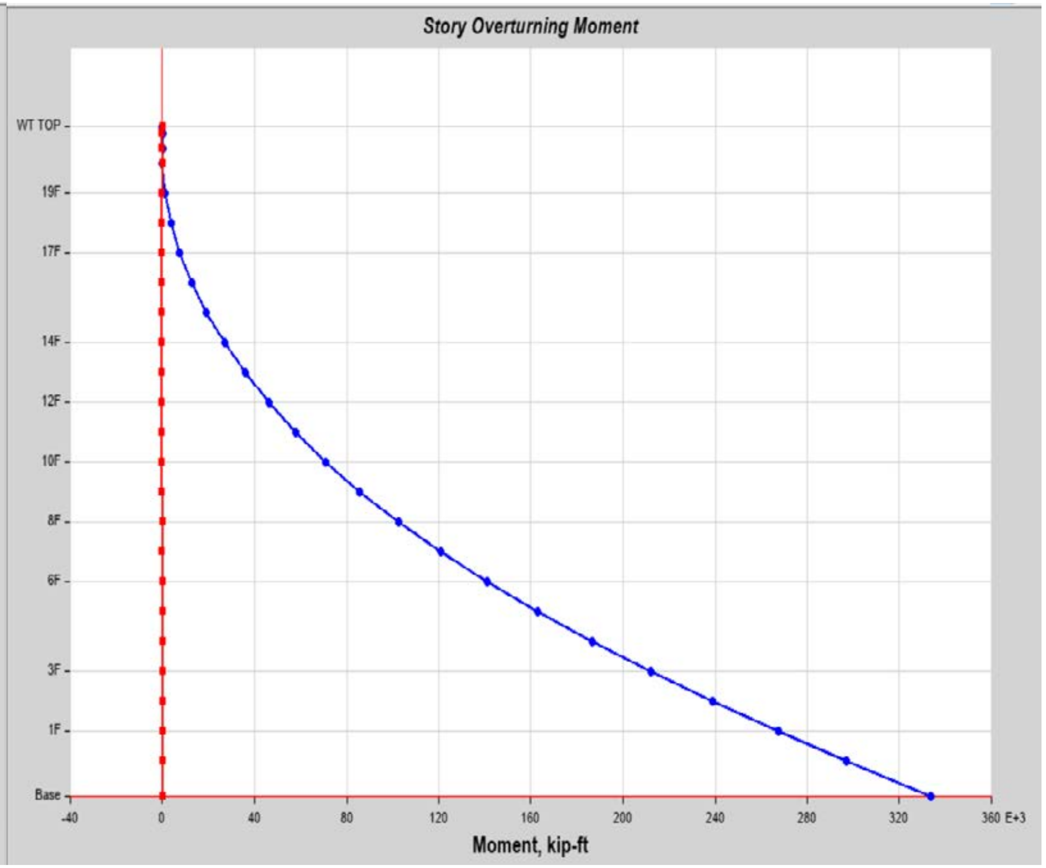




Braced Structure   Non-Braced Structure

Figure 4.19a: Overturning Moments due to Wind loads Story in +X direction.





Braced Structure

Non-Braced Structure

Figure 4.19b: Overturning Moments due to Wind loads Story in +Y direction.

Table 4.19a: Overturning Moments in +X direction.

Story	Braced	Non-Braced
	Resisting overturning moment kip-feet	**Resisting overturning moment kip-feet**
WT	0	0
Roof top	0	0
19th Floor	-871.02	-871.02
18th Floor	-2796.78	-2796.78
17th Floor	-5777.26	-5777.26
16th Floor	-9812.47	-9812.47
15th Floor	-14878.62	-14878.62
14th Floor	-20951.92	-20951.92
13th Floor	-28032.37	-28032.37
12th Floor	-36119.98	-36119.98
11th Floor	-45190.95	-45190.95
10th Floor	-55221.51	-55221.51
9th Floor	-67140.95	-67140.95
8th Floor	-80919.00	-80919.00
7th Floor	-96516.73	-96516.73
6th Floor	-113895.23	-113895.23
5th Floor	-133015.58	-133015.57
4th Floor	-153838.83	-153838.83
3rd Floor	-176317.43	-176317.43
2nd Floor	-200364.88	-200364.88
1st Floor	-225893.59	-225893.59
GF	-252845.18	-252845.18
Base	-286037.57	-286037.57

Table 4.19b: Overturning Moments in +Y direction.

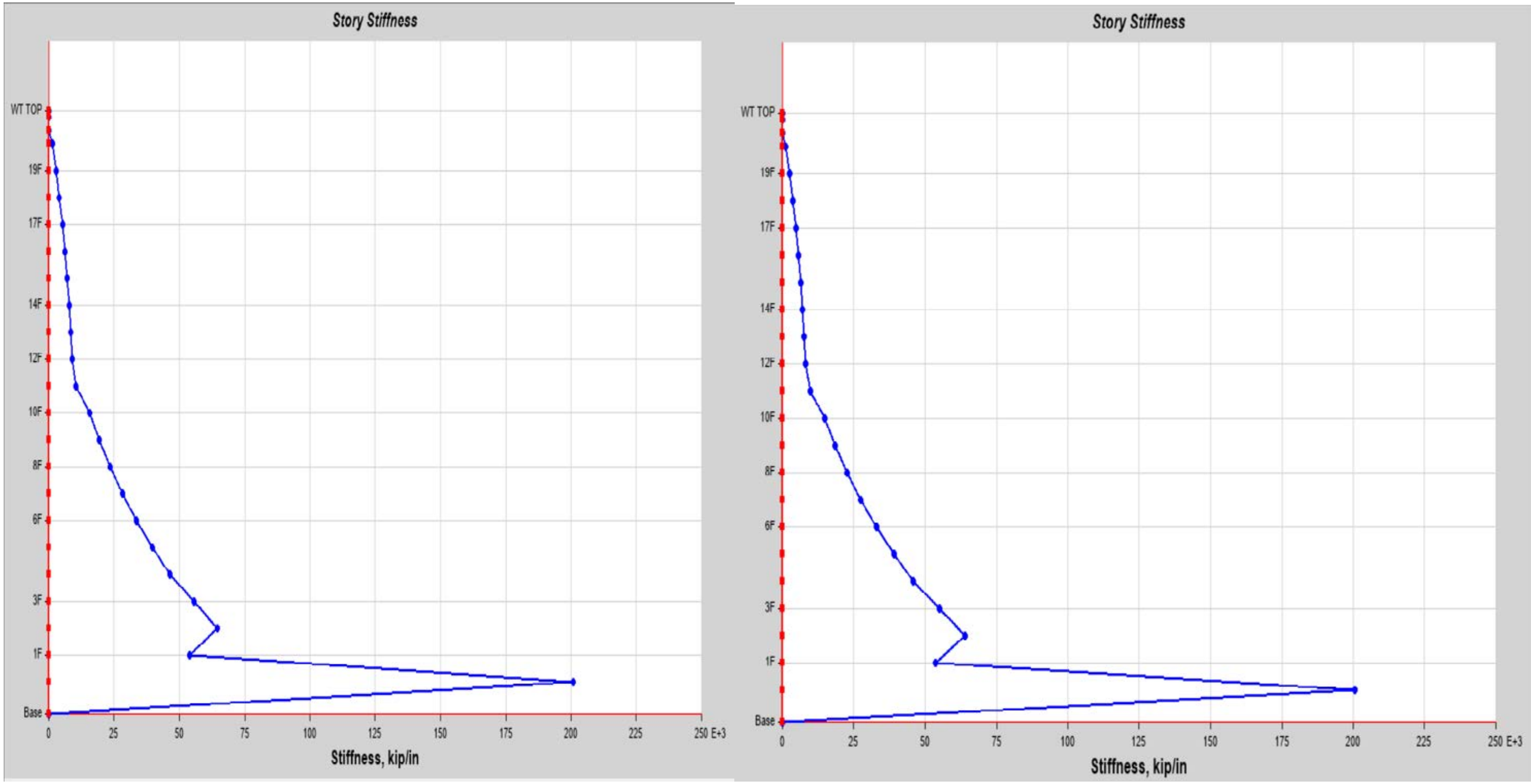
Story	Braced	Non-Braced
	Resisting overturning moment kip-feet	**Resisting overturning moment kip-feet**
WT	0	0
Roof top	0	0
19th Floor	1119.22	1119.22
18th Floor	3593.71	3593.71
17th Floor	7423.47	7423.47
16th Floor	12608.49	12608.49
15th Floor	19118.22	19118.22
14th Floor	26922.09	26922.09
13th Floor	36020.09	36020.09
12th Floor	46412.23	46412.23
11th Floor	58067.95	58067.95
10th Floor	70956.67	70956.67
9th Floor	85734.28	85734.28
8th Floor	102370.49	102370.49
7th Floor	120826.40	120826.40
6th Floor	141063.07	141063.07
5th Floor	163041.58	163041.58
4th Floor	186723.01	186723.01
3rd Floor	212059.77	212059.77
2nd Floor	238965.39	238965.39
1st Floor	267352.27	267352.27
GF	297162.03	297162.03
Base	333784.22	333784.22

6] Story Stiffness:

Figures 4.20(a ~b) illustrated below provide information about the response for story stiffness. Here the horizontal axis represents story stiffness in kip-inch and the vertical axis represents the stories of the building. Blue curves state the response due to lateral loads implying in X direction of the model and red curves in Y direction. Also, comparisons between responses about story stiffness of Braced and Non-Braced Structure in X and Y direction are clearly shown in Tables 4.20(a ~b) respectively.

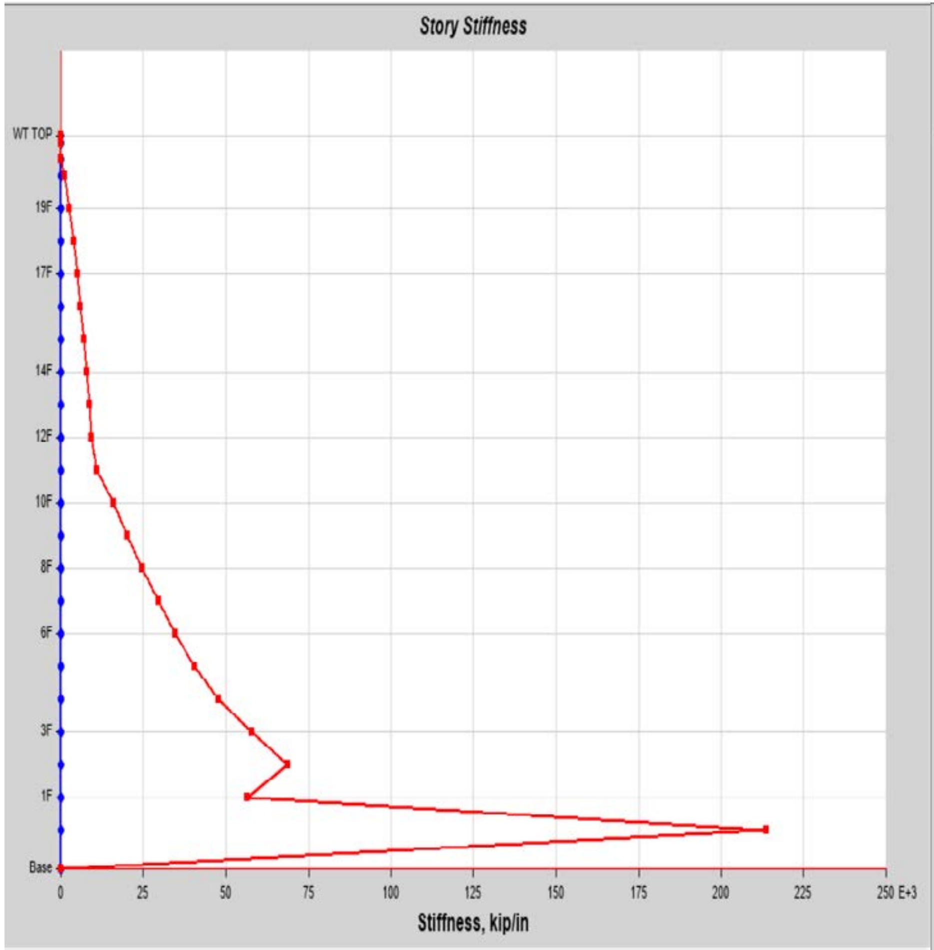
From figure it is clearly seen that, Non-Braced structure has lower stiffness compared to Braced structure.

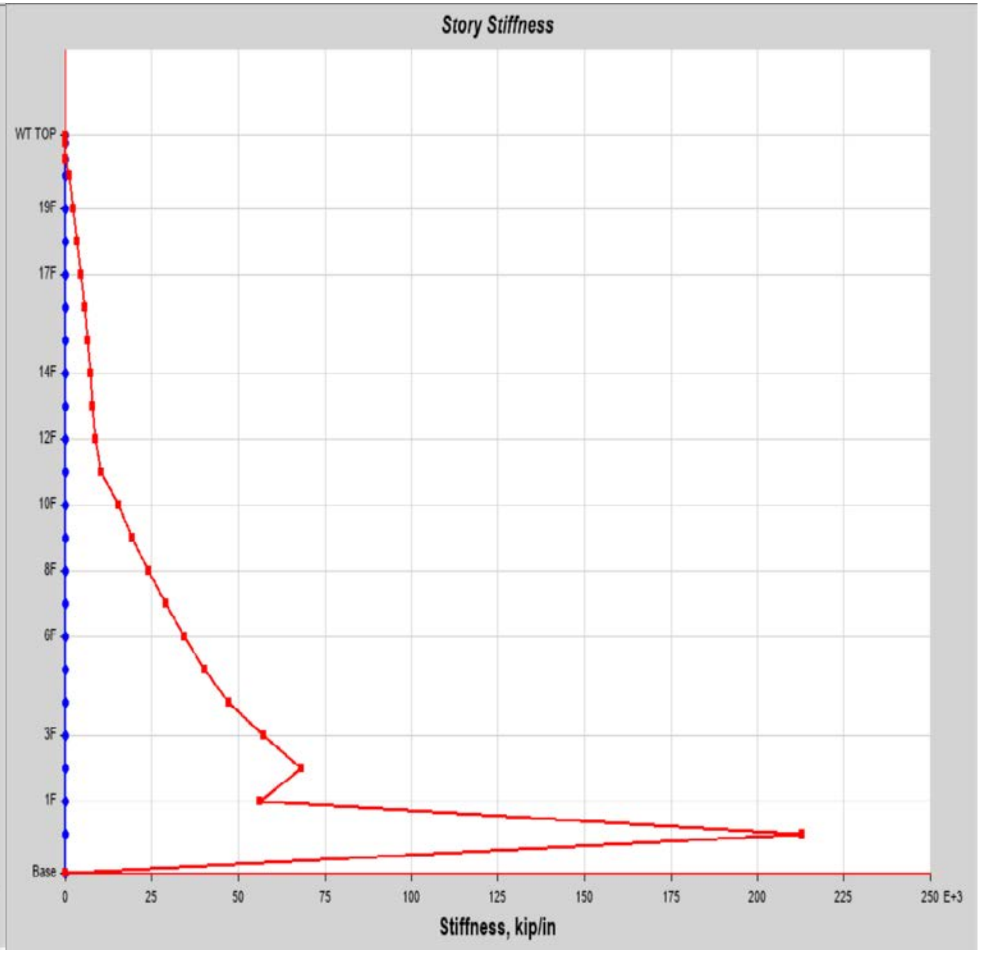
It shows that story stiffness value is maximum at ground floor. Stiffness value decreases at 1st floor because of sudden shock and increase again 2nd floor then gradually stiffness value decreases from 2nd floor to Roof top (due to Wind load impact)



Braced Structure Non-Braced Structure

Figure 4.20a: Story Stiffness due to Wind loads in +X direction.





Braced Structure

Non-Braced Structure

Figure 4.20b: Story Stiffness due to Wind loads in +Y direction.

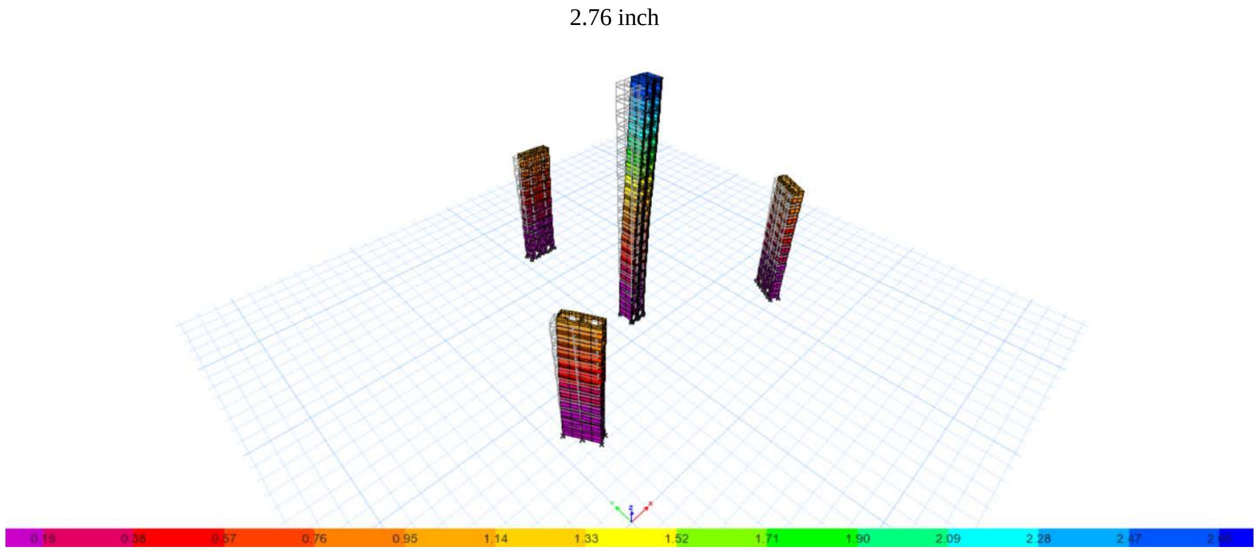
Table 4.20a: Story Stiffness in +X direction

Story	Braced	Non-Braced
	Stiffness of each story kip/in	**Stiffness of each story kip/in**
WT	0	0
Roof top	1277.47	1126.85
19th Floor	2729.04	2413.19
18th Floor	4029.92	3578.94
17th Floor	5189.10	4633.60
16th Floor	6207.28	5573.59
15th Floor	7062.27	6309.00
14th Floor	7754.35	6974.36
13th Floor	8380.09	7584.38
12th Floor	8940.69	8145.23
11th Floor	10460.52	9684.56
10th Floor	15577.50	14722.26
9th Floor	19318.65	18478.72
8th Floor	23503.00	22724.69
7th Floor	28159.71	27470.44
6th Floor	33471.60	32880.43
5th Floor	39565.92	39075.45
4th Floor	46241.55	45749.92
3rd Floor	55585.27	55082.58
2nd Floor	64449.77	63949.62
1st Floor	53862.77	53718.88
GF	200938.44	200532.76
Base	0	0

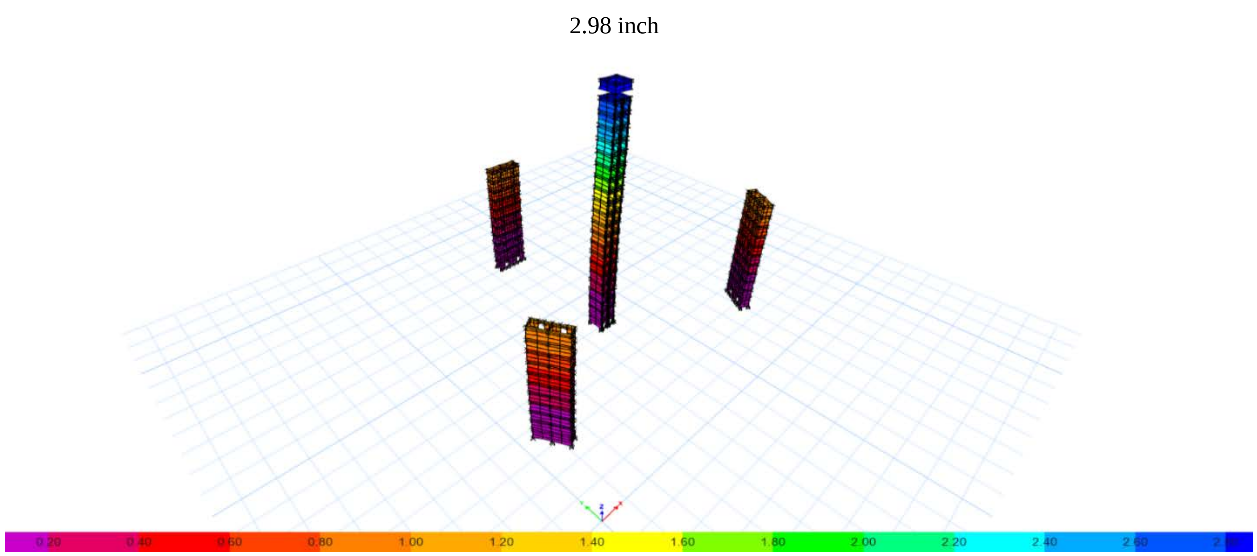
Table 4.20b: Story Stiffness in +Y direction.

Story	Braced	Non-Braced
	Stiffness of each story kip/in	**Stiffness of each story kip/in**
WT	0	0
Roof top	1205.67	1089.56
19th Floor	2577.29	2334.58
18th Floor	3816.51	3470.76
17th Floor	4937.39	4512.63
16th Floor	5962.81	5480.56
15th Floor	6967.43	6442.52
14th Floor	7833.38	7250.88
13th Floor	8527.33	7923.74
12th Floor	9156.41	8551.43
11th Floor	10972.54	10380.32
10th Floor	16046.67	15360.24
9th Floor	20059.94	19396.07
8th Floor	24592.13	23996.88
7th Floor	29526.70	29025.02
6th Floor	34653.20	34226.59
5th Floor	40625.45	40176.36
4th Floor	47681.09	47216.70
3rd Floor	57737.86	57254.94
2nd Floor	68580.11	68134.97
1st Floor	56362.81	56132.53
GF	213578.13	212966.69
Base	0	0

4.2.6 Deformed Shape of Lift Core due to Wind Loads



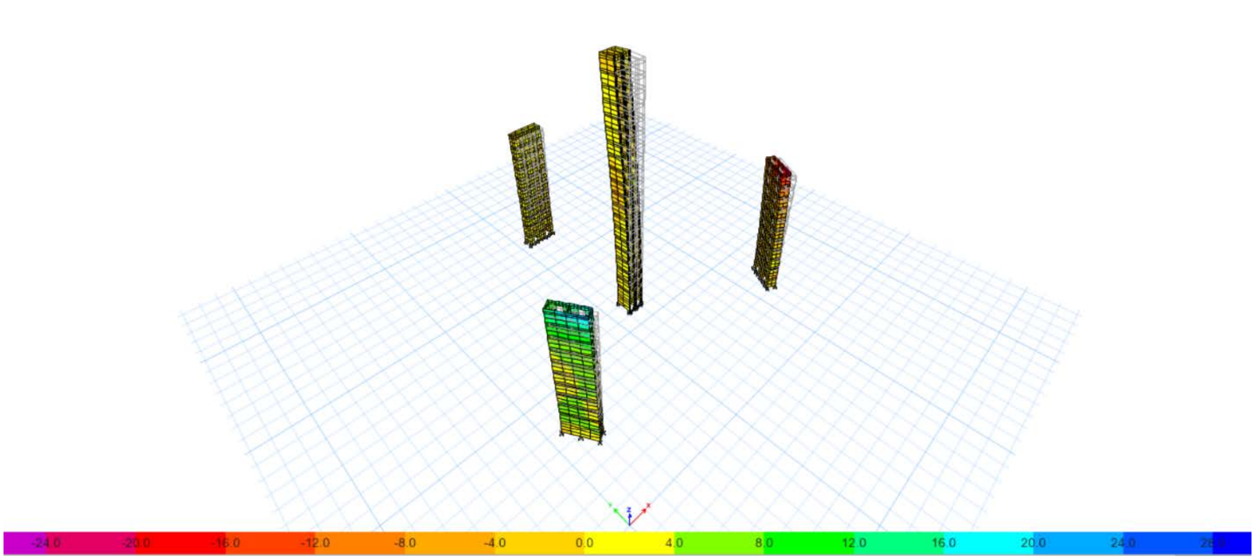
Braced Structure



Non-Braced Structure

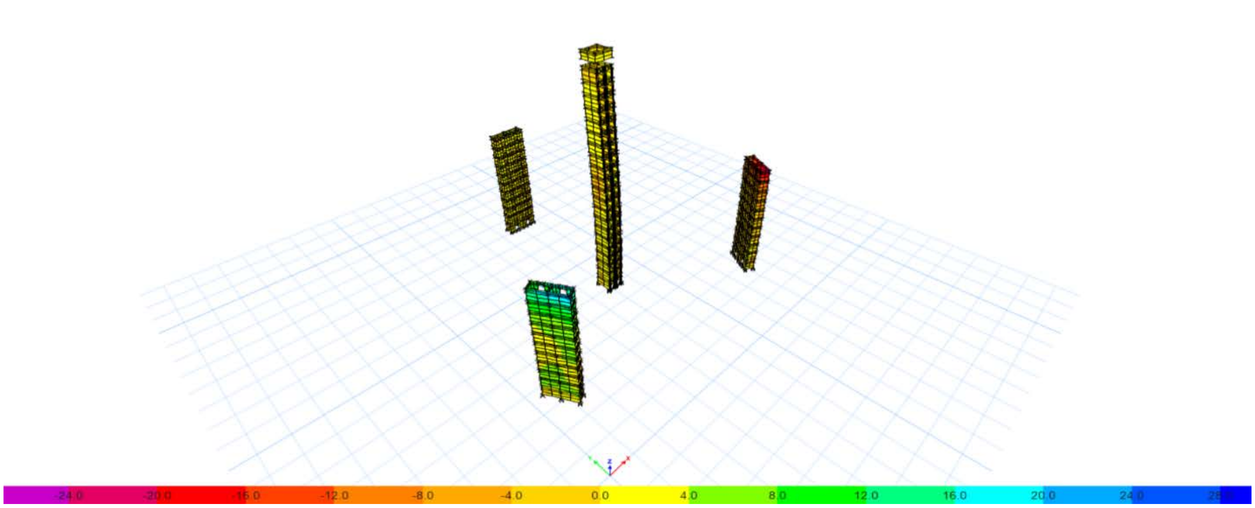
Figure 4.22a: Deformed shape of lift core due to Wind in +X direction

2.46 inch



Braced Structure

3.69 inch



Non-Braced Structure

Figure 4.22b: Deformed shape of lift core due to Wind in +Y direction

4.2.7 Common Table Contents

Table 4.21a: Base Reaction, Forces

Load Case	FX kip		FY kip		FZ kip	
	Braced	Non-Braced	Braced	Non-Braced	Braced	Non-Braced
Dead	0	0	0	0	105577.38	103987.11
Live	0	0	0	0	84104.43	84104.43
EQ+X	-4834.12	-4787.93	0	0	0	0
EQ-X	-4834.12	-4787.93	0	0	0	0
EQ+Y	0	0	-4834.12	4787.93	0	0
EQ-Y	0	0	-4834.12	-4787.93	0	0
Wind +X	-2766.03	-2766.03	0	0	0	0
Wind +Y	0	0	-3051.85	-3051.85	0	0

From this Table 4.21a, it is observed that Braced Structure can resist more base reactions due to dead, live, EQ and wind loadings compared to Non-Braced Structure.

Table 4.21b: Base Reaction, Moments

Load Case	**MX** kip-feet		**MY** kip-feet		**MZ** kip-feet	
	Braced	**Non-Braced**	**Braced**	**Non-Braced**	**Braced**	**Non-Braced**
Dead	13081467	12884274	-13091373	-12894381	0	0
Live	10409375	10409375	-10428949	-10428949	0	0
EQ+X	0	0	-626579.31	-617076.79	641292.06	635357.46
EQ-X	0	0	-626579.31	-617076.79	555414.00	549875.42
EQ+Y	626579.30	617076.79	0	0	-646693.8	-640668.23
EQ-Y	626579.30	617076.70	0	0	-552145.9	-546738.32
Wind +X	0	0	-286037.57	-286037.5	342988.08	342988.08
Wind +Y	-378429.37	333784.22	0	0	-378429.3	-378429.37

From this Table 4.21b, it is observed that Braced Structure can resist more base overturning moments due to dead, live, EQ and wind loadings compared to Non-Braced Structure.

Table 4.22: Comparison Table

Topic	Story Level	Braced		Non Braced	
		WIND+X	WIND+Y	WIND+X	WIND+Y
Lateral Loads to Stories (kip)	GF	70.87	70.87	70.87	70.87
	Top Floor	87.10	111.92	87.10	111.92
Maximum Story Displacement (inch)	GF	0.02	0.02	0.02	0.02
	Top Floor	2.64	3.29	2.84	3.49
Maximum Story Drifts	GF	0.0001	0.0001	0.0001	0.0001
	Top Floor	0.0011	0.0015	0.0012	0.0017
Story Shears (kip)	GF	-2766.03	3051.85	-2766.03	3051.85
	Top Floor	-87.10	111.92	-87.10	111.92
Story Overturning Moment (k-in)	Basement	286037.57	333784.22	286037.57	333784.22
Story Stiffness (kip/in)	GF	200938.44	213578.13	200532.76	212966.69
	Top Floor	1277.47	1205.67	1126.85	1089.56

From summary Table 4.22, it can be justified that Braced structure is the best one against lateral loadings with compared to Non-Braced structure.

CHAPTER 5
CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

From the analysis & findings, it can be concluded that:

Based on EQ [Table 4.13a, 4.13b & 4.14]

- Non-Braced structure shows 7.04% greater top story displacement at top floor due to earthquake effects compared to Braced structure.
- Braced structure can resist 1.54% higher story overturning moment at base due to earthquake effects compared to Non-Braced structure.
- Braced structure can resist 0.96% higher story shear at GF and 1.08% more lateral loads at top story due to earthquake effects compared to Non-Braced structure.
- Braced structure is 11.91% more stiffer than Non-Braced structure.
- Non-Braced structures have 7.69% higher story drift compared to Braced structure.
- Non-Braced structure shows 6.48% greater top shear wall displacement at top floor due to earthquake effects compared to Braced structure.

Based on Wind [Table 4.21a, 4.21b & 4.22]

- Non-Braced structure shows 7.58% greater top story displacement at top floor due to earthquake effects compared to Braced structure.
- Braced structure is 13.36% more stiffer than Non-Braced structure.
- Non-Braced structures have 9.09% higher story drift compared to Braced structure.
- Non-Braced structure shows 7.97% greater top shear wall displacement at top floor due to earthquake effects compared to Braced structure

Overall, it can be justified that Braced structure is the best one against lateral loadings specially Wind with compared to Non-Braced structure.

5.2 Recommendations

Based on the objectives, scopes and limitations of the study (stated in Chapter I), few recommendations can be proposed for further studies:

- This study was conducted based on 20 storied edge supported floor system, further analyses considering other floor system such as flat plate or flat slab floor system can be considered to see the change in lateral load, maximum story displacement, maximum story drifts, story shears, overturning moments, story stiffness in different building elements.
- This study can be further conducted based reinforcing bar areas requirement in braced and non-braced structures to identify the economic issues.
- This study was conducted based on Cross Bracing further study can be carried out considering V-Type, H-Type, Single Diagonal Type etc. For Bracing.

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