A RESEARCH PAPER ON SEISMIC ANALYSIS OF MULTISTOREY RC BUILDING WITH BRACING USING STAAD.PRO V8i

[1]Yaseen ahmad, [2]anuj verma, [3]nida nasir

[1]Student (M-Tech) Civil Engineering, [2]Assistant Professor & Head
[3]Assistant Professor
Department of Civil Engineering
Rajshree Institute of management and technology, Bareilly (UP) India

Abstract: Buildings are physical structures which provide shelter and safety for people. People prefer to live in their own individual spaces, so there is a requirement for many tall buildings to be constructed. Tall buildings have their own drawbacks such as lower resistance to wind and earthquake. Thus these buildings, if constructed in high seismic areas, may be susceptible to the severe damage which further leads to loss of life. Along with gravity load, structure has to withstand the lateral loads subjected to the building due to earthquake thus different lateral load resisting techniques are used now-a-days to make a tall structure stiff and stable. The present study focuses on the study of RC framed structure provided with three different types of bracing systems. For this study, a G+14 storied RC frame structure has been considered and the structural behavior has been studied for the seismic zones IV. The RC framed models are analyzed by Response spectrum Method using a computer aided software i.e., STAAD.Pro V8i. The structural behavior has been studied by using different types of bracing system such as X-bracing, Inverted-V bracing and V-bracing provided on the exterior faces of the buildings and at different locations on all the four sides. Comparative study of the braced and unbraced models is conducted for the parameters i.e. time period, base shear, storey drift, storey displacement, bending moment and peak storey shear. It has been observed that the storey displacement, storey drift, bending moment and time period of the braced frame decrease when compared to the un-braced frame and the base shear value of the braced models increases. Peak storey shear values are more for the braced frames. It is concluded that the model with the X-bracing provided at the mid-bays on the exterior faces of the buildings significantly contribute to structure stiffness as compared to the other bracing system.

Keywords: Bracing, earthquake analysis on the building, Storey Displacement, Base Shear, Storey Drift, STAAD- Pro v8i

I. INTRODUCTION

The term **earthquake** is used to describe any form of seismic event generating seismic waves that may be either natural or human-initiated. Earthquakes are typically triggered by ruptures in geological fault, but they may also be caused by volcanic activities, mine blasts, landslides and nuclear explosions. Seismic waves are generated because of the earthquake and the developed waves are further referred to as seismic force or lateral loads. The lateral loads thus minimize the structure's stability by creating a moment of sway and developing stresses in the structure. In such a situation, the structure's stiffness is more important than the structure's strength to resist the lateral load.

A number of earthquakes have occurred in India, causing significant and serious damage to residential, commercial and human infrastructure. According to the Indian seismic code IS 1893 (Part-1):2016, more than 60% of Indian land areas are clustered in the upper three seismic zones III, IV and V and only about 3% of the building area is properly engineered. With the increase in seismic activity around the world in recent years, seismic forces have drawn increased interest and have shown their effects to be more devastating. Structures located in areas at seismic risk can experience serious damage during a major earthquake. Because of the ground motion, deformations take place through the elements of the load-bearing system of buildings. A building has a limit to resist displacement so, there is a need to increase the strength of the building. Strengthening techniques are then used to ensure that a building's displacement demand is maintained below its displacement capacity. This can primarily be accomplished by the enhancement of the structure's displacement capacity. In general, there is smaller horizontal displacement requirements for buildings with greater stiffness and lower density.

Multi-storey reinforced concrete structures are vulnerable to extreme deformation, which allows special precautions to be placed in order to counteract this deformation. One of the lateral load opposing systems in multi-storey buildings is the steel braced structure. The steel bracing system increases the structure's resistance to horizontal forces and also increases its stiffness.

II. OBJECTIVES

1. Ensure safety of building against seismic forces.
2. Studying various output of seismic behavior in different zone.
3. Comparing various seismic parameters of multi storey building using bracing system.

III. Methods of Strengthening

Seismic strengthening is generally carried out in the following ways.

1. Structure level methods
2. Member level methods

1. **Structure Level Methods**

Two methods are used in the Structure Level Methods to increase the strength at the structure level-

i. Conventional methods based on increasing the seismic resistance of the buildings.
ii. Non-conventional methods based on reduction of seismic demands.

i. Conventional Method

In order to improve the seismic resistance of the structures by removing or minimizing the detrimental effects of design or construction, conventional methods are used and thus it maximize the strength of buildings. The techniques include solutions such as shear wall addition, infill walls or steel braces. Some techniques used in conventional methods is shown in the figure. 1.3.

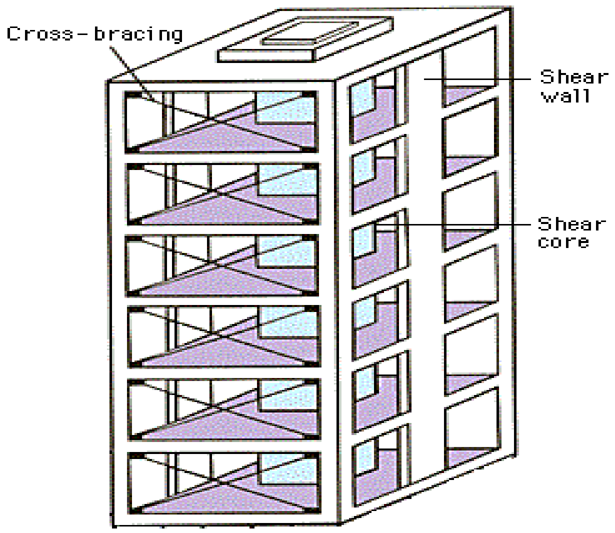


Fig. 1.3 Building with bracing and shear wall

iii. **Non-Conventional Method**

For non-conventional methods, the most common are the seismic base isolation and the addition of supplemented device techniques. These approaches continue with very distinct ideologies in the context that the horizontal seismic forces are essentially conceived to be decreased. The figure 1.4 shows a non-conventional method named base isolation.

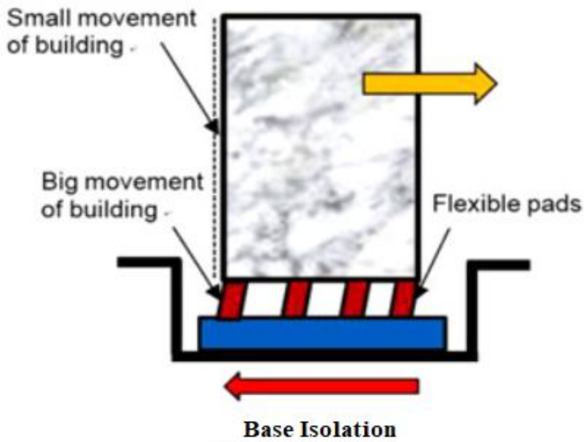


Fig. 1.4 Isolated base of a buiding

2. **Member Level Methods**

The strengthening approach at the member level is to upgrade the strength of the seismically deficient members. Compared to the solution at the structure level, this approach is more cost efficient. Jacketing is the most common way to increase the strength of each member in this method. It includes adding jackets of concrete, steel or fiber reinforced polymer (FRP) for use in confining columns, beams, joints and foundations of reinforced concrete. In figure 1.5 column has been jacketed with steel to increase its member level strength.

Fig. 1.5 Column Jacketing

IV. Detail of the Model

A G+14 storey RC frame building is selected for the seismic study and its performance is being checked when exposed to the seismic forces. It has been compared with the different bracing systems with the same configuration. A G+14 storey building is modeled and analyzed using a computer aided software STAAD.Pro V8i. The Plan and elevation of the bare (un-braced) RC frame of a building are shown in Fig. 3.2 and Fig. 3.3(a) respectively. In the structural plan of RC frame model of the structure, there are total 5 grid lines in both X and Z direction and having 4 bays each in both X and Z direction at a spacing of 3m i.e. it is a square plan building having plan dimension 12 m x 12m. The total height of the building is 45 m and the height of each floor is 3m.

The structural models of RC frames with different bracing systems and different location of the bracings and the plan and elevation of the building is shown in the figures 3.2 to 3.9(b). Plan consists of the position of the bracings in the building and the elevation consists of the 3D rendered view of that particular plan. The RC frame models used for the analysis with detailed description are-

Model 1- Shows the elevation and 3D view of RC frame structure without bracing (Bare frame) as shown in fig. 3.3(b)

Model 2- Shows the elevation and 3D view of RC frame structure with X Bracing in the mid 2-bays as shown in fig. 3.4(b)

Model 3- Shows the elevation and 3D view of RC frame structure with X Bracing on the side bays as shown in fig. 3.5(b)

Model 4- Shows the elevation and 3D view of RC frame structure with Inverted-V Bracing on the mid 2-bays as shown in fig. 3.6(b)

Model 5- Shows the elevation and 3D view of RC frame structure with Inverted-V Bracing on the side bays as shown in fig. 3.7(b)

Model 6- Shows the elevation and 3D view of RC frame structure with V Bracing on the mid 2-bays as shown in fig. 3.8(b)

Model 7- Shows the elevation and 3D view of RC frame structure with V Bracing on the side bays as shown in fig. 3.9(b)

The cartesian coordinates directions used in STAAD.Pro V8i for the analysis of the RC multi-storey building is shown in the fig.3.1. All the plans, elevations and 3D Rendered views are according to shown directions of the x, y and z portrayed in the fig. 3.1 of the three coordinates.

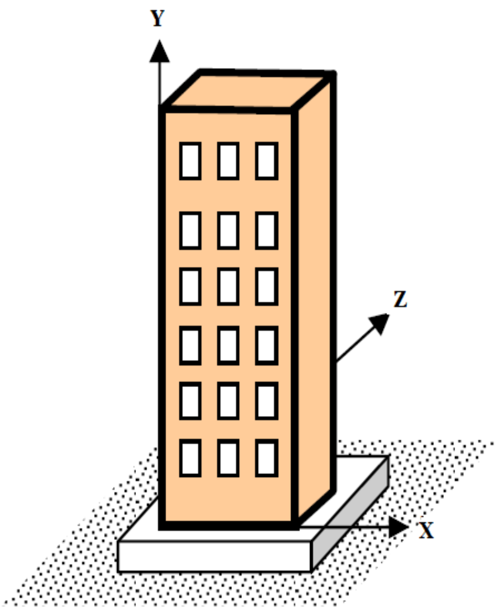


Fig 3.1 Cartesian coordinates directions in the building

The basic data details of the selected building frame for analysis are listed in Table 3.1. To study the seismic analysis of frames, the basic values are selected form IS 1893:2016 (part 1) to meet the basic requirement of the structure. Moreover, various IS code has been used to calculate the DL, LL, etc. and all are explained in detail.

V. Table 3.1 RC Frame Data Details Considered for the Analysis

The geometry of the structure	**Detail/ value**
Grids in the direction-X	5
Grids in the direction-Z	5
Grid line spacing line in X-direction	3m
Spacing of Grid line in Z-direction	3m
Number of Storey	G+14
Height of each storey	3m
Height of the ground-floor	3m
Beam's dimension	450 x 450mm
Column's dimensions	600 x 600mm
Steel bracing	ISMB 200
Soil Type	Medium
Support type	Fixed
Seismic Zone	IV
Dead Load	3kN/m^2
Live Load	4kN/m^2
Combination Method	CQC
Response Reduction Factor	5
Importance Factor(I)	1
Damping Ratio	5%

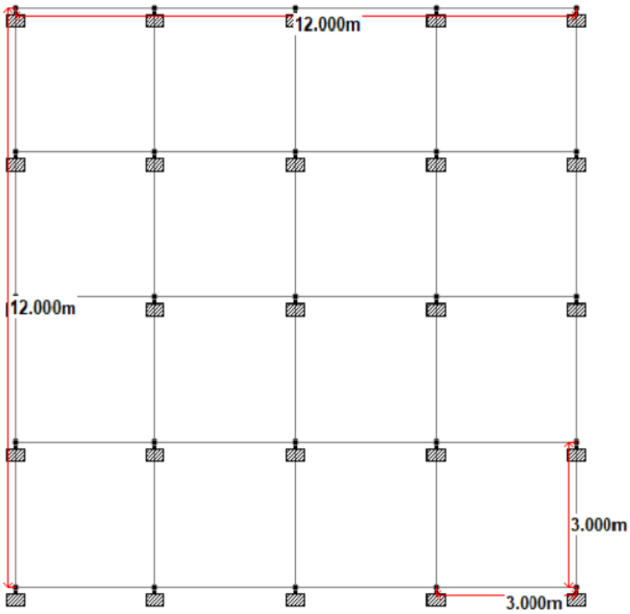


Fig.3.2 Structural Plan/Layout of RC Frame Model

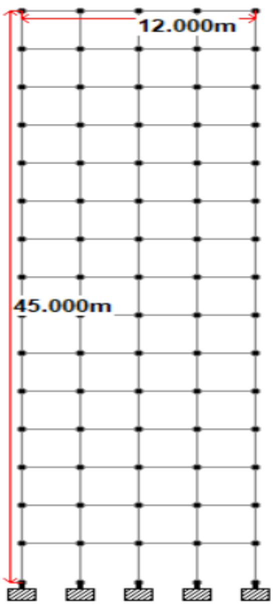


Fig.3.3(a) Structural Elevation of RC Frame Model

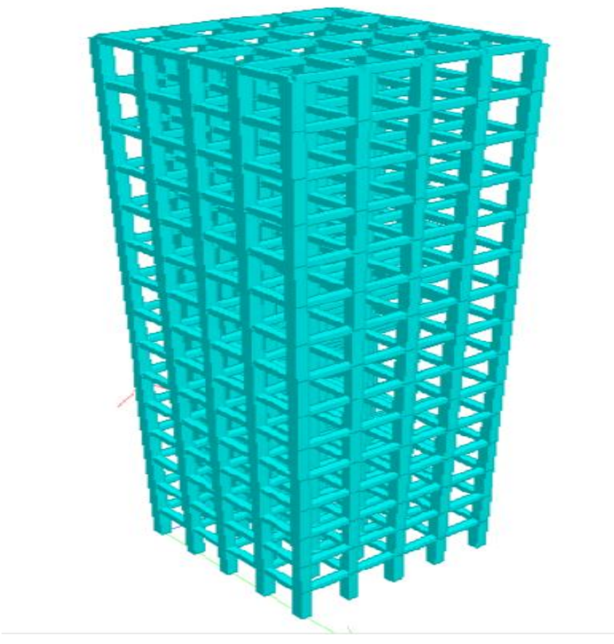


Fig.3.3(b) Rendered view of unbraced RC Frame (Model-1)

Fig.3.4(a) Structural Plan for X-braced RC Frame (Model-2)

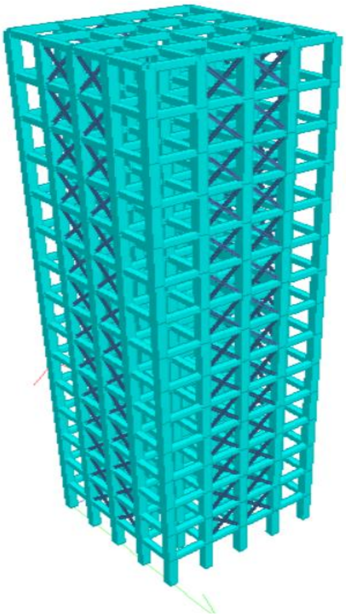


Fig.3.4(b) Rendered view for X-braced RC Frame (Model-2)

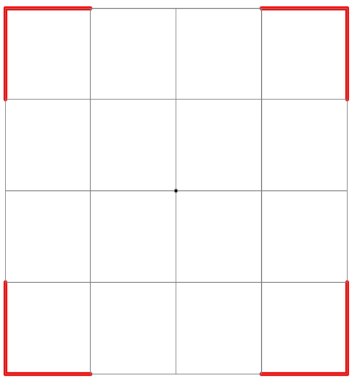


Fig.3.5(a) Structural Plan for X-braced RC Frame (Model-3)

Fig.3.5(b) Rendered view for X-braced RC Frame (Model-3)

VI.

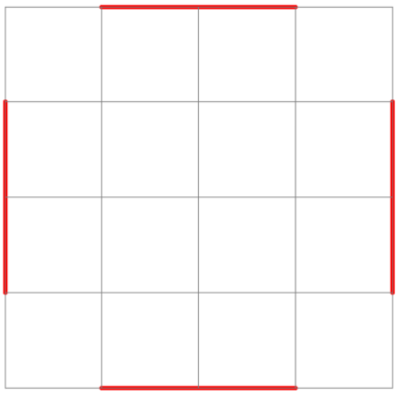


Fig.3.6(a) Structural Plan for Inverted V-braced RC Frame (Model-4)

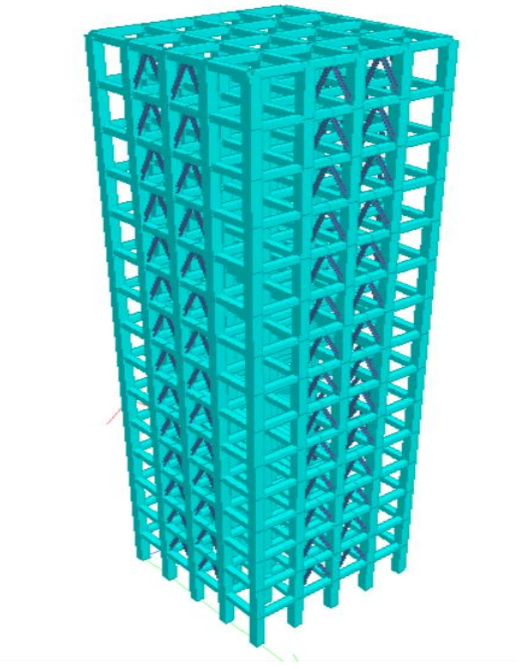


Fig.3.6(b) Rendered view for Inverted V-braced RC Frame (Model-4)

VII.

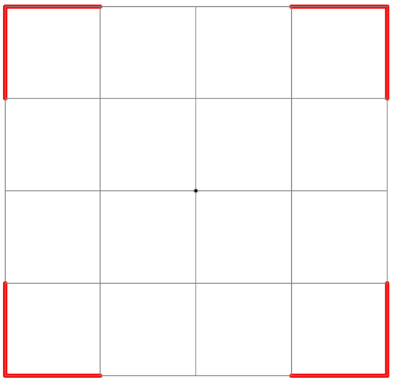


Fig.3.7(a) Structural Plan for Inverted V-braced RC Frame (Model-5)

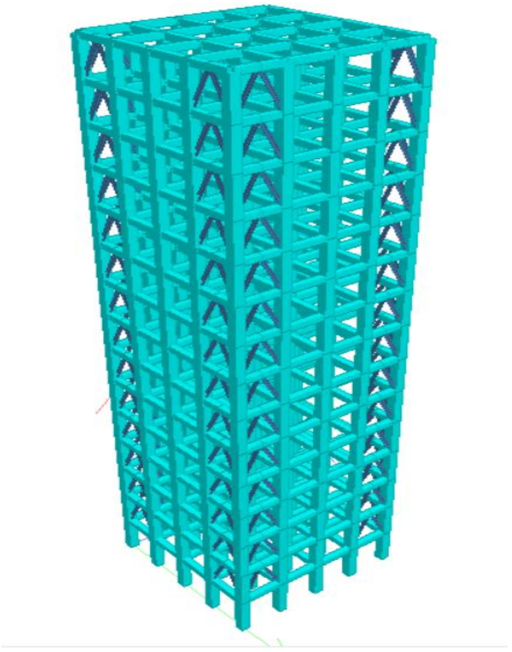
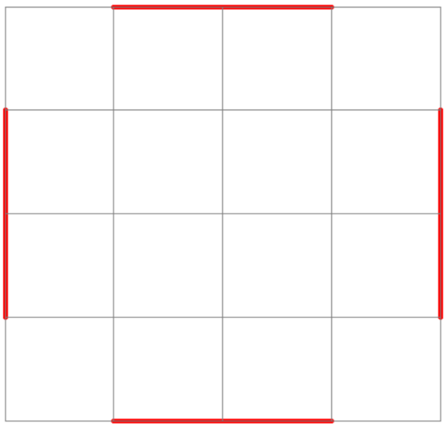


Fig.3.7(b) Rendered view for Inverted V-braced RC Frame (Model-5)

VIII.



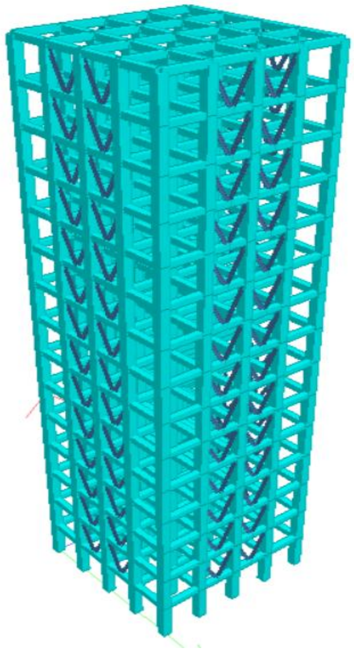
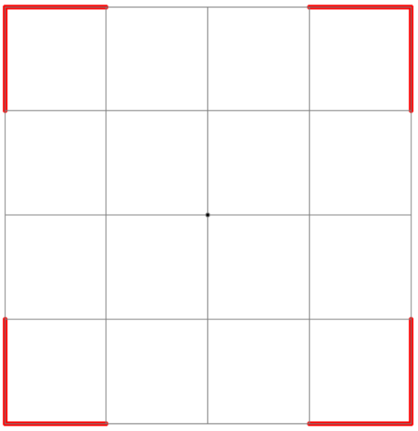


Fig.3.8(a) Structural Plan for V-braced RC Frame (Model-6)

Fig.3.8(b) Rendered view for V-braced RC Frame (Model-6)



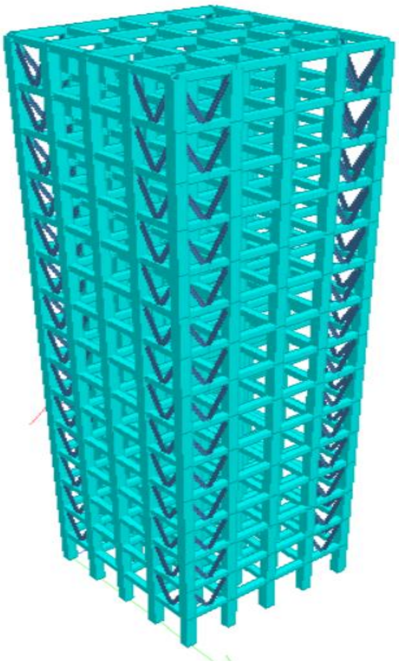


Fig.3.9(a) Structural Plan for V-braced RC Frame (Model-7)

Fig.3.9(b) Rendered view for V-braced RC Frame (Model-7)

4.2 Mass Participation Factor

It is the amount by which mode contributes during horizontal or vertical earthquake ground motion to the total oscillation of the structure. The amount of the system's mass participating in that mode represents the mass participation associated with each mode. The total sum of modal masses of the modes to be used in the earthquake shaking study along the direction considered should be at least 90% of the total seismic mass (IS 1893 part 1:2016).

In order to judge the importance of vibration mode, the modal mass participation factor is important. Modes of greater mass participation should be the most effective forms to concentrate on. It is less likely that modes with a lower mass participation factor would get excited, so these modes may be overlooked. Therefore, a mode with a large effective mass is usually a significant contributor to the system's response. There are six number modes considered in the study. All the models have been analyzed and examined for all considered parameters. For demonstration, the mass participation factor in percentage for the seismic forces in z-direction for model-2 is given in table 4.1.

Table 4.1 Mass participation factor in z-direction for Model-2

Mode	Mass Participation Factor (%)						
	Model-1	**Model-2**	**Model-3**	**Model-4**	**Model-5**	**Model-6**	**Model-7**
1	55.45	70.65	1.94	39.73	70.17	74.93	20.76
2	22.70	6.76	74.53	38.34	7.03	3.07	56.47
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	3.51	5.96	3.05	1.68	0.38	6.36	8.60
5	8.07	7.70	10.94	10.96	12.74	6.31	4.42
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Mode shape of oscillation associated with a natural period of a building is the deformed shape of the building when shaken at the natural period. Hence, a building has as many mode shapes as the number of natural periods. The deformed shape of the building associated with oscillation at fundamental natural period is termed its first mode shape. Similarly, the deformed shapes associated with oscillations at second, third, and other higher natural periods are called second mode shape, third mode shape, and so on, respectively. The different mode shapes of the most bracing system i.e., X-bracing is show in the figures 4.1 to 4.6.

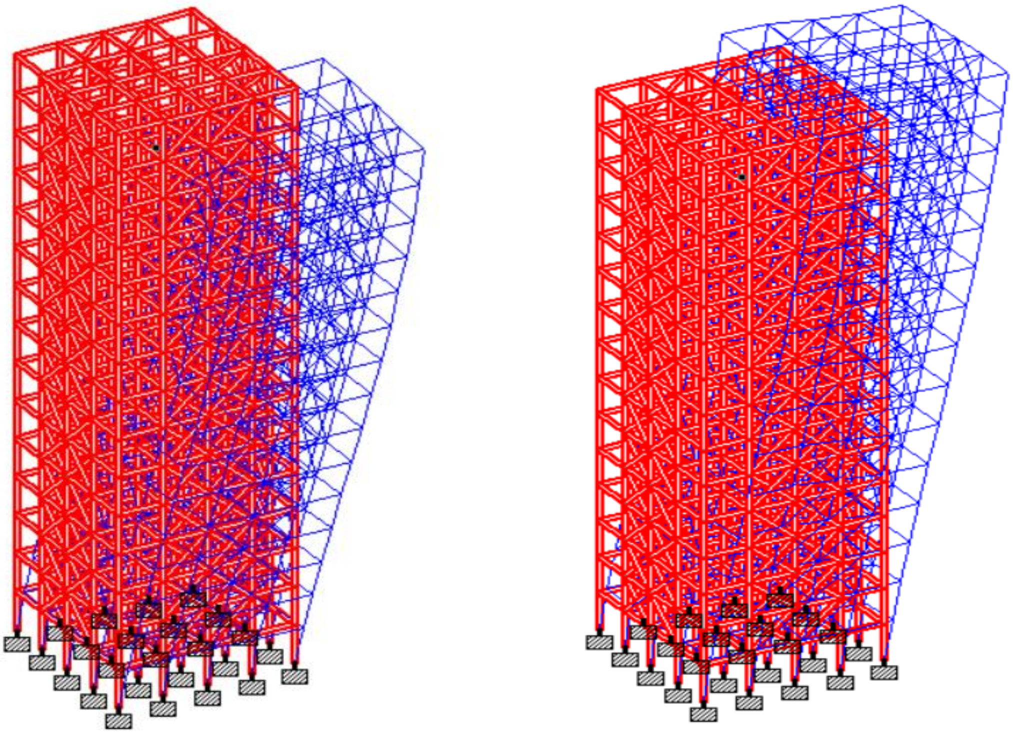
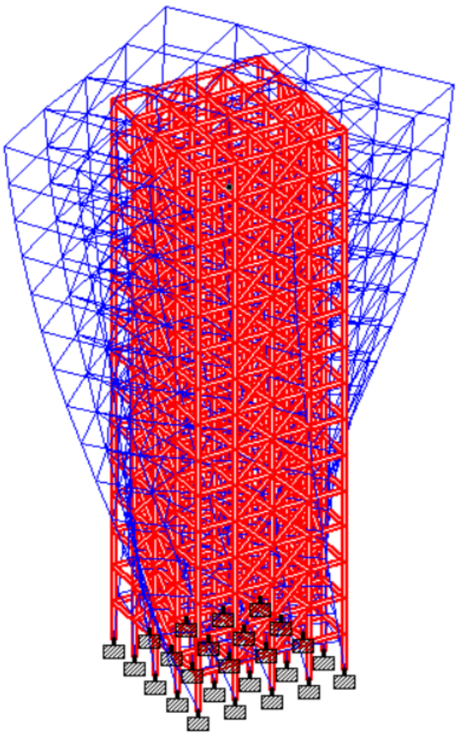


Fig.4.1 Mode Shape 1

Fig.4.2 Mode Shape 2



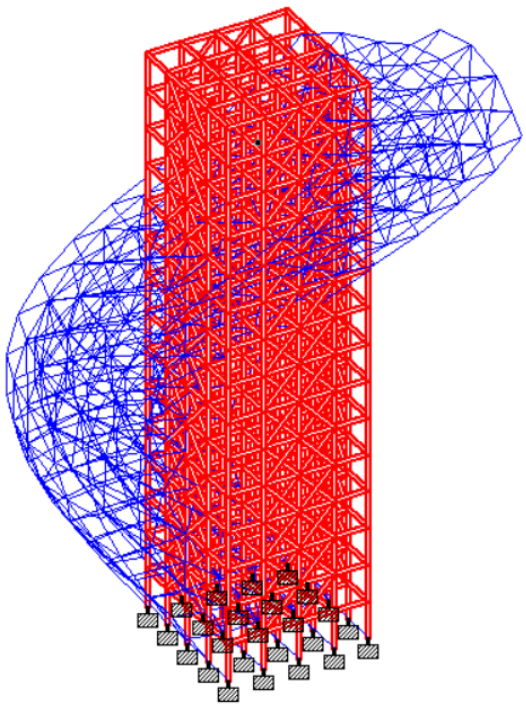
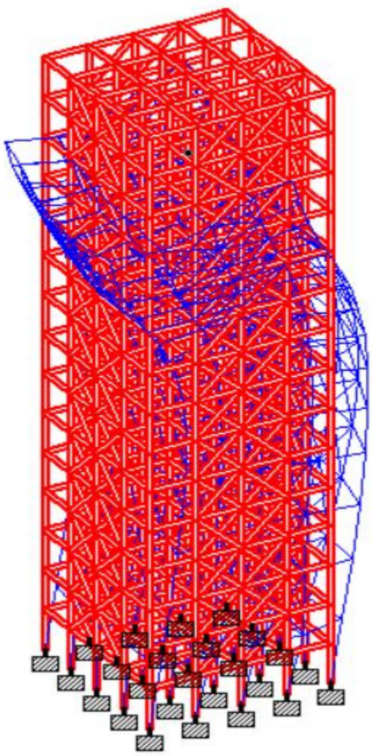


Fig.4.3 Mode Shape 3

Fig.4.4 Mode Shape 4



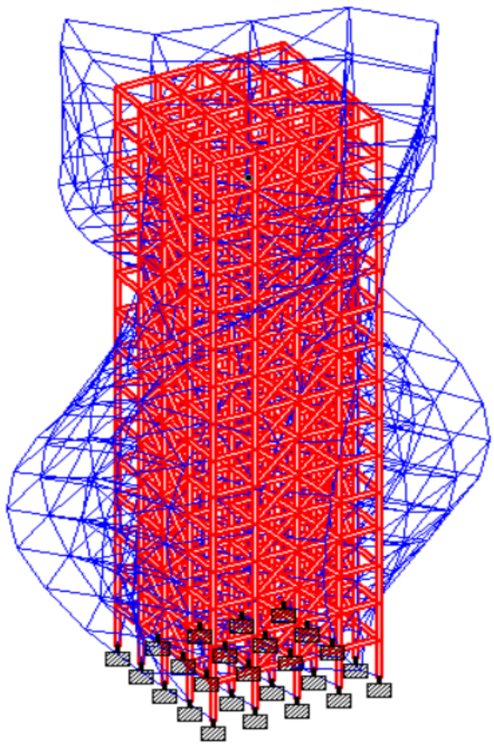


Fig.4.5 Mode Shape 5

Fig.4.6 Mode Shape 6

4.3 Time Period

For the time period observation, a RCC framed structure with and without a bracing system in seismic zone IV is studied.

Table 4.2 Time period for Different Models

Model	Time Period (sec)
Model-1	1.393
Model-2	1.125
Model-3	1.213

Model-4	1.187
Model-5	1.251
Model-6	1.200
Model-7	1.266

Using STAAD.Pro.V8i, various models without and with braces at different locations were evaluated and the time period values were extracted from the results. The time period obtained for the various models considered for study is tabulated the table 4.2. The graph for the Time period for different bracing system is shown in Fig 4.7.

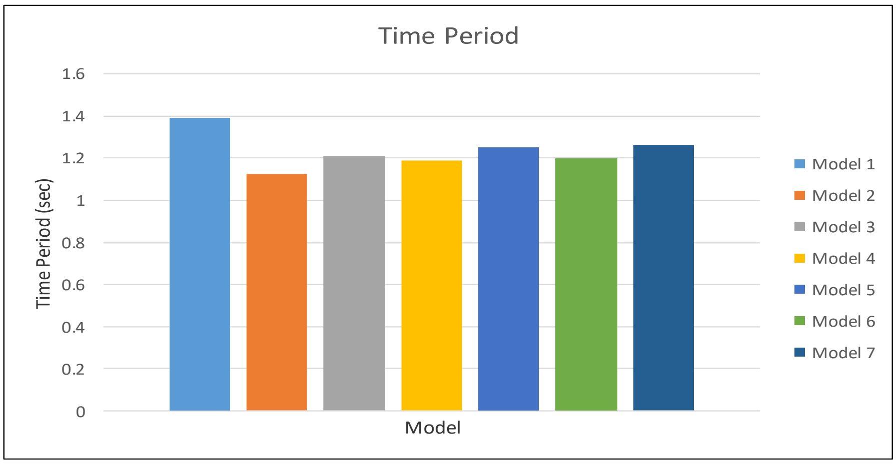


Fig. 4.7 Time Period for Different models

The values listed in the table 4.2 and graph 4.7 represent the time period values in seconds of the braced structure. The graph shows that, in relation to the bare frame, the time period reduces in the case of various bracing systems. The bar chart reveals that in the case of X bracing and Inverted-V, the value of the time period is low relative to other bracing and bare frame.

The percentage reduction in the time period of model-2 with respect to model-1(bare frame) is 19.24%. The X-bracing provided in the middle bays of the structure is the most efficient bracing from the data, i.e. Model-2 is the most effective.

4.4 Base Shear

The maximum lateral force produced at the base of the structure is base shear. The structure has been fixed at the base, which is at the foundation level, for analysis. For the evaluation of the base shear, a RCC framed structure with and without a bracing system in seismic zone IV was studied. The base shear obtained for the various models considered for study is set out in the table 4.3. The graph for the base shear for different bracing system is shown in Fig. 4.8.

Table 4.3 Base Shear for Different Models

Model	Base Shear (kN)
Model-1	724.66
Model-2	730.30
Model-3	730.30
Model-4	729.12
Model-5	729.12
Model-6	729.12
Model-7	729.12

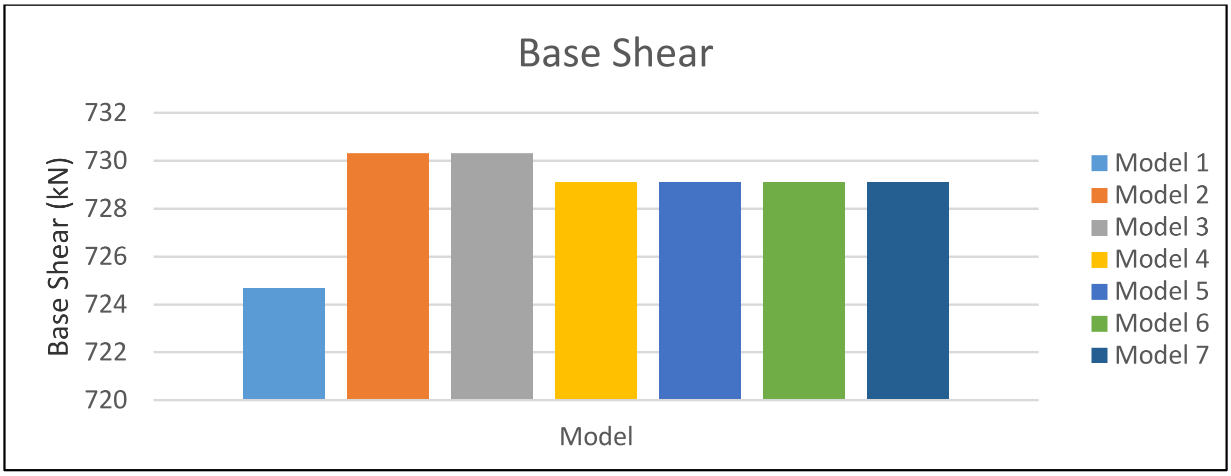


Fig.4.8 Base Shear for Different models

The values given in the table and the graph shows the magnitude of the base shear of the braced framework increase in the structure. The graph shows that, in the case of different bracing systems, the magnitude of base shear is almost the same. The base shear relation reveals that in the case of X bracing, the magnitude of the base shear is high relative to other bracing and bare frame.

4.5 Storey Displacement

Displacement refers to the movement of the whole structure from their original location when subjected to lateral forces. The overall displacement value of each storey has been taken through the study. The maximum displacement values obtained for the different models considered for analysis is given below in Table 4.4. The graph for the maximum lateral displacement for different bracing system is shown in Fig. 4.9.

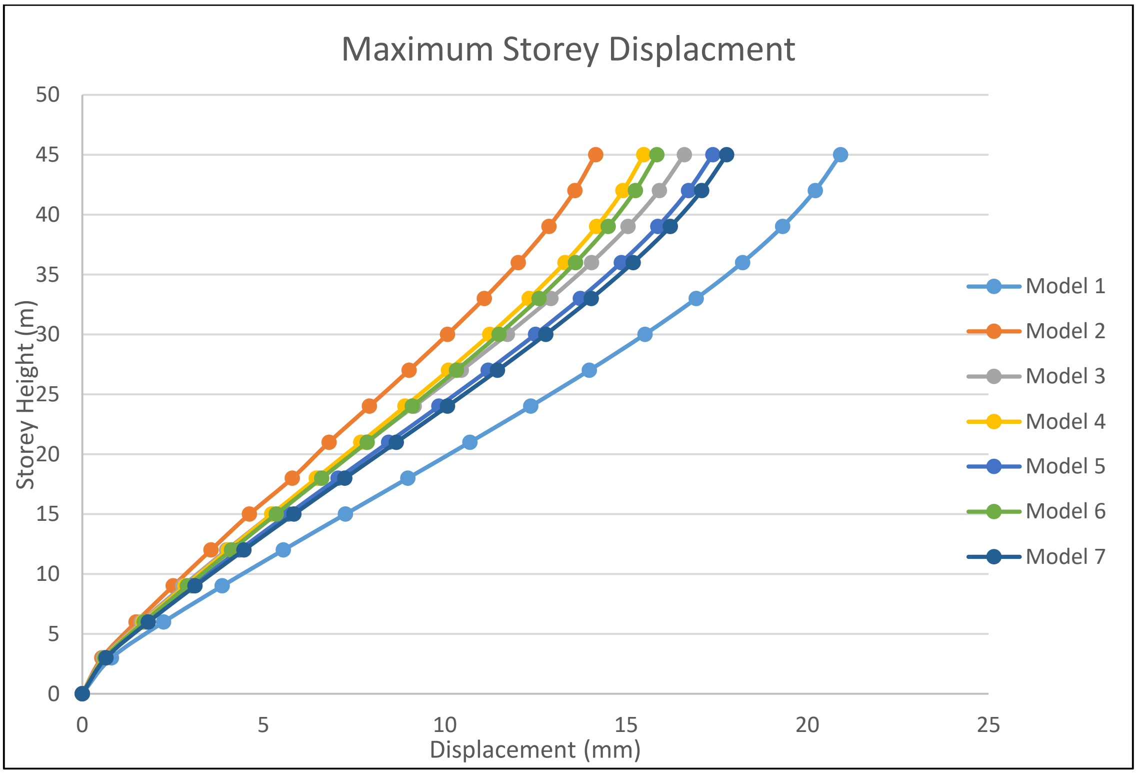


Fig. 4.9 Maximum storey displacement for different models for different storey

From the values given in the table and their plot, it was observed that the lateral displacement of the braced system decreases with an increase in building height. This decrease from the base to the top of the frame is incremental.

Table 4.4 Maximum storey displacement for different models for different storey

Storey Height (m)	Maximum Lateral Displacement (mm)						
	Model Without Bracing	Model With Bracing					
	Model 1	Model-2	Model-3	Model-4	Model-5	Model-6	Model 7
0	0	0	0	0	0	0	0

3	0.807	0.543	0.587	0.610	0.640	0.622	0.658
6	2.248	1.488	1.626	1.677	1.774	1.711	1.823
9	3.863	2.508	2.777	2.838	3.030	2.900	3.116
12	5.547	3.550	3.982	4.026	4.338	4.117	4.460
15	7.261	4.617	5.234	5.235	5.686	5.354	5.841
18	8.984	5.797	6.525	6.459	7.063	6.606	7.248
21	10.695	6.812	7.840	7.688	8.454	7.861	8.666
24	12.372	7.920	9.159	8.908	9.839	9.107	10.076
27	13.990	9.015	10.462	10.101	11.197	10.324	11.457
30	15.523	10.078	11.726	11.248	12.505	11.496	12.787
33	16.942	11.092	12.931	12.328	13.739	12.600	14.042
36	18.218	12.034	14.052	13.317	14.873	13.613	15.198
39	19.321	12.879	15.060	14.190	15.880	14.510	16.228
42	20.221	13.595	15.920	14.919	16.725	15.260	17.092
45	20.920	14.164	16.610	15.492	17.396	15.851	17.781

The graph shows that in the case of X bracing, the lateral displacement decreases very strongly compared to other bracing and bare frame. In the middle bays, the place of the X bracing is more effective than the other spot. The percentage reduction in lateral displacement at floor height of 24 m and 42 m for the different models with bracings in zone IV, compared to the unbraced model is given in Table 4.5, the soil medium is kept the same in the study.

Table 4.5 Percentage reduction in the storey displacement w.r.t Model-1

	Storey Height (m)	Types of Models with Bracings					
		Model-2	Model-3	Model-4	Model-5	Model-6	Model-7
Percentage Reduction	24	35.98	25.97	27.99	20.47	26.39	18.56
	45	32.29	20.60	25.94	16.84	24.23	15.00

Thus, the percentage decrease in displacement is very high in the case of the X bracing system. Because of the high shear rigidity, high ductility and high energy absorption power, this decrease in displacement in X bracing is high.

4.6 Storey Drift

The relative displacement between the floors above or below the storey under consideration is storey drift or inter storey displacement. Via STAAD.Pro, maximum storey drift values have been measured. The maximum values of storey drift obtained from the analysis at each storey level for the different models are given in the table below. Further, the storey drift values, which have been listed in Table 4.6, are plotted against the storey height to understand the effectiveness of different bracing system at different positions and the plot is shown in Fig.4.10.

The graph has been shown to display the comparable trend for the decrease in storey drift value per storey height. Initially, the storey drift reduction rate was found to be very low in all braced structures up to 2-3 storey level and then it has been observed that the decrease in storey drift values rises rapidly up to the level of 5-7th storey and there is a drop in storey drift values again after that.

Table 4.6 Maximum Storey Drift for Different models for different storey level

Storey Height (m)	Maximum Storey Drift (cm)						
	Model Without Bracing	Model With Bracings					
	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6	Model-7

0	0	0	0	0	0	0	0
3	0.1213	0.1007	0.1045	0.1062	0.1088	0.1078	0.1121
6	0.2158	0.1346	0.1477	0.1556	0.1653	0.1592	0.1694
9	0.2422	0.1430	0.1635	0.1664	0.1799	0.1711	0.1865
12	0.2522	0.1509	0.1764	0.1737	0.1920	0.1782	0.1977
15	0.2569	0.1573	0.1862	0.1789	0.2005	0.1832	0.2055
18	0.2581	0.1619	0.1929	0.1822	0.2058	0.1862	0.2102
21	0.2563	0.1645	0.1966	0.1831	0.2080	0.1870	0.2118
24	0.2511	0.1446	0.1969	0.1861	0.2068	0.1853	0.2104
27	0.2422	0.1623	0.1940	0.1774	0.2024	0.1810	0.2056
30	0.2294	0.1573	0.1876	0.1702	0.1945	0.1738	0.1976
33	0.2123	0.1497	0.1787	0.1600	0.1832	0.1638	0.1863
36	0.1908	0.1393	0.1664	0.1466	0.1685	0.1502	0.1717
39	0.1647	0.1260	0.1510	0.1298	0.1504	0.1335	0.1537
42	0.1345	0.1095	0.1324	0.1098	0.1291	0.1135	0.1325
45	0.1040	0.0903	0.1113	0.0881	0.1062	0.0917	0.1104

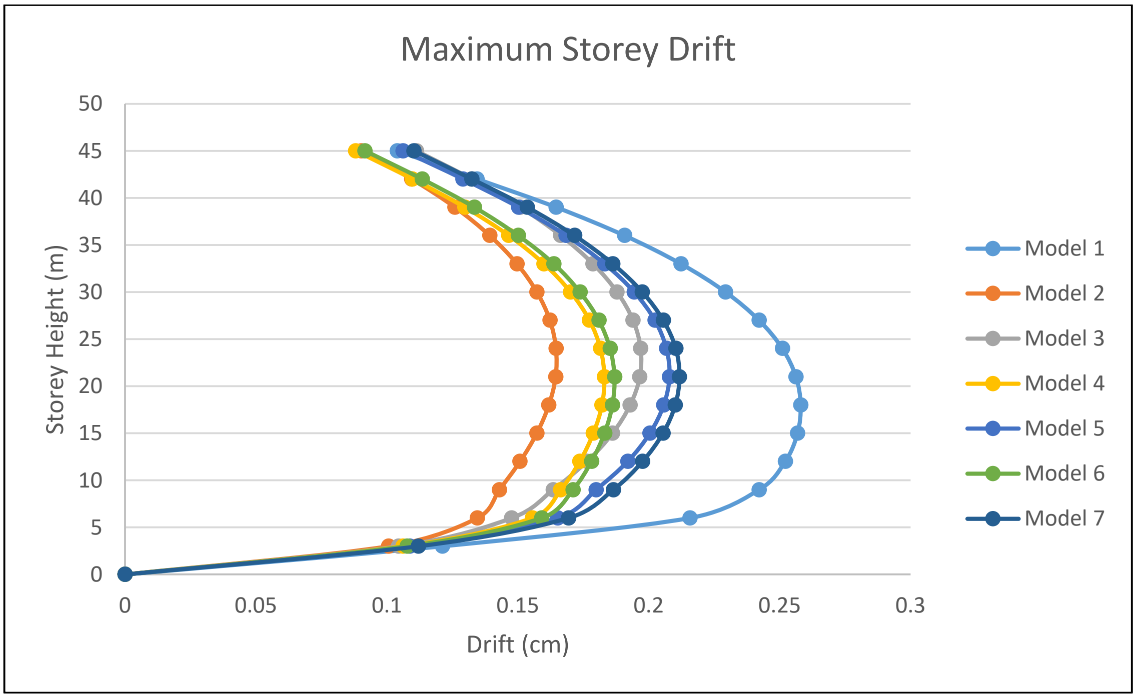


Fig. 4.10 Maximum Storey Drift for Different models for different storey level

However, the maximum storey drift value at various storey levels is displayed by different bracing systems provided at different locations. In the case of Model-2, relative to other braced and unbraced systems, the percentage decrease in storey drift is very high and is seen in the graph Fig.4.10.

Table 4.7 Percentage Reduction in the Storey Drift w.r.t Model-1

	Storey Height (m)	Types of Models with Bracings					
		Model-2	Model-3	Model-4	Model-5	Model-6	Model-7
Percentage Reduction	24	42.41	21.58	25.88	17.64	26.20	16.20
	45	13.17	7.02	15.28	2.11	11.82	6.15

Table.4.7. shows a percentage reduction in storey drift at floor height of 24 m and 42 m for the various models with braces in zone IV relative to the unbraced model.

4.7 Bending Moment

The purpose of the analysis was to study the occurrence of a maximum bending moment in the braced and unbraced frame structure column. From the analysis, the bending moment values are obtained for the columns at the centre of the frame and the values are shown in Table 4.8. The corresponding obtained result values of the bending moment are arranged in the form of the bar chart as shown in Fig.4.11.

Table 4.8 Maximum Bending Moment for Different Models

Model	Bending Moment (kNm)
Model-1	72.567
Model-2	54.560
Model-3	57.159
Model-4	59.283
Model-5	61.064
Model-6	60.092
Model-7	62.233

It has been found that when the bracing system is applied, the bending moment is decreased and it is good for the structure. Compared to other types of bracing system, the building construction with the X bracing system provided in the middle outer bays would have the least possible bending moment.

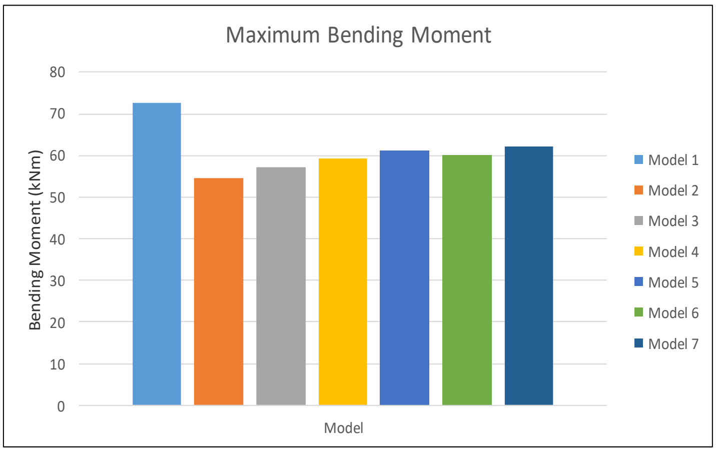


Fig. 4.11 Maximum Bending Moment for Different models

4.8 Peak Storey Shear

It is the design seismic force or wind force presumed to be applied at each floor level. It is calculated for each storey, changes from minimum at the top to maximum at the bottom of the building.A RC building frame with and without bracing has been studied for the peak storey shear in the seismic zone IV with the help of STAAD.Pro V8i. The values of the peak storey shear obtained from analysis of the structure are given in Table 4.9. The peak storey shear of different bracing system are represented by graph and have been shown in Fig 4.12.

Table 4.9 Peak Storey Shear for Different models

	Peak Storey Shear(kN)

Storey Height (m)	Model Without Bracing	Model with Different Bracings at different positions					
	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6	Model-7
45	3434.72	4083.67	3973.07	3859.87	3809.39	3841.21	3785.89
42	7103.66	8439.90	8153.14	7999.35	7876.46	7954.84	7795.29
39	10315.97	12269.50	11760.75	11655.73	11365.18	11580.25	11277.96
36	12997.13	15521.11	14752.92	14766.99	14300.26	14656.02	14179.01
33	15145.74	18213.98	17163.50	17340.66	16673.28	17191.09	16518.47
30	16840.44	20435.30	19100.15	19454.72	18578.39	19265.70	18391.86
27	18226.36	22321.92	20723.57	21241.30	20167.31	21014.95	19952.33
24	19478.06	24026.56	22208.30	22853.00	21611.48	22594.39	21372.53
21	20743.70	25674.69	23692.10	24417.41	23050.54	24133.82	22792.78
18	22091.00	27326.32	25232.64	25995.49	24546.11	25694.95	24274.65
15	23483.59	28959.11	26792.47	27562.40	26063.56	27252.08	25782.73
12	24799.96	30478.96	28258.55	29019.20	27489.86	28704.13	27202.55
9	25881.13	31750.91	29482.86	30226.96	28674.93	29909.60	28382.39
6	26586.51	32637.75	30327.11	31049.40	29478.88	30730.09	29181.06
3	26858.26	33037.60	30700.91	31400.18	29818.92	31078.84	29516.68
0	26858.26	33037.60	30100.91	31400.18	29818.92	31078.84	29516.68

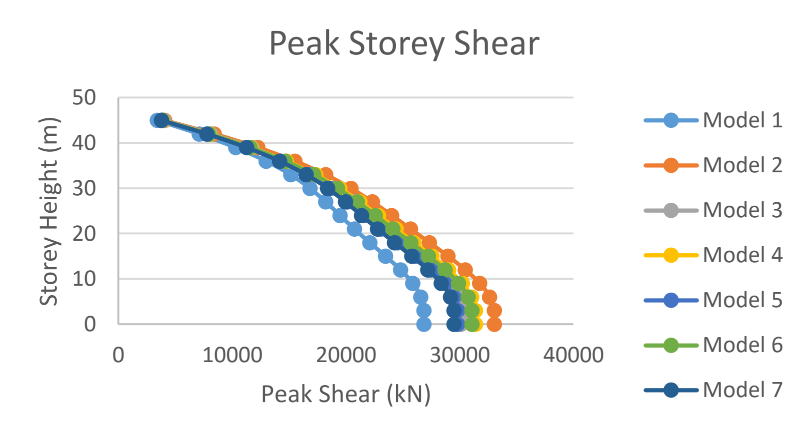


Fig. 5.12 Peak storey shear for Different models

The graph has been shown to display the comparable trend for the decrease in storey shear value per storey from the bottom to the top of the building. In general, it has observed that the storey shear values at the base was maximum and the decreased as we moved up to the next storey level. Storey shear is minimum at the top most floor. The comparison of the values shows the structure which can bear the maximum storey shear is most feasible and effective.

In the case of Model-2, relative to other braced and unbraced systems, it can withstand with high shear values at different storey level so it the most case suitable case braced frame and is seen in the graph Fig.4.12.

4.9 Validation of Thesis Work

On comparison with the previous study conducted by Aniket Katte, D.B. Kulkarni and P.P. Kumar Reddy, P. Ravi Kumar it was concluded that the X-type bracing is the most efficient one and the locations for the bracing at the mid bays is most feasible. The reduction in the displacements were almost similar. The data, analysis and results are compared in the table 4.10.

Table 4.10 Validation of the study conducted

Model Description	Thesis Work	Aniket Katte, D.B. Kulkarni	P.P. Kumar Reddy, P. Ravi Kumar
Analysis	Dynamic	Dynamic	Dynamic
Software used	STAAD.Pro V8i	E Tabs	E Tabs
Model Storey	G+14	G+15	G+9
Plan Dimension	12 x 12 m	16 x 16 m	25 x 20 m
Different bracings used	X-type, Inverted-V type and V-type	X bracing	X, diagonal, chevron and V bracings
Location of the bracing	Mid-bays and corner bays	Mid-bays, corner and core bays	Mid-bays
Beam	Concrete (450 x 450 mm)	Steel (ISWB 300 and ISLB 150)	Concrete (300 x 450 mm)
Column	Concrete (600 x 600 mm)	Steel (ISHB 200-250/16 & ISHB 300-400/16)	Concrete (380 x 600 mm)
Steel Bracing	ISMB 200	ISA 110 x 110 x 10	ISMB 300
Seismic Zone	IV	IV	II, III, IV and V
Soil Type	Medium	Medium	Medium
Parameters studied	Time period, storey drift, displacement, bending moment, base shear and peak storey shear	Displacement and storey drift	Displacement, storey drift and storey shear
Results	The displacement and drift of the structure was reduced by 32.29% and 20 % approx. with the use of X-bracing at the mid bays of the structure.	The displacement and drift of the structure was reduced by 34.45% and 38.05% with the use of X-bracing.	In Zone IV, maximum storey displacement of a building is reduced by 36.94% and The story shear of a braced building was very high when compared to unbraced building.
Conclusion	X-bracing provided at the mid-bays of the structure is the most efficient	X-bracing provided at the core and mid-bays of the structure is the most efficient	The X-type of bracing shows the best performance.

4.10 Performance Based Ranking

After the analysis and results the different models with and without bracings is compared. The bare frame (model-1) is the source taken to compare the different models with different bracings systems provided at two different locations in the building. The parametric study shows the performance of different models in the seismic zone IV. Based on the performance of the models considered for the analysis, these are ranked from 1 to 6 shown in the table 4.11.

Table 4.11 Performance based ranking of the braced models

	Performance based ranking of the structural configurations investigated					
Model	Model-2	Model-4	Model-6	Model-3	Model-5	Model-7
Ranking	1	2	3	4	5	6

Thus the model-2 i.e. the RC framed structure with X Bracing in the mid 2-bays is ranked-1 based on its overall performance and the least ranked model is model-7 i.e. the RC framed structure with V-Bracing on the side bays.

4.11 Summary

This chapter comprises the results which includes tables and graphs for the different models taken for the analysis. The tables includes the data for the different parameters and also the reduction in the parameters on the braced frames. Validation of the work is also mentioned in this chapt

I. CONCLUSIONS

For all the selected parameters namely, storey displacement, storey drift, base shear, maximum bending moment and peak storey shear, all braced frame models were analyzed by response spectrum analysis using STAAD.Pro V8i software. From the study of braced models, it was found that in the respective seismic zone considered i.e., zone IV, the braced structure displayed greater seismic resistance than an unbraced structure. In order to achieve improved results, a better spot for providing the different bracing was also observed. In comparison, it was found that model-2, i.e. the model with X-Bracing provided on the outside of the structure and on the mid bays, is a comparatively best choice from the structural point of view among all models considered. Therefore, the following conclusions display only the values of model-2.

II. Building's response during earthquake is known as time period, which means greater the time period greater is the response and lesser the time period, less is the response. As the time period of model-2 is less it means it is stiffer or it has more stiffness. Time period for the unbraced structure is 1.393 seconds which when compared with braced structure is more. In braced buildings, model-2 shows the lowest time period which is 1.125 thus it is the most effective compared to others. By comparing model-2 with the bare frame (model-1), time period is reduced by 19.24%.

III. As compared to the bare frame, the lateral displacement of the bracing system decreases with an increase in the building height. Compared to the other structural models of other bracing (inverted-V bracing and V-bracing) and unbraced structures in zone IV, the structural model-2 displays less lateral displacement. The reduction in lateral displacement values for model-2 in zone IV at a storey height of 24 m and 45 m is 35.98% and 32.29% respectively.

IV. The overall base shear correlation reveals that in the case of model-2 and model-3, the base shear value is high relative to other models. As compared to the un-braced RC frame model, the base shear of the braced models increases.

V. By using various forms of bracing in the model, the storey drift is minimized. Compared to the braced and unbraced structures, a structural model with X-bracing provided on the exterior of the structure and on the middle bays (model-2) shows less floor drift. The reduction in storey drift values for the model-2, compared with bare frame at storey height of 24 m and 45 m is 42.41% and 13.17% respectively.

VI. Compared to the unbraced frame, bending moment values for the column provided at the center are lower in the braced frame. In contrast to the other models, the braced model with the X-bracing provided in the mid bays has the least possible bending moment. Therefore, the X-bracing provided in the middle two bays of the structure is more efficient.

VII. Peak storey shear values at different levels of the building in the braced frame model increased when compared to unbraced frame model. The frame model-2 gave the better results as it could take more shear than the other models. It changes from minimum at the top to maximum at the bottom of the building. Thus, model-2 is more advantageous than other models.

5.3 Future Scope

There is a vast research study in this research field for future study. For additional analysis, the following possibilities can be used in research work:

1. In a further study, we can consider irregularity in the building.
2. Instead of steel bracing, the performance of a building can also be studied by using concrete bracing.
3. Eccentrically braced frame (EBF's) can also be used in the future study.
4. We can use the time history method for analysis in further studies.
5. Different soil conditions can be considered for the further research work.
6. Different zones can be considered and which bracing system will be more advantageous can be evaluated in the further studies.
7. These CBF's and EBF's can also be taken as retrofitting techniques for further studies.

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