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NONLINEAR DYNAMIC ANALYSIS OF STEEL BUILDING USING DIFFERENT TYPES OF BRACING SYSTEM

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Abstract - *In recent decades, steel structures have played an important role in the construction industry by providing strength, stability and ductility which are the main objectives of seismic design. Applying bracing in building is an efficient and economical method to withstand lateral forces in a frame structure, there are different types of steel bracings such as diagonal, X type, V type, inverted V type or chevron and eccentric bracings are used in structures. The present study focuses on seismic performance of three dimensional low rise and high-rise steel frame structures of 15 meter and 45 meter height of building with different types of bracing in frame structure. The braces have been applied in exterior faces and specified bays of the buildings only. X-braced frames, V-braced frame, Inverted V braced and 2 different types of eccentric braced frames with varying height of structure that is 15 meter and 45 meter are considered, and seismic performance is compared with moment resisting frame. To identify the non-linear behavior of frame elements in the structure, Time History Analysis is performed using ETABS 2015 software.*

Key Words: **Steel building, Steel bracings, Etabs 2015, Seismic Analysis (Time History Analysis), IS1893 (part-1)-2002,**

1. INTRODUCTION

Previous earthquakes in India show that most of the structures need to be designed in such a way that can perform well under seismic loading. Structural strength and stiffness in Steel moment resisting frames can be increased by introducing steel bracings in the structural system. Bracing can be applied in two ways as concentric bracing or eccentric bracing. There are various ways to arrange steel bracings, such as cross bracing 'X', diagonal bracing, 'V' type bracing and inverted 'V' type bracing. Steel moment resisting frames resist lateral forces by frame action i.e. by flexure and shear in beams and columns. In braced structure beams, columns and bracings are arranged to form a vertical truss and then lateral loading is resisted by truss action. In severe earthquake loading ductile failure at columns and beam connections are common. P-Δ effect is another problem associated with such structures in high rise buildings. So, to increase the structure Jan, 1995) Station - KJMA (Hypocentral Distance = 25.6 km) PGA (cm/s2): -805.45 (in X direction) earthquake data is used. Whose characteristics and acceleration record graph (in figure 1) are given below.

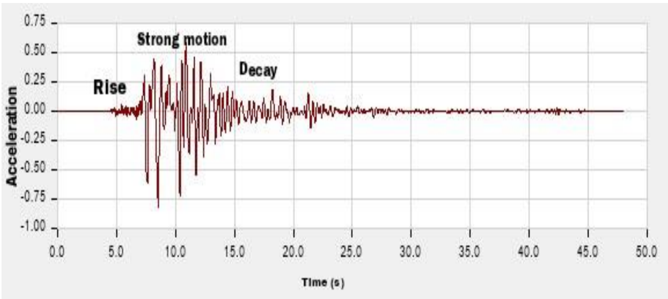


Fig.-1- Temporal evolution of an accelerogram and Kobe earthquake acceleration record (http://www.strongmotioncenter.org/vdc/scripts/plot.plx?stn=4039&evt=1098)

1.1 Objectives of the present work

Following are the main objective of the present study:

1) To analyze the seismic performance of a 5 story and 15 story steel frame building with moment resisting frame and then with different bracing arrangement in specified bays such as cross bracing 'X', 'V' bracing, inverted 'V' bracing and eccentric bracing, using nonlinear dynamic time history analysis.
2) To investigate the seismic response of a multi-story steel frame building under same bracing configuration but with variation of bay i.e. with varying location of bracing.
3) To investigate the seismic performance of 5 story and 15 story steel frame building in terms of base shear and storey displacement.

1.2 Moment resisting frame

Moment resisting frame are rectilinear assemblage of beam and column with the beam rigidly connected to the column. Resistance to lateral forces is provided primarily by rigid frame action that is, by the development of bending moment and shear force in the frame members and joints.

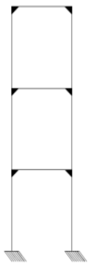


Fig-2-Moment resisting frame

1.3 Steel bracings

There are different types of bracing systems commonly used in multi-storey steel structures between beams and columns to transfer horizontal forces imposed on the structure. These are:

a) Concentrically braced frames (CBFs):

Concentric bracing may be designed to resist the entire seismic load, in which case the braces are used in combination with beam to column connections. In concentric braced frames having simple connections, the center lines of the members that meets at a joints intersects at a points to form a vertical truss system that resists lateral forces. Because of their geometry, these frames provide complete truss action with member subjected to primarily to axial forces in the elastic range.

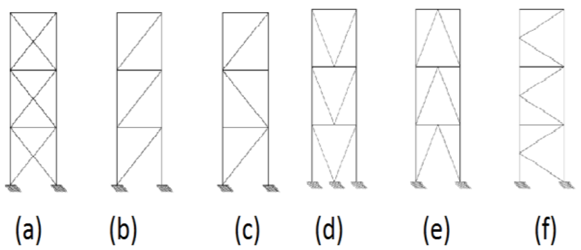


Fig-3-Examples of bracing schemes for concentrically braced frames: (a) X braced;(b) Diagonally braced; (c) alternative diagonally braced; (d) V braced;(e) Inverted V-braced; and (f) K-braced

b) Eccentrically braced frames (EBFS):

In EBFs, some of the bracing members are arranged so that their ends do not meet concentrically on a main member, but are separated to meet eccentrically. The eccentric link element between the ends of the braces is designed as a weak but ductile link which yields before any of the other frame members therefore it provides a dependable source of ductility [3]. The link length varies from 0.1 to 0.4 times of length of braced span. In the present thesis the link length is taken as 0.1 times of length of braced span that is 0.3 m.

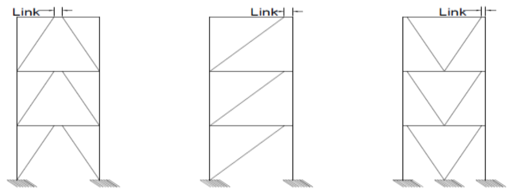


Fig-4- Examples of bracing schemes for eccentrically braced frames

2. Modelling of steel building

The models consist of frame structures which are made up of full of steel section. All columns and beams used in assembly of structure are Hot Rolled Indian I-section. All columns I-section are classified as under plastic, compact and semi compact section as per IS800 2007 As the building is made up of full of steel I-section so its need to optimize the section so that we can reduce the cost of the building. Structures were subjected to dead load, live load and earthquake loads, analyzed for all the possible load combination as per IS1893 2002.

For deciding the best section for the beam and column much iteration in the structure has done and the best suited section are selected. The building is first designed for dead load and live load in ETABS2015 as per IS800 2007, then the member are selected and further time history analysis in done in that building. The different bracing systems X bracing, V bracing, inverted V bracing, and two eccentric bracing along with MRF is used for analysis. The sizes of beams and columns of different bracing patterns are the same as that of MRF. The same sizes of braces are assigned to different bracings X bracing, V bracing, inverted V bracing, and two eccentric bracing. For selecting the beam and column I-section auto select list is created for beam Fe245 steel and for column Fe345 steel is used for entire member stress capacity ratio have been checked by limiting the stress capacity ratio 0.95 in ETABS 2015.

Table -1: Rolled section used in auto select list are-

For 5 story building-	
For beams	ISMB 150, ISMB 175, ISMB 200, ISMB 225, ISMB 250, ISMB 300
For columns	ISHB 200-1, ISHB 200-2, ISHB 225-1, ISHB 225-2, ISHB 250-1, ISHB 250-2
For bracing	ISA 75x75x8
For 15 story building-	
For beams	ISMB 200, ISMB 225, ISMB 250,

	ISMB 300, ISMB 350, ISMB 400,
For columns	ISHB 200-1, ISHB 200-2, ISHB 225-1, ISHB 225-2, ISHB 250-1, ISHB 250-2, ISHB 300-1, ISHB 300-2, ISHB 350-1, ISHB 350-2, ISHB 4000-1, ISHB 400-2
For bracing	ISA 90x90x12

Table -2: Plan and General detail of building-

Length of building (X-direction)	12 m
Width of building (Y-direction)	12 m
Bay spacing in X-direction	3 m
Bay spacing in Y-direction	3 m
Number of story	5 and 15
Height of each story	3 m
Height of plinth beam	0.6 m
Height of building above plinth beam	15 m and 45 m
Dead load of finishing	1 KN/m2
Live load on top floor	1.5 KN/m2
Live load on all other floor	3 KN/m2
Response reduction factor for moment resisting frame	5
Response reduction factor for concentrically braced frame	4
Response reduction factor for eccentrically braced frame	5
Soil site type	II
Seismic zone	IV

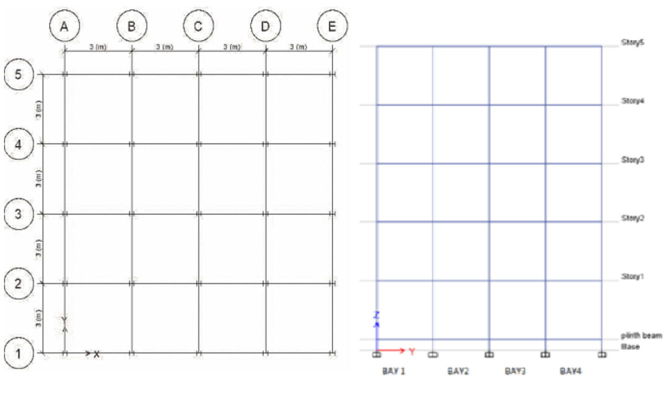


Fig-5-plan of both 5 and 15 story building and elevation of 5 story building

Nomenclature for braces:

MRF - Moment resisting frame (Fig 5)
X1 – X bracing are applied in bay 1 and bay 4 (Fig 5a)
X2 – X bracing are applied in bay 2 and bay 3 (Fig 5b)
V1 – V bracing are applied in bay 1 and bay 4 (Fig 5c)
V2 – V bracing are applied in bay 2 and bay 3 (Fig 5d)
IV1 – Inverted V bracing are applied in bay 1 and bay 4 (Fig 5e)
IV2 – Inverted V bracing are applied in bay 2 and bay 3 (Fig 5f)
E1 – eccentric bracing are applied in bay 1 and bay 4 (Fig 5g)
E2 – eccentric bracing are applied in bay 2 and bay 3 (Fig 5h)
E3 – eccentric bracing are applied in bay 1 and bay 4 (Fig 5i)
E4 – eccentric bracing are applied in bay 3 and bay 3 (Fig 5j)

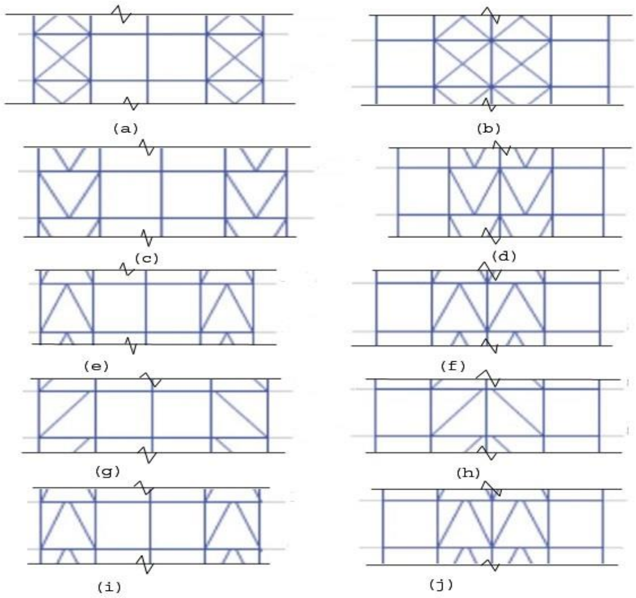


Fig 6 Elevation view of 5 and 15 story braced frames

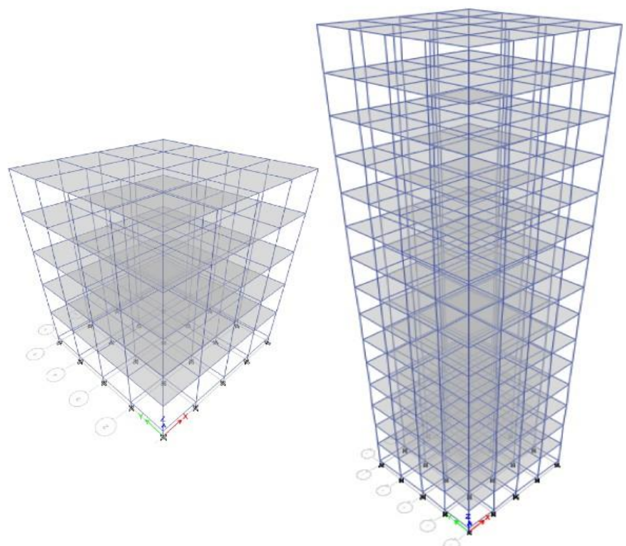


Fig 7- Isometric view of 5 story and 15 story building

3. Time history method: The procedure usually includes the following steps,

1. An earthquake record representing the design earthquake is selected.
2. The record is digitized as a series of small time intervals of about 1/40 to 1/25 second.
3. A mathematical model of building is setup, usually consisting of a lumped mass at each floor. Damping is considered proportional to the velocity in the computer formulation.
4. The digitized record is applied to the model as accelerations at the base of the structure.
5. The equations of motions are then integrated with the help of software program that give a complete record of acceleration, velocity and displacement of each lumped mass at each interval.

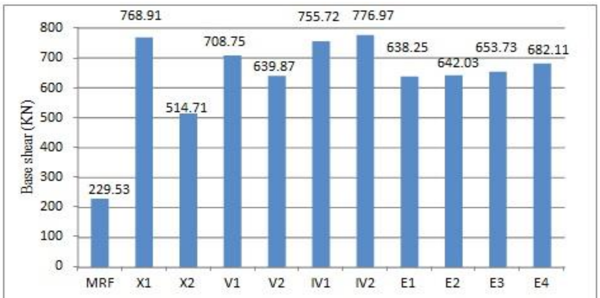
The accelerations and relative displacements of the lumped masses are translated into member stresses. The maximum values are found by scanning the output record. This procedure automatically includes various modes of vibration by combining their effect as they occur, thus eliminating the uncertainties associated with modal combination methods. The dynamic equilibrium equation for multi degree freedom, system is given by,

$$M\ddot{U} + C\dot{U} + KU = F(t)$$

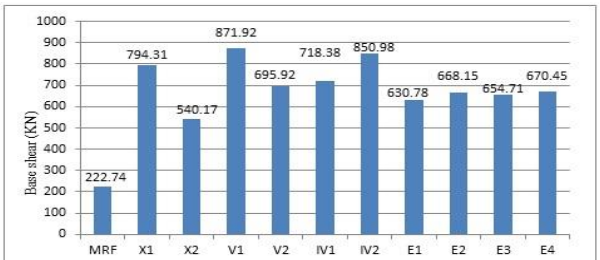
4. RESULT AND DISCUSSION:

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure.

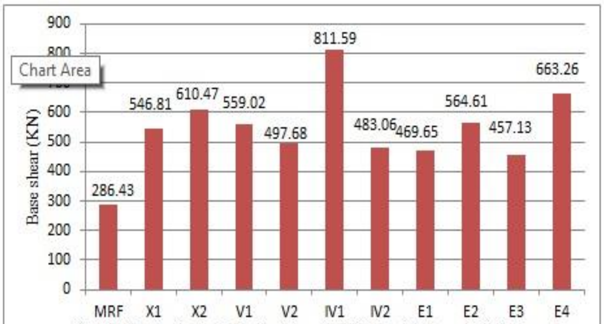
From graph it is clear by applying bracing in moment resisting frame the base shear increased. By applying bracing stiffness and weight of the structure is increased which increase the base shear.



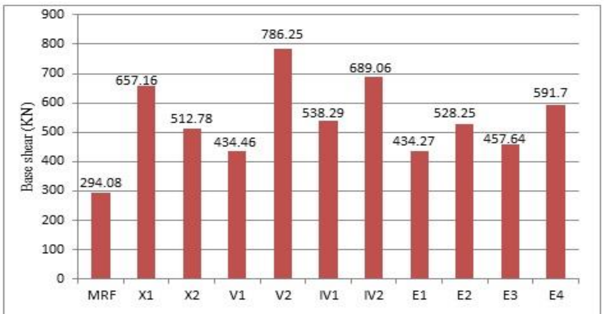
Graph- Base shear in X direction in KN for 5 story building



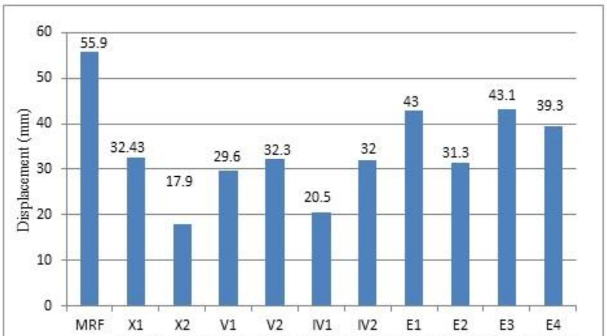
Graph - Base shear in Y direction in KN for 5 story building



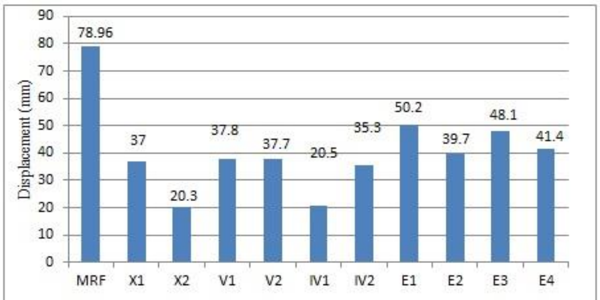
Graph- Base shear in X direction in KN for 15 story building



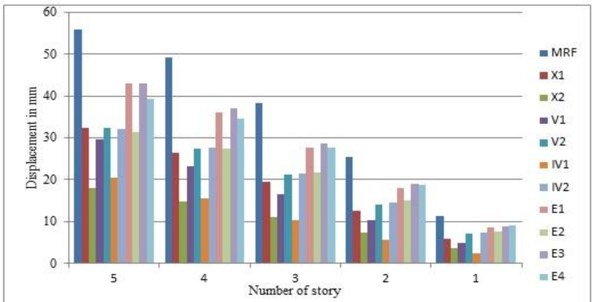
Graph - Base shear in Y direction in KN for 15 story building



Graph- maximum displacement at top story in X direction (in mm) for 5 story



Graph- maximum displacement at top story in y direction (in mm) for 5 story



Graph - Displacement in X direction for 5 story building

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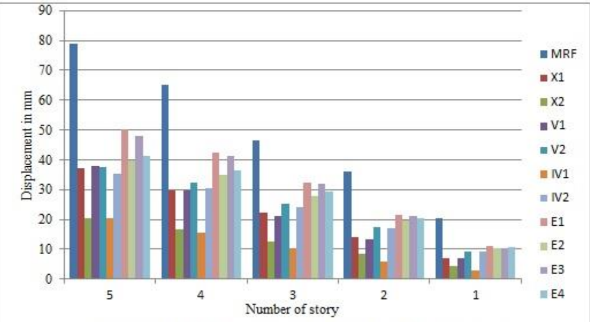
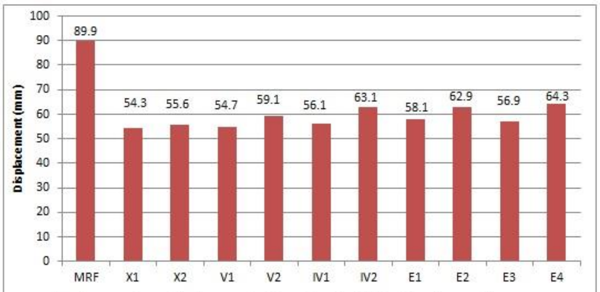


Graph 5.9 - Displacement in Y direction for 5 story building



Graph - maximum displacement at top story in X direction (in mm) for 15 story

Graph - maximum displacement at top story in Y direction (in mm) for 15 story

	MRF	X1	X2	V1	V2	IV1	IV2	E1	E2	E3	E4
story 5	55.9	32.4	17.9	29.6	32.3	20.5	32.1	43	31.3	43.1	39.3
story 4	49.1	26.3	14.7	23.1	27.4	15.4	27.6	36.1	27.3	37	34.6
story 3	38.3	19.4	11	16.5	21.1	10.3	21.5	27.5	21.7	28.6	27.5
story 2	25.5	12.4	7.2	10.2	14.1	5.6	14.4	18	14.9	18.9	18.7
story 1	11.2	5.8	3.6	4.9	7	2.3	7.2	8.6	7.5	8.8	9.1

Table- Maximum story displacement in X direction in mm for 5 story building

	MRF	X1	X2	V1	V2	IV1	IV2	E1	E2	E3	E4
story 5	79	37	20.3	37.8	37.7	20.5	35.3	50.2	39.7	48.1	41.4
story 4	65.2	29.9	16.7	29.6	32.3	15.4	30.5	42.3	34.9	41.3	36.6
story 3	46.5	22.1	12.6	21.3	25.3	10.4	24.1	32.5	28	32	29.4
story 2	36	14.2	8.3	13.5	17.4	5.9	17	21.7	19.6	21.3	20.4
story 1	20.3	7	4.4	6.9	9.3	2.7	9.3	11	10.5	10.5	10.6

Table- Maximum story displacement in Y direction in mm for 5 story building

	MRF	X1	X2	V1	V2	IV1	IV2	E1	E2	E3	E4
story 15	89.9	54.3	55.6	54.7	59.1	56.1	63.1	58.1	62.9	56.9	64.3
story 14	85.2	49.7	52.1	49.3	55.1	51.3	57.7	52.5	58.7	51.6	59.7
story 13	77.9	44.8	49.1	44.2	50.7	46	51.5	46.2	53.8	45.6	54.4
story 12	68.8	39.7	46.2	38.9	46	40.4	47.4	39.6	48.4	39	48.5
story 11	60.8	34.4	43	35.8	41	34.3	43	34.9	42.6	33.7	42.2
story 10	55.8	31.7	39.5	35	35.6	32	38.2	33.1	36.3	31.8	35.5
story 9	50.5	29.7	35.4	33.7	30	31	33	31	29.7	30	32
story 8	44.9	27.2	31	31.8	25.1	29.1	27.5	28.5	24.6	27.7	28.2
story 7	43.1	24.3	26.3	29	22.9	26.3	22.3	25.4	22.8	24.8	25.4
story 6	38.5	20.9	21.4	25.5	20.2	25.1	18.5	21.9	20.5	21.3	22.3
story 5	32.3	17.1	16.9	21.3	17.2	22.7	14.8	17.9	17.6	17.9	19
story 4	26.9	13.2	13.1	17.4	13.9	19.1	11.5	14.4	14.4	14.4	16.6
story 3	20.1	9.2	9.2	12.9	10.3	14.5	8.3	10.9	10.8	10.6	13.2
story 2	13.3	5.6	5.7	8.3	6.7	9.4	5.3	7.2	7.1	6.9	9.1
story 1	6.2	2.6	2.8	4	3.3	4.5	2.6	3.5	3.6	3.3	4.6

Table- Maximum story displacement in X direction in mm for 15 story building

	MRF	X1	X2	V1	V2	IV1	IV2	E1	E2	E3	E4
story 15	95.7	53.5	56.3	55	65.1	60.4	60.9	54.2	68.2	54	55.6
story 14	89.4	47.5	52	50.1	58.1	53.8	55.9	51.2	61.2	49.7	51.5
story 13	81.9	41.9	45.8	44.8	50.8	46.7	50.4	46	53.7	44.5	46.9
story 12	78.9	39.2	42.7	39.3	43.7	40.6	44.6	41.2	45.9	38.2	41.8
story 11	73.7	38.6	39.2	33.9	38.3	36.9	38.4	35.8	38	32.4	36.4
story 10	66.9	37.4	38.4	32.7	33.3	31.9	34.3	30.3	31.5	29.4	31.6
story 9	63.1	30.6	31.3	30.3	31.6	31.2	28.3	27.7	29.2	26.7	29.3
story 8	62	25.4	26.9	26.8	29.7	28.5	26.4	27.1	27.6	26.1	27.9
story 7	61	23.5	24.3	22.8	27.1	25.2	24.1	26.2	25.3	24.7	25.8
story 6	60.1	22.9	22.6	21.4	25	21.2	21.4	24.3	23	22.5	24
story 5	53.5	20.1	19.5	19.1	23.1	18.1	18.2	21.3	20.4	19.3	21.5
story 4	44.5	15.1	14.6	15.8	20.1	15	15.4	17.4	17.1	15.9	18.2
story 3	34.9	11.1	10.9	12	16	11.3	12	13	13.1	12	14.1
story 2	25	7.2	6.8	7.9	11.1	7.3	8.3	8.5	8.8	7.8	9.6
story 1	12.9	3.6	3.4	4	6.1	3.6	4.4	4.2	4.6	3.9	5

Table- Maximum story displacement in Y direction in mm for 15 story building

5. Conclusions:

The selected frame model was analyzed using time history analysis. The plan of the model is symmetry in X and Y direction. The height of the building is 15m and 45 meter. By analyzing these models several results are obtained and observing these results we concludes:

As expected top story displacement in 15 story building is more as compare to 5 story building and compare to moment resisting frame story displacement is less in all braced frames.

For 5 story building:

- Top story displacement is minimum for cross braced frame X2 as compare to all other braced and moment resisting frame in both directions.
- For cross braced frame displacement in X2 is less than X1 for both directions, it means cross bracing on bay 2 and 3 are more efficient to reduce displacement.
- For inverted V braced frame displacement in IV1 is less than IV2 for both direction, it means inverted V braced frame on bay 1 and bay 4 is more efficient to reduce displacement.
- For eccentric braced frame displacement in E1 is less than E2 for both direction, and for eccentric bracing displacement in E3 and E4 is nearly equal.

For 15 story building:

- Top story displacement is minimum for cross bracing X1.
- Above 9th story for all bracings, applying bracings on bay 2 and bay 3 are more effective to reduce displacement.
- Displacement in eccentric braced E4 is more then to E3 in both directions.
- Compare to X1 and X2, from story 15 to story 7, in X1 bracings displacement is less and below story 7 displacement in both bracings are nearly equal in both directions.
- Compare to V1 and X2, from story 15 to story 9 displacements in X2 is more in both direction and below 9th story displacement in V1 is more in X directions.

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