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Dynamic Analysis of Steel Braced RC Structure of Unsymmetrical Building Plan

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Abstract: Present analytical seismic study deals with optimum location of steel bracing to the RC structure with unsymmetrical building plan of G+30 stories in Zone 5 following IS 1893(part-1):2002and IS 13920:1993 by response spectrum analysis. Various steel bracing system such as X, Single Diagonal, Inverted V braces are provided at different locations of structure. Braces are connected within the story and more than one story considering five different types. The results are compared with bare frame and five types and optimum location of bracing are compared. The response of the structure is compared with lateral displacement, story drift, story stiffness, base shear, story torsion, eccentricity and time period.

Keywords: *Unsymmetrical Building plan, Steel Bracing, RC Frame, Response Spectrum Analysis, Diaphragms.*

1. Introduction

The preliminary requirement of the structure is to satisfy serviceability conditions, stiffness and safety. Today to serve serviceability conditions architects are preferring irregularities for aesthetic and other conditions. The shape and proportion of the structure effects on the distribution of forces. Due to irregularities structure will get deficient stiffness and continuous load path and tension capacity will be less at re-entrant corners.

Steel braces are retrofitted to increase the strength of RC framed structures and is good rehabilitation technique. Bracing provide high stiffness due to the horizontal shear is primarily absorbed and resist lateral forces by developing internal axial actions and relatively small flexural actions.

Raja Madhukar Vishnu, M. Prasanna Kumar and Y. Balakoti Reddy had done research on linear static and response spectrum analysis considering unsymmetrical building plan of G+30 storeys. They provided internal braces to the structure. They concluded that X and inverted V braces provides good stiffness control displacements but base shear increases [12].

A. Kadid and D. Yahiaoui evaluated on the static non-linear pushover analysis of three and six storied RC structure considering different types of steel braces such as X, inverted V, ZX, and Zipper braces. They concluded that selection of section for steel bracing effects on global capacity of building and X, Zipper braces provides good results [1]. Marc Badoux and James O. Jirsa conducted experimental and analytical research on the retrofitting of steel bracing for RC frame under cyclic lateral loading and analytical study done by using DRAIN-2D software focusing inelastic response of plane structures subjected to seismic loading. They concluded that steel bracing is well suited for lateral strengthening of multi-storey RC structure from drift and collapse prevention. Combining bracing with beam provides significant improvement inelastic behaviour of braced frame [2].

A. Murali Krishna and Dr. E. Arunakanthi presents an analytical research on high rise building for optimum location of shear wall for unsymmetrical building plan using linear static and response spectrum analysis. They concluded that providing different shapes of shear walls effects on eccentricity, time period with control of displacements and dynamic analysis is necessary for evaluating actual performance of the structure [3].

A. Massumi and M. Absalan proposed analytical and experimental work on steel bracing for RC frames by using ANSYS software. Non-linear analysis considering cyclic static loading was conducted and they concluded that adding Steel bracing strengthens and increases strength, stiffness, energy absorption capability for RC frame. Numerical analysis results provided that increase of 18.34% of the strength [4]. Jose A. Pincheira, and James O. Jirsa conducted study on seismic performance on non-ductile reinforced concrete (RC) frames using inelastic static and dynamic response analyses for five ground motions representative of major earthquakes on firm and soft soil conditions of 3, 7 and 12 storied RC frames using DRAIN-2D. Retrofit schemes included the installation of post-tensioned bracing, structural steel bracing, or infill walls of reinforced concrete. They concluded that, bracing systems the level of axial forces induced by steel braces would adversely affect the lateral strength of the existing reinforced concrete member [5].

T. Mahdi and V. Bahreini conducted nonlinear seismic behavior of intermediate moment resisting frames with unsymmetrical building plan of three, four and five storeys with infill walls. They concluded that infilled frames have high shear forces with small displacements [6]. M.R. Maheri, R. Kousari and M. Razazan conducted experimental research ductile RC frames with X and Knee braces. They concluded that X and Knee braces increases strength and capacity and decrease of global displacements. X bracing provides good stiffness but reduces ductility and Knee bracing provides desired ductility [7].

2. Analytical Information

Building plan is T-shape and the model information is considered from [12]. From [12] structure is G+30 storeys with zone 5 with importance factor 1 and response reduction as 5. Along X-direction plan is unsymmetrical and along Y-direction is symmetrical. Rigid diaphragms are provided to the structure. Figure 1, 2, 3, 4, 5 and 6 are taken from [12].

In the present research three different types of bracing systems X, Inverted V and single diagonal braces are provided to the structure and models are divided into five different types. In type 1 bracing is connected within the storey and results are taken from [12]. In type 2 bracing are connected between two storeys, type 3 three storeys, type 4 four storeys, type 5 five storeys and bracing are connected with the rest of the storeys in each type which are not connected in each type. For example in type 2 bracing is not connected for two storeys at top because of discontinuity.

Results are compared considering all the five types. In each type there are 12 models (figure 2, 3, 4 and 5) and model 1 is bare frame (figure 1). Figure 7 denotes elevation view pattern of each type considering Inverted V bracing and similarly X, single diagonal bracing are arranged similarly.

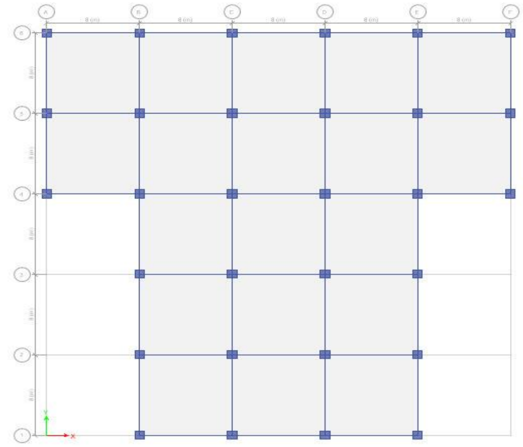

Figure 1: *Top view of Model1 (Without steel bracing)*

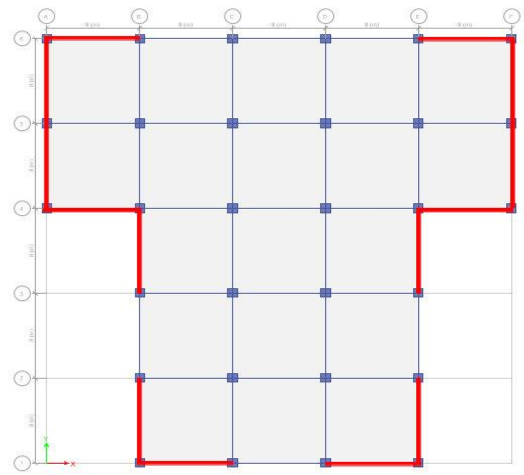

Figure 2: *Top view of Model 2 (X bracing), Model 3 (Inverted V bracing), Model 4 (Single Diagonal bracing) in highlighted part*

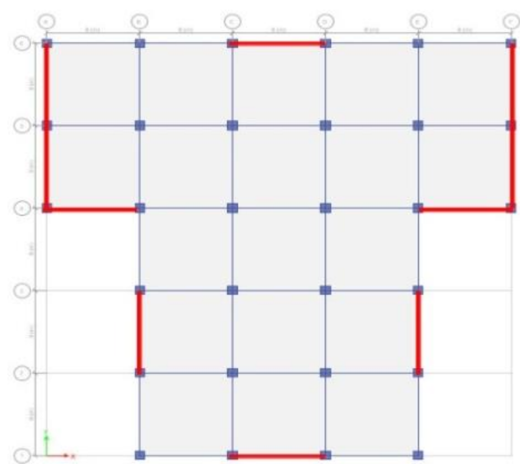

Figure 3: *Top view of Model 5 (X bracing), Model 6 (Inverted V bracing), Model 7(Single diagonal bracing) in highlighted part*

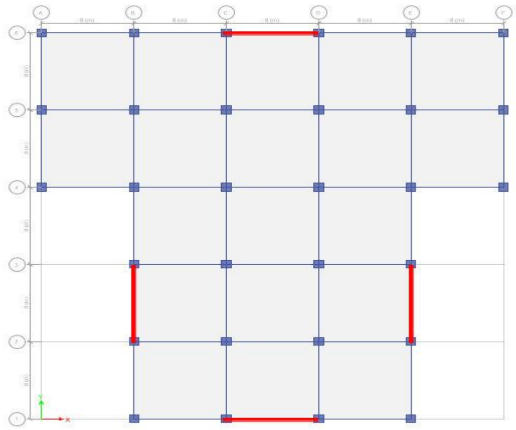

Figure 4: *Top view of Model 8(X bracing), Model 9(Inverted V bracing), Model 10(Single diagonal bracing) in highlighted part*

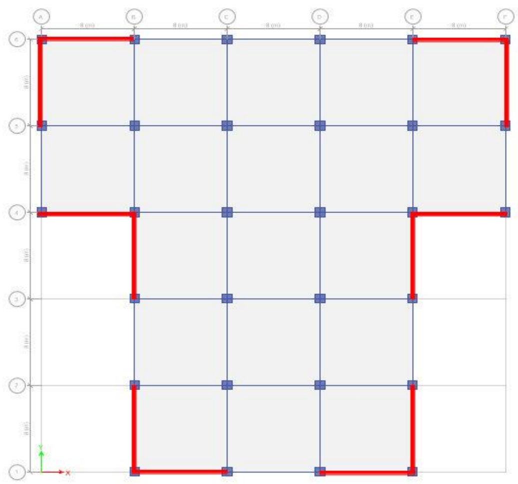

Figure 5: *Top view of Model 11 (X bracing), Model 12 (Inverted V bracing), Model 13 (Single Diagonal bracing) in highlighted part*

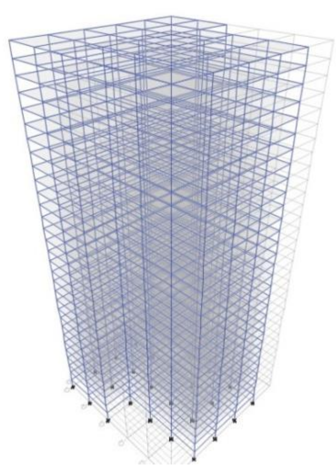

Figure 6: *3 Dimensional View of complete structure*

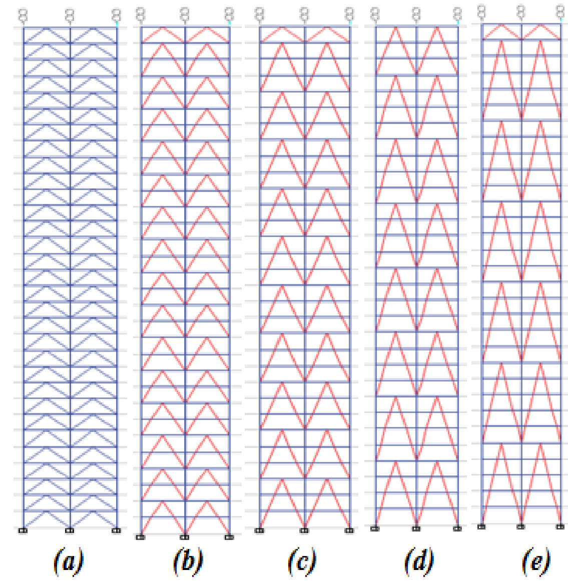

Figure 7: *Elevation view of five types of models (a) Type-1, (b) Type-2, (c) Type-3, (d) Type-4, (e) Type-5.*

3. Results and Discussions

Base shear, top storey displacements, eccentricity, maximum storey drift, time period, storey torsion and storey stiffness are compared with graphs in each type and tabulated.

Base shear is maximum in type 1 and it is reducing type 2, 3, 4 and 5. In type 5 base shear is minimum. Figure 8 and 9 provides comparative graph considering all models in Earthquake X and Y directions.

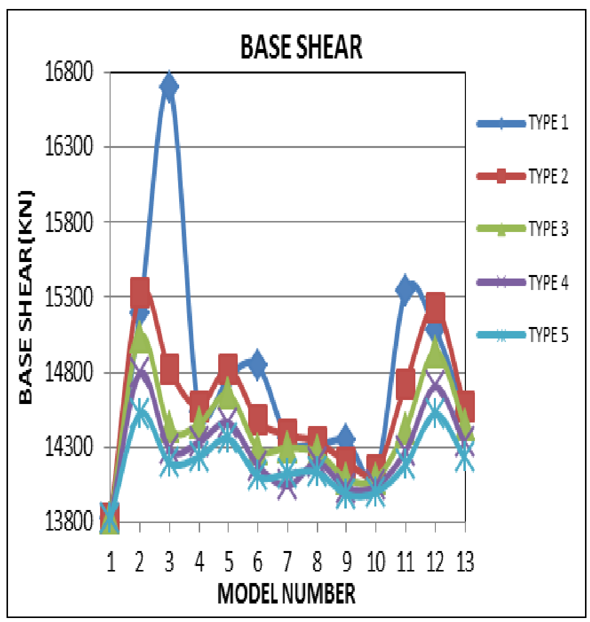

Figure 8: *Base shear along X direction considering all models in 0.9DL+1.5EQX load combination*

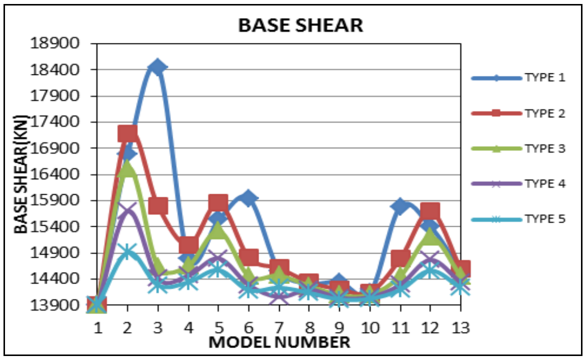

Figure 9: *Base shear along Y-direction considering all models in 0.9DL+1.5EQY load combination*

Table 1: *Summary of maximum Base shear in each type*

Type	Model No	Base shear (X) (KN)	Base shear (Y) (KN)
Bare frame	1	13826.37	13910.41
Type-1	3	16703.88	18442.3719
Type-2	2	15330.85	17189.4004
Type-3	2	15035.42	16520.2635
Type-4	2	14791.10	15702.7906
Type-5	2	14522.97	14911.88

Top storey displacements reduction is maximum in type 1 and relatively decreases. Figure 10 and 11 denotes graphical representation of the results.

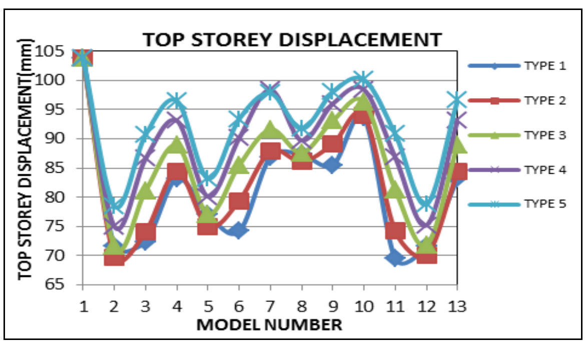

Figure 10: *Top storey displacements considering all models in DL+EQX load combination*

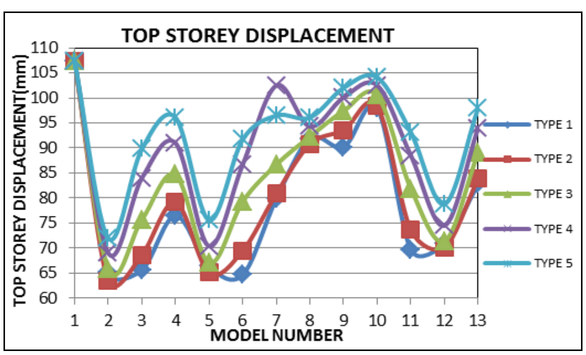

Figure 11: *Top storey displacements considering all models in DL+EQY load combination*

Table 2: *Summary of minimum top storey displacements in each type along X-direction*

Type	Model No	Top storey Displacement(mm)
Bare frame	1	103.8
Type-1	11	69.5
Type-2	2	69.8
Type-3	2	71.6
Type-4	2	75
Type-5	2	78.5

Table 3: *Summary of minimum top storey displacements in each type along Y-direction*

Type	Model No	Top storey displacement(mm)
Bare frame	1	107.4
Type-1	6	64.7
Type-2	2	63.4
Type-3	2	65.9
Type-4	2	69.1
Type-5	2	72

Eccentricity is developed along Y-direction due to asymmetry and decreases maximum in type 5 and minimum in type 1 compared to bare frame from figure 12.

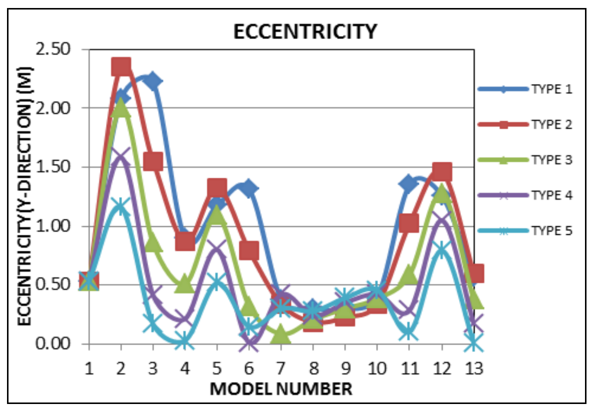

Figure 12: *Eccentricity considering all models along Y-direction.*

Table 4: *Summary of minimum eccentricity along Y-direction*

Type	Model no	Eccentricity(m)
Bare frame	1	0.5316
Type-1	9	0.292
Type-2	8	0.1848
Type-3	7	0.0839
Type-4	6	0.0084
Type-5	13	0.0053

Time period reduction is minimum in type 5 and maximum in type 1 compared to bare frame.

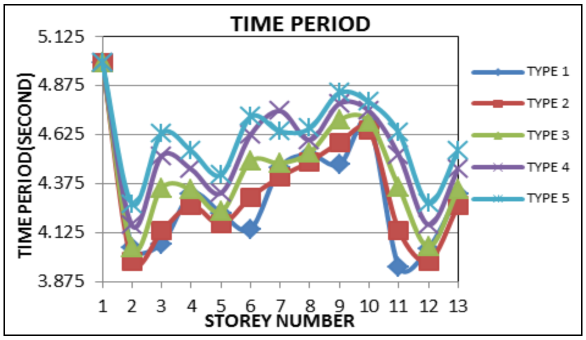

Figure 13: *Time period considering all models*

Table 5: *Summary of maximum time period considering each type*

Type	Model No	Time period (Sec)
Bare frame	1	4.991
Type-1	10	4.676
Type-2	10	4.647
Type-3	9	4.701
Type-4	9	4.783
Type-5	9	4.838

Storey stiffness is maximum in type 1 and relatively decreases in type 5.

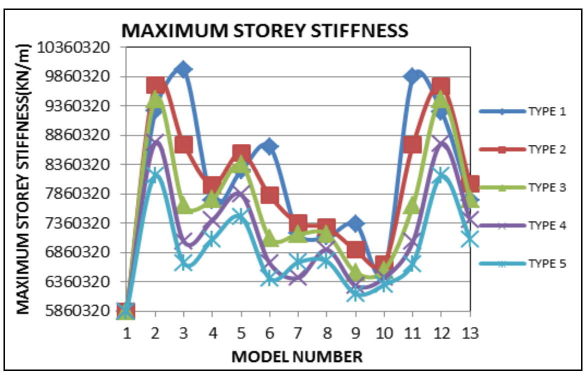

Figure 14: *Maximum storey stiffness considering all models along X-direction*

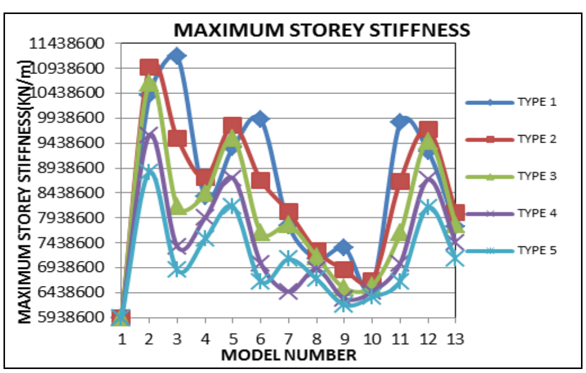

Figure 15: *Maximum storey stiffness considering all models along Y-direction*

Table 6: *Summary of maximum Storey stiffness considering each type*

Type	Model No	Maximum storey stiffness (X) (KN/m)	Maximum storey Stiffness (Y) (KN/m)
Bare frame	1	5860325.652	5938606.299
Type-1	3	9972533.136	11179166
Type-2	2	9710872.549	10956308
Type-3	2	9478038.514	10646560
Type-4	2	8729817.153	9602403.929
Type-5	2	8167492.373	8853174.123

Maximum storey torsion is maximum in type 1 and it is reducing type 2, 3, 4 and 5. In type 5 storey torsion is minimum. Figure 8 and 9 provides comparative graph considering all models in Earthquake X and Y directions.

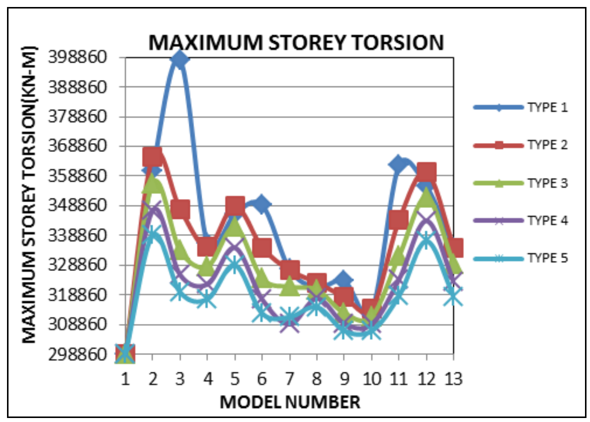

Figure 16: *Maximum storey torsion considering all models along X-direction in 0.9DL+1.5EQX load combination*

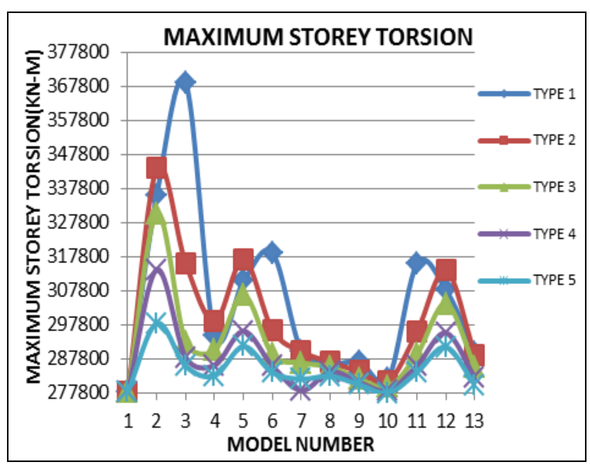

Figure 17: *Maximum storey torsion considering all models along Y-direction in 0.9DL+1.5EQY load combination*

***Table 6:** Summary of maximum Storey torsion considering each type*

Type	Model no	Maximum Storey torsion(X) (KN-m)	Maximum storey torsion(Y) (KN-m)
BARE FRAME	1	298860.6077	278208.3096
Type-1	3	397811.0946	368847.4828
Type-2	2	365311.6979	343787.9997
Type-3	2	356406.6689	330405.3359
Type-4	2	347301.9052	314055.8254
Type-5	2	338914.5589	298237.6936

Storey drift reduction is maximum in type 1 and relatively decreases considering type 2, 3, 4 and 5.

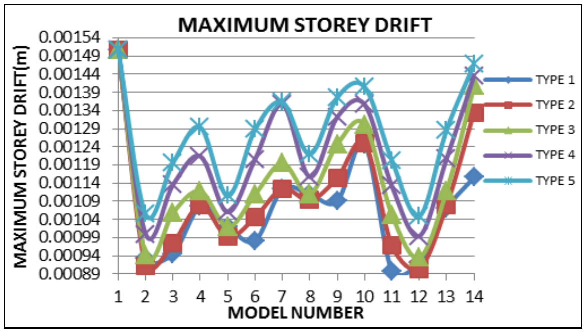

***Figure 18:** Maximum storey drift considering all models in DL+EQX load combination*

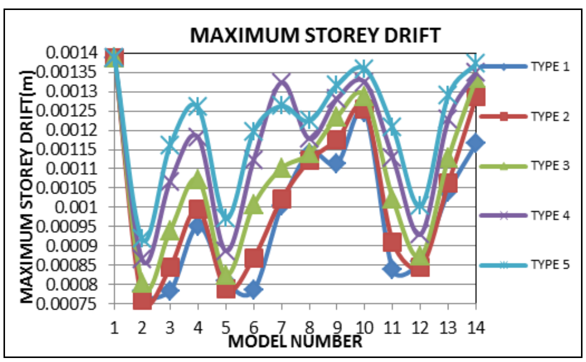

***Figure 19:** Maximum storey drift considering all models in DL+EQY load combination*

***Table 7:** Summary of maximum Storey drift considering each type along X-direction*

Type	Model No	Storey No	Max story drift(m)
Bare frame	1	6	0.001507
Type-1	11	14	0.000898
Type-2	12	14	0.000904
Type-3	12	12	0.000935
Type-4	12	12	0.000994
Type-5	12	11	0.001049

***Table 8:** Summary of maximum Storey drift considering each type along Y-direction*

Type	Model no	Storey No	Max story drift(m)
Bare frame	1	11	0.001389
Type-1	2	11	0.000783
Type-2	2	12	0.000758
Type-3	2	12	0.000804
Type-4	2	12	0.000864
Type-5	2	11	0.000917

4. Conclusion

The results can be concluded as follows:

1. Base shear is maximum by connecting bracing within the storey(type 1) and reduces when connecting more than one storey. More the connectivity between storeys shear reduces and ductility increases. X and inverted V bracing provides maximum base shear in type 1 but from type 2 to rest of models X bracing reduces base shear firmly.
2. Top storey displacement reduces maximum in type 1 along x-direction and type 2 along Y-direction. Displacement increases when connecting of bracing more than one storey along x direction and more than two storeys along y-direction. Top storey displacements are controlled by X bracing both along X and Y direction.
3. Max storey drift reduces maximum in type 1 along x-direction and type 2 along Y-direction. Drift increases when connecting of bracing more than one storey along x direction and more than two storeys along y-direction. Maximum storey drift are controlled by X bracing in type 1 and rest by inverted V bracing along X and X bracing along Y direction.
4. Storey stiffness is maximum in type 1 and minimum in type 5. If connecting of bracing between the storey increases stiffness decreases. Inverted V bracing provides maximum stiffness in type 1 and rest X bracing provides maximum results.
5. Eccentricity is maximum in type 1 and minimum in type 5. If connecting of bracing between the storey increases eccentricity decreases and torsion effect also decreases. Inverted V bracing reduces maximum in type 1 and 4, X bracing in type 2, single diagonal in type 3 and 5.
6. Storey torsion is maximum in connecting bracing within the storey(type 1) and reduces when connecting more than one storey. X bracing provides maximum torsion in type 1 and reduces from type 2.

7. Time period increases in type 5 and decreases minimum in type 1 because when shear rigidity increases time period decreases.
8. Providing adequate stiffness and continuous loadpath provides better results with good ductility.

5. Acknowledgements

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