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Behaviour of Multi-Storey R.C.C Structure with Different Types of Bracing against Earthquake Forces

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Abstract - *Nowadays, the construction of the high-rise multi-storey buildings has been increased due to the increasing population. Earthquake is one of the main phenomena causing damage to the structure. As the height of the structure increases, it undergoes larger seismic forces. So, it is important to improve the resistance of multi-storey building to lateral loads. There are many structural systems which resist lateral loads by the addition of different structural systems. In this project work, Steel Bracing structural system is considered and compared to their results against lateral forces. Here, seven structural systems are considered in which one is Unbraced framed structure and others are Braced frame structure. For the purpose G+15 storey multi-storey R.C.C structure with rectangular plan of dimension 30mx20m uniform throughout the height is considered and analyzed for gravity and lateral loads using ETABS 18 software. Its intention is to obtain the functioning characteristics like Storey displacements, Storey drift, Natural time period, and Base shear to evaluated and compare with unbraced frame structure. The use of Mega X-Bracing shows good performance in resisting lateral loads since Storey displacements and Storey drifts are found to be less than that of other bracing system.*

Key Words: Bracing, Earthquake Force, Storey displacements, Storey drift, Natural time period, and Base shear, ETABS etc

1. INTRODUCTION

Bracing is one of the most widely used lateral load resisting systems in multi-storied buildings. Bracing is a highly efficient and economical method of resisting horizontal force in a frame structure. Braced frame is a structural system, which is designed primarily to resist wind loads and earthquake forces. Braced frames can be an effective system for seismic retrofit due to their high stiffness. Braced frames are almost always composed of steel members.

The beams and columns that form the frame carry vertical loads, and the bracing system carries the lateral loads. Braced frames reduce lateral displacement, as well as the bending moment in columns. Steel bracing is economical, easy to erect, occupies less space and has flexibility to design for meeting the required strength and stiffness. It allows obtaining a great increase of lateral stiffness with a minimal added weight, and so it is very effective for existing structure for which the poor lateral stiffness is the main problem.

1.1 Different types of Bracings

Bracings are mostly a diagonal member which connects either beam-column junction or mid-point of beam or column span or length. On basis of that there are two types of bracing systems. First is **Eccentric** and another is **Concentric**.

- **Diagonal Bracing:** These are compression as well as tension type bracings. It consists of a single brace instead of two as in case of X - bracing.
- **V–Bracing:** Also called as chevron bracings. Here the braces intersect at the midpoint of the beam.
- **Inverted V–Bracing:** These are also inverted chevron or have the shape of alphabet V.
- **X–Bracing:** These are the commonly used bracing systems. Here the diagonals intersect each other to form alphabet X.
- **K–Bracing:** K-braces connect to the columns at mid-height. K-bracing is generally discouraged in seismic regions because of the potential for column failure if the compression brace buckles.

2. OBJECTIVE

In this project G+15 Storey R.C.C structure is analyzed to study the effect of lateral forces such as Earthquake forces for Zone III considering different bracing system.

Type of Structure Analyzed:

- RCC bare frame without bracing system.
- RCC Bare frame with bracing system.

Types of bracing system used are as follows:

- Diagonal Bracing
- V-Bracing
- X-Bracing
- Mega Diagonal bracing
- Mega V-Bracing
- Mega X-Bracing

The software to be used for the analysis is ETABS 18. The comparison of structural behavior is observed such as Storey Displacement of building, storey Drift, Natural Time Period,

Base shear and Conclusions are drawn based on the observations and better structural system is found out with this study.

3. METHODOLOGY

To achieve the above objective following step-by-step procedures are followed;

- Carried out literature study to find out the objectives of the project work.
- In the present investigation a G+15 storied building is considered, having general arrangement measurement of 30 m x 20 m along X and Y Direction with a bay size of 5 m in both the direction.
- Seven Structural systems is adopted in this work i.e., One Unbraced frame structure and others are Braced frame structure with different types of braces.
- Analyze all selected models using ETABS 18 Software by applying Design Loads as per IS 875.
- Evaluate the analysis results and verify the requirement of the geometrical limitations.

3.1 Problem Statement

Following types of structural arrangement is studied;

- Reinforced concrete multi-storey building without Bracing system.
- Reinforced concrete multi-storey building with Diagonal Bracing, V– Bracing, X–Bracing, Mega Diagonal Bracing, Mega V-Bracing, and Mega X-Bracing.

I. Geometrical Data:

- No of Stories : G+15
- No. of Bay in X-Direction : 6
- No. of Bay in Y-Direction : 4
- Type of Building Use : Residential
- Plan Dimension : 30m X 20 m
- Typical Storey Height : 3.0 m
- Bottom Storey Height : 3.0 m
- Height of Structure : 51 m

II. Materials:

- Concrete Grade : M20, M25, M30
- Steel (Rebar) : Fe500
- Steel (Bracing) : Fe250

III. Member Properties:

- Thickness of Slab : 150 mm
- Column Size : 600 mm X 600 mm
- Beam Size : 450 mm X 230 mm
- Bracing : ISNB 175H

IV. Loads Considered:

- Dead Load : Auto
- Live Load : 3 kN/m^2
- Floor Finish : 1.5 kN/m^2
- Wall Load : 13 kN/m (9" Thick)
- Other Loads : Seismic Load

V. Seismic Load:

Seismic design shall be done in accordance with IS: 1893:2016. The building is situated in earthquake zone III (Mangaluru). The parameters to be used for analysis and design are given below (As per IS: 1893:2016 (Part I)).

- Zone : III
- Zone Factor : 0.16 (IS 1893 (Part 1)
- Importance factor : 1.2
- Response Reduction Factor : 5.0 Special RC Moment Resisting Frame (SMRF)
- Structure Type : RC Frame Structure.

4. MODELING OF THE STRUCTURE

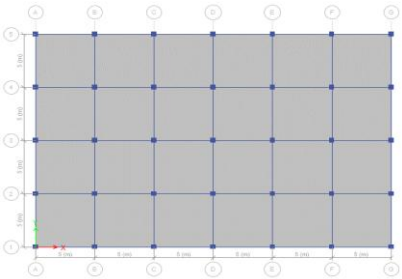

Fig -1: Plan of the Models

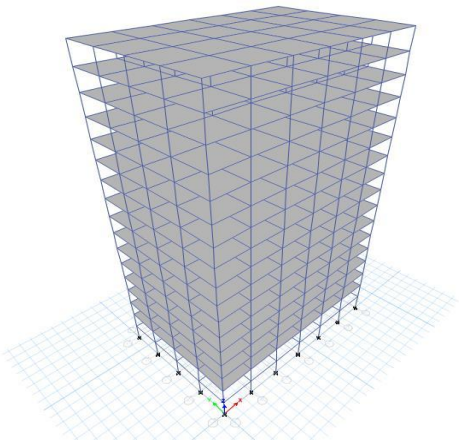

Fig -2: Unbraced Building (3D View)

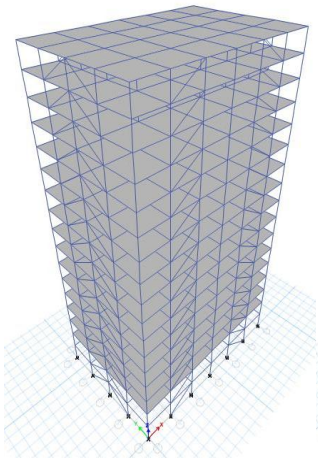

Fig -3: Diagonal Bracing (3D View)

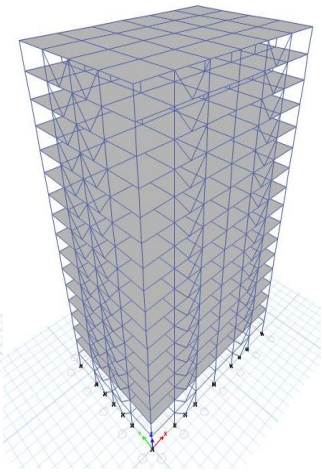

Fig -4: V-Bracing (3D View)

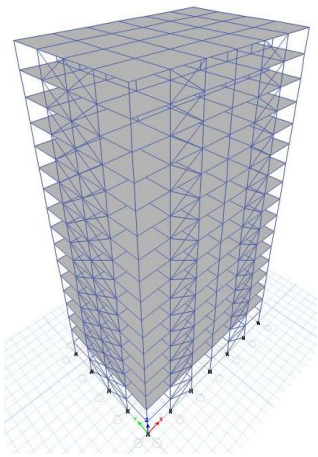

Fig -5: X-Bracing (3D View)

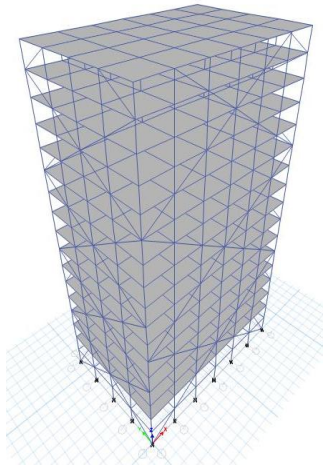

Fig -6: Mega Diagonal Bracing (3D View)

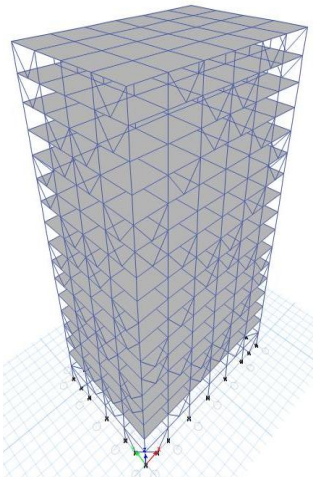

Fig -7: Mega V-Bracing (3D View)

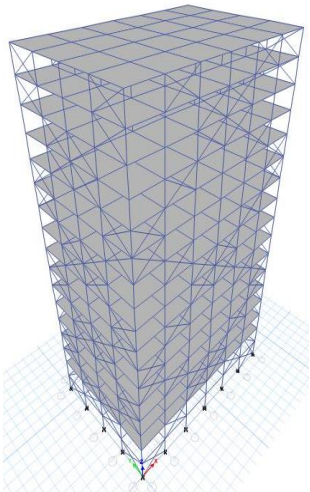

Fig -8: Mega X-Bracing (3D View)

5. RESULTS AND DISCUSSION

- Response Spectrum Analysis and Time History Analysis is carried out for Regular building without and with Bracing.
- The models are checked for Storey displacement, Storey drift, Natural Time Period, and Base Shear.

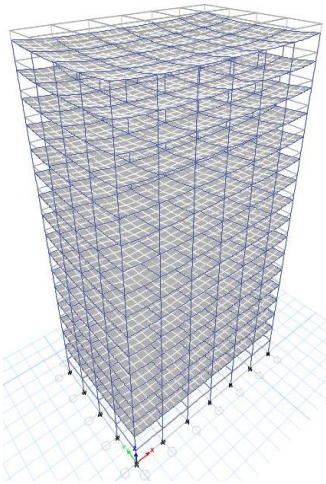

Fig -9: Displacement (3D View)

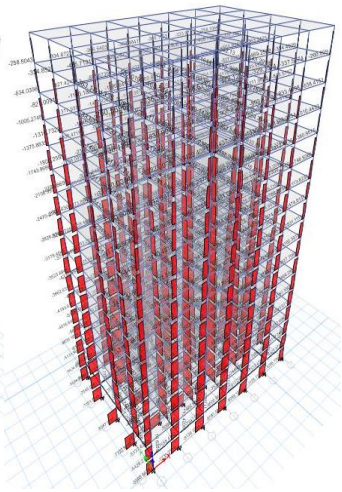

Fig -10: Axial Force Diagram (3D View)

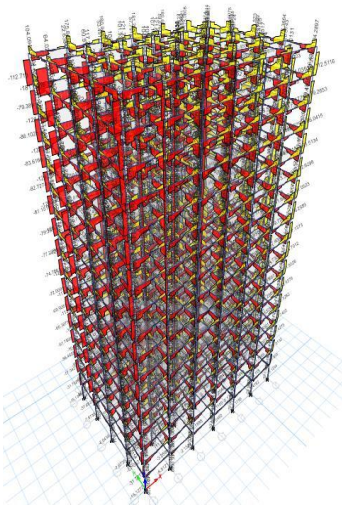

Fig -11: Shear Force (3D View)

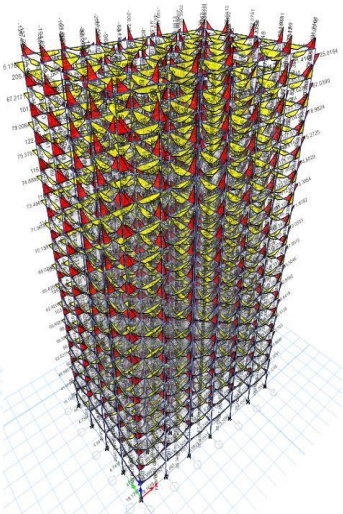

Fig -12: Bending Moment (3D View)

5.1 Max. Storey Displacement

- It is total displacement of the Top Storey with respect to ground.

I. Diagonal Bracing:

Floor Level	Diagonal Bracing	
	X-Direction	Y-Direction
15h Floor	82.693	82.768
14th Floor	81.214	81.192
13th Floor	79.076	78.994
12th Floor	76.268	76.147
11th Floor	72.842	72.698
10th Floor	68.86	68.708
9th Floor	64.388	64.242
8th Floor	59.488	59.358
7th Floor	54.214	54.106
6th Floor	48.609	48.529
5th Floor	42.717	42.664
4th Floor	36.574	36.549
3rd Floor	30.247	30.223
2nd Floor	23.794	23.775
1st Floor	17.172	17.18
Ground Floor	10.464	10.476
Plinth Level	4.3	4.33
Footing Level	0	0

Table -1: Max. Storey Displacement (mm) of Diagonally Bracing Building.

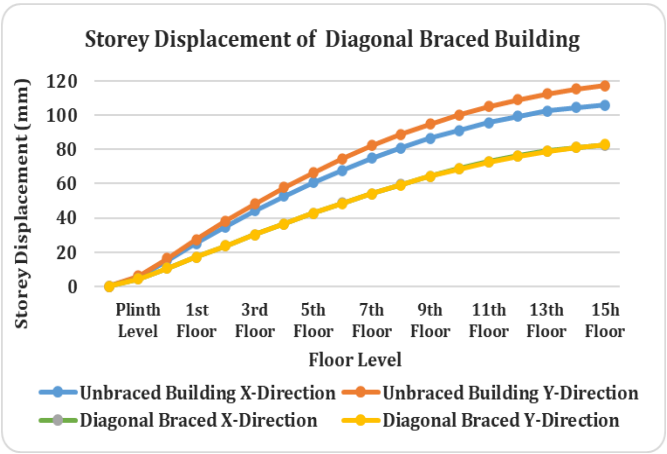

Fig -13: Max. Storey Displacement of Diagonally Braced Building.

I. V-Bracing:

Floor Level	V-Braced Building	
	X-Direction	Y-Direction
15h Floor	81.14	80.829
14th Floor	79.377	78.943
13th Floor	76.99	76.459
12th Floor	74.001	73.39
11th Floor	70.44	69.765
10th Floor	66.349	65.632
9th Floor	61.779	61.06
8th Floor	56.794	56.232
7th Floor	51.576	51.088
6th Floor	46.12	45.669
5th Floor	40.408	40.016
4th Floor	34.484	34.171
3rd Floor	28.398	28.175
2nd Floor	22.204	22.072
1st Floor	15.959	15.907
Ground Floor	9.724	9.727
Plinth Level	4.077	4.203
Footing Level	0	0

Table -2: Max Storey Displacement (mm) of V-Braced Building.

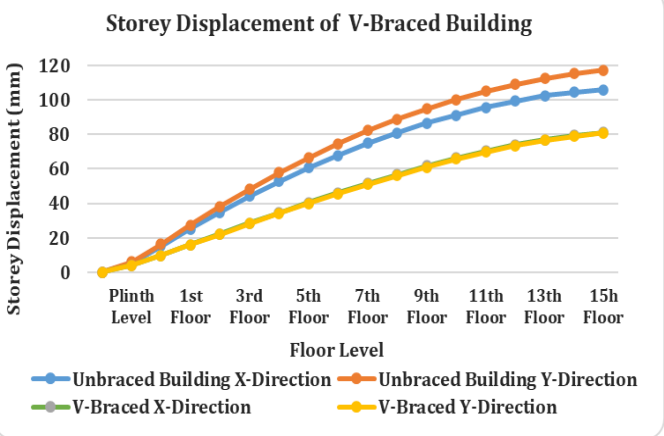

Fig -14: Max. Storey Displacement of V-Braced Building.

II. X-Bracing:

Floor Level	X-Braced Building	
	X-Direction	Y-Direction
15h Floor	78.229	74.236
14th Floor	76.397	72.376
13th Floor	73.949	69.951
12th Floor	70.925	66.992
11th Floor	67.366	63.541
10th Floor	63.323	59.65
9th Floor	58.853	55.378
8th Floor	54.017	50.784
7th Floor	48.873	45.925
6th Floor	43.477	40.852
5th Floor	37.883	35.803

4th Floor	32.198	30.578
3rd Floor	26.471	25.198
2nd Floor	20.638	19.713
1st Floor	14.774	14.178
Ground Floor	8.969	8.649
Plinth Level	3.597	3.575
Footing Level	0	0

Table -3: Max Storey Displacement (mm) of X-Braced Building

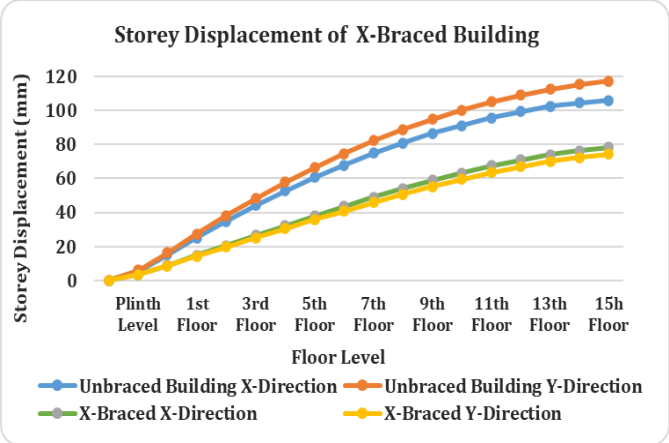

Fig -15: Max. Storey Displacement of X-Braced Building.

III. Mega Diagonal Bracing:

Floor Level	Mega Diagonal Bracing	
	X-Direction	Y-Direction
15h Floor	80.235	82.667
14th Floor	79.16	81.022
13th Floor	77.507	78.81
12th Floor	75.153	76.098
11th Floor	72.043	72.774
10th Floor	68.471	68.743
9th Floor	64.347	64.223
8th Floor	59.889	59.447
7th Floor	55.06	54.307
6th Floor	49.813	48.67
5th Floor	44.102	42.719
4th Floor	37.887	36.695
3rd Floor	31.351	30.556
2nd Floor	24.711	24.039
1st Floor	17.917	17.278
Ground Floor	10.977	10.504
Plinth Level	4.38	4.217
Footing Level	0	0

Table -4: Max. Storey Displacement (mm) of Mega Diagonally Braced Building.

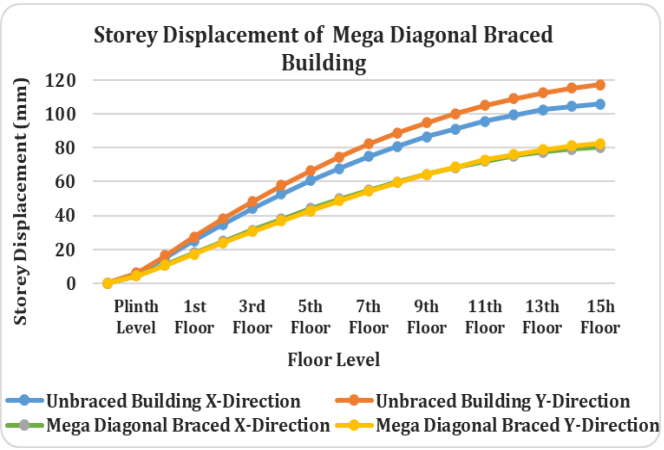

Fig -16: Max. Storey Displacement of Megs Diagonally Braced Building.

V. Mega V-Bracing:

Floor Level	Mega V-Braced Building	
	X-Direction	Y-Direction
15h Floor	56.352	71.894
14th Floor	55.622	70.261
13th Floor	54.563	68.157
12th Floor	53.064	65.701
11th Floor	51.03	62.737
10th Floor	48.397	59.116
9th Floor	45.386	55.1
8th Floor	42.222	50.958
7th Floor	38.844	46.516
6th Floor	35.183	41.823
5th Floor	31.27	36.831
4th Floor	26.984	31.795
3rd Floor	22.439	26.538
2nd Floor	17.832	20.898
1st Floor	13.094	15.113
Ground Floor	8.176	9.346
Plinth Level	3.686	4.357
Footing Level	0	0

Table -5: Max Storey Displacement (mm) of Mega V-Braced Building.

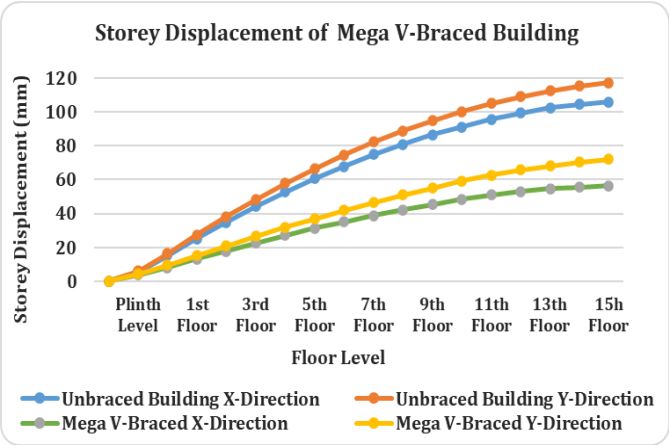

Fig -17: Max. Storey Displacement of Mega V-Braced Building.

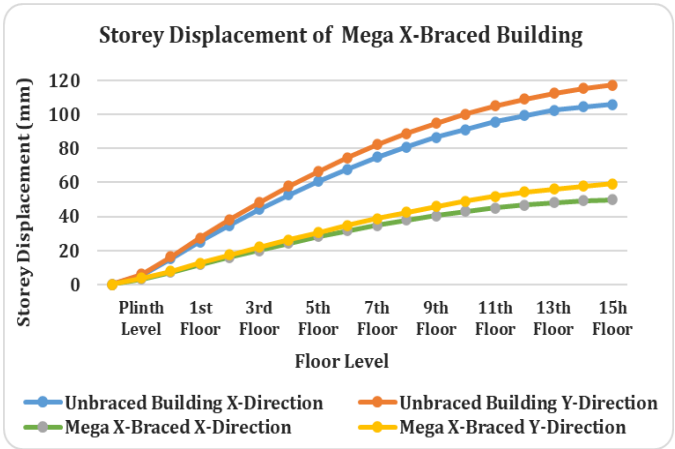

Fig -18: Max. Storey Displacement of Mega X-Braced Building.

VI. Mega X-Bracing:

Floor Level	Mega X-Braced Building	
	X-Direction	Y-Direction
15h Floor	49.854	59.275
14th Floor	49.155	57.922
13th Floor	48.142	56.215
12th Floor	46.763	54.268
11th Floor	45.138	51.922
10th Floor	42.971	49.015
9th Floor	40.454	45.772
8th Floor	37.791	42.431
7th Floor	34.906	38.818
6th Floor	31.728	34.743
5th Floor	28.187	30.463
4th Floor	24.218	26.272
3rd Floor	20.057	21.983
2nd Floor	15.902	17.335
1st Floor	11.664	12.552
Ground Floor	7.299	7.784
Plinth Level	3.305	3.718
Footing Level	0	0

Table -6: Max Storey Displacement (mm) of Mega X-Braced Building.

5.2 Comparison of Max. Storey Displacement:

% Reduction in Max. Storey Displacement				
Floor Level	Storey Displacement		% Reduction in Max. Storey Displacement	
	X-Dir.	Y-Dir.	X-Dir.	Y-Dir.
Unbraced Building	105.92	117.17	-	-
Diagonal Bracing	82.69	82.77	21.93	29.36
V-Bracing	81.14	80.83	23.40	31.01
X-Bracing	78.23	74.24	26.14	36.64
Mega Diagonal Bracing	80.24	82.67	24.25	29.44
Mega V-Bracing	56.35	71.89	46.80	38.64
Mega X-Bracing	49.85	59.28	52.93	49.41

Table -7: % Reduction in Max. Storey Displacement.

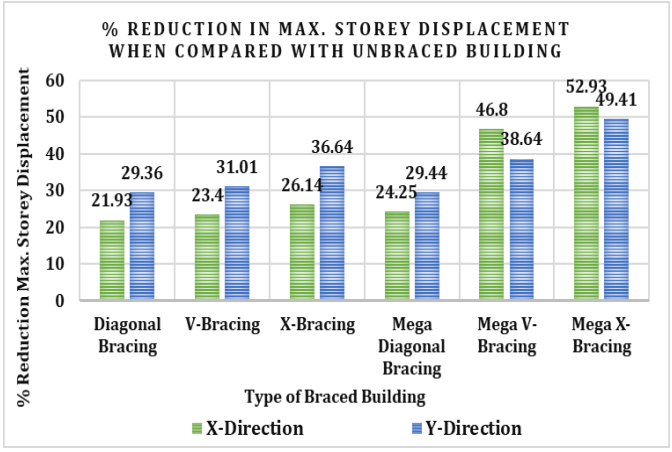

Fig -19: % Reduction in Max. Storey Displacement.

5.3 Max. Storey Drift

I. Diagonal Bracing:

Floor Level	Diagonal Bracing	
	X-Direction	Y-Direction
15h Floor	0.000495	0.000527
14th Floor	0.000714	0.000734
13th Floor	0.000936	0.00095
12th Floor	0.001142	0.001159
11th Floor	0.001327	0.001351
10th Floor	0.001491	0.001521
9th Floor	0.001638	0.001668
8th Floor	0.001769	0.00179
7th Floor	0.001878	0.001891
6th Floor	0.001966	0.001972
5th Floor	0.002047	0.002038
4th Floor	0.002117	0.002109
3rd Floor	0.002173	0.002166
2nd Floor	0.002212	0.002209
1st Floor	0.002236	0.002235
Ground Floor	0.002212	0.002218
Plinth Level	0.001433	0.001443
Footing Level	0	0

Table -8: Max. Storey Drift of Diagonally Bracing Building.

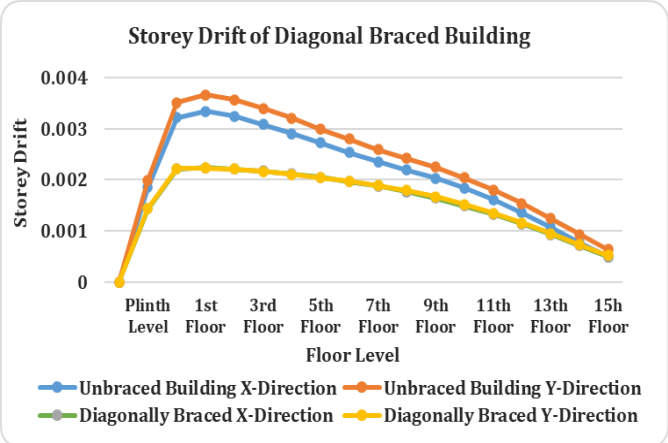

Fig -20: Max. Storey Drift of Diagonally Braced Building.

II. V-Bracing:

Floor Level	V-Braced Building	
	X-Direction	Y-Direction
15h Floor	0.000589	0.000631
14th Floor	0.000796	0.000829
13th Floor	0.000996	0.001023
12th Floor	0.001187	0.001208
11th Floor	0.001364	0.001378
10th Floor	0.001523	0.001529
9th Floor	0.001662	0.001658
8th Floor	0.001778	0.001766
7th Floor	0.001871	0.001851
6th Floor	0.001944	0.001916
5th Floor	0.001997	0.001963
4th Floor	0.002032	0.001999
3rd Floor	0.002065	0.002034
2nd Floor	0.002082	0.002055
1st Floor	0.002078	0.002063
Ground Floor	0.002056	0.002057
Plinth Level	0.001284	0.001318
Footing Level	0	0

Table -9: Max. Storey Drift of V-Braced Building.

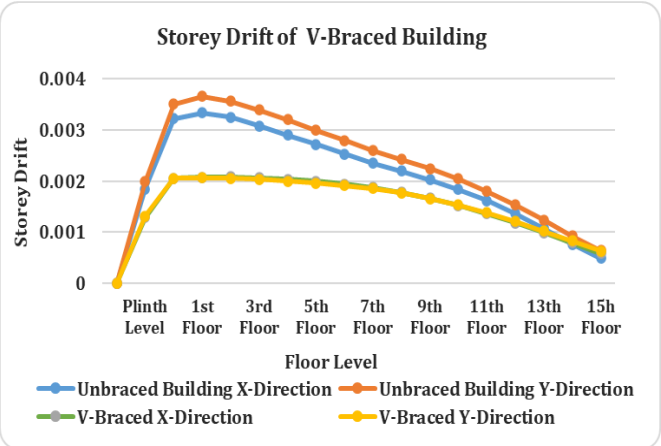

Fig -21: Max. Storey Drift of V-Braced Building.

II. X-Bracing:

Floor Level	X-Braced Building	
	X-Direction	Y-Direction
15h Floor	0.000612	0.000622
14th Floor	0.000817	0.000809
13th Floor	0.001008	0.000986
12th Floor	0.001186	0.00115
11th Floor	0.001348	0.001297

10th Floor	0.00149	0.001424
9th Floor	0.001612	0.001531
8th Floor	0.001715	0.00162
7th Floor	0.001799	0.001691
6th Floor	0.001865	0.001746
5th Floor	0.001914	0.001787
4th Floor	0.001945	0.001814
3rd Floor	0.001958	0.001828
2nd Floor	0.001954	0.001845
1st Floor	0.001935	0.001843
Ground Floor	0.001898	0.001831
Plinth Level	0.001199	0.001192
Footing Level	0	0

Table -10: Max. Storey Drift of X-Braced Building

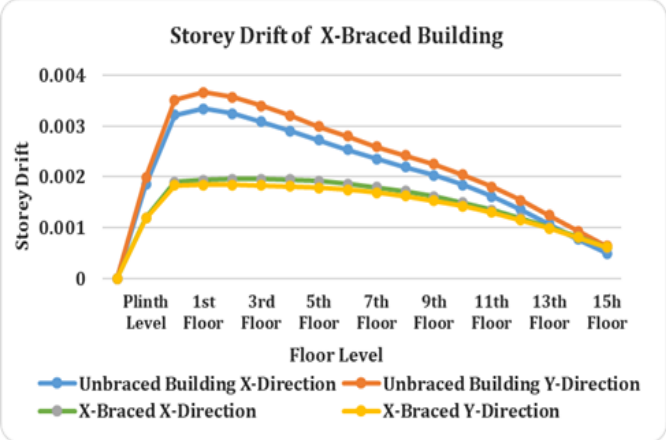

Fig -22: Max. Storey Drift of X-Braced Building.

VI. Mega Diagonal Bracing:

Floor Level	Mega Diagonal Bracing	
	X-Direction	Y-Direction
15h Floor	0.000358	0.000548
14th Floor	0.000551	0.000738
13th Floor	0.000785	0.000904
12th Floor	0.001037	0.001108
11th Floor	0.001294	0.001344
10th Floor	0.001468	0.001507
9th Floor	0.001557	0.001595
8th Floor	0.001656	0.001719
7th Floor	0.001771	0.001881
6th Floor	0.001904	0.001984
5th Floor	0.002072	0.002012
4th Floor	0.002178	0.00208
3rd Floor	0.002214	0.002188
2nd Floor	0.002265	0.002254
1st Floor	0.002314	0.002258
Ground Floor	0.002317	0.002226
Plinth Level	0.00146	0.001406
Footing Level	0	0

Table -11: Max. Storey Displacement (mm) of Mega Diagonally Braced Building.

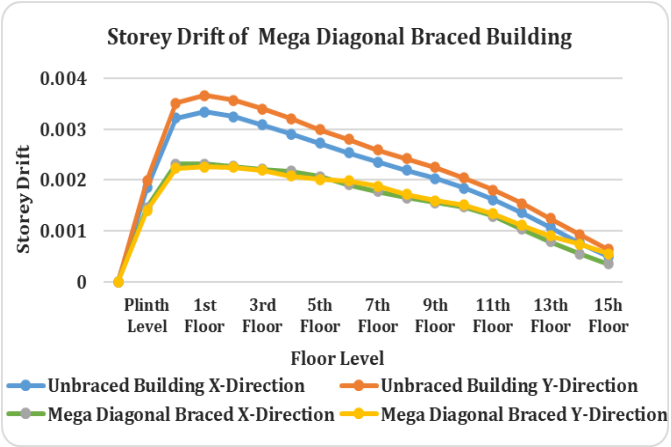

Fig -23: Max. Storey Drift of Mega Diagonally Braced Building.

X. Mega V-Bracing:

Floor Level	Mega V-Braced Building	
	X-Direction	Y-Direction
15h Floor	0.000257	0.000544
14th Floor	0.00038	0.000702
13th Floor	0.000537	0.000819
12th Floor	0.000717	0.000988
11th Floor	0.000912	0.001207
10th Floor	0.001026	0.001339
9th Floor	0.001062	0.001381
8th Floor	0.001126	0.001481
7th Floor	0.00122	0.001645
6th Floor	0.001338	0.001718
5th Floor	0.001477	0.001704
4th Floor	0.001539	0.001756
3rd Floor	0.001536	0.00188
2nd Floor	0.00158	0.001928
1st Floor	0.001639	0.001922
Ground Floor	0.001723	0.00197
Plinth Level	0.001193	0.001432
Footing Level	0	0

Table -12: Max. Storey Drift of Mega V-Braced Building.

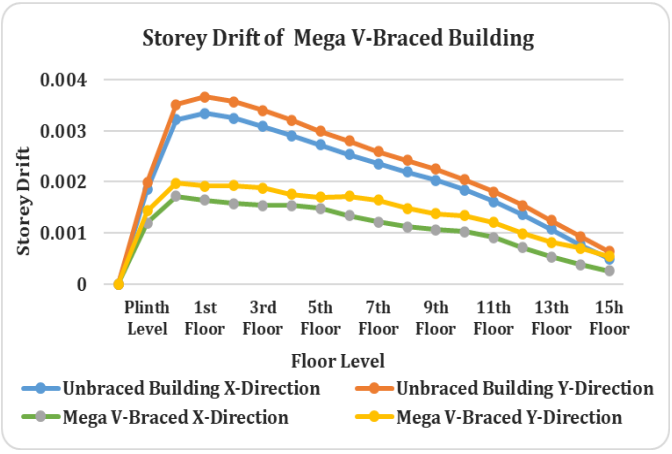

Fig -24: Max. Storey Drift of Mega V-Braced Building.

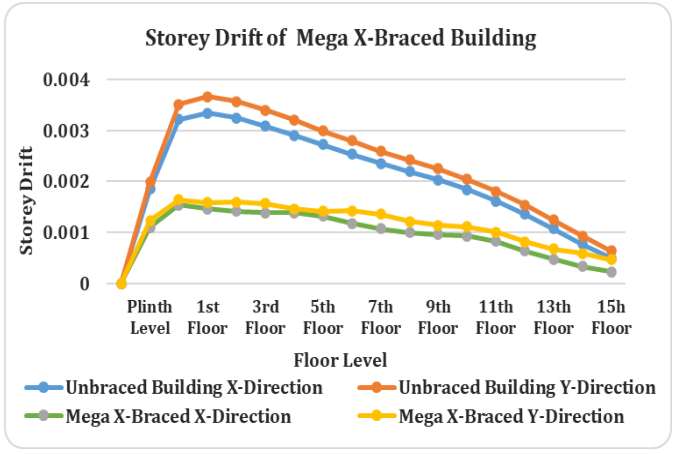

Fig -25: Max. Storey Drift of Mega X-Braced Building.

XII. Mega X-Bracing:

Floor Level	Mega X-Braced Building	
	X-Direction	Y-Direction
15h Floor	0.000233	0.000464
14th Floor	0.000338	0.000591
13th Floor	0.000476	0.000678
12th Floor	0.000642	0.000816
11th Floor	0.000828	0.001006
10th Floor	0.000932	0.001114
9th Floor	0.000956	0.001137
8th Floor	0.001002	0.001216
7th Floor	0.001074	0.001359
6th Floor	0.00118	0.001427
5th Floor	0.001323	0.001413
4th Floor	0.001387	0.00146
3rd Floor	0.001385	0.001564
2nd Floor	0.001413	0.001595
1st Floor	0.001458	0.001589
Ground Floor	0.001539	0.001639
Plinth Level	0.001102	0.001239
Footing Level	0	0

Table -13: Max. Storey Drift of Mega X-Braced Building.

5.4 Comparison of Max. Storey Drift:

% Reduction in Max. Storey Drift				
Floor Level	Storey Drift		% Reduction in Max. Storey Drift	
	X-Dir.	Y-Dir.	X-Dir.	Y-Dir.
Unbraced Building	0.0033	0.0037	-	-
Diagonal Bracing	0.0022	0.0022	32.99	38.95
V-Bracing	0.0021	0.0021	37.61	43.65
X-Bracing	0.0020	0.0018	41.32	49.60
Mega Diagonal Bracing	0.0023	0.0023	30.57	38.32
Mega V-Bracing	0.0017	0.0020	48.37	46.19
Mega X-Bracing	0.0015	0.0016	53.88	55.23

Table -14: % Reduction in Max. Storey Drift.

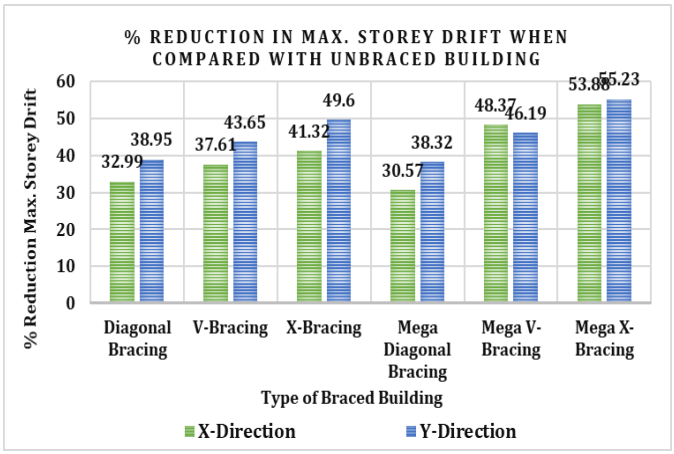

Fig -26: % Reduction in Max. Storey Drift.

5.5 Natural Time Period:

- The Natural time periods are the important factors, which affect the seismic behaviour of the structure.
- So, study has been made and it shows, the variation in fundamental time period for different braced structure as shown in figure.

Peak Time Period (Sec.)	
Different Braced Buildings	**Time Period (Sec.)**
Unbraced Building	2.94
Diagonal Bracing	2.46
V-Bracing	2.35
X-Bracing	2.28
Mega Diagonal Bracing	2.43
Mega V-Bracing	2.25
Mega X-Bracing	2.16

Table -15: Peak Time Period for different Braced Building.

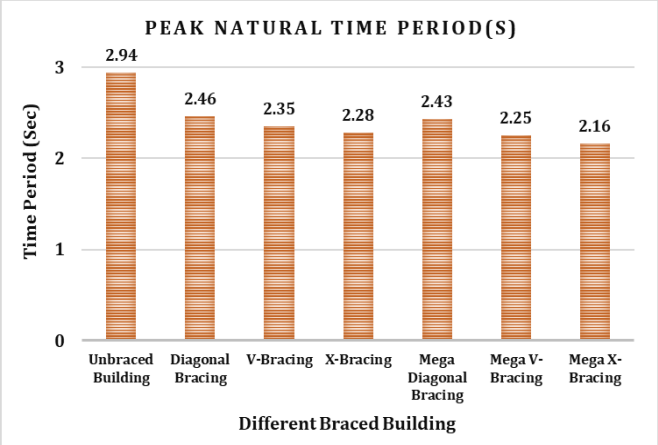

Fig -27: Peak Time Period for different Braced Building.

5.6 Seismic Base Shear:

- Seismic Base Shear reflects the seismic lateral vulnerability and is considered as one of the primary input for seismic design. The variation in Base shear for structure resting different type of soil is as shown in figure.

Seismic Base Shear		
Different Braced Buildings	**Base Shear (kN)**	
	X-Dir.	**Y-Dir.**
Unbraced Building	3225.14	3100.57
Diagonal Bracing	3319.63	3292.81
V-Bracing	3452.48	3466.25
X-Bracing	3546.64	3580.87
Mega Diagonal Bracing	3474.58	3331.25
Mega V-Bracing	3781.83	3598.46
Mega X-Bracing	3948.42	3750.44

Table -16: Seismic Base Shear for different Braced Building.

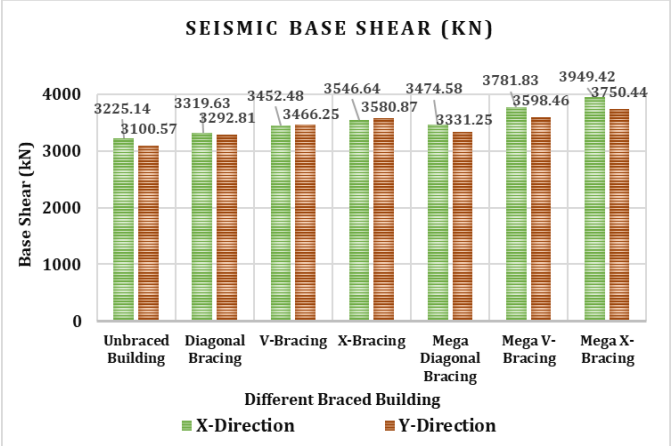

Fig -28: Seismic Base Shear for different Braced Building.

6. CONCLUSIONS

From the results discussed with respect to the building models considered, leads to the following conclusions;

- After the analysis of the structure with different types of Bracing, it has been concluded that the Storey Displacement and Storey Drift and Natural Time Period of the structure decreases after the application of bracing system.
- The maximum reduction in the storey displacement occurs after the application of Mega X-Bracing system.
- The displacement of the structure is reduced by 52.93% in X direction and 49.41% in Y direction with the use of Mega X-bracing when compared with Unbraced Building.

- The drift of the structure is reduced by 53.88% in X direction and 55.23% in Y direction with the use of Mega X-bracing when compared with Unbraced Building.
- Bracing increases the Seismic Base Shear of the building when compared with Unbraced Building along X and Y-Direction respectively.
- Building with bracing leads to minimum Displacement, maximum Base Shear and minimum Storey Drift compared to building without bracing.

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