

Comparative Performance and Techno-Economic Evaluation of Lateral Load Resisting Systems For G+11 With Double Cellar RCC and Steel Structures in High Seismic Zones

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Abstract - This study presents a comprehensive comparative performance and techno-economic evaluation of lateral load-resisting systems for G+11 with double cellar constructed using Reinforced Concrete (RCC) and structural steel in high seismic zones. The investigation focuses on three major lateral load-resisting strategies: shear wall systems, bracing systems, and base isolation systems, with the objective of identifying an efficient structural solution that provides enhanced seismic performance while maintaining economic feasibility. The structural behaviour of the considered systems is evaluated using Linear Static and Response Spectrum analyses in ETABS. In addition to structural performance, a detailed techno-economic assessment is carried out by comparing the quantities and costs of concrete, reinforcement steel, structural steel, bracing members, shear walls, and base-isolation devices. The study also examines the different lateral load-resisting systems on structural weight, material consumption, foundation requirements, and overall construction cost. The comparative results are used to evaluate the trade-off between initial investment and seismic performance, particularly for advanced systems such as base isolation and steel plate shear walls. The study aims to establish an optimal lateral load-resisting strategy by balancing seismic safety, structural efficiency, material utilization, and economic viability.

Key Words: Building modelling, lateral load-resisting systems, seismic analysis, response spectrum analysis, techno-economic evaluation.

1. INTRODUCTION

Accelerated urbanization, demographic expansion, and the rising need for constructed environments have led to the extensive proliferation of skyscrapers. As the elevation of a building rises, the impact of lateral forces intensify becomes more significant and must be carefully considered during structural design. Among the various lateral actions, earthquake loading is particularly critical because it produces dynamic forces and deformation can have a major impact on the stability and serviceability of high-rise structures. Hence, the selection of an appropriate lateral load-resisting system is essential for achieving adequate strength, stiffness, seismic safety, and economy.

RCC and structural steel are Frequently employed for skyscrapers construction because of their different structural and construction characteristics. The seismic response of these buildings can be controlled through suitable lateral load-resisting systems. Shear walls, bracing systems, and base isolation systems represent three distinct approaches to improving seismic performance. Shear walls provide high lateral stiffness and strength, thereby limiting lateral deformation. Support frameworks augment the lateral stability primarily through axial action in the bracing members while maintaining comparatively low structural weight. Base isolation differs from conventional lateral-resisting systems by reducing the transmission of earthquake-induced motion from the foundation to the superstructure.

This study examines the relative structural performance and techno-economic characteristics of G+11 RCC and structural steel buildings with a double cellar subjected to seismic loading. Separate structural models incorporating shear walls, bracing systems, and base isolation are developed and analyzed using ETABS. Linear Static and Response Spectrum analyses are carried out to assess key earthquake reaction metrics, including as base shear, inter-story drift, and storey displacement. The study further compares structural weight, material quantities, foundation requirements, and construction costs associated with the different systems. The objective is to identify a suitable lateral load-resisting strategy that provides an effective balance between seismic performance, structural efficiency, material utilization, and economic feasibility.

2. LITERATURE REVIEW

Umesh R. Biradar and Shivaraj Mangalgi (2014) investigated an eleven-story reinforced concrete frame's earthquake response using different bracing systems. The study used ETABS and considered Equivalent Static, Response Spectrum, Pushover and Time History analyses. The results showed that bracing reduced the storey drift, storey displacement, and time period compared storey drift, storey displacement, and time period compared with the bare frame, with X-bracing providing the best overall performance. The study concluded that X-bracing is a for enhancing RC structures' earthquake performance.

Lavitha V. and Gokul P. V. (2021) examined the seismic behaviour of G+6 steel frame with RCC in Seismic Zone IV using ETABS 2016 and the Equivalent Static Method. The study compared the structures based on storey stiffness, frequency, time interval, base shear, lateral forces, and seismic weight. The results indicated that the RCC structure had higher time period and base shear due to its greater seismic weight, while the steel structure exhibited greater ductility and lower lateral-force effects. The authors concluded that steel is a suitable structural system for seismic regions because of its lower weight and favourable strength-to-weight characteristics.

Krunal P. Suthar and Arjun M. Butala (2020) conducted a comparative seismic analysis of G+10 RCC, steel, and steel-concrete composite constructions' seismic analysis in Seismic Zone IV using ETABS 2017. Comparable Static and Reaction, Time period, displacement, drift, and base shear were assessed using spectrum techniques, stiffness and structural weight. The results showed that the composite structure experienced lower displacement and storey drift than the RCC and steel structures, indicating better stiffness and seismic performance. The study concluded that composite construction is a suitable alternative for high-rise buildings.

Dharanya A., Gayathri S. and Deepika M. (2017) compared the seismic performance of shear walls and cross bracings in a G+4 RC residential building with a soft storey in Seismic Zone V. The building was analysed using ETABS and the Equivalent Static Method based on IS 1893:2002. The results showed that both systems reduced lateral displacement. In contrast to the naked frame, while the shear-wall system produced the lowest displacement. The study concluded that shear walls provide better lateral stability and seismic performance than cross bracing for the investigated building.

Tulluri Vishnu Vardhan and D. V. Prasada Rao (2025) investigated the seismic behaviour of high-rise steel and RCC buildings with various bracing configurations using ETABS. Ten-storey and fifteen-storey buildings with Cross, V, Chevron and single bracing were analysed using Response Spectrum and Equivalent Static techniques in accordance with IS 1893:2016. The results showed that bracing reduced storey displacement and inter-storey drift, with Cross-bracing providing the most effective overall performance. The authors concluded that Cross-bracing is an effective seismic-resistant system for high-rise RCC and steel structures.

3. METHODOLOGY

This study's methodology is centered on comparing seismic performance and techno-economic evaluation of lateral load-resisting systems (LLRS) for a G+11 high-rise RCC and steel structure with a double cellar. The study considers three major seismic-resistant systems, namely shear walls, bracing systems, and base isolation. The general procedure includes of the building model, structural modeling in ETABS, seismic analysis, application of gravity and seismic loads in accordance with the applicable IS regulations, comparative evaluation, and cost estimation of the considered systems.

- AutoCAD was used to create the commercial building plan, which measures 35.68 m by 45.78 m and has G+11 storeys with a double cellar that is 4.6 m high..
- The building was modelled in ETABS based on the AutoCAD plan, including beams 300mm x 450mm, 300mm X 600mm, columns 450mm X 600mm, 600mm X 750mm and 750mm X 900mm, 900mm X 1050mm, 150 mm slabs thickness, fixed supports, Concrete M30, M40, M60 and Fe550, Fe415 steel material properties.
- For Steel Structure slab thickness 175mm, Infilled box section SHS 500 columns, ISMB350 for primary beam, ISLB275 for secondary beam.
- In accordance with the applicable design regulations, the necessary dead load, living load, wall load, floor finish load, and seismic load were added to the ETABS models.
- Key seismic response characteristics, including storey displacement, inter-story drift, and base shear, were derived by analyzing the conventional building model in ETABS.
- Under identical loading and modeling settings, distinct models with various lateral load-resisting systems—such as bracings, shear walls, and base isolation were created and examined.

- To evaluate the structural performance of the conventional and modified models, the seismic responses were evaluated based on base shear, inter-story drift, and storey displacement.
- Lastly, each lateral load-resisting system's construction costs and material amounts were estimated. The techno-economic analysis of the chosen systems was done by comparing the structural performance and associated costs

3.1 Building plan and Structural modeling

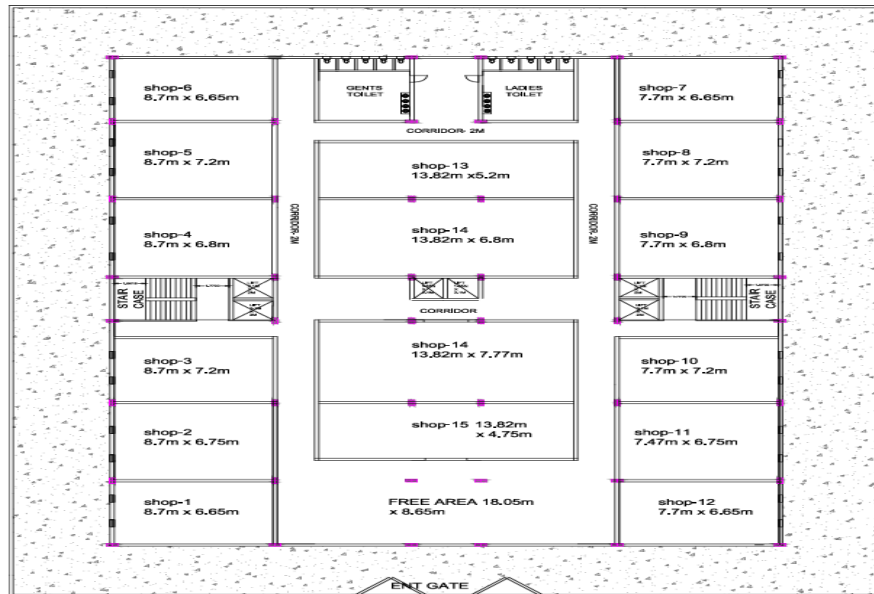


Figure-1 Commercial Building plan

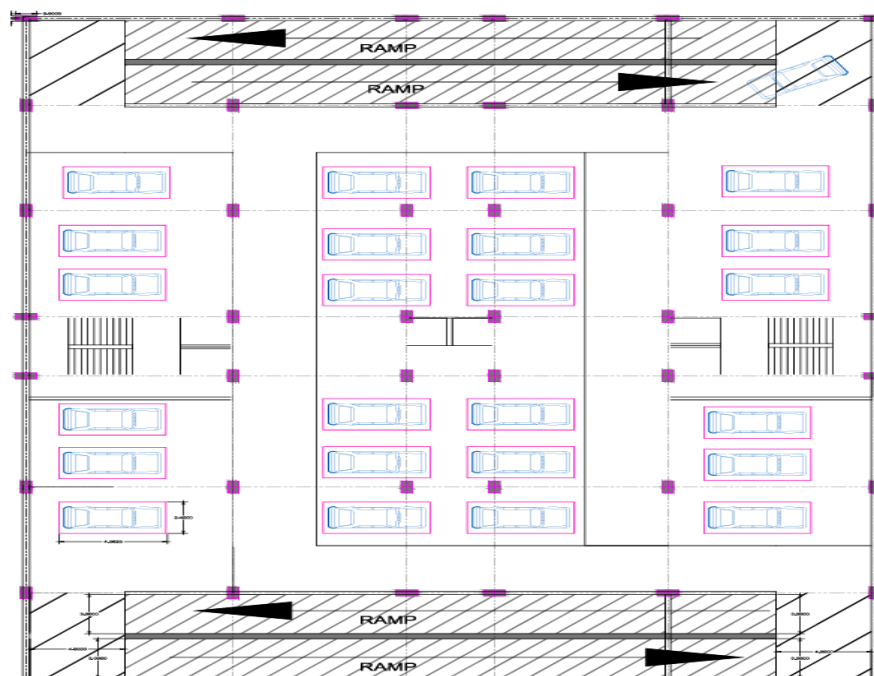


Figure-2 Cellular plan

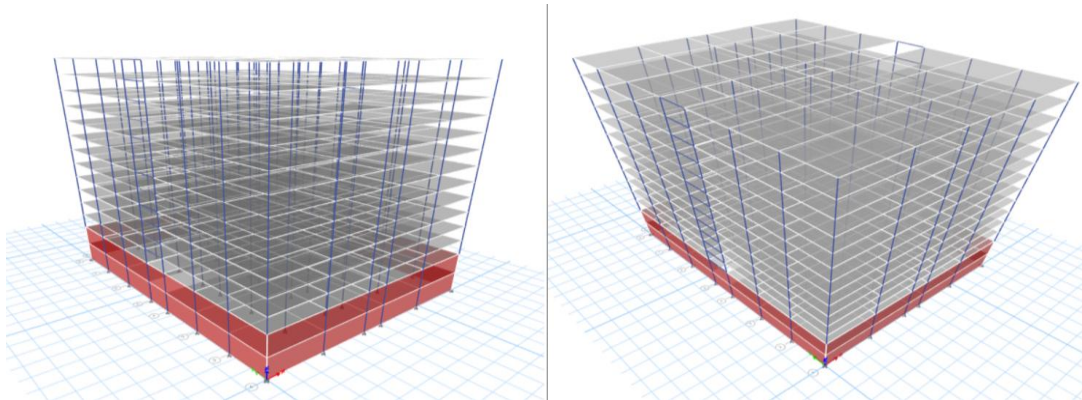


Figure-3 ETABS 3D Modelling of G+11 with double cellar commercial building

4. ANALYSIS

4.1 Fundamental natural time period

The time required for a structure to complete one sway cycle, an intrinsic property influenced by mass and stiffness. As per IS 1983:2016, clause 7.6.2, the approximate fundamental translational natural period T_a of oscillation, in seconds, shall be estimated by the following expression:

$$T_a = \frac{0.09h}{\sqrt{d}} \text{ (for other buildings)}$$

For a G+11 with double cellar:

$$1. \text{ In the direction of X, } T_x = \frac{0.09h}{\sqrt{d}} = \frac{0.09 \times 48.8}{\sqrt{35.68}} = 0.73 \text{ sec.}$$

$$2. \text{ In the direction of Y, } T_y = \frac{0.09h}{\sqrt{d}} = \frac{0.09 \times 48.8}{\sqrt{45.78}} = 0.64 \text{ sec.}$$

4.2 Response spectrum analysis:

Essential natural time period: The amount of time needed for a structure to go through one sway cycle is an inherent characteristic that is affected by stiffness and mass. According to IS 1983:2016, section 7.6.2, the following equation should be used to approximate the basic translational natural period T_a of oscillation in seconds:

Maximum Inter-storey drift (δ) should be less than 0.004 times of single storey height i.e., 3.3m.

$$\delta \leq 0.004h \rightarrow \delta \leq 0.004 \times 3300 \rightarrow \delta \leq 13.2 \text{ mm.}$$

From EATS, the drift index for the structure will be generated. The drift index in the ratio of deflection at the storey to the storey height.

$$\text{Drift index} = \frac{\text{Deflection at each storey}}{\text{Individual storey height}}$$

$$\text{Deflection} = \text{Drift index} \times \text{Individual storey height} \leq 13.2 \text{ mm}$$

$$\text{Roof displacement } \Delta = \frac{\text{Overall building height (in mm)}}{250}$$

$$\text{For a G+11 with double cellar: } \Delta = \frac{48800}{250} = 195.2 \text{ mm}$$

4.3 RCC Shear-Wall Properties

The RCC shear-wall models were developed using M40 concrete and Fe415 reinforcement. A wall thickness of 300 mm was adopted. Vertical reinforcement consisted of 16 mm bars at 150 mm centre-to-centre spacing on both faces, while 12 mm horizontal reinforcement was provided at 150 mm centre-to-centre spacing on both faces. Boundary reinforcement comprised 20 mm longitudinal bars with 10 mm ties at 100 mm centre-to-centre spacing. The manuscript specifies a clear cover of 25mm, which should be corrected to the intended unit/value after checking the original design input.

4.4 Steel Plate Shear-Wall Assumptions

For the structural steel shear-wall configuration, a Steel Plate Shear Wall (SPSW) system was considered. The design basis identified in the manuscript comprises IS 800:2007 and IS 1893 (Part 1):2016. IS 2062 Grade E345 steel was adopted, with a yield strength of 345 MPa and a minimum ultimate tensile strength of 490 MPa. The steel plate thickness was taken as 10 mm, with an elastic modulus of 200 GPa, Poisson's ratio of 0.30, and steel density of 7850 kg/m³.

4.5 Load Combinations

The structural models were evaluated using the load combinations specified in the manuscript. For the RCC structure, the combinations included dead load, live load, and positive and negative earthquake effects in both principal directions. The combinations reported for the concrete model include 1.0(DL + LL), 1.5(DL + LL), 1.5DL ± 1.5EQ, and 1.2DL + 1.2LL ± 1.2EQ. For the steel structure, the reported combinations include 1.0(DL + LL), 1.5(DL + LL), 1.5DL ± 1.5EQ, and 1.2DL + 1.2LL ± 0.6EQ in both X and Y directions.

4.6 Base-Isolation System

A base-isolation system was incorporated as one of the lateral load-resisting alternatives. The isolator properties used in the analysis were defined using the adopted isolator dimensions and mechanical characteristics. The parameters reported in the present model include a 1200 mm diameter, 271 mm overall height, and 1250 × 1250 mm plate size. The rubber thickness was taken as 130 mm, with a shape factor of 29.8.

The mechanical properties adopted for the isolator include a vertical stiffness of 6829 kN/mm, an effective horizontal stiffness of 3.84 kN/mm, a design displacement of 147 mm, and a horizontal design load of 510 kN. The maximum vertical static load was specified as 26,600 kN, while effective damping was reported as 10–15%.

5. RESULTS AND DISCUSSION

Building models were subjected to seismic analyzes using both the response spectrum approach and the equivalent static method in accordance with IS 1893:2016.

Table -1: Comparison of seismic parameters for the RCC structure in zone-3

RCC structure (Earthquake in Zone-3)							
S.no	Type of structure models	X-Direction			Y-Direction		
		Maximum displacement (mm)	Maximum storey drift	Base shear (kN)	Maximum displacement (mm)	Maximum storey drift	Base shear (kN)
1	Base Model	18.22	0.000588	2611.56	18.34	0.000595	2594.44
2	X -Bracing	16.07	0.000511	2969.13	14.92	0.000467	3181.14
3	Diagonal Bracing	16.92	0.000544	2812.74	16.10	0.000513	2934.95
4	Chevron Bracing	15.80	0.000505	3006.43	14.823	0.000468	3192.43

5	Plane Shear Wall	10.78	0.000319	5375.76	12.63	0.000381	4698.54
6	L-Type Shear Wall	10.00	0.000291	5875.91	12.092	0.000356	4890.03
7	C-Type Shear Wall	11.21	0.000322	5458.31	13.69	0.000397	4297.25
8	Base Isolator	25.74	0.000438	1930.84	26.02	0.000444	1930.84

Chart -1: Percentage of Maximum storey Displacement Reduction In a variety of seismic resistance systems

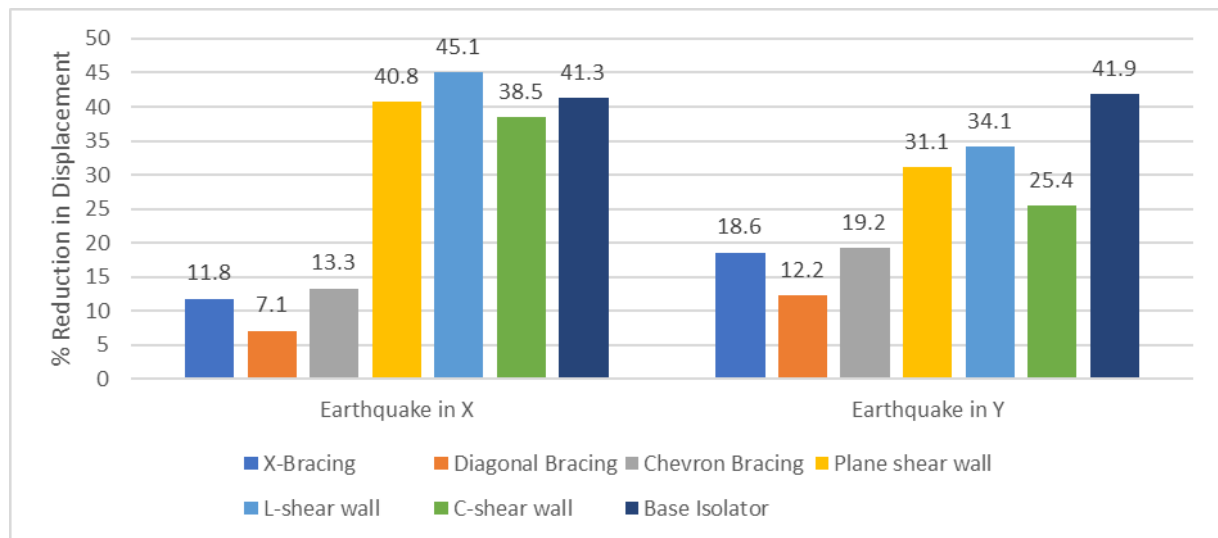


Chart 2: Reduction percentage of maximum storey drift across various seismic resisting systems

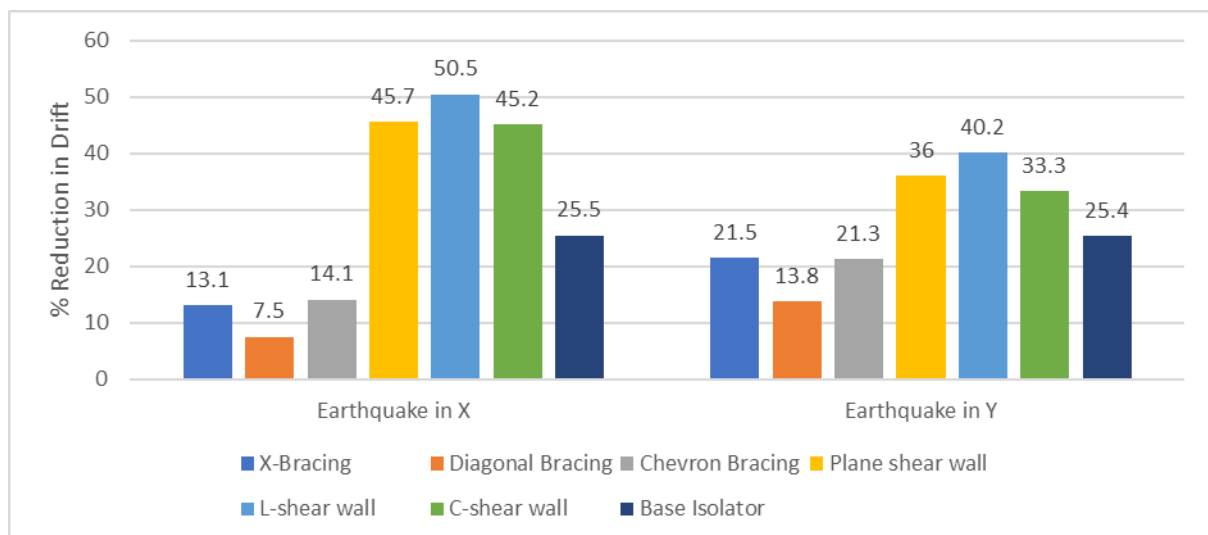


Table -2: Maximum storey Drift Reduction as a Percentage for Different Seismic Resistance Systems

RCC Structure (Earthquake in Zone-4)							
S.No	Type of structure models	X-Direction			Y-Direction		
		Maximum displacement (mm)	Maximum storey drift	Base shear (kN)	Maximum displacement (mm)	Maximum storey drift	Base shear (kN)
1	Base Model	27.335	0.000833	3917.19	27.51	0.000892	3891.66
2	X Bracing	24.11	0.000766	4453.70	22.38	0.0007	4771.72
3	Diagonal Bracing	25.389	0.000816	4219.12	24.15	0.000769	4402.42
4	Chevron Bracing	23.70	0.000757	4509.64	22.23	0.000701	4788.65
5	Plane Shear Wall	16.17	0.000478	8063.65	18.95	0.000572	7047.81
6	L -Type Shear Wall	15.00	0.000436	8813.66	18.13	0.000535	7335.05
7	C -Type Shear Wall	11.21	0.000322	5458.31	13.69	0.000397	4297.25
8	Base Isolator	37.44	0.000638	2808.50	37.860	0.000646	2808.50

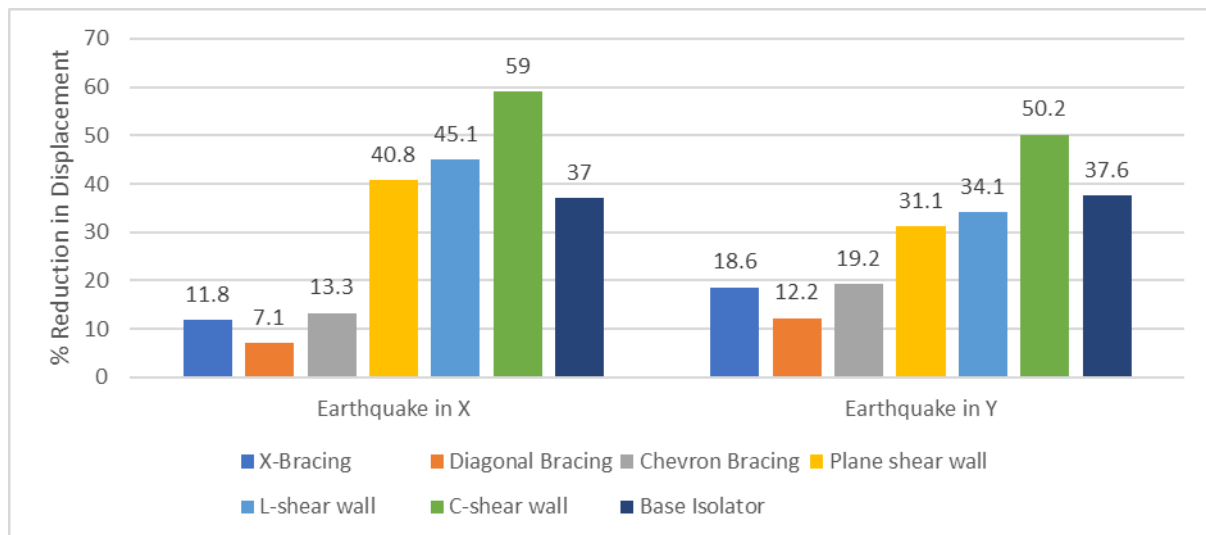
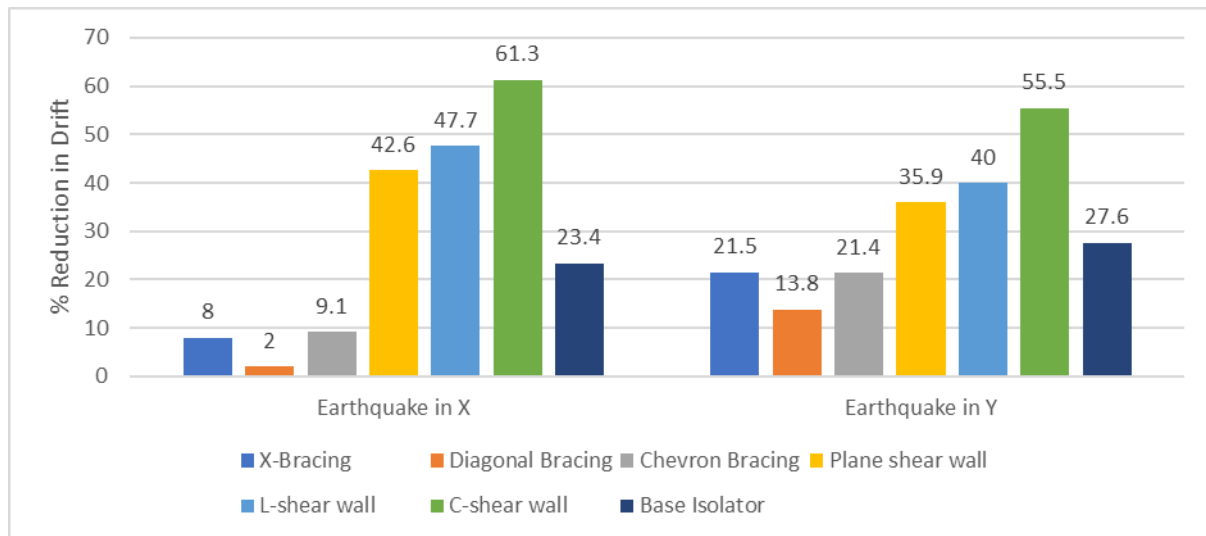
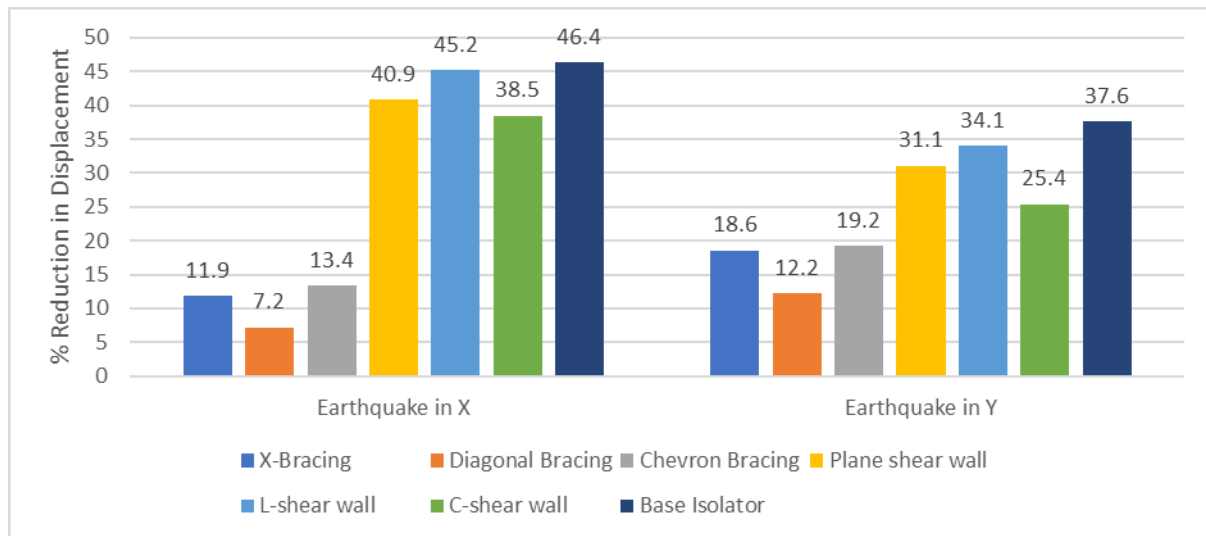
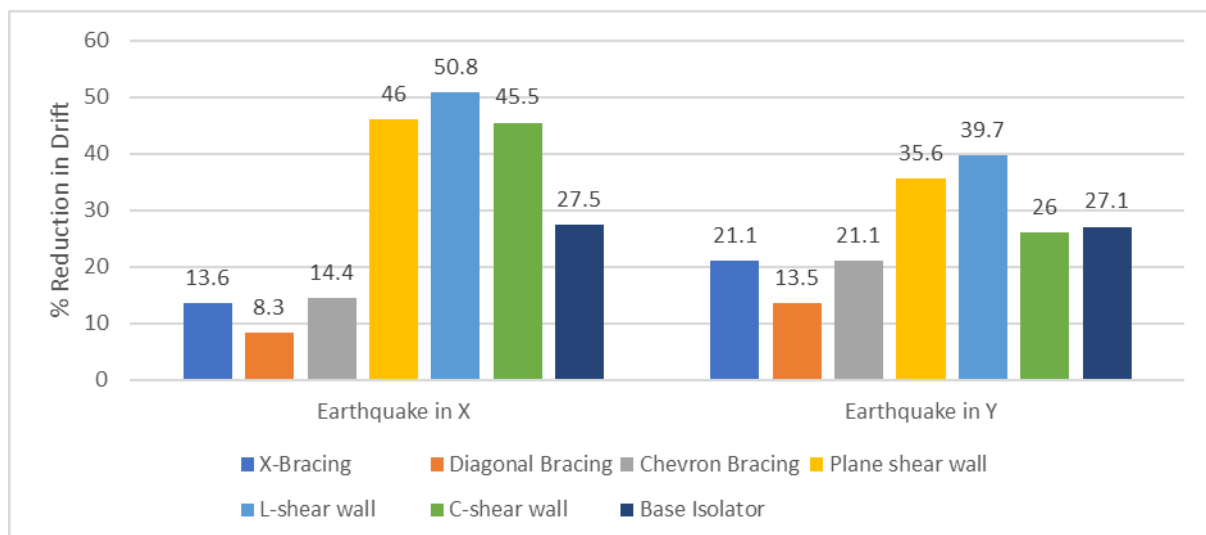
Chart -3: Percentage of Maximum Storey Displacement Reduction In a variety of seismic resistance systems


Chart 4: Maximum Storey Drift Reduction as a Percentage for Different Seismic Resistance Systems

Table -3: Comparison of seismic parameters for the RCC structure in zone-5

RCC Structure (Earthquake in Zone-5)							
S.No	Type of structure models	X-Direction			Y-Direction		
		Maximum displacement (mm)	Maximum storey drift	Base shear (kN)	Maximum displacement (mm)	Maximum storey drift	Base shear (kN)
1	Base Model	41.03	0.00132	5875.79	41.26	0.00133	5837.49
2	X Bracing	36.16	0.00114	6680.55	33.57	0.00105	7157.58
3	Diagonal Bracing	38.08	0.00122	6328.68	36.23	0.00115	6603.64
4	Chevron Bracing	35.55	0.00113	6764.47	33.35	0.00105	7182.97
5	Plane Shear Wall	24.26	0.000718	12095	28.43	0.000857	10572
6	L- Type Shear Wall	22.50	0.000654	13221	27.20	0.000802	11003
7	C -Type Shear Wall	25.22	0.000725	12281	30.80	0.000984	9668.81
8	Base Isolator	60.053	0.000957	4212.76	60.67	0.00097	4212.76

Chart -5: Percentage of Maximum Storey Displacement Reduction In a variety of seismic resistance systems

Chart 6: Maximum Storey Drift Reduction as a Percentage for Different Seismic Resistance Systems

Table -4: Comparison of seismic parameters for the Steel structure in zone-3

Steel Structure (Earthquake In Zone-3)							
S.No	Type of structure models	X-Direction			Y-Direction		
		Maximum displacement (mm)	Maximum storey drift	Base shear (kN)	Maximum displacement (mm)	Maximum storey drift	Base shear (kN)
1	Base Model	42.986	0.00144	1070.25	39.38	0.00133	1070.25
2	X Bracing	21.40	0.000683	1162.42	18.324	0.000589	1342.14
3	Diagonal Bracing	25.65	0.000842	1071.88	21.20	0.00071	1147.10
4	Chevron Bracing	20.61	0.000668	1193.35	18.090	0.000583	1356.43

5	Plane Shear Wall	14.80	0.000427	1913.20	16.31	0.000469	1736.22
6	L Type Shear Wall	11.976	0.000338	2331.75	14.76	0.000424	1910.03
7	C Type Shear Wall	13.72	0.000386	2132.46	18.36	0.000525	1531.80
8	Base Isolator	50.842	0.00144	1070.25	47.013	0.00133	1070.25

Chart -7: Percentage of Maximum Storey Displacement Reduction In a variety of seismic resistance systems

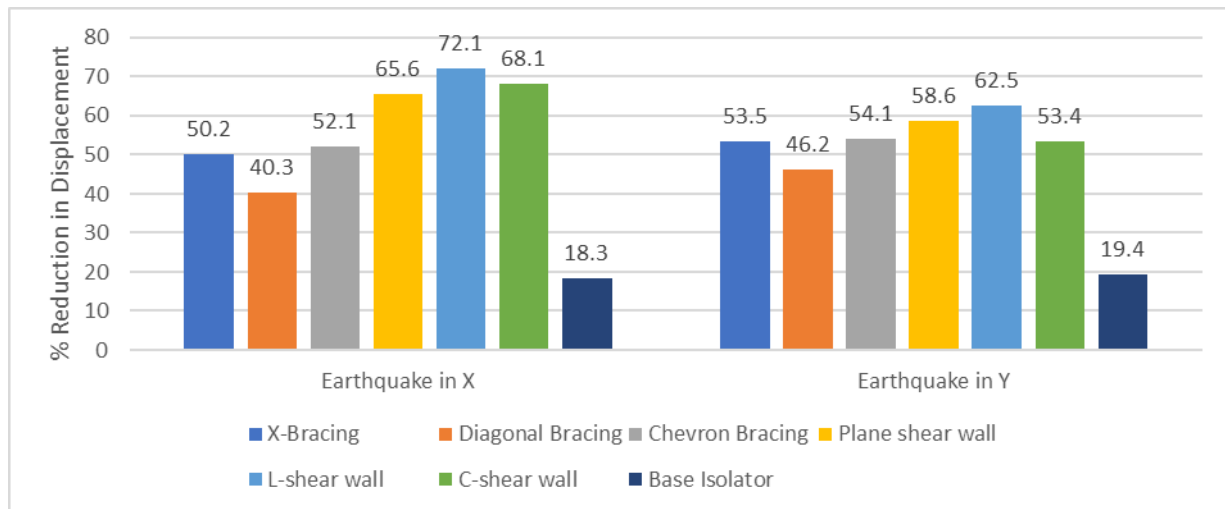


Chart 8: Maximum Storey Drift Reduction as a Percentage for Different Seismic Resistance Systems

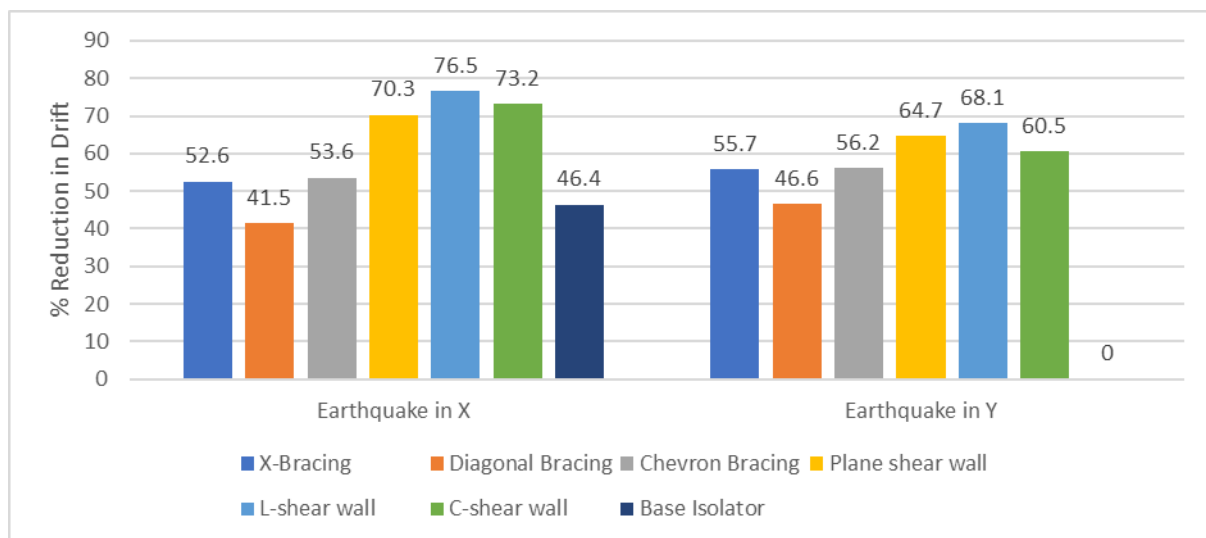


Table -5: Comparison of seismic parameters for the Steel structure in zone-4

Steel Structure (Earthquake in Zone-4)							
S.No	Type of structure models	X-Direction			Y-Direction		
		Maximum displacement (mm)	Maximum storey drift	Base shear (kN)	Maximum displacement (mm)	Maximum Storey drift	Base shear (kN)
1	Base Model	62.52	0.0021	1558.74	57.285	0.00194	1558.74
2	X Bracing	32.116	0.000884	1742.14	27.487	0.000102	2013.21
3	Diagonal Bracing	37.31	0.00122	1559.10	31.806	0.00106	1720.65
4	Chevron Bracing	30.928	0.000668	1193.35	27.135	0.000874	2034.65
5	Plane Shear Wall	22.20	0.00064	2869.81	24.47	0.000704	2604.34
6	L Type Shear Wall	19.964	0.000508	3497.63	22.144	0.000653	2865.04
7	C Type Shear Wall	20.58	0.000579	3198.70	27.54	0.000787	2297.71
8	Base Isolator	73.95	0.00208	1556.74	68.383	0.00194	1556.84

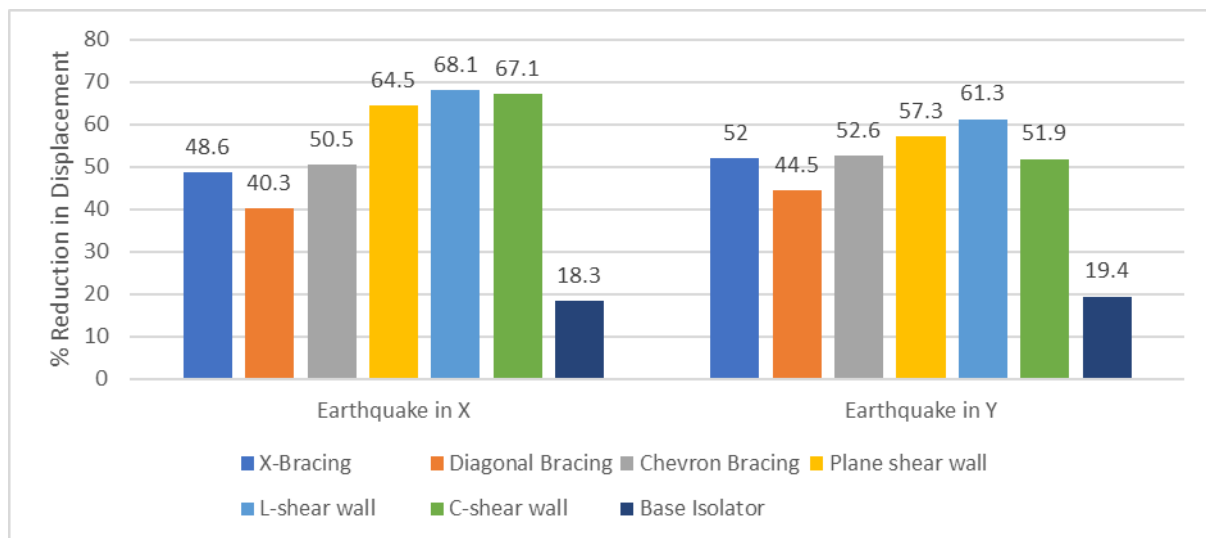
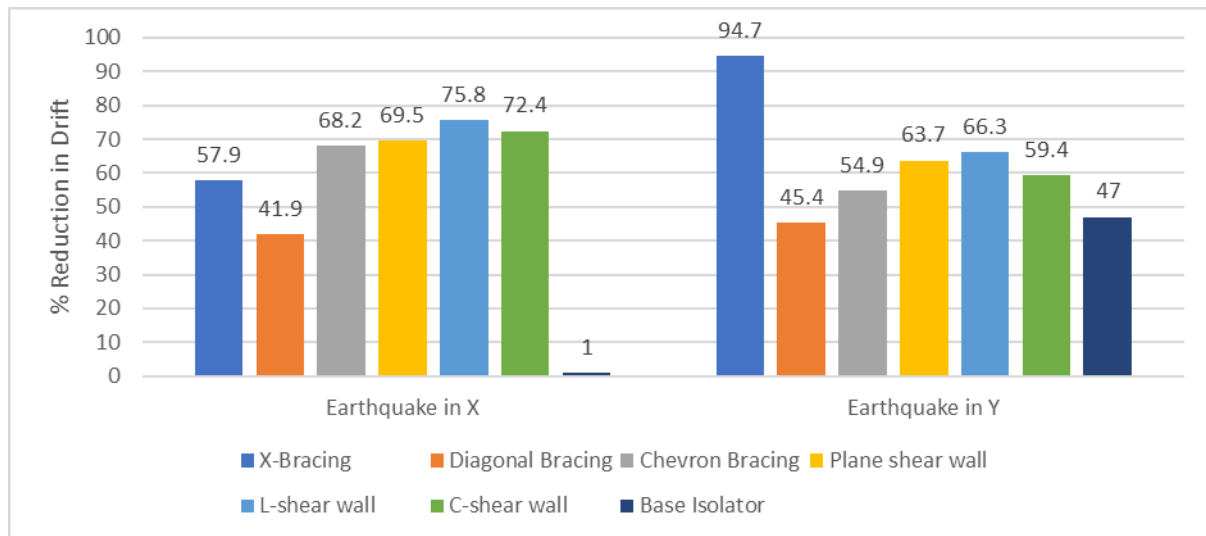
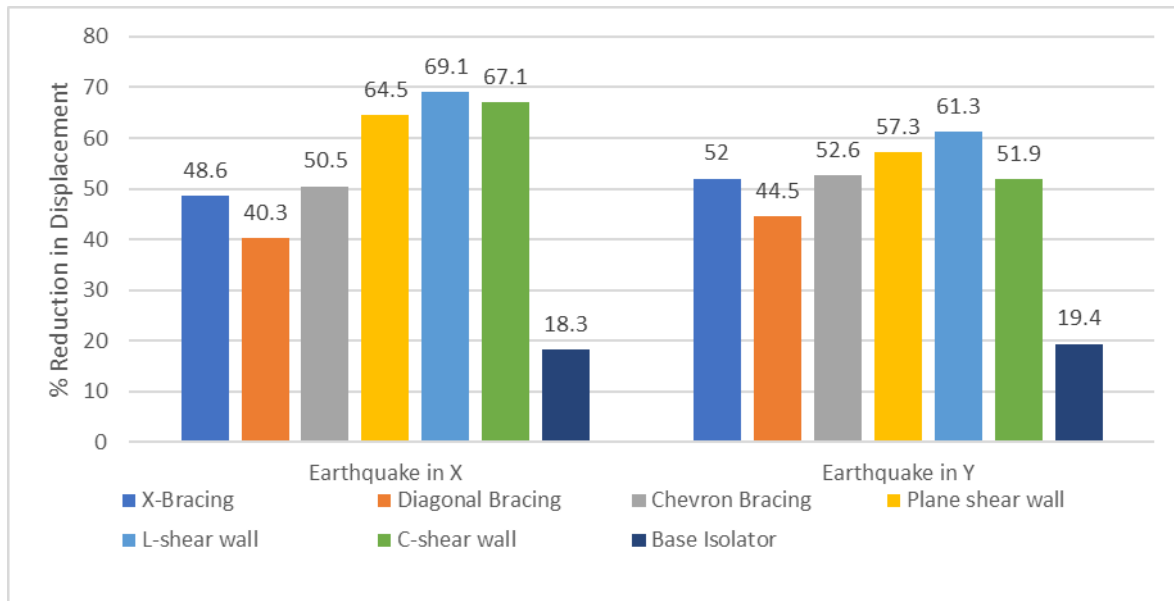
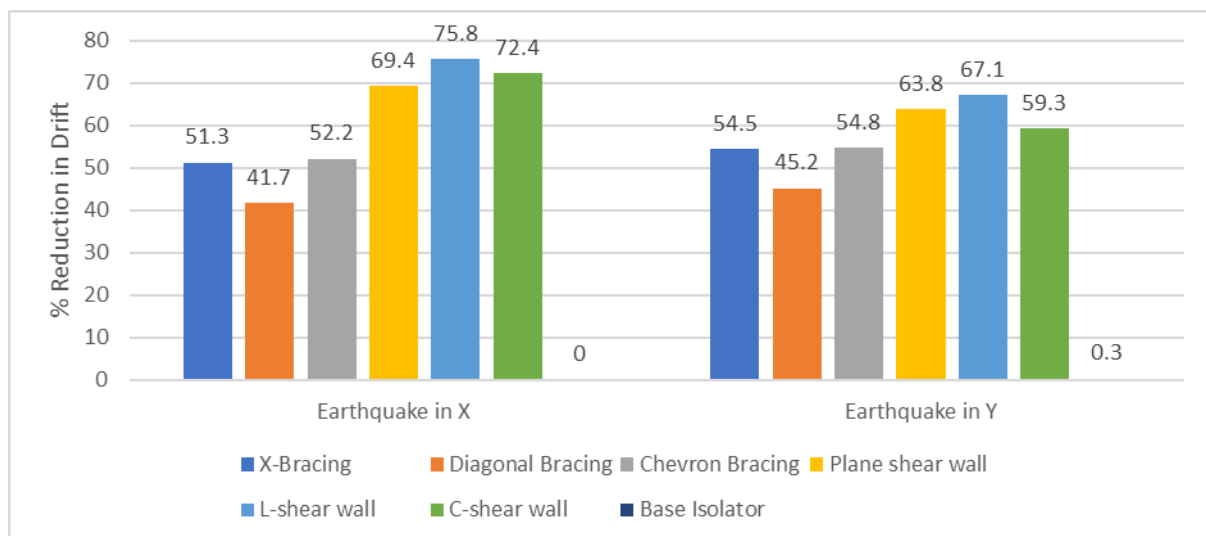
Chart -9: Percentage of Maximum Storey Displacement Reduction In a variety of seismic resistance systems


Chart 10: Maximum Storey Drift Reduction as a Percentage for Different Seismic Resistance Systems.

Table -6: Comparison of seismic parameters for the Steel structure in zone-5

Steel Structure (Earthquake in Zone-5)							
S.No	Type of structure models	X-Direction			Y-Direction		
		Maximum displacement (mm)	Maximum storey drift	Base shear (kN)	Maximum displacement (mm)	Maximum storey drift	Base shear (kN)
1	Base Model	93.789	0.00314	2335.11	85.92	0.0029	2335.11
2	X Bracing	48.17	0.00153	2613.21	41.231	0.00132	3019.82
3	Diagonal Bracing	55.97	0.00183	2338.66	47.710	0.00159	2580.98
4	Chevron Bracing	46.39	0.00150	2685.03	40.703	0.00131	3051.98
5	Plane Shear Wall	33.31	0.00096	4304.71	36.70	0.00105	3906.51
6	L -Type Shear Wall	28.94	0.000761	5246.45	33.21	0.000953	4297.56
7	C -Type Shear Wall	30.87	0.000868	4798.05	41.314	0.00118	3446.57
8	Base Isolator	110.92	0.00314	2335.11	102.57	0.00291	2335.11

Chart -11: Percentage of Maximum Storey Displacement Reduction In a variety of seismic resistance systems

Chart 12: Maximum Storey Drift Reduction as a Percentage for Different Seismic Resistance Systems

Table -7: Cost comparison of seismic resisting systems for RCC structure

S.no	Seismic load resisting systems in RCC Structure	Cost Estimated
1	X bracing system	29 lakhs
2	Inverted V bracing system	18.1 lakhs
3	Diagonal bracing system	17.lakhs
4	Plane shear wall system	1.1 crore
5	L-shear wall system	1.2 crore
6	C-shear wall system	1.3 crore
7	Base Isolator	2.88 Cr – 4.80 Cr

Table -8: Cost comparison of seismic resisting systems for Steel structure

S.no	Seismic load resisting systems in Steel Structure	Cost Estimated
1	X bracing system	23 Lakhs
2	Inverted V bracing system	15 lakhs
3	Diagonal bracing system	12 lakhs
4	Plane shear wall system	1.40 Cr
5	L-shear wall system	1.51 Cr
6	C-shear wall system	1.39 Cr
7	Base Isolator	2.88 Cr – 4.80 Cr

3. CONCLUSIONS

The following conclusions are based on the findings of the analyzes of the steel and RCC constructions.

- Using maximum displacement, storey drift, and base shear as the primary performance metrics, the study investigated several lateral load-resisting systems for RCC and steel structures under Zone 3, Zone 4, and Zone 5 seismic conditions.
- The findings demonstrate that, in comparison to the base model and bracing systems, shear-wall systems often offer reduced maximum displacement and storey drift. This suggests that shear walls significantly increase the lateral stiffness of both steel and RCC structural models.
- The L-type shear wall in the RCC Zone 5 model decreased the maximum displacement from 41.03 mm to 22.50 mm in the X-direction and from 41.26 mm to 27.20 mm in the Y-direction. Additionally, there was a significant decrease in the associated storey drift.
- The L-type shear wall in the steel Zone 5 model decreased the maximum displacement from 85.92 mm to 33.21 mm in Y and from 93.789 mm to 28.94 mm in X. Additionally, the storey drift decreased from 0.00290 to 0.000953 in Y and from 0.00314 to 0.000761 in X.
- The reaction of the base-isolation system differed from that of the traditional lateral systems. The maximum displacement for the RCC Zone 5 model rose from 41.03 mm to 60.053 mm in X and from 41.26 mm to 60.67 mm in Y, while the base shear decreased from 5875.79 kN to 4212.76 kN.
- Bracing systems are much more cost-effective than the stated shear-wall and base-isolation systems, according to the updated cost comparison. While the shear-wall systems cost between 1.1 crore and 1.3 crore, the updated costs for RCC are 29 lakhs for X-bracing, 18.1 lakhs for inverted-V bracing, and 17 lakhs for diagonal bracing.

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