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Original Article

Performance of Building with Composite Structural Elements Subjected to Lateral Loads

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Abstract *- This paper presents the comparative study of composite columns Concrete Encased I-section (C.E.S.) and Concrete Filled Steel Tube (CFST) along with the conventional R.C.C. columns for a 10-storey building subjected to lateral loading. Shear walls and bracings are used as lateral load resisting systems. ETABS software is used to model and analyze both symmetric and asymmetric loading. The seismic analysis is done according to I.S. 1893:2016 Part 1, and the wind forces are according to I.S. 875:2015 Part 3. All composite columns are designed according to Eurocode-4. The results are plotted for base shear, natural period, inter-storey drifts, and displacement. It is observed that the period is higher in the case of composite columns, while the base shear is much lesser than that compared to R.C.C. columns. The composite columns with bracings give the minimum value of storey drift when subjected to lateral loads.*

Keywords *- CFST, C.E.S., Lateral loads, Shear walls, Bracings, Base shear, Period, Storey drift.*

1. Introduction

Structural members are veritably large, heavy, costly, and reducing usable spaces in multi-story structures designed with conventional reinforced concrete. In recent times, composite columns have been gaining popularity for multi-storey structures because of their excellent static and earthquake-resistant properties such as lower mass, high strength, rigidity and stiffness, significantly high toughness and elasticity, and large energy dispersion capacity. Due to these reasons, composite members are gaining significance for making sky-scrapers, especially for high-rise structures of seismic regions worldwide. Composite construction refers to the load-carrying capacity of two structural members that are integrally connected and deflect as a single unit. It's preferred because concrete is good in compaction, and steel is good in tension. By joining the two materials together structurally, these strengths can be exploited to pan out in a highly efficient and lightweight design. The reduced self-weight of composite elements has a knock-on effect by reducing the forces in those elements and also offers benefits in terms of speed of construction. The floor depth reductions that can be achieved using composite construction can also deliver significant benefits in terms of the costs of services and the structure envelope.

1.1. Composite Columns

Composite columns are the combination of two traditional structural forms, structural steel and structural concrete. The design approach for composite columns is given in Euro code 4. Two types of composite columns are used in erecting construction. The first consists of a steel section encased in a reinforced concrete envelope. The alternate consists of a steel pipe or tube filled with structural concrete. A steel-concrete composite column is a compression member and is generally used as a load-bearing member in a composite framed structure. Due to the excellent static and earthquake-resistant properties of concrete-filled steel tubular are being used extensively in real civil engineering designs. They have high strength, ductility, and a large energy absorption capacity. Concrete-encased steel columns have a large load-carrying capacity and high local stability due to composite action, and high-strength materials enrich structural safety and space efficiency.

1.2. Steel Beams

Steel beams are a structural steel product that supports heavy loads. Steel beams come in different sizes and types, hence their different operations in constructing structures and structures. The specifications of a structure determine the geometry, size, and shape of beams. These beams can be straight or twisted.

The present study selects a G+9 storey structure with both R.C.C. and Composite columns (CFST and C.E.S.) built-up steel beams with plates on both flanges. The structure is subjected to both wind and seismic loads, and a comparative study between R.C.C. and Composite structures is done. For seismic analysis, the Response Spectrum method is used. The lateral load resisting systems like shear wall and bracing are included for better lateral load response**.**

2. Literature Review

In the past studies, Panchal and Marathe (2011) compared R.C.C, Steel, and Composite (G+30 Storey) Building; Composite structures were found to be more economical. Steel option is better than R.C.C. dead weight of the steel-framed structure is 32 % concerning R.C.C.

frame Structure, and Composite framed structure is 30 % for R.C.C. framed structure. Sharma et al. (2016) compared R.C.C and Composite Material G+20 for lateral responses, and the results recorded were within the permissible limit. R.C.C. imposed dead load. Sachin and Prasad (2018) compared the seismic behavior of CFST and C.E.S. columns for a G+14 multi-storey building for different setback conditions. It was concluded that CFST columns performed well compared to C.E.S. columns; hence it is better to adopt the CFST columns for irregular buildings. Bhagyamma and Kumar (2021) studied a G+12 framed multi-storey building in zone 3 with Steel and Concrete Filled Steel Tube (CFST).

Base shear and storey overturning moment induced by the seismic forces are reduced by 22 to 28% for composite columns. Roof displacement has been reduced by 26.6%. Georgios et al. (2016) considered steel H.E.B. columns fully encased in concrete, steel IPE beams, and steel L-bracings. The objective function was to minimize the total cost of materials. Based on Eurocodes 3 and 4 and checking the individual capacity of members. Optimization is done using non-linear pushover analysis and Eigenvalue analysis. Moa et al. (2021) analysed a concrete-filled composite shear wall (CFCSW) with connection configuration and steel plates. The structural behavior of the plates was studied. The results indicate that increased axial force ratio leads to rapid stiffness degradation and strength degradation of CFCSW when subjected to cyclic lateral loading. CFST boundary elements can enhance the structural performance of CFCSW. Todea et al. (2021) studied concrete walls with central openings (CSRCW) with steel profiles partially embedded on the edges, one conventional reinforced concrete wall (RCW) with central openings, and the solid specimen, which is also a composite steel-concrete wall. Seismic behavior and performance of composite steel-concrete coupled walls with regular openings and conventional reinforced coupling beams. It was observed that by embedding supplementary steel fibers in the concrete matrix, the ductility loss due to openings could be regained and significantly improved. The composite connection between the walls' structural steel and concrete web panel could successfully resist until the specimens reached the ultimate failure.

3. Objectives

1. To study the performance of G+9 R.C.C building with Composite structural elements, CFST and Concrete encased I-section column subjected to seismic and wind loads.

2. To study various parameters like base shear, inter-storey drift, natural period, and displacement.

3. To study the performance of CFST and Concrete encased I-section columns and a conventional system with various lateral load resisting systems (shear wall, bracings).

4. Numerical Study

The G+9 multi-story R.C.C. composite building in Zone 4 is modeled and analyzed using ETABS software. The plan dimensions are 21 m x 18 m, as shown in Figure 1, and the height of each storey is 3.5 m. Total height of the building is 35 m.

The grade of concrete for the R.C.C. column is M25 with reinforcement Fe500 and that for the Composite column is M30 with steel grade of Fe 345. Steel beams are built-up sections with plates on both flanges.

The models were analyzed for different conditions, i.e., Shear walls, bracing, and Conventional (without any lateral load resisting system) for symmetric and asymmetric loading. The parameters analyzed were Base shear, Inter storey drift, Storey displacement, and Natural period. The seismic analysis is done using the Response Spectrum Method according to I.S. 1893:2016 and wind load according to I.S. 875:2015 Part 3, all-composite columns are designed and checked according to Euro code 4.

The general data for all buildings is provided in Table 1.

Table 1. General data for all G+9 storey building

PROPERTIES	RCC BUILDING	COMPOSITE BUILDING
Grade of concrete	M 25	M 30
Grade of structural steel	---	Fe 345
Grade of reinforcement	Fe 500	
Slab	150 mm	
Shear wall	230 mm	
Bracings	I.S.B. 200X200X6	
Soil type	Medium	
Z	4	
I	1	
R	5	
Wind speed	50 m/s	
FF	1 kN/m^2	
BL	4.6 kN/m 16.1 kN/m	

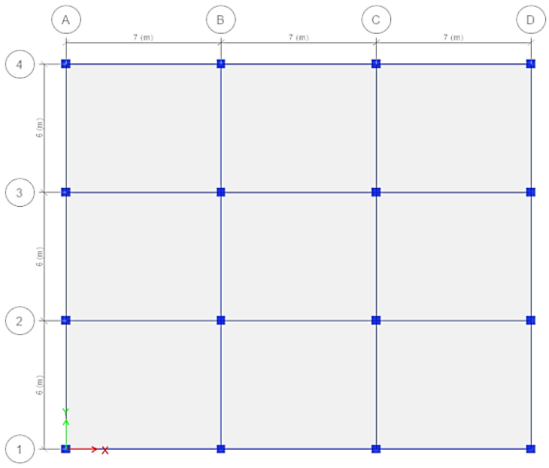

Fig. 1 Building plan 21 m x 18 m

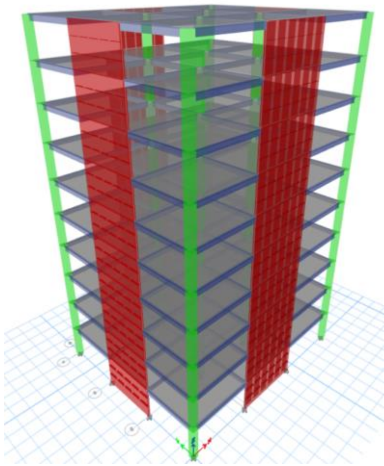

Fig. 3 G+9 storey building with Shear wall

4.1. Models

The section dimensions for beams and columns are different for each condition, and the dimensions for each case are given separately. The ETABS models are shown in figure 2, the 3D view for the G+9 conventional model; figure 3, the G+9 storey building with Shear walls; figure 4, the 3D view for buildings with bracings.

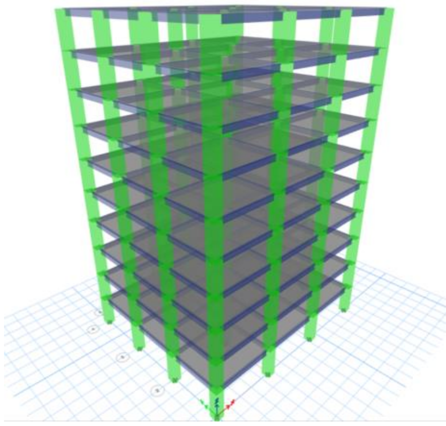

Fig. 2 Conventional G+9 storey building

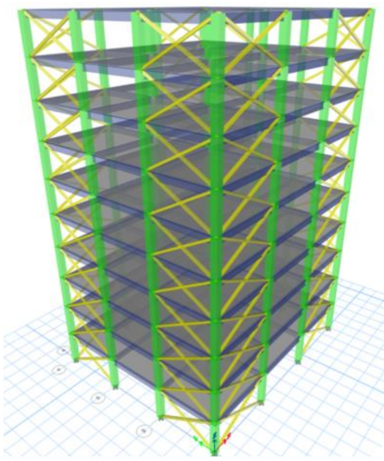

Fig. 4 G+9 storey building with bracings

4.2. Case 1: Symmetric Loading

The live load on the entire plan area of 21 m x 18 m is 4 kN/m^2. The section dimensions for symmetric loading are given in Table 2.

Table 2. Section Dimensions for Symmetric building

Cases	Beams	Columns
G+9 RCC	ISMB 550 with 20 mm plate	1000 mm x 1000 mm
G+9 RCC with Shear Wall	ISMB 400 with 20 mm plate	600 mm x 600 mm 500 mm x 500 mm
G+9 RCC with Bracings	ISMB 400 with 16 mm plate	550 mm x 550 mm
G+9 CFST	ISMB 450 with 20 mm plate	500 mm x 500 mm 350 mm x 350 mm
G+9 CFST with Shear Wall	ISMB 400 with 16 mm plate	450 mm x 450 mm 250 mm x 250 mm
G+9 CFST with Bracings	ISMB 400 with 16 mm plate	500 mm x 500 mm 350 mm x 350 mm
G+9 CES	ISMB 350 with 20 mm plate	950 mm x 950 mm (ISHB 350) 700 mm x 700 mm (ISHB 150)
G+9 CES with Shear Wall	ISMB 300 with 20 mm plate	800 mm x 800 mm (ISHB 150) 600 mm x 600 mm (ISHB 150)
G+9 CES with Bracings	ISMB 300 with 20 mm plate	900 mm x 900 mm (ISHB 150) 600 mm x 600 mm (ISHB 150)

4.3. Case 2: Asymmetric Loading

In the case of Asymmetric loading, two cases are considered for the lateral load analysis. The two conditions are the distribution of live loads over the plan of 21 m x 18 m. In the first case, the live load of 6 kN/m^2 is applied to 2/3rd of the plan, and on the rest, 2 kN/m^2 is applied to shift the centre of mass and produce an eccentricity of 10%. In the second case, the live load of 6 kN/m^2 is applied over 1/3rd of the plan and 2 kN/m^2 over the rest to produce an eccentricity of 15%. The section dimensions for the two cases are defined in Tables 3 and 4.

Table 3. Section Dimensions for Asymmetric building 10% Eccentricity

Cases	Beams	Columns
G+9 RCC	ISMB 550 with 25 mm plate	900 mm x 900 mm
G+9 RCC with Shear Wall	ISMB 400 with 20 mm plate	650 mm x 650 mm 500 mm x 500 mm
G+9 RCC with Bracings	ISMB 400 with 16 mm plate	600 mm x 600 mm
G+9 CFST	ISMB 450 with 16 mm plate	550 mm x 550 mm 250 mm x 250 mm
G+9 CFST with Shear Wall	ISMB 400 with 20 mm plate	500 mm x 500 mm 250 mm x 250 mm
G+9 CFST with Bracings	ISMB 400 with 16 mm plate	500 mm x 500 mm 350 mm x 350 mm
G+9 CES	ISMB 350 with 20 mm plate	1000 mm x 1000 mm (ISHB 350) 800 mm x 800 mm (ISHB 150)
G+9 CES with Shear Wall	ISMB 350 with 20 mm plate	800 mm x 800 mm (ISHB 150) 650 mm x 650 mm (ISHB 150)
G+9 CES with Bracings	ISMB 300 with 20 mm plate	900 mm x 900 mm (HB 150) 600 mm x 600 mm (ISHB 150)

Table 4. Section Dimensions for Asymmetric building 15% Eccentricity

Cases	Beams	Columns
G+9 RCC	ISMB 550 with 25 mm plate	900 mm x 900 mm
G+9 RCC with Shear Wall	ISMB 400 with 20 mm plate	650 mm x 650 mm 500 mm x 500 mm
G+9 RCC with Bracings	ISMB 400 with 16 mm plate	600 mm x 600 mm
G+9 CFST	ISMB 450 with 16 mm plate	550 mm x 550 mm 350 mm x 350 mm
G+9 CFST with Shear Wall	ISMB 400 with 20 mm plate	500 mm x 500 mm 250 mm x 250 mm
G+9 CFST with Bracings	ISMB 400 with 16 mm plate	500 mm x 500 mm 350 mm x 350 mm
G+9 CES	ISMB 350 with 20 mm plate	1000 mm x 1000 mm (ISHB 350) 800 mm x 800 mm (ISHB 150)
G+9 CES with Shear Wall	ISMB 350 with 20 mm plate	800 mm x 800 mm (ISHB 150) 650 mm x 650 mm (ISHB 150)
G+9 CES with Bracings	ISMB 300 with 20 mm plate	900 mm x 900 mm (HB 150) 600 mm x 600 mm (ISHB 150)

5. Results

The base shear and natural period are calculated using the response spectrum analysis for the different conditions. The inter-story drift and displacement for both seismic and wind forces are plotted.

5.1. Base Shear

Figures 5, 6, and 7 present the base shear for all buildings due to static and response spectrum methods. It is observed that the base shear is lower than 50% in buildings with composite columns compared to buildings with R.C.C. columns due to composite action, which reduces the overall lateral seismic force on the building. The least value of base shear is observed in buildings with CFST columns and Bracings in all conditions.

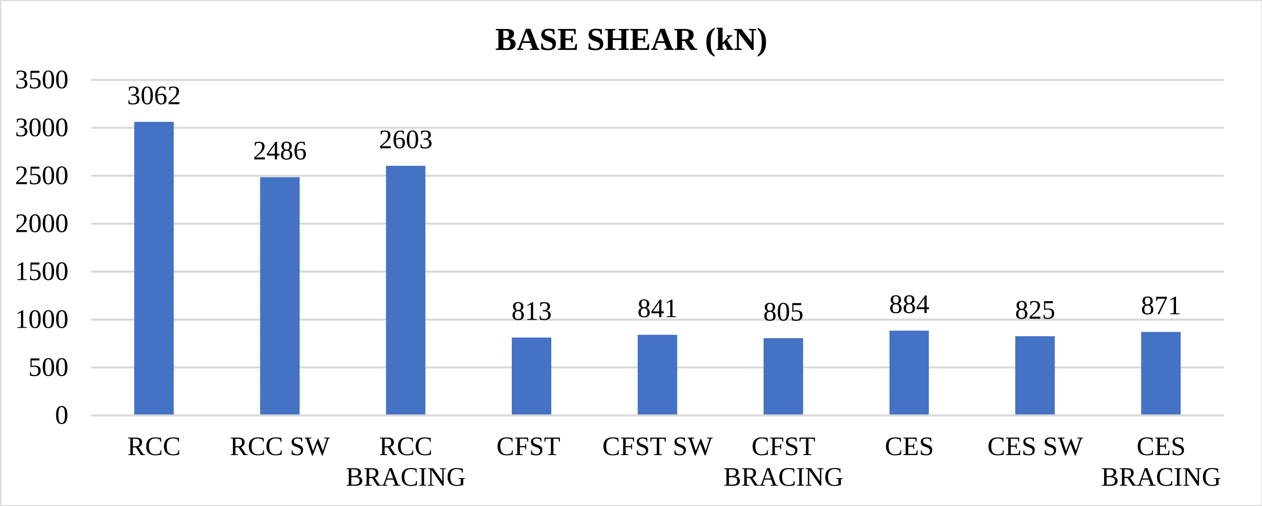

Fig. 5 Base shear Symmetric loading

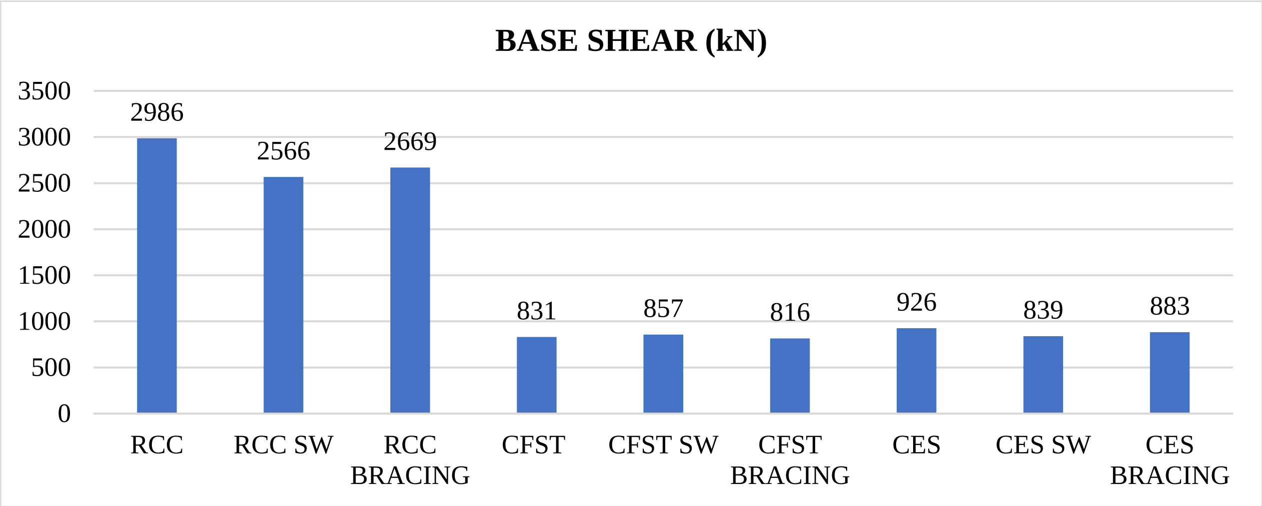

Fig. 6 Base Shear Asymmetric loading with 10% Eccentricity

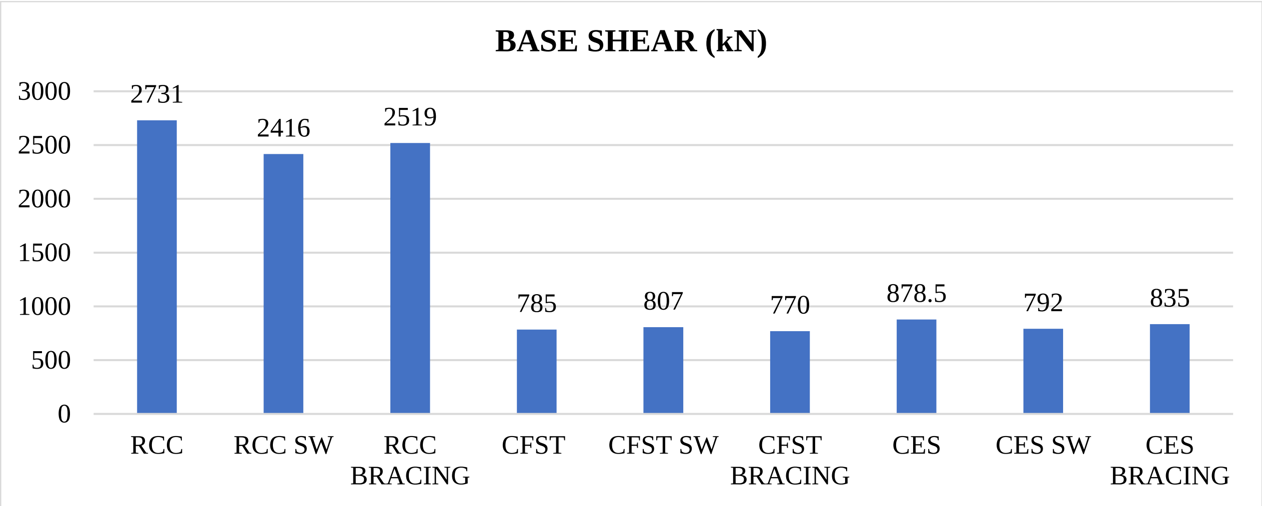

Fig. 7 Base Shear Asymmetric loading with 15% Eccentricity

5.2. Natural Period

The natural time for all buildings is calculated using the response spectrum method and static time according to I.S. 1893:2016, as shown in figure 8. The time in the first mode of response spectrum analysis is considered for all cases. The time is much higher in the case of composite columns because of their flexible nature, as shown in figures 9, 10, and 11. The R.C.C. column buildings have a lower time because of higher stiffness.

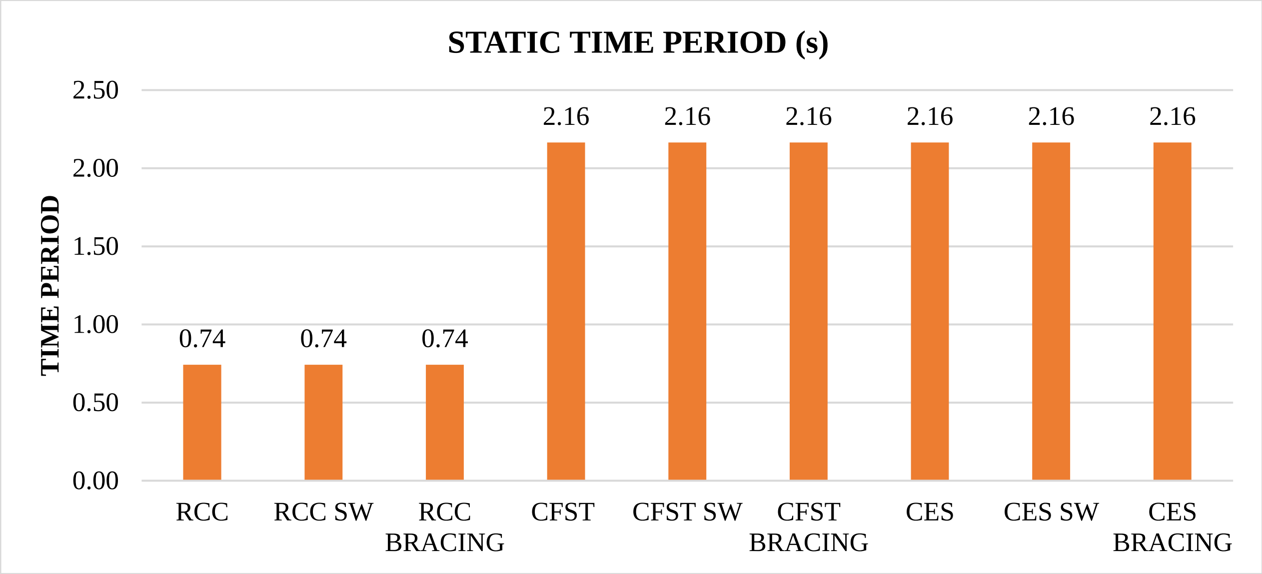

Fig. 8 Natural time Static method

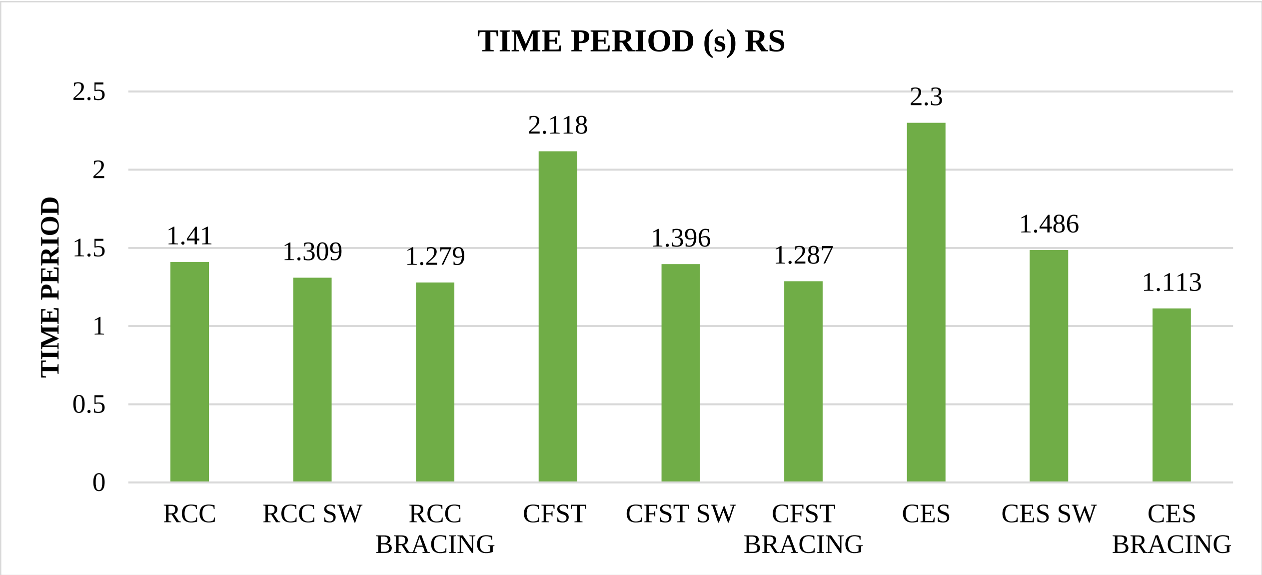

Fig. 9 Natural time Response Spectrum Symmetric building

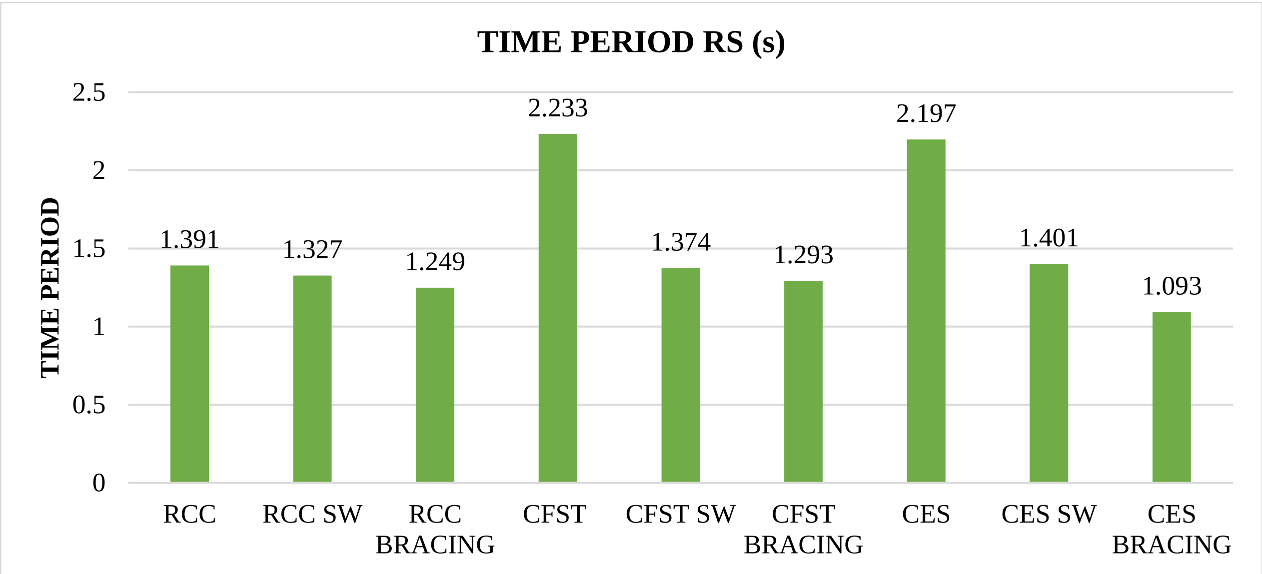

Fig. 10 Natural time Response Asymmetric Spectrum building with 10% eccentricity

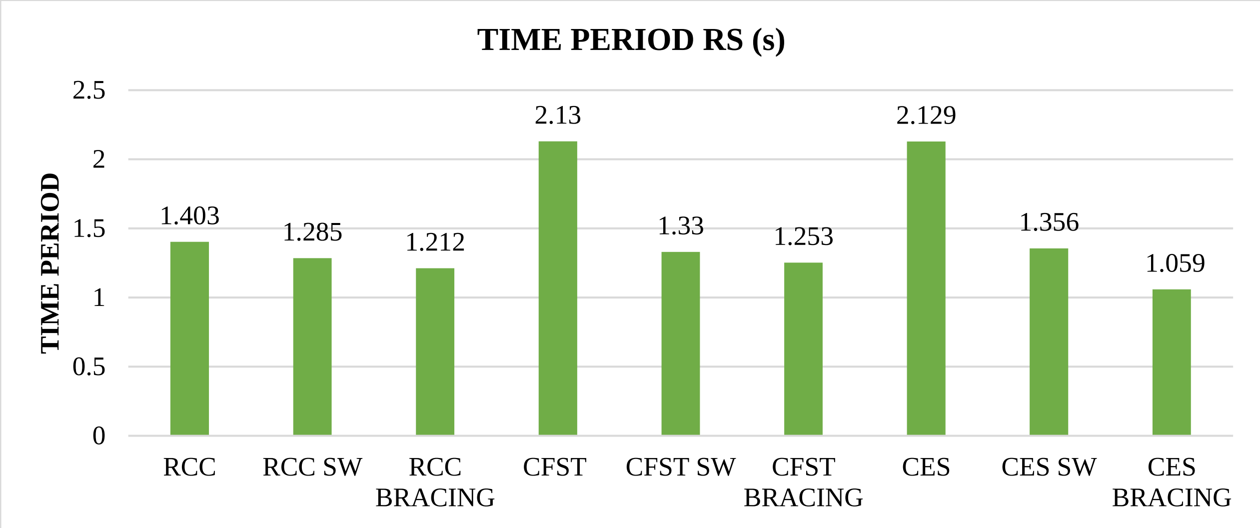

Fig. 11 Natural time Response Asymmetric Spectrum building with 15% Eccentricity

5.3. Inter-Storey Drift

All buildings are designed for inter-storey drift within the permissible limit of h/250, where h is the height of each storey in mm. The inter-storey drift is calculated for earthquake and wind loads in both directions for all conditions and plotted as shown in figures 12 to 23. The composite columns performed 60-70% better than the R.C.C. columns. The better lateral response is seen in C.E.S. columns with bracings in all cases for both seismic and wind loads.

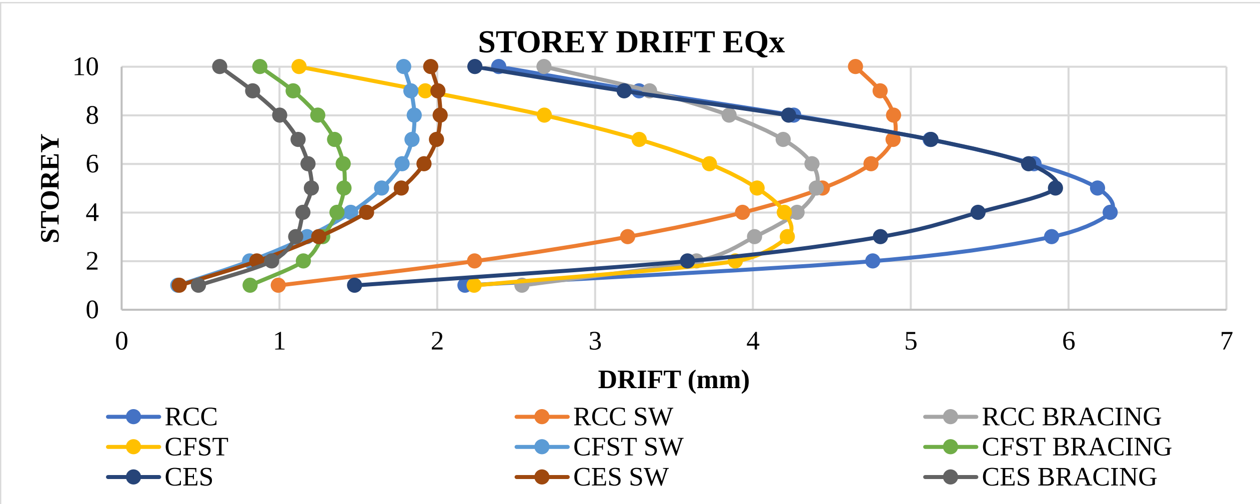

Fig. 12 Storey drift for EQx Symmetric loading

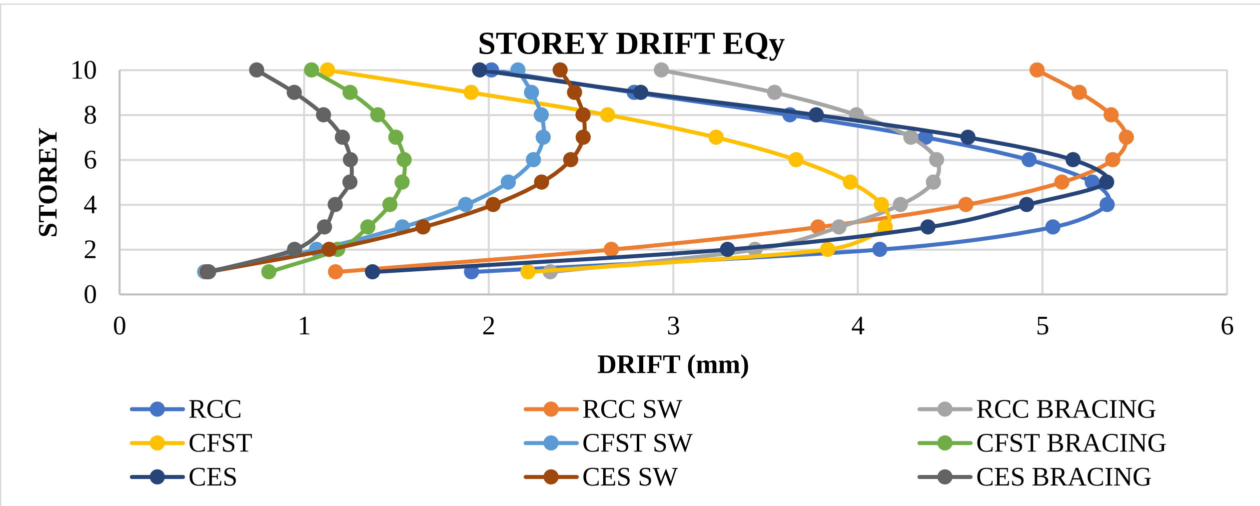

Fig. 13 Storey drift for EQy Symmetric loading

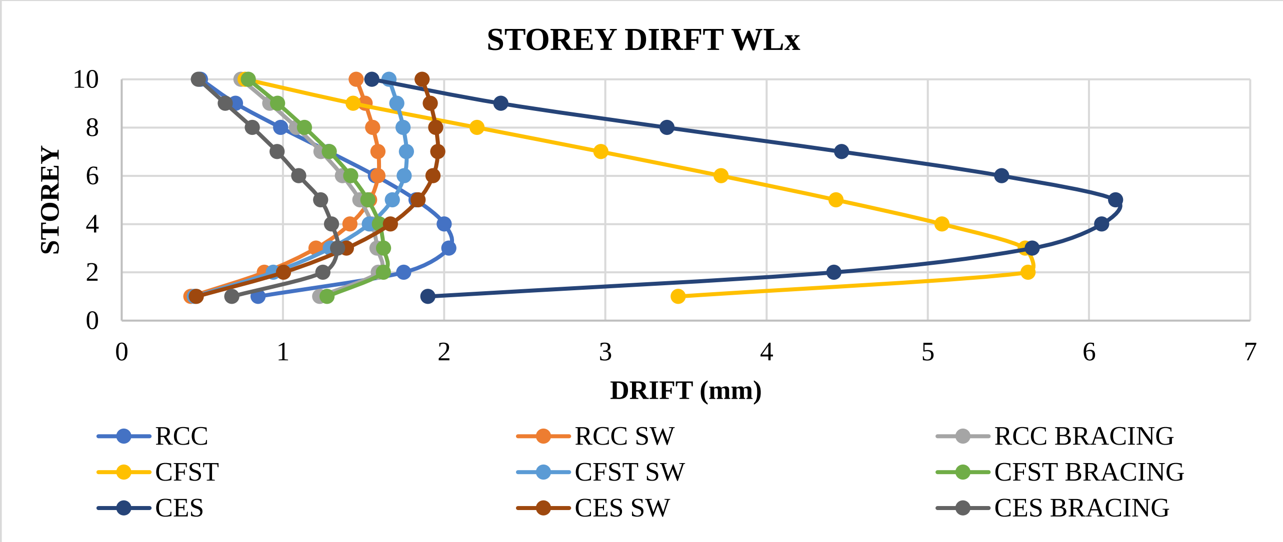

Fig. 14 Storey drift WLx Symmetric loading

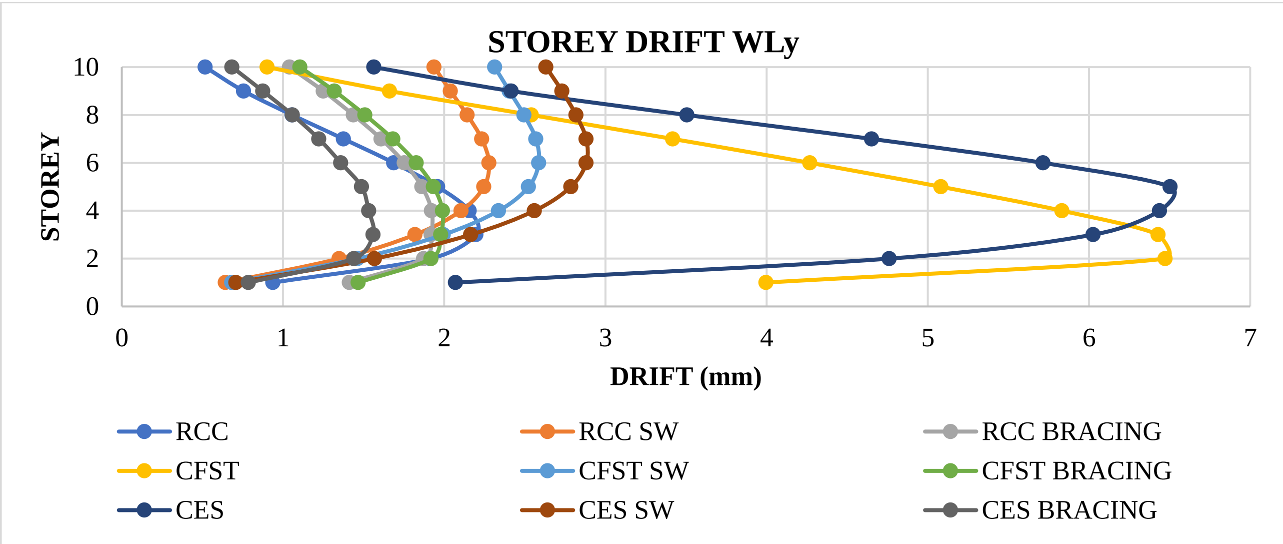

Fig. 15 Storey drift WLy Symmetric loading

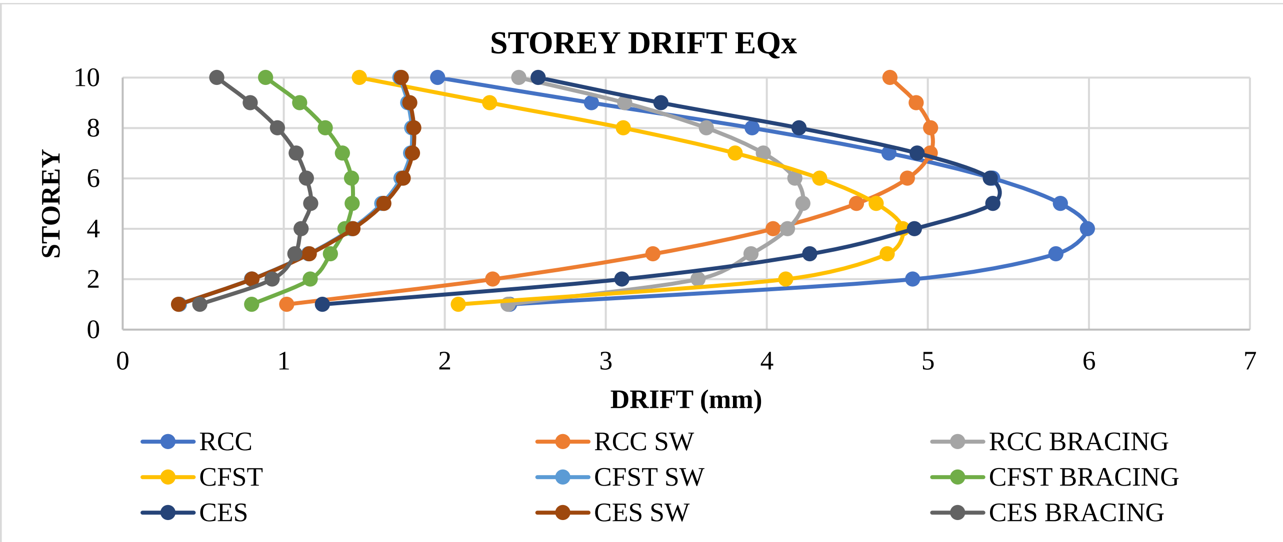

Fig. 16 Storey drift EQx Asymmetric loading with 10% Eccentricity

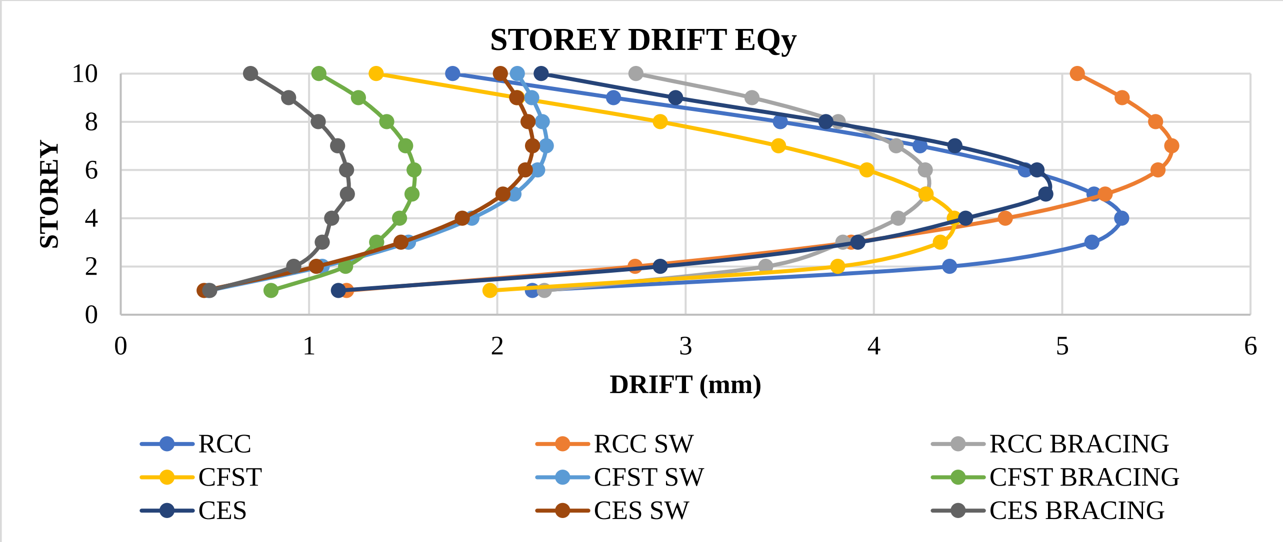

Fig. 17 Storey drift EQy Asymmetric loading with 10% Eccentricity

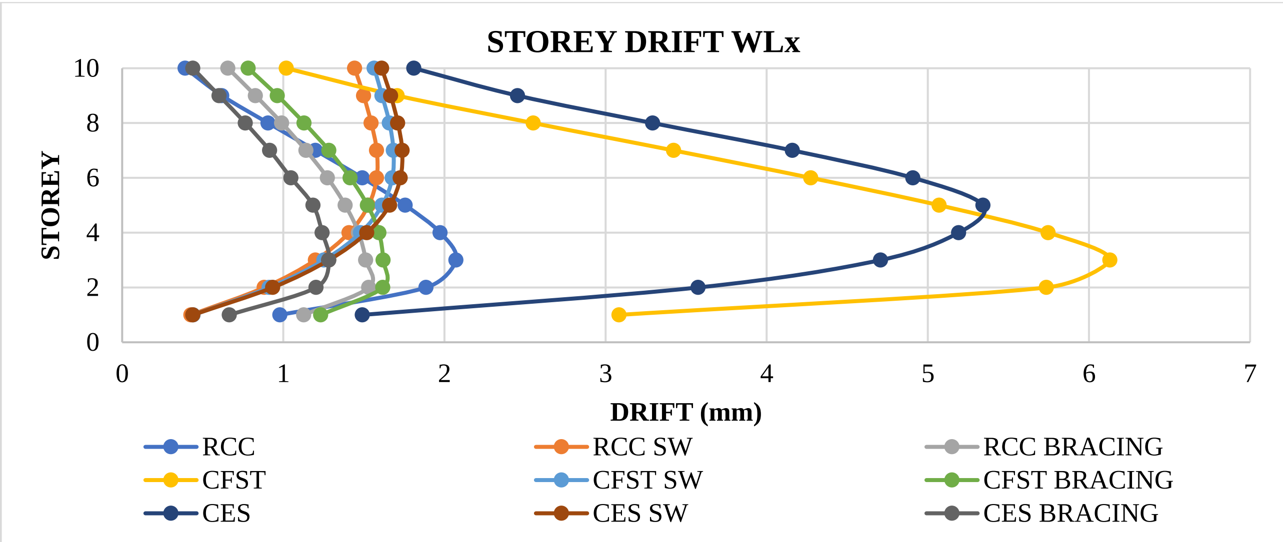

Fig. 18 Storey drift WLx Asymmetric loading with 10% Eccentricity

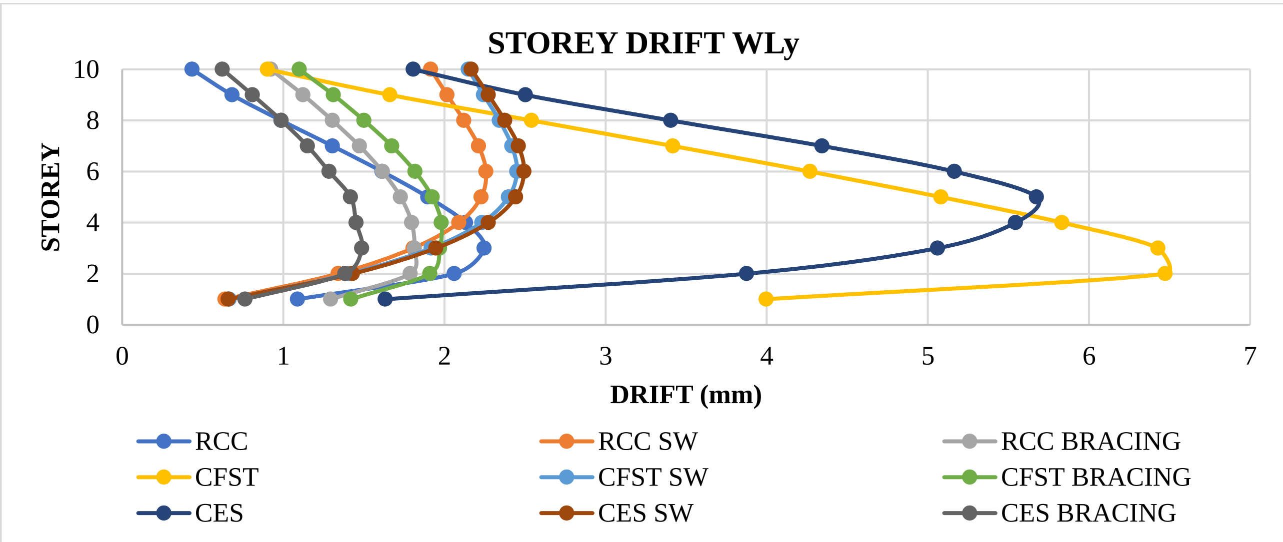

Fig. 19 Storey drift WLy Asymmetric loading with 10% Eccentricity

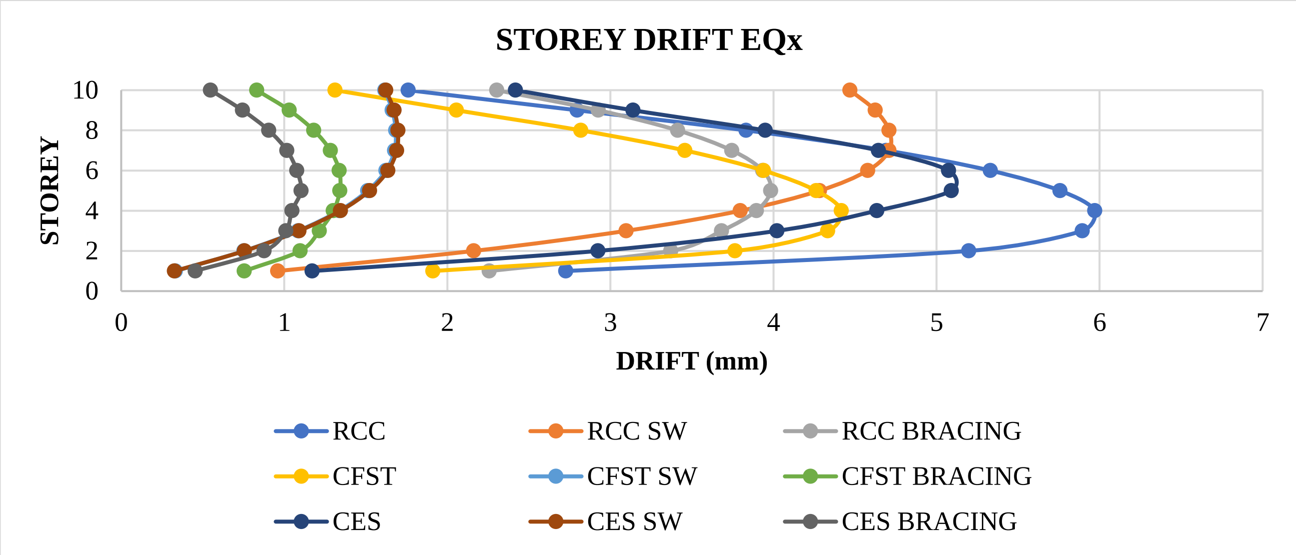

Fig. 20 Storey drift EQx Asymmetric loading with 15% Eccentricity

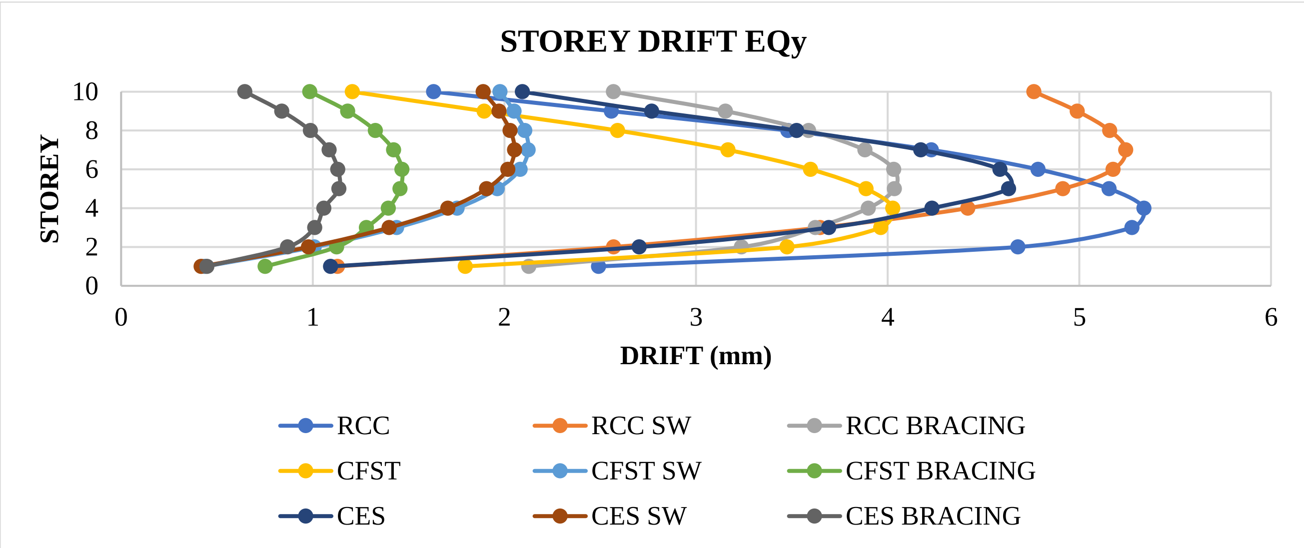

Fig. 21 Storey drift EQy Asymmetric loading with 15% Eccentricity

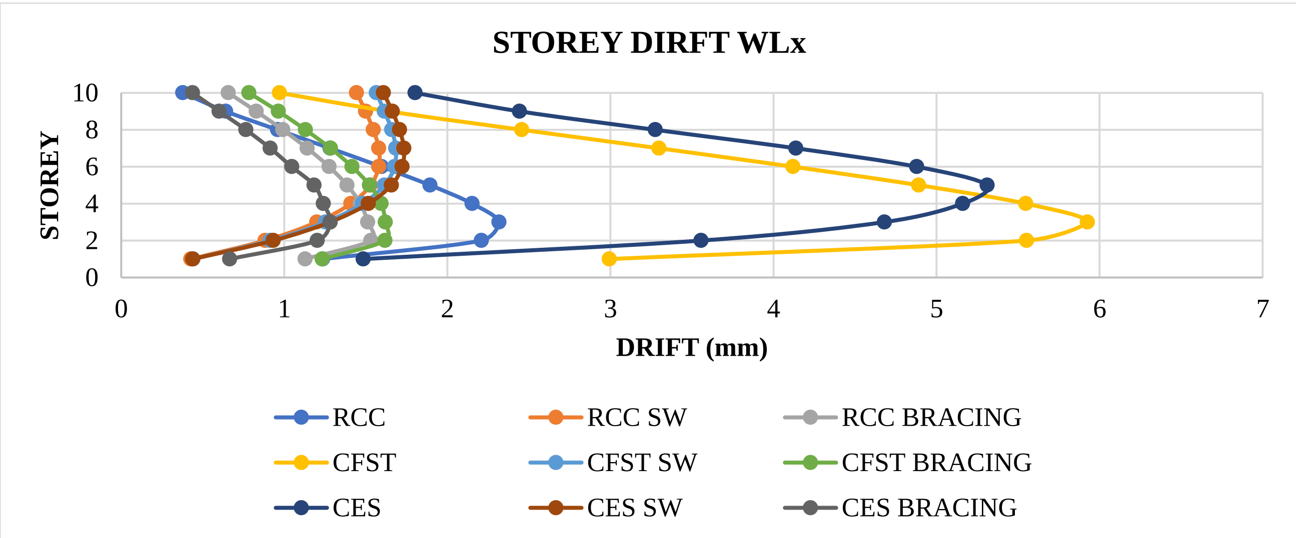

Fig. 22 Storey drift WLx Asymmetric loading with 15% Eccentricity

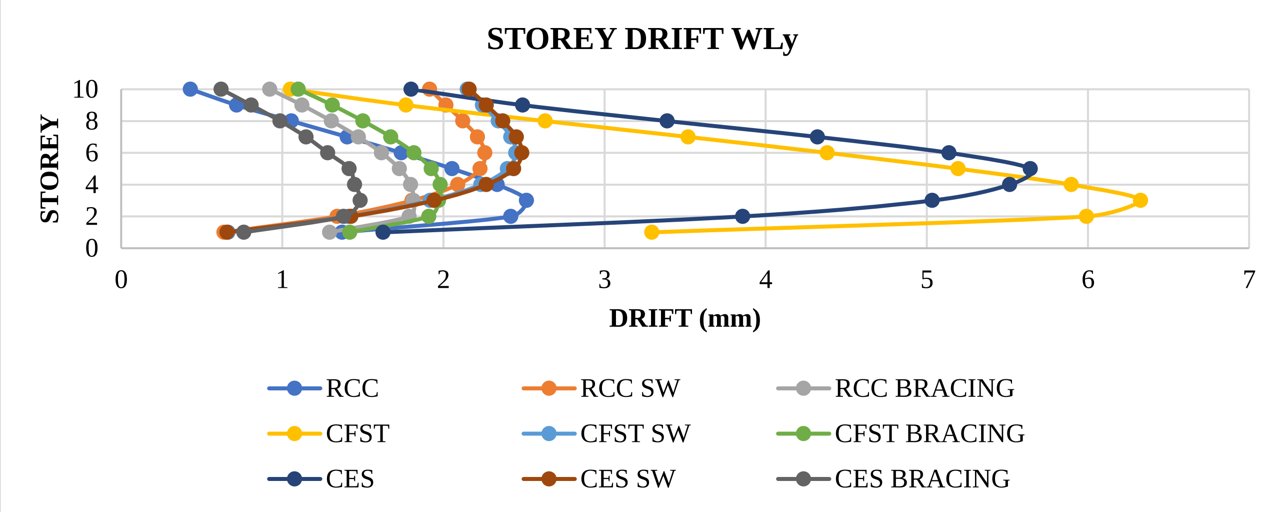

Fig. 23 Storey drift WLy Asymmetric loading with 15% Eccentricity

5.4. Displacement

Each building is checked for maximum displacement at top storey H/500, where H is the total height of the building in mm. The load combinations for maximum displacement for earthquake and wind load are considered and plotted as shown in figures 24 to 29. In all cases, the least value of maximum displacement is observed in building with C.E.S. columns and bracings for both wind and seismic loads.

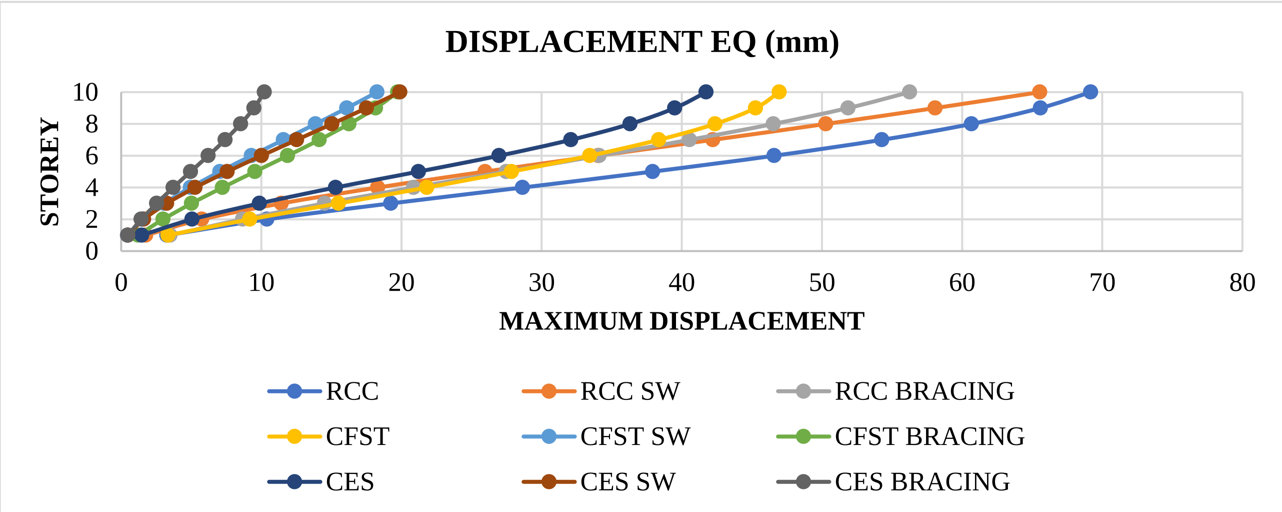

Fig. 24 Maximum displacement due to E.Q. Symmetric loading

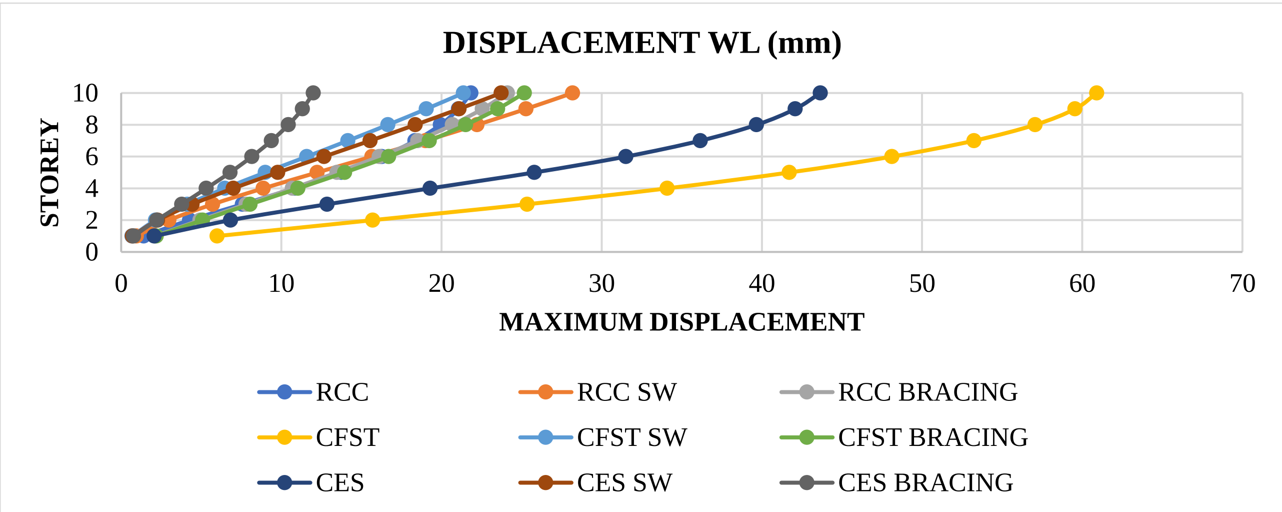

Fig. 25 Maximum displacement due to W.L. Symmetric loading

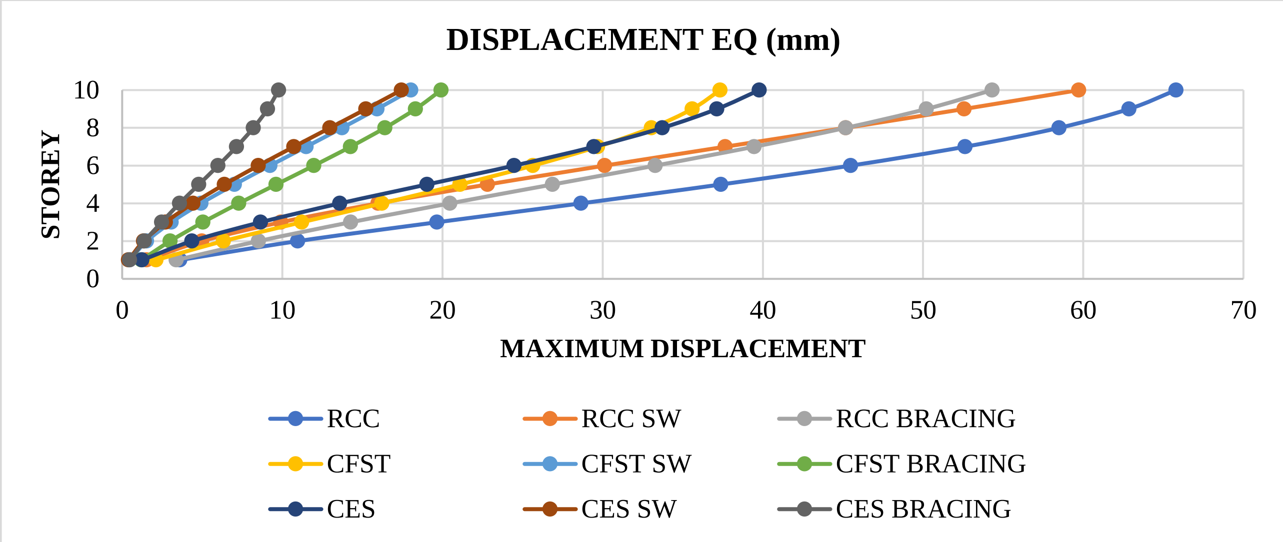

Fig. 26 Maximum displacement due to E.Q. Asymmetric loading with 10% eccentricity

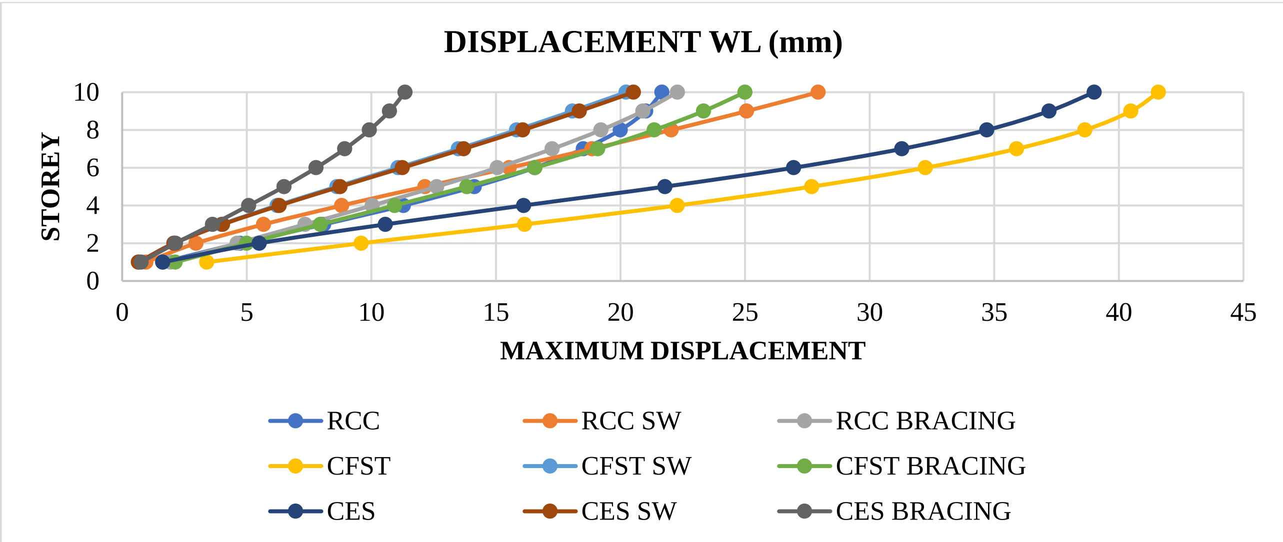

Fig. 27 Maximum displacement due to W.L. Asymmetric loading with 10% eccentricity

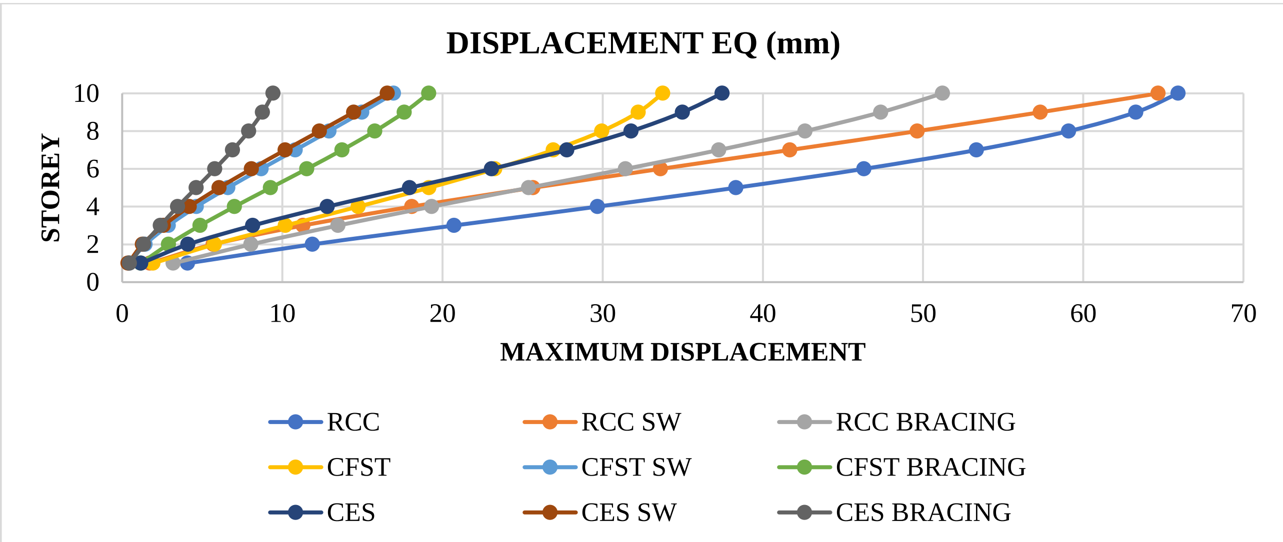

Fig. 28 Maximum displacement due to E.Q. Asymmetric loading with 15% eccentricity

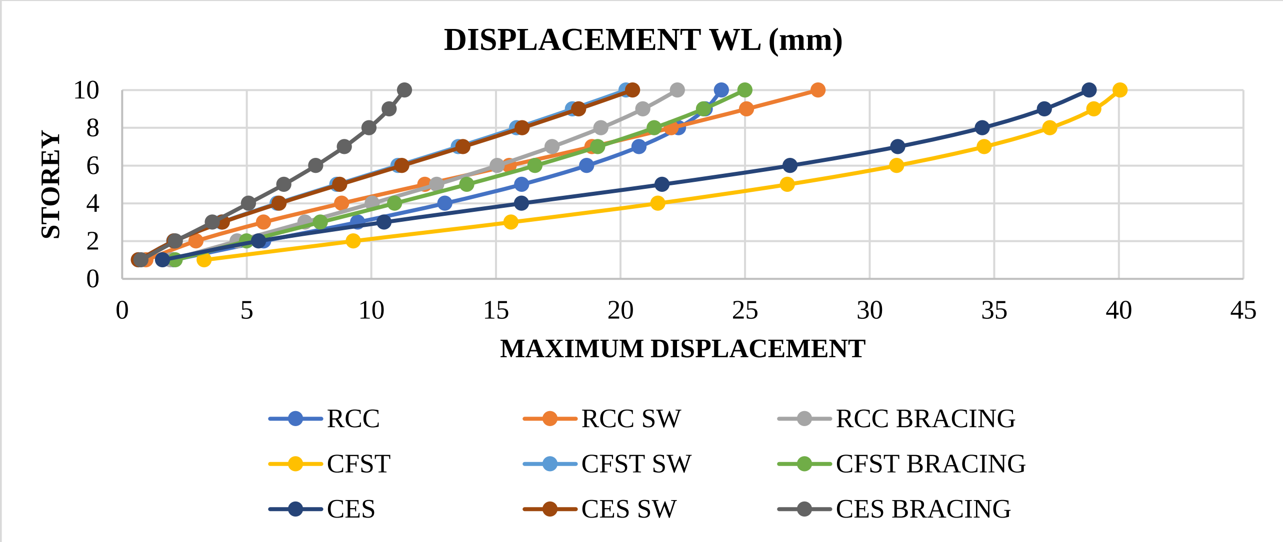

Fig. 29 Maximum displacement due to W.L. Asymmetric loading with 15% eccentricity

6. Conclusion

Based on the parametric comparison between conventional R.C.C. columns and Composite columns along with lateral load resisting systems for both seismic and wind loads in symmetric and asymmetric loading conditions, the following conclusions can be derived.

1. The structure with composite columns gives better resistance to lateral loads than the conventional R.C.C. column structure.
2. The base shear in the case of composite buildings is less than 50% of R.C.C. buildings in all three cases because of the steel-concrete composite action. At least in CFST columns with bracings.
3. The time is higher in the case of composite columns because of their flexible nature. The natural period due to seismic dynamic analysis is least in the case of buildings with C.E.S. columns and bracings.
4. The lateral displacement is almost 60-70% lower for composite buildings than R.C.C. buildings, least for C.E.S. columns with bracings.
5. Up to 55% better resistance to seismic loading in the case of composite buildings compared to conventional R.C.C. buildings.
6. In the case of asymmetric loading with 15% eccentricity, the base shear, period, and displacements are lower than the symmetric loading, while in the case of 10% eccentricity, the results are higher.
7. The conventional CFST column frame system gave better lateral resistance and lower base shear than the C.E.S. column frame system.
8. The R.C.C. column sections designed for a permissible limit of lateral load resistance need higher sections and are not economical compared to composite sections.

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