Comparative Study on Structural Integrity of High-Rise Buildings with Composite Columns System on Sloping Ground Under Seismic Loads

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***Abstract*—The seismic behaviour of a thirty-story high-rise building with four distinct column systems—conventional Reinforced Concrete (RC) columns, Concrete-Filled Steel Box (CFSB) tube sections, Double-Skinned Concrete-Filled Steel Tubular (DSCFT) columns, and Rectangular Encased Composite (REC) columns—is investigated in this study. The structure was constructed on a sloping site with slopes between 5° and 25°. Nonlinear dynamic time-history investigations were carried out using ground motion data to evaluate the effects of column type and slope angle on key structural properties like story displacement, inter-story drift, fundamental time period, and overall stiffness. The results demonstrate that composite column systems, particularly DSCFT and REC, significantly improve the structural performance of structures on inclined terrain.**

I.INTRODUCTION

This study will evaluate the seismic behaviour of a 30-story skyscraper on 5–25-degree slopes. Real-time structural performance data from nonlinear time history analysis is used to analyses seismic loading's structural reaction. Researching how ground conditions affect earthquake response is crucial. Different slope conditions and structural systems will be studied for displacement, story drift, stiffness, and fundamental time. This detailed method will show how the angle of the soil and the shape of buildings influence how well tall structures can withstand earthquakes, making designs in hilly and earthquake-prone areas safer and more effective. RC columns are popular but may not be strong enough for hillside high-rises. REC, CFSB, and DSCFT composite columns absorb more energy, have higher strength-to-weight ratios, and suffer less lateral deformation. They have latent earthquake resilience potential on sloping terrain.

The need to understand how slope inclination impacts structural behaviour sparked this research. Composite vs. RC column performance. Select the safest sloped seismic column system.

II.LITERATURE REVIEW

Rinki Varma, Krishna Kant Pathak, Virendra Pathak, and Ravindra Agrahari (2025)
A G+19-story building model was analysed using ETABS software, focusing on natural time, mode forms, base shear, story drift, stiffness, and displacement under seismic stress. Composite buildings on level ground outperformed traditional buildings on sloping terrain in seismic performance, with drift ratio reductions of 8–12% and story displacement reductions of 11–13%. At the collapse prevention level, the ductility-based damage index declined 32.3% and the stiffness-based index dropped 99.4%, improving structural resilience and energy dissipation. Composite dual system buildings are better for uneven or mountainous terrain due to their stiffness, reduced deformation, and higher seismic safety, according to the study

Wenke Yuan, Enhe Bao, Weizhe Zhou, Zhengwang Wang, Shiyi Ma, Bocheng Xie, and Ting Ding (2025)
In Structures (Volume 80, October 2025), Wenke Yuan et al. described "High-Strength Core Column Steel Frame Systems for Seismic Performance Enhancement," which investigates novel methods for reinforcing steel structures in seismically active areas. A

High-Strength Core Column (HSCC) steel frame design using high-strength steel to increase ductility and load-carrying capacity is suggested because traditional steel frames generally lack lateral stiffness under seismic loads. The study compares conventional and HSCC-reinforced high-rise models with 20 and 30 stories using static pushover and nonlinear time-history evaluations

Yusuf Yıldız and Fethi Şermet (2025)
Yusuf Yıldız and Fethi Şermet's study in the Challenge Journal of Structural Mechanics (Vol. 11, No. 2, 2025) analyses seismic risks from weak and soft story anomalies in buildings without ground floor infill walls. Adding infill wall stiffness and replacing ground-floor columns with composite ones are examined. It followed the Turkish Building Earthquake Code (TBEC-2018). By raising the cracked cross-section moment of inertia, stiffening the infill wall increases lateral load resistance by 5%. However, raising the stiffness irregularity coefficient by 33% caused uneven seismic force distribution. Composite columns on the ground level enhanced strength irregularity by 29% and decreased rigidity irregularity by 20%, resulting in a more constant lateral reaction

Rashma R.S.V, Jayalakshmi B.R, and Shivashankar R. (2025)
A comprehensive analysis of seismic and static shear pressure-based ground strengthening methods was published in the Emirati Journal of Civil Engineering and Applications (Vol. 3, Issue 1, March 2025) by Rashma R.S.V., Jayalakshmi B.R., and Shivashankar R. The approach addresses the performance constraints of ordinary stone columns, which cannot resist earthquake lateral spreading. The authors note the weak shear strength of stone columns and advise replacing them with pervious concrete columns based on experimental and analytical research. Pervious concrete columns have better shear performance and deformation control under static and dynamic settings, making them better for seismic ground improvement, according to their research.

III. MODEL INFORMATION

MODELS WITH 5 DEGREE SLOPPY GROUND
- Rcc model with 5degree slope
- concrete Filled composite column model with 5degree slope
- Encased I-section composite column model with 5degree slope
- double skinned concrete filled steel tubular (DSCFT) columns model with 5degree slope

MODELS WITH 10 DEGREE SLOPPY GROUND
- Rcc model with 10degree slope
- concrete Filled composite column model with 10-degree slope
- Encased I-section composite column model with 10-degree slope
- double skinned concrete filled steel tubular (DSCFT) columns model with 10-degree slope

MODELS WITH 15 DEGREE SLOPPY GROUND
- Rcc model with 15degree slope
- concrete Filled composite column model with 15degree slope
- Encased I-section composite column model with 15degree slope
- double skinned concrete filled steel tubular (DSCFT) columns model with 15degree slope

MODELS WITH 20 DEGREE SLOPPY GROUND
- Rcc model with 20-degree slope
- concrete Filled composite column model with 20-degree slope
- Encased I-section composite column model with 20-degree slope
- double skinned concrete filled steel tubular (DSCFT) columns model with 20-degree slope

MODELS WITH 25 DEGREE SLOPPY GROUND
- Rcc model with 25degree slope
- concrete Filled composite column model with 25degree slope
- Encased I-section composite column model with 25degree slope
- double skinned concrete filled steel tubular (DSCFT) columns model with 25degree slope

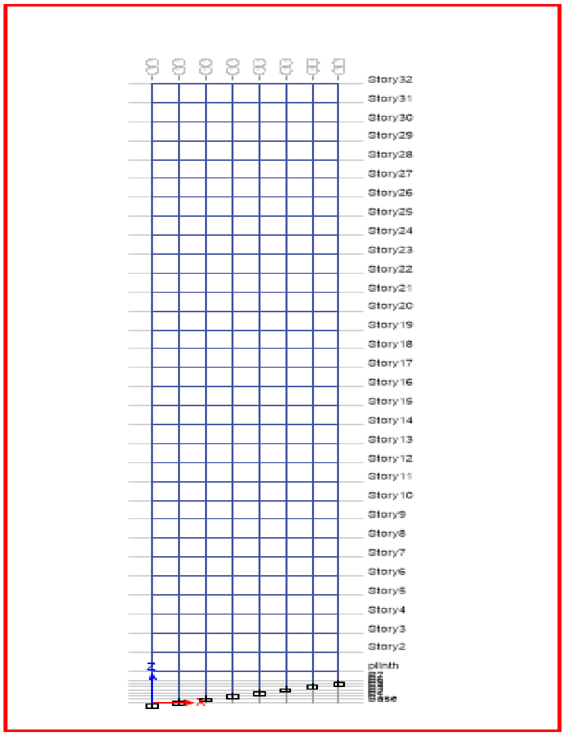


Figure 1 elevation view of g+30 with 5-degree slope in Etabs

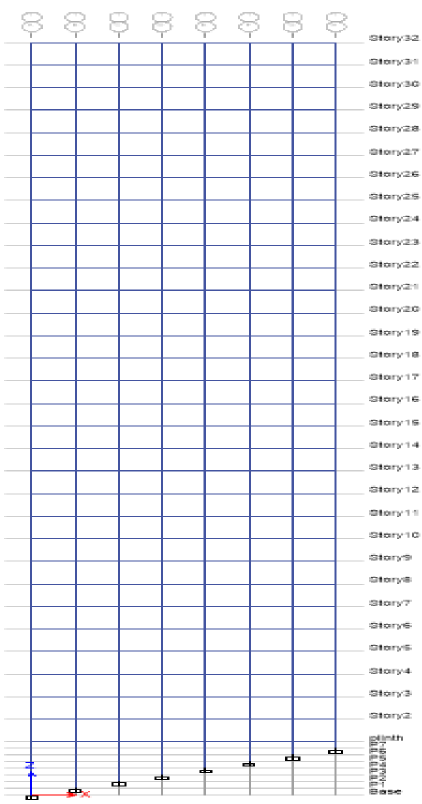


Figure 2: elevation view of g+30 with 10-degree slope in Etabs

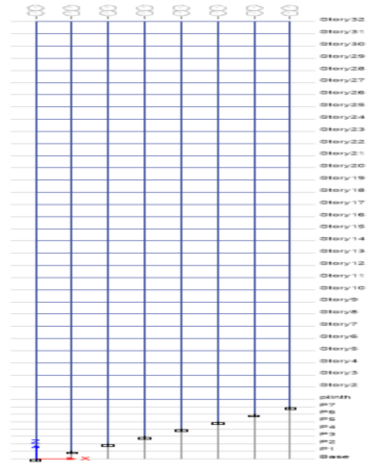


Figure 3 elevation view of g+30 with 15-degree slope in Etabs

Figure 4 elevation view of g+30 with 20-degree slope in Etabs

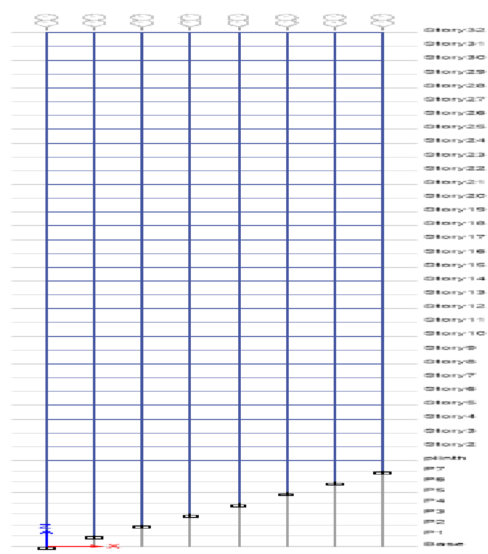


Figure 5 elevation view of g+30 with 20-degree slope in Etabs.

IV. RESULTS AND DISCUSSION FOR ZONE 5

STORY DISPLACEMENT RESULTS FOR 5 DEGREE SLOPE

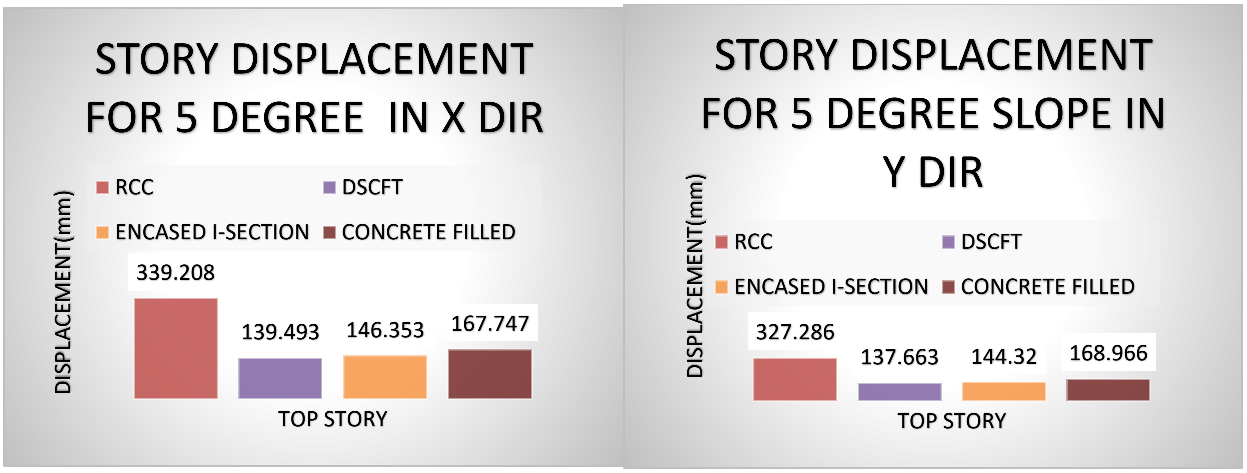


Figure 6: Story Displacement in X& Y-Dir. for G+30 with 5 Degree Slope of Ground

RESULTS FOR G+30 STORY WITH 10 DEGREE SLOPE

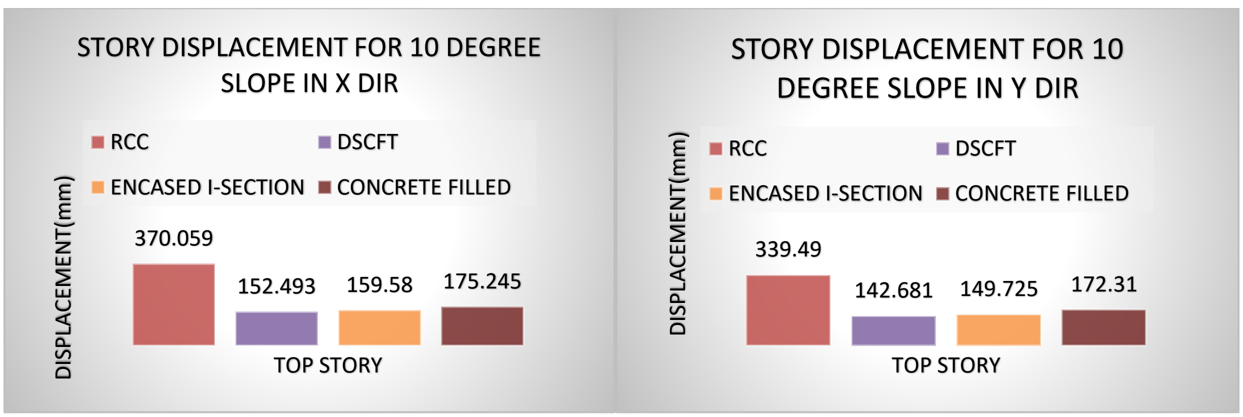


Figure 7: Story Displacement in X& Y-Dir. for G+30 with 10 Degree Slope of Ground

STORY DISPLACEMENT FOR G+30 STORY WITH 15 DEGREE SLOPE

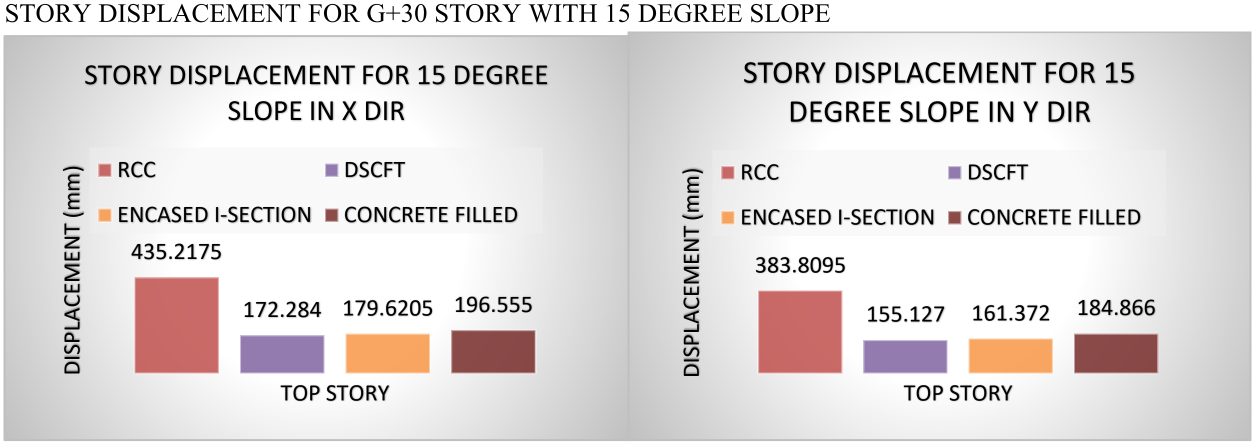


Figure8: Story Displacement in X& Y-Dir. for G+30 with 15 Degree Slope of Ground

STORY DISPLACEMENT FOR G+30 STORY WITH 20 DEGREE SLOPE

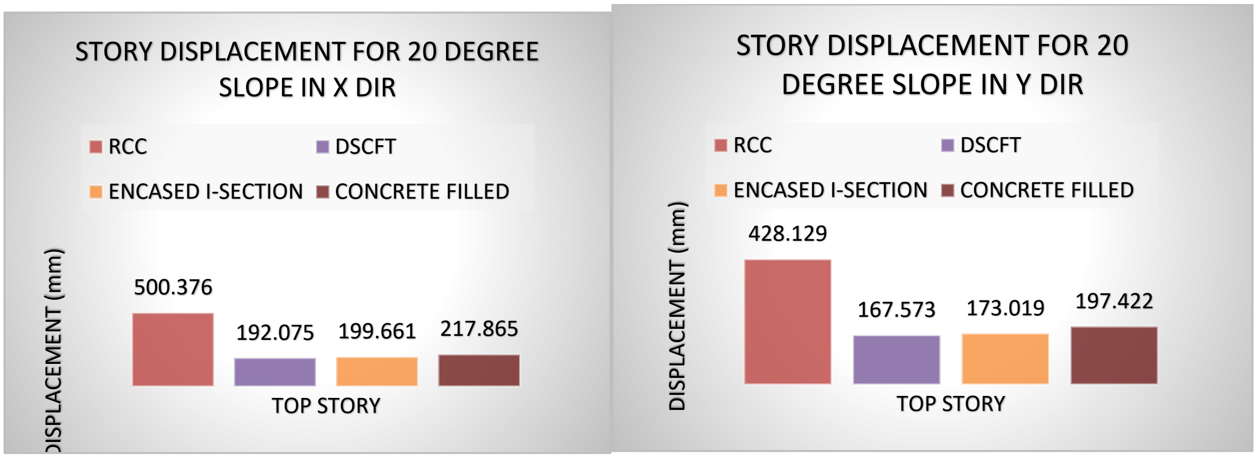


Figure 9: Story Displacement in X& Y-Dir. for G+30 with 20 Degree Slope of Ground

STORY DISPLACEMENT FOR G+30 STORY WITH 25 DEGREE SLOPE

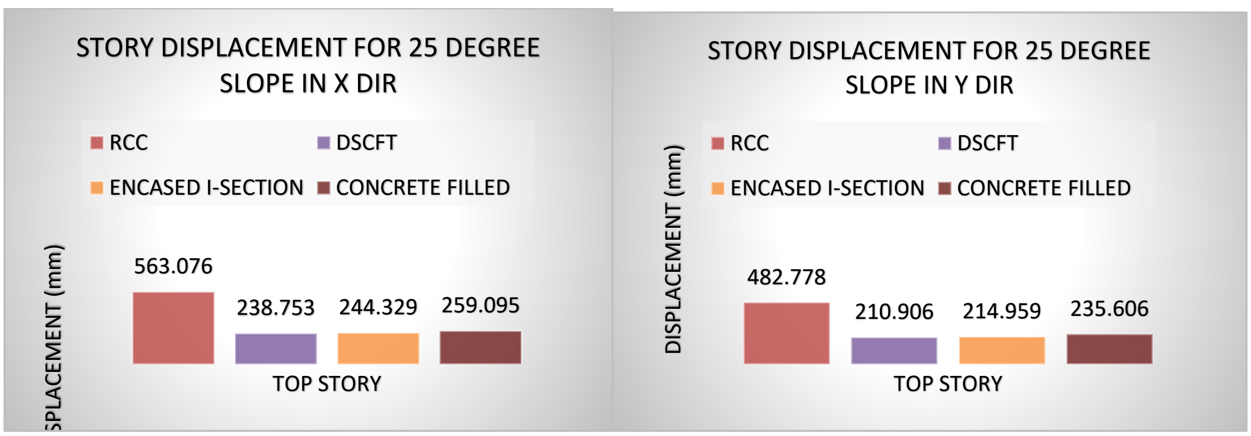


Figure 10: Story Displacement in X& Y-Dir. for G+30 with 25 Degree Slope of Ground

V. RESULTS AND DISCUSSION FOR ZONE 4

STORY DISPLACEMENT RESULTS FOR 5 DEGREE SLOPE

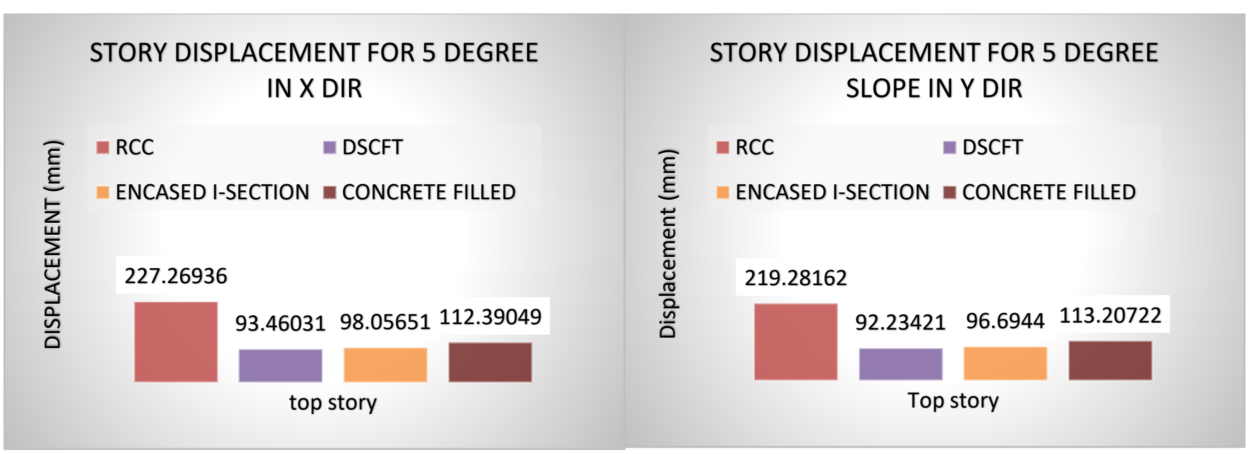


Figure 11: Story Displacement in X& Y-Dir. for G+30 with 5 Degree Slope of Ground

RESULTS FOR G+30 STORY WITH 10 DEGREE SLOPE

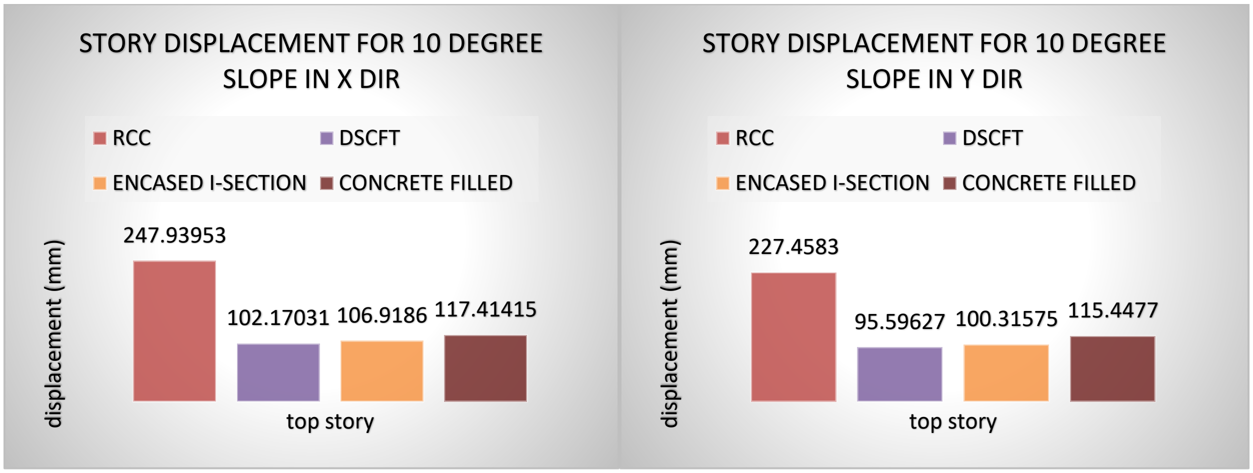


Figure 12: Story Displacement in X& Y-Dir. for G+30 with 10 Degree Slope of Ground

STORY DISPLACEMENT FOR G+30 STORY WITH 15 DEGREE SLOPE

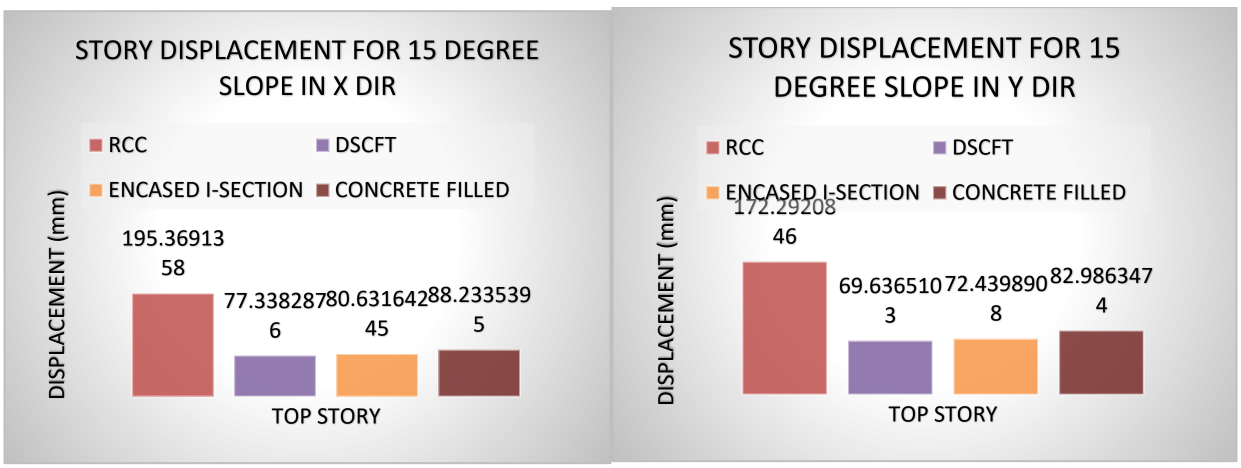


Figure13: Story Displacement in X& Y-Dir. for G+30 with 15 Degree Slope of Ground

STORY DISPLACEMENT FOR G+30 STORY WITH 20 DEGREE SLOPE

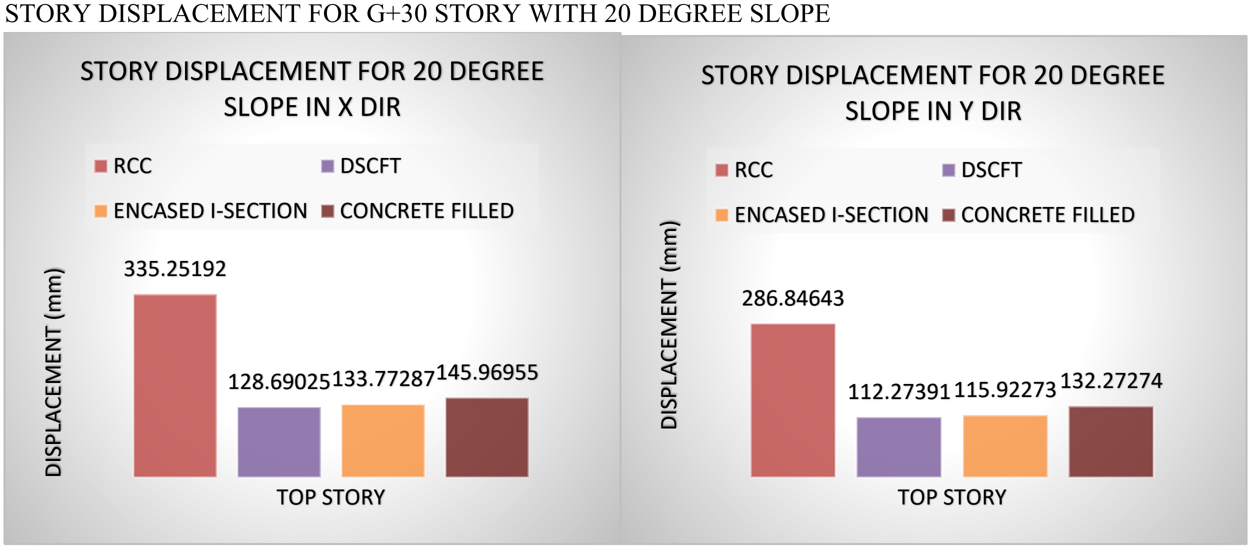
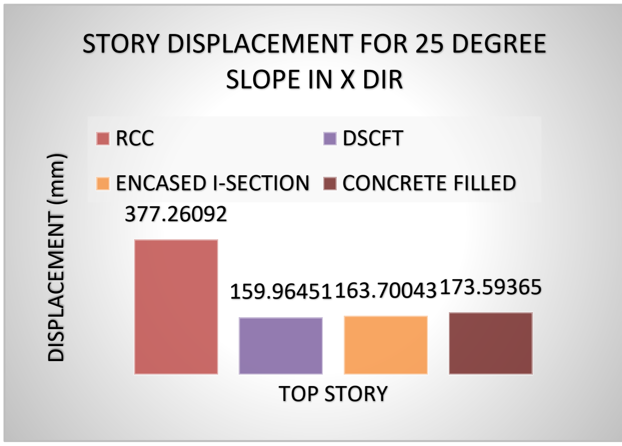


Figure 14: Story Displacement in X& Y-Dir. for G+30 with 20 Degree Slope of Ground

STORY DISPLACEMENT FOR G+30 STORY WITH 25 DEGREE SLOPE



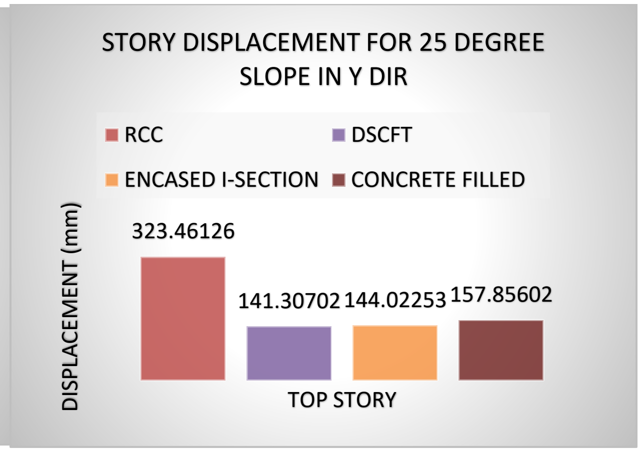


Figure 15: Story Displacement in X& Y-Dir. for G+30 with 25 Degree Slope of Ground

VI. CONCLUSION

1. DSCFT columns exhibit excellent structural performance due to their unique composite configuration, combining the strength and ductility of steel with the stiffness and energy absorption capacity of concrete. The double-skin design further enhances stability by reducing the effective slenderness of the column, leading to better resistance against lateral displacements. This makes DSCFT columns highly suitable for high-rise and heavily loaded structures.
2. The double-skin design of Double-Skinned Concrete-Filled Steel Tubular columns provides enhanced stiffness by increasing the cross-sectional moment of inertia and offering confinement to the concrete core.
3. The composite action between steel and concrete results in a stiffer system that resists lateral deformation more effectively, leading to a shorter time period.
4. The reduced flexibility of the Double-Skinned Concrete-Filled Steel Tubular column ensures better dynamic performance under lateral loads such as wind and earthquakes, making it highly suitable for high-rise structures.
5. Encased columns benefit from the synergy between the steel core and the surrounding concrete. The steel core provides excellent axial load capacity, while the concrete encasement improves buckling resistance and stiffness. Although not as effective as Double-Skinned Concrete-Filled Steel Tubular columns, encased columns provide a good balance between structural performance and ease of construction, making them a practical choice for medium-rise structures or applications requiring moderate lateral load resistance.
6. Encased columns benefit from the steel core, which significantly increases the stiffness of the system. The surrounding concrete further improves buckling resistance and stiffness, leading to a reduction in the time period
7. Filled box tube columns consist of a hollow steel tube filled with concrete, offering a combination of high axial strength and moderate stiffness. While effective, their performance is slightly lower than Double-Skinned Concrete-Filled Steel Tubular and encased columns due to the absence of the additional confinement effects provided by double skins or encasement. This makes filled box tube columns a cost-effective alternative for structures where moderate reductions in lateral displacement are acceptable.
8. Filled box tube columns achieve increased stiffness due to the composite action between the steel tube and the concrete core. However, the stiffness enhancement is slightly lower compared to Double-Skinned Concrete-Filled Steel Tubular and encased columns due to the absence of additional confinement mechanisms.

VII. FUTURE SCOPE

• Including flexible foundation and soil behavior will provide a better understanding of slope-induced amplification effects.

• Future studies can evaluate performance under Immediate Occupancy, Life Safety, and Collapse Prevention levels.
• Studies can explore optimized wall thickness, length, and placement for improved cost–performance balance.
• Research may extend to composite columns, steel–concrete hybrid walls, and outrigger–belt systems to enhance stability on sloping ground.
• Variation in floating column locations and transfer system types can be analyzed for more robust conclusions.

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