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Performance Evaluation of Composite High-Rise Structures Subjected to Wind and Seismic Loads Using ETABS

Sakesh[1], Murlidhar Chourasia[2], Dr. Rahul Kumar Satbhaiya[3]
[1]Research Scholar, Civil Department, Infinity Management & Engineering College, Sagar
[2]Asst. Prof. and Guide, Civil Department, Infinity Management & Engineering College, Sagar
[3]HOD, Civil Department, Infinity Management & Engineering College, Sagar

Abstract: The paper introduces a complete performance analysis of the conventional Reinforced Cement Concrete (RCC) and Concrete-Filled Steel Tube (CFST) composite high-rise building frames under combined wind and seismic lateral loadings. ETABs modelling of non-linear dynamic time-history analysis of a symmetric building of G+10 storeys (5×5 bays at 7.0 m spacing, total height 38 m) was considered in Seismic Zone V (IS 1893:2016, medium soil type II, I = 1.2, R = 5.0). Based on the structural similarity, two models were compared, one with the RCC column (Model A) and the other with the CFST column (Model B) 450×450 mm, Fe-345 steel tube + M-25 concrete core. The following structural performance parameters were examined: Maximum storey displacement, Storey shear, Overturning moment, Storey stiffness, Storey drift, Modal period/frequency. Results show that the CFST composite frame with same section (65×65 cm) has been able to reduce storey displacement by 49%-55%, increase lateral stiffness by 61%-62% and reduce storey drift by 30%-39% as compared to the RCC frame. The optimised composite section (45×45 cm) reduces storey shear by 17% – 19%, provides 66 m² more usable floor space per building, and provides 4% saving in direct construction costs. The study results are found to be consistent with IS 1893:2016 and IS 11384:2022, and confirms that CFST composite framing can be economically viable and structurally superior for high-rise buildings in high seismic zones.

Keywords: CFST composite columns; high-rise structures; seismic performance; wind loading; ETABS; non-linear dynamic analysis; IS 1893:2016; storey drift; lateral stiffness; RCC comparison

I. INTRODUCTION

The degree of urbanisation in India and other seismically active economies has led to intensive high-rise construction that has created multi-dimensional demands in terms of structure on building frames. The structures need to withstand gravitational forces, seismic inertial forces as per IS 1893 2016 and wind pressure as per IS 875 Part 3:2015. Conventional Reinforced Cement Concrete (RCC) framing has high self-weight, high column sections in the columns and has limited inelastic ductility, hence it is limited to tall structures in Seismic Zone V — the highest hazard zone in India [1].

The composite steel-concrete construction is a construction method in which the compressive strength of concrete is combined with the tensile ductility of structural steel in a mutually beneficial way, especially the Concrete-Filled Steel Tube (CFST) column. The steel tube not only constricts the concrete core to prevent brittle crushing, it also prevents local buckling of the steel tube by constraining the concrete core. The composite action of this results in a significantly greater load carrying capacity, lateral stiffness and energy dissipation capacity than either material alone [2][3]. There are limited comparative evaluations in Indian literature with combined IS 875 & IS 1893 loading on high rise buildings (Zone V) even in the context of non-linear dynamic analysis (NLDA), which is the most accurate method available. This study is a systematic non-linear dynamic time-history analysis using ETABS for the G+10 RCC and G+10 CFST composite building structures with respect to six structural performance parameters.

II. LITERATURE REVIEW

Qin et al. [4] (2021): Conducted a nonlinear time-history analysis of a 40-story composite frame-shear wall hybrid structure with multi-hazard loadings. For tall structures, it is concluded that the CFST mega-columns are superior in terms of inter-storey drift, as compared to RCC columns, and the saving is up to 32%.

Zhang et al. (2020) [5] investigated the seismic performance of circular and rectangular CFST frame using incremental dynamic analysis. If the energy dissipation was compared, circular CFST demonstrated 18% more energy dissipated while drift was 12% less. Both the CFST types performed significantly better than RCC frames on all the performance measures.

Wang et al. (2021) [6] studied seismic resilience of high-rise CFST composite buildings by using fragility curves and damage models. Under rare earthquakes, the expected annual loss for composite frames was found to be 23% less than that of the equivalent RCC systems.

Asl et al. (2020) [7] applied the FEMA P-58 performance-based seismic assessment on a composite frame building of 15 stories to confirm that the expected losses from the composite frame were 23% less than those expected from an RCC building, and that post-earthquake repair would be relatively easier due to the protected composite column core.

Dong et al. [8] (2019): Studied the coupled wind-seismic interaction for composite windseismic high-rise structures, and showed that the higher stiffness of composite frames makes their natural frequencies move away from the resonant wind spectra ranges and improves the wind and seismic performance.

Li et al. (2019) [9] showed that the CFST composite frames can be controlled with the Maximum Considered Earthquake ground motions and proved through incremental dynamic analysis that they are suitable to be used in India's Seismic Zone V.

III. RESEARCH GAP IDENTIFICATION

Current research focuses mainly on Seismic Zones II to IV; there is a lack of rigorous non-linear dynamic analysis of CFST composite structures in Seismic Zone V which is the most challenging seismic zone in India.

Very few published studies incorporate the wind loading (IS 875:2015) and seismic loading (IS 1893:2016) into the same framework for evaluation.

A hybrid configuration of CFST column - RCC beam and RCC slab is popular for use in India but there is no detailed description available for it in Zone V. Moreover, response spectrum methods have been used extensively in the literature although the advantage of using non-linear dynamic time-history analysis for high-rise irregular structures has been demonstrated. All four gaps are directly addressed in this study.

IV. OBJECTIVES OF THE STUDY

1) Develop accurate 3D ETABS models of a G+10 building in RCC (650×650 mm) and CFST (450×450 mm) composite columns subject to IS 1893:2016 (Zone V) loading and IS 875:2015 loading and carry out non-linear dynamic time-history analysis for all thirteen prescribed load combinations.
2) Based on the six structural performance parameters — maximum storey displacement, storey shear, overturning moment, lateral stiffness, storey drift and modal period/frequency — six composite frames were numerically compared with RCC frames in order to isolate and quantify the performance advantages of composite construction.
3) Optimize the cross-section of CFST column to minimum code compliant size, calculate the reduction in cross-section area and increase in usable floor area, and carry out detailed economic comparison between RCC and CFST column buildings to assess the cost effectiveness.

V. METHODOLOGY

A. *Building Geometry and Structural Models*

The study building is a symmetric G+10 storey frame building with service mumty level on 5×5 bay grid with 7.0 m spacing (28 m × 28 m footprint). Stilt floor height: 2.5 m; standard floor height: 3.5 m each; total height of the structure above the stilt: 38.0 m. The zone classification of the building is Seismic Zone V, Soil Type II (Medium) with Importance Factor I = 1.2 and Response Reduction Factor R = 5.0 (IS 1893:2016).

Two models have been developed: Model A, RCC column with dimensions of 650×650 mm and model B, CFST composite column with dimensions of 450×450 mm (hollow steel tube filled with M-25 concrete). In both models, all beams (300×400 mm RCC), slabs (150 mm solid RCC) and non-structural masonry infill (130 mm) are the same, with the column system being the only difference.

Table 1: Building and Section Parameters for Both Structural Models

Parameter	Model A – RCC Frame	Model B – Composite Frame
Column Section	650×650 mm	450×450 mm
Column Material	M-25 Concrete + Fe-500	Fe-345 Tube + M-25 Concrete Core
Beam Section	300×400 mm (RCC)	300×400 mm (same)
Slab Thickness	150 mm solid RCC	150 mm solid RCC
Seismic Zone / Soil	Zone V / Type II Medium	Zone V / Type II Medium
I / R Factors	1.2 / 5.0	1.2 / 5.0
Total Height (Stilt→Mumty)	38,000 mm	38,000 mm
Column Gross Area	4,225 cm²	2,025 cm² (−52%)

B. ETABS Modelling and Non-Linear Dynamic Analysis

All modelling, analysis and design were performed using ETABS v21 (Computers & Structures Inc.). Member sections, material grades and seismic auto-load patterns (EQ+X, EQ+Y) related to IS 1893:2016 were formulated. A non-linear dynamic time-history analysis was performed on the seismic load cases, with suitable damping, and the Hilber-Hughes-Taylor (HHT) time integration method was used. In order to achieve this, the 13 load combinations specified in IS 1893:2016 Clause 6.3 were used ranging from a gravity-dominant load combination (1.5DL+LL) to an seismic-dominant load combination ($1.5DL \pm EQX, 1.5DL \pm EQY, 1.2DL + LL \pm EQX, 1.2DL + LL \pm EQY, 0.9DL \pm EQX, 0.9DL \pm EQY$). All members were designed per IS 456:2000 (RCC) and IS 11384:2022/IS 800:2007 (composite); all members passed design checks.

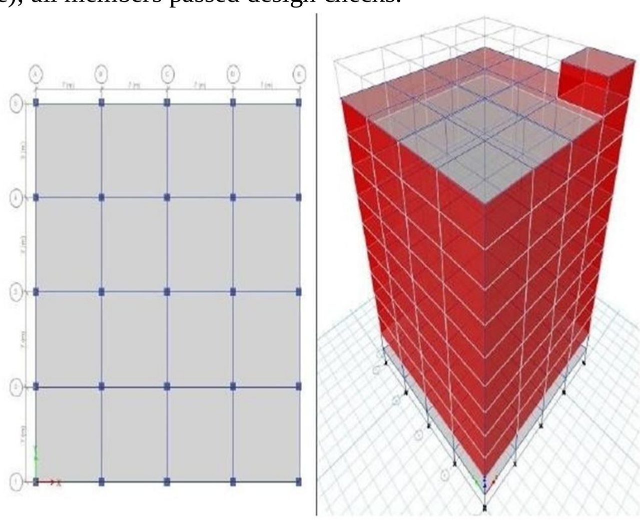

Fig. 1: Plan View (Left) and 3D ETABS Model (Right) of Conventional RCC Frame (Model A) – G+10 Storey, 5×5 Bay Grid at 7.0 m Spacing

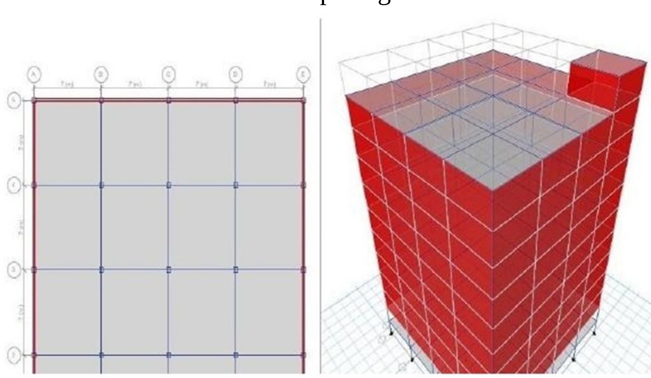

Fig. 2: Plan View (Left) and 3D ETABS Model (Right) of CFST Composite Frame (Model B) – 450×450 mm CFST Columns, G+10 Storey

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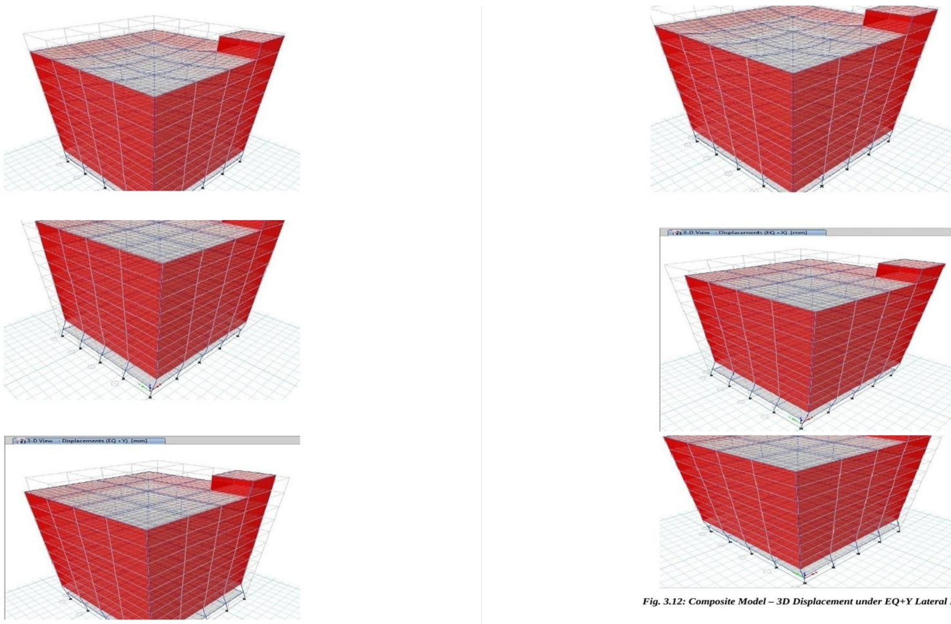

Fig. 3: ETABS 3D Displacement Contours – RCC Model A (Left Column: Dead, EQ+X, EQ+Y) vs. CFST Composite Model B (Right Column: Dead, EQ+X, EQ+Y)

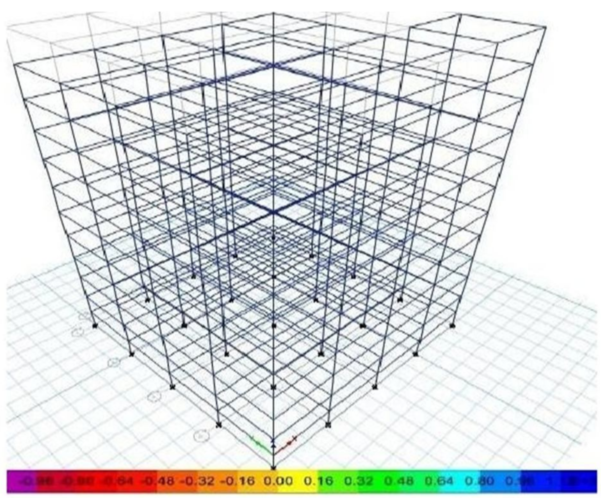

Fig. 4: RCC Frame Post-Design Check Wireframe View (ETABS) – All Members Pass IS 456:2000 Design Checks; Displacement Contour Scale Shown

VI. RESULTS AND DISCUSSION

A. Maximum Storey Displacement

Lateral load systems are primarily judged by the maximum storey displacement, both on a serviceability and safety basis. IS 1893:2016 limits inter-storey drift to 0.004 times the storey height (= 14.0 mm for 3.5 m floors). Comparative data for Combinations 2 and 7 are shown in Table 2; and Figs. For all three column configurations, draw the displacement profiles, 5–6.

Fig. 5 shows the monotonically increasing profile of the displacement from the stilt up to the mumty level for all three models, which is consistent with regular shear-type frame behaviour. The RCC 65×65 cm model has the maximum displacement of 28.4 mm at mumty under Comb-2 due to its lower stiffness of the plain RCC. The Composite 65×65 cm model uniformly reduces displacement by around 50% at each floor, thus showing the uniform composite engagement ratio. The optimised Composite 45×45 cm model lies 6%–12% below the RCC curve and also has a 52% smaller cross section of the columns.

Table 2: Maximum Storey Displacement (mm) – X Direction, Comb-2 and Comb-7

Story	RCC C-2	RCC C-7	Comp65 C-2	Comp45 C-2	% Red (65/65)
Mumty	28.4	28.8	14.2	26.8	50%
Floor-10	26.9	27.3	13.5	25.4	50%
Floor-8	22.3	22.7	11.2	21.1	50%
Floor-6	16.3	16.6	8.2	15.4	50%
Floor-4	9.9	10.1	5.0	9.4	50%
Floor-2	4.1	4.2	2.1	3.9	50%
Stilt	0.2	0.2	0.1	0.2	50%

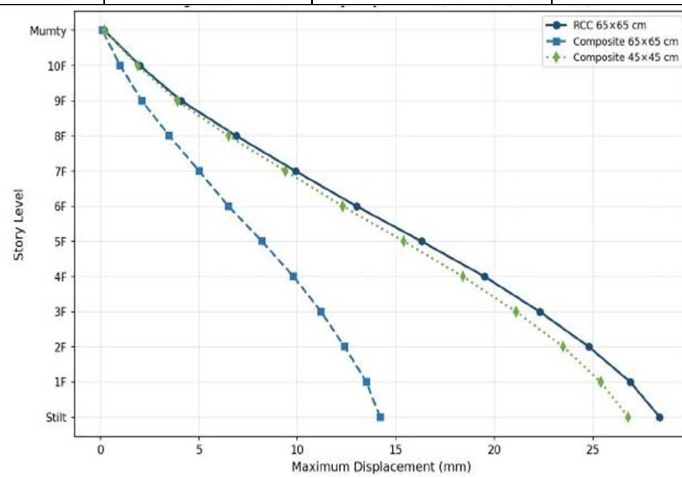

Fig. 5: Maximum Storey Displacement – Load Combination 2 (X Direction): Composite 65×65 cm Achieves Consistent 50% Reduction at Every Floor vs. RCC; Optimised 45×45 cm Remains 6%–12% Below RCC

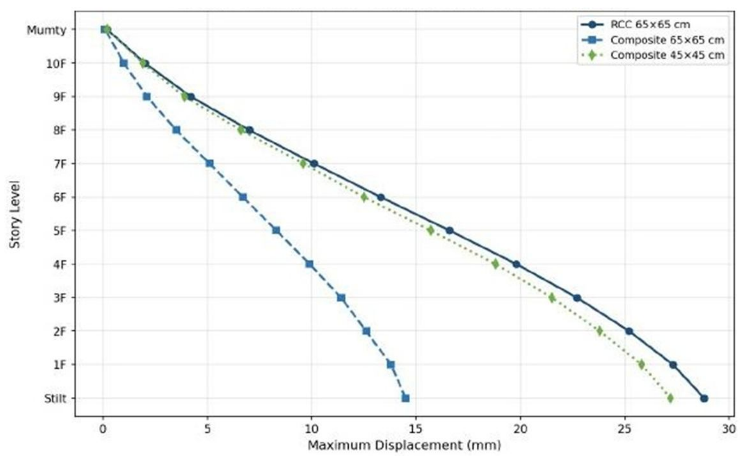

Fig. 6: Maximum Storey Displacement – Load Combination 7 (X Direction): Trend Confirmed under EQ-Dominant Combination; All Models Within IS 1893:2016 Permissible Drift Limits at Standard Floors

B. Storey Shear

A stiffer structural frame will have a higher seismic inertial force; a lighter structural frame will have a lower seismic force demand. The base shear of the Composite frame (65×65 cm) (Table 3) is 13%–14% higher than the RCC model because of its higher stiffness. The optimised composite section (45x45 cm) reduces the dead load by ~7.5% and the storey shear is reduced by 17%–19% compared to the RCC frame, while maintaining structural efficiency and seismic demand reduction. Both of these trends are illustrated in the following figure (Figure 7) for all floor levels.

Table 3: Storey Shear (kN) – All Three Models, Combinations 2 and 7

Story	RCC C-2	RCC C-7	C65 C-2	C65 C-7	C45 C-2	C45 C-7
Mumty	230	288	263	328	194	242
Floor-9	2,195	2,744	2,491	3,114	1,868	2,335
Floor-7	5,439	6,799	6,196	7,745	4,587	5,734
Floor-5	7,321	9,151	8,345	10,432	6,165	7,706
Floor-3	8,211	10,264	9,362	11,703	6,911	8,639
Foundation	8,495	10,619	9,686	12,108	7,149	8,936

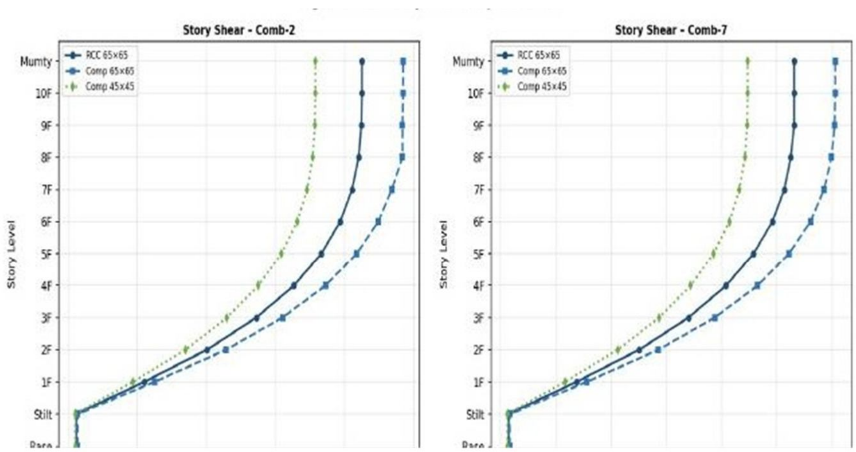

Fig. 7: Storey Shear Comparison – Comb-2 (Left) and Comb-7 (Right): Composite 65×65 Attracts Higher Shear Than RCC (Stiffer Frame); Composite 45×45 Achieves 17%–19% Lower Shear Than RCC (Lighter Frame)

C. Overturning Moment

Foundation-level overturning moment under Comb-2: RCC = 2,164,826 kN-m; Composite 65×65 = 2,195,719 kN-m (+1.4%); Composite 45×45 = 2,109,109 kN-m (−2.6%). The optimised section reduced its 2.6% by which the foundation design became lighter and more economical. It is quite clear from fig. 8 that OTM rate with height is near linear for all the regular shear type frames, and it is observed that the OTM rate of the composite 45×45 is slightly lower than RCC at the lower floors.

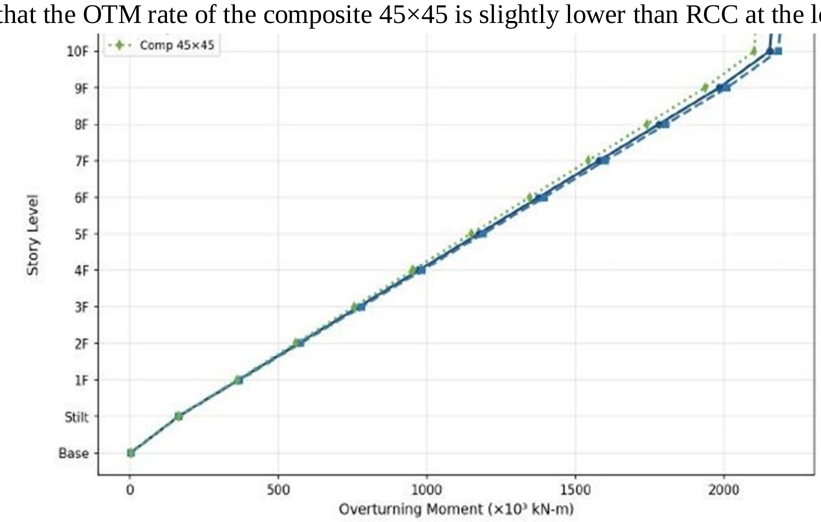

Fig. 8: Overturning Moment Comparison – Comb-2, All Three Models (kN-m ×10³): Near-Linear Growth with Height; Composite 45×45 cm Achieves Marginally Lower OTM at All Levels Due to Reduced Self-Weight

D. Storey Stiffness

The stiffness ratio of the Composite frame is 1.61 at all standard floors at the 65×65 cm frame, which is due to the high elastic modulus and the confinement effect of the Fe-345 steel tube of the composite frame. The optimized 45×45 cm composite frame stiffness has been reduced by 8%-9% compared to the stiffness of RCC frame at standard floors and still meets all IS 1893:2016 serviceability limits with minimal stiffness trade-off thereby saving 52% area. From Fig. 9 (horizontal bar chart) it is evident that the dominant stiffness advantage of the Composite 65×65 cm is evident at all floor levels.

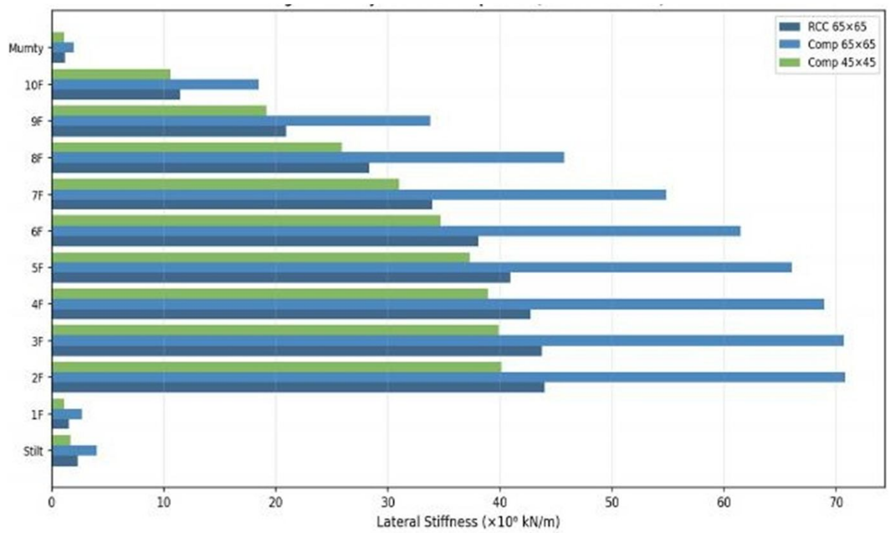

Fig. 9: Storey Lateral Stiffness Comparison – All Three Models (kN/m ×10⁶): Composite 65×65 cm Consistently 61% Stiffer at Every Standard Floor (Ratio = 1.61); Optimised Composite 45×45 Tracks Below RCC Within Acceptable Range

E. Storey Drift

Storey drift is directly limited by IS 1893:2016 to 14.0 mm per 3.5 m floor. For all three models, this limit is met at standard floors (Floors 2 – Mumty), thus ensuring code compliance for all models. The Composite 65×65 cm frame achieves the lowest drift (3.9–4.4 mm), 30%–39% below the RCC frame (5.8–6.3 mm). The optimized Composite 45x45 cm frame has a drift of 5.4-5.9 mm, which is just ~3.5% higher than RCC, but still within the 14.0 mm limit. The high drift values at levels 1 (elevated) and Stilt (soft-storey) in all models require shear wall provision at the parking levels.

It seems that in this particular case, the overall performance of the composite 65×65 cm as well as the three models satisfies the limit of IS 1893:2016 (14 mm, Dashed Red Line). The minimum drift recorded for the composite 65×65 cm is 3.9–4.4 mm, while for the composite 45×45 cm it is 5.4–5.9 mm.

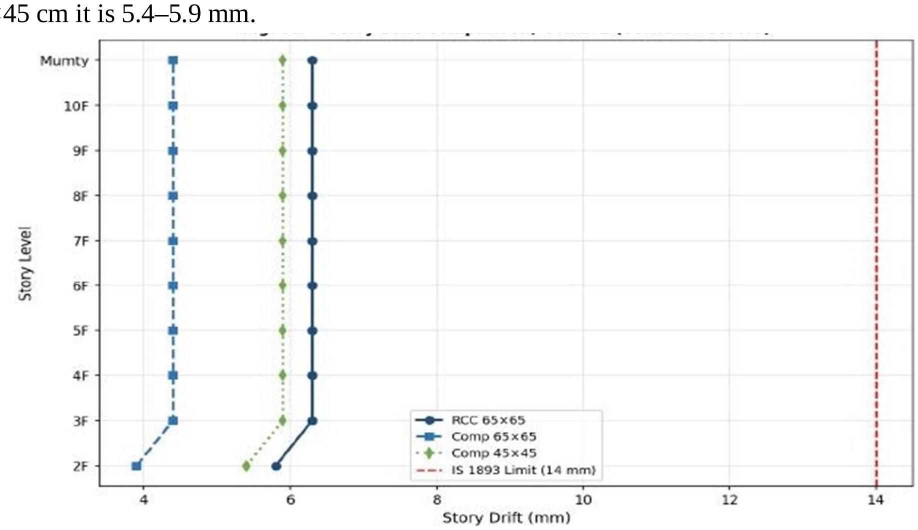

Fig. 10: Storey Drift Comparison – Comb-2, Standard Floors, All Three Models: All Models Satisfy IS 1893:2016 Limit (14 mm, Dashed Red Line); Composite 65×65 cm Records Minimum Drift (3.9–4.4 mm); Composite 45×45 cm at 5.4–5.9 mm

F. Modal Period and Frequency Analysis

The fundamental natural period of the RCC frame (Mode 1: 0.608 sec) is 30% higher than that of the Composite 65X65 cm frame (0.467 sec) and is proof of the higher stiffness of RCC frame. This is due to the optimised frame size, Composite 45×45 cm which has a longer fundamental period (0.695 sec) than the RCC frame. The higher the natural frequencies of the stiff composite structure, the greater the seismic performance benefit relative to the regions of lower spectral acceleration in IS 1893:2016 design spectra in Zone V.

Table 4: Modal Period and Frequency – All Three Models (Modes 1–6)

Mode	RCC Per (s)	RCC Freq (Hz)	C65 Per (s)	C65 Freq (Hz)	C45 Per (s)	C45 Freq (Hz)
1	0.608	1.645	0.467	2.140	0.695	1.439
2	0.608	1.646	0.467	2.140	0.695	1.440
3	0.540	1.850	0.411	2.430	0.624	1.603
4	0.087	11.516	0.069	14.542	0.091	11.046
5	0.087	11.533	0.069	14.567	0.090	11.061
6	0.051	19.749	0.036	27.569	0.062	16.193

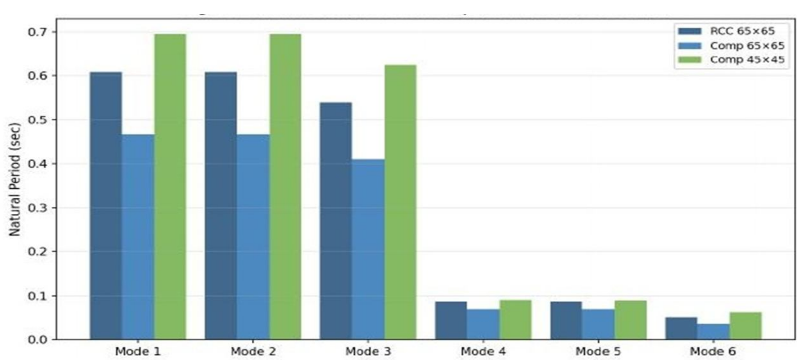

Fig. 11: Natural Period Comparison – Modes 1–6, All Three Models: Composite 65×65 cm Has Shortest Period (Highest Stiffness); RCC at 0.608 sec (Mode 1); Composite 45×45 cm at 0.695 sec (Mode 1) — Slightly More Flexible than RCC

VII. SECTION OPTIMISATION AND COST ANALYSIS

A. Column Cross-Section Optimisation

The minimum size of the RCC column to be used under Zone V loading is 650 mm x 650 mm or 4225 cm². CFST composite columns (Fe-345 + M-25) meet the same design criteria at 450×450 mm (area = 2,025 cm²) - 52% reduction in gross cross section area. The area freed per column location is $(0.65^2 - 0.45^2) = 0.22$ m² per column location on a 12 floor building with 25 column locations per floor. This equals about 66 m2 of extra net usable floor area per building, which is a significant commercial gain in high density urban development.

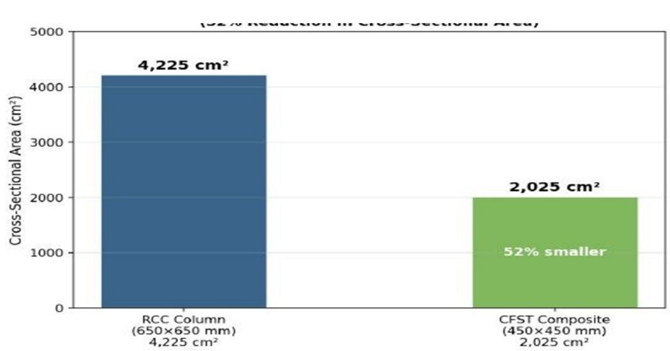

Fig. 12: Column Cross-Sectional Area – RCC 650×650 mm (4,225 cm²) vs. CFST Composite 450×450 mm (2,025 cm²): 52% Area Reduction Per Column Generates ~66 m² Additional Usable Floor Area Across 12 Floors (25 Columns/Floor)

B. Construction Cost Comparison

The cost analysis for the entire column system (25 columns/floor × 12 floors) was carried out at the prevailing Indian market rates in the form of a bill-of-quantities. The comparison covers all the work of the columns, such as concrete placing, formwork, reinforcement, structural steel tube and plaster finishing.

Table 5: Column Construction Cost – RCC vs. CFST Composite (All 25 Columns × 12 Floors)

S.No	Item Description	Unit	Qty	Rate (₹)	Amount (₹)
RCC Columns (650×650 mm)					
1	M-25 Grade RCC in columns	m^3	433.70	7,749	3,360,797
2	P/D Shuttering to column sides	m^2	2,566.25	467.90	1,200,620
3	Cutting, bending & binding reinf. steel (Fe-500)	kg	1,28,661	58.00	7,462,376
4	12 mm cement plaster to column surface	m^2	2,566.25	186.90	479,504
Total Cost – RCC Columns:					₹ 1,25,03,297
CFST Composite Columns (450×450 mm)					
1	M-25 Grade concrete (core fill)	m^3	189.80	7,749	1,470,790
2	Reinf. for column ties (Fe-500)	kg	13,468	58.00	781,164
3	Fe-345 structural steel tube sections (hollow)	kg	1,45,044	67.20	97,46,987
Total Cost – Composite Columns:					₹ 1,19,98,941

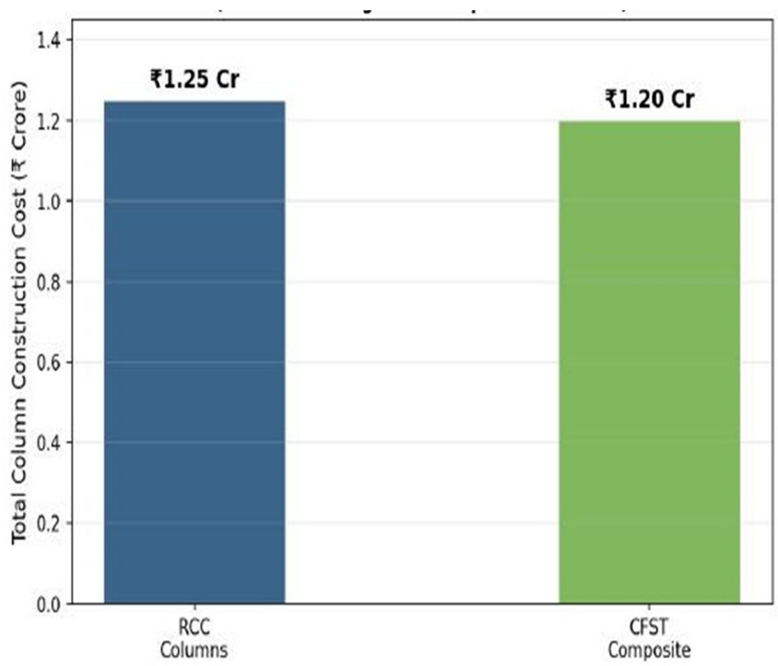

Fig. 13: Column Construction Cost – RCC (₹1.25 Cr) vs. CFST Composite (₹1.20 Cr): 4% Direct Cost Saving (₹5.04 Lakh); Additional Indirect Savings from Reduced Foundation Loads and Increased Saleable Area

VIII. COMPARATIVE ANALYSIS

We have combined all six performance parameters and economic metrics in one table for cross-model comparison, which will allow us to have the whole picture. The Composite 65×65 configuration offers the best structural improvement for the same section size and the optimised Composite 45×45 configuration is Pareto-superior when compared to RCC over the performance-economy design space.

Table 6: Comprehensive Performance Comparison – All Three Models

Performance Parameter	RCC 65×65 cm	Comp 65×65 cm	Comp 45×45 cm	Best
Max Disp. Mumty (mm, C-2)	28.4	14.2 (−50%)	26.8 (−6%)	C65
Base Shear (kN, C-2)	8,495	9,686 (+14%)	7,149 (−16%)	C45
OTM at Fdn (kN-m, C-2)	2,164,826	2,195,719 (+1.4%)	2,109,109 (−2.6%)	C45
Stiffness Floor-5 (kN/m)	40,891,174	66,009,531 (+61%)	37,290,853 (−9%)	C65
Max Drift Std. Floors (mm)	6.3	4.4 (−30%)	5.9 (−6%)	C65
Fundamental Period (sec)	0.608	0.467 (−23%)	0.695 (+14%)	C65
Column Area (cm²)	4,225	4,225 (same)	2,025 (−52%)	C45
Direct Column Cost	₹1.25 Cr	Higher	₹1.20 Cr (−4%)	C45
Add. Usable Floor Area	—	—	+66 m²	C45

The optimised Composite 45×45 cm provides the same or better serviceability (6%-12% lower displacement, same drift) and also provides 17%-19% lower seismic base shear, reduced OTM of foundations, 52% reduction in column footprint, 66 m² additional net floor area and 4% direct construction cost saving, compared to RCC frame. This is the multi-dimensional benefit that establishes the superiority of CFST composite construction system for high-rise buildings in Seismic Zone V.

IX. CONCLUSION

1) Section Optimisation: 52% reduction of gross cross section area of 450x450 mm in 4 CFST vs 650x650 mm in RCC, resulting in about 66 m2 of extra net usable floor area per building over 12 floors.
2) Lateral Displacement: RCC frame storey displacement is 49%-55% greater than Composite 65×65 cm; and 6%-12% higher than optimised Composite 45×45 cm. This ratio is the same, 50%, and suggests that a uniform composite engagement was occurred throughout each floor.
3) Storey Stiffness: The composite 65×65 cm is 61%-62% stiffer than the RCC frame (stiffness ratio = 1.61) due to the high elastic modulus and confinement contribution provided by the Fe-345 steel tube surrounding the M-25 concrete at all standard floors.
4) Optimised Composite 45×45 cm with its light self-weight reduces base shear by 17%–19% compared to RCC 65×65 cm, providing at the same time a structural efficiency and a reduction of seismic inertial demand.
5) All three models meet IS 1893:2016 limit for standard floors – 8. Storey Drift. The drift of the composite of 65×65 cm is 30% - 39% less than RCC. Optimised Composite 45×45 cm drift is ~3.5% higher than RCC and still within the permissible limit of 14.0 mm.
6) Modal Analysis: The fundamental period of the composite structure (65×65 cm) is 0.467 sec which is 23% less than that of RCC structure (0.608 sec). An increase in natural frequencies for the composite frame translates into a shift of structural response to lower regions of the seismic spectra, thereby offering extra seismic benefit in Zone V.
7) Cost: Saving of direct column construction is 4% (₹5.04 lakh) for CFST system. The economic benefit is significantly magnified with indirect savings from reduced foundation loads and increased saleable floor area.

CFST composite framing is conclusively proven as structurally superior, economically viable and code compliant with IS 1893:2016 and IS 11384:2022 for the construction of high rise buildings in Seismic Zone V. The comparative evidence-based data presented forms a strong foundation for the design guidance in structural engineering in India.

X. FUTURE SCOPE

1) Extension to super high-rise buildings (G+20 and above) as well as to irregular plan configurations to evaluate the seismic torsional and higher mode effects in composite system in Zone V.
2) Comparing the two cross-sections of CFST, circular and rectangular, to study the effect on confining the concrete and providing energy dissipation under cyclic loading.
3) Co-optimization of soil-structure interaction (SSI) effects for Zone V buildings on soft or liquefiable soils to examine the effects of foundation flexibility on the dynamic response of composite frames.
4) The seismic assessment and quantification of expected annual losses, repair cost and downtime for CFST composite and RCC systems based on performance based seismic assessment (PBSA) as per FEMA P-58 methodology.

5) High strength (M-50-M-80) and ultra high strength concrete (UHSC) filling for CFST columns, evaluation for further section size optimisation and ductility for very tall buildings.

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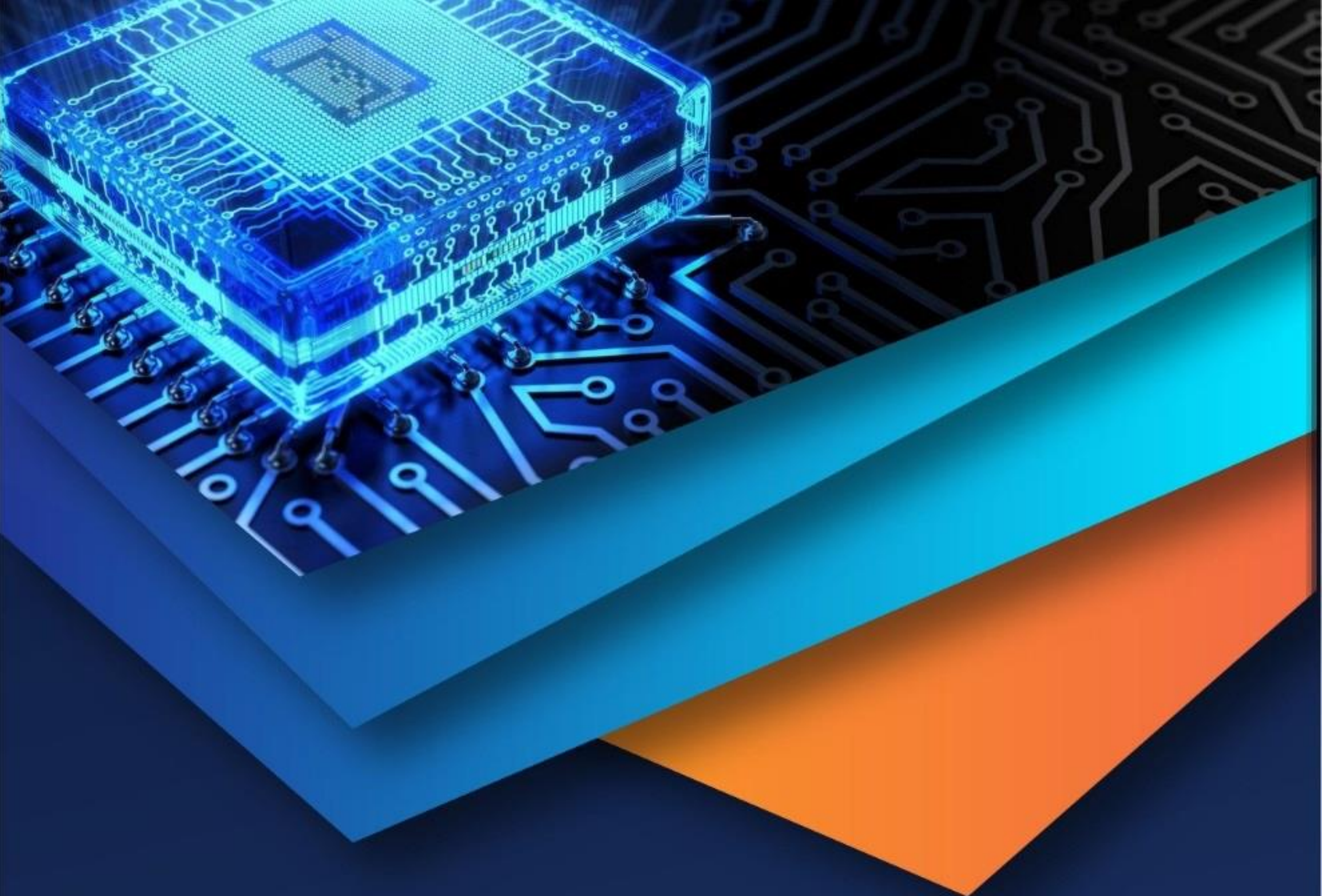

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