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Seismic Analysis of Multi-Storey Reinforced Concrete Buildings with Floating Columns: Structural Performance, Design, and Cost Assessment

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***Abstract:** In this paper, research on the structural behaviour of a G+2 reinforced concrete (RC) building both with and without floating columns (FC) subjected to seismic Zone II conditions in Mandideep, Bhopal (M.P.), India were carried out. The STAAD Pro V8i was used to achieve both the static (equivalent static method) and dynamic (response spectrum) analysis in accordance with the requirements of IS 1893 (Part 1): 2002, and the structural members were designed in accordance with the requirements of IS 456:2000. The major parameters considered are the displacement, bending moment, shear force, axial force, storey drift, peak storey shear, mode shapes and material cost. The findings indicate that floating columns present substantial structural anomalies: there is column movement by 61.8 percent, beam bending by 532 percent and base shear by 26.9 percent and the total cost of construction is 16.02 higher. The results are validated by benchmarking the findings with the results published in the recent past. The research provides a novel input to the existing literature through discussing an unsymmetrical plan with long-span transfer beam in the lowest Indian seismic zone - a set up which has not been represented in any literature.*

I. INTRODUCTION

Urban multi-storey buildings with open-ground floors are common where parking and commercial purposes are concerned but present severe seismic vulnerabilities. The total seismic base shear in a building is defined by the natural period of the building and the distribution of forces is controlled by mass and stiffness distribution as a function of height. The broken load lines, like floating columns, interrupt the direct line of load to the ground and form the so-called soft storey effect - a weaker lower storey prone to localized damage. This was demonstrated in the Bhuj earthquake of 2001 where a number of buildings that had floating columns or open ground floors were destroyed. A floating column (FC) is not a structural member that is extended up to the foundation. Rather, it is a product of a transfer beam, that transfers the point load concentration to the nearby ground columns. Although FCs allow large clearances, they create load anomalies which have a dramatic effect on seismic performance. The common floating column design with a transfer beam is shown in Figure 1.

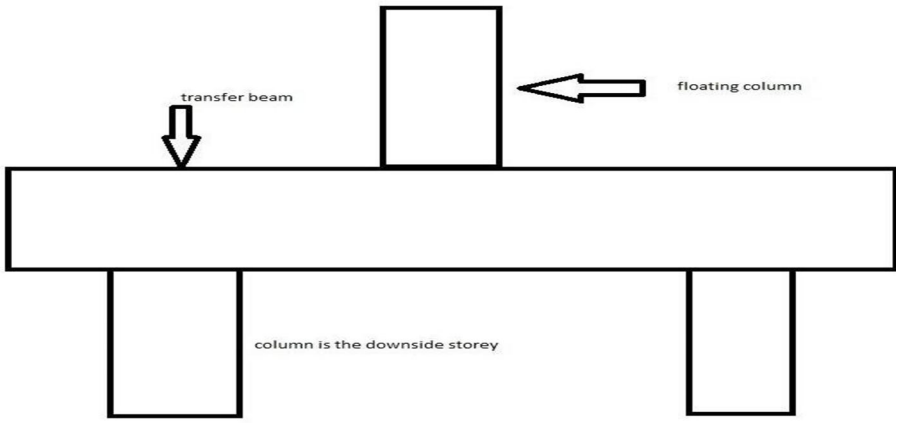


Figure 1: Floating column supported on a transfer beam

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According to the IS 1893 (Part 1): 2002, India is classified into four seismic zones (II -V). The structure under study is in zone II (zone factor = 0.10), which is the lowest classification of seismic. Nevertheless, the findings indicate that floating columns have high structural requirements even in low-seismicity areas.

II. LITERATURE REVIEW

Behera (2012) presented an example of the code written in the custom MATLAB FEM to demonstrate that the increase of ground floor columns size minimises the displacement and storey drift of FC buildings. Sekhar and Prasad (2014) conducted analysis of STAAD Pro which affirmed the high bending moments in supporting the beams with floating columns. Nonlinear pushover analysis undertaken by Kaveh and Fahimi-Farzam (2018) showed that centrally located FCs generate 23% more inter-storey drift than peripheral FCs, with the stiffness of transfer beams being important. On the five G+8 models, Patil and Kumbhar (2019) used ETABS 2016 and found that top-storey displacement had risen to 35% in FC buildings. The fragility curves developed by Sharma and Mungule (2020) proved that FCs in intermediate floors enhance the probability of damage at MCE-level. According to Rajput and Yadav (2022), STAAD Pro models with FCs have been found to reduce natural frequency by 18-24%. Mehta and Chauhan (2023) used FEMA P-58 and found that the expected annual losses in FC buildings were estimated to be 22 percent greater than in conventional ones.

Some of the gaps were identified: (i) symmetrical frames had been used in the previous literature; (ii) long-span transfer beam designs corresponding to Zone II had not been studied; (iii) the combination of the static-dynamic analysis with the IS 456:2000 design was scarcely studied. All these three gaps are taken care of in this research.

III. METHODOLOGY

The research makes a comparison between G+2 RC building frames with (FC) and without (WFC) floating columns under Zone II medium-soil seismic conditions according to the equivalent static method in IS 1893 (Part 1): 2002. This was analyzed in STAAD Pro V8i in the following order:

1) Determine geometry of 3D buildings (G+2 storey frame) 3D building geometry.
2) Assign material, section of members, support conditions and load cases.
3) Use: seismic zone (II) and medium soil parameters according to IS 1893 (Part 1): 2002.
4) Combine loads per IS 875 (Part V).
5) Compare and compare the WFC buildings and FC buildings both in STAAD Pro V8i.
6) Compare reinforcement and costs, design members per IS 456:2000..

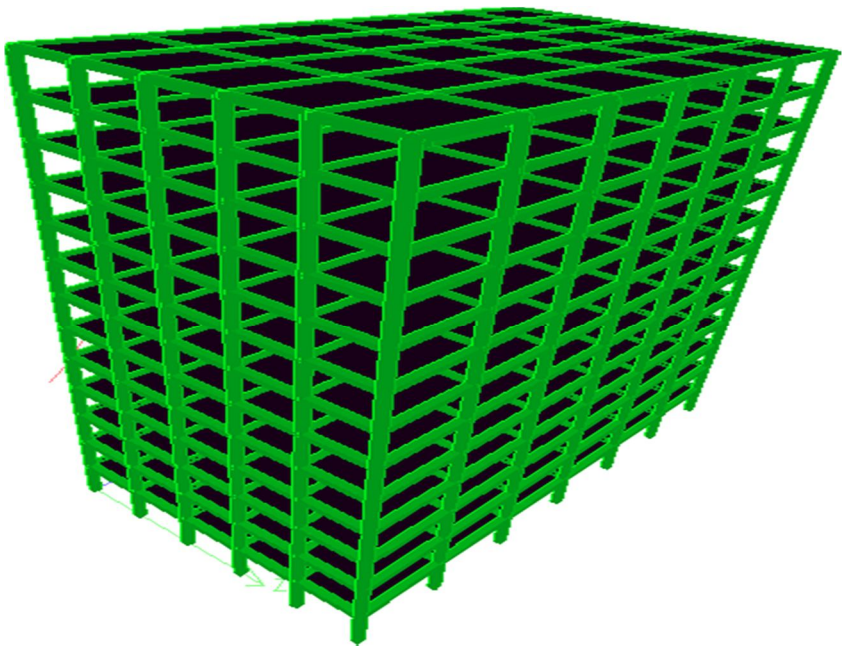


Figure 2: 3D rendering of the structural model in STAAD Pro

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IV. STRUCTURAL MODEL AND INPUT DATA

A. Building Geometry

The structure is a G+2 residential cum commercial structure at Mandideep, Bhopal (Zone II, zone factor = 0.10). Base: 18.520 x 31.200 m; Foundation: 2m; Ground floor height: 3.660 m; Upper floors: 3.050 m each; Height: 9.760 m. Frame type: Ordinary Moment Resistant Frame (OMRF). Soil: Medium.

FC building column dimensions: C1: 300 x300 mm; C2: 400 x300 mm; FC: 400 x400 mm. Support beam (SB): 500 x300 mm; Standard beam (B1): 300 x200 mm. WFC building: uniform column (300 x300 mm), uniform beam (300 x200 mm) all over.

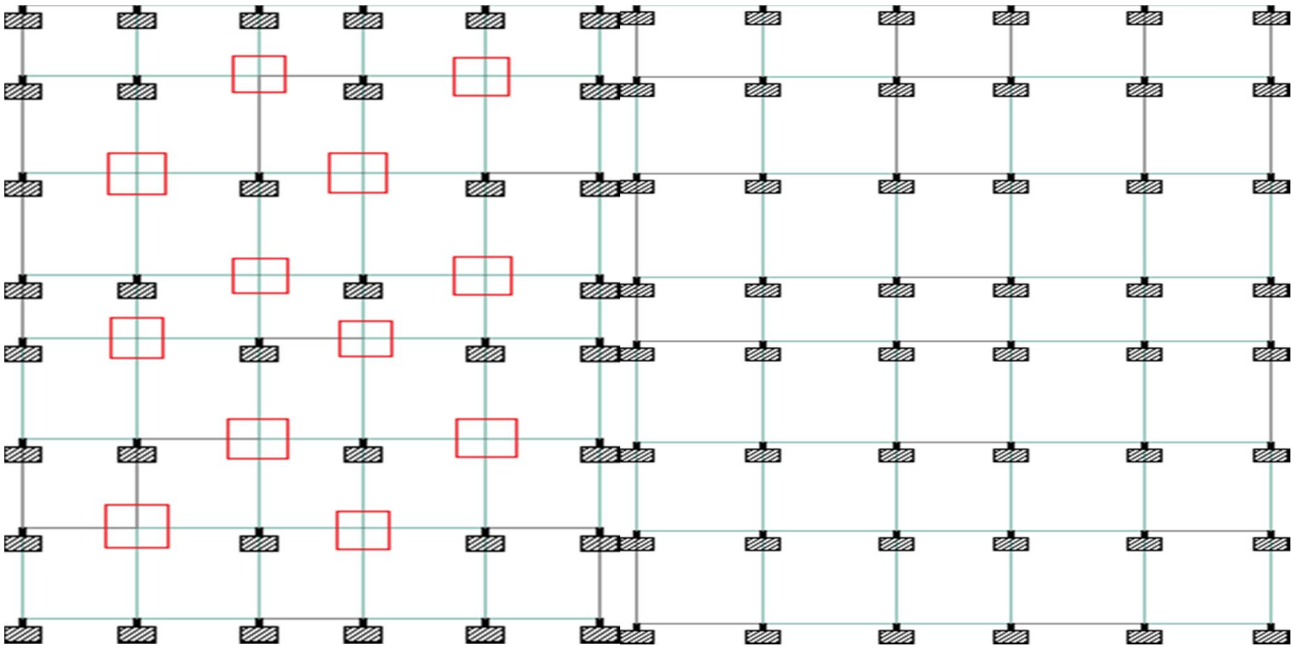


Figure 3: Building plan — with floating column (left) and without floating column (right)

B. Loading Parameters

Table 1: Dead and live load intensities applied to the building frame

No.	Load Type	Intensity
1	Ground floor outside wall (member load)	14.4 KN/M
2	Ground floor inner wall (member load)	7.21 KN/M
3	1st & 2nd storey inner walls	11.88 KN/M
4	1st & 2nd storey exterior walls	5.94 KN/M
5	Top parapet wall	1.8–3.0 KN/M
6	Floor live load	3.0 KN/m²

Table 2: Seismic zone factors as per IS 1893:2002 (Part-1) — Study location: Zone II (Z = 0.10)

No.	Seismic Zone (IS 1893:2002 Part-1)	Zone Factor
1	Zone II	0.10
2	Zone III	0.16
3	Zone IV	0.24
4	Zone V	0.36

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V. STATIC ANALYSIS RESULTS

The maximum load combinations that included the dead load, live load and seismic load in X and Z direction were taken as the static analysis. Figure 4 and 5 indicate the distributions of loads to the FC building.

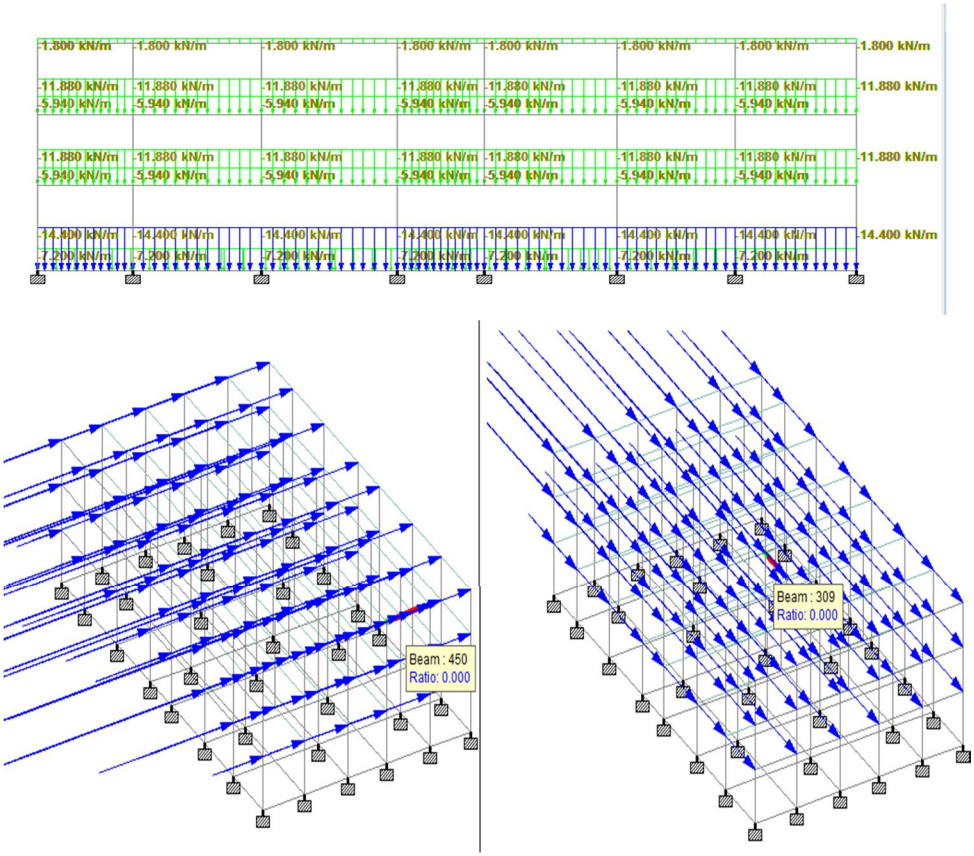


Figure 4: Dead load (left) and seismic load (right) diagrams for FC building — maximum load combination

A. Column Response

The columns of the FC building display a substantial increase in displacement, bending moment, shear force and axial force as compared to WFC building. The lift-off of the columns is maximal in the FC building (13.845 mm in the second floor) and the WFC building (8.555 mm) - the 61.8% rise can be credited to the localised flexibility of the transfer beam level. The columns that support the transfer beam contain the concentrated axial loads that need bigger cross-sections (400x 400 mm) and increased reinforcement ratios.

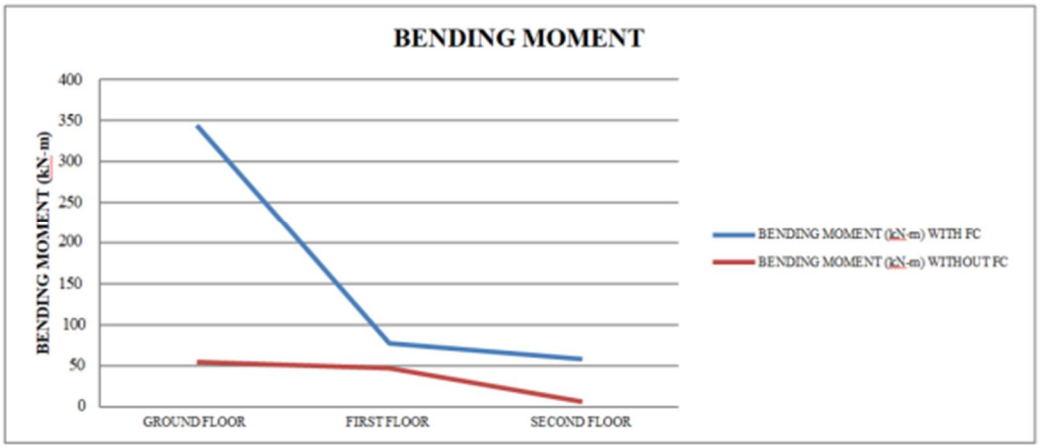


Figure 5: Bending moment comparison in columns — FC vs. WFC buildings

B. Beam Response

The FC building transfers the concentrated point loads of floating columns to transfer beams, which is much more drastically increased into bending moments. The FC building has maximum beam bendingmoment of 344.718 kN-m as opposed to 54.544 kN-m in WFC building -a 532% increase-that dictates the transfer beam design and necessitates massive reinforcement with deep sections (500300 mm).

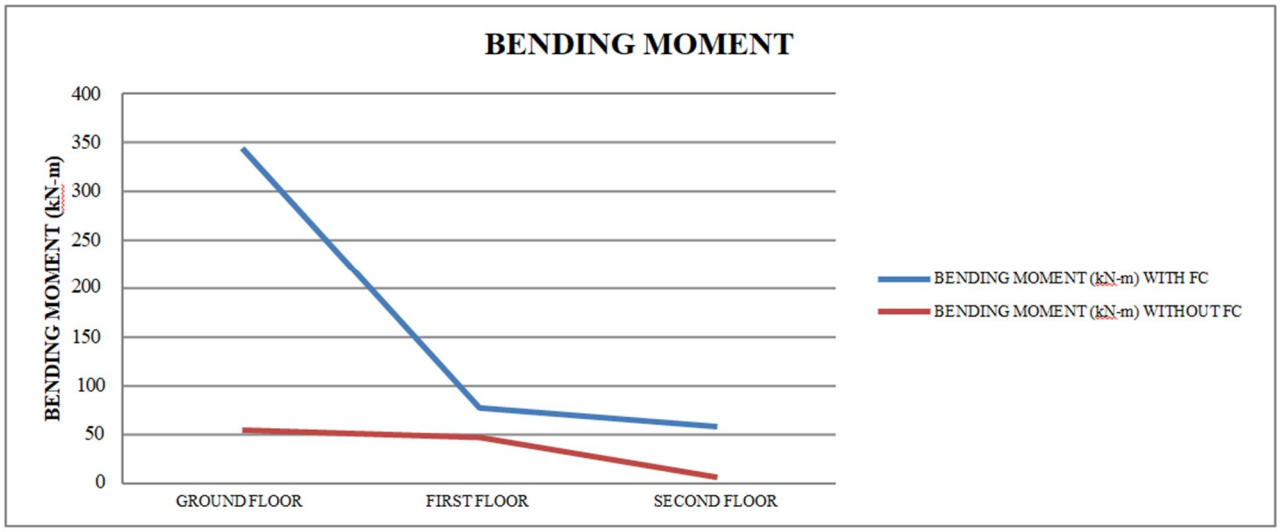


Figure 6: Bending moment comparison in beams — FC vs. WFC buildings

VI. DYNAMIC ANALYSIS RESULTS

A. Mode Shapes

The analysis done in terms of response spectrum is as per IS 1893 (Part 1): 2002. Six mode shapes have been taken out; Mode Shape 1 controls with the largest deviation values. FC building has lower natural frequency as it is more flexible and therefore it responds higher under seismic excitation compared to WFC building.

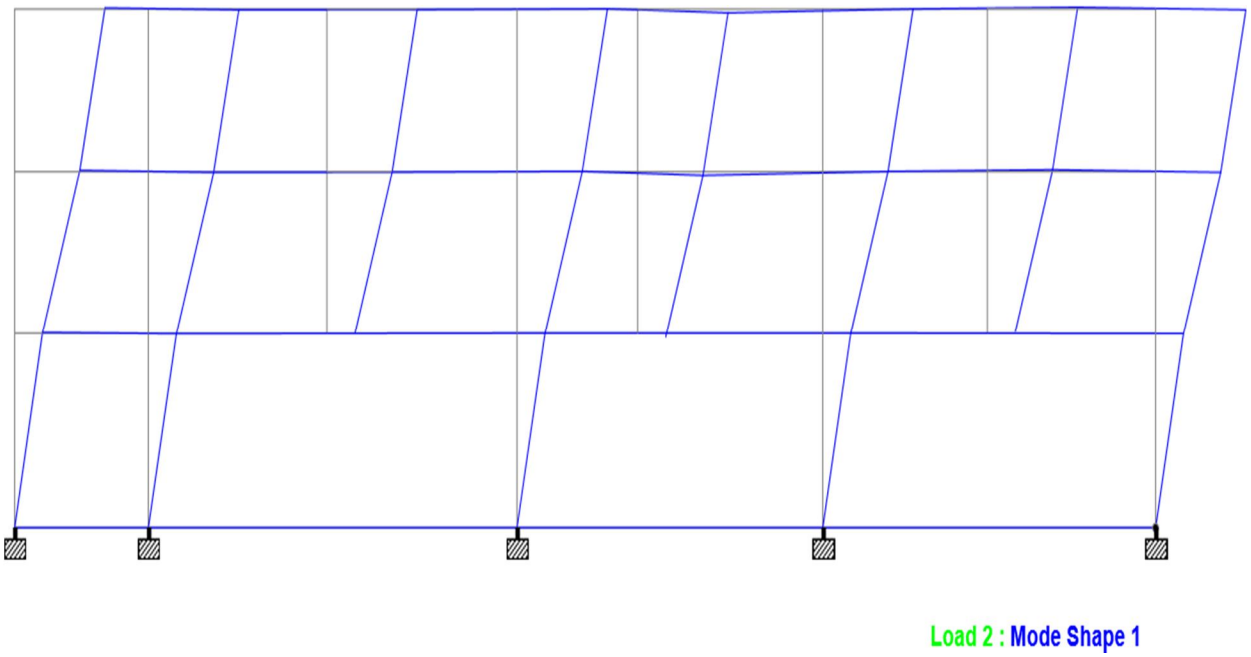
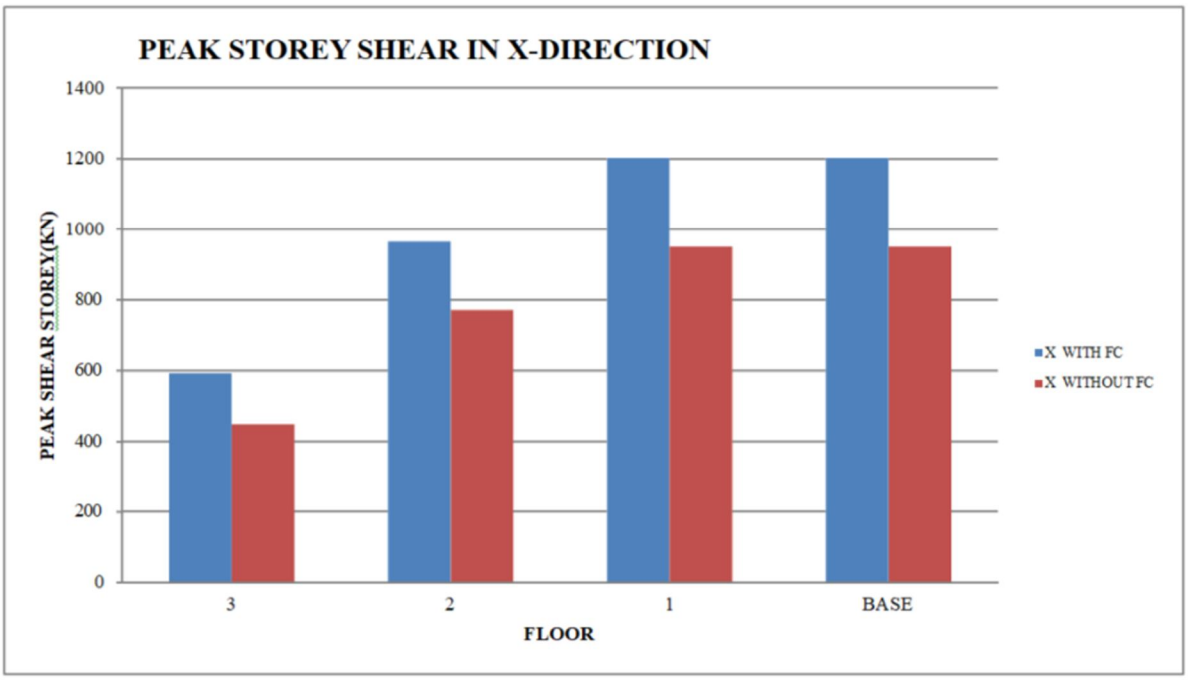


Figure 7: Mode Shape 1 of the FC building — maximum deformation profile

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B. Peak Storey Shear

FC building has a 1203.67 kN base shear on the X-direction vs. 948.78 kN (WFC) on base shear in the X-direction - an increase of 26.9%. This is because mass irregularity is added by the floating columns and transfer beam that change the mass distribution of seismics. The same trend in storey shear in the Z-direction exhibits that FC building was always at higher levels than WFC values at any one of the levels on the floor.



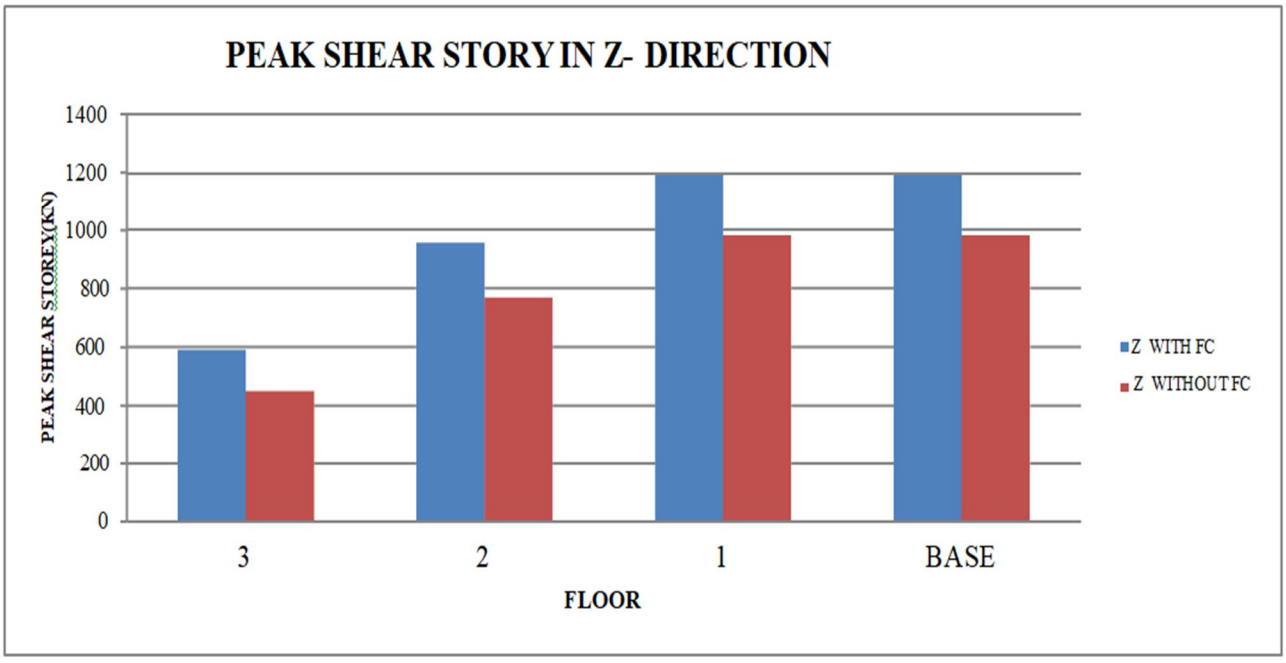


Figure 8: Peak storey shear in X-direction (left) and Z-direction (right) — FC vs. WFC buildings

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C. Storey Drift

The top storey of the FC building has a maximum storey drift of 0.0067 cm (X) and 0.0123 cm (Z) which is a 193% increase on the bottom storey drift of the WFC building 0.0000(X) and 0.000042 cm(Z). The result of this high drift is the direct consequence of the stiffness discontinuity that is created at the transfer beam level and concentrates the deformation demands at the higher floors.

D. Cost and Material Analysis

Table 3: Material quantity and cost comparison — FC vs. WFC buildings

Building	Concrete (m^3)	Reinf. (Tonne)	₹/m^3	₹/Tonne	Total (₹)
With FC	175.90	174.152	3380	40000	75,60,622
Without FC	127.70	147.936	3380	40000	63,49,066

FC building will consume 27.4 percent more concrete (175.90 m3 vs. 127.70 m3) and 15.1 percent more steel (174.152 T vs. 147.936 T), which will increase it by 16.02 percent in terms of cost (075,60,622 vs. 063,49,066). These higher material requirements are a result of the higher transfer beam sizes, the heavier reinforcing of the columns, as well as the extra member sizes needed to allow structural safety during seismic loading.

VII. STRUCTURAL DESIGN SUMMARY

Structural members were all stipulated as per the IS 456: 2000 with M25 concrete (fck = 25 N/mm 2) and Fe500 steel. Cover: 25 mm beams, 40 mm columns. The columns are meant to be used in combined axial loads and bi-axial bending according to the IS 456:2000, Cl. 39.6. Tie reinforcement is in compliance with the IS 456:2000.

All beams (supporting beams with floating column loads) are 500x300mm with 8o stirrups at 175mm c/c (2 legged). Beam lengths are 7,300 mm to 10,080 mm, and main reinforcement is 3 -12obars to 320obars (span and loading). The columns are supported by 300x300mm-400x400mm with 12-12o main bars, 8o at190mm c/c tie, and a necessary final load of2293.67 kN/column. The high reinforcement requirements bear out the greatly increased structural requirements of the floating column arrangement.

VIII. COMPARISON WITH RECENT LITERATURE

Table 4: Comparison of key structural parameters with recent published studies

Study / Reference	Building	Displacement Increase	Base Shear Increase	Cost Increase
Present Study (G+2, Zone II)	RC Frame FC	61.8%	26.9%	+16.02%
Patil & Kumbhar [14] (G+8, Z-III)	RC Frame FC	35%	~20–30%	Not reported
Kaveh & Fahimi-Farzam [13] (G+10)	RC Frame FC	Drift +23%	Significant	Not reported
Mehta & Chauhan [18] (G+10)	RC Frame FC	Higher damage prob.	Higher at MCE	Annual +22%

The 61.8 percent increase in displacement of the present study is higher than the documented values by Patil and Kumbhar (35 percent inter-storey drift) and Kaveh and Fahimi-Farzam (23 percent inter-storey drift) because the plan geometry is unsymmetrical and there is the use of long-span transfer beam in the present study. The increase in the base shear of 26.9 percent is comparable with the values reported in the literature. The 16.02 percent rise of the costs is consistent with the 22 percent rise of the annual loss that Mehta and Chauhan reported - the difference being due to the lower seismicity of Zone II. Every conclusion supports the pattern that has already been established: floating columns always increase displacement, base shear, and material demands irrespective of building height, zone, and software. What this work originally contributes to literature is the fact that it discusses an actual unsymmetrical residential-commercial building with long-span transfer beams in Zone II that has not been discussed in the literature.

IX. CONCLUSION

1) The design and analysis of a G + 2 RC building with floating columns and without floating columns using a complete seismic and a dynamic analysis including both the statical and dynamic analysis was carried out. One can conclude the following:

2) There is no problem with either building when loaded statically, although the internal forces and displacements are very large in the FC building.

3) Known problems FC structures cannot withstand dynamic seismic loading without extension of members. Only structural safety is ensured after deepening transfer beam to 500 mm and increasing column sections.

4) • FC building consume 27.4 percent more concrete, 15.1 percent more steel and 16.02 percent more construction cost compared to the WFC building.

5) Column shift is higher by 61.8, beam bending moment by 532 and base shear by 26.9 percent in the FC arrangement.

6) Storey drift increases in the Z-direction by 193% with Mode Shape 1 having control over the dynamic response.

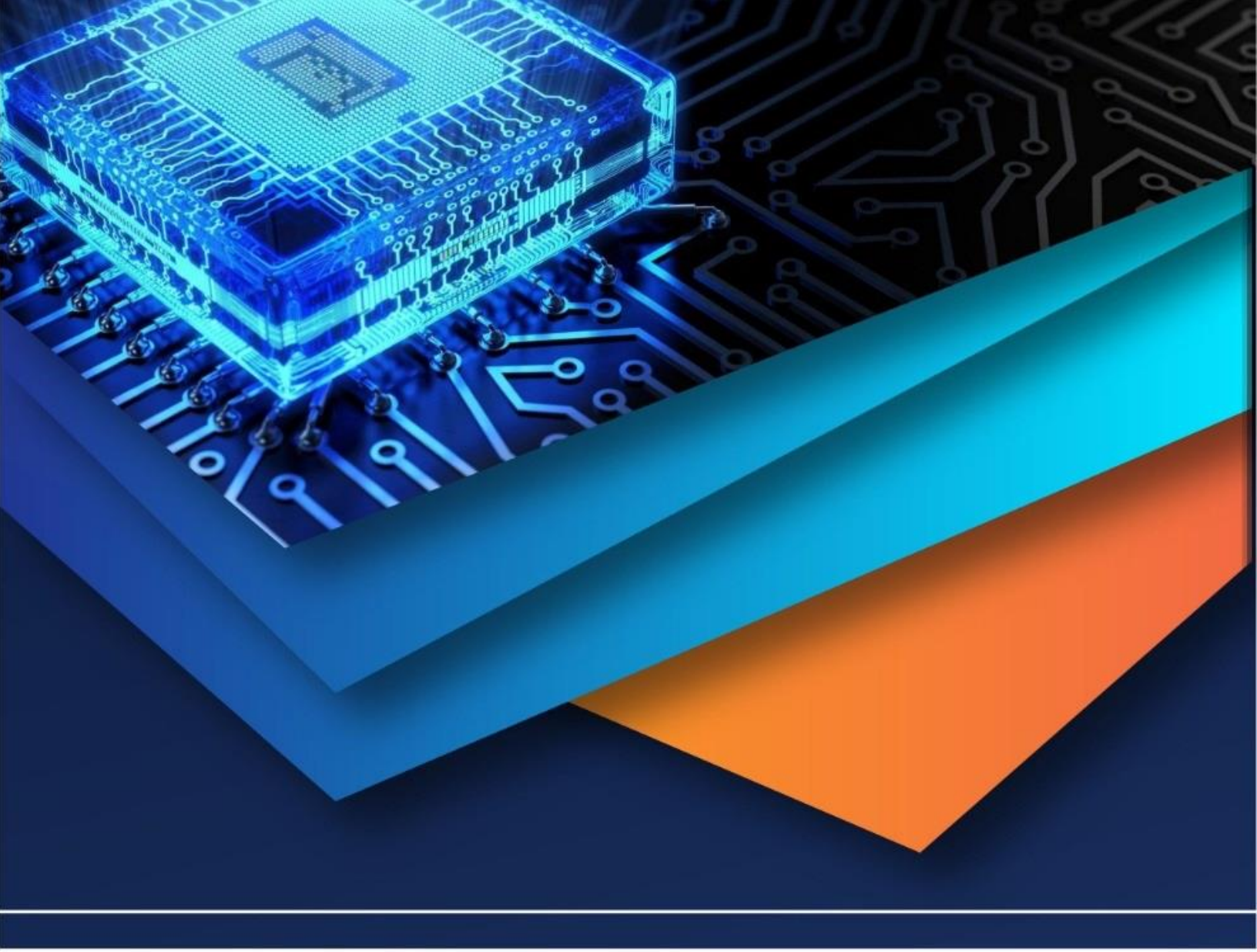
7) Although floating columns have structural issues, they are vital in architecture in terms of their layout remedial effects - removal of layout anomalies and the creation of large open spaces - and are structurally feasible with a good design, with detailed transfer beam detailing and reinforcement.

8) As a precautionary measure, seismic analysis and detailing of floating column buildings is required even in Zone II (lowest seismic zone)

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