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Comparative Evaluation of RCC Buildings with Interior and Multi-Level Floating Column Configurations Using STAAD.Pro

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Abstract: ***The presence of floating columns in RCC buildings alters stiffness distribution and affects seismic response. This study evaluates the influence of interior and multi-level floating column arrangements in a G+12 building. Four configurations are analyzed: exterior floating columns at intermediate level (M1), multiple exterior floating columns (M2), interior floating columns at lower levels (M3), and interior floating columns at upper levels (M4). Response spectrum analysis is performed as per IS 1893 (Part 1):2016. Results indicate that interior floating columns produce higher displacement and axial force concentrations compared to exterior configurations. Multi-level floating columns further amplify irregularity. The study identifies critical configurations and emphasizes the importance of stiffness continuity in seismic design.***
Keywords: ***Interior floating columns, RCC frames, seismic response, vertical irregularity, strong column–weak beam, STAAD.Pro,***

I. INTRODUCTION

Floating columns are vertical members that rest on beams or slabs rather than directly transferring loads to the foundation. This design approach allows for greater architectural flexibility, enabling the creation of large open spaces at lower levels without the obstruction of columns. Floating columns are commonly used in high-rise buildings, commercial complexes, and multi-story residential structures. Floating columns introduce discontinuity in vertical load transfer, especially problematic in interior configurations where load redistribution is complex.

A. Seismic Vulnerability of Vertical Irregularities

Vertical irregularities in reinforced concrete (RCC) buildings arise due to abrupt changes in mass, stiffness, strength, or load-transfer mechanism along the height of the structure. Common sources of vertical irregularity include soft storeys, setback buildings, floating columns, transfer girders, and sudden variation in column dimensions. Such irregular configurations disrupt the uniform distribution of seismic forces and significantly influence the dynamic response of structures during earthquakes.

B. Need for Strong-Column Weak-Beam Concept

The strong-column weak-beam (SCWB) concept is a fundamental seismic design philosophy aimed at ensuring ductile and predictable failure mechanisms in RCC moment-resisting frames. According to this concept, columns are designed to possess higher flexural strength than the beams framing into them, thereby forcing plastic hinges to form in beams rather than columns during severe seismic events.

In buildings with vertical irregularities such as floating columns, the seismic demand on columns increases significantly due to force redistribution and discontinuity in load transfer. If columns yield prematurely, it may lead to storey collapse or global instability. To prevent such catastrophic failure, IS 13920:2016 mandates the adoption of the strong-column weak-beam criterion, ensuring that columns remain essentially elastic while beams undergo controlled inelastic deformation.

This paper studies:

- Interior vs exterior floating columns
- Effect of multiple floating column levels
- Comparative seismic response

II. METHODOLOGY

A G+12 storey reinforced cement concrete (RCC) framed building is selected for the present study. The building configuration is kept identical for all models except for the variation in floating column arrangements, ensuring a fair comparison of results.

- Structural system: RCC moment-resisting frame
- Number of storeys: Ground + 12 storeys
- Typical storey height: 3.0 m
- Total building height: 39.0 m
- Building Plan: Rectangular (18m * 12m) (6 bays along the length and 4 bays along the width)
- Floor system: RCC slab supported on beams
- Foundation: Fixed support assumed at base level
- Seismic zone: Zone III
- Analysis type: Linear elastic dynamic analysis (Response Spectrum Method)
- Software used: STAAD.Pro

All beams and columns were modelled as frame elements, and slabs were idealised as rigid diaphragms by appropriate load distribution.

A. Structural Models Considered

To study the effect of different floating column configurations, four structural models are developed:

- Model 1 (M1): G+12 RCC building with exterior floating columns introduced at the 3rd storey level, placed at outer edges and central perimeter frames.
- Model 2 (M2): G+12 RCC building with exterior floating columns placed at central exterior frames at the 2nd, 3rd, 10th, and 11th storey levels.
- Model 3 (M3): G+12 RCC building with interior floating columns located at the ground floor and first floor levels.
- Model 4 (M4): G+12 RCC building with interior floating columns placed at the 4th, 5th, and 12th storey levels.

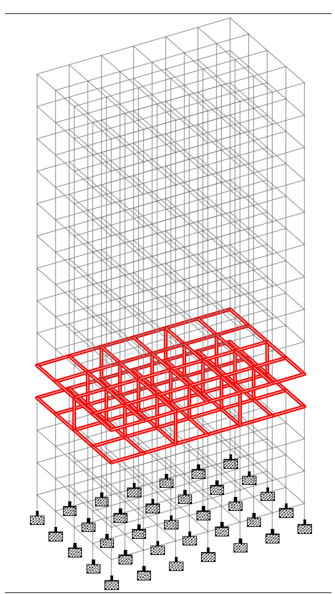

Fig. 1 STAAD.Pro Analytical Model M1

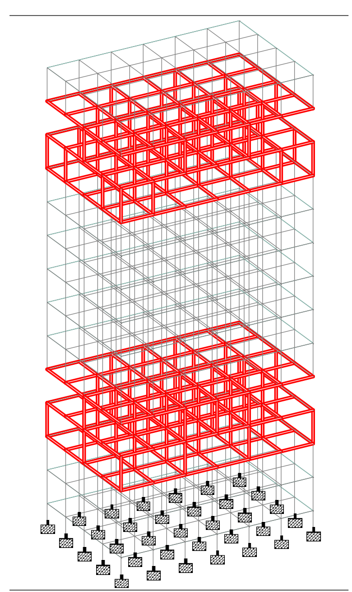

Fig. 2 STAAD.Pro Analytical Model M2

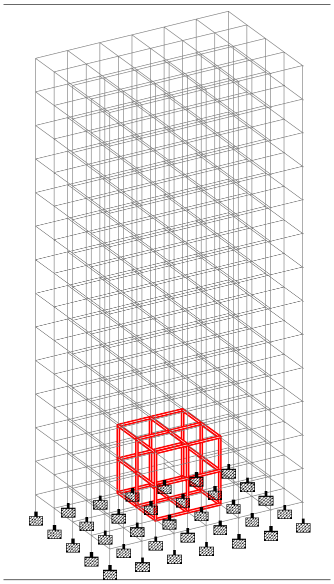

Fig. 3 STAAD.Pro Analytical Model M3

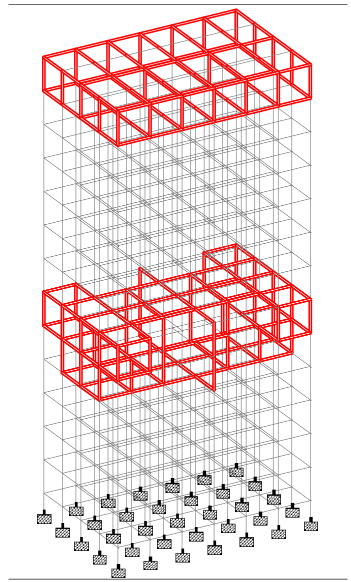

Fig. 4 STAAD.Pro Analytical Model M4

B. *Load Cases Considered*

The following basic load cases were defined in STAAD.Pro:

- DL – Dead Load
- LL – Live Load
- EQX, EQZ – Earthquake loads in X and Z directions
- WLX, WLZ – Wind loads in X and Z directions

Earthquake and wind loads were applied independently in both positive and negative directions to capture the most critical structural response.

The building is subjected to gravity loads and lateral loads as per the provisions of Indian Standard codes, ensuring realistic representation of service and extreme loading conditions.

C. *Seismic Design Parameters (EQ)*

The structural models were analysed and designed using STAAD.Pro in accordance with the relevant Indian Standards. The seismic analysis was carried out considering the building to be located in Seismic Zone III, as per IS 1893 (Part 1): 2016. Earthquake forces are considered independently in both X and Z directions.

- Seismic Zone: III
- Zone Factor (Z): 0.16
- Importance Factor (I): 1.0
- Response Reduction Factor (R): 5.0 (Assuming Special Moment Resisting Frame with ductile detailing as per IS 13920)
- Damping Ratio: 5%
- Soil Type: Medium

The design response spectrum corresponding to medium soil conditions was adopted as per IS 1893 provisions.

D. *Parameters Considered for Evaluation*

Comparative Evaluation Approach:

The results of Models M1, M2, M3, M4 are compared to quantify the effect of different floating column arrangements. Variations in displacement, drift, and member forces are analysed storey-wise to identify critical configurations and vulnerable storey levels.

The structural performance of each model is evaluated using the following parameters:

- Node displacement along X and Z directions
- Storey drift

- Axial forces (Fx) in columns
- Shear forces (Fy and Fz)
- Bending moments (Mz) along the height of the building

Results are extracted from ground level to roof level for critical load combinations.

III.RESULTS AND DISCUSSION

A quantitative evaluation of the seismic performance of four G+12 reinforced concrete building models analysed using linear elastic dynamic analysis (response spectrum method) in STAAD.Pro. The comparison is based on numerical results obtained for lateral displacement, storey drift, bending moments, shear forces, and axial forces.

A. Storey-wise Nodal Displacement

Storey-wise nodal displacement is a critical indicator of the lateral stiffness and overall seismic response of a structure. Displacements were extracted at each storey level from ground floor to roof level for earthquake loads acting in both X and Z directions from STAAD.Pro for all four structural models under design earthquake load combinations, and the results are summarized in Table 1.

TABLE I COMPARISON OF STOREY-WISE NODAL DISPLACEMENTS (X AND Z DIRECTIONS)

Node Displacement (mm)								
Storey Level	**M1**		**M2**		**M3**		**M4**	
	X	Z	X	Z	X	Z	X	Z
GF	4.886	5	4.632	4.607	5.181	5.473	5.018	5.372
1	7.859	8.032	7.494	7.461	8.465	9.023	8.264	8.925
2	10.562	10.729	11.922	11.854	11.764	12.635	11.644	12.644
3	16.733	18.218	16.92	19.51	15.03	16.25	15.195	16.557
4	20.531	22.909	20.798	24.121	18.225	19.816	18.953	20.747
5	24.389	27.661	24.672	28.797	21.308	23.282	22.745	25.052
6	28.122	32.284	28.389	33.367	24.225	26.588	26.081	28.832
7	31.643	36.692	31.873	37.74	26.916	29.667	28.968	32.138
8	34.873	40.811	35.033	41.839	29.314	32.445	31.455	35.039
9	37.739	44.571	37.844	45.614	31.345	34.845	33.529	37.512
10	40.17	47.913	40.974	49.231	32.935	36.786	35.147	39.508
11	42.116	50.809	42.819	52.109	34.023	38.207	36.275	40.989
12	43.686	53.379	43.859	54.037	34.679	39.178	36.994	42.036

For all models, storey displacement increases progressively from the ground floor to the roof level, exhibiting a typical cantilever-type deformation pattern expected in multi-storey RCC frame buildings. The maximum displacement occurs at the roof level (Storey 12) for all configurations, confirming realistic global structural behaviour.
Among the two horizontal directions, Z-direction displacements are consistently higher than X-direction displacements, indicating comparatively lower stiffness along the Z direction due to plan geometry and frame orientation.
A comparative assessment of all models reveals the following displacement hierarchy: M3 ≈ M4 < M1 < M2

This clearly demonstrates that:

- Floating columns at ground floor level are the most critical
- Exterior floating columns cause larger displacements than interior ones
- Multiple floating column levels amplify displacement nonlinearly
- Regular RCC frames provide the best seismic performance

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STAAD Post-Processing Results for Storey-Wise Node Displacement

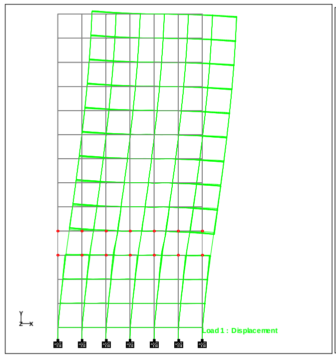


Fig 5 Node Displacement Pattern for Model M1

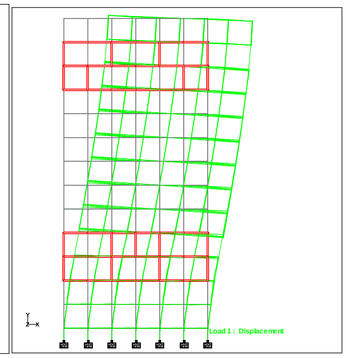


Fig 6 Node Displacement Pattern for Model M2

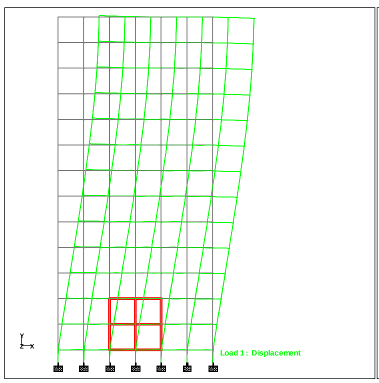


Fig 7 Node Displacement Pattern for Model M3

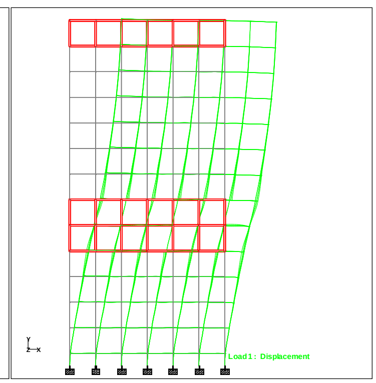


Fig 8 Node Displacement Pattern for Model M4

B. *Storey Drift Behaviour*

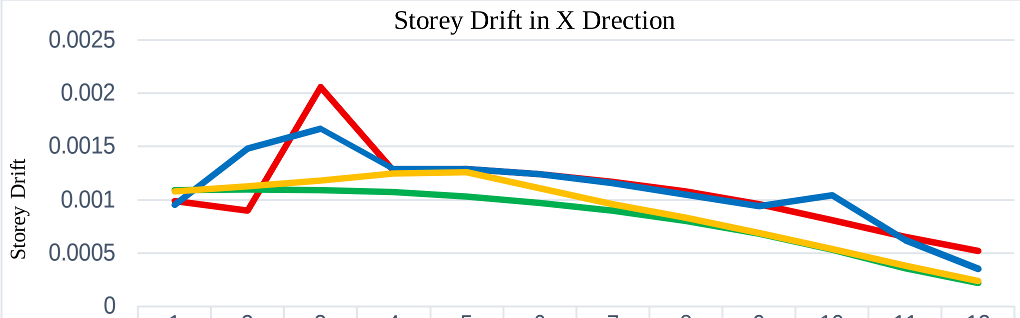
Storey drift is one of the most important seismic performance parameters, as excessive drift can lead to non-structural damage and potential structural instability. Storey drift was calculated as the relative displacement between consecutive storeys and was evaluated in both principal directions.

Storey drift was calculated as the relative displacement between consecutive storeys divided by the storey height of 3.0 m. Separate storey drift tables and plots were generated for each model based on the extracted node displacement values.

$$\text{Drift} = \frac{\Delta\text{displacement between consecutive storeys}}{3000}$$

IS 1893 (Part 1) permissible limit: $\text{Drift} \leq 0.004$

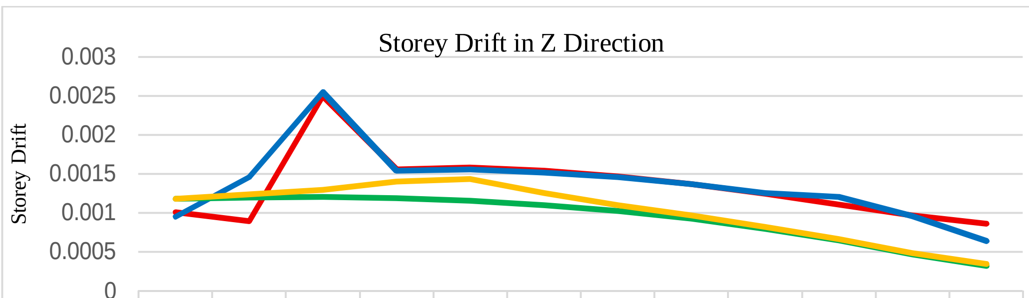
1) *Comparative Evaluation of Storey Drift in X and Z Direction:* As per IS 1893 (Part 1): 2016, the permissible storey drift limit is 0.004 times the storey height. The present study evaluates and compares storey drift responses in both X (longitudinal) and Z (transverse) directions for four RCC building models (M1–M4) incorporating different floating column arrangements shown in Fig.9 and Fig. 10.



	1	2	3	4	5	6	7	8	9	10	11	12
M1	0.001	0.0009	0.0021	0.0013	0.0013	0.0012	0.0012	0.0011	0.001	0.0008	0.0007	0.0005
M2	0.001	0.0015	0.0017	0.0013	0.0013	0.0012	0.0012	0.0011	0.0009	0.001	0.0006	0.0004
M3	0.0011	0.0011	0.0011	0.0011	0.001	0.001	0.0009	0.0008	0.0007	0.0005	0.0004	0.0002
M4	0.0011	0.0011	0.0012	0.0013	0.0013	0.0011	0.001	0.0008	0.0007	0.0005	0.0004	0.0002

Storey Number

Fig. 9 Comparison of Storey Drift in X-Direction



	1	2	3	4	5	6	7	8	9	10	11	12
M1	0.001	0.0009	0.0025	0.0016	0.0016	0.0015	0.0015	0.0014	0.0013	0.0011	0.001	0.0009
M2	0.001	0.0015	0.0026	0.0015	0.0016	0.0015	0.0015	0.0014	0.0013	0.0012	0.001	0.0006
M3	0.0012	0.0012	0.0012	0.0012	0.0012	0.0011	0.001	0.0009	0.0008	0.0007	0.0005	0.0003
M4	0.0012	0.0012	0.0013	0.0014	0.0014	0.0013	0.0011	0.001	0.0008	0.0007	0.0005	0.0004

Storey Number

Fig. 10 Comparison of Storey Drift in Z-Direction

2) Influence of Floating Columns on SCWB and Drift Concentration

In floating column models the introduction of vertical discontinuities disturbs the SCWB hierarchy by:

- Interrupting direct load transfer to columns below
- Increasing axial force and bending demand in supporting columns
- Reducing column overstrength relative to beams at transfer levels

Interior floating column models (M3 and M4) show comparatively lower drift values because:

- Load redistribution occurs more symmetrically
- Column demand increase is shared by multiple adjacent columns
- Partial preservation of SCWB hierarchy is achieved

In contrast, exterior floating columns (M1 and M2) cause:

- Torsional effects
- Localized column overstressing
- Drift amplification near frame edges

This confirms that exterior floating columns are more detrimental to SCWB behaviour, leading to higher drift concentrations.

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C. Axial Force Distribution

The axial force results clearly demonstrate that floating columns especially those located at lower storeys or arranged externally, tend to shift demand from beams to columns, thereby challenging the strong-column weak-beam philosophy. To ensure seismic safety, columns supporting floating columns must be designed with higher axial load capacity, increased flexural overstrength, and enhanced ductile detailing in accordance with IS 13920, so that beam hinging remains the governing failure mechanism during seismic events.

1) Comparison of Axial Force (Fx) Variation in Columns: The axial force (Fx) variation along the height of the building under the load combination 1.5(DL + EQZ) shows distinct behavioural differences. Table 2 presents the axial force values for each model.

TABLE 2 STOREY-WISE COMPARISON OF AXIAL FORCE (FX) IN COLUMNS

Axial Force Fx				
Storey Level	M1	M2	M3	M4
	558.768	611.263	1687.628	1797.141
GF	403.162	466.585	1533.4	1644.724
1	252.673	334.114	1385.686	1498.6
2	101.95	213.358	1239.25	1352.343
3	1922.111	2031.351	1095.089	1205.331
4	-30.375	-22.519	953.739	1054.641
5	-43.673	-24.432	815.775	987.8
6	-55.969	-26.039	681.921	747.109
7	-66.237	-26.194	553.098	606.731
8	-73.059	-23.33	430.423	474.412
9	-75.259	-16.774	315.209	350.115
10	-71.328	-8.821	208.933	234.866
11	-59.54	27.14	113.042	129.9
12	-37.704	-12.745	28.722	36.117

2) Key Observations from Axial Force (Fx) Table:

- Models M1 and M2 show sudden amplification of axial force at intermediate storeys (notably around Storey 3), followed by sharp reductions and even negative axial force values, indicating disrupted load paths and seismic overturning effects.
- Models M3, and M4 exhibit relatively smoother trends compared to other floating column configurations

3) STAAD.Pro Output – Storey-wise Axial Force Distribution:

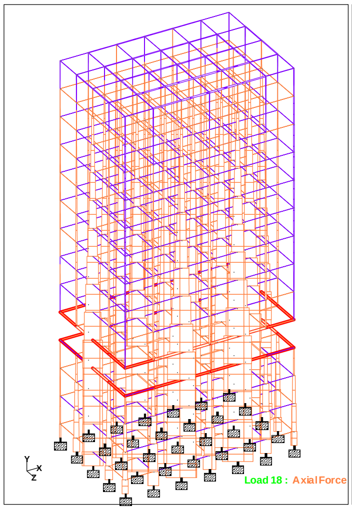

Fig. 11 Axial Force Distribution in M1

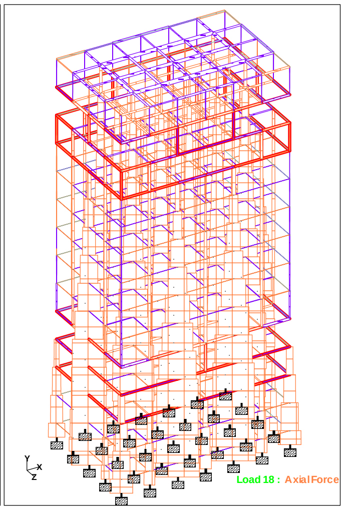

Fig. 12 Axial Force Distribution in M2

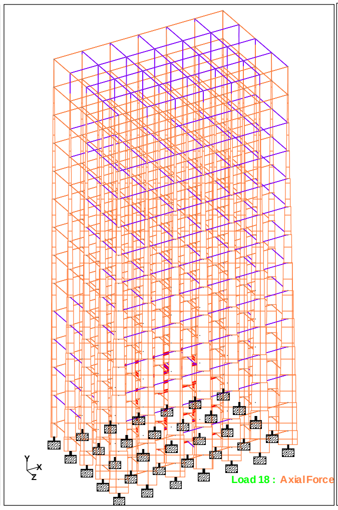

Fig. 13 Axial Force Distribution in M3

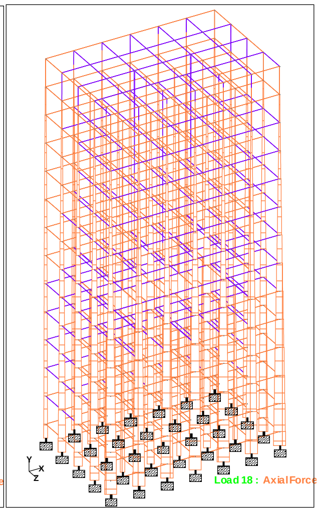

Fig. 14 Axial Force Distribution in M4

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D. *Shear Force Variation*

Shear forces in Fy and Fz directions were extracted along the height of the structure. Table 3 summarizes the maximum shear forces at critical storeys for all models.

Models with floating columns at lower storeys, particularly M3 (interior floating columns at ground and first floor), record significantly higher shear forces. These models show pronounced peaks in both Fy and Fz components near the ground and first storey levels, indicating severe shear demand on transfer beams and nearby columns. The high shear forces in these regions highlight their vulnerability under seismic excitation.

Exterior floating-column models M1 and M2 exhibit higher lateral shear force (Fz) concentrations compared to interior floating-column models. This behaviour is due to the disruption of the perimeter lateral load-resisting system, which causes exterior frames to attract higher seismic shear forces. Interior floating-column models M3 and M4 show relatively moderate but more widely distributed shear force amplification over multiple storeys. The interruption of the internal gravity load path forces redistribution through surrounding beams and columns, increasing shear demand over a larger height range rather than at a single transfer level.

TABLE 3 VARIATION OF SHEAR FORCE (FY AND FZ) ALONG BUILDING HEIGHT FOR DIFFERENT FLOATING COLUMN CONFIGURATION

Storey Level	Shear Force in Y and Z direction							
	M1		M2		M3		M4	
	Fy kN	Fz kN	Fy kN	Fz kN	Fy kN	Fz kN	Fy kN	Fz kN
	53.409	-48.072	51.44	-49.79	56.502	-33.681	54.402	-41.175
GF	55.768	-43.766	49.149	-44.577	60.402	-46.772	58.511	-29.827
1	49.404	-44.189	63.763	-67.7	61.157	-40.939	60.252	-22.734
2	64.307	-67.566	82.971	38.648	61.018	-21.699	62.142	-20.507
3	111.365	-31.859	114.277	-1.556	60.171	-27.852	65.379	13.7
4	89.003	4.736	59.756	-5.596	58.728	-25.895	71.94	-55.598
5	62.146	-0.969	66.174	-8.953	56.504	-24.153	74.449	-56.338
6	63.013	-2.669	61.979	-10.287	53.319	-21.786	60.953	-18.271
7	57.418	-2.558	57.124	-10.358	49.071	-18.833	52.036	-36.237
8	51.419	-1.05	50.405	-9.106	43.467	-15.208	44.831	-28.154
9	44.054	1.904	49.436	-6.303	36.559	-10.822	37.08	-23.3
10	35.505	6.481	-13.733	28.781	28.217	-5.469	28.492	-17.626
11	25.469	11.953	21.488	49.246	18.343	0.348	18.808	-9.601
12	20.475	29.201	14.25	66.768	10.2	12.633	11.661	2.295

E. *Bending Moment Distribution*

All floating column configurations exhibited a noticeable increase in bending moments at and below the floating column termination levels. The most significant amplification occurred in transfer beams, which act as critical load-redistributing elements. Models with floating columns at lower storeys, particularly M3, recorded the highest bending moments, indicating severe stress concentration due to abrupt vertical stiffness discontinuity.

For comparative evaluation, the maximum absolute bending moment about the Z-axis (Mz) was extracted for all models under governing load combinations. This parameter governs member design and effectively captures the impact of floating columns on force redistribution. The comparison indicates that:

- Exterior floating column models (M1 & M2) show substantial bending moment amplification.
- Interior floating column models (M3 & M4) exhibit moderate increases.

1) *Strong-Column Weak-Beam (SCWB) Interpretation*: Despite increased bending moment demands in floating-column models, the adoption of the strong-column weak-beam philosophy ensures that:
   - Columns retain higher moment capacity than beams
   - Plastic hinges preferentially form in beams
   - Progressive collapse is prevented at transfer levels

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Interior floating-column models demand greater column overstrength to satisfy SCWB requirements due to elevated Mz values.

2) Comparison of Bending Moment (Mz) Variation for Models M1–M4:

- Floating columns at lower storeys drastically increase bending moments in transfer beams and adjacent columns.
- Increased bending moments directly translate to:
    a. Heavier reinforcement demand
    b. Higher construction cost
    c. Reduced seismic reliability

The strong-column weak-beam philosophy plays a vital role in maintaining structural safety by preventing column hinging despite increased bending moments in floating-column models. Comparison of Bending Moment variation are shown in Table 4

TABLE 4 VARIATION OF BENDING MOMENT (MZ) ALONG BUILDING HEIGHT FOR DIFFERENT FLOATING COLUMN CONFIGURATION

Bending Moment (Mz)				
Storey Level	**M1**	**M2**	**M3**	**M4**
	66.899	64.11	70.512	67.954
GF	57.232	52.144	62.474	60.686
1	50.838	56.078	61.488	60.99
2	54.439	66.752	60.989	62.947
3	129.229	105.15	59.941	66.263
4	101.163	55.898	58.308	72.122
5	60.155	66.168	55.846	73.892
6	62.656	61.117	52.38	58.831
7	56.255	55.832	47.757	49.908
8	49.915	48.972	41.854	42.896
9	42.155	44.035	34.57	34.956
10	33.254	24.902	25.868	26.145
11	23.419	22.147	15.983	16.546
12	17.395	15.342	7.997	9.387

3) Bending Moment (Mz) Contours from STAAD.Pro:

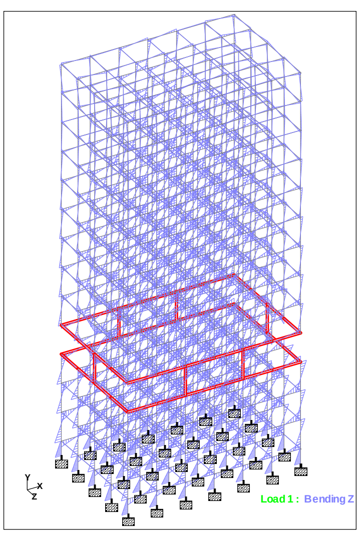

Fig. 15 Mz Distribution in Model M1

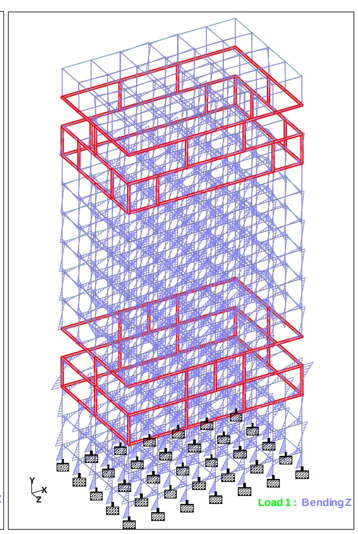

Fig. 16 Mz Distribution in Model M2

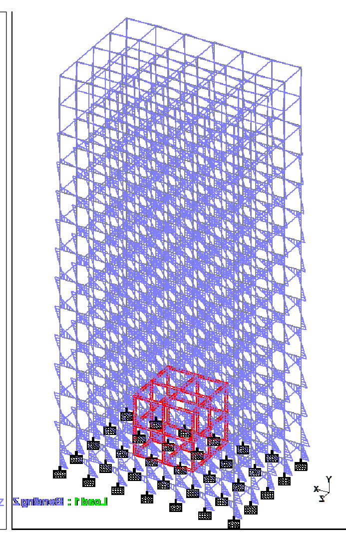
Fig. 17 Mz Distribution in Model M3

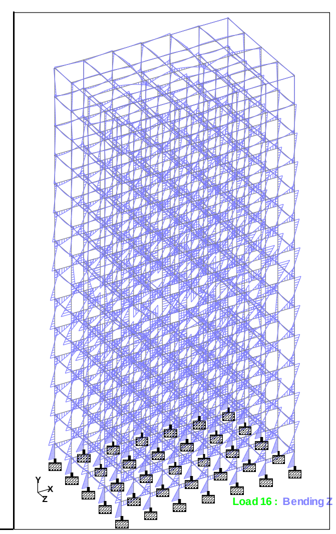

Fig. 18 Mz Distribution in Model M4

IV. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The study clearly establishes that floating columns significantly influence force transfer mechanisms, stiffness distribution, and seismic performance of multistorey RCC buildings.

- Interior floating columns are more critical than exterior ones
- Multiple floating column levels increase seismic vulnerability
- Lower storey floating columns create soft-storey effect
- Transfer beams supporting floating columns are the governing elements for bending and shear design.
- M3 is the most critical configuration

B. Recommendations

- Avoid interior floating columns at lower levels, if unavoidable, interior floating column configurations are preferable to exterior floating columns.
- Limit number of floating column levels
- Increase stiffness at discontinuity levels
- Drift-sensitive storeys should be identified during analysis and strengthened accordingly.
- Provide stronger transfer girders
- Follow SCWB strictly

The study conclusively establishes that while floating columns may be architecturally desirable, they significantly influence seismic performance by introducing stiffness irregularity, force concentration, and load path discontinuity. Interior floating columns perform better than exterior configurations, while inclined floating columns impose the highest structural demand.

Careful configuration selection, strict adherence to codal provisions, and enhanced detailing are essential to ensure safety and serviceability of floating column buildings in seismic regions.

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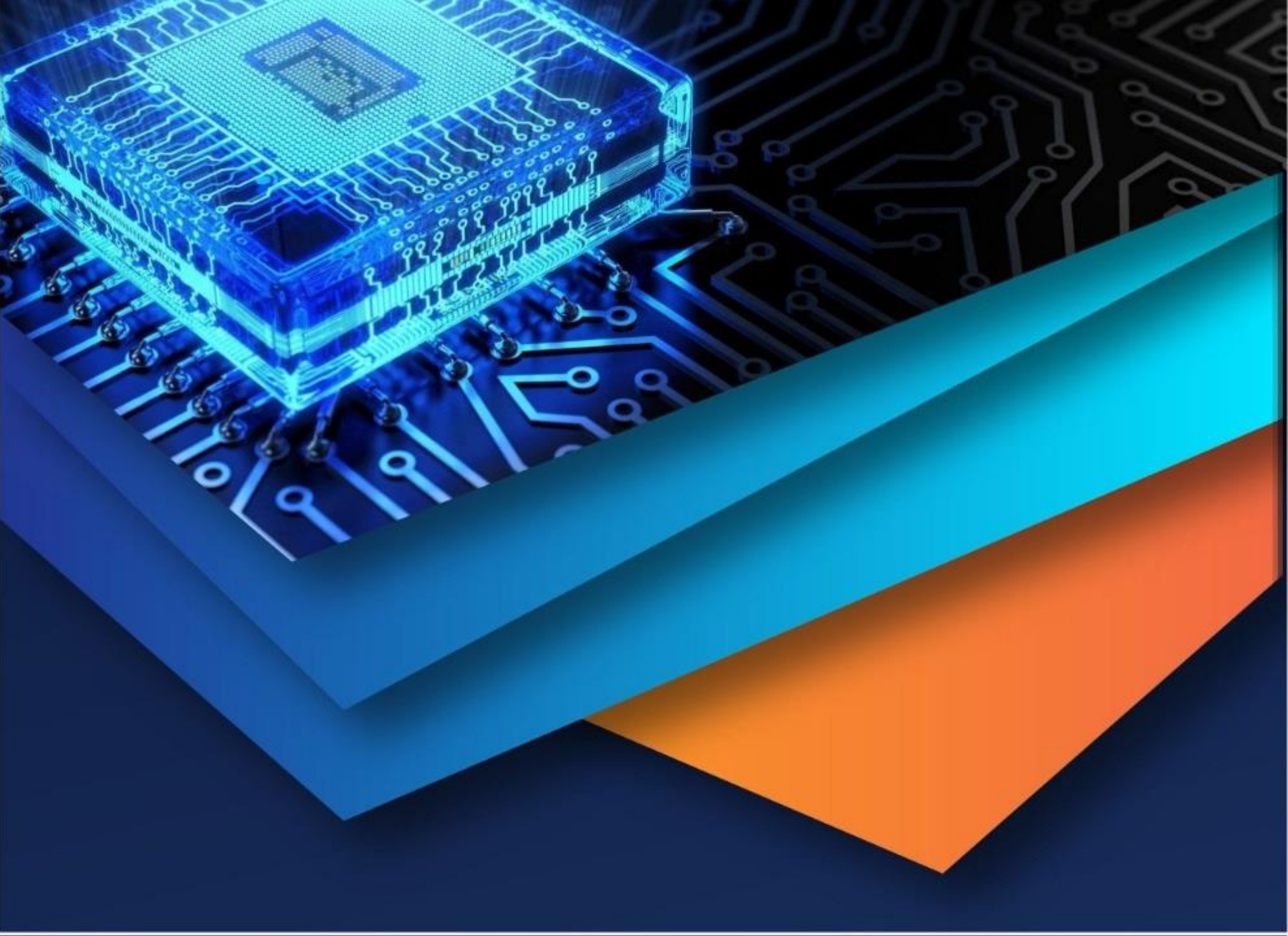

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