LINEAR AND NON-LINEAR SEISMIC ANALYSIS OF FLOATING COLUMN SUPPORTED BY TRANSFER BEAM.

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Abstract: *In the seismic design of regular buildings, two primary assumptions are commonly adopted. Firstly, lateral loads are presumed to vary linearly along the height of the building, serving as a conservative representation of the actual response to ground motion during an earthquake. Secondly, seismic force-resisting elements are assumed to experience uniform cyclic inelastic deformation demands. While these assumptions hold reasonably well for regular structures, they often prove inadequate when structural irregularities are introduced into the design. A key irregularity that disrupts seismic performance is the floating column, which introduces vertical discontinuities in mass and stiffness distribution. This type of irregularity adversely affects the overall structural response under seismic loading and can result in severe damage or collapse, particularly in high-rise buildings. To address such vulnerabilities, it becomes necessary to adopt corrective design factors and updated analysis procedures. Effective preventive measures, such as incorporating shear walls and modifying structural layouts, must be considered early in the design process to ensure safety and stability. To evaluate these measures, advanced analytical tools such as the Pushover Analysis Method are used. This method assesses the building's capacity by observing its behavior under increasing lateral loads and identifying its performance point. Another critical factor is material nonlinearity, which plays a vital role in achieving the ductility needed for a structure to withstand seismic events without catastrophic failure. Thus, finding an optimal balance between adequate seismic force resistance and sufficient ductility is essential for designing earthquake-resilient buildings. This project explores these seismic design concerns through the analysis of four G+9 symmetrical RCC building models using ETABS Ultimate v20.0.0. The first model is a regular structure without floating columns, serving as a control. The second model includes floating columns to assess their effect. The third and fourth models also include floating columns but incorporate shear walls as a countermeasure - at four corners in the third model and at intermediate exterior columns in the fourth. The location of shear walls is shown to significantly influence structural performance. Each model is analyzed using two methods: the Linear Dynamic Analysis (Response Spectrum Method) per IS 1893:2016, and the Nonlinear Static Analysis (Pushover Method) as per ATC 40, FEMA 356, and Euro code 8 guidelines.*

Keywords: Seismic design, floating column, structural irregularity, pushover analysis, response spectrum method, non-linear static analysis, lateral load distribution, ductility, seismic performance, shear wall placement, ETABS.

1. INTRODUCTION

During severe earthquakes, structural design focuses primarily on ensuring safety, serviceability, and minimizing economic losses. Unlike static or wind loading, earthquake forces are dynamic, resulting in large inelastic cyclic deformations. Therefore, structural behavior under seismic loading must be studied in detail beyond the elastic range. Most seismic design codes allow inelastic energy dissipation in structural systems, which means some level of structural damage is expected during strong earthquakes. The primary objective of seismic design is to reduce the risk of life loss during the most severe expected earthquakes. Building codes incorporate historical performance data and structural deficiencies to develop life safety provisions aimed at preventing collapse. The seismic performance of a structure depends on its strength, ductility, and a balanced lateral force-resisting system. Structures that remain within the elastic range perform well, but designing all buildings to stay elastic during strong earthquakes is often uneconomical. Hence, seismic codes permit yielding in specific members, enabling cost-effective resistance. • To ensure safety and resilience, seismic design provisions aim to: • Minimize hazards to human life, • Improve structural performance, and • Enhance post-earthquake functionality. Structures are therefore expected to withstand small earthquakes without damage, Experience minor structural damage and possible non-structural damage under moderate earthquakes, and Endure strong earthquakes with limited structural damage without collapse. Earthquake-induced damage in buildings is primarily caused by inertial forces generated during ground motion, not by direct impact or externally applied forces. The dynamic behavior of high-rise structures differs significantly from that of low-rise buildings. Structural response depends on parameters such as building mass, foundation type, ground motion characteristics, and the dynamic properties of the structure. If a structure were infinitely rigid, the inertial force would follow Newton's second law: F= ma. However, due to structural flexibility, actual forces are often lower. Yet, increased mass still causes adverse effects such as increased buckling, crushing, and P-Δ Effects. The P-Δ effect arises when vertical loads act on laterally displaced members, magnifying instability, especially in taller buildings with large displacements. The magnitude of lateral forces depends not only on ground motion but also on structural response and foundation conditions. Ground motion intensity diminishes with distance from the epicenter — a phenomenon known as attenuation. This attenuation is more rapid for high- frequency waves, although exact variation patterns remain complex and not fully understood.

Damping and Energy Dissipation in Structures:-

To resist earthquake loads effectively, structures must also consider damping mechanisms that reduce vibrations. Damping is typically expressed as a percentage of critical damping —the minimum required to halt oscillations. It arises from various sources:

1. External viscous damping – Generally negligible in structural systems.
2. Internal viscous damping – Proportional to velocity and alters the natural frequency of the structure.
3. Friction damping – Occurs at joints and support points; its effect is constant.
4. Hysteretic damping – The most significant in ductile structures; it absorbs energy during yielding. As a structure yields under seismic loads, hysteretic energy dissipation increases. This introduces a mutual dependence between the structure's capacity and demand. As yielding progresses, effective damping increases, which in turn influences the seismic demand. To account for this, reduction factors can be applied to the 5% elastic response spectrum to reflect energy dissipation and improved performance of ductile systems.

1. FLOATING COLUMN

A column is a primary vertical compressive structural member responsible for transferring the loads from the superstructure down to the foundation and eventually into the ground. In contrast, a floating column is also a vertical element but does not extend directly to the foundation. Instead, it rests on a horizontal structural member, typically a transfer beam, which then transfers the loads from the floating column to other columns located beneath it. The use of floating columns is often driven by architectural requirements, such as creating open spaces on lower floors for amenities like parking, lobbies, or halls. While such arrangements may serve functional or aesthetic purposes, they introduce serious structural concerns, especially under seismic loading conditions. Under vertical loads alone, a structure with floating columns may perform satisfactorily, as the load transfer remains relatively stable. However, during an earthquake, the discontinuity in the vertical load path becomes a critical issue, severely affecting the lateral load-resisting capability of the structure. Earthquake-induced lateral forces must be transmitted effectively from the upper stories to the ground. In the presence of floating columns, this transmission becomes disrupted, since the lateral loads from the upper stories must be diverted through cantilevered transfer beams, which are not inherently designed for significant lateral resistance. These beams, in turn, induce overturning moments and additional shear forces into the ground floor columns, which may already be under designed or inadequately detailed for such seismic demands. As a result, excessive stress concentrations develop at the beam- column joints, leading to sagging, deformation, and in severe cases, collapse of the ground floor columns. This failure mechanism is exacerbated by the lack of sufficient tensile strength, poor detailing, and inadequate stiffness of the cantilever beams and connections. Furthermore, floating columns generate tilting forces that must be transferred horizontally to other structural elements, inducing shear stresses in the transfer beam and overloading the adjacent columns. The connection zones, particularly where the floating column and the transfer system interface with the columns below, become the most vulnerable points in the structure. Hence, the primary concern in such configurations lies in ensuring the adequate strength and stiffness of the lower-level columns and the transfer beams, which collectively carry the irregular and redirected loads due to the floating column arrangement. To maintain structural integrity and prevent seismic failure, special attention must be paid to detailing, ductility, and redundancy in these critical load paths.

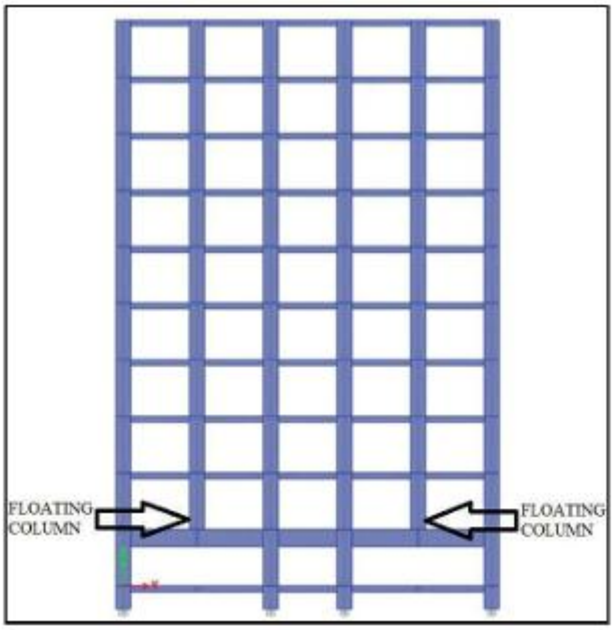


Fig No. 1 Floating Column

2. SHEAR WALL

A shear wall is a vital structural component used to resist lateral forces, especially those induced by wind or seismic activity. Functioning similarly to wide vertical beams, shear walls are designed to withstand shear stresses that would otherwise compromise the structural stability of a building. They are oriented vertically, typically starting at the ground level and continuing upward to the full height of the structure, forming a continuous system for load transfer. The thickness of shear walls usually ranges between 150 mm and 400 mm, depending on design requirements and building height. Shear walls are commonly provided in high-rise buildings, where the impact of lateral forces becomes more significant. These walls are usually placed strategically within the structural plan, often aligned with the breadth and length of the building to optimize stiffness and minimize lateral displacement. In cases where there is a significant eccentricity—for instance, a 30% or more offset between the structure's center of mass and the load-bearing center—shear walls help correct this by balancing the structural geometry and bringing the center of mass closer to the center of resistance. While shear wall buildings may resemble regular framed structures in form and layout, they differ markedly in how they transfer and resist lateral loads. Unlike conventional columns and beams, shear walls act as rigid vertical diaphragms, absorbing and channeling lateral forces safely down into the foundation. In residential buildings, shear Walls often form a box-like system, providing most or all of the lateral support necessary.
Over the past two decades, shear walls have become increasingly crucial in the design of mid- and high-rise residential buildings, where structural stability under seismic conditions is a top priority. When correctly positioned as at corners, cores, or symmetrical intervals—shear walls effectively reduce horizontal displacements, thereby enhancing the overall earthquake resistance of a structure and protecting it from excessive sway or collapse. Thus, shear-wall- integrated designs have become a standard solution in modern seismic-resistant architecture.

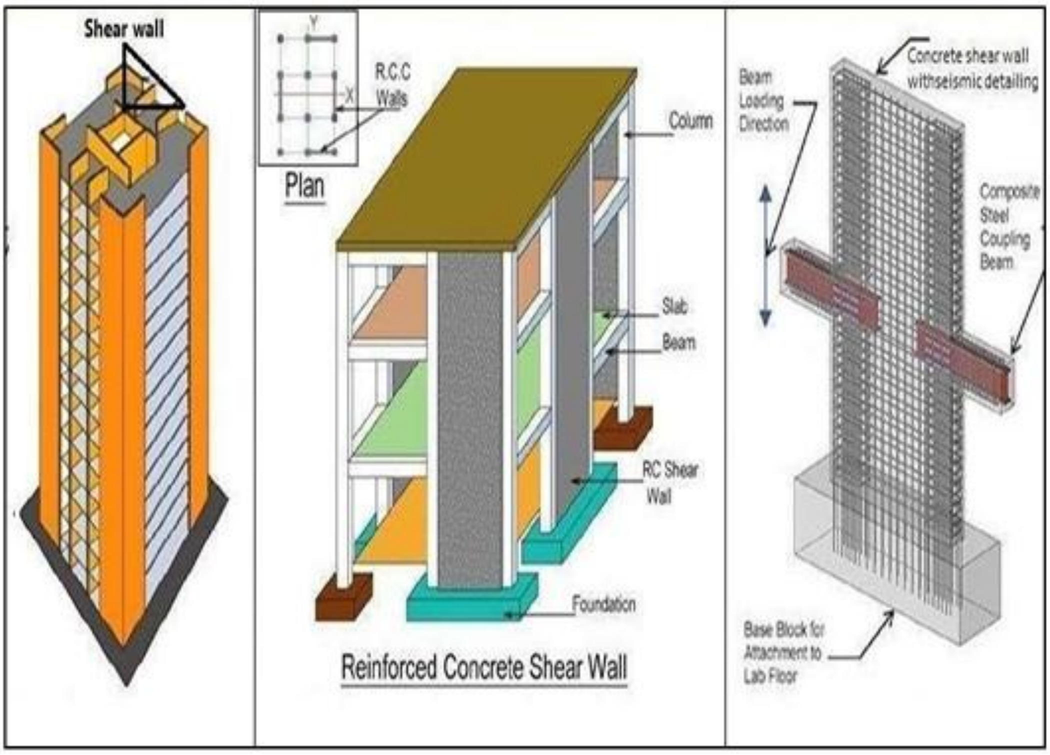


Fig. 2 Shear Wall

METHODOLOGY

2.1Problem Statement

To evaluate the seismic performance of high-rise buildings incorporating floating columns and shear walls, a G+9 structure located in the Shillong region was selected. The building occupies a 400 m² footprint with a square plan of 20 m × 20 m, and all four models assume a fixed-base condition and a uniform floor-to-floor height of 3 m. According to IS 1893 (Part 1):2016, the site lies in seismic Zone V on medium-type soil. Four distinct models were created for analysis using the response spectrum method:

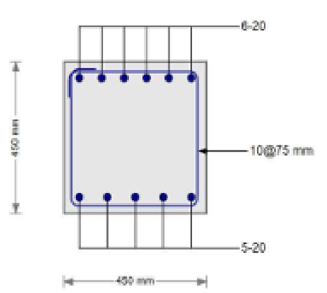
Model 1: Building without any floating columns.
Model 2: Building with floating columns only.
Model 3: Building with floating columns and shear walls located at the four corners.
Model 4: Building with floating and shear walls placed at intermediate exterior columns.

Properties of Building	
Height of building (m)	30
Plan area (sq.m)	400
Plan dimension (m)	20 X 20
Column sizes (mm)	
Base to 4th Storey	800 X 800
5th to 7th Storey	600 X 600
8th to 10th Storey	400 X 400
Beam size (mm)	450 X 450
Transfer Beam (mm)	900 X 900
Thickness of slab (mm)	125
External wall width (mm)	250
Internal wall width (mm)	150
Parapet wall width (mm)	250
Parapet wall height (m)	1
Shear wall width (mm)	250
Unit weight of concrete (KN/m^3)	25
Unit weight of masonry (KN/m^3)	20
Grade of Concrete	M25
Grade of Steel	Fe500

Loads Applied on Building	
Live Load Floor (KN/m)	2
Live Load Roof (KN/m)	1.5
Floor Finish (KN/m)	1.5
Roof Treatment (KN/m)	1.5
External Wall (KN/m)	13.5
Internal Wall (KN/m)	8.1
Parapet Wall (KN/m)	5

Seismic Parameters	
Seismic zone	V
Importance factor	1
Response reduction factor	5
Type of soil	II
Damping (%)	5

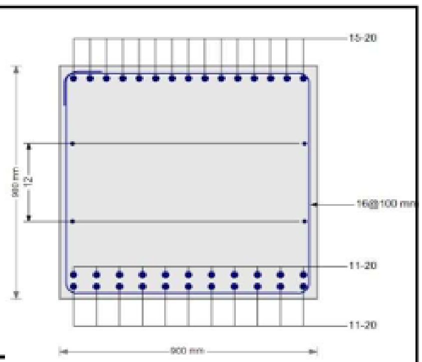
- **Reinforcements**



Beam 450 X 450

$A_{st} = 3456\ mm^2$

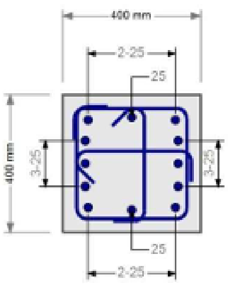
$P_t = 1.71\%$



Beam 900 X 900

$A_{st} = 12078\ mm^2$

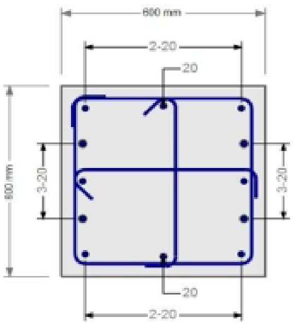
$P_t = 1.49\%$



Column 400 X 400

$A_{st} = 4909\ mm^2$

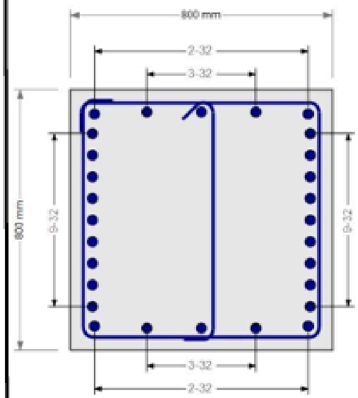
$P_t = 3.07\%$



Column 600 X 600

$A_{st} = 3770\ mm^2$

$P_t = 1.05\%$

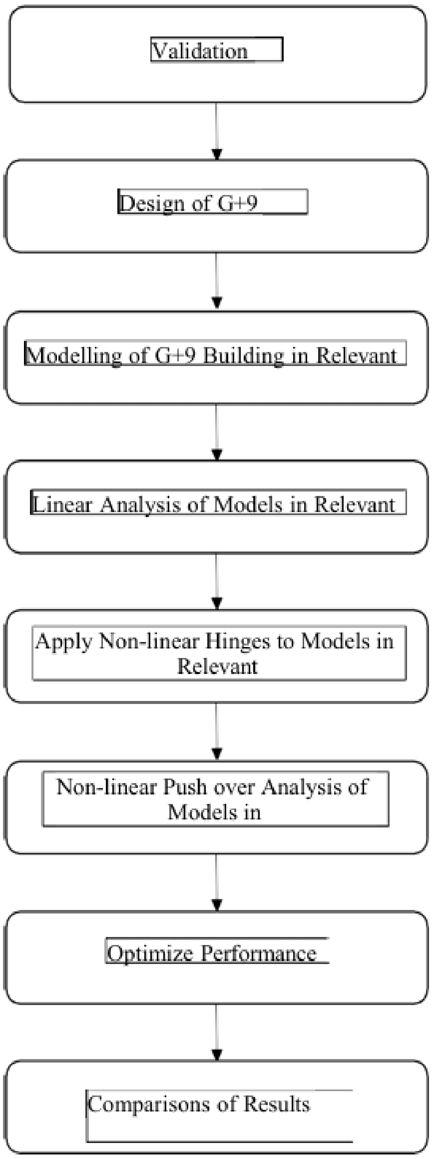


Column 800 X 800

$A_{st} = 17692\ mm^2$

$P_t = 2.76\%$

- **Methodology Chart**



2.2 Building without Floating Column

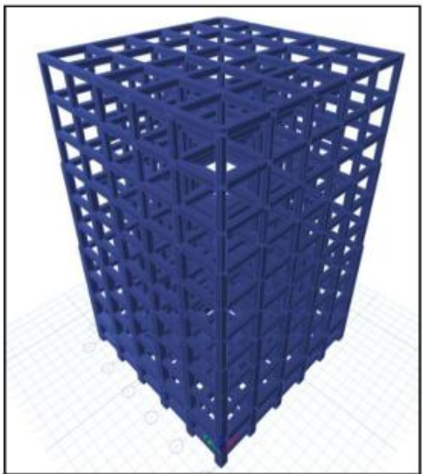


Fig. 8.1 3D Model

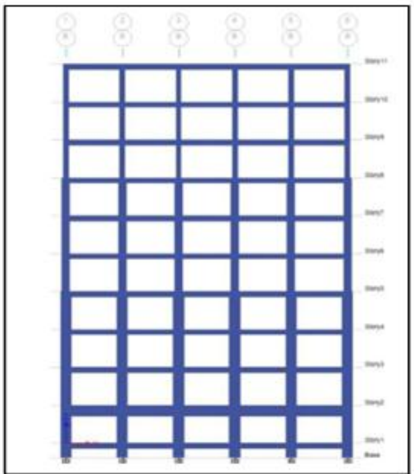


Fig. 8.2 Elevation

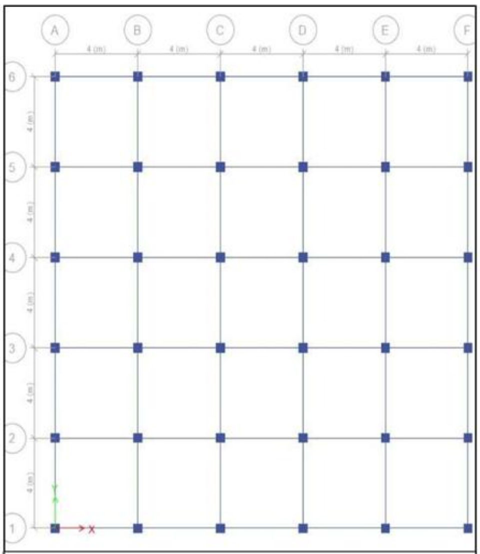


Fig. 8.3 Plan

2.3 Building with Floating Column

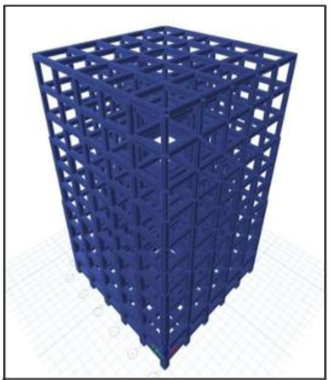


Fig. 8.4 3D Model

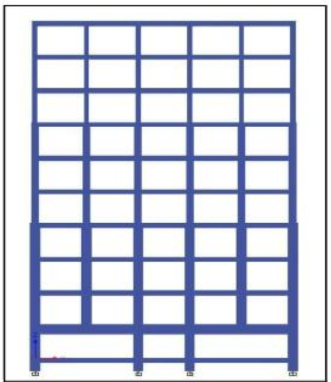


Fig. 8.5 Elevation

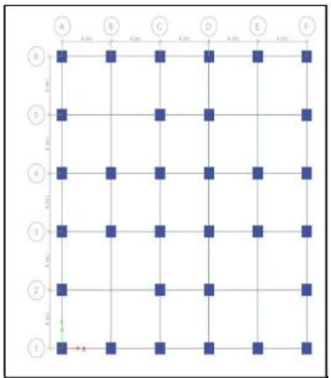


Fig. 8.6 Plan

2.4 Building with floating column and corner shear walls

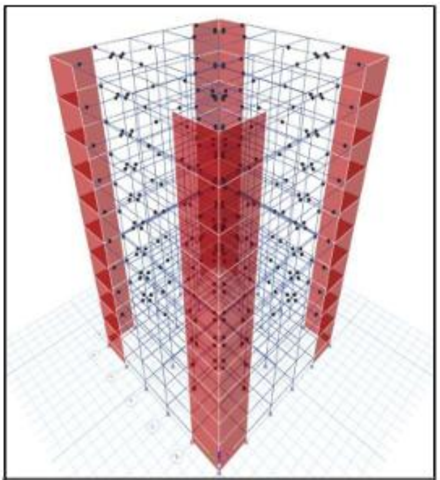


Fig. 8.7 3D Model

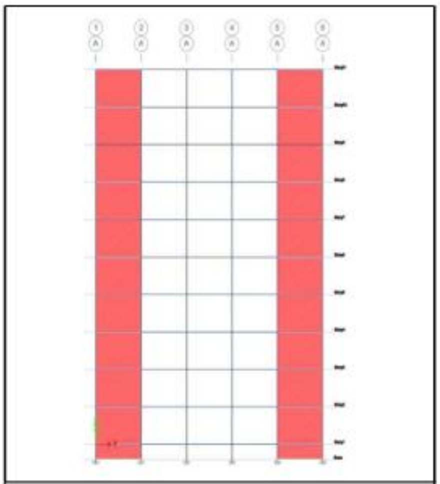


Fig. 8.8 Elevation

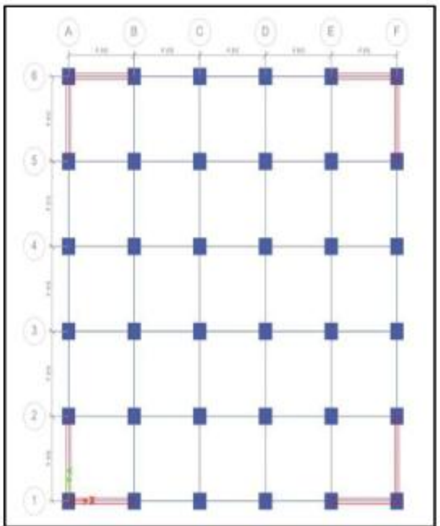


Fig. 8.9 Plan

RESULTS AND DISCUSSIONS

1. **Maximum Storey Displacement:**

Table 8.2 Displacement Vs Storey

Storey	Model 1	Model 2	Model 3	Model 4
0	0	0	0	0
1	0.967	0.972	0.774	0.482
2	2.586	2.59	1.865	1.039
3	5.326	5.492	3.436	1.777
4	8.418	8.866	5.261	2.605
5	11.862	12.661	7.34	3.528
6	14.988	16.21	9.578	4.508
7	17.712	19.389	11.883	5.508
8	21.213	23.284	14.266	6.521
9	23.632	26.131	16.609	7.506
10	24.814	27.648	18.868	8.44

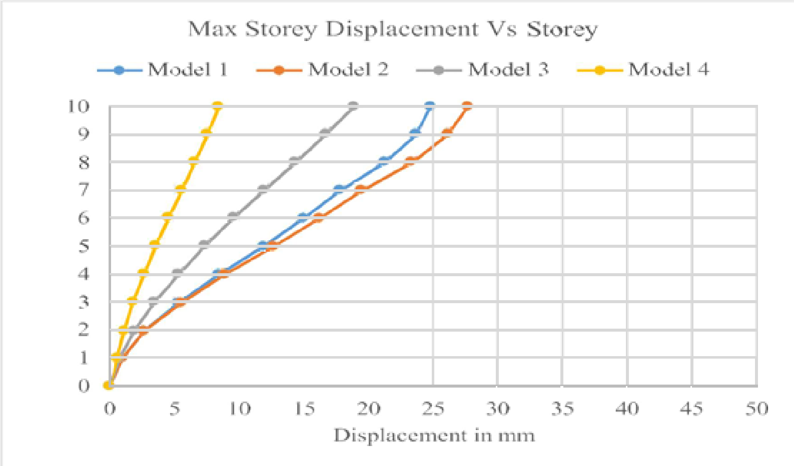


Fig. 8.13 Comparison of Maximum Storey Displacement for Response Spectrum Case in X - Direction

2. Storey Drift:

Table 8.3 Drift Vs Storey

Story	Model 1	Model 2	Model 3	Model 4
0	0	0	0	0
1	0.000275	0.000276	0.000224	0.000137
2	0.000541	0.000542	0.000365	0.000186
3	0.000918	0.000971	0.000525	0.000247
4	0.001039	0.001133	0.000611	0.000277
5	0.001171	0.001291	0.000697	0.00031
6	0.001087	0.00124	0.000752	0.000313
7	0.000975	0.001147	0.000759	0.000329
8	0.001326	0.001501	0.000775	0.000331
9	0.000974	0.001171	0.000789	0.000336
10	0.000492	0.000667	0.000803	0.000341

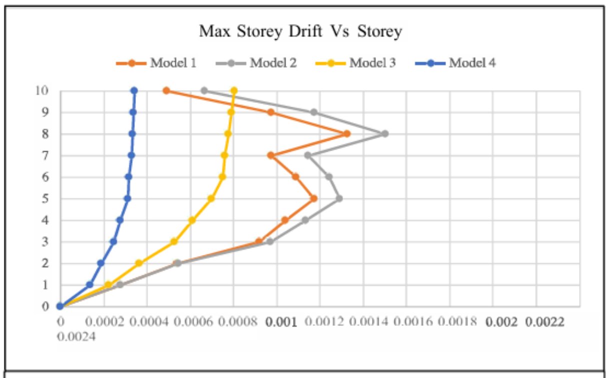


Fig. 8.14 Comparison of Maximum Storey Drift for Response Spectrum Case in X - Direction

3. Storey Shear:

Table 8.4 Storey Shear Vs Storey

Story	Model 1	Model 2	Model 3	Model 4
10	311.5495	549.7935	674.2999	938.6059
9	583.8566	989.2039	1561.195	2363.047
8	705.5321	1145.545	2213.414	3487.821
7	797.5477	1255.747	2721.888	4388.14
6	868.9562	1345.742	3139.287	5119.564
5	958.0424	1485.51	3494.126	5723.712
4	1078.815	1702.347	3797.875	6220.653
3	1196.936	1922.584	4044.362	6614.427
2	1301.075	2116.409	4218.441	6893.064
1	1436.021	2379.614	4375.659	7134.484
0	1447.754	2401.595	4387.186	7153.814

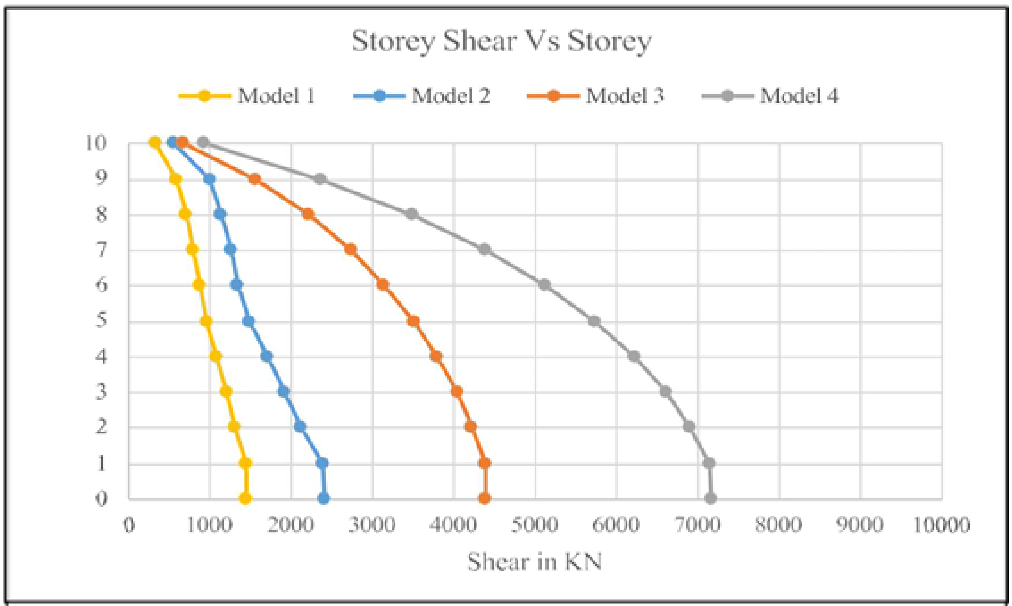


Fig. 8.15 Comparison of Maximum Storey Shear for Response Spectrum Case in X - Direction

4. Storey Shear:

Table 8.5 Displacement Vs Storey

Story	Model 1	Model 2	Model 3	Model 4
0	0	0	0	0
1	0.967	0.972	0.774	0.482
2	2.586	2.59	1.865	1.039
3	5.326	5.492	3.436	1.777
4	8.418	8.866	5.261	2.605
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9	23.628	26.131	16.609	7.506
10	24.81	27.648	18.868	8.44

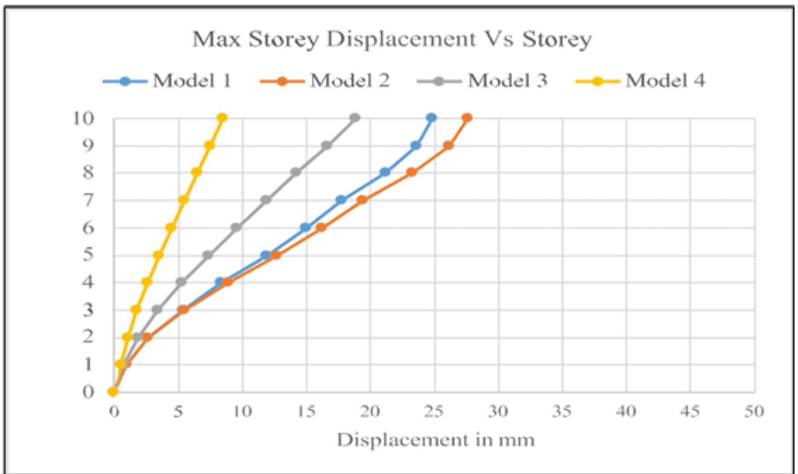

Fig. 8.16 Comparison of Maximum Storey Displacement for Response Spectrum Case in Y - Direction

CONCLUSIONS

1 Conclusions from Linear Analysis:-

1. In buildings with floating columns, the load from the floating storey is transferred to nearby columns via transfer beams, necessitating larger beam and column sections.
2. Compared to regular buildings, floating column buildings exhibit: 11.42% higher storey displacement, 13.28% higher storey drift, 65.88% higher storey shear.
3. Floating column buildings are more structurally unstable than conventional buildings.
4. Buildings with corner shear walls show: 31.75% less storey displacement, 48.36% less storey drift, 82.67% higher storey shear compared to floating column buildings.
5. Buildings with intermediate shear walls demonstrate: 69.47% less storey displacement, 77.94% less storey drift, 197.87% higher storey shear compared to floating column buildings.
6. The placement of shear walls significantly influences structural behavior, as observed from varying results in different models (e.g., Model 3 and Model 4).
7. As the building mass increases, storey shear also increases, indicating that greater mass attracts more earthquake force.
8. The time period of vibration is: 73.85% less in buildings with corner shear walls, 80.39% less in buildings with intermediate shear walls, compared to floating column buildings.
9. Installing shear walls in floating column structures greatly improves their seismic performance during earthquakes.

2 Conclusions from Non-linear Analysis:

1. In regular buildings, the base shear for a monitored displacement of 207 mm is 32.98% higher than in buildings with floating columns.
2. Buildings with corner shear walls have 166.08% higher base shear for the same displacement compared to floating column buildings.
3. Buildings with intermediate shear walls show an even greater increase, with 525.80% higher base shear for 207 mm displacement.
4. Higher base shear values indicate a greater ability to resist seismic loads while maintaining the same level of displacement.
5. In floating column structures, shear wall hinges near the floating storey reach the Life Safety (LS) state, while the floating column remains in the Immediate Occupancy (IO) state.

6. This behavior confirms the effectiveness of shear walls in protecting structural elements like floating columns and transfer beams, as failure occurs first in the shear wall rather than in the floating column system.

REFERENCES

1. *P. C. Wang and A. J. Philippacopoulos. Seismic Inputs for Nonlinear Structures. Journal of Engineering Mechanics, Vol. 110, No. 5, May, 1984. ©ASCE, ISSN 0733-9399/ 84/0005- 0828 (1984).*
2. *Jack P. Moehle and Luis F. Alarcon. Seismic Analysis Methods for Irregular Buildings. Journal of Structural Engineering, Vol. 112, No. 1, January, 1986. ©ASCE, ISSN 0733-9445 (1986).*
3. *Carlos E. Ventura and Bruce F. Maison. Dynamic Analysis of Thirteen-Story Building Journal of Structural Engineering, Vol. 117, No. 12, December,1991. ©ASCE, ISSN 0733- 9445/91/0012-3783 (1991).*
4. *Sudhir K. Jain. A Proposed Draft for IS:1893 provisions on seismic design of buildings – Part – II: Commentary and Examples. Journal of Structural Engineering Vol. 22 No. 2 July 1995 pp 73-90. (1995)*
5. *Jaswant N. Arlekar, Sudhir K. Jain, and C.V.R. Murty. Seismic Response of RC Frame Buildings with Soft First Storeys. Proceedings of the CBRI Golden Jubilee Conference on Natural Hazards in Urban Habitat, New Delhi. (1997).*
6. *Abbas Moustafa. Critical earthquake load inputs for multi-degree-of-freedom inelastic structures, Journal of Sound and Vibration (2009)*
7. *N. R. Chandak. Response Spectrum Analysis of Reinforced Concrete Buildings. Journal Institution of Engineers India Ser. A (May–July 2012) 93(2):121–128 (2012)*
8. *Keerthi Gowda B. S. and Syed Tajuddin. Seismic Analysis of Multistorey Building with Floating Columns. Proceedings of the First Annual Conference on Innovations and Developments in Civil Engineering, ACIDIC 2014, NITK, India. (2014)*
9. *Sabari S and Praveen J. V. Seismic Analysis of Multistorey Building with Floating Column. International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online) Vol. 2, Issue 2, pp: (12-23), Month: October 2014 - March 2015 (2015)*
10. *Sarika Yadav, Raksha Parolkar. Seismic Behaviour of Multistorey Buildings Having Floating Columns. International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online) Vol. 4, Issue 1, pp: (87-94), Month: September 2016 (2016)*
11. *Israa H. Nayel, Zahraa M. Kadhum, and Shereen Q. Abdulridha. The Effect of Shear Wall Locations in RC Multistorey Building with Floating Column Subjected to Seismic Load. International Journal of Civil Engineering and Technology (IJCIET), Volume 9, Issue 7, July 2018, ISSN Print: 0976-6308 and ISSN Online: 0976-6316 (2018).*
12. *N. H. M. Kamrujjaman Serker and Kishalay Maitra. Evaluation of Seismic Performance of Floating Column Building. American Journal of Civil Engineering. Vol. 6, No. 2, 2018, pp. 55-59. doi: 10.11648/j.ajce.20180602.11 (2018).*
13. *Rashi Chaurasia and Ankit Pal. Comparative Analysis of Multi-Storey RC Frame Building with and without Floating Column using Base-Isolation in Seismic Zone V. International Journal of Advanced Engineering Research and Science (IJAERS) [Vol -6, Issue-6, June- 2019], ISSN: 2349-6495(P) | 2456-1908(O) (2019).*
14. *Ahmed Ibrahim and Hamed Askar. Dynamic Analysis of a Multi-story Frame RC Building with and Without Floating Columns. American Journal of Civil Engineering. Vol. 9, No. 6, 2021, pp. 177-185. doi: 10.11648/j.ajce.20210906.11 (2021).*