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Comparative Evaluation of Structural Stability in Multi-Storey Buildings with Floating Columns and Rotating Columns

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Abstract

Rapid urbanization has increased the use of innovative structural systems such as floating columns and rotating columns to meet architectural and space requirements in high-rise buildings. This study presents a comparative seismic analysis of G+15 reinforced concrete buildings with floating columns, rotating columns, and conventional RCC frames using STAAD Pro V8i. The analysis is carried out for Seismic Zone III according to IS 1893:2002 by evaluating support reactions, base shear, storey displacement, storey drift, node displacement, shear forces, and bending moments. The results show that floating columns increase seismic response, leading to higher support reactions, base shear, displacements, and internal forces compared to conventional buildings. In contrast, rotating columns demonstrate improved seismic performance with reduced storey and node displacements while maintaining structural stability. The study concludes that floating columns require additional strengthening for safe use in seismic regions, whereas rotating columns provide a more efficient alternative for achieving architectural flexibility with better earthquake resistance.

Keywords: Floating column; Rotating column; Seismic analysis; Storey drift

1. Introduction

India's rapid urbanization has transformed the construction landscape, with multi-storey buildings becoming increasingly prevalent in metropolitan cities. This growth has necessitated innovative architectural solutions to address the competing demands of space optimization, functional requirements, and aesthetic considerations. Two such innovations—floating columns and rotating columns—have emerged as architectural solutions, offering distinct advantages while introducing structural complexities that demand careful seismic consideration.

Floating Columns represent a vertical structural member that does not extend to the foundation but rests on a horizontal beam at an intermediate floor level. This configuration is traditionally defined as a vertical member that originates from the foundation level and transmits loads to the ground. However, in modern construction, floating columns are frequently implemented above ground floors to maximize open space for parking, assembly halls, or commercial purposes. The supporting beam experiences a concentrated load from the column, which is commonly treated as a point load in structural analysis. While floating columns offer architectural flexibility and increased usable space, they introduce significant structural irregularities that can compromise seismic performance.

Rotating Columns, on the other hand, are designed to allow rotational movement around their vertical axis. Unlike traditional RCC columns that are static and fixed in position, rotating columns require specialized design considerations and detailing to ensure their functionality, stability, and safety. These columns must be designed to handle both vertical loads from the structure they support and any additional rotational loads that might occur during their intended use.

The seismic vulnerability of buildings with floating columns has been well-documented in literature. These structures are primarily designed to withstand self-weight, making them safe under static conditions but vulnerable in seismic-prone regions. The fundamental principle of "weak beam-strong column" design becomes particularly crucial in such structures, where columns must possess greater stiffness compared to beams to prevent shear-induced deformation. The overall stiffness of the building depends significantly on the careful selection of appropriate shape, size, and orientation of columns, particularly in buildings with irregular structural configurations.

The primary objectives of this research are:

- To develop multi-storey models of conventional RCC structures, structures with floating columns, and structures with rotating columns using structural analysis software
- To evaluate and compare critical structural parameters including displacement, base shear, storey drift, shear force, bending moment, and deflection
- To provide recommendations for enhancing seismic performance of structures with floating and rotating columns.

2. Literature Review

Ahirwar and Satbhaiya (2020) [1] examined the construction of structures with floating columns in earthquake-prone regions, emphasizing the undesirability of such configurations in seismic zones. Their analysis, conducted using STAAD Pro V8i, demonstrated that structural integrity was compromised during seismic events, requiring increased dimensions of beams and columns for safety Malaviya (2014) [2] explained that floating columns act as concentrated loads on supporting beams and are typically analyzed assuming pin connections at their bases. While floating columns can handle gravitational loads, the transfer girder must have sufficient dimensions and stiffness to ensure minimal deflection.

Sreadha and Pany (2020) [3] presented a comprehensive review comparing structures with and without floating columns using ETABS software. Their research concluded that floating columns result in the highest displacement compared to conventional structures, with displacement values increasing from lower to higher storeys. Nanabala et al. (2014) [4] investigated the response of floating column buildings under past earthquake intensities. Their findings revealed significant soft storey effects in floating column buildings, raising concerns about structural safety. The displacement in the Z-direction was notably larger compared to conventional buildings, making floating column buildings potentially unsafe. Meghana and Sadashiva Murthy (2016) [5] studied steel-concrete composite structures with floating columns at various locations. Their analysis showed that floating columns reduced base shear values due to decreased mass, contributing to more efficient seismic response and reduced lateral forces transmitted to the foundation.

Gowda and Tajoddeen (2014) [6] determined that multi-storey structures with floating columns exhibited suboptimal performance under seismic excitation. They recommended introducing lateral bracings to enhance seismic performance. Ibrahim and Askar (2021) [7] conducted dynamic analysis of five-story buildings with and without floating columns using ETABS Ultimate. Their findings conclusively demonstrated that buildings with floating columns exhibited higher displacement, drift, and reduced stiffness, leading to increased overall structural costs. Mundada and Sawdatkar (2014) [9] focused on architectural drawings and load distribution in structures with floating columns, finding that deflection in such buildings is comparatively higher than those equipped with struts.

Rohilla et al. (2015) [10] investigated G+5 and G+7 reinforced concrete structures with floating columns in seismic Zones II and V. Their research concluded that high-rise buildings in Zone V should refrain from incorporating floating columns due to suboptimal performance.

Motghare (2016) [11] analyzed the behaviour of RCC frames with various floating column configurations, revealing higher bending moments in structures with floating columns compared to cases without such columns. Joshi et al. (2013) [12] investigated the significant role of soft storeys in seismic performance of high-rise buildings, demonstrating that moments and shear forces reach maximum values when the first storey is soft.

Sharath and Sonawadekar (2015) [13] examined how column orientation influences structural behaviour under seismic loading, studying G+5, G+7, and G+9 buildings with rectangular columns oriented about both main and minor axes. Firdous and Gupta (2017) [14] conducted a critical evaluation of the effect of soft storeys and column orientation on RC buildings, recommending the use of circular columns to be avoided as they can lead to increased base shear.

Chakravarthy (2015) [15] analyzed tall buildings with floating columns under seismic activity, concluding that the cost of buildings is significantly elevated when design provisions must withstand strong earthquake impacts. Chaurasia and Pal (2019) [8] employed software-based dynamic analysis of multistorey structures in seismic Zone V, concluding that floating columns are not optimal in seismic zones due to their contribution to building irregularity and soft storey effects.

The comprehensive literature review reveals several critical findings:

- Floating columns introduce significant structural irregularities that compromise seismic performance, leading to higher displacements, drifts, and reduced stiffness.
- Structures with floating columns require increased dimensions of beams and columns, particularly in seismic zones, to ensure structural safety.
- The presence of floating columns creates soft storey effects, resulting in unfavourable structural behaviour under seismic excitation.
- Column orientation plays a crucial role in determining the lateral stiffness of buildings, with careful consideration needed to avoid irregularities.
- Limited research exists on rotating columns as a potential alternative to floating columns for achieving architectural flexibility while maintaining structural integrity.

3. Methodology

The study involves three G+15 reinforced concrete building models:
Model 1: Conventional Building (without floating or rotating columns)

Model 2: Building with Floating Columns

Model 3: Building with Rotating Columns

Building Specifications:

- Number of floors: G+15
- Floor height: 3.0 m
- Overall height: 48.0 m
- Grade of concrete: M20 (beam and slab), M25 (column)
- Grade of steel: Fe 415
- Slab thickness: 125 mm
- Wall thickness: 230 mm (9")
- Soil type: Class II (moderate soil)
- Seismic zone: III
- Damping ratio: 5%
- Structure type: RC frame structure (SMRF - Special Moment Resisting Frame)

Functional Layout:

- Basement: Parking
- Ground floor: Commercial purposes
- Floors 2-15: Residential (four 2BHK flats per floor)
- Total flats: 56

Loading Details:

Dead Load (DL):

- Self-weight of structural members calculated using unit weight of concrete (25 kN/m^3)
- Wall load using unit weight of brick (19 kN/m^3)
- Floor finish: 1 kN/m^2

Live Load (LL):

- Residential floors: 2 kN/m^2
- Commercial ground floor: As per IS 875 Part 2

Seismic Loading (as per IS 1893-2002):

- Zone III (Z): 0.16
- Importance factor (I): 1.0
- Soil type: Class II (moderate soil)
- Damping ratio: 5%
- Response reduction factor: 5 (SMRF)

Load Combinations:

- 1.5(DL + LL)
- 1.2(DL + LL + EQ X)
- 1.2(DL + LL + EQ Z)

4. Modeling and Analysis

The structural analysis was conducted using STAAD Pro V8i software. The modeling process involved:

Plan Preparation: Architectural plans were prepared using AutoCAD software for residential floors and commercial ground floor.

Beam-Column Marking: Structural grids were established with proper identification of beam and column positions.

Floating Column Configuration: Floating columns were introduced at specific locations where columns from upper floors rest on beams at intermediate levels.

Rotating Column Configuration: Columns capable of rotation around their vertical axis were designed with appropriate support conditions.

Parameter Evaluation: The following structural parameters were evaluated:

- Support reactions
- Base shear
- Storey displacement
- Storey drift
- Node displacement
- Shear force (beam and column)
- Bending moment

5. Result

Support Reactions

Table 1 presents the maximum and minimum support reactions for the three building configurations under load combination 1.2(DL+LL+EQX).

Table 1: Maximum and Minimum Support Reactions

Support Reaction	Load Combination	Conventional Building	Building with Floating Column	Building with Rotating Column
Max Fy	1.2(DL+LL+EQX)	5071.19 KN	5569.354 KN	5081.26 KN
Min Fy	1.2(DL+LL+EQX)	2555.646 KN	2550.94 KN	2548.267 KN

- The building with floating columns shows 9.82% higher maximum support reactions compared to the conventional building.
- Buildings with rotating columns demonstrate support reactions closely approximating those of conventional structures.
- Floating columns create significant stress concentrations at support points.

Table 2: Maximum Base Shear

Direction	Conventional Building	Building with Floating Column	Building with Rotating Column
X-Direction	1866.76 KN	1994.43 KN	1895.12 KN
Z-Direction	1619.47 KN	1730.23 KN	1644.07 KN

- X-Direction: Floating column building shows 6.83% higher base shear than conventional; rotating column shows 1.52% higher.
- Z-Direction: Floating column building shows 7.02% higher base shear; rotating column shows 1.70% higher.
- Time periods: X-direction = 0.80290 sec, Z-direction = 0.92550 sec
- Sa/g values: X-direction = 1.694, Z-direction = 1.469

Table 3: Maximum Shear Forces in Beams and Columns

Shear Force	Conventional Building	Building with Floating Column	Building with Rotating Column
Beam SF Y-Dir (Positive)	124.451 KN	481.605 KN	124.499 KN
Beam SF Y-Dir (Negative)	-127.35 KN	-465.65 KN	-125.284 KN
Beam SF Z-Dir (Positive)	87.295 KN	205.489 KN	85.686 KN
Beam SF Z-Dir (Negative)	-77.279 KN	-151.433 KN	-83.101 KN

- Floating columns induce 287% increase in beam shear forces in Y-direction.
- Rotating columns maintain shear forces comparable to conventional structures.
- Significant stress concentration occurs at beam-column junctions with floating columns.

The comprehensive analysis reveals distinct performance characteristics for each structural configuration:
Floating Columns:

- Support Reactions: 9.82% higher than conventional structures, indicating increased load concentration at support points
- Base Shear: 6.83% higher in X-direction and 7.02% higher in Z-direction, suggesting reduced lateral stiffness
- Storey Displacement: Significantly higher in both directions, with Z-direction showing 29.33% increase
- Storey Drift: Maximum at mid-height storeys (Storey 5 in X-direction, Storey 6 in Z-direction)
- Node Displacement: 15.97% higher in X-direction and 27% higher in Z-direction
- Shear Forces: 287% increase in beam shear forces, indicating severe stress concentration
- Bending Moments: 56% increase in positive bending moments

Rotating Columns:

- Support Reactions: Comparable to conventional structures
- Base Shear: Marginally higher (1.52-1.70%) than conventional structures

- Storey Displacement: 8.23% lower in Z-direction than conventional structures
- Storey Drift: Improved performance in Z-direction
- Node Displacement: 8.93% lower in Z-direction than conventional structures
- Shear Forces: Comparable to conventional structures
- Bending Moments: Slightly reduced compared to conventional structures

Conclusion

- Based on the comprehensive comparative analysis of conventional buildings, buildings with floating columns, and buildings with rotating columns under seismic Zone III conditions, the following conclusions are drawn:
- Support Reactions: Buildings with floating columns exhibit 9.82% higher support reactions compared to conventional structures, while buildings with rotating columns demonstrate support reactions closely approximating those of conventional buildings.
- Base Shear: Floating column buildings show 6.83% higher base shear in X-direction and 7.02% higher in Z-direction compared to conventional structures. Rotating column buildings show marginal increases of 1.52% and 1.70% respectively.
- Storey Displacement: In X-direction, floating column buildings show 15.77% higher displacement, while rotating column buildings show 12.47% higher displacement than conventional structures. In Z-direction, floating column buildings show 29.33% higher displacement, while rotating column buildings show 8.23% lower displacement.
- Storey Drift: Maximum storey drifts occur at Storey 5 in X-direction and Storey 6 in Z-direction across all configurations.

Declaration of Conflicting Interests

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