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BEHAVIOR OF GRAVITY COLUMN UNDER SEISMIC LOADING

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ABSTRACT

The seismic performance of RC structures incorporating gravity column in conjunction with shear wall has evolved significantly over the years, driven by the need for cost- efficient structural system. This study evaluates a G+6 RC building under seismic loading, comparing three configurations, conventional column (Model-1), conventional column and shear wall (Model-2) and conventional column and shear walls (Model-4). Gravity column were modelled in ETABS using moment release (M22 and M33) to ensure they resist only vertical loads, a method validate for its accuracy and constructability. Response spectrum analysis (RSA) revealed that Model-2 exhibited the highest lateral stiffness, with 14-20% lower time period and 10-15% reduced displacement compared to Model-1. Model-4 incorporating gravity columns, achieved 85-95% of Model-2's performance, with marginal 1.4-2.4% reduction in base shear and 3.2% longer time periods, indicating balanced stiffness and flexibility. The finding highlights the practical application of gravity column in mid-rise building, particularly in seismic zone-III where they optimize space, reduce construction cost.

Keywords: Gravity Column, Reinforced Concrete Structure, Seismic Events, Load Distribution

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1. Introduction

Reinforced concrete (RC) structures are engineered to endure various loads, including both gravitational and lateral forces. Structural lateral support system, such as shear walls and moment-frames, are specifically designed to counteract earthquake loads. However, gravity columns, which primarily facilitate vertical load transfer, play a vital yet frequently underestimated role in the overall structural behaviour. The performance of these gravity columns during seismic events can greatly influence the building's stability, stiffness, and failure modes. In numerous existing RC buildings, gravity columns are often designed with limited attention to lateral loads, which may create vulnerabilities in seismic event. The interaction between gravity load columns and LFRSs, especially regarding load redistribution and stiffness contributions, is a complex issue that necessitates comprehensive analysis. The risk of soft-story mechanisms, where the failure of gravity columns at a specific level results in excessive damage, poses a serious threat to the structural integrity. This review paper intends to compile and critically assess the current research concerning the impact of gravity columns on the seismic performance of RC buildings. It will explore the effects of various factors, including column configuration, reinforcement detailing, and their interaction with LFRSs. Additionally, it will review existing design codes and guidelines to pinpoint areas that require enhancement in the design and detailing of gravity columns. By emphasizing the necessity of accurately evaluating the role of gravity columns, this review aims to foster a deeper understanding of their significance in seismic performance and to advocate for the development of effective design strategies for safer and more resilient RC structures. The gravity column plays a crucial role in the overall stability and functionality of a building structure. Its primary importance lies in carrying and transferring vertical loads which include self-weight from the structure itself, imposed loads from occupancy safely down to the foundation. This interaction is particularly critical in mid- rise structures, where moderate building height leads to measurable drift that affects gravity column performance. If not properly detailed, these columns may become susceptible to instability, P-Δ effects, and even failure under combined axial and lateral loads.

II. Methodology

Response Spectrum Analysis (RSA) is a widely used method in structural engineering for evaluating seismic response, particularly for multi-degree-of-freedom systems. It is a linear dynamic analysis technique that estimates the peak responses of structures during an earthquake by using a predefined response spectrum, which represents the maximum response of a system subjected to ground motion. Instead of applying time-varying seismic loads directly, RSA simplifies the analysis by considering the maximum response contribution of each mode of vibration

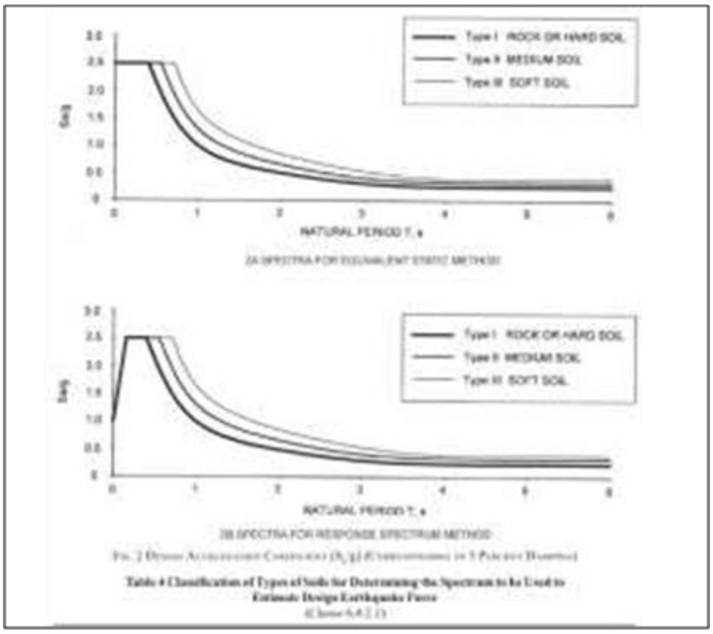

Fig. 1 Response Spectrum Curve

In seismic analysis, particularly Response Spectrum Analysis (RSA), the design response spectrum provided in IS 1893 (Part 1): 2016 serves as a critical input for evaluating structural response to earthquakes. This standardized spectrum represents the peak responses of an idealized single-degree- of-freedom system subjected to a specified level of ground motion and is defined for various soil types and damping levels. The code offers a normalized acceleration spectrum based on the Peak Ground Acceleration (PGA) for a given seismic zone, which is scaled by the Zone Factor (Z). The spectral acceleration values are further influenced by the Importance Factor (I), Response Reduction Factor (R), and soil type (through spectral shape coefficients). During analysis, this curve is used to compute the maximum expected response of each mode of a structure, which are then combined to estimate total seismic demand.

III. Model Description

A. Model Description:

The building model considered for analysis is a multi-storey reinforced concrete (RC) frame structure with a total height of 25.6 meters from the ground level to the top of the parapet wall. The building spans 49.47 meters in the horizontal direction (X) and 21.8666 meters in the vertical direction (Y), measured from centre to centre of the outermost columns.

Table 1 Model Description

Building Height (From Ground to Parapet Wall)	25.6 m.
Building Length X-direction	49.47 m. c/c
Building Length Y-direction	21.8666 m. c/c
Parking Floor Height	5.2 m.
Beam Size	230 mm X 600 mm
Column Size	350 mm X 920 mm
Shear Wall Thickness	230 mm
Floor to Floor Height (Typical)	3 m.
Seismic Zone	III
Importance Factor	1
Response Reduction Factor	5
Concrete Grade	M30
Steel Grade	Fe500

B. ETABS Model:

The structural model was developed and analyzed using ETABS, a widely used finite element software for structural analysis and design. The building modelled as G+6 reinforced concrete structure. The building is analyzed using response spectrum analysis and lateral loads were applied in accordance with the codal response spectrum.

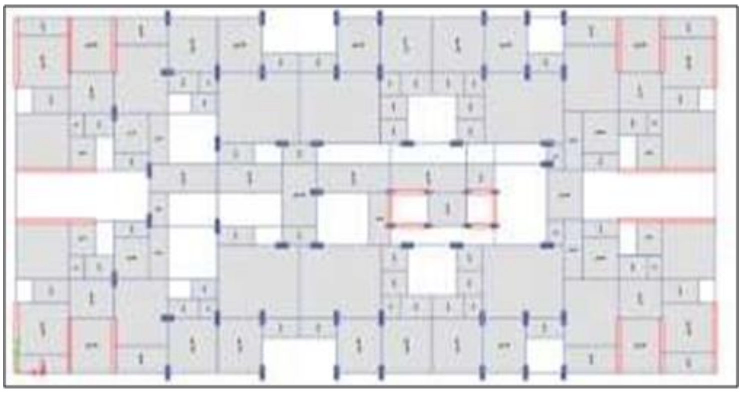

Fig. 2 ETABS Model with conventional columns

As per fig. 2 ETABS modelled with importing center line plan into AutoCAD. Total 16 shear walls are used excluding lift shear walls. This shear walls increase overall lateral stiffness of structure because maximum lateral force is resisted by shear wall.

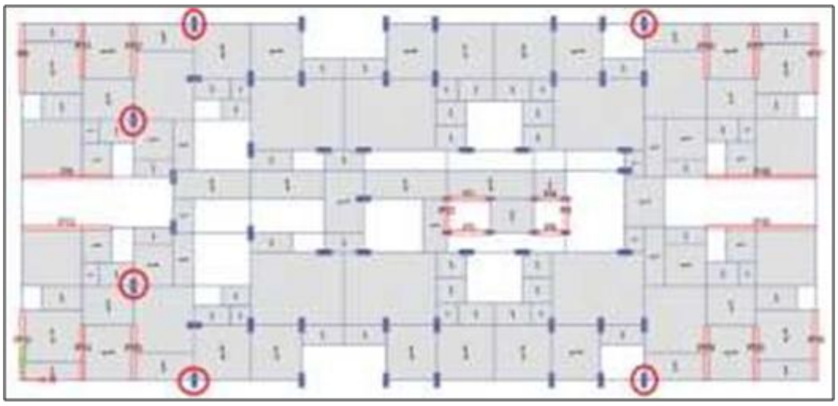

Fig. 3 ETABS Model considering Gravity Columns

So if we can make some column as gravity column means only for vertical load only and separating gravity load and lateral load resisting system the column would require less cross section resulting in minimizing reinforcement and increasing carpet area. As shown in fig. 3 the 6 columns which are marked with red are considered as gravity column by assigning moment release (M22 and M33). This assign will make results in exclusion of this marked column from resisting lateral load. Also all six selected columns are located at the outer edge of the floor plan, where lateral stiffness contribution of column to overall structure is less compared to core column because of introduction of shear walls at periphery. By preserving moment resisting in central core column while releasing moment/ modifying stiffness in edges, we can reduce torsion irregularities.

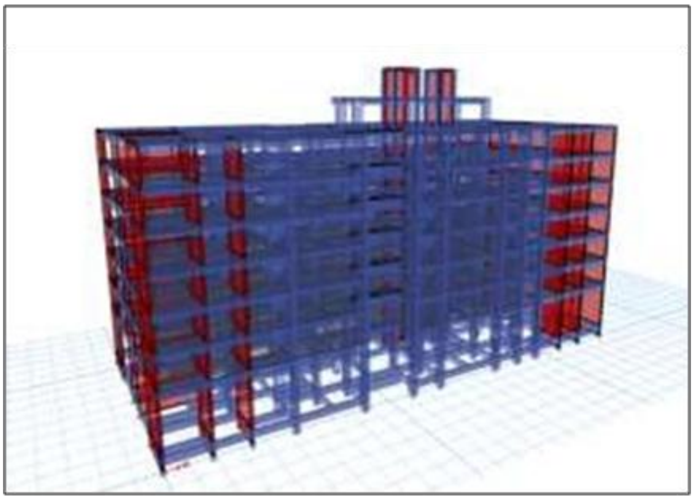

Fig. 4 ETABS 3D Model

There is another option for assigning column as gravity column in ETABS. By assigning stiffness modifier to column at top and bottom (I22 & I33=0.01) [1] which means reducing flexure stiffness of column so that column would not take moment or minimal moments. These modifiers represent the moment of inertia about the local 2-2 and 3-3 axes, respectively, which directly influence the bending stiffness of the column in those directions. When modelling a gravity column—one that is intended to carry only vertical (gravity) loads and not contribute to lateral load resistance engineers often reduce these stiffness values significantly. By setting I22 and I33 to 0.01, the column's bending stiffness is reduced to just 1% of its original value in both principal directions. This makes the column nearly incapable of resisting moments, effectively removing its ability to contribute to the shear wall. As a result, the column behaves like a gravity-only member, meaning it supports vertical loads but does not engage in resisting seismic or wind-induced lateral forces.

Table 2 Models used for Comparison

Models	**Description**
Model-1	Base Model
Model-2	Moment Release
Model-3	Stiffness Modifier

Model-1 consist of shear wall and conventional column as shown in fig. 1. In which shear walls are strategically placed so that there should be effective load distribution and removetorsion regularity. Model-2 consist of 6 columns with red circle marked in fig. 3 with moment release to make them as only gravity columns. Model-3 consist of 6 columns same from fig. 3 with stiffness modifier 0.01. This 3 models are analyzed and compared and checked which model has effective results and which method is effective to assign column as gravity column with considering real word scenario and ease of construction.

C. Loads:

In this study, the structural analysis of a G+6 reinforced concrete (RC) building was carried out using ETABS, where appropriate loading conditions were defined as per the guidelines of IS 875 (Part 1 & 2) and IS 1893:2016 for seismic evaluation. The gravity loads included self-weight (automatically assigned in ETABS), dead loads such as floor finishes (1.5 KN/m² in rooms and passages, and 4.0 KN/m² in lift/toilet areas), and imposed live loads (2.0 KN/m² for rooms, 3.0 KN/m² for passages, and 15.0 KN/m² for lift cabin areas). Additional distributed loads like hidden beam loads (2.8 KN/m²) were also applied over slabs to simulate realistic weight distribution. Additionally, 25 load combinations were defined under the Ultimate Limit State (ULS), combining dead loads, live loads, seismic loads (EQ±X, EQ±Y), and wind loads (WL±X, WL±Y) with appropriate load factors (e.g., 1.5DL + 1.5LL, 1.2DL + 1.2LL ± 1.2EQX/Y). These combinations ensure the building is checked for the most critical design scenarios, satisfying structural safety and serviceability requirements under both vertical and lateral actions.

IV. Results and Discussion

After analysing this results further models are compared with key parameters like time period, storey drift, and results are evaluated to assess the performance of structure having gravity column under seismic loading and effective technique for assigning column as gravity only column.

A. Time Period:

The fundamental natural time period of a structure refers to the duration it takes for the building to undergo one complete cycle of free vibration after being disturbed from its original resting state. This property is crucial for understanding how the structure reacts to seismic or dynamic forces.

Table 3 Time Period (Sec)

Mode Shape	Model-1	Model-2	Model-3
1	0.84	0.86	0.87
2	0.74	0.76	0.76
3	0.71	0.74	0.75
4	0.20	0.21	0.21
5	0.18	0.18	0.18
6	0.17	0.17	0.17
7	0.16	0.17	0.17
8	0.08	0.08	0.08
9	0.08	0.08	0.08
10	0.06	0.06	0.06
11	0.04	0.04	0.04
12	0.03	0.04	0.04

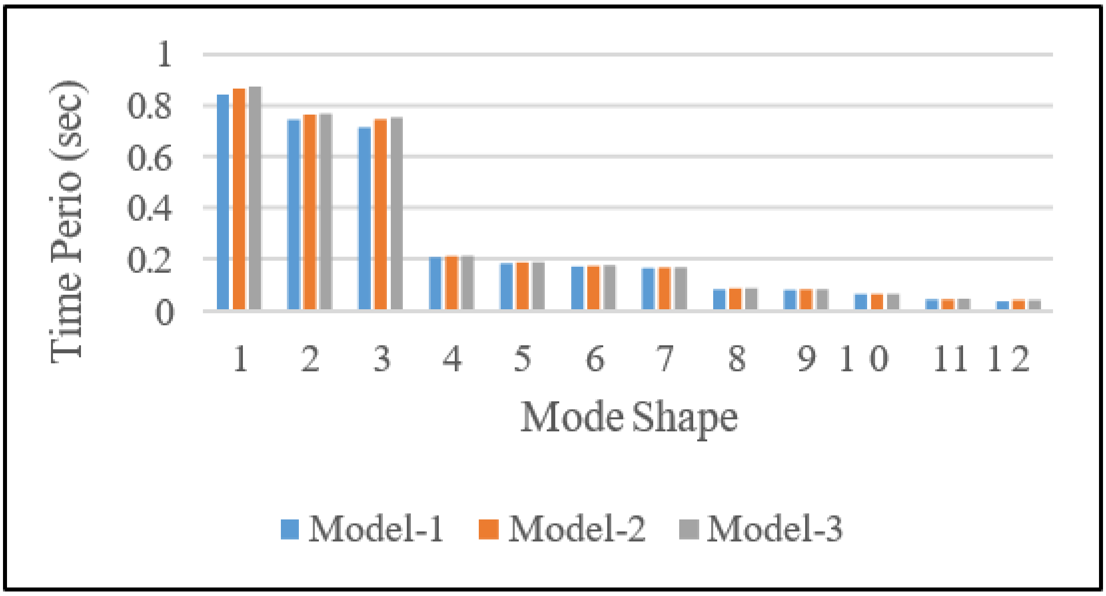

Fig. 5 Time Period (Sec)

The fig. 5 illustrates the comparison of time period between three models. In the first three modes, which typically govern the lateral behaviour of the structure, there is a clear increase in the time period from Model-1 to Model-3. For Mode-1, the time period increases from 0.84 seconds in Model-1 to 0.86 seconds in Model-2 2.38% increase, and further to 0.87 seconds in Model-3 with 3.57% increase compared to the base. Similar trends are observed in Mode-2 and Mode-3, with Model-2 showing a modest increase around 2.7% for Mode 2 and 4.2% for Mode-3, and Model-3 showing slightly more around 2.7% for Mode 2 and 5.6% for Mode-3. This indicates that both the moment release and stiffness modifier methods reduce the lateral stiffness of the structure, leading to longer time periods. The structure sways more and becomes dynamically more flexible. However, the stiffness modifier method results in a slightly greater reduction in stiffness, likely due to the columns still retaining minimal bending stiffness rather than being fully pinned.

B. Storey Drift (SPEC-X):

Storey drift is the horizontal movement between different levels of a building, primarily caused by forces like wind or seismic activity. This measurement is crucial in structural design and earthquake resilience since excessive drift can result in damage to both structural and non-structural elements, including walls, partitions, and windows even if the structure itself remains standing.

Table 4 Drift (mm) SPEC-X

Floor Levels	Model-1	Model-2	Model-3
GL	0.000012	0.000062	0.000065
1st	0.000031	0.000112	0.000112
2nd	0.00029	0.000167	0.000167
3rd	0.000303	0.000186	0.000186
4th	0.000294	0.000193	0.000193
5th	0.000281	0.00019	0.00019
6th	0.000256	0.000182	0.000182
7th	0.00032	0.000169	0.000169

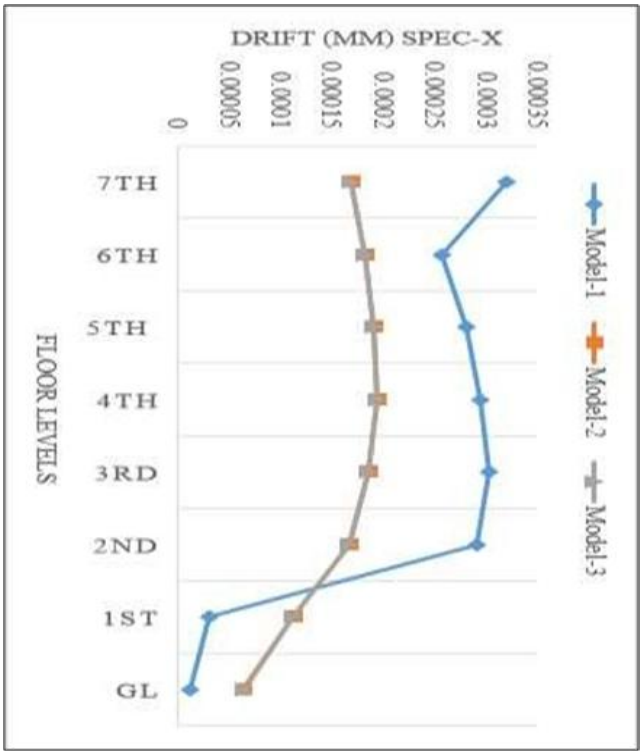

Fig. 6 Storey Drift (mm) SPEC-X

The storey drift behavior in the X-direction (SPEC-X) for the three ETABS models — Model-1 (Base Model), Model-2 (Moment Release), and Model-3 (Stiffness Modifier) reveals notable differences in lateral deformation, particularly in the mid and upper storeys. Model-2 and Model-3 are both effective in controlling storey drift compared to the base model. The reduction in drift is about 39% at critical storeys, due to deactivation of gravity columns from participating in lateral resistance — either by moment release (Model-2) or by applying stiffness modifiers (Model-3). Although both methods yield similar drift patterns, Model-3 is technically more refined, as it provides a physically closer approximation to real-world gravity columns, which may still offer some residual stiffness.

C. Column Force:

Table 5 Column Force Model-1 SPEC-Y

Story	Column	P	M3
		KN	KN-m
PL	C4	114.488	23.1297
PL	C14	124.4245	27.7551
PL	C24	114.1967	23.2097
PL	C31	156.4555	27.9756
PL	C32	152.6456	27.7388
PL	C46	124.0089	27.768

Table 6 Column Force Model-2 SPEC-Y

Story	Column	P	
		KN	KN-m
PL	C4	81.3088	0
PL	C14	83.2444	
PL	C24	80.7886	0
PL	C31	111.9155	0
PL	C32	121.4152	0
PL	C46	82.0096	0

Table 7 Column Force Model-3 SPEC-Y

Story	Column	P	M3
		KN	KN-m
PL	C4	88.8553	0.6632
PL	C14	90.5916	0.7206
PL	C24	88.3342	0.6695
PL	C31	115.4575	1.2694
PL	C32	125.5337	1.2676
PL	C46	89.4896	0.7221

The comparison of column forces under seismic loading in the SPEC-Y direction for Models 1, 2, and 3 provides valuable insights into how different modeling approaches affect column behavior and force distribution. The parameters of interest are the axial force and the bending moment about the major axis for select ground-level (PL) columns. In Model-1 (Base Model), where all columns are fully fixed and actively participate in lateral load resistance, with effect of vertical loads along with bending action are relatively high. In contrast, Model-2 shows a distinct behavioral shift. Here, moment releases at the M22 & M33 of the designated gravity only columns result in zero bending moments. Model-3 significantly reduced compared to Model- 1, ranging from 0.6632 KN-m to 1.2676 KN-m, which is 95– 97% lower than the base model.

V. Conclusion

This study investigates the seismic performance of a G+6 reinforced concrete structure by comparing three structural configurations: Model-1 (Base Model with fully fixed columns), Model-2 (Gravity columns modeled via moment release), and Model-3 (Gravity columns modeled via stiffness modifiers with I22 and I33 = 0.01). The aim was to understand the effects of different modeling techniques for gravity columns on the structural behavior under seismic loading, focusing on time period, storey drift, and column force behavior.

1. Time Period:

I. Model-1 showed the shortest time period (0.84 s in Mode 1), indicating the highest overall lateral stiffness. In Model-2, the time period increased to 0.86 s — a 2.38% increase, while Model-3 exhibited a further increase to 0.87 s — a 3.57% increase.
II. This reflects a reduction in lateral stiffness due to the exclusion of gravity columns from taking lateral load.
III. The increase in flexibility is more pronounced in Model-3, due to the partial (but not full) removal of moment resistance via stiffness modifiers, allowing minimal rotational stiffness to remain.

2. Storey Drift SPEC-X:

I. The maximum storey drift occurred at the 3rd floor, with Model-1 showing 0.000303 mm. Both Model-2 and Model-3 reduced this to 0.000186 mm, representing a 38.6% reduction in drift.
II. This reduction demonstrates that removing or minimizing the flexural contribution of gravity columns leads to a more efficient and centralized lateral force-resisting system.
III. Model-3 again provides similar drift control as Model-2 but is slightly more realistic due to the residual stiffness retained by the stiffness modifiers.

3. Column Forces:

I. Model-1 displayed the highest axial forces (up to 156.45 KN) and bending moments (up to 27.97 KN-m), indicating full flexural and axial engagement of columns. In Model-2, axial forces dropped by an average of 29.7%, and all bending moments were eliminated.

II. Model-3 showed slightly higher axial forces than Model-2 average reduction from Model-1 was 24.0% and retained small bending moments (0.66–1.27 KN-m).

4. Model-2, with moment releases, represents an idealized gravity column and simple shear connection can be used to take minimal moments.
5. Model-3, using stiffness modifiers, offers a more practical and constructible solution by realistically reducing flexural stiffness while still preserving axial load capacity and minor rotational behavior

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