

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.*

Key Words: Floating Column, Vertical Discontinuity, Pushover Analysis, Response Spectrum Method, Shear Wall, ETABS Ultimate v20.0.0, Structural Irregularities, Ductility, Nonlinear Static Analysis.

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.

1.1 . 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.

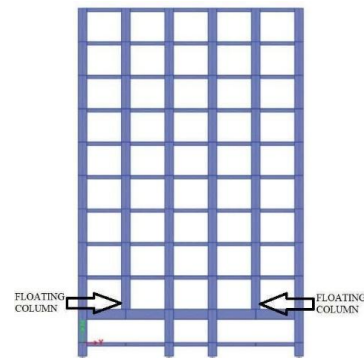
1.2 FLOATING COLUMN

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.



2. LITERATURE REVIEW

Ahmed Ibrahim and Hamed Askar (2021) conducted a study to assess the seismic performance of five-story reinforced concrete (RC) buildings, both with and without floating columns, utilizing RC frames as the primary lateral force-resisting system. The analysis was performed using ETABS software. Load cases, load combinations, static lateral load patterns, and response spectrum functions were defined in accordance with ASCE 7-16 standards, while the design criteria adhered to ACI 318-14 specifications. The comparison between the models was based on parameters such as storey displacement, storey drift, storey stiffness, and response spectrum outcomes. The study found that while floating columns serve essential architectural purposes,

especially in multi-functional or subdivided spaces, they adversely impact the seismic performance of the structure. Specifically, the presence of floating columns resulted in reduced stiffness, increased lateral displacement and storey drift, and a longer modal time period. As a result, the buildings required a stiffer lateral force-resisting system, thereby increasing overall structural costs.

Rashi Chaurasia and Ankit Pal (2019) observed that earlier studies offer valuable insights derived from both manual and software-based analytical methods applied to various structural configurations. These analyses have significantly enhanced the understanding of structural behavior, especially under seismic conditions. Their study encourages further exploration into new parameters and broader structural topics. The findings highlight that floating columns are not ideal for incorporation into multi-storey buildings, particularly in seismic zones. These members contribute to structural irregularities, often resulting in the formation of soft storeys, which can severely compromise the building's seismic performance. Floating columns demand a larger dimensional footprint and require enhanced ductile detailing to ensure effective load distribution. The presence of vertical irregularities, such as those introduced by floating columns, leads to increased storey drift and displacement. To mitigate seismic effects, the study recommends the implementation of base isolation techniques to reduce base shear at the structure's foundation.

N. H. M. Kamrujjaman Serker and Kishalay Maitra (2018) conducted a study to assess the seismic behavior of buildings with and without floating columns. The analysis involved five structural models, each differing in the location of floating columns and the size of columns. The study aimed to evaluate how these variations influence seismic performance. The results indicated that buildings with floating columns experienced a 56.96% increase in floor displacement compared to conventional buildings. A notable torsional irregularity was observed, especially when floating columns were introduced asymmetrically. Additionally, the presence of floating columns led to a longer fundamental time period and a reduction in lateral stiffness. Interestingly, redistributing the lost cross-sectional area—caused by floating columns—to the ground floor columns helped reduce storey displacement and base shear, while also increasing transverse stiffness. Based on these findings, the study concluded that floating columns should be avoided in seismic-prone areas. If their use is unavoidable, they must be placed symmetrically to mitigate torsional irregularities, and column sizes should be increased to prevent the formation of soft storeys.

Israa H. Nayel, et al. (2018) conducted a study emphasizing the importance of checking drift ratios to evaluate building deflections and storey drifts. Their findings revealed that deflections significantly increase with building height—displacements are greater on upper floors and smaller on lower ones. The analysis showed that displacement varies depending on

the structural model and the placement of shear walls—whether at the corners, sides, or internally. Notably, stiffness was observed to be higher in the first storey of buildings with L-shaped corner shear walls compared to buildings with floating columns and no shear walls. The results clearly indicated that buildings with shear wall systems performed better, particularly when shear walls were placed at the corners. Additionally, base shear was highest in models with centrally located core shear walls. These differences were most prominent in the upper storeys, suggesting that such configurations may be recommended for improved seismic performance. Detailing to ensure effective load distribution. The presence of vertical irregularities, such as those introduced by floating columns, leads to increased storey drift and displacement. To mitigate seismic effects, the study recommends the implementation of base isolation techniques to reduce base shear at the structure's foundation.

Sarika Yadav et al. (2016) This study observed that although floating columns are beneficial for increasing the Floor Space Index (FSI) of a building, they pose significant risk by increasing the building's vulnerability during seismic events. Analysis results showed that lateral displacement and inter-storey drift progressively increase from lower to higher seismic zones, correlating with the increasing intensity and magnitude of seismic forces. The study also highlighted that the introduction of shear walls in floating column buildings helps to reduce lateral displacement and drift across all structural models analyzed. Therefore, the research provides valuable insights into the seismic performance of multi-storey buildings with floating columns, both with and without shear walls, and stresses the importance of structural strengthening measures in high seismic zones.

Sabari S. et al. (2014) This study emphasizes the critical need to explicitly account for the presence of floating columns during structural analysis. To address the irregularity introduced by floating columns, the authors proposed special measures involving floor stiffness balancing. Finite Element Method (FEM) analysis was conducted on 2D multi-storey frames, both with and without floating columns, to evaluate the structural responses under various ground motions differing in frequency content, while keeping the Peak Ground Acceleration (PGA) and time duration constant. Key structural parameters such as inter-storey drift, roof displacement time history, base shear, and axial column force were computed for both types of buildings. The study involved consistent time history data, and the free and static vibration results obtained using the developed finite element code were verified. Further, dynamic analysis was performed by varying column dimensions. The results concluded that increasing the column size effectively reduces inter-storey drift and maximum displacement values, thereby improving structural performance under seismic excitation.

Keerthi Gowda B. S. et al. (2014) investigated the presence of torsional irregularities in buildings with floating columns. Their study revealed that torsional irregularities are present in Cases 2 and 3, where floating columns are introduced only on the left side of the structure. However, in Cases 4 and 5, where floating columns were removed from all edge sides, no torsional irregularities were observed. This indicates that torsional irregularity is not dependent on the number of floating columns or the size of ground floor columns but is primarily influenced by the location of the floating columns. Additionally, it was noted that Buildings with floating columns exhibit lower storey stiffness compared to conventional buildings. The natural time period of buildings with floating columns is significantly longer than that of typical framed buildings. Furthermore, when floating columns are placed asymmetrically, torsional modes are activated earlier during the first mode of vibration compared to conventional or symmetrically designed floating column buildings.

Abbas Mustafa (2009) this study focused on the modeling of earthquake ground motions as input for the seismic design of inelastic multi-degree-of-freedom (MDOF) structures. A series representation approach was used to estimate coefficients that maximize normalized inelastic inter-storey displacement under a set of predefined constraints. These constraints reflect the known characteristics of recorded ground motions, including earthquake energy content, the Fourier spectral bounds of ground acceleration, and upper limits for Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), and Peak Ground Displacement (PGD). The material behavior under force-displacement was modeled using hysteretic bilinear and elastic-plastic models. The study revealed that the critical ground motions for inelastic structures differ significantly from those for elastic or flexible systems, particularly in terms of temporal deformation behavior. Unlike elastic structures, inelastic systems dissipate energy via compliance and damping, which alters their seismic response characteristics. Additionally, the study explored nonlinear damping modeling using a nonlinear Rayleigh model, and validated the proposed formulation through the inelastic seismic response analysis of a two- storey frame. The research concluded that accurate seismic modeling for complex structures can be effectively achieved by integrating nonlinear optimization techniques with nonlinear finite element analysis tools, offering a more realistic

Jaswant N. Arlekar et al. (1997) this study examined the seismic performance of reinforced concrete (RC) frame buildings with open first storeys, which have been observed to perform poorly during strong earthquake shaking. Through the analysis of an example structure, the paper illustrates the seismic vulnerability associated with soft first storeys. It was found that the strength and drift demands on the first-storey columns in such buildings are significantly high. However, it is often impractical to provide adequate capacity in these columns, making these

buildings susceptible to damage or collapse during intense seismic events. Given that open first storeys are often a functional necessity in urban multi-storey buildings—for purposes such as parking—eliminating them is not feasible. Therefore, Alternative structural measures must be adopted. The study emphasizes that the core solution lies in avoiding soft storeys altogether and ensuring the presence of sufficient lateral strength and stiffness at the base level. Two practical strategies proposed include providing stiffer columns in the first storey to reduce lateral drift, and incorporating a concrete service core to reduce both drift and strength demands effectively. The authors call for urgent recognition of this issue in Indian construction practices and the implementation of corrective design measures.

Carlos E. Ventura et. al. (1991) this study presented the results of computer-aided dynamic analyses performed on a 13-story moment-resisting steel frame building. The dynamic properties and responses derived from these analyses were compared with actual recorded data from the building during two real earthquake events. It was found that standard analytical models, commonly used in structural design practice, were capable of predicting the building's dynamic properties with reasonable accuracy, especially under linear-elastic response conditions. A key observation was that the actual seismic time-history response exhibited amplitude modulation, attributed to the coupling of modes with closely spaced natural periods. The study concluded that state-of-practice design models can effectively approximate the seismic response of real buildings, provided that nonlinear behavior is limited or minimal.

Jack P. Moehle et al. (1986) in this research, an experimental and analytical investigation was conducted on reinforced concrete structures with vertical irregularities, subjected to strong base excitations. Two scaled frame-wall structures were built and tested using shaking table simulations. The study compared the measured structural responses with those calculated using several conventional analytical techniques, including: Elastic static analysis Elastic modal spectral analysis Inelastic static analysis Inelastic dynamic (time-history) analysis The results revealed that dynamic analysis methods had the clear advantage of accurately predicting maximum displacement responses, whereas static methods failed to capture these critical values. However, apart from this specific benefit, dynamic methods offered no significant advantage over static ones in other response metrics. Moreover, the inelastic methods, both static and dynamic, outperformed the elastic methods in assessing the influence of structural discontinuities, such as irregular geometries.

3. OBJECTIVE

- 1 To study the behavior of multistorey buildings with floating columns under seismic load.
- 2 To study the behavior of floating column building under seismic load by providing shear walls at different locations.
- 3 To compare the performance of floating column building,

normal building, and floating column building with shear walls after performing linear dynamic analysis.

- 4 To check whether plastic hinges will form at floating columns under earthquake excitation provided during push over analysis.

4. METHODOLOGY

Seismic analysis is essential for understanding a high-rise building's actual behavior under earthquake loading, and it can be performed using various methods depending on complexity and height. For relatively simple, low-rise structures—typically up to about 15 m tall—a linear static (equivalent static) analysis is often sufficient. Taller or more complex buildings require linear dynamic analysis, such as the response spectrum method, which accounts for the structure's vibration characteristics while still assuming elastic behavior. To capture inelastic behavior without a full time-history, engineers use nonlinear static (pushover) analysis, which incrementally applies lateral forces to identify capacity and deformation patterns. Finally, nonlinear dynamic (time history) analysis remains the only approach capable of accurately tracing a building's inelastic response throughout actual ground motion records, although it is the most data- and computation-intensive and still has practical limitations.

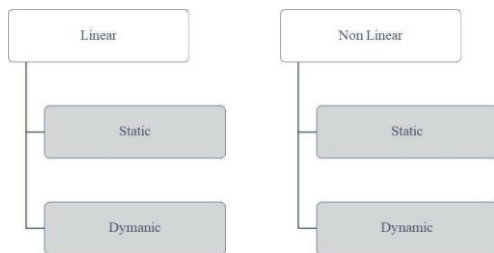


Fig. 2 Classification of Seismic Analysis

5. CONCLUSIONS

- 1 IRJET sample template format ,Conclusion content comes here. Conclusion content comes here Conclusion content comes here Conclusion study the behavior of multistorey buildings with floating columns under seismic load.
- 2 study the behavior of floating column building under seismic load by providing shear walls at different locations.
- 3 compare the performance of floating column building, normal building, and floating column building with shear walls after performing linear dynamic analysis.
- 4 check whether plastic hinges will form at floating columns under earthquake excitation provided during push over analysis.

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