Comparative seismic analysis of G+4 RC Structures with and without floating columns using pushover analysis according to Moroccan seismic code RPS 2011

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Abstract. Floating columns without ground floor extensions—are commonly added in current architectural design for architectural flexibility but may have a significant influence on seismic behavior of structures. This article presents a comparative analysis of three configurations of a typical four-story residential building (G+4): a baseline one with no floating column, the second one with a mid-column floating column, and the third one with an edge-column floating column in cantilever. The computation is carried out under nonlinear static analysis (Pushover) according to the Moroccan Seismic Design Code (RPS 2011). The results determine the effect of floating column position on overall capacity, lateral displacements, plastic hinge formation. The structures with floating columns, especially with cantilever edge configuration, are more susceptible. The study reiterates the importance of having due consideration for floating column position in seismic zones.

1 Introduction

Floating columns—vertical structural elements that do not transfer loads vertically to the foundation but rather bear on transfer slabs or beams—are increasingly used in modern architecture to create open space such as parking or commercial areas. Such arrangements, however, in seismically active regions disrupt the vertical load path, generating stress and structural irregularities that can significantly lower seismic resilience [1]. Pushover analyses and post-earthquake analyses (e.g., Bhuj 2001) have shown that such discontinuities increase seismic vulnerability to lateral loadings [2].

From a structural perspective, floating columns offer the drawback of sudden stiffness discontinuity between stories that localize seismic demand into localized regions. Architecturally, they offer the advantage of flexible interior design by permitting spacious open halls, minimizing columns at the ground level, and enhancing facade planning. This is most difficult in mid-rise buildings, wherein combined vertical and lateral loading causes greater torsional response and stress irregularities [3]. The consequences are especially

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dangerous in soft-story construction or if there are floating columns at the top stories supported by long-span transfer beams.

As illustrated in Figure 1, real-life collapses have this susceptibility. The mid-story collapse in this reinforced concrete building, analyses after a major seismic event, represents a trend of partial collapse aligned with the formation of vertical discontinuities due to floating column conditions. Over a soft or transfer level, the failure is localized, representing stiffness discontinuity and load path discontinuity. All these phenomena reflect the significance of vertical load path integrity in seismic design.

Fig. 1. On-site damage survey after earthquake in Turkey (https://cme.uic.edu) [4].

Analytical studies also support such conclusions. Varma and Bhalchandra [3] conducted nonlinear pushover analysis for RC frames with and without floating columns and observed significant increases in lateral displacement and decrease in base shear capacity with floating columns. Kandukuri & Reddy [5] compared various column heights (G+4, G+9, G+15) and observed that inter-story drift and plastic hinge formation were much more pronounced in mid-span or edge floating column configurations. Their research also indicated that changing the height of the building had a considerable effect on displacement and storey drift while vertically irregular structures and buildings utilizing floating columns are also more seismically vulnerable.

Despite these findings, most of the current research is based on international codes such as IS 1893 or ASCE 7, and there are very few studies focusing on buildings that were designed after the Moroccan Seismic Design Code (RPS 2011). In addition, extensive research is still needed comparing the effect of floating column position—center versus edge-cantilever—on seismic performance in typical Moroccan mid-rise structures.

This research seeks to fill these voids through comparative pushover analysis of three structural layouts of a G+4 reinforced concrete frame: (I) a reference building with no floating column, (II) a building with a floating column at mid-span, and (III) one with an edge-placed floating column in cantilever. The seismic capacity, inter-story drift, lateral displacement, and plastic hinge formation are studied at length under RPS 2011 [6]. The paper provides region-specific details to Moroccan engineers and designers working in Moroccan seismic regions, as it emphasizes the importance of rational floating column positioning in seismic-resistant structural systems.

2 Materials and methods

2.1 Construction materials

The materials used in this study are consistent with the common values specified by Eurocode 2 (EN 1992-1-1) [7]. The adopted concrete is class C25/30, which is commonly used in building structures [8], and reinforcing steel is grade B500B. Material properties were assumed to be isotropic and homogeneous.

The mechanical characteristics considered for concrete as well as steel reinforcement are given in Table 1. These were utilized consistently in all structural models to conduct an unbiased comparative study.

2.2 Structural overview

The frames in question are reinforced concrete moment-resisting frames characteristic of typical common mid-rise structures in seismic regions. The models all share the same geometry and loading conditions. The only variation between the models is in their inclusion and positions of floating columns.

The analysis is aimed at demonstrating how structural deficiencies in terms of vertical discontinuities formed by floating columns affect global seismic behavior. The structural elements such as beams, columns, and slabs are idealized as prismatic elements, while the floor system is rigid in-plane to facilitate effective distribution of the lateral load.

Table 1. Mechanical properties of materials (according to Eurocode 2).

Property	Symbol	Value	Reference
Characteristic compressive strength (concrete)	f_{ck}	25 MPa	EN 1992-1-1 §3.1.2(2)

Mean tensile strength (concrete)	f_{ctm}	2.6 MPa	Table 3.1, EC2
Modulus of elasticity (concrete)	E_{cm}	31 476 MPa	Table 3.1, EC2
Density of concrete	—	2500 kg/m³	§3.1.4 EC2
Yield strength of steel	f_{yk}	500 MPa	Table 3.2, EC2
Elastic modulus of steel	E_s	200,000 MPa	§3.2.7 EC2

3 Numerical investigations

3.1 Building description

Three different structural configurations of a mid-rise reinforced concrete (RC) building have been investigated in this work to evaluate the impact of floating column positions on seismic performance. All the models are of a standard G+4 RC frame building with five stories of uniform height of 3 meters and thus the building height is 15 meters.
The structural plan consists of five longitudinal columns spaced at 5 meters, having a plan size of 20 meters. The columns have a square cross-section of 35 × 35 cm2 and the beams are rectangular with dimensions 35 × 50 cm2. The floor system consists of a 20 cm thick solid slab, which is assumed as a rigid diaphragm.
These profiles were not chosen randomly; they resulted from preliminary static calculations performed under gravity load conditions, which include dead load and live load of 2.5 kN/m² and 1.5 kN/m², respectively. The aim was to impart the structure with enough stiffness and load-carrying capacity without sacrificing its ductility behavior under seismic loading. This sizing is also in line with common practice for Moroccan mid-rise buildings in seismic areas.
Three models of the structure were built for comparison:

- Model I: Standard frame without floating column (base model).
- Model II: Frame with floating column placed at the mid-span of an interior beam.
- Model III: Frame with floating column at the edge, supported by a cantilever beam.

Figures 2-3 and 4 show the structural configurations of the three models, the spatial distribution and precise positions of the floating columns.

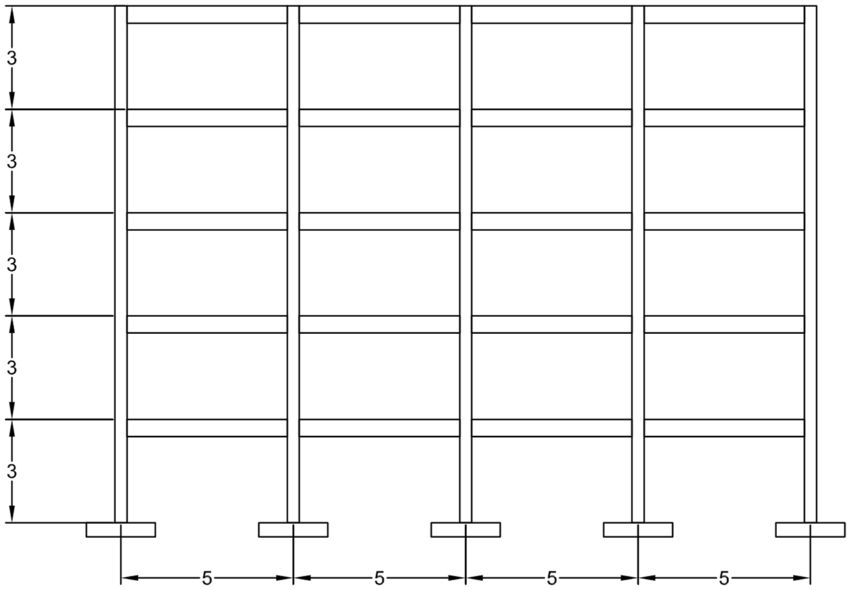

Fig. 2. Structural layout of the reference model without floating columns (Model I)

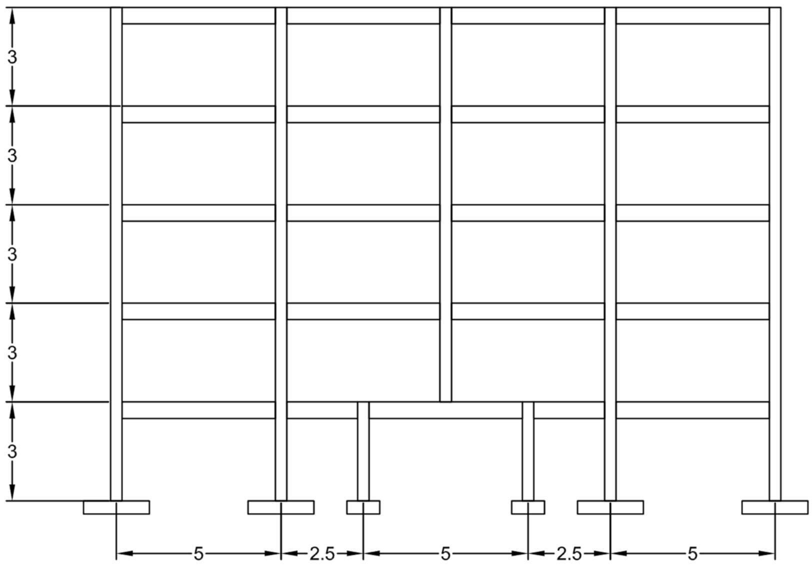

Fig. 3. Structural layout of the reference model without floating columns (Model I)

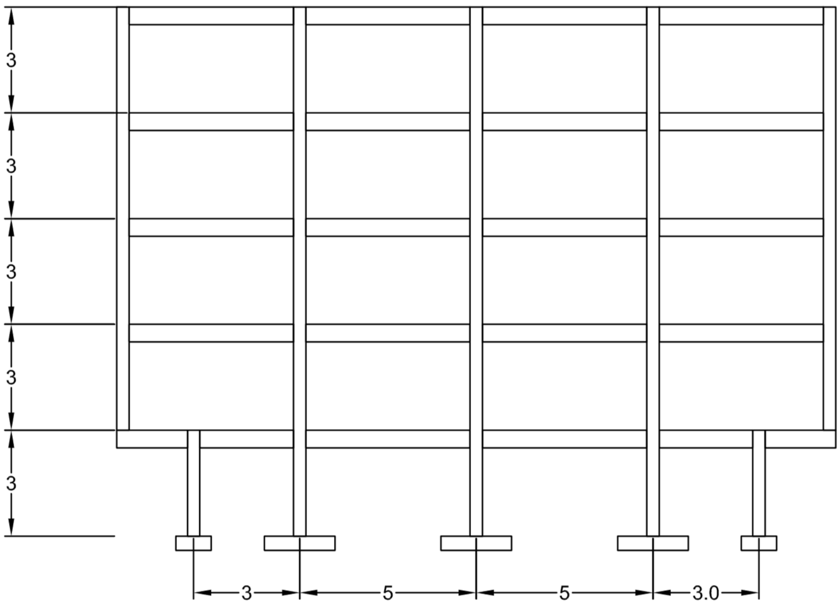

Fig. 4. Structural layout of the model with an edge floating column in cantilever (Model III)

3.2 Parameters of the study

Pushover analysis and structural modeling were accomplished using the finite element program SAP2000 v23 [9], a comprehensive software with extended capabilities for nonlinear static and dynamic analysis of frame structures. All three building configurations were modeled as three-dimensional reinforced concrete moment-resisting frames with nonlinear frame elements, capable of modeling strength degradation as well as post-elastic behavior.

All primary structural components—columns, beams, and slabs—were explicitly modeled to consider their contribution to the global stiffness and seismic mass of the building. The floor slabs were idealized as rigid diaphragms, a simplification widely accepted for cast-in-place concrete slabs, to enable realistic lateral load distribution between the vertical elements.

Beam and column members were modeled with their actual geometric dimensions and were given nonlinear material properties based on Eurocode 2 principles. To simulate inelastic behavior under seismic loading, plastic hinges were located at member ends, following default moment–curvature relationships as proposed by FEMA-356 [10]. Only flexural plasticity (moment hinges) was considered, based on the assumption that shear capacity is adequately fulfilled through code-based design.

The non-structural elements—infill walls, partitions, and façade components—were not modeled, as they typically have variable stiffness, brittle behavior, and negligible contribution to global ductility. The analytical models therefore account for the structural frame system only, which controls the building's lateral response.

Support conditions were assumed to be fully fixed at the base level. Foundation flexibility and soil–structure interaction effects were ignored, in line with normal assumptions in comparative seismic studies.

All adopted material and seismic parameters used in the nonlinear analysis are summarized in Table 2 below.

Table 2. Summary of structural and seismic parameters adopted according to the Moroccan Seismic Code (RPS 2011)

Parameter	Value	Note / Reference
Seismic zone	Zone 4	High hazard – RPS 2011
Soil type	S2 (medium)	Moderate stiffness soil
Importance factor I	1.0	Residential buildings
Peak ground acceleration (PGA)	0.24g	Corresponds to Zone 4
Damping ratio	5%	Standard value
Seismic mass definition W	G+0,2Q	Seismic mass definition
Force reduction factor K	5	Per RPS 2011 – Table 4.3

According to the Moroccan Seismic Code (RPS 2011), seismic base shear force (F_b) is computed using the equation:

$$F_b = \frac{V.S.D.I.W}{K} \quad (1)$$

- V is the seismic zone coefficient (based on location),
- S is the site coefficient (depending on soil class),
- D is the structural behavior factor (related to ductility),
- I is the important factor,
- W is the seismic weight of the structure (i.e., dead load + 0.2 × live load),
- K is the reduction factor.

These terms are used to determine the respective lateral force for pushover analysis, which subsequently is applied proportionally in line with the first vibration mode shape.

4 Results and discussion

4.1 Natural periods of vibration

The natural periods of the three types of RC structures were determined by modal analysis using SAP2000. The first four vibration modes for every condition are listed in Table 3: the reference model without floating column (Model I), the model with central floating column (Model II), and the model with edge floating column in cantilever (Model III). The global fundamental period of the regular structure (Model I) is shorter (0.296 s) compared to those of the two irregular structures. The presence of floating columns increases the global flexibility of the structure, further causing an extension in the global fundamental period—to 0.317 s for Model II and to 0.324 s for Model III.
This is consistent with conventional theory in structural dynamics, where natural vibration period is inversely proportional to the square root of the lateral stiffness. Design models with floating columns have lower stiffness due to the vertical load transfer path discontinuities, especially cantilever. These anomalies cause seismic demand underestimation unless

effectively treated during the design process. Therefore, thorough analysis of such environments is imperative in seismically prone regions.

$$T = 2\pi\sqrt{\frac{m}{K}} \qquad (2)$$

where T is the natural period, m is the modal mass, and k is the lateral stiffness of the structure.

Table 3. Natural periods of vibration

Mode number	Model I	Model II	Model III
1	0,296	0,317	0,324
2	0,097	0,103	0,096
3	0,057	0,060	0,047
4	0,040	0,058	0,035

Figures 5 through 10 show the first and second mode shapes of vibration for all structural models under free vibration analysis. Figure 5 reveals that the reference model (Model I) reflects a standard first mode shape, i.e., an even lateral displacement over the structure height, with a fundamental frequency of 3.37 Hz. The second mode (Figure 6) demonstrates an increased frequency of 10.27 Hz, alongside a more rigid dynamic response in the higher mode.

Model II when a floating column is added in the middle, demonstrates a slightly more flexible first mode (Figure 7) at a frequency of 3.14 Hz and an associated second mode at 9.64 Hz (Figure 8). The addition of vertical discontinuity impacts dynamic behavior.

The most irregular configuration, Model III with cantilever floating column at the edge, has the lowest first-mode frequency (3.08 Hz, Figure 9), which is indicative of a severe loss of stiffness. The second mode (Figure 10) also displays local deformation around the cantilever area, with a frequency of 10.3 Hz. This indicates that torsional and flexural effects are more pronounced due to the eccentricity introduced by the cantilevered floating column.

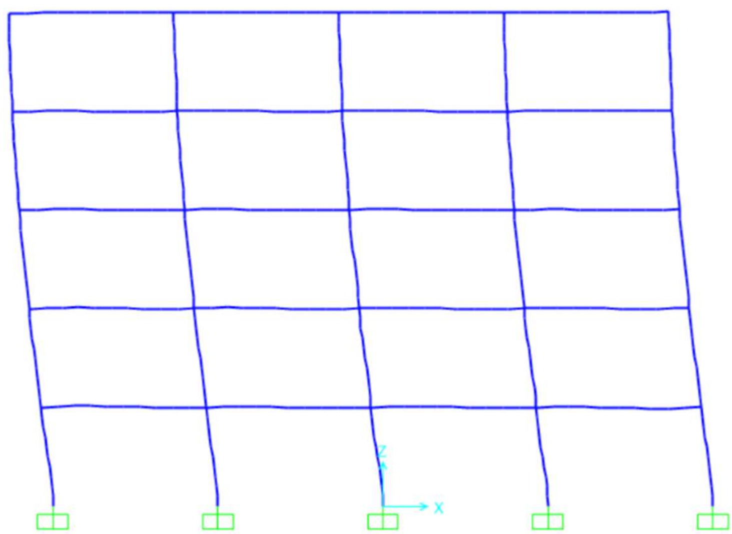

Fig. 5. Model I first mode of vibration (frequency=3,37)

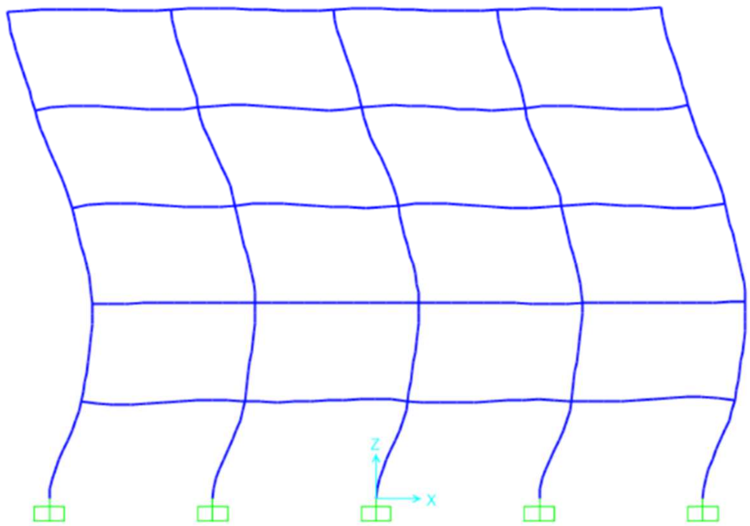

Fig. 6. Model I second mode of vibration (frequency=10,27)

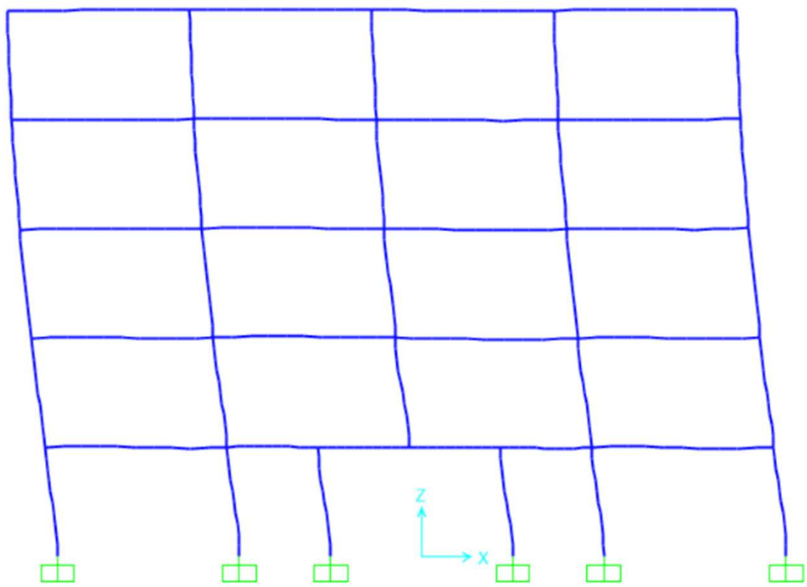

Fig. 7. Model II first mode of vibration (frequency=3,14)

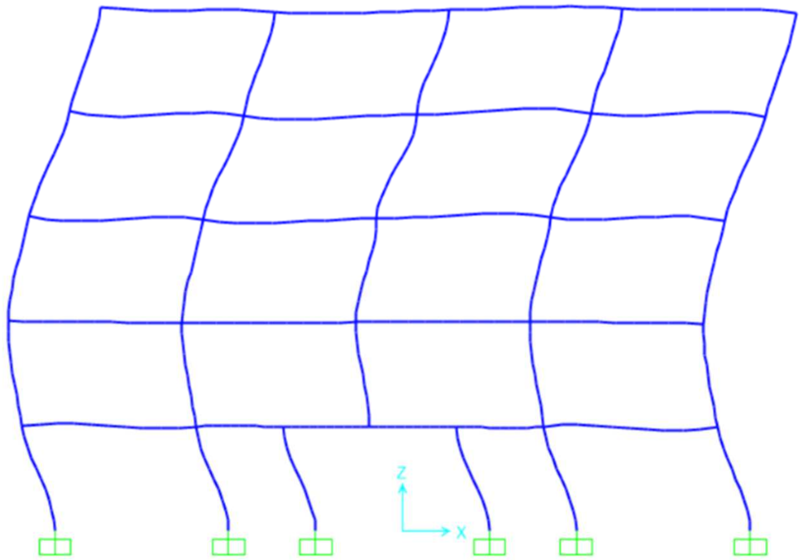

Fig. 8. Model II second mode of vibration (frequency=9,64)

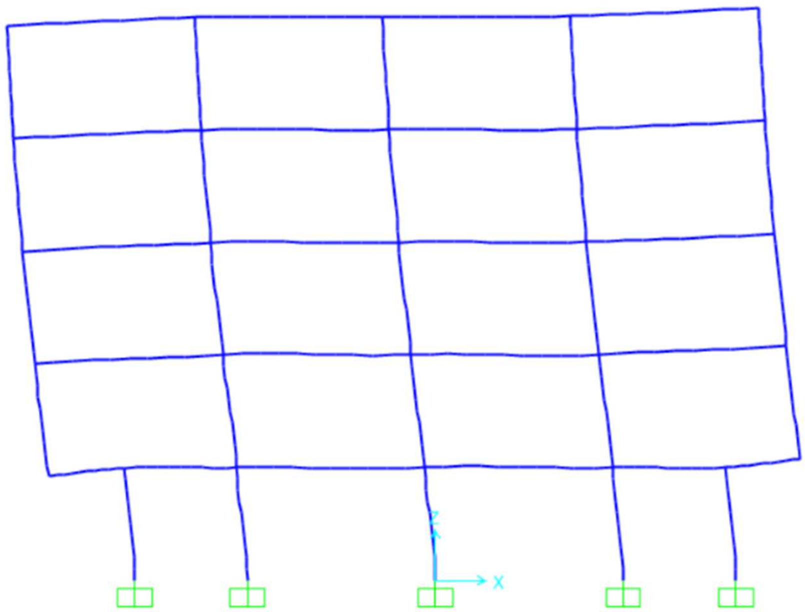

Fig. 9. Model III first mode of vibration (frequency=3,08)

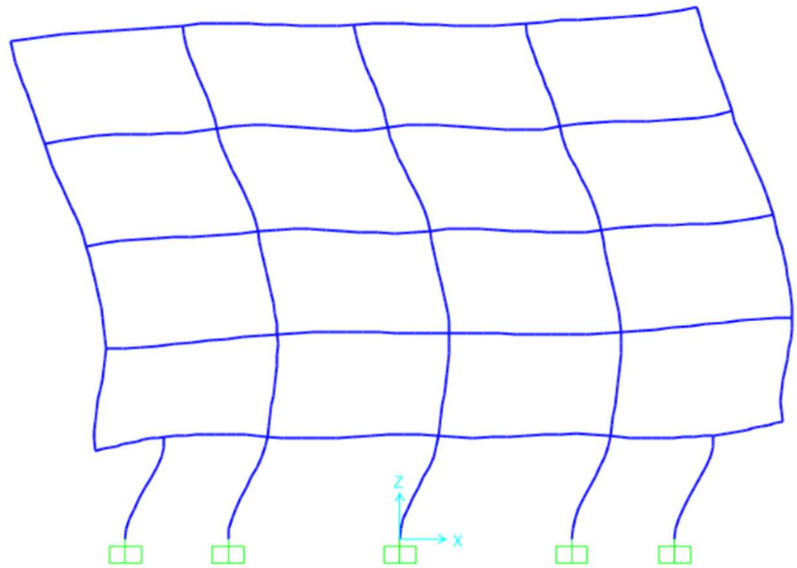

Fig. 10. Model III second mode of vibration (frequency=10,3)

4.2 Lateral strength and stiffness

Pushover analysis was used to evaluate the lateral performance of the three models, and Figure 11 depicts their results. Model I possesses the largest lateral strength with a maximum base shear of 988.95 kN at a displacement value of 0.1477 m. The same indicates greater overall stiffness as well as seismic force-resisting capacity. Model II had a lower base shear capacity of 923.22 kN at 0.1964 m, and Model III, which contained an edge-positioned floating column, had the lowest strength at 855.36 kN, which was equivalent to a displacement of 0.2125 m.

While Model III appeared stiffer at initial appearance based on initial displacement increments, the pushover curve shows that Model I possesses a steeper and more linear slope during the response, which confirms a larger effective lateral stiffness. This shows a more ductile and uniform energy dissipation mechanism. Reduction in lateral capacity for Models II and iii is mainly caused by the introduction and location of floating columns, which weaken load paths and create stress concentration.

These observations point towards the importance of structural continuity and regularity in seismic design. Cantilever arrangements involving floating columns, particularly at structural boundaries, like in Model III, are most catastrophic for the overall seismic performance. These arrangements are marked by an irregular distribution of stiffness and hence are strongly discouraged in seismic buildings.

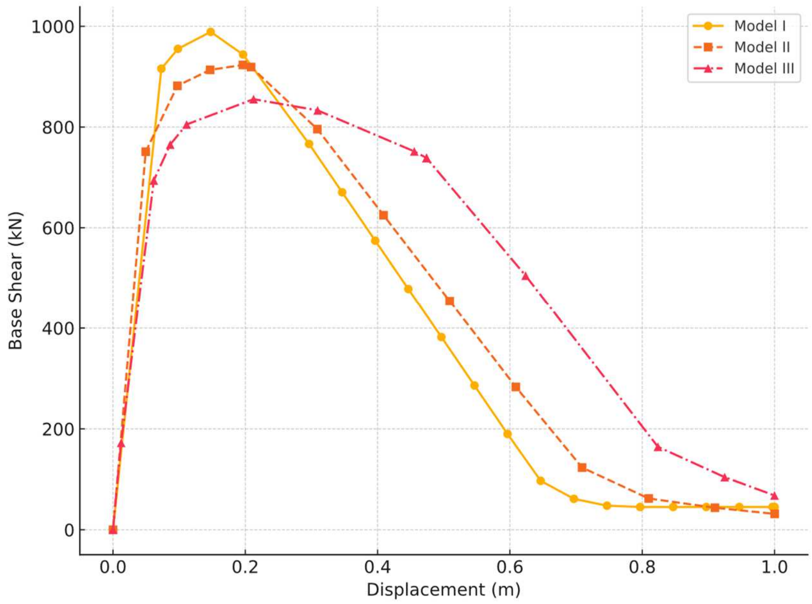

Fig. 11. Pushover curves for the three models

4.3 Plastic hinge

The nonlinear pushover analysis showed significant variation in the plastic hinge progression patterns among the three models. Figure 12 illustrates the moment-rotation relationship of a plastic hinge, as defined in FEMA 356 and ATC-40 [11].

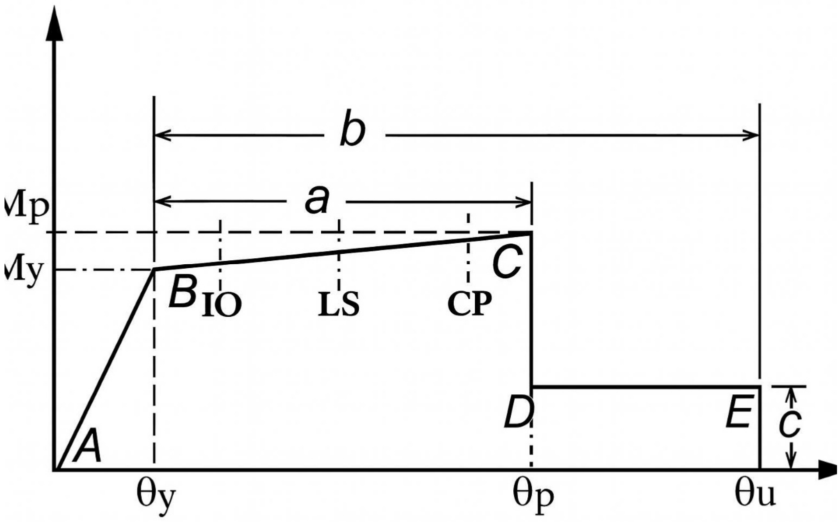

Fig. 12. Moment –rotation relation of plastic hinge [12]

In Model I, plastic hinge development is under a ductile and gradual mode. From Figure 13, the early hinges are predominantly in beam-column joints and base columns, indicated with color B (green), indicating the onset of yielding. With more lateral displacement, the plasticity extends into intermediate stories, as seen in Figure 14, where hinges develop to C (cyan) and even to E (red) in Figure 15, all focused at ground-level columns. Such a distribution indicates that the frame deforms in a stable and consistent way, with energy dissipation reasonably well distributed over the structure. The absence of abrupt hinge concentration is a sign that structural regularity and continuity of load path are successful. Model I also has the largest initial stiffness and lateral capacity in agreement with its pushover curve.

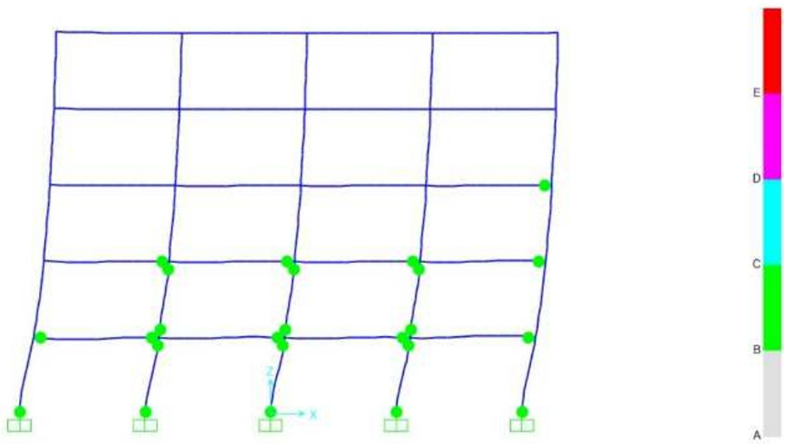

Fig. 13. Plastic hinge distribution at Step 1 – Model I

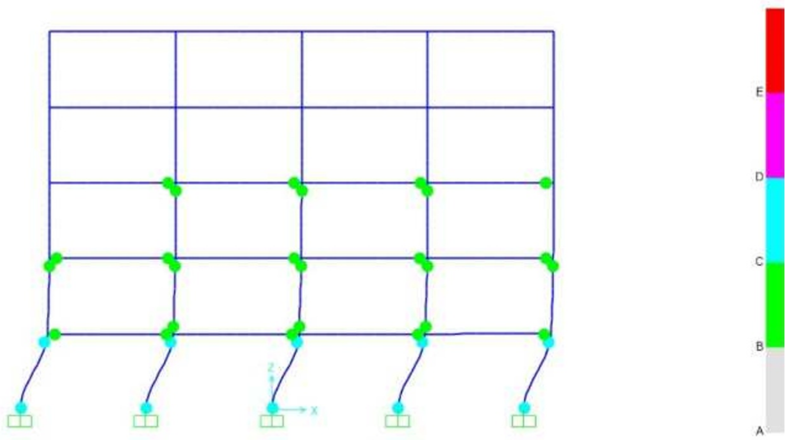

Fig. 14. Plastic hinge distribution at Step 11 – Model I

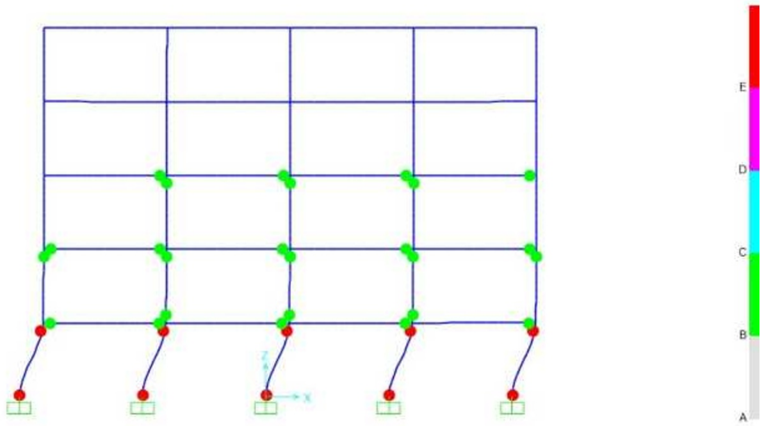

Fig. 15. Plastic hinge distribution at Step 20 – Model I

Model II (Frame with Central Floating Column), on the other hand, has poor behavior. As seen from Figure 16, plastic hinges occur similarly at the base but evolve faster due to the vertical discontinuity created by the mid-span floating column. In Figures 17 and 18, several hinges reach D (magenta) and E (red), particularly below the floating column and adjacent beams. Such local concentration indicates widespread stress accumulation and premature yielding in these regions. The presence of the floating column disobeys stiff consistency and ruins the energy dissipation mechanism. For this reason, this configuration provides a soft-story effect, reduces redundancy, and reduces global ductility.

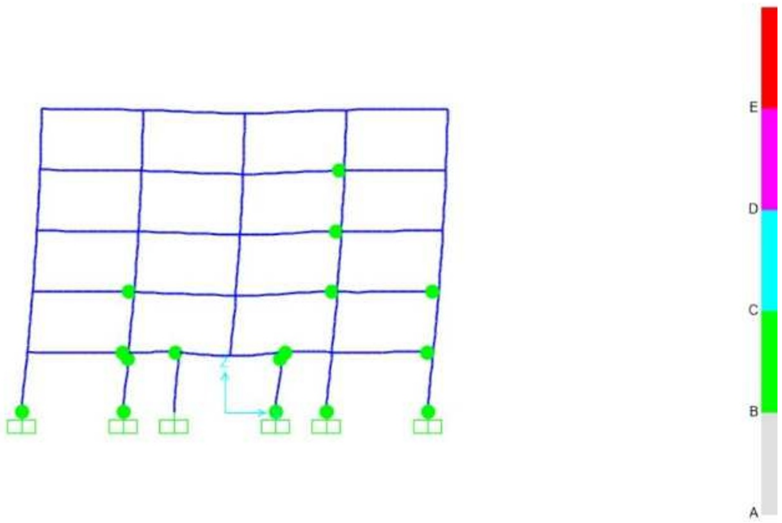

Fig. 16. Plastic hinge distribution at Step 1 – Model II

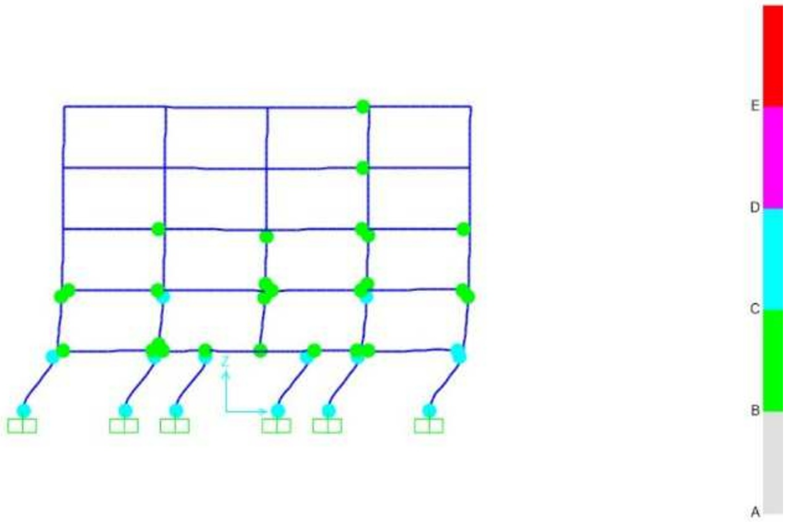

Fig. 17. Plastic hinge distribution at Step 8 – Model II

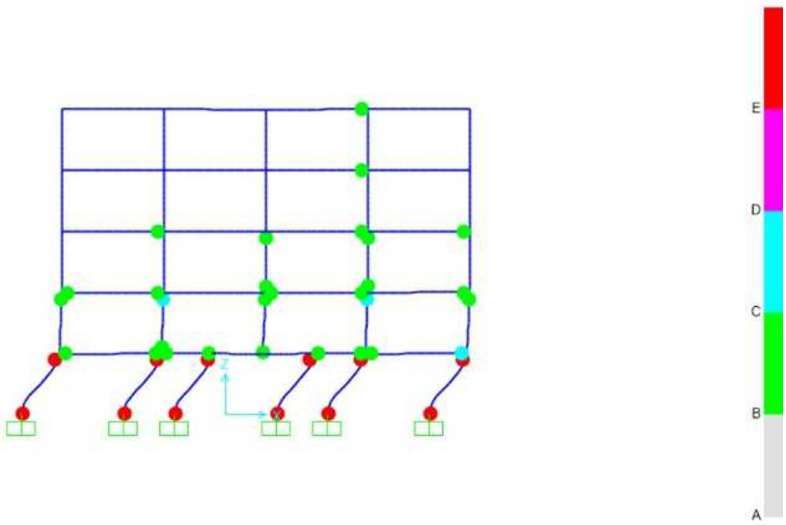

Fig. 18. Plastic hinge distribution at Step 13 – Model II

Model III (Frame with Edge Floating Column) exhibits the worst plastic hinge behavior among the three. By Figure 19, hinges are already beginning to form near the cantilever support region at early stages, and by Figure 20, these rapidly evolve toward higher performance levels (C and D). By Figure 21, red hinges (E) overtop the bottom of the edge columns, representing a near-collapse state. The floating column's eccentric location introduces high torsional effects and an asymmetrical load path that enhances the structural irregularities. This leads to early deterioration, inadequate capacity for redistribution, and low energy dissipation.

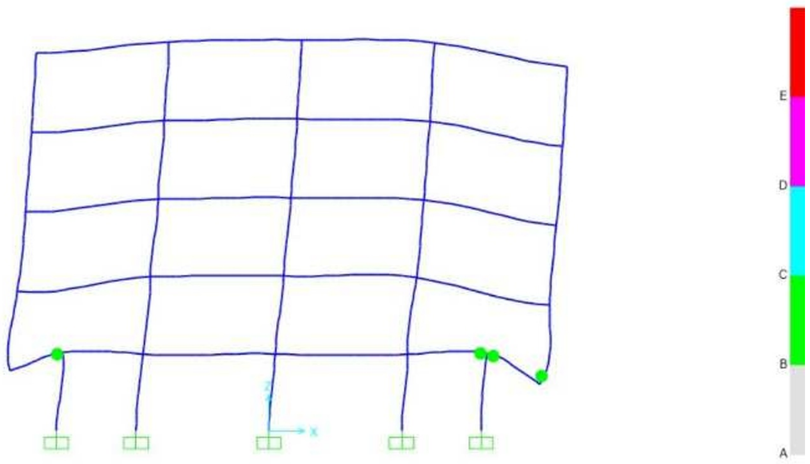

Fig. 19. Plastic hinge distribution at Step 1 – Model III

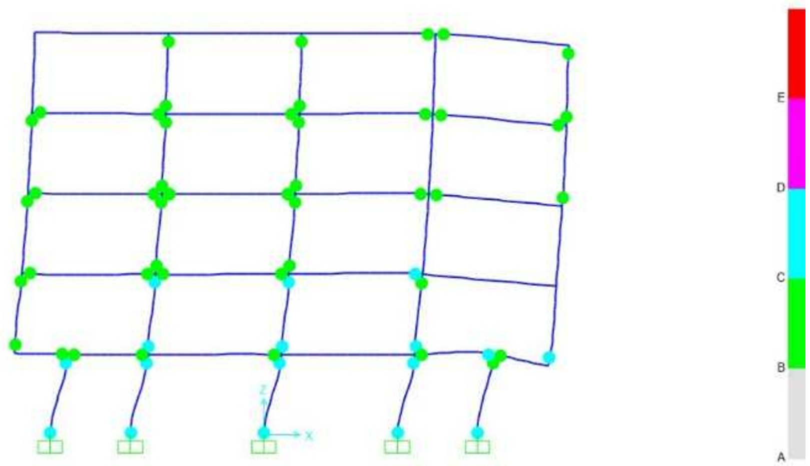

Fig. 20. Plastic hinge distribution at Step 10 – Model III

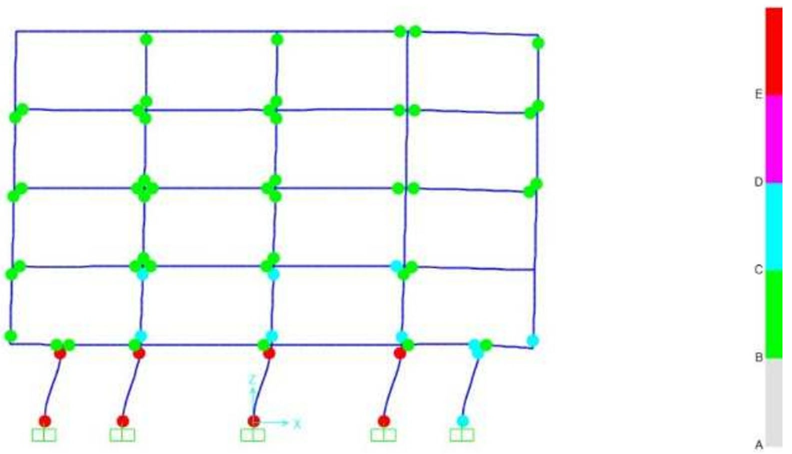

Fig. 21. Plastic hinge distribution at Step 14 – Model III

Summary, then, is that plastic hinge formation confirms that Model I exhibits optimal seismic performance with progressive plasticity and distributed ductility. Model II suffers from local failures that are very localized in the region of the floating column, and Model III is distinguished by premature and severe failure due to eccentricity and torsion. These findings render even more necessary to eliminate or carefully reinforce floating columns, especially those which are on the periphery, in seismic design.

5 Conclusion

In the present research study, the seismic behavior of three reinforced concrete frame configurations, as per nonlinear static pushover analysis, according to the Moroccan Seismic Design Code (RPS 2011), has been analyzed: a regular bare frame (Model I), an incenter floating column frame (Model II), and an edge-located floating column frame (Model III). The research focused on the key seismic parameters like lateral strength, stiffness, fundamental periods, pushover capacity curves, and the plastic hinge formations development.

The findings robustly validate that the exposed frame (Model I) exhibits better response, with increased lateral strength and stiffness and ductile and uniform hinge formation. Yet, the introduction of floating columns—especially in eccentric edge locations (Model III)—catastrophically degrades the structural performance through premature collapse mechanism activation, torsional irregularity, and severe plastic concentration at areas of risk.

The novelty of this research lies in its specific comparison of the location of floating columns in Moroccan seismic-provisioned mid-rise RC buildings. While floating columns are widely utilized in practice for convenience in architecture, limited research has comparatively examined their undesirable effect quantitatively based on precise placement. By offering a detailed, code-level examination of such structural discontinuities, the study fills an important knowledge gap in seismic design literature and presents practical, evidence-based recommendations for engineers, architects, and regulators.

Finally, this paper stresses the essential principles of structural regularity, continuity of the load path, and strategic prevention of floating columns in seismically active regions. The results significantly contribute to earthquake-resistant design by promoting safer building methods that are in accordance with national seismic code standards and by preventing architectural designs that compromise structural integrity.

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