Civil Engineering and Architecture 14(1): 442-460, 2026 http://www.hrpub.org
DOI: 10.13189/cea.2026.140129

Accidental Eccentricity in Response Spectrum Analysis: Comparison Between Static Torsional Loading and Dynamic Mass Displacement

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Received July 25, 2025; Revised November 27, 2025; Accepted December 22, 2025

Cite This Paper in the Following Citation Styles

(a): *[1] Rosali Ramos Rojas, Albert Jorddy Valenzuela Inga, Carlos Javie Huamán Albino, Nelfa Estrella Ayuque Almidon, Aron Jhonatan Aliaga Contreras, Jean Fernando Perez Montesinos , "Accidental Eccentricity in Response Spectrum Analysis: Comparison Between Static Torsional Loading and Dynamic Mass Displacement," Civil Engineering and Architecture, Vol. 14, No. 1, pp. 442 - 460, 2026. DOI: 10.13189/cea.2026.140129.*

(b): *Rosali Ramos Rojas, Albert Jorddy Valenzuela Inga, Carlos Javie Huamán Albino, Nelfa Estrella Ayuque Almidon, Aron Jhonatan Aliaga Contreras, Jean Fernando Perez Montesinos (2026). Accidental Eccentricity in Response Spectrum Analysis: Comparison Between Static Torsional Loading and Dynamic Mass Displacement. Civil Engineering and Architecture, 14(1), 442 - 460. DOI: 10.13189/cea.2026.140129.*

Abstract Accidental torsion in buildings is a relevant structural phenomenon caused by the discrepancy between the center of mass and the center of rigidity, generating undesired rotational responses under seismic loading. This study aims to compare two approaches used in modal response spectrum analysis to address this phenomenon. The first is the conventional quasi-static procedure, which introduces equivalent torsional moments through an artificial five percent eccentricity in plan. The second is the dynamic procedure, which incorporates this eccentricity by directly displacing the center of mass in the structural model. Eight reinforced concrete buildings with different geometric configurations were modeled using ETABS software. Critical structural response variables were evaluated, including inter-story drift, base shear, and the torsional irregularity index. The results showed significant differences between both procedures, with absolute drift variations of up to ±20 %, base shear increases of up to 12.7 %, and torsional amplification reaching 2.2 % under the dynamic approach. This method enabled the activation of rotational modes that the quasi-static analysis cannot capture, thus providing a more realistic representation of the system's dynamic behavior. It is concluded that the dynamic procedure offers relevant technical advantages for the analysis of structures with potential for accidental torsion. Although the study is based on linear elastic models, its findings provide valuable evidence for seismic-resistant design and the evolution of code-based design criteria.

Keywords Accidental Eccentricity, Seismic Torsion, Dynamic Analysis

1. Introduction

In seismic design, one of the most underestimated yet critical phenomena is accidental torsion, particularly in buildings with irregular floor plans or non-uniform distributions of mass and stiffness. This torsional response originates from a mismatch between the center of mass and the center of rigidity, leading to significant torsional moments under lateral seismic loads.

Clear evidence of its impact was observed during the 2007 Pisco earthquake in Peru, where several buildings experienced partial collapse due to excessive displacements caused by accidental eccentricities. As shown in Figure 1, these conditions amplified lateral demands at the diaphragm edges, critically affecting structural stability. This issue remains highly relevant in seismic-prone regions, where inertial effects combined with unfavorable structural configurations can severely compromise the seismic performance of both new and existing buildings [1].

Figure 1. Building collapse due to accidental torsion effects during the Pisco earthquake, associated with the eccentricity between the center of mass and the center of rigidity

Research has shown that ignoring or underestimating accidental torsion can introduce substantial errors into predictions of structural response, even for geometrically regular buildings. To mitigate this, seismic codes such as ASCE/SEI 7-22 [2] prescribe an artificial eccentricity of 5% of the plan dimension perpendicular to the loading direction. This requirement is commonly addressed through the quasi-static method, which applies to a torsional moment at each level proportional to the lateral seismic force and the specified eccentricity. The quasi-static procedure is embedded by default in widely used structural analysis software such as ETABS and SAP2000.

Despite its practicality, the quasi-static approach has notable limitations because it treats torsion as an external effect rather than an intrinsic outcome of structural dynamics. Consequently, it does not capture modal interaction, inertial redistribution, or amplification arising from higher torsional modes or irregular configurations.

As an alternative, dynamically displacing the center of mass within the structural model alters its dynamic properties and allows accidental torsion to develop naturally during response-spectrum or time-history analyses [3]. This dynamic modeling enables a more rigorous assessment of the interaction among eccentricity, stiffness, and mass.

In India, multiple studies have evaluated torsional behavior in irregular buildings. A study from the Maharaja Sayajirao University of Baroda modeled structures with various configurations, determines that local zones in asymmetric floor plans generate significant torsion, especially in the lower stories [4].

Another investigation analyzed 13-story irregular buildings, showing that “L”-shaped configurations increase drifts and internal forces, while strategically placed shear walls effectively reduce torsion [5]. At the National Institute of Technology Karnataka, it was found that the combination of soft stories and plan eccentricity intensifies rotations and displacements, prompting the proposal of a new coefficient to characterize such irregularity [6].

Researchers from IIT Roorkee studied buildings in severe seismic zones, concluding that “T”- or “+”-shaped plans are more vulnerable, whereas shortened shear walls provided significant improvements [7]. A parametric study also proposed a torsional irregularity coefficient, evidencing that this increases as the number of stories decreases [8]. Another work revealed how asymmetric configurations such as “T” and “U” exacerbate seismic effects, particularly in drifts and torsional moments [9]. Lastly, the influence of shear walls was evaluated in buildings with seemingly regular plans, concluding that correct placement effectively mitigates torsional response [10].

In Australia, the University of Melbourne proposed a simplified method to estimate torsional stiffness in reinforced-concrete buildings. It was demonstrated that structures with an elastic radius below 1.1 show greater torsional instability, and a preliminary visual method was offered for design purposes [11]. In another Australian study, an algorithm for estimating torsional amplifications under inelastic seismic response was validated, showing that ratios of elastic and yield radii are decisive in asymmetric buildings [12].

In Nepal, researchers from the Institute of Engineering analyzed six-story buildings with seemingly regular geometry. They observed that service openings induced significant torsion, which could be mitigated with properly positioned shear walls [13].

In Iran, a study on box-type buildings revealed that mass eccentricity is more critical than stiffness, increasing drift by up to 2.45 times [14]. Another Iranian work evaluated collapse safety in torsional irregular buildings through incremental dynamic analysis, highlighting that safety margins are acceptable if adequate ductility mechanisms are considered [15].

In Greece, it was confirmed that accidental mass eccentricities do not significantly affect the inelastic torsional response if the structure is primarily translational [16]. Another Greek study demonstrated that aligning the mass axis with the optimal torsional axis minimizes torsional response [17].

In Mexico, seismic reliability functions were developed for buildings with variable torsion over height, and the validity of empirical correction factors in the local code was questioned [18]. Simultaneously, Mexico proposed a simplified design procedure for static torsion, capable of reproducing code-compliant results through a single 3D analysis [19]. Additional mass eccentricity values were also evaluated in torsional stiff buildings, and practical equations were proposed for soft-soil zones [20].

In Canada, researchers proposed a practical method for locating centers of rigidity in multi-story buildings, demonstrating its normative applicability [21]. In Colombia, the validity of the 5% code-defined eccentricity was analyzed, concluding that it can underestimate or overestimate actual torsional effects depending on the seismic event and structural configuration [22].

In Egypt, a new definition of torsional irregularity based on floor rotations was proposed, indicating that standards such as EC8 and ASCE 7-16 are non-conservative in certain cases [23]. In Turkey, a practical method was developed to model accidental eccentricities in buildings with semi-rigid diaphragms, validated through numerical models [24].

In Germany, 18 representative structures were evaluated, concluding that the placement of walls significantly influences torsional behavior and that code provisions can be reliable if advanced analyses are used [25]. In the United States, the applicability of the torsional parameter defined in ASCE 7-16 was assessed, confirming its usefulness in asymmetric buildings under high seismic demand [26].

In Romania, an algorithm was proposed to enhance the inelastic torsional representation in actively controlled multi-story buildings, improving seismic performance [27]. In Oman, it was concluded that structural irregularities such as torsion or soft stories reduce structural capacity and increase collapse risk, and conservative criteria were recommended [28].

In Peru, it was demonstrated that mass eccentricities in base-isolated structures amplify displacements, and their explicit consideration in design was recommended [29]. In Russia, a nonlinear model was applied to improve the evaluation of torsional strength, showing that elastic models tend to overestimate seismic response [30]. In Bangladesh, it was found that floor-plan shape significantly affects dynamic demands, with “I” and “T” shapes being the most critical [31].

Finally, in Hong Kong, China, a 1991 study highlighted the need to interpret building codes considering nonlinear dynamic torsional effects, emphasizing deficiencies in rigid-edge provisions [32], while in Colombia, it was found that the response-spectrum method provides a better estimate of eccentricity than the equivalent lateral force method [33].

The literature demonstrates significant progress in understanding torsional effects in irregular buildings. Key factors such as floor plan configuration, stiffness to mass distribution, and accurate modeling of accidental eccentricity are crucial for controlling drift, shear, and torsion. Overall, there is a clear trend toward more practical and reliable methods applicable to modern seismic design.

Limitations of prior work. Much of the existing research relies on the quasi-static representation of accidental torsion, which tends to underrepresent higher torsional modes and modal interaction; evidence regarding the code-prescribed 5% eccentricity is also mixed across plan configurations and soil conditions. In addition, few studies report overturning-moment demands alongside drift and shear, and there is limited evidence based on as-built models of real Peruvian buildings or considering semi-rigid diaphragms. These gaps motivate a side-by-side comparison between quasi-static and dynamic approaches using consistent models, acceptance criteria, and metrics.

Contributions and novelty. This paper benchmarks the quasi-static procedure against a dynamic center-of-mass-shift approach, allowing accidental torsion to develop naturally in modal response-spectrum analysis, and employs as-built three-dimensional ETABS models of eight real Peruvian buildings. It evaluates inter-story drift, shear, torsional irregularity, and overturning moment under acceptance criteria consistent with ASCE/SEI 7-22 and the Peruvian code, and offers practical guidance on when code procedures suffice and when a dynamic approach is warranted.

The need to compare the quasi-static and dynamic approaches has become increasingly apparent, especially in buildings with asymmetric layouts and pronounced torsional irregularities. Their influence on key seismic parameters such as inter-story drifts, shear force, torsional irregularity, and overturning moments has driven the development of more precise procedures to properly account for accidental torsion effects in structural design.

In this context, the present study carries out a comparative evaluation of the quasi-static procedure and the dynamic approach that displaces the center of mass, analyzing eight real buildings constructed in Peru. Three-dimensional models were developed with ETABS software and subjected to modal response-spectrum analysis, which made it possible to delineate the technical and practical differences between the two methods and to formulate methodological recommendations aimed at preventing uncontrolled torsional effects from compromising structural functionality or causing partial or total failure.

2. Materials and Methods

This study evaluates the effects of accidental eccentricity using two analytical procedures: the quasi-static method and a dynamic approach involving the displacement of the center of mass. Eight three-dimensional structural models were developed using ETABS software. The analysis focused on three response variables: inter-story drift, base shear, and torsional irregularity.

2.1. Structural Models

Eight reinforced concrete buildings located in urban areas of Peru were selected, chosen for their structural diversity. Total heights range from 33 to 72.8 meters, with 10 to 23 stories. The floor plan configurations include both symmetric and asymmetric layouts, with various combinations of basements and semi-basements. Table 1 summarizes the geometric properties of each model, including total height, story heights, plan dimensions along the X and Y axes, and the number of levels above and below grade.

The structural models were developed using ETABS version 22.5.1, a validated software for the analysis and design of buildings subjected to gravity and seismic loads. Each building was modeled in three dimensions, using frame elements for columns and beams, shell elements for structural walls, and membrane elements for slabs.

The physical and mechanical properties of the structural materials were defined according to the Peruvian Technical Standards E.020 [34] and E.060 [35], including parameters such as modulus of elasticity, unit weight, damping ratio, and Poisson’s ratio, which are fundamental for modal and spectral analysis. Table 2 summarizes these properties, which were applied consistently across all models to ensure comparability.

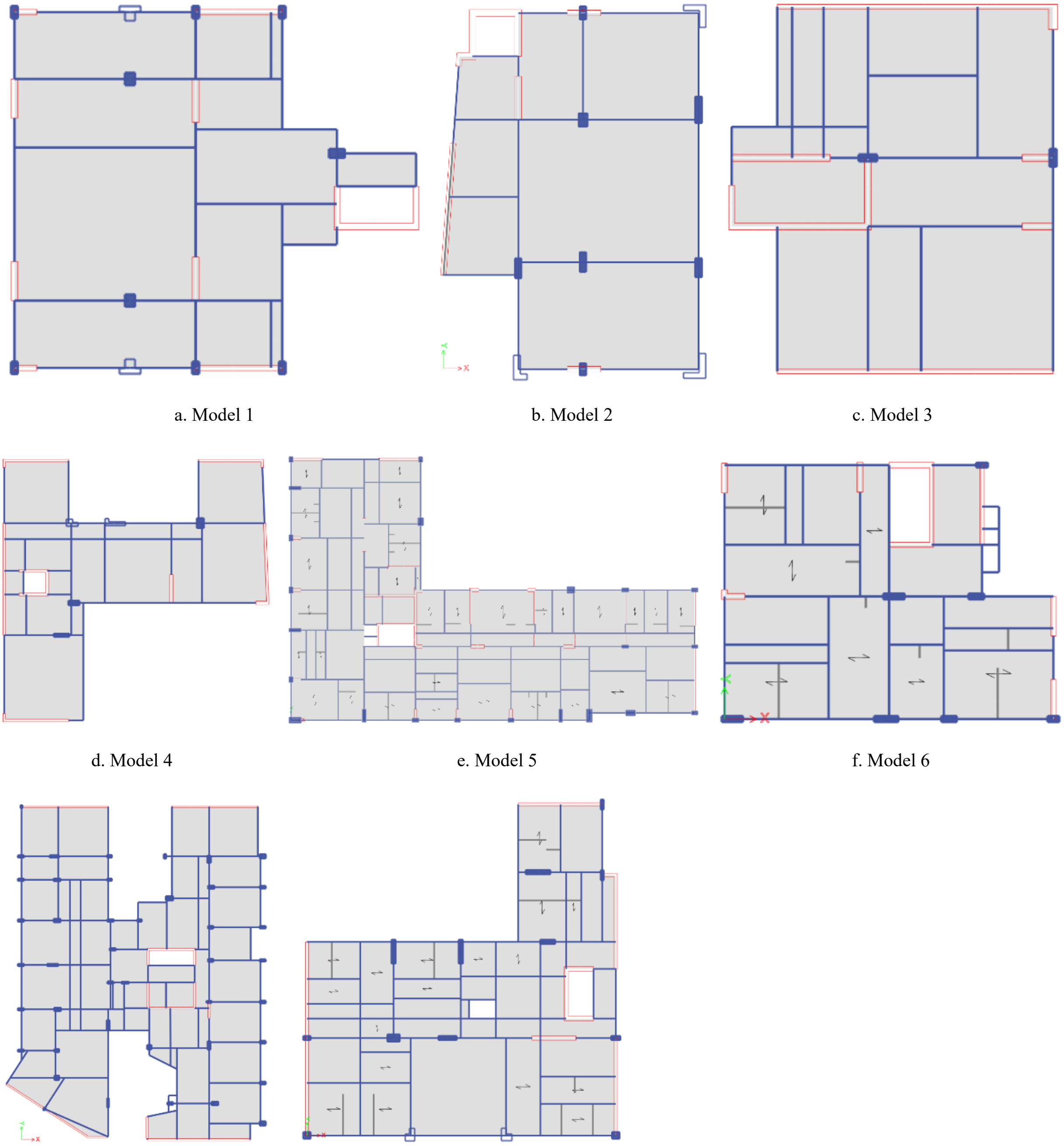
Based on the mechanical properties described, the eight structures selected for analysis were modeled. Figure 2 shows the floor plan layout of one of the models, highlighting the general arrangement of structural walls and other main elements. Figure 3 presents a three-dimensional view of the same model, allowing for visualization of the overall building geometry and the volumetric distribution of its representative floors.

Table 1. Geometric and Structural Characteristics of the Analyzed Buildings

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Total Height [m]	38.08	38.08	38.08	33.00	60.32	72.80	44.20	58.70
First Floor Height [m]	2.68	2.68	2.68	2.70	2.72	3.05	2.70	3.16
Typical Floor Height [m]	2.68	2.68	2.68	2.70	2.72	2.75	2.70	2.70
First Basement Height [m]	3.00	3.00	3.00	3.15	2.80	4.15	2.80	3.72
Typical Basement Height [m]	2.80	2.80	2.80	2.85	2.80	2.90	2.80	2.82
Dimension in X [m]	58.26	58.26	58.26	22.78	44.27	16.98	35.48	24.59
Dimension in Y [m]	15.94	15.94	15.94	22.50	28.45	24.68	41.70	26.32
Number of Stories	11	11	11	10	17	23	11	17
Number of Basements	3	3	3	2	3	2	4	4

Table 2. Material Properties

Concrete		Reinforcement Steel	
Material	Value	Material	Value
γ_c (kgf/m^3)	2400.00	γ_s (kgf/m^3)	7850.00
f'_c (kgf/cm^2)	280.00 350.00	f_y (kgf/cm^2)	4200.00
E_c (kgf/cm^2)	$15000\sqrt{f'_c}$	E_s (kgf/cm^2)	2000000.00
μ	0.15	-	-

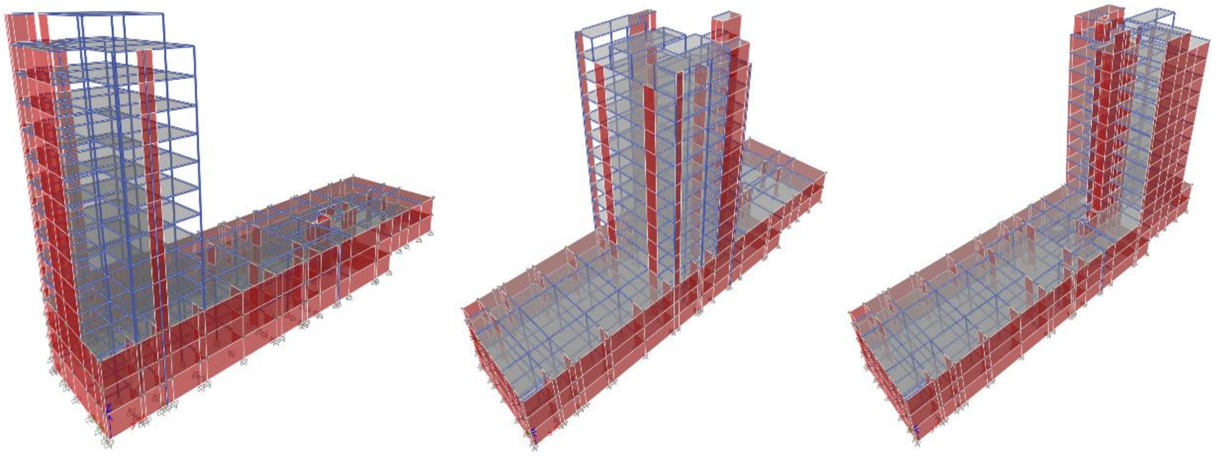


a. Model 1 b. Model 2 c. Model 3

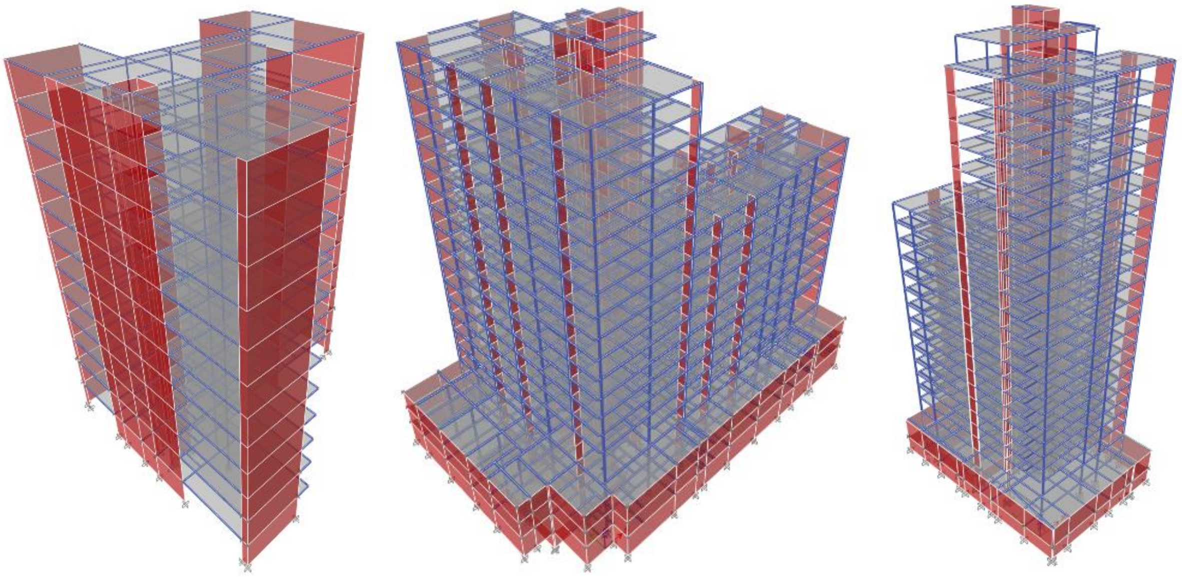
d. Model 4 e. Model 5 f. Model 6

g. Model 4 h. Model 5

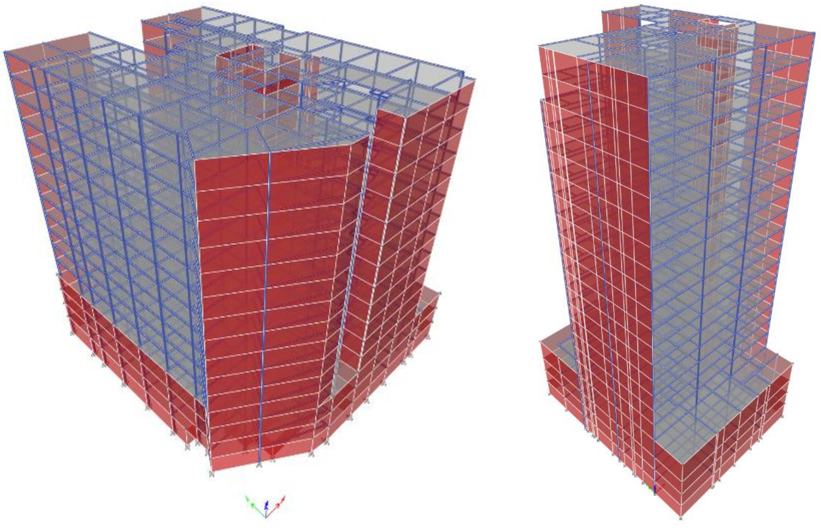
Figure 2. Plan Configuration of the Structural Models



a. Model 1 b. Model 2 c. Model 3



d. Model 4 e. Model 5 f. Model 6



g. Model 7 h. Model 8

Figure 3. Three-Dimensional View of the Structural Models

Each structural model corresponds to a real building constructed in the urban areas of Peru. In addition to the general geometric configuration, elements were assigned dimensions based on stiffness, continuity, and structural proportionality criteria, aiming to faithfully represent typical design conditions in reinforced concrete structures. The cross-sectional dimensions of columns, walls, and slabs were defined individually for each building, considering structural stability and performance requirements. Table 3 summarizes these geometric characteristics.

Table 3. Assigned Structural Element Dimensions by Model

Section	Material (f'c)	Thickness
C100x60	350	-
C75x35	280	-
C75x35	350	-
CL100x75x55x40	280	-
CL100x75x55x40	350	-
V30X58	280	-
V30x80	280	-
V35x120	280	-
V35X58	280	-
M25	280	0.25
M25	350	0.25
M40	280	0.40
M40	350	0.40

Regarding the gravitational loads considered in the structural analysis, the values established by the Peruvian Technical Standard E.020 [34] were adopted. Dead loads were defined based on the self-weight of structural and non-structural elements, including slabs, walls, finishes, and partitions. For live loads, a value of 200 kgf/m² was assigned, corresponding to residential use, which represents a typical load for multifamily housing buildings.

2.2. Seismic Parameters

The seismic analysis of the eight structural models was carried out in accordance with the guidelines established in Peruvian Standard E.030 [36], which defines the minimum criteria for estimating seismic forces in buildings located in areas of high seismic activity.

For all models, Seismic Zone 4 was adopted, corresponding to regions of very high seismic hazard in the national territory. A use category C was considered, which includes common buildings such as multifamily housing, and a soil type S1 was assumed, representative of very stiff soils. In all cases, the structures exhibit irregular configurations and were modeled as shear wall structural systems, consistent with real design conditions. Table 4 presents the seismic design parameters adopted in the study.

Table 4. Seismic Parameters Considered for the Spectral Analysis

Parameter	Valor
Seismic Zone 4	0.45
Use Category C	1.00
Soil Type S1	1.00
Response Modification Factor R	6.00

To evaluate the structural response in terms of maximum lateral displacements, the provisions of the Peruvian Technical Standard E.030 [36] were considered. This standard establishes amplification factors that must be applied to the results of linear elastic analysis to estimate displacement demands under severe seismic events.

For regular structures, displacements are obtained by multiplying the analysis results by a factor equal to 0.75R, where R is the response modification factor. In the case of irregular structures such as those analyzed in this study, the code requires the use of a factor equal to 0.85R. This adjustment enables a more realistic approximation of inelastic displacement demands by accounting for the global nonlinear behavior of the structure. Figure 4 shows the response spectrum used in the analysis.

2.3. Quasi-Static Procedure

The quasi-static procedure consists of applying torsional moments at each story level of the building, which are generated based on the accidental eccentricity specified as a percentage of the diaphragm dimension perpendicular to the direction of analysis. In this study, an eccentricity of 5% was adopted, in accordance with the Peruvian Seismic Code E.030 [36] and other international regulations such as ASCE/SEI 7-22 [2], as well as seismic codes from countries like Mexico, India, and Japan reinforcing its applicability as a standard measure for simulating the effects of accidental eccentricities in structural analysis.

This approach represents torsional effects through additional static loads superimposed on the response obtained from the response spectrum modal analysis. In computational environments like ETABS, these loads are automatically generated when an eccentricity value is defined in the seismic load cases, allowing displacement, shear, and internal force results to account for the combined effects.

Figure 5 schematically illustrates the generation of the torsional moment through the action of lateral forces offset from the center of mass, highlighting the formulation used in the quasi-static procedure.

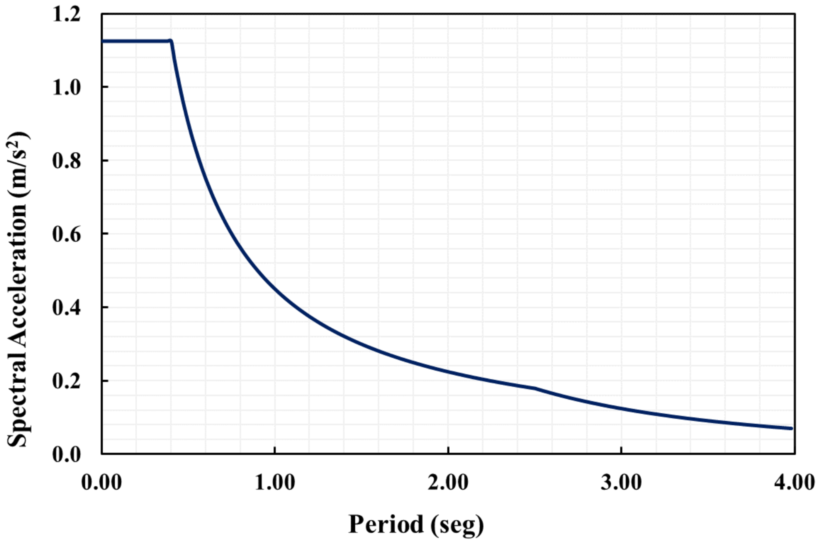


Figure 4. Elastic Spectrum Corresponding to Seismic Zone 4, Use Category C, and Soil Type S1

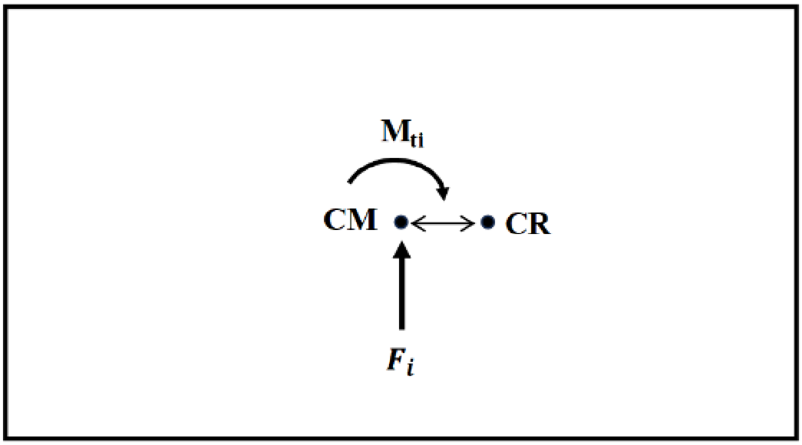


Figure 5. Representation of accidental torsion introduced through a torsional moment applied at the center of mass (CM), generated by the eccentricity with respect to the center of rigidity (CR) and the lateral force Fi

2.4. Dynamic Procedure with Mass Displacement

This procedure consists of intentionally displacing the center of mass of the structural model, incorporating accidental eccentricity as an inherent part of the system's dynamic configuration. Unlike the quasi-static method, this approach modifies the global stiffness matrix, natural frequencies, and mode shapes, allowing torsional effects to develop naturally during response spectrum modal analysis.

To achieve this, the center of mass was shifted by 5% of the diaphragm dimension perpendicular to the direction of analysis, in accordance with Peruvian Standard E.030 and international codes.

Figures 6 and 7 illustrate the effect of this intentional displacement in plan, highlighting the creation of an eccentricity between the center of mass and the center of rigidity, as well as the activation of torsional modes in the resulting modal analysis.

2.5. Evaluation of Variables

In order to analyze how the quasi-static and dynamic procedures affect the structural response to accidental eccentricity, a set of key variables was defined to quantitatively compare the results obtained with each method. These variables were selected for their normative relevance and ability to reflect torsional effects in buildings. The analysis was carried out in principal X and Y directions, considering the most representative modal results for each structure.

The first variable evaluated was the maximum inter-story drift, calculated as the ratio between the relative displacement of two consecutive floors and the story height. This parameter is critical for estimating accumulated lateral distortion and is directly related to both structural and non-structural damage levels. Assessing how this value varies between procedures helps identify differences in lateral performance, which can be compared with the limits established in Peruvian Standard E.030 [36].

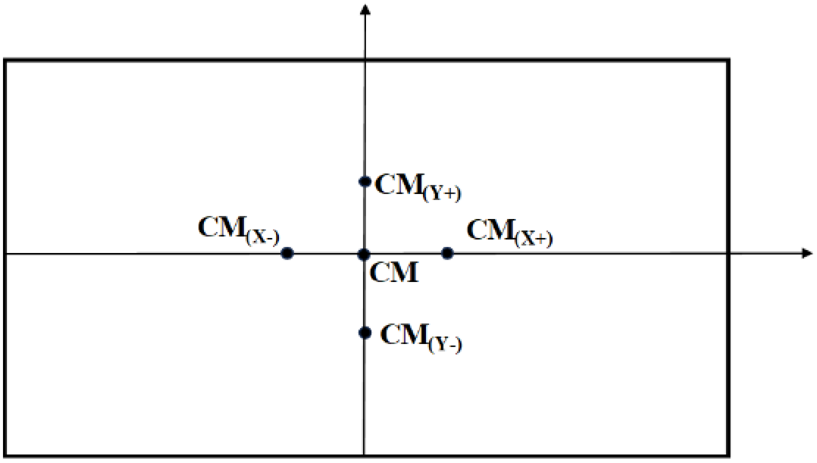


Figure 6. Schematic representation of the center of Mass displacement

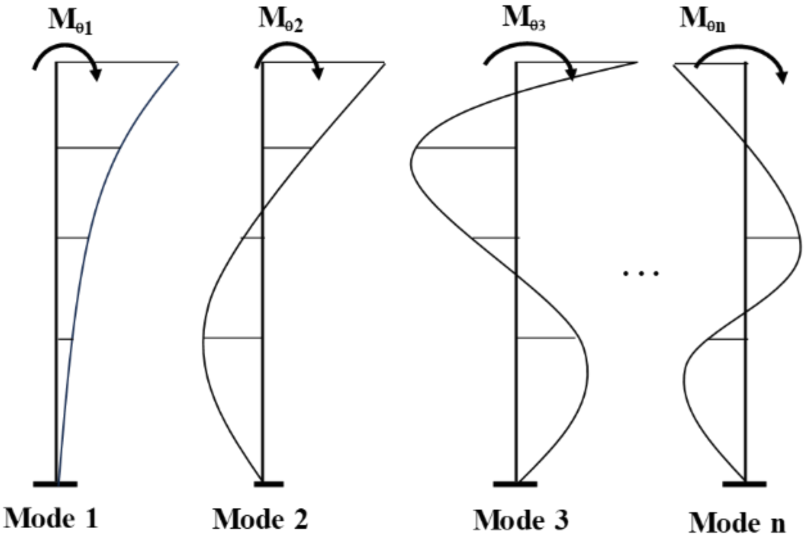


Figure 7. Incorporation of accidental torsion in each vibration mode through the dynamic mass displacement procedure

The base shear was also analyzed, defined as the total sum of horizontal forces generated by seismic action at the base of the structure. This magnitude represents the overall demand transmitted to the foundation system. Comparing this value between both approaches helps determine whether the treatment of accidental eccentricity significantly modifies the global seismic demand.

Another critical variable was the overturning moment, calculated as the product of lateral forces and their respective heights. This variable was used to assess the global stability of the building and to verify whether the introduced eccentricities increase the risk of overturning, especially in tall buildings or those with asymmetric mass and stiffness distribution.

Finally, torsional irregularity was assessed, defined as the ratio between the maximum and average displacements at the diaphragm edges of each floor. According to the criteria in Standard E.030 [36], a building is considered to have torsional irregularity if this value exceeds 1.3. This variable made it possible to evaluate how each procedure influences the activation of torsional modes and the in-plan stiffness distribution.

The comparative analysis of these variables clearly identified the differences induced by each procedure in the seismic response of the structures, providing evidence on the accuracy and applicability of each approach in scenarios with significant torsional potential.

3. Results

This section presents the results obtained from the analysis of eight structural models, considering both the quasi-static and dynamic mass displacement procedures. The comparison focuses on three key variables: inter-story drift, base shear, and torsional irregularity.

3.1. Inter-Story Drift

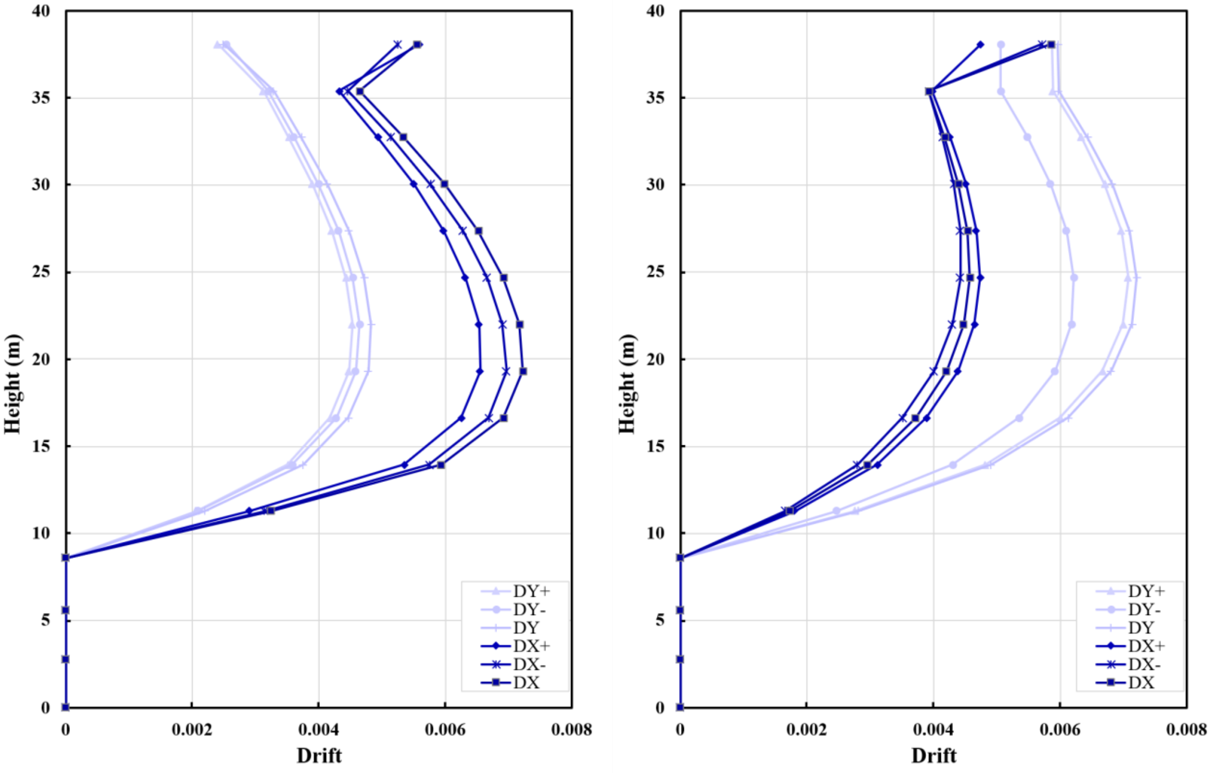
The evaluation of inter-story drift is a fundamental criterion in seismic-resistant design, as it is directly related to structural performance and potential damage to non-structural components. In this study, drift variations were analyzed in the principal X and Y directions for the eight models, applying both procedures under rigid diaphragm conditions.

The results revealed heterogeneous behavior among the structures. Model 3 presented the largest increase in drift (+11.88%), followed by Model 6 (+6.07%) and Model 2 (+4.99%). These increases indicate that certain geometric configurations and stiffness distributions are more sensitive to torsional effects generated by center-of-mass displacement. Such conditions promote the concentration of deformations at critical levels, which could compromise code compliance and structural safety.

In contrast, significant reductions were also identified. Model 4 recorded a 20.59% decrease, Model 7 a 20.00% reduction, and again Model 2 reached −18.90%. These reductions are associated with modal redistribution resulting from changes in the system's dynamic properties, which lessen the relative displacement demands between stories in certain cases. This shows that the dynamic procedure can both amplify and mitigate drifts, depending on the structural configuration.

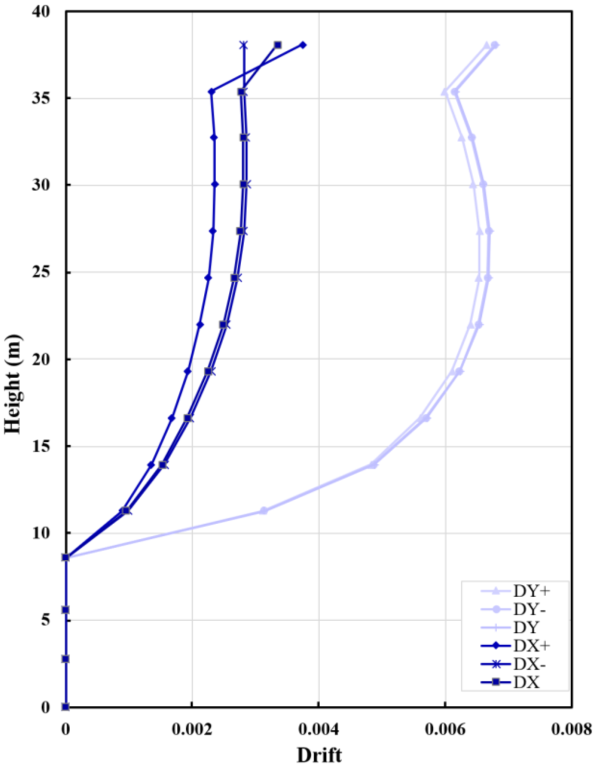
From a design perspective, these differences are particularly relevant because several models exceeded the 10–15% range, a practical threshold often used to determine the need for more detailed analysis. This confirms that while the quasi-static procedure may be adequate for regular buildings, it is limited in irregular configurations where accidental torsion plays a decisive role. For this reason, drift verifications should always be cross-checked with the limits established in E.030 and ASCE/SEI 7-22, with the dynamic procedure serving as the reference in cases where significant variations are observed.

Figure 8 graphically summarizes these percentage variations in inter-story drift for the eight models, enabling a direct comparison of the impact of each procedure on lateral response.

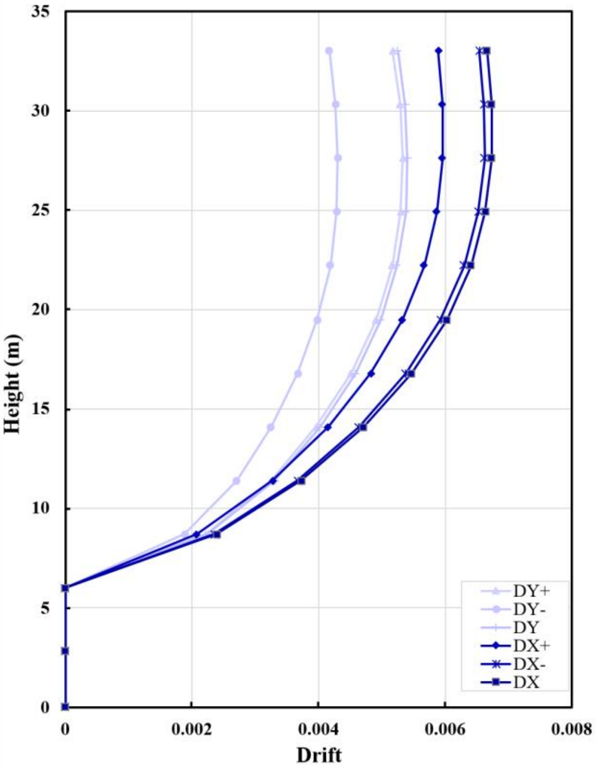


a. Model 1

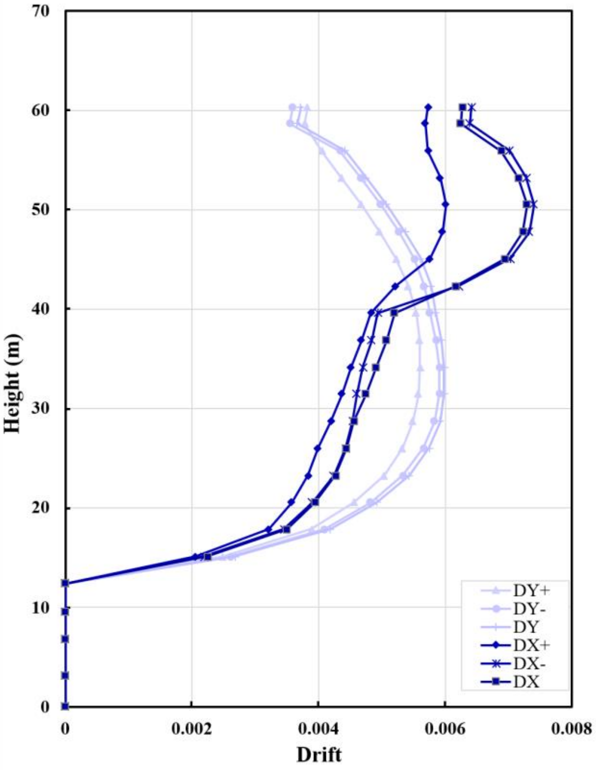
b. Model 2



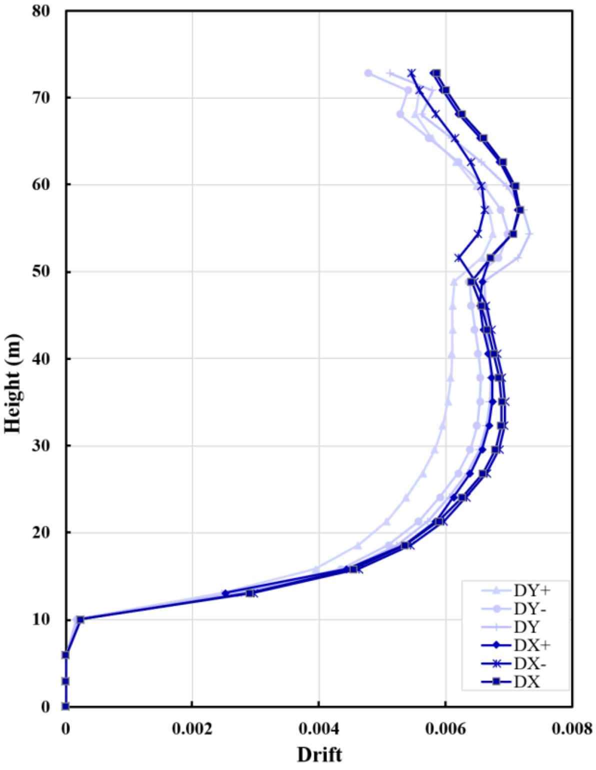
c. Model 3



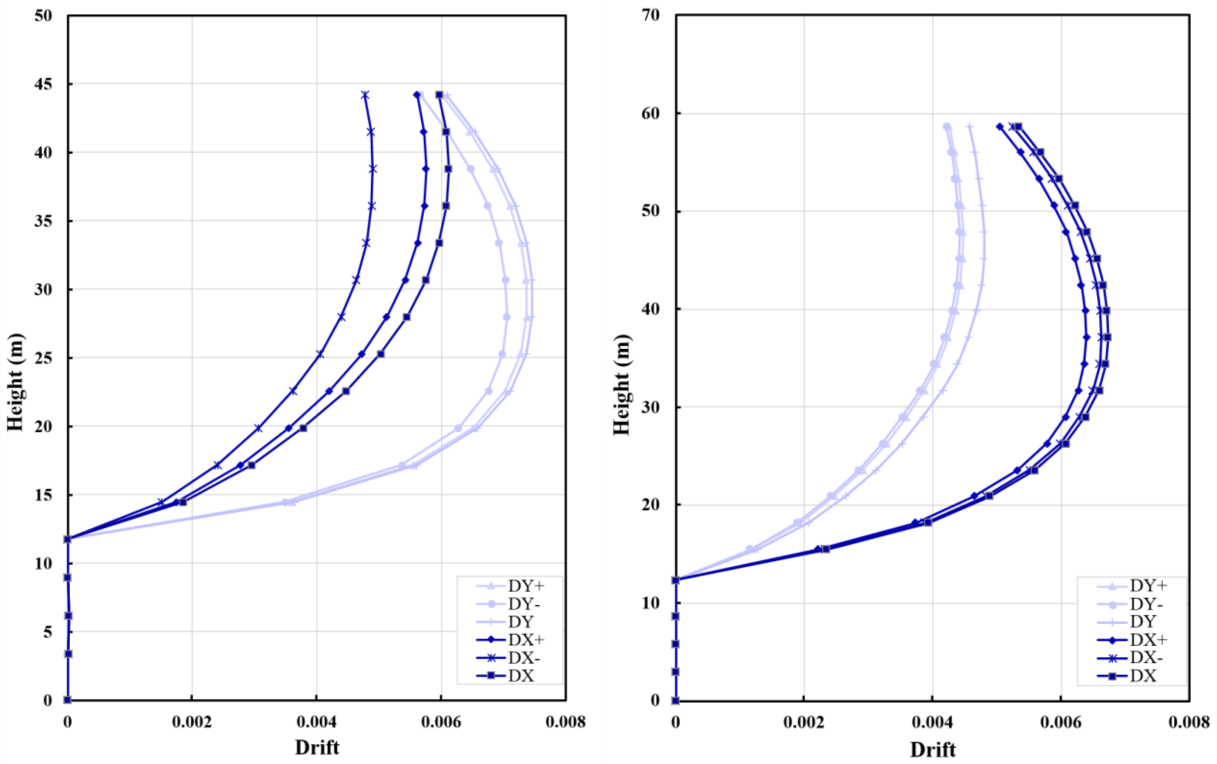
d. Model 4



e. Model 5



f. Model 6



g. Model 7

h. Model 8

Figure 8. Inter-Story Drift

3.2. Base Shear

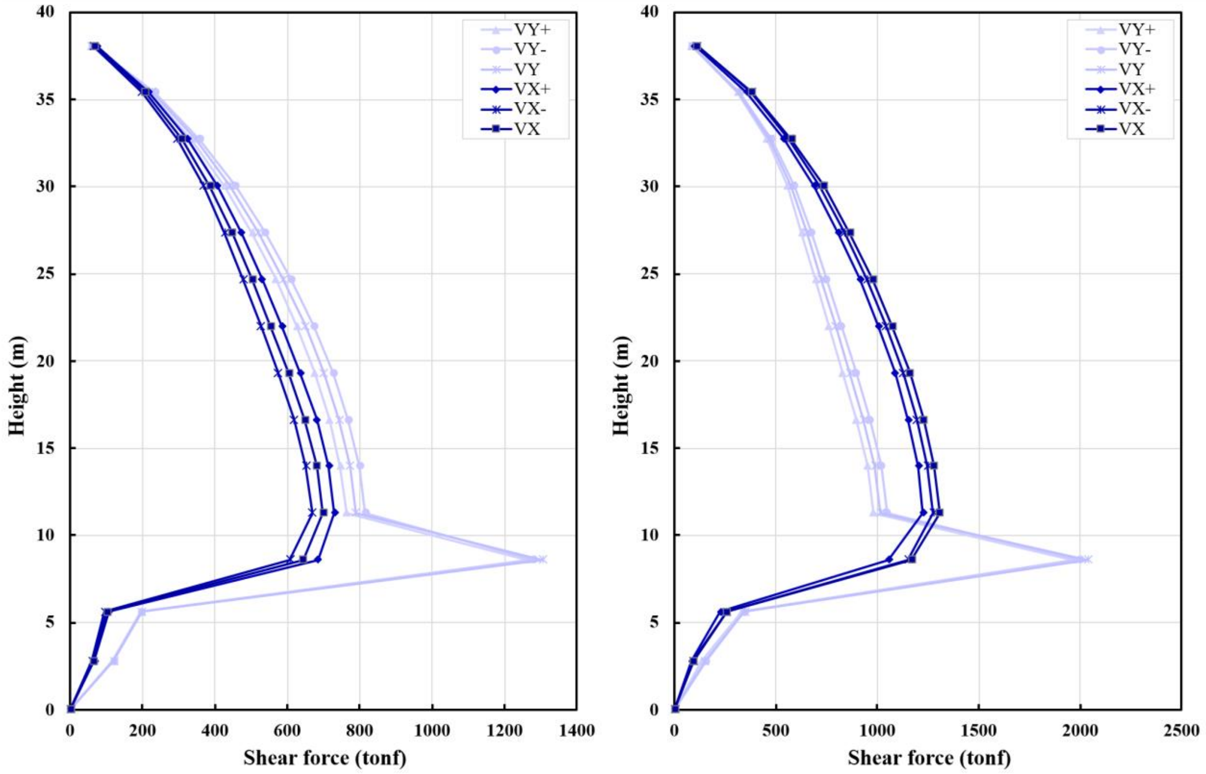
The evaluation of base shear is a key parameter for estimating the total seismic demand acting at the foundation of a building. In this study, the effect of accidental eccentricity on this variable was analyzed by comparing the results obtained from the quasi-static procedure and the dynamic mass displacement procedure applied to the eight evaluated models.

The results revealed significant variations depending on the structural configuration. Regarding increases, values ranged from +2.26% in Model 3 to a maximum of + 11.85% in Model 5, indicating that taller buildings and those with irregular stiffness distribution tend to show a notable rise in base shear when the dynamic procedure is applied. Similarly, Models 6 and 7 recorded increases of +10.56% and +9.65%, respectively, suggesting higher structural sensitivity to torsional effects and increased demand on vertical load-resisting elements.

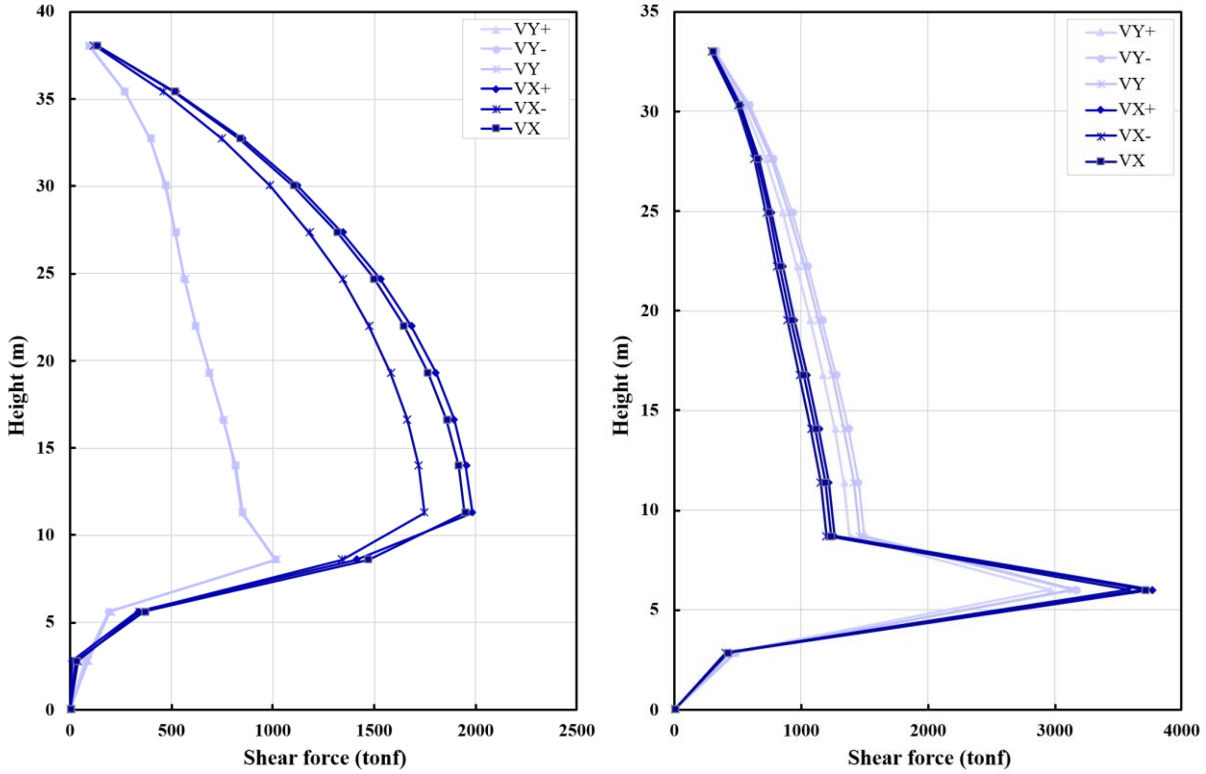
On the other hand, notable reductions were also identified, with decreases reaching −17.08% in Model 6 and −11.62% in Model 2. These reductions can be explained by modal redistribution: shifting the center of mass modifies the vibration modes and the way inertial forces are distributed across the structure, leading to lower base reactions in certain cases. This highlights the dual nature of the dynamic procedure, which may either amplify or mitigate demands depending on the geometric and stiffness configuration.

From a design perspective, these results are particularly relevant. Increases above 10% may imply the need to re-evaluate the sizing of shear walls, frames, or foundations to ensure compliance with seismic design provisions. Conversely, reductions should be carefully interpreted, as they may mask local amplifications at specific levels that are not reflected in global base shear values. For this reason, relying solely on quasi-static procedures can underestimate critical effects, while the dynamic approach provides a more complete representation of seismic demands.

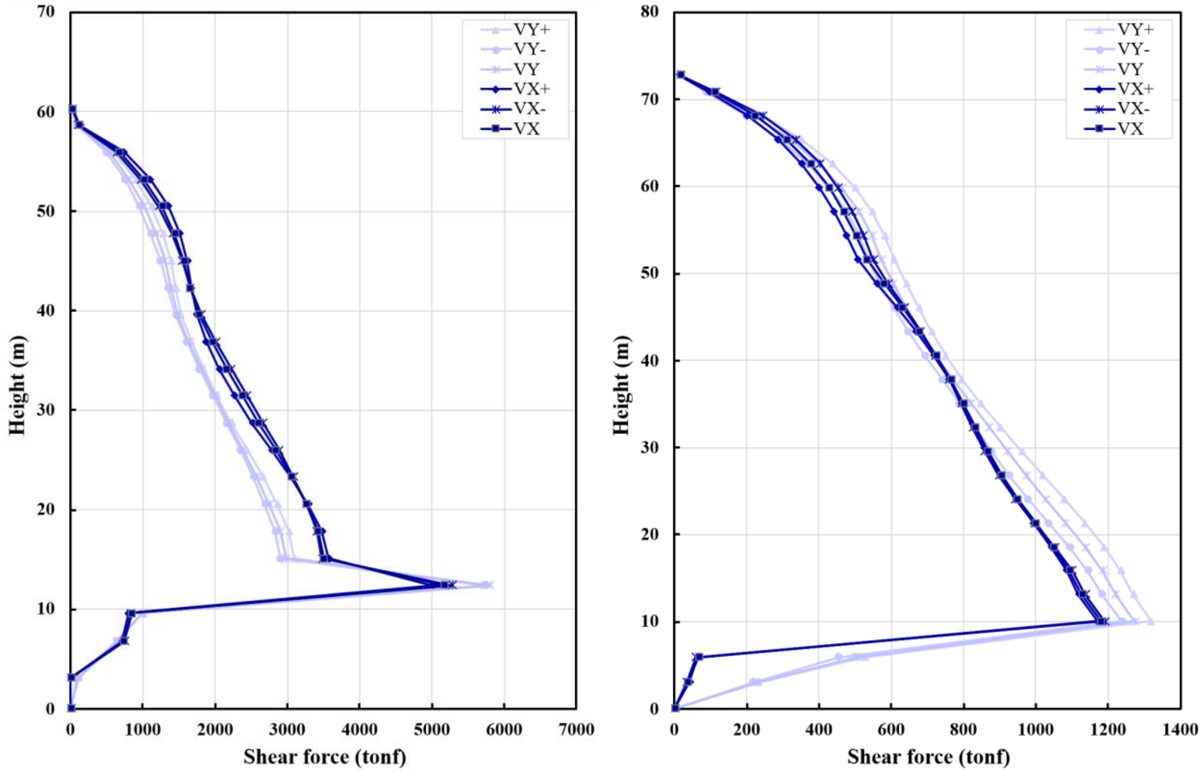
Figure 9 comparatively presents the percentage increases and decreases in base shear for each model, clearly illustrating the influence of the analytical procedure on this critical design variable.



a. Model 1 b. Model 2

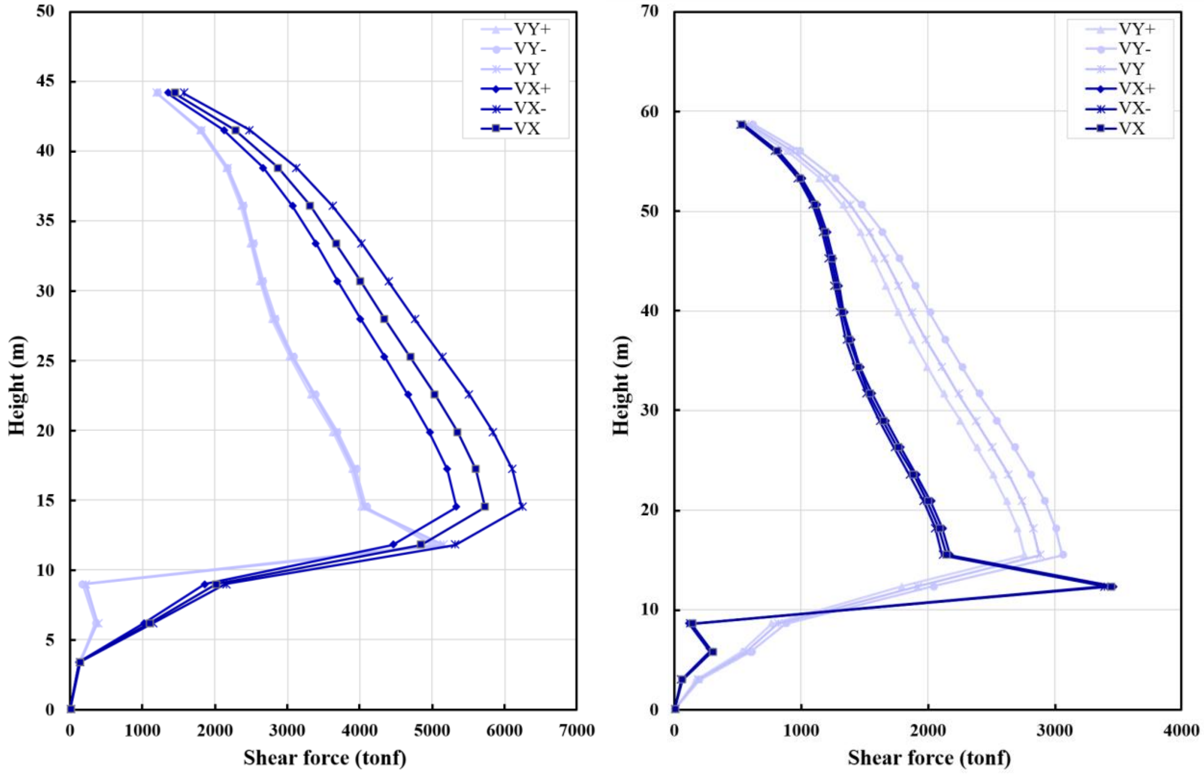


c. Model 3 d. Model 4



e. Model 5

f. Model 6



g. Model 7

h. Model 8

Figure 9. Shear force

3.3. Torsional Irregularity

The evaluation of torsional irregularity is essential for estimating a building's rotational response under seismic loads. This condition arises when there is a significant difference between the extreme displacements at the same floor level, producing unwanted rotation around the building's vertical axis. The torsional index, defined as the ratio between the maximum and average edge displacement of the diaphragm, is directly influenced by the in-plan distribution of stiffness and mass.

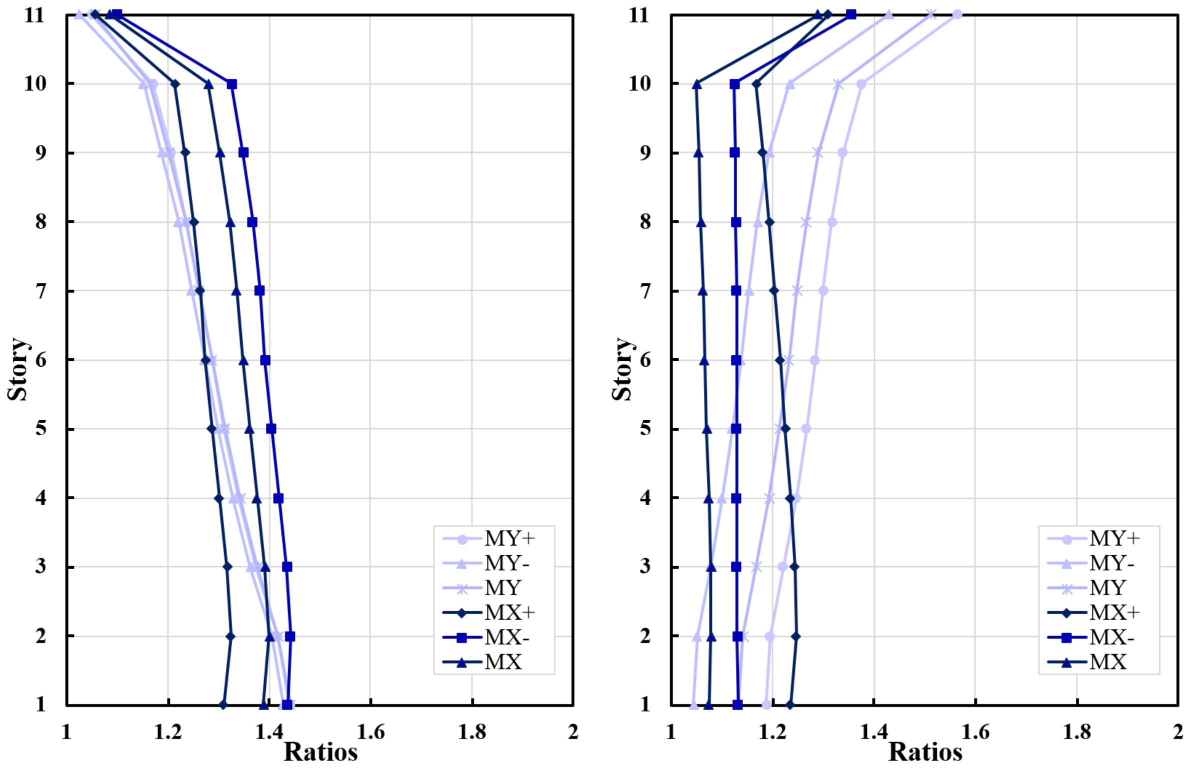
The results revealed a more critical response in the Y direction. Model 3 reached the highest torsional index value of 1.779, followed by Model 2 (1.563), Model 5 (1.480), and Model 6 (1.461). In the X direction, the maximum values were observed in Model 7 (1.408), Model 3 (1.340), and Model 1 (1.324), indicating significantly asymmetric behavior even under rigid diaphragm assumptions.

When analyzing the impact of mass center displacement implemented in the dynamic procedure, a systematic increase in torsional irregularity was observed in several models. For instance, in Model 3, the index in the Y direction rose from 1.74 to 1.779, and in Model 2 from 1.29 to 1.563. These increments confirm that dynamic eccentricity amplifies the susceptibility to rotational effects by altering inertial distribution and modal participation.

Conversely, certain models exhibited slight reductions in the torsional index under the dynamic procedure. These cases may be explained by favorable stiffness redistribution or a greater share of non-torsional modes in the dynamic response. Nonetheless, in most of the evaluated cases, shifting the center of mass tended to amplify torsional irregularity, particularly in structures with irregular plan geometries, variable stiffness elements, or asymmetrically located shear walls.

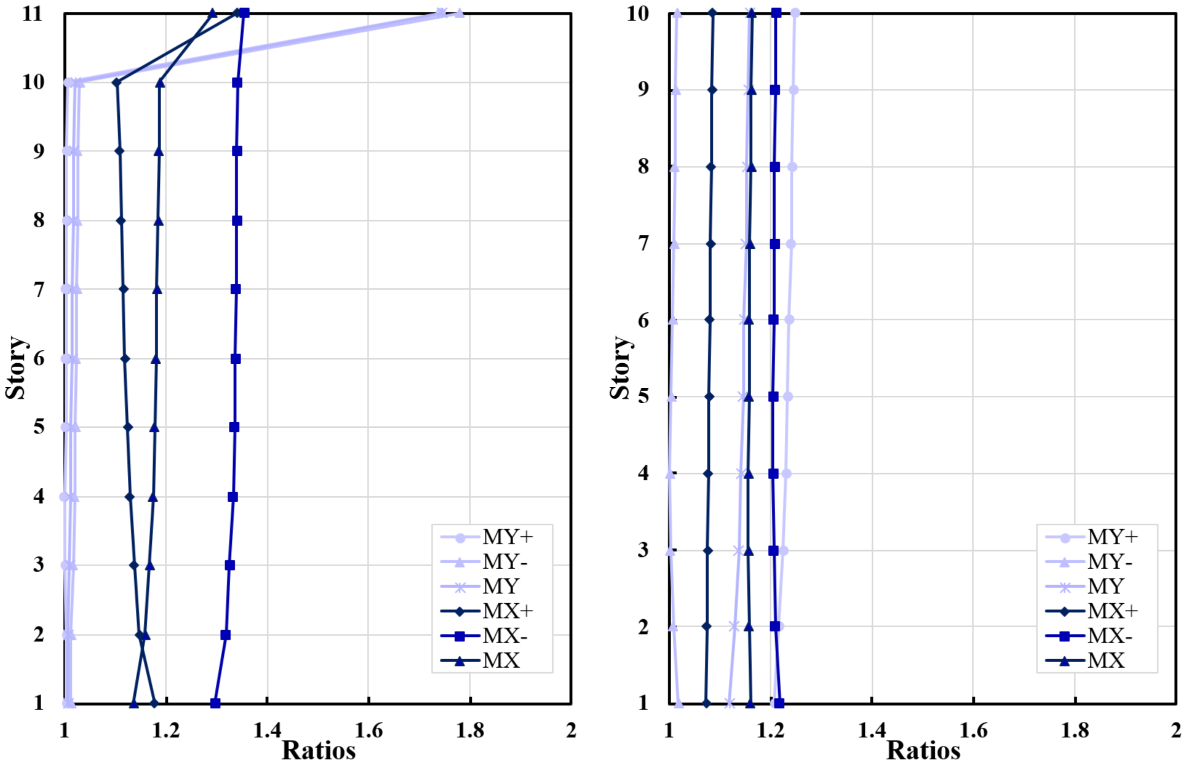
From a design standpoint, these results are highly relevant because values above 1.2–1.3 already indicate torsional irregularity according to seismic codes. The fact that several models exceeded 1.4–1.7 highlights the need for enhanced design checks and possibly mitigation measures such as strategic wall placement or diaphragm stiffening. This confirms that the quasi-static approach may underestimate torsional demands, while the dynamic procedure provides a more reliable assessment for irregular structures.

Figure 10 summarizes the maximum torsional irregularity index values in both principal directions, offering a direct comparison between the quasi-static and dynamic procedures.



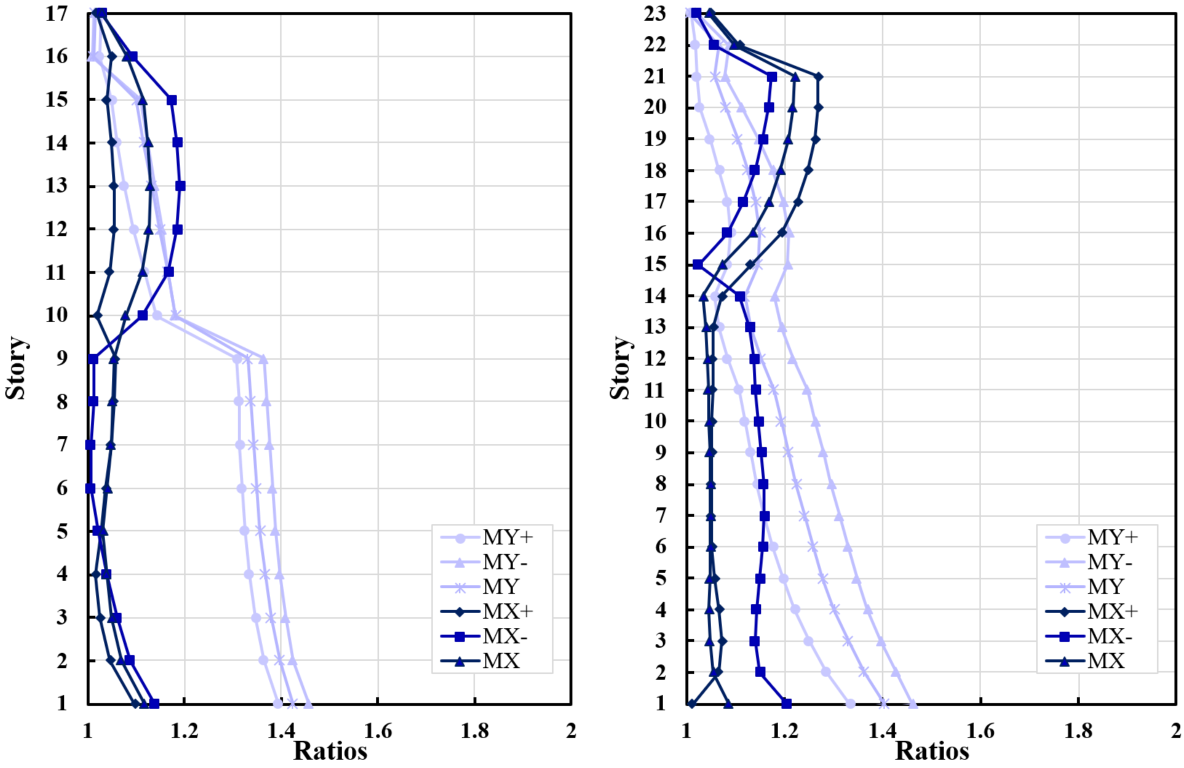
a. Model 1

b. Model 2



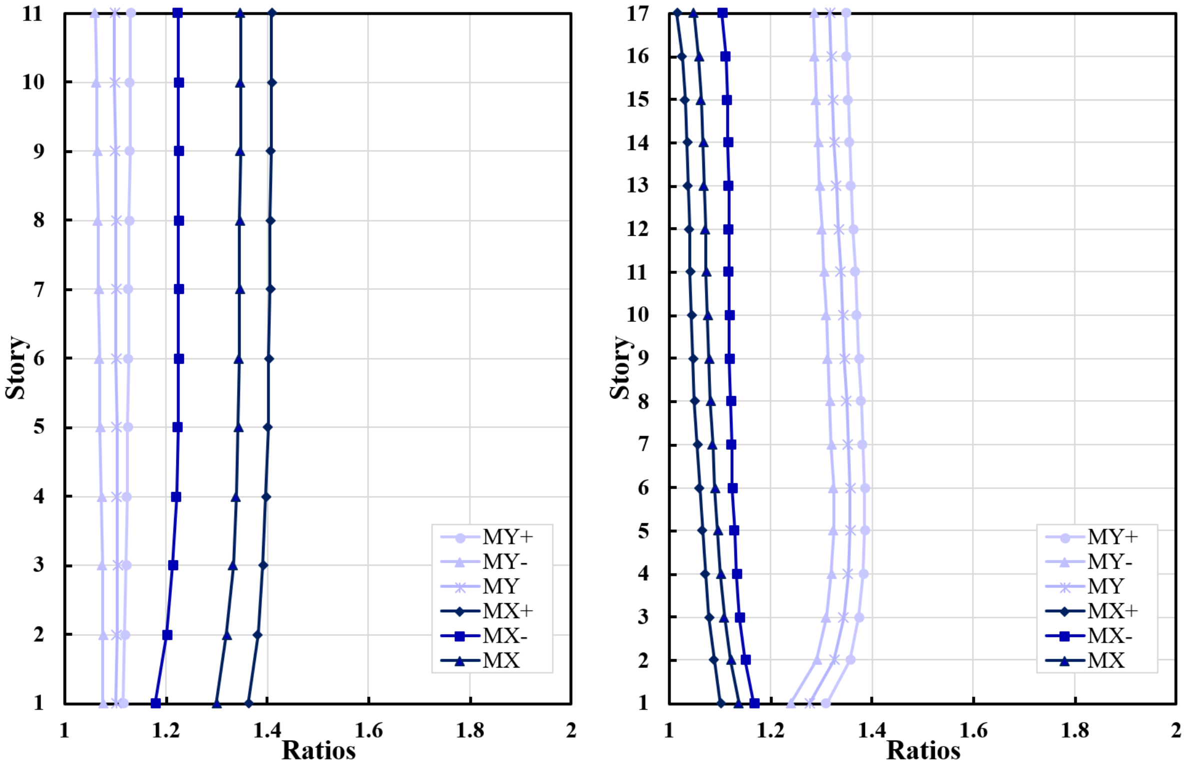
c. Model 3

d. Model 4



e. Model 5

f. Model 6



g. Model 7

h. Model 8

Figure 10. Torsional irregularity coefficient

4. Discussion

The results obtained demonstrate that the dynamic procedure based on mass center displacement has a significant impact on the global seismic response of buildings with real geometries and varying structural configurations. Compared to the quasi-static approach, notable differences were observed in inter-story drift, base shear, overturning moment, and torsional irregularity.

Regarding lateral drift, important variations were identified between the two procedures. Model 2 showed a reduction of 18.90 %, and Model 4 recorded a decrease of 20.59 %, suggesting that the dynamic approach can, in certain cases, produce a more favorable redistribution of displacements. These findings are consistent with results from IIT Roorkee, where it was shown that buildings with “T” or “+” shaped floor plans exhibit high torsional sensitivity, although this can be mitigated through appropriate modal representation [7].

Conversely, significant increases in drift were also observed. Model 3 recorded an increase of 11.88 % and Model 6 of 6.07 %, indicating that mass center displacement may amplify dynamic effects in structures with irregular stiffness distribution. This aligns with the study by the National Institute of Technology Karnataka, which demonstrated that soft stories or plan asymmetries intensify torsion and drift when dynamic eccentricity is considered [6].

In terms of base shear, Models 5, 6, and 7 showed increases exceeding 9 %, with Model 5 reaching 11.85 %. These results imply greater structural demand, which could affect the design of vertical resisting elements. A similar pattern was reported by Pérez and Hernández in Mexico, who, while proposing a simplified static torsion method, highlighted that dynamic eccentricities can significantly alter shear demands in torsional stiff structures [19].

For an overturning moment, Model 5 exhibited a 12.70 % increase, whereas Model 7 showed a 23.28 % reduction. These contrasting responses indicate that inertial redistribution from mass displacement may either amplify or reduce demand, depending on the building configuration. This behavior was also studied in Iran by Mousavi and Ghasemi, who concluded that mass eccentricity affects moment amplification more than stiffness, potentially doubling the response in box-type buildings [14].

Torsional irregularity also showed critical values in several models. For example, Model 1 reached 1.4 in the X direction and Model 3 reached 1.744 in the Y direction, particularly under the dynamic procedure. These results confirm the conclusions drawn by researchers at the Institute of Engineering in Nepal, who found that even minor mass asymmetries in otherwise regular structures can induce significant torsional responses when modal effects are not adequately considered [13].

In summary, the findings of this study reinforce the growing international consensus: accurate treatment of accidental eccentricity is crucial for reliable seismic assessment. In buildings with irregular geometry or non-uniform distributions of mass and stiffness, the dynamic procedure offers a more precise representation of torsional behavior, supporting the conclusions of studies conducted in India [4], Nepal [13], Iran [14], and Mexico [19].

The results show that the discrepancies between the code-based procedure and the response spectrum analysis are mainly due to modal interaction and the irregular distribution of stiffness and mass, conditions that the quasi-static method cannot fully capture. Consequently, the code can be considered sufficient for regular buildings with symmetric floor plans, centrally placed walls, and controlled drifts; whereas in “L,” “T,” or “U” shaped configurations, with eccentric walls, semi-rigid diaphragms, or soft-story conditions, it is necessary to complement the analysis with dynamic procedures to avoid underestimation of seismic demand.

5. Conclusions

This study compared two methodologies for addressing accidental eccentricity in reinforced concrete buildings using response spectrum modal analysis: the conventional quasi-static procedure and the dynamic approach based on mass center displacement. The findings clearly demonstrate that the selected method significantly affects the seismic response, particularly in buildings with irregular mass and stiffness distribution in plan and elevation.

Lateral drift variations reached up to ±20 %, indicating that the dynamic approach may either amplify or reduce seismic demand depending on the building’s geometry. Likewise, significant differences were observed in base shear and overturning moments, revealing that inertial redistribution resulting from center of mass displacement alters internal force patterns. Additionally, several models exceeded the torsional irregularity threshold, reinforcing the importance of properly representing accidental eccentricity during the design process.

Overall, the results confirm that the dynamic procedure offers a more realistic representation of torsional behavior, as it naturally captures modal interactions and the redistribution of inertial forces. In contrast, the quasi-static approach remains a practical tool for regular buildings or early-stage evaluations. Therefore, it is recommended to adopt the dynamic procedure either as a complementary tool or as a substitute, especially in structures exhibiting high torsional sensitivity, as part of a comprehensive seismic design strategy. For future research, we recommend comparing these findings using nonlinear time-history analyses on a representative subset, introducing realistic center of mass perturbations to quantify variability and help calibrate code-oriented criteria for when quasi-static procedures are sufficient versus when a dynamic approach is warranted.

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