# Impact of Vertical Irregularities on High-Rise Buildings and Their Effect on Internal Forces and Horizontal Displacement

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**Abstract**

Vertical irregularities in high-rise buildings present unique challenges to structural performance under lateral forces like wind and seismic loads. These irregularities involve changes in mass, stiffness or geometry of structures and cause disturbance in forces and deformations, bringing stress concentrations and irregular displacement patterns. Such vulnerabilities cause high possibilities of structural failure depending on such regions as those that experience an earthquake frequently. The effects of vertical irregularities in high rise structural framework are examined comprehensively through computational simulations which have been verified with experimental analysis in this paper. The analysis focuses on three key types of irregularities: The first include mass discontinuities, stiffness variations and geometric setbacks. Calculation results show that mass irregularities greatly increase axial forces, bending moments, and shear stresses within the transition floors. Lateral load distribution disparities like soft story cause excessive inter story drift than required whereas geometric dispersions affect torsional responses and disrupts flow of displaced length. Related to this, the findings stress the importance of using performance-based design methods to respond to existing vertical gradient irregularities. Possible control measures are: massive strengthening of weak stories with shear walls, mass re-arrangement for balanced structure behavior, and increasing the torsional stiffness by better detailing and these findings provide valuable design guidelines for engineers and designers towards development of improved structures whose design withstands the exercise of the extreme events. In turn, this research aims to develop design concepts for higher structures and identify how to improve their safety and lifespan in cases of seismic activity.

**Keywords:** Vertical Irregularities; High-Rise Structures; Seismic Response; Internal Forces; Inter-Story Drift

## 1. Introduction

Modern society increasingly relies on vertical development in urban areas to address the challenges of limited land availability and the need to accommodate growing populations efficiently. High-rise buildings, however, often include vertical irregularities such as mass discontinuities, stiffness variations, and geometric setbacks, resulting from architectural, functional, or economic considerations [1,2]. These irregularities disrupt the distribution of structural forces and deformations, creating weaknesses that are particularly critical under lateral forces such as wind and

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seismic loads [3,4]. As a result, understanding the impact of vertical irregularities on structural behavior is essential for evaluating and improving the performance of tall buildings, especially in regions prone to extreme loading events.

Athanassiadou (2008) demonstrated that vertical irregularities in reinforced concrete frames significantly affect seismic performance, particularly through increased inter-story drift and localized structural weaknesses [5]. Similarly, Humar and Mahgoub (2003) emphasized that stiffness irregularities, such as soft stories, amplify shear demands and compromise lateral stability under seismic loading [6]. Das and Nau (2003) further showed that geometric irregularities, including setbacks, introduce torsional effects that can destabilize building structures and intensify damage during earthquakes [7]. These foundational studies offer critical insights into the behavior of individual irregularities; however, they often lack an integrated approach to evaluating the combined influence of mass, stiffness, and geometric irregularities on overall structural performance.

Efforts to address irregularities include computational and experimental studies. Al-Ali and Krawinkler (1998) analyzed the effects of vertical irregularities on structural systems, showing that mass and stiffness variations impose higher demands on critical structural components [8]. Goel and Chopra (2008) proposed modal pushover analysis as a reliable method for predicting the nonlinear seismic response of irregular frames, with findings corroborated by Molina and Roule (2011) through shake table experiments [9,10]. While these studies offer valuable methods for analysing irregularities, they often focus on individual irregularity types, leaving gaps in understanding their combined effects.

Despite advancements, there remains limited research examining the cumulative impact of mass discontinuities, stiffness variations, and geometric setbacks on high-rise structures. Current design codes, such as ASCE/SEI 722, emphasize the importance of structural regularity but provide minimal guidance for mitigating irregularities [11,12]. This study addresses these gaps by conducting a comprehensive investigation of irregular high-rise buildings, employing advanced computational simulations validated by experimental data to offer actionable insights for engineers and designers.

## Materials and Methods

In both the regular and irregular models, all primary structural elements—including slabs, beams, columns, and shear walls—were modeled using reinforced concrete with a compressive strength of 4000 psi. The slab elements were defined as shell-thin elements, with two different thicknesses in the irregular model: an 8-inch-thick slab (Slab1) used for most floors, and a 4-inch-thick slab (Slab2) applied specifically at the 20th floor to simulate vertical mass irregularity. In contrast, the regular model used a uniform slab thickness of 8 inches across all stories.

Shear walls were also modeled as shell-thin elements with a constant thickness of 10 inches throughout the structure in both models, serving as the primary lateral load-resisting system. Beam elements in both models were rectangular reinforced concrete sections with dimensions of 24 inches by 30 inches, applied uniformly across all stories. Column sections varied depending on their location and structural demand, with cross-sectional dimensions of 26"×26", 32"×32", and 40"×40" used at different levels to support the varying load paths in the high-rise configuration.

### *2.1 Computational Modelling*

Three 30-story high-rise building models were developed using ETABS:

Model A: Regular high-rise structure.

Model B: Structure with mass irregularities.

*2.2 Key Metrics Evaluated*

Key performance metrics included:

Internal Forces: Axial, shear, and bending forces.

Horizontal Displacement: Maximum inter-story drift and displacement profiles.

Failure Mechanisms: Identification of stress concentrations and yielding zones.

## 3. Results

Mass irregularities increased axial forces by up to 10.83% at transition levels, while Bending Moment caused a 183.00% rise and also the shear Force Difference is 72.30%. These findings confirm prior observations that irregularities amplify localized stresses, compromising structural integrity show in table 1.

Table 1. Detail of Internal Forces

| Parameter | Percentage Difference |
|---|---|
| Axiel Force | 10.83% |
| Moment | 183.00% |
| Shear Force | 72.30% |

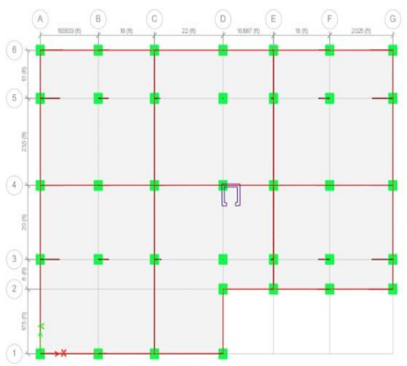


**Figure 1.** Layout of story no 20

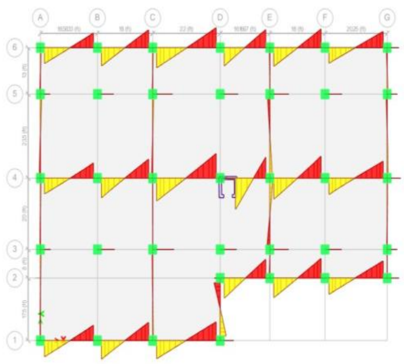
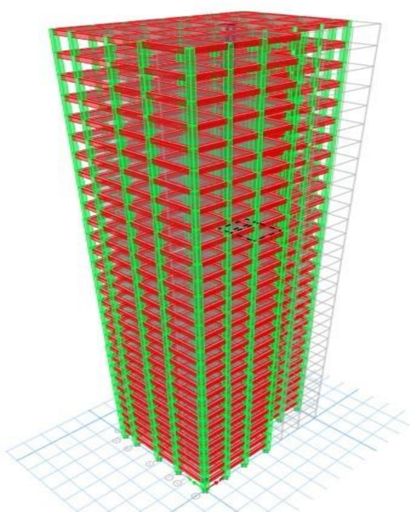


**Figure 3.** Bending Moment

The figure (Figure 1) shows the layout of 20th story where the geometry had been changed by reducing the number and size of beams. The modifications applied to the geometry are essential in analyzing changes in structural stiffness and forces within the structure. (Figure 2) This figure indicates bending moment and shear force diagrams of the modified 20th story. The diagrams indicate areas of high stress intensity and shifting of internal force PSD due to geometrical modification. Posted below are such visual aids which create a perfect representation of how compromised structures affect efficiency.



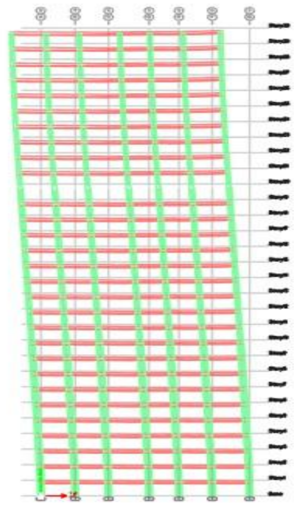
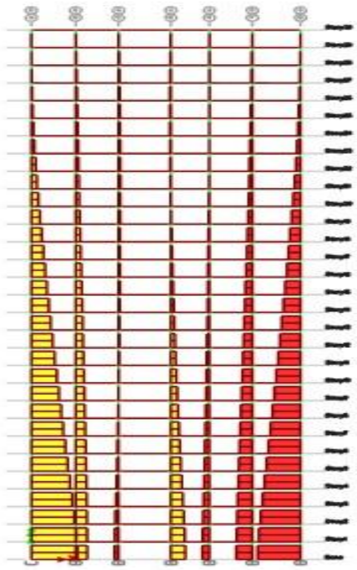


**Figure 3.** 3D Model of Building **Figure 4.** Deformed shape

The fig 4 show the 3d model of the building and the fig 5 illustrates the Deformed shape of the building, showcasing the structural response under dynamic loading conditions. The analysis highlights the deformation pattern at various time intervals, where the minimum time is recorded at 0.1 seconds, and the maximum time reaches 5 seconds. The green and red lines in the diagram represent the lateral displacement of structural elements under seismic excitation, providing a clear visual of the irregular deformation through the building height.



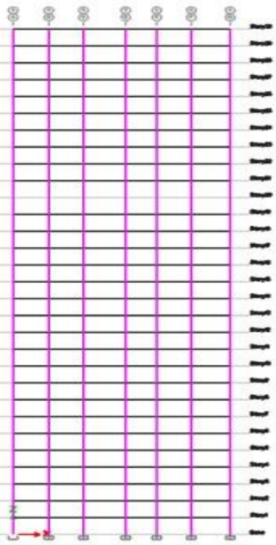


**Figure 5.** Axial Force **Figure 6.** Design Cheak

The values of axial forces at various floors of the structure are provided in the form of the fig 6. These variations are most apparent at the transition levels at which vertical irregularities create large stress concentrations. The fig 7 presents the number of design checks done to confirm the structural conformity of the model. Such analysis, guarantees that the structural parts have adequate safety and performance characteristics under earthquake loading conditions.

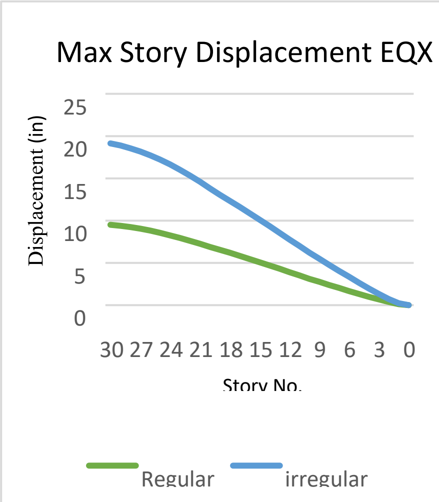



**Figure 7.** Displacement Graph

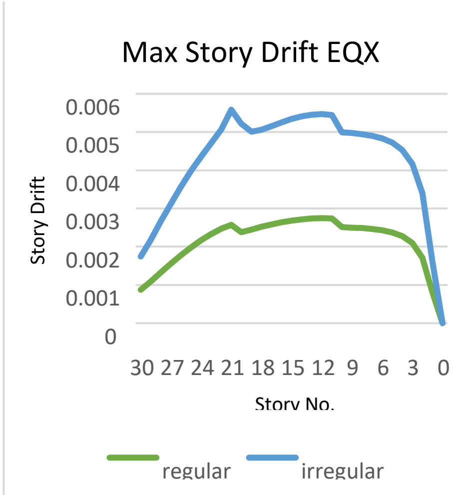



**Figure 8.** Story Drift Graph

Horizontal Displacement Structures with stiffness irregularities exhibited maximum inter-story drifts exceeding 2.5%, compared to 1.2% in regular buildings show in fig 8. This represents an increase of approximately 108% in inter-story drift for irregular structures show in fig 9. Similarly, displacement in irregular structures was observed to be 50% higher, while stiffness variation was 40% greater compared to regular buildings.

## 4. Discussion

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighting the findings thus emphasize the significance of vertical asymmetry on structural behavior in earthquake region. Where stress concentrations are most prevalent, namely at transition levels, mass irregularities were found to substantially increase axial force and bending moment demands. The augmented internal forces make them more susceptible to failure than other regions of a country.

Soft stories, or stiffness discontinuities, led to large inter-story drifts, and the distribution of maximum drift ratios was significantly greater than 2.5%. This underlines the significance of controlling stiffness changes in order to prevent stiction and possible structure failure during earthquakes. Additionally, geometrical irregularities cause torsional effects which arrest smooth displacement and add further structural vulnerability.

The graphic analysis supports these conclusions by comparing displacement and drift diagrams with structural irregularity to show increased danger levels. The distribution of the bending moment and axial force is another evidence that there is a great deal of stress at certain sections for which special attention has to be paid during the design procedure.

## 5. Conclusions

This work systematically assessed and quantified the impact of mass, stiffness, and geometric vertical irregularities on the high-rise buildings' structural response to lateral loads including seismic and wind loads. The conclusion I have drawn from this study is that comparatively large mass irregularities result in higher axial forces and bending moments, as well as shear forces, at transition levels and stressing concentrations. Like all irregularities, stiffness irregularities, especially soft stories, significantly increased the inter-story drifts and horizontal displacement with drift ratio of more than 2.5% as compared to 1.2% in a regular structure. Geometry brought torsional effects into the design, complicated the displacement profile, and added more instability to the structures.

These results support the need for a precise design treatment to offset the risks posed by vertical irregularity conditions. Actions like connecting soft stories to shear walls, adjusting the building's mass balance or increasing the torsional stiffness at changes in geometric properties helps reduce risks greatly. Computational modelling at an enhanced level and experimentation delivery the strong platform for the performance-based design methodologies. The findings of this research advocating for the conformity to seismic design codes like the ASCE/SEI 7-22 while searching for more effective ways of making the irregular high-rise buildings safer and more responsive to any seismic event in regions that are vulnerable to such challenges.

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