Effect of Vertical Irregularities in Stiffness Due to Seismic Activity with and without Girder

Musaddique Q. Bandirkar[1]

[1]ME Student, KJ’s Educational Institute, KJ College of Engineering and Management Research, Pune, Maharashtra (Affiliated to Savitribai Phule Pune University)

Prof. Abhijeet R. Undre[2]

[2]Associate professor, KJ’s Educational Institute, KJ College of Engineering and Management Research, Pune, Maharashtra (Affiliated to Savitribai Phule Pune University)

Dr. Atul Pujari[3]

[3]Associate professor/Dr., KJ’s Educational Institute, KJ College of Engineering and Management Research, Pune, Maharashtra (Affiliated to Savitribai Phule Pune University)

Abstract

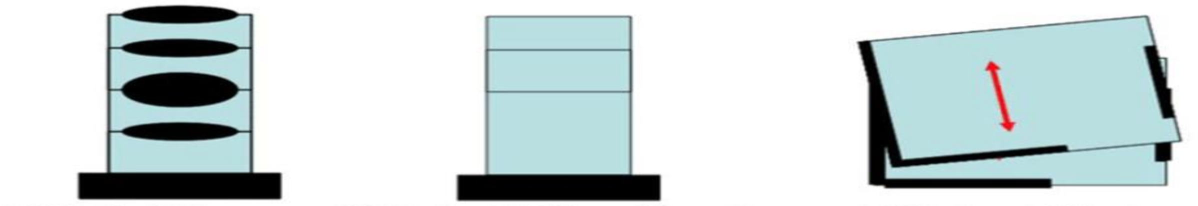
Vertical irregularities in structural stiffness play a crucial role in the seismic performance of multi-storey buildings, particularly in earthquake-prone regions. These irregularities arise from variations in the lateral rigidity of a building’s structural elements along its height, leading to uneven distribution of seismic forces. This study investigates the impact of vertical stiffness irregularities on the seismic behavior of buildings, focusing on the "soft-storey" effect where certain floors experience disproportionately higher seismic forces. Additionally, the role of girders in improving the lateral stiffness and overall seismic resilience of such buildings is explored. By analyzing buildings with and without girders, the research highlights how the inclusion of girders helps distribute seismic forces more uniformly, reducing inter-storey drift and mitigating the risk of structural failure. The findings underscore the importance of incorporating girders in the design of buildings with vertical irregularities to enhance their seismic performance and ensure greater structural stability. This paper also explores the challenges and potential solutions in improving building designs to withstand seismic events effectively.

Keywords: vertical irregularities, seismic performance, soft-storey effect, lateral stiffness, girders, structural stability.

1. Introduction

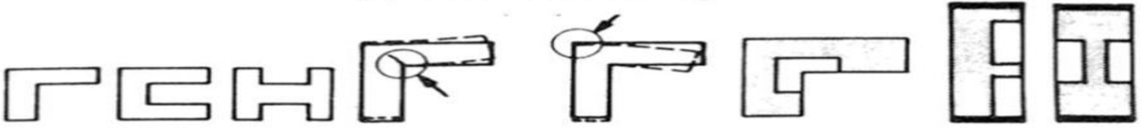
Vertical irregularities in stiffness significantly influence the seismic performance of multi-storey buildings, particularly in regions prone to earthquakes. These irregularities, which arise from variations in the lateral rigidity of structural elements across a building's height, can lead to uneven distribution of seismic forces. This unevenness creates localized concentrations of stress, particularly in the softer storeys, leading to increased inter-storey drifts and a higher risk of structural failure. The most common cause of vertical irregularities is the architectural or functional design of buildings, such as open ground floors, larger windows on certain levels, or inconsistent column sizes. Such irregularities disrupt the uniformity of seismic force distribution, making the building more vulnerable to lateral forces. The "soft-storey" effect is a prime example, where a building's ground floor, typically more flexible than upper floors, attracts disproportionate seismic forces, often resulting in excessive damage or even collapse during an earthquake. To mitigate the effects of these irregularities, structural elements such as girders are often incorporated into the design. Girders, as horizontal members connecting columns, play a crucial role in enhancing the overall stiffness of the building, thereby reducing lateral displacements and limiting excessive deformations. Their presence helps distribute seismic forces more uniformly across the structure, preventing localized failures that might otherwise occur in buildings without such reinforcement. The role of girders becomes particularly important in buildings with vertical stiffness irregularities, as they can provide the necessary stability to counteract the vulnerabilities introduced by irregular stiffness.

Despite the recognized importance of girders in improving the seismic resilience of buildings, there remains a limited understanding of how their presence impacts the seismic performance of structures with vertical stiffness irregularities. Most studies have either focused on the effects of irregularities or the benefits of girders independently, but few have examined the combined effect of these factors. This research seeks to fill this gap by analyzing the seismic behavior of buildings with vertical stiffness irregularities, both with and without girders, to evaluate how the inclusion of girders influences the distribution of seismic forces, storey drifts, and overall structural stability during seismic events. By employing advanced modeling techniques such as ETABS software and conducting both static and dynamic analyses, this study will provide valuable insights into the impact of vertical irregularities on seismic performance and the potential of girders to mitigate these effects. The findings aim to inform better design practices and retrofit strategies for buildings in earthquake-prone regions, ultimately contributing to safer, more resilient structures.



(a) Vertical Mass (b) Vertical Stiffness/Strength (c) Horizontal Torsion

(d) Vertical Discontinuity



(e) Plan Discontinuity

Fig 1. Types of Structural Irregularities in Buildings

2. Seismic Behavior of Structures

The seismic behavior of structures is a critical aspect of structural engineering, particularly in regions prone to earthquakes. When seismic waves propagate through the Earth, they generate forces that affect buildings and other structures. These forces are primarily horizontal but can also have vertical components. Seismic forces induce dynamic loads that cause structures to vibrate, resulting in displacements, accelerations, and inertial forces. The response of a structure to these seismic forces depends on several factors, including its mass, stiffness, damping properties, and the distribution of forces within the building. A key aspect of seismic behavior is the structure's ability to absorb and dissipate the energy generated by the seismic waves. The stiffness of a building dictates how much it will deform under lateral loads; structures with higher stiffness will resist deformation, while those with lower stiffness will experience more significant displacements. Mass plays a crucial role as well, as heavier structures are subjected to greater inertial forces during an earthquake. The interaction between mass and stiffness determines the dynamic response of the building, particularly its natural frequency and mode shapes. In addition to mass and stiffness, damping also influences the seismic response. Damping refers to the mechanism by which a structure dissipates seismic energy, typically through materials or systems designed to absorb vibrations. A building with adequate damping will experience reduced oscillations, improving its overall stability during seismic events. Structures with irregularities, such as vertical stiffness irregularities, pose additional challenges to seismic performance. These irregularities can lead to uneven force distribution, creating stress concentrations in certain areas, which may result in structural damage or even failure. The presence of elements like girders, shear walls, or braces can enhance the lateral stiffness of a building, thereby improving its ability to resist seismic forces and minimizing the risk of failure. Understanding and addressing these factors is essential for ensuring the safety and stability of buildings in seismic zones.

3. Vertical Irregularities in Structural Stiffness

Vertical irregularities in structural stiffness refer to variations in the lateral rigidity of a building's structural elements along its height. These irregularities occur when certain floors of a building are more flexible or rigid than others, leading to an uneven distribution of seismic forces. Common causes of vertical stiffness irregularities include variations in column sizes, changes in floor plans, or the removal of infill walls for architectural or functional purposes, such as creating open spaces on lower floors for parking or commercial areas. Buildings with vertical stiffness irregularities often experience disproportionate force concentrations in weaker storeys during an earthquake. The most notable phenomenon resulting from such irregularities is the "soft-storey effect," where floors with reduced stiffness attract higher lateral forces, leading to excessive inter-storey drift and potential structural failure. This effect is especially critical in high-rise buildings, where the cumulative seismic forces can cause significant deformation and damage. To mitigate the impact of vertical irregularities, it is essential to ensure a gradual transition in stiffness along the building's height, using elements such as shear walls, bracing systems, or girders. These elements help to distribute forces more evenly across the structure, improving its seismic performance and preventing localized failures. Understanding and addressing vertical irregularities are crucial for designing earthquake-resistant buildings, especially in seismic zones.

4. Role of Girders in Structural Stiffness and Seismic Response

Girders are essential horizontal structural elements that contribute significantly to the overall stiffness and stability of a building. In reinforced concrete (RC) and steel-framed buildings, girders connect vertical columns and provide support to floor slabs, facilitating uniform distribution of vertical and lateral loads. The role of girders in enhancing structural stiffness is particularly crucial during seismic events, where lateral forces, caused by ground motion, interact with the building's structure, inducing deformation and stresses. The inclusion of girders in a building's design improves its lateral stiffness by ensuring that seismic forces are evenly distributed across the structure. Girders reduce excessive inter-storey drift, which occurs when different floors of a building move relative to each other during seismic shaking. Without girders, buildings, especially those with vertical irregularities like soft-storey configurations, may experience concentrated forces and deformation in weaker storeys, increasing the risk of collapse. By connecting columns and supporting slabs, girders provide continuity to the structural system, which reduces the likelihood of localized failures and minimizes overall displacement during an earthquake.

Moreover, girders help to mitigate torsional effects that arise when the building's center of mass does not coincide with its center of rigidity. Torsional motion amplifies stresses and can cause uneven distribution of seismic forces across the building. Girders help in reducing torsional amplification by improving the building's rigidity, thereby ensuring that lateral forces are better resisted. Studies have shown that buildings with well-designed girders exhibit a more uniform response during seismic loading, experiencing lower bending moments and shear forces compared to structures without girders. In summary, girders are integral to the seismic response of a building. Their primary role in enhancing lateral stiffness, reducing inter-storey drift, and improving the overall force distribution makes them essential for maintaining the structural integrity of buildings during seismic events. Proper girder design is crucial, especially for buildings with vertical stiffness irregularities, ensuring better seismic resilience and safety.

5. Comparison of Seismic Response with and without Girders

The inclusion of girders in the design of multi-storey buildings significantly improves their seismic performance, particularly in terms of lateral stiffness, inter-storey drift, and torsional effects. Buildings with girders benefit from enhanced lateral stiffness, as girders distribute seismic forces uniformly across the structure. By connecting columns and floor slabs, girders form a continuous load path that resists lateral forces effectively, leading to reduced displacement during seismic shaking. This uniform distribution of forces ensures that all storeys share the seismic load, preventing localized stress concentrations, especially in weaker storeys. As a result, buildings with girders tend to exhibit smaller displacements and experience lower risks of structural failure during earthquakes. In contrast, buildings without girders lack the horizontal continuity that girders provide, making them more flexible and prone to larger displacements. The absence of these structural elements means that seismic forces are not evenly distributed, causing forces to concentrate in certain areas, particularly in buildings with vertical irregularities like soft-storey configurations. This results in excessive inter-storey drift, which is the relative displacement between consecutive floors. Buildings without girders are more susceptible to torsional motion as well, especially when the center of mass does not align with the center of rigidity. Without girders, torsional effects amplify, causing uneven distribution of forces and increased stress on specific parts of the structure, leading to potential damage.

In summary, buildings with girders perform better under seismic loads by enhancing stiffness, reducing inter-storey drift, and minimizing torsional effects. Without girders, buildings experience higher displacement, greater drift, and amplified torsional motion, making them more vulnerable to seismic damage and collapse.

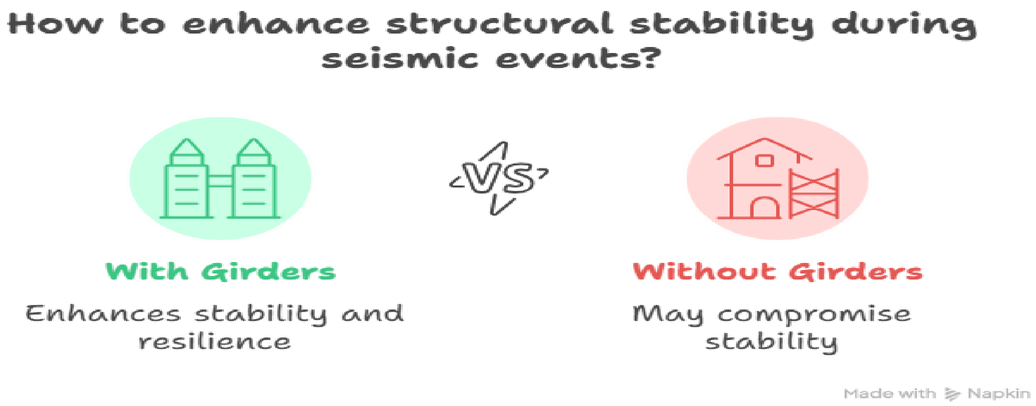


Fig 2. . Comparison of Seismic Response with and without Girders

5.1 Construction Time and Cost:

Construction time and cost are significant factors that need careful consideration in the implementation of Performance-Based Design (PBD). While PBD offers a more tailored approach to seismic resilience, it often results in longer construction timelines and higher initial costs compared to traditional design methods. The design phase of PBD is more complex, requiring detailed analysis such as nonlinear time-history analysis, which can extend the overall design period. This is because PBD involves evaluating different seismic scenarios and optimizing structural systems to meet specific performance objectives, such as life safety, immediate occupancy, or collapse prevention. Additionally, the construction phase of PBD may be lengthened if specialized materials or advanced systems, such as base isolators, dampers, or reinforced shear walls, are necessary to achieve the desired performance levels. These systems are typically more intricate to install and require specialized labor and expertise. Regarding cost, PBD generally leads to higher initial expenditures. The enhanced safety measures, custom-designed structural systems, and the use of advanced materials all contribute to an increase in construction costs. For existing buildings, retrofitting to meet performance-based standards can also be expensive. Despite these initial costs and time extensions, the long-term benefits of PBD—such as reduced earthquake damage and enhanced safety—often justify the higher upfront investment, especially for critical infrastructure.

5.2 Seismic Performance

Seismic performance of buildings with vertical stiffness irregularities is highly influenced by the presence or absence of girders. Vertical irregularities often arise from architectural decisions such as open ground floors or variations in column sizes, which disrupt the uniform distribution of seismic forces across storeys. This uneven load distribution can lead to excessive inter-storey drift, torsional motion, and potential collapse, particularly in structures with "soft-storey" configurations. Girders, by connecting columns and supporting floor slabs, play a crucial role in mitigating the adverse effects of these irregularities. They provide continuity and improve lateral stiffness, reducing inter-storey drift and force concentration at weak storeys. Their presence enhances the seismic resilience of structures by ensuring that seismic forces are distributed more evenly across the building. Computational studies have shown that well-designed girders can reduce lateral displacements by 15–25%, thus preventing localized failures. Without girders, buildings with vertical stiffness irregularities are more vulnerable to seismic forces. The lack of horizontal continuity results in localized failures, higher lateral displacements, and increased risk of collapse. Therefore, the presence of girders significantly enhances the overall seismic performance, highlighting their importance in earthquake-resistant design.

5.3 Structural Integrity and Durability

Structural integrity and durability are fundamental to ensuring the safety, functionality, and longevity of buildings, especially in earthquake-prone regions. Structural integrity refers to the ability of a building to withstand various loads—such as seismic, wind, and live loads—without experiencing failure or excessive deformation. It is achieved through careful design, material selection, and construction practices that ensure all components of the structure work together cohesively to resist external forces. Durability, on the other hand, pertains to a structure's ability to maintain its performance over time, resisting degradation from environmental factors such as moisture, temperature changes, and chemical reactions. A durable structure requires proper materials and coatings that can withstand these forces without compromising its strength or functionality. The combination of structural integrity and durability is essential for the safety of a building throughout its life cycle. Ensuring both requires regular maintenance, timely retrofitting to address potential weaknesses, and the use of high-quality materials that resist wear and tear. In seismic design, this includes incorporating elements like shear walls, girders, and proper reinforcement to prevent structural failure. In sum, structural integrity and durability are interlinked and crucial for the long-term performance and safety of buildings, particularly in regions exposed to natural hazards like earthquakes.

Table 1: Summary of Relevant Studies on Vertical Irregularities and Seismic Performance

Sr. No	Author / Year	Title	Methods	Key Observation
1	Bhatt, M.R. (2017)	Study on the Effect of Vertical Irregularities on Infilled RC Frames under Seismic Effect	Linear time history analysis using ETABS for special moment-resisting RC frames with vertical mass and stiffness irregularities.	Stiffness irregularity in lower storeys significantly affected inter-storey drift; mass irregularity increased overturning moments in upper storeys.
2	Raj, K.G. et al. (2025)	Impact of Irregularities on Seismic Fragility of Reinforced Concrete Structures	Nonlinear static (pushover) analysis using ETABS; analysis of buildings with vertical irregularities in stiffness, mass, or combination of both.	Buildings with combined mass and stiffness irregularities exhibited critical seismic response, with higher displacements and lower base shear capacity.
3	Santos, D. et al. (2024)	Comparative Analysis of the Impact of Vertical Irregularities on Reinforced Concrete Moment-Resisting Frame Structures	Eurocode 8 provisions; analyzed 13 five-storey moment-resisting frame buildings using SeismoStruct v2024.	Increasing the height of lower or middle stories worsened seismic performance; column geometry variations strongly affected drift and base shear.
4	Mungalkar, G. et al. (2024)	Assessing Vertical Irregularity in Buildings across Seismic Zones: A Comparative Study	15 models of irregular buildings analyzed for height (21m, 30m, and 42m) and seismic loading conditions.	Taller buildings exhibited longer periods, with increased mass and stiffness, leading to variations in dynamic response under seismic loads.
5	Pandey, A.V. et al. (2024)	Comparative Study of Seismic Analysis of Vertically Irregular R.C. Frame Using Indian and Euro Code	Dynamic structural analysis comparing Eurocode 8 and IS 1893:2016 for buildings with vertical irregularities.	Eurocode 8 resulted in higher base shear, increased story displacement, and higher drift compared to IS 1893, indicating stricter seismic design criteria.
6	Ahmed, M. et al. (2021)	Seismic Analysis of Multi-Storey Building with Vertical Irregularities in Stiffness and Mass Under Various Soil Conditions	Response spectrum analysis using ETABS for a G+6 Storey building with varying positions of stiffness and mass irregularities.	Models with mass and stiffness irregularities showed significantly higher displacement and drift; soil conditions had a secondary effect.

Sr. No	Author / Year	Title	Methods	Key Observation
7	Ghanem, A. et al. (2023)	Seismic Vulnerability of Reinforced Concrete Frame Structures: Obtaining Plan or Vertical Mass Irregularity from Structure Use Change	Nonlinear dynamic response history analysis with 21 frame models for mass irregularities in plan and elevation.	Uneven live-load distribution in structures with vertical irregularities drastically affected seismic performance, influencing fragility curves and damage states.
8	Raagavi, M.T. et al. (2021)	A Study on Seismic Performance of Various Irregular Structures	Model analysis methods such as Response Spectrum Analysis and Time History Analysis. Evaluated displacement, base shear, storey drift, and strength.	Irregularly configured structures exhibited larger lateral deflections and storey drifts under earthquake loads, increasing the likelihood of failure compared to regular structures.
9	Sayyed, O. et al. (2017)	Seismic Analysis of Vertical Irregular RC Building with Stiffness and Setback Irregularities	Response spectrum analysis (RSA) of G+10 RC buildings with stiffness and setback irregularities using ETABS.	Buildings with stiffness irregularities and setbacks were unstable during seismic loading, with increased overturning moments and drift.
10	Satheesh, A.J. et al. (2020)	Effect of In-Plan Eccentricity on Vertically Stiffness Irregular Buildings under Earthquake Loading	Transient analysis of three-dimensional building frames subjected to seismic loading, considering in-plan eccentricity and vertical stiffness irregularities.	Combining vertical stiffness irregularities with in-plan eccentricity led to significant torsional effects, further increasing seismic vulnerability, especially in buildings with soft-storey configurations.

6. Performance-Based Design in Seismic Engineering

Performance-Based Design (PBD) in seismic engineering represents a shift from traditional code-based design approaches, focusing on achieving specific performance objectives during seismic events. Rather than solely meeting prescriptive requirements, PBD emphasizes designing structures to perform in a manner consistent with the expected levels of damage, safety, and functionality. This approach tailors the design to the building's intended use, seismic zone, and performance goals, ensuring that the structure will meet both safety and operational requirements during and after an earthquake. A core concept in PBD is the establishment of seismic performance levels, which define the building's expected behavior under varying earthquake intensities. These levels, often categorized into immediate occupancy, life safety, and collapse prevention, guide engineers in determining acceptable levels of damage for each performance objective. For example, a hospital or emergency response facility may require minimal damage and immediate re-entry after an earthquake, while a less critical structure might be designed to sustain moderate damage but remain safe for occupants. To evaluate the performance of a structure, advanced analytical techniques such as nonlinear static (pushover) and nonlinear dynamic (time-history) analyses are employed. These methods simulate the building's response to different seismic scenarios, providing a comprehensive understanding of its behavior, including potential weak points that could lead to failure. The results of these analyses inform decisions on material selection, structural system design, and retrofitting needs.

Performance-Based Design is particularly useful for buildings with vertical irregularities, such as soft-storey configurations, which are more vulnerable to seismic damage. By focusing on specific performance objectives, PBD allows for more targeted interventions, such as reinforcing weak floors, adding girders, or implementing energy dissipation systems. In the context of retrofitting, PBD ensures that existing structures are upgraded in a cost-effective and tailored manner, improving their resilience while meeting the desired performance criteria. In conclusion, Performance-Based Design offers a more flexible, risk-informed approach to seismic engineering, enhancing the safety, sustainability, and functionality of buildings in earthquake-prone regions.

6.1 Considerations in Performance-Based Design:

Performance-Based Design (PBD) in seismic engineering is a flexible approach that focuses on meeting specific performance objectives for a building during seismic events. Unlike traditional design methods, which primarily adhere to prescriptive code requirements, PBD allows engineers to tailor the design based on the building's intended use, the severity of potential seismic events, and the performance targets. Several key considerations must be addressed to ensure that the building meets these performance goals while balancing safety, cost, and functionality. A fundamental consideration in PBD is the establishment of seismic performance levels, which define the expected behavior of the building during an earthquake. These levels often include categories such as "Immediate Occupancy," "Life Safety," and "Collapse Prevention." Each level dictates the maximum allowable damage and operational capacity of the building post-event. For example, a hospital might need to remain fully operational with minimal damage even after a strong earthquake, while a residential building may be acceptable with greater damage as long as it doesn't collapse. Defining these performance levels is crucial to setting realistic design targets that align with the building's intended use and location. Site-specific seismic hazard analysis is another critical consideration in PBD. The seismic risk varies significantly depending on factors such as the building's location, soil type, and potential for secondary effects like liquefaction. A detailed understanding of these factors allows engineers to tailor the seismic design to the specific risks the building will face. This helps in selecting the appropriate performance levels and determining which design strategies will provide the best protection against those risks.

The choice of the structural system is also a vital factor. In PBD, the selected system—such as moment-resisting frames, shear walls, or base isolators—should be chosen based on the building's specific needs. For example, buildings with soft-storey configurations may benefit from additional shear walls or damping systems to enhance lateral stiffness and reduce inter-storey drift during seismic activity. The chosen system should address any vertical irregularities and ensure that the building can resist seismic forces effectively while minimizing damage. Nonlinear static (pushover) and nonlinear dynamic (time-history) analyses are essential tools in PBD. These analyses allow engineers to simulate the building's behavior under various earthquake scenarios, providing insights into how the structure will respond to different intensities of ground shaking. By evaluating factors such as lateral displacement, drift, and failure modes, engineers can identify potential vulnerabilities and optimize the design to meet the desired performance levels. Cost-benefit analysis is another important consideration in PBD. While higher performance levels, such as "Immediate Occupancy," may provide better resilience, they often require additional reinforcements or specialized materials. Engineers must balance the performance objectives with the construction budget to ensure that the design is both effective and economically feasible. In many cases, retrofitting existing buildings is a more cost-effective approach, where engineers can improve seismic resilience by adding shear walls, installing base isolators, or incorporating energy dissipation systems without a complete overhaul.

Finally, regulatory and code compliance remains essential in PBD. Although PBD offers more flexibility than traditional methods, any design deviating from the standard must be justified through rigorous analysis. Ensuring compliance with local building codes and seismic regulations guarantees that the performance objectives are met without compromising safety. In conclusion, Performance-Based Design offers a dynamic, risk-informed approach to seismic engineering. By carefully considering seismic performance levels, site-specific hazards, structural system selection, advanced analyses, cost, retrofitting strategies, and regulatory compliance, engineers can design buildings that provide enhanced resilience, safety, and functionality during seismic events. The goal is to ensure that buildings perform as expected, protecting both human life and property.

7. Challenges and Research Gaps in Performance-Based Design

Performance-Based Design (PBD) represents a paradigm shift in seismic engineering, focusing on meeting specific performance objectives during seismic events. However, several challenges remain in its implementation, and notable research gaps need to be addressed to optimize its effectiveness across different building types and seismic zones. One of the foremost challenges is the uncertainty inherent in seismic hazard modeling. Accurate prediction of ground motion, seismic intensities, and the resulting structural response is difficult due to the variability of seismic events, geological conditions, and lack of historical data in certain regions. This uncertainty often leads to conservative or potentially ineffective design choices, as performance-based targets may not fully account for extreme seismic scenarios that could result in significant damage. Improving seismic hazard assessment models, including the prediction of rare, high-intensity events, is a crucial research gap that must be addressed to enhance the reliability of PBD. Another key challenge lies in the modeling of nonlinear structural behavior. Many buildings experience complex inelastic deformations during seismic loading, and capturing this behavior accurately requires sophisticated computational methods, such as nonlinear time-history analysis. However, modeling the nonlinear response of materials, joints, and connections under dynamic loads remains challenging. Traditional design methods often oversimplify these complex interactions, leading to potential underestimation of structural vulnerability. There is a need for advanced modeling techniques that can better predict the post-peak performance of structural elements and assess failure mechanisms more accurately. Research is also needed to develop more reliable methods to simulate the behavior of composite structures, where different materials interact during seismic events.

Furthermore, integrating non-structural elements—such as walls, partitions, ceilings, and HVAC systems—into performance-based design is an ongoing challenge. These elements, while not directly part of the load-carrying system, significantly influence the building’s overall functionality and safety during seismic events. Currently, most PBD frameworks focus primarily on the structural system, neglecting the impact of non-structural components. Future research should aim to incorporate these elements into seismic analysis to provide a more comprehensive understanding of overall building performance. The communication of seismic risk to stakeholders is another critical issue. PBD often involves complex performance metrics, such as inter-storey drift and displacement, which may be difficult for non-technical stakeholders, including building owners and developers, to fully comprehend. Effective risk communication strategies are needed to ensure that all parties involved understand the implications of different performance objectives and can make informed decisions regarding seismic resilience.

Lastly, while PBD is widely applied to new constructions, its application to existing buildings is less common. Retrofitting older structures to meet performance-based targets poses unique challenges, particularly when considering the cost-effectiveness and feasibility of such interventions. Research into retrofitting strategies that can enhance the seismic resilience of existing buildings, particularly those with vertical irregularities, is a critical area of future focus. Additionally, the lack of standardized methods and frameworks for PBD remains a barrier to its widespread adoption. Research is needed to develop universal guidelines that can be integrated into building codes to ensure consistency and reliability in seismic performance across various regions and building types. In conclusion, while Performance-Based Design holds great potential in improving seismic resilience, addressing these challenges and research gaps will be essential in advancing its application. Enhanced seismic hazard modeling, improved nonlinear analysis techniques, integration of non-structural elements, better communication strategies, and practical retrofitting solutions are key areas where research can contribute to the evolution of PBD.

8. Conclusion

This paper highlighted the significant effects of vertical irregularities in stiffness on the seismic behavior of multi-storey buildings, particularly focusing on buildings with "soft-storey" configurations. Vertical irregularities, such as variations in column sizes and the architectural design of lower floors, disrupt the uniform distribution of seismic forces, resulting in increased inter-storey drifts and a higher potential for structural failure during seismic events. The role of girders was also examined, as they contribute crucially to the overall stability and stiffness of buildings, ensuring a more uniform distribution of seismic forces. The inclusion of girders significantly mitigates the adverse effects of vertical stiffness irregularities by reducing inter-storey drift and preventing localized failures. Moreover, the comparative analysis of buildings with and without girders demonstrated that buildings with girders exhibit better seismic performance, with reduced displacement and lower risk of collapse. The paper also explored the implications of Performance-Based Design (PBD), which offers a more tailored approach to seismic resilience compared to traditional methods. While PBD enhances the safety and functionality of buildings, especially in earthquake-prone regions, challenges remain, particularly in terms of seismic hazard modeling, nonlinear structural behavior, and retrofitting of existing structures. Ultimately, this study underscores the importance of considering vertical irregularities and the potential benefits of incorporating girders in the design process. The findings serve as a foundation for better design practices, informing both new constructions and retrofitting strategies aimed at improving the seismic resilience of buildings. Further research is needed to optimize PBD methodologies, address challenges in seismic modeling, and develop effective retrofitting techniques to ensure the safety and durability of structures in the face of seismic hazards.

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