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Examining Out-of-Plane Offset in Multistory Buildings: A Comprehensive Review

Sapana Rawat[1], Prof. Prachi Chincholikar [2]
[1]M. Tech. Scholar, [2]Assistant Professor, Department of Civil Engineering, Vikrant Institute of Technology and Management, Indore (M. P.), India

Abstract: India has a high population density, leading to a shortage of land for residential and commercial use. To address this issue, engineers are building taller structures with more land coverage and aesthetically pleasing designs. However, these architectural buildings can become unstable due to their unique designs.
This review paper provides an in-depth analysis of various research papers associated with the topic of increasing stability in architectural buildings.
Through a thorough literature review and analysis of previous works in this field, our study has identified conclusive outcomes that form the basis of our research objectives for improving the stability of these structures. We aim to provide technical insights and recommendations for future research in this area.
Keywords: Lateral Drift., Out of plane offset, Core type Shear wall, Vertical elements

I. INTRODUCTION

The current trend in construction is to prioritize financial customs in order to reduce costs. However, this approach can make achieving structural stability a difficult task as it often requires the use of heavy sections, leading to increased expenses. Moreover, modern tall structures must also meet seismic safety requirements, which may involve adding stiffness-resisting members and shear walls.
While these measures can improve the building's stability and protect against earthquakes, they often require the use of heavy reinforced concrete components, which increase the weight and base shear of the building.

A. Out of Plane Offset

The term "out of plane offset" in the context of multistorey buildings and vertical elements typically refers to the horizontal displacement of a structural element, such as a column or beam, in a direction perpendicular to its axis, in relation to adjacent structural elements.
The out of plane offset in multistorey buildings' vertical elements may occur due to design considerations, construction tolerances, or settlement of the building's foundation. However, excessive displacement may negatively affect the building's structural integrity and stability.
Therefore, it has crucial to monitor and control the out of plane offset during the design and construction phases of the building to ensure its safety and longevity.
To ensure the safety and durability of multistorey buildings, it has crucial to assess and control the out of plane offsets carefully during the design and construction phases.

B. Recommendation Provided as per Indian Standards

Out-of-plane offset of vertical elements in a building can disrupt the load path and put in danger the building's earthquake safety. This irregularity occurs when structural walls or frames deviate from the building's plane in any story along its height. If the building is in Seismic Zone II, it had been advisable to consult specialized literature for designing the building.
In Seismic Zones III, IV, or V, two conditions must be met to ensure the building's safety. First, the lateral drift in the story with the offset and the stories below it must be less than 0.2 percent. Second, specialized literature should be consulted to remove the out-of-plane offset irregularity.

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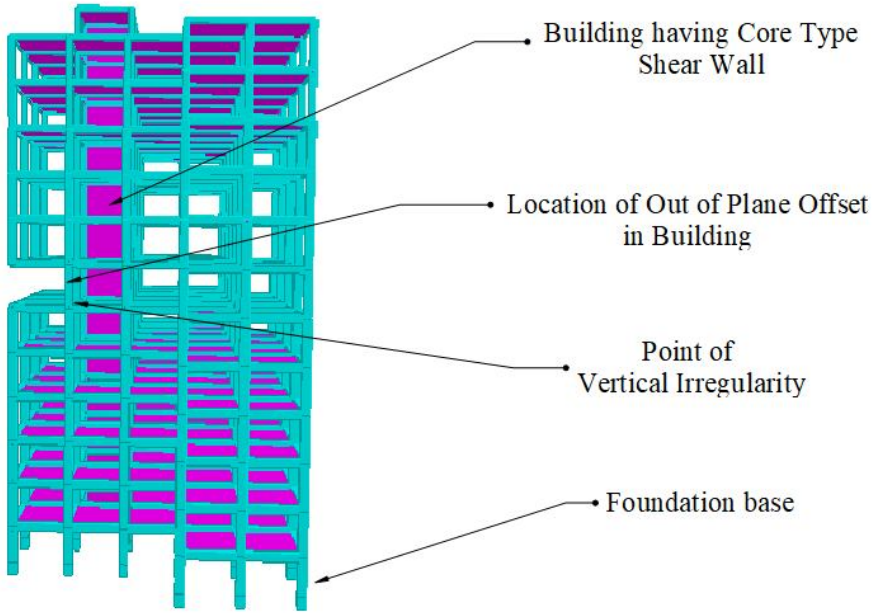

Fig. 1: Structure having out of plane configuration with dual structure configuration

The paragraph above outlines the recommendations given by Indian Standardization for managing out-of-plane offsets in multistorey buildings. The accompanying figure, Fig. 1, depicts an example of an out-of-plane offset in such a building. Additionally, Fig. 2 shows a dual structural configuration in a building with a shear wall at its core, while Fig. 3 provides a structural view with an out-of-plane offset.

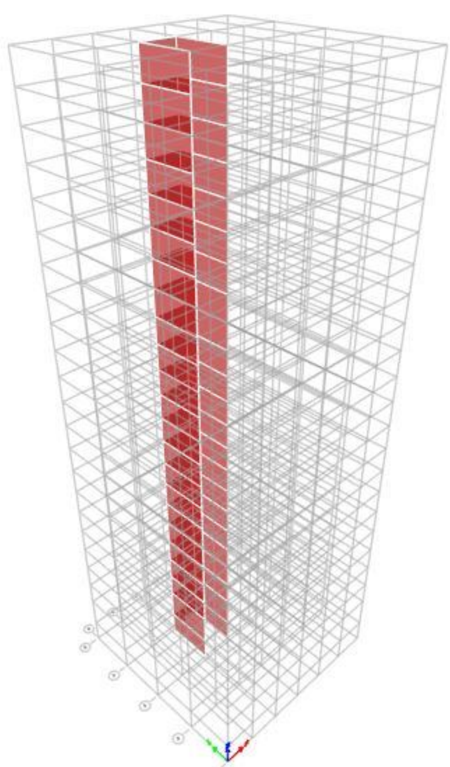

Fig. 2: Structure with shear Wall at Core

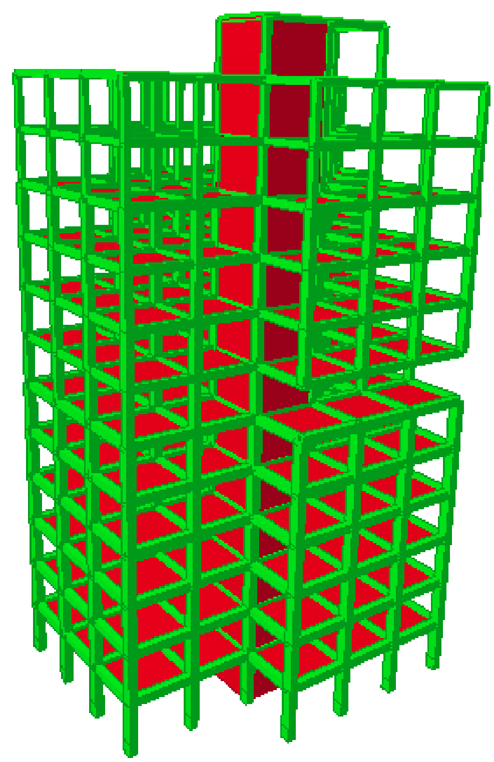

Fig. 3: Structure view with out of plane offset

II. LITERATURE REVIEW

The research project utilized CSI ETABS software to analyse multiple high-rise buildings and assess their seismic behaviour using response spectrum analysis. The buildings studied included H-shaped, O-shaped, and C-shaped buildings, with varying numbers of stories. The study found that the H-shaped building had superior performance compared to the other shapes, and the 12-story building had more favourable results than the 16-story building. Although heavy masses were transferred, there was minimal lateral sway observed, with only slight variations in maximum displacement. However, the 16-story L-shaped building exhibited the highest displacement among the irregular shapes analysed. Overall, the study concluded that bending moments and shear forces increased by 1.17% to 1.84%, with the O-shaped building showing the greatest variation in these forces. (Krishna Prasad Chaudhary et. al.)

The IS-1893: 2002 (Part-I), a standard code in India, recommends specific analysis methods for buildings with structural irregularities. This study focuses on a 10-story plane frame and examines the effects of mass and stiffness irregularities on the building's response to lateral loads. Mass irregularities are introduced by altering the properties of members on the fourth and seventh storeys, while stiffness irregularity was induced by decreasing stiffness's on the fourth and fifth storeys. The study also examines the impact of floating columns and unusually tall first storeys on the building's dynamic response. The research concludes that irregular structures exhibit a moderate increase in response quantities compared to their regular counterparts, due to the criteria outlined in the IS code. The study analyses the impact of irregularities on storey-shear forces, storey drifts, and beam deflections. (Poonam et. al.)

The response of a multi-storey framed building to powerful earthquake movements was influenced by the distribution of mass, stiffness, and strength in both the horizontal and vertical planes of the structure. Structural weaknesses typically occur in the lateral load resisting frames, which are associated with discontinuities in stiffness, strength, or mass between adjacent storeys. This study investigates the behaviour of a reinforced concrete (RCC) framed structure, comparing a regular and a vertically geometrically irregular building configuration. Five building geometries, including one regular frame and four irregular frames, are modelled and analysed using the Staad.Pro V8i software. The analysis is conducted in accordance with IS 1893:2002 part (1), applying seismic zone IV and medium soil strata to all cases. Various seismic responses, such as shear force, bending moment, storey drift, and storey displacement, are obtained and compared at different heights and bays. The study aims to identify the differences in seismic response between regular and irregular framed structures. (Dileshwar Rana et. al.)

The study utilizes advanced software, such as ETABS, to analyse the behaviour of vertically irregular buildings through Non-Linear Dynamic analysis. Three types of irregularities, namely mass, stiffness, and setback irregularities, are examined and compared to a regular building. The study focuses on factors such as Base shear, Displacement, and Story Drift. The analysis was particularly important for understanding the behaviour of vertically irregular buildings in seismic zones, which can experience torsion effects due to misalignment of their centre of mass and centre of gravity. Structural engineers face challenges in designing such buildings, and the results of this study can aid in designing vertical irregular buildings that meet necessary standards. (V. Shiva Kumar et. al.)

The exponential growth of the population has led to an unprecedented demand for high-rise buildings, which must be designed to withstand earthquake forces. Regular structures, characterized by uniform mass, stiffness, strength, and structural form, exhibit predictable behaviour under seismic loads. In contrast, irregular structures with mass irregularities, torsion irregularities, weak stories, and diaphragm discontinuities exhibit unpredictable behaviour. Mass irregularity, in particular, has a significant impact on a structure's seismic response, especially when the seismic weight of a story exceeds 200% of that of its adjacent stories. This can be achieved by increasing the weight of some floors relative to others. The impact of irregularity varies depending on the structural model, location of irregularities, and analysis method. In this thesis, ETABS software was used to analyse a regular building with uniform mass and four irregular buildings with varying masses, focusing on Base shear, Mode shapes, storey drift, story shear, and Torsion moment. Suitable codes are employed for analysis and design. (Darshan D. et. al.)

As urban areas face space constraints, constructing buildings with irregularities has become necessary, but such irregularities may lead to failures during earthquakes due to weakness in mass, stiffness, and geometry. Performance-based seismic analysis was now an essential tool to assess and design large structures. This paper focuses on a building with vertical irregularities, particularly mass irregularity, by modelling the roof diaphragm as rigid and semi-rigid. The study employs pushover analysis, a static nonlinear analysis, using ETABS 2015 software. The results reveal that mass regular structures perform better than mass irregular ones, as the storey shear increases with greater vertical irregularity. These findings underscore the need for static and dynamic analyses when designing high-rise structures under performance-based seismic design. (T.M.Prakash et. al.)

A column is a structural member that typically runs vertically to transfer loads from the superstructure to the foundation. However, in some cases, a vertical element called a floating column is used due to specific architectural designs or site conditions. This design involves the lower part of the floating column resting on a horizontal member known as a beam, which subsequently transfers the load to other columns below it. The use of floating columns is prevalent in multi-story buildings, where open spaces are desired on the ground floor for functions like assembly halls or parking. To support these columns, transfer girders must be appropriately designed and detailed, especially in seismic zones. These columns are treated as concentrated loads on the beam and are typically assumed to be pinned at the base, causing a point load on the transfer beam. STAAD Pro V8I software can be utilized to analyse such structures. Although floating columns can bear gravity loads, the transfer girders must be adequately sized and stiff to minimize deflection. (Pratyush Malaviya et. al.)

The research paper focuses on comparing the performance of reinforced concrete (RC) frame buildings with and without floating columns under both seismic and normal loading conditions. The presence of floating columns in buildings can result in poor seismic performance due to irregularities in the structure. The study aims to analyse the effect of earthquake forces on different building models using response spectrum analysis. The objective was to determine which structure performs better under both seismic and normal loading conditions. The study will compare results such as storey drifts, storey displacement, and amount of steel required to reach a definitive conclusion regarding the superiority of the two structures. By conducting this analysis, the study aims to provide valuable insights for structural engineers and architects on the performance of structures with floating columns in earthquake-prone areas. The analysis will be carried out using advanced software such as ETABS or SAP2000 to accurately simulate the behaviour of the structures under different loading conditions. (Prof. Rupali Goud)

III. CONCLUSIONS AND OUTLINE OF PROPOSED WORK

It seems that there has a research gap in the literature regarding the effect of out-of-plane offsets in multistorey buildings under seismic loading. This could be an important factor to consider in the structural design of such buildings, as it may affect their behaviour and performance during earthquakes. Further research will be needed to investigate the effect of this factor and to develop suitable design guidelines for mitigating its impact on the structural response.

Based on the literature review, we have reached a conclusion that highlights the key findings of the research and lists the necessary outcomes:

1) Conducting a study on multistoried buildings with vertical irregularities for out-of-plane effects in both directions is necessary to calculate lateral forces.
2) It is important to validate various analysis parameters as per the Indian Standards and ensure that they fall within acceptable limits.
3) To ensure accuracy in the analysis, it has recommended to use actual soil data that corresponds to the specific site and structure being analyzed.
4) The seismic zonal analysis should be examined to analyse the data for different seismic zones in dual structural configurations.
5) It has essential to evaluate the lateral effects, such as displacements and prescribed limits for lateral drift, according to the Indian Standards.

The primary objective of this study is to determine the feasibility of constructing an out of plane structure and to establish the maximum allowable limits under realistic soil conditions that has going to be a major study for upcoming proposed work.

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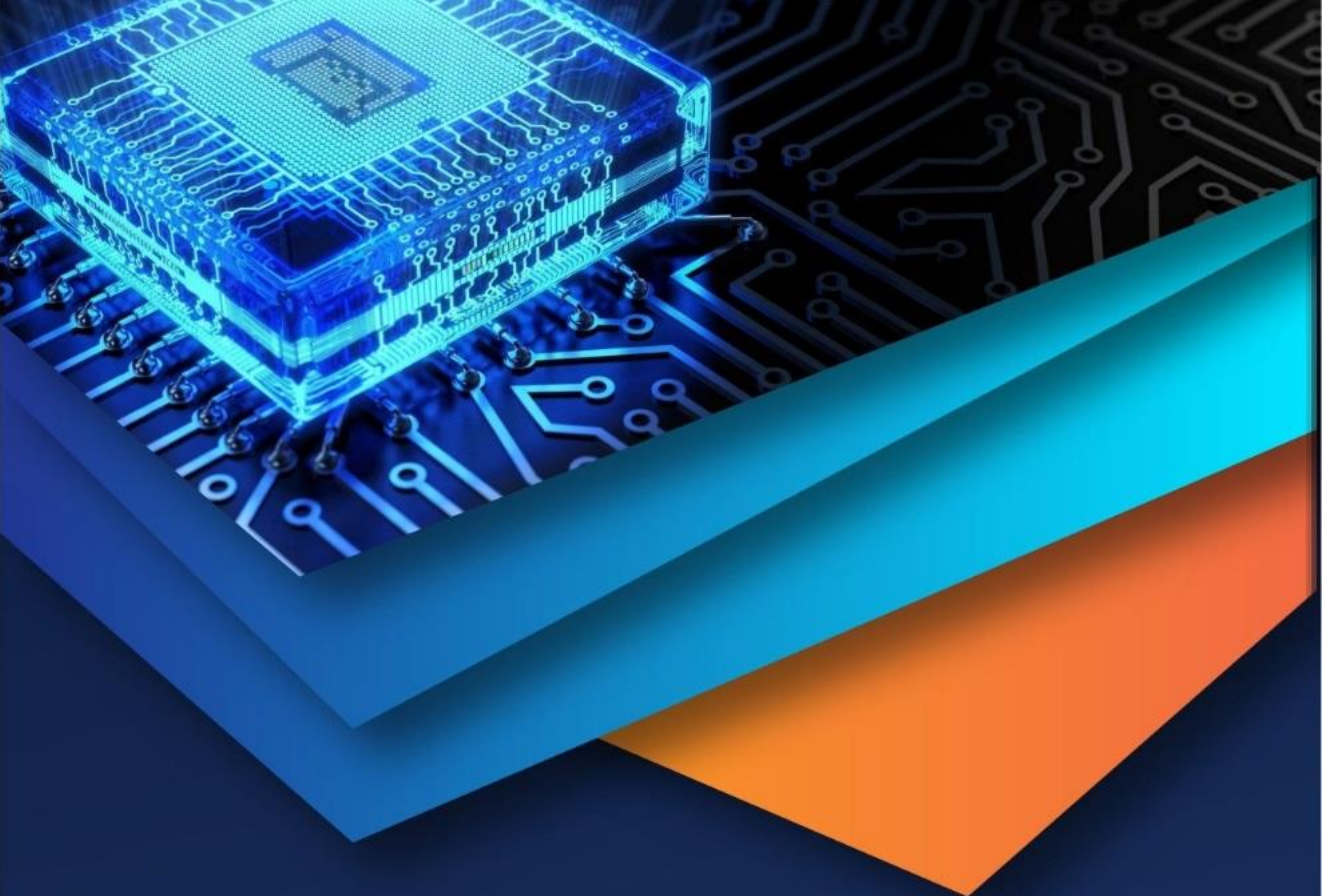

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