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Seismic Evaluation of RCC Frames with Plan Irregularities Using Push Over Analysis: A Review

Dr. A. R. Gupta[1], Ms. A. H. Deshmukh[2], Miss Harshal Khandare[3]

[1]Head of Department, Dept. of Civil Engineering,
[2]Supervisor, Dept. of Civil Engineering,
[3]Student M.E. (Structural Engineering), Dept. of Civil Engineering,
[1,2,3]C.O.E.T., Akola, India

ABSTRACT

This study presents a comparative seismic performance evaluation of high-rise reinforced cement concrete (RCC) buildings with different plan irregularities using nonlinear static pushover analysis. Using ETABS software, G+15 storey buildings were modeled with three plan geometries (rectangular, square, circular) and two types of irregularities (L-shape and diaphragm discontinuity). The analysis focused on structural performance parameters such as storey displacement, storey drift, base shear, and time period. The results reveal that plan irregularities significantly influence the seismic response, with L-shaped and diaphragm-discontinuous configurations showing increased displacement and torsional effects.

Keywords – **ETABS, plan irregularities, plan geometries**

I. INTRODUCTION

Rapid urbanization has prompted the construction of high-rise reinforced cement concrete (RCC) buildings, often with complex plan geometries due to architectural requirements. In seismic zones, these irregular configurations, such as L-shaped projections or diaphragm discontinuities, affect building performance by introducing torsion, stress concentration and irregular load paths. Traditional linear methods often fall short in accurately predicting the response of such structures under seismic loading.

This study adopts nonlinear static pushover analysis to assess and compare the seismic performance of G+15 RCC buildings with different plan irregularities. The result aim to guide better design strategies for high-rise buildings in earthquake-prone areas.

A. Objectives

1. **To model a high-rise (G+15) RCC building** with various plan geometries such as rectangular, square and circular geometry using ETABS software.
2. **To introduce plan irregularities and geometric variations** in each model to simulate real-world asymmetry and mass/stiffness discontinuity.
3. **To perform nonlinear static pushover analysis** on each model to assess seismic performance in terms of:
   - Storey displacement
   - Storey drift
   - Base shear
   - Time period

B. Limitations of the Study

Despite the comprehensive analysis carried out in this study, certain limitations exist due to assumptions made and the scope defined. These limitations are outlined as follows:

Structural Type Restriction: The study is limited to Reinforced Concrete (RC) framed buildings only. Other structural systems, such as steel or composite frames, are not considered.

Building Configuration: The analysis is performed on G+15 storey buildings without basements or shear walls. The absence of shear walls limits the lateral load-resisting system and may not represent all high-rise building configurations.

Infill Wall Assumptions: The contribution of infill walls to lateral stiffness and strength is neglected. Although the dead load from infill walls is considered, their structural interaction with the RC frame is assumed to be non-integral.

Out-of-Plane Action of Masonry Walls: The out-of-plane behaviour of masonry walls is not accounted for in the analysis, which could be significant under seismic loading conditions.

Soil-Structure Interaction (SSI): The supporting foundation medium is assumed to be rock or rock-like material, and hence soil-structure interaction effects are not considered. This assumption may not hold true for all site conditions and could affect the accuracy of the seismic response.

Rigid Diaphragm Assumption: Floor diaphragms are assumed to be perfectly rigid in their own plane, thereby ignoring any in-plane flexibility which may influence the seismic behaviour in buildings with plan irregularities.

Fixed Base Assumption: The base of the columns is considered to be fixed, neglecting any rotational or translational flexibility that may exist in real foundations.

Neglect of Time-Dependent Effects: Secondary effects such as P-Δ (P-delta), shrinkage, and creep are not included in the analysis, which could influence the long-term behaviour of the structure under lateral loads.

Limitations of Static Pushover Analysis: The study employs static nonlinear pushover analysis, which, although useful, does not fully capture the dynamic and cyclic nature of seismic loading, particularly higher mode effects.

II. LITERATURE SURVEY

Numerous studies have evaluated the seismic performance of reinforced concrete (RC) structures with plan irregularities using analytical, experimental, and code-based approaches. The following review highlights significant research contributions in this domain:

A. Deekshithay and Kiran analysed G+14 RC buildings with plan shapes such as C, H, and L, along with soft storey irregularities. Using ETABS, they concluded that plan irregularity significantly alters seismic response—C- and H-shaped buildings showed increased base shear, while L-shaped plans experienced greater lateral displacement due to torsional effects. The presence of infill walls reduced displacements and improved lateral stiffness.

B. Ali Kadhim Sallal (2018) conducted a comparative structural analysis of an eight-storey RCC building using ETABS and manual IS code calculations. Results confirmed the accuracy of software in predicting deflection, shear, and bending moment under seismic and wind loads.

C. Lavanya et al. (2017) emphasized efficient seismic design by optimizing beam and column dimensions in RC buildings on medium soil. Their findings revealed that upper storeys experience higher shear and moment, necessitating careful top-storey detailing.

D. Salihovic and Ademovic (2017) compared nonlinear modeling in SAP2000 and VecTor2 with experimental results. They observed that simplified models in SAP2000 could not fully capture inelastic behavior, highlighting the importance of advanced modeling techniques for detailed seismic assessment.

E. Kakpure (2016) examined the limitations of static analysis for irregular buildings and recommended dynamic methods like response spectrum and time-history analysis, especially for taller structures where static methods overestimated displacements.

F. Guleria (2015) studied the impact of various plan configurations in a 15-storey RC frame and found L- and I-shaped buildings to exhibit larger drift and lateral displacements. The study stressed that asymmetric geometries introduce significant torsional behavior and should be addressed during the design phase.

G. Balaji and Selvarasan (2014) observed that static and dynamic methods gave comparable results up to five storeys in a G+13 structure. However, for higher storeys and irregular plans, dynamic analysis was preferred due to better accuracy in capturing torsional and displacement behavior.

H. Patil and Sonawane (2014) validated ETABS outputs against manual IS code calculations and reported strong correlation, reinforcing the tool's reliability for symmetric buildings while recommending manual verification for critical sections.

I. Eskandari assessed RC braced frames under near-fault and far-field ground motions using OpenSees. Near-fault records caused higher inter-storey drift and hinge formation, emphasizing the need to incorporate such conditions in seismic design.

J. Penelis highlighted limitations of linear modal analysis in evaluating a 16-storey RC building with irregular mass distribution. Nonlinear static and dynamic analyses revealed post-yield behaviour and torsional effects that linear methods could not capture.

K. Memari evaluated multiple nonlinear analysis tools and concluded that while pushover analysis effectively identified probable failure mechanisms, it was less effective in quantifying damage extent compared to dynamic analyses.

L. Chopra provided foundational knowledge on the influence of torsional and higher vibration modes in irregular buildings. He advocated for modal and time-history analysis to accurately capture seismic responses in asymmetric systems.

M. Paulay and Priestley emphasized inelastic design and ductile detailing for irregular RC and masonry buildings. They recommended redundancy and confinement in regions of plan irregularities, such as re-entrant corners.

N. Patel and Shah compared L- and T-shaped buildings using pushover analysis in ETABS. Both configurations exhibited higher displacement and earlier hinge formation than rectangular plans, especially near re-entrant zones. The study suggested strengthening these areas with shear walls or bracing.

O. Ghosh and Basu used pushover analysis to show that irregular plans had lower ductility and energy dissipation capacity. Performance points were reached earlier, and hinges concentrated near corners and asymmetrical limbs.

P. Moghadam and Tso studied the dynamic behavior of asymmetric buildings with mass and stiffness eccentricities. They found that torsional coupling amplified displacements on the flexible side and recommended symmetric layouts and dual lateral load-resisting systems.

Q. Sahu and Datta further examined torsional coupling, finding that asymmetrical plans led to irregular hinge formation and increased shear demands. The study called for design measures such as torsional reinforcement and balanced mass distribution.

R. Kabeyasawa et al. and Bhagat and Bhilare addressed diaphragm discontinuities, demonstrating that slab openings significantly disturbed lateral force transfer and increased stress concentrations. Both studies emphasized edge reinforcement and collector detailing around openings.

S. Naik and Jaiswal investigated base-isolated irregular buildings and observed that isolation effectively reduced base shear and drift while mitigating torsional effects, particularly in L- and U-shaped structures.

T. Ravikumar et al. analysed mass irregularity in multi-storey buildings and found that eccentric mass distribution increased torsional effects and led to early yielding near heavy regions. Balanced mass layout was recommended.

U. Deshmukh and Pawar reported that L-shaped buildings with higher aspect ratios showed increased displacement and early hinge formation. The study advised limiting aspect ratios in irregular buildings or enhancing stiffness in slender directions.

V. Mehta and Shah compared L-shaped and setback buildings using pushover analysis. Setback buildings performed better due to progressive mass reduction along height, yielding higher base shear capacity and ductility.

W. Chintan and Prajapati evaluated diaphragm discontinuities and observed increased inter-storey drift and early hinge formation near slab openings. Reinforced diaphragm edges and continuity elements were recommended.

X. Krawinkler introduced pushover analysis as a practical tool for performance-based design. He emphasized systematic hinge formation and capacity curves to predict structural behaviour beyond elasticity.

Y. Moghaddam and Dowling were among the first to apply pushover methods to multistorey buildings. Their work revealed realistic patterns of hinge formation and collapse, which laid the groundwork for capacity spectrum approaches.

Z. Sharifi et al. used fragility curves to show that plan-irregular buildings are more vulnerable to damage at lower seismic intensities. They recommended integrating fragility-based risk assessments into design processes.

The AISC Seismic Provisions (2016) outlined ductile detailing strategies and nonlinear analysis requirements for steel buildings, many of which are applicable to RC structures with plan irregularities, particularly under performance-based frameworks.

IS 1893 (Part 1): 2016 classifies plan irregularities (e.g., torsional, diaphragm, setback) and mandates dynamic analysis for buildings over 15 m height if such irregularities are present. **IS 456:2000** provides detailing norms for ductile RC design, particularly beam-column joints and plastic hinge zones.

FEMA 356 (2000) established performance-based seismic evaluation through nonlinear pushover analysis, defining performance levels like Immediate Occupancy, Life Safety, and Collapse Prevention, and offering modeling guidelines for hinge properties.

III. CONCLUSIONS

From the extensive literature reviewed in this chapter, it is evident that plan irregularities in reinforced concrete (RCC) buildings—such as re-entrant corners, diaphragm discontinuities, asymmetric mass and stiffness distributions—have a profound impact on seismic performance. Irregular configurations consistently exhibit higher lateral displacements, increased inter-storey drift, premature hinge formation, and greater vulnerability to torsional effects when compared to regular geometries. Numerous studies have validated nonlinear static pushover analysis as an effective and insightful method for evaluating the seismic capacity of both regular and irregular structures. Key performance indicators such as capacity curves, base shear, displacement profiles, and hinge mechanisms offer critical information about a building's ability to withstand earthquake-induced forces. The research also emphasizes that conventional linear or static methods often fall short in capturing the complex behaviour exhibited by irregular structures under dynamic loads. Guidelines such as IS 1893 (Part 1):2016, IS 456:2000, FEMA 356, and AISC Seismic Provisions provide essential frameworks for assessing irregularity effects, reinforcing the importance of ductile detailing, diaphragm continuity, and symmetry in plan and elevation. Design strategies such as introducing shear walls, base isolation, symmetric core placement, and diaphragm reinforcement have been proposed to counteract the adverse effects of plan irregularities. The insights gained from the literature form a crucial foundation for the present study, which seeks to evaluate the seismic behaviour of RCC frames with three distinct plan geometries—square, rectangular, and circular—subjected to plan irregularities such as L-shaped projections and diaphragm discontinuities. The application of nonlinear pushover analysis in this research aims to quantitatively compare and assess the effect of these irregularities on structural performance parameters, thereby contributing to more resilient and performance-oriented design practices in seismic zones.

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