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Seismic Performance Assessment of Shear Walls Using Linear and Nonlinear Analysis in ETABS

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Abstract - Modeling the complex behavior of reinforced concrete in its nonlinear domain presents challenges that have historically led engineers to depend on empirical formulas. Nonlinear analysis, however, has become a vital tool in the assessment and design of reinforced concrete structures. This paper presents a pushover analysis of reinforced concrete (RC) frames with and without vertical irregularities using ETABS software. Key outcomes include the evaluation of pushover curves, storey drifts, lateral displacements, hinge behavior, and performance points.

Key Words: Pushover analysis, ETABS, nonlinear static analysis, hinge properties, seismic performance, vertical irregularity, RC frames.

1. SUMMARY OF INTRODUCTION

1. The introduction discusses the shift in seismic design philosophy towards Performance-Based Seismic Design (PBSD).
2. It emphasizes the relevance of nonlinear static analysis (pushover analysis) over traditional elastic methods.
3. The goal is to understand the realistic post-yield behavior of structures under seismic loads.
4. The section sets the context for using ETABS as the software tool and highlights the core concepts of the study:
   - **Hinge formation**
   - **Displacement patterns**
   - **Performance points**

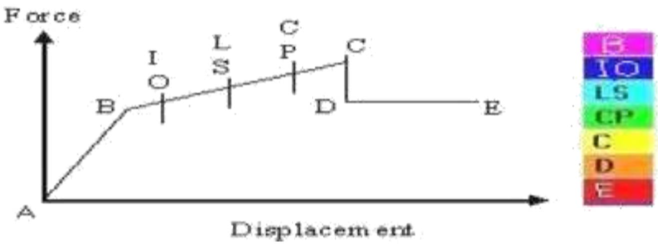


Fig -1: Hinge Properties

1.1 KEY POINTS

1. **Performance-Based Approach:**
   - Reflects modern seismic design thinking where structures are designed for desired performance levels (e.g., Immediate Occupancy, Life Safety).
   - Moves beyond mere force resistance to understanding deformations and damage control.
2. **Use of Pushover Analysis:**
   - Described as an effective tool to assess structural vulnerabilities due to lateral loads.
   - Pushover analysis simulates progressive failure and force redistribution, which is critical for seismic assessments.
3. **Use of ETABS:**
   - Establishes the role of ETABS in modeling and simulating nonlinear seismic responses.
   - Points to the use of hinges and performance points to evaluate behavior.
4. **Research Significance:**
   - Validates the motivation for comparing structures with and without vertical irregularities.
   - Sets the stage for deeper study into hinge modeling and performance evaluation.

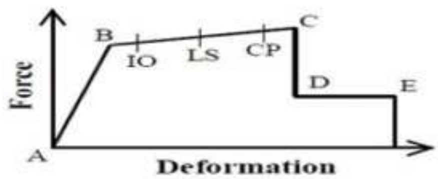


Fig -2: Force-Deformation for Pushover Hinge

1.2 OBJECTIVES

The objectives of the study are:

- To assess the seismic performance of RC frames with/without vertical irregularities.
- Compare results from different lateral load patterns.
- Use user-defined hinges to analyze and validate performance.

1. 3 SCOPE OF THE STUDY

- Focused on modeling in ETABS.
- Evaluation of load-deformation behavior and hinge formation.

- Comparative study under various analysis scenarios.

2. LITERATURE REVIEW

The literature review indicates that structures subjected to severe seismic loading exhibit significant inelastic behavior, necessitating nonlinear analysis methods for reliable performance evaluation. Among such methods, pushover analysis has emerged as a widely adopted simplified nonlinear static procedure due to its conceptual clarity and computational efficiency [1]. Prior studies [2]–[5] emphasize that pushover analysis provides meaningful insights into displacement demand, hinge formation, ductility, and overall seismic capacity of reinforced concrete frames. However, the accuracy of the method is highly dependent on appropriate modeling assumptions, load pattern selection, and hinge property definitions, with user-defined hinge models often yielding more realistic results than default properties [6]. Researchers have further highlighted the role of masonry infills [7], reinforcement ratios [8], and optimized hinge formulations [9] in influencing seismic performance predictions. While pushover analysis is well-suited for low- to mid-rise structures where the fundamental mode governs the response, its limitations in capturing higher-mode effects in irregular and high-rise buildings necessitate complementing it with nonlinear dynamic analysis [10]. Overall, the reviewed literature establishes pushover analysis as an effective yet approximate tool in performance-based seismic design, particularly when integrated with advanced modeling techniques and reliability-based approaches [11].

3. PUSHOVER ANALYSIS

Pushover analysis is a static, nonlinear procedure recommended by FEMA-356 and ATC-40 for performance-based seismic evaluation of structures. It involves subjecting a structural model to incrementally increasing lateral loads under constant gravity loading until a target displacement or collapse condition is reached, thereby establishing the force–displacement relationship or capacity curve [1]. The method effectively identifies cracking, yielding, hinge formation, and progressive strength degradation of reinforced concrete members, providing valuable insight into weak links and performance levels such as Immediate Occupancy, Life Safety, and Collapse Prevention [2]. Nonlinear behavior is incorporated through hinge modeling, with default and user-defined hinges based on ATC-40 and FEMA criteria, while plastic hinge parameters are commonly expressed using empirical formulations such as those proposed by Priestley et al. [3], B.I.A. [4], and FIB Bulletin [5]. Compared with elastic methods like equivalent static and response spectrum analysis, pushover analysis directly captures post-elastic behavior, making it more suitable for seismic demand estimation [6]. Although inelastic time history analysis remains the most accurate approach, its complexity and computational demand limit its routine application, thereby positioning pushover analysis as a practical and widely accepted alternative [7]. Simplified nonlinear procedures such as the Capacity Spectrum Method, Displacement Coefficient Method, and Secant Method further enhance its applicability in evaluating displacement demand and seismic capacity [8]. Overall, pushover analysis offers an efficient means to assess the seismic performance of low- to mid-rise reinforced concrete structures, though its limitations in addressing higher-mode effects and irregular geometries necessitate supplementary nonlinear dynamic analyses for comprehensive evaluation [9].

Formulations for plastic hinge length (Lp) are discussed:

- Priestley et al. (1987): Lp=0.08L+6dbL_p = 0.08L + 6d_bLp=0.08L+6db
- B.I.A. (1996): Lp=0.08L+0.022fydbL_p = 0.08L + 0.022f_y d_bLp=0.08L+0.022fydb
- FIB Bulletin (2003):
  - Monotonic: Lp=0.18Ls+0.025fydbL_p = 0.18L_s + 0.025f_y d_bLp=0.18Ls+0.025fydb.
  - Cyclic: Lp=0.08Ls+0.017fydbL_p = 0.08L_s + 0.017f_y d_bLp=0.08Ls+0.017fydb.

These expressions highlight how parameters like span length, bar diameter, reinforcement, and axial load influence ductility and hinge rotation.

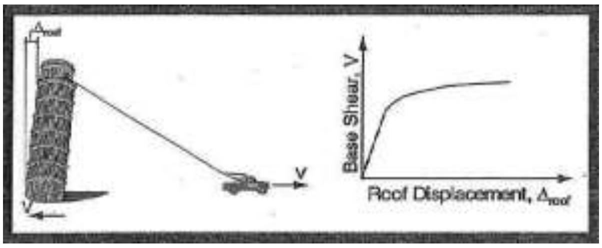


Fig -3: Pushover curve

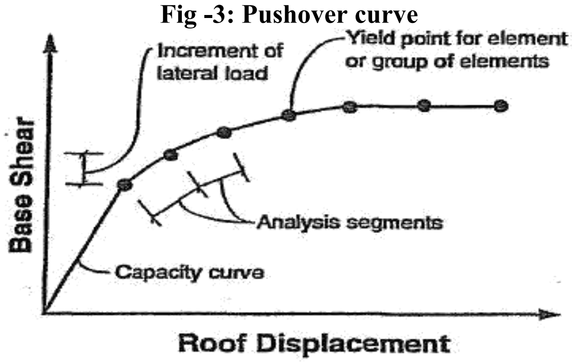


Fig -4: Conceptual Development of the Capacity Spectrum

3.1 Key Takeaways

- Pushover analysis provides a practical means to evaluate seismic capacity and expected damage levels of RC structures.
- Its results depend on hinge properties, load distribution patterns, and modeling assumptions.
- While it offers simplicity and valuable insights for low- to mid-rise buildings, it must be complemented with dynamic analysis for irregular or high-rise structures.

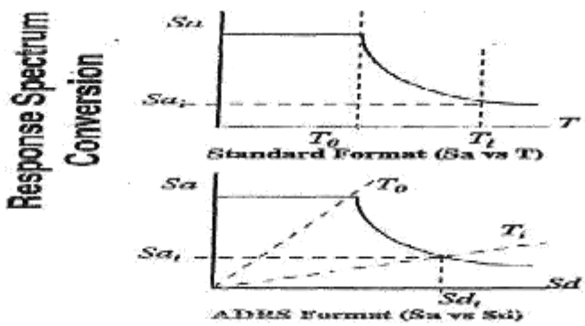


Fig -5: Response spectrum conversion

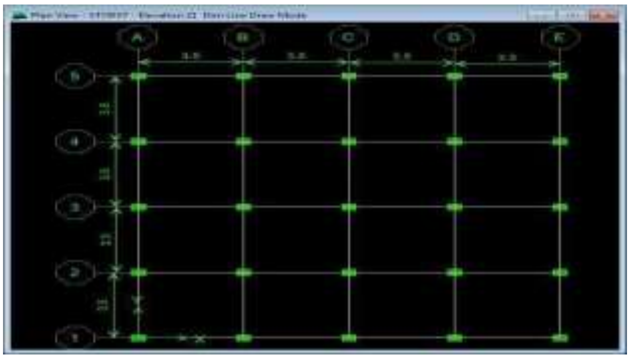


Fig -6: Plan and Elevation of model geometry

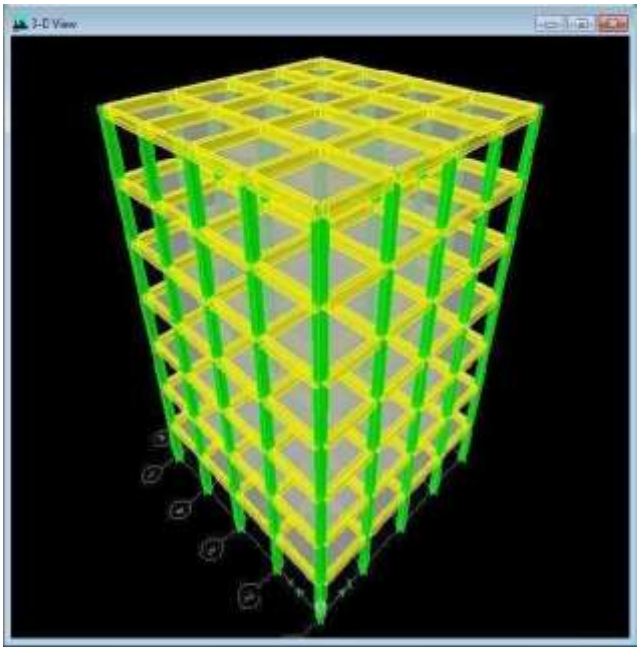
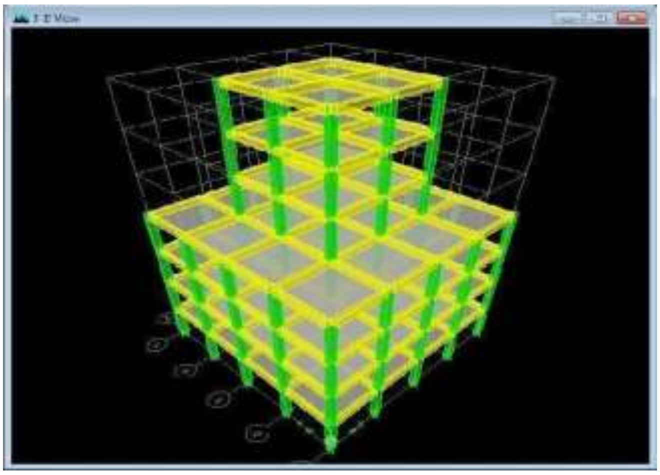


Fig -7: Elevation of model-01

4. MODELLING ON ETABS

In this study, reinforced concrete (RC) frames with and without vertical irregularities were modeled using ETABS software to evaluate their seismic performance through pushover analysis. ETABS provides a three-dimensional modeling environment capable of incorporating nonlinear material behavior and hinge properties in accordance with FEMA-273 and ATC-40 guidelines [1]. Frame elements, including beams and columns, were represented as line elements with elastic properties, while nonlinear force–deformation characteristics were captured by assigning both default and user-defined hinge properties at critical locations [2]. The modeling process involved the application of static gravity loads followed by incrementally increasing lateral seismic loads, as prescribed by IS 1893–2002, until a target displacement or collapse mechanism was achieved [3]. The analysis outputs included capacity curves (base shear versus roof displacement), hinge formation patterns, inter-storey drifts, and shear force distribution along the height of the structure [4]. The results demonstrated that user-defined hinge properties provided a more realistic representation of inelastic response compared to default hinges, highlighting the importance of detailed modeling in seismic assessment [5]. Furthermore, comparative analysis of regular and vertically irregular frames indicated that irregular structures are more vulnerable to seismic effects, exhibiting larger drifts and premature hinge formation [6]. Overall, ETABS was shown to be an effective tool for nonlinear seismic evaluation, enabling performance-based design and retrofitting strategies through capacity curve development and hinge progression monitoring [7].

Fig -8: Elevation of model-02



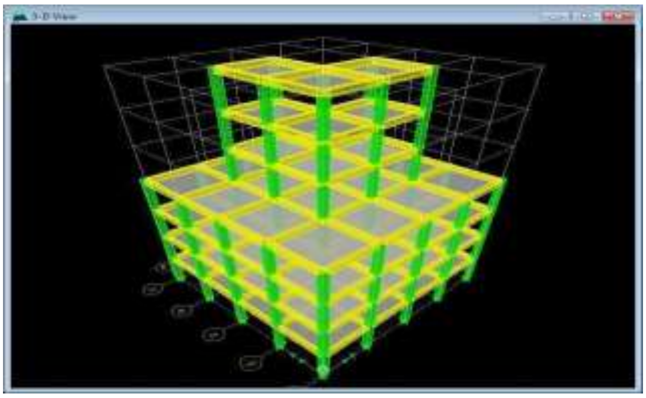


Fig -9: Elevation of model-03

4.1 KEY OUTCOMES

- ETABS provides an efficient platform for nonlinear seismic analysis by integrating default codes with user-modified hinge properties.
- It allows engineers to track hinge progression, inter-storey drift patterns, and displacement demands under seismic loading.

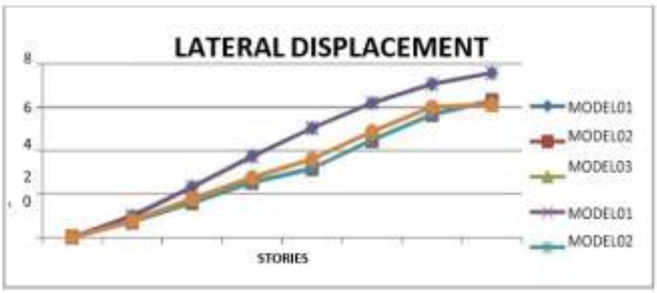


Fig -10: Lateral Displacement (Mm) In X- Direction

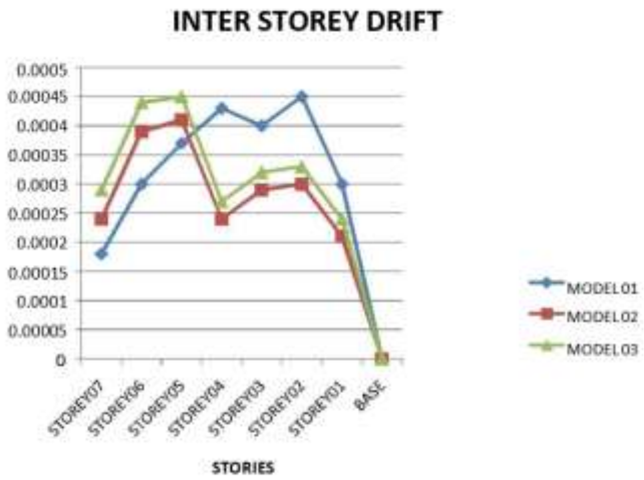


Fig -11: Inter Storey Drift Plot

Fig -12: Storey Shear Graph

- The modeling confirms that irregular structures exhibit greater vulnerability, highlighting the importance of pushover analysis in design and retrofitting.

5. RESULTS AND DISCUSSIONS

- In this paper the discussion results were presents the outcomes of pushover analysis performed using ETABS on reinforced concrete (RC) frames, both regular and with vertical irregularities.
- The results are interpreted in terms of capacity curves, hinge formation, displacement demands, inter-storey drift ratios, and shear distribution.
- Comparisons were made between the structural behavior of regular and irregular frames under seismic loading.

5.1 KEY RESULTS

- Capacity curves (base shear vs. roof displacement) were generated.
- Regular frames showed higher base shear capacity and greater stiffness compared to vertically irregular frames.
- Irregular frames exhibited larger displacements at lower load levels, indicating reduced seismic performance.
- Hinges formed progressively at beam ends and column bases.
- In regular frames, hinge development followed a uniform pattern, while in irregular frames hinges concentrated in certain stories, especially at the points of irregularity.
- Collapse mechanisms were reached earlier in irregular frames.
- Regular frames-maintained drift ratios within permissible code limits, whereas irregular frames showed excessive drifts, particularly in the soft-story regions.
- This suggests that vertical irregularities significantly amplify inter-storey drift demands.
- Shear forces were more evenly distributed across storeys in regular frames.
- In irregular frames, discontinuities in shear distribution were observed, leading to stress concentration and higher vulnerability.
- The study highlights that structural regularity plays a crucial role in seismic performance.
- Regular frames exhibit better ductility, stability, and uniform hinge progression, whereas vertically irregular frames are more prone to premature failure.
- Pushover analysis effectively captured capacity reduction, hinge behavior, and drift irregularities in RC frames, aligning with findings in previous literature.
- It was concluded that pushover analysis, when combined with user-defined hinge properties, provides a reliable tool for performance-based seismic design and retrofitting assessment.

6. CONCLUSIONS

- The study demonstrated that pushover analysis in ETABS is an effective method for assessing the seismic performance of reinforced concrete (RC) frames.
- Regular frames exhibited higher strength, stiffness, and uniform hinge progression compared to vertically irregular frames, which showed premature hinge concentration and higher displacement demands.
- Vertical irregularities significantly affected performance by producing larger inter-storey drifts and stress concentration zones, making such structures more vulnerable under seismic loading.
- The pushover curves (base shear vs. roof displacement) clearly highlighted the superior seismic capacity of regular frames.
- It was concluded that pushover analysis is a reliable and practical nonlinear static procedure for evaluating building performance in line with performance-based seismic design principles.

7. FUTURE WORK RECOMMENDATIONS

- Regular structural configuration should be preferred in seismic-prone areas, as irregularities amplify seismic vulnerability.
- For irregular structures, additional strengthening and retrofitting measures are necessary to control drifts and enhance ductility.

- Use of user-defined hinge properties in ETABS is recommended over default hinges, as they provide more realistic simulation of nonlinear behavior.
- Pushover analysis should be complemented with nonlinear dynamic analysis for tall or complex structures to capture higher-mode effects more accurately.
- Future work may focus on extending the study to include different loading patterns, material variations, and irregularities in both plan and elevation, to better understand seismic responses.

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