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A REVIEW ON PERFORMANCE BASED DESIGN OF SHEAR WALL STRUCTURES USING PUSHOVER ANALYSIS

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Abstract - *Performance-Based Design (PBD) offers a targeted approach to enhancing the seismic performance of structures, moving beyond traditional safety compliance to achieve specific performance goals. This review explores the application of pushover analysis—a nonlinear static method—for optimizing shear wall structures under seismic forces. Shear walls, crucial for lateral stability, are examined in terms of configuration, material selection, and reinforcement to maximize structural resilience. PBD not only identifies weak points through detailed performance evaluation but also ensures efficient material use and cost savings. By integrating advancements in design methodologies and innovative materials, PBD enhances both safety and functionality, particularly for critical infrastructure. This paper synthesizes current research to highlight the role of PBD in reducing repair costs, ensuring operational continuity, and promoting sustainable practices, while identifying gaps and proposing future directions for further improving seismic design strategies.*

Key Words: Performance-Based Design, Pushover Analysis, Seismic Resilience, Shear Wall Structures, Earthquake Engineering, Structural Optimization.

1. INTRODUCTION

Performance-Based Design (PBD) is an advanced approach to structural engineering that aims to predict how buildings will perform under specific conditions, particularly during seismic events. Unlike traditional design methods that primarily focus on meeting basic safety standards, PBD sets predefined performance objectives that ensure structures meet specific goals such as operational functionality, immediate occupancy, life safety, and collapse prevention. This allows for a more tailored and effective design that prioritizes both the safety and usability of the building during and after an earthquake.

A key tool in PBD is Pushover Analysis, a nonlinear static method used to evaluate a structure's capacity to resist seismic forces. In this method, lateral forces are gradually applied to the structure, simulating the effect of increasing seismic loads until failure occurs. This incremental approach helps identify the building's weak points and assesses its overall performance, providing valuable insights for optimizing structural design to enhance safety and resilience during seismic events. Pushover Analysis, therefore, plays a crucial role in ensuring that buildings designed using PBD can withstand and function effectively during earthquakes, mitigating damage and safeguarding occupants.

1.1 Performance Levels in Performance-Based Design

Performance-Based Design (PBD) is an advanced structural engineering methodology that moves beyond traditional design codes by focusing on how a building will perform during seismic events. Unlike conventional approaches that often aim for compliance with basic safety requirements, PBD sets specific, measurable performance objectives tailored to a building's intended use and occupancy. These objectives help ensure that structures remain functional, resilient, and safe, even under the extreme conditions caused by earthquakes. By focusing on performance rather than simply meeting code-prescribed safety thresholds, PBD offers a more refined and adaptable approach to earthquake-resistant design.

The performance objectives in PBD are organized into four distinct levels, each reflecting a different degree of damage tolerance and building usability. These levels not only provide clear targets for engineers to design to but also offer a flexible framework that allows for tailored solutions depending on the building's role, location, and importance.

Operational Level (O): This level represents the highest priority for functionality, where the building should experience little to no damage after a minor earthquake. Critical infrastructure, such as hospitals, emergency response centres, and data centres, are often designed to meet this standard. The goal is to ensure that these buildings remain fully operational immediately after an earthquake, with no disruption to their essential services. Such buildings are expected to withstand minor tremors without any impact on their functionality.

Immediate Occupancy (IO): For buildings designed at the Immediate Occupancy level, the structure must allow immediate use following a moderate earthquake. The building should sustain minimal damage, with no need for immediate repairs to the primary structural elements. This level of performance is critical for public safety buildings, offices, or residential complexes where quick recovery and minimal disruption are important. While some cosmetic damage may occur, the building's core functionality and the safety of its occupants should be unaffected, ensuring that it can continue serving its intended purpose.

Life Safety (LS): The Life Safety performance level focuses on protecting human life during a severe earthquake. In this case, the building may experience significant structural damage, but the design ensures that there is no collapse. Occupants should be able to evacuate the building safely, and the risk of injury or death is minimized. This performance level is typically applied to buildings where the primary concern is occupant safety, such as schools, commercial buildings, and residential buildings. The design ensures that the building is still usable for evacuation but may require extensive repairs before it can be reoccupied.

Collapse Prevention (CP): The Collapse Prevention level is aimed at preventing the total collapse of the building during a major earthquake. Although the building might experience significant damage, it is engineered to stay intact long enough to allow safe evacuation of occupants. The primary focus here is minimizing the risk of catastrophic failure and protecting human life by preventing structural collapse. This level of performance is typically applied to older buildings or those that cannot be designed for higher performance levels due to cost or other constraints. While these buildings may not be immediately usable after an earthquake, they will not pose a significant risk to the safety of the people inside during the event.

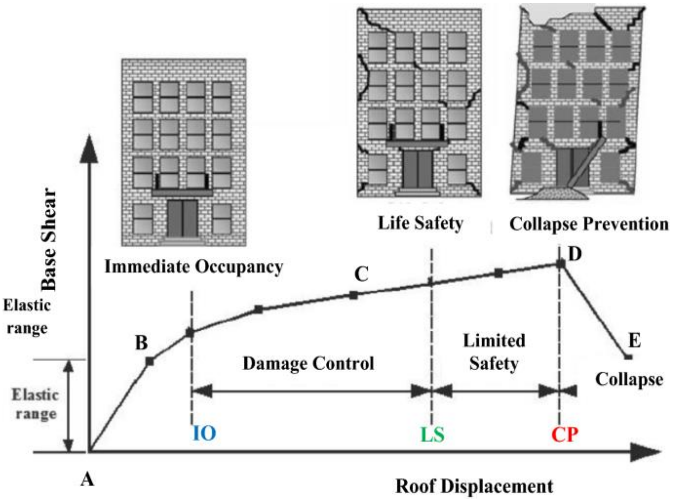

Fig -1: Capacity Curve of Structures

1.2 Role of Plastic Hinges in Pushover Analysis Design

Plastic hinges are vital in pushover analysis because they indicate where inelastic deformation occurs in structural members, such as beams and columns. As lateral forces are applied to the structure, these hinges form at specific locations, allowing energy to be dissipated through plastic deformation. This mechanism is crucial for effectively managing seismic loads, as it enables engineers to pinpoint vulnerable areas that could jeopardize the building's overall performance during an earthquake. By understanding the behaviour of plastic hinges, engineers can design structures that better withstand seismic events, ensuring enhanced safety and resilience.

Understanding the formation and behaviour of plastic hinges enables engineers to make informed design decisions, ensuring that structures can meet critical performance objectives like life safety and collapse prevention. By strategically designing around the anticipated locations of these hinges, engineers can enhance the resilience of buildings, ensuring they can withstand significant seismic events while protecting occupants and minimizing damage.

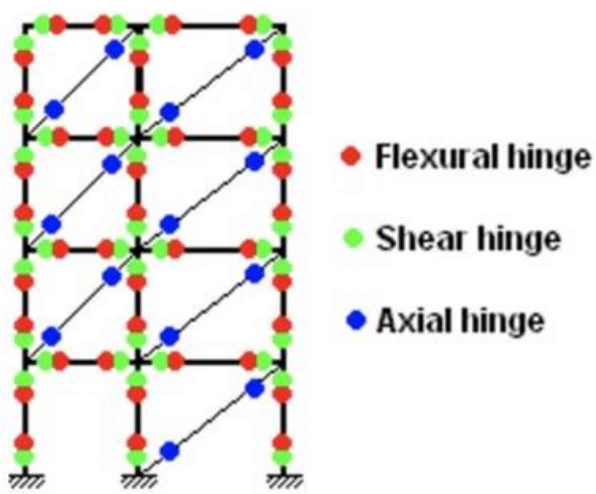

Fig -2: Plastic Hinge Locations

2. LITERATURE REVIEW

Pradyut Anand et al. [2022] conducted performance-based seismic design of G+10 RCC structure. A nonlinear pushover analysis was done after modifying column sizes and reinforcement, using STAAD PRO and ETABS software. The study focused on analysing roof displacement and base shear. Increasing column size and reinforcement reduced displacement, but over-enlarging columns beyond 150mm increased roof displacement.

M.Dinesh et al. [2021] conducted a nonlinear static pushover analysis on a G+4 RCC frame using ETABS, comparing displacement and base shear. They generated pushover curves and evaluated seismic performance. The study analysed a G+4 RCC building's seismic performance using ETABS, focusing on roof displacement and base shear through pushover analysis to assess structural resilience against earthquakes.

Shashi Shankar et al. [2020] conducted a performance-based seismic design of a G+20 structure using nonlinear pushover analysis. The study evaluated reinforcement variations and their effects on building performance using ETABS and SAP2000. A G+20 building's seismic performance was analysed by adjusting reinforcement levels. The nonlinear pushover method highlighted structural improvements and suggested enhanced design methods for better performance and economy.

I. N. Sinarta et al. [2020] analysed a reinforced concrete hotel building in Bali using direct displacement and pushover analysis methods, assessing performance against earthquake loads per Indonesian regulations and FEMA 356. The study validates that both direct displacement and pushover analysis yield similar results in assessing structural performance, recommending direct displacement as a viable method for earthquake-resistant design. Additionally, the research highlights the efficiency of direct displacement analysis in simplifying complex seismic evaluations while ensuring compliance with performance-based design principles. The findings underscore the adaptability of these methods for varying structural configurations and earthquake intensities, offering valuable insights for resilient building practices in seismic regions.

Prashant G. Ingle et al. [2018] evaluated the seismic performance of a six-story RC building using pushover analysis per IS 456:2000, focusing on plastic hinge formation and comparing results for life safety and collapse prevention. The study highlights performance-based seismic design (PBSD) as superior to force-based methods, emphasizing non-linear pushover analysis for improved structural assessment during earthquakes, ensuring minimal damage and economic loss.

Orlando Arroyoa et al. [2017] analysed a 10-story RC moment frame building using the PBEE framework to evaluate a seismic design approach minimizing the fundamental period. Nonlinear dynamic analyses assessed collapse risk, annual losses, and casualty rates while investigating column-to-beam strength ratios and structural changes due to optimization. The study found that optimizing the fundamental period resulted in uniform drift distribution, reduced collapse risk, and enhanced seismic resilience. Structural modifications included larger columns at lower stories and smaller sections at higher levels, improving strength ratios and damage distribution. The optimized design demonstrated superior seismic performance compared to traditional buildings.

Atul N. Kolekar et al. [2017] performed dynamic analysis of a G+12 reinforced concrete building using SAP2000, employing response spectrum and time history methods based on the Koyna and Bhuj earthquake data. Key seismic parameters such as base shear, storey displacement, and drift were evaluated, and a pushover analysis was performed to assess the building's seismic safety. The study showed that time history analysis provided more accurate predictions of structural response than the response spectrum method. Base shear, displacements, and drifts were within permissible IS 1893-2002 limits. Pushover results indicated ductile behaviour with hinges in beams, demonstrating seismic safety and strong resistance to collapse.

Chetan Ingale et al. [2017] conducted a performance-based seismic design of a G+5 RCC building using nonlinear static pushover analysis. They evaluated seismic performance across various zones, ensuring compliance with safety standards. The study emphasizes a performance-based approach for designing buildings, focusing on realistic seismic performance. The analysis revealed that building displacement and base shear vary with seismic zones, affecting overall structural safety.

Pramodini Naik et al. [2016] evaluated the seismic performance of a nine-storey residential building in Goa using performance-based design principles and nonlinear pushover analysis with ETABS, assessing safety under earthquake loading. The study results show the building performs safely in seismic zone III, with user-defined hinges improving ductility and reducing base forces, suggesting opportunities for design optimization.

Balesh. B. Koni et al. [2016] analysed 7-story flat slab structures under seismic loads using ETABS, considering configurations like drops and edge beams. Parameters such as hinge locations, ductility, safety ratio, and global stiffness were evaluated through pushover analysis in seismic zone III conditions. The study revealed that edge beams improved stiffness, while drops increased ductility in infill walls. Critical hinges formed primarily in interior columns. The performance point was within life safety to collapse prevention, with edge beam models showing the least displacement.

Shef Amir Arasy et al. [2016] analysed a 14-story reinforced concrete building with a dual system of shear walls and columns to resist lateral forces. They compared prescriptive code-based design (CBD) with performance-based design (PBD) under Maximum Considered Earthquake (MCE) conditions in Jakarta. The study aimed to evaluate PBD's effectiveness in optimizing structural and architectural features. The research concluded that PBD achieved life safety performance under MCE, reducing column size by 30% with 1% reinforcement. Compared to CBD, PBD offered a more realistic design approach, enhancing architectural space efficiency by minimizing structural dimensions while maintaining seismic safety.

Md Zibran Pawaar et al. [2015] analysed different shear wall arrangements in dual systems (flat slabs and shear walls) for seismic zone V, using ETABS software, evaluating parameters like displacements, base shears, and pushover curves. The study showed that E-shaped models with shear walls and flat slabs performed better in minimizing storey drifts and achieving more efficient base shear handling than diaphragm discontinuity models.

Dr. Mohd. Hamraj et al. [2014] conducted a performance-based seismic analysis of three R.C.C. buildings (G+4, G+8, and G+20) with varying heights, comparing structural responses considering infill walls using pushover analysis in ETABS. The study demonstrates that incorporating infill walls significantly reduces top storey displacement in G+4, G+8, and G+20 buildings, emphasizing the need to include infill in seismic analysis for better performance.

P. B. Oni et al. [2013] investigated the seismic performance of G+2 and G+5 buildings with plus-shaped shear walls using linear and nonlinear analyses, comparing pushover analysis with response spectrum and static methods. The study emphasizes using pushover analysis for accurate seismic response assessment of taller and unsymmetrical buildings, while the equivalent static method is effective for lower, symmetric structures.

Mrugesh D. Shah et al. [2011] analysed two RCC buildings (G+4 and G+10) using performance-based seismic engineering, considering three infill conditions: bare frame, infill as membrane, and infill as equivalent strut. Models with varying bays (2×2, 3×3, 4×4) were studied to evaluate lateral load capacity and displacement characteristics under seismic loads. The study revealed that bare frames without infill had the lowest lateral load capacity, while equivalent strut models performed best. Increasing bays enhanced load capacity without significant displacement increase, whereas taller buildings showed increased displacement but no improvement in lateral load capacity.

3. SUMMARY OF LITERATURE REVIEW

The literature review conducted as part of the study reveals that there are numerous studies focused on performance-based design (PBD) and pushover analysis in shear wall structures. A brief review of the literature indicates that PBD significantly enhances a structure's ability to withstand seismic events. It is also found that structures lacking adequate lateral support are more vulnerable to seismic loads and require more attention than those with regular configurations. The key conclusions derived from the previous studies are as follows:

1. Performance-based design (PBD) improves the ability of RCC residential buildings to withstand earthquakes.
2. The pushover method and direct displacement method are key techniques for accurately analyzing earthquake loads on structures.
3. Dual structural systems improve seismic performance in multi-storey reinforced concrete buildings.
4. Non-linear static analysis is useful for assessing how structures respond to earthquake forces.
5. Local seismic features greatly influence design approaches, as demonstrated by comparisons between the Koyna and Bhuj earthquakes.
6. Performance-based design improves flat slab structures and ensures safety during earthquakes.
7. Performance-based design helps evaluate slender buildings to enhance their seismic performance and stability.
8. Pushover analysis reveals weaknesses in shear-walled RCC buildings and irregular frames, helping guide design enhancements.

4. GAPS IN LITERATURE REVIEW

After an extensive review of numerous research papers, several significant gaps have been identified, highlighting areas where further investigation is crucial to advance the understanding and application of performance-based design in seismic engineering:

1. **Focus on High-Rise Structures:** Existing studies largely emphasize low to mid-rise buildings, neglecting the unique challenges of applying Performance-Based Design (PBD) to high-rise structures, such as lateral loads, dynamic behaviour, and structural flexibility during seismic events.
2. **Member Sizes and Reinforcement Configurations:** Limited research explores the impact of varying member sizes and reinforcement percentages on seismic performance. Understanding these factors is critical for optimizing PBD in diverse building scenarios.
3. **Shear Wall Performance in Real Plans:** While shear walls are key to lateral stability, their behaviour within actual building plans under seismic conditions remains underexplored, leaving gaps in improving PBD methodologies.
4. **Height-Based Performance Comparisons:** There is insufficient comparative analysis of buildings of varying heights. Studies rarely examine how seismic performance metrics, such as lateral displacement and dynamic response, evolve with height.
5. **Seismic Zone Variations:** Research inadequately addresses performance differences across various seismic zones, which is critically important for

developing effective and region-specific PBD design strategies.

6. **Real-World Validation:** Analytical models are rarely validated with empirical data from actual seismic events, weakening their reliability. Comprehensive case studies could bridge this gap, enhancing model accuracy.

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