© September 2025| IJIRT | Volume 12 Issue 4 | ISSN: 2349-6002

Performance Based Analysis and Design of Frame Shear Wall

Priyanka A. Bagade[1], P. R. Barbude[2] and S. A. Rasal[3]
[1]*Post Graduate Student, Dept. of Civil Engineering, Datta Meghe College of Engineering, Airoli, Navi Mumbai 400708, Maharashtra, India*
[2,3] *Assistant Professor, Dept. of Civil Engineering, Datta Meghe College of Engineering, Airoli, Navi Mumbai 400708, Maharashtra, India*

***Abstract*— Performance-based design aims to control structural damage during earthquakes by accurately estimating how buildings will respond to seismic forces. It is an iterative and detailed process that ensures both code requirements and desired performance levels are met. This study uses nonlinear pushover analysis to evaluate the seismic performance of reinforced concrete (RC) moment- resisting frame buildings. Buildings with G+4, G+6, and G+8 storeys were initially designed according to IS 456:2000 and analyzed using SAP2000. Redesign was done by adjusting the sizes and reinforcement of beams and columns to improve performance. The process includes selecting performance objectives, creating a preliminary design, checking if it meets the objectives, and making necessary changes until the desired performance is achieved. The study identifies the most effective and economical reinforcement combinations that reduce structural damage and allow the building to remain functional after an earthquake, showing how performance-based design can improve safety and resilience.**

***Index Terms* — Performance based Design, finite element analysis, non-linear Pushover Analysis, high rise building.**

I. INTRODUCTION

An earthquake is one of the most devastating natural phenomena, and unlike other hazards such as floods, cyclones, or storms, it strikes suddenly without any advance warning, leaving no opportunity for evacuation or preventive measures. As a result, earthquakes often cause severe destruction to both human life and property within a very short span of time. This unpredictability emphasizes the necessity of designing buildings that can sustain seismic actions and continue to function with minimal damage. The concept of earthquake-resistant design has therefore emerged as the only reliable and sustainable strategy for mitigating seismic risk. Over the years, seismic design philosophies have undergone significant. refinement, with continuous improvements derived from the systematic study of building damages observed in various past earthquakes across the world. Each structural failure or case of distress has served as a valuable source of information for engineers and researchers, enabling the development of improved design codes, innovative construction techniques, and performance-based approaches, all directed towards enhancing the resilience and safety of occupants in seismic-prone regions.

In structural engineering practice, buildings are conventionally designed to withstand permanent (dead), semi-permanent (live), and occasional (environmental) loads. Among these, earthquake loads are classified as occasional but are of paramount importance due to their highly dynamic, irregular, and multi-directional nature. Unlike gravity loads, seismic loads act on the entire structure simultaneously, inducing inertia forces as different components undergo differential movements with respect to the foundation in a very short time interval. This rapid relative deformation generates complex internal stresses and demands additional strength, ductility, and energy dissipation capacity from the structure. Consequently, earthquake engineering has evolved into one of the most advanced branches of structural engineering, focusing extensively on dynamic behavior and performance-based design methodologies. Investigations of building responses to historic and recent seismic events, supported by seismological studies and analytical research, have contributed to the progressive development of codal provisions, numerical modeling techniques, and construction practices. The combined efforts of past and present researchers have thus established a comprehensive foundation for modern earthquake-resistant design, offering a realistic understanding of structural performance under seismic excitations.

II. REVIEW OF LITERATURE

Pradyut Anand *et al.* carried out a performance-based seismic design investigation on a G+10 reinforced cement concrete (RCC) building using nonlinear pushover analysis implemented in both STAAD.Pro and ETABS. The study specifically examined the influence of variations in column cross- sectional dimensions and reinforcement detailing on the seismic response of the structure. Key response parameters such as roof displacement and base shear were evaluated under different design configurations. The results demonstrated that increasing column dimensions and reinforcement generally contributed to a reduction in roof displacement, thereby improving overall lateral stiffness and seismic performance. However, it was observed that when the column size was increased beyond 150 mm, roof displacement exhibited an unexpected rise, indicating a threshold beyond which further enlargement of column sections may not enhance performance effectively and could lead to counterintuitive structural behavior.

M. Dinesh *et al.* performed a nonlinear static pushover analysis on a G+4 reinforced cement concrete (RCC) frame structure using ETABS software. The study focused on evaluating the seismic response by comparing displacement demands and base shear capacities under incremental lateral loading. Pushover curves were developed to represent the progressive behavior of the structure, capturing its stiffness degradation and strength characteristics. Particular emphasis was placed on roof displacement and base shear as critical performance parameters, serving as indicators of the structural system's overall resilience and capacity to withstand seismic forces.

Shashi Shankar *et al.* carried out a performance-based seismic design study on a G+20 reinforced concrete structure employing nonlinear pushover analysis. The investigation primarily addressed the influence of reinforcement variation on the global seismic performance of the building, with ETABS and SAP2000 utilized as analytical tools. A comprehensive assessment was performed by systematically modifying reinforcement levels within the G+20 building model to examine their effect on critical response parameters such as lateral displacement and base shear. The nonlinear pushover analysis results demonstrated considerable improvements in structural performance due to optimized reinforcement detailing, emphasizing the role of reinforcement distribution in enhancing both safety and cost-effectiveness. The study concluded that judicious adjustment of reinforcement can serve as an effective design strategy for achieving improved seismic resilience while simultaneously ensuring material efficiency. Balesh B. Koni *et al.* examined the seismic performance of a seven-storey flat slab structure using ETABS by considering different structural configurations, including the presence of drops and edge beams. Nonlinear pushover analysis was performed under seismic Zone III conditions to evaluate parameters such as hinge formation, ductility demand, safety ratio, and global stiffness. The findings revealed that the incorporation of edge beams significantly enhanced the overall stiffness of the structure, while the inclusion of drops improved the ductility performance of infill wall systems. It was further observed that the majority of critical hinges were concentrated in the interior columns, highlighting their vulnerability during seismic events. The performance point for the analyzed structural models was determined to lie between the Life Safety (LS) and Collapse Prevention (CP) levels, with models incorporating edge beams exhibiting the least displacement and demonstrating better overall seismic resistance.

Indu G. and Amlan K. *et al.* investigated the seismic performance of a four-storey low-rise building with a centrally located shear wall. Nonlinear pushover analyses were conducted using SAP2000 for two modeling approaches: a simplified shear wall represented by equivalent column elements and a refined shear wall modeled with wall panels incorporating multi-layered membrane elements. The study compared pushover curves obtained from both models. To define shear hinge properties in the simplified model, the softened truss model was employed, enabling a more accurate representation of nonlinear shear behavior.

Kubin *et al.* employed finite element modeling to analyze the behavior of shear walls under seismic loading. Two modeling approaches were considered: shear walls modeled using shell elements with varying mesh sizes, and shear walls modeled using frame elements following the mid-pier approach. Nonlinear pushover analysis was performed for both models, and the resulting pushover curves were compared to evaluate the influence of modeling techniques on structural response.

The present study aims to carry out Linear Dynamic Analysis and Nonlinear Static (Pushover) Analysis of frame shear wall building systems in order to investigate the interaction behavior between the frame and shear wall components. Further to conduct a comparative evaluation of Performance-Based Design for frame–shear wall buildings with heights of five (15m), seven (21m), and ten (29m) storey, focusing specifically on their structural response at the Immediate Occupancy (IO) performance level.

III. METHODOLOGY

The structural configuration considered in this dissertation comprises multi-storey RC buildings of G+4, G+6, and G+8 with symmetrical plans. Analysis and design were carried out for gravity loads and seismic loads corresponding to Zone V, assuming medium soil conditions. An Importance Factor of 1.0 and a Response Reduction Factor of 5 were adopted for base shear calculation, while wind loads were neglected. Each building consists of 5 longitudinal bays (5.3 m each) and 3 transverse bays (6.3 m, 2.3 m, and 6.3 m), resulting in overall plan dimensions of
26.5 m × 14.9 m. Heights of the buildings are 15 m, 21 m, and 27 m for G+4, G+6, and G+8, respectively.

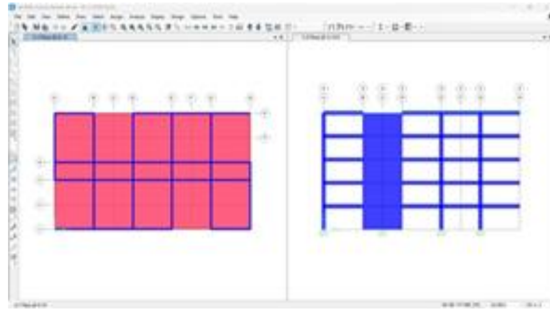


Fig-1: Plan and Elevation of G + 4 Strorey Model

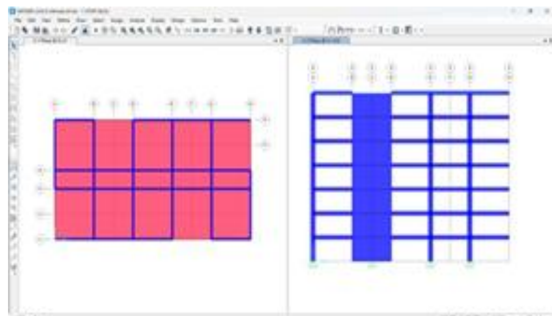


Fig-2: Plan and Elevation of G + 6 Strorey Model

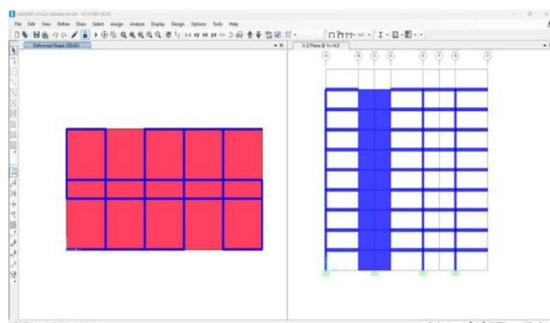


Fig-3: Plan and Elevation of G + 8 Strorey Model

The bare frame models of the three buildings were developed in SAP2000 using beam and column elements with fixed supports and rigid diaphragm action at each floor level. Shear walls were modeled using the wide-column approach, wherein an equivalent column representing the wall section was placed at the bay centerline. At each floor, very stiff beams were introduced across the shear wall to simulate its finite width and ensure proper force transfer.
The applied loads on the buildings include dead load, live load, and earthquake load in both longitudinal and transverse directions. Dead load consists of the self-weight of beams, columns, slabs, and infill walls, considered as uniformly distributed loads on beams. A live load of 3 kN/m² was applied on slabs as area loads,

with no live load considered on the roof. Seismic weight was taken as dead load plus 25% of live load in accordance with codal provisions. Earthquake loading was applied through the Response Spectrum method as per Indian Standards for medium soil conditions in both directions of the buildings. Linear dynamic analysis was performed to determine the fundamental time periods and mode shapes, and the results of this analysis are presented in the subsequent sections

IV. RESULTS AND DISCUSSION

Resultant Base Shear vs Monitored Displacement

The Resultant Base Shear vs Monitored Displacement relationship is a key tool in Performance-Based Seismic Design (PBSD), especially within Pushover Analysis and Nonlinear Time History Analysis, used to evaluate the global seismic response and deformation capacity of structural systems.

Resultant Base Shear: The total horizontal reaction developed at the base of the structure due to lateral seismic loads, calculated as the sum of all horizontal base reactions during nonlinear analysis. It is expressed in kilonewtons (kN) and represents the seismic demand transferred to the foundation, indicating the overall lateral strength and stiffness of the structure.

Monitored Displacement: The lateral displacement of a designated control node used to track structural deformation, typically measured at the roof level, top of shear walls or braced cores, or at critical joints. It is measured in millimetres (mm) or centimetres (cm) and reflects the structure's global deformation response and ductility capacity.

Resultant Base Shear vs Monitored Displacement Curve: A nonlinear force– deformation curve obtained from incremental lateral load application or peak responses in dynamic analysis. The X-axis represents monitored displacement, and the Y-axis represents resultant base shear. The curve shows key response stages: elastic range (linear, undamaged), yield point (onset of inelastic behavior), plastic range (post-yield ductile response), ultimate point (maximum lateral load capacity), and post- peak degradation (strength loss and near- collapse).

Purpose and Applications: This relationship is used for seismic performance assessment, helping quantify structural capacity and deformation limits. It supports performance level classification such as Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP), and is essential for design and code compliance based on guidelines from FEMA, ATC, and IS 1893.

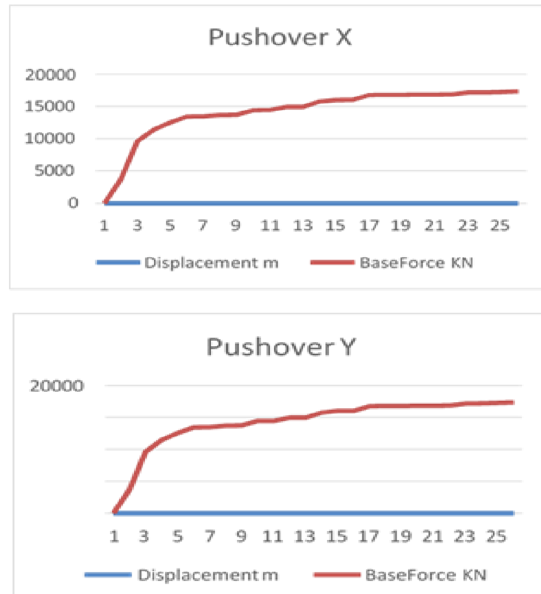


Fig 4: Base Shear Vs. Displacement for G+4 storey

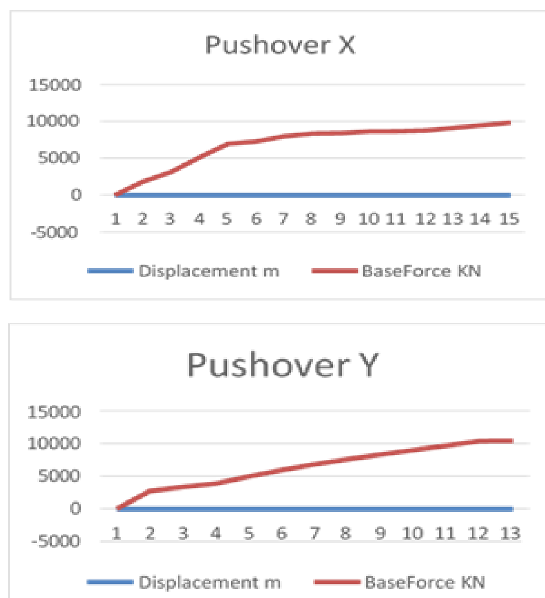
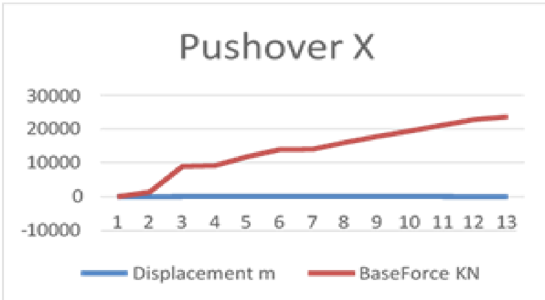


Fig-5: Base Shear Vs. Displacement for G+6 storey



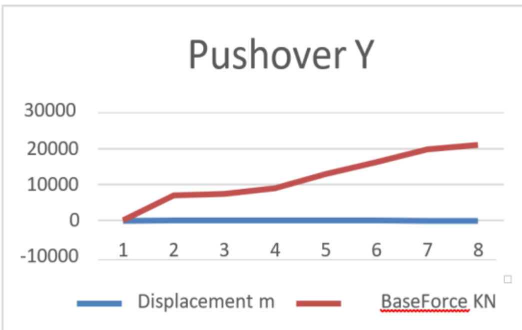


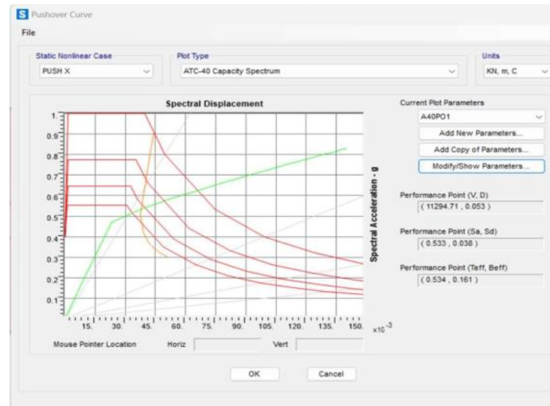
Fig-6: Base Shear Vs. Displacement for G+8 storey4

ATC 40 Capacity Spectrum Method:

Performance Point

In the ATC-40 procedure, the Performance Point is where the structure's seismic capacity intersects the seismic demand, representing its expected inelastic state during a design-level earthquake.

- The capacity curve, obtained from nonlinear Pushover Analysis, shows the structure's base shear versus displacement response and indicates its lateral strength and deformation capacity.
- The demand curve, developed from site- specific or code-based response spectra in acceleration–displacement response spectrum (ADRS) format, represents the expected seismic demand and ground motion intensity.
- The Performance Point is the intersection of the capacity and demand curves on the ADRS plot.
- At this point, the structure experiences a specific lateral displacement (monitored at the roof or control node) and resists a corresponding base shear.
- This displacement is used to classify the seismic performance level as:
    - Immediate Occupancy (IO): Minimal damage, fully functional
    - Life Safety (LS): Significant damage, collapse avoided
    - Collapse Prevention (CP): Severe damage, near-collapse



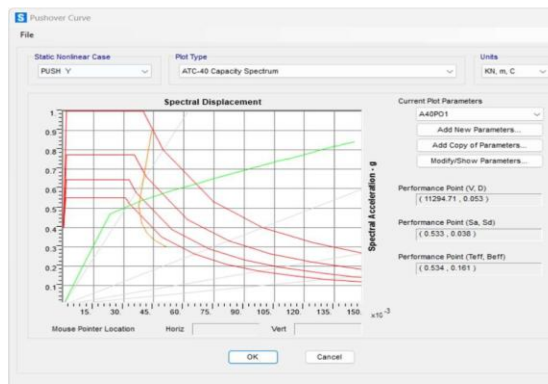
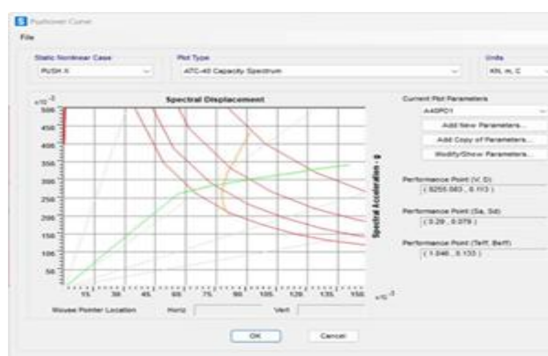


Fig-7: ATC-40 Capacity Spectrum for G+4 storey



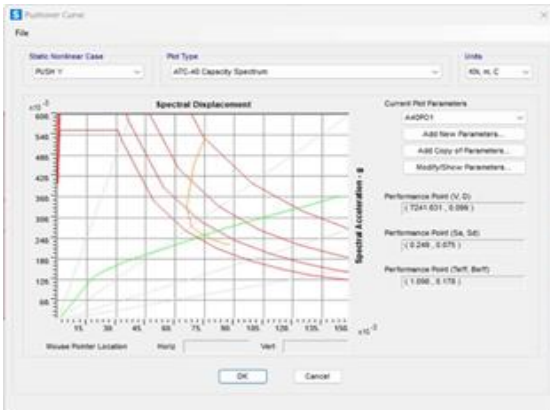


Fig-8: ATC-40 Capacity Spectrum for G+6 storey

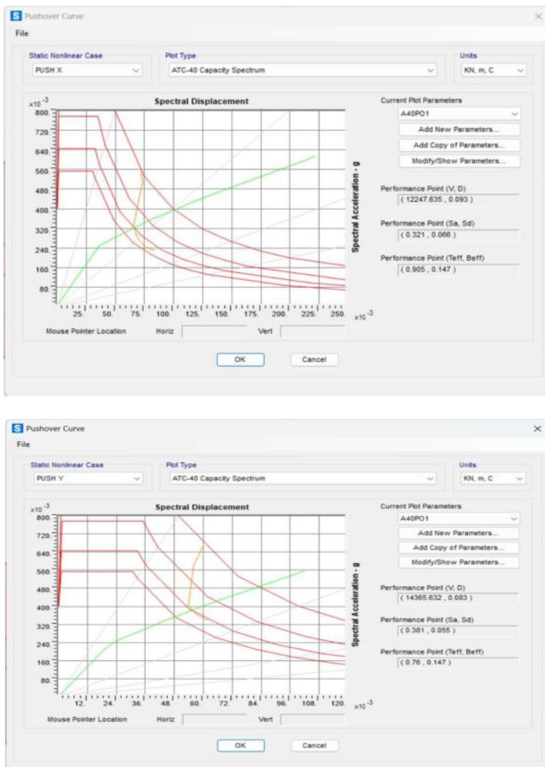


Fig-9: ATC-40 Capacity Spectrum for G+8 storey

Performance Level

A Performance Level in Performance-Based Seismic Design (PBSD) defines the expected post- earthquake condition and functionality of a structure, indicating how safe, serviceable, and repairable it will be based on the extent of damage to structural and non-structural components.

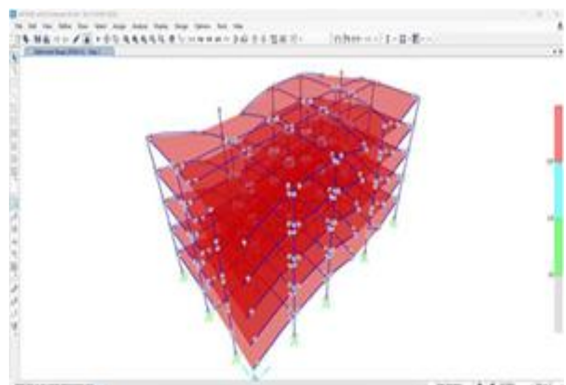
Purpose: Establishes safety and serviceability targets for buildings during and after seismic events, and enables quantitative damage assessment to support risk-based design decisions.

Components Considered: Includes structural elements (columns, beams, shear walls, braces), non-structural elements (partitions, ceilings, cladding, mechanical/electrical systems), building contents (equipment, furnishings, operational systems), and life-safety systems (emergency lighting, fire exits, escape routes).

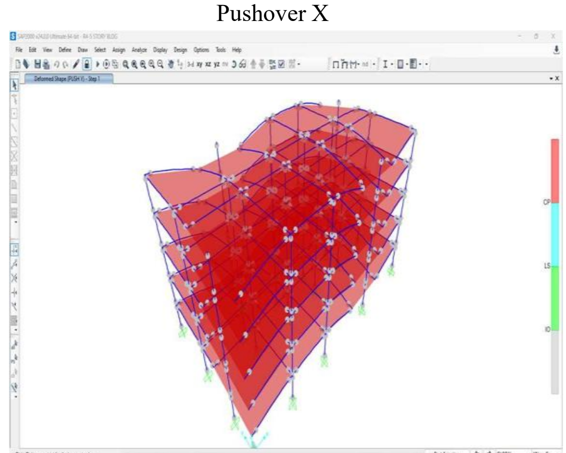
Applications: Used in performance-based seismic design frameworks to define design objectives:

Hospitals and emergency facilities are designed for Immediate Occupancy (IO)

Residential and commercial buildings commonly target Life Safety (LS) Existing vulnerable structures are often retrofitted to achieve at least Collapse Prevention (CP) Provides criteria for evaluating and retrofitting existing buildings to meet desired post-earthquake performance levels.

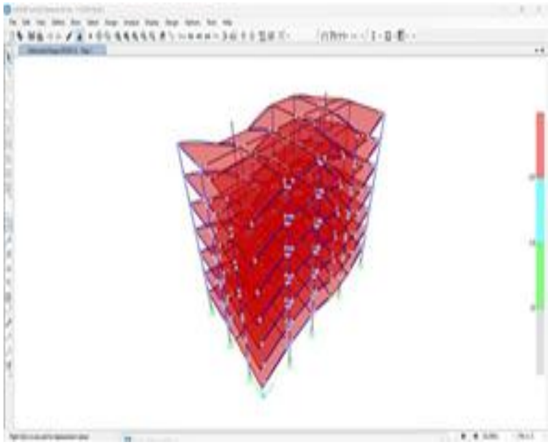


Pushover X

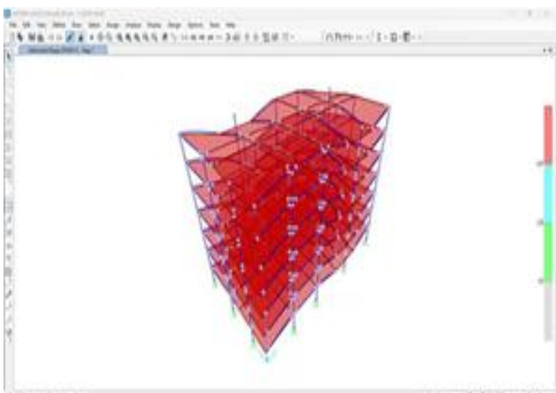


Pushover Y

Fig-10: Plastic Hinge Formation for G + 4 storey

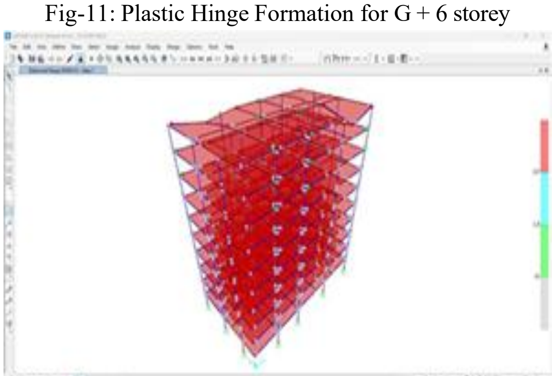


Pushover X

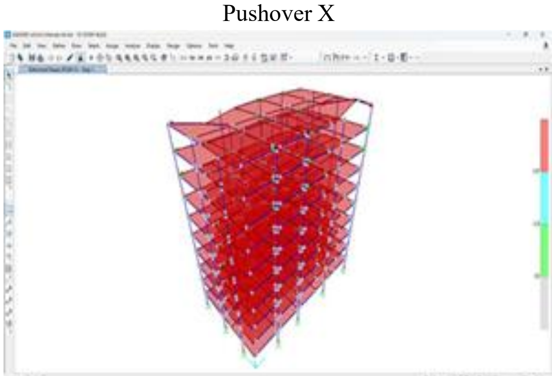


Pushover Y

Fig-11: Plastic Hinge Formation for G + 6 storey



Pushover X



Pushover Y

Fig-12: Plastic Hinge Formation for G + 8 store

Base Shear is defined as the total horizontal seismic force acting at the base of a structure due to earthquake ground motion. It represents the overall lateral load demand imposed on the structure by seismic excitation and is a critical parameter in both linear and nonlinear seismic analysis.

The plot below presents the computed base shear values for the three structural models developed and analysed under the design seismic load case. These values reflect the lateral load-resisting capacity of each model and serve as a basis for comparative seismic performance evaluation.

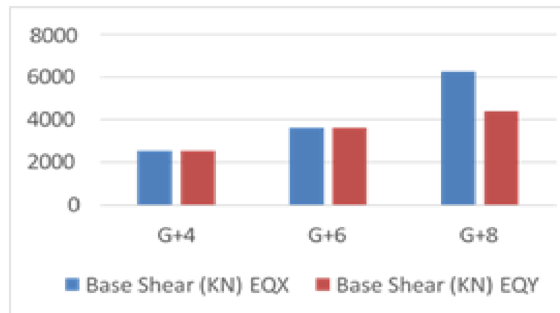


Fig-13: Base Shear

VII. CONCLUSION

- Performance-based design offers a rational and systematic framework for evaluating the seismic response of structures, providing a more realistic understanding of their inelastic behavior compared to conventional prescriptive design methods. By focusing on actual performance under earthquake loading rather than code compliance alone, it enables more accurate assessment of strength, ductility, and energy dissipation characteristics.
- This approach directly relates design decisions to targeted performance objectives, ensuring that structures sustain minimal damage and retain operational functionality after seismic events. It allows for an optimized balance between safety, serviceability, and material economy, making it highly suitable for critical and high-risk structures in seismic regions.
- Incorporating shear walls significantly enhances the lateral stiffness, strength, and overall stability of reinforced concrete frames. Their high energy dissipation capacity reduces inter- storey drifts and

global displacements, thereby limiting damage and improving the seismic reliability of the structural system.

- Optimized configuration and proportioning of shear walls further improve their efficiency, ensuring uniform lateral load distribution and minimizing stress concentrations. This not only enhances seismic performance but also improves material utilization, reducing construction cost while maintaining structural safety.
- Conversely, bare frame systems exhibit lower lateral stiffness and higher deformability, resulting in excessive displacements and increased seismic vulnerability. Their limited energy dissipation capacity constrains them to basic safety levels and makes them unsuitable for achieving higher performance objectives under severe ground motions.
- Overall, integrating shear walls within a performance-based design framework results in seismically robust, ductile, and dependable structural systems capable of sustaining strong earthquake demands while maintaining post- event functionality and occupant safety.

REFERENCE

[1] Indu and K. Sengupta et.al (2014), “Modeling of framed Shear Walls for Pushover Analysis of RC Buildings”, The Indian Concrete Journal, The Associated Cement Companies Limited, Vol. 88, No.5, May, pp 58 – 68.

[2] Nitin Choudhary1 Prof. Mahendra Wadia2 (2014) “Pushover Analysis of R.C. Frame Building with Shear Wall.”, “IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 2 Ver. V, PP 09-13.”

[3] Kubin, J., Fahjan, Y .M and Tan, M. T. (2008), “Comparison of Practical Approaches for Modelling Shear Walls in Structural Analysis of Buildings”, Proceedings, 14th World Conference on Earthquake Engineering, October 12 -17, Beijing,China.

[4] Kasliwal Sagar K.et.al (2012), “Effect of Number and Positions of Shear Walls on Seismic Behavior of Multistory Structure”, IJAIR ISSN: 2278-7844.

[5] Shashi Shankar, Mohd. Tauseef Husain, (2020) “Performance Based Design and optimization of Multi-storeyed Structure: A Simulative Performance Analysis.” “Journal of Xi’an university of architecture & Technology, Volume XII, Issue V”

[6] Pradyut Anand, Prashant Kumar (2022) Seismic Design on a G+10 RCC Residential Structure based on Performance - “International journal of Architectural Engineering & Urban Planning, Volume 32, Number 03, 2022”

[7] M. Dinesh (2021) “Earthquake Performance of G+four existing R.C.C Building by using Etabs software” – “International Journal of Creative and Innovative Research in All Studies, Volume 04 Issue 01, June 2021”

[8] Mr. Prashant G. Ingle, Prof. Vijaykumar P. Bhusare (2018) Performance Based Seismic Design of Reinforced Concrete Building by Non-linear Static Analysis – “Journal of Advances and Scholarly Researches in Allied Education, Volume XV, Issue No. 02, (Special Issue) April-2018”

[9] Atul N.Kolekar, Y.P.Pawar, Dr. C. P. Pise, D. D. Mohite, S. S. Kadam, C. M. Deshmukh (2017) Comparative study of Performance of RCC Multi-Storey Building for Koyna and Bhuj Earthquakes “International Journal of Engineering Research and Applications (IJERA), Volume 7, Issue 5, (Part 2) May 2017, pp.45-52”

[10] Mr. Chetan Ingale, Prof. M.R.Nalamwar (2017) Performance Based Seismic Design Of Rcc Building – “International Research Journal of Engineering and Technology (IRJET), Volume 04, Issue 10, Oct 2017”

[11] Pramodini Naik, Satish Annigeri (2016) Performance evaluation of 9 storey RC building located in North Goa – “Science Direct, 11th International Symposium on Plasticity and Impact Mechanics, Implast 2016”

[12] Balesh.B.Koni, S.S.Dyavanal (2016) Performance Based Evaluation of Flat Slab Structures with Square Columns – “International Research Journal of Engineering and Technology (IRJET), Volume 05, Issue 07, Jul-2016”

[13] Shef Amir Arasy, Bambang Budiono, Wiratman Wangsadinata, Junisa Arini Patrisia (2016) The Effectiveness of Performance Based Design to Establish Architectural Feature of Structural Design for Slender Building – "Journal of Engineering Technology (JET), Volume 04, Issue 01, 2016 pp. 81-87"
[14] Md Zibran Pawaar, Khalid Nayaz Khan, Syed Ahamed Raza (2015) Performance Based Seismic Analysis Of Rc Building Considering. The Effect of Dual Systems – "International Research Journal of Engineering and Technology (IRJET), Volume 04, Issue 05, May 2015"
[15] Dr. Mohd. Hamraj (2014) Performance Based Pushover Analysis Of R.C.C Frames For Plan Irregularity – "International Journal of Science, Engineering and Technology, Volume 02, Issue 07, Sep – Oct 2014"
[16] P. B. Oni, Dr. S. B.Vanakudre (2013) Performance Based Evaluation of Shear Walled RCC Building by Pushover Analysis "International Journal of Multidisciplinary Educational Research, Volume 03, Issue 04, Jul Aug 2013 pp-2522-2525"
[17] Mrugesh D. Shah, Atul N. Desai, Sumant B Patel (2011) Performance Based Analysis of R.C.C. Frames – "National Conference on Recent Trends in Engineering & Technology, 13-14 May 2011"
[18] Mrugesh D. Shah, Atul N. Desai, Sumant B Patel (2011) Performance Based Analysis of R.C.C. Frames – "National Conference on Recent Trends in Engineering & Technology, 13-14 May 2011"
[19] Kulkarni Aniruddha Shailesh, Dr. M.R. Shiyekar (2021) " Pushover Analyisis of high rise RC building with various aspect ratios of shear wall."
[20] Federal Emergency Management Agency, FEMA-356. Prestandard and commentary for seismic rehabilitation of buildings. Washington (DC); 2000.