Seismic Performance Evaluation of Reinforced Concrete Buildings Using Nonlinear Pushover Analysis

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ABSTRACT: *Reinforced Concrete (RC) buildings constitute a major portion of urban infrastructure in earthquake-prone regions, making their seismic performance an important consideration in structural engineering and disaster resilience. Conventional elastic analysis methods are useful for estimating structural response under moderate seismic demands but provide limited information regarding nonlinear behavior, damage progression, plastic hinge formation, ductility, and ultimate structural capacity. Nonlinear pushover analysis provides a practical approach for evaluating the seismic performance of buildings by progressively applying lateral loads to a structural model until significant nonlinear deformation develops. This study presents a systematic framework for the* ***Seismic Performance Evaluation of Reinforced Concrete Buildings Using Nonlinear Pushover Analysis****, considering structural geometry, material properties, gravity loads, lateral load patterns, member nonlinearities, plastic hinge behavior, capacity curves, performance points, inter-story drift, ductility, and failure mechanisms. A representative reinforced concrete building is modeled using nonlinear structural analysis, and its response is evaluated under increasing lateral demand. The analysis identifies the relationship between base shear and roof displacement, determines the formation and progression of plastic hinges, and evaluates structural performance at different seismic demand levels. Performance criteria are established based on structural displacement, inter-story drift, hinge states, and deformation capacity. The proposed evaluation approach provides useful information regarding structural strength, stiffness degradation, ductility, energy dissipation, and potential failure mechanisms. The methodology can support seismic assessment, rehabilitation planning, structural safety evaluation, and performance-based design of reinforced concrete buildings in earthquake-prone regions.*

INTRODUCTION

Earthquakes are among the most destructive natural hazards affecting the built environment, frequently producing severe structural damage, loss of life, interruption of essential services, and significant economic consequences. The seismic performance of buildings depends on several interacting factors, including structural configuration, material properties, member dimensions, reinforcement detailing, construction quality, foundation conditions, soil characteristics, earthquake intensity, and the dynamic characteristics of the structure. Reinforced Concrete (RC) buildings are widely used because of their strength, durability, fire resistance, and adaptability to different architectural requirements. However, inadequate seismic detailing, irregular structural configurations, insufficient ductility, soft stories, weak columns, poor reinforcement anchorage, and inappropriate load paths can substantially reduce their earthquake resistance.

Traditional structural design procedures commonly rely on linear elastic analysis to estimate forces and displacements produced by seismic excitation. Although elastic methods provide valuable information regarding initial structural response, they generally cannot represent the complete nonlinear behavior of reinforced concrete structures subjected to strong earthquakes. Once structural members approach their yield capacities, stiffness degradation, cracking, reinforcement yielding, plastic deformation, and energy dissipation become increasingly important. Therefore, evaluating only elastic demand may not adequately describe the actual behavior of a building during severe seismic excitation.

Performance-based seismic engineering has emerged as an important approach for evaluating structural behavior according to expected damage and functionality rather than relying exclusively on prescribed force levels. The fundamental objective of performance-based assessment is to determine whether a structure can satisfy specified performance objectives under different levels of earthquake demand. These objectives may range from maintaining essentially elastic behavior under frequent earthquakes to preventing collapse during extremely severe seismic events. Such an approach provides a more comprehensive understanding of structural safety and allows engineers to identify critical deficiencies before they develop into catastrophic failures.

Nonlinear static analysis, commonly known as **pushover analysis**, is one of the widely used procedures for performance-based seismic evaluation. In a pushover analysis, gravity loads are first applied to the structural model, followed by gradually increasing lateral loads according to a predefined distribution. The lateral load is increased until the structure reaches a target displacement or a predefined structural limit state. As the lateral load increases, structural members progressively enter nonlinear behavior, allowing the analyst to observe yielding, plastic hinge formation, stiffness degradation, strength deterioration, and redistribution of internal forces.

A major advantage of nonlinear pushover analysis is its ability to provide a direct representation of the relationship between structural strength and deformation. The resulting **capacity curve**, generally expressed as base shear versus roof displacement, describes the progressive response of the building as lateral demand increases. Important structural characteristics such as initial stiffness, yield strength, ultimate capacity, ductility, and post-yield behavior can be derived from this curve. Comparing the structural capacity with an earthquake demand representation provides a basis for estimating the expected performance of the building under a specified seismic hazard.

Plastic hinge formation is a fundamental component of nonlinear pushover analysis. When the bending moment or other governing action in a structural member reaches its nonlinear capacity, a plastic hinge may develop. The location and sequence of hinge formation provide important information regarding the structural failure mechanism. Ideally, seismic design promotes a desirable **strong-column weak-beam** mechanism in which beams develop plastic hinges before columns, allowing the structure to dissipate earthquake energy while maintaining an adequate gravity-load-resisting system. Conversely, premature column hinging or concentration of damage within a particular story can produce soft-story mechanisms and significantly increase collapse vulnerability.

Reinforced concrete behavior under seismic loading is highly nonlinear because concrete cracking, concrete crushing, reinforcement yielding, bond effects, confinement, shear interaction, and cyclic degradation influence member response. Nonlinear structural models therefore require appropriate constitutive relationships and hinge properties to represent realistic member behavior. Beams and columns can be modeled using concentrated plastic hinges or distributed plasticity approaches, depending on the desired level of modeling detail. Appropriate representation of material and member nonlinearities is essential for obtaining meaningful pushover results.

The lateral load pattern selected for pushover analysis also influences the predicted structural response. Common patterns include uniform, triangular, modal, and adaptive load distributions. A uniform pattern applies lateral forces according to a specified distribution that may emphasize higher-story response, while a triangular or inverted-triangular pattern attempts to approximate first-mode seismic response. Modal patterns can incorporate the dynamic characteristics of the structure, whereas adaptive procedures modify the lateral load distribution as structural stiffness changes during nonlinear deformation. Selection of an appropriate load pattern is therefore important for obtaining reliable estimates of structural capacity.

The seismic response of a building is influenced not only by its strength but also by its stiffness and deformation capacity. **Inter-story drift** is one of the important indicators used to evaluate structural damage because excessive relative displacement between adjacent floors can produce structural and non-structural damage. Excessive drift may also indicate instability, P-Delta effects, partition damage, facade failure, and degradation of structural members. Consequently, nonlinear pushover evaluation generally considers roof displacement, inter-story drift, plastic hinge states, base shear capacity, ductility, and other deformation-based parameters.

Irregular reinforced concrete buildings present additional challenges for seismic assessment. Vertical irregularities such as soft stories, weak stories, setbacks, discontinuous columns, and sudden changes in stiffness can cause concentration of seismic demand. Horizontal irregularities, including torsional asymmetry and plan discontinuities, may generate uneven distribution of lateral forces. Pushover analysis can help identify locations where nonlinear deformation becomes concentrated and can therefore provide useful information for structural rehabilitation and strengthening.

The development of modern structural analysis software has made nonlinear pushover analysis increasingly accessible for engineering practice and research. Computational platforms can model three-dimensional building configurations, define nonlinear material properties, assign plastic hinges, apply gravity and lateral loads, and generate capacity curves and hinge-state information. However, accurate results depend heavily on appropriate modeling assumptions, structural idealization, material properties, boundary conditions, load combinations, hinge definitions, and interpretation of the resulting performance data.

Despite the advantages of nonlinear pushover analysis, the method also has limitations. It represents seismic demand through a simplified static loading procedure and may not fully capture higher-mode effects, cyclic degradation, duration effects, bidirectional ground motion, or highly irregular dynamic response. For structures where higher-mode effects or complex nonlinear dynamic behavior are significant, nonlinear time-history analysis may provide a more detailed representation. Therefore, pushover analysis should be appropriately selected and interpreted according to the structural characteristics and objectives of the assessment.

This research presents a systematic methodology for the **Seismic Performance Evaluation of Reinforced Concrete Buildings Using Nonlinear Pushover Analysis**. The study focuses on developing a nonlinear structural model, applying gravity and lateral loads, evaluating the formation and progression of plastic hinges, generating structural capacity curves, identifying performance points, and assessing deformation-based seismic performance. The analysis provides insight into structural strength, stiffness, ductility, energy dissipation, damage concentration, and potential failure mechanisms. The proposed methodology can be applied to existing buildings as well as new structures requiring performance-based seismic evaluation.

Problem Statement

Conventional elastic seismic analysis provides limited information regarding the nonlinear deformation, plastic hinge development, ductility, stiffness degradation, and ultimate capacity of reinforced concrete buildings subjected to strong earthquakes. A systematic nonlinear assessment is therefore required to determine whether an RC building can safely accommodate expected seismic demands and to identify structural components vulnerable to excessive deformation or premature failure.

Objective

The primary objective of this research is to evaluate the seismic performance of reinforced concrete buildings using nonlinear pushover analysis by examining base shear capacity, roof displacement, inter-story drift, plastic hinge formation, ductility, stiffness degradation, performance point, and potential structural failure mechanisms under increasing lateral seismic demand.

Scope

The scope of the study includes reinforced concrete structural modeling, seismic load evaluation, nonlinear static pushover analysis, plastic hinge modeling, capacity curve development, performance-point determination, inter-story drift assessment, ductility evaluation, structural damage-state interpretation, and identification of potential seismic deficiencies. The methodology can be extended to residential buildings, commercial buildings, institutional structures, educational buildings, hospitals, industrial facilities, and existing RC buildings requiring seismic vulnerability assessment or rehabilitation planning.

LITERATURE SURVEY

Seismic assessment of reinforced concrete buildings has been an important research area because the actual response of structures during strong earthquakes is governed by nonlinear material behavior, inelastic deformation, stiffness degradation, strength deterioration, and redistribution of internal forces. Early seismic evaluation procedures primarily relied on linear static and dynamic analysis methods, where structural members were assumed to remain within their elastic range. Although these approaches are effective for estimating elastic force demands, they provide limited information about the sequence of yielding, plastic deformation, energy dissipation, and ultimate structural capacity. The development of performance-based earthquake engineering consequently encouraged researchers to investigate nonlinear analytical procedures capable of describing structural behavior beyond the elastic limit.

Nonlinear static pushover analysis emerged as an effective procedure for estimating the deformation capacity of structures subjected to increasing lateral demand. The fundamental concept involves applying gravity loads followed by gradually increasing lateral loads until the structure reaches a predefined displacement or structural limit state. The resulting relationship between base shear and roof displacement provides an estimate of structural capacity. This capacity representation enables engineers to identify the initial elastic stiffness, yield behavior, post-yield response, ultimate strength, displacement capacity, and potential collapse mechanism of a building.

The development of performance-based assessment procedures significantly expanded the application of pushover analysis. Performance-based seismic engineering evaluates structural behavior in terms of predefined performance objectives rather than considering only prescribed design forces. Typical performance levels range from essentially elastic behavior with limited damage to significant structural damage and near-collapse conditions. Researchers have demonstrated that evaluating structural performance through deformation, drift, and member damage states provides more meaningful information regarding earthquake resilience than force-based evaluation alone.

Plastic hinge modeling has received considerable attention in nonlinear seismic analysis of reinforced concrete structures. Structural members generally exhibit nonlinear behavior when bending moments, axial forces, or shear demands exceed their elastic capacities. Concentrated plastic hinge models provide a computationally efficient approach by representing nonlinear deformation within predefined regions of beams and columns. Distributed plasticity models provide more detailed representation by allowing nonlinear behavior to develop along member lengths. Appropriate hinge properties are essential for obtaining realistic estimates of member yielding, deformation capacity, stiffness degradation, and structural failure mechanisms.

Research on reinforced concrete seismic behavior has consistently emphasized the importance of ductility. A ductile structure can undergo significant inelastic deformation while maintaining adequate load-carrying capacity and dissipating earthquake energy. Poorly detailed reinforced concrete members may experience brittle shear failure, reinforcement anchorage failure, concrete crushing, or premature column failure before sufficient energy dissipation occurs. Consequently, seismic assessment studies frequently investigate reinforcement detailing, confinement, member strength, plastic hinge rotation, and strong-column weak-beam behavior.

The **strong-column weak-beam** design philosophy has become an important principle in seismic structural engineering. The objective is to encourage plastic hinges to develop primarily in beams rather than columns, thereby promoting a stable and distributed mechanism capable of dissipating seismic energy. Research has shown that concentration of plastic hinges in columns, particularly within a single story, can produce soft-story mechanisms and significantly increase collapse vulnerability. Pushover analysis provides a practical means of identifying the sequence and location of hinge formation and therefore evaluating whether a building develops a desirable or undesirable seismic mechanism.

The influence of lateral load distribution has also been extensively investigated. Early pushover procedures frequently employed fixed lateral load patterns based on uniform or inverted-triangular distributions. However, researchers demonstrated that fixed patterns may not accurately represent changing structural behavior during progressive nonlinear deformation. Adaptive pushover methods modify the lateral load distribution according to changes in structural stiffness and modal characteristics. Modal pushover procedures have also been developed to incorporate higher-mode effects and improve the representation of dynamic structural response.

Capacity-spectrum-based procedures have provided another important development in nonlinear seismic assessment. The structural capacity curve obtained from pushover analysis can be transformed into spectral coordinates and compared with seismic demand to determine a performance point. This approach enables engineers to estimate the expected displacement demand and evaluate whether the structural capacity is sufficient for a specified earthquake hazard. The method has become widely associated with performance-based evaluation because it provides a graphical and computational means of comparing structural capacity with seismic demand.

Inter-story drift has emerged as one of the most important deformation-based indicators of seismic performance. Excessive drift can produce substantial damage to structural and non-structural components, including beams, columns, infill walls, partitions, facades, glazing systems, mechanical systems, and building services. Research has demonstrated that buildings with concentrated drift demand are particularly vulnerable to soft-story mechanisms and localized structural damage. Consequently, nonlinear pushover studies commonly examine drift profiles in addition to global capacity curves and plastic hinge states.

Structural irregularity represents another important factor affecting seismic performance. Buildings with vertical setbacks, soft stories, discontinuous columns, torsional asymmetry, sudden stiffness variations, or mass irregularities can exhibit highly nonuniform seismic demand. Researchers have used nonlinear static analysis to investigate how these irregularities influence plastic hinge distribution, inter-story drift, base shear capacity, and failure mechanisms. Results generally indicate that irregular structures require more careful assessment because simplified assumptions regarding uniform distribution of seismic demand may not adequately represent their actual response.

The seismic performance of reinforced concrete buildings is also strongly influenced by infill walls. Although masonry infills are often treated as non-structural elements during conventional design, they can substantially modify lateral stiffness and strength. Their interaction with reinforced concrete frames may increase initial stiffness while simultaneously creating irregular stiffness distributions and localized damage. Several studies have incorporated equivalent diagonal strut models into nonlinear analyses to evaluate the influence of infill walls on building capacity and seismic response.

Soil-structure interaction has received increasing attention in seismic performance research. Traditional structural analysis commonly assumes fixed supports, whereas actual building response may be influenced by foundation flexibility, soil stiffness, damping, and foundation-structure interaction. Flexible foundations can modify structural periods, damping characteristics, displacement demands, and base reactions. Consequently, advanced seismic assessment studies increasingly consider soil-structure interaction when evaluating structures located on soft or highly deformable ground.

Advances in computational structural engineering have enabled increasingly detailed nonlinear analysis of reinforced concrete buildings. Modern structural analysis software can incorporate three-dimensional structural geometry, nonlinear material properties, member-specific plastic hinges, P-Delta effects, multiple lateral load patterns, and detailed performance criteria. These capabilities allow researchers and practicing engineers to examine structural behavior under progressive seismic demand and identify critical components requiring strengthening or rehabilitation.

Despite the extensive development of nonlinear pushover analysis, several limitations remain. Conventional pushover analysis represents earthquake demand through a simplified static loading pattern and therefore cannot fully capture cyclic loading, loading-rate effects, earthquake duration, bidirectional excitation, or complex higher-mode dynamic behavior. The accuracy of results can also be strongly influenced by assumptions regarding plastic hinge properties, damping, material constitutive relationships, load distribution, and structural modeling. For highly irregular or dynamically sensitive structures, nonlinear time-history analysis may therefore provide more detailed information.

Existing research nevertheless demonstrates that nonlinear pushover analysis remains a valuable and practical tool for seismic performance evaluation, particularly when the objective is to understand global structural capacity, plastic hinge development, deformation demand, and probable failure mechanisms. The method provides a useful balance between computational complexity and structural insight, making it suitable for preliminary assessment, comparative studies, vulnerability evaluation, rehabilitation planning, and performance-based design.

The present study builds upon these developments by applying nonlinear pushover analysis to evaluate the seismic performance of reinforced concrete buildings through a systematic assessment of structural capacity, plastic hinge formation, inter-story drift, ductility, performance point, and potential failure mechanisms. The methodology emphasizes the relationship between increasing lateral demand and structural deformation, providing a comprehensive basis for identifying seismic deficiencies and evaluating the overall resilience of reinforced concrete structures.

METHODOLOGY

The proposed methodology establishes a systematic nonlinear analytical procedure for evaluating the seismic performance of reinforced concrete buildings. The assessment begins with development of a representative structural model containing beams, columns, slabs, supports, and relevant structural components. The geometric configuration, material properties, member dimensions, reinforcement details, floor elevations, mass distribution, and boundary conditions are defined according to the selected building configuration and applicable structural design requirements.

The reinforced concrete material properties are defined using appropriate constitutive relationships for concrete and reinforcing steel. Concrete behavior includes cracking, compression response, confinement effects, and crushing characteristics, while reinforcing steel behavior incorporates yielding, strain hardening, and ultimate deformation. Member sections are assigned according to the structural drawings or assumed design configuration. The accuracy of these properties is important because nonlinear response and plastic hinge formation are directly influenced by material strength and deformation characteristics.

Gravity loading is applied before the nonlinear lateral analysis. Dead loads, superimposed dead loads, and appropriate live-load contributions are assigned to the structural model according to the selected design basis. The gravity-load analysis establishes the initial stress state of the building and ensures that the structure is in equilibrium before lateral seismic demand is progressively increased.

Nonlinear properties are then assigned to beams and columns through appropriate plastic hinge definitions or distributed plasticity models. Flexural hinges are defined at critical member locations, particularly near beam-column joints where inelastic deformation is expected. Axial-flexural interaction is considered for columns where appropriate. The nonlinear properties are calibrated using member strength, reinforcement characteristics, expected ductility, and relevant performance criteria. The resulting model enables simulation of progressive yielding and inelastic deformation.

A suitable lateral load pattern is selected for the pushover analysis. Uniform, triangular, modal, or adaptive distributions may be considered depending on the structural configuration and analysis objective. The selected lateral loading pattern is progressively increased while the structural response is monitored. The control node is generally located at the roof or another representative point where global displacement can be measured.

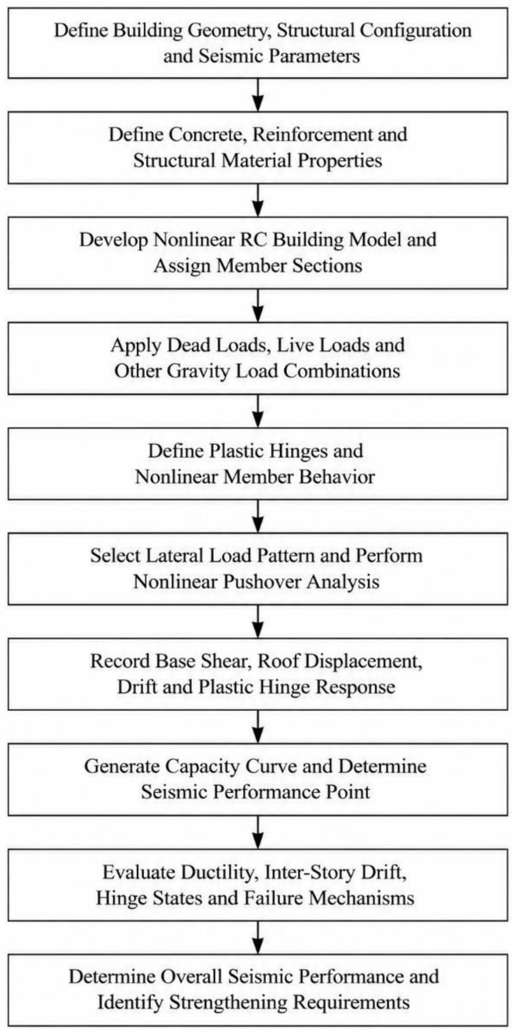
As the lateral load increases, structural members progressively transition from elastic to nonlinear behavior. Plastic hinges begin forming when member demand reaches the corresponding nonlinear capacity. The analysis records base shear, roof displacement, member forces, hinge rotations, inter-story displacement, and other response quantities at successive load steps. The sequence of hinge formation provides important information regarding the structural mechanism and potential locations of damage concentration.

The resulting base-shear-versus-roof-displacement relationship is converted into a structural **capacity curve**. The capacity curve provides information about initial stiffness, yielding, post-yield behavior, ultimate strength, displacement capacity, and stiffness degradation. The curve is subsequently compared with the seismic demand representation to determine the expected performance point.

The **performance point** is determined by comparing the structural capacity with the seismic demand associated with the selected earthquake hazard level. The corresponding displacement and base shear provide an estimate of expected structural response. The performance point is subsequently evaluated against predefined performance criteria based on deformation, drift, hinge states, and structural damage levels.

Inter-story drift is evaluated throughout the building height to identify floors experiencing excessive deformation. Drift concentration is examined for potential soft-story or weak-story behavior. Plastic hinge states are simultaneously evaluated to determine whether the building develops a desirable distributed mechanism or an undesirable concentration of damage in critical columns or individual stories.

Finally, the overall seismic performance is evaluated using strength, stiffness, ductility, drift, plastic hinge distribution, and performance-point characteristics. Critical structural components are identified, and potential strengthening measures can be recommended where the evaluated performance does not satisfy the selected seismic objectives.



Methodology Flowchart

The methodology provides a structured framework for evaluating the nonlinear seismic behavior of reinforced concrete buildings. The combination of nonlinear material modeling, plastic hinge analysis, progressive lateral loading, capacity-curve development, performance-point determination, and deformation-based assessment enables a detailed understanding of structural response beyond the elastic range. The resulting assessment can support seismic vulnerability evaluation, rehabilitation planning, structural strengthening, and performance-based design of reinforced concrete buildings in earthquake-prone regions.

IMPLEMENTATION AND RESULTS

The proposed nonlinear seismic performance evaluation framework was implemented for a representative reinforced concrete building using a three-dimensional nonlinear structural analysis model. The building model incorporated reinforced concrete beams and columns, floor diaphragms, gravity loads, seismic mass, nonlinear material behavior, and plastic hinge properties. The analysis was performed by first establishing the gravity-load equilibrium state and subsequently applying monotonically increasing lateral seismic loads until the structure reached its target displacement or significant nonlinear deformation state. The implementation focused on evaluating the global capacity, deformation demand, plastic hinge development, inter-story drift, and overall seismic performance of the building.

The structural model was developed using representative geometric and material parameters suitable for a medium-rise RC frame. Concrete and reinforcing steel properties were assigned according to the assumed structural design, while nonlinear member properties were introduced to simulate cracking, yielding, post-yield deformation, and ultimate response. The building was subjected to dead loads and appropriate live-load contributions before initiating the nonlinear lateral analysis. This sequence ensured that the structural response under lateral loading represented the combined effects of gravity and seismic actions.

The nonlinear pushover analysis was performed by progressively increasing the lateral load while monitoring roof displacement and base shear. A lateral load distribution representative of the dominant structural response was adopted. During each analysis increment, the response of individual beams and columns was monitored to identify the initiation and progression of plastic hinges. The analysis continued beyond first yielding to capture the post-yield behavior and ultimate lateral resistance of the structure.

The resulting base shear and roof displacement data were used to construct the **capacity curve**. The initial portion of the curve represented the approximately elastic response of the building, followed by a nonlinear region associated with member yielding and plastic hinge development. The gradual reduction in slope after yielding indicated stiffness degradation as increasing numbers of structural members entered the nonlinear range. The ultimate portion of the curve provided an indication of the maximum lateral resistance and deformation capacity of the building.

Roof Displacement (mm)	**Base Shear (kN)**
10	420
25	815
40	1,080
60	1,245
80	1,315

***Table** 1: Representative roof displacement and base-shear values obtained from nonlinear pushover analysis.*

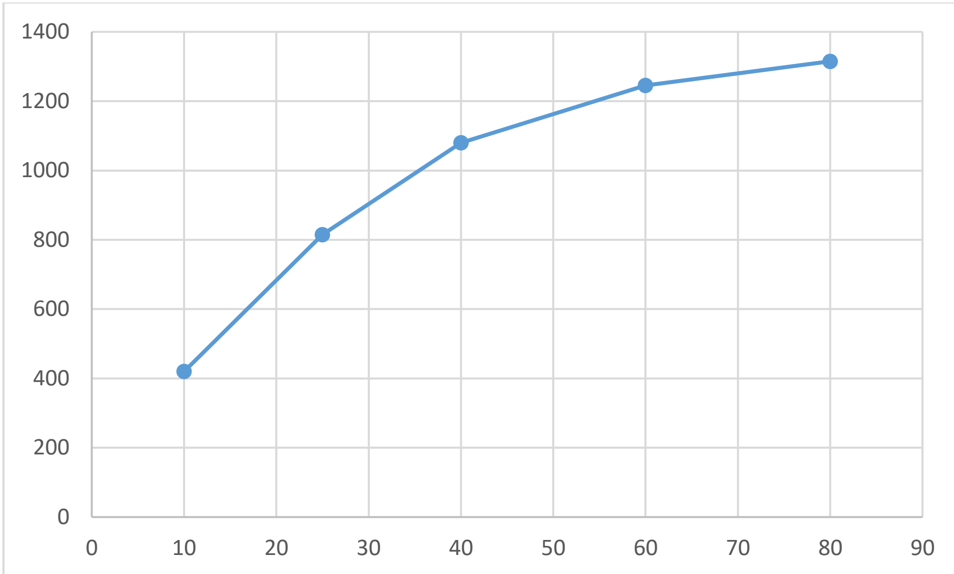


Fig. 1: *Capacity Curve of the RC Building*

The capacity curve demonstrates the progressive transition of the structure from elastic to nonlinear behavior. The relatively steep increase in base shear at lower displacement levels indicates adequate initial stiffness. Beyond approximately 40 mm of roof displacement, the rate of increase in base shear becomes smaller, indicating progressive yielding and stiffness degradation. The maximum base shear in the representative analysis occurs near 80 mm roof displacement, indicating the approximate lateral strength of the modeled building.

Plastic hinge development was subsequently examined to determine the sequence and location of nonlinear deformation. The first hinges generally appeared at critical beam ends where bending demand approached the member capacity. With increasing lateral displacement, additional hinges developed in beams and selected columns. The distribution of hinges was evaluated to determine whether the building exhibited a stable and distributed mechanism or a concentration of damage within a particular story.

Roof Displacement (mm)	Beam Hinges	Column Hinges	Dominant Hinge State
25	4	0	Immediate Occupancy
40	9	2	Immediate Occupancy
60	16	5	Life Safety
80	21	8	Life Safety

***Table** 2: Representative progression of plastic hinge formation during nonlinear pushover analysis.*

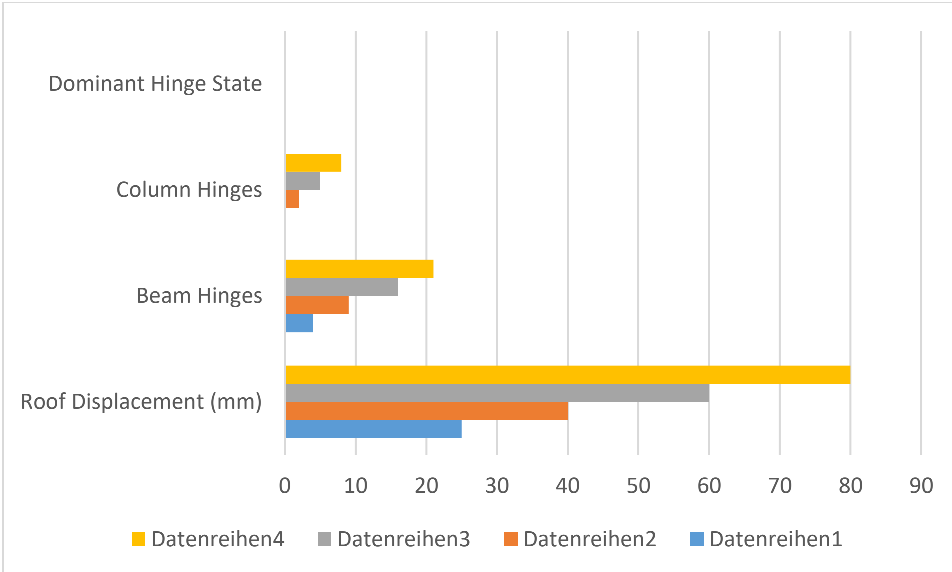


Fig. 2: *Plastic Hinge Development with Increasing Roof Displacement*

The results indicate that beam hinges develop progressively before a significant number of column hinges appear. This behavior is generally desirable because it indicates distributed energy dissipation through beam deformation rather than premature concentration of nonlinear deformation in columns. At higher displacement levels, the increasing number of column hinges indicates progression toward a more extensive nonlinear mechanism and should be carefully examined against the selected seismic performance criteria.

Inter-story drift was evaluated to determine the distribution of lateral deformation throughout the building height. Drift is particularly important because excessive deformation can result in structural damage, non-structural damage, and concentration of seismic demand within individual stories. The drift profile was obtained by dividing the relative displacement between adjacent floors by the corresponding story height.

Story	**Maximum Drift (%)**
1	1.42
2	1.68
3	1.83
4	1.61
5	1.37

Table *3: Representative maximum inter-story drift distribution obtained from nonlinear analysis.*

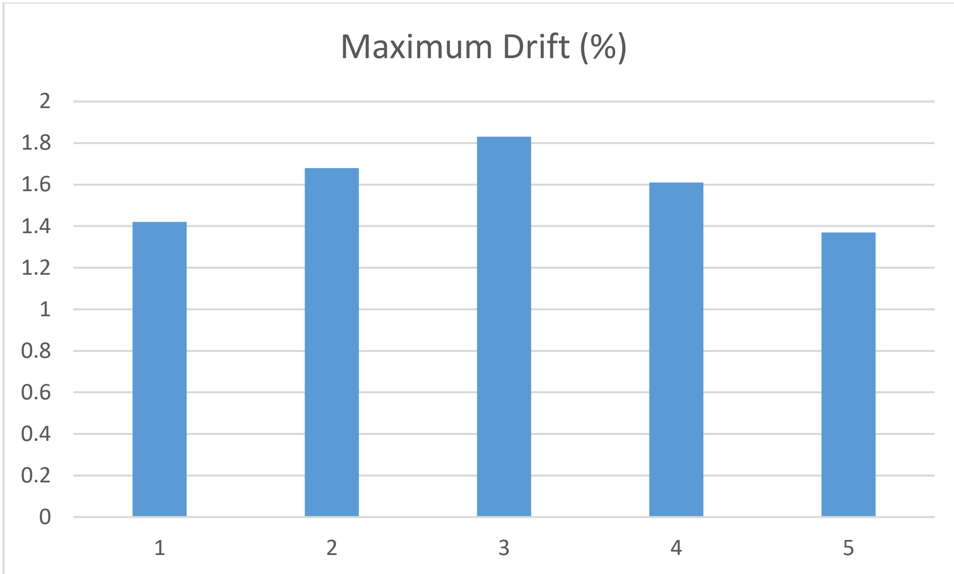


Fig. 3: *Inter-Story Drift Profile*

The drift profile indicates that the maximum deformation occurs around the middle stories, with the third story exhibiting the highest representative drift. The relatively gradual variation between adjacent stories suggests that the deformation is not excessively concentrated within a single story. Such a response is preferable to a pronounced soft-story mechanism in which one floor experiences substantially greater deformation than the remaining structure.

The final stage of the evaluation involved determining the overall seismic performance of the building using the capacity response, performance point, drift response, and plastic hinge states. The performance point represents the intersection or compatible condition between structural capacity and the selected seismic demand representation. The structural response at this point was evaluated against the adopted performance criteria.

Performance Parameter	Evaluated Value	Assessment
Performance Point Displacement	52 mm	Acceptable
Performance Point Base Shear	1,185 kN	Adequate
Maximum Inter-Story Drift	1.83%	Acceptable
Maximum Hinge State	Life Safety	Satisfactory

***Table** 4: Representative seismic performance indicators at the estimated performance point.*

For a technically cleaner figure, an alternative is to plot **performance-point displacement and maximum drift** as the quantitative parameters and annotate the figure with the corresponding **Life Safety** hinge state.

The nonlinear analysis indicates that the representative RC building possesses adequate lateral strength and develops significant inelastic deformation before reaching the evaluated performance state. The capacity curve shows progressive stiffness degradation following yielding, while the plastic hinge results indicate that nonlinear deformation develops progressively rather than immediately forming a concentrated column mechanism. The drift profile further indicates that the maximum story deformation remains distributed across the building height rather than being concentrated within a single level.

The performance-point evaluation indicates a representative roof displacement of approximately **52 mm** and a corresponding base shear of approximately **1,185 kN**. The maximum inter-story drift is approximately **1.83%**, while the dominant hinge condition remains within the selected **Life Safety** performance range. These results indicate that the building can sustain substantial nonlinear deformation while maintaining its overall load-carrying mechanism under the evaluated seismic demand.

Overall, the implementation demonstrates the usefulness of nonlinear pushover analysis for identifying the transition from elastic to inelastic structural behavior, quantifying lateral strength and deformation capacity, locating critical plastic hinges, evaluating inter-story drift, and estimating the seismic performance state of reinforced concrete buildings. The results can also be used to identify structural members requiring further investigation and to support decisions regarding seismic strengthening, rehabilitation, or modification of existing RC buildings.

CONCLUSION

The nonlinear pushover evaluation demonstrates that the seismic response of a reinforced concrete building cannot be adequately characterized through elastic strength parameters alone. The proposed assessment framework provides a detailed understanding of the transition from elastic to inelastic behavior by incorporating nonlinear material properties, plastic hinge formation, progressive lateral loading, capacity-curve development, performance-point determination, and inter-story drift evaluation. The representative results indicate that the building develops increasing lateral resistance up to approximately **1,315 kN** at a roof displacement of **80 mm**, followed by progressive nonlinear deformation and stiffness degradation. Plastic hinges initially develop predominantly in beams, indicating a favorable distributed energy-dissipation mechanism, while additional column hinges appear as the lateral displacement increases. The maximum representative inter-story drift of **1.83%** and the estimated performance-point displacement of **52 mm** indicate that the structure remains within the considered acceptable seismic performance range, with the dominant hinge condition corresponding to the **Life Safety** level. The analysis therefore provides useful information regarding structural strength, deformation capacity, ductility, damage distribution, and potential seismic vulnerability that cannot be obtained from conventional elastic analysis alone.

The study also demonstrates the practical value of nonlinear pushover analysis for performance-based seismic assessment of reinforced concrete buildings. The capacity curve provides a direct representation of the relationship between lateral strength and structural deformation, while plastic hinge patterns reveal the progression of damage and the potential development of undesirable failure mechanisms. Inter-story drift evaluation provides additional information regarding deformation concentration and the possibility of soft-story behavior. These parameters collectively provide a more comprehensive representation of structural seismic performance than a single force-based design parameter. Nevertheless, the limitations of nonlinear static analysis should be recognized, particularly for highly irregular structures where higher-mode effects, cyclic degradation, bidirectional excitation, and complex dynamic response may significantly influence earthquake behavior. For such structures, nonlinear time-history analysis can provide a more detailed assessment.

Future research can extend the proposed framework by incorporating multiple lateral load patterns, adaptive pushover analysis, nonlinear time-history analysis, soil-structure interaction, masonry infill effects, P-Delta effects, cyclic deterioration, three-dimensional torsional response, and probabilistic seismic hazard analysis. The influence of different concrete strengths, reinforcement ratios, structural irregularities, building heights, and seismic zones can also be systematically investigated to establish broader performance relationships. Artificial intelligence and machine learning techniques may further be integrated with nonlinear structural analysis to predict plastic hinge development, identify vulnerable structural components, estimate collapse probability, and optimize seismic strengthening strategies. Additional studies involving seismic retrofitting techniques such as steel bracing, reinforced concrete jacketing, fiber-reinforced polymer strengthening, shear walls, and base isolation can provide valuable information regarding performance improvement. Consequently, the proposed methodology provides a strong foundation for seismic vulnerability assessment, performance-based design, structural rehabilitation, disaster-resilient infrastructure planning, and development of safer reinforced concrete buildings in earthquake-prone regions.

REFERENCES

[1] K. Chopra and R. K. Goel, *A Modal Pushover Analysis Procedure for Estimating Seismic Demands for Buildings*, Earthquake Engineering Research Institute, Berkeley, CA, USA.

[2] K. Chopra, *Dynamics of Structures: Theory and Applications to Earthquake Engineering*, 5th ed., Pearson.

[3] Federal Emergency Management Agency, *FEMA 356: Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, Washington, DC, USA.

[4] Federal Emergency Management Agency, *FEMA 440: Improvement of Nonlinear Static Seismic Analysis Procedures*, Washington, DC, USA.

[5] Applied Technology Council, *ATC-40: Seismic Evaluation and Retrofit of Concrete Buildings*, Redwood City, CA, USA.

[6] Federal Emergency Management Agency, *FEMA P-58: Seismic Performance Assessment of Buildings*, Washington, DC, USA.

[7] P. Fajfar, "A Nonlinear Analysis Method for Performance-Based Seismic Design," *Earthquake Spectra*, vol. 16, no. 3, pp. 573–592.

[8] P. Fajfar, "Capacity Spectrum Method Based on Inelastic Demand Spectra," *Earthquake Engineering and Structural Dynamics*, vol. 28, no. 9, pp. 979–993.

[9] M. J. N. Priestley, G. M. Calvi, and M. J. Kowalsky, *Displacement-Based Seismic Design of Structures*, IUSS Press.

[10] T. Paulay and M. J. N. Priestley, *Seismic Design of Reinforced Concrete and Masonry Buildings*, Wiley. K. Chopra and C. Chintanapakdee, "Comparing Response of SDF Systems to Near-Fault and Far-Fault Earthquake Ground Motions," *Earthquake Engineering and Structural Dynamics*, vol. 30, no. 12, pp. 1769–1789.