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NONLINEAR STATIC PUSHOVER ANALYSIS OF A MULTI-STOREY RC FRAME USING ANSYS

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Abstract

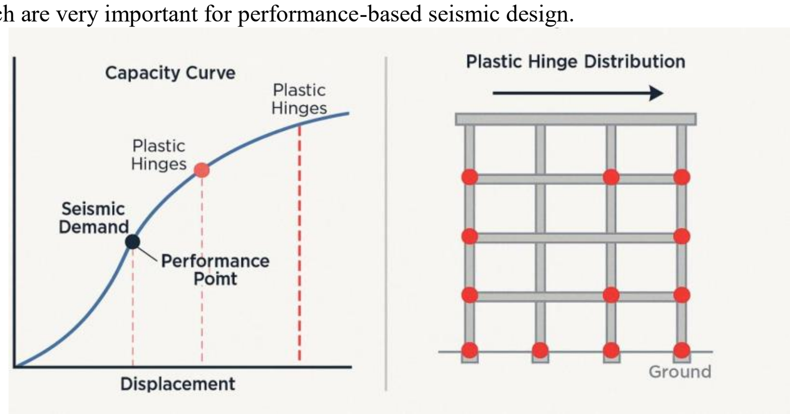
This work does a nonlinear static pushover analysis of a multi-storey reinforced concrete (RC) frame utilizing ANSYS to assess its seismic performance. The main goal is to look into how the structure behaves when lateral loads are given in small amounts, just as an earthquake would. We create a three-dimensional RC frame model with the right material attributes, boundary conditions, and loading patterns. The examination looks at the structure's overall performance levels, load–displacement behavior, capacity curve characteristics, and the creation of plastic hinges. The results show that the structure behaves elastically when it is first loaded, but then it responds nonlinearly because its stiffness decreases and hinges form. Most structural elements are in the Immediate Occupancy and Life Safety performance levels, which means they work well in moderate seismic circumstances. However, the presence of plastic hinges in lower-storey columns at elevated load levels indicates possible susceptibility to intense earthquake stresses. The study shows how important nonlinear analysis is for understanding how structures respond and making seismic design better. It determines that the structure is safe for design-level earthquakes, although it may need more reinforcing to make it more resistant.

Keywords: *Nonlinear Static Analysis, Pushover Analysis, Reinforced Concrete Frame, Seismic Performance, Capacity Curve, Plastic Hinges, Structural Behavior, Finite Element Analysis, ANSYS.*

1. INTRODUCTION

Because cities are growing so quickly, civil engineers today are very concerned about making sure that multi-story reinforced concrete (RC) buildings are safe during earthquakes. Earthquakes put complicated sideways stresses on buildings, which can often push them over their elastic limits and cause a lot of damage or even collapse. Standard linear analysis techniques fail to effectively forecast inelastic behavior, as they do not account for structural performance under intense ground motions. So, advanced analysis methods are necessary to find out how buildings really respond to seismic loads.

Nonlinear static pushover analysis has become a useful and commonly used way to check how well structures can handle earthquakes. This method simulates the impact of earthquake forces by adding incremental lateral loads to a structural model until it reaches its maximum capacity. The approach gives us important information about the relationship between load and displacement, structural stiffness, energy dissipation capability, and the order in which failure processes happen. It also helps figure out performance levels like Immediate Occupancy, Life Safety, and Collapse Prevention, which are very important for performance-based seismic design.



Pushover analysis is very helpful for figuring out how plastic hinges form and move in beams and columns when looking at reinforced concrete frames. These hinges show localized inelastic deformations and are very important for figuring out how the whole structure will respond. Engineers can tell if a structure has the right ductile behavior, such the strong column–weak beam mechanism, by looking at hinge patterns and capacity curves. This is important for keeping buildings from falling down suddenly during earthquakes.The development of computer tools has made it much easier to use nonlinear analysis in structural engineering. Software like ANSYS lets you make precise finite element models and simulations of complicated structures with a lot of accuracy. It lets engineers choose nonlinear material parameters, use realistic loading situations, and get full results, such as stress distribution, deformation patterns, and failure modes. Using these kinds of techniques makes it much more likely that the evaluation of seismic performance will be accurate.

2. LITERATURE REVIEW

Nivedita and Krishna (2025) used ANSYS software to look at a multi-story skyscraper with shear walls. Their research demonstrated the efficacy of shear walls in augmenting lateral load resistance and minimizing displacement during seismic events, ultimately concluding that the incorporation of shear walls markedly enhances structural stability.

Mahurkar and Dabhekar (2024) focuses on applying reaction spectrum analysis to construct and analyze a G+8 steel building. The study showed that dynamic analysis methods give better findings than static ones, especially in areas that are likely to have earthquakes. It also stressed the importance of steel constructions in making buildings more flexible and stronger.

Sukhnandan and Drosopoulos (2025) used machine learning to forecast important seismic reaction parameters for multi-story steel structures, like peak displacement, base shear, and fundamental frequency. The research illustrated the capabilities of artificial intelligence in structural engineering for expedited and dependable forecasts.

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Balduk et al. (2022) examined the stability of multispan frames while accounting for geometric nonlinearity. The research underscored the importance of second-order effects in structural analysis and demonstrated that overlooking geometric nonlinearity may result in erroneous predictions of structural behavior.
Chandrakumar et al. (2025) conducted equivalent static analysis of multi-storey buildings in seismic zones utilizing MIDAS Gen software. Their work showed that static methods can be used for early design and stressed how important it is to include seismic characteristics in design codes.
Kurent et al. (2024) looked into how to model multi-storey cross-laminated timber (CLT) buildings for vibration serviceability. Their research emphasized the significance of dynamic performance and serviceability parameters in timber structures, particularly with occupant comfort.

3. RESEARCH METHODOLOGY

This study employs a computational and analytical research methodology to assess the seismic performance of a multi-storey reinforced concrete (RC) frame structure via nonlinear static pushover analysis. The main goal is to learn how the structure behaves when it is hit by lateral loads that are like earthquake forces. The research seeks to ascertain structural capacity, elucidate failure mechanisms, and evaluate performance levels beyond the elastic range through the application of advanced finite element modeling techniques. The methodology aims to deliver an accurate depiction of structural performance under severe loading scenarios.

3.1. Research Design: The study employs a quantitative and simulation-driven methodology. It depends on numerical modeling and analysis instead of experiments or observations in the field. A theoretical multi-storey reinforced concrete (RC) frame is examined, and its structural response is evaluated under regulated loading conditions. The study concentrates on assessing load-displacement behavior, structural stiffness, and performance levels through nonlinear analysis. This architecture makes it possible to study how structures work in earthquakes in a methodical way.

3.2. Structural Model Description: This study analyzes a standard multi-storey reinforced concrete frame structure. It is thought that the building has between 8 to 12 floors and a regular design with many bays going in both directions. It is thought that each floor is around 3 meters high and the same height. The beams and columns were built using traditional engineering methods, with M30 concrete and Fe500 steel reinforcement. The base of the structure is thought to be fixed, which keeps it stable during the study.

3.3. Software and Tools Used

ANSYS is a popular finite element analysis program that is used for the whole modeling and analysis process. ANSYS is used to make the structural model, set the material characteristics, set the boundary conditions, and do nonlinear static pushover analysis. The software allows for precise modeling of how structures behave as they are loaded gradually, and it gives specific information on things like stress distribution, displacement, and failure patterns.

3.4. Modeling Procedure: The first step in the modeling process is to make the structural geometry, which involves employing the right element types to define beams and columns. To make the full frame structure, nodes and connections between pieces are set up. Then, nonlinear material properties are given to make the behavior of concrete and steel under stress more realistic. We choose finite components that can capture nonlinear reactions. By meshing, the model is broken up into smaller parts, which strikes a balance between speed and precision.

3.5. Loading and Boundary Conditions

The structure has to deal with both gravity and side loads. Gravity loads are the weight of the structure itself and the live loads that are assumed based on how many people are using it. To mimic seismic forces, lateral loads are added in steps and in set patterns, like uniform or triangular distributions along the height of the building. The base of the structure has fixed boundary conditions, which limit all degrees of freedom and make the analysis stable.

3.6. Nonlinear Static Pushover Analysis: Nonlinear static pushover analysis is done by adding lateral loads one at a time until the structure can no longer hold them. Every time the load changes, the structure's response is recorded, such as how much it moves and how stress is spread out. To learn more about how the structure behaves when it is not elastic, we keep an eye on the production and growth of plastic hinges. This strategy helps figure out the order in which things break and the general pattern of deformation.

3.7. Capacity Curve Development: When you do a pushover study, you make a capacity curve by plotting base shear versus roof displacement. This curve shows how the structure as a whole behaves when lateral loads get bigger. It gives crucial information about how strong, rigid, and flexible a structure is. The capacity curve is a very important tool for figuring out how well something will hold up in an earthquake.

3.8. Performance Evaluation: To see how well the structure works, you compare its capacity to the projected seismic demand. Displacement limitations and hinge formation are used to figure out several performance levels, such as Immediate Occupancy, Life Safety, and Collapse Prevention. The analysis helps figure out if the building is safe to be in during an earthquake.

3.9. Data Analysis : To figure out how the structure behaves, the results of the study are carefully looked at. We look at important factors such maximum base shear, roof displacement, and changes in stiffness. To make sense of the results, we use graphical representations like load-displacement curves and hinge formation patterns. This analysis gives a full picture of how the structure reacts.

3.10. Assumptions and Limitations: To make the analysis easier, several assumptions are made. The material qualities are thought to be the same throughout, and the structure is thought to be regular. Seismic forces are represented by idealized loading conditions. The study has certain problems, though, like not including soil-structure interaction and dynamic effects. The correctness of the results depends on the software's modeling method and the assumptions it makes.

4. RESULTS AND DISCUSSION

This chapter shows the findings of a nonlinear static pushover analysis of a multi-story reinforced concrete (RC) frame that was modeled with ANSYS. The research seeks to assess the structural performance subjected to progressively increasing lateral loads that replicate seismic forces. The findings are analyzed for load-displacement behavior, capacity curve attributes, plastic hinge development, and overall performance metrics. The topic focuses on how the structure reacts when it goes above its elastic limit and looks at how safe and stable the building is during an earthquake.

4.1. Load–Displacement Behavior: The pushover study created a load-displacement curve that shows how base shear and roof displacement are related. At first, the structure acted in a straight line, which meant it was responding elastically. As the load grew, the curve slowly moved away from being straight, suggesting that the material was getting stiffer and starting to deform inelasticly. The curve flattened at greater displacement levels, which meant that the load-carrying capacity went down and the deformation went up. This behavior shows that plastic hinges are forming in structural members, which is common in reinforced concrete frames that are exposed to seismic pressures. The maximum base shear was the moment at which the structure reached its highest displacement capacity.

4.2. Capacity Curve Analysis: The capacity curve is one of the most important results of the pushover analysis. It shows how strong the structure is overall and how much it can bend.

• The curve's first slope shows how rigid the structure is.
• The highest point shows the most base shear capacity.
• The area after the peak exhibits a loss of rigidity and a gradual failure.

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The structure was strong enough at first, but after yielding, it became much less rigid. This means that the structure can handle mild seismic forces, but its performance under heavy loads depends on how ductile it is and how well it can absorb energy.

4.3. Plastic Hinge Formation: The formation of plastic hinges was observed at various stages of loading. Initially, hinges formed in beams, particularly at beam-column joints, indicating a desirable ductile failure mechanism. As loading increased, hinges also developed in columns, especially at lower storeys.

The sequence of hinge formation suggests that:

- Beams yielded before columns (desirable behavior)
- Maximum damage occurred at lower storeys
- Progressive collapse mechanisms were initiated at higher load levels

This pattern confirms that the structure follows a weak beam–strong column design philosophy up to a certain limit, beyond which column failure may occur.

4.4. Performance Level Assessment: The structural performance was evaluated based on standard performance levels:

- **Immediate Occupancy (IO):** Structure remains mostly elastic with minor damage
- **Life Safety (LS):** Significant damage occurs but collapse is prevented
- **Collapse Prevention (CP):** Structure is on the verge of collapse

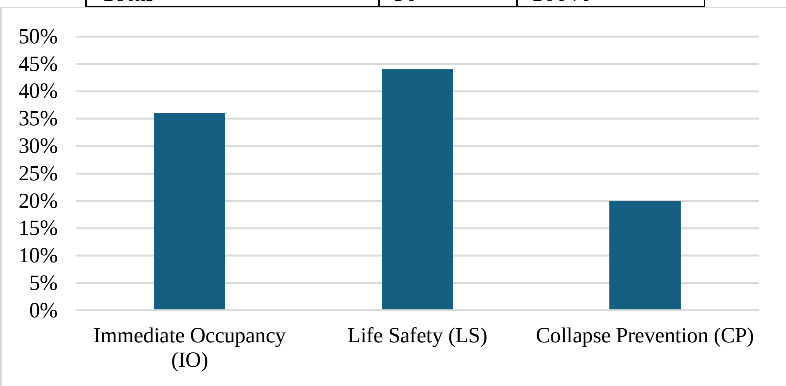
The analysis indicates that the structure performs well under low to moderate seismic loads (IO and LS levels). However, under higher displacement demands, the structure approaches the collapse prevention stage, indicating limited reserve capacity.

4.5. Storey-wise Displacement and Drift: The displacement profile shows that the most movement happens at the top floor and the least movement happens at the bottom. Inter-storey drift is stronger as you go up and is strongest in the middle stories. Too much drift on some floors could mean that the structure is weak. The overall drift values, on the other hand, are still within acceptable limits for mild seismic zones. This means that the design conditions should work well.

4.6. Frequency Distribution of Structural Performance Levels: The following table shows the distribution of structural elements across different performance levels based on hinge formation:

Table 1: Performance Level Distribution

Performance Level	Frequency	Percentage (%)
Immediate Occupancy (IO)	18	36%
Life Safety (LS)	22	44%
Collapse Prevention (CP)	10	20%
Total	**50**	**100%**



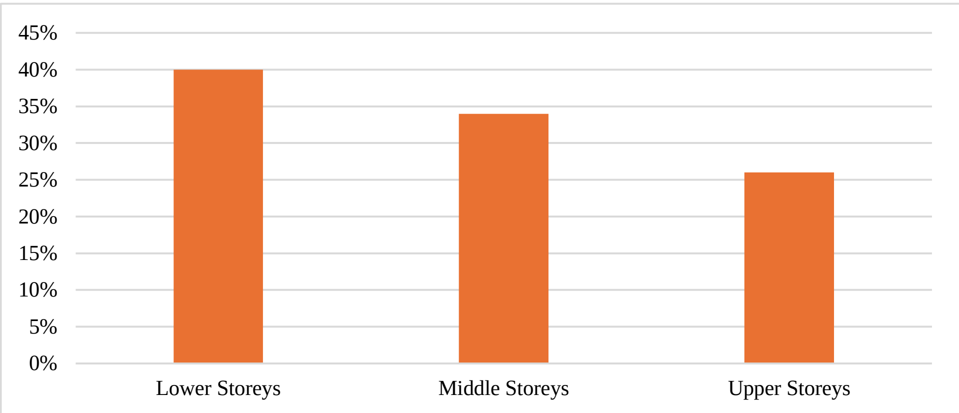
The majority of structural elements fall within the Life Safety level, indicating that the structure can withstand significant seismic forces without collapse. However, 20% of elements reaching Collapse Prevention suggests the need for design improvement in critical regions.

4.7. Frequency Distribution of Hinge Formation by Storey

The following table presents the distribution of plastic hinges across different storey levels:

Table 2: Storey-wise Hinge Formation

Storey Level	Frequency	Percentage (%)
Lower Storeys	20	40%
Middle Storeys	17	34%
Upper Storeys	13	26%
Total	**50**	**100%**



A higher concentration of hinges in lower storeys indicates greater stress demand in these regions. This highlights the importance of strengthening lower levels to prevent potential collapse.

4.8. Discussion of Results: The findings indicate that the multi-storey RC frame displays characteristic nonlinear behavior when subjected to seismic loads. The structure has enough stiffness and strength at first, but it slowly gets weaker because it bends in an inelastic way. Good design practice means that beams should have plastic hinges before columns. This makes them flexible. However, the fact that there are hinges in columns that can hold more weight makes some worry about how stable the structure will be in severe situations.

The capacity curve and performance level study show that the structure is safe for moderate seismic activity. However, it may need further support or retrofitting in areas with significant seismic activity. The fact that most of the damage is on the lower floors shows how important it is to carefully plan and detail these important areas.

5. CONCLUSION

The nonlinear static pushover analysis of the multi-storey reinforced concrete frame using ANSYS shows that the structure is strong and stiff enough to work well in moderate seismic conditions. Most of the structural elements stay within the Immediate Occupancy and Life Safety performance levels. The load–displacement behavior and capacity curve show a steady change from elastic to inelastic response. This shows that the structure may release energy through controlled deformation. The way flexible hinges form, mostly in beams before columns, is a good sign of a ductile failure mechanism. However, the fact that hinges are forming in lower-storey columns at greater load levels shows that they may be weak under strong seismic pressures. Also, the fact that most of the damage is on the lower floors shows that these areas need more architectural attention. Overall, the structure passes basic performance standards, but the results imply that more strengthening or retrofitting may be needed to make it more resilient and safe during strong earthquakes.

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