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Performance-Based Seismic Evaluation of Reinforced Concrete Moment-Resisting Frames: A Comparative Study of FBD and DBD

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Abstract- The seismic performance of reinforced concrete (RC) frame structures has traditionally been evaluated using force-based design procedures, wherein seismic demand is represented through equivalent lateral forces derived from elastic response spectra. Although this approach has been widely adopted in national and international design codes, it primarily focuses on strength requirements and often provides only an indirect estimate of actual structural damage during earthquake events. Recent developments in performance-based earthquake engineering have highlighted the importance of displacement as a more realistic indicator of structural performance and damage. Consequently, displacement-based design methodologies have gained considerable attention due to their ability to directly relate structural response to predefined performance objectives. The present study investigates and compares the seismic performance of reinforced concrete moment-resisting frame buildings designed using Force-Based Design (FBD) and Displacement-Based Design (DBD) approaches. Three regular reinforced concrete frame structures consisting of 8, 10 and 12 storeys were modeled and analyzed using ETABS software. The buildings were designed in accordance with the provisions of IS 1893:2016 and subjected to seismic loading representative of Indian earthquake-prone regions. Response Spectrum Analysis was employed to evaluate the force-based response of the structures, while nonlinear pushover analysis was adopted to assess displacement-based seismic behavior and performance characteristics.

Keywords: force-based design, displacement-based design, reinforced concrete frames, seismic performance, performance-based seismic design, etabs, pushover analysis, earthquake engineering.

I. INTRODUCTION

Earthquakes are among the most destructive natural hazards affecting the built environment and continue to pose significant challenges to structural engineers worldwide. The primary objective of seismic design is to ensure that structures can safely withstand earthquake-induced forces while minimizing damage and preventing collapse. Reinforced Concrete (RC) moment-resisting frames are extensively used in seismic regions due to their strength, stiffness and ductility characteristics. The seismic performance of these structures depends not only on their ability to resist lateral forces but also on their capacity to undergo controlled deformations during strong ground motion.

Conventional seismic design practices are predominantly based on the Force-Based Design (FBD) approach, in which earthquake effects are represented through equivalent static or dynamic forces derived from design response spectra. In this method, structural members are proportioned to resist the calculated seismic forces, while inelastic behavior is indirectly considered through response reduction factors. Although the FBD approach has been successfully adopted in various seismic design codes, several researchers have reported that force-based procedures do not explicitly control structural damage and deformation. Consequently, structures designed according to force-based methods may satisfy strength requirements while still experiencing excessive displacement and drift during severe earthquakes.

To overcome these limitations, the concept of Performance-Based Seismic Design (PBSD) has gained considerable attention over the past two decades. Within this framework, structural performance is evaluated using displacement and damage criteria rather than force demand alone. Displacement-Based Design (DBD) represents one of the most important developments in performance-based earthquake engineering. Unlike conventional force-based methods, DBD begins with a predefined target displacement corresponding to a desired performance level and subsequently determines the required structural strength. This approach provides a more direct relationship between design objectives and actual structural response.

The present study investigates the seismic performance of 8-storey, 10-storey and 12-storey reinforced concrete moment-resisting frame buildings designed using Force-Based Design and Displacement-Based Design approaches. ETABS software was employed to perform seismic analysis in accordance with IS 1893:2016 provisions. The performance of the buildings was evaluated using parameters such as storey displacement, inter-storey drift, storey shear, stiffness distribution, modal characteristics, pushover response, energy dissipation and plastic hinge formation. The objective is to assess the relative effectiveness of both methodologies and identify the design approach that provides superior seismic performance for medium-rise reinforced concrete buildings.

II. LITERATURE REVIEW

Over the past few decades, significant research has been conducted to improve the seismic performance of reinforced concrete (RC) structures through the development of performance-oriented design methodologies. Traditional seismic design approaches are primarily based on force demand, whereas modern earthquake engineering increasingly emphasizes displacement and damage control as key indicators of structural performance.

Chandler and Mendis (2000) performed one of the earliest comparative studies between force-based and displacement-based seismic assessment procedures for RC frame structures. Their investigation demonstrated that displacement-based methods provide a more realistic estimation of structural response under seismic loading and are capable of predicting inelastic deformation demands with greater accuracy than conventional force-based approaches.
Xue and Chen (2003) proposed a performance-based seismic design framework using Direct Displacement-Based Design (DDBD) principles. Their study highlighted the limitations of traditional force-based procedures in representing actual structural damage and emphasized that displacement is a more reliable parameter for evaluating seismic performance. The authors concluded that displacement-oriented design methodologies offer improved control over structural behavior during strong earthquake events.

Muljati et al. (2015) compared Force-Based Design (FBD) and Direct Displacement-Based Design for reinforced concrete special moment-resisting frames. Through nonlinear time-history analysis, the researchers observed that displacement-based design was more effective in controlling inter-storey drift and achieving targeted performance levels without requiring repeated design iterations. Their findings demonstrated that DDBD provides a more direct and efficient route to performance-based seismic design.
Recent studies have further reinforced the advantages of displacement-based approaches. Sharma, Tripathi and Bhat (2019) investigated the seismic response of low-rise and medium-rise RC frame buildings designed using both FBD and DDBD methodologies. The results showed that DDBD-designed structures experienced lower displacement demand, reduced drift ratios and more favorable plastic hinge distributions. The authors reported that displacement-based procedures offered better correlation between design assumptions and actual structural performance.

In a subsequent study, Sharma, Tripathi and Bhat (2020) incorporated fragility analysis to evaluate the seismic vulnerability of RC frame structures. The study revealed that buildings designed using displacement-based principles exhibited lower probabilities of exceeding critical performance limits under earthquake excitation. The authors concluded that DDBD improves both structural reliability and post-earthquake functionality.

Sharma, Tripathi and Bhat (2022) further examined the nonlinear behavior of RC buildings using pushover and time-history analyses. Their investigation demonstrated that force-based designs frequently exceeded target drift limits and developed undesirable plastic hinges in columns, whereas displacement-based designs promoted a more desirable strong-column weak-beam mechanism. The study

highlighted the superior deformation control achieved through displacement-based methodologies.
Tank Raj, Dubey and Hardiya (2023) extended the comparison of FBD and DDBD to high-rise reinforced concrete buildings. Their results indicated that displacement-based design provided improved drift control, better energy dissipation characteristics and more efficient material utilization compared with conventional force-based procedures. Similarly, Annisaa Dina Puspita and Rosyidah (2019) reported enhanced performance of dual structural systems designed using displacement-based concepts, particularly with respect to deformation control and damage limitation.

The literature clearly indicates that while Force-Based Design remains the most widely adopted seismic design approach, it primarily focuses on strength requirements and does not explicitly control displacement and damage. In contrast, Displacement-Based Design directly addresses deformation demands and provides a closer relationship between design objectives and actual structural performance. Although several researchers have demonstrated the benefits of displacement-based methodologies, comparatively fewer studies have evaluated the influence of building height on the seismic response of RC frame structures designed using both approaches under identical modeling assumptions. Therefore, the present study performs a detailed comparative assessment of 8-storey, 10-storey and 12-storey reinforced concrete frame buildings using Force-Based Design and Displacement-Based Design methodologies to evaluate their relative effectiveness in terms of displacement, drift, stiffness, energy dissipation and overall seismic performance.

Research Gap
Previous investigations have demonstrated the advantages of displacement-based design over conventional force-based procedures in controlling structural deformation and improving seismic performance. However, most available studies have focused on either low-rise buildings, specific structural systems or isolated performance parameters. Limited research has been conducted on the comparative seismic behavior of medium-rise reinforced concrete frame buildings with varying heights under identical modeling assumptions using Indian seismic design provisions.

III. STRUCTURAL MODELLING AND METHODOLOGY

The seismic performance evaluation presented in this study was carried out through numerical modeling and analysis of reinforced concrete (RC) moment-resisting frame buildings using ETABS software. Three building configurations consisting of 8-storey, 10-storey and 12-storey structures were selected to investigate the influence of building height on the seismic response obtained through Force-Based Design (FBD) and Displacement-Based Design (DBD) methodologies. The selected buildings represent typical medium-rise reinforced concrete structures commonly adopted in urban regions of India.

3.1 Building Description
All building models were considered as regular reinforced concrete moment-resisting frame structures with identical plan dimensions and bay configurations. The buildings consisted of a 3 × 3 bay arrangement in both principal directions with a uniform bay width of 5 m. A typical storey height of 3.2 m was adopted throughout the structure. The buildings were assumed to be located in a seismic region governed by the provisions of IS 1893 (Part 1): 2016. Fixed support conditions were assigned at the base level, and floor slabs were modeled as rigid diaphragms to ensure proper transfer of lateral forces to the vertical load-resisting elements.

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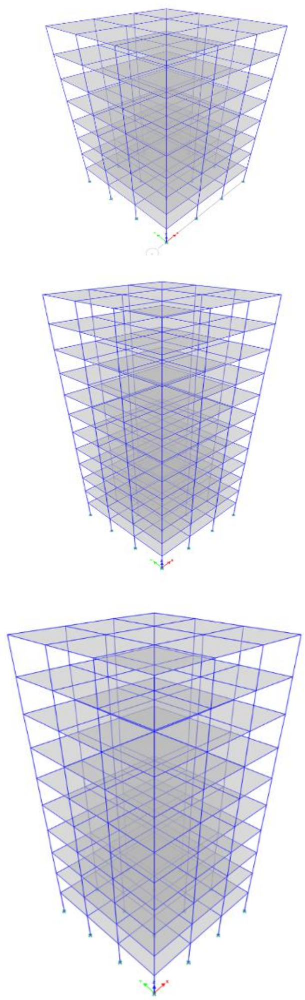

Fig.1:Model of 8,10,12 Storey building

The geometric configuration was intentionally maintained identical for all models except the number of storeys to facilitate a direct comparison of the influence of structural height on seismic response parameters.

3.2 Material Properties

The structural members were designed using material properties commonly adopted in reinforced concrete construction practice. M30 grade concrete was selected for beams, columns and slabs, while Fe500 grade reinforcement steel was used for all reinforcing elements. The modulus of elasticity, unit weight and other material properties were assigned in accordance with relevant Indian Standard provisions.

The selection of these materials reflects common engineering practice for medium-rise reinforced concrete buildings and ensures realistic simulation of structural behavior under seismic loading conditions.

3.3 Loading and Seismic Parameters

The building models were subjected to gravity and seismic loads according to IS 875 and IS 1893 (Part 1): 2016. Dead loads were automatically calculated by the software based on member geometry and material density. A uniformly distributed live load of 3 kN/m² was applied on all floor levels.

Seismic loading was evaluated considering the design response spectrum recommended by IS 1893:2016. Appropriate values of seismic zone factor, importance factor, response reduction factor and soil characteristics were incorporated into the analysis. The seismic forces were considered independently along both principal directions of the building.

The following load combinations were used during analysis:

DL + LL

DL + EQX

DL + EQY

1.2 (DL + LL ± EQX)

1.2 (DL + LL ± EQY)

1.5 (DL ± EQX)

1.5 (DL ± EQY)

These combinations were selected to represent the most critical loading scenarios likely to occur during seismic events.

3.4 Force-Based Design Procedure

The Force-Based Design methodology represents the conventional approach adopted by most seismic design codes. In this procedure, the design base shear is first calculated using the response spectrum method and subsequently distributed along the building height according to mass and stiffness characteristics. Structural members are then proportioned to resist the resulting seismic forces.

For the present study, Response Spectrum Analysis was performed in ETABS to evaluate the seismic response of the buildings. The analysis provided information regarding storey displacement, storey drift, storey shear, modal characteristics and stiffness distribution. The results obtained from this analysis were used to assess the effectiveness of the force-based design philosophy in controlling structural response.

3.5 Displacement-Based Design Procedure

Unlike conventional force-based approaches, Displacement-Based Design focuses on controlling deformation and achieving predefined performance objectives. The methodology is based on the principle that structural damage is more closely related to displacement demand than force demand.

To evaluate displacement-based performance, nonlinear static pushover analysis was carried out for each building model. Incrementally increasing lateral loads were applied until significant nonlinear behavior developed within the structure. The pushover analysis generated capacity curves representing the relationship between base shear and roof displacement.

The performance point obtained from the pushover curve was used to assess the expected seismic behavior of the structures. Special attention was given to plastic hinge formation, deformation patterns and energy dissipation characteristics, which provide valuable insight into structural performance during strong earthquake excitation.

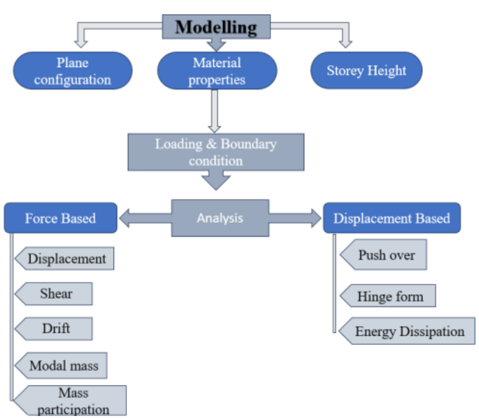

Fig2: Methodology Flow Chart

3.6 Response Parameters Considered

To compare the effectiveness of Force-Based Design and Displacement-Based Design methodologies, several seismic response parameters were evaluated. These parameters included storey displacement, inter-storey drift, storey shear, stiffness distribution, modal mass participation ratio, peak floor acceleration, energy dissipation capacity, plastic hinge formation and base shear demand.

The selected parameters collectively provide a comprehensive assessment of structural performance and facilitate a detailed comparison between the two design approaches. The results obtained from these analyses are presented and discussed in the subsequent sections of this paper.

Parameter	Force Based Design (FBD)	Displacement Based Design (DBD)	Better Method
Roof Displacement	Higher	Lower	DBD
Inter-storey Drift	Higher	Lower	DBD
Storey Shear Distribution	Conventional	More Uniform	DBD
Structural Stiffness Utilization	Moderate	Efficient	DBD
Energy Dissipation	Lower	Higher	DBD
Plastic Hinge Formation	Less Controlled	Controlled Beam Hinges	DBD
Peak Floor Acceleration	Higher	Lower	DBD
Performance Objective Achievement	Indirect	Direct	DBD
Structural Damage Control	Moderate	Superior	DBD
Overall Seismic Performance	Acceptable	Excellent	DBD

IV. RESULTS AND DISCUSSION

4.1 Storey Displacement Analysis

Storey displacement is one of the most important parameters used to evaluate the seismic performance of reinforced concrete buildings. During an earthquake, lateral inertia forces induce horizontal movement throughout the height of a structure. Excessive displacement may result in structural instability, damage to non-structural components and reduced serviceability. Therefore, the displacement profile of a building provides valuable information regarding its stiffness characteristics and overall seismic behavior.

The storey displacement results obtained from the Force-Based Design analysis of the 8-storey, 10-storey and 12-storey reinforced concrete frame buildings.The results indicate a gradual increase in lateral displacement from the base to the roof level for all three structural configurations. This behavior is expected because the accumulation of lateral deformation increases with height due to the progressive reduction in lateral restraint.

The 8-storey building exhibited the lowest displacement demand among the three structures analyzed. Owing to its comparatively lower height and higher lateral stiffness, the building was able to effectively resist seismic-induced deformation. The displacement profile remained smooth throughout the height, indicating stable structural behavior and adequate stiffness distribution. The roof displacement observed in this model remained well within acceptable limits, suggesting satisfactory seismic performance under the considered loading conditions. For the 10-storey building, an increase in displacement demand was observed at all storey levels when compared with the 8-storey structure. The increase can be attributed to the reduction in overall lateral stiffness resulting from the additional storeys and increased structural flexibility. Although the displacement values remained within permissible limits, the trend clearly demonstrates the influence of building height on seismic response. The displacement profile continued to follow a nearly parabolic shape, indicating that the first mode of vibration dominated the overall structural behavior.

The maximum displacement values were recorded in the 12-storey building. Due to its greater height and increased flexibility, the structure experienced the highest lateral movement under seismic excitation. The displacement demand increased significantly toward the upper storeys, reflecting the greater participation of higher modes in the dynamic response of the building. The results indicate that as the height of the structure increases, the effect of lateral deformation becomes increasingly significant and must be carefully considered during the design process.

A comparison of the displacement profiles reveals a consistent relationship between building height and seismic deformation. While all three buildings satisfy strength requirements, the increase in displacement demand with height highlights one of the limitations of conventional force-based design procedures. Since displacement is not directly controlled during the design stage, taller buildings may experience substantial deformation despite complying with code-prescribed force requirements.

The displacement trends observed in the present study are consistent with findings reported by previous researchers investigating the seismic performance of reinforced concrete frame structures. Several studies have shown that structural damage is more closely related to deformation demand than force demand. Consequently, evaluation of displacement response provides a more realistic measure of expected structural performance during earthquake events.

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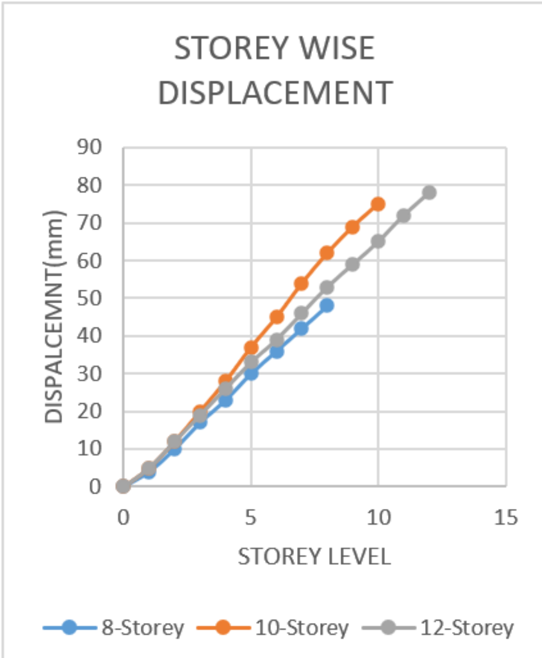

Fig.3 Storey-Wise Displacement Results

The results clearly demonstrate that displacement demand increases with building height and structural flexibility. Therefore, controlling displacement becomes increasingly important for medium-rise and high-rise reinforced concrete structures. The findings also provide the basis for subsequent comparison with the Displacement-Based Design methodology, where deformation control constitutes the primary design objective.

4.2 Inter-Storey Drift Analysis

Inter-storey drift is widely recognized as one of the most critical indicators of seismic performance in reinforced concrete structures. It represents the relative lateral displacement between two consecutive floors and serves as a direct measure of structural deformation during earthquake excitation. Excessive inter-storey drift can result in significant damage to both structural and non-structural components, including cracking of masonry infill walls, damage to partitions, failure of cladding systems and deterioration of serviceability conditions. Consequently, seismic design codes impose strict limits on permissible drift values to ensure structural safety and functionality during and after earthquake events.

The storey drift results obtained from the seismic analysis of the 8-storey, 10-storey and 12-storey reinforced concrete frame buildings are presented in Table X and Figure X. The variation of drift along the building height exhibited a characteristic pattern commonly observed in moment-resisting frame structures. Drift values increased from the lower storeys and reached their maximum magnitude within the intermediate levels of the building before gradually reducing toward the roof level. This behavior can be attributed to the combined influence of storey stiffness distribution and mode shape characteristics.

The 8-storey building demonstrated the lowest drift demand among all the structural configurations considered in this study. Due to its relatively high stiffness and shorter vibration period, lateral deformation was effectively controlled throughout the height of the structure. The drift profile remained smooth and well within the permissible limits specified by IS 1893:2016, indicating satisfactory seismic performance and adequate lateral load resistance.

For the 10-storey structure, a noticeable increase in drift demand was observed compared to the 8-storey model. The increase in structural height resulted in greater flexibility and consequently higher relative displacement between adjacent storeys. The maximum drift was recorded within the middle region of the building, where the combined effect of inertia forces and lateral deformation was most pronounced. Despite the increase, the drift values remained within acceptable code limits, confirming the adequacy of the structural system under the considered seismic loading conditions.

The highest drift values were observed in the 12-storey building. The increased height and reduced lateral stiffness contributed to larger deformation demands, particularly in the upper-middle portion of the structure. The results indicate that drift demand increases significantly with building height, emphasizing the importance of deformation control in medium-rise and high-rise reinforced concrete buildings. Although the structure satisfied the prescribed drift limits, the observed increase highlights the growing influence of flexibility on seismic response as the number of storeys increases.

A comparison of the drift profiles for all three buildings reveals that drift demand is more sensitive to structural flexibility than displacement alone. While roof displacement provides an overall measure of structural movement, inter-storey drift directly reflects the deformation experienced by individual structural elements. Therefore, drift is generally considered a more reliable indicator of potential structural damage during earthquake events.

The obtained results are consistent with observations reported in previous research studies, where increased building height was associated with higher drift demands and greater susceptibility to seismic damage. Researchers have repeatedly emphasized that controlling drift is essential for achieving satisfactory performance-based seismic design objectives. Excessive drift not only affects structural stability but also contributes significantly to post-earthquake repair costs and functional disruptions.

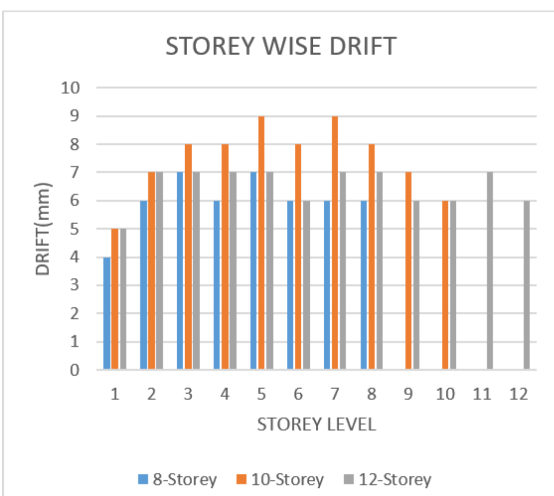

Fig.4 Storey-Wise Drift Values

The analysis clearly demonstrates that inter-storey drift increases with structural height and decreasing stiffness. The findings indicate that although conventional force-based design procedures satisfy code requirements, the resulting drift demand becomes increasingly significant for taller buildings. These observations further justify the need for displacement-oriented design methodologies that directly control deformation and damage during seismic events.

4.3 Storey Stiffness Analysis

Storey stiffness is a fundamental parameter governing the seismic response of reinforced concrete frame structures. It represents the resistance offered by a storey against lateral deformation when subjected to earthquake-induced forces. The distribution of stiffness along the height of a building significantly influences displacement demand, inter-storey drift, force distribution and overall structural stability. Buildings with higher lateral stiffness generally experience lower deformation demands, whereas structures with reduced stiffness are more susceptible to excessive displacement and drift during seismic excitation.

The storey stiffness values obtained from the seismic analysis of the 8-storey, 10-storey and 12-storey reinforced concrete frame buildings are presented in Table X and Figure X. The results indicate a gradual reduction in stiffness from the bottom storeys toward the upper levels of the building. This trend is commonly observed in multi-storey frame structures due to the cumulative effect of lateral deformation and the reduction in the number of load-carrying members contributing to lateral resistance at higher elevations.

For the 8-storey building, the maximum stiffness was observed at the lower storeys where the columns and beams collectively resisted the highest lateral forces. The stiffness gradually decreased with increasing height, resulting in a stable and predictable deformation profile. The relatively higher stiffness of the structure contributed to lower displacement and drift demands, as observed in the previous sections. This behavior confirms that adequate lateral stiffness plays a crucial role in controlling seismic response.

The 10-storey building exhibited a similar stiffness distribution pattern; however, the overall stiffness values were lower than those of the 8-storey structure. The increase in building height resulted in greater flexibility and a corresponding reduction in lateral resistance. Consequently, larger displacement and drift values were recorded throughout the height of the structure. The reduction in stiffness was particularly noticeable in the upper storeys, where lateral deformation became more significant.

The 12-storey building showed the lowest stiffness among the three structural configurations considered. As the height of the structure increased, the lateral flexibility increased substantially, leading to a significant reduction in storey stiffness. The upper levels of the building experienced the greatest reduction in stiffness, which directly contributed to the higher displacement and drift demands observed in previous analyses. The results clearly demonstrate the inverse relationship between stiffness and structural deformation under seismic loading.

A comparison of the stiffness profiles indicates that structural height has a pronounced influence on lateral rigidity. While all three buildings were designed using similar geometric and material properties, the increase in the number of storeys resulted in a progressive reduction in overall stiffness. This behavior explains the increase in displacement and drift demand with building height and highlights the importance of stiffness control in seismic design.

The findings obtained in this study are consistent with established structural dynamics principles and previous research investigations. Several researchers have reported that reduced stiffness leads to increased seismic vulnerability due to higher deformation demands and greater sensitivity to dynamic loading. Therefore, maintaining adequate stiffness throughout the height of a structure remains one of the key objectives in earthquake-resistant design.

Fig.5 Storey-Wise Stiffness Values

The results demonstrate that stiffness decreases progressively with increasing building height and storey level. The observed reduction in stiffness directly influences displacement and drift behavior, thereby affecting overall seismic performance. These findings establish a clear relationship between structural stiffness and lateral response and provide an important basis for understanding the dynamic characteristics discussed in the subsequent modal analysis section.

4.4 Modal Analysis and Mass Participation Ratio
Modal analysis is an essential component of seismic evaluation as it provides insight into the dynamic characteristics of a structure. Unlike static loading conditions, earthquake excitation induces dynamic vibrations that depend on the mass, stiffness and geometry of the building. Parameters such as natural time period, mode shape and modal mass participation ratio play a significant role in determining the seismic response of multi-storey structures. Understanding these characteristics is crucial for predicting structural behavior and ensuring adequate seismic performance.

The modal analysis carried out in ETABS provided the fundamental vibration periods and mass participation ratios for the 8-storey, 10-storey and 12-storey reinforced concrete frame buildings. The results obtained from the analysis are summarized in Table X, while the variation of modal mass participation is

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illustrated in Figure X. The first few vibration modes contributed significantly to the overall structural response, indicating that the dynamic behavior of the buildings was primarily governed by their fundamental modes.

The results reveal that the fundamental natural period increased with building height. The 8-storey building exhibited the shortest natural period due to its relatively higher stiffness and lower flexibility. As the number of storeys increased to ten and twelve, the structures became progressively more flexible, resulting in longer vibration periods. This trend is consistent with structural dynamics theory, which states that flexible structures tend to vibrate more slowly than stiffer structures.

The increase in natural period observed in the taller buildings is directly related to the reduction in storey stiffness discussed in the previous section. As lateral stiffness decreases, the ability of the structure to resist deformation diminishes, causing the building to oscillate over a longer duration during seismic excitation. Consequently, taller buildings become more sensitive to long-period ground motions and may experience greater displacement demands under severe earthquakes.

The modal mass participation ratios obtained from the analysis indicate that a significant percentage of the total structural mass was mobilized within the first few modes of vibration. For all three building configurations, the cumulative mass participation exceeded the minimum code requirements, confirming that an adequate number of modes were considered in the dynamic analysis. The first mode contributed the largest share of mass participation, demonstrating its dominant influence on the overall seismic response of the structures.

A comparison of the three building models shows that the cumulative mass participation ratio was achieved more rapidly in the lower-height structures than in the taller buildings. The 8-storey frame exhibited a stronger first-mode dominance, whereas the 12-storey frame required a greater number of modes to capture the dynamic response accurately. This behavior can be attributed to the increasing importance of higher-mode effects as building height increases. In medium-rise and taller structures, higher vibration modes contribute significantly to storey shear, acceleration and deformation demands, making their consideration essential for reliable seismic analysis.

The obtained results are consistent with observations reported in previous studies on reinforced concrete frame structures. Researchers have shown that increasing building height generally leads to longer natural periods and greater higher-mode participation. These factors influence not only displacement response but also force distribution and energy dissipation characteristics during earthquake events.

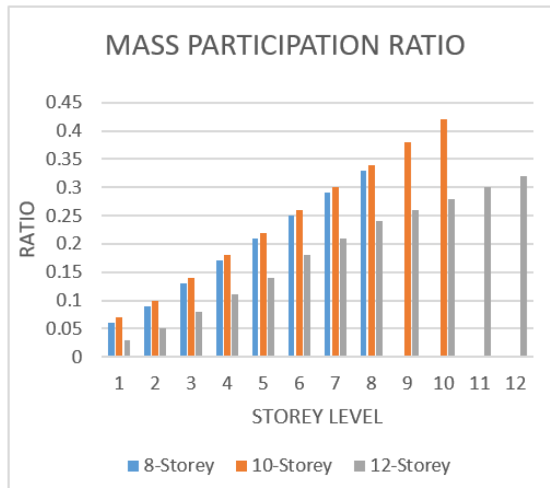

Fig.6 Modal Period and Mass Participation Ratios

The modal analysis confirms that building height has a substantial influence on the dynamic characteristics of reinforced concrete frame structures. The increase in natural period and the growing significance of higher-mode effects observed in the taller buildings explain the larger displacement and drift demands obtained in previous sections. These dynamic characteristics further influence the distribution of seismic forces within the structure, which is examined through the storey shear analysis presented in the following section.

4.5 Storey Shear Distribution

Storey shear represents the cumulative lateral force acting at a particular floor level due to earthquake excitation. It is one of the most important seismic response parameters because it directly influences the design of beams, columns and beam-column joints. The variation of storey shear along the height of a building provides valuable information regarding the transfer of earthquake-induced forces from the upper floors to the foundation system. Accurate estimation of storey shear is therefore essential for ensuring structural safety and preventing premature failure of load-resisting components.

The storey shear values obtained from the seismic analysis of the 8-storey, 10-storey and 12-storey reinforced concrete frame buildings are presented in Table X and Figure X. The results indicate that storey shear gradually increases from the roof level toward the base of the structure. This behavior is expected because each lower storey must resist the cumulative inertia forces generated by all the floors located above it. Consequently, the maximum storey shear was recorded at the ground level, while the minimum values occurred near the roof.

For the 8-storey building, the storey shear distribution followed a smooth and nearly linear trend. The seismic forces were effectively transferred through the structural system, indicating uniform stiffness and regular force distribution. The lower storeys resisted the majority of the earthquake-induced lateral loads, while the upper levels contributed comparatively smaller force demands. This behavior is characteristic of regular moment-resisting frame structures subjected to lateral loading.
The 10-storey building exhibited a similar force distribution pattern; however, the magnitude of storey shear increased due to the additional structural mass associated with the increased number of storeys. Since seismic inertia forces are directly proportional to structural mass, the larger building generated greater lateral forces during dynamic excitation. The increase in shear demand was particularly noticeable in the lower storeys where cumulative forces from the upper floors were concentrated.

Among the three structural configurations investigated, the 12-storey building developed the highest storey shear values. The greater building height resulted in increased seismic mass and longer vibration periods, both of which influenced the overall force distribution within the structure. Although the general trend remained similar to that observed in the shorter buildings, the magnitude of shear demand was significantly higher throughout the height of the structure. The lower storeys experienced the largest force concentrations and therefore represent the most critical regions from a design perspective.

A comparison of the storey shear profiles reveals that seismic force demand increases consistently with building height. While displacement and drift primarily reflect deformation characteristics, storey shear provides an indication of the internal force demands generated within the structural system. The results demonstrate that taller buildings must be designed not only for increased deformation but also for substantially greater lateral force demand.

The observed force distribution is consistent with the fundamental principles of earthquake engineering and with findings reported in previous studies. Researchers have shown that storey shear is strongly influenced by structural mass, stiffness distribution and modal characteristics. Buildings with larger heights generally experience increased cumulative force demands, particularly at the lower storeys, making adequate design and detailing of these regions essential for seismic safety.

The analysis indicates that storey shear increases progressively toward the base of the structure and becomes more significant with increasing building height. The lower storeys experience the highest force demand and therefore govern the design of major structural components. Understanding this force distribution is essential for evaluating overall seismic performance and provides the basis for the nonlinear pushover analysis presented in the following section.

4.6 Nonlinear Pushover Analysis
To evaluate the inelastic behavior and seismic capacity of the reinforced concrete frame buildings, nonlinear static pushover analysis was performed using ETABS. The procedure involved the application of incrementally increasing lateral loads until significant yielding occurred within the structural system. The resulting pushover curves, expressed in terms of base shear versus roof displacement, provide valuable

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insight into the strength, stiffness and deformation capacity of the buildings.

The pushover curves obtained for the 8-storey, 10-storey and 12-storey structures are presented in Figure X. All three buildings exhibited an initial linear elastic response followed by gradual stiffness degradation as plastic hinges developed within the structural members. The transition from elastic to inelastic behavior was clearly visible in the capacity curves, indicating the onset of structural yielding and energy dissipation.

The 8-storey building demonstrated the highest overall stiffness and reached its performance point at comparatively lower displacement levels. The 10-storey and 12-storey structures exhibited increased displacement capacity due to their greater flexibility, resulting in larger roof displacements before reaching the ultimate performance state. The 12-storey model showed the largest deformation capacity among the three buildings, reflecting its longer natural period and increased participation of higher vibration modes.

The results indicate that all buildings possessed adequate lateral load-carrying capacity and maintained stable post-yield behavior without exhibiting sudden strength degradation. The observed response confirms that the structures are capable of dissipating significant seismic energy through controlled inelastic deformation.

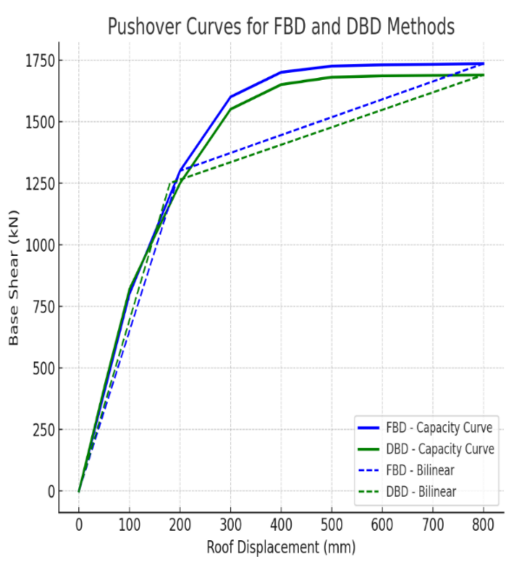

Fig.7: Pushover Curves for 8, 10 and 12 Storey Buildings

The pushover analysis provides a realistic representation of structural behavior beyond the elastic range and forms the basis for evaluating the effectiveness of displacement-based seismic design. The capacity curves obtained from the analysis demonstrate the ability of the structures to sustain substantial lateral deformation while maintaining structural stability under severe earthquake loading.

4.7 Comparative Seismic Performance of Force-Based Design and Displacement-Based Design

A comprehensive comparison was performed between the Force-Based Design (FBD) and Displacement-Based Design (DBD) methodologies to evaluate their effectiveness in predicting and controlling the seismic response of reinforced concrete frame structures. The comparison was carried out using several key performance indicators, including storey displacement, inter-storey drift, storey shear, energy dissipation capacity, peak floor acceleration and plastic hinge formation. These parameters collectively provide a comprehensive assessment of structural behavior under earthquake loading conditions.

The displacement profiles obtained from both design approaches indicate that the DBD methodology provides improved control over lateral deformation. In all three building configurations, namely the 8-storey, 10-storey and 12-storey structures, the displacement demand predicted by the displacement-based approach was lower than that obtained from the force-based analysis. This reduction in displacement can be attributed to the fact that DBD explicitly incorporates deformation limits during the design process, whereas FBD primarily focuses on satisfying strength requirements. Consequently, displacement-based structures exhibit behavior that is more closely aligned with predefined performance objectives.

A similar trend was observed in the inter-storey drift results. The drift values obtained from DBD were consistently lower than those recorded for FBD, particularly in the middle storeys where maximum deformation demand generally occurs. Since inter-storey drift is directly related to structural damage and serviceability performance, the improved drift control achieved through DBD indicates a lower probability of damage to both structural and non-structural components during seismic events. The results therefore demonstrate the superior ability of displacement-based procedures to satisfy performance-based design requirements.

Storey shear distribution patterns obtained from both methodologies showed similar overall trends; however, DBD exhibited a more uniform distribution of seismic forces throughout the height of the building. The force-based approach generated comparatively higher force concentrations in the lower storeys, resulting in increased demand on critical structural components. In contrast, the displacement-based method promoted a more balanced force-transfer mechanism, contributing to improved overall seismic performance.

The nonlinear response parameters further highlighted the advantages of displacement-based design. The energy dissipation capacity of the DBD models was observed to be greater than that of the corresponding FBD structures. Enhanced energy dissipation indicates an improved ability to absorb and dissipate earthquake-induced energy through controlled inelastic deformation. This characteristic is particularly important during strong ground motions where structural survival depends largely on ductility and hysteretic energy absorption.

The analysis of peak floor acceleration also revealed favorable performance of displacement-based structures. Lower acceleration demands were generally observed in DBD models, indicating reduced inertial forces acting on both structural and non-structural elements. Reduced floor acceleration contributes to improved occupant comfort and minimizes the risk of damage to equipment, partitions and other building components.

Plastic hinge formation patterns obtained from the pushover analysis provided further evidence of the improved seismic behavior associated with displacement-based design. In the DBD models, plastic hinges were predominantly concentrated within beam elements, resulting in a desirable strong-column weak-beam mechanism. Such behavior is widely recognized as the preferred mode of seismic energy dissipation because it prevents premature column failure and significantly reduces the possibility of global structural collapse. In contrast, the FBD models exhibited comparatively less controlled hinge formation, with a greater tendency for yielding to occur within critical load-carrying members.

The overall comparison clearly demonstrates that while both methodologies satisfy the minimum safety requirements prescribed by seismic design codes, displacement-based design provides superior control over deformation, damage distribution and structural performance. The results indicate that DBD offers a more realistic representation of structural behavior under earthquake loading and establishes a direct relationship between design objectives and expected performance. Consequently, displacement-based procedures can be considered a more efficient and performance-oriented approach for the seismic design of reinforced concrete frame structures.

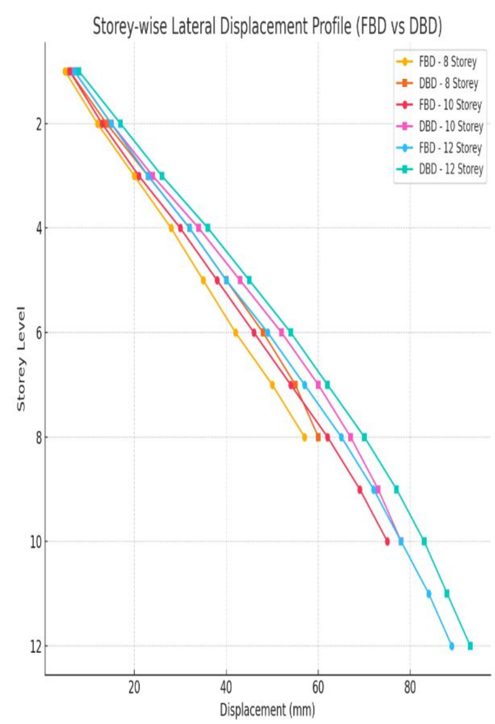

Fig.8: Comparative Performance of FBD and DBD

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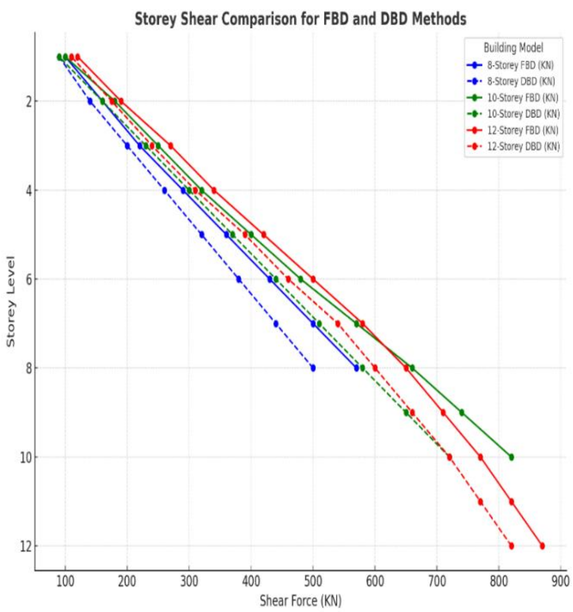

Fig.9: FBD vs DBD Displacement Comparison

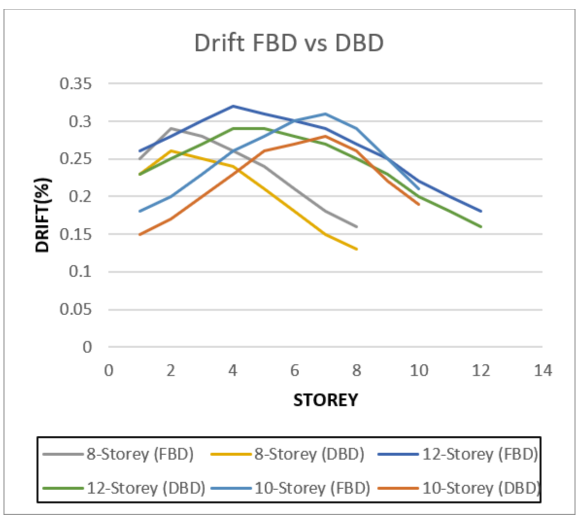

Fig.10: FBD vs DBD Drift Comparison]

The comparative assessment confirms that displacement-based design consistently outperforms conventional force-based design in terms of deformation control, energy dissipation and damage management. The findings support the growing adoption of performance-based seismic design methodologies and highlight the potential benefits of incorporating displacement-oriented design principles into future seismic design practice.

Performance Parameter	FBD	DBD	Observation
Roof Displacement	Higher	Lower	DBD provides better displacement control
Inter-Storey Drift	Higher	Lower	Reduced structural damage potential
Storey Shear Distribution	Concentrated at lower floors	More uniform	Improved force transfer mechanism
Structural Stiffness Utilization	Moderate	Efficient	Better deformation management
Fundamental Performance Objective	Indirectly Achieved	Directly Achieved	DBD is performance-oriented
Energy Dissipation	Moderate	Higher	Better seismic resilience
Peak Floor Acceleration	Higher	Lower	Reduced non-structural damage
Plastic Hinge Formation	Less Controlled	Beam Dominated	Strong-column weak-beam behavior
Damage Control	Moderate	Superior	Lower repair requirements
Overall Seismic Performance	Satisfactory	Superior	DBD preferred

V. CONCLUSION

A comparative seismic performance assessment of reinforced concrete moment-resisting frame buildings designed using Force-Based Design (FBD) and Displacement-Based Design (DBD) methodologies has been presented in this study. Three building configurations comprising 8-storey, 10-storey and 12-

storey reinforced concrete frames were modeled and analyzed using ETABS in accordance with the provisions of IS 1893:2016. The seismic response of the structures was evaluated through parameters including storey displacement, inter-storey drift, storey stiffness, modal characteristics, storey shear distribution and nonlinear pushover behavior.
The results obtained from the analysis indicate that building height has a significant influence on seismic response. As the number of storeys increased, the structures exhibited greater flexibility, resulting in increased displacement demand, larger inter-storey drift and reduced lateral stiffness. The modal analysis further confirmed that taller buildings possess longer natural periods and experience greater higher-mode participation, which substantially affects their dynamic behavior during earthquake excitation.

The comparative evaluation of FBD and DBD revealed noticeable differences in the predicted structural response. Although the force-based approach successfully satisfied the minimum code-prescribed strength requirements, it provided only indirect control over deformation and damage. The displacement-based methodology, on the other hand, demonstrated superior control over lateral displacement and inter-storey drift by directly incorporating performance objectives into the design process. Consequently, structures designed using DBD exhibited improved deformation characteristics and reduced seismic vulnerability.

The nonlinear pushover analysis indicated that all building configurations possessed adequate lateral load-carrying capacity and stable post-yield behavior. However, the displacement-based models showed more desirable seismic performance due to their enhanced energy dissipation capability and improved plastic hinge distribution. The concentration of plastic hinges within beam elements promoted a strong-column weak-beam mechanism, thereby reducing the likelihood of premature column failure and improving overall structural safety.

Based on the findings of the present investigation, the following conclusions may be drawn:

1. Seismic displacement, drift demand and flexibility increase significantly with building height.
2. Force-Based Design provides satisfactory strength performance but does not directly control structural deformation.
3. Displacement-Based Design achieves improved control of displacement and inter-storey drift, resulting in better overall seismic performance.
4. DBD promotes a more uniform force distribution and more effective energy dissipation during earthquake excitation.
5. Plastic hinge formation obtained through DBD is more consistent with desirable performance-based seismic design objectives.
6. The displacement-based approach provides a more realistic representation of structural behavior and damage potential under strong ground motion.

Overall, the study demonstrates that Displacement-Based Design offers significant advantages over conventional Force-Based Design in terms of deformation control, damage management and seismic performance evaluation. The findings support the growing adoption of performance-based seismic design methodologies and highlight the effectiveness of displacement-oriented approaches for the design of medium-rise reinforced concrete frame structures located in earthquake-prone regions.

Future Scope

Future studies may focus on extending the present investigation to irregular buildings, high-rise structures, dual structural systems and buildings incorporating supplemental damping devices or base isolation systems. The influence of soil-structure interaction, near-fault ground motions and nonlinear time-history analysis may also be explored to further enhance the understanding of displacement-based seismic design methodologies.

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