PERFORMANCE BASED SEISMIC DESIGN OF HIGH-RISE BUILDING WITH SEISMIC ZONE-V

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Abstract: *The performance-based seismic design (PBSD) of high-rise buildings is a critical aspect of modern structural engineering, particularly in regions exposed to high seismic risks. This project investigates the seismic performance of a G+20 high-rise building in seismic zone V using two advanced seismic design methods: Force-Based Design (FBD) and Direct Displacement-Based Design (DDBD), implemented through the ETABS software. The study aims to compare the effectiveness of these methods in terms of drift, base shear, and demand-capacity curve values. The analysis reveals that DDBD results in lower drift values and more efficient use of the building's energy dissipation capacity, leading to reduced base shear demands compared to the traditional FBD approach. Additionally, DDBD's demand-capacity curve indicates a more realistic response to seismic loading, emphasizing the structure's inelastic behavior and ensuring better control over displacements. The results suggest that DDBD provides a more accurate and cost-effective design, optimizing both material usage and structural safety. This research highlights the importance of performance-based methods in high-rise buildings, offering a more sustainable and reliable approach to seismic design, especially in regions with severe seismic hazards like seismic zone V.*
Keywords: *Performance-based seismic design, high-rise buildings, seismic zone V, ETABS, Force-Based Design (FBD), Direct Displacement-Based Design (DDBD), base shear, drift, demand-capacity curve, seismic response, inelastic behavior.*

1. INTRODUCTION

Seismic design is a crucial aspect of structural engineering, particularly for high-rise buildings located in seismic-prone regions. The growing trend of urbanization and the increasing height of buildings in earthquake-prone areas, such as seismic zone V, necessitate advanced design techniques to ensure safety and resilience against seismic forces. Traditionally, seismic design has relied on force-based methods, which emphasize strength and stiffness to resist seismic forces. However, these methods often result in overly conservative designs and may not fully utilize the building's potential to absorb seismic energy through inelastic deformations.

In contrast, performance-based seismic design (PBSD) focuses on achieving specific performance objectives, allowing structures to undergo controlled inelastic deformations without compromising safety. Among the various performance-based methods, the Direct Displacement-Based Design (DDBD) method has gained prominence for its ability to account for both the strength and displacement capacity of a structure, resulting in more efficient and accurate designs. This approach ensures that the structure's behavior during

an earthquake is considered holistically, focusing not only on strength but also on the capacity to undergo deformation while maintaining stability.
This project aims to compare two seismic design approaches—Force-Based Design (FBD) and Direct Displacement-Based Design (DDBD)—for a G+20 high-rise building located in seismic zone V, using ETABS software for structural analysis. The primary objective is to evaluate and compare the drift, base shear, and demand-capacity curve values obtained from both methods, highlighting the advantages and disadvantages of each in terms of seismic performance. Through this study, the goal is to demonstrate how performance-based methods, particularly DDBD, can lead to more cost-effective and reliable designs while ensuring the safety and resilience of high-rise buildings in seismic zones.

This chapter deals with a brief review of the past and recent study performed by researchers on performance based seismic design approaches. A detailed review of each literature would be difficult to address in this chapter. The literature review focuses on find out most of the case studies on the various buildings which were faced during the last few decades.

1. J.P. Moehle (2018) presented **"Performance-Based Seismic Design of Tall Buildings in the U.S."** In his work, J.P. Moehle discussed the increasing adoption of performance-based seismic design (PBSD) for tall buildings in the U.S., highlighting both the research and practical aspects of its application. U.S. building codes typically include prescriptive seismic design requirements, but alternative performance-based provisions are becoming more common, especially for tall buildings. Implementing PBSD necessitates a deep understanding of how performance correlates with nonlinear structural response, as well as the selection and application of appropriate ground motions based on seismic hazards. Additionally, it requires the use of suitable nonlinear models and analysis techniques, interpretation of results to determine design parameters, and ensuring proper structural detailing, often reviewed by qualified experts. The use of PBSD for tall buildings in the U.S. is supported by research, software tools, and real-world applications, which help in performing effective nonlinear dynamic analyses. These analyses allow for a more accurate identification of a building's response under seismic conditions, including mechanisms of yielding, internal forces, deformation demands, and necessary detailing. By employing PBSD and nonlinear analysis, designers can create more efficient and reliable designs that exceed the traditional prescriptive code requirements, offering enhanced safety and performance. However, further research is needed to refine and improve design practices and to address ongoing challenges in the field.
2. Arjun Sil, Gourab Das, Pritam Hait (2019) presented **"Characteristics of FBD and DDBD techniques for SMRF buildings designed for seismic zone-V in India"** This paper presents the results of nonlinear time history analysis on six different reinforced concrete moment frames, designed using two seismic design methods: Force Based Design (FBD) and Direct Displacement Based Design (DDBD). While FBD is the conventional method, DDBD represents a performance-based approach. In this study, 4, 8, and 12-story reinforced concrete buildings with two × three bays were designed following Indian standards and Federal Emergency Management Agency (FEMA) guidelines, using both design methods. The analysis was conducted using SAP2000 v15.1 software, with five different real ground motion records from the northeastern region of India. Parameters such as inter-storey drift, displacement, material strain, and ductility demand were obtained from the analyses and compared between the two design approaches.
3. Nilkanth K. Sutariya, Dr. Bimal A. Shah (2016) presented **"A Comparative Study of Force Based Design and Direct Displacement Based Design for R.C. Buildings"** The traditional Force-Based Design (FBD) method (IS 1893:2002) for reinforced concrete buildings subjected to seismic loads presents several challenges, such as issues with the initial stiffness characterization of structures, inappropriate response reduction factors,

and the use of a height-dependent formula to calculate the fundamental time period. These limitations prevent FBD from achieving target design objectives for a specified hazard level, prompting the need for an alternative approach, which led to the development of Performance-Based Design (PBD). The Direct Displacement-Based Design (DDBD) method, based on PBD, was studied in this research. The design and analysis were conducted for reinforced concrete frame buildings with 8, 10, 12, 14, and 16 stories, following IS 456 and IS 1893:2002 codes, using ETABS 2015 software. Nonlinear static pushover analysis was employed to evaluate the performance of buildings designed using both FBD and DDBD. Parameters such as base shear, storey drift at the performance point, and the consumption of steel and concrete were compared. Nonlinear static push-over analysis confirmed that the performance of all frames designed using both methods was satisfactory. Thus, the study concluded that buildings designed with DDBD are more economical than those designed with FBD.

1.1 Advantages of Project

i. PBD provides a more realistic understanding of a structure's behavior under seismic forces, allowing for designs that meet specific performance objectives rather than code-prescribed limits.
ii. It offers greater flexibility, enabling engineers to optimize designs for different hazard levels, enhancing safety and functionality during earthquakes.
iii. PBD allows for a more customized approach, considering the unique needs of each building and its environment, leading to efficient resource use.
iv. FBD is a simple and widely accepted design approach that follows established codes, making it easy to implement and understand.
v. It ensures that structures have adequate strength to resist seismic forces, providing reliable safety through a conservative approach.
vi. The method is computationally less intensive compared to other advanced seismic design methods, making it cost-effective for standard buildings.
vii. DDBD results in a more economical design by reducing base shear and allowing for smaller structural sections while maintaining safety.
viii. It focuses on controlling displacement and drift, which are more critical to building performance during an earthquake, improving flexibility and reducing structural damage.
ix. DDBD enhances the accuracy of seismic design by considering the dynamic response of structures, leading to better life safety and serviceability.

1.2 Aim

This project aims to address these gaps by designing a high-rise building for Seismic Zone V using both FBD and DDBD methodologies, analyzing their performance, and identifying the most effective approach. Advanced modeling and analysis using ETABS will be employed to ensure accuracy and reliability, while factors such as lateral load-resisting systems, interstory drifts, material efficiency, and soil-structure interaction will be thoroughly evaluated. The findings will provide valuable insights into the strengths and limitations of each methodology, contributing to the development of safer, more resilient high-rise buildings in seismically active regions.

2. OBJECTIVES

Objectives of study:

i. To compare the seismic performance of reinforced concrete buildings designed using Force-Based Design (FBD) and Direct Displacement-Based Design (DDBD) methods under different seismic conditions.
ii. To evaluate the effectiveness of FBD and DDBD in controlling key seismic parameters such as inter-storey drift, displacement, base shear, and ductility demand.
iii. To assess the cost-efficiency of DDBD compared to FBD by analyzing the reduction in structural member sizes and reinforcement requirements.
iv. To perform nonlinear time history analysis using real earthquake ground motions to simulate actual seismic responses of the buildings.
v. To determine the performance levels and safety margins of buildings designed with both methods to meet specific seismic hazard levels as per the Indian standards.
vi. To explore the applicability of DDBD as an alternative approach for performance-based seismic design, offering improved resource efficiency and structural safety.
vii. To investigate the impact of seismic zone classification on the design parameters and overall performance of buildings designed with both FBD and DDBD methods.

3. METHODOLOGY

This methodology focuses on the seismic design of a 20-story high-rise building (G+20) located in Seismic Zone V, as per the Indian seismic design code IS 1893:2016. Seismic Zone V represents areas prone to high-intensity earthquakes, necessitating robust design and analysis to ensure the building's safety and performance. Both Force-Based Design (FBD) and Direct Displacement-Based Design (DDBD) approaches are employed and analyzed using ETABS. The FBD approach follows traditional codal guidelines, where strength is the key design parameter. The design process for the G+20 building begins by defining its geometry in ETABS, which includes a total height of 63 m (with each of the 20 stories being 3 m tall), material properties such as concrete and steel, and the lateral load-resisting system, such as moment frames and shear walls.

4. MODELING AND ANALYSIS

In the Force-Based Design (FBD) method, the ETABS modelling of the G+20 building starts by defining the building's geometry, material properties, and mass distribution to accurately represent the structure. Lateral load-resisting systems, such as moment frames or shear walls, are set up, and seismic forces are applied according to codal provisions (e.g., IS 1893). The analysis aims to distribute these forces throughout the structure, ensuring that each member is designed for strength and complies with the required force and stress limits. Dynamic properties like mode shapes and fundamental periods are assessed, and base shear and force demands are obtained using a response spectrum analysis or equivalent static method.

In the Direct Displacement-Based Design (DDBD) method, the modelling process incorporates both linear and nonlinear behaviours to ensure the structure achieves the desired displacement. The initial ETABS model is used to calculate dynamic properties such as effective mass and fundamental period. Additional external calculations are performed to determine parameters like equivalent stiffness and damping, which are then applied to the model. Seismic analysis in ETABS is conducted using a modified displacement spectrum that reflects these parameters. After the design is completed to meet the target displacements, validation is carried out through pushover or time-history analysis to ensure that the structure meets the performance objectives under seismic loads.

4.1 Material Properties and Section Properties:

Concrete grade: M30
Steel grade: FE415, FE500

4.2. Load calculations:
Dead load and live load calculation on slab (As Per IS 875- 2015 Part-1 & Part-2 clause 3.1 Table 1):
Dead load calculation (from IS 875 part 1):
Dead Load = 1.5 KN/m^2
Live Load = 2 KN/m^2

4.3 Trial Sizes of elements:
Beam- 350X750 MM
450X750 MM
Column- 650X900 MM
Slab thickness- 250 MM

4.4 Earthquake load (IS-1893-Part: 1-2016):
The building location where seismic Zone is V with factor 0.36. Since it is a residential building, which is having importance factor 1. A Lateral force resisting system in which RC SMRF with response reduction factor (R) 5 is taken. Project building is located on soft soil site. For time history analysis, Fast Nonlinear Analysis Method is used to get accurate results.
Performing Direct Displacement-Based Design (DDBD) in ETABS involves a series of steps that bridge theoretical concepts of DDBD with practical modeling and analysis capabilities of ETABS. Since ETABS does not have a built-in feature specifically for DDBD, the process requires manual calculations and iterations based on the DDBD methodology, combined with modeling and verification within ETABS. Here's a step-by-step guide:

Step 1: Define Performance Objective and Target Displacement (Δt)

a. Performance Objectives:
   - Set target performance objectives, such as Life Safety (LS) or Immediate Occupancy (IO).
   - Define the target displacement **(** Δt **)** at the roof level or other critical points.

b. Number of Stories:

$$\Delta_t = \theta_{max} \cdot H$$

N=Total Height / Storey Height = 63 / 3= 21

Assume the following typical values for calculations (specific site and building data would refine these):

- Seismic Design Level: Design-level earthquake (response spectrum provided).
- Mass per storey (mi): Use a representative mass for each storey, mmm, assumed constant.
- Target Displacement (Δt): Typically based on performance objectives. For this calculation, we assume a target roof displacement of 2.0% drift for initial evaluation:
  Δt = 0.02 X Total Height = 0.02 X 63 = 1.26 m

Step 2: Convert to Equivalent SDOF System

1. Effective Mass (m_e)
   The effective mass of the system is determined as a fraction of the total mass (m_t) participating in the first mode. Typically, 80%-90% of the total mass participates in the first mode for a regular building. Assume:
   $m_e = 0.85 \text{ X } m_t$

   Here, $m_t = \sum mi = \text{N X } m_t$ for simplicity, we continue assuming the effective mass as a proportion of total mass.
2. Effective Height (He):
   The effective height is the height of the equivalent SDOF system. This is calculated based on the mode shape and distribution of mass:

   $H_e = \sum(mi \ X \ hi \ X \ \phi i) \ / \ (\sum(mi \ X \ \phi i))$

For simplicity in initial approximation, use He=0.7 X H for a regular first mode shape.

$He = 0.7 \text{ X } 63 = 44.1 \text{ m}$

Total Mass (Mt): 284553.7 kN

= 29000 tonnes

First Mode Time Period (T1): 1.918s ____From Etabs

Modal Mass Participation Ratio ($\Gamma = 0.78$): First mode participation factor from Etabs

Target Displacement (Δt) Assume 1.26 m (based on performance objectives).

The effective mass participating in the first mode is:

$\text{Me} = \Gamma \text{ X } M_t$

Substituting:

Me =0.78 X 29000 = 22620 tonnes

Effective Stiffness (Ke)

The effective stiffness can be calculated using the relationship:

$\text{Ke} = (4\pi^2 \cdot \text{Me}) / T_1^2$

Substituting values:

$\text{Ke} = (4\pi^2 \text{ x } 22620) / 1.918^2$

Ke ≈ 244,643.3 kN/m

Base Shear (Vb)

The base shear is the product of the effective stiffness and the target displacement:

$\text{Vb} = \text{Ke x } \Delta t$

Substituting:

Vb = 308,246.5 kN

Equivalent Damping (ζ_{eq})

The total equivalent damping ratio is:

$\zeta_{eq} = \zeta_e + \zeta_h$

- ζ_e : Elastic damping (typically 5% for buildings).
- ζ_h : Assumed based on the lateral load-resisting system. For reinforced concrete moment frames, assume 10%.

$\zeta_{eq} = \zeta_e + \zeta_h = 5\% + 10\% = 15\%$

Table 1. Summary of DDBD Parameters

Parameter	Value

Total Mass (Mt)	29000 tonnes
Modal Mass Participation (Γ)	0.78
Effective Mass (Me)	22620 tonnes
First Mode Period (T1)	1.918 Sec.
Target Displacement (Δt)	1.26 m
Effective Stiffness (Ke)	244,643.3 kN/m
Base Shear (Vb)	308,246.5 kN
Equivalent Damping (ζ_{eq})	15%

4.5. Modeling in ETABS 2018- version 18.1.1

Figure 1. Plan Layout of Structure Considered

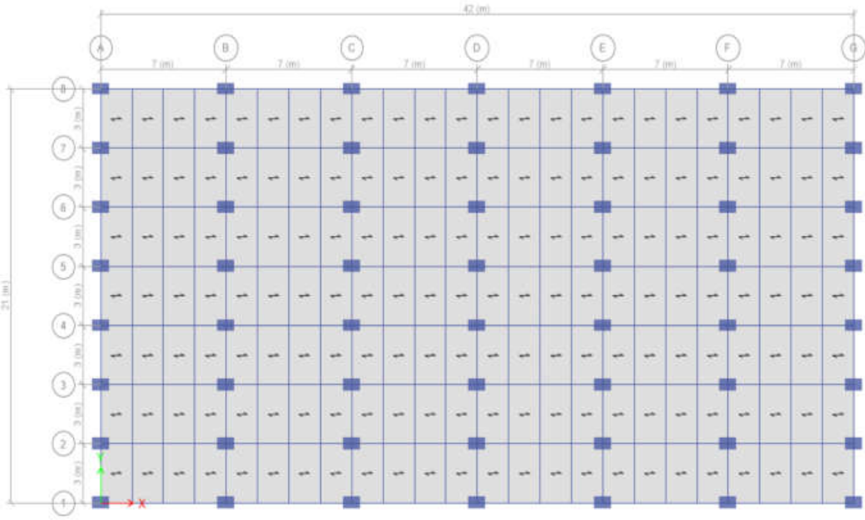
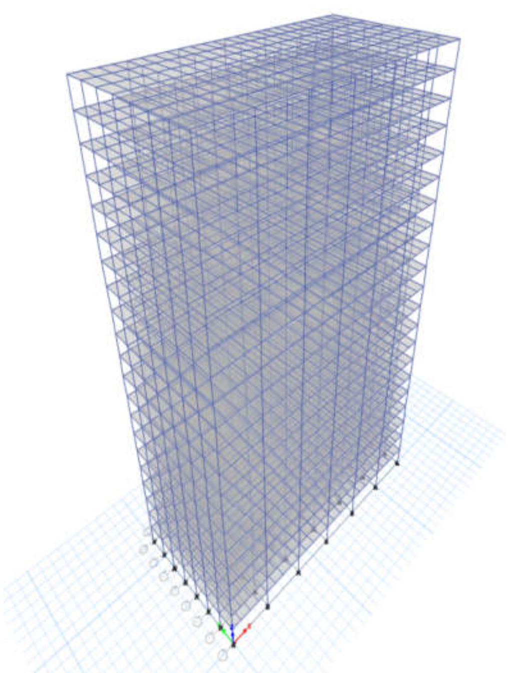


Figure 2. 3-D Layout of Structure Considered



5. RESULTS AND DISCUSSION

5.2 Drift :

The drift comparison between Force-Based Design (FBD) and Direct Displacement-Based Design (DDBD) for a G+20 building highlights fundamental differences in their approaches and resulting outcomes. Drift, being the relative displacement between two consecutive stories, is a key indicator of structural performance under seismic loads. The observed differences stem from the contrasting philosophies of these methods, particularly in how they address stiffness, force distribution, and target performance.

Figure 3. Drift for FBD and DDBD in X-Direction

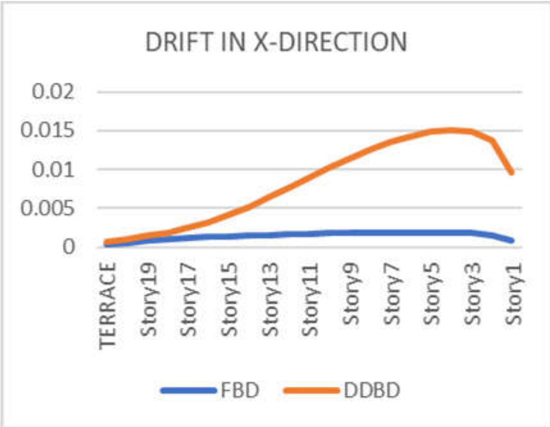
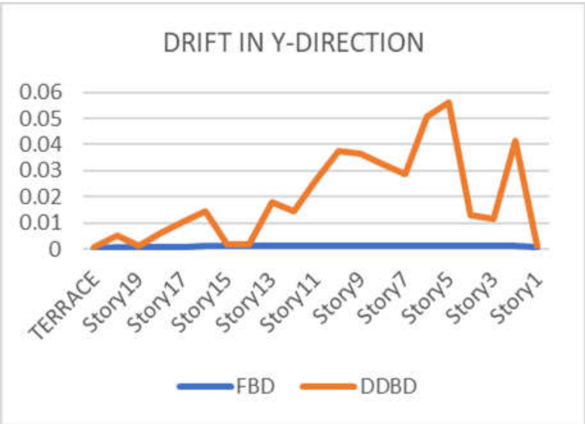


Figure 4. Drift for FBD and DDBD in Y-Direction

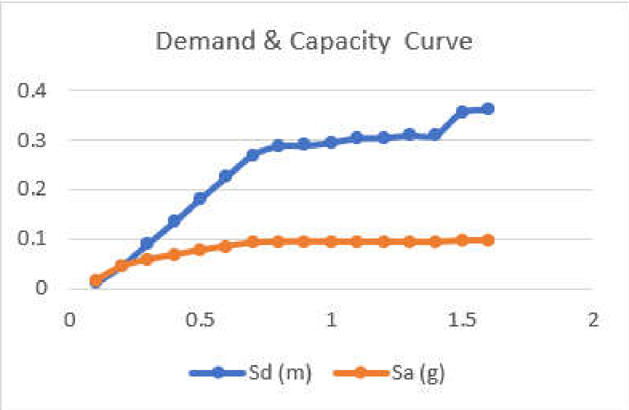


The drift behavior observed in the Force-Based Design (FBD) and Direct Displacement-Based Design (DDBD) methods highlights some significant differences in how the two approaches manage drift across a building's height. In the FBD method, the drift magnitudes are generally higher in the lower stories due to the building's increased stiffness, which limits deformations in these regions, while the drift values peak in the middle stories before decreasing toward the upper stories. This distribution is influenced by the force-based design philosophy, where stiffness is prioritized, and drift control is indirect. In contrast, DDBD results in a more uniform drift distribution across the building's height. While the drift is more gradual in the lower stories, some localized peaks are observed in the mid-height sections, indicating controlled deformation under displacement-based objectives. These differences are primarily due to the design philosophy and stiffness distribution in the two methods.

The FBD method, which focuses on strength and stiffness, distributes seismic forces based on building mass and height. As a result, the drift values tend to be higher in the middle stories where stiffness is lower, leading to uneven drift distribution. The DDBD method, however, explicitly targets displacement as the primary design criterion, ensuring a smoother, more uniform distribution of drift across the height of the building. This is achieved by directly accounting for the building's dynamic behavior, including inelastic deformation. Additionally, DDBD incorporates effective damping, which enables the structure to dissipate energy more efficiently, allowing for more controlled deformations, particularly in the lower and mid-height regions, where greater drift is expected. On the other hand, FBD relies on elastic properties and may overestimate forces and stiffness, which can lead to higher drifts in certain areas, especially in the upper stories.
Furthermore, the seismic response of the building in FBD is based on linear elastic analysis, which does not fully capture nonlinear behavior, resulting in concentrated deformations at certain levels. DDBD, however, uses nonlinear pushover analysis to better represent the building's performance under seismic loads, ensuring that the drift is within the acceptable performance limits for all stories. This explicit verification process in DDBD ensures that the structure performs as intended during an earthquake, providing a more accurate and efficient design, particularly in the critical regions where displacement control is most important. In summary, the FBD method's reliance on force-based design leads to uneven drift distribution, while the DDBD method's emphasis on displacement provides a more uniform and controlled distribution, leading to better overall structural performance under seismic conditions.

5.2 Capacity-Demand Curve

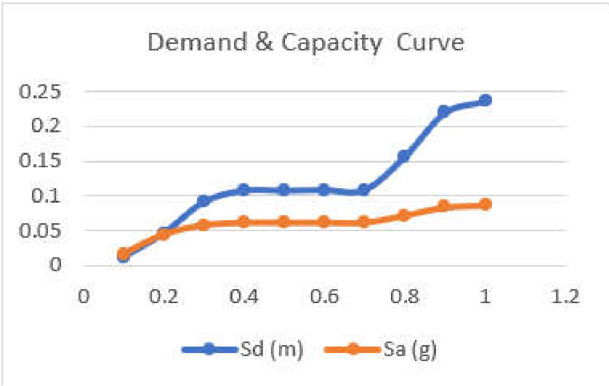
Figure 5. Capacity and Demand Curve of DDBD Method



The demand-capacity curve derived from the Direct Displacement-Based Design (DDBD) analysis illustrates the relationship between spectral displacement (Sd) and spectral acceleration (Sa), two critical parameters used to assess a structure's seismic performance. This curve reflects how the structure behaves under varying seismic demands, providing insight into its displacement and acceleration characteristics as seismic intensity increases. The spectral displacement (Sd) values in the analysis range from 0.010924 m (10.924 mm) to 0.360842 m (360.842 mm), showing a progressive increase as the seismic intensity escalates. Initially, the increase in Sd is gradual, suggesting that the structure is behaving elastically, where its stiffness and elasticity govern the response. As Sd increases further, the structure transitions into the inelastic range, where mechanisms such as energy dissipation through yielding and damping become more significant, indicating the structure's ability to deform without experiencing catastrophic failure. The spectral acceleration (Sa) values, starting from 0.015553 g and peaking at 0.09637 g, initially rise steadily in response to increasing seismic demands. This early rise reflects the elastic behavior of the structure. However, as Sd continues to increase, Sa stabilizes or grows

more slowly, marking the point where the structure begins to experience inelastic behaviour. This signifies that the forces within the structure are being redistributed and energy is being dissipated, which is a key feature of performance-based design. The design allows for significant displacement without excessive force buildup, ensuring the structure remains within acceptable performance limits.
The shape of the demand-capacity curve emphasizes the balance between stiffness and ductility in the structural design. At lower Sd values, the structure remains stiff, causing a proportional increase in Sa. As Sd increases further, the structure's ductility takes over, enabling it to accommodate larger displacements with minimal increase in force demands. This behavior is in line with the principles of DDBD, where the primary goal is to control displacement and mitigate seismic risk by allowing controlled deformations while minimizing the risk of failure. In conclusion, the demand-capacity curve confirms the structure's ability to control displacement and absorb seismic energy effectively. The gradual stabilization of Sa at higher Sd values highlights the structure's resilience under seismic loading, demonstrating the effectiveness of the DDBD approach in achieving performance objectives by focusing on displacement control rather than traditional force-based criteria.

Figure 6. Capacity and Demand Curve of FBD Method

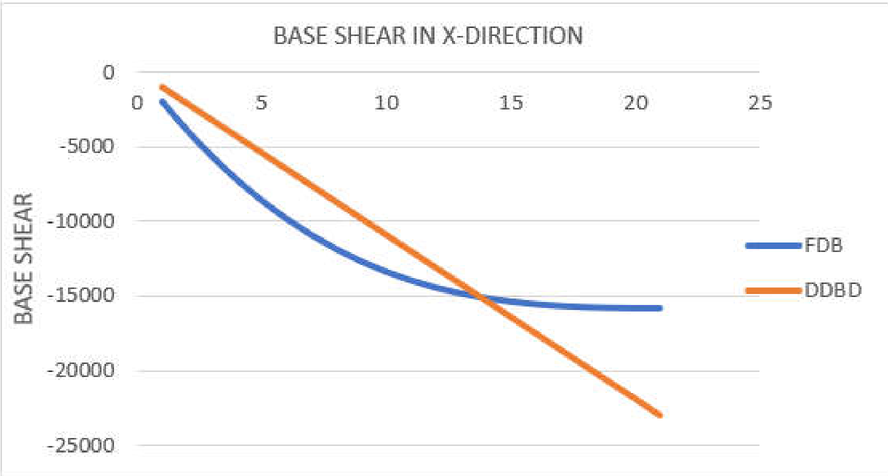


The demand-capacity curve values derived from the Force-Based Design (FBD) analysis highlight the relationship between spectral displacement (Sd) and spectral acceleration (Sa), both of which are essential parameters for understanding a structure's dynamic response to seismic forces. These values help evaluate the expected behavior of the structure under varying seismic loads, ensuring its safety and performance during an earthquake.
The spectral displacement (Sd) values in the analysis start at 0.010924 m (10.924 mm) and gradually increase to a maximum of 0.236339 m (236.339 mm). Initially, as seismic demand increases, spectral displacement rises slowly, indicating that the structure remains in the elastic range, where it behaves rigidly, and displacement increases linearly with seismic intensity. As Sd grows, the structure begins to experience higher levels of deformation, signaling the onset of inelastic behavior and the need for energy dissipation mechanisms in the design.
The spectral acceleration (Sa) values start at 0.015553 g and increase to a peak of 0.086706 g. Initially, the acceleration increases steadily, reflecting the structure's elastic response, where it resists deformation by generating corresponding acceleration. As displacement increases, spectral acceleration reaches its peak and stabilizes, which is characteristic of the structure transitioning into the inelastic range. This stabilization suggests that the structure is no longer solely resisting forces elastically but is dissipating energy through plastic deformation or damping, with force demands increasing at a slower rate as displacement continues.

The key characteristic of the demand-capacity curve is the gradual increase in spectral acceleration at first, followed by stabilization after reaching a certain displacement. This pattern indicates that the structure is designed to withstand varying seismic accelerations while controlling displacement. The progressive increase in spectral displacement, coupled with the stabilization of spectral acceleration, shows that the FBD method ensures the structure remains within acceptable displacement limits while managing the forces generated during an earthquake. The curve's overall behavior demonstrates a balance between strength (acceleration) and ductility (displacement), allowing the structure to deform without failure, thus providing adequate safety and functionality.
In conclusion, the spectral displacement (Sd) and spectral acceleration (Sa) values from FBD analysis confirm that the structure is designed to resist seismic forces while maintaining controlled displacement. The gradual rise in spectral displacement and the subsequent stabilization of spectral acceleration reflects the structure's capacity to absorb seismic energy through inelastic deformations, ensuring it stays within the desired performance limits for both safety and serviceability during an earthquake.

5.3 Base Shear :

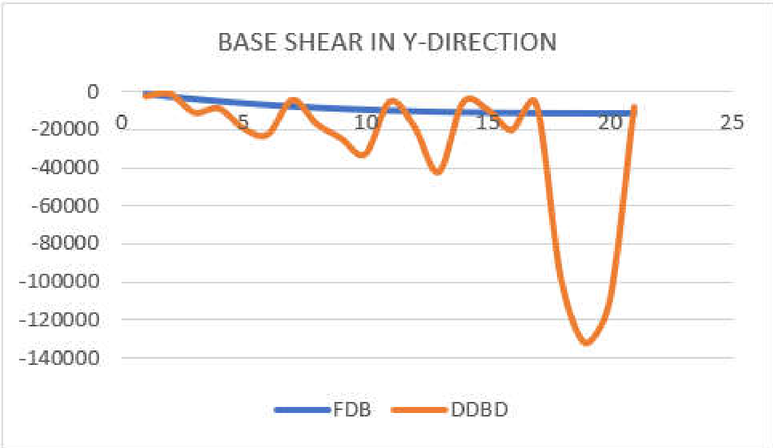
Figure 7. Base Shear for FDB and DDBD in X-Direction



In comparing the base shear trends between Force-Based Design (FBD) and Direct Displacement-Based Design (DDBD), significant differences emerge. FBD results in higher base shear values across all stories, with a sharp increase from the terrace to the base (Story 1), reaching its peak at the ground level. This pattern aligns with the codal approach, where seismic forces are distributed using seismic coefficients and modal shapes. Conversely, DDBD produces significantly lower base shear values, particularly in the lower stories, with a smoother increase from the terrace to the base. The lower magnitude of base shear in DDBD reflects its performance-based philosophy, where the structure is designed to control displacement rather than overestimate seismic forces. These differences are most noticeable at the ground story, where FBD base shear is 30-40% higher than in DDBD, though the gap narrows at the upper stories.
The differences in base shear values can be attributed to the calculation methods and the distribution of forces. In FBD, base shear is derived from building weight, seismic zone factors, and response reduction factors, resulting in larger forces at the lower levels. This leads to over-estimation of force demands, especially in lower stories, while ignoring energy dissipation due to inelastic behavior. DDBD, on the other hand, uses effective stiffness and damping derived from target displacements, allowing for energy dissipation and reduced seismic force demands. The nonlinear pushover analysis used in DDBD

ensures a more accurate force distribution, leading to smoother transitions of forces across the building. Overall, FBD tends to over-design the structure, resulting in higher base shear values and inefficient material use, while DDBD optimizes the design by focusing on controlled displacement and energy absorption, ensuring a more efficient and performance-oriented outcome.

Figure 7. Base Shear for FDB and DDBD in Y-Direction



The base shear trends observed in the Force-Based Design (FBD) and Direct Displacement-Based Design (DDBD) methods show distinct differences in force distribution across the height of the building. In FBD, the base shear values in the Y-direction gradually increase as one moves from the terrace to the base, with the maximum base shear value occurring at Story 1 (-11214.26 kN). This reflects the accumulation of seismic forces based on the structure's weight and the code-prescribed distribution approach, which leads to a more uniform distribution pattern. In contrast, DDBD exhibits a much more variable and nonlinear base shear distribution, with significant spikes in certain stories (e.g., Story 9: -42022.46 kN, Story 4: -97690.89 kN, Story 3: -132496.06 kN) and much lower values in others (e.g., Story 15: -3891.21 kN). This variation is due to DDBD's focus on accommodating target displacements and the incorporation of effective damping, which causes forces to redistribute more realistically across the building's height.

The differences in base shear magnitudes and distributions can be explained by the contrasting design approaches of the two methods. FBD follows a codal approach that calculates base shear based on the building's seismic weight, mode shape, and linear force distribution patterns. This results in higher shear values at the lower stories and a uniform distribution, but it doesn't account for inelastic behavior or energy dissipation, leading to potentially higher forces than necessary. In DDBD, the base shear is determined by the target displacement, stiffness, and damping characteristics of the structure, which allows for the redistribution of forces and energy dissipation through controlled inelastic deformations. This approach results in significant variations in base shear values, with higher forces concentrated in areas of higher displacement, particularly in mid-height and lower stories where inelastic behavior is expected. Additionally, FBD assumes an elastic seismic response, leading to simplified force distributions, while DDBD accounts for dynamic nonlinear behavior, providing a more accurate and performance-based distribution of forces. The observed concentration of forces in certain critical areas of DDBD ensures the structure can meet its performance objectives without over-designing less critical sections.

6. CONCLUSION

The DDBD (Direct Displacement-Based Design) method proves to be the more effective approach for seismic design, particularly in seismic zone V, due to its focus on both the strength and inelastic deformation capacity of the structure. It offers a more realistic and efficient design by reducing base shear and drift while optimizing energy dissipation. In contrast, the FBD (Force-Based Design) method tends to overestimate seismic demands, leading to overdesign and higher construction costs. DDBD is especially beneficial for performance-based seismic design in high seismic activity regions.

The drift values obtained from both methods show that DDBD consistently results in lower drift across all stories compared to FBD. This indicates better control over lateral displacements, improving the efficiency of energy dissipation and yielding more favorable drift performance. FBD, on the other hand, shows higher drift values, particularly in the upper stories, suggesting a greater reliance on strength to resist seismic forces, which can lead to higher demand on structural elements in higher seismic zones.

Base shear values also differ significantly between the two methods. DDBD provides a more accurate reflection of the seismic response by considering inelastic deformations, leading to lower base shear, particularly in the upper stories. FBD tends to overestimate base shear due to its force-based approach, resulting in higher demands on structural elements, especially in tall buildings.

The demand-capacity curves further highlight the advantages of DDBD, as it shows a steady increase in spectral displacement with a stabilization in spectral acceleration. This is more consistent with performance-based design principles. In contrast, FBD exhibits a gradual increase in both spectral displacement and spectral acceleration, which overestimates acceleration demands and can lead to overdesign. DDBD's ability to manage large displacements through ductility and energy dissipation is crucial for high-rise buildings in severe seismic zones.

Overall, the DDBD method is more effective in controlling drift, base shear, and spectral displacement, ensuring better seismic performance with efficient material usage. It aligns with modern seismic design principles, focusing on performance objectives and reducing material costs without compromising safety, making it the preferred choice for high-rise buildings exposed to severe seismic events. FBD, while still effective for some traditional designs, tends to overestimate seismic demands and is less efficient in accounting for inelastic behavior.

7. REFERENCES

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