International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2024.0369

e ISSN: 2855-2854
Volume: 02
Issue: 08 August 2024
Page No: 2553-2558

Performance Based Seismic Design of Reinforced Concrete Building

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Abstract

A novel approach is devised for the displacement-based design of diverse buildings, enabling them to withstand the seismic pressures encountered. The suggested approach necessitates figuring out the structure's yield and final displacements. These characteristics are derived from rough empirical relationships for the preliminary design. The inelastic demand spectrum corresponding to the estimated yield strength and the ductility capacity is then used to calculate the necessary strength of the structure. The structural strength required is then determined from the inelastic demand spectrum that coincides with the yield strength estimate and the ductility capacity. By converting it into an analogous single degree of freedom system, the method can be used to systems with many degrees of freedom. A modal analysis is performed on a model of the structure based on its preliminary design in order to determine the final design. For forces distributed according to the first mode, a pushover analysis of the structure now provides improved estimations of the yield and final displacements. The needed strength is then more precisely calculated using these improved estimates. To achieve convergence between the estimated and calculated values of the design displacements, it could be necessary to perform iterations. Lastly, to take into consideration the impact of higher modes on high-rise moment-resistant frames and shear wall systems.

Keywords: *Bio PBSD, Performance Level, Non-Linear static Analysis, Performance Level, Plastic Hinge.*

1. Introduction

In traditional earthquake force-based design for building structures, the determination of seismic forces involves calculating an equivalent seismic base shear. This base shear is derived from the estimated fundamental period of the structure and an elastic response spectrum that reflects the seismic characteristics of the site. This base shear is calculated using the structure's estimated fundamental period and an elastic response spectrum that takes into account the site's seismic characteristics. The structure's height, and consequently its period, have a major impact on the design base shear value. By ensuring that structures are constructed to withstand seismic pressures appropriate for their location, this method improves structural integrity and safety during earthquakes. Usually, the design process proceeds by taking into account elements like the foundation soil's composition, kind, and relevance in addition to the structure's location and type. The initial seismic base shear calculation is modified to take into consideration the structure's expected over-strength and ductility capacity. The forces at each story level are then calculated using empirical relationships and this corrected base shear distributed along the building's height. The estimated elastic drifts provide the design forces, which are then compared to the specified displacement limits. To make sure that displacements stay within the predetermined bounds, the structure is strengthened if needed. Seismic design codes worldwide, such as the National Building Code of Canada (Canadian Commission 2005), extensively employ this technique.

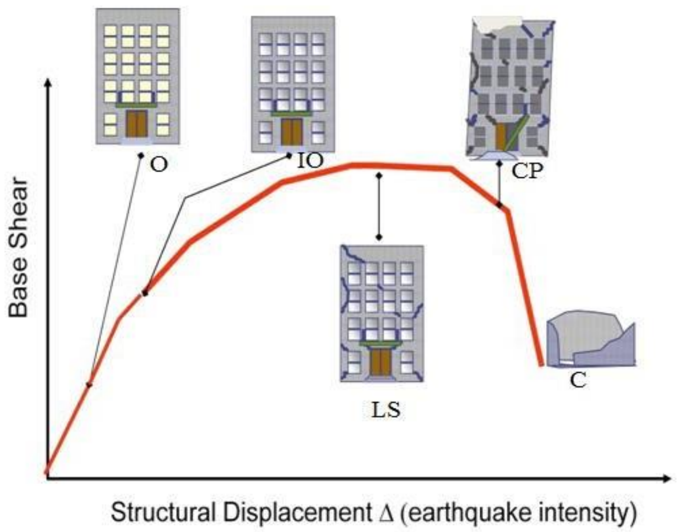

Figure 1 **Performance level**

Performance levels: Once the seismic base shear has been initially calculated, the design process proceeds by considering a number of important variables, such as the kind, location, and importance of the structure as well as the properties of the foundation soil. Adjustments to the base shear are made to accommodate the structure's ductility capacity and expected over-strength, ensuring it can adequately withstand seismic forces.

Capacity: The expected ultimate strength of a structural component refers to its maximum capacity to resist flexure, shear, or axial loading, excluding the reduction factors (Φ) typically applied in concrete member design. This capacity is frequently found along the capacity curve of the structure or at the element's yield point. In components subject to deformation control, such as those experiencing strain hardening, the ultimate capacity extends beyond the elastic limit. This means that the structural element can withstand higher loads and deformations without compromising its overall integrity. Engineers consider these factors carefully when designing to ensure that structures can endure significant stresses and strains while maintaining safety and functionality. This approach helps to accurately predict and manage potential failure modes, ensuring robustness and reliability in structural design. It is now commonly known that a structure's ability to withstand an earthquake depends on the ductility demand it encounters as well as displacements and interstory drifts. The conventional force-based design approach controls displacements indirectly while mainly regulating strengths. However, it does not consistently ensure uniform performance levels, leading to concerns about the reliability and cost-efficiency of current design practices. In response, displacement-based design (DBD) methods have emerged as more effective alternatives. These approaches prioritize controlling and managing displacements and drifts directly, rather than solely focusing on strength levels. By directly addressing these parameters, DBD methods aim to enhance structural performance by ensuring that deformations during seismic events are within acceptable limits. This approach not only improves the reliability of structural designs but also potentially optimizes the economic aspects by better aligning performance goals with design outcomes. Displacement-based design methods have garnered significant interest in recent years due to their potential to ensure consistent and reliable performance levels in structures during seismic events. These methods are increasingly being viewed as the preferred approach in future seismic design codes. In ongoing studies, a novel displacement-based design method is being developed that can be applied across various structural systems. This method not only facilitates the design process but also offers a means to assess the performance of existing structures. Notably, by adopting displacement-based design across different hazard levels, engineers can tailor the seismic performance of structures to meet specific safety criteria under varying levels of earthquake intensity. The versatility of displacement-based design makes it a cornerstone of performance-based design strategies. This approach enables engineers to systematically evaluate and improve structural resilience by directly addressing displacements and drifts, thereby ensuring that structures maintain functionality and safety during

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seismic events. As seismic design continues to evolve, displacement-based methods are poised to play a pivotal role in advancing structural engineering practices towards greater reliability and efficiency.

1.1. Objectives Of the Study

1) Displacement-based design guidelines represent a progressive approach in seismic engineering, emphasizing the control and management of displacements and inter-story drifts as primary design criteria. Unlike traditional force-based methods that predominantly focus on regulating strength, displacement-based design ensures that structural elements can withstand seismic forces while maintaining acceptable levels of deformation.
2) Existing displacement-based design (DBD) methods in seismic engineering represent a significant advancement in ensuring structural resilience and performance under earthquake conditions. These methods have evolved to address shortcomings in traditional force-based approaches by directly focusing on controlling displacements and inter-story drifts, which are critical indicators of structural integrity during seismic events
3) Developing a new displacement-based design (DBD) method that is both practical and suitable for regular structures involves several key actions to ensure effectiveness and simplicity in design:

- Approximate Yield Displacement of Structural Systems: Approximate yield displacement of the structural system is assessed as the initial stage in the suggested DBD method. This involves estimating the displacement at which the structure begins to exhibit significant yielding and nonlinear behavior. This can be determined through empirical formulas or simplified analytical models that consider the stiffness and mass distribution of the structure.
- Evaluation of Ultimate Displacement of Structural Systems: The structural system's ultimate displacement capability must next be assessed. This is the greatest displacement that the structure will bear before collapsing or suffering permanent harm. Ultimate displacement is typically higher than yield displacement and is crucial for assessing the structure's overall ductility and resilience.
- Application of Nonlinear Static Analysis and Pushover Analysis: During the preliminary design phase, nonlinear static analysis and pushover analysis are used to improve the yield and ultimate displacement estimates. Engineers can simulate the nonlinear behavior of the structure under increasing lateral stresses by using nonlinear static analysis, commonly referred to as pushover analysis. This analysis provides better insights into the distribution of displacements and forces throughout the structure, helping to refine the design and estimate yield and ultimate displacements more accurately.

4) Ground Motion Prediction Equations (GMPEs): Utilize ground motion prediction equations suitable for the region to estimate the expected ground motions. These equations relate earthquake characteristics (magnitude, distance, site conditions) to ground motion parameters (acceleration, velocity, displacement)
5) The roof drift of a building is influenced by the cumulative effects of inter-story drifts throughout the structure. As seismic forces propagate through the building, they induce inter-story drifts that accumulate to produce the roof drift.
6) Generally, the maximum inter-story drift occurs at the floor levels where the structural response is most pronounced. This maximum inter-story drift contributes directly to the overall roof drift

1.2. Literature Surveys

There has been a lot of research on PBSD in the literature. This study's methodology, guiding concepts, and other PBSD-related factors are reviewed. The following section discusses a few related works. Studying seismic safety and re-

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strengthening, seismic evaluation and retrofitting of concrete buildings are examined [1]. Additionally, ASCE FEMA repost offers pre-standards and discussion on the seismic rehabilitation of buildings, along with provisions for the same [2]. carried out research on the use of PBSD in the seismic design and assessment of building structures. In the discussion of the deterministic and probabilistic approaches, the capacity spectrum method from ATC-40 and the typical pushover analysis from FEMA 356 are briefly mentioned. ATC-40 and FEMA 356 are studied in comparison (Farzad Naeim, Hussain Bhatia, 2008) [3]. In addition to outlining and contrasting the three approaches, this paper also discusses them in relation to previous performance-based design approaches and conventional force-based seismic design. A crucial performance limit that must be included is residual displacement, which is one of the factors that define the various performance levels that were addressed. A study on the seismic design and assessment of building structures using PBSD was carried out by Sashi K. Kunnath in 2006. In the discussion of the deterministic and probabilistic approaches, the capacity spectrum method from ATC-40 and the typical pushover analysis from FEMA 356 are briefly mentioned. An analysis is conducted to compare ATC-40 and FEMA 356 (Farzad Naeim, Hussain Bhatia, 2008). An overview of the benefits and drawbacks of performance-based seismic engineering is given in this work. We introduce and explore the cutting-edge approaches and strategies found in the two most authoritative recommendations on the issue, ATC-40 and FEMA 273/274. To illustrate the real-world uses of the techniques covered, numerical examples are given (Vivinkumar, R.V., 2013). The two main seismic design approaches—force-based design and direct displacement-based design—are discussed in this paper. The former is a traditional method, while the latter takes a performance-based approach to design. Based on the codes IS 456, IS 1893:2000, and FEMA 356, design and analysis were completed on two-dimensional bare frames of four, eight, and twelve stories [4]. The two design approaches were also examined.

2. Methodology

The building's lateral displacement serves as the primary demand and capacity parameter in a nonlinear static technique or pushover analysis. The building's capacity for a specific force distribution and displacement, such as foundation shear vs. roof displacement, is represented by the capacity curve. The building's reaction must fall somewhere along this capacity curve if it moves laterally. A point on the curve designates a certain structural damage status. A point on the capacity curve that indicates the maximum displacement of the building that an earthquake will cause can be discovered by comparing it to the seismic demand produced by a particular earthquake or the severity of the ground shaking. The performance point, or target displacement, is defined at this moment. The capacity curve's performance point's location is correlated with performance levels, which show whether or not the design satisfies performance objectives. If necessary, this leads to a redesign and reevaluation until the intended performance objective is attained.

2.1. Model Data

The G+5 storey reinforced concrete frame building located in zones 3, 4, and 5 maximum considered earthquake is the subject of this study's design-based earthquake analysis. Figure 1 depicts the size and quantity of bays. The building is eighteen meters tall overall. Slab thickness is measured in millimetres (mm). The size of the column and beam is 600 x 600 mm. The structure has a response reduction factor of 5.0 and is classified as a Special RC moment resisting frame (SMRF). Because its importance factor is 1.5, this structure is classified as an educational building. In accordance with IS 456: 2000 and IS 1893(part 1): 2002, load combinations are determined. A slab's dead load is calculated at 5 Kn/m2. Live load on a slab is calculated at 4 Kn/m2, without including the roof. The dead load of outside beams is 12.5 kn/m, while the dead load of inner beams is 8.1 kn/m. The capacity spectrum approach is used in accordance with ATC 40 rules. [5] Figure 3 Comparison of Storey Displacement Zone 5, 4 and 3 Maximum Considered Earthquake.

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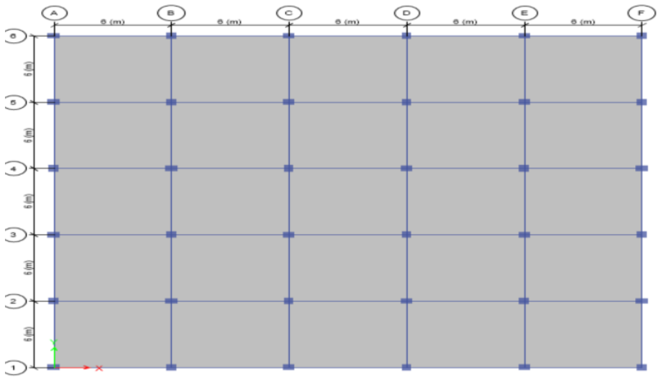

Figure 2 Building Plan

2.2. Results And Discussion

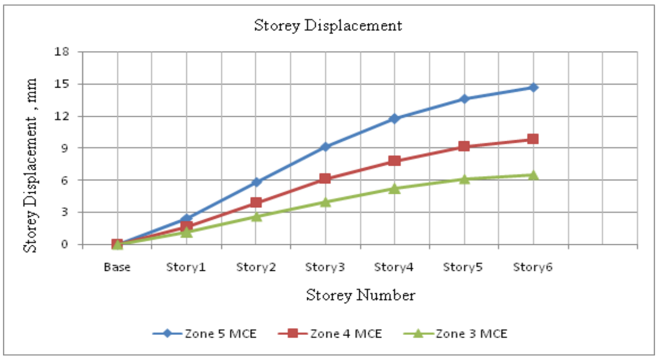

Figure 3 Comparison of Storey Displacement Zone 5, 4 and 3 Maximum Considered Earthquake

Table 1 Story Response

STORY	ELEVATION	LOCATION	X- DIR (mm)	Y- DIR (mm)
6	18	TOP	1.021	0.826
5	15	TOP	0.811	0.667
4	12	TOP	0.630	0.515
3	9	TOP	0.445	0.363
2	6	TOP	0.263	0.212
1	3	TOP	0.086	0.069
Base	0	TOP	0	0

The building is therefore in the immediate occupancy performance level by design. Thus, the design's necessary performance aim has been met. The following table shows the provided building's final design following non-linear statics analysis. Figure 2 shows Building Plan. Story response is shown in Table 1 and the results obtained from story displacement is shown in table 2.

Table 2 Results Obtained from Story Displacement

Target roof displacement ratios at various performance level				
Performance level	Operational	Immediate occupancy	Life safety	Collapse prevention
Lateral drift ratio=(δ/h)	0.37	0.7	2.5	5
Zone 3 DBE	0.17			
Zone 3 MCE	0.36			
Zone 4 DBE	0.33			
Zone 4 MCE		0.70		
Zone 5 DBE	0.40			
Zone 5 MCE		0.82		

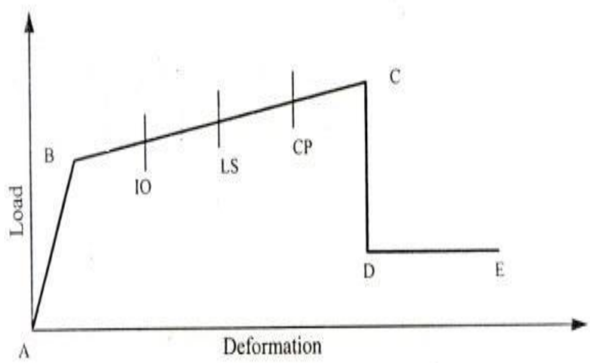

Figure 4 Load-Deformation Curve

Point 'A' corresponds to the unloaded condition.
Point 'B' corresponds to the onset of yielding.
Point 'C' corresponds to the ultimate strength.
Point 'D' corresponds to the residual strength.
Point 'E' corresponds to the maximum deformation capacity with the residual strength.

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Table 3 Results Obtained from Capacity Spectrum Curve

Plastic hinge formation results						
	A-B	B-C	C-D	D-E	>E	Total hinges
	A-IO	IO-LS	LS-CP	>CP		
Zone 3DBE	1796	418	78	12		2304
Zone 3MCE	1908	392	4	0		2304
Zone 4DBE	2268	36	0	0		2304
Zone 4MCE	2000	296	0	8		2304
Zone 5DBE	1856	404	22	22		2304
Zone 5MCE	1918	378	0	8		2304

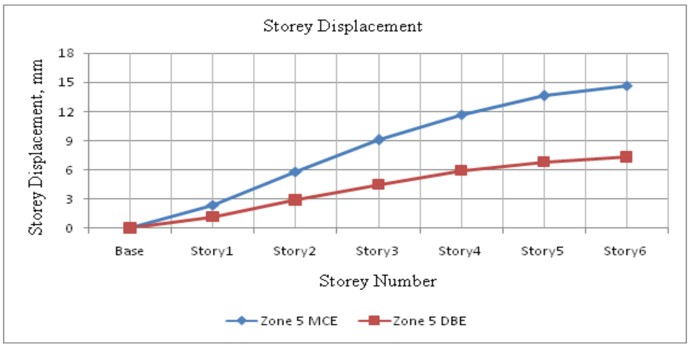

Figure 5 Comparison of Story Displacement Zone 5 Design Based Earthquake and Maximum Considered Earthquake

Conclusion

1) Based on the findings, it is evident that both story displacement and story drift increase as the seismic zone classification increases. This trend indicates that structures located in higher seismic zones experience greater displacements and drifts during earthquakes compared to those in lower zones. Results obtained from Capacity Spectrum is shown in Table 2.
2) As the seismic zone classification increases, it is observed that the base shear tends to increase while displacement decreases. This trend suggests that structures located in higher seismic zones experience higher forces exerted at their base, indicating greater seismic loads. Concurrently, the displacements experienced by these structures during earthquakes tend to be reduced. Figure 5 shows The Comparison of Story Displacement Zone 5 Design Based Earthquake and Maximum Considered Earthquake
3) By using performance-based design, we can find actual performance from practical point of building for applied zone, lower zone and farther zone.
4) [Plastic hinges formed in columns and beams are within immediate occupancy and life safety, as they are designed with “strong column and weak beam concept”.

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