

# Performance-based Seismic Design of reinforced concrete Structure - A Review

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## Abstract

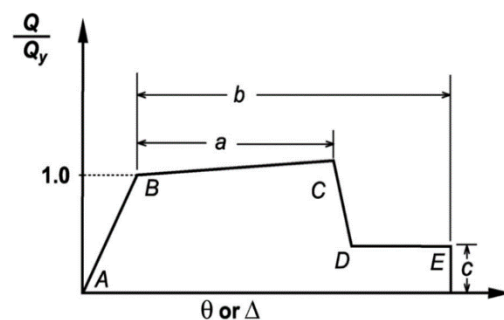
In recent times, in multistory buildings, the seismic demands were met using the code-based method of seismic analysis and design of the structure, although the design of building can be more optimized by a more modern and realistic design approach in the form performance based design. As per the code, the building performance under seismic response are categorized into different levels of performance checks for the actual ground motions or some sets of ground motions, limiting the global damage and thereby creating a scope for optimization at material level and at cross section level of the reinforced concrete structure. The building can be designed or checked based on this code prescribed performance levels, reducing the potential risk of the future earthquake as well as the damage or the loss caused due the earthquake. This review paper highlights numerous studies done by researchers comparing the responses from the code-based design and performance-based design, paving the way for use of performance-based design in the structure.

**Keywords:** Reinforced concrete frames, Performance-based design, Collapse Capacity, inter storey drift, Ground motions, Structural optimization.

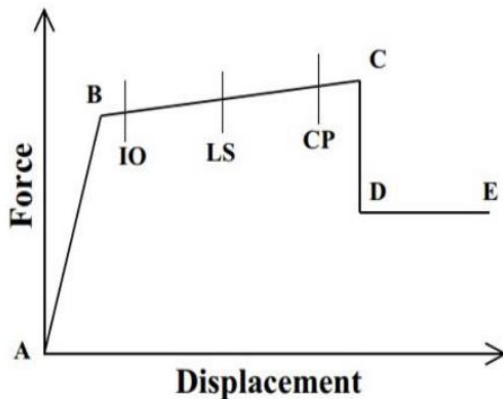
## 1. Introduction

Performance-based seismic design (PBSD) is a concept that permits the design and construction of buildings with a realistic and reliable understanding of the risk to life, occupancy and economic loss that may occur because of future earthquakes. PBSD is a based on an assessment of a building's design to determine the probability of experiencing different types of losses, considering the range of potential earthquakes that may affect the structure. This allows a building owner or regulator to select the desired performance goal for their building []. It is an approach in which structural design criteria are expressed in terms of achieving a set of performance objectives. It ensures the structure reaches specified demands in both service and strength design levels. PBSD also quantify the performance of the designed

buildings. The different levels of performance checks are Immediate occupancy (IO), Life safety (LS) and Collapse prevention (CP). The ground motions used for PBSD is a set of spectral matched ground motions having a set of 11 ground motions as per ASCE 7. The below figure shows the force deformation relation and the modelling parameters to be used.



**Figure 1** Force-Deformation Relation



**Figure 2 Acceptance Criteria**

## 2. Seismic Application of Reinforced Concrete Structure

This literature survey includes previous work conducted by some researchers on performance based seismic design of reinforced concrete structures. Geyu Dong et.al. 2023 conducted analysis and design of 3,5,10,15 storey RC frames with the set of six spectra compatible earthquake ground motion records. This research also focuses on the concept of uniform damage distribution (UDD). The damage caused in the structure at global level reducing the global level damage up to (88%), hence preventing local level damage after optimization and the impact is also seen in the inter storey drifts as well as plastic rotation reducing up to (58%) and (78%) respectively. Also maintaining a reducing in material level i.e. concrete and steel consumption up to 20% and 43%. The optimization is done at material level and cross section level for optimum results to be achieved for comparison of code based design as well as from performance based design. The different performance parameters to satisfy multi performance objectives which are IO, LS, CP under different earthquake intensity levels from frequent earthquake to rare earthquake cases. In order to obtain economic and optimal design solution, use of optimization based on mean of the set of spectral compatible records are recommended [1]. X.K. Zou et.al. 2018 describes the development of a Multi objective optimization aimed at incorporating performance based seismic design methodology into the design of concrete building structures. Different objectives highlighted in this

research paper to minimize the life cycle cost of a reinforced concrete frame which includes both initial material cost and expected damage loss due to seismic events. The initial material cost is expressed in terms of design variables and the expected damage loss is quantified based on seismic performance levels. The design constraints explicitly considered is inelastic response forming plastic hinges. The optimization algorithm is based on strain constraint method which effectively produces pare to optimal set of solutions, this allows the decision makes to select the best compromise solution between initial material cost and damage loss, emphasizing the effectiveness and practical applicability of the optimization techniques in designing RC building structures that can withstand seismic events while minimizing life cycle cost. [2] Orlando Arroyo et.al. 2016 the study examines the effectiveness of the design procedure by analyzing various structural performance metrics. The results show that the proposed designed methods yield building with distribution of strength and stiffness across different heights, showing considerable reduction of drifts at lower stories, decreased collapse risk and lower expected casualties compared to traditional designs. This research emphasizes to enhance seismic resilience of structural and mitigate potential risks associated with seismic events. The findings highlight several benefits of optimized RCF buildings over traditional counterparts remarkably added advantages of optimized design despite modest difference in period between traditional and optimized designs [3]. Iman Hajirasouliha et.al. 2012 The study shows the utilization method based on uniform damage distribution to determine the optimum design load distribution for seismic design of both regular and irregular shear building, optimization method is based on uniform damage distribution throughout the structure, which improves the load distribution in such a way that the structural element experiences similar levels of damage minimizing overall damage to the structure. The optimized building experience up to 40% reduction in global damage in the practice of performance based seismic design. The study also reveals that

optimal load distributions for structures with similar fundamental periods and maximum ductility demand but different soil profiles (from hard rock to stiff soil) are nearly identical, whereas structures on soft soil profiles show slightly different optimal load distributions. [4] Ashish R. Akhare et al. 2015 says that, for structures of code exceeding design considerations, such a design method is efficient and effective to avoid any futuristic casualties as the performance-based design study fulfills the acceptance criteria for immediate occupancy and life safety limit for given intensities of earthquake. For the study, buildings generated using ETABs having building level as 'G+6' and the shape of the building varies from regular to L, C, and T shaped. The analytical techniques used are Standard pushover analysis and Modal pushover analysis. Non-linear time history analysis is also carried to validate the method accuracy. The study states that for regular building, the results obtained from both the analytical methods and the time history results are the same. But, for irregular structures, better and more considerable results are obtained by the two methods than the time history analysis. The torsion produced in irregular building is 20% more than regular buildings [5]. Ms. Pallavi Dhawane et al. 2023 illustrates the performance behavior of the columns undergoing through seismic activity. Performance based seismic design methodology were adapted for designing the G+1 story building modelled using ETABs having square and rectangular columns of different cross-section. The shape, size, orientation, and direction of the columns were studied after seismic action. In this analysis, the base section, lateral movement, deviation between floors and time are found. The analysis result of each model was compared according to base movement, upper layer displacement, layer deviation and period. [6] Iman Hajirasouliha et al. 2011 provides a study stating that the results obtained from the similar structural weight, designed structures undergo up to a 30% reduced global damage compared with the code-designed structures. The study is done by applying design algorithm on 5, 10 and 15 story RCC frames that satisfies intermediate ductility requirements.

Non-linear time-history analysis using IDARC computer program was the analytic method used. Optimum seismic design for design spectrum were carried out for each building type. The review provides us with a concept of altering the steel reinforcement ratio in beams as the proposed method leads to 33% less longitudinal reinforcement, simultaneously satisfying the LS and CP performance objectives. RC frames designed with average synthetic earthquake exhibit less global damage and more uniform inter-storey drift distribution [7]. Vahid Mokarram et al. 2018 provides a more economical model for solving structural multi-objective optimization framework than the Non-linear time-history analysis. The new metaheuristic surrogate model called as the Surrogate FC-MOPSO which is an algorithmic extension of FC-MOPSO. Methods like NTHA and Push over analysis, are also employed for validating the responses. The model developed not only reduces the cost and leads to considerable reduction of runtime of the problem. Adopting PAs as the only evaluation tool in optimal performance-based design of structures can result in unreliable solutions. The author suggests that though FC-MOPSO gives good results on multiple function evaluation, but it was not practical to use it on PBD frameworks where NTHA methods for evaluation is used, as NTHA method proves to be more accurate. [8] Navid Razavi et al. 2021 study on assessment of seismic collapse capacity of PBD RCC frames comprises of two parts, PBD optimization and Seismic collapse safety assessment. Illustrative models of 3, 6, and 12 storey frames were used. Optimization methodology like efficient metaheuristic algorithm was adopted with objective of evaluating the initial and final cost. In the second part, the collapse capacity is evaluated by conducting seismic fragility analysis. In conclusion, considerable reduction in the initial and total cost were obtained for designs in Performance Group T (PGT) compared to the designs of Performance Group I (PGI). Also, the collapse capacity results of PGT models were also much better than the PGI models. [9]

## Conclusion

Through literature survey it can be concluded that the adopting the method of performance based design compared to the traditional code based method has advantage of focus in reduction in global level damage and minimizes local level damage due to distribution of load over the entire structure is uniform hence the damage is uniform thereby optimizing the structural elements at cross section level and material level significantly reducing the consumption making it economic and robust structural seismic design against the future earthquake and forecasting the damage loss occurred after an earthquake event increasing the life safety of the owner and fulfilling the performance for which the structure is to be designed.

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