Review on Performance Based Seismic Analysis of Reinforced Concrete Structures.

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Abstract— Buildings built according to conventional earthquake resistance standards were severely damaged in the earthquakes that occurred around the world in the past. This shows that the force based approach is not sufficient and the seismic design approach needs to change from the traditional to performance based design, which is cost effective and provides actual behavior of structures. Effect of cyclic loading and nonlinear behaviour can be effectively addressed by this method. In addition, the system also provides information about the potential risk to life & financial loss, subsequently increasing the reliability and efficiency of building construction with considering the effects of seismic events. The purpose of performance based seismic analysis method is to evaluate performance of structure under specific seismic hazards and to incorporate analysis & evaluation of potential performance into the design process. Nonlinear static method such as pushover analysis allows analysis of the buildings response to lateral loads. It provides information about the sequential formation of plastic hinges in members and other important factors.

Keywords — Performance based seismic analysis, Non-linear analysis, Displacement based design, Forced based design, Pushover analysis and target displacement.

I. INTRODUCTION

As earthquakes can cause the most severe damage among all natural disasters, it is necessary to enhance engineering tools for analyzing structures under their unpredictable & random seismic force. In traditional earthquake resistant design approach, the structures are designed to withstand forces significantly lower than those predicted during a design earthquake. Therefore when subjected to intense ground motion during a severe earthquake, these structures experience inelastic deformation [1][5]. To study the inelastic behavior of structure nonlinear static analysis is used. The pushover analysis or nonlinear static analysis is expected to give sufficient information about the seismic demands placed on the structural system and its constituent parts by the design ground motion. It helps to determine how a structure should perform when subjected to significant forces and adjusting the design accordingly [3][4].

II. LITERATURE REVIEW

Many researchers have extensively explored Performance Based Seismic Analysis, employing various computer software programs such as,

A. Tushar Donga, Dr. Vinay Agarwal and Dr. Rajesh Gupta[1]

The study utilized the nonlinear static analysis conducted in ETABS software to evaluate seismic performance of reinforced concrete buildings specifically focusing on shear walls. Various models were developed with shear walls in different configurations including outer periphery of the core and diagonal corners of the building. The behaviour of structures beyond their elastic boundaries was studied by incremental lateral force application in pushover analysis. Parameters such as pushover curves, deflection, base shear and storey drift were compared across different models to assess the impact of shear walls on the structural system. Results indicated that RCC frames having shear walls gives an increase in resistance to base shear and decreased displacement as compared to those without shear walls. The study also explained different types of pushover analysis methods such as Displacement Coefficient Method and Capacity Spectrum Method as well as various hinge property. The study offers valuable points into the seismic behaviour of RCC structures and highlights the effectiveness of shear walls in enhancing structural performance against seismic forces.

B. Chunyu Zhang and Ying Tian[2]

This study presented a simplified performance-based optimal seismic design approach for multi-story reinforced concrete moment frames. The proposed approach aimed to minimize construction cost while meeting seismic performance requirements. It incorporated member plastic

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rotation and optionally inter-story drift as optimization constraints. The optimization procedure involved determining the feasible region boundary in strength and stiffness domains. It also optimized material consumption. The capacity spectrum method was used to estimate global and local deformation demands at peak dynamic response. The approach was applied to the design of a six-story reinforced concrete frame. It demonstrated a reduction in flexural strength and cross-sectional area from the initial strength-based design. Nonlinear time-history analyses were conducted on the optimized structure using historical ground motions scaled to represent three levels of seismic hazard. Challenges hindering the adoption of performance-based seismic design for new building designs were discussed. There was a need for developing optimal PBSD procedures. Various objective functions were highlighted, which included performance measurements and constraints used in existing optimization methods. The importance of nonlinear static analyses in formulating a performance-based optimal design was emphasized.

C. Sayed Shuaib Qammer, Sejal P. Dalal and Purvang Dalal[3]

The paper presented an analysis and design of reinforced concrete moment resisting frames using direct displacement-based design (DDBD) and performance-based plastic design (PBPD) methods aligned with the Indian standard code IS 1893:2016. The study involved 4-, 8- 12- and 15-storied frames, evaluating their seismic performance through nonlinear static pushover analysis. It highlighted the use of design spectra from the Indian standard code and included base shear calculations. Emphasis was placed on the satisfactory performance of both methods in terms of capacity and deformation, with the study revealing that the response reduction factor values obtained for both DDBD and PBPD methods were greater than the specified value in the Indian standard code, indicating enhanced ductility for both approaches. Additionally, there was discussion on design acceleration spectrum and seismic zone factor, along with the calculation and distribution of base shear in both DDBD and PBPD methods, providing insights into lateral load distribution. The calculation of base shear effective stiffness and seismic performance evaluation were thoroughly discussed, alongside the illustration of pushover curves, deformation profiles, and response reduction factor values for the study frames to showcase their seismic performance. The study also highlighted discrepancies between the design base shear values obtained using DDBD and PBPD methods, suggesting the need for further exploration and the implementation of displacement-based design methods in seismic code provisions.

D. Bhupendra Sharma and Abhijeet Galatage[4]

This study has focused the need to assess resistance to seismic activity of existing structures and highlights the significance of performance based seismic engineering. A Parking+G+12 storey reinforced concrete structure laying in zone-II was selected for analysis. The structure was first analyzed by response spectrum method & then nonlinear static analysis was carried out using SAP2000 & ETABS software. Explanation of reasons of failure like twisting, excessive mass on the upper floors, P-Δ effect and lack of ductility in the bottom layer were given. Various analysis parameters like story shear, displacement, base shear Vs monitored displacement performance objective on the basis of development of hinges & pushover curve where compared.

E. Anurag Sharma, R.K. Tripathi and Govardhan Bhat[5]

Four-storey and eight-storey buildings were analyzed and performance of that buildings using force based design and direct displacement based design was evaluted. The structures were designed for seismic parameters by using IS 1893(part 1)-2016 with the help of SAP2000 software. For force based design IS 456-2000 was used & linear analysis was carried out, nonlinear analysis was used for direct displacement based design. Analysis parameters like base shear, maximum displacement & inter-storey drift ratio were compared. Additionally, the study explained the use of FEMA 356 for assigning lumped plasticity hinges for beams and columns. The results of this study was base shear values, stiffness and acceleration demand were less of DDBD when compared to FBD. Overall DDBD method was proved to be more effective than FBD.

F. Mohd. Zameerudin and Keshav K. Sangle[6]

The objective of this study was to examine the behavior of reinforced concrete moment frames. Fifteen moment resisting frames divided as 4, 6, 8, 10 and 12 storey heights and on the basis of number of bays were used for analysis. These structures were initially designed by using IS 456-2000 and IS 13920 and then a displacement controlled nonlinear analysis was carried using SAP2000 software. The author specified the target displacement value which is to be considered as per ATC 40, 1996. The analysis of all this structures were carried in two steps i.e, force controlled method was used for the gravity analysis and then for nonlinear analysis lateral loads were applied monotonically in various steps and various parameters were compared. They concluded that damages in structures can be effectively assessed by nonlinear response of the structure.

G. Hozan Himdad Majeed and Bayan Salim Al-Nu'man[7]

This study emphasized on utilizing pushover analysis to assess the seismic performance of reinforced concrete members. It highlighted how essential it was to fully understand how a structure behaved after an earthquake. It explained the purpose of using pushover analysis over conventional methods for evaluating the performance of the structure by using ETABS software. Pushover analysis is

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therefore an effective for determining the precise nature of failure modes that are certain to be seen on a building structure as a result of earthquake events. Pushover study validated the structure's serviceability and assessed the building category status at the performance point.

H. B. Shiva Shankar Raju and Dr. S M V Narayana[8]

The main purpose was to carry out seismic analysis of reinforced concrete structure which was designed with shear wall, concentric steel bracing and the combination of both shear wall and bracing. A rigid frame structure was also considered for the comparison. A 25 storey RC building was considered which is situated in seismic zone II and analysis was carried out using ETABS 2016 version software. Stiffness comparison was made between different types of system. Different structural system were divided as rigid frame, model with only shear wall, shear wall with bracing and model with concentric bracing. They concluded that the structure having both lateral load resisting system i.e shear wall and bracing reduces the displacement to greater extent as compared to other structural systems.

I. Mr. Chetan Ingale and Prof. M.R. Nalamwar[9]

This paper thoroughly studied the performance based seismic design and nonlinear static analysis of reinforced concrete structures. A G+5 RCC building is considered and was designed using Indian Standards i.e IS 1893(Part-1):2002 and IS 456-2000 with the concept of strong column and weak beam concept. The structure assumed were analyzed for different zone like zone V, IV and III for maximum considered earthquake and design basis earthquake with the help of ETABS software. Pushover analysis as per guidelines of ATC 40 was carried out. The author has given detailed explanation about performance levels, performance objectives, maximum considered earthquake, design basis earthquake, capacity curve and demand curve. After analysis, this study proposed that with an increase in the zone, both displacement and storey drift increase, along with an increase in base shear. Contrary to that displacement decreases as the zone increases. Moreover the formation of plastic hinges in beams and columns remained within limits, ensuring immediate occupancy and life safety.

J. Dilip J. Chaudhari and Gopal O. Dhoot [10]

A four-storey RC frame structure was analyzed and designed and its performance was evaluated by nonlinear static analysis using SAP2000 software. The analysis methods, such as pushover analysis, capacity demand spectrum, inter-storey drift & plastic hinge results were discussed. The buildings performance was assessed across different levels including operational, immediate occupancy, life safety and collapse prevention. This study provided insights into the order of yielding and failure modes of members of buildings under earthquake loads and gave the importance of taking displacement as a measure of building performance.

K. Ziaulla Khan, B.R Narayana and Syed Ahamed Raza[11]

In this paper, the author has considered a special moment resisting frame building which was situated in zone IV as per IS 1893 (part-1) 2016. Four different types of models with different bracing systems were considered for analysis. The structures like the bare frame, structure with concentric X-bracing at center bay, eccentric X-bracing at center bay, concentric inverted V-bracing at adjacent bay and eccentric inverted V-bracing at adjacent bay were analyzed using ETABS software. The main objective was to study the elastic & plastic behaviour and comparative study for concentrically and eccentrically placed system at various locations in the structure with linear static & nonlinear static analysis method. After all this comparison X-bracing structure gave good response as compared to other lateral load resisting system for both linear and non-linear static analysis.

L. Dimpleben Sonwane and Prof. Dr. Kiran B. Ladhan [12]

This study has considered an unsymmetrical L-shaped G+4 reinforced concrete structure. The main purpose was to verify about the structures performance when designed with IS code. The structures were divided on the basis of percentage of reinforcement provided in beams and columns in different percentage. In beams reinforcements were increased by 7.5% and 15% on each storey and 36.11% and 50% in different columns throughout all story. Nonlinear pushover analysis was carried for checking the performance of the structures. They concluded that increasing reinforcement percentage in columns increases the performance which results in decrease in roof displacement, this also increases the base shear. By changing reinforcement percentage in beams of 1st story, a major affect was seen in base shear.

M. Satpute S G and D B Kulkarni [13]

This study has incorporated the performance based concepts for evaluation of damage control in the structure. 10-storey RC shear wall building with different percentage of openings and without openings were compared five different models with opening percentage of 0%, 14%, 25%, 33% & 42% were modelled in SAP2000 software and non-linear static analysis was carried out. They have explained the fundamentals of various methods of seismic analysis like nonlinear static analysis, nonlinear time history analysis, nonlinear modal time history analysis and nonlinear direct integration time history analysis. The results were compared and base shear, storey displacement & storey drift increases as the percentage of opening was increased. The top displacement values comes to be 71.14%, 78.32%, 81.21% and 82.63% which indicates that

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there was increase in displacement as the opening percentage increases.

N. Shaik Kamal Mohammad Azam and Vinod Hosur[14]

Seismic analysis was carried out for reinforced concrete framed building having different shear wall arrangements. Eight models of each of 6, 12, 24 ad 36 storey buildings were considered. The structural behaviour were compared in terms of stiffness, strength & damping. They explained various nonlinear properties and which should be given to the elements of structure i.e, moment hinge for beams, P-M-M hinge for columns and P-M-M interaction hinge for shear walls. Analysis was carried out using loads & load combination as per IS 1893 (Part-1)-2002. The structures were lying in zone-II & the members were designed as per IS 456-2000. The reports summarizes that shear walls are very significant in resisting the lateral forces whereas shear walls which were placed in the outermost of the frames symmetrically and interconnected in perpendicular direction gave better performance while seismic hazard.

O. Mrugesh D. Shah and Sumant B. Patel[15]

They have explained why there is need of carrying pushover analysis by using software as it is a iterative process and it cannot be solved by hand calculation. ETABS 9.7 software has features to perform nonlinear static analysis and properties of hinges can be assigned as per ATC-40. The step by step procedure of how to perform nonlinear static analysis was described briefly in this study.

III. FINDINGS

The paper has been summarized, focusing on its main parameters, and a comprehensive conclusion of the work has been provided.

1. For studying the exact non-linear behaviour of the structure, pushover analysis is an effective way.
2. After comparison between conventional design approach and performance based seismic design method, PBSD gives proper performance of the structures during seismic activity.
3. It was noted that as the zone changes, both storey displacement and storey drift increases.
4. As the performance of reinforcement in the column increases, the overall performance of the structure improves leading to decrease in roof displacement.
5. The study highlights discrepancies in design base shear values obtained through different methods, underscoring the need for further exploration and the implementation of displacement-based design methods in seismic code provisions to ensure consistency and accuracy.

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