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SEISMIC ASSESSMENT USING PUSHOVER ANALYSIS: AN OVERVIEW

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Abstract: Earthquakes have created serious damages to structures. The structures which are already built are vulnerable to future earthquakes. This serious damage to structures can cause deaths, injuries with economic loss. There is an urgent need for seismic assessment of structures. Performance based seismic engineering is a simple and modern approach to earthquake resistant design to achieve desirable and predictable performance of structures. The concept of performance based seismic engineering is becoming future direction for seismic design codes. Nonlinear static pushover analysis is becoming popular tool because of its simplicity with for seismic evaluation of existing and new structures. Many structural engineers are interested in this concept, as it gives better understanding of the structural behavior during the strong earthquake ground motion. The present study gives an overview of past work done in this recently growing concept of performance based seismic assessment using nonlinear static pushover analysis.

Keywords: Nonlinear Static Analysis; Pushover Analysis; Performance Based Seismic Assessment.

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INTRODUCTION

An earthquake is the result of a sudden release of energy in the Earth's crust that creates seismic waves. These waves arrive at various instant of time, have different levels of energy. These waves can create serious damages to structures which can cause deaths, injuries, and economic loss. Many buildings built over past decades are seismically deficient because of lack of awareness regarding seismic behavior of structures. Due to this, there is an urgent need of seismic assessment of existing and new building.

The performance based earthquake engineering is a modern approach used for design the structures which are at seismic risk. This concept is published in many recent guidelines like, ATC-40, FEMA-356 and FEMA-273 etc. Using this method, structures can be designed so as to meet a particular objective under rare or moderate earthquakes. This method is generally used for earthquake resistant design of structures.

This method aims to produce structures with predictable seismic performance. The three key elements of this method are: -

Capacity: - It is a representation of the structures ability to resist the seismic demand.

Demand: - It is a representation of the earthquake ground motion.

Performance: - It is an intersection point of capacity spectrum and demand spectrum.

In nonlinear static pushover analysis the structure is subjected to permanent vertical loads. The equivalent static lateral loads approximately represent earthquake induced forces. A total base shear vs. top displacement curve is plotted. The analysis is carried till the failure, which gives collapse load and ductility capacity of the structures. The analysis shows any premature failures or weakness in the structures. The pushover analysis is used for assessment of important performance parameters, including global drift, inter storey drift, inelastic element deformations between elements. It is a method used for predicting seismic force and deformation demands, which redistributes the internal forces that no longer can be resisted within the elastic range of structural behavior.

A building performance level is a combination of the performance levels of the structure and the nonstructural components. A performance level describes a limiting damage condition which may be considered satisfactory for a given building with specific ground motion. The performances levels as per FEMA, ATC 40 and vision 2000 [19]:

Immediate occupancy IO: damage is relatively limited; the structure retains a significant portion of its original stiffness and most if not all its strength.

Life safety LS: substantial damage has occurred to the structure, and it may have lost a significant amount of its original stiffness. However, a substantial margin remains for additional lateral deformation before collapse would occur.

Collapse prevention CP: at this level the building has experienced extreme damage, if laterally deformed beyond this point; the structure can experience instability and collapse.

II. Literature review

A. S. Moghdam and W. K. Ts [1] to study the seismic response estimates of three types of asymmetrical building systems, a response spectrum based pushover procedure was used. The procedure included some of the 3-D effects caused by the response of torsion. The main features of the procedure were the use of elastic response spectrum analysis of the building to obtain the target displacements and the load distributions used in the pushover analyses and there is no need to model the inelastic behavior of all elements in the building. The studies showed good estimates and the use of load distribution resulted from response spectrum analysis in pushover analysis, improves the result for the frame building and deteriorates the results for the setback and wall-frame systems.

Xiao-Kang Zou and Chun-Man Chan [2] an effective computer based technique that incorporates pushover analysis together with numerical optimization procedures to automate the pushover drift performance design of reinforced concrete buildings was studied on a 10 storey 2 bay frame to provide the required ductility of RC building frameworks. Steel reinforcement appears to be the more cost-effective material which can be used to control the drift beyond the occurrence of first yielding. The proposed optimization methodology provides a good basis for more comprehensive performance-based optimization of structures as more accurate nonlinear pushover procedures taking into the higher mode effects are developed and multiple levels of performance criteria and design objectives are to be simultaneously considered.

Rahul Rana et al [3] performed pushover analysis on 19 story slender concrete tower consisting of shear wall located in San Francisco to understand the importance of pushover analysis as a useful tool of performance based seismic engineering to study post-yield behaviour of a structure which requires less effort and deals with much less amount of data than a nonlinear response history analysis.

Singh and Das [4] have analyzed three set of RC buildings, 4 storeyed, 8 storeyed and 16 storeyed with the effect of brick masonry infill. The URM masonry was modeled as a diagonal strut using the expression given by FEMA 356. Displacement based nonlinear analysis procedure was adopted using SAP2000 nonlinear analysis software. Two stiff zones have been concentrated at the faces of the joints and elements by introduction of plastic hinges. Variations of axial force, bending moments for columns are compared. From results authors interpreted that the masonry infill have significant effect on dynamic characteristic, stiffness, strength and seismic performance of buildings.

N. Lakshmanan [5] performed pushover analysis on the representative building using displacement coefficient method included in FEMA-356 and the number of hinges in beams and columns for each performance range and to these, weightage factor was assigned and vulnerability index was found out from which good or poor performance of building elements during earthquake was studied.

Shailesh Kr. Agrawal and Ajay Chourasia [6] presented the methodology for estimation of seismic vulnerability of Indian City based on qualitative and quantitative approach. Based on these approaches they have explained the method for computation of demand capacities ratios for masonry as well as for RC buildings.

Houssam Mohammad Agha et al [7] investigated the nonlinear performance of a ten story special moment resisting frame and found that estimates of building response from the nonlinear linear static analysis are generally insensitive to the pattern of lateral load in the height-wise distribution used to perform the pushover analysis and none of the invariant lateral load patterns could capture the approximate dynamic behavior globally and at story levels.

Mansour Bagheri and Mahmoud Miri [8] discussed future seismic design needs based on defined multiple performance objectives and earthquake hazard levels and showed that the benefit of performance based seismic design is to achieve a predictable seismic performance of structure with a very uniform risk.

Dalal Sejal et al [9] studied about performance based seismic design method along with its applications and advantages and observed that more research work is needed for development of performance based plastic design method for various other different types of structures.

Mrugesh D. Shah et al [10] analyzed two RCC buildings of G+ 4 storeys and G+ 10 storeys to cover the broader spectrum of high rise and low rise building construction. Different modeling issues were incorporated through nine models of G+4 and G+10 storey buildings to do comparative study of bare frame (without infill), having infill as membrane and replacing infill as diagonal struts and strut. From the analysis results it has been observed that for G+4 and G+10 storeys in bare frame without infill have lesser lateral load capacity (performance point value) compared to bare frame with infill as membrane and bare frame with infill having lesser lateral load capacity compare to bare frame with equivalent strut. Also conclude that as the number of bays increases lateral load carrying capacity increases but with the increase in bays corresponding displacement is not increases.

N. Choopool and V. Boonyapinyo [11] performed nonlinear static analyses and nonlinear dynamic analysis under seismic loadings in Bangkok according to the newly proposed seismic specifications of Thailand (DPT 1302-52) to study the effect of the new guidelines on cost estimates and the investigation of seismic performance for nine-story reinforced concrete moment resisting frames with various ductilities. The frames designs were predicted to achieve the immediate occupancy performance level. The results showed that all the frames including gravity load designed building was able to withstand a design earthquake. It was also observed that special ductile and intermediate ductile frame were the two best options in consideration of cost and seismic performance.

K. Rama Raju et al [12] performed nonlinear static analysis pushover analysis on a typical 6-storey office building which was designed for four design cases as per the provisions in three revisions of IS: 1893 and IS: 456 and it was analyzed using user-defined nonlinear hinge properties or default-hinge properties, given in SAP 2000 based on the FEMA-356 and ATC-40 guidelines. The possible differences in the results of pushover analysis due to default- and user-defined nonlinear component properties at different performance levels of the building were studied. Based on the observations in the hinging patterns, it was shown that the user-defined hinge model is more successful in capturing the hinging mechanism compared to the model with the default hinge.

K. Soni Priya et al [13] performed pushover analysis on G+2 storey building with flat slabs using SAP2000 software to study their responses under seismic condition and to evaluate seismic retrofit scheme. From the results it was observed that pushover curve was initially linear but starts to deviate from linearity as the columns undergo inelastic actions and the curve again becomes linear when the building was pushed well into the inelastic range, but with a smaller slope.

Kavita Golghate et al [14] aimed at evaluating the zone – IV selected 4 storey reinforced concrete building to conduct the nonlinear static analysis pushover analysis. The pushover analysis showed the pushover curves, capacity spectrum, plastic hinges and performance level of the building. The nonlinear static analysis also gives better understanding and more accurate seismic performance of buildings of the damage or failure element. The results were obtained in terms of pushover demand, capacity spectrum and plastic hinges the real behaviour of structure. Hinges were developed in the beams and columns showing the three stages immediate occupancy, life safety and collapse prevention. The column hinges had limited the damage.

Nivedita N. Raut and Swati D. Ambadkar [15] investigated the effect of the layout of masonry infill panels over the elevation of masonry infilled RC frames on the seismic performance and potential seismic damage of the frame under strong ground motions using nonlinear static pushover analysis based on realistic and efficient computational models. From the analysis results, comparisons of base shear vs. displacement for bare frame, infill wall frame and weak storey frame was done and it was observed that displacement in bare frame is more than other two frames and displacement at ground floor in weak storey is more than other two frames. Mostly hinges are formed in beams than in column.

A. Vijay and K. Vijayakumar [16] concentrates on a computer based push-over analysis technique for performance-based design of steel building frame works subjected to earthquake loading. The analysis was performed for 2D steel frameworks of solid and hollow members with constant bay width and storey height for various stories. Investigation aimed to analyse the difference in structural behaviour between hollow and solid frames. From the analysis results it was concluded that when the number of storey decreases corresponding base shear increases and also when the no. of stories increases corresponding displacement increases. It was also observed that drift to height ratio is limited to 35 storeys and the comparative results of solid and hollow sections for base shear vs. displacement curve indicated that the hollow sections are far better than solid ones.

Suchita Hirde and Dhanshri Bhoite [17] studied the effect of modeling of masonry infill on the response of multi-storied reinforced concrete frame building under seismic loading using three different models and to understand the contribution of infill walls in formation of plastic hinges in beams and columns in multistory frame. The results of bare frame analysis and frame with infill effects were compared in the form of capacity spectrum curve, performance point and hinge formation at performance point and concluded that masonry infill contributes significant lateral stiffness, strength, overall ductility and energy dissipation capacity.

Sofyan Y. Ahmed [18] analyzed a ten storey five bay reinforced concrete frame (2D beams and columns system) subjected to seismic hazard of the Mosul city, Iraq by performing pushover analysis using SAP2000 v14. From analysis results it is observed that sequence of formation of plastic hinges (yielding) in the frame members has been seen in the beams and the building behaves like the strong column-weak beam mechanism. It has observed that maximum total drift, maximum inelastic drift, and structural stability do not exceed the limitations of the performance level which shows that the building is considered safe for persons against seismic force. It is also observed that any missing of the international codes requirements or mistakes in the design may result in collapse of the building.

M. Mouzzoun et al [19] assessed the seismic performance of a five storey reinforced concrete residential building designed according to the Moroccan seismic code RPS2000. Pushover analysis was performed using SAP2000 software to detect the locations of the plastic hinges and the results obtained from the study showed that designed building performed well under moderate earthquake, but it is vulnerable under severe earthquake.

Govind M et al [20] briefly discussed the behavior of G+20 storied RC frame buildings (H shape in plan, with and without T shaped column) subjected to earthquake, located in seismic zone III using ETABS software. Gravity loads and laterals loads as per IS 1893-2002 were applied on the structure and it is designed using IS 456. Displacement control pushover analysis was carried out. It is observed that when earthquake load is applied in X direction, model with T shaped column can resist more base shear than model with rectangular column and when earthquake load is applied in Y direction, it is found that model with T shaped column can resist more base shear than model with rectangular column. But the percentage increment is acceptable. The results obtained in terms of demand, capacity spectra showed real behavior of structures.

III. Summary

Pushover analysis is a very new and modern approach in seismic engineering of the structures. It involves exhaustive and intricate computational efforts. It is a very iterative process to meet designer and code requirements. Use of pushover analysis has been done extensively in previous studies. It is used for performance evaluation of structural system. It involves determination of performance levels, and the estimation of the structural strength and deformation demands. Many studies consider pushover analysis for performance check of the structures. Several approaches for performance based seismic method proposed by researchers design have been briefly reviewed in this paper and it is observed precise and important development have been made in the past decades, but still there are many basic issues along with the fundamental content of the approach is to be tackled

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