

Non-Linear Static Analysis (Pushover Analysis) A Review

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Abstract— In recent years, substantial amount of study has been carried out in order to evaluate building's performance during a seismic event. During seismic action, the building is expected to deform in-elastically and therefore seismic performance evaluation is required considering post-elastic behavior of the structure. Performance based seismic design is a modern approach to earthquake resistant design of RC buildings. It is not only simple but also a systematic design method for structural systems to achieve the desirable and predictable performance of structure. Performance based design of building structures requires rigorous non-linear static analysis. Non-linear static analysis or pushover analysis is generally carried out as an effective tool for performance based design. Pushover analysis came into practice after 1970. In non-linear static analysis or pushover analysis, a building under constant gravity loads and monotonically increasing lateral forces during a seismic event is analyzed until a target displacement is reached. Pushover analysis provides better understanding of seismic performance of buildings and also traces the progression of damage and failure of building's structural elements. By pushover analysis, one may get an insight about the behavior of building in non-linear zone. It is generally believed that the conventional elastic design analysis method cannot capture many important aspects that control the seismic performance of the building structure. The capacity of building to undergo in-elastic deformations governs the structural behavior of building during seismic event. For that reason, the evaluation of building should consider the in-elastic deformations demands due to seismic loading. On the other hand, linear elastic analysis does not provide information regarding real strength, ductility and energy dissipation in the structure.

Index Terms— Performance based design, Non-Linear Static Analysis, Literature Review

I. INTRODUCTION

Buildings are usually designed for seismic resistance using elastic analysis, most of which experiences significant inelastic deformations under large seismic actions. Modern performance based design methods require ways to determine the real behavior of structures under such conditions.

As such, non-linear analysis can play an important role in the design of new and existing buildings [1].

Non-linear analysis involves significantly more efforts to perform and should be approached with specific objectives.

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Typical instances where non-linear analysis is applied with respect to the building's performance evaluation are as follows:

- To assess and design seismic retrofit solutions for existing buildings.
- Design new buildings that employ structural materials, systems, or other features that do not conform to current building code requirements.
- To assess the performance of buildings for specific owner requirements.

In contrast to linear elastic analysis and design methods that are well established, non-linear inelastic analysis techniques and their application to design are still evolving and may require engineers to develop new skills. Non-linear analysis requires thinking about inelastic behavior and limit states that depend on deformations as well as forces [1].

II. PERFORMANCE BASED DESIGN

Performance based design refers to a methodology in which structural criteria are expressed in terms of achieving a performance objective. This is contrasted to a conventional method in which structural criteria are defined by limits on member forces resulting from a prescribed level of applied shear force. A performance objective specifies the desired seismic performance of the building. Seismic performance is described by designating the maximum allowable damage state (performance level) for an identified seismic hazard (earthquake ground motion). A performance objective may include consideration of damage states for several levels of ground motion and would then be termed a dual or multiple level performance objectives [2].

III. NON-LINEAR STATIC ANALYSIS

Non-Linear Static Analysis or *pushover analysis* is a useful tool for assessing inelastic strength and deformation demands in the structure, and for exposing design weaknesses [2]. Its foremost advantage is that it facilitates the design engineer to recognize important seismic response quantities and to use engineering judgement to alter suitably the force and deformation demands and capacities that control the seismic response close to failure [3].

The main output of the pushover analysis is in the form of a force-displacement curve, called *pushover curve*. It is a plot of the base shear (total lateral load) versus the lateral displacement at some point at the roof level, including all the stages of lateral load/displacement increments.

It may be noted that the pushover analysis is approximate and does not account for dynamic characteristics such as hysteresis, higher mode participation etc. It is known to give good results for regular buildings (without torsional irregularity). In such cases, the pushover curve can be converted to acceleration versus displacement response spectrum, where it represents the 'seismic capacity' of the structure. It is possible to include in the same plot the 'seismic demand', to see whether the capacity meets the demand. The meeting of seismic capacity and demand is called a *performance point* [3].

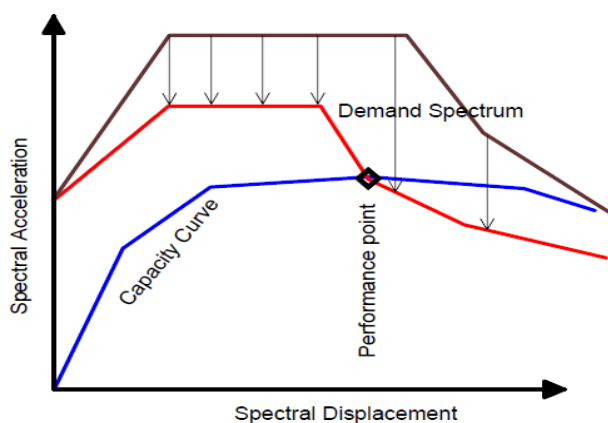


Fig-1 Capacity curve, Demand Spectrum and Performance Point

IV. LITERATURE REVIEW

Various literature reviewed on pushover analysis is presented in this section. A review of literatures is presented in brief summarizing the work done by different scholars and researchers on pushover analysis of building structures.

Joheb Ahmed and Syed Ahamad Raza (2014) carried out study on seismic vulnerability of RC buildings by considering plan irregularities using pushover analysis. Various models were considered in order to identify the performance of the structures to withstand against disaster for building structures. They have conducted study on 'G+9' storey building situated in zone V having plan irregularities like, rectangular, diaphragm discontinuity, and Y-shaped building. Pushover analysis has been performed using FEM based analytical software ETABS 9.7.4 version. They have presented their results in terms of pushover demand, capacity spectrum and plastic hinges. They have concluded that base shear for rectangular model is greater than diaphragm discontinuity and Y-shaped models. Point displacements are greater for diaphragm discontinuity model as there is an opening in the centre for that model. Finally, they concluded that among the three models considered for study purposes, rectangular model is most vulnerable to seismic effect.

K Rama Raju, A Cinitha and Nagesh R Iyer (2012) performed seismic performance evaluation of existing RC buildings designed as per past codes of practice. They have considered a typical 6 storey reinforced concrete building frame. Analysis is done using user-defined non-linear hinge

properties or default-hinge properties in SAP 2000 software based on the FEMA 356 and ATC 40 guidelines. An analytical procedure is developed to evaluate the yield, plastic and ultimate rotation capacities of RC elements of the framed buildings and these details are used to define user-defined inelastic effect of hinge for columns as P-M-M and for beams as M3 curves. Building's performance in terms of target building performance levels are studied with the non-linear static analysis (pushover analysis). They have studied the possible differences in the results of pushover analysis due to default and user-defined non-linear component properties at different performance levels of the building. Their study clearly brought out the necessity of enhancing the lateral strength of existing buildings designed as per the codes of practice IS 1893 (Part I) : 2002 and IS 456:2000. A significant variation is observed in base shear capacities and hinge formation mechanisms with default and user-defined hinges at yield and ultimate. They have concluded that the user-defined hinge model is more successful in capturing the hinging mechanism compared to the model with the default hinge.

Mohammed Anwaruddin, Md. Akberuddin, Mohd. Zameeruddin and Mohd. Saleemuddin (2013) carried out another study on pushover analysis of medium rise multistorey RCC frame with and without vertical irregularity using ETABS software. Their study aims at evaluating and comparing the response of five reinforced concrete building systems by the use of different methodologies described by ATC 40 and FEMA 273 using non-linear static procedures. The methodologies are applied to a three storey frames system with and without vertical irregularity, both designed as per the IS 456:2000 and IS 1893 (Part I) : 2002 in the context of Performance Based Seismic Design procedures. A Non-linear Static Analysis (Pushover Analysis) had been used to obtain the inelastic deformation capability of frame. Their analysis results compared the bare frame models with and without irregularity. They concluded that 'G+3' storey bare frame without vertical irregularity have more lateral load capacity as compared to bare frames with vertical irregularity.

Mrugesh D. Shah, Atul N. Desai and Sumant B Patel (2011) conducted a study on performance based analysis of RCC frames. They considered two RCC buildings 'G+4' and 'G+10'. Different modeling types were incorporated through nine models made for 'G+4' building and 'G+10' building. They were bare frame (without infill), having infill as membrane, and infill as diagonal strut. Comparative study were made for bare frame (without infill), having infill as membrane, and infill as diagonal strut. They concluded that for 'G+4' and 'G+10' storey buildings, bare frame without infill possess lesser lateral load capacity as compared to bare frame with infill as membrane and bare frame with infill possess lesser lateral load capacity compare to bar frame with equivalent strut. On the other hand, it is also shown that as the number of bays increases, lateral load carrying capacity increases but with the increase in bays corresponding displacement does not increases.

Mr. A. Vijay, Mr. K. Vijayakumar (2013) performed a study which concentrates on a computer based push-over analysis technique for performance-based design of steel

building frame works subjected to earthquake loading. 2-D frames were modeled for solid and hollow sections, for various stories with constant bay width and storey height which was analyzed and concluded that

- When the number of stories decreases then the corresponding base shear increases and also when the number of stories increases then the corresponding displacement increases.
- Drift to height ratio is limited to thirty five stories.
- On comparing the results of solid and hollow sections base shear versus displacement curve, it is shown that the hollow sections are far better than solid ones.

R.K. Goel (2008) evaluated the non-linear static procedures specified in the FEMA 356, ATC 40, and FEMA 440 documents for seismic analysis and evaluation of building structures using strong motion records of RC buildings. The maximum roof displacement predicted from the non-linear static procedure (pushover procedures) was compared with the value derived directly from recorded motions for this purpose. It was shown that

- Non-linear static procedures either overestimates or underestimates the peak roof displacement for several of the buildings considered in the investigation.
- The Coefficient Method, which was based on recent improvements to the FEMA 356 Coefficient Method suggested that FEMA 440 document does not necessarily provide better estimate of the roof displacement.
- The improved FEMA 440 Capacity Spectrum Method provided better estimates of the roof displacement compared to the ATC 40.

Ms. Nivedita N. Raut and Ms. Swati D. Ambadkar (2013) under strong ground motions using non-linear static pushover analysis effect of the layout of masonry infill panels was investigated over the elevation of masonry infilled RC frames on the seismic performance and potential seismic damage of the frame based on realistic and efficient computational models and compared base shear versus displacement in bare frame, infill wall frame and ground. At roof level in bare frame it was seen that displacement was more than other two frames and at ground floor in weak story displacement was more than other two frames. Less hinges were formed in column than beam.

Rasmita Tripathy (2012) carried out study of pushover analysis of RC setback building frames. The study proposes an improved procedure for estimating target displacement of buildings with setbacks. A parametric study is also carried out to understand the applicability of existing lateral load patterns on the pushover analysis of setback building. It is found that mass proportional uniform load pattern is most suitable amongst others for pushover analysis of setback buildings. The results of the study shows that pushover analysis carried out by mass proportional uniform load pattern and proposed modification in target displacement estimation procedure consistently predicting the results close to that of non-linear dynamic analysis.

Riza Ainul Hakim, Mohammed Sohaib Alama and Samir A. Ashour (2014) performed seismic assessment of an RC building using pushover analysis. Their study aims at

investigating building's performance on resisting expected seismic loadings. Two 3-D frames were investigated using pushover analysis according to ATC 40. One was designed according to a design practice that considers only the gravity load and the other frame was designed according to the Saudi Building Code (SBC 301). Their study showed that the building designed considering only the gravity load was found inadequate. On the other hand, the building designed according to SBC 301 satisfies the Immediate Occupancy (IO) acceptance criteria according to ATC 40.

Nitin Choudhary and Prof. Mahendra Wadia performed pushover analysis of RC frame building with shear wall. They conducted their study on two multistoried RC frame building. One building is symmetrical in plan while other is 'L' shaped unsymmetrical in plan. Their study shows the effect of shear wall on RC building frame when shear wall providing along the longer and shorter side of the building. Their study concluded that by providing shear wall in both the buildings, there is considerable decrease in base shear and roof displacements.

V. CONCLUSION

A brief review of several literatures presented shows that non-linear static analysis (pushover analysis) proves to be efficient tool for studying the behavior of the structure in non-linear zone. Structure's failure modes due to seismic actions become more apparent by performing pushover analysis. There is future scope for further study in this area.

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