

# A Review on Seismic Analysis of RCC Bridge with Non Linear Pushover Analysis

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**ABSTRACT:** This paper describes a literature review on seismic analysis of bridges with non-linear static Pushover analysis. Nonlinear pushover analysis is a powerful tool and is widely used for analytical evaluation of the behaviour of structure in the inelastic range which identifies failure mechanisms and weak structural elements. But conventional nonlinear pushover analysis is limited by its overtly restrictive assumptions such as fundamental mode controlling structural response, fixed spatial distribution of lateral force predetermination of monitoring node and target displacement. Effort to include higher modes effects to 'standard' pushover analysis (SPA) so as to match the results of nonlinear time history analysis attracted the attention of researchers. . Till now most of work unilaterally targeted building frames, while corresponding work for bridges has been very limited. Hence, the aim of this study is to investigate the extension of the modal pushover method to bridges, and the investigation of its applicability in the case of complex bridges.

**KEYWORDS:** Non-linear static analysis, RCC Bridge, Pier capacity, Pushover Analysis

## I. INTRODUCTION

In India, reinforced concrete bridges were designed by outdated building codes that did not account for large seismic activities. Secondary reinforcement provided with typical transverse reinforcement spacing far exceed today's standards and are therefore insufficient to resist the laterally applied seismic loads. With the advancement in technology and software, seismic analysis of rcc structures with non linear static methods has gained wide spread acceptance internationally. Guidelines for the application of non linear pushover analysis for regular and asymmetric plan building are available in several seismic guidelines (ATC 40 and FEMA 356) and design codes (Eurocode 8 and PCM 3274).

A lot of work has been done in analyzing multi-storey building with nonlinear static pushover analysis method. At first the technique was used for building with symmetric geometry and regular plan. A Modified Pushover Analysis model is developed to analyze buildings with irregularities in elevation and plan. This model is further developed with necessary alteration in procedure to analyze RC bridges. Several authors reported their work on Pushover analysis of Reinforced Concrete Bridges. This paper reports literature review on pushover analysis of bridges.

## II. PUSHOVER ANALYSIS

Pushover analysis is a static nonlinear procedure in which the magnitude of the lateral load is increased monotonically maintaining a predefined distribution pattern along the height of the building (Fig.1 a). Building is displaced till the 'control node' reaches 'target displacement' or building collapses. The sequence of cracking, plastic hinging and failure of the structural components throughout the procedure is observed. The relation between base shear and control node displacement is plotted for all the pushover analysis (Fig.1 ).

Pushover analysis provides sufficient insight into the full response till failure. Pushover analysis is performed with different load pattern to arrive at most suitable load pattern for the analysis of bridges. By pushover analysis, the base shear versus top displacement curve of the structure, usually called capacity curve, is obtained. To evaluate whether a structure is adequate to sustain a certain level of seismic loads, its capacity has to be compared with the requirements corresponding to a scenario event. The aforementioned comparison can be based on force or displacement.

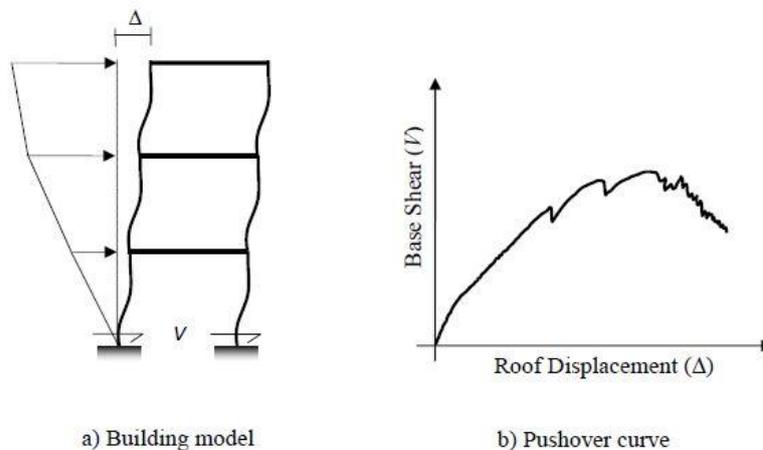


Fig 1

### III. LITERATURE REVIEW APPLICATION OF PUSHOVER ANALYSIS AND ITS APPLICATION TO BRIDGES

**Chiorean** (2003) evaluated a nonlinear static (pushover) analysis method for reinforced concrete bridges that predicts behavior at all stages of loading, from the initial application of loads up to and beyond the collapse condition. He developed NSP method using “line elements” approach, and are based on the degree of refinement in representing the plastic yielding effects. Distributed plasticity model and plastic hinge model were used to model elasto-plastic behavior. He investigated the collapse behavior of a three span pre-stressed reinforced concrete bridge of 115m in total length and used Capacity Spectrum Method as per Eurocode 8 (2003). The bridge modeling was done using NAFCAD (structural analysis software). Target displacement, base shear and deformation of plastic zone (hinges) were obtained and to be compared with time history analysis as future work.

**Chung and Hamed** (2003), performed seismic analysis of bridges using control displacement approach. A three-span bridge of 97.5 meters (320 ft) in total length was analyzed using both the Nonlinear Static Procedure/Displacement Coefficient Method and nonlinear time-history. Nine time-histories were implemented to perform the nonlinear time-history analysis. Three load patterns were used to represent distribution of the inertia forces resulting from earthquakes. Demand (target) displacement, base shear, and deformation of plastic hinges obtained from the Nonlinear Static (Pushover) Procedure are compared with the corresponding values resulting from the nonlinear time history analysis. Analysis was performed using two levels of seismic load intensities (Design level and Maximum Considered Earthquake level). Performance of the bridge was evaluated against these two seismic loads. Comparison shows that the Nonlinear Static Procedure gives conservative results, compared to the nonlinear time history analysis, in the Design Level while it gives more conservative results in the Maximum Considered Earthquake level.

**R. Pinho, et al** (2007) investigated the effectiveness of pushover analysis in assessing bridges subjected to seismic action. The author proposed adaptive pushover scheme based on variable force distribution accounting for structural yielding and the associated changes in the vibration properties. The author conducted parametric study on a suite of continuous multi-span bridges applying convention NSP with invariant force distribution and the proposed adaptive NSP approach. The study showed attainment of improved predictions over two pushover methods. Two bridges consisting of four spans (50m) with continuous deck and different pier height were selected for the study. Pushover analysis of bridges was performed as per Eurocode 8. Target displacement at top of central pier was from 45mm to 160mm for different mode shapes. He concluded that the use of single-run pushover analysis might still be feasible even for such irregular bridge configurations, for as long as a displacement-based adaptive version of the method is employed.

**Muljati and Warnitchai** (2007) investigated the performance of Modal Pushover Analysis (MPA) to predict the inelastic response of the continuous bridge decks with no intermediate movement joints. He performed pushover analysis using an invariant lateral force distribution for each mode independently. The peak responses determined from every mode are combined using square-root of sum-of-square (SRSS) combinations. The authors reported that the performance of MPA in nonlinear range shows a similar tendency with MPA in linear range. Being an approximate method, MPA gives an acceptable accuracy beside of simplicity and efficiency in calculation.

**Kappos et al.** (2010) used Modal Pushover analysis as means of seismic assessment of bridge structure. They investigated the extension of the modal pushover method to bridges, and also its applicability in the case of complex bridges. He proposed a clearly defined procedure for applying the MPA in the case of bridges and then attempted to quantify the relative accuracy of the three main inelastic analysis methods (i.e. SPA, MPA and nonlinear time history) by focusing on the realistic case of a complex, long and curved actual bridge. To this effect, a real, long and curved bridge is chosen, designed according to current seismic codes; this bridge is assessed using the aforementioned three nonlinear analysis methods. Comparative evaluation of the calculated response of the bridge illustrates the applicability and potential of the modal pushover method for bridges, and quantifies its relative accuracy compared to that obtained through the 'standard' pushover approach. The author concluded that MPA is a promising approach and yielded more accurate results compared to the 'standard' pushover, without requiring the high computational cost of the Non Linear Time History Analysis.

**Bernardo. F** (2012), assessed the feasibility and accuracy of non-linear static analysis in comparison with Time History Analysis. He developed two MATLAB programs and performed pushover analysis (NSPA), one as per methodology presented in Eurocode-2008 and second by ATC-40, Capacity Spectrum method. Analysis was performed on existing multi-span RC bridge of total length 360m with 12 equal spans. Pushover demand was compared with Time History Analysis results of bridge. He concluded that Demand Displacement obtained from CSM was smaller than Eurocode and time history analysis and Euro code results were more accurate and safer. For complex bridges the relative differences between the displacements obtained with both pushover methodologies were higher for more irregular structures and the difference increased with the value of the force ductility factor.

**Jingyao Zhang, et al. (2008)**, proposed a new approach for determination of equivalent static seismic loads, for evaluating peak seismic responses. The responses were estimated by series of multi-modal pushover analysis considering possible phase differences in the dominant modes: the loads are directly applied in the elastic systems, and the damping due to plastic dissipation is modeled by equivalent linearization in inelastic systems. The accuracy of the proposed method was demonstrated in the numerical example of an arch-type long-span truss. Numerical studies on a long-span arch model, of which the seismic response is dominated by two vibration modes, show that the proposed method has good performance in estimating the peak responses for elastic systems as well as inelastic systems. Although the proposed method requires eigen value analysis and pushover analysis for several load patterns, it is effective and accurate enough for estimating peak seismic responses of spatial structures, as an alternative tool of the time-consuming time-history analysis.

**Nasim K. Shatarat (2012)**, emphasize on determining the nonlinear properties of the bridge element. In this study, pushover analysis of two highway bridges built with little attention to seismic forces was performed in an effort to evaluate the difference in global response predicted by using the user-defined nonlinear hinge properties and automated hinge properties in the software SAP2000. The results demonstrated that user-defined hinge model is capable of capturing the effect of local failure mechanisms, in the plastic hinge region, on the global response of the bridge; while the automated-hinge model cannot capture this effect. Therefore, automated-hinge properties should be used with a lot of care, especially for old bridges that might include local failure mechanisms in the plastic hinge region. User defined hinge properties can be obtained using the recommendations of the Seismic Retrofit Manual by the Federal Highway Administration. Automated-hinge properties in SAP2000 are computed automatically from the element material and section properties according to Caltrans criteria.

**N.K. Manjula et al. (2013)** compared and identified the differences among the pushover analysis methods given in international standards, considering one reinforced concrete (RC) building frame, designed as per IS 1893-2002 provisions. The performance of the building which is designed based on strength based method with sufficient ductile detailing is also evaluated. They performed the pushover analysis using two different levels of ground motion with ATC-40 method, FEMA340 method and their modified method in FEMA440. It was concluded that the difference between the results fir four method is negligible for low seismic activity while appreciable variation in case of high seismic activity.

#### IV. SUMMARY

Nonlinear pushover analysis is a powerful tool and is widely used for analytical evaluation of the behaviour of structure in the inelastic range which identifies failure mechanisms and weak structural elements. But conventional nonlinear

pushover analysis is limited by its overtly restrictive assumptions such as fundamental mode controlling structural response, fixed spatial distribution of lateral force predetermination of monitoring node and target displacement. Effort to include higher modes effects to 'standard' pushover analysis (SPA) so as to match the results of nonlinear time history analysis attracted the attention of researchers. In First of many efforts to include the effects of higher modes in pushover analysis, the multi-mode pushover methodology was utilized by Freeman[15]. He extended the Capacity Spectrum Method (CSM) to compare earthquake demand with building capacity. Multiple adaptive pushover analogies were proposed by Kunnath et al[16], Gupta et al[4] and Antoniou et al[5] including multiple modes in defining lateral load patterns which are determined by combining modal load using modal combination rules(SRSS). Modal combination is performed at the stage of loading.

In a different approach for modal superimposition Goel and Chopra [7,8], proposed performing pushover analysis for each significant mode individually and combining the response quantities using an appropriate combination rule (SRSS or CQC). With new development in recent years an alternative type of nonlinear static analysis was proposed [7-14] involving multiple run pushover analyses. Each run corresponded to a given modal distribution and the overall structural response was estimated by combining individual seismic responses (displacement drifts etc) with combination rule. Since pushover procedure followed was conventional such approach had advantage of compatibility as it could be performed commercially available standard software packages.

In further development another theory for nonlinear static analysis called "incremental response spectrum analysis (IRSA)" was proposed by Aydinoglu [17], which proposed that with every formation of hinge, the elastic modal spectrum analysis for structure to be performed considering the changed dynamic properties of structure due to yielding. It was observed that for regular bridge geometry single run conventional pushover analysis yielded conservative results. In case of irregular or complex bridge structure multiple run adaptive pushover approach performed better and lead to better estimation of seismic responses. The level of accuracy in all mentioned approaches for pushover analysis is satisfactory but needs further work to reach international consensus of researchers.

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