Pushover Analysis of RC Bridge Structure

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ABSTRACT *Free vibration response of structures is very important to determine their nature when subjected to dynamic loading like earthquake and wind. Also, when the structures are subjected to strong earthquake or wind storm, they exhibit inelastic behavior, which cannot be evaluated the performance of structure tacking into accounts the post elasticbehaviorandpredicts the vulnerability of the structure. Pushover analysis determine the structural performance by estimating the forces and deformation capacity and seismic demand using a nonlinear algorithm.*
The Pushover Analysis can be performed using Capacity spectrum method (ATC 40), Displacement coefficient method (FEMA 356) and Displacement Modification method (FEMA 440).

Keywords: *ATC 40, FEMA 356,FEMA 440, Pushover Analysis.*

1. Introduction

Pushover analysis is a static, non-linear procedure in which the magnitude of the lateral seismic loading is incrementally increasing with a certain predefined pattern until predetermined displacement reaches a target value or failure modes occur. The principle of this method shows one mathematical model with nonlinear behavior of structure affected by lateral load pattern and increasing with until the certain node of the structure reaches the target displacement.

2. Literature Review

[1]**Abdul Raheem, et.al (2015)** In this paper the authorcarry out seismic study on RC bridge by using non liner static (pushover) analysis and study the loads and loads combination. An existing RC T-Beam bridge was evaluated using non liner analysis namely modal pushover analysis (MPA). MPA was performed in both transverse and longitudinal direction of bridge. The capacity curve represent the response of the bridge in transverse and longitudinal direction for the particular modes of vibration were generated using MPA. In this study a 20 span RC T-Beam bridge is taken. The bridge was modelled in SAP 2000 software and by FEMA 356 Auto hinge and conducted a nonlinear static analysis using ATC 40 capacity spectrum method. Presently no comprehending guideline to assist the structural engineer to evaluate the existing bridges and suggest design and retrofit schemes. In this study it is concluded that theseismic evaluation for an RC bridge analysis as per ATC 40 was to verify the results.

[2]**Rajeev Sharma (2015)** Earthquake of Bhuj in 2001 & in Kashmeer in 2005 derive much attention on seismic assessment of existing building. The aim of this study to carry a nonlinear static analysis of existing RC bridge. For the study a 3 span bridge was selected which was situated at Gaziabad, UP on hindon river. This area is earthquake prone and comes in zone-4. The open sees model is used to describe various performance of the bridges. By comparing varying the static and dynamic analysis. The concrete developed by Chang &Mander was used for assessment. This new material was used in assessment improve the existing bridge capacity against the bridge element damage during the seismic activity.

[3]**A.H.M.Muntasir Billah, et.al (2016)** The aim of this study is to develop performance based damage states for shape memory alloy (SMA)-reinforced concrete bridge piers considering different types of SMAs and seismic hazard scenarios. Using incremental dynamic analysis (IDA), this study conclude that quantitative damage states corresponding to different performance levels (cracking, yielding, and strength degradation) and specific probabilistic distribution for RC bridges piers reinforced with different types of SMAs. From the study it was concluded that the progression of damage was similar for all the RC bridges piers reinforced with different SMAs concrete cracking, longitudinal reinforcement yielding, cover spalling, and core crushing. For all SMA-RC bridges piers, the cracking occurred at the same level of drift (due to same cross section) while the drift at other performance levels varied based on the mechanical properties of SMA used.

[4]**Jitendra Awasthi, et.al (2016)** The pushover analysis mainly used to study the strength and drift capacity of existing structures and the seismic demand for the structure for selected earthquake intensities. The effectiveness of pushover analysis and its computation easiness brought this procedure to seismic guideline (ATC 40 and FEMA 356) and design codes (Euro code 8 and PCM 3274). In this study n existing RC bridge had been analyzed by time history method and ATC 40 spectrum method. The response had been determined by both the methods and compered. From this study it is found that the pushover curve for acceleration load case had a huge drop in base reaction but in case there is a minute drop in base reaction. From the study it had been found that result showing by ATC 40 Capacity spectrum method was closer to the time history analysis. Hence the further investigation required in order to make a generalized evaluation procedure for bridges structure with different configurations.

3. Conclusion

The available literatures on pushover analysis of RC bridges are very limited whereas we can get number of published literatures in pushover analysis of buildings. Hence the literature survey is presented here in two broad areas:

(i) Standard pushover analysis and its improvements and
(ii) Application of pushover analysis to bridges.

Pushover Analysis

The use of the nonlinear static analysis (pushover analysis) came in to practice in 1970's but the potential of the pushover analysis has been recognized for last 10-15 years. This procedure is mainly used to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake. This procedure can be used for checking the adequacy of new structural design as well. The effectiveness of pushover analysis and its computational simplicity brought thisprocedure in to several seismic guidelines (ATC 40 and FEMA 356) and design codes (Euro code 8 and PCM 3274) in last few years. Pushover analysis is defined as an analysis wherein a mathematical model directly incorporating the nonlinear load-deformation characteristics of individual components and elements of the building shall be subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a 'target displacement' is exceeded. Target displacement is the maximum displacement (elastic plus inelastic) of the building at roof expected under selectedearthquake ground motion. Pushover analysis assesses the structuralperformance by estimating the force and deformation capacity and seismic demand using a nonlinear static analysis algorithm. The seismic demand parameters are global displacements (at roof or any other reference point), storey drifts, storey forces, component deformation and component forces. The analysis accounts for geometrical nonlinearity, material inelasticity and the redistribution of internal forces. Response characteristics that can be obtained from the pushover analysis are summarized as follows:

a) Estimates of force and displacement capacities of the structure. Sequence of the member yielding and the progress of the overall capacity curve.
b) Estimates of force (axial, shear and moment) demands on potentially brittle elements and deformation demands on ductile elements.
c) Estimates of global displacement demand, corresponding inter-storey drifts and damages on structural and non-structural elements expected under the earthquake ground motion considered.
d) Sequences of the failure of elements and the consequent effect on the overall structural stability.
e) Identification of the critical regions, where the inelastic deformations are expected to be high and identification of strength irregularities (in plan or in elevation) of the building.

Pushover analysis delivers all these benefits for an additional computational effort (modelling nonlinearity and change in analysis algorithm) over the linear static analysis. Step by step procedure of pushover analysis is discussed next.

Pushover Analysis Procedure

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. 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. Generation of base shear – control node displacement curve is single most important part of
Pushover analysis. This curve is conventionally called as pushover curve or capacity curve.
The capacity curve is the basis of 'target displacement' estimation. So the pushover analysis may be carried out twice:

(a) First time till the collapse of the building to estimate target displacement and
(b) Next time till the target displacement to estimate the seismic demand.

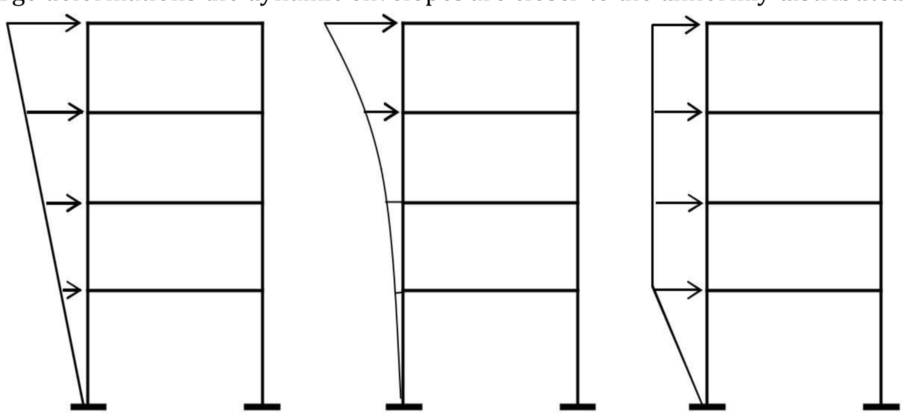
The seismic demands for the selected earthquake (storey drifts, storey forces, and component deformation and forces) are calculated at the target displacement level. The seismic demand is then compared with the corresponding structural capacity or predefined performance limit state to know what performance the structure will exhibit. Independent analysis along each of the twoorthogonal principal axes of the building is permitted unless concurrent evaluation of bidirectionaleffects is required.

Lateral Load Patterns

In pushover analysis the building is pushed with a specific load distribution pattern along the height of the building. The magnitude of the total force is increased but the pattern of the loading remains same till the end of the process. Pushover analysis results (*i.e.*, pushover curve, sequence of member yielding, building capacity and seismic demand) are very sensitive to the load pattern. The lateral load patterns should approximate the inertial forces expected in the building during an earthquake. The distribution of lateral inertial forces determines relative magnitudes of shears, moments, and deformations within the structure.

The distribution of these forces will vary continuously during earthquake response as the members yield and stiffness characteristics change. It also depends on the type and magnitude of earthquake ground motion. Although the inertia force distributions vary with the severity of the earthquake and with time, FEMA 356 recommends primarily invariant load pattern for pushover analysis of framed buildings.

Several investigations **(Mwafy and Elnashai, 2000; Gupta and Kunnath, 2000)** have found that a triangular or trapezoidal shape of lateral load provide a better fit to dynamic analysis results at the elastic range but at large deformations the dynamic envelopes are closer to the uniformly distributed force pattern.



(a) Triangular **(b) IS Code Based** **(c) Uniform**

Fig. Lateral load pattern for pushover analysis as per FEMA 356 (considering uniform mass distribution)

Target Displacement

Target displacement is the displacement demand for the building at the control node subjected to the ground motion under consideration. This is a very important parameter in pushover analysis because the global and component responses (forces and displacement) of the building at the target displacement are compared with the desired performance limit state to know the building performance. So the success of a pushover analysis largely depends on the accuracy of target displacement. There are two approaches to calculate target displacement:

(a) Displacement Coefficient Method (DCM) of FEMA 356 and
(b) Capacity Spectrum Method (CSM) of ATC 40.

Both of these approaches use pushover curve to calculate global displacement demand on the building from the response of an equivalent single-degree-of-freedom (SDOF) system. The only difference in these two methods is the technique used.

a) Displacement Coefficient Method (FEMA 356)

This method primarily estimates the elastic displacement of an equivalent SDOF system assuming initial linear properties and damping for the ground motion excitation under consideration. Then it estimates the total maximum inelastic displacement response for the building at roof by multiplying with a set of displacement coefficients.

b) Capacity Spectrum Method (ATC 40)

The basic assumption in Capacity Spectrum Method is also the same as the previous one.

That is, the maximum inelastic deformation of a nonlinear SDOF system can be approximated from the maximum deformation of a linear elastic SDOF system with an equivalent period and damping. This procedure uses the estimates of ductility to calculate effective period and damping. This procedure uses the pushover curve in an acceleration displacement response spectrum (ADRS) format. This can be obtained through simple conversion using the dynamic properties of the system. The pushover curve in an ADRS format is termed a 'capacity spectrum' for the structure. The seismic ground motion is represented by a response spectrum in the same ADRS format and it is termed as demand spectrum.

Shortcomings of Standard Pushover Analysis

Pushover analysis is a very effective alternative to nonlinear dynamic analysis, but it is an approximate method. Major approximations lie in the choice of the lateral load pattern and in the calculation of target displacement. FEMA 356 guideline for load pattern does not cover all possible cases. It is applicable only to those cases where the fundamental mode participation is predominant. Both the methods to calculate target displacement (given in FEMA 356 and ATC 40) do not consider the higher mode participation. Also, it has been assumed that the response of a MDOF system is directly proportional to that of a SDOF system. This approximation is likely to yield adequate predictions of the element deformation demands for low to medium-rise buildings, where the behaviour is dominated by a single mode.

Many publications (Aschheim, *et. al*., 1998; Chopra and Chintanapakdee, 2001; Chopra and Goel, 1999; Chopra and Goel, 2000; Chopra, *et. al*., 2003; Dinh and Ichinose, 2005; Fajfar, 2000; Goel and Chopra, 2004; Gupta and Krawinkler, 2000; Kalkan and Kunnath, 2007) have demonstrated that traditional pushover analysis can be an extremely useful tool, if used with caution engineering judgment, but it also exhibits significant shortcomings and limitations, which are summarised below:

- **a)** One important assumption behind pushover analysis is that the response of aMDOF structure is directly related to an equivalent SDOF system. Although in several cases the response is dominated by the fundamental mode, this cannot be generalised. Moreover, the shape of the fundamental mode itself may vary significantly in nonlinear structures depending on the level of inelasticity and the location of damages.
- **b)** Target displacement estimated from pushover analysis may be inaccurate for structures where higher mode effects are significant. The method, as prescribed in FEMA 356, ignores the contribution of the higher modes to the total response.
- **c)** It is difficult to model three-dimensional and torsional effects. Pushover analysis is very well established and has been extensively used with 2-D models. However, little work has been carried out for problems that apply specifically to asymmetric 3-D systems, with stiffness or mass irregularities. It is not clear how to derive the load distributions and how to calculate the target displacement for the different frames of an asymmetric building. Moreover, there is no consensus regarding the application of the lateral force in one or both horizontal directions for such buildings.
- **d)** The progressive stiffness degradation that occurs during the cyclic nonlinear earthquake loading of the structure is not considered in the present procedure. This degradation leads to changes in the periods and the modal characteristics of the structure that affect the loading attracted during earthquake ground motion.
- **e)** Only horizontal earthquake load is considered in the current procedure. The vertical component of the earthquake loading is ignored; this can be of importance in some cases. There is no clear idea on how to combine pushover analysis with actions at every nonlinear step that account for the vertical ground motion.
- **f)** Structural capacity and seismic demand are considered independent in the current method. This is incorrect, as the inelastic structural response is load-path dependent and the structural capacity is always associated with the seismic demand.

4. References

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