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Evaluate Seismic Performance of Multistorey R.C.C Buildings with Different Structural Configuration by Pushover Analysis

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Abstract

The paper presents a simple computer - based pushover analysis technique for performance - based design of the building framework subject to earthquake loading. The technique used is nonlinear static pushover analysis. In this study, multi-storey RC building with different structural configuration, bare frame, shear wall and infill wall is modeled and analyzed with the help of SAP2000 software. From output of analysis different parameters like base shear, displacement, effective damping, effective period, spectral acceleration and spectral displacement is obtained and compared. It is seen that at roof level displacement in bare frame is more than other two structural configurations and base shear is maximum in the frame with shear wall due to more self-weight.

Keywords: *Symmetrical Building; Asymmetrical Building; Earthquake; Push Over Analysis*.

1. Introduction

Buildings are usually design for seismic resistance using elastic analysis. Linear analysis means correlation of Force and Displacement is linear. This analysis is only valid for material that has elastic linear property. After steel yielding, it becomes Non-Linear. Non-Linear includes geometry nonlinear and material nonlinear. To obtain accurate and real situation we need Non Linear analysis. There are situations in which structure have to be designed for strong motion of earthquake. In such cases the normal structure will undergo inelastic deformation. Since elastic capacity is limited, there will be problem for the building .The maximum harmful and loss cause for irregular buildings the irregularity of building may be in plan or in elevation. In case of irregular structure, center of mass and center of stiffness or center of gravity do not coincide with each other. This creates an eccentricity between center of mass and center of stiffness. The recent advent of performance based design has brought the nonlinear static pushover analysis procedure to the forefront.

Push over analysis is also called as Nonlinear static analysis. Nonlinear structure developed over the past twenty years. It has become the preferred analysis procedure for design and seismic performance evaluation of post elastic behavior of structure. The analysis involves certain approximations and simplifications that some amount of variation is always expected to exist in seismic demand prediction of pushover analysis.

Push over analysis is an Improvement over the linear static and dynamic analysis in the sense that allows the inelastic behavior of the structure. In this analysis set of incremental lateral load over the height of the structure. This method is relatively simple to be implemented and provides information about the strength deformation and ductility of the structure and distribution demand.

Push over analysis can be done by force controlled method. It will carried out & all parameter like base shear, story drift, point drift, story shear, story displacement. The main Output of push over analysis is in the form of force displacement Curve. It is plot base shear Vs lateral displacement. Push over analysis does not account of dynamic characteristics. It gives better result for regular building without torsional irregularity.

1.1 Definition of Pushover Analysis as per FEMA 273 and ATC 40

Pushover analysis is a static, nonlinear procedure using simplified nonlinear technique to estimate seismic structural deformations. It is an incremental static analysis used to determine the force-displacement relationship, or the capacity curve, for a structure or structural element. The analysis involves applying horizontal loads, in a prescribed pattern, to the structure incrementally, i.e. pushing the structure and plotting the total applied shear force and associated lateral displacement at each increment, until the structure or collapse condition. Dynamic behavior of such tanks must take into account the motion of the water relative to the tank as well as the motion of the relative to the ground.

1.2 Purpose of Pushover Analysis

It is expected that most buildings rehabilitated in accordance with a standard, would perform within the desired levels when subjected to the design earthquakes.

Structures designed according to the existing seismic codes provide minimum safety to preserve life and in a major earthquake, they assure at least gravity-load-bearing elements of non-essential facilities will still function and provide some margin of safety. However, compliance with the standard does not guarantee such performance. They typically do not address performance of non-structural components neither provide differences in performance between different structural systems. This is because it cannot accurately estimate the inelastic strength and deformation of each member due to linear elastic analysis.
Account for redistribution of forces during progressive yielding. To overcome this disadvantages different nonlinear static analysis method is used to estimate the inelastic seismic performance of structures, and as the result, the structural safety can be secure against an earthquake. Inelastic analyses procedures help demonstrate how buildings really work by identifying modes of failure and the potential for progressive collapse. The use of inelastic procedures for design and evaluation helps engineers to understand how structures will behave when subjected to major earthquakes, where it is assumed that the elastic capacity of the structure will be exceeded. This resolves some of the uncertainties associated with code and elastic procedures. The overall capacity of a structure depends on the strength and deformation capacities of the individual components of the structure. In order to determine capacities beyond the elastic limit some form of nonlinear analysis, like Pushover Analysis, is required.

1.3 Advantages of the Pushover analysis

It can be seen that pushover analysis procedure leads to evaluation of those response quantity which are otherwise is not possible by static analysis. Response characteristics that can be obtained with the pushover analysis include with

i. Realistic force demands on potentially brittle elements, such as axial demands on columns, moment demands on beam-to-column connections or shear forces demands on short, shear dominated elements.
ii. Estimates of the deformation demands on elements that have to deform in elastically, in order to dissipate energy.
iii. Consequences of the strength deterioration of particular elements on the overall structural stability.
iv. Identification of the critical regions, where the inelastic deformations are expected to be high.
v. Identification of strength irregularities in plan or elevation that cause changes in the dynamic characteristics in the inelastic range.
vi. Estimates of the inter-storey drifts, accounting for strength and stiffness discontinuities. In this way, damage on non-structural elements can be controlled.
vii. Sequence of the member's yielding and failure and the progress of the overall capacity curve of the structure.
viii. Verification of the adequacy of the load path, considering all the elements of the system.

1.4 Load-Deformation Behavior of the Element

In pushover analysis, it is necessary to model the non-linear load-deformation behavior of the elements. Beams and columns should have moment versus rotation and shear force versus shear deformation hinges. For columns, the rotation of the moment hinge can be calculated for the axial load available from the gravity load analysis. All compression struts have to be modeled with axial load versus axial deformation hinges. There are two approaches for specifying the hinge properties.

- Distributed plasticity model
- Point plasticity model.

In the first model, the zone of yielding (plasticization) is assumed to be spread over a certain length (length of the plastic hinge). In the second model, the zone of yielding is assumed to be concentrated at a specific point in the element.

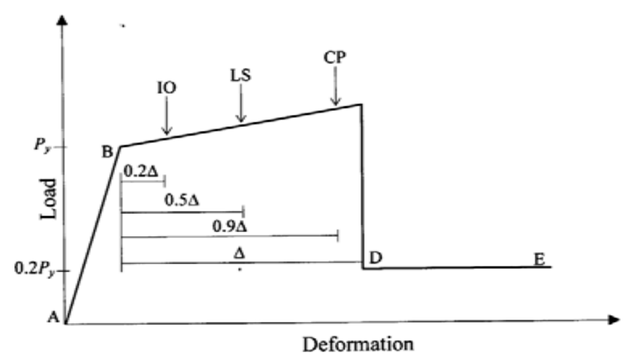

Figure 1 Idealized load-deformation curve

An idealized load-deformation curve is shown in Figure. It is a piece-wise linear curve defined by five points as explained below.

i. Point 'A' corresponds to the unloaded condition.
ii. Point 'B' corresponds to the onset of yielding.
iii. Point 'C' corresponds to the ultimate strength.
iv. Point 'D' corresponds to the residual strength.
v. For the computational stability, it is recommended to specify non-zero residual strength. In absence of the modeling of the descending branch of a load- deformation curve, the residual strength can be assumed to be 20% of the yield strength.
vi. Point 'E' corresponds to the maximum deformation capacity with the residual strength. To maintain computational stability, a high value of deformation capacity equal to 15Δy can

be assumed, where Δy is the deformation at the onset of yielding.

2. Literature Review

Chopra, et al. (2004) Stated in their research paper that PEER report proposed an innovative Pushover analysis Procedure known as Modal Pushover analyses for seismic evaluation. They utilize the basic of structural dynamics to build the background of the proposed procedure. This method essentially takes different modal contribution into account. Procedure consist of determining a modal load pattern corresponding to particular mode, performing pushover analysis with this load pattern and determining the target displacement from proposed Force displacement relationship for ESDF system. Several pushover analysis procedures are carried out to get contribution for each modal response which is then combined according to SRSS modal combination rule. Usually first two or three models are sufficient to get reliable results.

Giordano, et al. (2008), explained in their paper that the nonlinear behavior of a two-storey irregular masonry building having rectangular floor plan. The building presents stiffness and mass eccentricity due to an asymmetric plan layout. Nonlinear static and dynamic analyses are carried out using a refined finite element approach. The dynamic analyses are performed by using both a spectrum-compatible ensemble of generated acceleration records and El Centro earthquake record. The pushover analyses are carried out using a lateral load distribution proportional to the masses distribution within walls and floors. The magnitude of the torsional response is assessed comparing the asymmetric building response with the one of the corresponding plan symmetric building variant. The effectiveness of the pushover procedure is recognized comparing the results with the ones obtained through the nonlinear dynamic analyses. The comparison is essentially carried out referring to the lateral displacement envelope of wall elements.

Mwafy, et al. (2001), explained in their paper that compares' inelastic static pushover analysis compares with inelastic dynamic analysis. In this paper seismic response is predicted by the inelastic static pushover analysis. They concluded that static pushover analysis is more appropriate for low rise and short period frame structures. The result of inelastic static pushover analysis procedure should good correlation with dynamic analysis. It helps to eliminate the errors between static and dynamic analysis result. They find top displacement, Base shear and behavior of displacement versus base shear for static pushover (codal provision), static pushover (Multimodal), and static pushover (uniform). The applicability and accuracy of inelastic static pushover analysis in predicting the seismic response of RC buildings are investigated. Twelve RC buildings with various characteristics, incremental dynamic analysis employing eight natural and artificial records, static pushover analysis using three lateral load distributions and local and global limit state criteria are utilized. Based on the large amount of information obtained, which is nonetheless far from comprehensive, the following conclusions are drawn: I Subject to adequate modeling of the structure, careful selection of the lateral load distribution and articulate interpretation of the results, pushover analysis can provide insight into the elastic as well as the inelastic response of buildings when subjected to earthquake ground motions. I Static pushover analysis am more appropriate for low rise and short period frame structures. For well-designed buildings but with structural irregularities, the results of the procedure also show good correlation with the dynamic analysis. In this study, response obtained for a group of four 8-storey irregular frame buildings using an inverted triangular lateral load distribution is identical to inelastic time–history analysis. I the experience gained from previous studies can help to eliminate the discrepancies between static and dynamic analysis results for special and long period buildings. These differences are mainly due to the limited capability of the fixed load distribution to predict higher mode effects in the post-elastic range. To overcome this problem, more than one load pattern should be selected to guarantee providing an accurate or slightly conservative prediction of capacities and demands. I the investigation carried out on two sets of four 12- story frame buildings and four 8-storey frame-wall structures show that a conservative prediction of capacity and a reasonable estimation of deformation is obtained using the simple triangular or the multimodal load distribution. The same load patterns slightly underestimate the demand of some buildings in the elastic range. On the other hand, the uniform load provides a conservative prediction of seismic demands in the range before first collapse. It also yields an acceptable estimation of shear demands atom the collapse limit state.

3. Methodology

A. Pushover Methodologies Based On Invariant Load Pattern

3.1 FEMA-273

FEMA-273 suggests the use of two different load patterns for the pushover analysis. For the determination of the target displacement FEMA uses the Coefficient method where different coefficient are used to take into account the structural properties such as P-Delta effect, pinching effect etc. Other documents which discuss the Pushover analysis Procedure are the FEMA 273 and FEMA 274, FEMA356 being the latest one.

3.2 Multimode Pushover analysis (MMP)

This method is proposed by Paret et al. [1996] and Sasaki et al. [1998]. This method comprises several pushover

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analyses under forcing vectors representing the various nodes deemed to be excited in the dynamic response. The individual pushover curves are converted to the Acceleration- Displacement Response Spectrum (ADRS) format and the Capacity Spectrum Method is utilized to compare the structural capacity with the earthquake demand. In this way, it becomes apparent which mode is more critical and where damage is likely to occur. The procedure is intuitive, and does indeed provide qualitative information and identify potential problems due to higher modes that conventional single mode pushover analysis fails to highlight. However, the effects of higher modes cannot be easily quantified, since the method does not provide estimation of the response.

3.3 Pushover Result Combination (PRC) Method:

This Method is developed by Moghadam and Tso (2002). This Method is refinement the multimode pushover procedure According to this method; the maximum seismic response is again estimated by combining the results of several pushover analyses, which are carried out using load patterns that match the modal shapes of a predefined number c nodes.

3.4 Upper Bound Pushover Analysis Procedure (UBPA)

This methodology is proposed by Jan et al (2002). This methodology utilizes a propose expression for lateral load pattern and for target displacement determination An absolute sum modal combination rule is utilized for combination of first and second node to get an upper bound seismic analysis results.

3.5 Modal Pushover analysis (MPA)

This Pushover methodology is developed by Chopra et al (2002).This method takes into account the higher mode effect for the seismic evaluation of structures. The method consist in application of invariant modal lateral load pattern to the structure, performing of pushover analysis, determining target displacement from the proposed force displacement relationship of Equivalent Single Degree of Freedom System (ESDF) system and extracting the demands at that target displacement. Similar steps are carried out for other mode and modal responses are then combined according to the SRSS modal combination rule.

3.6 Modified Modal Pushover Analysis (MMPA)

This Methodology is again developed by Chopra et al (2004), which proposes modification over the modal pushover analysis procedure. In this methodology the demand for the first mode are evaluated same as by the Modal Pushover Analysis Procedure. But recommend modification in procedure for higher mode contribution. For evaluating higher mode effects the structure is as elastic and its response is then evaluated by standard Response spectrum analysis procedure. The responses from all the modes are then combined according to SRSS modal combination rule. Usually first three or four modes are sufficient.

B. Pushover Methodologies Based On Variant Load Pattern

3.7 Adaptive Pushover Analysis

This method is originally proposed by Gupta and Kunnath (2000. In this methodology applied loads are constantly updated, depending on the instantaneous dynamic characteristics of the structure; in addition, a site-specific spectrum can be used to define the loading pattern. According to the method, Eigen value analysis is carried out before each load increment, utilizing the current structural stiffness state. The number of mode of interest that will be taken into account is predefined and the story forces for each node are estimated.

3.8 Adaptive Modal Combination (AMC) procedure

This methodology is proposed by E Kalkan and S K Kunnath (2006) .The methodology offers a direct multimode technique to estimate seismic demands and attempts to integrate concepts built into the capacity spectrum method recommended in ATC-40, the adaptive method originally proposed by Gupta and Kunnath (2000) and the modal pushover analysis advocated by Chopra and Goel (2002). The AMC procedure accounts for higher mode effects by combining the response of individual modal pushover analysis and incorporates the effects of varying dynamic characteristics during the inelastic response via its adaptive feature. The applied lateral forces used in the progressive pushover analysis are based on instantaneous inertia force distributions across the height of the building for each mode. A novel feature of the procedure is that the target displacement is estimated and updated dynamically during the analysis by incorporating energy-based modal capacity curves in conjunction with constant ductility capacity spectra. Hence it eliminates the need to approximate the target displacement prior to commencing the pushover analysis.

4. Result and Analysis

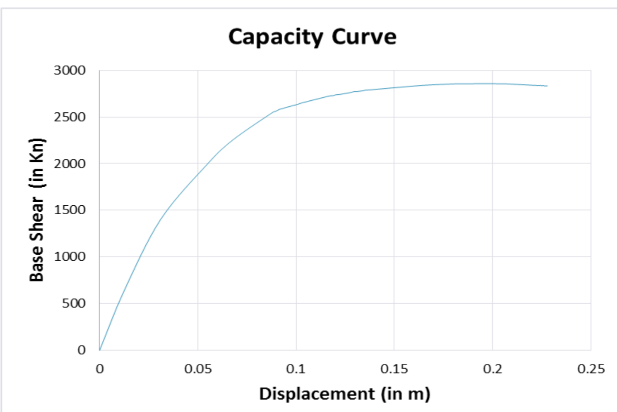
Pushover Analysis was carried out over the designed 5, 12 and 22 story buildings respectively using SAP 2000(V16). The members were assigned with their self-weight of the building considering beams, columns slabs and as well as brick infill. And the analysis was carried out for combinations of loads as per IS 1893-2002. The building is pushed in lateral directions until the collapse mechanism is reached. The various curves resulting from the analysis are briefly discussed below.

4.1 The Pushover analysis of G+4 RC Building

The following figure shows the Pushover curve base shear vs lateral displacement.
The unit for Base Reaction is KN and Displacement is meter. The maximum node displacement is equal to 0.230m. The Pushover Curve shows that the building has objectively high Base Shear Capacity than the Design Base Shear.
The Design base shear (VB) was found to be 1742 in chapter 3 and the capacity is 2900KN which is much higher, hence the building is safe for this level of earthquake.

Table 1 the conclusion from Performance point of G+4

Base shear(KN)	2679.179	Roof displacement (m)	0.108
Spectral Acceleration, Sa (m/s)	0.488	Spectral displacement, Sd (m)	0.082
Effective time period, Teff (s)	0.823	Effective damping, βeff	0.189



Graph 1 Push Over Curve For G+4 Building

In Graph 1 showing the push curve of L-shape,T-shape and symmetrical building. In this graph shows the Performance point of occupancy and collapse point of the building when push over analysis is carried out.

5. Conclusion

- The displacement in symmetric building is very small as compare to in asymmetric building.
- The torsional moment in asymmetrical building is more as compare to symmetric building.
- By using push over analysis performance of symmetrical building is better than asymmetrical building.

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