Response Spectrum-Based Pushover Analysis for Predicting Earthquake Induced Forces in Buildings

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Abstract: ***This paper proposes the uses of nonlinear static analysis of masonry building for seismic assessment behavior. In this methodology consist push over analysis on the modal building. The push over analysis is a more realistic assessment of seismic vulnerability. Since it can give a higher number of possible failure mechanism then in the pushover analysis restricted to the two principle directions of the structure. according to this method the peak story drift, displacement and shear obtained from response spectrum analysis can resolve in to their translation and rotational components and related lateral forces and moments can be calculated. The development of result of pushover analysis using constructed load pattern is consider the seismic demand of the structure. The target displacements of the nonlinear static analysis can be calculated using the available codes IS 1893-2016, IS 456-2000, ASCE 41-13, FEMA-356,213 and ATC-40.***

Keywords: Masonry structure, Nonlinear static analysis, story drift ratio, Response spectrum, Seismic assessment, Earthquake engineering, ETABS

1. Introduction

Pushover analysis is a nonlinear static analysis method where a structure is subjected to loads and a displacement-controlled lateral load pattern which continuously increases on frame through elastic and inelastic behaviour of frame until an ultimate condition points is reached. The range of base shear induced by earthquake loading may represent the Lateral load, and its configuration may be proportional to the mode shapes, distribution of mass along building height, or another practical means.

Nowadays the use of numerical methods is customary in the field of structural engineering. Many researchers have proposed numerical methodologies to simulate the complex material behavior of masonry. A general overview of modelling techniques for masonry structures is summarized in [1]. A special attention on discrete element methods (DEM) and finite element methods (FEM) offer a wide range of modelling strategies. Mismodeling [2–6] distinguishes among the masonry components (units and joints) and is very accurate, but still too expensive in terms of computation time when applied to large structures. Macro-modelling [7–13] represents the material as a homogenized continuum and thus offers wide applicability to real scale structural applications.

The nonlinear static procedures (NSP) have been developed for the seismic assessment of structures whose behavior are primarily translational. So, In-plan irregularity appears to have the most adverse effects on the applicability of these procedures in accurately estimating their seismic-induced response parameters. In recent years, various attempts have been made to extend the NSPs to plan asymmetric buildings in which the effect of their torsional modes is considerable. Therefore, for these buildings in which the first translational mode is not an adequate representative of a complex structural system, the conventional NSP is not a reliable method to estimate the structural demands. On the other hand, the code specifications still do not provide clear and specific guidelines for the seismic analysis of such structures. In the following, a brief review of enhanced pushover procedures for estimating the seismic demands in asymmetric buildings is presented.

Nonlinear static and dynamic analysis methods have been employed to assess the seismic behavior of masonry buildings without box behavior structure [15,16], i.e. presenting flexible floors-to floor or deficient floor-to-wall or wall-to-wall connectivity. These studies have shown possibilities and limitations for the different approaches to account for the defects of box behavior in the analysis of the seismic response of the building. Existing masonry structures often exhibit structural irregularities, as possible consequence of historical interventions and subsequent modifications to their layout. Such irregularities, which can be observed both in plan and in elevation, are frequent in historical masonry structures, especially in those of the urban centers. Static analysis methods present several limitations for this class of buildings, since they cannot represent properly the complex 3D dynamic response during the earthquake.

The evaluation of the seismic capacity in NSA refers to the relationship between the total base shear and the displacement of a representative control node. The choice of the control node is straightforward in buildings with rigid floors well connected to the walls. For such cases, the control point to be located at the center of mass at the top floor level. However, the choice of a suitable control node becomes difficult in NSA of irregular buildings with flexible diaphragms [17,18] since the lack of box behavior leads to local damage and failure mechanisms [16,19–21]. Recent works propose the selection of different control nodes in NSA in order to follow the response of the most critical structural members during the analysis [14,22,17].

2. Methodology

The nonlinear dynamic analysis (NDA) is currently the most accurate procedure for the seismic assessment of masonry structures, but the nonlinear static analysis (NSA) is usually preferred in common practice due to its easier implementation and lower computational cost. However, the conventional NSA presents restrictions about the applicability to irregular masonry buildings whose dynamic behavior is the result of the complex interaction among local vibration modes. In addition, conventional pushover procedures show important limitations when applied to structures without box behaviors. This research presents a novel approach based on the execution of multiple NSAs along different geometrical orientations of the investigated building. The objective is to obtain an improved representation of the local damage and failures, with a specific attention to out-of-plane mechanisms that show to be the more recurrent in irregular masonry buildings without box behavior. This section discusses the operation of the proposed multi directional pushover analysis (MDPA) technique, after having presented an overview of available NSA approaches, including both conventional and updated techniques to deal with structural irregularity.

2.1. Overview of available pushover procedures

2.1.1. Conventional approaches

The conventional NSA approach evaluates the seismic capacity by increasing monotonically an invariant lateral load pattern applied to the structural model. The gradual increase of horizontal loads leads to progressive damage, and thus to gradual decrease of the stiffness until reaching the collapse condition. The Indian codes [23] recommends the use of the “uniform” and “modal” loading patterns in NSA. The first consists in lateral forces proportional to mass regardless of elevation, while the second is proportional to lateral force distributions given by previous elastic (modal) analysis. The applicability of the conventional pushover approach is confine to structures vibrating predominantly in the first mode and with time-independent deformation shape. For this reason, the N2 method [24], suggested by EC8 to determine the seismic demand, is applicable only to structures fulfilling specific requirements for plan and elevation regularity. A recent research [17] suggests the application of a proper lateral load pattern in the pushover analysis of masonry buildings with low participating mass in the first mode.

The evaluation of the seismic capacity in NSA refers to the relationship between the displacement and the base shear of a representative control node. The choice of the control node in buildings with rigid floors well connected to the walls.

2.1.2. Extension to irregular buildings

The Eurocode 8 have a procedure for the estimation of the torsional effects, also known as extended N2 method [25]. It consisting the definition of a proper factor for the displacements, based on the analysis results of an elastic modal. The method combines the results from an NSA of the irregular structure with those from a linear dynamic analysis, in order to estimate the torsion effect. The extended N2 method has been applied to the pushover-based seismic analysis of asymmetric reinforced concrete framed structures with rigid floors [25,26]. Available standards are need for the improvement in order to provide practical specifications for the analysis of irregular masonry buildings. Different researches have suggested the possibility of extending the applicability of conventional pushover analysis procedures by trying to overcome some of their inherent limitations [27]. The modal pushover analysis (MPA) [28] considers the inertia force distributions for different modes with the aim of including also the contributions from higher vibration modes. These modal contributions are then combined by using the Complete Quadratic Combination (CQC) or Square Root of the Sum of Squares (SRSS) rules.

3. Building modelling, Analysis and Design

A G+12 reinforced concrete building is modelled, analyzed and studied. The study is carried out in the seismic zone III of India. The input data required for the design of G+12 building is presented in the tables below.

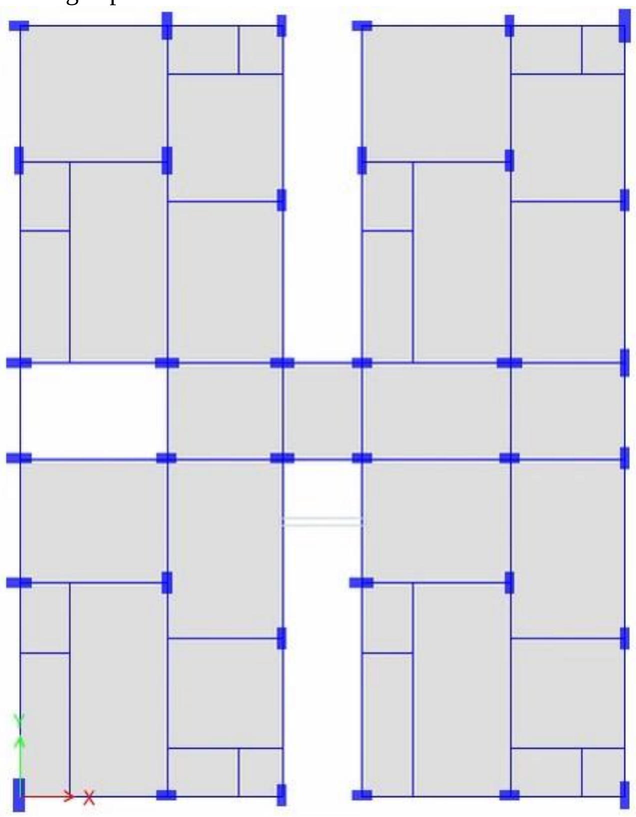

Figure 1: Plan of the Structure

NOTE

Structure dimensions
- Area of site — 550 m^2
- Dimensions of site — 22m x 25m
- Basement level height — 3m
- Ground level height — 3m
- 1st to 12th height — 3m
- All remining dimensions are shown in plan

Beams
- B 230 X 230
- B 300 X 450
- B 300 X 610
- B 380 X 610

Columns
- C 300 X 610
- C 300 X 750
- C 300 X 920
- C 380 X 920

Depth of slab 120 mm

Material usage
- Grade Concert (Fck) — 20 N/mm^2
- Grade Steel (Fy) — 500 N/mm^2

Restraints
- Columns are fixed at base
- Structure is laterally restrained at ground level

Seismic parameters
- Seismic zone III
- Soil type II (medium soil)
- Importance factor 1
- Damping ratio 5%
- Time period $T = \frac{0.09\,h}{\sqrt{d}}$
- 0.8790 (X-direction)
- 0.8154(Y-direction)

Response spectrum
- Scale factor $\left(\frac{Ig}{2R}\right)$ 1.635

Structural details

4. Pushover Analysis

Pushover analysis is used to find the force–deformation behavior of a structure for a specified distribution of forces, typically lateral forces. With some assumption of force distribution, nonlinear static analysis is called pushover analysis.

pushover curve is generating which plots a strength-based parameter to deflection. the strength level achieved in certain members to the lateral displacement at the top of the structure, or bending moment may be plotted against plastic rotation based on the structure performance. In pushover analysis Results getting insight into the load level, and deflection ductile capacity, and indicate the mechanism of the structural system at which failure occurs.

When analyzing structural objects, material nonlinearity is assigned to find hinge locations where plastic rotation occurs according to FEMA and different set of code-based or user-defined criteria. Displacement control, Strength drop, and all other nonlinear software features, including link assignment and P-Delta effect are available during pushover analysis.

4.1. Pushover Analysis Procedure

1). Create 3d structure by define material properties and section properties then assign all properties properly and shown in fig (1) Plan and fig (2) 3d rendering view.
(2) define and assign load case details such as dead load, live load, floor loads as per INDIAN codes IS 875.
(3) generate Load combinations as per Indian code IS 456-2000 and firstly carried linear static analysis.
(4) after linear static analysis generate seismic loads and response spectrum of structure as per IS 1893-2016.
(5) create hinge formations of structure like provide plastic hinges at ends of the flexural members and compression members and then carry analysis.

5. Results and discussion

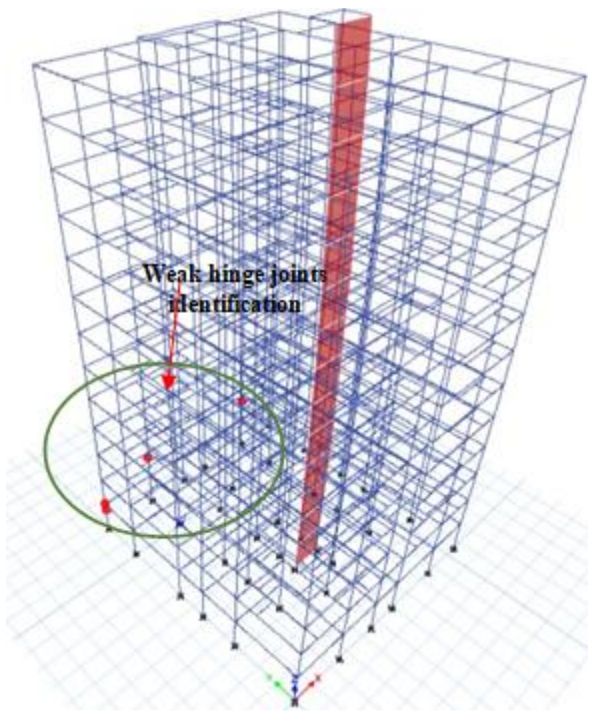

Figure 2: Hinge pattern in structure

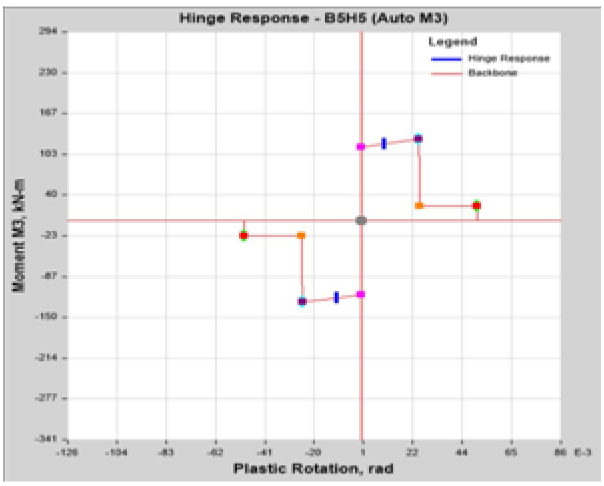

Figure 3: Hinge response graph

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Shown in fig 2 and 3 pushover analysis Plastic hinge (yielding) formation sequence in the structural elements can be studied by this force deflection curve. Fig. 3 shows the structure behavior of beam and column based on the weak hinge formations. The points shown in the Fig. 4 explains different states.

If the formation of hinge in between A to B then the hinge is in elastic state.

If the formation of hinge in between B to IO then it is below immediate occupancy state. At this state, the structure can be occupied immediately with minor repair works. Structural elements did not fail.

If the formation of hinge in between IO (Immediate Occupancy) to LS (Life Safety) then the life of the structure is safe but minor structural element repair works are to be needed and rehabilitation methods are applied if necessary.

If the formation of hinge in between LS (Life Safety) to CP (Collapse Prevention) then the structural elements are damaged but structure won't collapse. At this state structure needs sometimes retrofitting methods and rehabilitation works should be implemented based on the level of failure.

If the formation of hinge in between CP (Collapse Prevention) to C (Ultimate Capacity) then the structure crosses its ultimate strength. At point B, yielding starts and structure enters into nonlinear range.

If the formation of hinge in between C (ultimate capacity) to D (residual strength) then the structural elements drop the load and there is reduction in load carrying capacity. Then the structure redesign that particular elements at that point.

If the hinge falls at D or beyond D then there will be no increase in load carrying capacity, however Pushover Analysis of RC Building: Comparative Study on Seismic Zones of India the structure continues to deform.

If the formation of hinge beyond the E, then the structure will collapse

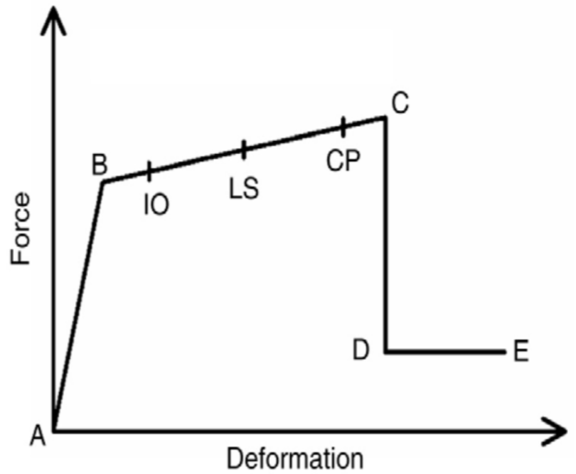

Figure 4: Force - Displacement curve

Shown in Figures 5 and 6 are the story drift ratios obtained by described pushover procedures, EQA and RSA for 12-storey frames. The figures illustrate that the EQA, RSA and POA procedures produce satisfactory estimates of storey drifts. The POA provides better estimates of storey drifts that the EQA at some storeys, whereas the POA errors are less than the general EQA at some other (lower) storeys.

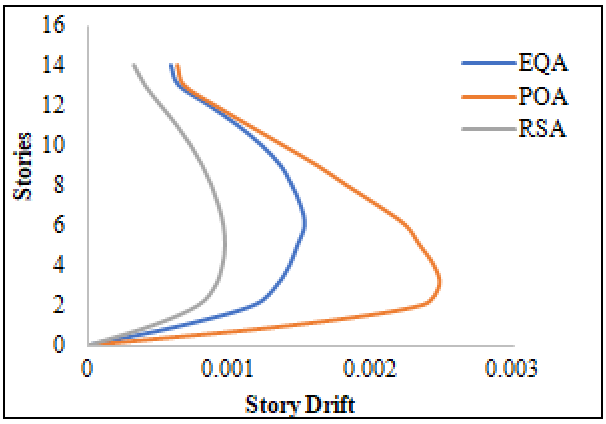

Figure 5: Story drifts in X – direction

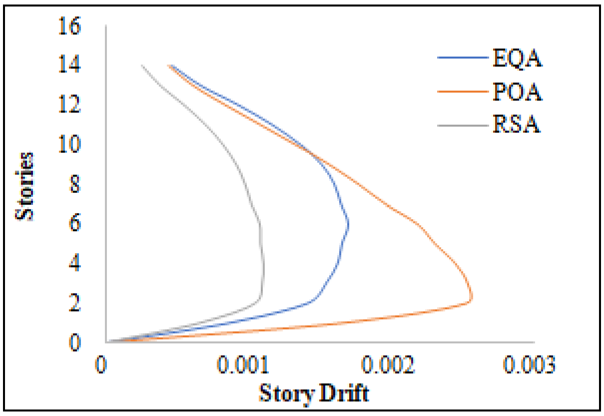

Figure : 6 story drifts in Y -direction

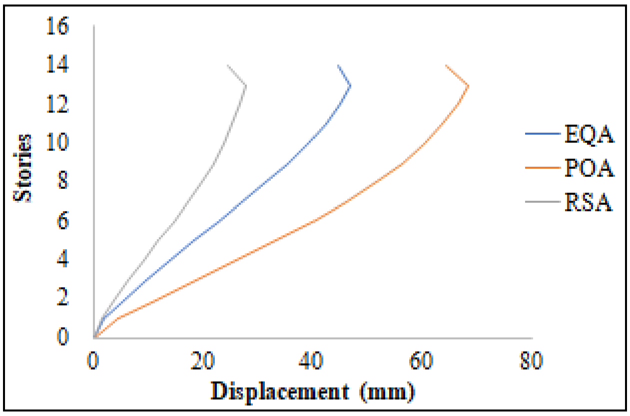

Figure 7: Displacements in X-direction

The story displacements of the frames are shown in Figures 7 and 8. The POA fails to accurately predict displacements at upper floor of 12story frames, while noticeable improvement has been achieved in the estimates derived from the POA procedure so that the POA are significantly more accurate than EQA.

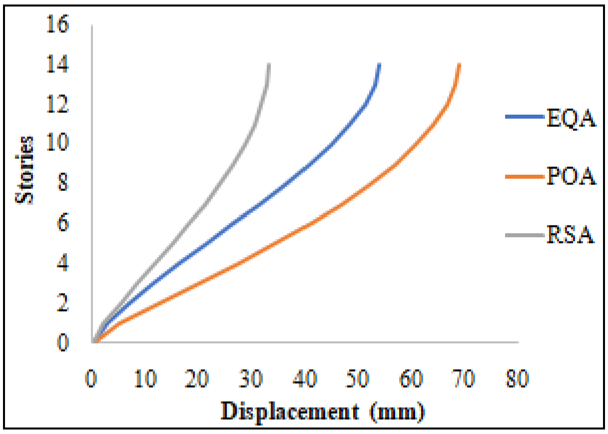

Figure 8: Displacements in Y-direction

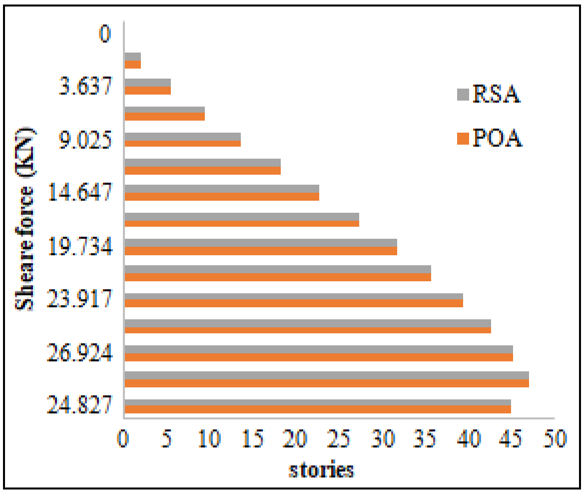

Figure 9: Shear force in X-direction

Shown in Figures 9 and 10 are the story shear obtained by described pushover procedures and RSA for 12-storey frames. The figures illustrate that the RSA and POA procedures produce satisfactory estimates of storey drifts. The POA and RSA provides same storey shear

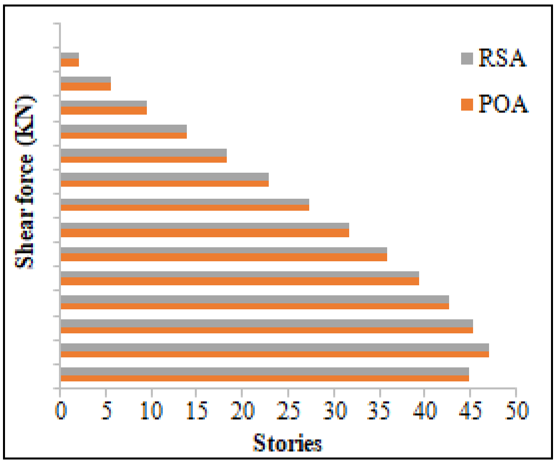

Figure 10: Shear force in Y-direction

6. Conclusions

To take into account of higher mode effects in pushover analysis for predicting seismic demands of tall building structures. In SPA, a linear response spectrum analysis procedure is incorporated into the SPA method to consider the linear combination effect of vibration modes in the seismic response of buildings, especially the earthquake-induced forces. A case study of two high-rise, special moment-resisting frame (SMRF) buildings with different heights of structure is conducted and the results from the proposed SPA method.

The one standard deviation range is a part of the value range of the earthquake-induced forces that are computed following the requirements of the codes of practice, so the one standard deviation range can be a good measure for the judging the reasonability of the pushover analysis methods. promising tools for the fast predict of the earthquake-induced forces in high-rise buildings, in particular, high-rise frame structures.

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