

Non-linear static pushover analysis for multi-stored building by using ETABS

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Abstract: Pushover analysis involves certain approximations and simplifications that some amount of variation is always expected to exist in seismic demand prediction of pushover analysis. In literature, some improved pushover procedures have been proposed to overcome the certain limitations of traditional pushover procedures. The effects and the accuracy of invariant lateral load patterns utilized in pushover analysis to predict the behaviour imposed on the structure due to randomly selected individual ground motions causing elastic and various levels of nonlinear response were evaluated in this study. For this purpose, pushover analyses using various invariant lateral load patterns and Modal Pushover Analysis were performed steel moment resisting frames covering a broad range of fundamental periods.

The primary observations from the study showed that the accuracy of the pushover results depends strongly on the load path properties of the structure and the characteristics of the ground motion. The accuracy of approximate procedures utilized to estimate target displacement was also studied on frame structures. The accuracy of the predictions was observed to depend on the approximations involved in the theory of the procedures, structural properties and ground motion characteristics.

Keywords— Earthquake analysis, Static Analysis, Pushover Analysis, ETABS.

Introduction

The Buildings, which appeared to be strong enough, may crumble like hours of cards during earthquake and deficiencies may be exposed. Experience gain from the recent earthquake of Bhuj, 2001 demonstrates that the most of buildings collapsed were found deficient to meet out the requirements of

the present day codes. In last decade, four devastating earthquakes of world have been occurred in India, and low to mold intensities earthquake of world frequently. Due to wrong construction practices and ignorance for earthquake resistant design of buildings in our country, most of the existing buildings are vulnerable to future earthquakes. In the simplest case, seismic design can be viewed as a row-step process. The first, and usually most important one, is the conception of an effective structural system that needs to be configured with due regards to all important seismic performance objectives, ranging from serviceability consideration to life safety and collapse prevention. This step comprises the art of seismic engineering, since no rigid rules can, or should, be imposed on the engineer's creativity to devise a system that not only fulfills seismic performance objectives, but also pays tribute to functional and economic constraints imposed by the owner, the architect, and other professionals involved in the design and construction of a building. By default, this process of creation is based on judgment, experience, and understanding of seismic behavior, rather than rigorous mathematical formulations. Rules of thumb for strength and stiffness targets, based on the fundamental knowledge of ground motion and elastic and inelastic dynamic response characteristics, should involve a demand/capacity evaluation at all important performance level, which requires identification of important capacity evaluation at all important performance level, which

requires identification of important capacity parameters and prescription of acceptable values of these parameters, as well as the prediction of the demands imposed by ground motions. Suitable capacity parameters and their acceptable values, as well as suitable methods for demands prediction will depend on the performance level to be evaluated. In light of these facts, it is imperative to seismically evaluate the existing building with the Present day knowledge to avoid the major destruction in the future earthquakes. The Buildings found to be seismically deficient should be retrofitted or strengthened. **Necessity of Non-Linear Static Pushover Analysis:**

The existing building can become seismically deficient since seismic design code requirements are constantly upgraded and advancement in engineering knowledge. Further, Indian buildings built over past two decades are seismically deficient because of lack of awareness regarding seismic behavior of structures. The widespread damage especially to RC buildings during earthquakes exposed the construction practices being adopted around the world, and generated a great demand for seismic evaluation and retrofitting of existing building stocks.

1.3 Pushover Analysis:

The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity. On a building

frame, and plastic rotation is monitored, and lateral inelastic forces versus displacement response for the complete structure is analytically computed. This type of analysis enables weakness in the structure to be identified. The decision to retrofit can be taken in such studies.

The seismic design can be viewed as a two-step process. The first, and usually most important one, is the conception of an effective structural system that needs to be configured with due regard to all important seismic performance objectives, ranging from serviceability considerations. This step comprises the art of seismic engineering. The rules of thumb for the strength and stiffness targets, based on fundamental knowledge of ground motion and elastic and inelastic dynamic response characteristics, should suffice to configure and rough-size an effective structural system.

Elaborate mathematical/physical models can only be built once a structural system has been created. Such models are needed to evaluate seismic performance of an existing system and to modify component behavior characteristics (strength, stiffness, deformation capacity) to better suit the specified performance criteria.

Purpose of Non-linear Static Pushover Analysis:

The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating performance of a structural system by estimating its strength and deformation demands in design earthquakes by means of static inelastic analysis, and comparing these demands to available capacities at the performance levels of interest. The evaluation is based on an assessment of important performance parameters, including global drift, inter story drift, inelastic element deformations

(either absolute or normalized with respect to a yield value), deformations between elements, and element connection forces (for elements and connections that cannot sustain inelastic deformations). The inelastic static pushover analysis can be viewed as a method for predicting seismic force and deformation demands, which accounts in an approximate manner for the redistribution of internal forces that no longer can be resisted within the elastic range of structural behavior.

The pushover is expected to provide information on many response characteristics that cannot be obtained from an elastic static or dynamic analysis. The following are the examples of such response characteristics: The realistic force demands on potentially brittle elements, such as axial force demands on columns, force demands on brace connections, moment demands on

- ❖ beam to column connections, shear force demands in deep reinforced concrete spandrel beams, shear force demands in unreinforced masonry wall piers, etc.
- ❖ Estimates of the deformation demands for elements that have to form in elastically in order to dissipate the energy imparted to the structure.
- ❖ Consequences of the strength deterioration of individual elements on behavior of structural system.
- ❖ Consequences of the strength determination of the individual elements on the behavior of the structural system.
- ❖ Identification of the critical regions in which the deformation demands are expected to be

high and that have to become the focus through detailing.

- ❖ Identification of the strength discontinuities in plan elevation that will lead to changes in the dynamic characteristics in elastic range.
- ❖ Estimates of the understory drifts that account for strength or stiffness discontinuities and that may be used to control the damages and to evaluate P-Delta effects.

Verification of the completeness and adequacy of load path, considering all the elements of the structural system, all the connections, the stiff nonstructural elements of significant strength, and the foundation system.

Limitations of Pushover Analysis:

Although pushover analysis has advantages over elastic analysis procedures, underlying assumptions, the accuracy of pushover predictions and limitations of current pushover procedures must be identified. The estimate of target displacement, selection of lateral load patterns and identification of failure mechanisms due to higher modes of vibration are important issues that affect the accuracy of pushover results.

Target displacement is the global displacement expected in a design earthquake. The roof displacement at mass Centre of the structure is used as target displacement. The accurate estimation of target displacement associated with specific performance objective affect the accuracy of seismic demand predictions of pushover analysis.

Nonlinear Behavior of Structural Elements:

The nonlinear behavior of building structure of a building structure depends on the nonlinear response

of the elements that are used in the lateral force resisting system. Therefore, before applying any nonlinear analysis method on a building structure, the nonlinear behavior of such elements must be clearly described and evaluated. In FEMA-273, the generalized load deformation relation of a structural member while exhibiting nonlinear behavior is shown in figure. After the member yields (When applied load/yield load proportion (Q/Q_y) is equal to 1), the subsequent strain hardening accommodation the strain hardening in the load-deformation relation as the member d7.

Element Description of Etabs

In ETABS, a frame element is modeled as a line element having linearly elastic properties and nonlinear force-displacement characteristics of individual frame elements are modeled as hinges represented by a series of straight line segments. A generalized force-displacement characteristic of a non-degrading frame element (or hinge properties) in ETABS.

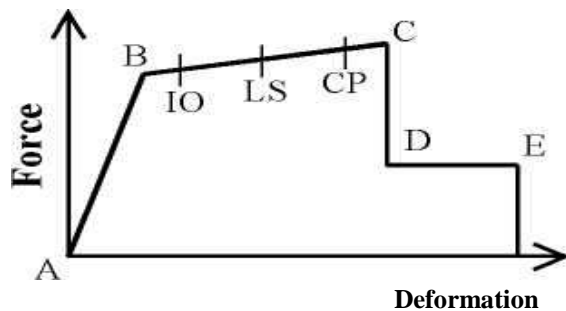


Fig. 1.1. Force-Deformation for Pushover Hinge

Point A corresponds to unloaded condition and point B represents yielding of the element. The ordinate at C corresponds to nominal strength and abscissa at C corresponds to the deformation at which significant strength degradation begins. The drop from C to D represents the initial failure of the element and resistance to lateral loads beyond point C is usually unreliable. The residual resistance from D to E allows the frame elements to sustain gravity loads. Beyond point E, the maximum deformation capacity, gravity load can no longer be sustained.

Hinges can be assigned at any number of locations (potential yielding points) along the span of the frame element as well as element ends. Uncoupled moment (M_2 and M_3), torsion (T), axial force (P) and shear (V_2 and V_3) force-displacement relations can be defined. As the column axial load changes under lateral loading, there is also a coupled P - M_2 - M_3 (PMM) hinge which yields based on the interaction of axial force and bending moments at the hinge location. Also, more than one type of hinge can be assigned at the same location of a frame element. There are three types of hinge properties in ETABS. They are default hinge properties, user-defined hinge properties and generated hinge properties. Only default hinge properties and user-defined hinge properties can be assigned to frame elements.

When these hinge properties (default and user-defined) are assigned to a frame element, the program automatically creates a new generated hinge property for each and every hinge. Default hinge properties could not be modified and they are section dependent. When default hinge properties are used, the program combines its built-in default criteria eforms towards the expected strength

METHODOLOGY

Capacity Curve:

It is the plot of the base shear v , on a structure, against the lateral deflection, d , of the roof of the structure as shown in Fig. 3.1 This is often referred to as the pushover curve.

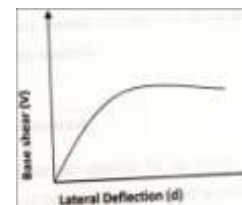


Fig 3.1 Pushover curv

3.2.3Capacity Spectrum:

It is the capacity curve transformed from shear force vs roof displacement (v vs d) coordinates

into spectral accelerations vs. spectral displacements (sa vs sd) coordinates as shown in Fig 3.2

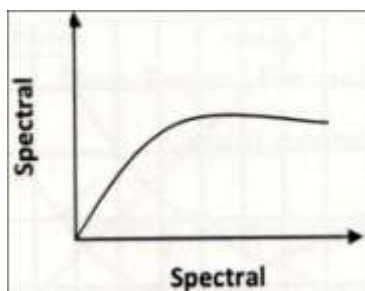


Fig 3.2 Capacity curve

3.2.4 Demand:

It is a representation of the earthquake ground motion or shaking that the building is subjected to. In nonlinear static analysis procedures, demand is represented by an estimation of the displacements or deformation that the structure is expected to undergo. This is in contrast to conventional, linear elastic analysis procedure in which demand is represented by prescribed lateral forces applied to the structure.

3.2.5 Elastic response spectrum:

The locus of the demand points in the ADRS plot is referred to as the demand spectrum. The demand spectrum corresponds to the inelastic deformation of the building.

3.2.6 Performance point:

The 'performance point' is the point where the capacity curves cross the demand curves as shown in fig. 3.3. If the performance point exists and the damage state at this point is acceptable, the structure satisfies the target performance level.

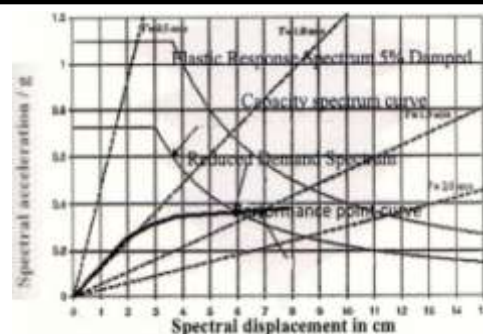


Fig 3.3 Determination of Performance Point

3.2.7 Modeling Aspects of building elements:

Beams and columns are modeled as line elements and slab as membrane element. Nonlinearity in structure is achieved by considering material nonlinearity only. Geometric nonlinearity is ignored. Nonlinear plastic hinges are assigned to all of the primary elements. Default moment hinges (M3) are assigned to beam elements and default axial moment2-moment3 hinges (PMM) are assigned to column elements. The hinge features are shown in Fig3.4 for rigid floor idealization the floor diaphragms are modeled by assigning diaphragm constraint and for flexible floor idealization the method of constraining the diaphragm is presented. The model with all the above features created in ETABS is reproduced.

Lateral Load Calculations for rigid floor idealization:

The total base shear is given by

$$V_b = A_h \cdot W$$

Where A_h = is the design horizontal seismic coefficient.

$$A_h = \frac{Z}{2} \cdot \frac{I}{R} \cdot \frac{S_a}{g}$$

Where

Z = Zone factor given in table 2 of IS: 1893-2002

I = Importance factor given in table 6 of IS: 1893-2002

R = Response reduction factor given in table 7 of IS: 1893-2002.

IS parabolic lateral load (PLL) at floor "i" is given by

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^n W_j h_j^2}$$

Triangular lateral load (TLL) at floor “T” is given by

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^n W_j h_j^2}$$

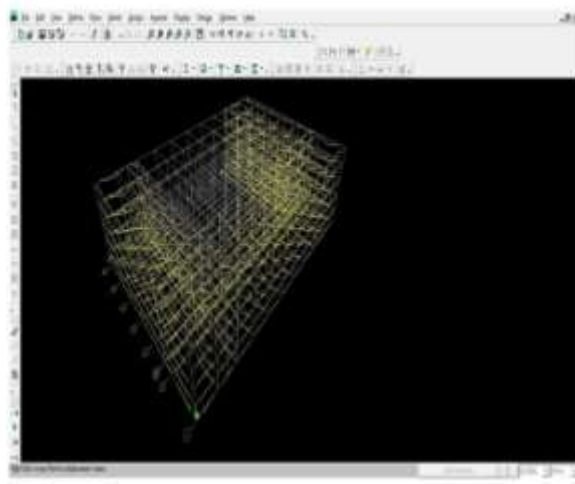
Q_p = Lateral loads as per IS: 1893 – 2002 and ATC – 40 at each floor level

W = Total seismic weight the structure

W_i = Seismic weight floor of i

h_i = High of floor measured from base

n = is the number of leaves at which the masses are lumped



CONCLUSIONS

The frame behaved linearly elastic up to a base shear value of around 180 KN at the value of base shear 360 KN it depicted non linearity in its behavior. Increase in deflection has been observed to be drop down with load increments at base shear of 360 KN. The frame has shown variety of failures like beam-column joint failure, flexural failure and shear failure. Flexural failures have been seen in beams. The Pushover Analysis was including 8 steps it has been observed that one sub sequent push to building, hinges started forming in beams first. Initially hinges were in A-B stage and subsequently proceeding to B-IO stage. Out of 198 hinges 194 in A-B stage, 4 in B-IO stage. Overall performance of building is said to be B-IO stage.

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