Review on Pushover Analysis of Static Non-Linear RCC Framed Structure

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Abstract— In recent years, an extensive examination going on performance of structure during a seismic event. During seismic action, building will deform in in-elastic zone, soits required evaluation which consider post-elastic behavior of structure. Performance based seismic design is a modern technique to earthquake resistance which can predict performance of structure using rigorous non-linear static analysis. Easy and most used method to evaluate performance of structure is non-linear static analysis widely known as pushover analysis. As name implies, it's a process of pushing structure horizontally, with a prescribed loading pattern incrementally, i.e "pushing" structure & plotting total applied shear force & associated lateral displacement at each increment, until structure reaches a limit state or collapse condition. It provides better understanding of seismic performance of building & also give identification of progression of damage and subsequently failure of building's structural element .By pushover analysis, One can get behavior of building in non -linear zone, which is not covered in conventional elastic design.

Key words: Non-linear Static Analysis, Performance based design, Capacity, Demand, Performance point, ETABS 9.7, Pushover analysis, RCC Framed structure

I. Introduction to Pushover Analysis

Seismic hazard in the context of engineering design is generally defined as the predicted level of ground acceleration which would be exceeded with 10% probability at the site under consideration due to the occurrence of an earthquake anywhere in the region, in the next 50 years. A lot of complex scientific perception and analytical modelling is involved in seismic hazard estimation. A computational scheme involves the following steps: delineation of seismic source zones and their characterization, selection of an appropriate ground motion attenuation relation and a predictive model of seismic hazard. Although these steps are region specific, certain standardization of the approaches is highly essential so that reasonably comparable estimates of seismic hazard can be made worldwide, which are consistent across the regional boundaries. India has identified as one such center, responsible for estimating the seismic hazard for the Indian region. As it is well known, earthquake catalogues and data bases make the first essential input for the delineation of seismic source zones and their characterization. Thus, preparation of a homogeneous catalogue for a region under consideration is an important task. The data from historic time to recent can broadly be divided in to three temporal categories:

1) since 1964, for which modern instrumentation based data are available
2) 1900-1963, the era of early instrumental data, and
3) pre 1900, consisting of pre-instrumental data, which is based primarily on historical and macro-seismic information. In India, the scenario is somewhat similar.

The next key component of seismic hazard assessment is the creation of seismic source models, which demand translating seismo-tectonic information into a spatial approximation of earthquake localisation and temporal recurrence. For this purpose, all the available data on neo-tectonics, geodynamics, morpho structures etc., need to be compiled and viewed, overlain on a seismicity map. These maps then need to be critically studied for defining areal seismic source zones and active faults. An earthquake recurrence model is then fitted to these source zones, for defining the parameters that characterise the seismicity of the source region, which go as inputs to the algorithm for the computation of seismic hazard. It is an iterative process that begins with the selection of performance objectives, followed by the development of a preliminary design, an assessment as to whether or not the design meets the performance objectives, and finally redesign and reassessment, if required, until the desired performance level is achieved.

II. Pushover Analysis

Pushover analysis is an approximate analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. Pushover analysis consists of a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure.

A two or three dimensional model which includes bilinear or trilinear load-deformation diagrams of all lateral force resisting elements is first created and gravity loads are applied initially. A predefined lateral load pattern which is distributed along the building height is then applied. The lateral forces are increased until some members yield. The structural model is modified to account for the reduced stiffness of yielded members and lateral forces are again increased until additional members yield. The process is continued until a control displacement at the top of building reaches a certain level of deformation or structure becomes unstable. The roof displacement is plotted with base shear to get the global capacity curve.

Pushover analysis can be performed as force-controlled or displacement-controlled. In force-controlled pushover procedure, full load combination is applied as specified, i.e, force-controlled procedure should be used when the load is known (such as gravity loading). Also, in force-controlled pushover procedure some numerical problems that affect the accuracy of results occur since target displacement may be associated with a very small positive or even a negative lateral stiffness because of the development of mechanisms and P-delta effects.

Pushover analysis has been the preferred method for seismic performance evaluation of structures by the major rehabilitation guidelines and codes because it is conceptually and computationally simple. Pushover analysis allows tracing the sequence of yielding and failure on member and structural level as well as the progress of overall capacity curve of the structure.

III. Analysis Purpose of Doing Pushover

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 reinforced concrete beams, etc.

- Estimates of the deformations 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 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 discontinuous in plan elevation that will lead to changes in the dynamic characteristics in elastic range.
- Estimates of the inter-story 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 systems, all the connections, and stiff non-structural elements of significant strength, and the foundation system.

IV. Background

Nonlinear static analysis, or pushover analysis, has been developed over the past twenty years and has become the preferred analysis procedure for design and seismic performance evaluation purposes as the procedure is relatively simple and considers post- elastic behavior. However, the procedure involves certain approximations and simplifications that some amount of variation is always expected to exist in seismic demand prediction of pushover analysis. Although, pushover analysis has been shown to capture essential structural response characteristics under seismic action, the accuracy and the reliability of pushover analysis in predicting global and local seismic demands for all structures have been a subject of discussion and improved pushover procedures have been proposed to overcome the certain limitations of traditional pushover procedures. However, the improved procedures are mostly computationally demanding and conceptually complex that use of such procedures are impractical in engineering profession and codes. As traditional pushover analysis is widely used for design and seismic performance evaluation purposes, its limitations, weaknesses and the accuracy of its predictions in routine application should be identified by studying the factors affecting the pushover predictions. In other words, the applicability of pushover analysis in predicting seismic demands should be investigated for low, mid and high-rise structures by identifying certain issues such as modeling nonlinear member behavior, computational scheme of the procedure, variations in the predictions of various lateral load patterns utilized in traditional pushover analysis, efficiency of invariant lateral load patterns in representing higher mode effects and accurate estimation of target displacement at which seismic demand prediction of pushover procedure is performed.

V. Performance Based Design

Performance based Performance-based design is a major shift from traditional structural design concepts and represents the future of earthquake engineering. The procedure provides a method for determining acceptable levels of earthquake damage. Also, it is based on the recognition that yielding does not constitute failure and that preplanned yielding of certain members of a structure during an earthquake can actually help to save the rest of the structure.

VI. Static Non-Linear Analysis

In performance based design response of structure is considered beyond elastic limit as opposed to code based approach. Static non-linear analysis is one of the analysis technique used for performance based design. Two types of pushover analysis are as:

A. Force Controlled

Used when load is known and structure is desired to support this load. For gravity load on structure force controlled, push over analysis is used.

B. Displacement Controlled

Used when load is unknown but displacement is known and structure is desired to lose their strength and become unstable. For lateral load on structure displacement controlled, pushover analysis is used.

1) Three main steps involved in this analysis procedure.

1) Evaluation of Capacity of building i.e. Representation of the structure's ability to resist a force.
2) Evaluation of Demand curve i.e. Representation of earthquake ground motion.
3) Determination of Performance point i.e. Intersection point of demand curve and capacity curve.

C. Capacity

Fig. is represents the increasing lateral displacement as a function of the force applied monotonically from zero to the ultimate level corresponding to the incipient collapse of the structure and response behavior is gauged by measurement of strength of structure. The simplified non-linear procedure is followed for the generation of the capacity curve.

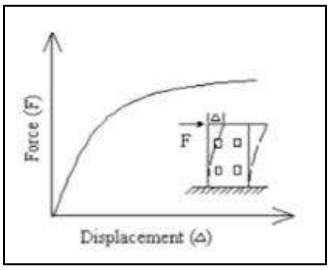

Fig. 1: capacity curve

D. Demand

Spectral Acceleration (Sa) versus Time Period (T) curve is given in IS: 1893 (Part1)-2002 which is converted in to Spectral Acceleration (Sa) versus Spectral Displacement (S_d) curve. Capacity curve and Demand curve are generated in spectral coordinates to find out performance point.

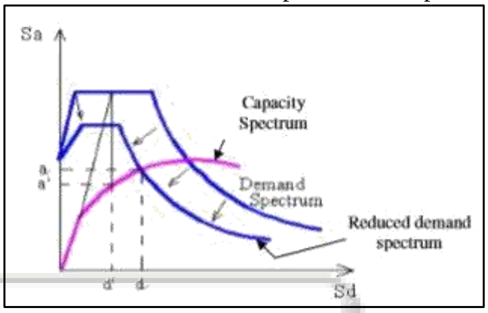

Fig. 2: DemandSpecrum Curve

E. Performance

The intersection of the pushover capacity and demand spectrum curves defines as the “performance point" as shown in fig.

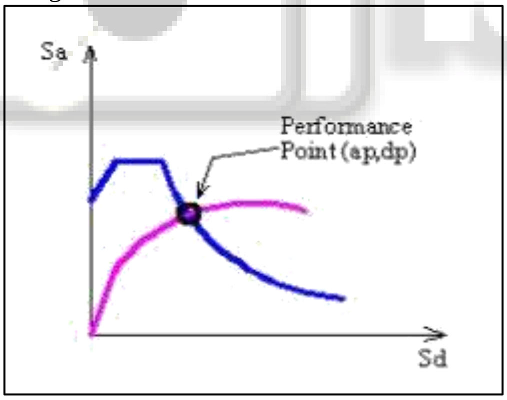

Fig. 3: Performance Point

F. Capacity Spectrum Method

1) Capacity curve

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 limits, some form of nonlinear analysis is required. This procedure uses sequential elastic analysis, superimposed to approximate force-displacement diagram of the overall structure. The mathematical model of the structure is modified to account for reduced resistance of yielding components. A lateral force distribution is again applied until additional components yield. A typical capacity curve is shown in fig.1

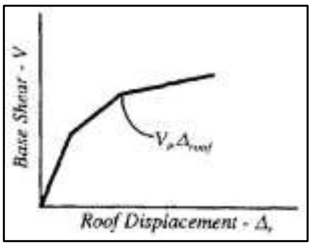

Fig.1 Capacity curve

2) Capacity spectrum

To convert the capacity curve, into the capacity spectrum, the required equation to make the transformation. (Refer ATC-40, Volume-1, p-8.9):

A typical capacity spectrum is as shown in fig.2.

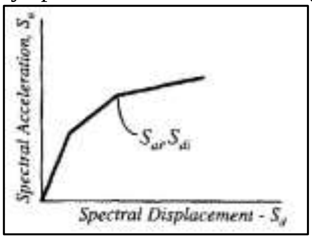

Fig. 2: Capacity spectrum

3) Demand curve

Ground motion during an earthquake produces complex horizontal displacement patterns which may vary with time. Tracking this motion at every time step to determine structural design requirements is judge impractical. For a given structure and a ground motion, the displacement demands are estimate of the maximum expected response of the building during the ground motion. Demand curve is a representation of the earthquake ground motion. It is given by spectral acceleration (Sa) Vs. Time period (T) as shown in fig.3.

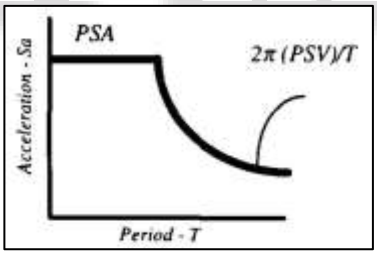

Fig. 3: Demand curve (Traditional spectrum)

Fig.4. illustrates the construction of an elastic response spectrum (Demand curve) (Refer ATC-40, Volume-1, p-4-12).

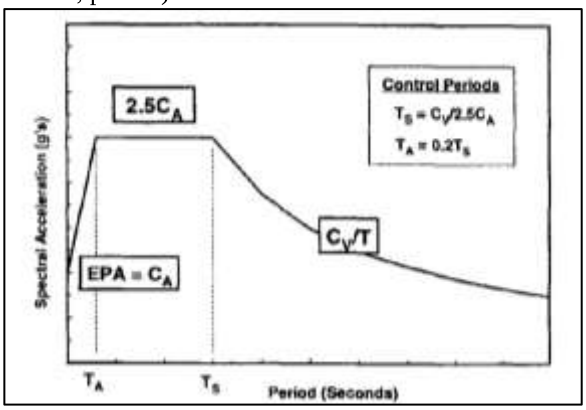

Fig. 4: Construction of a 5% damped elastic response spectrum (Demand Curve)

As per provisions and commentary on Indian seismic code IS 1893(part-1), equivalent seismic coefficient Ca is given by,

Ca = Z*g*Sa/g Cv = 2.5*Ca*Ts

G. *Capacity curve*

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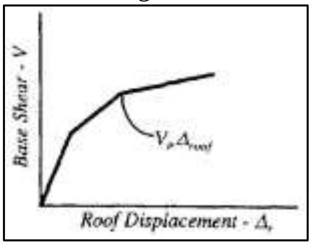

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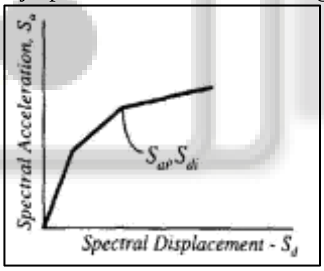

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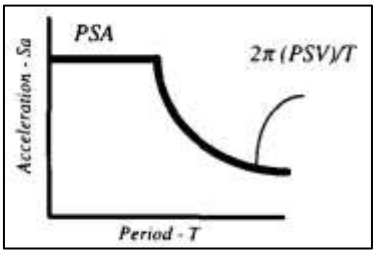

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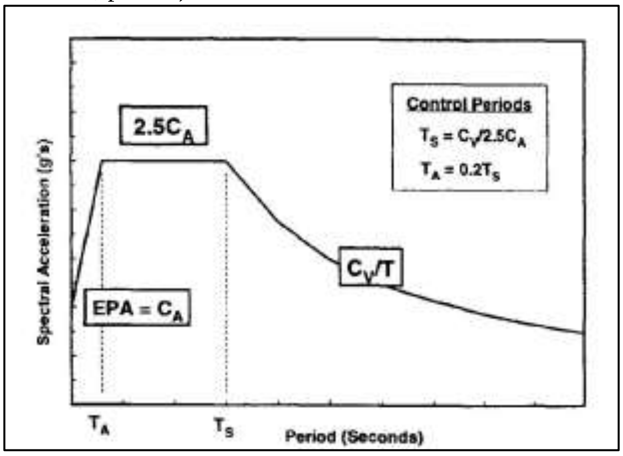

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H. *Demand spectrum*

To convert Demand curve (traditional spectrum-Sa Vs T format) into demand spectrum (acceleration displacement response spectrum-Sa Vs Sd format). (Refer ATC-40, Volume-1, p-8-10).

A typical demand spectrum is as shown in fig.5.

Only plastic deformation beyond point B will be exhibited by the hinge.

Point C represents the ultimate capacity for pushover analysis.

Point D represents a residual strength for pushover analysis. However, you may specify a positive slope from C to D or D to E for other purposes.

Point E represents total failure. Beyond point E the hinge will drop load down to point F (not shown).

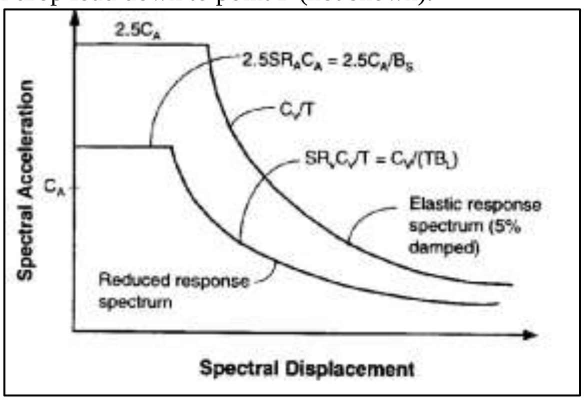

Fig. 5: Reduced response spectrum d) Performance point

Performance point can be obtained by superimposing capacity spectrum and demand spectrum and the intersection point of these two curve is performance point. Fig.6. shows superimposing demand spectrum and capacity spectrum.

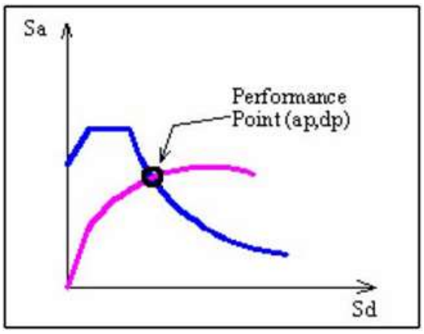

Fig. 6: Performance point

Check performance level of the structure and plastic hinge formation at performance point. A performance check verifies that structural and non-structural components are not damaged beyond the acceptable limits of the performance objective for the force and displacement implied by the displacement demand.

I. Pushover analysis in ETABS 9.7

The nonlinear analysis of a structure is an iterative procedure. It depends on the final displacement, as the effective damping depends on the hysteretic energy loss due to inelastic deformations, which in turn depends on the final displacement. This makes the analysis procedure iterative. Difficulty in the solution is faced near the ultimate load, as the stiffness matrix at this point becomes negative definite due to instability of the structure becoming a mechanism.

Extended Three Dimensional Buildings Systems (ETABS) and Structural Analysis Program finite element program that works with complex geometry and monitors deformation at all hinges to determine ultimate Steps used in performing a pushover analysis of a simple three-dimensional building. ETABS 9.7 general purpose, three-dimensional structural analysis program, is used as a tool for performing the pushover. The following steps are included in the pushover analysis.

1) Creating the basic computer model in the usual manner.
2) Define properties and acceptance criteria for the pushover hinges. The program includes several built-in default hinge properties that are based on average values from ATC-40 for concrete members. These built in properties can be useful for preliminary analyses, but user defined properties are recommended for final analyses.
3) Locate the pushover hinges on the model by selecting one or more frame members and assigning them one or more hinge properties and hinge locations.
4) Define the pushover load cases. In ETABS 9.7 more than one pushover load case can be run in the same analysis. Typically a gravity load pushover is force controlled and lateral pushovers are displacement controlled.
5) Run the basic static analysis and, if desired, dynamic analysis. Then run the static nonlinear pushover analysis.
6) Display the pushover curve and the table.
7) Review the pushover displaced shape and sequence of hinge formation on a step-by-step basis.

J. Plastic Deformation curve:

For each degree of freedom, one can define a force-displacement (moment-rotation) curve that gives the yield value and the plastic deformation following yield. This is done in terms of a curve with values at five point A-B-C-D-E as shown in fig 7.

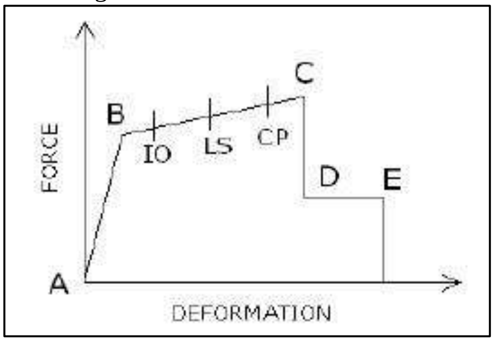

Fig. 7: Force V/s Deformation curve

The shape of this curve as shown in fig.7.is intended for pushover analysis. The following points should be noted:

Point A is always the origin.

Point B represents yielding. No deformation occurs in the hinge up to point B, regardless of the deformation value specified for point B. The displacement at point B will be subtracted from the deformation at point C, D, and E.

VII. CONCLUSION

A brief review of several literatures presented shows that non-linear static analysis (pushover analysis) proves to be efficient tool for studying the behavior of the structure in non-linear zone. Structure"s failure modes due to seismic actions become more apparent by performing pushover analysis. There is future scope for further study in this area.

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