PERFORMANCE BASED DESIGN CONSIDERING PUSH OVER ANALYSIS:A REVIEW

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ABSTRACT

From last ten years widely used performance based design is discussed here.the well known part of it called nonlinear pushover analysis is discussed in detail, which is now a days widely used for earthquake response predication of building structures under severe earthquakes at different locations considering nonlinearity of the structure.push over method called capacity Spectrum Method is discussed and reviewed in detail

Key words — Pushover analysis, Earthquake response, Performance based design, Capacity Spectrum Method

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1 INTRODUCTION TO PERFORMANCE BASED DESIGN

This paper describes a well-known computer-based nonlinear static push-over analysis technique for performance-based design of structure. While conventional limit-state design is typically a two-level design approach having concern for the service operational and ultimate-strength limit states for a building, performance-based design can be viewed as a multi-level design approach that additionally has explicit concern for the performance of a building at intermediate limit states related to such issues as occupancy and life-safety standards, which is also a repetitive method in nature. With introduction of the performance-based design, there is a need to develop corresponding analysis tools and do time consuming analysis e.g. nonlinear dynamic analysis. Nonlinear static (push-over) analysis is rapidly used as an attractive choice in this regard because of its simplicity and ability to identify component. Nonlinear static pushover analysis is an incremental iterative method which gives the base shear versus roof displacement relationship which is also called as capacity curve in general.

From last few years with the development of performance-based design procedures, the demand for the definition of simplified methods to estimate earthquake response in nonlinear range, with an adequate level of confidence,for structures is increased. For the seismic evaluation of yielded systems, the consideration of inelastic displacements rather than elastic forces should be a better approach, since as the structure starts responding in inelastic manner the displacements keep enlarging at relatively constant levels of lateral forces. Traditional Force-Based Design procedures (FBD) are clearly flawed. Some of the major drawbacks are that (i) they do not account for force redistribution following yielding, and (ii) they don’t consider potential failure modes that arise from mid and upper storey mechanisms caused by the influence of higher modes. The application of Performance-Based Design principles (PBD) thus requires the definition of analysis procedures able to provide an adequate prediction of such inelastic mechanisms which avoids an excessive computational effort.

It is clearly understood that nonlinear dynamic analysis is the most accurate method for assessing the response of structure subjected to earthquake and similar forces. In order to employ dynamic analysis for seismic design and/or assessment of structures, an ensemble of site-specific ground motions compatible with the seismic hazard spectrum for the site are to be simulated. It is generally assumed that until better guidance on record selection/generation will be made available to earthquake engineer designers, this first step will remain as difficult to use dynamic time-history analysis in design office applications. Also, considering the significant increase in computing power witnessed in recent years, nonlinear time-history analysis remains computationally demanding, This problem becomes even the more significant if one considers that the analyses will need to be repeated a significant amount of times, not only because design codes or guidance documents require for a relatively large number of earthquake records to be employed in order to warrant minimum probabilistic validity of the results, but also, and perhaps mainly, because the process of analysing any given structure is invariably an iterative one, given that modelling errors are commonly encountered as the design/assessment process evolves. Thirdly, even in those situations where the expertise and resources for running time-history analyses are available, it is often the case that preliminary simpler analysis (i.e. modal and static analyses,etc.,) are run to enable a first check of the model; errors in the definition/assemblage of a finite elements model are difficult to detect from dynamic analysis results, whilst they tend to be relatively evident from the output of eigenvalue or pushover runs.Static analyses, even if representing simplified methods, provide also many important structural response information, such as (i) identification of critical regions, where large inelastic deformations may occur, (ii) individuation of strength irregularities in plan and elevation that might cause important changes in the inelastic dynamic response, (iii) evaluation of the force demand in potentially brittle elements, and (iv) prediction of the sequence of yielding and/or failure of structural members. In addition, the explicit insight that pushover-derived base shear vs. top displacement capacity curves provide into the stiffness, strength and ductility of a given structure, constitutes the type of qualitative data that is always most informative and useful, within a design application, even when time-history analysis is then employed for the definitive verifications.

2 NONLINEAR STATIC PUSHOVER ANALYSIS IN EARTHQUAKE ENGINEERING

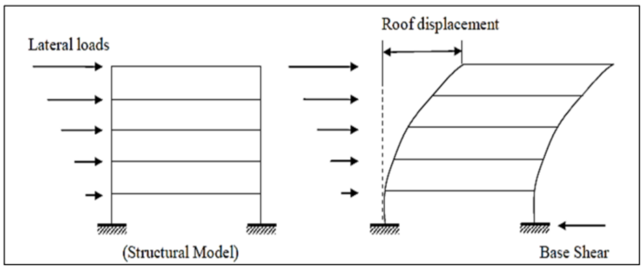
Static nonlinear analysis can consist of any number of cases. Each static nonlinear case can have a different distribution of load on the structure. For example, a typical static nonlinear analysis might consist of three cases. The first would apply gravity load to the structure, the second would apply one distribution of lateral load over the height of the structure, and the third would apply another distribution of lateral load over the height of the structure. A static nonlinear case may start from zero initial co nditions, or it may start from the results at the end of a previous case. In the previous example, the gravity case would start from zero initial conditions, and each of the two lateral cases could start from the end of the gravity case. The distribution of load applied on the structure for a given static nonlinear case is defined as a scaled combination of one or more of the following:

- Any static load case.
- A uniform acceleration acting in any of the three global directions. The force at each joint is proportional to the mass tributary to that joint and acts in the specified direction.
- A modal load for any Eigen or Ritz mode. The force at each joint is proportional to the product of the modal displacement, the modal circular frequency squared, and the mass tributary to that joint, and it acts in the direction of the modal displacement.

The load combination for each static nonlinear case is incremental, i.e., it acts in addition to the load already on the structure if starting from a previous static nonlinear case.Two distinctly different types of control are available for applying the load. Each case can use a different type of load control. The choice generally depends on the physical nature of the load and the behavior expected from the structure:

1) Force control: The full load combination is applied as specified. Force control should be used when the load is known (such as gravity load), and the structure is expected to be able to support the load. Force control is required for staged construction.

2) Displacement control: A single Monitored Displacement component (or the Conjugate Displacement) in the structure is controlled. The magnitude of the load combination is increased or decreased as necessary until the control isplacement reaches a value that you specify. Displacement control should be used when specified drifts are sought (such as in seismic loading), where the magnitude of the applied load is not known in advance, or when the structure can be expected to lose strength or become unstable. Displacement control cannot be used for staged construction.



Static aproximations in the pushover analysis

Pushover Analysis Procedure

The following steps are included in the pushover analysis. Steps 1 through 4 discussecreating the computer model, step 5 runs the analysis, and steps 6 and 7 review the pushover analysis results (A. Habibullah, 1998).

1. Create the basic computer model (without the pushover data) in the usual manner. The graphical interface of SAP2000 makes this a quick and easy task.

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 and average values from FEMA-356 for steel members. These built in properties can be useful for preliminary analysis, but user-defined properties are recommended for final analysis.

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.

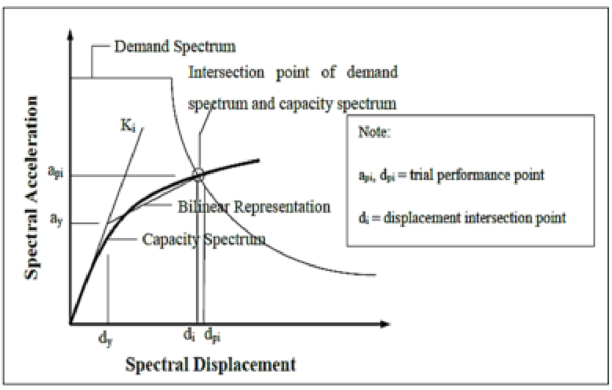
4. Define the pushover load cases. In SAP2000 more than one pushover load case can be run in the same analysis. Also a pushover load case can start from the final conditions of another pushover load case that was previously run in the same analysis. Typically the first pushover load case is used to apply gravity load and then subsequent lateral pushover load cases are specified to start from the final conditions of the gravity pushover. Pushover load cases can be force controlled,
that is, pushed to a certain defined force level, or they can be displacement controlled, that is, pushed to a specified displacement. Typically a gravity load pushover is force controlled and lateral pushovers are displacement controlled. SAP2000 allows the distribution of lateral force used in the pushover to be based on a uniform acceleration in a specified direction, a specified mode shape, or a user-defined static load case.
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 that gives the coordinates of each step of the pushover curve and summarizes the number of hinges in each state as defined.
7. Review the pushover displaced shape and sequence of hinge formation on a stepby-step basis. Hinges appear when they yield and are color-coded based on their state.

Capacity Spectrum Method

The capacity spectrum method, a nonlinear static analysis procedure that provides a graphical representation of the expected seismic performance of the existing or retrofitted structure by the intersection of the structure's capacity spectrum with a response spectrum (demand spectrum) representation of the earthquake's displacement demand on the structure. The intersection is the performance point, and the displacement coordinate, dp, of the performance point is the estimated displacement demand on the structure for the specified level of seismic hazard.Two key elements of a performance-based design procedure are demand and capacity.Demand is a representation of the earthquake ground motion. Capacity is a representation of the structure's ability to resist the seismic demand. The performance is dependent on the manner that the capacity is able to handle the demand. In other words, the structure must have the capacity to resist the demands of the earthquake such that the performance of the structure is compatible with the objectives of the design. Simplified nonlinear analysis procedures using pushover methods, such as the capacity spectrum method, require determination of three primary elements: capacity, demand
(displacement) and performance. Each of these elements is briefly discussed below.

- **Capacity**: The expected ultimate strength (in flexure, shear, or axial loading) of a structural component excluding the reduction factors commonly used in design of concrete members. The capacity usually refers to the strength at the yield point of the element or structure's capacity curve. For deformation controlled components, capacity beyond the elastic limit generally includes the effects of strain hardening. 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, such as the pushover procedure, is required. This procedure uses a series of sequential elastic analysis, superimposed to approximate a force-displacement capacity 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. This process is continued until the structure becomes unstable or until a predetermined limit is reached. The pushover capacity curve approximates how structures behave after exceeding their elastic limit [ATC-40, 1996].

- **Demand (displacement):** 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 deformations that the structure is expected to undergo. This is in contrast to conventional, linear elastic analysis procedures in which demand is represented by prescribed lateral forces applied to the structure. Ground motions during an earthquake produce complex horizontal displacement patterns in structures that may vary with time. Tracking this motion at every time-step to determine structural design requirements is judged impractical. Traditional linear analysis methods use lateral forces to represent a design condition. For nonlinear methods it is easier and more direct to use a set of lateral displacements as a design condition. For a given structure and ground motion, the displacement demand is an estimate of the maximum expected response of the building during the ground motion



Intersection Point of Demand and Capacity Spectrum

- **Performance**: Once a capacity curve and demand displacement are defined, a performance check can be done. A performance check verifies that structural and non-structural components are not damaged beyond the acceptable limits of the performance objective for the forces and displacements implied by the displacement demand. The performance point is derived which is the intersection of the capacity spectrum with the appropriate demand spectrum in the capacity spectrum method.

Structure capacity is represented by a pushover curve. The most convenient way to plot the force-displacement curve is by tracking the base shear and the roof displacement. In order to determine compliance with a given performance level, a displacement along the capacity curve must be determined that is consistent with the seismic demand. The capacity spectrum method is based on finding a point on the capacity spectrum that also lies on the appropriate demand response spectrum, reduced for nonlinear effects, and is most consistent in terms of graphical representation and terminology as per ATC40.The demand Displacement in The capacity spectrum method occurs at a point on the capacity spectrum called the performance point. This performance point represents the condition for which the seismic capacity of the structure is equal to the seismic demand imposed on the structure by the specified ground motion. The location of the Performance Point must satisfy two relationships: 1) the point must lie on the capacity spectrum curve in order to represent the structure at a given displacement, and 2) the point must lie on a spectral demand curve, reduced from the elastic, 5 percent-damped design spectrum, that represents the nonlinear demand at the same structural displacement.

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