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A SEISMIC DESIGN PROCEDURE FOR FRAME STRUCTURES THROUGH A PUSHOVER ANALYSIS

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1. Introduction

The pushover analysis is a simplified nonlinear analysis technique that can be used to estimate the structural performance imposed by earthquake ground motions. In recent years, with the realization of the importance of evaluating the ductility of structures in seismic designs, the pushover analysis method has attracted more and more concerns of researchers.

In most of the studies, the pushover analysis is used to determine the demand of a structure[1]. However, there are several shortcomings in such an implementation, such as, (1) Some parameters must be predetermined implicitly (e.g. the ductility and the deformation profile of the structure); (2) It is not convenient for the systematic study of capacities of structures with different geometric dimensions and materials.

In this paper, an alternative pushover procedure, used to determine the capacity of a structure, is presented. With such a procedure, the characteristics of the structures are analyzed independently from the seismicity. Hence, the real structural parameters can be explicitly used in the design and for a certain type system, the conceptual design can be optimized by the parametric study. This paper addresses fundamental steps of such a procedure for multi-story frame structures and its feasibility and limitations in predicting inelastic dynamic characteristics.

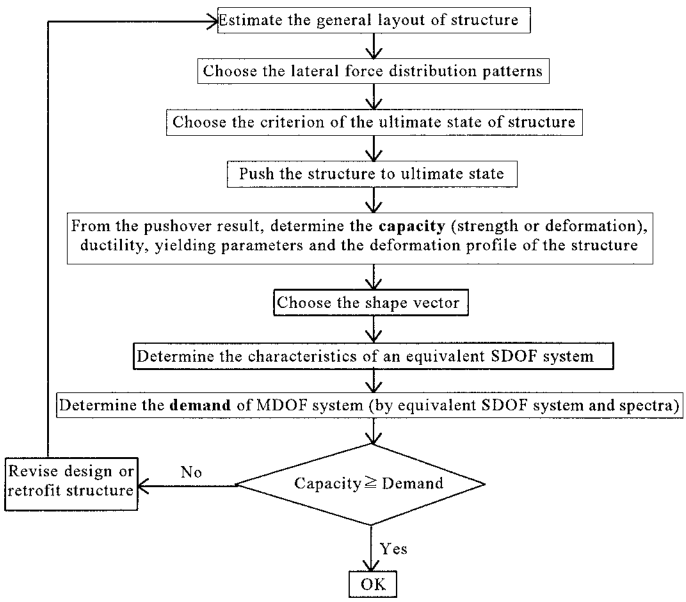

Fig. 1 Pushover Capacity Analysis Process

2. Description of the pushover capacity analysis procedure

The pushover analysis in this paper is considered to follow the sequence of operations in the flow chart in Fig. 1. The details in each step are outlined below.

Step1: Choose initial parameters. Determine the global dimension of system, section type and size, materials and vertical loads.

Step2: Carry out pushover analysis

Step2a: Choose a lateral force distribution pattern (predetermined patterns, e.g., inverted triangular distribution[1] or uniform distribution[3], or adaptive patterns[2]).

Step2b: Choose the ultimate state criterion for the structure. There are several options for this ultimate state, e.g., the formation of a plastic mechanism, reaching of the plastic rotation capacity of a plastic hinge, exceeding of a prescribed global or interstory drift, the detection of a brittle failure, attainment of the maximum local ductility[3], or appearance of a negative stiffness[3].

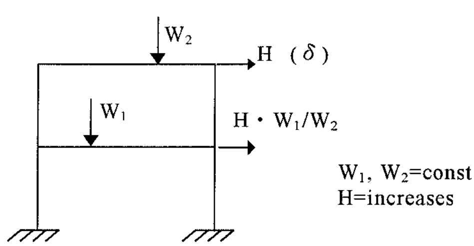

Fig.2 A Given Frame (the case of uniform distribution[3])

Step2c: Make structural analysis (elasto-plastic finite displacement analysis).

Step2d: From the analysis results (see Figs. 2, 3), obtain the following useful parameters:

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(i) the ultimate base shear and displacement of the structure (V_u and δ_u)
(ii) the yielding base shear and displacement (V_y and δ_y)
(iii) the ultimate deformation profile

Step2e: Determine structural ductility

$$\mu = \delta_u / \delta_y \tag{1}$$

Step3: Establish the equivalent SDOF system

Step3a: Estimate the deformation shape vector. There are several choices, such as, (i) the ultimate deformation profile from the pushover analysis results; (ii) the elastic first mode shape

Step3b: Determine the parameters of the equivalent SDOF systems as follows[1]

$$M^* = \{\phi\}^T[M]\{1\} \tag{2}$$

$$\delta^* = \frac{\{\phi\}^T[M]\{\phi\}}{\{\phi\}^T[M]\{1\}}\delta \tag{3}$$

$$K^* = \frac{V_y}{\delta_y} \tag{4}$$

$$V^* = \{\phi\}^T\{Q\} \tag{5}$$

$$T^* = 2\pi\sqrt{\frac{M^*}{K^*}} \tag{6}$$

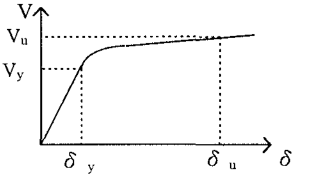

Fig.3 Base shear-deformation curve of pushover analysis

where [M]= the mass matrix, {ϕ}=deformation shape vector, δ=horizontal displacement at the top of the structure, V_y=yielding base shear, {Q}=story force vector, M^*, K^*, δ^*, V^*, T^* =the properties of the equivalent SDOF system.

Step4: Determine the demands of MDOF system

Step4a: With the elastic acceleration spectra and equivalent SDOF system, the elastic deformation and strength demand of equivalent SDOF system, δ^*_{el} and V^*_{el}, *are determined as follows [3]*

$$\delta^*_{el} = \frac{T^{*2}}{4\pi^2}S_a(T^*) \tag{7}$$

$$V^*_{el} = M^* S_a(T^*) \tag{8}$$

Step4b: With the force reduction factor, R, the inelastic demand of equivalent SDOF can be computed by [3]

$$\delta^*_{in} = \frac{\mu}{R}\delta^*_{el} \tag{9}$$

$$V^*_{in} = V^*_{el}/R \tag{10}$$

Step4c: With Eq. (3) or Eq. (5) the demands of the equivalent SDOF are transferred to the MDOF demands

Step5: Compare the demand with capacity to check the safety of the structure.

3. Discussion of feasibility and limitations

The pushover analysis can provide much more relevant information than an elastic or even dynamic analysis. For structures that vibrate primarily in the fundamental mode, such an analysis will likely provide reasonably reliable estimates of global as well as local inelastic characteristics[1][4].

It should be noted that the pushover analysis is a useful, but not infallible, tool for structural nonlinear performance. The most essential assumption of the pushover analysis is the time-independent lateral displacement shape and the lateral force distribution pattern. Therefore, the influence of the higher modes cannot be taken into account properly[1][4]. In general, these limitations do not apply to low rise structures (2-5 stories)[1], but show up in taller structures, in which the higher modes become more important.

4. Conclusions

This paper describes a pushover capacity analysis procedure for frame structures. This procedure is different from current other procedures in two ways. First, nonlinear behavior information from pushover analysis is treated explicitly in the determination of the demands of MDOF systems through the equivalent SDOF systems. Second, the capacity of some certain kinds of structures with different parameters (e.g., geometric dimensions) can be analyzed systematically, which will benefit for the optimum conceptual designs.

5. References

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