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Static Pushover Method for the Seismic Analysis of Structures

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During the last twenty years the use of a static pushover analysis of many different types of structures has increased significantly. The maximum static displacement from such an analysis is referred to as the Displacement Capacity of the structure. The Demand Displacement is then estimated from a linear elastic time history earthquake analysis of the structure. (In the case of a design earthquake spectrum input, the CQC method of modal combination is used to combine the modal responses to estimate the Demand Displacement.) The Demand/Capacity ratios calculated by this approach must be less than 1.0 to prevent collapse.

There are many variations of this simplified explanation; however, they are all based on the "Equal Displacement Rule". It appears that this ad hoc rule has been accepted by many researchers and most structural engineers as a fundamental law in the field of earthquake design and analysis of structures.

It appears the justification of the the rule was first proposed in 1960 by Veletsos and Newmark in a paper presented at the 2rd WCEE in Tokyo in which they studied a one DOF system. During the period 1957 to 1963, I worked with Professor Ray Clough for my Master's and Doctor's degrees and as a research engineer. At that time Ray had a over 15 years experience using analytical and experimental methods studying the dynamic behavior of many different types of structures. His first reaction to the paper was that the equal displacement recommendation could not be used for multi-degree-of-freedom structural systems. By 1962 the speed and capacity of computers had improved to the point where it was possible to perform **very accurate time-history dynamic analysis** of both linear and nonlinear two-dimensional frame systems. In 1963 I had completed a very efficient large capacity, nonlinear dynamic analysis program where it was possible to develop plastic hinges at the ends of all beams and columns. Wilson and Clough 1963. The FORTRAN program was given to all engineering firms that wanted to analyze real structures for dynamic nonlinear behavior. However, at that time there were very few recorded earthquake records available to use as input to their structures.

Based on this program our paper "Inelastic Earthquake Response of Tall Buildings" was presented at the 3rd World Conference on Earthquake Engineering in January 1965 which was held in New Zealand. I just found this **"lost paper"** a few months ago in my storage room. It is now on the web site http://nisee.berkeley.edu/elibrary/ . (Ray wrote and presented the paper while Ed was working at Aerojet).

Based on the Nonlinear Analysis of 20 Story Steel Frames, the 1965 New Zealand paper indicated the following three conclusions (written by Ray in 1964, condensed by elw):

1. The displacements, obtained from a nonlinear time history analysis, were significantly greater than a linear analysis of the same structure subjected to the same earthquake record. This conclusion is contrary to the equal displacement results based on the analysis of a one story building that was presented by Veletsos and Newmark at the 2nd WCEE in Tokyo.

2. The linear moment deformations did not provide a direct estimation of the deformations obtained from a nonlinear analysis. In addition, they varied significantly between different members of the structure.

3. If tall buildings are designed for elastic column behavior and restrict the nonlinear bending behavior to the girders, it appears the danger of total collapse of the building is reduced.

After over fifty years, engineers continue to use the equal displacement rule to justify nonlinear static pushover analyses. The following paper indicates some of the problems associated with the current use of the pushover method: Pushover Analysis: Why, How, When and When Not to Use It by Professor Helmul Krawinkler 1996 SEAOC Conf.

My personal experience with the retrofit of buildings on the UC Berkeley Campus indicates the distribution of damage predicted by the pushover method is significantly different than from a time-history, nonlinear analysis. Also, if the linear response spectrum method is used to predict the demand, the errors are significantly larger (BOOK-Wilson\15-SPEC.pdf page 15.16).