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Comparison of simplified procedures for performance-based seismic evaluation of structures

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The structural engineering community has developed a new generation of design and seismic evaluation procedures that incorporates performance-based engineering concepts. In a short term, the most appropriate approach seems to be a combination of the nonlinear static (pushover) analysis and the response spectrum approach. Examples of such an approach are the capacity spectrum method (CSM), applied in ATC 40 (Seismic Evaluation and Retrofit of Concrete Buildings, 1996) in U.S. Army Corps of Engineers, Technical Manuals (Seismic Design for Buildings and Seismic Design Guidelines for Upgrading Existing Buildings, 1998), and in Japanese Building Standard Law (BSL 2000), the nonlinear static procedure, applied in FEMA 356 (Prestandard and Commentary for the Seismic Rehabilitation of Buildings, 2000), the N2 method developed at the University of Ljubljana (Fajfar, 2000) and implemented in the draft Eurocode 8 (Design of structures for earthquake resistance, 2001), and the Modal Pushover Analysis (Chopra and Goel, 2001). All methods combine the pushover analysis of a multi-degree-of-freedom (MDOF) model with the response spectrum analysis of an equivalent single-degree-of-freedom (SDOF) system. Inelastic spectra or elastic spectra with equivalent damping and period are applied. As an alternative representation of inelastic spectrum the Yield Point Spectrum has been proposed (Aschheim and Black, 1998). Some other simplified procedures based on deformation-controlled design have been developed, e.g. the approaches developed by Priestley (1997, 2000) and by Panagiotakos and Fardis (1998).

The aim of the study is to evaluate the suitability of the above procedures for practical application based on accuracy, simplicity, transparency and clarity of theoretical background. All methods have been applied for analysis of three types of reinforced concrete structures of low-height (5 stories) with different lateral resisting mechanism: one moment resisting frame, one structural wall and one dual frame-wall. The main results are compared with the results of nonlinear dynamic analyses.

The comparison of results indicates that most of the employed simplified procedures yield results of adequate accuracy for relatively flexible structures. For the case of the stiff structures the results are much scattered. The global quantities (like top displacement) are generally more accurate than the local ones (like rotations at member ends). The most important factor in the assessment of the response proved to be the provided displacement response spectrum due to the fact that final results are approximately in the same ratio as the ratios of the spectral values. CSM variant provided by BSL 2000 offers the best estimation granted mainly to the accuracy of the provided displacement response spectrum.

The essential difference is related to the determination of the displacement demand (target displacement). If an equivalent elastic spectrum is used, displacement demand is determined based on equivalent stiffness and equivalent damping, that depend on the target displacement and, consequently, iteration is needed. The quantitative values of equivalent damping, suggested by different authors, differ considerably. On the other side, for the methods using inelastic spectra, bilinear idealization of the pushover curve is required. If the bilinear idealization depends on the displacement demand, then the computational procedure becomes iterative, also. It is questionable if this complication is warranted.

The procedures differ also in the assumed lateral load pattern, used in pushover analysis, and in the displacement shape, used for the transformation from the MDOF to the SDOF system (and vice versa). Only if the two vectors are related, i.e. if the lateral load pattern is determined from the assumed displacement shape, the transformation from the MDOF to the SDOF system is based on a mathematical derivation. However, Ai distribution from BSL 2000 proves to offer the most accurate distribution of the interstory drifts once more, even if the lateral load pattern is not rigorously connected to the displacement shape.