ON THE IMPROVEMENT OF NONLINEAR STATIC PROCEDURES SUBJECTED TO NEAR-FAULT GROUND MOTIONS CONSIDERING VARIOUS FAULTING MECHANISMS

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FEMA 440 (2005) presents the results of a comprehensive study on the improvement of nonlinear static procedures (NSPs). This document reviews the related documents, namely FEMA 356 (2000) and ATC-40 (1996), and proposes improvements in calculating the inelastic displacement demand for a given ground motion. FEMA 440 includes descriptions of the two NSPs that were recommended by above-mentioned codes and used in practice. FEMA 356 utilized a displacement modification procedure (Displacement Coefficient Method, DCM), in which several empirically derived factors were used to modify the response of an elastic SDOF model of the structure to account for inelastic effects. The alternative Capacity-Spectrum Method (CSM) of ATC-40 used empirically derived relationships for the effective period and damping as a function of ductility to estimate the response of an equivalent linear SDOF oscillator in an iterative procedure. Recommendations of FEMA 440 have been implemented in some recent codes of practice such as ASCE 41-06 (2007). Although many beneficial improvements have been presented for the DCM and the capacity spectrum method in FEMA 440, but a review of the data used for this purpose shows that improvements consider far-fault (FF) ground motions mainly, and less data have been produced for near-fault (NF) earthquakes. NF ground motion with directivity or fling effects is significantly influenced by the rupture mechanism and is substantially different from FF records. Many of the buildings and bridges destroyed during the earthquake in Kobe are obvious instances for visualization of the effects of this kind of ground motions (Shaw et al., 2004). Many studies in recent years have investigated the dynamic response of structures to these pulse-like ground motions (Iervolino et al., 2012; Baker, 2007). In order to identify pulse-like NF ground motions, a systematic procedure was proposed by Baker (2007). This approach uses wavelet analysis to extract the largest velocity pulse from a given ground motion, which mostly occures in the FN component of records. Based on this, a set of 96 records (most of them identified earlier by Baker et al., 2007) from the NGA (Next Generation Attenuation project) database (http://peer.berkeley.edu/nga/) has been collected.

This paper deals with the improvement of nonlinear static analysis of structures subjected to NF pulse-like ground motions, which differ considerably from those of FF ground motions and also parallel component of NF ones. The objective of this paper includes two main parts. In the first part, the results are utilized to improve the nonlinear static procedure (NSP) called DCM by introducing a NF modification factor, C_N, which improves the estimated target displacement of structures subjected to NF ground motions. A set of 96 near-fault ground motions along with 20 far-fault (FF) ground motions and the responses of various Single Degree of Freedom (SDOF) systems constitute the dataset. SDOF oscillators have Elastic-Perfectly Plastic (EPP) bilinear load-displacement relationships. Nonlinear Dynamic Analysis (NDA) is utilized as the benchmark for comparison with Nonlinear Static Analysis (NSA) results. Considerable influences of different faulting mechanisms are also observed on inelastic seismic demands. For a SDOF system, the inelastic to elastic displacement ratio, referred as C_R in literature, is expressed as the maximum inelastic displacement demand divided by the maximum elastic displacement demand, for a system with the same properties, including the same stiffness and mass, subjected to the same earthquake ground motion. This coefficient is used as C_1 in FEMA for calculating the target displacement. The results are demonstrated in Figure 1 with the periods normalized by the pulse period of the NF ground motions. The coefficient C_1 used in DCM of FEMA 440 underestimates the NF ground motion responses in T/T_p<0.6 ranges and it overestimates the results in 0.6<T/T_p<2.0 range. Therefore, modification factor C_N, is presented in this paper for improving the results.

$$C_R = \frac{\delta_{inelastic}}{\delta_{elastic}} \tag{1}$$

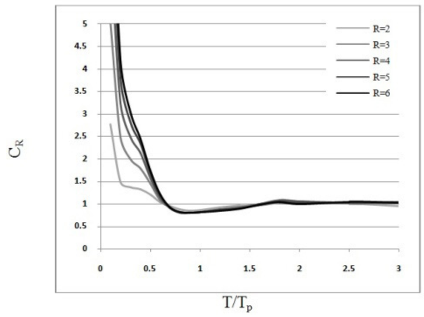

Figure 1. Mean Inelastic Displacement Ratios for different *R* values vs. normalized period for NF Ground Motions

$$C_N = \begin{cases} \theta_1.\left(\frac{T}{T_p}\right)^4 + \theta_2.\left(\frac{T}{T_p}\right)^3 + \theta_3.\left(\frac{T}{T_p}\right)^2 + \theta_4\left(\frac{T}{T_p}\right) + \theta_5 & \frac{T}{T_p} \le 0.6 \\ \theta_6.\left(\frac{T}{T_p}\right)^5 + \theta_7.\left(\frac{T}{T_p}\right)^4 + \theta_8\left(\frac{T}{T_p}\right)^3 + \theta_9\left(\frac{T}{T_p}\right)^2 + \theta_0\left(\frac{T}{T_p}\right) + \theta_1 & 0.6 < \frac{T}{T_p} \le 2.0 \\ 1 & \frac{T}{T_p} > 2.0 \end{cases} \tag{2}$$

The second objective is the improvement of lateral load patterns for the NSA of steel moment-resisting frames, subjected to NF motions, inasmuch as current lateral load patterns are not capable of considering exact effects of NF ground motions on MDOF structures. The family of structural models used in this study is composed of six to eighteen-story 2-D moment resisting frame steel structures with fundamental periods of vibration that vary from 0.6 *s* to 3.0 *s*, considering medium to tall frame models. Two basic types of ground motions are used as the input side: FF and NF ground motions. NDA analysis in comparison to pushover analysis constitutes the database, from which the inefficiencies of current load patterns are derived and an appropriate load pattern is presented for considering the NF effects in better estimation of inter-story drifts. The proposed lateral load patterns are a function of the fundamental period of the structural system, the target level of inelastic behaviour (or damage), the total height of structures, and the frequency content of the ground motions.

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