Bias in Nonlinear Structural Response Produced by Scaled Ground Motion Records

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Abstract

With the advent of Performance-Based Earthquake Engineering, and the availability of sophisticated structural analysis software and faster computers, nonlinear dynamic time-history analysis (NDTHA) has become more widely used for both design and evaluation of structures. One of the biggest obstacles preventing more widespread use of NDTHA is the selection of "appropriate" ground motion records. Engineers seek to obtain from seismologists real ground motion records that closely match the spectral acceleration, S_a, at a specified hazard level (e.g., 10% in 50 years) as well as the magnitude-distance, M_w-R_{close}, pair(s) of the event(s) controlling the seismic hazard at the building site. The S_a of interest in seismically active regions such as California is often relatively large, and the controlling earthquake scenarios are often large magnitude events on nearby faults. Limitations in the existing ground motion database force the scaling of real records to obtain accelerograms that are consistent with the ground motion target for structural design and evaluation. In the engineering seismology community the acceptance of the limits for "legitimacy" of scaling varies from one (no scaling allowed) to ten or more. The concerns expressed by detractors are mostly based on the knowledge of systematic and unquestionable differences in ground motion characteristics for different magnitude-distance scenarios and much less on their effects on structures. At the other end of the spectrum some researchers have claimed that scaling is not only legitimate but also useful for assessing post-elastic response statistics of structures. Their studies, however, did not draw conclusions valid over the entire spectrum of structural vibration periods, and did not state the conditions under which scaling may fail. By comparing the post-elastic response of both SDOF and MDOF structures we show that, statistically speaking, scaling *randomly selected* records can introduce a bias in nonlinear structural response that increases with the degree of scaling. On the engineering side, the bias depends on (i) the fundamental period of vibration of the structure, (ii) the overall strength of the structure, and (iii) the sensitivity of the nonlinear structural response to higher (than the first) modes of vibration. On the seismology side, the bias also depends on the characteristics of the causative earthquake (e.g., M_w-R_{close}) of the records that are scaled, as well as those of the target ground motion scenario. For the most part, the bias can be explained by systematic differences between the elastic response spectra for records that are scaled and those that are naturally (without scaling) at a target spectral acceleration level. This consideration can be favorably exploited to guide the selection of records that, when scaled, possess a significantly reduced potential for producing biased post-elastic responses of specific structures of given period and strength.

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