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ENERGY-BASED INTENSITY MEASURE FOR SEISMIC DEMAND MODELING

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A structural seismic demand model attempts to characterize the behavior of the structure in terms of the characteristics of the load. In the case of seismic excitation, the ground motion (load) is characterized by intensity measures (typically spectral accelerations at various modal periods), and the structural behavior is usually represented by the maximum inter-story drift ratio (MIDR). An adequate and optimal demand model should be independent of the suite of records that is used to calibrate it. This, however, is not the case when the intensity measures selected to develop the model are elastic spectral quantities.

Energy-based intensity measures offer an alternative way of characterizing the ground motion. The structural response (e.g., deformation) is related to a measure of energy which depends on both the frequency content of the ground motion and the dynamic response of the structure (which itself is dependent on the time sequence of the loading). The use of elastic response spectra as ground motion intensity measures does not account for the effects of loading history (the elastic response spectra of a ground motion time history and its transpose are identical). Effective Cyclic Energy (ECE) has been shown by Kalkan and Kunnath (2007) to correlate well with the peak displacement demand to near-fault ground motions and is also sensitive to the loading history. This energy measure is defined as the incremental work (viscous damping and hysteretic) done during the finite time interval between two consecutive zero-crossings of the effective system velocity.

In this study, the use of ECE as an intensity measure is investigated with the goal of developing a seismic demand model that accounts for both the characteristics of ground motion and the inelastic response of the structure. It is demonstrated that the ECE of a multi-degree of freedom (MDOF) system can be approximated by the ECE of the inelastic equivalent single degree freedom (ESDOF) oscillators at the first few modal periods of the structure. The introduction of an energy-based predictor variable in the development of a structural seismic demand model is shown to improve the sufficiency of the model. This is demonstrated through an extensive simulation study wherein different equivalent single-degree-of-freedom models were subjected to over 250 recorded accelerograms. Since many of the records produced only elastic behavior, they were scaled in intensity (by a uniform factor that increased the peak ground acceleration) so as to induce varying degrees of inelastic demands.

Figure 1 shows the performance of a demand model calibrated to $S_a(T_1)$. While at first glance the models appear to be reasonable, a closer investigation reveals that there is considerable scatter as the response quantities get larger and the models are subjected to increasing inelastic demands. For the range of systems considered in the study, the yield drift was approximately 1%. It is evident from Figure 1 that the model performs well in the low-demand range (response values less than 1% drift) but that the performance begins to degrade at higher demands.

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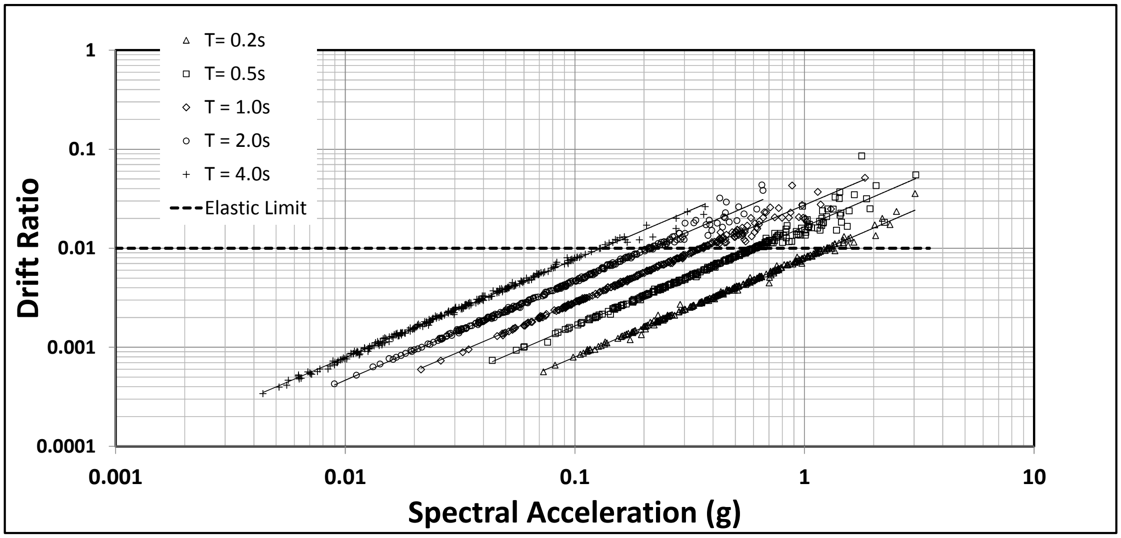
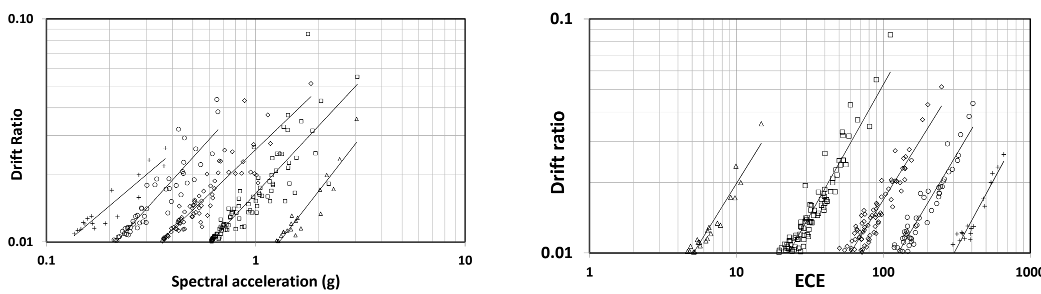


Figure 1. Demand model calibrated to $S_a(T_1)$ when considering all responses

Figure 2 shows the performance of demand models calibrated to $S_a(T_1)$ and ECE when only the inelastic responses are considered. In the case when the model is based on $S_a(T_1)$, the R^2 value of the regression fits vary from a low of 0.65 to a high of about 0.80 whereas in the case of the model based on ECE the R^2 value is consistently above 0.90. It is evident that ECE is a better indicator of expected inelastic demands. Additional studies on the use of ECE as an intensity measure for multi-degree-of-freedom systems are underway.



(a) (b)

Figure 2. Performance of demand models considering inelastic responses only: (a) calibration based on $S_a(T_1)$; (b): calibration based on Effective Cyclic Energy (ECE)

REFERENCE

Kalkan, E. and Kunnath, S.K. (2007). Effective Cyclic Energy as a Measure of Cyclic Demand, Journal of Earthquake Engineering, 11 (5), 725-751.