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A NEW METHOD TO ESTIMATE HYSTERETIC ENERGY SPECTRUM CONSIDERING SOIL TYPE EFFECTS

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Displacement spectra just show maximum response of the system and, unlike the energy spectrum, does not directly include features such as frequency contents and earthquake effective duration, which are two important parameters for cumulative damage assessment. Directly including deterioration within multiple inelastic cycles during an earthquake can be accounted as the most significant feature of the energy-based design methods, while it has not been taken into account by force- and displacement-based design methods (Samimifar et al., 2019). As a result, hysteretic energy is evaluated as a comprehensive seismic demand parameter in this study. Many researchers in recent years have tried to predict seismic energy demand of nonlinear systems through explicit equations. In many of these studies, hysteretic energy is defined as a function of several parameters such as spectral acceleration, reduction factor of ductility, number of earthquake cycles and record characteristics including PGA, PGV and PGD (Fajfar and Vidic, 1994; Manfredi, 2001; Arroyo and Ordaz, 2007; Molazadeh and Saffari, 2018; Zhai et al., 2018). The outputs of some of these studies are based on limited inputs or simplified assumptions, and subsequently cannot be generalized. Some limited equations outside of this, although relatively precise, are depended on numerous variables and their complexity cause not to have the required efficiency to utilize in seismic codes.

To overcome the deficiencies and complexities of the previous approaches, a new equivalent linearization method has been proposed in this study to predict seismic hysteretic energy of bilinear SDOF models at different levels of ductility, taking advantages of linear displacement spectra. In this regard, a wide range of BLH single degree of freedom models, including systems with short-to-long natural period and different ductility ratios of up to 6 are considered. The methodology is formed on the finding that generally by defining an equivalent linear model with increased period and damping comparing to that of original nonlinear system, a constant seismic energy-based equivalent displacement can be achieved. The concept of equating energy of inelastic and corresponding elastic systems has been used to derive this parameter. In the other words, a new displacement spectrum has been proposed to be used as an indicator of hysteretic energy demand. The root mean square averaged spectral error is calculated based on the comparison of linear displacement and proposed energy-based equivalent displacement spectra. It has been defined over the two-dimensional parameter space of equivalent to initial period ratio and equivalent damping as the representative characteristics of the proposed linear model. The error minimization process has resulted in optimum equivalent parameters. To investigate effects of soil conditions on hysteretic energy and on equivalent period lengthening of SDOF systems, two sets of ground motions recorded respectively on soil profiles C and D are selected as the inputs of seismic analyses according to the NEHRP site classification. Nonlinear regression analysis has been carried out to develop equations for predicting the calculated equivalent period ratios as a function of ductility for bilinear hysteretic model subjected to these two sets of ground motions. Assuming a constant equivalent damping, the equivalent period ratios increase as the ductility increases. In addition, it is concluded that for a given value of ductility, the softer the soil, generally the greater the linear spectral displacement and also the energy absorbed by the system and corresponding equivalent displacement is, especially for systems with longer period. However, it is necessary to investigate the percentage difference between these two parameters to be able to evaluate the results. Since the percentages difference of energy-based equivalent displacement between C and D soil conditions are greater than the percentages difference of linear spectral displacement, a slightly larger ratio of equivalent to initial period for the stiffer soil is expected comparing to that of the softer soil. Although in short periods the effect of soil type can be neglected, in medium to long periods, the ratio of equivalent to initial period is partly affected by the soil conditions. Moreover, it is observed that increasing the equivalent damping leads to greater differences in results. Figure 1 compares optimized ratio of equivalent to initial period for BLH systems subjected to NEHRP site classes of C and D. Although the proposed algorithm consists of several different steps, its results in the form of equivalent linear model are very simple to use. First, the value of the linear displacement spectrum at the equivalent damping and the equivalent period obtained for the intended system with a constant given ductility is determined, which is equal to the displacement equivalent to the hysteretic energy. Given the amount of equivalent displacement and its equation, the seismic hysteretic energy demand can be easily calculated.

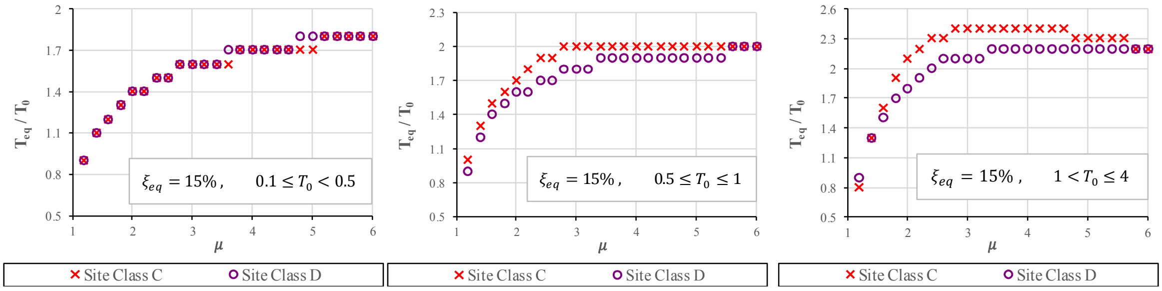

Figure 1. Soil type effects on equivalent period ratio of BLH models for equivalent damping of 15%.

The ratio of hysteretic to seismic input energy can be defined as a function of ductility as presented by Cheng et al. (2015) and Dindar et al. (2015). In these type of relationships, calculation of hysteretic energy is not possible individually, and it is necessary to have the input energy value as the prerequisite. Therefore, one of the important improvements of this research is that seismic hysteretic energy demand of an inelastic system can be directly estimated using the proposed equivalent linear model without the need for any nonlinear analysis. Comparing to previous studies to estimate seismic energy demand, more efficiency has been provided by the new proposed model because of its independency to earthquake characteristics and response related parameters.

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