SEISMIC CRITICAL EXCITATION FOR EARTHQUAKE INPUT ENERGY

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In the design of earthquake-resistant structures, the designer is faced with many uncertainties. One of the major uncertainties is the selection of appropriate design earthquake. For intermediate and low importance structures, the design earthquake is typically provided by the seismic codes as a design spectrum. However for important structures, for which time-history analysis should be performed, the use of recorded ground motions as input is inevitable. In the conventional method, time-histories of ground motion acceleration are used that satisfy design earthquake requirements and has site conditions that are similar to the desired site. However, an important factor is being overlooked, and that is the structure. Each structure has its own dynamic characteristics, and its response to a certain earthquake is different. In other words, each structure should be designed for its specific design earthquake. On the other hand, employing available records without adequate consideration may also be misleading. This means that if we consider an earthquake as a random process, available records are just a few realizations of this process. Experiences of past earthquakes indicate that sole reliance on existing data will never resolve all real issues, and new damage problems have being recently occurred. In order to overcome this problem, a new paradigm has to be used. Concept of "critical excitation" and the structural design based on this concept can become one of such new paradigms.

Critical excitation is aimed to finding the excitation that maximizes desired quantity of structure response from a class of allowable inputs. Using this method and by introducing two restraints on acceleration and velocity of input ground motion, Takewaki (2004) derived a bound on the earthquake input energy per unit mass for a damped elastic single degree of freedom (SDOF) system.

$$\frac{E_I}{m} = \int_0^{+\infty} F(\omega)\left|A(\omega)\right|^2 d\omega \tag{1}$$

in which E_I/m is the input energy per unit mass of the SDOF system, $F(\omega)$ denotes the energy transfer function, and $A(\omega)$ indicates the Fourier transform of input acceleration. The total input energy of Cape Mendocino earthquake with respect to natural period of structures may be calculated using Eq. (1) as illustrated in Figure 1. It can be seen that the actual input energy in the shorter natural period range is bounded appropriately by the bound for acceleration constraints, while that in the intermediate and longer natural period range is bounded properly by the bound for velocity constraints.

Investigations on the time-history of ground motions show that even for the same energy bound for acceleration constraints, the maximum amount of energy is not constant. Moreover, this maximum value can occur in different periods. This bound is only related to the area of the PSDF of excitation (power) and the maximum value of it (intensity). These two parameters can define a class of ground motions that existing record is just one realization of it. In other words, by using the critical excitation method a sample of ground motion can be used to determine required ground motions so that they are consistent with the structure.

It is assumed that the input base acceleration can be described by a uniformly modulated non-stationary random process, which is the product of a deterministic envelope function (c), and another probabilistic function representing a stationary random Gaussian process with zero mean (w). If the mean of the input energy considered as the objective function as given by

It may be shown that

$$E\left[\frac{E_I}{m}\right] = \int_{-\infty}^{+\infty} H_E(t,\omega) S_w(\omega)\, d\omega \qquad (2)$$

$$H_E(t,\omega) = -\int_0^t c(\tau)\,\mathrm{e}^{-i\omega\tau}\left[\int_0^\tau c(\zeta)\,\mathrm{e}^{i\omega\zeta}\,\dot{g}(\tau-\zeta)\,d\zeta\right] d\tau \qquad (3)$$

where $S_w(\omega)$ implies the power spectral density (PSD) function of $w(t)$. In addition, $c(\tau)$ is a deterministic envelope function, and $\dot{g}(t)$ denotes the time derivative of the unit impulse response function.

Given floor mass, story stiffness and structural viscous damping of an elastic SDOF, as well as the envelope function, critical PSD function can be found so that for a given energy level, maximizes mean of the input energy.

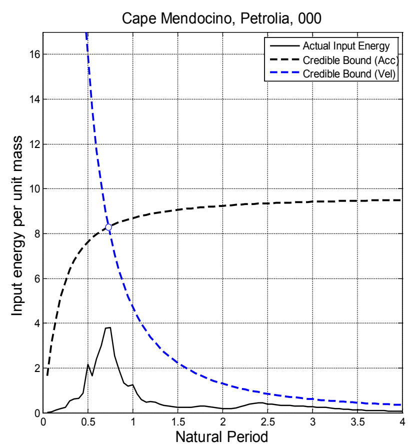

Figure 1. Total input energy of Cape Mendocino, Petrolia, 000

This study shows that maximum displacement of a SDOF system is related to the earthquake input energy. This is illustrated by investigating response spectrum of various ground motions with different input energy level. Then, the idea was used for multi degree of freedom (MDOF) system and the behavior of three models with different fundamental period subjected to 7 ground motions were studied. It can be concluded that total input energy per unit mass is an appropriate criterion for selection of desirable ground motions. In cases that existing motions are not consistent with the structure, the proposed method can be used to generate artificial records so that maximize the input energy with the same energy level. Results show that generated records can properly predict behavior of the structure as if it was subjected to the corresponding ground motion.

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