Soil Dynamics and Earthquake Engineering 31 (2011) 996–1008

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Spectral shape proxies and nonlinear structural response

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ARTICLE INFO

Article history:
Received 15 September 2009
Received in revised form
22 October 2010
Accepted 8 March 2011
Available online 9 April 2011

ABSTRACT

In this paper, spectral-shape-based intensity measures (*IMs*) are discussed with respect to ordinary, pulse-like and narrow-band records. First, the analyses address the ability of these *IMs* to capture the peak and cumulative damage potentials of ground motions. Second, a new vector-valued ground motion *IM* based on the spectral acceleration at the first mode of the structure, $Sa(T_1)$, and a parameter proxy for the spectral shape, namely N_p, is introduced. The vector $\langle Sa, N_p \rangle$ is compared to other state-of-the-art *IMs* in terms of estimation of the seismic response of nonlinear single degree of freedom systems, reinforced concrete and steel moment resisting frames. Results show that $\langle Sa, N_p \rangle$ may be especially useful to represent the ground motion potential in the case of records with peculiar spectral shape. Further, it is shown that $\langle Sa, N_p \rangle$ has the properties of efficiency, sufficiency and scaling robustness. Finally, a scalar ground motion *IM* based on $Sa(T_1)$ and N_p is also discussed, and the possibility to compute the seismic hazard analysis for it is illustrated.

1. Introduction

Probabilistic seismic demand analysis (PSDA) is part of the procedure to estimate the risk of structures subjected to earthquakes in probabilistic terms. As it is well-known by past studies (e.g. [1–3]) the PSDA can be carried out computing the mean annual frequency (MAF) of exceeding an engineering demand parameter (*EDP*) (e.g. interstory drift ratio, dissipated hysteretic energy or Park and Ang damage index) via an application of the total probability theorem:

$$\lambda_{EDP}(x) = \sum_i v_i \int_{IM}\int_M\int_R P[EDP > x|IM,M,R] f(IM|M,R)\, f(M,R)\, dr\, dm\, d(im) \quad (1)$$

where $\lambda_{EDP}(x)$ is the MAF of the *EDP* exceeding the value x, v_i is the rate of earthquakes for a specific seismogenic source i affecting the site of interest, $f(IM|M,R)$ is the conditional probability density function (PDF) of the *IM* given magnitude (M) and the source-to-site distance (R) or a ground motion prediction equation (GMPE), $f(M,R)$ is the joint PDF of M and R; $P\,[EDP > x|IM,M,R]$ is the probability of *EDP* exceeding x given *IM*, M and R. If $P[EDP > x|IM,M,R] = P[EDP > x|IM]$, then the *IM* is said to be sufficient [1,2] since its ability to predict the structural response is independent of M and R given *IM*. If *IM* is sufficient, Eq. (1) can be expressed as

$$\lambda_{EDP}(x) = \int_{IM} P[EDP > x|IM]\,|d\lambda_{IM}(im)| \quad (2)$$

where $d\lambda_{IM}(im)$ is the differential of the ground motion hazard curve for the *IM*. Note that *IM* in Eqs. (1) and (2), in general, can not only be a scalar measure, but also a vector-valued. In general, the desirable properties for an *IM* are sufficiency, efficiency and scaling robustness [1–4].

A sufficient *IM* is important because it can be used in the probabilistic structural assessment decoupling the hazard and structural analysis. Efficiency is defined as good explanatory power of the *IM* with respect to some *EDP*; this may help in reducing the number of records used to estimate the structural response with given accuracy. Robustness means that the amplitude (linear) scaling of records does not induce bias in the estimation of the seismic demand.

Because of the interest in relating the structural response to ground motion features, it is a long time since the *IMs* have started being investigated. In 1952, Housner [5] proposed to use the area under the velocity spectrum as an *IM*; some years later Von Thun et al. [6] suggested the area under the acceleration spectrum in the range of period from 0.1 to 0.5 s to assess the seismic response of dams. In the last years, the peak ground acceleration PGA and the spectral acceleration at the first mode period of the structure (hereinafter $Sa(T_1)$ or Sa) became very popular, especially because classical hazard analysis quantifies the seismic threat in terms of probability of exceedance of these quantities.

Recently, other advanced *IMs*, both scalar and vector-valued, which are claimed to overcome some shortcomings of traditional *IMs* (e.g., insufficiency); have been proposed. In particular, the vector $\langle Sa, \varepsilon \rangle$ (where epsilon is the number of standard deviations by which an observed logarithm of spectral acceleration differs

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doi:10.1016/j.soildyn.2011.03.006