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A statistical study on the peak ground parameters and amplification factors for an updated design displacement spectrum and a criterion for the selection of recorded ground motions

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ABSTRACT

The development of performance-based design methodologies and displacement-based approaches requires a special attention to the correct definition of the seismic input to be used for the analyses and in particular of reliable displacement response spectra. In this paper, the characterization of the schematized response spectra has been deeply investigated with the purpose of obtaining a more accurate displacement design spectrum and a simple but efficient criterion for the selection of recorded ground motions. First, a correlation analysis between peak ground motions parameters and other intensity measures has been performed. The independent parameters which are both necessary and sufficient for an engineering characterization of the seismic input at a specific site have been identified as the three peak parameters (*PGA*, *PGV* and *PGD*). Second, the amplification factors have been modeled as random processes in order to identify their fundamental properties in terms of mean values and variability. Based on the obtained results, an updated formulation for the design displacement spectrum is proposed and compared with that suggested by the Eurocode 8. Finally, a criterion for the selection of recorded ground motions for time-history analyses is presented.

1. Introduction

Over the last decades, response spectra and their design schematizations [39,22] have assumed a fundamental role for the definition of the input for seismic analyses and have been progressively adopted by seismic codes as the basic tools for response spectrum analyses. The conventional response spectrum analysis [21,22] is grounded on the traditional Force Based Design (FBD) and is usually conducted using the acceleration design spectrum, which is constructed starting from the knowledge of the peak ground acceleration (*PGA*) at the site as result of hazard analyses. Modern design codes also introduces design displacement spectra which are simply derived from the corresponding acceleration spectra employing the relationship between the displacement and the pseudo-acceleration.

In more recent years, with the developments of Performance-Based-Design (PBSD) and Displacement-Based-Design (DBD) approaches [43,16,41], the issue of defining displacement spectra leading to realistic displacement demand has received increasing attention among the scientific community. In 2000 Bommer et al. [18] showed that displacement spectra obtained by simple conversion of the design acceleration spectra given by codes result in unrealistic spectral shapes and amplitudes.

Many scientific works approached the issue of developing more realistic displacement spectra. Bommer and Elnashai [17] have carefully processed a dataset of European strong motions and derived new frequency-dependent ground motion prediction equations for horizontal displacement spectral ordinates, in order to provide simplified displacement spectral shapes in a linearized form. Tolis and Faccioli [48] studied high-quality digital recordings from the 1995 Hyogoken-Nanbu (Kobe) earthquake in order to identify possible trends in long-period spectral displacements. Lam et al. [34] developed a simple and rational procedure, termed the “frame analogy soil amplification” (FASA) model, which can be used to build response spectra accounting for the effects of soil amplifications. Guan et al. [30] developed a ground motion data processing procedure for the purpose of correcting the noise in the earthquake records and generating consistent displacement

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response spectra for seismic design. Faccioli et al. [26] have related the displacement spectral shape in the long-period range to the magnitude (high influence on the spectra) and the source distance (small influence), identifying a “corner period” T_d beyond which the spectral ordinates remain roughly constant or gently decrease towards the peak ground displacements. Akkar and Özen [6] recognized the fundamental effect of the peak ground velocity on single-degree-of-freedom deformation demands, for decreasing the dispersion due to record-to-record variability.

The above cited works highlighted the need of including further ground motions parameters for a reliable evaluation of appropriate displacement spectra rather than the only peak ground acceleration. Nonetheless, despite the number of research works devoted to the study of correlations between input parameters such as spectral ordinates at selected periods and structural response parameters, few systematic studies on the correlation between parameters characterizing the input (such as the peak ground parameters or other intensity measures) can be found in the scientific literature. Akkar and Özen [6] provided some correlations analyses between *PGV* and *PGA* and between *PGV* and the effective duration. Akkar et al. [4], investigating on the influence of long-period filter cut-off on the spectral displacement, studied the correlation between corner period T_c and magnitude. Aochi and Dougles [8] studied the correlation between the Arias Intensity AI [9] and significant duration RSD [45]. Furthermore, it has to be noted that response spectra provide information about amplitude and frequency distribution but information about strong motion duration is missed. Previous research works showed that strong motion duration may largely influence the inelastic demand of short-period structures with stiffness and strength degradation [25,46,20,19, 31,38].

In this paper, a systematic statistical analysis between the main ground motion parameters is conducted considering an ensemble ground motion of 177 historical records in order to identify the key-parameters and features for an accurate characterization of the earthquake input in terms of displacement spectrum. First, a correlation analysis between various ground motion parameters is conducted. Then, the amplification factors of the peak ground parameters are investigated. Based on the obtained results, an updated formulation for the design displacement spectrum is proposed and compared with that suggested by the Eurocode 8. Finally, a criterion for the selection of recorded ground motions for time-history analyses is presented.

2. The schematised tripartite response spectrum

A compact graphical representation of the displacement (S_D), pseudo-velocity (S_V) and pseudo-acceleration (S_A) spectra, apparently first introduced by Veletsos and Newmark [50], is given by the well-known tripartite response spectrum. A possible schematized (for design purposes) spectrum is represented in Fig. 1, where T represents the vibration period of the structure. It may be defined through the following groups of parameters [21]:

I. Peak ground acceleration, peak ground velocity, and peak ground displacement (*PGA*, *PGV*, and *PGD*, respectively).
II. Acceleration, velocity, and displacement amplification factors (α_A, α_V, and α_D, respectively).
III. Corner periods T_a, T_b, T_c, T_d, T_e, T_f.

Peak ground parameters *PGA*, *PGV*, *PGD* are generally given by seismic hazard analysis. Amplification factors and corner periods T_a, T_b, T_e and T_f are generally calculated through statistical analyses on large number of records and are assumed to be constant. Newmark and Hall [39] recommended the following values of the corner periods: $T_a = 1/33$ s, $T_b = 1/8$ s, T_e 10 s, $T_f = 33$ s, respectively.

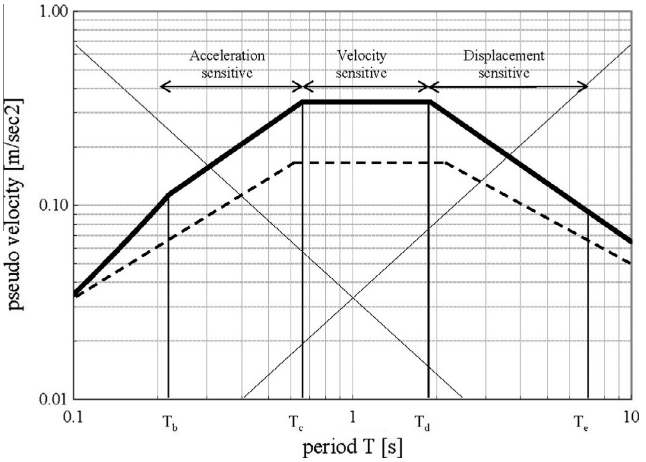

Fig. 1. The schematised tripartite response spectrum.

The analytical expression of the schematized pseudo-acceleration spectrum for the different period ranges as suggested by Chopra [21] is:

- for $0 \leqslant T \leqslant T_a$:

$$S_A(T) = PGA \tag{1}$$

- for $T_a \leqslant T \leqslant T_b$:

$$S_A(T) = PGA\left[(\alpha_A - 1)\frac{T}{T_b - T_a} + \frac{T_b - \alpha_A T_a}{T_b - T_a}\right] \tag{2}$$

- for $T_b \leqslant T \leqslant T_c$:

$$S_A(T) = \alpha_A PGA \tag{3}$$

- for $T_c \leqslant T \leqslant T_d$:

$$S_A(T) = \alpha_V PGV\left(\frac{2\pi}{T}\right) \tag{4}$$

- for $T_d \leqslant T \leqslant T_e$:

$$S_A(T) = \alpha_D PGD\left(\frac{2\pi}{T}\right)^2 \tag{5}$$

- for $T_e \leqslant T \leqslant T_f$:

$$S_A(T) = PGD\left[(\alpha_D - 1)\frac{T}{T_e - T_f} + \frac{T_e - \alpha_D T_f}{T_e - T_f}\right]\left(\frac{2\pi}{T}\right)^2 \tag{6}$$

- for $T_f < T$:

$$S_A(T) = PGD\left(\frac{2\pi}{T}\right)^2 \tag{7}$$

The corresponding pseudo-velocity and displacement spectra can be simply obtained by employing their definitions: $S_V(T) = S_A(T)\cdot T/2\pi$ and $S_D(T) = S_V(T)\cdot T/2\pi$.

Each of these three spectra has a range of period characterized by a linear variation of the response. Namely:

- in the displacement response spectrum, for $T_c \leqslant T \leqslant T_d$:

$$S_D(T) = \varphi_D \cdot T \tag{8}$$

- in the pseudo-velocity response spectrum, for $T_b \leqslant T \leqslant T_c$:

$$S_V(T) = \varphi_V \cdot T \tag{9}$$

- in the pseudo-acceleration response spectrum, for $T_a \leqslant T \leqslant T_b$:

$$S_A(T) = \varphi_A \cdot T \tag{10}$$