An Inspection on the Analytical Structure of Velocity and Displacement Bi-Normalized Response Spectra for Near-Field Earthquake Records

Safoora Morshed Shekarchi[1], Afshin Meshkat-Dini[*1], Ali Massumi[1]

1. Department of Civil Engineering, Faculty of Engineering, Kharazmi University, Tehran, Iran.

Received: 21 August 2021 Accepted: 6 February 2022

(Paper pages 1-17)

Introduction

For various seismic building codes, the site-specific design spectrum is concluded according to the average normalized response spectra corresponding to a symbolic single degree of freedom system. Also, there are different effective parameters in this procedure. This research is focused around the assessment of the pseudo velocity response spectra, the normalized displacement response spectra, and the bi-normalized response spectra (BNRS) corresponding to strong near-field ground motion records containing forward directivity effects with regards to the predominant period and velocity pulse time domain. Near-fault ground motions have powerful impulsive nature which is characterized by the distinct long period and high amplitude pulses, the relatively short duration, the intensive strong waveforms as well as the special spectral shape especially in low-frequency band. Evidently, the strong ground motions which have been recorded within forward directivity process are qualitatively quite different from the far-field ones.

In the analysis procedure in this research, an ensemble of the selected seismic tremors containing 36 pairs of the related horizontal components has been utilized. These notified ground acceleration time histories have been recorded during the Imperial Valley 1979 and the Northridge 1994 earthquake events in California, as well as the two powerful earthquake tremors which occurred in Tabas (1978) and Bam (2003), Iran.

Methodology

The selected earthquake records were categorized in relation to the parameter of kinematic energy amplitude, peak ground velocity (PGV), and peak ground acceleration (PGA). Moreover, the analytical effects due to the above-mentioned factors have been evaluated based on the computational concepts of the pseudo velocity response spectra, the normalized displacement response spectra and the bi-normalized response spectra.

The normalized response spectrum (NRS) is analytically resulted by considering its numerical ratio over a specific period (T) per the corresponding PGA or target spectral parameter. Hence, it can be shown as bellow:

$$N\_A(T) = \frac{\omega'}{PGA}\left|\ddot{x}(\tau)e^{-\xi\omega(t-\tau)}\left[\left(1-\frac{\xi^2}{1-\xi^2}\right)\sin\omega'(t-\tau)+\frac{2\xi}{\sqrt{1-\xi^2}}\cos\omega'(t-\tau)\right]d\tau\right|_{max} \tag{1}$$

Accordingly, the corresponding bi-normalized response spectrum (BNRS) is obtained by quantifying the reference period axis with regards to the energetic frequency band of a notified earthquake record. It is noteworthy that the BNRS which is obtained using the Duhamel's integral solution with respect to the numerical ratio of the system vibration period per the predominant period (i.e., T/T_P), demonstrates the response spectrum of a symbolic single degree of freedom system. Accordingly, the Duhamel's integral is rewritten as follows:

$$BN\_A(T)=\frac{(\omega' T_P)}{PGA}\left|\ddot{x}(\tau)e^{-\xi(\omega T_P)(t-\tau)}\left[\left(1-\frac{\xi^2}{1-\xi^2}\right)\sin(\omega' T_P)(t-\tau)+\frac{2\xi}{\sqrt{1-\xi^2}}\cos(\omega' T_P)(t-\tau)\right]d\tau\right|_{max} \tag{2}$$

Moreover, pseudo acceleration and velocity response spectra can be computed by proportionating the displacement response spectra (Sd) as $Sa=\omega^2 Sd$ and $Sv=\omega Sd$, respectively.

Results and Discussion

Based on the results of this research, it was concluded that the analytical skeleton of the normalized velocity response spectrum based on various evaluation criterions, especially in higher periodic domain would have a wide range of inconsistent variations by a stochastic characteristic. The physical characteristics of distinct velocity pulses have essentially influences in this manner.

Moreover, the analytical notifications to the bi-normalized response spectra by the criterion of predominant period, denote that the computational sensitivity of the spectrum components will increase significantly, especially in spectral domain close to the predominant period range.

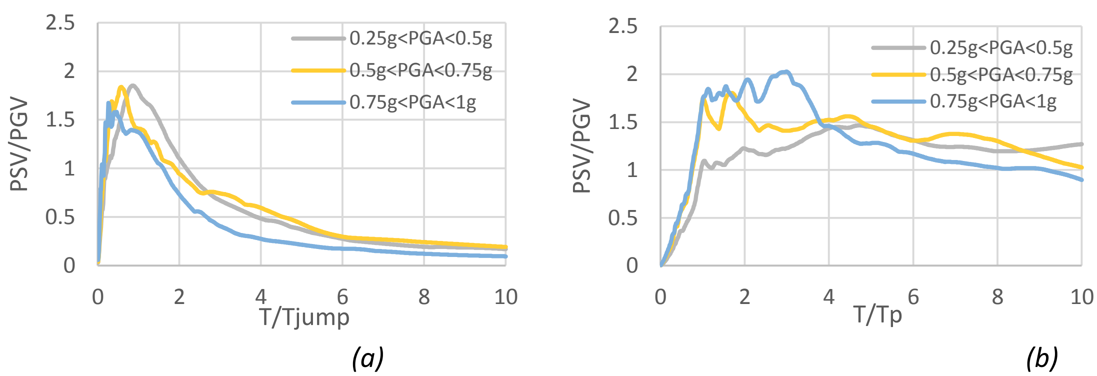

Figure 1- Illustration of the bi-normalized pseudo velocity response spectra; (a) with respect to the T_{jump} criteria, (b) with respect to the T_P criteria.

Evaluation of the obtained results due to both types of the implemented criterions for response spectra (Figure 1), showed that normalizing the spectral period parameter with respect to the pulse time step (T_{jump}) can decrease the spectral values in the domain of greater spectral ratios.

Based on the obtained results, it was recognized that the ups and downs of the spectra at the ranges of larger periodic ratios can appeared on a lower scale. The normalization of the response spectra period axis (i.e., the horizontal axis) with regards to the pulse time step (T_{jump}) would lead to the reduction of evaluation parameters variation effects, in the analytical structure of the displacement and velocity spectra.

Keywords: Normalized Response Spectra (NRS), Bi-Normalized Response Spectra (BNRS), Near-Field Record, Predominant Period, Velocity Pulse, Pulse Time Step

*Corresponding Author: meshkat@khu.ac.ir