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ANALYTICAL ASPECTS OF BI-NORMALIZED RESPONSE SPECTRA BASED ON GROUND VELOCITY AND DISPLACMENT TIME HISTORIES IN NEAR FAULT

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Near-fault ground motions have powerful impulsive nature which is characterized by long period and high amplitude pulses, relatively short durated and intensive strong waveforms as well as unusual spectral shape especially in low-frequency band. The strong ground motion recorded within forward directivity process are qualitatively quite different from the far-field ones (Wuchuan et al., 2018). The strong near-fault ground motions have often waveform of pulses in the ground velocity history, so that in a time domain most of the kinematic energy considerably emanates through fault rupture mechanism. In this paper, the analytical aspects of bi-normalized response spectra (BNRS) according to the ground velocity and displacement in near fault has been notified and assessed numerically. The ground motions which are needed for this purpose have been selected based on the pulse-like records.

The ensemble of the selected seismic tremors contains 16 records related to the Imperial Valley 1979 and the Northridge 1994 earthquake events. Moreover, BNRS of a symbolic single degree of freedom (SDOF) system was compared with corresponding normal response spectra (NSP). Toward this objective, the parameters including the kinematic energy ratio of fault parallel component (i.e. LN) to fault normal component (i.e. TR), peak ground velocity (PGV) and peak ground acceleration (PGA) were taken into account. Xu et al. (2004) proposed bi-normalized response spectrum based on performing statistical analyses on the records due to the 1999 Chi Chi earthquake. The study was concentrated on the interaction effects of soil conditions, epicentral distance, hanging wall and damping circumstances on the corresponding BNRS. Also, different criterions for normalizing the spectral period parameter (as oriented axis) have been investigated. Pavel et al. (2014) used predominant period and temporal control for assessing of bi-normalized velocity response spectra and notifications related to the dynamic amplification factor. Due to the importance of wave-like records, time duration of the distinct pulse can be an appropriate criterion for normalizing spectral period parameter (as oriented axis). In order to normalize the acceleration response spectrum, the numerical ratio of this spectra over a specific period (T) per the corresponding PGA must be applied. Hence, it can be resulted as bellow:

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

The normal response spectrum (NSP) is more noticeable than the absolute response spectrum, specially respect to the process of eliminating of noise frequencies. Each earthquake excitation has a different value of predominant period (Tp). On the other hand, the profile of the corresponding normal acceleration response spectrum has relatively similar trend before and after Tp. Accordingly, the corresponding bi-normalized response spectrum is obtained by normalizing the reference period axis, regarding to the strong frequency band of earthquake record (Morshed et al., 2018). It is noteworthy that the BNRS which is obtained using the Duhamel's integral solution 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 as explained above (Xu et al., 2004). Since the duration of near-fault ground motion pulses characterizes the intensity as well as the distribution of the input energy, then the evaluation of the jump-up period ($T_{\mathbf{jump}}$ in Figure 1) can be established on energy-based parameters. The parameter T_{jump} corresponding to the record JFP due to the Northridge earthquake 1994 is shown in Figure 1. Accordingly, the Duhamel's integral is rewritten as follows (Morshed et al., 2018):

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

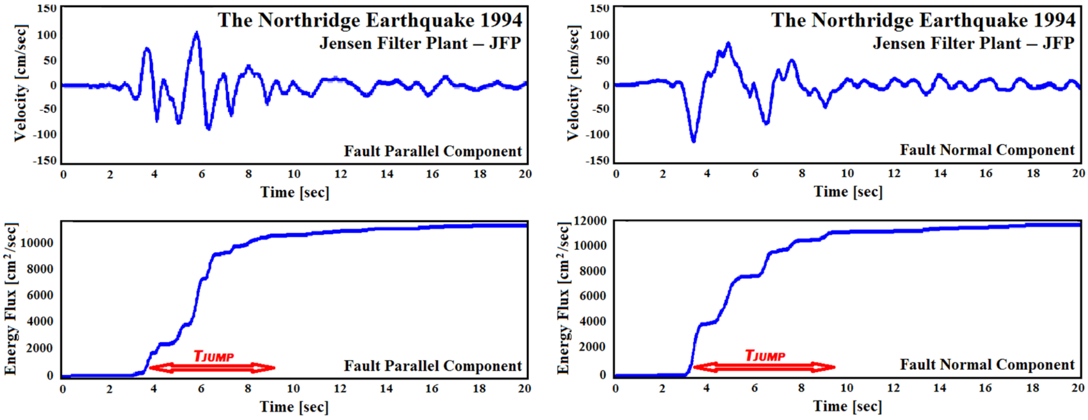

Figure 1. Illustration of the parameter T_{jump} related to the record JFP.

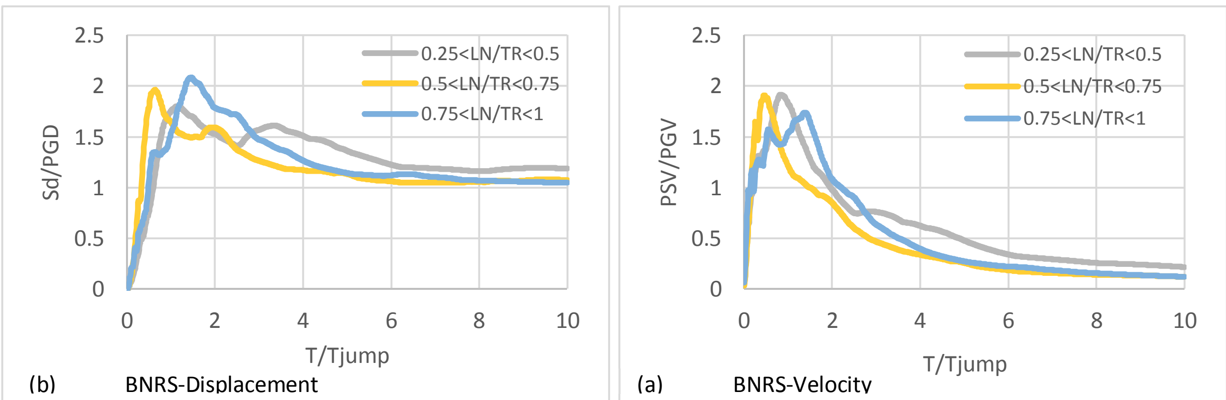

Figure 2. Illustration of bi-normalized response spectra with respect to the T_{jump} criteria; (a) the displacement type out-put, (b) the velocity type output.

Moreover, pseudo acceleration and velocity response spectra can be computed by proportionate the displacement response spectra (Sd) as $Sa = \omega^2 Sd$ and $Sv = \omega Sd$, respectively. Evaluation of the results due to both types of response spectra as mentioned above (Figure 2), showed that the bi-normalization process with respect to T_{jump} parameter can smooth the graph of response spectrum, relatively. It also reduces the effects of energy ratio. The results of this research emphasize on the importance of jump-up period (i.e. T_{jump}) and its selection as an appropriate criterion for the evaluation of the response spectra.

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