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Effects of tectonic regime and soil conditions on the pulse period of near-fault ground motions

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ABSTRACT

In this article, the effects of site conditions (rock vs. soil) and tectonic regime (interplate vs. intraplate) on the pulse period of near-fault forward-directivity ground motions are investigated through linear regression analyses, and appropriate scaling laws that relate the pulse period to the earthquake magnitude are derived. The analyses of rock and soil sites are performed using interplate records only. The results show that for earthquakes of smaller magnitude, the pulse period is longer at soil sites than at rock sites. As the earthquake magnitude increases, the pulse period values at rock and soil sites converge. This observation is in agreement with findings reported in previous studies. However, as shown in this article, the effect of soil conditions on the pulse period is not statistically significant at the 10% level based on the available near-fault ground motion datasets. Regression analyses for interplate and intraplate records are also performed, including regressions with and without self-similarity. The results show that the pulse periods of interplate records are significantly longer (factor of 2.45, on average) than the pulse periods of intraplate records with similar magnitude. It is demonstrated that this difference should also be reflected in the rise times of the events originating in the two different tectonic regimes. Using the specific barrier model as a “tool” of analysis, it is shown that the significant difference in the pulse periods also implies a significant difference (factor of 4) in the local stress drops for the events of the two tectonic regimes. This latter conclusion is supported by recent reports in the literature of the reanalysis of eastern North American earthquakes, accounting more carefully for attenuation.

1. Introduction

Not all ground motion time histories recorded at stations in the vicinity of a fault exhibit intense velocity pulses in the event of an earthquake. The existence of pulse-like ground motions in near-fault records primarily depends on the relative position of the station that recorded the motion with respect to the direction of propagation of rupture on the causative fault plane and on the magnitude and direction of slip on that segment of the fault that is located in the extended neighborhood of the station. Whenever these ground motion pulses do occur, they are typically caused by the forward directivity and/or permanent translation (fling) effects (e.g. [70,1,54]).

Fig. 1 illustrates a large number of actual near-fault ground motion records with “distinct” velocity pulses. These records are part of the near-fault ground motion database compiled by Mavroeidis and Papageorgiou [55]. It is evident that the pulse duration (or period), the pulse amplitude, as well as the number and phase of half-cycles are the key parameters that define the waveform characteristics of the near-fault records. Therefore, an analytical model with a small number of input parameters should in principle suffice to describe the key features of the pulse-like ground motions observed in the near-fault region.

Such an analytical model for the representation of the coherent component of the near-fault seismic excitations was proposed by Mavroeidis and Papageorgiou [55]. The mathematical formulation for the velocity pulses is the product of a harmonic oscillation and

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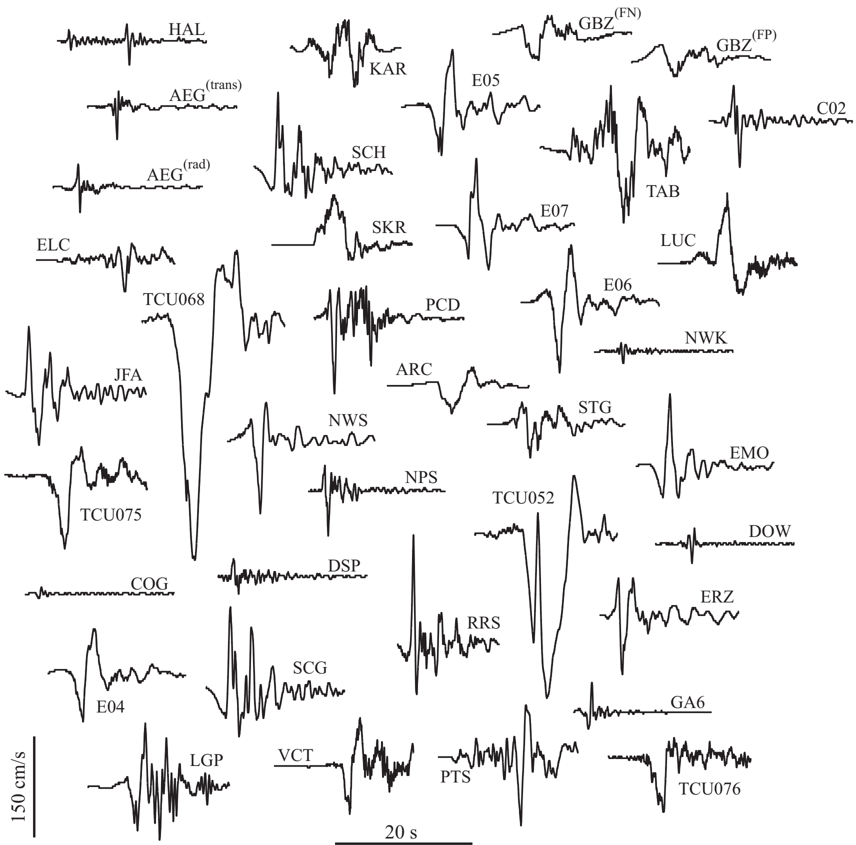

Fig. 1. Near-fault ground motion records with "distinct" velocity pulses (from [55]).

a bell-shaped function. That is:

$$v(t)=\begin{cases}\frac{A}{2}\left[1+\cos\left(\frac{2\pi f_P}{\gamma}(t-t_0)\right)\right]\cos\left[2\pi f_P(t-t_0)+\nu\right], & t_0-\frac{\gamma}{2f_P}\le t\le t_0+\frac{\gamma}{2f_P}\text{with } \gamma>1\\ 0, & \text{otherwise}\end{cases} \quad (1)$$

where A controls the amplitude of the signal, f_P is the frequency of the amplitude-modulated harmonic (or the prevailing frequency of the signal), ν is the phase of the amplitude-modulated harmonic, γ is a parameter that defines the oscillatory character of the signal, and t_0 specifies the epoch of the envelope's peak. The pulse period (T_P) is defined as the inverse of the prevailing frequency (f_P) of the signal, thus providing an "objective" assessment of this important parameter:

$$T_P=\frac{1}{f_P} \quad (2)$$

The mathematical model of Eq. (1) was calibrated using a large number of actual near-fault records. It successfully replicated a large set of displacement, velocity and, in many cases, acceleration time histories, as well as the corresponding 5% damped elastic response spectra [55]. The scaling characteristics of the model input parameters were also investigated through regression analyses, and simple empirical relationships were proposed [55,53,27].

Furthermore, a simplified methodology for generating realistic broadband ground motions that are adequate for engineering analysis and design in the near-fault region was proposed by Mavroeidis and Papageorgiou [55]. Based on this methodology, the coherent (long-period) ground motion component is simulated using the mathematical model of Eq. (1), whereas the incoherent (high-frequency) seismic radiation is synthesized using the specific barrier model [60,61,59] in the context of the stochastic modeling approach (e.g. [8]). This simplified methodology for generating broadband ground motions has been applied to both hypothetical and actual earthquakes (e.g. [55,27]).

The pulse period (T_P) emerged as the key parameter for the effective normalization of the elastic and inelastic response spectra of the single-degree-of-freedom oscillator subjected to actual near-fault ground motion records. Such normalization made feasible the specification of design spectra, strength reduction factors and damping coefficients appropriate for analysis and design in the near-fault region [53,43]. The pulse period (T_P) scales directly with the moment magnitude (M_W) (e.g. [70,71,55,13], among others) and is related to the rise time (τ) (e.g. [70,71,53]), an important parameter of the fault rupture process controlled by the typical dimension of the subevents (referred to as barrier interval in the context of the specific barrier model) that compose the mainshock.

In this article, the effects of soil conditions and tectonic regime on the pulse period (T_P) of near-fault ground motions are investigated. This includes (1) augmenting the near-fault ground motion database compiled by Mavroeidis and Papageorgiou [55] with near-fault data obtained from recent interplate earthquakes, (2) compiling a near-fault ground motion database from intraplate earthquakes, (3) fitting the displacement, velocity, and acceleration time histories, as well as the corresponding 5% damped pseudo-velocity response spectra of the collected ground motion records with the analytical model proposed by Mavroeidis and Papageorgiou [55], (4) utilizing the T_P values obtained by the synthetic pulse fitting to investigate, through regression analyses, the effects of soil conditions and tectonic regime on the pulse period of near-fault ground motions, and (5) investigating the interrelationships between pulse period, rise time and local stress drop of interplate and intraplate earthquakes in the context of the specific barrier model. This study leads to the derivation of scaling laws that relate the pulse period (T_P) to the moment magnitude