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Seismic assessment of the rigid sliding displacements caused by pulse motions

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ABSTRACT

This paper presents a comprehensive study on the rigid block sliding displacement of slopes subjected to ground motions with large velocity pulses. A comparison of the performance of various existing empirical displacement models is provided through analyses of the displacement residuals of slopes subject to pulse-like motions. Except for the PGA- and PGV-based Saygili and Rathje model (2008, referred to as SR08), positive medians of residuals are observed for selected models, indicating an underestimation. There is a negative constant shift in the total residuals for the SR08 model, which can be easily fixed by changing the constant term in the predictive equation. The residuals from the SR08 model also have the smallest standard deviation compared to the other models. A modified SR08 model is developed for predicting rigid block sliding displacements for pulse-like motions. The modified predictive model is used in probabilistic seismic displacement analyses of slopes in a hypothetical near-fault region.

1. Introduction

Pulse-like earthquake ground motions may occur at near-fault sites when the fault rupture direction and fault slip direction, relative to a site, coincide, and when the velocity of the fault rupture is close to (generally slightly less than) the shear wave velocity of the rock near the source. These effects are commonly called forward directivity effects [1]. Previous research has shown that pulse-type motions can cause larger Newmark-type displacements [2] in slopes than ordinary ground motions [3–7], and that the displacement demand level of flexible slopes highly depends on the ratio of the slope period to the pulse period [6,7].

There are various published models for the prediction of earthquake-induced Newmark displacement [8–16]. While these empirical displacement models cannot replace site-specific seismic response analyses of slopes (e.g., Refs. [17,18]), they are valuable for the assessment of seismic risk of slopes both at the local and regional levels. These predictions, however, have been developed without taking into considerations the unique characteristics of pulse-type ground motions. Recently, a comprehensive database comprising 243 pulse-like motions was identified from the NGA-West2 database [19]. This database may enable an improvement in the characterization of the effects of pulse-like ground motions on the seismic performance of slopes; however, it may not be large enough to develop a defensible predictive model of Newmark displacement. An alternative approach is to perform an analysis of the residuals of an appropriate predictive model relative to the displacements from the set of pulse-like motions. Most of the available empirical models were developed using displacements of a rigid-block. The rigid-block model is popular in practice because fewer soil parameters are required. Moreover, in natural slopes, a common failure mode for seismic landslides is a thin, veneer slope failure [20], where a rigid sliding block procedure is applicable. Deeper sliding surfaces are more common in engineered earth slopes although shallow failure surfaces can also occur in these cases [12].

This paper presents a comprehensive examination of the residuals of the sliding displacement of rigid blocks subject to pulse-like motions using existing empirical displacement models. Modified equations for the median and standard deviation of the displacement are developed for predicting sliding displacements for pulse-like motions. An example application is presented including the modified predictive model in the seismic assessment of the

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Newmark displacement of rigid sliding blocks in the near-fault region.

2. Seismic sliding of a rigid block for pulse-like motions

The pulse feature in the pulse-type ground motions is typically observed at the beginning of fault-normal velocity time histories [1]. Fig. 1 illustrates the observed velocity time histories and 5% damped spectral acceleration of the El Centro Array #4 records during the Imperial Valley-06 (1979) earthquake. Observe that the peak ground velocity (PGV) of the fault-normal (FN) component is significantly larger than that of the fault-parallel (FP) component (Fig. 1a). The FN spectral acceleration is also larger at periods close to the period of the pulse (T_p), which is 4.6 s for this record [21].

The sliding displacements of a rigid sliding block with a yield acceleration (k_y) of 0.05 g for the El Centro Array #4 ground motions are shown in Fig. 2. A sliding episode begins when the ground motion acceleration exceeds k_y and continues until the relative velocity between the base and the sliding block becomes zero. The relative velocity is numerically integrated to obtain the relative sliding displacement for each sliding episode and the sum of the displacements for each sliding episode represents the cumulative sliding displacement. As can be seen, the sliding displacement from the FN excitation is significantly larger than that resulting from the FP ground motion. In addition, the displacement for the FP component gradually increases with multiple sliding episodes, resulting in an incremental build-up of sliding displacements. On the other hand, the displacement for the FN motion is associated with just one significant step with a duration approximately equal to the duration of the pulse.

The peak ground acceleration (PGA) of the FN component is smaller than that of the FP orientation (Fig.1b), and the FN Arias intensity (I_a) is also smaller (0.94 m/s for the FN component and 1.33 m/s for the FP component). The larger displacement of the FN motion is likely the result of the pulse characteristic of the motion, which allows for a long sliding increment in few cycles. Similar results are also observed for pulse-type ground motion records from other earthquakes, e.g., the Gilroy Array #6 records during the Morgan Hill (1985) earthquake, the Lucerne records during the Landers (1992) earthquake and the Pacoima Dam records during the Northridge (1994) earthquake. However, most of the existing

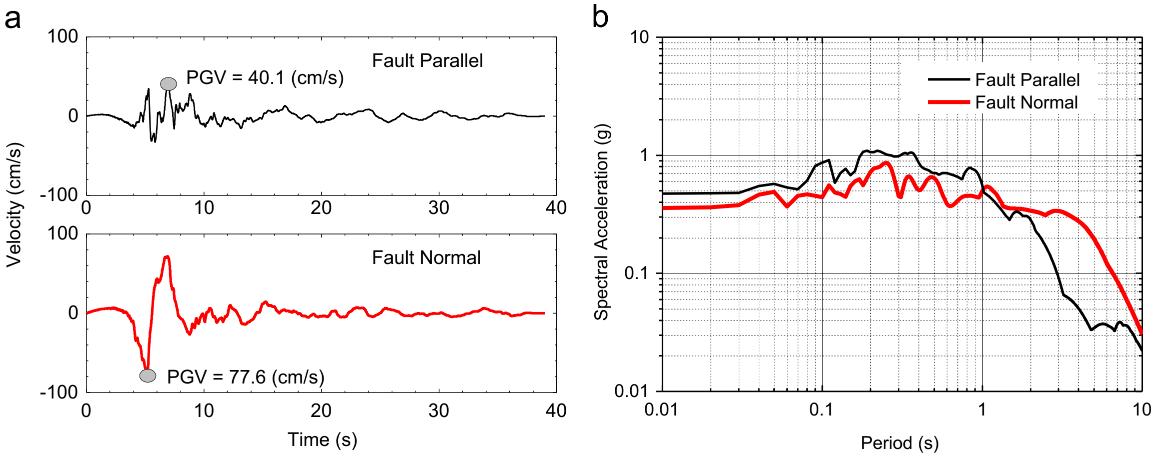

Fig. 1. Effects of forward directivity on the: (a) fault-normal velocity time-history; (b) spectral acceleration for El Centro Array #4 ground motion recorded in the Imperial Valley-06 (1979) earthquake.

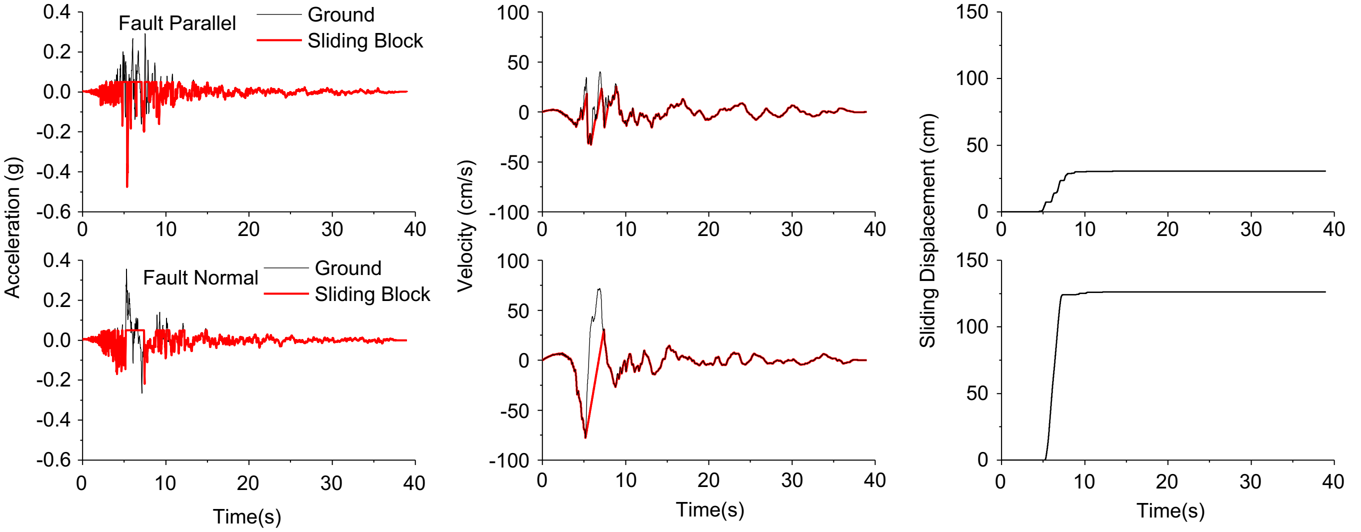

Fig. 2. Time histories of acceleration, velocity and sliding displacement of a rigid sliding block (k_y=0.05 g) to the fault-parallel and fault-normal components of the El Centro Array #4 ground motion recorded in the Imperial Valley-06 (1979) earthquake.