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Broad-Band Near-Fault Strong Motion Time Histories Simulations – Surface Faulting and Rupture Directivity Effects

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Abstract
Unique to the near-source large earthquake is the occurrence of strong impulsive long-period ground motion and surface faulting. The well-recorded time history event of the 1999 Chi-Chi earthquake has confirmed the existence of permanent displacements, referred to as 'fling-step', coupled with rupture directivity motions. The objective of this study is to characterize forward directivity and fling effects as a function of limited number of model input parameters for synthesizing broad-band time histories. The results show that the overall agreement between developed analytical methodology, and the recorded waveforms as well as the available empirically based predictive relationships is quite satisfying.
Keywords: Near-source, Strong motion, Surface faulting, Directivity.

1. Introduction

Seismic ground motions close to a ruptured fault can be significantly different than those observed further away. Near-fault motions are noticeably influenced by the forward directivity when the fault rupture propagates toward a site and by permanent ground displacement resulting from tectonic movement. Depending on the first factor, ground motions in the near-fault zone can exhibit the dynamic consequences of strong velocity and displacement pulses oriented in normal to the fault direction. Depending on the second factor, near-fault ground displacements may show a ramp-type waveform, indicating permanent ground deformation. Pulse-type motions have been identified as critical in the elastic and inelastic design of engineering structures subjected to near-fault records [1, 2, and 3]. They indicated that the amplitude and period of the pulse in the velocity–time history are parameters that control the performance of structures. However, the 1999 Kocaeli earthquake in Turkey and 1999 Chi-Chi earthquake in Taiwan showed the devastating effects of fault rupture on dwellings and civil infrastructures. This is a serious threat to mega cities spreading over active fault traces, and is posing us difficult problems about minimizing the fault-rupturing-related damage. Hence, additional work in this emerging area of earthquake engineering is warranted. The Chi-Chi event recordings provide a rare opportunity to investigate the fault movements of an earthquake using near-fault measurements.

Stochastic finite fault modeling [4] has been widely applied to produce acceleration time series with relative large amplitude of low frequencies descritizing causative fault into elements, each element is treated as a small source [5]. However, inclusion of long-period pulses is believed to substantially improve the ability of waveform generated by the mentioned method in order to model broad-band time histories over a wide range of frequencies [6]. According to [6], the mean ratio of simulated to observed spectra from the near-source Chi-Chi earthquake is very close to unity for frequencies larger than about 1 Hz, whereas at lower frequencies and very close-to-fault distances there is a systematic under-prediction. This indicates that the employed stochastic method may lack in adequate prediction of exceptional waveforms with strong long-period velocity pulses and large permanent ground displacements at near-fault sites sufficiently close to the rupture plane. These special aspects of near-fault motions will be addressed in the present work.

The purpose of this study, therefore, is to analyze the velocity and displacement waveforms at stations very near to the activated Chelungpu fault for inference of velocity pulses and permanent offsets. A simple analytical approach is used to describe the displacement offset and impulsive character of near-fault ground motions as a function of the limited number of model input parameters. Based on the findings in this article, we are able to estimate rational near-fault ground motions generated by earthquakes with similar source characteristics. From an engineering standpoint, these results are important for structures with intermediate-to-long natural periods. Such structures, if located near a large active fault, could be subjected to significantly higher long-period amplitudes in the direction normal to the fault.