Soil Dynamics and Earthquake Engineering 31 (2011) 59–76

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Response spectrum-oriented pulse identification and magnitude scaling of forward directivity pulses in near-fault ground motions

Yuchuan Tang, Jian Zhang *

Department of Civil and Environmental Engineering, University of California, Los Angeles, USA

ARTICLE INFO

Article history:
Received 19 April 2010
Received in revised form
18 August 2010
Accepted 20 August 2010

ABSTRACT

This paper presents a novel approach to identify the pulse-like motions in earthquake recordings that dominate the maximum structural responses over a wide period range. The identification method is based on the congruence relationship between the response spectrum and the dimensionless Π-response spectrum established in this study through straightforward dimensional arguments of linear and bilinear SDOF oscillators subject to pulse-like ground motions. By evaluating the geometric match and dislocations of the Π-response spectrum of a given waveform with the dimensional response spectrum in bi-logarithm plotting, one can identify the simple pulses and their parameters that match simultaneously the kinematic characteristics and the response spectrum of earthquake recordings that exhibit pulse-like features. The developed pulse identification method has been implemented in a computer program and applied successfully to detect the pulse-like motions in the PEER NGA strong motion database. Both velocity and acceleration pulses potentially due to forward directivity effects in near fault regions are identified. The identified velocity pulses show strong correlation with the seismological parameters. They are subsequently used in regression analysis to derive the empirical scaling laws that relate the directivity pulse parameters to the earthquake magnitude and rupture distance. The study confirms some magnitude scaling laws in literature and demonstrates the accuracy and efficiency of the proposed pulse identification method.

1. Introduction

Near-fault ground motions often exhibit distinguishable pulse-like features in their velocity time histories, occasionally also observed in acceleration time histories. The main causes for the velocity pulses are the rupture forward directivity and fling-step effect [1,2]. The forward rupture directivity, which occurs when the fault rupture propagates toward a site at a velocity close to the shear wave velocity and the direction of slip on the fault is aligned with the site, causes most of the seismic energy from the fault rupture to arrive in a single large long-period pulse near the beginning of ground shaking representing the cumulative effect of almost all the seismic radiation from the moving dislocation on the fault [1,3–5]. In addition, fling-step effect, which is associated with the permanent tectonic offset of the ground, can also result in one-sided velocity pulse in the fault-normal direction for dip-slip faults or in the fault-parallel direction for strike-slip faults [2,5]. On the other hand, the pulse contents in acceleration time histories (e.g. local acceleration pulses that override the long period velocity pulses) have also been found important for structural responses [6,7].

In the past two decades, several major earthquakes (e.g. 1994 Northridge, 1995 Kobe, and 1999 Chi-Chi earthquakes among others) caused extensive damages in civil structures in the near-fault regions. Following the pioneering work by Bertero et al. [8,9], many previous studies have demonstrated that pulse-like near-fault motions can impose extreme demands on structures, much more than the ordinary far-field ground motions [7,10–13]. From the probabilistic seismic hazard analysis and the engineering design perspectives, it is important to characterize the pulse-like motions and quantify their impact on the structural responses. This requires developing improved representation of near-fault ground motions that uses time domain parameters such as the amplitude, period, and number of cycles of the near-fault pulse in addition to the design response spectrum. Furthermore, it is important to identify the inherent energetic pulses that control the design spectrum so as to select appropriate earthquake motions for design purposes, because the directivity pulse or fling pulse is present in some but not all near-fault motions [14].

Various pulse identification methods were developed to detect the directivity pulses in near-fault ground motions with simple pulse models ([10,15–21] among others). Based on the identified pulses, predictive relationships have been established to relate

* Corresponding author. Tel.: +1 310 825 7986; fax: +1 310 206 2222.
E-mail addresses: ytang@air-worldwide.com (Y. Tang), zhangj@ucla.edu (J. Zhang).

0267-7261/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soildyn.2010.08.006