Soil Dynamics and Earthquake Engineering 115 (2018) 232–245

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

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

Fling-step ground motions simulation using theoretical-based Green's function technique for structural analysis

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ARTICLE INFO

Keywords:
Fling-step
Ground motion simulation
MO-GA
NTH analysis
Seismic response

ABSTRACT

The article aims to **a.** introduce a technique to generate long-period waveforms having fling-step effect at near fault and **b.** study the effect of fling-step on the structural performance of buildings. The study focuses on the fling-step effect which is related to large co-seismic displacement. For this purpose, seismological parameters of Kocaeli 1999 earthquake have been computed through an evolutionary multi objective approach (MO-GA) and Theoretical-based Green's Function (TGF) method with regard to specific objectives such as permanent displacement, response spectra, and multi-taper spectra. Thereafter many accelerograms were generated at desired near stations and the fling-step effects were removed from the accelerograms by a specific technique. Subsequently, three3-, 9- and 20-story steel frames were modeled in Opensees and the structural responses were obtained using nonlinear time history analyses. Findings from this study demonstrate that fling-step would affect the seismic demand fairly high when the ratio of the fundamental period of the structure to fling rise time (pulse duration) varies from 0.5 to 1.1. Also a good agreement between the responses of the structures subjected to generated ground motions and as-recorded ground motions was observed when this ratio equals 0.5. In most cases, an increase in seismic demand was observed in the absence of fling-step pulse.

1. Introduction

Some previous earthquakes such as Landers (USA, 1992), Northridge (USA, 1994), Kocaeli (Turkey, 1999), Chi-chi (Taiwan, 1999), Bam (Iran, 2003), and Tohoku (Japan, 2011) have shown distinct characteristics rather than far-field ground motions. Such earthquake records which are near the ruptured fault are significantly different from those observed further away from the causative fault. The evidences show two distinctive characterizations of near-fault ground motions which are: **a.** large velocity pulse and **b.** large fault displacement. Koketsu and Miyake [1] have performed a seismological study on long-period ground motions. Motions with long-period pulses can exhibit two major consequences: “fling-step” or “forward directivity” which depend on tectonic displacement in the fault and rupture mechanism and also slip direction relative to the site. In general, forward directivity and permanent tectonic displacement are the two main causes for the velocity pulses observed in near-fault regions [2–4]. These effects can bring about severe structural damage [5–10]. Heaton et al. [11] investigated the potential damaging effects of a thrust earthquake of Mw 7.0 on high-rise and base-isolated structures via a case study. The strong ground motions which were used in the study were achieved through a simulation of the fault slip; the motions in the vicinity of faults were defined by large-ground velocities and large displacement pulses. Various studies on characterization of pulse-type ground motions and their effects on structures can be found in some previous studies (e.g. [12–21]). Their studies imply that near-fault ground motions can be represented by equivalent pulse models. Also valuable studies including such effects on the seismic behavior of structures have been carried out by some researchers [22–27]. Taniguchi et al. [28] showed that the energy balance approach plays an important and essential role in the derivation of the solution of an elastic–plastic critical response. These near-source consequents will cause the great majority of the seismic energy from the rupture to reach a single coherent long-period pulse of motion. The is caused by accumulation of energy at faults and their continuous rupture [29]. Also, such kinds of ground motions may generate high demands that persuade the structures to dissipate the input energy with few large displacement excursions. Failures of many structures (even modern engineered ones) observed within the near-fault region in Northridge earthquake (1994) have shown the vulnerability of existing buildings subjected to pulse-type ground motions [23]. In spite of various investigations on forward directivity, the effect of fling-step on the response of structures has not been widely studied. The need to investigate the effect of fling-step (static offset or permanent

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https://doi.org/10.1016/j.soildyn.2018.08.023
Received 7 March 2018; Received in revised form 19 June 2018; Accepted 16 August 2018
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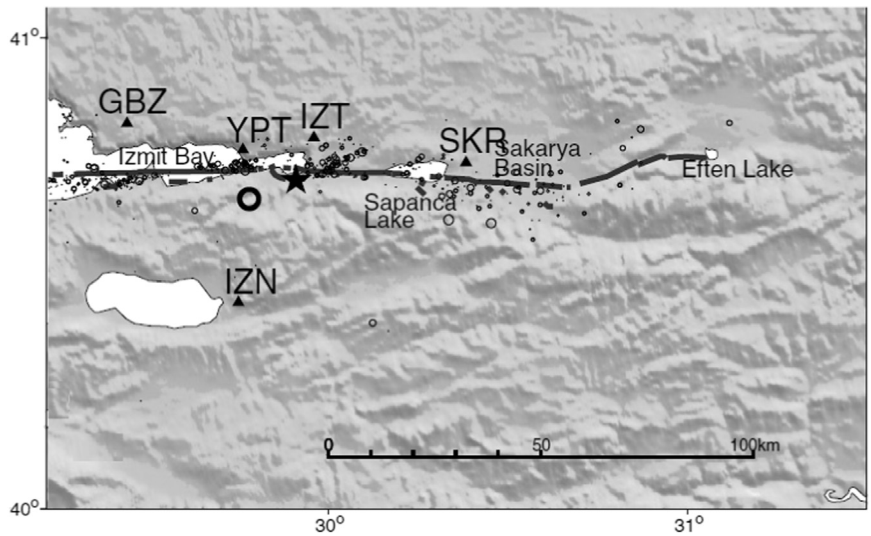

Fig. 1. Shematic alignment of Kocaeli EQ, (adopted from Sekiguchi and Iwata [46]).

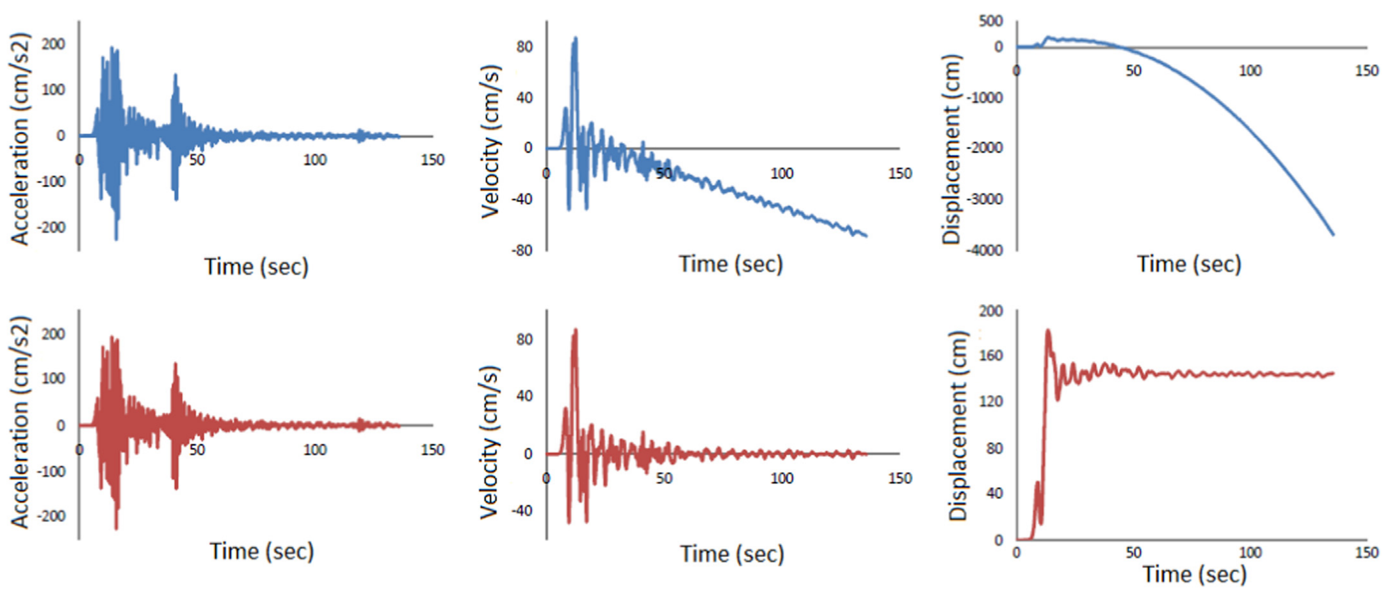

Fig. 2. Raw acceleration versus the corrected one (blue: raw; red: corrected). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

displacement) on the buildings is obvious. Because of lack of near-fault recorded ground motions having fling-step, we first focused on the earthquake simulation technique in near-fault region; thereafter, the generated ground motions were used as the input of nonlinear time history analysis for structural performance study. In this study, a method was developed to find seismological parameters of Kocaeli earthquake using inversion solution technique, Multi Objective Genetic Algorithm (MO-GA) and Theoretical-based Green's Function (TGF) procedure. *Response spectra*, *Multi-taper spectra* and *Permanent displacement* of recorded and generated accelerograms were considered as the comparison criteria. The first two mentioned criteria are of high importance for compatible ground motions simulation for structural investigations. It is worth mentioning that the goals and criteria for ground motions simulation may vary in different studies. The focus might be on seismological aspects mostly (e.g. [30–32]) or on structural engineering aspects (e.g. [33,34]). The use of *Multi-taper spectra* in this study reduces the biased estimates on the account of spectral leakage for seismic waveforms. The accuracy of obtained seismological parameters has been verified at other station. Afterwards, many accelerograms were generated at obligatory near stations having fling-step effect. With this technique, the problem of the lack of near-fault earthquakes can be partially overcome. The effect of fling-step was removed from the accelerograms by the method introduced in Section (3.1). Three 3-, 9- and 20-story steel moment frames, representative of various buildings were modeled in Opensees [35] and subjected to the generated ground motions. The effects of the aforementioned ground motions (with and without fling-step) on the structure and its corresponding performance were investigated. To be sure that the generated ground motions can be well used in case of lack of as-recorded data, the studied structures were also subjected to 7 well-known earthquakes with considerable fling-step effect and compared with the case of generated ground motions.

2. Ground motion generation; Techniques and procedures

Chapter 16 of ASCE-7 governs the selection of the ground motions for analysis of new buildings and requires recordings that meet specified criteria. If a sufficient number of recordings cannot be found, it

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