Engineering Structures 33 (2011) 1338–1347

Contents lists available at ScienceDirect

Engineering Structures

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

Effects of soil–foundation–structure interaction on seismic structural response via robust Monte Carlo simulation

M. Moghaddasi [a,*], M. Cubrinovski [a], J.G. Chase [b,1], S. Pampanin [a], A. Carr [a]

[a] Department of Civil and Natural Resources Engineering, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand

[b] Mechanical Engineering Department, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand

ARTICLE INFO

Article history:
Received 21 December 2009
Received in revised form
8 January 2011
Accepted 12 January 2011
Available online 12 February 2011

Keywords:
Monte Carlo simulation
Soil–foundation–structure interaction
Equivalent linear model
Ground motion
Uncertainties

ABSTRACT

Uncertainties involved in the characterization and seismic response of soil–foundation–structure systems along with the inherent randomness of the earthquake ground motion result in very complex (and often controversial) effects of soil–foundation–structure interaction (SFSI) on the seismic response of structures. Conventionally, SFSI effects have been considered beneficial (reducing the structural response), however, recent evidence from strong earthquakes has highlighted the possibility of detrimental effects or increase in the structural response due to SFSI. This paper investigates the effects of SFSI on seismic response of structures through a robust Monte Carlo simulation using a wide range of realistic SFS systems and earthquake input motions in time-history analyses. The results from a total of 1.36 million analyses are used to rigorously quantify the SFSI effects on structural distortion and total horizontal displacement of the structure, and to identify conditions (system properties and earthquake motion characteristics) under which SFSI increases the structural response.

1. Introduction

The complexity of the seismic soil–foundation–structure interaction (SFSI) problem [1–4] accompanied with the inherent uncertainty in SFS system parameters and earthquake motion characteristics has resulted in a somewhat controversial interpretation of SFSI effects on the structural seismic response. Traditionally, the effects of inertial SFSI are explained by a period lengthening and increased damping of the system [5–7], and on this basis, it has been concluded and implemented in design codes [8,9] that including SFSI in the analysis has a beneficial effect (or reduction) in the seismic response of structures. However, it has been also argued that the perceived beneficial role of SFSI is an oversimplification of the reality and indeed is incorrect for certain soil–structure systems and earthquake motions [10–14]. In addition, it has been recently shown that uncertainties arising from structural and geotechnical properties as well as input loading play an important role in performance prediction of seismically excited structures [15–18]. In particular, for systems considering soil–structure interaction, the effect of uncertainty on structural demand is even more pronounced [19–23].

In this context, the current study presents an effort for a comprehensive and systematic investigation of the effects of SFSI on the seismic response of structures. A robust statistical analysis utilizing Monte Carlo simulation was conducted using idealized soil–shallow foundation–structure models following the current design practice [24]. Emphasis was given to a random selection of model parameters in a typical SFS system, such that a wide range of soil, foundation and structural properties were considered and a large number of widely varying but representative and realistic SFS models were generated. In these models, the superstructure is assumed to be a linear single-degree-of-freedom (SDOF) system with 5% equivalent viscous damping. The reasons behind choosing a linear structural model were: (i) to follow the approach that has been adopted in building codes for developing design spectrum and defining the seismic forces acting on the structure; and (ii) to systematically address the problem and evaluate the SFSI effects, starting with a more simple linear behaviour. Note that in the second phase of this study which is reported elsewhere [25], the SFSI effects on structural nonlinear response were considered. The soil–foundation part is represented by an equivalent linear cone model [26] taking into account nonlinearity in the soil stress–strain behaviour via the equivalent linear approach [27]. It should be acknowledged that the adopted soil–foundation element does not cover the extreme material nonlinearity or geometrical nonlinearity (uplift or sliding) since they are beyond the scope of this study. The generated SFS models were excited by an ensemble of 40 earthquake ground motions recorded on stiff/soft soils to account for variability in the input motion. Thus soil, SFS system and earthquake ground motion variability are considered in this study.

* Corresponding author. Tel.: +64 3 364 2250.
E-mail address: masoud.moghaddasi@pg.canterbury.ac.nz (M. Moghaddasi).
1 Tel.: +64 3 364 2596.

0141-0296/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2011.01.011