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Soil–pile-bridge structure interaction in liquefying ground using shake table testing

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ABSTRACT

The evaluation of seismic pile response is particularly useful for geotechnical engineers involved in the design of foundations in liquefying site. Shake table testing was performed to study the dynamic interactive behavior of soil–pile foundations in liquefying ground under different shaking frequency and amplitude. The soil profile consisted of a clayey layer over liquefiable sand over clay. The model was tested with a series of El Centro earthquake motions with peak accelerations ranging from 0.15*g* to 0.50*g*, and time step from 0.006 to 0.02 s. Representative data, including time histories of accelerations and excess pore pressure ratios that characterize the important aspects of soil–pile interaction in liquefying ground are presented. The shaking frequency has no significant effect on the magnitudes of excess pore pressure ratio, ground and pile accelerations and pile bending moments. Excess pore pressure ratio, ground acceleration and pile acceleration, and pile bending moment largely depend on the shaking amplitude.

1. Introduction

Pile foundations are used extensively to support bridges and other structures. A number of pile foundations have been found damaged or failed during last major earthquakes. The key causes of the damage and failures of pile foundations in earthquakes are liquefaction and lateral ground movements due to liquefaction. The observed damage and cracking to pile foundations often occurs at the upper and lower boundaries of the liquefied soil layer where there is a sudden change in soil properties, or at the connection with the pile cap. More damages are liable to happen to piles when there is a non-liquefied soil layer overlying a liquefiable soil layer. These damages and failures of piles suggest the importance of seismic response analyses of pile foundations in layered liquefying soils and inadequacy of current seismic design methods for pile foundations. Therefore, efforts are needed to improve our understanding of the dynamic behavior of pile foundations and our design analysis methods.

The soil–pile-structure interaction in liquefying ground is an extremely complex process involving inertial interaction between structure and pile foundation, kinetic interaction between piles and soils, seismically induced pore-water pressures and the non-linear response of soils to strong earthquake motions. In particular, field investigation and subsequent analyses after the earthquake confirmed that kinematic effects arising from the ground movement as well as inertial effects from superstructure had significant impact on the damage to pile foundations. Besides using theoretical means, the soil–pile-structure interaction (SPSI) has also been investigated using the centrifuge test [1–6] and shaking table tests. Kagawa and Kraft [7] performed the shake table testing on dynamic response of piles in saturated sand, excited by sine wave, and found the stiffness of pile–soil-structure system decreased gradually. Mizuno and Liba [8] investigated seismic building-pile–soil interaction using shake table testing. Sasaki et al. [9], Tokida et al. [10] and Ohtomo and Hamada [11] investigated lateral spreading of liquefied soil on pile group using shake table testing. Liu and Chen [12] studied the behavior of pile foundation in liquefiable soil by conducting shake table testing on pile group in saturated sand. Miyajima et al. [13] conducted shake table testing on liquefaction-induced large ground motion and found that the mean sloping displacement of pile depends on the soil layer thickness and ground slope. Hamada et al. [14] investigated the effects of liquefaction-induced ground displacement on in-ground structure. Kagawa et al. [15] performed shaking table tests on piles in liquefying sand. Meymand [16] studied non-linear soil–pile-superstructure interaction in soft clay using shaking table scale model test. Towhata et al. [17] investigated subgrade reaction of pipe embedded in sandy liquefied subsoil. Tokimatsu and Suzuki [18] studied the effects of pore pressure response around pile on horizontal subgrade reaction during liquefaction and lateral spreading in large shaking table tests. Chau et al. [19] performed non-linear seismic soil–pile-structure

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