

Effects of Layer Thickness and Density on Settlement and Lateral Spreading

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Abstract: This paper presents the results of six large-scale centrifuge model tests that were performed to study the effect of relative density and thickness of sand layers on the amount of settlement and lateral spreading. The models included a “river” channel with clay flood banks underlain by layers of loose and dense sand of variable thickness, and a bridge abutment surcharge on one of the banks. The model container was tilted to provide an overall slope to the model. Each model was subjected to three or four significant ground motion events, which were obtained by scaling the amplitude of recordings of the Kobe (1995) and Loma Prieta (1989) earthquakes. Several measurements of acceleration, pore water pressure, settlement, and lateral movement are presented. The liquefaction potential index and a deformation index, which combine the influences of depth, density, and layer thickness, were found to correlate reasonably well with liquefaction induced settlements and lateral deformations for the range of models tested and indicate that centrifuge results are consistent with field observations.

DOI: 10.1061/(ASCE)1090-0241(2004)130:6(603)

CE Database subject headings: Centrifuge model; Earthquakes; Liquefaction; Clays; Sand; Soil deformation; Soil settlement; Thickness.

Introduction

Earthquake field case histories in the last decade such as Kobe, Taiwan, and Turkey demonstrate the devastating effects of soil liquefaction and the associated settlements and lateral spreading, but the detailed documentation of field case histories of soil liquefaction is limited. Centrifuge model tests are therefore a useful source of well documented data to study soil liquefaction problems (Schofield 1981; Arulanandan and Scott 1993; Dobry et al. 1995; Kutter 1995).

Tokimatsu and Seed (1987) produced a chart that allows the liquefaction induced volumetric strains of saturated sands to be estimated by considering the standard penetration test (SPT) $(N_1)_{60}$ values and an equivalent cyclic stress ratio (CSR) of $M = 7.5$ earthquake. Ishihara and Yoshimine (1992) produced another approach to estimate the volumetric strains caused by the liquefaction using factor of safety against liquefaction and either the maximum cyclic shear strain, relative density, SPT resistance or, cone penetration test (CPT) resistance.

Bartlett and Youd (1992) introduced an empirical relationship to estimate the lateral spread displacements at liquefied sites.

These equations were developed from multilinear regression (MLR) of case history data set. The modified MLR equations were later proposed by Youd et al. (1999) to estimate the lateral displacements for both free face conditions and ground slope conditions. These equations consider the effect of thickness of the sand layer as the cumulative thickness of saturated granular layers with corrected SPT blow count, $(N_1)_{60}$, less than 15, but do not consider the combined effect of thickness and relative density.

This paper presents the results of six large-scale highly instrumented centrifuge model tests. The primary purposes of this series of tests is to systematically study the effects of relative density and thickness of the liquefying sand layer on the amount of settlement and lateral spreading of liquefied soils. Two tests were conducted to obtain information on the effects of ground motion and slope of the floodplain. Experimental results were transformed from model units to prototype units by using the scaling laws applicable to centrifuge modeling. Scaling laws for centrifuge modeling were described in detail by Schofield (1981) and Kutter (1995).

Model Details

The models represented a hypothetical bridge site consisting of a river and its flood banks. Nevada Sand and San Francisco Bay Mud were used to construct the models. Models were subjected to different scaled versions of the earthquake acceleration time histories from 1995 Kobe (from 80 m deep sensor in the vertical array at Port Island) and 1989 Loma Prieta (Santa Cruz record). All the models were tested at 30 g on the large geotechnical centrifuge at Univ. California Davis. Unless otherwise indicated, the model configurations and results are presented using prototype-scale units.

Fig. 1 and Table 1 define the model configurations. The models consisted of a dense sand layer at the bottom, overlain by a

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Note. Discussion open until November 1, 2004. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on January 3, 2002; approved on August 26, 2003. This paper is part of the *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 6, June 1, 2004. ©ASCE, ISSN 1090-0241/2004/6-603-614/\$18.00.