Cyclic Pore Pressure Generation, Dissipation and Densification in Granular Mixes

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ABSTRACT

Knowledge of cyclic load induced pore pressure generation, post-liquefaction dissipation and volumetric densification characteristics of sands, silty sands, and silts are important for the analysis of performance of loose saturated granular deposits in seismic areas. This article presents results from an experimental study of these characteristics for such soils containing 0 to 100% non-plastic silt. Pore pressure generation characteristics are studied using undrained cyclic triaxial tests. Pre- and post-liquefaction compressibility and coefficient of consolidation, and post-liquefaction volumetric densification characteristics are determined from consolidation data prior to cyclic tests and pore pressure dissipation tests following undrained cyclic tests. Effects of fines content on these characteristics compared to those of clean sands are examined in the context of intergranular void ratio and intergranular contact density concepts.

Keywords: Compressibility, Earthquake, Intergranular Void Ratio, Liquefaction, Sand, Silt, Silty Sand

INTRODUCTION

Soil liquefaction and its post-liquefaction response have been of great interest in geotechnical engineering for more than three decades. Liquefaction induced failures include landslides, sand boils, cracks, excessive ground settlements, lateral spreading, and foundation failures. Pore water pressure builds up in loose saturated soil deposits due to cyclic shearing. At the same time, dissipation and redistribution of this shear induced pressure take place at a rate depending on the hydraulic conductivity and volume compressibility characteristics of the soil deposit and drainage conditions. When the rate of pore pressure generation and build up is significant, a non-plastic soil temporarily loses a large portion of its strength, which may lead to liquefaction and breakdown of the soil structure. Pore pressure dissipation will usually be accompanied by rearrangement of particles, reconsolidation and a reduction in volume of voids, hence settlement of ground surface. Current knowledge on pore pressure generation and post-liquefaction dissipation and volume

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change characteristics of granular soils rely primarily on data from clean sands (Ishihara & Yoshimine, 1992; Lee & Albaia, 1974; Pyke et al., 1975; Silver & Seed, 1971a,b; Seed et al., 1976; Tatsuoka et al., 1984; Tokimatsu & Seed, 1984, 1987; Yoshimi et al., 1975). However, recent earthquake case histories indicate that sites containing a significant percentage of fine grains, mostly non-plastic, also liquefy due to seismic loading (Seed et al. 1983, Youd et al. 2001). Only a limited amount of research information is available for silty soils. Therefore, not surprisingly, evaluation of liquefaction characteristics of silty soils has recently attracted attention of researchers. Recently there has been advances in the understanding of the effects of silt content on monotonic and cyclic strength and liquefaction resistance of silty soils and to a lesser extent on post-liquefaction response of silty soils (Andrews & Martin 2000, Chang 1990, Georgiannou et al. 1990, 1991, Ishihara 1993, Koester 1994, Pitman et al. 1994, Shenthan 2001, Singh 1994, Thevanayagam et al. 2001, Thevanayagam and Martin 2002, Thevanayagam et al. 2002, Thevanayagam et al. 2007a-b, Vaid 1994, Yamamuro & Lade 1998). Data on post-liquefaction characteristics of such soils are scarce.

This article presents results from an experimental study of pre- and post-liquefaction characteristics of non-plastic sand-silt mixes at silt contents from 0% to 100% by weight, and three natural non-plastic silts. Undrained cyclic triaxial tests followed by dissipation of cyclic-induced pore pressures were carried out in order to determine pore pressure generation, pre- and post-liquefaction compressibility, pre- and post-liquefaction coefficient of consolidation, and post-liquefaction densification characteristics of these soils. Findings from this study are summarized. The influence of silt content on these characteristics is examined in the context of intergranular void ratio and intergranular contact density concepts (Vaid 1994, Thevanayagam et al. 2002, Thevanayagam 2007a).

**EXPERIMENTAL PROGRAM**

**Materials**

The experiments in this study involved several granular mixes prepared by mixing Ottawa Silica Sand (OS-F55, US Silica Company, Illinois) with a non-plastic silt (crushed silica fines Sil-co-Sil #40) at silt contents of (a) 0%, (b) 15%, (c) 25%, (d) 40%, (e) 60%, and (f) 100% fines by dry weight. The dry soils were mixed thoroughly until there was no obvious color difference. A limited number of tests were also conducted on three remolded natural silts from New Jersey; Los Angeles, CA; and San Fernando, CA, USA. Figure 1 shows the gradation data. Table 1 summarizes the index properties of the Ottawa sand-silt mixtures and the three natural silts. The New Jersey silt was non-plastic sandy silt, and the Los Angeles, CA silt was also non-plastic sandy silt or very low plasticity material classified as ML according to USCS classification. The San Fernando, CA silt was classified as ML-CL, a low plasticity silt material.

**Specimen Preparation**

The experiments were conducted on relatively large cylindrical specimens of 155 mm in height and 75 mm in diameter prepared using Moist Tamping Method. Each specimen was prepared at a different final void ratio. A known weight of dry solids required to reach the target void ratio was weighed and mixed thoroughly with water at a water content of about 5%. The soil was divided into four equal portions. Each portion was poured into a mold mounted on a triaxial cell, and tamped gently using a wooden rod until the height corresponding to the target void ratio was achieved. The specimen was then percolated with CO$_2$ and saturated with deaired water using back pressure saturation. The back pressure was increased gradually while maintaining the effective confining pressure at 15 to 20 kPa. This process was continued until the $B (=\Delta u/\Delta \sigma_c)$ factor exceeded 0.95. Following
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