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Contraction and pore pressure behavior of a silty sand deposit subjected to an extended shaking history

W. El-Sekelly[a,d,*], V. Mercado[b], T. Abdoun[c], R. Dobry[c], A. Sepulveda[b]

[a] Dept. of Structural Eng., Mansoura University, Mansoura, Egypt
[b] Dept. of Civil and Environmental Eng., Universidad del Norte, Barranquilla, Colombia
[c] Dept. of Civil and Environmental Eng., Rensselaer Polytechnic Institute, 110 8th Street, JEC 4049, Troy, NY 12180, United States
[d] New York University Abu Dhabi, Abu Dhabi, UAE

ABSTRACT

The paper presents the implementation of an identification technique to characterize the pore pressure behavior of a silty sand centrifuge deposit subjected to more than 70 seismic shakings with full pore pressure dissipation between shakings. The seismic shakings were meant to crudely simulate the seismic history of field deposits in some very seismically active zones in California. The technique estimates shear stresses and strains based on acceleration and pore pressure recorded using a vertical array of sensors in the deposit. A constitutive model was implemented to identify optimal material parameters controlling the contractive behavior of the soil based on the recorded response of all shakings. It was found that the seismic history of soil deposits plays an important role in determining the contractive tendency of the material, significantly influencing the pore pressure response of the deposit. That is, the seismic history can reduce or increase the resistance of a deposit to contraction and liquefaction.

1. Introduction

Liquefaction of sandy soils has caused devastating consequences, as observed by both researchers and practitioners after recent earthquakes in Haiti, Chile, Japan and New Zealand. Liquefaction potential evaluation is mainly based on the simplified procedure suggested by Seed and Idriss [1] which was found to work well for young sandy soils. It has the advantage of being easy to use, as it depends mainly on the maximum ground surface acceleration, a_{max}.

Researchers have attempted to simulate earthquakes experimentally by using physical models that range from small to large and full scale. Small scale experiments, while relatively easy and generally inexpensive, may not yield the best simulation of the liquefaction mechanism that happens in the field, due to the strong dependency of the soil properties on confining pressure. On the other hand, field or full scale experiments are more representative but very expensive. Centrifuge testing has the advantage of closely representing field performance by achieving realistic confining pressures while being relatively inexpensive. Dobry et al. [2] confirmed that centrifuge testing produces realistic results in agreement with the liquefaction response of recent artificial sandy fills in the field subjected to the Loma Prieta 1989 earthquake in California.

Most of the research work performed so far deals with recently deposited fills and neglect the effect of the shaking history of soil deposits. El-Sekelly [3] found that previous shaking history has a significant effect in changing the resistance of sandy deposits to liquefaction. This was confirmed by field studies as well as an extensive experimental program aimed at capturing the effect of shaking history on the behavior of clean and silty sand deposits.

The recent collection of data from seismically excited soil deposits, however, needs further interpretation in order to broaden the understanding of the mechanisms of the dynamic behavior of soil leading to pore pressure build up. In this regard, several researchers have proposed system identification techniques to characterize soil and pore pressure behavior of excited saturated soil deposits based on the recorded acceleration and pore pressure response. Yang and Elgamal (2003), for instance, presented an unconstrained optimization analysis for the calibration of a multi-surface plasticity soil model used to simulate the coupled soil behavior and pore pressure buildup of a centrifuge liquefaction experiment. Groholski et al. [4] applied a self-learning inverse analysis algorithm (SelfSim), that can learn and extract both soil behavior and pore pressure response from recorded events using neural networks. More recently, Mercado et al. [5] presented an identification technique that incorporates pore pressure records, as well as shear stress and strain estimates of a soil deposit subjected to dynamic excitation, in order to characterize the coupled shear–volume soil response that can lead to significant generation of pore water pressure. In their work, the authors related the pore pressure generation to the ratio of the volumetric to deviatoric plastic strain rate, controlled by a single calibration parameter.

* Corresponding author at: Dept. of Structural Engineering, Mansoura University, Elgomhorya Street, Mansoura 35516, Egypt.
E-mail address: waleed.elsekelly@gmail.com (W. El-Sekelly).

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The research work presented herein analyzes the rate of contraction and pore pressure generation of a deposit, taking into account the effect of shaking history through the implementation of the identification algorithm proposed by Mercado et al. [5]. The paper initially discusses the significance of shaking history on the pore pressure behavior of soil deposits, as observed by researchers over the years. The paper then describes a centrifuge experiment performed specifically to study the shaking history effect, also known as preshaking effect. Results of this centrifuge experiment are then subjected to the identification analysis in order to extract information on the contraction tendency, pore pressure generation, and damping behavior of the deposit.

1.1. Effect of preshaking

Preshaking can be defined as previous straining of soil deposits due to the occurrence of past earthquakes [3]. It has been observed by several researchers that seismic history has a significant effect on the subsequent liquefaction potential of sandy soil deposits. Dobry et al. [6] and El-Sekelly et al. [7] studied case histories in California and concluded that the geologically recent, natural silty sands in the Imperial Valley of Southern California have increased liquefaction resistance because of their intense preshaking history. Other researchers have observed that natural soil deposits are more resistant to liquefaction than artificial fills due to both aging effects as well as the effect of preshaking [6,8–14].

On the other hand, several researchers have also observed that if a soil deposit is subjected to a very strong shaking that causes full liquefaction, the resistance of the deposit to liquefaction is reduced in subsequent events. Andrus et al. [15] observed that the 200,000-year old Ten Mill Hill sand beds in South Carolina behave as geologically young deposits. Andrus et al. attributed this behavior to the very strong 1886 Charleston earthquake which had caused extensive liquefaction in the previous century. They concluded that full liquefaction resets the liquefaction behavior of sandy deposits to what it had been immediately following deposition. Yasuda and Tohno (1988) observed a similar behavior in the northern part of Tohoku district, Japan due to the 7.7 magnitude earthquake in 1983. They observed that the liquefaction damage due to the aftershocks were significant and attributed that to the disturbance of the deposit because of the original 1983 earthquake event that caused extensive liquefaction of the deposit. Another example is the Canterbury Earthquake Sequence in 2010–11 in Christchurch, New Zealand, where a main shock was followed by thousands of aftershocks ranging from very small magnitudes to M_w = 7.1. Up to ten of these events caused liquefaction, and some sites experienced repeated liquefaction, with increased severity of liquefaction in some subsequent events [16–20].

Several researchers have used small scale experiments to study the effect of preshaking and extensive liquefaction. Seed et al. [21] presented the results of shaking table tests representing 5 earthquake events of magnitude 5 with full pore water pressure dissipation between events. The events caused excess pore pressure short of liquefaction which gradually decreased in subsequent earthquake events. By the end of the experiment, the liquefaction resistance had increased by 50%, despite the negligible change in relative density. Finn et al. [22], on the other hand, presented the results of cyclic triaxial and direct simple shear tests in which the soil was subjected to high strain loading causing full liquefaction. Finn et al. found that full liquefaction caused partial or full loss of liquefaction resistance of the deposit, with the effect increasing with larger strain amplitude.

El-Sekelly [3] performed an extensive study on the effects of preshaking using centrifuge and large scale experiments. The following section briefly describes one of the experiments which crudely simulates the seismic history of the Wildlife site in the Imperial Valley of Southern California. The rest of the paper focuses on the analysis and parameter identification of the centrifuge experiment.

1.2. Centrifuge experiment

The centrifuge experiment presented herein was performed in the 2D laminar container shown in Fig. 1. The laminar container has the

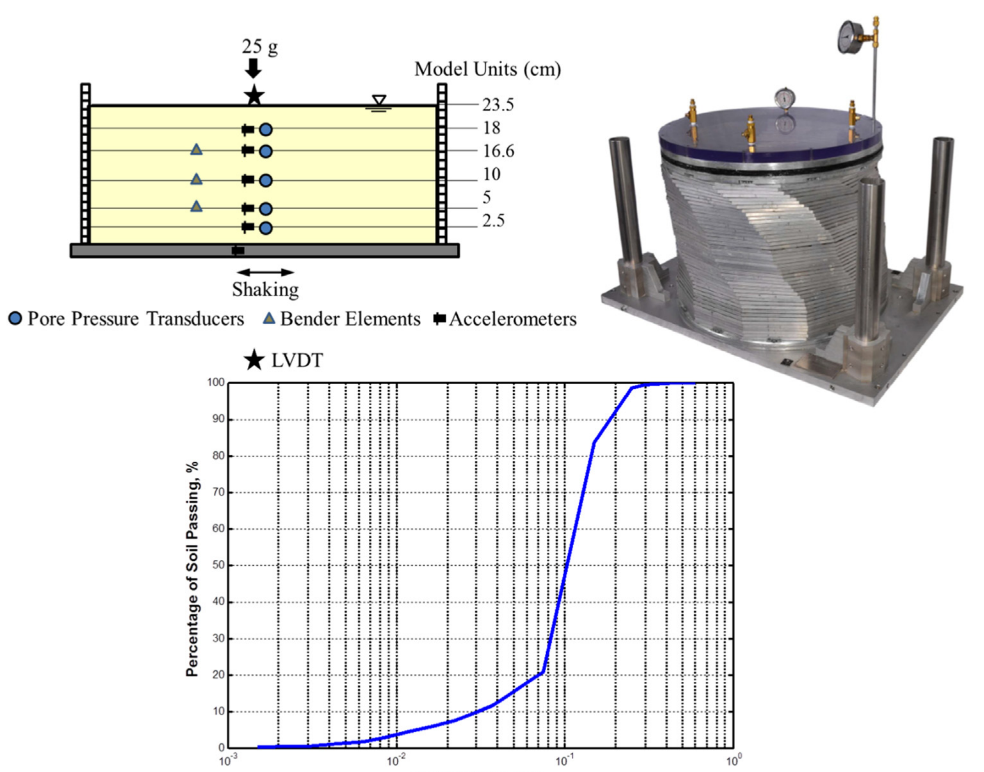

Fig. 1. Experiment setup, 2D laminar container and grain size distribution of sand.