Journal of Rock Mechanics and Geotechnical Engineering xxx (2018) 1–11

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full Length Article

A comparative study between gravel and rubber drainage columns for mitigation of liquefaction hazards

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ARTICLE INFO

Article history:
Received 31 July 2017
Received in revised form
19 December 2017
Accepted 5 March 2018
Available online xxx

Keywords:
Liquefaction
Soil improvement
Drainage columns
Shaking table test

ABSTRACT

Liquefaction is one of the most destructive natural hazards that cause damage to engineering structures during an earthquake. This study aims to examine the effect of rubber and gravel drainage columns on the reduction of liquefaction potential of saturated sandy soils using a shaking table. Experiments were carried out in various conditions such as construction materials, different arrangements and diameters of drainage columns. Effects of the relative density and the input motion on the base test were investigated as well. The results demonstrate that rubber drainage columns have slightly better performance compared to gravel drainage columns at high relative density and high input acceleration. Soil improvement using gravel drainage columns, which leads to reduction in liquefaction effects at moderate input acceleration and low relative density, is a more effective method than that using rubber drainage columns. By increasing the number and diameter of gravel and rubber drainage columns, deformations due to liquefaction are reduced. The drainage rate of gravel drains is higher than that of rubber drains after shaking. Totally, the outcomes indicate that densification is the most important factor controlling liquefaction.

1. Introduction

Liquefaction of sandy soils is one of the challenging issues in geotechnical engineering. Whenever loose saturated granular soils are exposed to cyclic loadings, they tend to decrease in volume, which produces an increase in their pore water pressures and consequently a decrease in shear strength. One of the methods to mitigate the damaging effects of earthquake-induced liquefaction is to provide rapid dissipation of excess pore pressures applying vertical drains through the liquefiable materials. When the pore pressures dissipate rapidly, the effective stress will not be significantly reduced, and liquefaction will not occur. Applying drains with high permeability leads to foresaid result.

Seed and Booker (1977) introduced drainage techniques employing stone columns (gravel drains). They carried out field research using the gravel drainage system to prevent liquefaction of the soil under structural engineering. Outperformance of the drainage columns was proven during the earthquakes in Japan in the 1990s. Then prefabricated vertical drains (PVDs) have been used for liquefaction remediation (JGS, 1998).

Sasaki and Taniguchi (1982) conducted shaking table tests to examine the effects of partial-depth drains on a roadway. In their particular configuration, they indicated that pore pressures remained elevated for a longer period when their drains did not reach the model base compared to that when they were full-depth. The model in this case was very shallow and liquefaction would be anticipated at the base in the unremediated model.

The use of stone columns in silt deposits was examined by Adalier et al. (2003), who found that the primary effect was to increase the stiffness of the soil mass during cyclic loadings, leading to a reduction in the shear strains and thus the generation of excess pore water pressure.

Brennan and Madabhushi (2006) examined the liquefaction modification by vertical drains with different depths of penetration applying centrifuge tests. The results showed that deeper soils benefit from the presence of drains more quickly. They also observed that the additional burden placed on the deep penetrating drains prevented them from operating efficiently. Moreover,

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Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

https://doi.org/10.1016/j.jrmge.2018.03.008

they indicated that a standard design chart may overpredict an improvement in drain performance.

Geng et al. (2012) presented analytical methods for a single vertical drain with vacuum and time-dependent preloading in membrane and membraneless systems. These methods enhanced the accuracy of estimating pore water pressure dissipation and associated settlement. Howell et al. (2012) presented centrifuge modeling of PVDs for liquefaction remediation. The results revealed that drains were effective in expediting the dissipation of excess pore water pressures and decreasing deformations. Wang et al. (2015) showed that soil improvement with stone columns has a significant influence on the mitigation of liquefaction hazards. Rasouli et al. (2016) examined liquefaction modification by drainage pipes and their combination with sheet-pile walls in different groundwater levels utilizing shaking table tests. The results indicated that the settlement of the structure cannot be reduced significantly unless there is a perfect nonliquefied layer under the foundation of structure. Huang et al. (2016) demonstrated that the effectiveness of gravel columns for mitigation of soil liquefaction during an earthquake depends on the following three aspects: (1) the densification of the surrounding soils, (2) drainage along the stone column, and (3) reduction in the total cyclic shear stress of the soil (because the cyclic shear stress is partially shared by the stone column). Salem et al. (2017) indicated that considering the densification and stiffening effects considerably improves the assessment of liquefaction potential of reinforced soil by drainage columns.

Miranda et al. (2017) studied the influence of the geotextile encasement on the behavior of soft soils improved by fully penetrating encased columns. Their results illustrated that pore pressures dissipate faster in samples with encased stone columns compared to those with non-encased columns, and the reduction of settlements is higher when the column is encased.

Waste material expulsion is one of the environmental issues faced in many countries. Accumulation of non-degradable polymeric materials in landfills has serious environmental consequences. Only a few percentages of scrap tires are burned to produce electricity. Efforts to find new ways of soil improvement and reinforcement have drawn attention of researchers towards the use of new recycled materials like scrap tires derivatives.

Derivatives of scrap tires have different applications in civil engineering such as reinforcing soft soil (Anvari et al., 2017; Yadav and Tiwari, 2017), as a drainage layer in landfills (Kaushik et al., 2016), as filler materials (Assadollahi et al., 2016), as lightweight material for backfilling in retaining structures (Shrestha et al., 2016), for vibration isolation (Hadad et al., 2017), and in reinforced concrete (Guo et al., 2017). In spite of the widespread utilization of tire chip in geotechnical engineering, its application to liquefaction mitigation is not yet fully developed.

Bahadori and Farzalizadeh (2018) examined the effects of adding scrap tires on the liquefaction potential and the dynamic properties of loose saturated sandy soil. Their results demonstrated that excess pore water pressure and settlement due to liquefaction significantly decrease with increasing percentage of tire powders. In addition, they observed that the mean damping ratio and shear modulus increase in the reinforced models.

Based on the literature review, it appears that further studies are required to assess the performance of soil improved with rubber drains on reducing liquefaction potential. In this paper, the shaking table test results for improvement of sand with rubber and gravel drainage columns are presented.

2. Physical model

2.1. Shaking table and instrumentation

The shaking table and the positions of utilized instruments are demonstrated in Fig. 1. The container has inner dimensions of 2000 mm × 500 mm × 700 mm (length × width × height). A plastic plate was rigidly fixed and sealed carefully at the center of the container to separate improved models with gravel and rubber drains. The shaking table is designed to resonate at a frequency of around 2 Hz. The input shaking in all tests was a one-dimensional (1D) and harmonic sinusoidal wave. The dynamic loadings used for this study were not meant to be representative of actual earthquake ground motions. Contrary to real earthquakes, the applied vibration was 1D, of approximately uniform amplitude, and constant frequency. These loading conditions allowed for a good observation of the dynamic behavior of the materials and relative comparisons of their responses. Similar types of loadings have been frequently used in other liquefaction researches (Pépin et al., 2012; Bahadori and Manafi, 2015).

Different types of transducers were used to measure acceleration, pore water pressure, and displacement at different positions. The pore pressure transducers were fixed in a spot to monitor the pore water pressure in exact locations. The acceleration transducers were fixed on the base to avoid tilting during test and were free to move with the adjacent soil. The linear variable differential transducers (LVDT) LVDT1 and LVDT2 were installed at the ground surfaces of samples, improved with rubber drainage columns and gravel drainage columns, respectively.

The shaking table container is rigid; it is obvious that boundary conditions could affect the test results. Thus, a 2-cm thick absorbing layer of foam was employed in shaking direction of the container (Lombardi et al., 2015). Moreover, an attempt was made to reduce its effect by band filtering data (acceleration raw data) to eliminate some of the erroneous data.

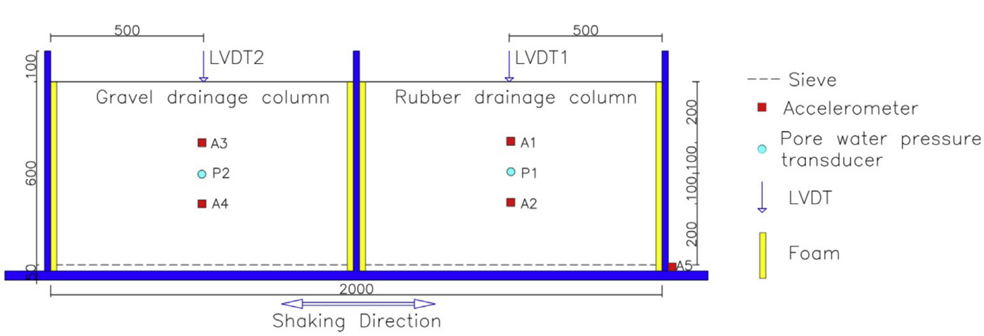

Fig. 1. Model and instrumentation (dimension: mm).