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Centrifugal modeling of a composite foundation combined with soil–cement columns and prefabricated vertical drains

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Abstract

A new soft ground improvement method is proposed combined with soil–cement columns and prefabricated vertical drains (PVDs) to increase the bearing capacity and to accelerate the consolidation process of soft soil. A series of centrifugal modeling tests is conducted on an embankment on a composite foundation, combined with soil–cement columns and PVDs. The effects of column spacing and column length on the behavior of the composite foundation are considered. For comparison, two centrifugal modeling tests are conducted on the embankment, one involving only soil–cement columns and the other involving only PVDs. The embankment loads are applied in four stages using a hydraulic jack mounted on top of a strongbox. Scaled-down model columns and a kind of wool strings are used to simulate the prototype soil–cement columns and PVDs, respectively. The load sharing ratio, defined as the proportion of external loads carried by the columns, is used to evaluate the load transfer between the columns and the surrounding soil. The test results indicate that the load sharing ratio increases with an increase in column length and a decrease in column spacing. The ground settlement and the lateral displacement decrease with an increase in column length and a decrease in column spacing. Finally, the use of the combined method to mitigate differential settlements at a bridge approach is discussed.

Keywords: Centrifugal modeling; Composite foundation; Soil–cement column; PVDs; Consolidation

1. Introduction

Thick soft soil deposits are widely distributed in eastern coastal regions of China with low shear strength, high water content, and large settlement, with which arise a number of geotechnical problems for the construction of embankments. To enhance the properties of this type of problematic soft soil ground, Xu and Ye et al. (2006) proposed a new ground improvement method combining soil–cement columns and prefabricated vertical drains (PVDs), and considered that soil–cement columns can increase the bearing capacity and reduce the total settlement of the ground, while PVDs can accelerate the consolidation of soft soil by shortening the drainage paths. Limited researches on composite foundations that combine soil–cement columns and PVDs have been conducted so far. Ye and Zhang et al. (2012) deduced an analytical solution for calculating the consolidation process of composite foundations under time-dependent loading by considering PVDs as cylindrical drain wells. Ye and Zhang et al. (2013) performed finite-element analyses to evaluate the performance of an embankment on soft soils improved by soil–cement columns and PVDs, and the conclusions drawn

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were that the combined method accelerated the consolidation of the soft soils and reduced the post-construction settlement.

To further investigate the performance of embankments on soft soils with soil–cement columns and PVDs, a centrifugal modeling technique was employed in this study. Due to its feasibility in reproducing the same stress levels in scaled-down models as in full-scale prototypes, centrifuge model testing has been proved to be a useful tool and is widely used nowadays to resolve geotechnical problems (Kitazume and Maruyama, 2006, 2007; Najser et al., 2010; Hölscher and Van Tol et al., 2012; Tamura and Higuchi et al., 2012; Sawada and Takemura, 2014). In centrifugal modeling tests, geotechnical structures are scaled down by scaling laws to 1/*N* prototype dimensions in an acceleration field of *N* times the acceleration of gravity, *g*. With easy controllability and repeatability of the centrifugal modeling tests, a detailed study of the behaviors of a composite foundation, combining soil–cement columns and PVDs, could be conducted with instrumentation.

A set of model tests on an embankment on a composite foundation, combined with soil–cement columns and PVDs, was performed in the geotechnical centrifuge TLJ-150 in Tongji University, Shanghai. Two centrifugal modeling tests were conducted for comparison with the same model dimensions, but with different ground improvement methods, i.e., one with only soil–cement columns and the other one with only PVDs. All of the model tests were carried out with instrumentation of miniature pore pressure transducers (MPPTs), strain gauges, miniature earth pressure sensors (MEPSs), and differential displacement transducers (DDTs). The measured results, such as settlement, lateral displacement, excess pore water pressure, and axial stress along the column shaft, are presented. The use of the composite foundation to mitigate differential settlements at the bridge approach is discussed.

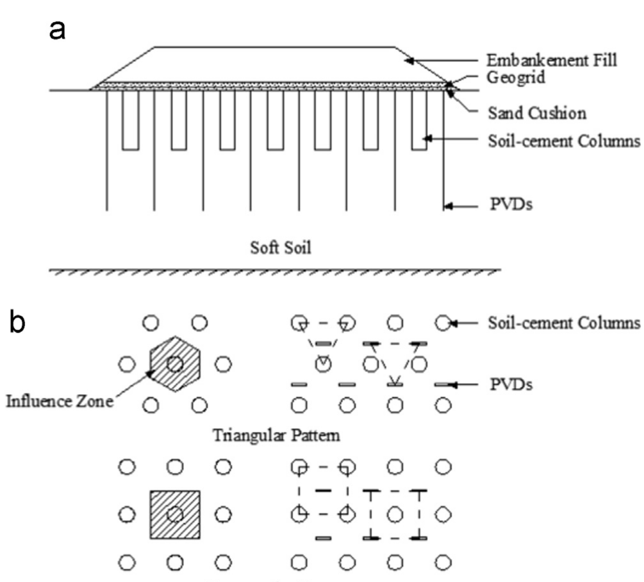

Fig. 1. (a) Cross-sectional and (b) planar views of the composite foundation.

2. Description of composite foundation

The cross-sectional and planar views of the embankment over the composite foundation, combined with soil–cement columns and PVDs, are shown in Fig. 1. Soil–cement columns and PVDs are usually installed in a triangular or rectangular pattern.

3. Centrifuge apparatus

The centrifuge used here has a nominal radius of 3 m. The payload of the centrifuge under its maximum acceleration of 200*g* can be up to 750 kg. The acceleration was taken as 80*g* in this study. The strongbox employed here was a top-open rectangular box, whose inside dimensions were 900 mm × 700 mm in planar dimensions and 700 mm in height. The strongbox was made of stainless steel plates, except for the front side that was made of a transparent Plexiglas plate to allow the observation of deformation during the testing. Digital images were taken in-flight by a high-definition digital camera from the front side of the strongbox, and the images were processed using digital image analysis technology.

4. Centrifugal modeling tests

All the centrifugal test cases are listed in Table 1. Five modeling tests of the subsoil improved by the combined method were conducted. The factors of column length and column spacing were taken into account. For comparison, two modeling tests on the embankment on the ground were designed as well, namely, one only with soil–cement columns and the other only with PVDs. The columns and the PVDs were arranged in an equilateral triangular pattern. The area replacement ratio of the soil–cement column was defined as the ratio of the cross-sectional area of a single soil–cement column to its corresponding influence zone. The scale factor applied was 80 (corresponding to an acceleration of 80*g*), and the main dimensions of the models are given in Table 2.

To easily identify the modeling tests in the following sections, each case is referred to by the name of the case followed by a bracket including its column length and column spacing, except for Case PVD. For example, the modeling test of DMA is

Table 1
Test cases.

Method	Cases	S (mm)	a_r (%)	L_c (mm)	L_d (mm)
Soil–cement columns combined with PVDs	DMA	40.6	11.56	100	200
	DMB	46.4	8.85	100	200
	DMC	52.2	6.99	100	200
	DMD	46.4	8.85	75	200
	DME	46.4	8.85	125	200
Only columns	DMP	46.4	8.85	200	/
Only PVDs	PVD	46.4	/	/	200

Note: S = column spacing; a_r = area replacement ratio of soil–cement column; L_c = column length; L_d = PVD length.