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Technical note

Comparative analysis on performance of vertical drain improved clay deposit under vacuum or surcharge loading

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ABSTRACT

This paper presents two well-instrumented large-scale field tests of PVD-improved soft soil with vacuum and surcharge preloading, respectively. The two large-scale field tests were conducted adjacent to each other with the same preload. A comparative analysis was performed to investigate the performance of subsoil (i.e., the ground settlement, the layered settlement, the lateral displacement of subsoil and pore water pressure) under vacuum preloading and equivalent surcharge preloading. Some design methods were verified based on the field data. Cone Penetration Tests (CPT) and Vane Shear Tests (VST) were conducted to assess the improvement effects on subsoil after preloading. The results showed that as compared with surcharge preloading, vacuum preloading mitigated the differential settlement of the ground. The vacuum pressure transmitted into the soil with a minor loss through the PVD length. From a practical point of view, the improvement effects by vacuum preloading and surcharge preloading were similar in terms of influence depth and soil strength based on the in-situ tests.

1. Introduction

The subsoil in the eastern coastal area in China consists of thick layers of saturated soft clays. However, with a rapid growth of economy in this region, the demand for infrastructure development on such geotechnical condition continuously increases. This unfavorable soft soil with low shear strength and high compressibility has to be strengthened to increase the bearing capacity and reduce the excessive settlement. Among the various ground improvement techniques feasible for soft soil, the application of preloading with prefabricated vertical drains (PVDs) is still regarded as one of the most popular and cost-effective alternatives in practice, especially for the soil improvement of large areas, such as airport, highway and tank (Yan and Chu, 2003; Indraratna et al., 2004; Mesri and Khan, 2012).

In the preloading system, the PVDs are used to shorten the drainage path and activate the soil radial consolidation. Recently, some new types of PVDs are also introduced into preloading method (Artidteang et al., 2011; Long et al., 2015; Sun et al., 2017). Artidteang et al. (2011) introduced the thermo-PVDs into the vacuum preloading method resulting in increasing the coefficient of horizontal consolidation with associated reduction of smear effect. Fu et al. (2016) and Wang et al. (2016) demonstrated that the vacuum preloading combined with variable-spacing electro-osmosis had a better improvement effect than the conventional vacuum preloading based on a field test.

The effective preloading pressure can be realized through either surcharge material or vacuum pressure. As compared with surcharge preloading, using vacuum pressure has several advantages. It has no failure possibility in vacuum preloading. Suction pressure along the vertical drains induced by vacuum preloading increased the radial hydraulic gradient toward the drain, which accelerated the consolidation rate and minimize the risk of shear failure (Indraratna et al., 2004). In addition, the cost for vacuum preloading is reported to be more economical than surcharge preloading since the transportation and placement of fill spend time and money (Yan and Chu, 2003).

The vacuum pressure was considered as an equivalent surcharge in design formerly. However, a lot of studies indicated that the mechanism of soil consolidation subjected to negative pressure (i.e, vacuum-assisted consolidation) is comparable to, but not exactly equal to, surcharge consolidation latter on (Indraratna et al., 2004). Several methods have been proposed to predict the performance of subsoil with vacuum preloading (Mesri and Khan, 2012; Perera et al., 2016; Indraratna et al., 2016). Rujikiatkamjorn and Indraratna (2007) presented a method to calculate the consolidation of soil subjected to vacuum pressure considering both vertical and horizontal drainage. Chai and Rondonuwu (2015) proposed a method for determining the optimum surcharge loading rate which will result in minimum lateral

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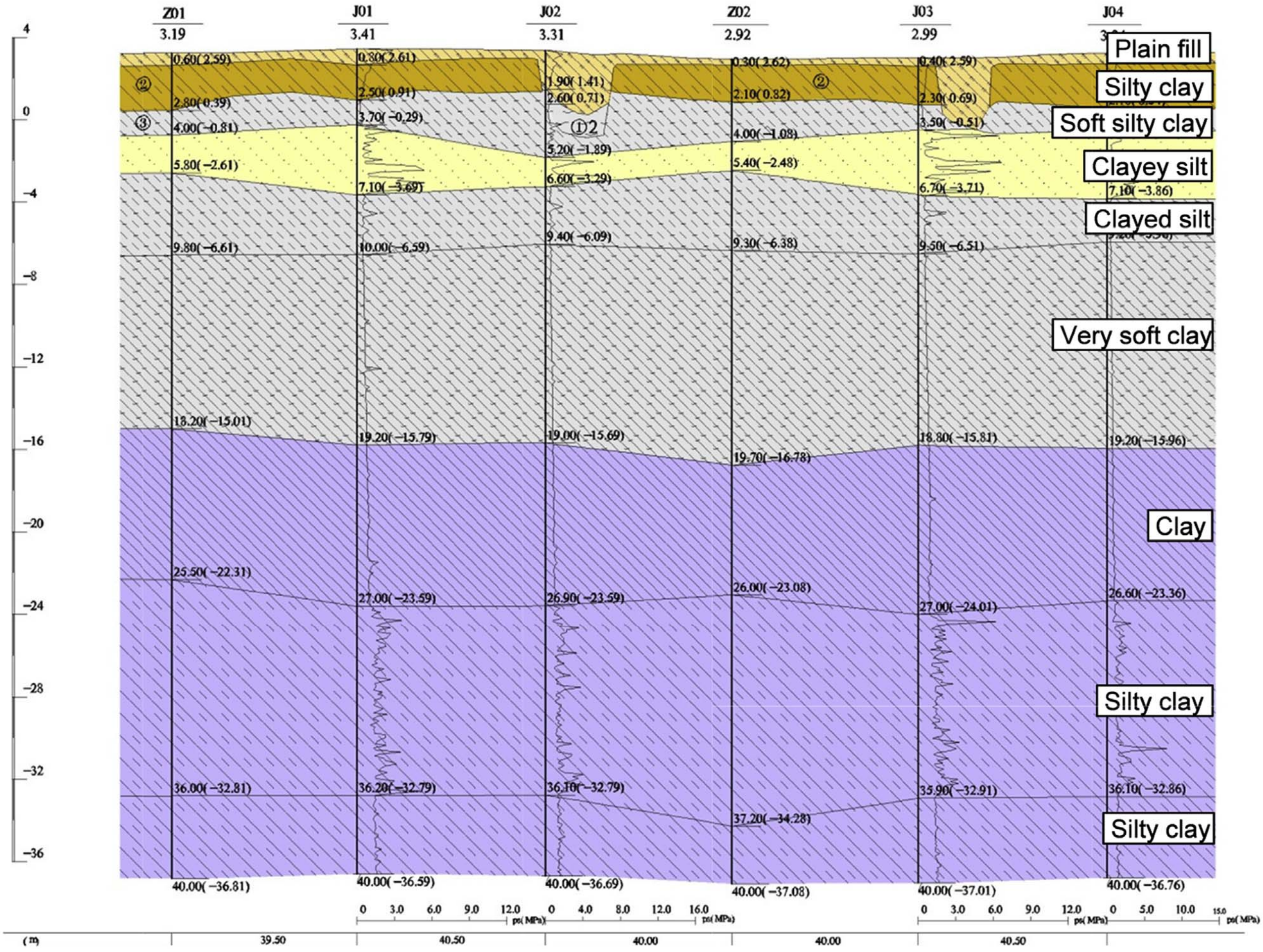

Fig. 1. Soil profiles on the test site.

displacement of a deposit under combined vacuum and surcharge loading. Indraratna et al. (2016) proposed a numerical solution for large-strain consolidation incorporating non-Darcian (nonlinear) radial flow with varying compressibility and permeability coefficients.

In this paper, two well-instrumented large-scale field tests were conducted to investigate the difference of performance of PVD-improved soft soil under vacuum pressure and the corresponding surcharge pressure. The performances of the soft soil induced by vacuum and surcharge preloading were compared to each other on the basis of surface settlements, layered settlements, lateral displacements, and pore water pressures (PWP). The coefficients of horizontal consolidation were back-calculated based on the measured pore water pressures. Some design methods were verified based on the field data. Cone Penetration Tests (CPT), Vane Shear Tests (VST) and relevant laboratory tests were conducted to evaluate the improvement effects of soil induced by vacuum and surcharge preloading.

2. Test site condition

The site for the field tests is located in Shanghai, China. Fig. 1 shows the profiles of the soil stratification on this site by the geotechnical investigation. The soil strata within a depth of 10 m varied relatively markedly in thickness as compared the soil strata below 10 m deep. The groundwater table was at a depth of 0.5 m from ground surface. Table 1 tabulates the main properties of the subsoil strata.

3. Field tests

3.1. Construction

A square area with a size of 90 m×90 m was designated to conduct the vacuum preloading test denoted as T1. The test site for surcharge preloading denoted as T2 were adjacent to vacuum-treated area and had a dimension of 60 m × 60 m. Fig. 2 shows the cross section and plan view of the field tests. In both tests, a 0.5 m thick sand blanket was placed on the ground surface as a working platform for placing the horizontal perforated pipes in the vacuum preloading test and as a horizontal drainage layer in the surcharge preloading test. The PVDs with a cross section of 100 mm × 4 mm and a length of 20.0 m were installed in a triangular pattern at a spacing of 1.1 m. The product discharge capacity of the PVDs was 800 m^3/yr.

The subsoil had a clayey silt with relative high permeability of 9.45×10^{-5} cm/s at an elevation from −0.29 m to −3.86 m. To minimize the vacuum loss due to the clayey silt with relative high permeability and the boundary effect, a mixed slurry wall with two-row columns was installed to seal the boundary. The mixed slurry columns had a length of 10 and a diameter of 700 mm with an overlap of 200 mm between adjacent columns. Fig. 2(a) presents the close-up view of the mixed slurry columns. A clay cofferdam was constructed along the boundary of vacuum-treated area. The cofferdam had a crest width of 1.0 m, a slope of 1H:1V, and a height of 2.0 m. A layer of impermeable membrane was used to cover the test area.