

Improvement of ultra-soft soil using prefabricated vertical drains

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Abstract

A case study of using prefabricated vertical drains (PVDs) to accelerate the consolidation of an ultra-soft fine-grained soil with high moisture content for a land reclamation project is described in this paper. Large-scale laboratory model tests were carried out to assess the suitability of the selected PVD and the effectiveness of the PVD in the consolidation of the ultra-soft soil. The model tests indicate that the discharge capacity of the drain can decrease substantially after the drain has experienced large deformations. To overcome this problem, PVDs were installed in two rounds. The first round was before the application of surcharge, and the second round was after substantial settlements have taken place. Field instrumentations were utilized to monitor the performance of PVDs during consolidation. The monitored settlement and pore water pressure results are presented and discussed. The study shows that it is effective to use PVD for the consolidation of the ultra-soft soil if special care has been taken in selection and installation of PVD and in fill placement to overcome the difficulties involved in the consolidation of ultra-soft soil.

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1. Introduction

Prefabricated vertical drains (PVDs) have been used successfully in many soil improvement and land reclamation project in Asia and the rest of the world (Hansbo, 1979, 2005; Holtz, 1987; Holtz et al., 1991; Bergado et al., 1990, 1993a, b, 1996, 2002; Indraratna and Redana, 2000; Li and Rowe, 2001; Bo, 2002, 2004; Bo et al., 2003, 2005a; Arulrajah et al., 2004; Chu et al., 2004; Rowe and Li, 2005; Indraratna et al., 2005). However, the cases of using PVDs for the improvement of ultra-soft soil, that is soil with no or little shear strength, are still rare. There are several technical difficulties in the use of PVDs for ultra-soft soil: (1) the grain size of the soil can be very fine and in suspension state so PVD having filter of smaller pore opening sizes may be required; (2) the PVD may experience much greater deformation as the ultra-soft soil is highly compressible; and (3) difficulties may be encountered during the installation of PVDs in ultra-soft soil.

In this paper, a case study of using PVD for the consolidation of ultra-soft soil with very high moisture content, high fines content and fine grain sizes is presented. The background of the project and the soil improvement technique adopted are described. Factors affecting the performance of PVD in ultra-soft clay are discussed. Results of laboratory model tests to assess the suitability of the PVD selected and the effectiveness of the PVD in the consolidation of ultra-soft soil are reported and discussed. The use of a method to install PVDs in two stages in the project is described. Field instrumentation scheme adopted is described. Settlement and pore water pressure data monitored during surcharging and the consolidation characteristics of the ultra-soft soil are presented and discussed. The study shows that it is effective to use PVD for the consolidation of ultra-soft soil, particularly when the method to install the drains in two stages is adopted. However, special attentions are required in the selection and installation of PVD and in the surcharging processes to overcome the additional difficulties involved in the consolidation of ultra-soft soil.

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2. Background of the project

As part of the Changi East Reclamation Project in Singapore (Choa et al., 2001, Bo et al., 2005b), a slurry pond of about 180 ha has to be reclaimed. The slurry pond was trapezoid in shape with roughly 2000 m in length and 750–1050 m in width, as shown in Fig. 1. This slurry pond was created by dredging seabed to an elevation of -22 mCD (Chart Datum) between 1975 and 1978 as a process of sand quarrying. A containment sand bund to the crest level of about 5 mCD was constructed around this borrow pit in 1986. Subsequently, silt and clay washings from other sand quarrying activities in the eastern part of Singapore was transported through pipelines with water and discharged into this contained area to form a slurry



Fig. 1. Slurry pond that contains ultra-soft soil.

pond. Therefore, the slurry inside the pond consisted of mainly clays and silts. The top elevation of the slurry was at -3 to -4 mCD and the water level in the pond was at $+3$ mCD. The mean sea level was at 1.6 mCD.

The grain size distribution curves of the soil in the slurry pond are shown in Fig. 2. It can be seen that the upper bound of D_{50} was 0.024 mm, but mostly in the range smaller than 0.001, and D_{85} was in the range of 0.004–0.02 mm. The fines content was in the range of 70–93%. The water content of the slurry was mainly in the range of 140–180%. The bulk unit weight of the slurry ranged mainly from 11 to 13 kN/m³. The other physical properties of the soil in the slurry pond are shown in Table 1. The thickness of the ultra-soft slurry varied from 1 to 20 m with an average value of 15 m. As the slurry was deposited recently with little consolidation, it was ultra-soft and highly compressible. The slurry had very little strength although the strength increased slightly with depth (Bo et al., 1998).

The procedure adopted for the reclamation of the slurry pond was by placing a sand capping layer on top of the slurry before PVDs could be installed and used for the consolidation of the slurry. As the slurry had essentially no strength, the land reclamation work had to be carried out by spreading thin layers of sand using a specially designed sand spreader (Bo et al., 2005b). To ensure the stability of the fill, small lifts of 20 cm were used in the first phase of the spreading. This phase of sand spreading took about 13 months including the waiting time between the lifts. When the fill reached an elevation between -1 and $+2$ mCD, a failure in the form of slurry bursting occurred at one location. The failure was caused by uneven thickness of the fill placed and the differential settlement induced. As the

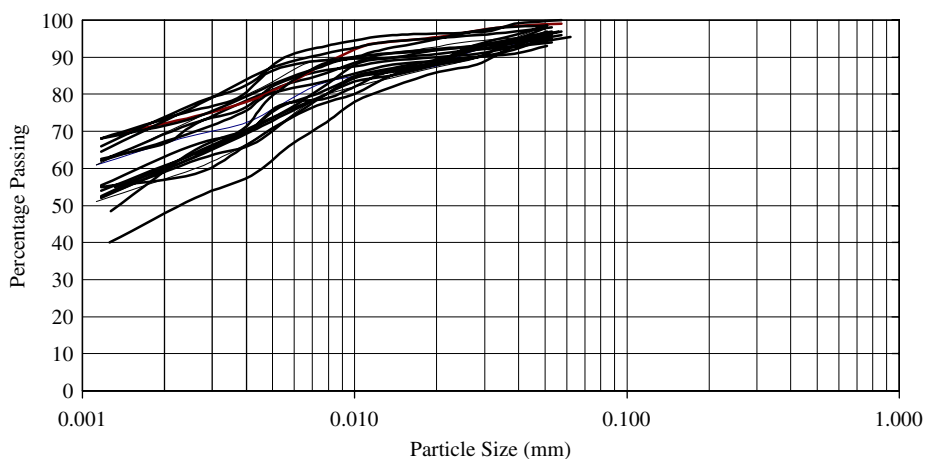


Fig. 2. Grain size distribution curve of the ultra-soft soil.

Table 1
Properties of soil in the slurry pond

Liquid limit (%)	Plastic limit (%)	Water content (%)	Bulk unit weight (kN/m ³)	Specific gravity	Void ratio	Fines content (%)
65–115	22–45	75–180	11.0–16.0	2.67	2.0–4.5	70–90

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