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Abstract

In this study, the smear zone due to vertical drain installation is studied using a large, in situ sample to capture the realistic characteristics of the smear zone in relation to the in situ soil structure. The smear zone extent for Bulli clay (New South Wales, Australia) is quantified on the basis of normalised permeability and the reduction in the water content prior to consolidation. The permeability and compressibility of the soil are used to determine the extent to which the soil surrounding the PVD had become disturbed. In laboratory testing, the soil consolidation behavior due to a prefabricated vertical drain (PVD) is studied using a large scale consolidometer apparatus.

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Characterization of Smear Zone Caused by Mandrel Action

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ABSTRACT: In this study the smear zone due to vertical drain installation is studied using a large, in-situ sample to capture the realistic characteristics of the smear zone in relation to the in-situ soil structure. The smear zone extent for Bulli clay (New South Wales, Australia) is quantified on the basis of normalised permeability and the reduction in the water content prior to consolidation. The permeability and compressibility of the soil are used to determine the extent to which the soil surrounding the PVD had become disturbed. In laboratory testing, the soil consolidation behaviour due to a prefabricated vertical drain (PVD) is studied using a large scale consolidometer apparatus.

INTRODUCTION

Vertical drains have been commonly used to accelerate the consolidation process of soft clay layer. The installation of prefabricated vertical drains using mandrel causes a major disturbance to the surrounding soil particularly in the interface contact with the mandrel. In result, the disturbance occurred generates a smear zone with significant variation in soil structure and permeability which impedes the consolidation process (Indraratna et al. 2008; Rujikiatkamjorn and Indraratna 2009; Rujikiatkamjorn et al. 2013). The presence of the smear zone significantly influences the horizontal consolidation, and classical solutions (Hansbo, 1981; Sathananthan et al. 2008, Indraratna et al. 2010). Many researchers have suggested various sizes of the smear zone both based on laboratory tests, analytical and numerical approach. In previous researches, the extents of the smear zone are given as follows, r_s = 1.5 r_m (Hansbo, 1981), r_s = 2 r_m (Bergado et al., 1991), r_s = 4–5 r_w (Indraratna et al., 1998), r_s = 4 r_m (Sharma & Xiao, 2000) and r_s = 2.5 r_m (Sathananthan and Indraratna, 2006). The results based on laboratory tests mostly obtained from engineered or reconstituted soil samples where there was no presence of soil structure in the soil sample.

In the present study, a large-scale undisturbed sample obtained directly from the field was tested to assess the actual extent of the smear zone after the installation of prefabricated vertical drains. The test was aimed to represent a close to real smear zone size according to the initial soil state in the field. The presence of soil structure and natural water content of the sample was expected to provide liable in-situ characteristics of smear zone. By inserting prefabricated vertical drains and performing consolidation test to the large-scale undisturbed sample and following by small-sized sampling, the characteristics of the smear zone was quantified by measure the variation of the moisture content, compressibility and permeability of the surrounding soil.

APPARATUS

The schematic design of the large-scale corer and consolidometer is given in Fig.1.

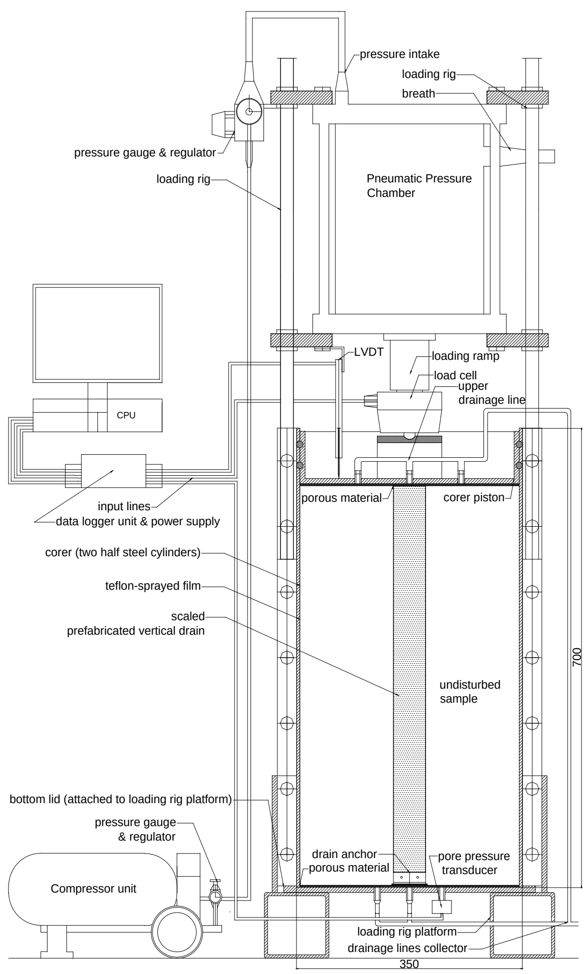

Fig. 1. Two-in-one Large-Scale Corer and Consolidometer

The two-in-one large-scale corer and consolidometer consists of three main parts; (1) the cylinder (corer with top cap, bottom lid and piston), (2) loading rig platform, and (3) loading rig and pneumatic air pressure chamber. The main parts of clay corer are made of specially rolled steel plate to form half cylinder of the corer and has an internal diameter of 345 mm and wall thickness of 5 mm. Special designed sleeves on both ends of half cylinder corer were made to join and formed a perfect rounded cylinder. In order to match perfect rounded symmetry, sets of bolts and nuts are placed to tighten the cylinder. Teflon-spray film was applied to the whole inner wall surface to reduce the friction along the corer wall. The cylinder is outfitted with two plates of a top cap and a bottom lid. The top cap was made of 6 mm thick steel and it was designed to be strong enough to retain force during retrieve the sample in the field. The top cap was also designed with a 2 mm groove deep located at the same radius of the cylinder. This groove will allow the cylinder fit with the top cap. The bottom lid has mimic designed to the top cap and it will be attached to the cylinder and sit on a platform. Both top cap and bottom lid were designed with three drainage holes that could be plugged or unplugged during the sampling. A piston of 342 mm in diameter made of stainless steel was put in order to distribute the load sourced from the pneumatic air pressure chamber. The piston was grooved on two position of its outer wall to accommodate 5 mm o-rings to ensure there was no air or water leakage during the test. After the completion of soil sampling preparation then the lower part of cylinder was docked onto platform and the upper part will be attached to special designed loading rig. A load cell connects the piston and the loading ramp of the pneumatic air pressure chamber. An axial displacement transducer was installed on top of the piston to measure the settlements. Both applied load and settlements were recorded on a set of data taker. Although the size of the cylinder was relatively large but in order to avoid more disturbances to the sample, the instruments such as miniature pore pressure transducer was not installed inside the sample. A hollow rectangular mandrel made of 1.5 mm thick stainless steel plate was designed to install a resize band-shaped drain. The mandrel outer sizes were 5 mm in thickness and 55 mm in width and the equivalent radius of mandrel, r_m, would be 16.2 mm. A rectangular drain anchor of the same size to the mandrel was also designed and to be attached to the drain prior to installation.

UNDISTURBED SAMPLE AND PVDs

The clay used in this experiment was an undisturbed sample obtained from a site at Bulli, New South Wales, Australia. The physical properties of the soil are given in Table 1. The soil was categorized as a medium high plasticity (MH) according to Cassagrande Plasticity Chart. The drain was a common band-shaped (rectangular cross section) prefabricated vertical drain consisting of a non-woven synthetic geotextile material surrounding a plastic core. The drain was resized in width into a smaller size meanwhile the drain thickness was in original size (Fig. 2). The width of the drain was set to 50 mm (r_w = 13.5 mm) based on extent of smear zone of $r_s = 4–5r_w$ so that the radius of expected smear zone would not exceed the radius of the clay corer.

Table 1. Some physical properties of Bulli Clay.

Properties	
Liquid Limit, LL (%)	50
Plastic Limit, PL (%)	25
Plasticity Index, PI	25
Specific Gravity, Gs	2.62
Water Content, Mc (%)*	41.4
Void Ratio, e*	1.13
Wet Unit Weight (kN/m3)*	18

*) obtained from small-sized undisturbed sample

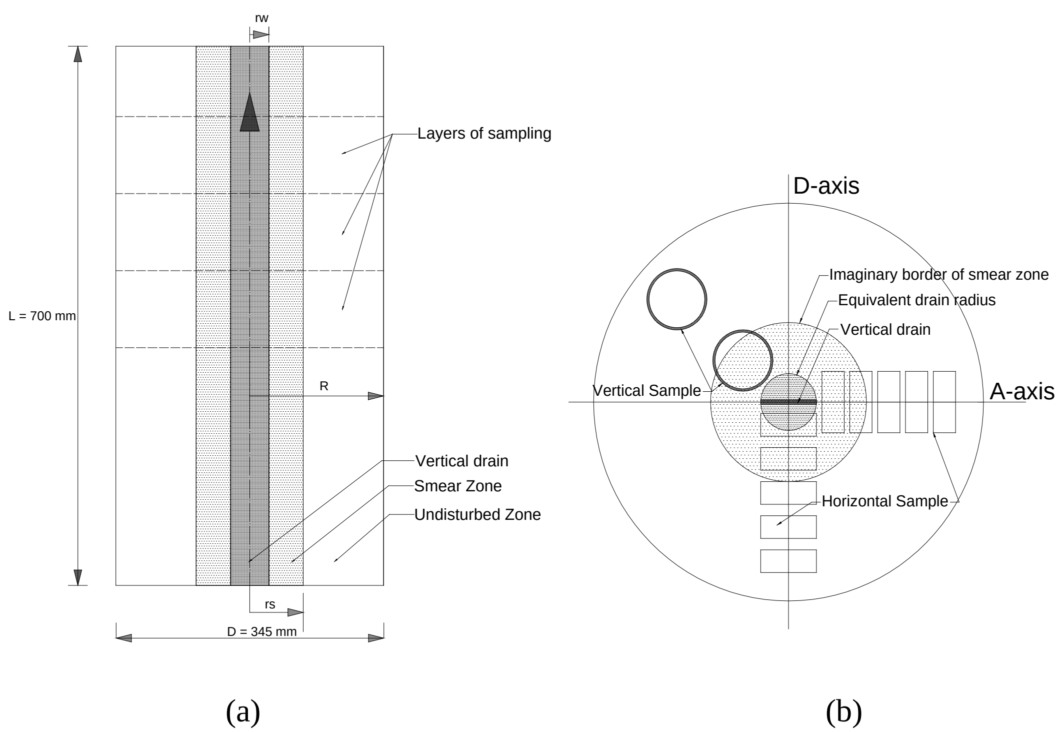

Fig. 2. (a) Unit Cell; (b) Schematic Plan of Sampling Locations for Oedometer Test.

EXPERIMENTAL ARRANGEMENT AND TEST PROCEDURE

The large-scale test was carried out in 3 phases: (1) sample and loading rig preparation, (2) installation of the resized prefabricated vertical drain and consolidation test, (3) small sample coring for moisture-content test and oedometer test. In the first phase, the corer contained with the large-scale undisturbed sample was attached to the loading rig platform and the bottom lid was sealed. The top cap was removed and prior to the placement of the piston a layer of porous material was placed on the top surface of the undisturbed sample. The upper part of the corer was then attached to the two support rods to form the loading rig. The pneumatic pressure chamber equipped with pressure gauge and regulator was clammed to the rods and its position was adjusted to be in the centre of the corer. The instruments such as load cell and axial displacement transducer were set and connected to the data taker. Both the drainage lines from piston's drainage and bottom lid's holes were joined to collect the excess water. In this phase, vertical consolidation pressure of 20 kPa was applied to simulate the field pre-consolidation pressure.

In the second phase, after the completion of vertical compression for applied pre-consolidation pressure, the piston and the porous material on the large-scale sample were removed. A mandrel guide apparatus is bolted on the two sleeves at top boundary of corer to sustain the mandrel alignment during installation. The mandrel was driven into the soil sample and once the mandrel reached the bottom lid, the mandrel was withdrawn immediately and leaved the drain installed inside the soil sample. The piston and porous material layer were put back into the corer. The test was continued and vertical consolidation pressures generated from the pneumatic pressure chamber were applied to the sample until the completion of primary consolidation process. Both the pressure and displacement readings were recorded by data taker and stored in the computer.

After the completion of primary consolidation process, the test was stopped and the corer was disengaged from the platform and loading rig. By undo the bolts and nuts, the corer then was split into two parts to ease the small-sample collection. Horizontal and vertical undisturbed samples were obtained from two layers in a certain distance from the bottom of the large-scale sample as shown in Fig. 2(b). Oedometer tests were conducted on these small-samples to obtain the compressibility and permeability of the clay sample. At the same time, the moisture-content samples were taken from three considered sampling layers of the large-scale undisturbed sample. The three sampling layers were in the distance of 450 mm, 350 mm, and 250 mm from the corer base respectively. In each layer, two series of samples consists of five samples at a certain distance from the centre of the drain were obtained in D-axis and A-axis.

TEST RESULTS

Moisture contents

The moisture-content figures for the tests are shown in Fig. 3. As predicted, the moisture content decreases in the direction of the drain, and the moisture content tends to have greater value towards base of the corer. The extent radius significantly influenced by the drain installation for moisture contents of the soil surrounding the drain is within radius of 60 – 100 mm from the centre of the drain.

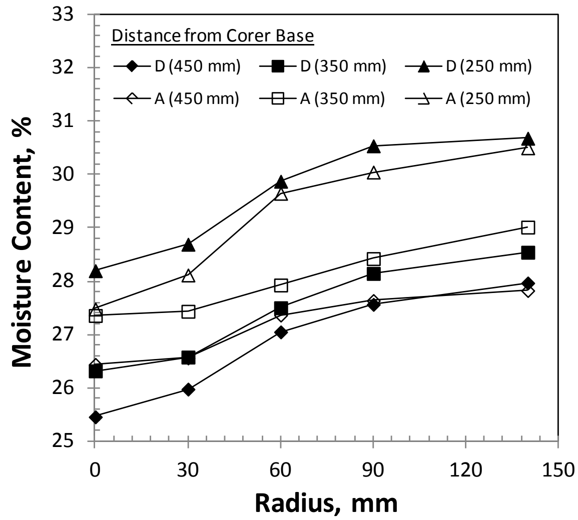

Fig.3. Moisture-content figure of the large-scale undisturbed sample

Soil Compressibility

Fig. 4. shows the results of horizontal small-samples collected for both large-scale undisturbed samples with maximum pressure of 50 kPa and 200 kPa tested in oedometer apparatus. The distribution of void ratio in radial direction determines that the higher compression of soil occurred in the region adjacent to the drain. There is a significant drop in void ratio values in a region within radius of 60 mm from the centre of the drain. The void ratios tend to have a relatively constant value at a distance more than 60 mm towards the corer boundary.

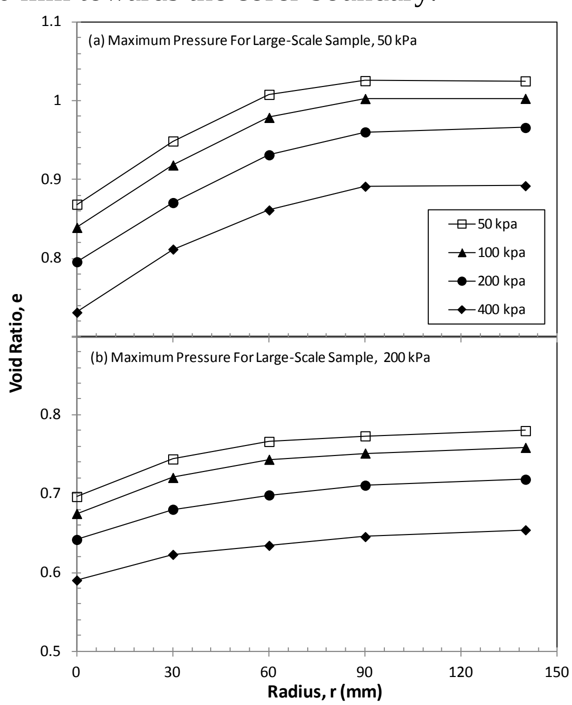

Fig. 4. Radial distribution of horizontal compressibility of the large-scale undisturbed sample

Permeability

As mentioned previously, horizontal and vertical sample collected from the large-scale undisturbed sample at the end the test were tested in Oedometer apparatus. Fig. 5 shows the variation of horizontal permeability in radial direction. Both test results with maximum pressure of 50 kPa and 200 kPa during large-scale sample consolidation show similar trend which the permeability close to the drain has lower value compare to permeability of small-samples distance from the drain. Fig.5 also shows the permeability of large-scale sample with higher maximum pressure during large-scale consolidation has lower permeability especially in the region adjacent to the drain interface. The permeability at the outer radius of 60 mm tends to have a constant value. The extent of permeability value significantly influenced by the drain installation agrees well within the estimated size of smear zone based on both the moisture-content and compressibility figures.

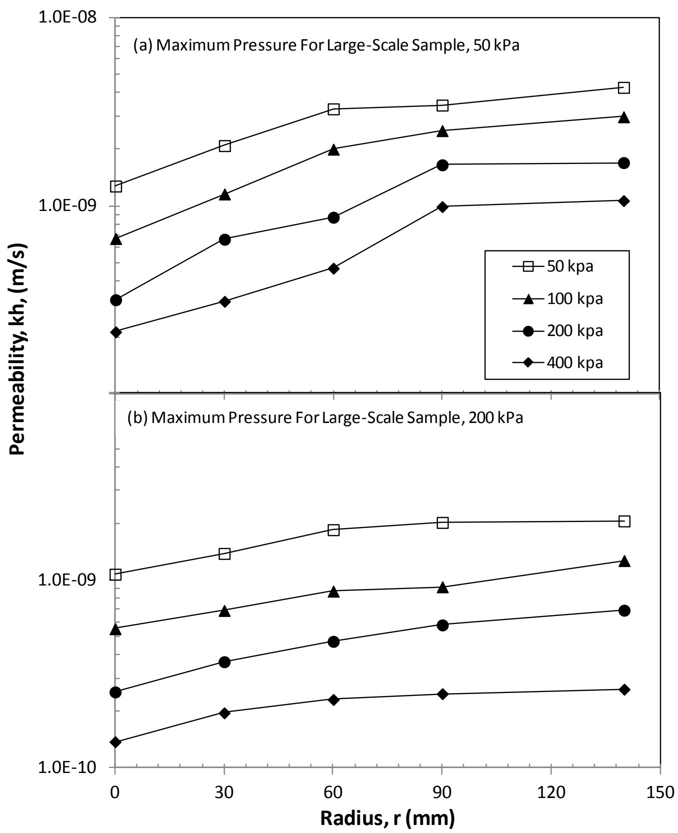

Fig. 5. Radial distribution of horizontal permeability of the large-scale undisturbed sample

CONCLUSIONS

These tests were carried out on a large scale undisturbed sample of Bulli Clay, New south Wales, Australia that had been tested on a specially designed large scale consolidometer. Two large samples were consolidated with consolidation pressures of 50 kPa and 200 kPa prior to tests conducted on small cored samples in a conventional oedometer. Data from the tests were analysed to establish the characteristics of the smear zones and prediction of disturbance due to the soil being de-structured in the smear zone. The extent of the smear zone was estimated on the basis of the change in the water content. The smear zone and the marginally disturbed zone were found to be about 3.7 times and 5.5 times the equivalent radius of the mandrel, respectively. It was clear that the soil lost a significant amount of its structure after the drain was installed, especially in the region close to the drain. When the soils were disturbed, the permeability, coefficient of consolidation and coefficient of volume change values, decreased. Therefore, based on this finding, the variation of soil compressibility with radius needs to be taken into account during design apart, from the variation of soil permeability.

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