A Study of Soil Disturbance Associated with Mandrel-driven Geosynthetic Vertical Drains

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ABSTRACT:The installation of mandrel driven vertical drains creates a disturbed region (the smear zone) around the drain. To predict therate of consolidation accurately, the extent of the smear zone and the ratio of the horizontal coefficient of permeability in the undisturbed zone over that in the smear zone must be estimated correctly.However the effects of soil disturbance under field conditions have not been captured properly by previous work carried outin this area. Indeed, most prior work was limited to laboratory experiments where relatively shorter drains were driven into the soil with scaled down mandrels. In this study the characteristics and extent of the smear zone were investigated using samples obtained around a vertical drain installed beneath an embankment built at Ballina, Australia, and then the normalized permeability (k_h/k_{hu}), water content, and the volume compressibility across the smear zone was used to determine the properties of the smear zone. According to this study, the smear zone observed under field conditions was larger than the smear zone identified in the laboratory studies and therefore a convenient method of calculating the extent of the smear zone is proposed.

1 INTRODUCTION

Urbanisationhas led to the construction of infrastructure on marshy areas that had not previously been used for any construction work. These low lying areas possess unfavourable conditions for construction due to theirweak geotechnical characteristics such as high compressibility and low bearing capacity. Vertical drains have been a cost effective and popular method to improve these soils because they reduce the drainage path and accelerate consolidation. However, vertical drainsinstalledwitha steel mandrel alter the structure of the clay and create a disturbed region known as the smear zone. In this region the lateral permeability and compressibility are altered, which is why an accurate estimation of the extent of thesmear zone and the subsequent reduction of horizontal permeability within is needed to predict the consolidation response.

Hansbo (1981) incorporated the effects of smear and well resistance to the original radial consolidation theory developed by Barron (1948). Chai and Miura (1999) stated that the extent of the smear zone and the ratio between the horizontal permeability of the smear zone and undisturbed zone are the two main aspects used to characterize the smear zone. Indraratna and Redana (1998) found that the radius of the smear zone wasabout 4 to 5 times the equivalent radius of the drain, and the permeability ratio between the vertical and horizontal directions approaches unity close to the drain within the smear zone. Sathananthan and Indraratna (2006) investigated the characteristics of the smear zone formed by mandrel driven PVDs and concluded that the extent of the smear zone wasabout 2.5 times the equivalent mandrel radius. Their study was based on the water content and reduction in horizontal permeability. Rujikiatkamjorn et al. (2013) studied the smear effects from mandrel installation using large scale undisturbed samples where the effects of changes in the soil structure were incorporated, but the actual amount of shearing experienced while the drains were installed could not be simulated due to the limited depth of the sample and scaled down steel mandrel.

The smear zone characteristics derived in these laboratory experiments may not provide anaccurate picture of the soil disturbance associated with field conditions, so in this current study the smear zone characteristics were investigated using the in-situ samples extracted from around a mandrel driven PVD beneath the Ballina embankment, and a more accurate method of calculating the extent of smear zone is proposed based on variations of the coefficient of horizontal permeability and the water content.

2 SAMPLE EXTRACTIONS AND TESTING PROGRAMME

Samples of clay for this study were obtained from the site in Ballina, Australia where highly compressible and saturated layers of 15m thick clay were encountered. The natural water content (w) of the soil was 94.7%, the liquid limit (LL) was 98%, and the Plasticity index (PI) was 66%.

100mm wide, 3mm thick wick drains were installed in a square pattern at1.2m spacing, to a depth of 15m using a 120mm x 60mm steel mandrel. A rectangular shoe (140mm x 90mm) was attached to the drain to anchor it. Immediately after the drain was installed, 11 samples were extracted for one dimensional consolidation tests. The moisture content of each sample was also measured in the laboratory. Shelby tubes (50mm diameter and 450mm long) were used to extract the samples and they were in accordance with the recommendations made by Hvorslev (1949).The area ratio of the Shelby tubes was 6.88%, which was clearly within the allowable limits. Gap of at least 300mm was maintained between the adjacent sampling locations in order to minimise the disturbance when collecting the samples.

All the samples obtained for this study were extracted from 2.5m below ground level. Since it was imperative to minimise any disturbance while extracting these samples, a truck mounted rotary auger was used to bore a 2.5m deep hole. The bottom of the hole was then cleaned and the Shelby tubes were carefully pushed into the ground using hydraulic force to ensure continuous and steady insertion. The tube remained in position for several minutes and was then rotated slowly and removed at a uniform speed. The sample was cleaned properly and both ends were sealed with paraffin wax to prevent any loss of moisture. Plastic caps were then attached to eachend of the tube, which was then wrapped with shock absorbing bubble wrap and transported to the laboratory. The sample tubes were then stored in a room kept at a constant temperature of 10^0C and 95% humidity to minimize the moisture loss.

According to Sathananthan and Indraratna (2006),variations in the moisture content along the radius of the drain can be used to estimatethe extent of the smear zone, so the water content of these samples was measured as soon as they reached the laboratory. About 30 mm of soil from the bottom of each sample was removed and then used to measure the water content of each sampling tube. The average moisture content of each tube was then used in the analysis.

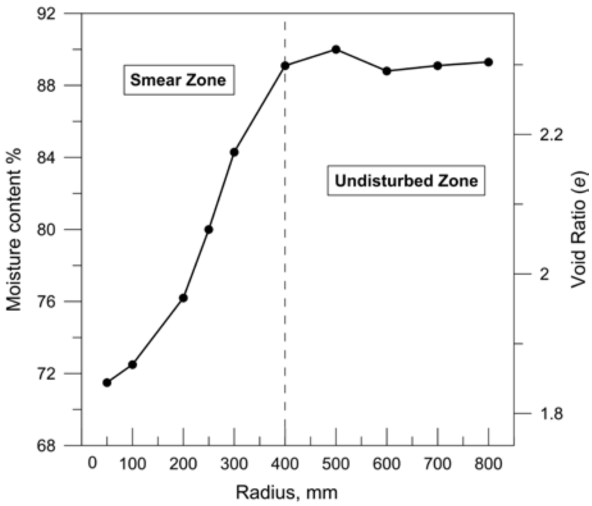

Fig. 1 Variation of moisture content along the distance away from the drain

To obtain the variation of permeability and compressibility, oedometer tests on the samples extracted horizontally and vertically were carried out; each sample was prepared, fitted to an oedometer ring, and then set up in the consolidation apparatus. Each sample received 3.4 kPa of initial pressure, which was then doubled after each 24 hour period until the pressure reached 218.7 kPa.

3 TEST RESULTS AND ANALYSIS

The variations in the water content along the radial distance are presented in Fig. 1; the in situ moisture content was between 93% and 95%, but at 400mm away from the drain, along the radius,the water content increased from about 70% to 90%, and which it remained relatively constant. This variation in thewater content agreed with the observations made by Sathananthan and Indraratna (2006), and Rujikiatkamjorn et al., (2013).

The change in the void ratio along the radius is shown in Fig. 2a, and it was similar to the variations in the water contents shown in Fig. 1. Terzaghi's one dimensional consolidation theory was used to calculate the horizontal permeability, and Casagrande's log time method was used to obtain the coefficient of consolidation in the horizontal direction (c_h)

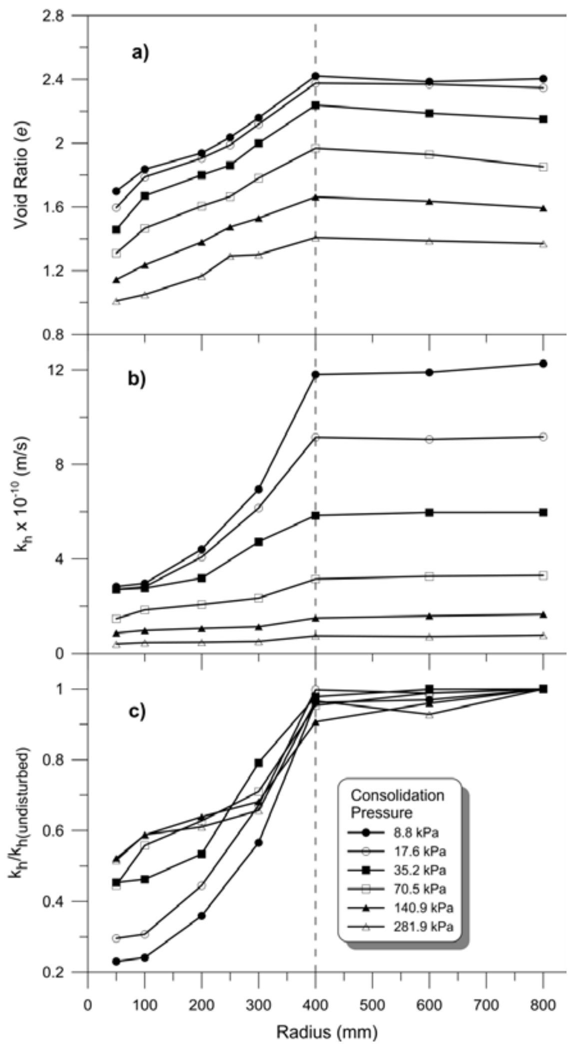

Fig. 2 Variations of a) Void ratio; b) Permeability; and c) Normalised permeability along the distance away from vertical drain (Indraratna et. al., 2014)

The lateral permeability was affected by the drain installation was clearly visible because outside the 400mm area, the horizontal permeability was constant, but inside this region it had decreased markedly towards the drain. In the highly disturbed region near the drain, the normalised permeability was 0.2-0.5; this increased away from the drain and remained close to 1 in the relatively undisturbed region. Moreover, despite different pressures applied, all the curves were constricted into a narrow band, and the average value of normalised permeability inside the smear zone was about 0.6.

Apart from those changes to the void ratio and permeability, the compressibility of the soil was also altered due to drain installation. Fig. 3a and 3b presents the compression curves for the vertical samples and horizontal samples respectively, and they show that the compression curves very close to the drain had been disturbed more than the compression curves from the samples taken further away from the drain.Indeed the soil near the drain (50mm) was almost remolded, which indicated severe disturbance.

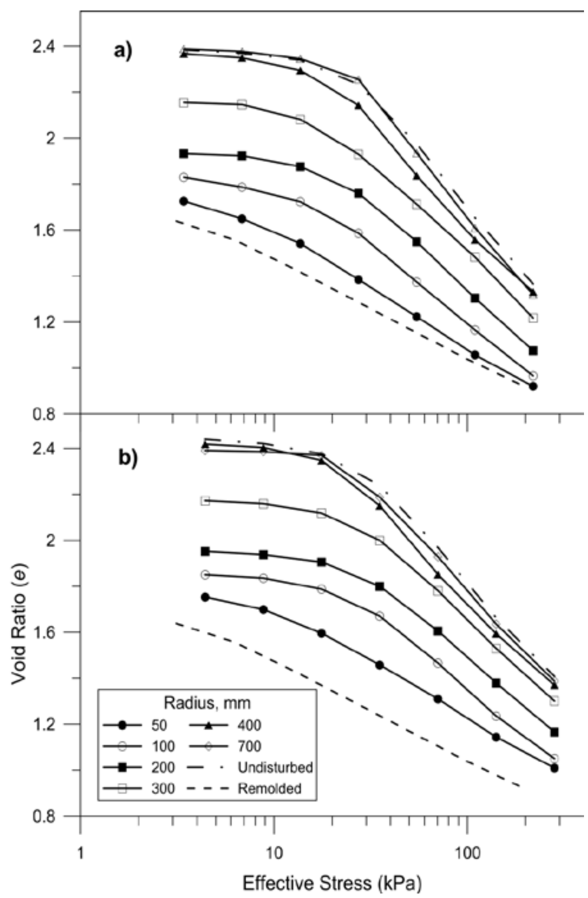

Fig. 3 Compression curves for, (a) vertical samples and (b) Horizontal samples (Indraratna et. al., 2014)

The test results of the water content, void ratio, and normalised permeability, indicated that the smear zone was 6.3 times larger than the size of the equivalent mandrel. This wasmuch higher than the previous values obtained in laboratory experimentswhere reconstituted soils and scale model mandrels were used, and therefore under field conditions, soil is subjected to more disturbance from drain installation than had previously been assumed. This is due to the higher shear created by the longer vertical drains and the higher installation speeds used.

4 NUMERICAL ANALYSIS

To understand how the extent of the smear zone affects the rate of consolidation, two embankments having the same properties but different size smear zones were simulated using PLAXIS. The smear zones were 400mm and 200mm respectively. The permeability and void ratios were takenfrom the experimental results, and the parameters needed for the analysis were as follows. The embankment was loaded in two stages with each stage applying 30kPa to a final applied pressure of 60kPa.

Table 1. Soil parameters

Zone	λ	κ	e_0	$\Delta\sigma$ Total (kPa)	k_h $x10^{-10}$(m/s)	k_v $x10^{-10}$ (m/s)
Disturbed	0.50	0.06	2.0	60.0	7.2	7.2
Undisturbed	0.57	0.06	2.4	60.0	12.0	10.0

A numerical analysis shows that the rate of consolidation decreased when the smear zone was increased.

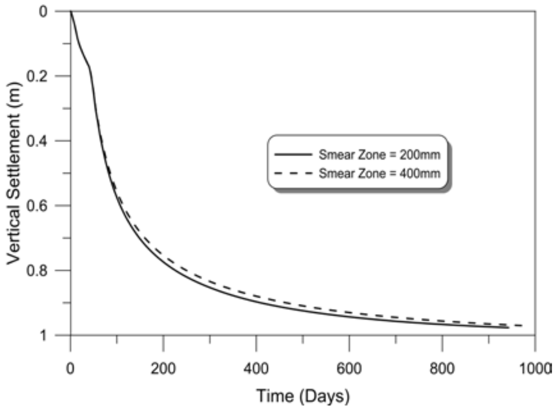

Fig. 4 Time settlement curves for different smear zones

5 CONCLUSIONS

Soil disturbance associated with the installation of vertical drains was investigated using samples extracted from a soft clay site in Ballina, NSW. The extent of the smear zone wasestablished using variations in the water content, normalised permeability, and soil compressibility. It was observed that the water content gradually increased within a 400mm radial distance from the drain, and then remained relatively constant. The void ratio and lateral permeability also followed the same trend. All these results indicate a smear zone that was 6.3 times the equivalent mandrel dimension.Most of the previous studies werelimited to laboratory experiments and scaled down mandrels driven into relatively shallow soil. This study revealed that soil is subjected to much more disturbance in the field than had been previously assumed due to higher rates of drain installation and longer drains. The parameters of the smear zone have a significantly influence on the rate and amount of final settlement, and therefore it is recommended that required parameters should be assessed using undisturbed samples obtained around the vertical drains in order to obtain a better prediction of settlement.

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