Smear Zone Characterization using Field Samples

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Abstract

In this study the smear zone were characterised using undisturbed samples collected at various locations after vertical drains were installed in the field. The aim was to determine more realistic smear zone characteristics in relation to the in-situ structure of soil. The extent of the smear zone for Ballina clay was determined on the basis of normalised permeability (k_h/k_{hu}), the change in soil compressibility and a reduction in the water content. The permeability and compressibility of the soil were investigated to determine the extent to which the soil surrounding the PVD had become disturbed.

Keywords: Disturbance, Smear zone, Soft Soils, Vertical drains

1. INTRODUCTION

In-situ soils usually possess a structure, whose engineering response is changed from the same material in a reconstituted state (e.g., Burland 1990; Leroueil and Vaughan 1990; Cuccovillo and Coop 1999). There have been numerous studies on developing constitutive models that consider the structure of the soil, such as Gens and Nova (1993), Whittle (1993), Wheeler (1997), Rouainia and Muir Wood (2000), and Liu and Carter (2002). Liu and Carter (2002) introduced a structured cam-clay model where its parameters can be determined in the laboratory.

Prefabricated vertical drains (PVDs) have been extensively employed to accelerate the consolidation. PVDs are inserted into the clay foundation with a steel mandrel that houses the drain and its anchor. The installation creates a disturbed zone, which is identified as smear zone, where the structure and permeability of the clay are changed, which affects the time required for the soil to consolidate. The required parameters to assess the smear zone are the size of smear zone radius, and the change in the horizontal coefficients of permeability (Chai and Miura, 1999). Using reconstituted soils, Onoue et al. (1991) showed the variation of the lateral coefficient of permeability through laboratory experiments and established a three-zone model. Indraratna and Redana (2000) determined the smear zone to be 4 – 5 times the radius of PVDs and the lateral to vertical permeability ratio to be unity in the smear zone. Hird and Moseley (2000) stydies the smear zone in multi-layered and then showed that a smear zone radius of three times the equivalent drain radius. Based on large scale physical model tests, Sharma and Xiao (2000) and Ghandeharioon et al. (2010) concluded that the smear zone is approximately 4 times the equivalent radius of the drain and 3.1 times the equivalent radius of the mandrel, determined using elliptical cavity expansion theory, respectively. In previous studies, an estimation of the smear zone was mainly based on laboratory testing using remolded soil, where its structure was fully or partially disturbed during preparation. In recent years, researchers and practitioners have pointed out the difficulties associated with estimating the smear zone of in-situ soil (Bo et al. 2003, Chu et al., 2000). Indraratna and Redana (2000) proposed a preliminary analytical and numerical model to capture the effect of the smear zone, but the role played by the structure of the soil was not properly captured. However, as the above findings were based on testing reconstituted soils, none of these approaches correctly captured the role of the soil structure; hence the corresponding deformation and excess dissipation of pore pressure associated with soft clays subjected to radial consolidation may not accurately represent the actual behavior.

In this paper, undisturbed soil samples were collected after the PVDs were installed in the field. They were employed to assess the altered soil properties such as permeability and compressibility in the smear zone. The objective was to capture the more realistic smear zone with special reference to the structure of the soil. The de-structuring of clay during installation was assessed through changes in the void ratio, permeability, and compressibility.

2. SOIL SMAPLE COLLECTION

Soil samples were collected from a site in Ballina, New South Wales. The soil can be classified as high plastic clay according to the Unified Soil Classification System. The PVDs were installed using mandrel (120mm x 60mm) with a rectangular shoe (140mm long x 90mm wide x 1mm thick). After installation, samples were retrieved immediately at 2.5 to 2.95 m depth below ground surface (Figure 1). The tubes were then kept in a bubble wrap sheet and sent and stored in a humidity room to maintain their water content before being tested in the laboratory.

3. TESTING PROGRAMME

Oedometer tests were conducted using the 20mm thick specimens extracted in vertical and horizontal directions. The former were used to determine the change in vertical compressibility and the latter were mainly used to investigate the variation in lateral permeability along radial distance. The specimen was fitted directly onto a ring for a consolidation test. An initial 3.4 kPa seating stress was applied and each loading increment was 1 day, and the loading was increased until 218.7 kPa.

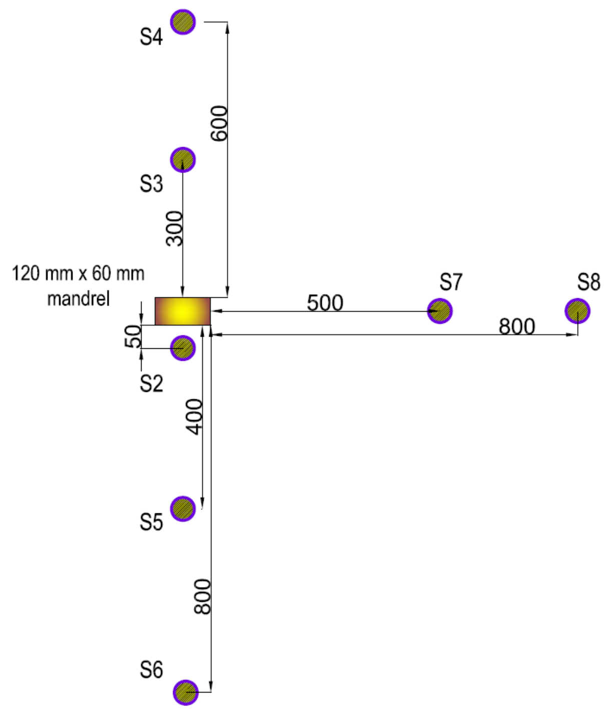

Fig. 1. Soil Sampling locations (modified after Indraratna et al. 2014)

4. RESULTS AND ANALYSIS

The smear zone created by drain installation can be assessed using the variation of compressibility, permeability, and water content along the radius from the PVDs as proposed by Sathananthan and Indraratna (2006). Fig. 2 shows the variation of water content along the radial distances. The water content gradually increased up to 89-90% and then remained relatively constant at a distance more than 400mm away from the drain.

The variations in the void ratio along the radial distance are shown in Fig. 3 with a similar trend to the variation in the water content. Variations in the lateral permeability along radial locations are presented in Fig. 4. The horizontal permeability was almost constant beyond 400mm away from the drain, but it decreased towards the drain. The changes in the moisture content, void ratio, and permeability confirmed that the smear zone extent was about 6.3 times the equivalent diameter of the mandrel, a result that was larger than those obtained in previous studies. It is therefore evident that in field conditions, the soil can be further disturbed when longer vertical drains are installed, with a longer shearing period during installation.

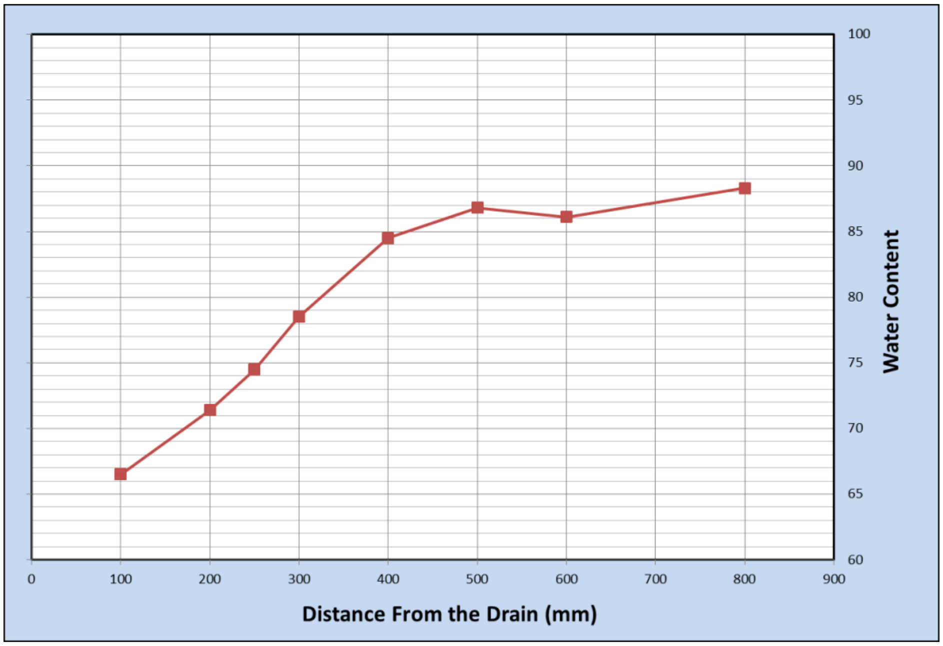

Fig. 2. Variation of water content along the radial distances

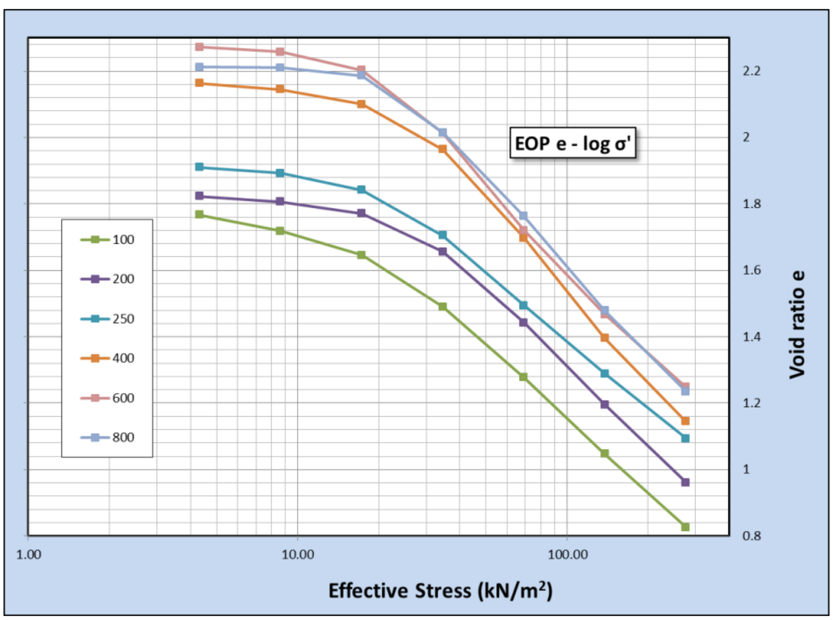

Fig. 3. Soil compressibility curves

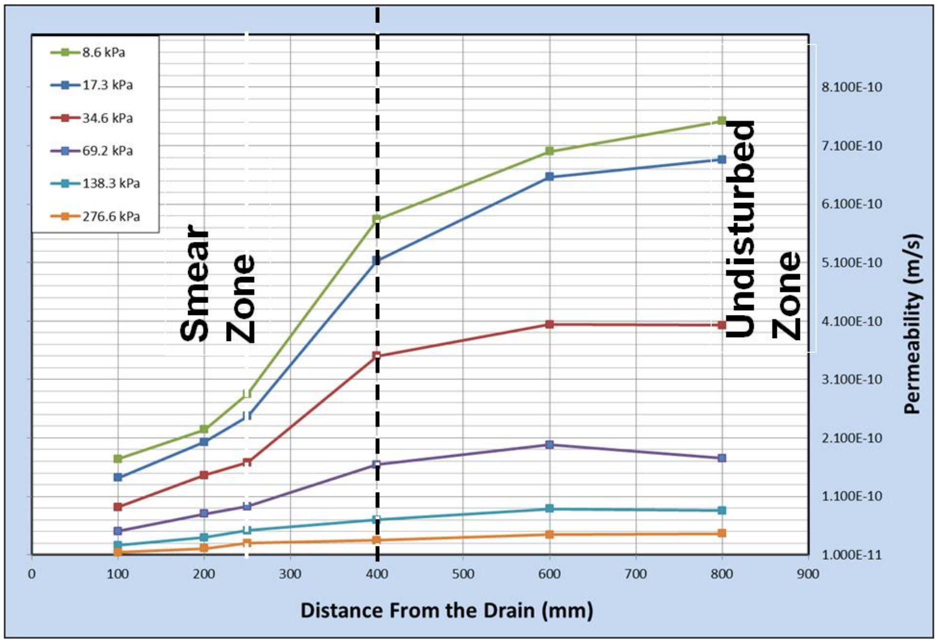

Fig. 4. Lateral soil permeability variation

5. CONCEPTUAL MODEL CAPTURING SOIL DISTURBANCE AROUND PVDS

Soil destructuration can occur while samples are being retrieved or drains are being installed by the steel mandrel. The degree of disturbance can be quantified using the compression curves (Schmertmann, 1953; Nagaraj et al, 1990; Nagaraj et al, 2003; Prasad et al, 2007). Most specimens with some degree of disturbance will show a compression curve that falls in between the compression curves of the undisturbed and completely remolded samples (Rutledge, 1944). Therefore, a structured soil represents an ideal condition for insignificant disturbance while a reconstituted soil represents a disturbed soil, or the condition of destructuration. In view of the above, a conceptual model to evaluate the degree of disturbance in relation to the soil structure is proposed using the compression curves shown in Figure 5 and the conceptual description given below.

a) The compression curves of partially disturbed soil can be obtained by plotting the various void ratios against the mean effective stress. It is assumed that the yield stress of the partially disturbed soil is located on the extrapolation of the line AB (Fig. 6) through the yield stress points intersecting the horizontal line from the in-situ void ratio. This line is perpendicular to the intrinsic state line (Nagaraj. et.al., 1990).

b) Based on the concept of a Structured Cam Clay Model, in the elastic behaviour region. The laboratory testing in this study was carried out under one dimensional conditions, and the original parameters λ, κ, and p' were substituted with c_c, c_s, and σ'_v, respectively.

c) Line **AB** can be constructed to obtain the loci of yield stress for the partially disturbed soil. The proposed line where the yield stress points locate is the line through point B of the value of the initial yield stress ($\sigma'_{v,y,i}$) of the structured soil and the perpendicular intersect of the ICL of the reconstituted soil at point A

A small sample of undisturbed clay and a remolded sample were tested using conventional oedometer apparatus to set up the boundaries of the virgin undisturbed curve and the remolded curve. The specimens cored along the radial distance from the centre of the drain considered to be partially disturbed, were also tested with the oedometer apparatus.

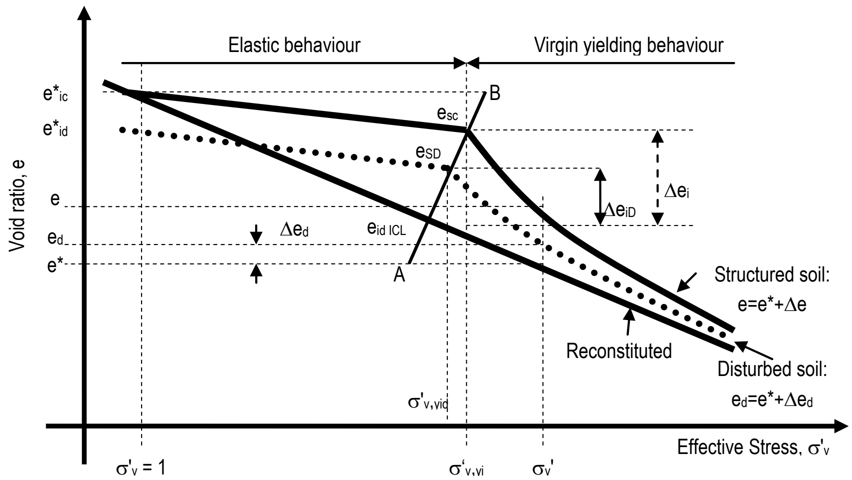

Fig. 5. Proposed concept to evaluate the degree of soil disturbance (Rujikiatkamjorn et al. 2013).

6. CONCLUSIONS

Soil disturbance associated with vertical drain installation was investigated using samples extracted from a soft clay site in Ballina, NSW. Extent of the smear zone is established based on the variation of water content, normalised permeability and soil compressibility. It can be observed that water content was steadily increased within 400mm radial distance from the soil-drain interface and then remains relatively constant. Void ratio and horizontal permeability also have the same trend. They indicate that higher disturbance was within the 400mm from the centre of the drain and it became relatively less disturbed in the outer section. All of these results confirm a smear zone of 6 times of equivalent mandrel radius which is significantly larger than the previously studies. However previous experimental studies were limited to remoulded specimens and relative small mandrels, driven to relatively thin soil (less than 1m). This study shows that soil can experience higher amount of disturbance as a result of higher installation rates with longer drains in the field. Smear zone parameters significantly affect the rate and magnitude of final settlement therefore it is recommended that related parameters should be determined using undisturbed samples to obtain a better prediction of settlement and pore water pressure dissipation.

ACKNOWLEDGMENTS

Authors would like to acknowledge the support given by Dr. Richard Kelly formerly at Coffey

Geotechnics and the Centre of Excellence for Geotechnical Science and Engineering. The third Author's PhD was sponsored through the Endeavour Scholarship scheme by the Australian government.

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