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EFFECT OF CONSTRUCTION SEQUENCE ON THE PERFORMANCE OF GEOTEXTILE TUBES IN A CONTAINMENT BUND

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ABSTRACT: Geotextile tubes (geotubes) filled with lightly Cement-Mixed Soil (CMS) are used to construct a containment bund. The proposed containment bund was made of three layers of geotextile tubes, where each of the geotube was infilled to a height of 2m and stacked to form a 6m high containment bund in the shape of a triangular prism. Three geotubes were placed side by side to form the first layer of the containment bund. The shear strength development of the CMS of the first layer containment bund was evaluated using a modified mini Cone Penetration Test (CPT) after the infilling. The results suggested that the shear strength developed in the centre geotube is generally lower than the edge geotubes. It was hypothesised that the edge geotubes, which were installed before the centre geotube, hindered the dewatering action of the centre geotube during its infilling process. Hence, a study on a scaled-down version of the three geotubes arrangement was conducted in the field with instrumentation. The hypothesis mentioned above was examined through the changes in volume and strain mobilised in the geotextile of geotube, the dewatering rate, and the shear strength development of the CMS, pore pressure and total pressure changes during infilling and dewatering phase of the geotubes. The study showed that the construction sequence of the geotubes indeed affects the shear strength development of the CMS.

Keywords: Geotextile tubes, Lightly cemented clay, Containment bund, Dewatering, Shear strength

1. INTRODUCTION

Geotextile tube can be used for coastal and shore protection, forming embankments, jetties, breakwaters, artificial reefs, slope buttressing and temporary protection dykes [1-3]. Sand is conventionally the preferred infill material of geotextile tubes (geotubes) to construct a stable containment bund. There are lots of study in the application of sand slurry filled geotubes in the marine engineering application, as in [4] and [5]. However, due to the shortage of sand in Singapore, lightly CMS is being studied as alternative infilling material for geotubes. Few successful case studies in using CMS as infilling material for geotube were reported as in [6] and [7].

In one of Singapore's land reclamation projects, a containment bund was made up of three layers of geotubes, where each geotube was filled to a height of 2m and stacked to form a 6m high containment bund in the shape of a triangular prism as shown in Fig.1.

The first layer of the containment bund was made up of three geotubes placed side-by-side. After approximately three months since the infilling of the first layer of geotubes with CMS, the shear strength of the infill material was measured using a miniature CPT equipment. It was found that the geotube in the centre had a lower shear strength as compared to the edge geotubes, as shown in Fig. 2.

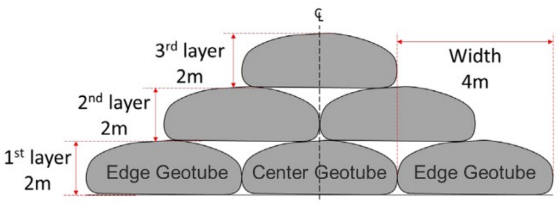

Fig.1 Cross section of geotubes containment bund (schematic).

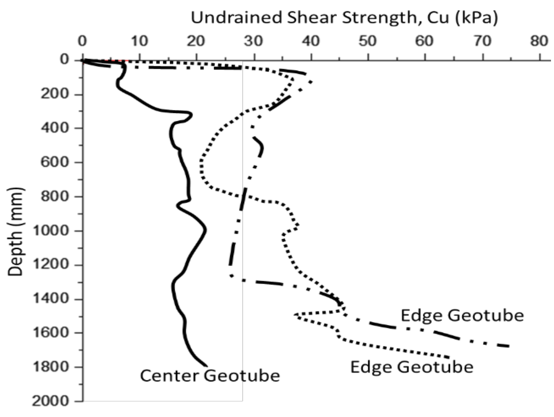

Fig. 2 Undrained shear strength, Cu of geotubes.

This was believed to be related to the construction sequence, where two edge geotubes were installed before the installation of the centre geotube. A hypothesis was made that the installed edge geotubes somehow hindered the dewatering action of the centre geotube during its infilling process. The hypothesis can be illustrated in Fig. 3.

In order to verify the proposed hypothesis, a field test with a scaled-down version of the three geotubes arrangement, as shown in Fig.4 was conducted to simulate the actual large containment bund. These small geotubes were well-instrumented.

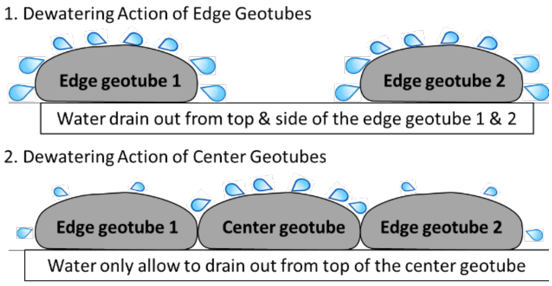

Fig.3 Hypothesis of geotube's dewatering action.

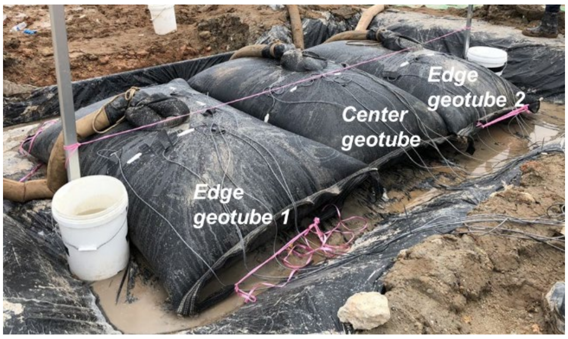

Fig. 4 Scaled-down version of the three geotubes arrangement.

2. MATERIALS

This section presents the materials used in this study. The properties of the geotextile, type of soil, cement, and monitoring instruments are elaborated.

2.1 Properties of Geotextile Materials

The scaled-down instrumented geotubes have a length of 2m and a circumference of 2.52m. The targeted height of the geotube was approximately 0.6m when filled. The geotube was made of Polypropylene (PP) woven geotextile, and the properties of the geotextile are tabulated in Table 1.

2.2 Properties of Cement-Mixed Soil (CMS)

The Unified Classification of the soil used to produce the CMS infilling material is Sandy-Clayey SILT, the particle size distribution of this soil can be found in [8]. The soil is then mixed with Ordinary Portland Cement (OPC). The cement content used was 7% to the dry unit weight of the soil. The bulk density of the CMS was determined to be 1.25 – 1.35 g/m^3.

Table 1 Properties of geotextile material

Properties	Test Standard	Unit	Values
Tensile strength (MD/CD)	ISO 10319	kN/m	120/120
Elongation at break (MD/CD)	ISO 10319	%	20/15
Seam strength (CD)	ASTM D4884	kN/m	85
CBR puncture resistance	ISO 12236	kN	>14
Water permeability	ISO 11058	l/m^2/s	13
Pore size, O_{90}	ISO 12956	mm	<0.25

2.3 Monitoring Instruments

The instrumentation plan for the geotextile tubes is shown in Fig.5. All three geotubes were each instrumented with six strain gauges to capture the mobilised strains at the locations that were more prone to tearing.

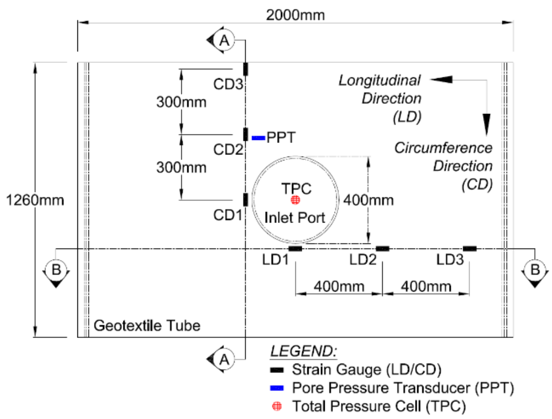

Fig. 5 Monitoring instruments layout on geotube when placed on flat (plan view).

Three strain gauges were attached in the Circumferential Direction (CD), and the other three were attached in the Longitudinal Direction (LD) as shown in Fig.6. The strain gauges installation method proposed by Chew [9] was used in this study. Each geotubes was also fitted with one Total Pressure Cell (TPC) and one Pore Pressure Cell

(PPC) near the bottom of inlet port to measure the variation of total pressure and pore water pressure with time, especially during the infilling process. A camera was used to capture the height change of the geotubes during the infilling and dewatering stages.

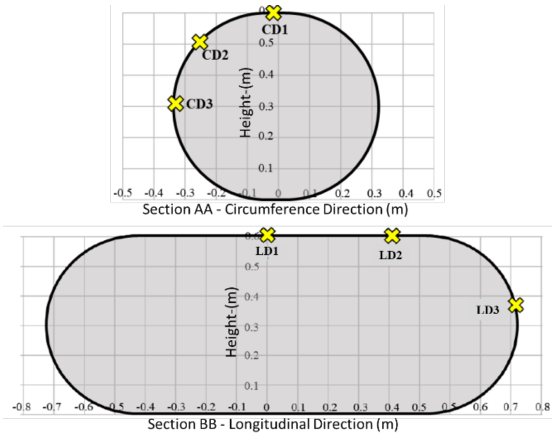

Fig. 6 (Section AA & BB from Fig. 2) - Strain gauges location in CD & LD.

3. FIELD TEST SETUP & TEST PROCEDURE

The field test setup comprises of (a) a mixing pit with pump and pipeline, (b) the infilling and dewatering platform for the geotubes, and (c) a sump pit to collect the "dewatered" water from the geotubes. A layer of geomembrane was laid on the platform before the geotubes were laid on top of it. The geotubes were overlapped by up to 0.4m to simulate the actual construction conditions of the geotube containment bund. In addition, two levelling rods were positioned at both sides of the edge geotubes. The changes in the height of the geotubes can then be analysed through the photos recorded by a camera positioned in front of the geotubes. Fig.7 shows the field setup mentioned above.

The field test began with the preparation of the CMS in the mixing pit. The infilling sequence followed with the first geotube on the right (GT1). After the GT1 had attained a height of 0.6m, the geotube on the left (GT2) was immediately infilled. Simultaneously, the water drained out from both of the geotubes during the dewatering process was collected in the sump pit. The volume of water collected was measured.

The infilling process of the centre geotube (GT3) started after the dewatering process of the two edge geotubes (GT1 & GT2) ended. Similarly, the volume of water drained from the centre geotube was measured. The entire infilling and dewatering process was recorded with a camera, which provides a record of the volume and height change of geotube with time. Fig. 8 illustrates the infilling sequence of geotubes.

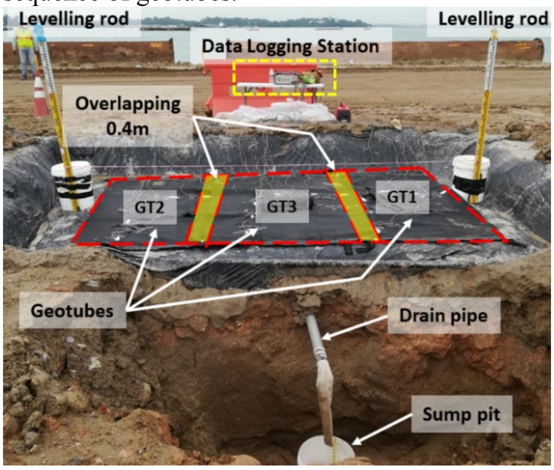

Fig. 7 Field Test Setup.

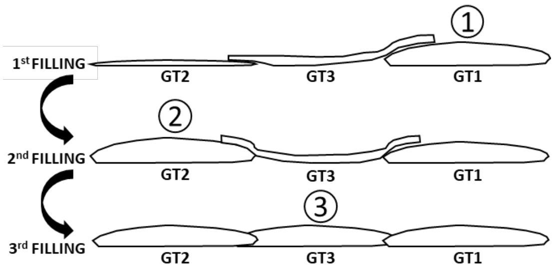

Fig. 8 Filling sequence (front view).

4. RESULTS & DISCUSSIONS

4.1 Changes in Shape, Height & Volume

Fig. 9 shows the changes in height and shape of the geotubes with time during the infilling and dewatering process. This enables the calculation of the change in volume of the geotubes with time by applying Eq. (1) proposed by Yee et al. [10]:

$$V_T = L_T {D_T}^2 \left[\left(\frac{h_T}{D_T} \right)^{0.815} - \left(\frac{h_T}{D_T} \right)^{8.6} \right] \quad (1)$$

where V_T is the volume of the geotube, L_T is the length of the geotube, h_T is the measured height of the geotube, and D_T is the theoretical diameter of the geotube. In this study, L_T = 2m and D_T = 0.802m.

The volume change of each geotube during the dewatering stage with infilling time is presented in Fig.10. It illustrates that the results for GT1 and GT2 are consistent as they are identical in boundary condition at infilling and dewatering stages. It also clearly shows that the volume reduction of GT3 was much slower than that of GT1 and GT2. This suggests that the dewatering rate of the center geotube, GT3 was lower as compared to the edge geotubes. This suggestion can be further proved from the actual dewatering rate analysis of each geotube that will be presented in the next section.

4.2 Dewatering Rate

The dewatering rates of each geotube during the dewatering stage are plotted in Fig.11 using the recorded volume of effluent from the geotubes with time. For simplicity of calculation, the edge geotubes (GT1 and GT2) were assumed to have the same dewatering rate in this test. Hence, the volume of effluent collected from the edge geotubes (GT1 & GT2) was aggregated, and the average volume was taken to compute the dewatering rate as they took place under the same time. From Fig. 8, the centre geotube (GT3) showed a lower dewatering rate after 20 minutes as compared to that of the edge geotubes (GT1 & GT2). This result matches the hypothesis in the earlier section and leads to the conclusion that the centre geotube will be blocked or hindered by the edge geotubes, and thus the dewatering action will be slowed down during the dewatering stage.

4.3 Shear Strength Development

After infilling, the geotubes were left untouched for dewatering action and cementation reaction to take place. A modified mini CPT was then conducted on the geotubes after 7 days and 28 days to ascertain the shear strength development of the infilled CMS. At 7 days, only one CPT testing point was conducted at each geotube, while two CPT testing points were conducted for each geotube at 28 days. Fig.12a and Fig.12b show the shear strength development of the CMS in the geotubes at 7 days and 28 days, respectively.

The shear strength of the CMS at 7 days was in the range of 5kN/m^2 to 12kN/m^2 and increased to approximately 10kN/m^2 to 20kN/m^2 at 28 days. GT3 consistently had a lower shear strength at 7 days and 28 days than that of GT1 and GT2. This result proves that the slow dewatering rate mentioned in the earlier section leads to a slightly lower shear strength development in GT3. It is also interesting to note that the shear strength at 7 days was uniformed with depth, while at 28 days, the CMS seemed to develop a higher shear strength with depth for all three (3) geotubes.

4.4 Mobilised Local Strain

The mobilised local strains in the circumferential and longitudinal direction on geotextile material of the geotubes are shown in Fig. 13a and Fig.13b, respectively. The strain data in both directions show that the highest local strain is generally generated at the moment when the maximum infilling height is attained. CD3-GT2 malfunctioned and thus has not been included in the analysis.

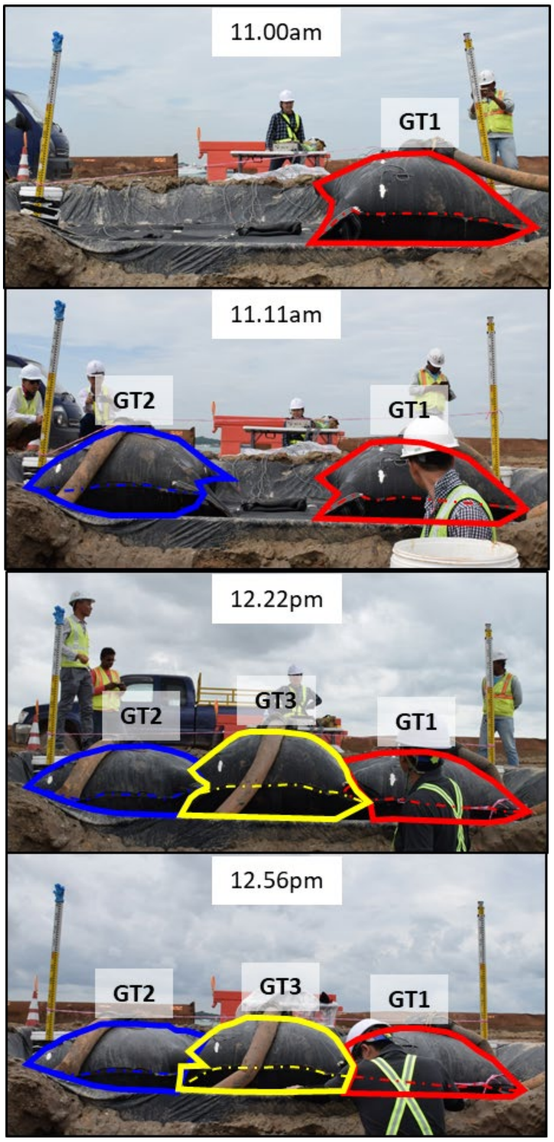

Fig. 9 Shape and height changes of geotubes.

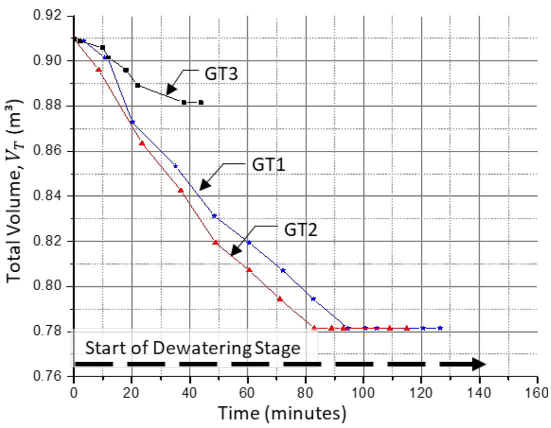

Fig. 10 Volume changes of geotubes over time of infilling.

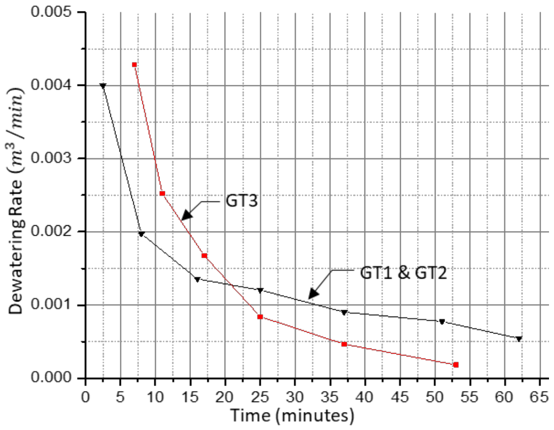

Fig. 11 Dewatering rate of geotubes.

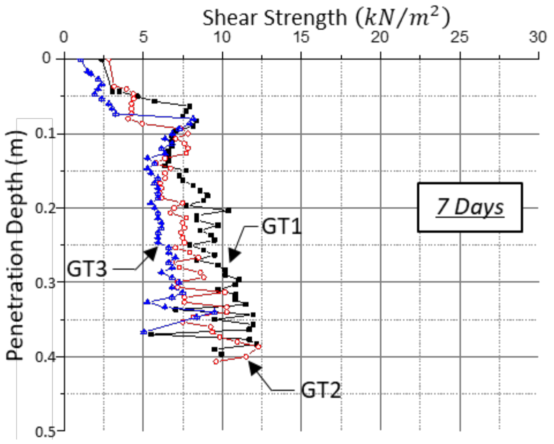

Fig. 12(a) Shear strength of infilling material at 7 days.

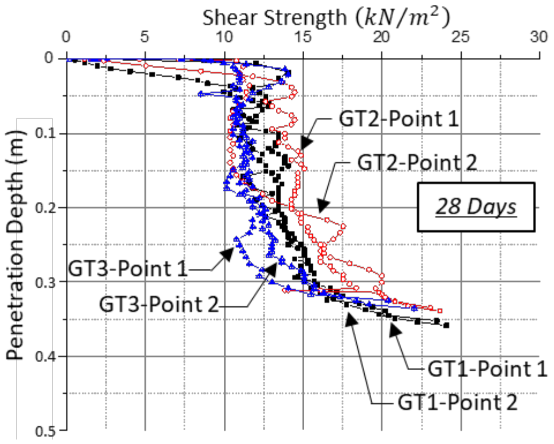

Fig. 12(b) Shear strength of infilling material at 28 days.

CD1-GT1 and LD3-GT1 registered the maximum local strain of 1.7% and 1.5% in the circumferential and longitudinal direction, respectively. This is because CD1-GT1 was attached nearest to the inlet port, and LD3-GT1 was attached at the highest curvature point. Surprisingly, LD2-GT3 also registered the maximum local strain of 1.5% in the longitudinal direction. It could be due to the infilling sequence where the infilling of GT3 commenced immediately after GT1 and GT2 were filled. The edge geotubes would have obstructed the expansion of GT3 in the circumferential direction leading to higher strain developed in the longitudinal direction for GT3 at that moment.

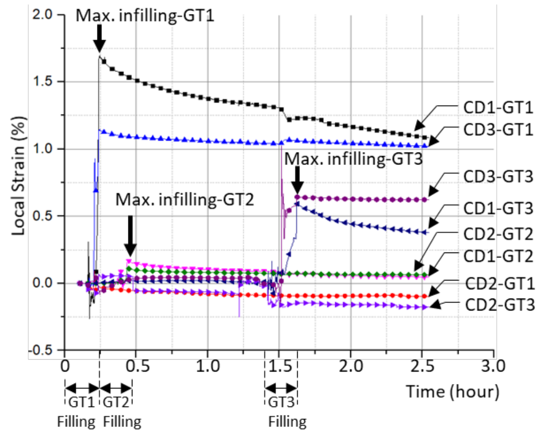

Fig. 13(a) Mobilised strain at CD on geotubes over time. (Refer to Fig. 3 for the location of the strain gauges)

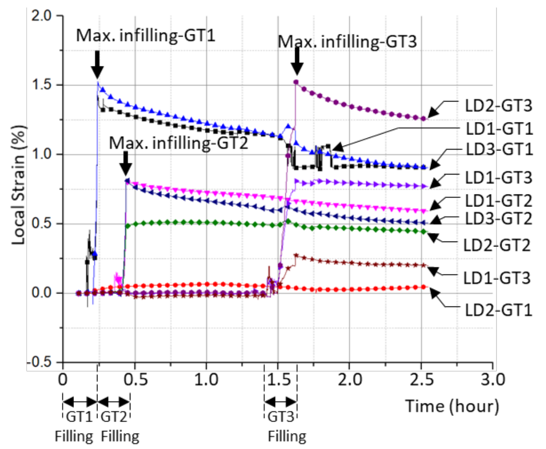

Fig. 13(b) Mobilised strain at LD on geotubes over time. (Refer to Fig. 3 for the location of the strain gauges)

4.5 Total Pressure & Pore Pressure

The total pressure in the geotubes during the test are shown in Fig.14, with the times when the geotubes infilling took place indicated. It is shown that all geotubes registered the maximum total pressure at the end of infilling, and the total pressure subsequently gradually decreased with time.

The pore pressure measured within the geotubes with time is shown in Fig.15. The maximum pore pressures of GT1 and GT2 were at the end of infilling when the geotubes were pumped to an approximate height of 0.6m. Subsequently, during the dewatering stage, the pore pressures decreased. However, the pore pressure in GT3 increases gradually with time even during the dewatering stage. It might occur due to a malfunction of the pore pressure transducer in the GT3.

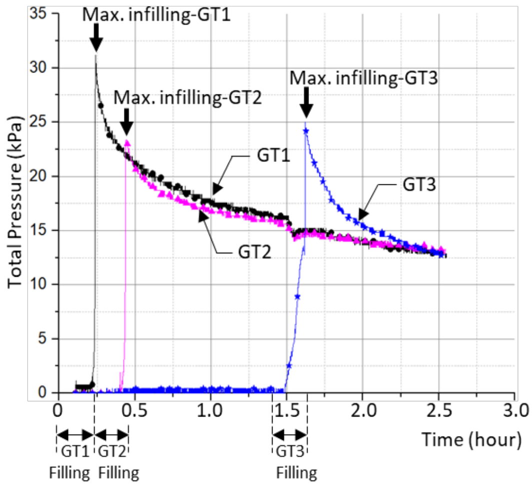

Fig. 14 Total pressure development of geotubes.

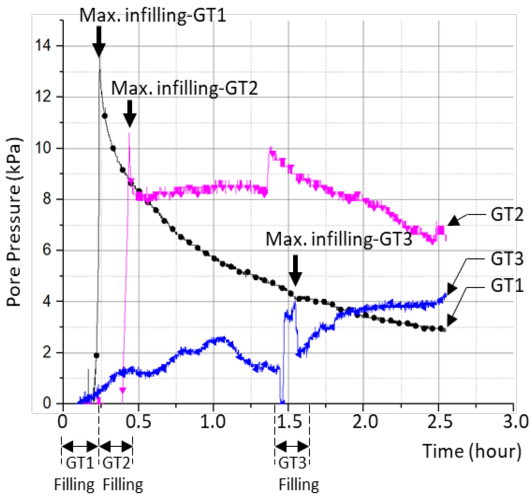

Fig. 15 Pore pressure development of geotubes.

5. CONCLUSION

A field test with scaled-down size geotubes filled with CMS material was conducted to model the effect of the construction sequence of the first layer of containment bund.

Three geotubes were modelled according to the actual construction sequence, where the two edge geotubes were installed first, followed by the centre geotube. It was found that the volume reduction with time of the centre geotube is generally slower than the edge geotubes. This result is consistent with the observation that the dewatering rate of the centre geotube is also the lower than the two edge geotubes.

The shear strength development of the CMS in the geotubes further supports the finding above, where the centre geotube had slightly lower shear strength amongst the three geotubes at 7 days and 28 days. It was also observed that the limited space for centre geotube to expand sideways during the infilling stage caused the longitudinal direction of the centre geotube to experience slightly higher strain as compared to that in the circumferential direction.

In conclusion, the construction sequence of the geotubes for the first layer in a containment bund would affect the behaviour of the geotubes, particularly the centre geotube.

6. ACKNOWLEDGEMENTS

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