Performance of pilot test of geotextile tube filled with lightly cemented clay

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ABSTRACT: The sand-filled geotextile tube is common, and has been well-established in coastal engineering applications. However, the use of soft clay or dredged material as the infill material for geotextile tube containment bunds is not widely used due to technical concerns on the stability and excessive settlement of the geotextile tubes. To minimize shape deformation and settlement of geotextile tubes associated with the use of soft clay, a modified infill material is proposed – lightly cement-mixed-soil (CMS). This study is aims to investigate the response of a full-scale, instrumented geotextile tube of 20m length, 12.6m circumference and inflated height of approximately 2m when filled with lightly CMS and subjected to surcharge. The surcharge simulates the condition where the geotextile tubes are stacked on top of each other to form a containment bund. The shear strength development at 3-days and 7-days curing of the CMS were also evaluated. This study will provide valuable insights into the design and construction of containment bunds using geotextile tubes infilled with soft clay or dredged material.

Keywords: geosynthetics, geotextile tube, field study, cemented soil, clay, containment bund

1 INTRODUCTION

The usage of geotextile tubes have been well-established and widely used in the coastal engineering and dewatering industry. To construct a stable containment bund with geotextile tubes, sand slurry has always been the preferred infill material (Lawson 2008, Adel and Pilarczy 1996, Bezujien and Vastenburg 2012). In Singapore's context, the utilization of soft clay or dredged material (which is comparatively more readily available than sand) as the infill material for geotextile tubes, has the potential to yield economic benefits and cost savings when used to construct long containment bunds. However, there are technical challenges when using soft clay or dredged material as an infill material, including the problem of excessive settlement and concerns with the stability of the geotextile tube (Shin and Oh 2007).

To minimize shape deformation and settlement of geotextile tubes associated with the use of soft clay, a modified infill material is proposed – lightly cement-mixed-soil (CMS). A study had previously been carried out on a series of scaled-down geotextile tubes with varying cement and initial water content (Chew 2017). As a continuation to the previous study, this study aims to investigate the responses of a full-scale, instrumented geotextile tube of 20m length, 12.6m circumference and inflated height of approximately 2m when filled with lightly CMS and subjected to a surcharge. The loading simulates the condition where the geotextile tubes are stacked on top of each other to form a containment bund.

To minimize shape deformation and settlement of geotextile tubes associated with the use of soft clay, a modified infill material is proposed – lightly cemented soft clay. A preliminary study conducted on a series of scaled-down geotextile tubes filled with lightly cemented clay of varying initial water content of 140% to 165% and varying cement content of 0% to 8% by weight (Chew 2017). It was concluded from this previous study that the construction of containment bunds with geotextile tubes infilled with lightly cemented clay is technically feasible and stable with the use of sufficiently strong (i.e. adequate tensile strength) geotextile tube material. The study also concluded that the adequate control on the dosage of cement content, and suitable water content of infilling soft clay material are critical factors for the success of this application. As a continuation from the previous study, a cement content of 5% was used for the full-scale geotextile tube (of 12.6m circumference) in this study.

2 MATERIALS

2.1 *Properties of geotextile tube*

For this study, the instrumented geotextile tube has a length of 19.9m and a circumference of 12.6m. When filled, the geotextile tube is targeted to attain a height of approximately 2m.

The geotextile tubes were stitched from panels of Polypropylene (PP) woven geotextile. This woven geotextile provides the high strength and strong integrity required in withstanding harsh offshore conditions. The properties of the geotextile are tabulated in Table 1:

Table 1. Properties of geotextile material

Properties	Test Standard	Unit	Values
Tensile strength (MD/CD)	ISO 10319	kN/m	120/120
Tensile 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

2.2 *Properties of cement-mixed-soils (CMS)*

The CMS used as the infill material for the geotextile tube is soil recycled from excavations at construction sites around Singapore. The unified soil classification of the soil is SILT and its particle size distribution of this soil is shown in Figure 1. This soil is mixed with Ordinary Portland Cement (OPC) in mixing pool on site. The cement content used was 5% 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.

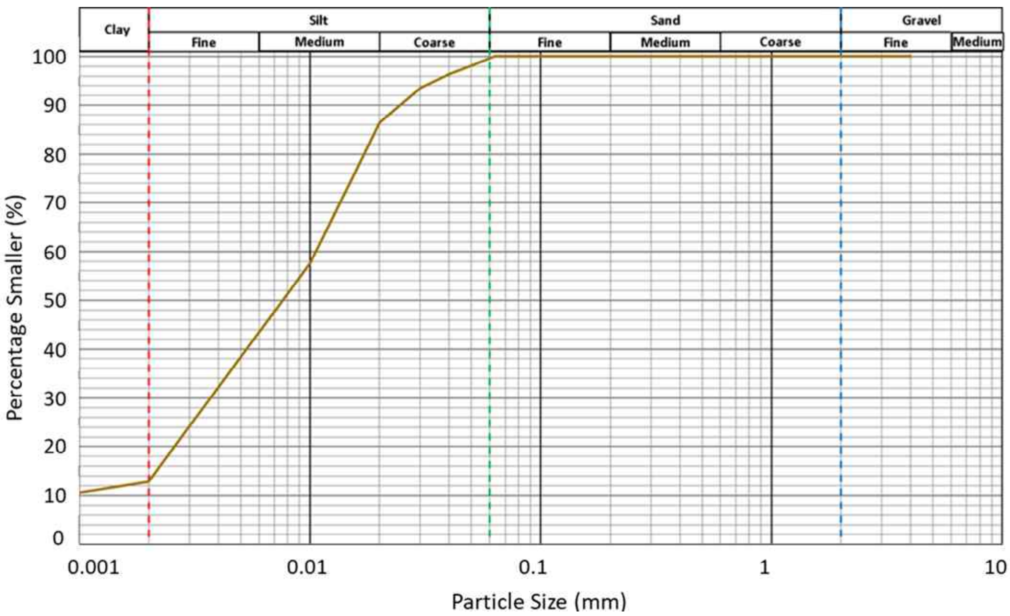


Figure 1. Particle size distribution of the soil used in the cement-mixed-soil (CMS)

2.3 *Monitoring instruments*

A total of 23 strain gauges were installed to capture the mobilized strain in the geotextile tube in the circumferential (11 units), longitudinal (6 units) and diagonal (6 units) directions. The strain gauges were labelled as CD, LD and DD where they denote the circumferential, longitudinal and diagonal directions respectively. The strain gauges were attached using the method proposed by Chew et al. (2000) on the inner surface of the geotextile tube. In addition, one unit of total pressure cell (TPC) and one unit of pore pressure transducer (PPT) were installed at the bottom of the geotextile tube to measure the variation of total pressure and pore water pressure over time. The layout of the sensors on the inner surface of the geotextile tube is shown in Figure 2.

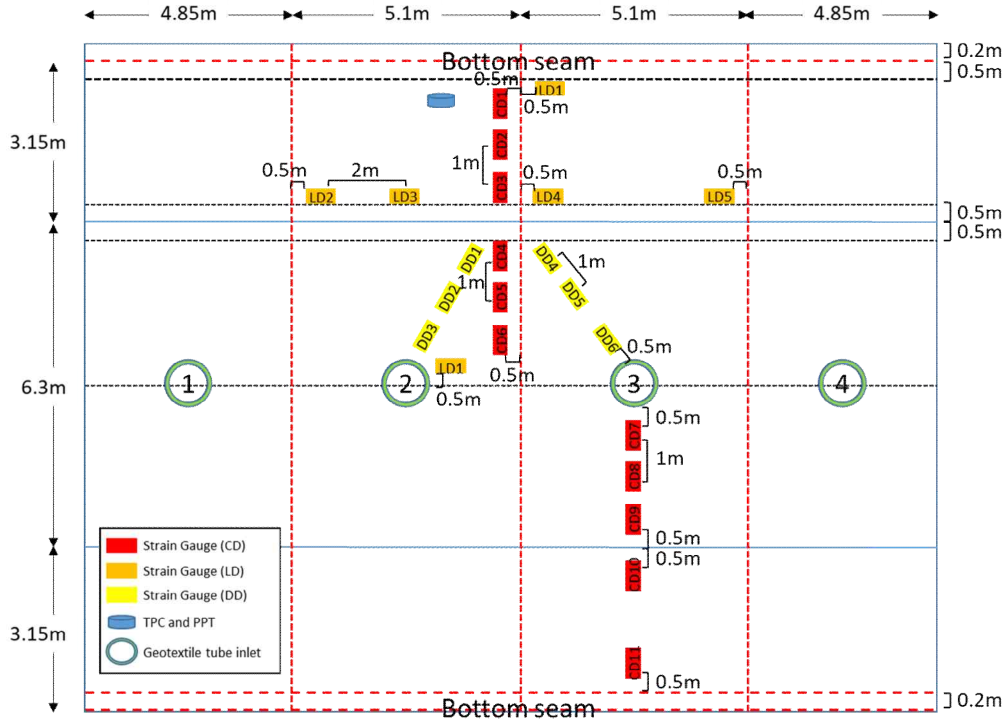


Figure 2. Placement of sensors on the inner surface of the geotextile tube

A modern instrument called Shape-Array-Accelerator (SAA) of 12m was also installed horizontally at the bottom of the geotextile tube to measure its settlement profile over time. Settlement plates were also installed. Figure 3 shows the cross-section of the geotextile tube with the SAA and settlement plates during the loading stage.

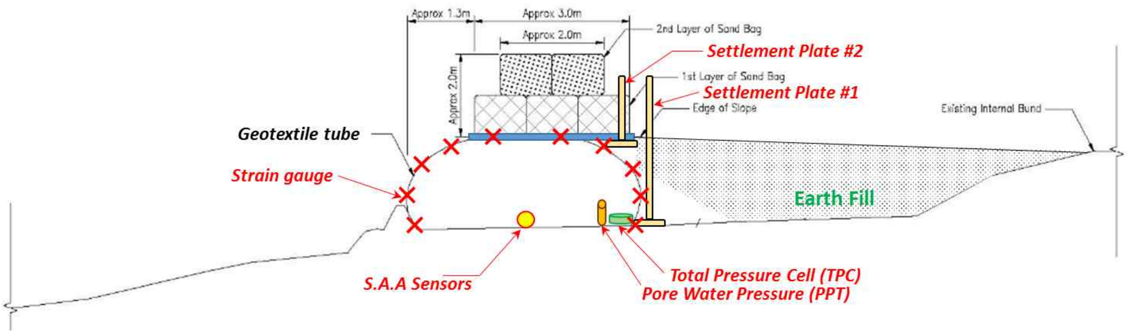


Figure 3. Cross-sectional view of the geotextile tube during loading stage

3 FIELD WORKS

The geotextile tube infilled with CMS was constructed at the edge of a reclamation site in Singapore. The field works of this study included the development of field mixing facilities, preparation of the test platform, infilling and dewatering activities of the geotextile tube, and the subsequent loading on the geotextile tube. Except for the loading activity, the setup was largely similar to that elaborated in Chew (2017).

3.1 *Filling and dewatering stage*

There were two infilling cycles for the geotextile tube used in this study. The first was where CMS was pumped into the geotextile tube until it had attained a height of approximately 1m. The second cycle of infilling was carried out till the filled height of about 2m after approximately 20h. Subsequently, the geotextile tube was left to dewater for approximately 1.5 months before surcharge was applied onto it. The monitoring of the sensors started with the commencement of the infilling works. Figure 4 shows the completed geotextile tube after two cycles of infilling.

Figure 4. Geotextile tube after the two cycles of infilling

Due to the gentle sloping ground conditions and the geotextile tube not being aligned in a straight line at the beginning of the infilling stage, the sensors installed on the geotextile shifted during the first filling cycle. The TPC and PPT shifted near to the edge of the geotextile tube as shown in Figure 5(a). During the second cycle of infilling, it was observed that the further inflation and distortion of the geotextile tube lifted the TPC and PPT to the edge of the geotextile tube as shown in Figure 5(b).

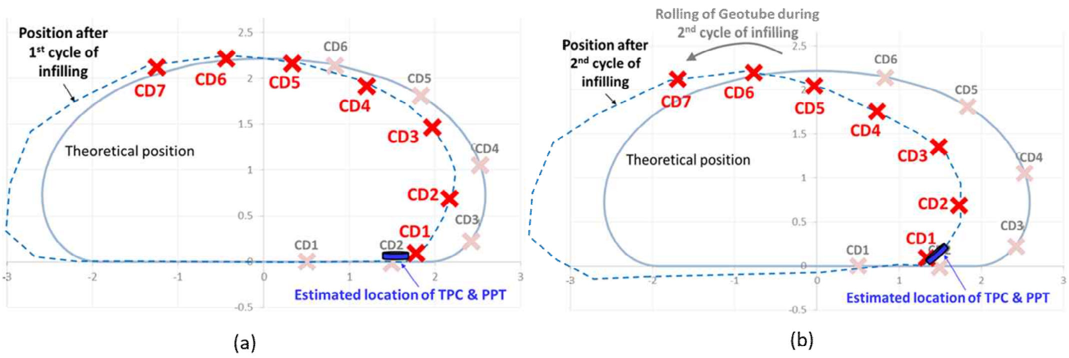


Figure 5. Approximate position of strain gauges, TPC and PPT after:
(a) first cycle of infilling; (b) second cycle of infilling

3.2 *Loading stage*

A surcharge of approximately 500kN was subsequently applied slowly on the geotextile tube to investigate the response of the filled geotextile tube. This partially simulated the condition where the geotextile tubes are stacked on top of each other to form a containment bund.

4 RESULTS AND DISCUSSIONS

4.1 *Mobilised local strain*

4.1.1 *Infilling and dewatering stage*

Figure 6(a) and Figure 6(b) show the mobilised strain at the different locations on the geotextile tubes in the circumferential, longitudinal and diagonal direction respectively. Strain on the geotextile increased rapidly during the infilling stages, and slowly decreased in the dewatering stage. According to the strain data, the highest local strains were at the end of the second cycle of infilling (i.e. at the maximum filling height). CD7 and LD6 registered the maximum local strains of 1.6% and 3.2% in the circumferential and longitudinal directions respectively. For the diagonal direction, due to the shifting of the geotextile tube during the first cycle of infilling, the maximum strain of 3.6% was observed at DD3.

The maximum strains were found to be located at the top of the geotextile tube. This is consistent with the theoretical calculation. As the geotextile tube rolled slightly during its construction, it is to note that the position of the strain gauges shown in Figure 6(a) and 6(b) had shifted slightly from its original position as shown in Figure 5.

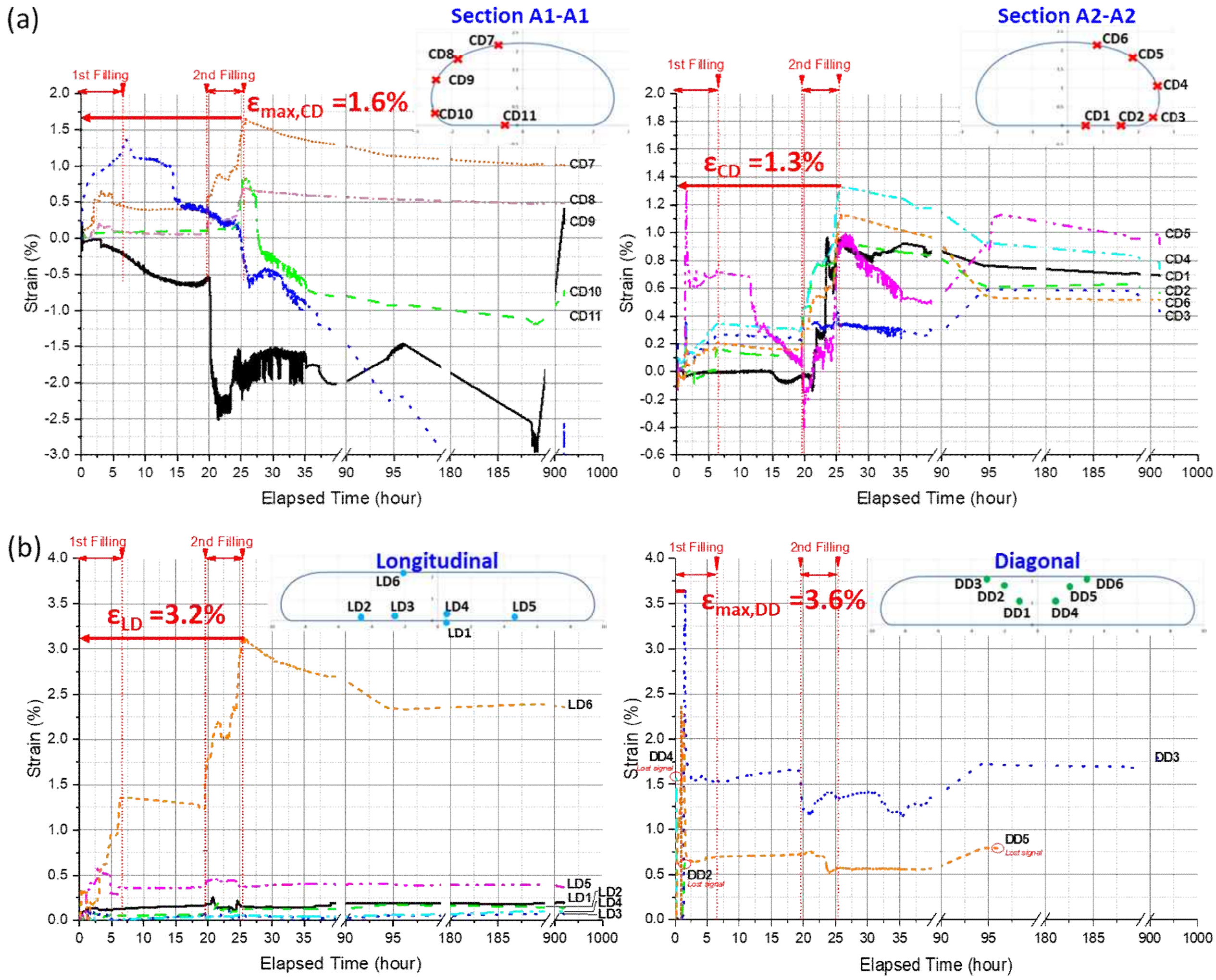


Figure 6. The mobilised strain on the geotextile tube over time during infilling and dewatering: (a) circumferential direction; (b) longitudinal direction and diagonal direction

4.1.2 *Loading stage*

Figure 7 and Figure 8 show the incremental mobilised strain when the geotextile tube was subjected to loading. In all directions, the incremental mobilised strain was insignificant in this stage with $\varepsilon < 0.5\%$. This testified that the geotextile tube infilled with lightly cement-mixed-clay is indeed very stable after some curing time. It can withstand some vertical load without much deformation.

4.2 *Total pressure and pore pressure*

4.2.1 *Infilling and dewatering stage*

Figure 9(a) shows the variation of measured total pressure and pore water pressure at the bottom of geotextile tube. It is observed that the total pressure increased with the filled volume of CMS during the two cycles of infilling, with a peak of approximately 15 kPa attained at the end of the first infilling stage, and subsequently a second peak at approximately 33 kPa. A rapid drop in total pressure was observed before the end of the second infilling cycle. This is likely due to the distortion of the geotextile tube, causing the TPC to be lifted off the edge of the geotextile tube and even rotated. The pore water pressure in both infilling cycles followed the trend of total pressure, but with a lower magnitude in measurement. The rotating of the PPT will not cause drop in pore water pressure at the end of the second infilling cycle.

It is interesting to note that the pressure registered in the TPC should be higher had the TPC not been lifted and rotated. Figure 9(b) shows the total pressure registered by a TPC at the base of a 0.6m high mini geotextile tube conducted in a previous study by Chew (2017).

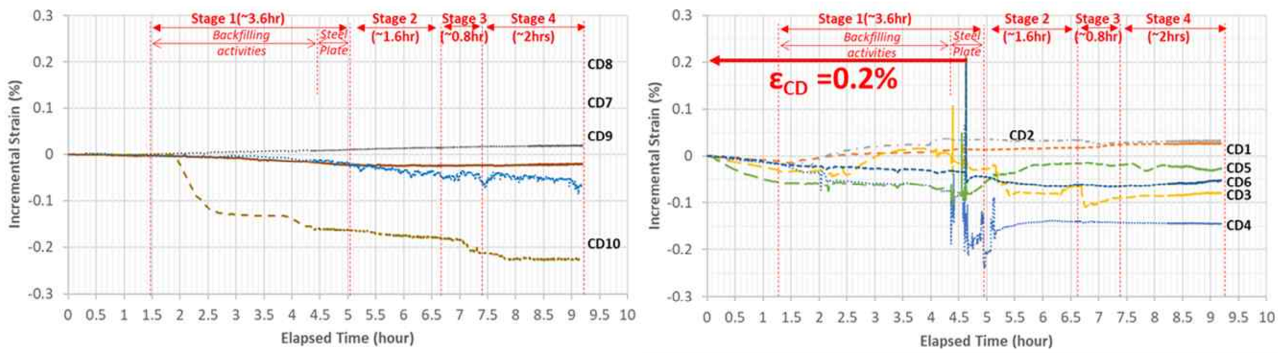


Figure 7. The incremental mobilised strain on the geotextile tube over time during loading in the circumferential direction for Section A1-A1 (left) and Section A2-A2 (right)

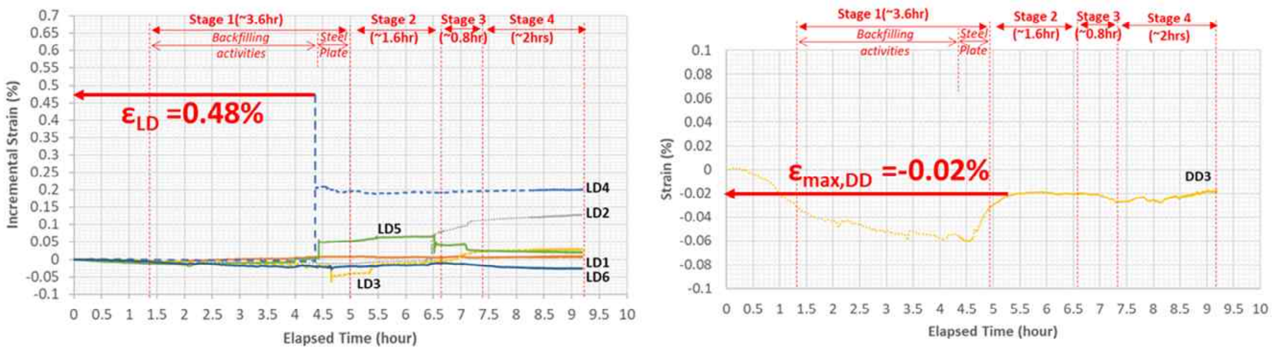


Figure 8. The incremental mobilised strain on the geotextile tube over time during loading in the longitudinal direction (left) and diagonal direction (right)

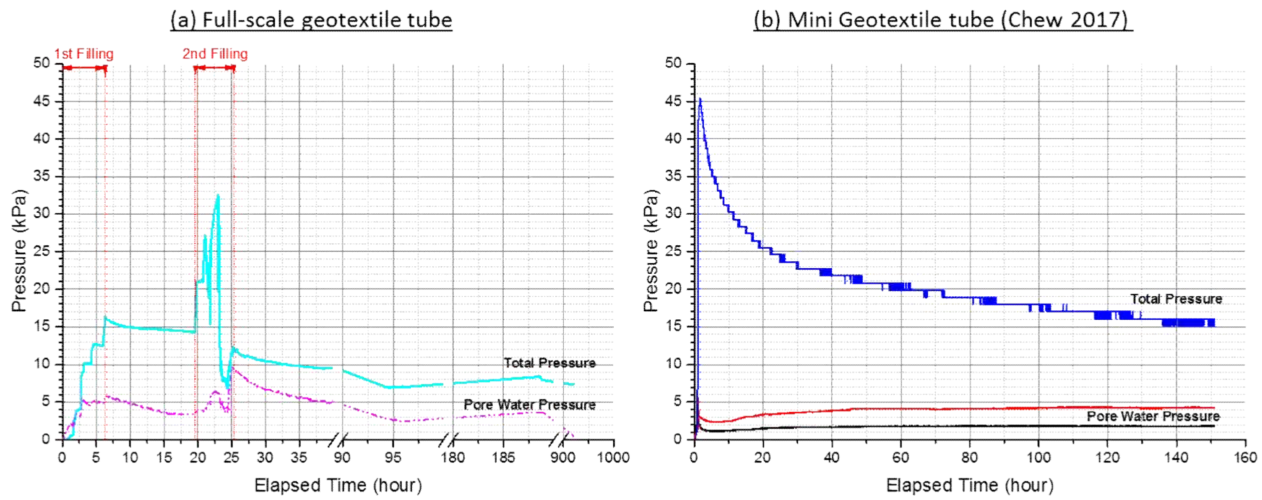


Figure 9. Variation of measured total pressure and pore water pressure at the bottom of geotextile tube for: (a) full-scale geotextile tube; (b) mini geotextile tube (Chew 2017)

4.2.2 *Loading stage*

Figure 10 shows the increase in total pressure and pore water pressure corresponding to the stages where the surcharge added. Stage 1 was loading preparation, where earth fill was dumped beside the geotextile tube and a steel plate was laid on top of the geotextile tube. Stages 2 and 3 was the application of vertical loading on the geotextile tube with two layers of sand bags, and Stage 4 was the maintenance of a constant load on the geotextile tube for two hours.

The instrumentation data showed that the rate of increase of total pressure and pore water pressure are the same in Stage 1 to Stage 3. According to the measured pressures, the geotextile tube was able to withstand some additional surcharge load. In Stage 4, the total pressure reached a stable reading, while the pore water pressure continued to build up for another 30 mins.

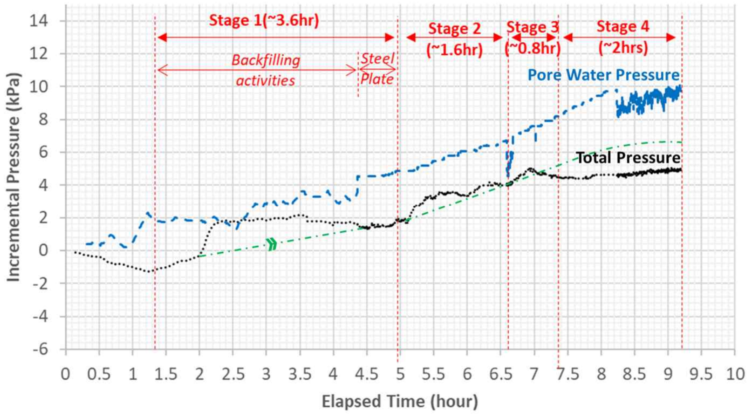


Figure 10. The incremental total pressure and pore water pressure in the geotextile tube over time when loaded

4.3 *Settlement profile*

The Shape-Array-Accelerator (SAA) installed provided very useful insights to the settlement profile at the bottom of the geotextile tube when it was subjected to loading. Figure 11 shows the SAA measurements relative to the reference point during the loading stage. During the duration of the loading, the maximum total settlement recorded was 15mm at the end of the SAA. This was located approximately at the middle of the geotextile tube. When the settlement profile from the SAA is plotted against time as shown in Figure 12(a) and 12(b), for location of 8m and 11.2m from one end, it is evident that when loaded, settlement of the geotextile tube at 11.2m is larger than that at the 8m location. The maximum settlement due to the sand bag loading at 11.2m is about 11mm.

The settlement plate #1 data showed similar results to that obtained from SAA, with a settlement of 10mm recorded as shown in Figure 13. This is comparable to the 11mm recorded from the SAA. Thus, the SAA measurement is accurate and validated. Based on the differential settlement recorded in the two settlement plates, it can be concluded that the height reduction of the geotextile tube due to loading was 8.1mm. This is equivalent to a 0.41% reduction in height.

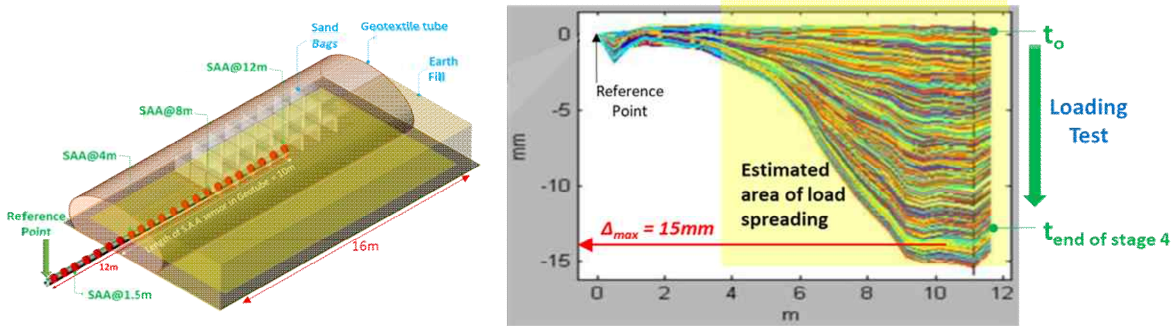
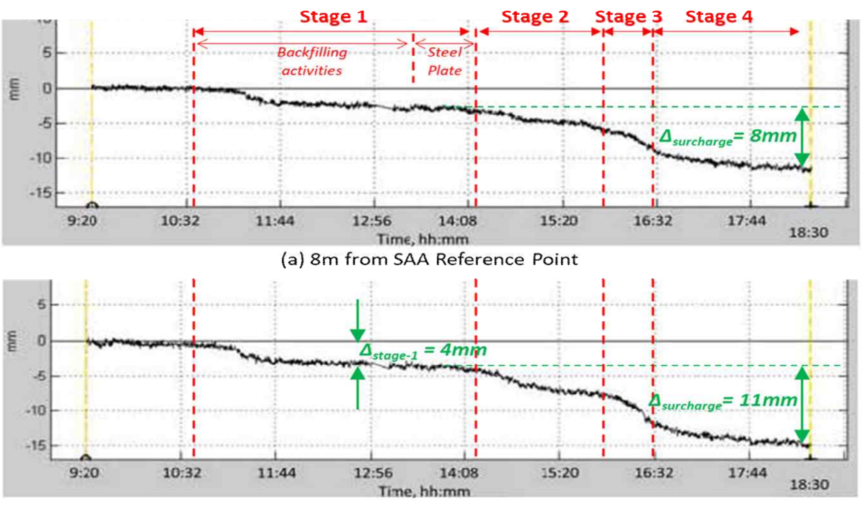


Figure 11. SAA measurements relative to the reference point during the loading



(b) 11.13m from SAA Reference Point

Figure 12. Settlement profile obtained from the SAA plotted against time at:
(a) 8m from SAA reference point; (b) 11.3m from SAA reference point

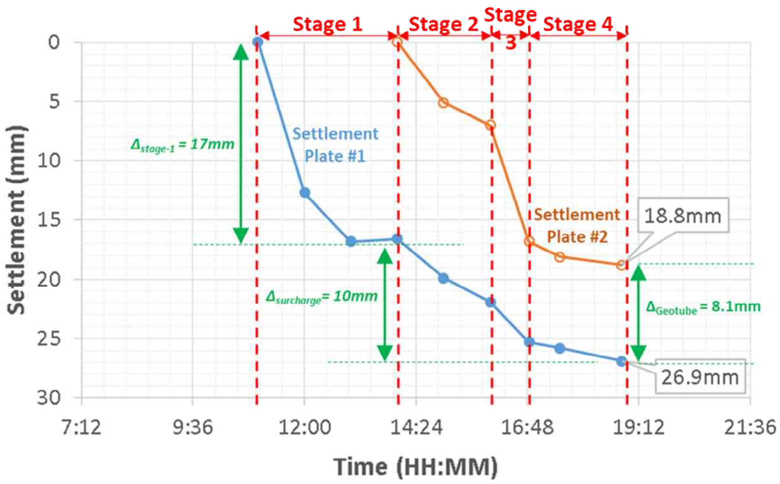


Figure 13. Settlement plate data

5 CONCLUSION

The extensive results from the strain gauges installed on this full-scale geotextile tube infilled with CMS material demonstrated consistent mobilization of tensile forces on the geotextile corresponding to the infilling activity, dewatering stage and subsequent loading stage. The mobilised strain was found to be in the order of 1 – 4%. In addition, there was very small change in mobilised strain and insignificant shape deformation when the geotextile tube was loaded after the CMS material has been cured for some time.

The TPC and PPT also provided valuable insights on the response of the geotextile tube during infilling and when it was subjected to loading. According to measured pressure, a geotextile tube filled with 5% of cemented-clay is able to provide confinement to distribute the top surcharge load to the bottom.

According to measured settlement from the SAA and settlement plates, the geotextile tube experienced a small height reduction at about 0.5% from its filled height when subjected to a surcharge load equivalent to another layer of geotextile tube.

Hence, a geotextile tube filled with 5% of lightly cemented-clay material shall be feasible for the application as a containment bund in a stacked structure with minimum shape deformation and settlement.

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