Experimental analysis on the stress and strain of geotextile tubes during filling and dewatering of dredged soil

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ABSTRACT: In general, it is very important to calculate the stresses and strain of geotextile tubes during filling and dewatering of dredged soil. Generally, the tension force is calculated by stress equilibrium, considering the angle between the tangent along a cross sectional element of the tube and the horizontal. However, a design concept on the stress and deformation of geotextile tubes during filling and dewatering has not been well established, considering that the fill material state changes from liquid with zero shear to solid with shear strength. In this study, the scale model test (SMT) and half-cross section test (HCST) were conducted to quantitatively measure the soil pressure, circumferential force, and strain of the tube structure. The measured data obtained from the tests were analyzed and relationships between the circumferential tension force (T), coefficient of earth pressure (K), vertical bottom pressure (P_{bot}) were established. With the relationships obtained from the tests, a more economical and reliable design of geotextile tube structures can be achieved, increasing the confidence of engineers in using such technology.

Keywords: filling, dewatering, geosynthetic tube, soil pressure, dredged soil, tension force, soil-geosynthetic interaction

1 INTRODUCTION

As the world's population increases, the need for land increases. As a result, environmental damage occurs as major activities such as quarrying are carried out to support the growing population. Geotextile tube technology has been suggested by some to replace the traditional rubble or concrete systems, especially in land reclamation works, due to its constructability, cost effectiveness, and minimum impact on the environment. Furthermore, this new technology has been successfully applied in a few countries such as Bahrain, the Netherlands, and Ecuador (Fowler et al. 2002).

2 LATERAL EARTH PRESSURE

In designing soil-retaining structures such as retaining walls, it is necessary determine the magnitude of the lateral pressures to which the structure is subjected. The lateral earth pressure (σ_h) is calculated using Eq. (1), wherein K is the coefficient of earth pressure and σ_v is the vertical earth pressure. The lateral pressure will vary depending on whether the soil is static or whether the wall is pushed away from or towards the soil.

$$\sigma_h = K\sigma_v \tag{1}$$

Janssen (1895) devised his theory of arching when conducting a series of experiments to determine the lateral and vertical loads on a corn silo. Results showed that the weight of the corn placed within the silo's wall was reduced at the bottom of the silo. As a result, Janssen proposed the arching theory and developed an equation that predicts the pressure on the silo's sidewalls. The arching theory can also be used for granular soils, such is in the case of narrow backfills (Al-Hassan et al. 2011). The lateral pressure for narrow backfills is predicted using Eq. (2).

$$\sigma_h = \frac{\gamma B}{2tan\delta}\left[1 - \exp\left(-2K\frac{z}{B}tan\delta\right)\right] \tag{2}$$

where γ = unit weight of soil, *B* = backfill width, *z* = depth from top of wall, *δ* = friction angle between the backfill and wall and rock (assumed equal), and *K* = lateral earth pressure coefficient.

3 MODEL TESTS

A design concept regarding the stress and deformation of geotextile tubes during filling and dewatering has not been well established. Therefore, a series of tests were performed to measure the stresses, forces and strain of the geotextile tube.

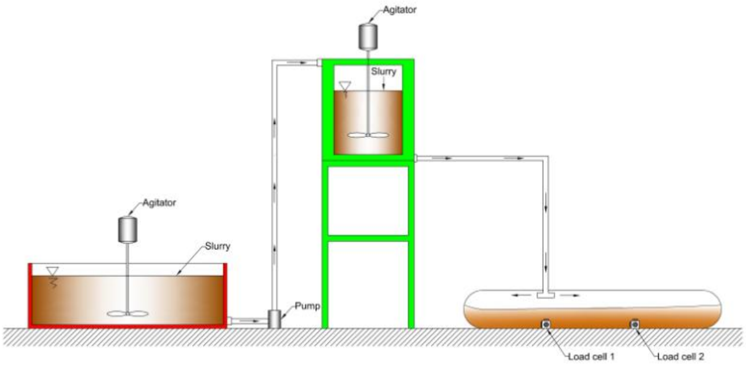

Figure 1. Scale model test setup

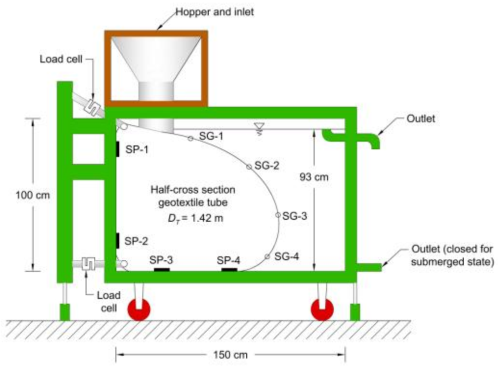

Figure 2. Half-cross section test setup

3.1 *Scale model test*

The scale model test setup is shown in Figure 1. It consists of a mixing tank, pumping station, and gravity tank. Soil and water are combined in the mixing tank with the use of an electric agitator to produce a slurry material. The slurry is then pumped into the gravity tank and is continuously agitated to maintain a homogeneous mixture. To fill the geotextile tube, the gate valve at the bottom of the tank is opened. The pumping pressure is based on the hydraulic head, which is equal to the difference between the elevation of the bottom of the gravity tank and the inlet. Load cells or soil pressure gauges were installed at the bottom of the tube, as shown in Figure 1, to measure the soil pressures in the x, y, and z directions. Strain gauges were also installed in the outer skin of the tube to measure the elastic deformation along the circumference.

3.2 *Half cross-section test*

The experimental setup is shown in Figure 2. The observation tank is 1.5 m in width and 1.0 m in height. The tank, which was supported by steel bar framing, consists of transparent glasses for easy viewing of the test specimen. Soil pressure (SP) gauges were placed in the manner as shown in Fig. 2 to monitor the horizontal and vertical soil pressures. SP-1 and SP-2 measure the horizontal soil pressures, while SP-3 and SP-4 measure the vertical soil pressures. Subsequently, the half-cross section tube was installed and supported by two electronic load cells at the top and bottom to monitor the tensile and compressive forces in the tube. The tube was filled with dredged soil in 11 stages to a height of 60% the theoretical diameter via the inlet. Similar to the scale model test, strain gauges (SG) were installed at the outer skin of the geotextile tube, as shown in Figure 2. In this test, 4 different stages or conditions were experienced by the tube. In sequential order, the stages experienced were the filling stage, submerged stage, dewatering stage, and dry stage.

4 RESULTS AND DISCUSSION

Figures 3 and 4 show the pressure gauge readings for the scale model test (SMT) and half-cross section test (HCST), respectively. The pressure in the x, y, and z direction represent the longitudinal, transverse, and vertical pressures of the tube, respectively. Load cell 1 (LC1) is located nearer the inlet while load cell 2 (LC2) is located farther away from the inlet. Results of the scale model test show that the pressure in the z direction was low compared to the pressures in the x and y direction in both load cells. Results also showed that the longitudinal pressures in each load cells were the largest. The confining effect, which pushes the soil inward, could be the possible cause of this phenomenon (Kim et al. 2014).

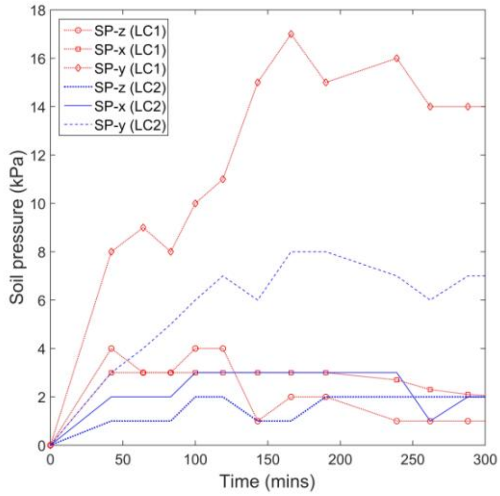

Figure 3. Pressure gauge readings (scale model test)

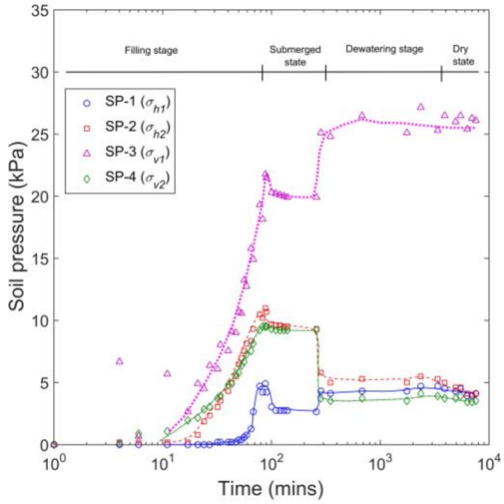

Figure 4. Pressure gauge readings (half-cross section test)

In the HCST, the soil pressures continuously increased as the tube height increased during the filling stage, as shown in Figure 4. At the start of the submerged state, the soil pressures decreased due to removal of filling pressure and due to buoyancy. The outlet at the bottom of the observation tank was then opened, draining out water, removing the effect of buoyancy. As a result of dewatering or consolidation, pressure readings at SP-1 and SP-3 increased while the pressure readings at SP-2 and SP-4 decreased. Also, as the tube spread outward, the tube height at SP-4 also decreased, resulting in the decrease of pressure readings.

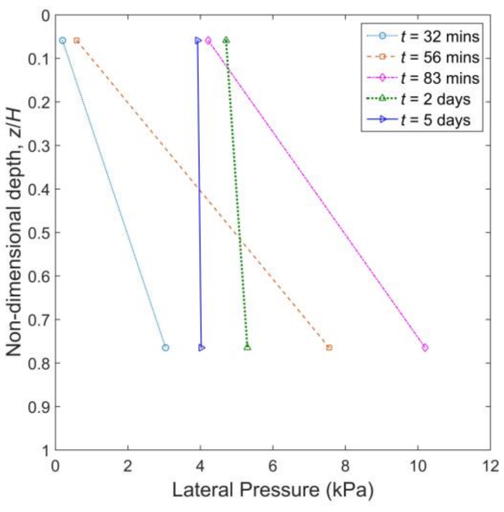

Figure 5. Lateral pressure with respect to depth (half-cross section test)

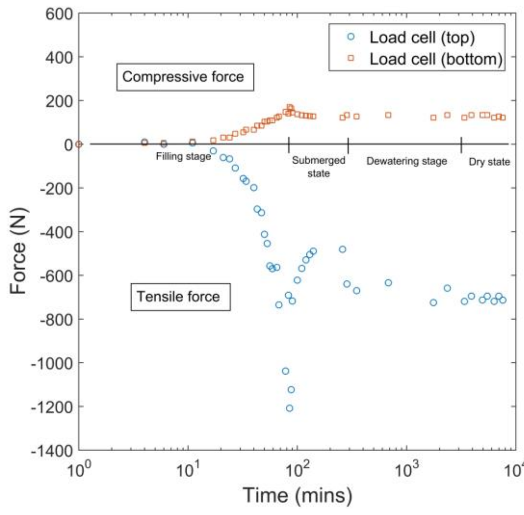

Figure 6. Circumferential tension force with respect to time

Figure 5 shows the lateral pressure with respect to depth. During the filling stage and submerged state, the lateral pressure at the bottom of the tube was significantly larger than the lateral pressure at the top of the tube. However, at the dewatering stage, the horizontal pressure at the top portion of the tube increased while the horizontal pressure at the bottom decreased. This may be a manifestation of arching. Therefore, it could be possible to apply the arching theory in geotextile tubes.

In the SMT, the tensile force could not be measured. However, with the half-cross section test, the forces acting on the circumference of the tube was measured. During filling, the tube was exposed to high tensile stress resulting in elongation (Moo-Young et al. 2002). It was found that tension occurs at the top of the tube while compression occurs at the bottom due to the confining effect of the geotextile. Also, the maximum tensile and compressive forces are experienced during the filling stage, as shown in Figure 6.

The strain gauge readings are shown in Figures 7 and 8. In the scale model test, the readings indicate an increase in geotextile strain during the filling stage and a decrease in strain during dewatering. It can also be seen that minimal strain occurs at the bottom of the geotextile. Initially, at LC2, the strain at the top increases due to filling pressure. As time elapsed, the strain at the top decreased as the tube width decreased. On the other hand, as the confinement effect at the sides of the tube increased, the strain at the sides of the tube increased. Similar to the scale model test, the strain gauge readings in the half-cross section test increased during filling and decreased as the filling pressure was removed. Also, the strain at the sides of the tube grew larger as the tube height increased.

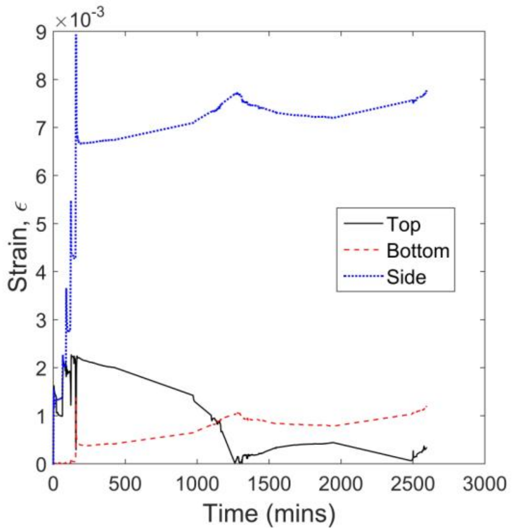

Figure 7. Strain gauge readings at LC2 (scale model test)

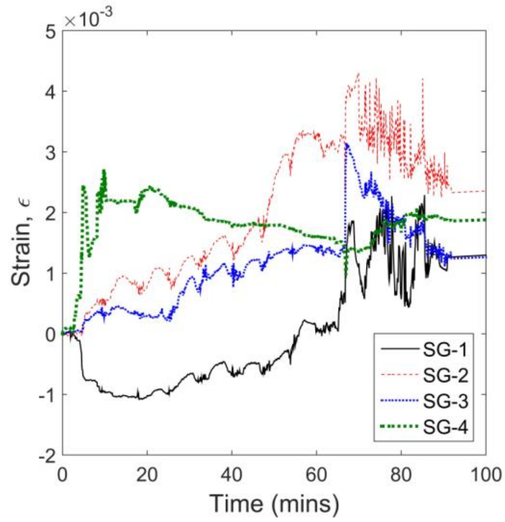

Figure 8. Strain gauge readings (half-cross section test)

5 ANALYSIS OF RESULTS

The nonlinear relationship between the circumferential tension force (T) and vertical bottom pressure (P_{bot}) during filling is shown in Figure 9, wherein the R^2 value is 0.95. As the bottom pressure increases, tension increases. This relationship may be applicable for submerged tubes. However, for tubes filled in land, the tension force is significantly higher. On the basis of polynomial regression, Equation 3 gives the nonlinear relationship between P_{bot} and T during filling for the submerged tube:

$$T = 0.0021{P_{bot}}^2 + 0.0154P_{bot} - 0.0309 \tag{3}$$

From Figures 3 and 4, the coefficient of earth pressures with respect to time for the scale model test (SMT) and the half-cross section test (HCST) were obtained using Eq. (1), as shown in Figure 10. Note that the scale model test did not experience the submerged state. During the filling stage, the coefficient of earth pressures increased for both the SMT and HCST. At the end of the filling stage, the coefficient of earth pressure decreased and stabilized, as the filling pressures were removed. However, as the observation tank in the HCST was dewatered, the coefficient of earth pressure (K_{top}) at z/H = 0.06 increased while the coefficient of earth pressure (K_{bot}) at z/H = 0.76 decreased.

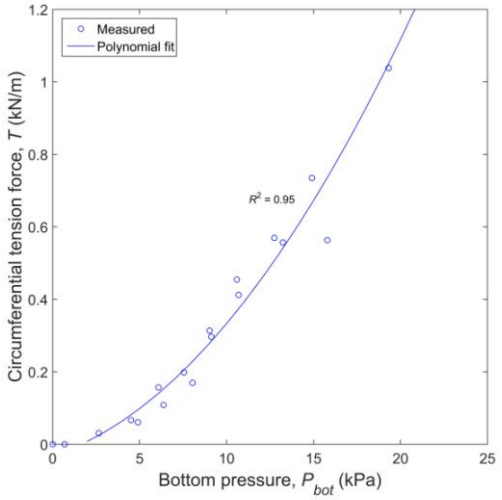

Figure 9. Relationship between P_{bot} and T during filling

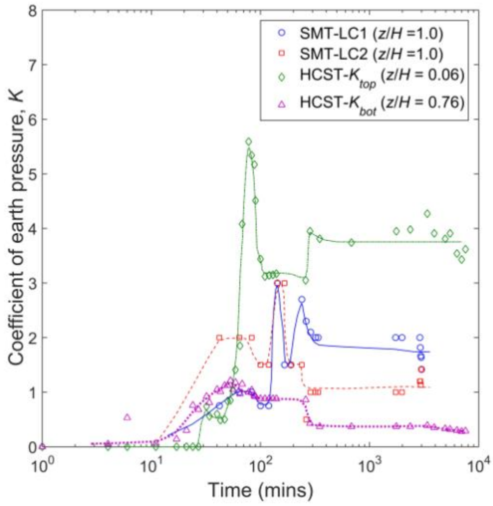

Figure 10. Coefficient of earth pressure with respect to time

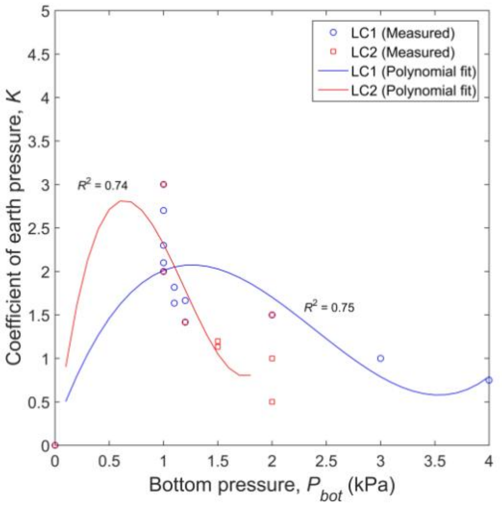

Figure 11. Relationship between P_{bot} and K (scale model test)

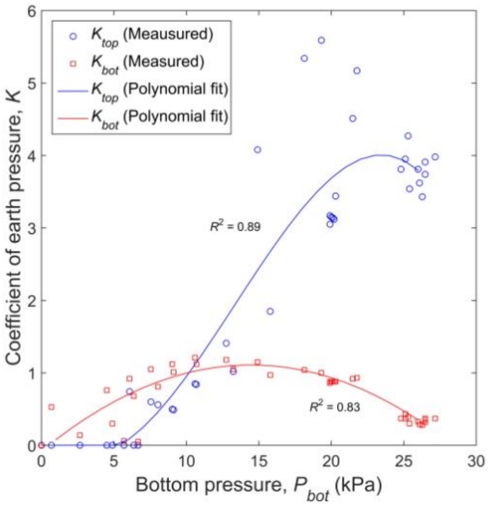

Figure 12. Relationship between P_{bot} and K (half-cross section test)

From Figure 10, the relationship between K and P_{bot} was established for the SMT and HCST, as shown in Figures 11 and 12, respectively. In Figure 11, the R^2 value for LC1 is 0.75 while the R^2 value for LC2 is 0.74. In Figure 12, the R^2 value for K_{top} and K_{bot} are 0.89 and 0.83, respectively. Results show that the K increased initially as the P_{bot} increased for both the tests. The initial increase in K was caused by the filling pressure. However, as the filling pressure was removed, the K decreased. On the basis of polynomial regression, Eqs. 4 and 5 give the relationship between P_{bot} and K for the SMT:

$$K_{LC1} = 0.2542{P_{bot}}^3 - 1.829{P_{bot}}^2 + 3.3998P_{bot} + 0.1867 \quad (4)$$

$$K_{LC2} = 2.9775{P_{bot}}^3 - 10.663{P_{bot}}^2 + 9.9884P_{bot} + 0.019 \quad (5)$$

For the HCST, Eqs. 6 and 7 give the relationship between P_{bot} and K:

$$K_{top} = -0.001{P_{bot}}^3 + 0.04{P_{bot}}^2 - 0.2262P_{bot} + 0.212 \quad (6)$$

$$K_{bot} = -0.0057{P_{bot}}^2 + 0.1647P_{bot} - 0.08 \quad (7)$$

6 CONCLUSION

In this study, the scale model test and half-cross section test were conducted to determine the soil pressure, circumferential force, and strain of the tube structure. The measured data obtained from the tests were analyzed and relationships between the circumferential tension force (T), coefficient of earth pressure (K), vertical bottom pressure (P_{bot}) were established. With the relationships obtained from the tests, a more economical and reliable design of geotextile tube structures can be achieved, increasing the confidence of engineers in using such technology.

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REFERENCES

Al-Hassan, A., Katkhuda, I., Barghouthi, A. 2011. Narrow backfill lateral earth pressure. *Proc. 5th Jordanian International Civil Engineering Conference*, pp. 1-10.
Fowler, J., Arroyo, R. & Ruiz, N. 2002. Riprap covered geotextile tube embankments. unpublished.
Janssen, H.A. 1895. Versuche uber getreidedruck in silozellen. *Zeitschrift des Vereins deutscher Ingenieure*, Vol. 39, pp. 1045-1049.
Kim, H.J., Lee, K.H., Jo, S.K. & Jamin, J.C. 2014a. Stress and strain behavior investigation on a scale model geotextile tube for Saemangeum dike project. *Ocean Systems Engineering*, Vol 4(4), pp.309-325.
Moo-Young, H.K., Gaffney, D.A. & Mo, X. 2002. Testing procedures to assess the viability of dewatering with geotextile tubes. *Geotextiles and Geomembranes*, Vol. 20(5), pp. 289-303.