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A study on stress behavior of geotextile tubes filled with dredged soil by half-cross section model test

Hyeong-Joo Kim[1)], *Sung-Gil Moon[2)], Tae-Woong Park[3)], Peter Rey Tan Dinoy[4)], Hyeong-Soo Kim[5)], and Ri Zhang[6)]

[1)] *Department of Civil Engineering, Kunsan National University, Gunsan 573-701, Korea*
[2), 3), 4), 5), 6)] *Department of Civil Engineering and Environmental Engineering, Kunsan National University, Gunsan 573-701, Korea*
[2)] *giri@kunsan.ac.kr*

ABSTRACT

So far, studies about geotextile tubes are mainly about geometric dimensioning, geotextile fabric properties (strength, durability, and permeability), and consolidation or dewatering characteristics. Studies on the development of the earth pressure inside the tube (when the tube is used as reinforcement in slope structures such as embankments) has not yet been attempted. Therefore, it is important to evaluate the horizontal earth pressure and tensile strength of the geotextile tube. For this reason, a half cross-section model test was carried out to quantitatively evaluate the tensile strength, and earth pressure (vertical and horizontal) of a geotextile tube filled with dredged soil and water. Results of the test show that tension occurs at the top while compression occurs at the bottom of the tube. Also, the horizontal earth pressure was distributed differently because the deformation conditions that occur are also different. In general, the development of tensile forces and earth pressure vary depending on the different stages or conditions (filling stage, submerged state, dewatering stage, dry state) being experienced by the tube. With the scale model test, the earth pressure distribution, the plastic zone, and the elastic zone can be calculated by considering the earth pressure coefficient and by correlating the tensile force due to geostatic stress.

1. INTRODUCTION

Geotextile tubes are made of strong, sustainable, and permeable textile fibers that can contain, filter, and reinforce soil (Kim et al. 2014). Many researchers have studied geotextile-reinforced embankments, including Madhavi Latha et al. (2006), Taechakumthorn and Rowe (2012), Yee et al. (2011), Yapage et al. (2013), and Kim et al. (2014). However, the deformation, stability, and strength of geotextile-reinforced

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[1)] Professor
[2), 3). 4), 5), 6)] Graduate Student

structures must be analyzed. One of the important aspects in designing geotechnical engineering structures is the lateral earth pressure, which affects the consolidation behavior and strength of the soil.

2. THEORETICAL BACKGROUND

2.1 Underground stress, vertical stress, and horizontal stress

Underground stress occurs due to external loading and self-weight of the soil. There are many complicated situations when dealing with stresses caused by self-weight. When the ground is flat and static, the stresses caused by self-weight comes out in simple shape. When shearing stress does not occur in the vertical and horizontal plane, it is easy to calculate the vertical stress using the weight of the soil. The formulas used to calculate the vertical stress of the soil considering that the unit weight of the soil is stable or unstable with depth is shown in Eq. (1). In order to design soil-retaining structures such as retaining walls, it is necessary to determine the magnitude of the lateral pressures to which the structure is subjected. The horizontal earth pressure is also calculated using Eq. (1), wherein *K* is the coefficient of 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.

$$\sigma_v = \gamma \cdot z = \int_o^z \gamma \cdot z\,;\ \sigma_h = K\sigma_v \tag{1}$$

2.2 Lateral earth pressure coefficient and wall deformation

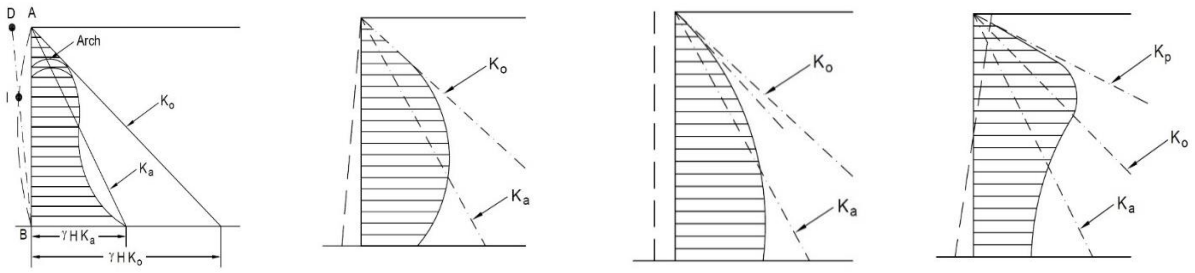
The coefficient of earth pressure, which is expressed as *K*, is the ratio of horizontal stress to the constant vertical stress. Jaky (1944) proposed a simplified equation to predict the coefficient of earth pressure at rest, K_o for normally consolidated soils:

$$K_o = \frac{\sigma_h}{\sigma_v} = 1 - sin\emptyset \tag{2}$$

Various values of *K* used for backfilling construction methods are as follows: For normally consolidated soil, $K = 1 - \sin\phi$. For compacted soil, *K* = 1~2. For compacted backfill, *K* = 2~6. For overconsolidated soil, *K* = 1~4. For medium compacted sand, *K* = 0.5. For dense compacted sand, *K* = 1~5. When an earth retaining structure moves away from a retained soil, the value of *K* decreases until becomes equal to the coefficient of active earth pressure, K_a. The soil is then in what is known as the active Rankine state. When an earth retaining structure is forced against a soil mass, the value of *K* increases until it becomes equal to the coefficient of passive earth pressure, K_p. The soil is then said to be in the passive Rankine state.

Fig. 1(a) shows the distribution of earth pressure of a flexible structure, where the upper and lower ends of the wall are fixed, and a rigid retaining wall in which movement in the lower end is restricted. The position of the intersection point I with the

deformation gives an indication of the boundary to move from the stationary pressure to the main working pressure. As a result, it exhibits an *S* shape, which is somewhat lower than the main working pressure under one point. The reason for this is that the upper sand is constrained in the lateral direction, so that a large wall frictional force is generated upward and the silo or arch action resists the vertical soil pressure. Thus, instead of increasing the earth pressure at the upper part of the wall, it decreases at the lower part and does not change greatly. The lateral earth pressure distribution profile for other representative deformation modes are shown in Figs. 1(b), 1(c), and 1(d). Note that when the wall moves at the bottom end, the shear force from the ground also works at the bottom end, and tends to decrease below the main working pressure. The amount of displacement at the lower ends are the same in Figs. 1c and 1d. The soil pressure in Fig. 1(d) tends to be smaller than in Fig. 1(c) due to the presence of the arching effect.



(a) (b) (c) (d)

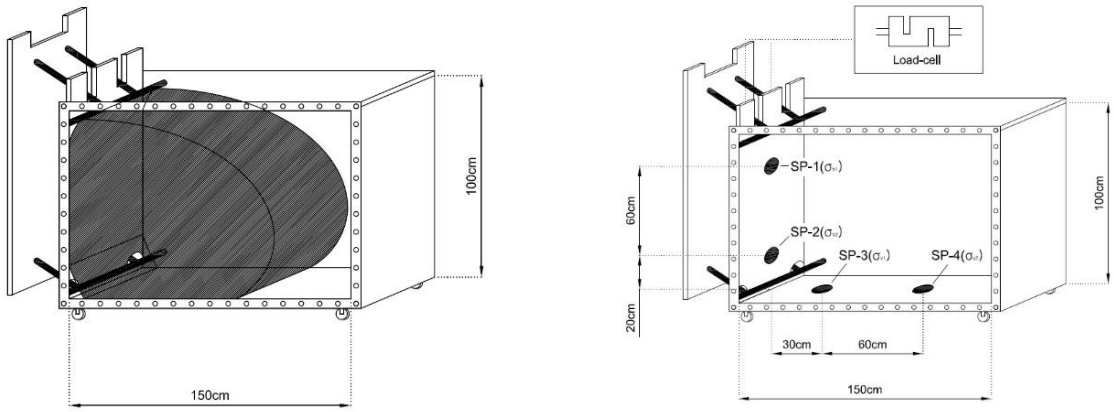
Fig. 1 Displacement and lateral earth pressure distribution: (a) Rigid and flexible wall, (b) Restrained top, (c) Unrestrained, and (d) Arching effect

3. HALF CROSS-SECTION TEST SETUP

The dredged fill material was obtained from a local dredging site in the Saemangeum river estuary near Gunsan City. The physical properties of the dredged fill are shown in Table 1. The geotextile fabric used in the test was polyethylene (PET). The experimental setup is shown in Fig. 2. The dimensions of the observation tank, as shown in Fig. 2(a) are 1.5 m (L) x 1.0 m (W) x 1.5 m (H). The tank, which was supported by steel bar framing, consist of transparent glasses for easy viewing of the test specimen. Pressure gauges were placed in the manner as shown in Fig. 2(b) to monitor the development of 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 load cells at the top and bottom to monitor the tensile and compressive forces developing in the tube. The pressure gauges and load cells were connected to a data logger which transmits the data readings into a desktop PC. The tube was filled in 11 stages to a height of 60% the theoretical diameter via the inlet. The filling procedure was done by initially filling the tube with dry soil. Thereafter, water was added to evenly distribute the soil in the tube and to simulate the tube in submerged conditions. The process was continuously repeated until the desired tube height was achieved.

Table 1. Dredged Fill Properties

Item	Unit	Quantity
Specific gravity of soil solids, G_s	N/A	2.705
Percent passing #200 sieve	%	26.2
D_{10}	N/A	0.028
D_{30}	N/A	0.081
D_{60}	N/A	0.750
C_U	N/A	6.25
C_C	N/A	1.34
Soil classification (USCS)	N/A	SM (Silty-Sand)



(a) (b)

Fig. 2 Experimental setup: (a) Model test apparatus and (b) Gauge placement

4. RESULTS AND DISCUSSION

In this study, 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. The filling stage and submerged stage transpired for 85 mins and 45 mins respectively. After the submerged stage, the observation tank was allowed to dewater for 2 days until the dry stage was achieved. The results of the scale model test are shown in Figs. 3-6. During filling, the tube is 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 at the center of the tube (rigid wall) are experienced during the filling stage.

Fig. 4 shows the developing soil pressures with respect to time and Fig. 5 shows the vertical soil pressure with respect to depth at different conditions. Arrows indicate the development of the soil pressure. At the filling stage, the soil pressures continuously increased as the tube height increased. In the submerged stage, the vertical soil pressure decreased as the density of the soil decreased. Also, the horizontal soil pressure decreased due to lateral spreading, as the tube started to stabilize in the submerged condition. Due to dewatering, the vertical soil pressure near

the center of the tube rapidly increased as the density increased and was constant thereafter. As the tube height decreased due to spreading, the vertical soil pressure outside the central region of the tube decreased at the start of the dewatering stage and was constant thereafter. In the dewatering stage, the increase in horizontal pressure at the top portion of the tube while the bottom horizontal pressure decreases, shows the effect of arching. The arching effect at the upper portion and the stress drop at the bottom portion increases, as the density of the soil increases (Fang and Ishibashi, 1986).

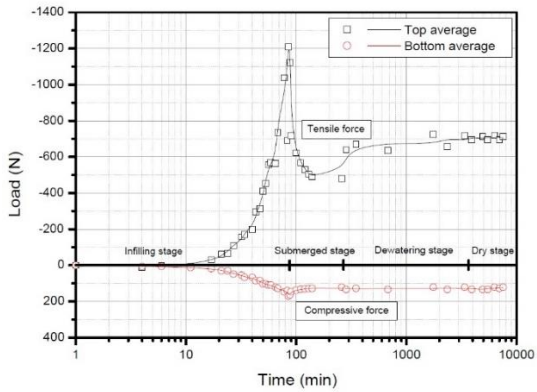


Fig. 3 Tensile and compressive forces developing in the tube

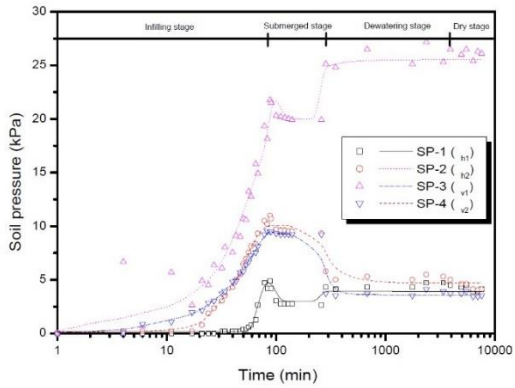


Fig. 4 Soil pressures developing in the tube

Fig. 6 shows the coefficient of earth pressure with respect to time. Results show that the coefficient of earth pressure increases during the filling stage. This is because of high filling pressures and due to increasing tube height. After the removal of the filling pressure, the coefficient of earth pressure decreased until the tube was stable or at rest during the submerged stage. However, as the observation tank was dewatered or as the density increased, the coefficient of earth pressure at SP-1/SP-3 (depth of 5cm) increased while the coefficient of earth pressure at SP-2/SP-3 (depth of 65 cm) decreased due to the arching effect. The coefficient of earth pressure at SP-2/SP-4 (depth of 65 cm) increased as the tube height decreased due to spreading.

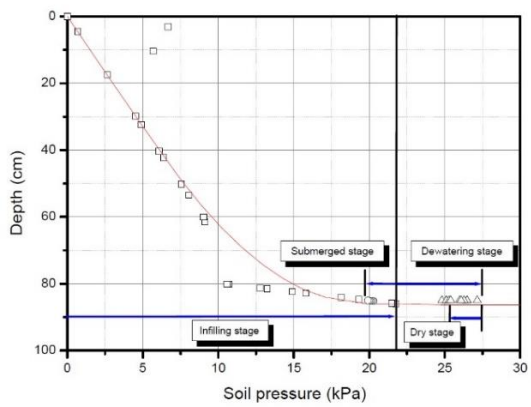


Fig. 5 Soil pressure with respect to depth

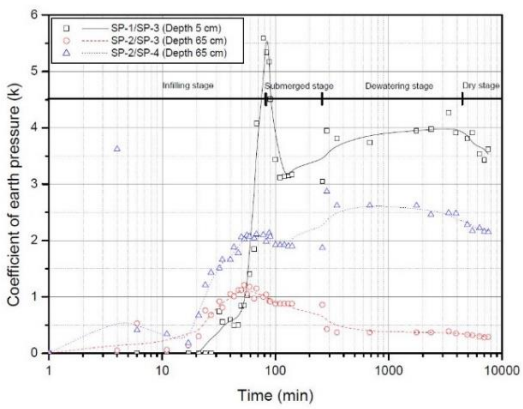


Fig. 6 Coefficient of earth pressure (*K*) with respect to time

During the 4 stages experienced by the tube, the *K* at the top portion of the central region ranges between 3.00~5.60 while the bottom portion ranges between 0.29~1.15. Farther from the central region, the *K* at the bottom portion ranges from 1.98~2.50.

5. CONCLUSION

A half cross-section model test was carried out to quantitatively evaluate the tensile strength, and earth pressure (vertical and horizontal) of a geotextile tube filled with dredged soil and water. Based on the laboratory test conducted, the following conclusions are drawn:

- It was found that tension occurs at the top of tube while compression occurs at the bottom due to the confining effect of the geotextile.
- In the dewatering stage, the increase in horizontal pressure at the top portion and the decrease in horizontal pressure at the bottom, shows the effect of arching. The arching effect at the upper portion and the stress drop at the bottom portion increases, as the density of the soil increases.
- The coefficient of earth pressure increases during the filling stage due to high filling pressures and due to increasing tube height.
- The coefficient of earth pressure is extremely high at the top portions of the tube. Conversely, the coefficient of earth pressure is low at bottom portions of the tube. It can also be concluded that the coefficient of earth pressure is higher at distances farther away from the center of the tube.

ACKNOWLEDGEMENT

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