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Modified geotextile tube – a new geotextile tube for optimized retaining efficiency and dewatering rate

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ABSTRACT

In recent years, dredged soil is being used as fill material for geotextile tubes. Geotextile tubes are usually used as one of the main components of shoreline infrastructures, such as embankments, to provide either flood protection or slope protection. A modified geotextile tube (MGT) is a tube having two different types of geotextile fabric around its circumference for the purpose of accelerating the dewatering rate or for improving the retaining efficiency. The consolidation analysis of the present invention was performed by applying the areal strain method and Terzaghi's consolidation theory in conjunction with an analytical procedure to model the tubes. The analyses follow the concept of multilayer consolidation and were performed to understand the deformation mechanism of the MGT. This is because two different types of geotextile fabrics were unified, both having different AOS, permeability, tensile strength, etc. The consolidation constants were determined from the void ratio-effective stress-permeability relationship of the woven polypropylene (PP) and composite polyethylene (PET) fabric, which was obtained from the seepage induced hanging bag test. Results show that the fabric placement can affect the consolidation speed. The advantage of an MGT is that combinations of different geotextiles and ratios result in different performances for its suited purpose.

1. INTRODUCTION

Presently, geotextile tube technology is considered as one of the viable alternatives to conventional ruble mound structures in cases where temporary protection is required or rock is not obtainable and difficult to transfer to the site (Kim et al., 2015a). In order to optimize retaining efficiency, dewatering efficiency, and tensile

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strength, a modified geotextile tube is proposed in this study. A modified geotextile tube, as shown in Fig. 1, is defined as a tube having two different types of geotextile fabric along its circumference. Different types of geotextile fabrics are shown in Fig. 2. Each geotextile fabric has its own advantages and may serve well for different functions or applications. Woven polypropylene (PP) geotextile tubes are usually injected with sandy fill materials and are commonly used for shoreline protection. Conversely, composite polyethylene (PET) geotextile tubes are usually used for dewatering fines and wastes such as contaminated soil, sludge, etc., and is very efficient in retaining fines. The non-woven (PET) fabric in Fig. 2c is usually used to reinforce either the PP or PET fabric to improve the filtering capability of the geotextile tube.

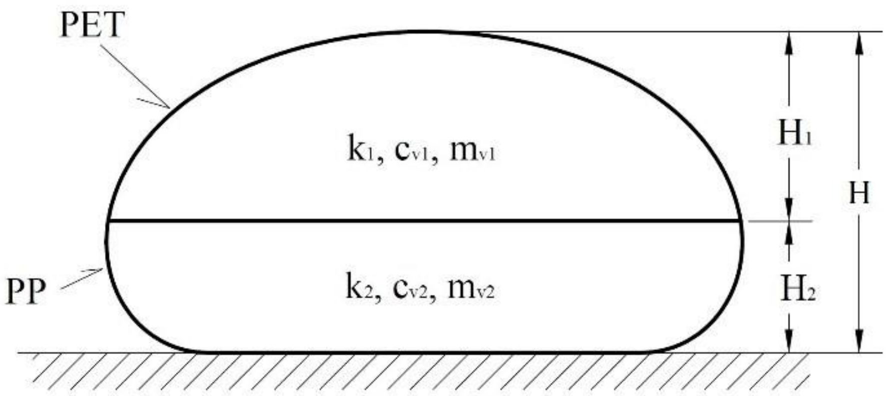


Fig. 1 Typical modified geotextile tube

(a) Woven (PP) (b) Woven (PET) (c) Non-woven (PET)
Fig. 2 Types of geotextile fabric

2. THEORETICAL BACKGROUND

Gray (1945) presented solutions for a system of two contiguous clay layers with either permeable or impermeable external boundaries. The solution is obtained by applying Terzaghi's differential equation within each layer and formulating a continuity relation at the interfaces between the two layers. The solution requires that there be a single excess pore water pressure at the interface and that the flow from one layer must be equal to the flow into the other layer, as shown in Eqs. (1) and (2). The requirement presented in Eqs. (1) and (2) can be simply inserted into the finite difference analysis by using a backward difference and a forward difference. If the subscript 1 is used to indicate the upper layer and 2 for the lower layer, and where *z* is at the interface as shown in Fig. 3, the excess pore pressure u_z at any time *t* is then calculated from the finite difference equation in Eq. (3). Substituting Eq. (4), the excess pore water pressure u_B at the interface, is calculated using Eq. (5). Detailed solution of multilayer consolidation is shown in the work of Kim and Mission (2011).

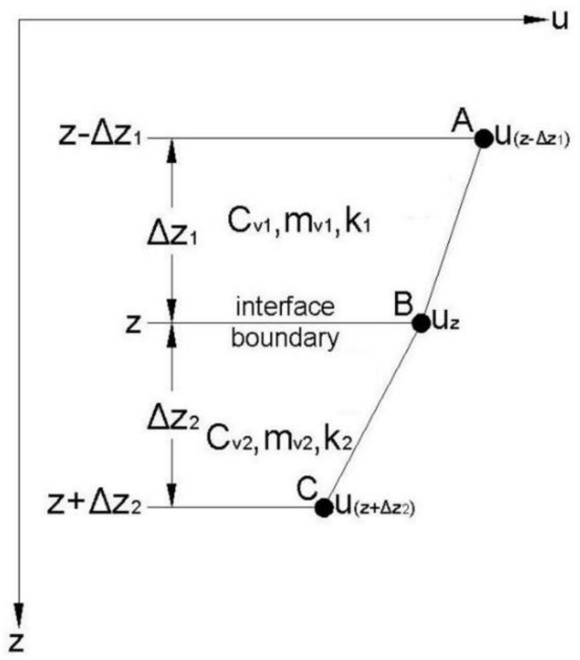


Fig. 3 Isochrone and interface

$$q = \frac{k_1}{\gamma_w}\left(\frac{\partial u}{\partial z}\right)_1 A = \frac{k_2}{\gamma_w}\left(\frac{\partial u}{\partial z}\right)_2 A; \tag{1}$$

$$k_1\left(\frac{\partial u}{\partial z}\right)_2 = k_2\left(\frac{\partial u}{\partial z}\right)_2 \tag{2}$$

$$k_1\frac{u_z - u_{(z-\Delta z_1)}}{\Delta z_1} = k_2\frac{u_{(z+\Delta z_2)} - u_z}{\Delta z_2}; \tag{3}$$

$$\alpha_1 = \frac{k_1}{\Delta z_1};\ \alpha_2 = \frac{k_2}{\Delta z_2} \tag{4}$$

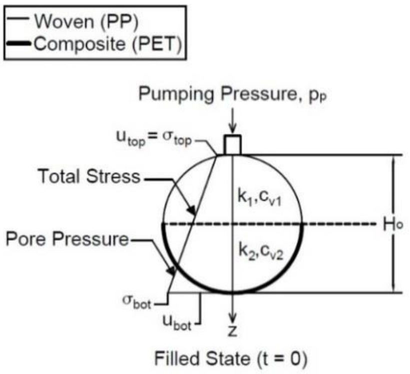
$$u_B = \frac{\alpha_1 u_A + \alpha_2 u_C}{\alpha_1 + \alpha_2} \tag{5}$$

The tube's areal strain and change in area (Kim et al. 2015b, 2016) is computed using Eqs. (6) and (7).

$$\varepsilon = m_v(\sigma' - u) \tag{6}$$

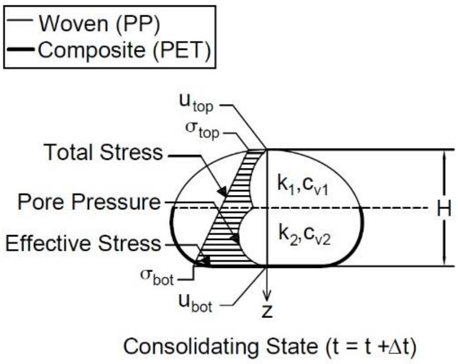
$$A = \frac{A_o}{exp^{\varepsilon}} \tag{7}$$

The boundary conditions of the modified geotextile tube are shown in Figs. 4, 5, and 6. The effective stress (σ′) at t = 0 is equal to zero, as the total stress (σ) produced by the weight of the soil is carried by excess pore water pressure (*u*), as shown in Fig. 4. At $t = t + \Delta t$, the excess pore water pressure at both drainage boundaries becomes zero, as shown in Fig. 5. At the end of consolidation, the excess pore water pressure is fully dissipated, as shown in Fig. 6.



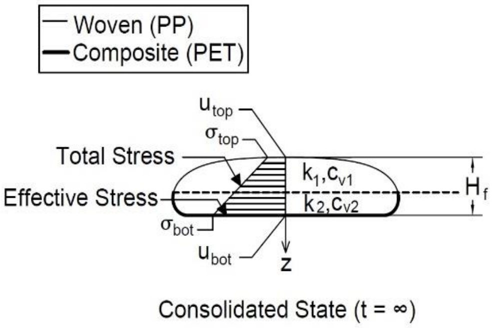
$$\sigma_{top} = u_{top} = p_p$$
$$\sigma_{bot} = u_{bot} = p_p + \gamma'_o H_o$$
$$\sigma'_{top} = \sigma_{top} - u_{top} = 0$$
$$\sigma'_{bot} = \sigma_{bot} - u_{bot} = 0$$

Fig. 4 Boundary condition of filled state



$$\sigma'_{top} = \sigma_{top} = p_p$$
$$\sigma'_{bot} = \sigma_{bot} = p_p + \gamma'_o H_o$$
$$u_{top} = u_{bot} = 0$$

Fig. 5 Boundary condition of consolidating state



$$\sigma'_{top} = \sigma_{top} = p_p$$
$$\sigma'_{bot} = \sigma_{bot} = p_p + \gamma'_o H_o$$
$$u_{top} = u_{bot} = 0$$

Fig. 6 Boundary condition of consolidated state

3. NUMERICAL SIMULATION

Two modified tubes, are shown in Figs. 7 and 8. The ratios used for the simulations are 50% woven (PP) and 50% composite (PET). Modified tube 1 has the woven (PP) in the bottom layer while modified tube 2 has the composite (PET) in the bottom layer. The numerical procedure proceeded by applying the multilayer consolidation theory proposed by Gray (1945) and the areal strain method proposed by Kim et al. (2015b, 2016) in conjunction with the analytical procedure proposed by Plaut and Suherman (1998) in modeling geotextile tubes. Consolidation parameters used in the calculations are obtained from the seepage induced hanging bag test performed by Kim et al. (2015c).

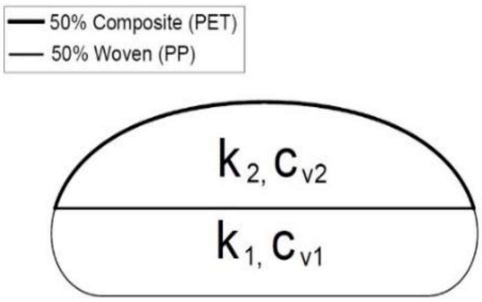


Fig. 7 Modified Tube 1 (MGT1)

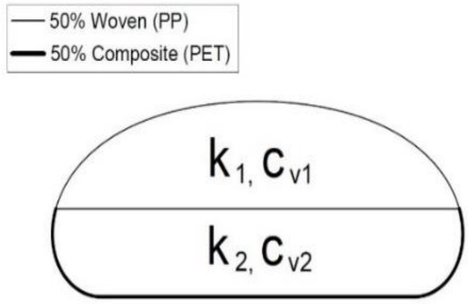


Fig. 8 Modified Tube (MGT2)

Both modified tubes have diameters of 0.55 m and lengths of 4 m. The initial properties of the tube are as follows: H_o = 0.417 m, w_o = 90.73%, and A_o = 0.219 m^2. The specific gravity G_s of the fill material is 2.687. Figs. 9 and 10 show the excess pore water isochrones of MGT1 and MGT2. Although the same ratios of fabric were used, results show that the dissipation of excess pore water pressure was faster in the MGT 1. This is because high excess pore water pressure values are located at the bottom of the tube. And because the woven (PP) fabric has a higher permeability than the composite (PET) fabric, these high excess pore water pressure values were easily dissipated in MGT1. Due to the composite (PET) fabric's low permeability, water could not easily flow out of the bottom portion of the MGT2, thus delaying the consolidation the tube.

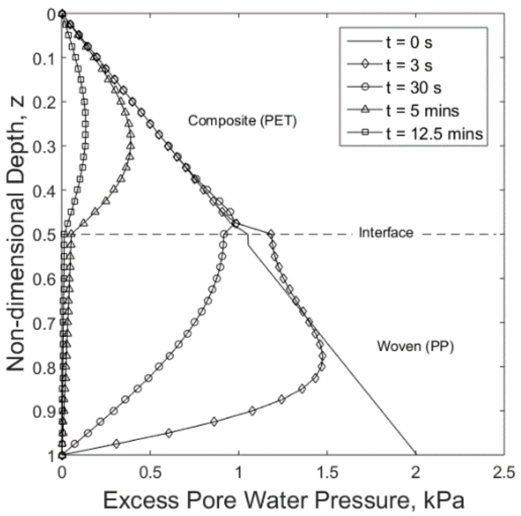


Fig. 9 Excess pore water pressure isochrones (MGT1)

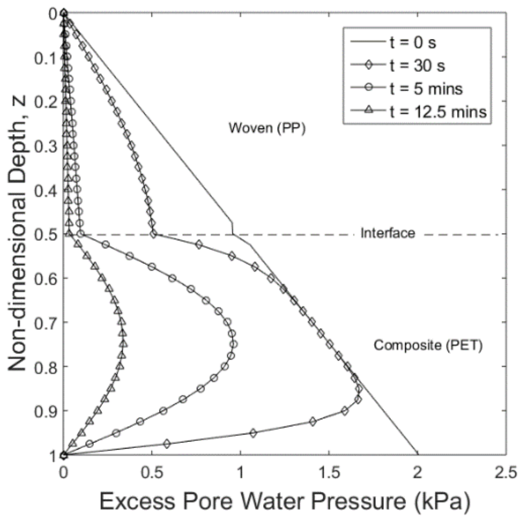


Fig. 10 Excess pore water pressure isochrones (MGT2)

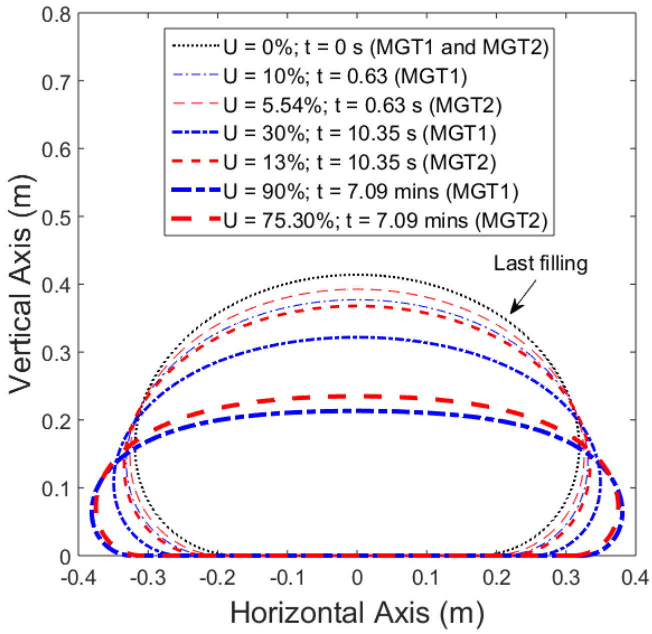


Fig. 11 Geotextile tube deformation of MGT1 and MGT2 during consolidaiton

Fig. 11 shows the deformation of the MGT1 and MGT2 during consolidation. The consolidated properties of the MGTs are: $H_f = 0.201$ m, $w_f = 41.67\%$, and $A_f = 0.135$ m^2. The MGT1 has a degree of consolidation U of 90% in 7.09 mins as compared to the MGT2 which has a degree of consolidation U of 75.30% in 7.09 mins. This shows that the fabric placement can affect the consolidation speed. This also shows that geotextile tubes can be modified and optimized to improve either retaining efficiency or dewatering efficiency by changing the fabric's ratio or location.

4. CONCLUSION

In order to optimize retaining efficiency, dewatering efficiency, and tensile strength, a modified geotextile tube is proposed in this study. The consolidation analysis of the present invention was performed by applying the areal strain method and Terzaghi's consolidation theory in conjunction with an analytical procedure to model the tubes. The analyses follow the concept of multilayer consolidation and were performed to understand the deformation mechanism of the MGT. The consolidation constants were determined from the void ratio-effective stress-permeability relationship of the woven and composite fabric, which was obtained from the seepage induced hanging bag test. Although the same ratios of fabric were used in the numerical calculations, results show that the dissipation of excess pore water pressure was faster in the MGT1. This is because high excess pore water pressure values are located at the bottom of the tube. And because the woven (PP) fabric has a higher permeability than the composite (PET) fabric, these high excess pore water pressure values were easily dissipated in MGT1. Due to the composite (PET) fabric's low permeability, water could not easily flow out of the bottom portion of the MGT2, thus delaying the consolidation the tube. This shows that the fabric placement can affect the consolidation speed. This also shows that geotextile tubes can be modified and optimized to improve either retaining efficiency or dewatering efficiency by changing the fabric's ratio or location.

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