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A study on the two-dimensional consolidation of geotextile tubes

Hyeong-Joo Kim[1)], Tae-Woong Park[2)], Hyeong-Soo Kim[3)], Peter Rey Dinoy[4)], and Ji-Ho Yu[5)]

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

ABSTRACT

One of the important aspects that must be considered in designing geotextile tube structures is the prediction of the consolidation time of geotextile tubes, which is crucial in developing the construction schedule. In this study, a two-dimensional solution, which considers areal strain and horizontal drainage, is proposed in order to provide a more reliable prediction of the geotextile tube consolidation phenomenon. The solution proposed in this study alleviates the limitations of the one-dimensional method when the foundation drainage condition is considered. There are several foundation drainage conditions, such as when the foundation is highly permeable, permeable, and impermeable. With the solution proposed in this study, the consolidation of the geotextile tube in the field considering these conditions, can be represented.

1. INTRODUCTION

The traditional practice of constructing shoreline protection involves the use conventional materials, such as rocks, aggregate, and concrete (Kim et al. 2018). As a result, low cost novel systems have been sought after in an effort to mitigate the effects of traditional methods on the environment. Presently, geotextile tube technology has been gaining popularity since it is cost and time efficient, and environmentally friendly. Geotextiles tubes offer a great alternative to traditional structures and are widely used for dewatering, flood control, and coastal protection.

One of the important aspects that must be considered in designing geotextile tube structures is the prediction of the consolidation time of geotextile tubes, which is crucial in developing the construction schedule. In this study, a two-dimensional solution, which considers areal strain and horizontal drainage, is proposed in order to provide a more reliable prediction of the geotextile tube consolidation phenomenon.

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

2. THEORETICAL BACKGROUND

Kim et al. (2018) have shown that the relationship between the height and area of geotextile tubes is nonlinear. Therefore, the consolidation ratio in terms of height (ζ_H), the consolidation ratio in terms of area (ζ_A), the degree of consolidation in terms of height (U_H), and the degree of consolidation in terms of area (U_A), are introduced to define the deformation of the tube, as shown in Eqs. (1) and (2).

$$\zeta_H = \frac{H_0}{H};\ \zeta_A = \frac{A_0}{A} \tag{1}$$

$$U_H = \frac{H_0 - H}{H_0 - H_f}; U_A = \frac{A_0 - A}{A_0 - A_f} \tag{2}$$

where H_0 and A_0 are the initial height and area of the tube, respectively; H and A are the height and area of the tube at any time during consolidation, respectively; H_f and A_f are the final height and area of the tube, respectively.

The conventional one-dimensional method assumes that consolidating fill material moves only in the vertical direction, neglecting the lateral movement of the tube. However, the areal method offers an alternative analysis approach where both the vertical and lateral movements of the consolidating material are considered. The disparity of these two methods is shown in Fig. 1. As shown, the consolidation ratio in terms of height (ζ_H) is overestimated as the tube consolidates. The overestimation of the consolidation ratio can lead to the underestimation of the consolidation time. Therefore, calculating the consolidation or deformation of geotextile tubes using the areal method would be more appropriate.

Kim et al. (2018) used the areal method in conjunction with the one-dimensional large strain consolidation theory to predict the consolidation of geotextile tubes. However, the method has limitations especially when considering the drainage condition of the foundation. Fig. 2 shows the limitation of using one-dimensional drainage condition. In Fig. 2a, the geotextile tube rests on an impermeable layer and a one-dimensional drainage condition is assumed in the downward direction. If this assumption is used, the tube cannot undergo consolidation. In Fig. 2b, the geotextile tube rests on an impermeable layer and a one-dimensional two-way drainage condition is assumed. If this assumption is used, water would drain out from the bottom to the top of the tube, which would be unrealistic. Therefore, a two-dimensional solution with acceptable boundary conditions must be proposed to accurately predict the consolidation of geotextile tubes.

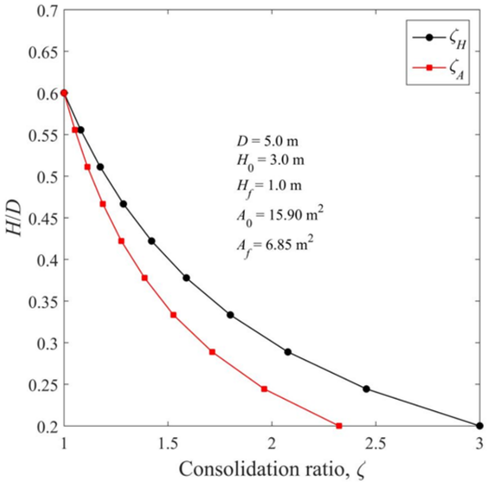


Fig. 1. Relationship between the change in normalized tube height (H/D) and consolidation ratio (ζ)

(a) (b)

Fig. 2. Limitations of using one-dimensional drainage condition: a) one-way drainage with impermeable foundation and b) two-way drainage with impermeable foundation

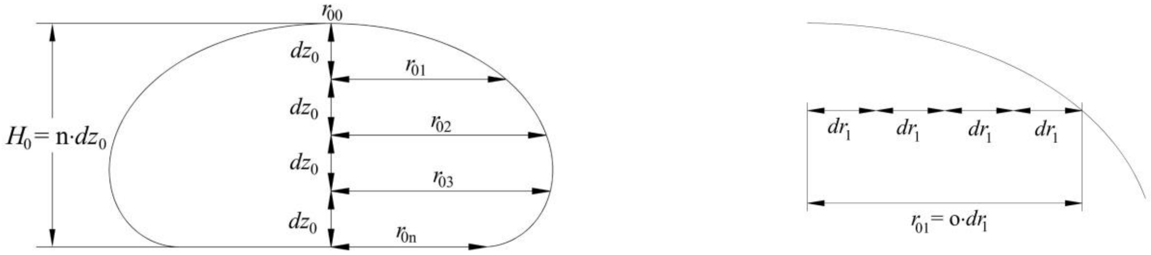
3. TWO-DIMENSIONAL CONSOLIDATION OF GEOTEXTILE TUBES

Several researchers have studied and proposed multi-dimensional consolidation equations for soils. Two-dimensional and three-dimensional equations have been proposed in an attempt to provide a more reliable prediction of the consolidation phenomenon, which is predominantly influenced by the soil dimensions and soil properties. The equation governing the process of consolidation based on the Terzaghi theory is the following:

$$\frac{\partial u}{\partial t} = c_v\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \tag{3}$$

where u is the excess hydrostatic pressure at any point (x, y, z) at any time t, and c_v is the coefficient of consolidation.

The consolidation theory proposed by Terzaghi (1925) and Mikasa (1963) are strictly restricted to a one-dimensional problem neglecting the horizontal dimensions of the soil. However, the consolidation of geotextile tubes is greatly influenced by the soil properties, geotextile properties, and drainage length. Therefore, a two-dimensional solution must be developed. Since the length of the geotextile tube usually exceeds five times the maximum width, the consolidation problem can be resolved using a two-dimensional solution. The two-dimensional solution is done in conjunction with any geotextile tube modeling procedure proposed in literature. After obtaining the model, the required tube dimensions, as shown in Fig. 3, can now be obtained. The required dimensions are H_0, r_{00}, r_{01}, r_{02}, to r_{0n}. These dimensions are discretized and then the consolidation equations shown in Eq. (4) can now be solved. In this study, one-way vertical drainage in the downward direction is assumed. Horizontal drainage was also assumed starting from the center of the tube to the geotextile boundary. The boundary conditions are as follows: At t = 0, the consolidation ratio (ζ) is equal to 1 at all points in the tube; at t > 0, the consolidation ratio (ζ) at the boundary of the geotextile tube is equal to the final consolidation ratio, $\zeta_f = f_0/f_f$, depending on the direction of drainage, where f_0 is the initial volume ratio and f_f is the final volume ratio.



(a) (b)

Fig. 3. Required tube dimensions: a) initial tube geometry and b) discretization of initial horizontal drainage length

$$\frac{\partial \zeta_v}{\partial t} = \zeta_v^{\,2}\left[c_v\frac{\partial^2 \zeta_v}{\partial {z_0}^2} + \frac{dc_v}{d\zeta_v}\left(\frac{\partial \zeta_v}{\partial z_0}\right)^2\right];\ \frac{\partial \zeta_r}{\partial t} = \zeta_r^{\,2}\left[c_r\frac{\partial^2 \zeta_r}{\partial {r_0}^2} + \frac{dc_r}{d\zeta_r}\left(\frac{\partial \zeta_r}{\partial r_0}\right)^2\right] \quad (4)$$

where ζ_v and ζ_r are the consolidation ratio in vertical and horizontal directions, respectively; c_v and c_r are the coefficient of consolidation in the vertical and horizontal directions respectively; z_0 and r_0 are the depth and horizontal drainage length, respectively; t is time.

Drainage takes place in both directions simultaneously. Thus, the average areal degree of consolidation (U_A) is calculated using Eq. (5). In Eq. (5), U_{Av} is the vertical average areal degree of consolidation and U_{Ar} is the horizontal average areal degree of consolidation.

$$U_A = 1 - (1 - U_{Av})(1 - U_{Ar}) \quad (5)$$

Fig. 4 shows the shape and water content variation of a 25.0 m long composite (PET) geotextile tube filled with silty sand using the two-dimensional procedure proposed in this study. The initial tube geometry and properties are shown in Fig. 4a. The initial and consolidated properties of the tube are given in Table 1 and the soil-geotextile f-log c_v relationship is $f = 1.48 - 1.89 \log (c_v/0.001)$. In Table 1 and Fig. 4, V_0 and V_f are the initial and final volume of the tube, respectively; C is the tube circumference; ω_{ave} is the average water content of the tube. Results show that the geotextile tube is more consolidated near the geotextile tube boundary and less consolidated at the top portion during the initial stages of consolidation. But as time elapsed and as the tube consolidated, the water content in the tube was almost similar.

Table 1. Initial and consolidated properties of the geotextile tube

Initial properties		Consolidated properties	
Description	Quantity	Description	Quantity
H_0 (m)	1.22	H_f (m)	0.68
A_0 (m^2)	3.55	A_f (m^2)	2.21
f_0	3.23	f_f	2.01
V_0 (m^3)	88.75	V_f (m^3)	55.37

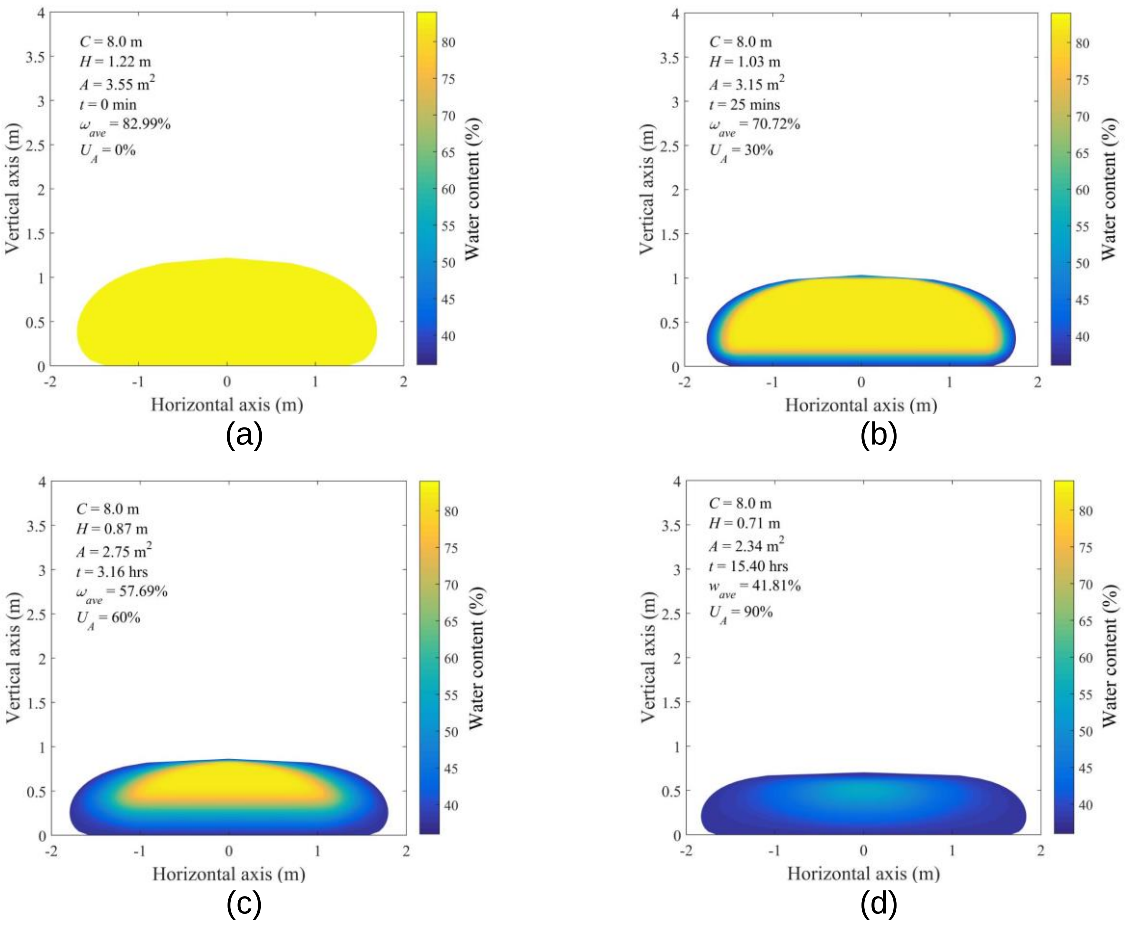


Fig. 4. Shape and water content variation of a composite (PET) geotextile tube: a) U_A = 0%, b) U_A = 30%, c) U_A = 60%, and d) U_A = 90%

4. CONCLUSIONS

The assumptions and the results of the one-dimensional method are unrealistic in comparison to actual field behavior. Therefore, a two-dimensional geotextile tube consolidation solution was developed in this study. The two-dimensional solution was done in conjunction with a geotextile tube modeling procedure proposed in literature. The solution proposed in this study alleviates the limitations of the one-dimensional method when the foundation drainage condition is considered. There are several foundation drainage conditions, such as when the foundation is highly permeable, permeable, and impermeable. With the solution proposed in this study, the consolidation of the geotextile tube in the field considering these conditions, can be represented.

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REFERENCES

Kim, H.J., Park, T.W., Dinoy, P.R., Kim, H.S., and Kim, H.J. (2018). Design and consolidation analysis of geotextile tubes for the Saemangeum project in Korea. Geosynthetics International, doi: 10.1680/jgein.18.00015

Mikasa, M. (1963). The Consolidation of Soft Clay - A New Consolidation Theory and its Application, Kajima Institution Publishing Co., Ltd., Tokyo, Japan.

Terzaghi, K. (1925) Principles of soil mechanics, IV—Settlement and consolidation of clay," Eng. News-Rec., vol. 95, no. 3