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A simplified method for design of geosynthetic tubes

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ABSTRACT

A simplified method for the design of impermeable geosynthetic tubes inflated using liquid is proposed in this paper. Adopting a computer program for an existing theoretical model, relationships between pumping pressure and geometric parameters for geosynthetic tubes can be established. A set of simplified dimensionless design equations are then derived using the Chapman–Richard curve fitting method. The validity of this simplified method was verified using other established methods and laboratory model tests. The proposed simplified method can thus be used for routine or preliminary design.

1. Introduction

Geotextile tubes have been widely used for various engineering applications, such as breakwaters and beach restoration projects (Leshchinsky et al., 1996; Shin and Oh, 2007; Lawson, 2008; Cantré and Saathoff, 2011; Yan and Chu, 2010; Chu et al., 2011, 2012; Yee et al., 2012; Yee and Lawson, 2012; Lee and Douglas, 2012). However, the design of geotextile tubes is still not a straight forward task. Several analytical solutions for the liquid filled geosynthetic tubes resting on rigid foundation have been proposed by Leshchinsky et al. (1996), Plaut and Suherman (1998), Guo et al. (2011), and Cantré and Saathoff (2011). Most of these solutions are based on the assumptions that the tube is long enough to be simplified into a plane strain problem, the friction between geosynthetic and internal water are neglectable and the tubes are resting on a rigid base. As there is no close-form solution for the proposed theories, all the above analytical solutions require the running of computer programs. This is not convenient for preliminary design where some trial and error processes or parametric studies are involved in the selection of the dimensions of the geosynthetic tubes and types of geotextiles to be used. The alternative method is to use design charts (Guo et al., 2014). However, the accuracy of using design charts is not always satisfactory.

Another simplification method is to use curve fitting which is presented in this paper. An analytical model (Guo et al., 2011) was used to generate dimensionless design charts. Then the Chapman–Richard method was adopted to derive best-fit equations for these curves. These best-fit equations form a simplified method which was verified using other established analytical solutions and laboratory model tests. As the equations so derived are dimensionless, theoretically they should be applicable to any design situation. In this paper, only solutions for impermeable geosynthetic tubes filled with uniform liquid is proposed. However, these solutions may also be used to a permeable geotextile tube at where the tube is inflated to its fullest by assuming that the dewatering during filling period can be neglected. It should also be pointed out that the proposed curve fitting method may not be suitable to cases when geosynthetic tubes are partially or fully submerged by external water.

2. Analytical solution adopted

The analytical solution proposed by Guo et al. (2011) was adopted to derive relationships between pumping pressure and geometry parameters. In the solution by Guo et al. the following assumptions are adopted, (1) the geosynthetic tube is sufficiently long to be assumed into a plane strain problem; (2) the geosynthetic sheet is thin, flexible so that its weight and extension can be neglected; (3) the friction between the geosynthetic tube and the fill material, or that between the geosynthetic tube and the rigid foundation are neglected. Some of the above hypotheses are also made in the exiting theoretical solutions such as Leshchinsky et al. (1996), Plaut and Suherman (1998), Cantré (2002), Cantré and Saathoff (2011), Guo et al. (2014). This solution

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(Guo et al., 2011) is proposed for a geosynthetic tube inflated by liquid with uniform unit weight, γ. The free body diagram of a half cross-section of the tube is plotted in Fig. 1a. The height and width of the cross-section of the geosynthetic tube are written as H and B, respectively. The contact width between the tube and the subgrade is b. The tensile force along the geosynthetic tube per unit length is defined as T. The forces acting on the free body along the horizontal direction involve the hydraulic force and the tensile force. The forces equilibrium along the horizontal direction yields the expression of tensile force as shown in Eq. (1). A free body diagram of a section from point O to a point $S(x, y)$ on the cross-section is selected for force equilibrium analysis as shown in Fig. 1b. The angle between the tangent direction at point $S(x, y)$ and the x axis is denoted as θ. The forces acting along the horizontal direction could solve the expression of $\sin\theta$, x and y as shown in Eqs. (2)–(4), respectively. Factor Q in Eq. (4) is a non-dimensional factor related to pumping pressure which can be calculated by Eq. (5).

$$T = \left(p_0 H + \frac{1}{2}\gamma H^2\right) \Big/ 2 \tag{1}$$

$$\sin\theta = 1 - \left(p_0 x + \frac{1}{2}\gamma x^2\right) \Big/ T \tag{2}$$

$$x = \frac{1}{\gamma}\left[-p_0 + \sqrt{p_0^2 + 2\gamma T(1 - \sin\theta)}\right] \tag{3}$$

$$y = -\sqrt{\frac{T}{2\gamma}} \int \left(\sqrt{Q - \sin\theta} - \frac{Q}{\sqrt{Q - \sin\theta}}\right) \mathrm{d}\theta \tag{4}$$

$$Q = \frac{1}{2\gamma T}\left(p_0^2 + 2\gamma T\right) \tag{5}$$

Given unit weight of fill, γ, pumping pressure, p_0, height of cross-section, H, and boundary conditions $x = 0$, $\theta = \pi/2$ and $x = H$, $\theta = -\pi/2$, the cross-section and tensile force can be calculated using Eqs. (1)–(5). As Eq. (5) contains the first and second elliptic integrals and thus has no closed-form solutions, a computer program is needed to solve this equation using the adaptive Runge–Kutta–Merson method (RKM4) (Lukehart, 1963; Christiansen, 1970). The iteration procedure is as follows: (a) input the initial parameters: γ, p_0, H; (b) calculate T, Q, and $\sin\theta$ using Eqs. (1), (2) and (5), respectively; (c) solve Eqs. (3) and (4) to get the cross-section of the filled tube using the RKM4 method. If the

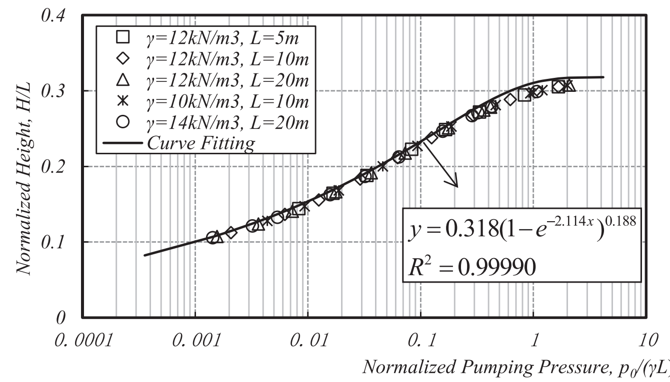


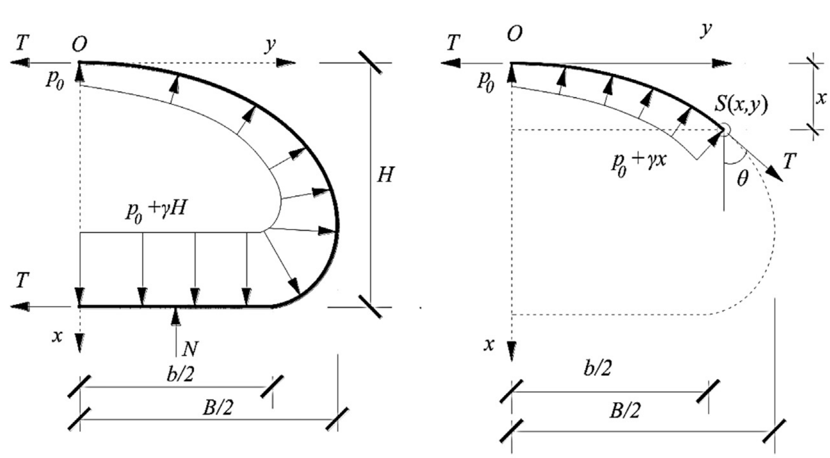
Fig. 2. Curve fitting for the relationship between $p_0/(\gamma L)$ and H/L.

perimeter, L, is taken as an input rather than H, the iteration can be done by assuming $H_{try} = L/\pi$ for the above steps (a) to (c) to solve the equations and calculate the generated perimeter of cross-section, L_{try}. If $L_{try} \neq L$, then modify H_{try} and repeat step (a) to (c) until the difference between generated L_{try} and given L is less than 1.0E−6.

Using a computer program written for the method by Guo et al. (2011), the relationships between pumping pressure and the geometry of the geosynthetic tubes can be established. Fig. 2 shows the pumping pressures versus height of cross-section curves calculated using different unit weights, γ, and perimeter, L. For generality, dimensionless parameters, such as the normalized height, H/L, and the normalized pumping pressure, $p_0/(\gamma L)$, are used in Fig. 2. As a single curve is obtained for different ranges of parameters, the relationship shown in Fig. 2 can be considered general. Similar relationships between normalized pumping pressure and normalized area, A/L^2, normalized width of cross-section, B/L, normalized contact width with ground, b/L, and normalized tensile force, $T/(\gamma L^2)$, are shown in Figs. 3–6, respectively. The normalization method adopted is similar to that by Plaut and Suherman (1998). It should be noted that a range of parameters are adopted as shown in Fig. 2 to testify that these relationships are applicable over a wide range of design situations.

3. Curve fitting methods

The Chapman–Richard model (Ratkowsky, 1990) is adopted to get best-fit equations for the numerical results presented in



(a) Free body of half cross-section (b) Free body of calculated curve OS

Fig. 1. Free body diagrams of geosynthetic tube resting on rigid foundation.