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2-D finite element analysis and stability calculation of geotextile tubes

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ABSTRACT: The mechanical behaviors of stacked geotextile tubes are very complex and they are involved in the properties of the filling material, geotextile and foundation. Using the commercial finite element analysis program ABAQUS, this paper extends the 2-D finite element load model of Cantré to include the part of the foundation. The aim of this study is to explore the maximum circumferential tension of geotextile tubes with various properties of soils of foundation. The authors compare the results of finite element analysis with Cantré's. It is suggested that the influence of foundation can't be neglected. The stability analysis of geotextile tubes is composed of hydraulic and geotechnical stability analysis. This paper uses the recommended hydraulic stability design criteria by Pilarczyk to calculate the hydraulic stability of geotextile tubes. These calculation results show that the 70% or 80% of filling degree is the preferable and the double tubes on the bottom can improve the hydraulic stability. The Minikin approach is provided in this paper to deduce the calculation formulas of the factors of safety against sliding and overturning. This paper shows that the calculation equations deduced from Minikin approach can aid the design of geotechnical stability of geotextile tubes.

1 INTRODUCTION

As nature rock is increasingly more difficult to obtain, traditional forms of coastal and river structures have become very expensive to build and maintain. With the main advantages of the reductions in work volume, execution time and cost compared with the traditional forms, there will be increased demand for geotextile tubes.

Geotextile tubes have been used widely in coastal protection, flood fighting, erosion control and dewatering. They can also be used to construct dikes, groins, dunes, and similar structures. Nowadays, geotextile tubes hydraulically filled with dredged materials have been used in the application of cofferdam, sea reclamation and erosion control in China.

When application in the coastal and hydraulic engineering, the design of geotextile tubes has so many problems, which include the geotextile selection, filling material selection, filling degree, determination of dimensions, construction processes, etc. Whereas, the mechanical properties during the process of filling, stacked and the stability due to current and wave action are the two main design issues.

Recently, some researchers study the mechanical behaviors of geotextile tubes using the methods of numerical analysis, such as GeoCoPS, SOFFTWIN and finite element analysis. Some stability calculations have also been conducted.

Using the commercial finite element analysis program ABAQUS, the paper extends the 2-D finite element load model of Cantré (Cantré 2002) to include the part of the foundation. The aim of this study is to explore the maximum circumferential tension of geotextile tubes with various properties of soils of foundation. The hydraulic and geotechnical stability of geotextile tubes are also analysed, according to the recommended hydraulic stability design criteria by Pilarczyk (Pilarczyk 2000) and the approach of Minikin (Minikin 1983) respectively.

2 2-D FINITE ELEMENT ANALYSIS

2.1 *Stacked modes*

The most straightforward way to improve the stability of a simple geotextile tube is by stacking the tubes. Two tubes can be simply piled vertically (one tube at the bottom and the other tube at the top, 1-1 formation). Also, three tubes can be stacked (two tubes at the bottom, the other tube at the top, 2-1 formation) for more stability.

In this paper, the mechanical behaviors of 3-2-1 stacked formation are analysed. Because of the symmetry, the left-bottom geotextile tube (including the foundation) is researched.

2.2 *Load model of finite element*

The mechanical behaviors of stacked geotextile tubes are very complex and they are involved in the properties of the filling material, geotextile and foundation. The finite element analyses are performed. A commercial multi-purpose finite element program, ABAQUS (ABAQUS 6.3), is used.

If we assume that the theoretical diameter of geotextile tube is 1m, the filling degree is 80% and the pumping pressure of bottom is16.88 kPa, then Fig. 1 shows the shape of geotextile tube after filling according to the method of elliptic integrals (Plaut and Suherman 1998).

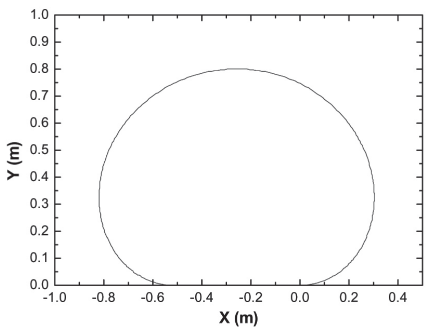

Figure 1. Import shape of geotextile tubes of the load finite element model.

Geosynthetic materials (Perkins 2000) are known to exhibit thermo-visco-elastic-plastic, direction dependent and normal stress dependent behaviors. In this paper, geotextile is modelled as linearly elastic material and used as beam elements in ABAQUS. Table 1 shows the properties of beam elements.

Table 1. Properties of the beam elements.

	Properties
Density (kg/m^3)	400
Modulus of elasticity (pa)	7G
Poisson's ratio	0.4
Cross-section (m^2)	10^{-3}
Moment of inertia (m^4)	10^{-10}

There are following types of stress-strain laws of soils: linear elastic, non-linear elastic, elastic-plastic and cyclic hardening plasticity. In this analysis, the filling soil and foundation are used as an elastic-plastic material with a Mohr-Coulomb failure criterion. Their properties are given in Table 2.

Figure 2 shows the finite element model adopted for stacked. The filling soils and foundation are used

Table 2. Properties of filling materials and soils of foundation.

	Properties	
	Filling materials	Foundation
Density (kg/m^3)	1800	1600
Modulus of elasticity (pa)	100 000	20M
Poisson's ratio	0.3	0.292
Friction angle	20°	36°
Dilation angle	0°	7°

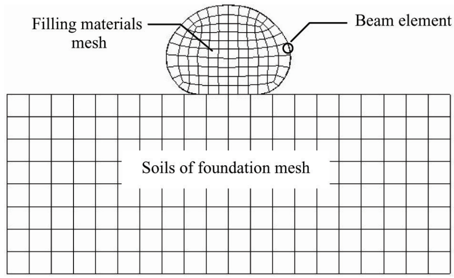

Figure 2. Finite element models of geotextile tube and foundation.

four node plane strain elements (CPE4), while the geotextile is modelled using two-node beam elements (B22), respectively. The dimension of foundation is 4 m long by 1.6 m high.

Between the geotextile and filling soil, tie of method is used. And between the geotextile and foundation, a friction of $\mu = 0.5$ is applied. A linear loading of 12 kN is applied to the geotextile due to weight of the top stacked geotextile tube. It acts along the top-right circumference of the tube.

The process of finite element calculation is divided into two Static steps: the first is used to form an equilibrium state caused by the gravity of the soils and the second is the deformation caused by the load.

2.3 *Analysis of results*

Figure 3 shows that the largest deformation of geotextile tube is about 0.11 m. Figure 4 shows the maximum section force of beam element is about 788 N/m. And the maximum section force of Cantré

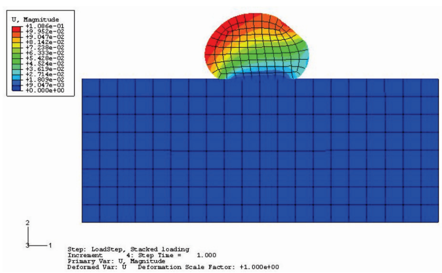

Figure 3. Deformations of the finite element model.

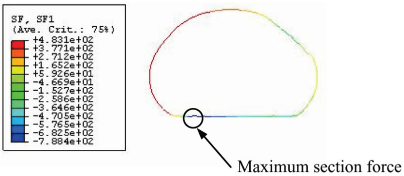

Figure 4. Circumferential tensile force of geotextile.

on the rigid foundation is 804 N/m, so these two results are different a little.

Figure 5 shows that when the elastic modulus of soils of foundation is decreasing, the maximum circumferential tensile force of geotextile is increasing. Therefore, the influence of foundation can't be neglected.

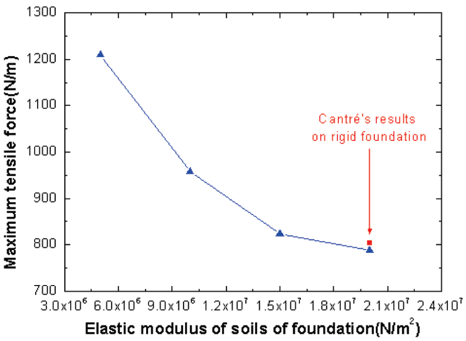

Figure 5. Maximum tensile force versus elastic modulus of soils of foundation.

Based on the method of elliptic integrals of Plaut et al, the circumference tension of geotextile is 4.943 kN/m during the process of filling. Thus from the analysis of the Fig. 5, we know that the largest tensile force occurs the filling process.

3 STABILITY CALCULATION

3.1 *Hydraulic stability*

Pilarczyk (Pilarczyk 2000) has discussed and proposed the hydraulic stability calculation for geotextile tube.

When the tube is lying parallel to the axis of a breakwater, the stability is approximated by:

$$\frac{H_s}{\Delta W} = 1.0 \tag{1}$$

where H_s is the significant wave height; Δ is the relative density, $\Delta = (\rho_s - \rho_w)/\rho_w$, ρ_s is the density of filling materials, ρ_w is the density of water; W is the width of a tube, one may roughly assume $W = D_c(1 + \sqrt{1-\varphi})$, D_c is the theoretical diameter of a tube, φ is filling degree, when the double tubes, the equivalent width is equal to $2 \times W$.

When the tube is placed perpendicular to the axis of a breakwater, the stability is approximated by:

$$\frac{H_s}{\Delta l} = 1.0 \tag{2}$$

where l is the length of a tube.

When the tube is lying parallel to the axis of a breakwater, the relationship between hydraulic stability and H_s is shown in Fig. 6. This figure shows that the 80% of filling degree is the best and the double tubes on the bottom can improve the hydraulic stability.

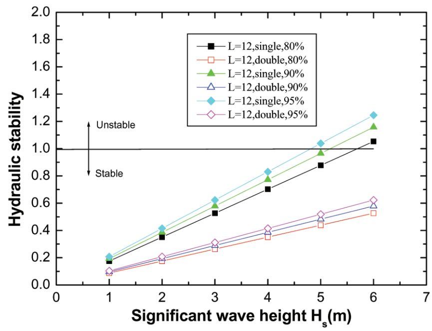

Figure 6. Hydraulic stability.

3.2 *Geotechnical stability*

Due to current and wave action, the geotextile tubes can incite a scour hole directly adjacent to it, possibly resulting in geotechnical instability. Therefore, designers should consider the sliding and overturning stability.

Current and wave forces must be estimated to assess the stability of geotextile tube. It is suggested that the Minikin method can be used to determine the geotechnical stability of geotextile tubes (Sprague 2001). Therefore, the approach of Minikin (Minikin 1983) (as shown in Fig. 7) is used to deduce the formulas of the factor of safety of geotechnical stability.

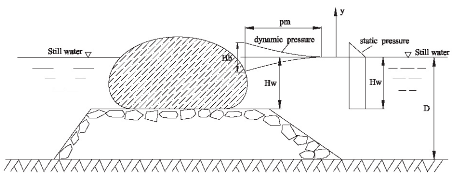

Figure 7. Minikin approach.

The peak pressure is assumed to be at still water level and it can be approximated by:

$$p_{\max} = 100\,\rho g H_w \left(1 + \frac{H_w}{D}\right)\frac{H_b}{\lambda} \tag{3}$$

Where H_w is the height of the retained water, D is the depth of water, H_b is the wave height of breaking wave (trough to crest), λ is wavelength (crest to crest).

The peak pressure diminishes rapidly to zero at the crest of the wave at a height of $0.5H_b$ both above the peak pressure and below the peak pressure. The total pressures due to the dynamic action of the wave is:

$$R_d = \frac{1}{3} p_m H_b \tag{4}$$

There is also the hydrostatic pressure of the water due to half the height of the wave above still water:

$$\begin{cases} p_s = 0.5\ \rho g H_b \left(1 - \dfrac{2y}{H_b}\right), 0 \le y \le 0.5\ H_b \\ p_s = 0.5\ \rho g H_b\ , y \le 0 \end{cases} \tag{5}$$

Then the total hydrostatic pressure on the geotextile tube is:

$$R_s = \frac{1}{2} \rho g H_b \left(H_w + \frac{H_b}{4} \right) \tag{6}$$

Hence, the total horizontal thrust due to the breaking wave and the hydrostatic pressure is:

$$R_t = R_d + R_s \tag{7}$$

Therefore, the factor of safety against sliding is determined by the following equation:

$$f_s = \frac{N'\ \tan\phi}{F_h} = \frac{N'\ \tan\phi}{F_t} \tag{8}$$

where N' is vertical effective force, $N' = G - F_v$, G is the total weight of the tube, F_v is the vertical uplift force on the tube due to waves, $F_v = 0.5\ \rho g H_b B$; ϕ is the angle of friction of the foundation/geotextile tube interface; F_h is the horizontal force on the tube due to waves.

The factor of safety against overturning can be described as:

$$f_o = \frac{M_R}{M_O} = \frac{G \times 0.5B}{F_h \times 0.5H_e + F_v \times 0.5B} \tag{9}$$

where M_R is the restoring moment, M_O is the overturning moment, H_e is the arm of force of the horizontal force on the tube due to waves.

4 CONCLUSIONS

In this paper, both the mechanical behaviors of geotextile tubes during the stacking and the geotechnical stability of geotextile tubes were investigated based on the methods of 2-D FEA and Minikin approach.

The 2-D FEA numerical example results show that though the largest tensile force occurs the filling process, the influence of foundation for the mechanical behaviors can't be neglected. And the formulas of the factor of safety deduced from the Minikin approach can be applied in the design of geotechnical stability.

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