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A three-parameter model for the ultimate pull-out force of geogrids

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ABSTRACT : A three-parameter model has been proposed to predict the ultimate pull-out force of geogrids in this study. Eighteen pull-out tests were performed using three types of geogrids embedded in Ottawa Sand. It was observed that the ratio of the ultimate pull-out force to the normal stress decreased as the normal stress increased. The proposed model predicted the above behavior and the ultimate pull-out force very well.

1 INTRODUCTION

The friction between the interface of soils and geosynthetics is usually obtained by direct shear tests or pull-out tests in the design of reinforced soils. It is a common practice to employ the Mohr-Coulomb criterion to estimate the friction of the interface. However, results of pull-out tests usually don't follow it. Hence, a three-parameter model is present in this study takes into account the deformation modulus of the material and the applied normal stress. The model must be able to describe the relation between the ultimate pull-out force and the normal stress and to predict the ultimate pull-out force well compared with the pull-out test results.

2 TEST EQUIPMENT AND TEST MATERIAL

The dimension of pull-out box is 60cm × 35cm × 20cm(length × width × height). The ultimate pull-out force (12.5tons) was applied by electric motor. The vertical load system consists of a rubber air bag and a jack. Load cells and LVDT were used to measure pull-out force and displacement. A data acquisition device, an AD card, and a personal computer were used for test control and record.

Test materials contained geogrids and sands. The material properties of three types of Tensar Geogrid used in the tests are summarized in Table 1. The test sand was Ottawa Sand (No.109) that has specific gravity 2.65, maximum void ratio 0.732, and minimum void ratio 0.387. The strength parameters are c=0.7 kN/m^2, ϕ =36 ° for relative density Dr=85%, and c=5 kN/m^2, ϕ =32° for Dr=50%.

Table1 Physical Properties of Geogrids

	Geogrid A	Geogrid B	Geogrid C
Ultimate tensile strength (kN/m)	110	80	55
Secant modulous Es at 5% strain (kN/m)	1320	960	660
Secant modulous Es at10% strain (kN/m)	880	640	440

3. THE PROPOSED MODEL

In engineering practice, it is usually assumed that the friction of the interface between geogrids and soils follows the Mohr-Coulomb criterion :

$$\tau = c + \sigma \tan \phi \quad (1)$$
$$P = A\tau$$

where τ : friction of the interface
σ : normal stress
c : apparent cohesion intercept

ϕ : friction angle
P : ultimate pull-out force
A : embedded area of geogrids

The proposed three-parameter model is as follows :

$$\tau = \sigma(a_1 + a_2 e^{-a_3 \frac{\sigma}{E}}) \qquad (2)$$

$$P = A\tau$$

where a_1 、a_2 、a_3 : parameters

E : deformation modulus of geogrids

The model uses the normal stress σ and the deformation modulus E to describe the behavior of shear strength. In a pull-out test, the deformation modulus of the soil was related to the normal stress. Hence, the term $\frac{\sigma}{E}$ of Eq.(2) is able to describe the relativity of soil deformation and geogrid deformation. It is the characteristic of this model.

4 TEST RESULTS and ANALYSIS

The ultimate pull-out forces of test results are summarized in Table 2. It was observed that the force increased with the normal stress. However, the relation is nonlinear. The results through Mohr-Coulomb criterion together with pull-out test data are shown Figure 1. The Mohr-Coulomb criterion appears to be a poor application, not only poor regression but also the cohesion interpect is greater than zero for sands.

Table 2 The ultimate Pull-out Force of Geogrid

Group I (Ottawa Sand Dr=85%)

Normal stress (kN/m²)	Geogrid A (kN)	Geogrid B (kN)	Geogrid C (kN)
50	7.73	6.99	6.15
100	13.64	12.44	9.84
150	****	****	11.80
200	19.30	16.34	****

Group II (Ottawa Sand Dr=50%)

Normal stress (kN/m²)	Geogrid A (kN)	Geogrid B (kN)	Geogrid C (kN)
50	5.96	5.32	4.45
100	10.32	9.85	8.18
150	14.08	12.69	11.12

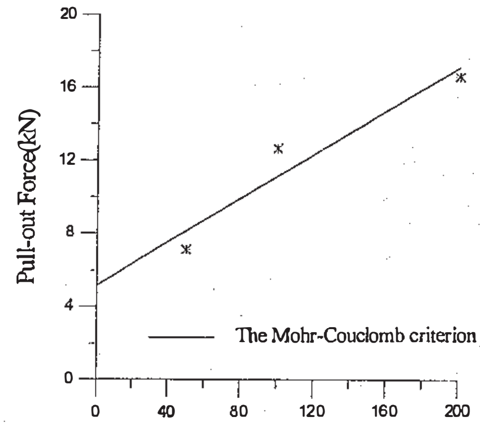


Fig 1 Ultimate pull-out force versus normal stress for geogrid B embedded in Ottawa Sand

The procedure used to analyze test results is described in the following paragraph:

a. determine the deformation modulus :

Geogrids are flexible materials whose modulus behaves nonlinearly during deforming. Therefore, this model will correct the deformation modulus according to the strain : for simplicity, while the pull-out force is less than 5% strain corresponding with tensile force P'($P' = E_S \times 5\% \times W$, $E_S = E_S$ at 5% strain, W = specimen width)the deformation modulus is chosen as secant modulous at 5% strain. Otherwise, the deformation modulus is secant modulous at 10% strain.

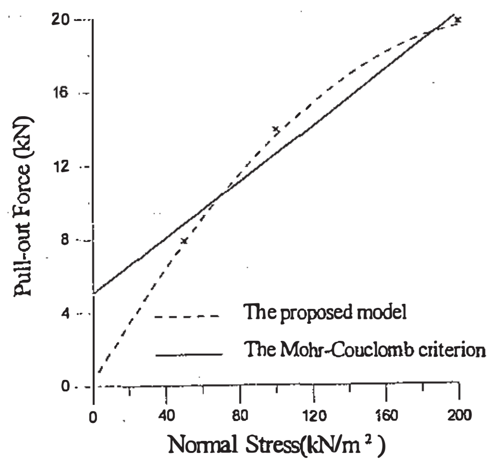
b. determine a_1 、a_2 、a_3 parameters :

Three sets of test data can be used in Eq.(2) to determine a_1 、a_2 、a_3 parameters.

c. compute the ultimate pull-out force through Eq.(2) incorporating with a_1 、a_2 、a_3 parameters and secant deformation modulus at 5% strain.

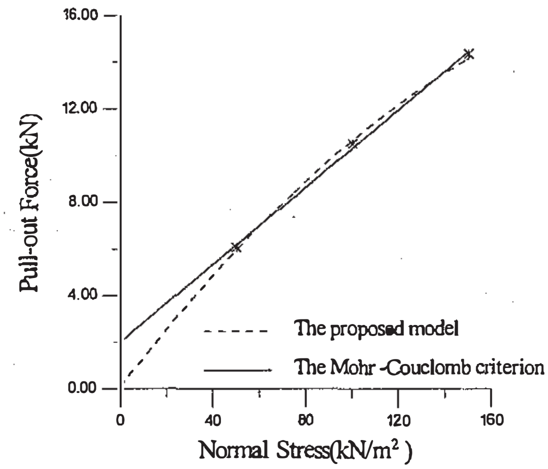
If the strain corresponding with the computed ultimate pull-out force exceeded 5%, then this step is repeated with the secant modulus at 10% strain.

For geogrid A, pull-out results of group I in Table 2, the parameters are a_1 =760 、a_2=1056 、 and a_3=683 respectively by the above mentioned method. The comparison of the proposed model and Mohr-Coulomb criterion for pull-out test data is shown in



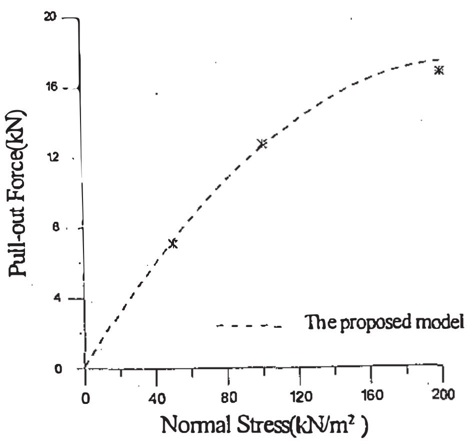
geogrid A and Dr=85%

Fig 2 The comparison of the proposed model with Mohr-Coulomb criterion

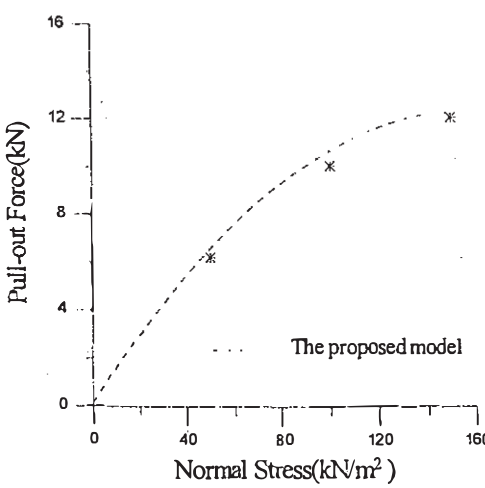


geogrid A and Dr=50%

Fig 4 The comparison of the proposed model with Mohr-Coulomb criterion

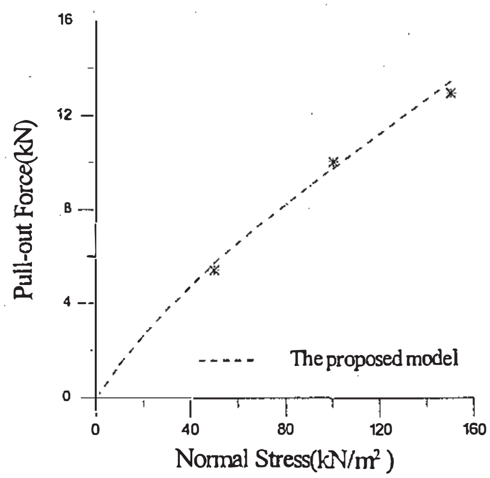


(a) geogrid B and Dr=85%

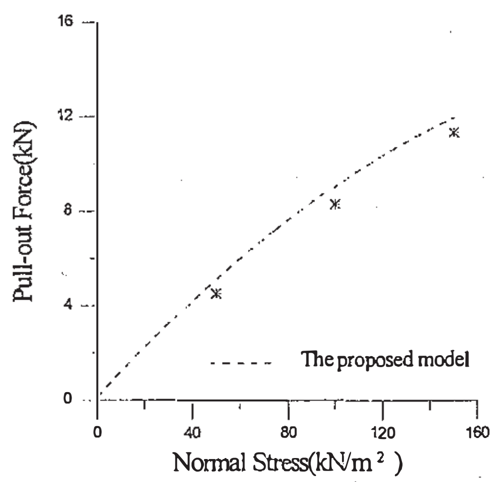


(b) geogrid C and Dr=85%

Fig 3 The results of predicting ultimate pull-out force



(a) geogrid B and Dr=50%



(b) geogrid C and Dr=50%

Fig 5 The results of predicting ultimate pull-out force

Figure 2. It is found that the proposed model is better than Mohr-Coulomb criterion, and its apparent cohesion force is zero which is consistent with the property of the test soil. The errors in predicting ultimate pull-out forces of grids B and C are within 10% (Dr=85%) shown in Figure 3. The results of group Π (see Table 2) using the proposed model are shown in Figures 4 and 5, respectively. The results also indicate that the model appeared to be a good application. However, the maximum errors of prediction are 15%(for Dr=50%), but they are within acceptable scopes.

5 CONCLUSIONS

a. The dimensionless term $\sigma/_E$ is introduced in this model to describe the behavior of pull-out force. It is the characteristic of this model.

b. Many researchers pointed out that $\tau/_\sigma$ decreased with increasing normal stress. The proposed form of

$\frac{\tau}{\sigma} = a_1 + a_2 e^{-a_3 \frac{\sigma}{E}}$, with constant a_1 、 a_2 、 a_3 parameters, is able to describe this phenomenon.

c. If E approaches infinity, Eq.(2) becomes $\tau = \sigma(a_1 + a_2)$, which is a special case of Mohr-Coulomb criterion.

d. The model used for Tensar geogrid in pull-out test to be better than Mohr-Coulomb criterion. It is also found that the model has the results seemed ability of predicting ultimate pull-out force.

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