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FEM simulation of pullout resistance of geogrid in soil

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ABSTRACT: It is believed that the pullout resistance of geogrid from soil is induced from two sources. One is the friction and cohesion between the surface of geogrid and surrounding soil, and the other is the bar resistance of the geogrid. To investigate the ultimate pullout resistance of geogrid from soil, in this paper, an approach is developed. In this approach, both the bar resistance and friction are taken into account. The finite element method is used to simulate the behavior of a single bar of geogrid in soil, and find the ultimate bar resistance. The problem is simplified as a plane strain one. The friction and cohesion are obtained by using conventional methods. Employing results of a test by other researchers, the pullout resistance of the geogrid in the test is analyzed using the proposed approach, and the approach is validated.

1 INTRODUCTION

Polymeric geogrids as reinforcements in soil are being used in an increasing number in civil engineering. In estimating the performance of reinforced soil structure the pullout resistance of geogrid is one of the most important parameters. The pullout resistance is generally described by parameters of the pullout friction angle and pullout cohesion between soil and geogrid, and they are often determined from pullout test.

A number of researchers, such as Kuwano et al. (2004), Ju et al. (2004) and Hironaka et al. (2004), have studied the pullout resistance by using pullout tests, but it is difficult to find general rule of the resistance due to the limitation of the tests. The boundary effects may be significant in laboratory tests. The test specimen of geogrid is often small in size, and the edge of geogrid specimen is obvious to influence the pullout resistance compared to the real case, in which the size of a sheet of geogrid is very large. It is an important issue to determine the pullout resistance simply and accurately, and should be studied intensively. To eliminate the limitation in test, analytical or numerical method may be effective.

It is commonly reorganized that the pullout resistance of geogrid from soil may be divided into two parts. One is the friction and cohesion (called "surface force") between the surface of geogrid ribs (including transverses bar and longitudinal rib) and surrounding soil, and the other is the resistance of transverses bar (hereafter "bar resistance"). In pullout test, the two factors, the friction and cohesion of bar surface and bar resistance, can be accounted together, and is described by the pullout friction angle and pullout cohesion.

Yan and Barr (1997) ever proposed a method to calculate the surface force and bar resistance, respectively. In this method, the pullout resistance is computed by a plane-stress finite element method, but the friction spring coefficient and bar resistance coefficient are difficult to determine. To investigate the ultimate pullout resistance of geogrid from soil, an approach is developed by using the finite element method to simulate the behavior of a single bar of geogrid in soil in this paper. In this approach, the problem is simplified as a plane strain one, and the surface force and bar resistance are determined separately.

The approach of FEM simulation used in this paper is different from the ones generally used. The general method just simplifies the geogrid as a membrane (a plate). In the approach of this paper, however, almost no simplification is given on the structure of the geogrid, and the geogrid is taken as a net with bars, ribs and junctions. The approach is validated by analyzing the results of a test by Wu et al. (2001) and Yan & Barr (1997).

2 APPROACH DETERMINING THE ULTIMATE RESISTANCE

For either uniaxial geogrid or biaxial geogrid, the pullout resistance includes two parts. One is the friction and cohesion between the surface of geogrid and surrounding soil, and the other is the bar resistance. The surface force between the two materials is relatively simple to be determined by using general friction test, and there are experiences, which can be learned. Even in case of no test results for certain geogrid and soil, we may give estimation to it and it will not result in great error. The studies by Yan and Barr (1997) indicated that the friction and cohesion takes a small percentage comparing to the bar resistance. Therefore, the accurate estimation of the bar resistance is very significant, and plays an important role in the determination of the pullout resistance.

In this study, the authors determine the surface force and ultimate bar resistance separately. The bar resistance is strongly related to a number of factors of the geogrid and soil, such as size of aperture, dimension of bars and ribs, strength of soil, etc. All these factors influence the interaction between geogrid and soil. However, this interaction cannot be accurately taken into account in general finite element analysis, in which the geogrid is assumed as a membrane. Even in three-dimensional analysis, the geogrid is still taken as a membrane, otherwise the finite element model will be very large. If the geogrid is simplified as a membrane, the interaction between geogrid and soil takes as surface interaction including friction and cohesion. Although the bar resistance and other factors may be combined into the friction and cohesion, it is obvious that the mechanism is not reflected in the "membrane" method, and the authors believe that the bar resistance cannot be simulated properly using this method.

To properly reflect the bar resistance but not too complicated, an approach using plane-strain finite element method (FEM) is presented. In this approach, we just analyze one bar embedded in soil. The problem of the single bar of geogrid embedded in soil may be taken as a plane-strain problem. If the resistance of a single bar is determined by using plane-strain FEM, the total bar resistance in a given area (as shown in Fig. 1 (a)) may be summarized by the resistance of each bar within this area. For example, if the ultimate resistance of a single bar is T(kN/m) and there are n bars within 1m^2 of the geogrid, then the bar resistance in 1m^2 of the geogrid is $n \times T$, and thus the bar resistance on unit area is $\tau_{bar} = nT$ (kN/m^2).

In Fig. 1 (b), $ABCD$ is the section of a single bar. In FE simulation, there are shear stress on surface of the bar due to the friction and cohesion, i.e. on AB and CD (as shown in Fig. 1 (b)). In present approach, the friction and cohesion is accounted in other

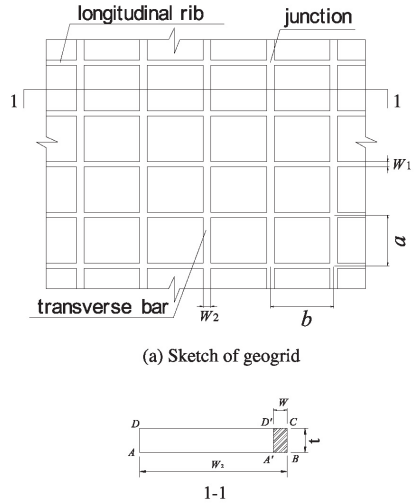

Figure 1. Sketch of geogrid.

approach instead of FEM, so it should not be considered in FEM. To minimize the friction and cohesion on surface of bar, the FE model is established using a simplification. In the FE model, the bar is assumed very thin along direction of w_2, and is w other than w_2, namely $A'BCD'$ is taken as the bar. Meanwhile, at both the topside and bottom side, a soft element, as shown in Fig. 2, is set to minimize the friction and cohesion.

Because there are longitudinal ribs linked to transverse bars, the actual bar resistance T_a should be smaller than T determined by 2D-FEM. If the longitudinal rib with wideness w_1 links to transverse bar at a distance a, T_a should be equal to $T \times (a\text{-}w_1)/a$, and the bar resistance on unit area is $\tau_{bar} = n \times T \times (a - w_1)/a$ (kPa). However, if the junction is thicker than the transverse bar, this revision may be not necessary.

For the cohesion, c, on the surface of geogrid, we may ignore it in case of sand, and certain discount of the soil cohesion may be assumed in case of clayey soil. As for the friction, it may be determined by normal stress σ_n and friction coefficient, say tan δ, which may be found from friction test. In case of no tan δ available, it can be assumed according to the friction angle of soil. The friction force F on unit area of geogrid is then equal to $\tau_{friction} = 2S\sigma_n \tan\delta$ (where S is the contact area between geogrid and soil on unit area of geogrid, and equal to $a \times b - (a - w_1)(b - w_2)$ in which a, b, w_1, w_2 are shown in Fig. 1). The cohesion force on unit area of geogrid can be given by $\tau_{cohesion} = 2Sc$, in which c is the cohesion on the contact face between geogrid and soil. Because the friction and cohesion take a small percentage in the pullout resistance, these assumptions should not result in great errors.

Finally, the pullout resistance on unit area of geogrid is $\tau = \tau_{bar} + \tau_{friction} + \tau_{cohesion}$.

3 VALIDATION OF APPROACH

To validate the approach presented above, test results (Wu et al., 2001) are employed. In the test, the geogrid Type is TGSG15, which is made in Taian, China. The properties of the geogrid are listed in Table 1.

Table 1. Properties of the geogrid.

a(mm)	b(mm)	w_1(mm)	w_2(mm)	t(mm)
40	50	4	6	1

The plane-strain FE model used in the simulation is shown in Fig. 2. Due to the symmetry, half of the structure is employed. A pressure σ_n is applied on the top surface, and then a load T exerts on the bar in steps. The applied load T on bar should be equal to the bar resistance. In the FE model, the bar is assumed rigid and elastic and a large modulus is given. The soil is a sand with friction angle 43.3° and cohesion 0. It is assumed ideal elastic and plastic and follows Mohr-Coulomb criterion. For soil element, which is in a state of failure, the Young's modulus is set to 10 kPa.

The parameters are listed in Table 2. Poisson's ratio and Young's modulus of each material are assumed. The authors performed a number of computations to vary the magnitude of the modulus of soil, and it is found that the modulus has little influence on the bar resistance. This implies that the modulus can be estimated and not to result in great errors. As for Poisson's ratio of soil, 0.3 is a commonly acceptable value in analysis of earth structure, and

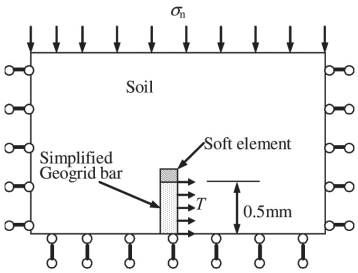

Figure 2. Sketch of FE model.

Table 2. Parameters used in FE simulation.

Material	Young's modulus (kPa)	Poisson's ratio	Friction angle (°)	Cohesion (kPa)
Soil	20000	0.3	43.3	0
Bar	90000000	0.3	–	–
Soft element	1000	0.3	–	–

Poisson's ratio of bar and soft element should has little influence due to the rigidity and small area.

The relationship between displacement of bar, R, and applied force, T, can be obtained from the FE simulation, as shown in Fig. 3. From a curve in Fig. 3, the force corresponding to the point at which the displacement dramatically increases is taken as the ultimate bar resistance T at certain normal stress σ_n. The ultimate resistance is not necessary to be revised by considering the longitudinal rib because the geogrid used in the test (Wu et al., 2001) is a kind one of which the junction is thicker than the transverse bar, and the thickness of junction is about two times of that of transverse bar. Because we obtain is the ultimate bar resistance, the pullout resistance using present approach is the ultimate pullout resistance.

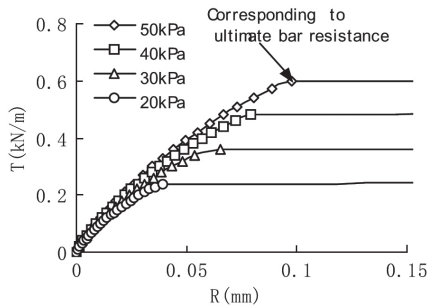

Figure 3. Relationship between displacement of a single bar and applied force T.

On the other hand, the surface friction coefficient tan δ is found from Yan and Barr (1997), and is equal to 0.19. According to a = 40 mm, b = 50 mm, w_1 = 4 mm, and w_2 = 6 mm, the geogrid surface is calculated to be $S = 0.21 * 10^6 mm^2$. The friction force on unit area of geogrid thus can be obtained by $\tau_{friction} = 2S\sigma_n \tan\delta$ The tested soil is a sand, and no cohesion is to be considered.

According to the bar resistance and friction force, the ultimate pullout resistance on unit area of geogrid is found under different normal stress. The test data and computed results are shown in Fig 4. In this figure, the ultimate pullout resistance on unit area, τ, is defined as $\tau = \tau_{bar} + \tau_{friction}$, and the normal stress σ_n is the stress applied on the flat surface geogrid.

In Fig. 4 the computed curves are obtained form different soil modulus, which is 10 MPa, 20 MPa and 40 MPa. It is found that the difference between the computed results is small, and thus the influence of modulus of soil on pullout resistance is neglectable.

From Fig. 4 it is found that the computed pullout resistance is a little smaller than that of test data. It is very possible that the error results from the test boundary condition, especially the boundary squelching effect. In the model pullout test (Wu et al., 2001), the stresses in soil concentrate in the nearby zone of the mouth that

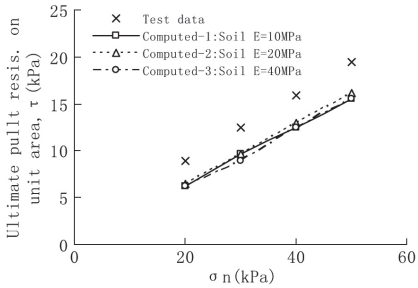

Figure 4. Relationships between normal stress and ultimate pullout resistance.

geogrid is pulled out due to the restricting of rigid wall of the model. The test data show that there is an intersection with τ-axis. However, the tested soil is cohesionless, there should be no pullout resistance if normal stress σ_n is equal to 0.

Figure 5 shows the contour lines of stain in horizontal direction in the zone around the geogrid under ultimate pullout load of geogrid on which normal stress $\sigma_n = 50$ kPa is applied. In Fig. 5 "-" means that the strain is in extension. It is found that the maximum extension strain is about –13%, and the maximum compressive strain is 3% only.

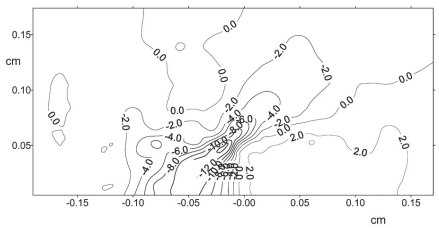

Figure 5. Contour lines of stain (%) in horizontal direction.

4 SUMMARY

The pullout resistance of geogrid in soil can be divided into two parts, the friction and cohesion between the surface of geogrid and surrounding soil and resistance of transverse bars. They can be determined separately. A new approach is presented to estimate the ultimate pullout resistance. The bar resistance can be obtained from plane-strain FEM, and the friction and cohesion are given by conventional method. The approach is validated using results of a test.

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