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Structural Features of High Density Polyethylene Steel-Plastic Tenon Geogrid

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By attaching the tenon design to the high-density polyethylene (HDPE) steel-plastic composite geogrid, one new type of geogrid structure named steel-plastic tenon geogrid is designed, which can improve the anti-extraction stability of the grid, further improve the stability of rock and soil, reduce the number of grids, and save project investment. Therefore, it is very important to study and master the structural features of the tenon geogrid in engineering applications. Through a large number of studies about laboratory pull-out tests, the author applied related software to numerically simulate the structural features of the tenon geogrid, and then obtained the relative rule between the tenon thickness, the tenon side length, the mesh size of the grid, and the geogrid-soil interface parameters. This is of great significance to the design and application of the steel-plastictenon geogrid.

1. Introduction

Steel-plastic composite geogrid is made of high-strength steel wire wrapped by high-density polyethylene (HDPE) into high-strength strips. Thanks to its excellent physicochemical properties such as low failure elongation, high strength, low creepage, anti-acids alkali and oil, anti-ultraviolet radiation, no invasion by water and microorganisms, and good friction property with soil, it has been widely used in the engineering. For the tenon, as one common anti-sliding measure, it has been widely used in earth-retaining walls and wave walls (Zhao et al., 2005; Du et al., 2007). The main purpose for installing geosynthetics in high-fill slopes is to use its diffusive soil stress, increase soil modulus, limit the reinforcements such as soil lateral displacement etc., and thus ensure the key issue of slope-stability.

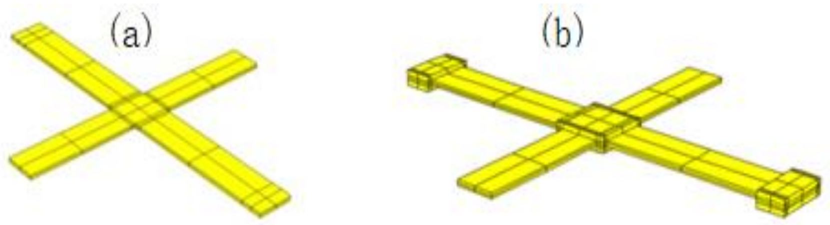


Figure 1: Non-tenon geogrid model unit(a) and Tenon geogrid model unit(b)

By applying the tenon design to the high-density polyethylene (HDPE) steel-plastic composite geogrid, one new type of geogrid structure is formed, as the steel-plastic tenon geogrid (Figure 1(b)), which can improve the locking effect of grid on the rock-soil mass and increases the passive resistance of the rock and soil to the grid ribs, Thereby this shall further restrict the lateral displacement of the soil particles, enhance the interaction between the rock and soil, and reduce the deformation of the rock and soil. The installation of the tenon can increase the anti-pulling stability, reduce the number of grids under the premise of ensuring stability, and thus save the investment. Therefore, it is of great significance for the design and use of the tenon geogrid to study and master the contribution of the structural features and size of the tenon in engineering applications, e.g., the effect of the tenon thickness, the tenon side length, and the mesh size of the grid etc., in the actual project. Interfacial mechanical parameters between materials are important ones in engineering design. Many studies have shown that it's usually determined by shear test and pull-out test (Yin et al., 2004; Shi et al., 2009). In this paper, the numerical simulation was made for the pull-out test of the steel-plastic tenon geogrid in order to obtain the relative rule between the grid structure feature size and the geogrid-soil interface parameters.

2. Structural features of tenon geogrid

The structural features of the tenon geogrid can be described by the width w1 and the thickness d of the longitudinal grid rib, the width w2 and the thickness d of the transverse rib, and the mesh size L1×L2. The tenon is described by the tenon side length tL and tenon thickness td (Figure 2).

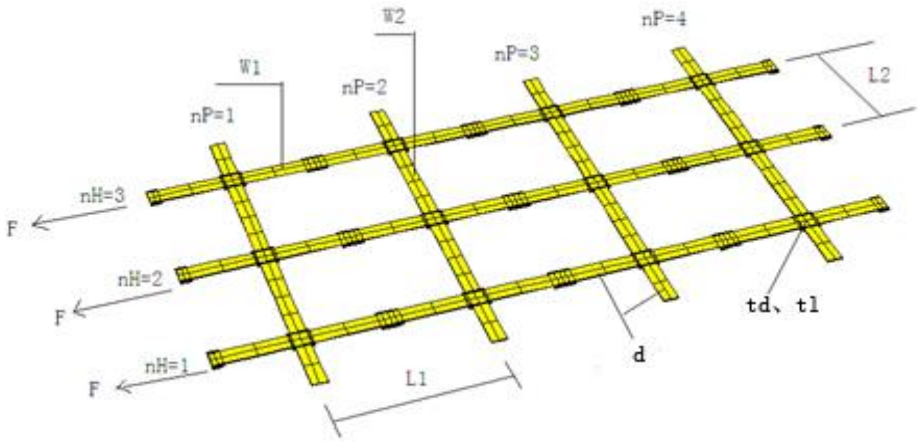
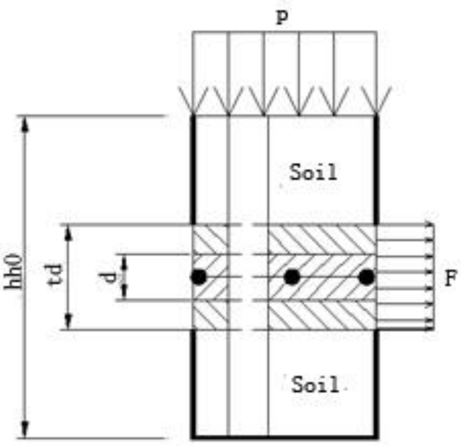


Figure 2: Structural features of tenon geogrid

3. Numeral simulation method of pull-out test

According to the specification (Ministry of Transport of the People's Republic of China, 2006), in the drawing process one certain pull rate is given in terms of the soil property (the displacement rate of 0.2 ~ 3.0mm/min is commonly used). At such rate, the geogrid ribs were pulled out of the soil (Figure 3), and then calculation was made for the friction coefficient or equivalent friction angle of the grid and soil in the pull-out test according to the maximum pull-out force Td and the corresponding overburden pressure P in the drawing process.



hh0-soil thickness; td-tenon thickness; d-grid thickness; F-stretching force; p-soil-overburden pressure

Figure 3: Pull-out test model

The numerical simulation of the pull-out test was carried out in the following steps:
(1) Select the physical dimensions of grid ribs and tenon;
(2) Divide the grid model according to the grid ribs and the tenon size;
(3) Set the physical mechanical parameters of the material;
(4) Apply the overburden pressure p;
(5) Gradually apply the pull-out force F of the grid ribs level by level.

3.1 Material model

The material units were selected as follows:
(1) Simulation of soil material: adopt the Mohr Coulomb constitutive model;
(2) Geogrid model: In order to simulate and optimize the structure of the tenon geogrid, the geogrid structural unit by Flac3d software was used;
(3) Tenon: apply geogrid + elastic entity unit for simulation.
For the Geogrid structural unit, the triangular unit was adopted. Through the Link between nodes, the connection and mechanical action (effective lateral stress σ_m and shear stress τ) were generated between this unit and the solid units, and the mechanical model of the Link was simulated by using the “spring + slider”. The shear force at the geogrid-rock soil interface is controlled by the adhesive friction characteristics, i.e., jointly determined by the connecting spring parameters: stiffness K of unit area, bonding strength c, friction angle Φ, and effective lateral stress σ_m. The model parameters are calculated as shown in Table 1.

Table 1: Parameters of Geogrid structural unit

No.	Parameters	Calculation
1	Density:	1.2kg/m^2
2	Isotropic/orthotropic:	Isotropic
3	Thexp:	Not consider
4	Thickness:	According tothe actual thickness
5	cs_scoh and cs_sfric:	According to the empirical coefficient
6	cs_sk:	According to the empirical coefficient
7	Slide:	Not consider

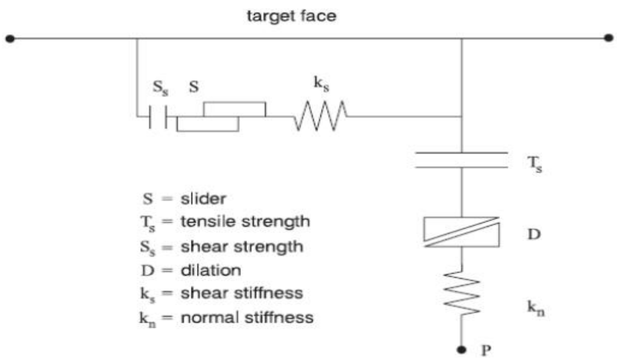


Figure 4: Spring + slider model

3.2 Material parameters

The material parameters simulated in the pull-out test are shown in Table 2 and 3, in which the interface friction parameters were obtained according to the existing laboratory pull-out test.

Table 2: Parameters of soil layer

Material No.	Density (g/cm^3)	Deformation modulus (MPa)	Poisson’s ratio μ	Cohesion (kPa)	Internal friction angle Φ(°)	Remarks
S_1	1.80	8.3	0.33	25.40	13.59	Fine-grained soil

Note: The test materials were taken from the site of LIUPANSHUI YUEZHAO Airport

Table 3: Interface friction parameters

Material No.	Tenon geogrid interface frictional parameters		Non-tenon geogrid interface frictional parameters		Remarks
	Cohesion (kPa)	Internal friction angle Φ(°)	Cohesion (kPa)	Internal friction angle Φ(°)	
S_1	29.15	10.05	21.93	7.27	Fine-grained soil

3.3 Simulation scheme

In the simulation, the factors such as the type of landfills, tenon thickness, tenon density, and the thickness of the overburden etc. were mainly considered. According to the principle of orthogonal test design, the simulation scheme is as follows:

(1) Type of soil filling: select the backfills of airfield area at LIUPANSHUI Airport;
(2) Tenon thickness td: 4mm-10mm;
(3) Tenon side length: Use the tenon side length tL to make simulation, and tL is 25mm-45mm;
(4) Grid mesh: Take different mesh sizes L1 × L2; L1 × L2 changes in the range of 150-300mm × 150 - 250mm;
(5) Upper load: 50kPa, 100kPa, 150kPa, 200kPa, 250kPa, 300kPa, and 400kPa. That is, the thickness of the corresponding overlying soil layer is: 2.78m, 5.56m, 8.33m, 11.11m, 13.89m, 16.67m, and 22.22m (select the density of the overlying soil layer for 1.8g/cm3 for this calculation).

During the pull-out test, the area of each model material is calculated as follows:

(1) Model area: The area of the entire model, including ribs, is L1×L2;
(2) Rib area: only refer to the area of the grill/grid rib, L1×w1+(L2-w1)×w2;
(3) Increased area with tenon ribs: (tL-w1)×tL+(tL-w1)×(tL-w2).

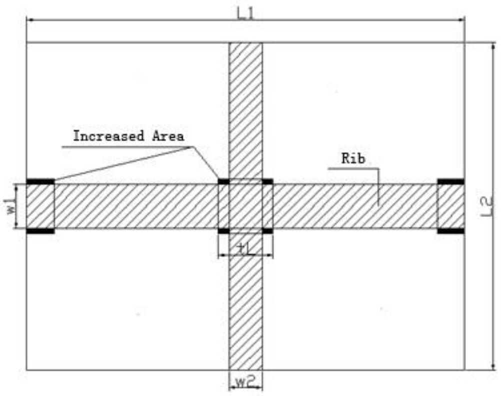


Figure 5: Area calculation for each material

3.4 Determination of the maximum pull-out force

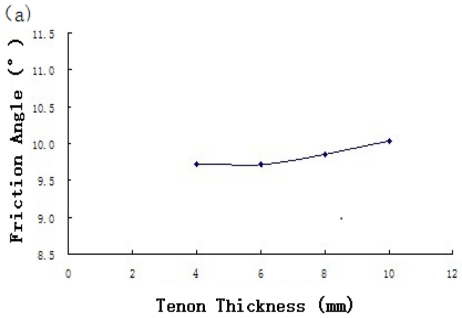
During the simulation of the pull-out test, the rib displacement increases with the pull-out force. With the increase of the pull-out force, the proportion of plastic deformation in the soil unit increases, and the deformation of the soil increases significantly. This further cause the significant increase in displacement. Therefore, in this simulation process, the turning point where the pull-out displacement is significantly increased can be selected as the criterion, and the corresponding pull-out force is the maximum in the test.

4. Simulation results of tenon thickness

The simulation scheme of pull-out test for the tenon thickness is as follows:

(1) Soil layer: Take the S1 soil layer of Table 2 and 3;
(2) Mesh size of grid: 200mm × 145mm, thickness 2.5mm; tenon side length 25mm, involving the ribs coverage of 20.47%, ribs area of 0.02374m^2;
(3) Tenon thickness: 4mm, 6mm, 8mm and 10mm;
(4) Model size: 1 × 4 grid (145mm × 800mm);
(5) Upper load: 50kPa, 100kPa, 150kPa, 200kPa, 300kPa, 400kPa;
(6) Horizontal drawing load: apply the load level by level, 0.1kN for each level;
(7) Drawing speed: Use 200 steps/level to simulate the loading rate of the drawing load.

The simulation results are shown in Figure 6(a), which shows:
(1) With the increase of the tenon thickness, the friction angle gradually increases in the strength parameters, while the cohesion force changes little;
(2) The minimum thickness of tenon should not be less than 6mm.



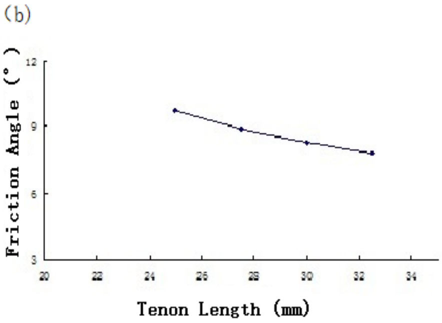


Figure 6: Relationship between tenon thickness(a), tenon length(b) and friction angle (Soil s1, tenon-mounted, front node, simulation at 200 steps per level)

5. Simulation results of tenon side length

In the simulation scheme for the tenon side length, the pull-out tests were performed by taking the tenon length 25 × 25mm, 27.5 × 27.5mm, 30 × 30mm, and 32.5 × 32.5mm, etc., and the tenon thickness of 6mm; the other parameters are the same as in Chapter 3.
The simulation results are shown in Figure 6(b). It can be seen from the results that with the increase of the tenon side length, the cohesion and friction angle in the strength parameters decrease, and the cohesion force changes little, but the friction angle decreases more significantly. The main reason is that the geogrid-soil interface strength is less than soil strength, and then increasing the grid coverage will lower the friction characteristics of the contact surface. At this time, even if the contact area between the grid and the soil is increased, the friction characteristics of the soil will not be enhanced but be reduced.

6. Simulation results of tenon geogrid mesh size

Table 4: Grid size and drawing loads

Mesh Size of Grid (mm)	50 (kN)	100 (kN)	150 (kN)	200 (kN)	300 (kN)	400 (kN)	Cohesion (kPa)	Friction Angle (°)	Rib Area (m^2)
125×125	46.91	57.41	66.67	75.00	90.74	105.86	40.50	9.45	0.0169
145×145	43.18	54.10	63.70	72.23	87.95	102.35	37.19	9.48	0.01978
165×165	40.81	51.83	61.68	70.36	85.60	99.91	35.06	9.46	0.02266
185×185	38.94	49.83	60.09	68.26	83.54	98.20	33.15	9.47	0.02554
200×145	38.82	50.04	60.37	69.34	84.61	99.64	32.92	9.71	0.0223
200×165	38.41	49.66	59.85	68.55	84.04	98.68	32.60	9.63	0.02374
200×185	37.84	49.11	59.38	68.04	82.93	97.83	32.20	9.56	0.02518
200×200	36.24	48.06	58.14	66.86	82.36	96.90	30.72	9.66	0.02662

In the simulation, 8 different dimensions of tenon grid size, including125×125mm, 145×145mm, 165×165mm, 185×185mm, 200×145mm, 200×165mm, 200×185mm and 200×200mm were adopted in the pull-out test; the tenon side length of 25×25mm and the thickness 6mm were taken; the other parameters are the same as those in Chapter 3.
The simulation results are shown in Table 4. It can be seen that increasing the density of the grid cannot effectively improve the friction angle and only has a certain influence on the cohesion. Therefore, under the condition of ensuring grid strength, the wide grid size can be properly used to save costs.

7. Conclusions

According to the above-mentioned change rule between the structural features of the steel-plastic tenon geogrid and the geogrid-soil interface parameters, the structural features can be obtained as follows:
(1) As the tenon thickness increases, the friction angle gradually increases in the strength parameter, but the cohesion force does not change much. Besides, the tenon thickness should not be less than 6mm.
(2) Since the frictional characteristics of the interface between the grid material and the soil is lower than that of the soil itself, the frictional characteristics of the soil cannot be enhanced by increasing the contact area between the tenon and the soil.
(3) Increasing grid density cannot effectively increase the friction angle, and it only affects cohesion. Therefore, under the condition of ensuring grid strength, the wide grid size can be properly used to save costs.

Acknowledgments

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