Research on the interface properties of geogrid with different mesh sizes

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Abstract: Due to its special mesh structure, geogrid can be embedded in the surrounding soil so effectively that the effects of reinforcement are comparatively better the other geotechnical composite materials. Geogrid has been adopted more and more widely in steep embankment reinforcement engineering. In practical engineering, the design of a reinforced body of soil with geogrid is usually based on Finite Elemental Method (FEM) numerical methods and calculation is carried out as a two-dimensional plane strain problem. This simplifies the geogrid with mesh structure into a single strip. The plausibility of calculating the strength indexes of the interface through interface parameters without considering the influence of the mesh size of the geogrid on the features of the interface should be studied. The current research on the interface properties of geogrid with different mesh sizes does not examine this issue thoroughly. By using large-sized shear experiments and FEM numerical methods, this paper studies the influences of the mesh size of geogrid on interface properties. The influence of mesh size on the features of the interface with geogrid can be displayed directly and quantitatively. This shows that larger mesh sizes result in higher strength indexes of the interface and a clearer reinforcement effect. The corresponding requirements of the geogrid material also increase; otherwise, the tensile strength would not be satisfied. The research results provide effective guarantees for the construction and operation of steep embankment reinforcement engineering, which is meaningful for safety engineering.

Key words: geogrid; mesh structure; interface property; strength index; high embankment reinforcement engineering

1 Introduction

Increasing urbanization has decreased the amount of land in China which is available for construction, This has led to important infrastructures being built in mountainous areas, and to steep embankments being used in construction. Embankments should be stabilized effectively to avoid serious engineering accidents. Traditional methods of landslide prevention are hard to apply to steep embankments because of technological challenges and high costs. Reinforced material with a geogrid can be adopted in steep embankment reinforcement engineering due to its special mesh structure, which can effectively embed the surrounding soil and reinforce the embankment [1-4].

Design and calculation methods for geogrid technology have developed extensively as geogrids have been increasingly used in reinforcing bodies of soil. The numerical methods, such as the Finite Element Method (FEM), have received increasing attention and are likely to be the trend of the future[5-8]. FEM considers the filling soil and reinforced material respectively and sets a contact interface between the two materials. The interaction between the two materials can be displayed through the strength indexes of the interface. This method is straightforward and widely used. The strength indexes are identified primarily through indoor experiments, or, they can be calculated through the interface friction coefficient or coefficient ratio of interfacial friction suggested by various standards [9-12].

The commonly used indoor experiment methods are the direct shear test and the pull out test. These two methods have mechanical differences, which result in differences in strength indexes, deformation characters and the relationship of the stress-strain curve to the interface. Researchers around the world have studied the plausibility and adaptability of these two methods, but a definitive conclusion has not yet been reached [13-16]. Some parameters,such as the interfacial friction coefficient or coefficient ratio of interfacial friction, only consider the difference of reinforced materials. For instance, the Application and Technology Standard of Road Geo-synthetics of China（JGT/T D32-2012）suggests that the coefficient ratio of interfacial friction K for geo-textile should be 0.67 and the for geogrid should be 0.9. In this method, the coefficient ratio of interfacial friction is $K=\tan\varphi_{GS}/\tan\varphi_S$, where φ_{GS} is the friction angle between geogrid and soil, and φ_S is the inner friction angle of filling soil. The method does not consider the different characteristics of filling soil and the influence of the geometric size of the mesh structure of the geogrid on the interfacial characteristics; further research is needed to study the plausibility of this approach.

Since the geogrid in a steep embankment can have tens or hundreds of layers, the three-dimensional numerical model cannot be established if the FEM numerical method is used according to the geometric sizes of geogrid such as the grid width and the opening size. This results in three-dimensional problems frequently being simplified into two-dimensional equations to find the numerical model using plain-strain theory[17-19]. In designing and calculating reinforced structures with geogrids in steep-embankment engineering, the two-dimensional problem simplifies the geogrid with mesh structure into a single strip. This keeps the influence of mesh sizes from being considered. The same interfacial friction coefficient and the coefficient ratio of interfacial friction are used in the calculation of the strength indexes of the interface. Given these restrictions, the plausibility of this approach should be further studied.

2 Research on the interface characteristics between geogrid and soil

The research on the interface characterisrics of geogrid works to identify the strength indexes of the interface between the soil and geogrid. This is the basis for the design and calculation of reinforcing structures with geogrid. The different mechanisms of direct shear experiments and pull out experiments lead to different results from the two methods. In a direct shear friction experiment, the geogrid remains still and passive friction occurs on the grid due to soil displacement. Single side friction occurs between the geogrid and soil, causing the shear stress to be located on the function plane where soil displacement happens. In the pull-out experiment, the geogrid is actively pulled out and friction is applied to both sides. Shear stress occurs on the upper and lower surface of the geogrid. In practical engineering, the following three forms of relative deformation occur between the geogrid and soil when a steep embankment reinforcement structure fails:

(1)When the geogrid is behind the potential sliding surface, which is the grid of the anchor section, the relative deformation that occurs is that the geogrid material is pulled out from the soil during the failure. The failure happens between the geogrid and soil. In this circumstance, the pull out experiment is the most appropriate method to study the interfacial characters.

(2) When the geogrid is parallel to the sliding surface, the relative deformation that occurs is that shear sliding happens along the single surface of the geogrid inside the sliding surface during the failure; this failure happens between the geogrid and soil. In this case, the shear experiment is more reasonable.

(3) When a certain angle forms between the geogrid and the sliding surface, an unstable failure happens on the reinforced structure due to the large deformation of the reinforced body or the tensile failure of the geogrid. The stability at this moment is decided both by the ultimate tensile strength and the axial tensile stiffness.

The scope of application of the direct shear experiment and the pull out experiment can be identified when the relative deformation between the geogrid and soil and the mechanism of the two experiment types are combined.

When a steep embankment is reinforced with geogrid, the potential sliding surface often appears behind the reinforced structure and slides out along the bottom of the reinforced body. Shear sliding happens along the single surface of the geogrid inside the sliding surface. The stability at this moment is decided by both the strength of the filling soil outside of the sliding surface and the strength of the interface of the geogrid. The failure mechanism of a steep embankment structure reinforced with geogrid,and the relative deformation between the geogrid and soil make the shear experiment the more reasonable method of studying the character of the interface of geogrid. Therefore, this paper uses a large-sized indoor shear experiment to study interface characteristics and the influence of geogrid mesh size on the interface characteristice.

3 Large-sized shear experiment

3.1 Experiment facility

A large-sized facility was used in this experiment. The model used was ZY50-2G. The diameter of the upper and lower shear boxes is 25cm and the height is 25cm.The maximum vertical and horizontal output loads are both 700kN and the permitted shear displacement is 50mm. The facility is shown in Figure 1.

Fig.1 Experiment facility

3.2 Experiment scheme

(1) geogrid material

The geogrid material used in the experiment was prepared by Chongqing Yonggu Construction Material Company. For the convenience of comparison and analysis, two special conditions were considered: (1) Without grid and (2) Fully-paved with grid in which the geogrid is jointed and fully paved by being cut into slices. The contact area (A) between the grid and soil is $0m^2$ when the grid is not paved. When the grid is fully paved, the contact area between the grid and soil is equal to the section area of the shear box resulting in $A=0.1963m^2$. The simplified figure of the geogrid product is shown in Figure 2. Table 1 shows the physical size and technical parameters of the geogrid in the different experiment schemes. Figure 3 shows the contact area between the geogrid and soil.

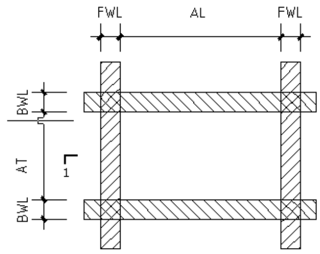


Fig.2 Product of the geogrid

Tab. 1 Geometric sizes and technical parameters of the geogrid under different experiment schemes

Scheme	AT/ mm	AL/ mm	BWL /mm	FWL /mm	Limit standard Tensile strength /kN		Elonga tion/%
					Longitudinal	Transverse	
I		No geogrid			/	/	/
II	115	115	14	14	120	120	≤3
III	49	49	14	14	120	120	≤3
IV		Fully paved			120	120	

（a）Scheme II （$A=0.0362m^2$） （b）Scheme III （$A=0.0700m^2$）

Fig. 3 Area of contact interface between the geogrid and soil under different experiment schemes

(2) Filling material

The interfacial strength indexes of different filling materials vary dramatically. This, coupled with the complication of the friction between the grid and soil, results in an inability to obtain regulations for the filling material. Standard sand with the same grain size and comparatively simple mechanical characters is used as filling material in this study. The cohesion of filling material c is 0.01kPa (approximately equal to 0kPa) and the inner friction angle φ is 30°, obtained by the indoor shear experiment.

Fig. 4 Standard sand in experiment

(3) Experiment methods

The sand capacity of the shear box is identified through the density of standard sands. The volume and compactness of each experiment is the same. The lower shear box is fixed first and a vertical load of 400kPa is imposed. After repeatedly filling and imposing loads, the surface of the filling material is flush to the upper edge of the lower shear box. Then, the geogrid is laid according to the experiment scheme before fixing the upper shear boxes as shown in Figure 4. The grid should be connected firmly with the lower shear box to avoid relative displacement and in order to ensure the single-side shear effect between the geogrid and soil. Only shear displacement happens between the standard sand in the upper shear box and the geogrid; the displacement ratio is 2mm/min. The obtained shear strength has clear physical meaning. Vertical loads of 100,200,300 and 400kPa are imposed to measure the horizontal thrust when shear failure happens under different vertical loads.

3.3 Experiment results and analysis

The normal stress σ on the interface between the grid and soil can be solved according to the vertical load. The shear stress τ on the interface can be calculated by the ratio between the horizontal thrust and the cross-sectional area of the shear box. The experiment results are shown in Table 2. Linear fitting of normal stress and shear stress is conducted as shown in Figure 5. The constant of linear formula is the cohesion of interface c_{inter} and the coefficient is the tangent of the inner friction angle φ_{inter}. Therefore, the strength indexes of the interface can be obtained as shown in Table 3.

Tab. 2 Results of large-sized shear experiment

Experiment scheme \ Shear stress of interface τ（kPa）	normal stress of interface σ（kPa） 100	200	300	400
Scheme I	58.92	114.32	169.46	231.93
Scheme II	53.40	105.85	160.09	212.40
Scheme III	49.01	96.39	146.14	194.29
Scheme IV	35.31	70.48	105.65	140.82

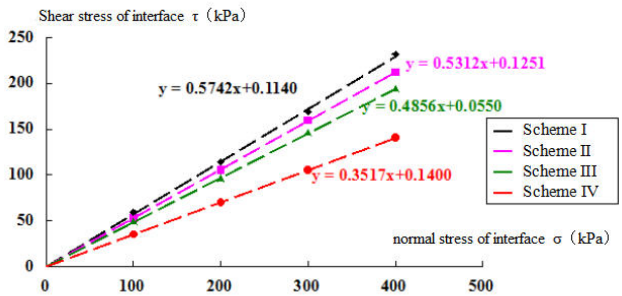


Fig. 5 Linear fitting of normal stress σ and shear stress τ of the interface

Tab. 3 Strength indexes of the interface of geogrid under different experiment schemes

Strength indexes of interface	Scheme I	Scheme II	Scheme III	Scheme IV
c_{inter}（kPa）	0.114	0.125	0.060	0.140
$\tan\varphi_{inter}$	0.574	0.531	0.486	0.352
φ_{inter}（°）	29.86	27.98	25.90	19.38
Coefficient ratio of interfacial friction K	0.99	0.92	0.84	0.61

The definition of the coefficient ratio of interfacial friction is adopted in the Application and Technology Standards of Road Geo-synthetic of China(JGT/T D32-2012), namely $K=\tan\varphi_{inter}/\tan\varphi_{soil}$, where φ_{soil} is the inner friction angle, $\varphi_{soil}=30°$. Coefficient ratios of interfacial friction K are shown in different schemes in Table 3.

Since no geogrid is paved in scheme I, the strength index of the interface should be equal to that of the standard sand filling. So c_{inter} and φ_{inter} are equal to 0.114kPa and 29.86°respectively. In the indoor shear experiment, cohesion of the standard sand c is 0.01kPa and the inner friction angle φ is 30°. The above results are very close and the coefficient ratio of interfacial friction K is similar to 1.

At the same time, results of the large-sized shear experiment show that the coefficient ratio of interfacial friction between the geogrid and standard sand is related to the contact area between the grid and soil. With the change of the mesh size of the geogrid, the coefficient ratio of interfacial friction also changes. The influence of the property of the interface on the geogrid and soil cannot be ignored.

The change of the coefficient ratio of interfacial friction in Table 3 shows that the coefficient ratio reduces gradually with the reduction of mesh size of the geogrid. As the contact area between the geogrid and soil increases the contact area between soil and soil is reduced. When the geogrid is fully paved (scheme IV) the coefficient ratio of interfacial friction K reaches its minimum, 0.61. The primary reason is that the coefficient ratio of interfacial friction is tested when the geogrid contacts the soil in the upper shear box. Since the interface between the geogrid and soil is smoother than the interface between soil, the coefficient ratio of interfacial friction is 1 when the interface is between soil(scheme I); the maximum coefficient ratio of interfacial friction is 1. If only contact between the geogrid and soil exists in the interface, the coefficient ratio of interfacial friction is less than 1. A larger contact area between the geogrid and soil results in a smaller coefficient ratio. When the whole interface consists of contact between the geogrid and soil (scheme IV), the coefficient ratio of interfacial friction is 0.61, which is its minimum. If the geogrid is fully paved, only contact between the geogrid and soil exists in the interface. Therefore, the coefficient ratio of interfacial friction shows the inherent property of friction between the geogrid and standard sand as the filling material.

4 Numerical simulation of large-sized shear experiment

It is difficult to obtain strength indexes of the interface between the soil and geogrid with different mesh-sizes through large-sized shear experiments because of the variety of geometrical sizes of geogrid and the different properties of filling materials. The numerical method is used to simulate a large-sized shear experiment and examine the properties of the geogrid interface.

The FEM program of PLAXIS developed by the PLAXIS B.V. Company of Holland is used in this numerical simulation. The contact between the geogrid and soil is simulated through an interface unit, as shown in Figure 6.

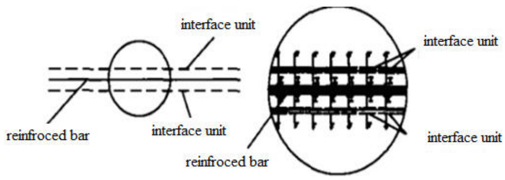


Fig. 6 Interface unit

The PLAXIS program simulates the interaction of the interface between the geogrid and soil based on the elastic-plastic model. The strength index can be solved either through the calculation of the interface parameter R_{inter} and the strength index of surrounding soil, or through identifying the interface cohesion c_{inter} and inner friction φ_{inter} directly.

When using the interface parameter R_{inter} and the strength index of the surrounding soil to calculate the strength index of the interface, the expression is:

$$\tan\varphi_{inter}=R_{inter}\tan\varphi_{soil}, c_{inter}=R_{inter}c_{soil} \quad (1)$$

Where, the c_{soil} and φ_{soil} are the strength indexes of the surrounding soil and c_{inter} and φ_{inter} are the strength indexes of the interface calculated through R_{inter}.

In the program, the interface parameter R_{inter} can be identified through the pseudo friction coefficient f of the geogrid, which is usually obtained through the following experiment:

$$f=\tan\varphi_1 \quad (2)$$

φ_1 is the friction angle of the contact interface between geogrid and soil, namely φ_{inter}. R_{inter} can be worked out through combining the expressions (1) and (2).

$$R_{inter}= \tan\varphi_{inter}/\tan\varphi_{soil}= f/\tan\varphi_{soil} \quad (3)$$

This expression demonstrates that interface parameter R_{inter} equals the above coefficient ratio of interfacial friction K.

When identifying the cohesion c_{inter} of the interface and the inner friction φ_{inter} of the interface directly, the calculation can be carried out through practical strength indexes of the interface, which is more reasonable and feasible than the method of using the interface parameter R_{inter} to calculate the strength indexes of interface.

This paper adopts the FEM numerical method to study the interface property of the geogrid and the interface cohesion and inner friction angle of the interface are evaluated directly to identify the strength index. Eleven different kinds of geogrids are used in the numerical simulation as shown in Table 4. The ultimate tensile strength in the longitudinal and transverse are both 120kN.

Tab. 4 Mesh sizes of different geogrid

Grid mode	Mesh size				Remarks
	AT/ mm	AL/ mm	BWL /mm	FWL /mm	
GSA	/	/	14	14	As scheme IV
GSB	11	11	14	14	
GSC	19	19	14	14	
GSD	31.5	31.5	14	14	
GSE	41.5	41.5	14	14	
GSF	49	49	14	14	As scheme III
GSG	57.5	57.5	14	14	
GSH	80	80	14	14	
GSI	86	86	14	14	
GSJ	115	115	14	14	As scheme II
GSK	236	236	14	14	

The shear process is simulated through setting the facial displacement at 0.05m for the upper shear box and through imposing vertical loads on the top of the model. Interface units are set on the contact surface of the geogrid and soil and on the contact surface of the soil and on the soil between the upper and lower shear boxes to simulate contact between the geogrid and soil as well as the contact between soil and soil, as shown in Figures 7 and 8.

Fig. 7 Setting of interface unit (The green color is the interface between geogrid and soil. The yellow color is the interface between soil and soil)

(a)Before setting the interface unit (b)After setting the interface unit

Fig. 8 Setting of interface between geogrid and soil

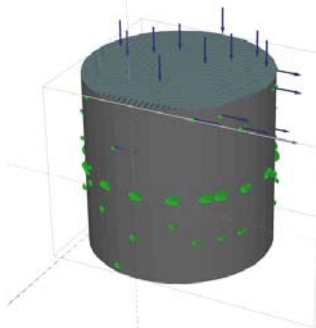


Fig.9 FEM model

Through the numerical calculation of the model, it is possible to calculate the approximate horizontal segment in the latter part of the relationship curve between the composite force on the interface and the loading step. The composite shear force on the interface when shear failure happens under various vertical loads can be obtained, as shown in Figure 10. Through the ratio between the composite shear force and the size of the shear section, the shear stress τ under various vertical loads can be calculated. If taking the shear stress τ on the interface as the vertical coordinate and the positive stress σ as the horizontal coordinate, the strength indexes under different contact area of the geogrid and soil can be obtained through linear fitting. The coefficient ratio of interfacial friction at this moment is $K=\tan\varphi_{inter}/\tan\varphi_{soil}$.

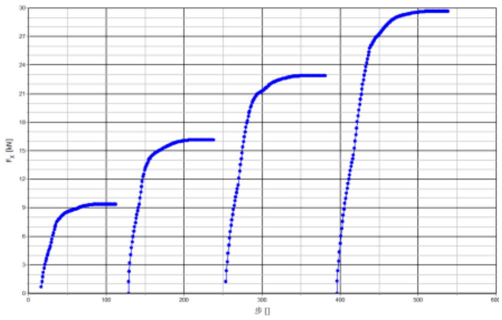


Fig. 10 Relationship curve of the corporate force on the interface and the loading step

When using standard sand as the filling material, the cohesion c_{soil} is 0kPa and the inner fiction angle φ_{soil} is 30°. When the grid is fully paved, the interfacial strength indexes of the geogrid and soil can be calculated through the experiment results in scheme IV. The coefficient ratio of interfacial friction is 0.61. The cohesion of the interface between geogrid and soil c_{inter} is 0kPa and the inner friction angle φ_{inter} is 19.40°. The results of the numerical simulation is shown in Table 5. The ratio of the contact area between soil equals the ratio between the contact area and the section of shear box, which is 0% when the grid is fully paved.

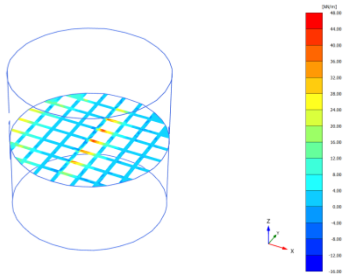
Tab. 5 Strength parameters of the interface under different contact sizes between the geogrid and soil when the filling material is standard sand

Number	Contact area between grid and soil /m^2	Ratio of contact area between soil and soil/%	c_{inter} /kPa	φ_{inter} /°	Coefficient ratio of Interfacial friction K	Maximum axial tension/kN
GSA	0.1963	0.00	0.16	19.37	0.61	17.25
GSB	0.1572	19.92	0.17	21.43	0.68	25.42
GSC	0.1285	34.54	0.21	22.85	0.73	35.90
GSD	0.1002	48.96	0.23	24.37	0.78	41.42
GSE	0.0833	57.56	0.25	25.37	0.82	45.90
GSF	0.0700	64.34	0.24	25.80	0.84	47.93
GSG	0.0661	66.33	0.25	26.06	0.85	52.66
GSH	0.0543	72.34	0.29	26.79	0.87	56.49
GSI	0.0467	76.21	0.31	27.01	0.88	61.98
GSJ	0.0362	81.56	0.33	27.62	0.91	65.59
GSK	0.0265	82.03	0.30	27.57	0.91	67.21

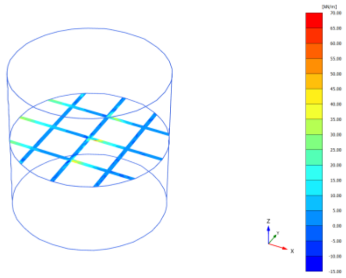
Table 5 shows that when the filling material is standard sand, numerical simulation can calculate the inner friction angles of the interface responding to the geogrid of model GSF and GSJ as 25.80° and 27.62°. This is close to the inner friction angles 25.90° and 27.98° obtained through scheme III and II in the large-sized shear experiment. This demonstrates that it is feasaible to use the FEM model to simulate a large-sized shear experiment.

Analyzing the strength indexes of the interface under different mesh sizes shows that the mesh size of geogrid has a clear influence on the properties of the interface. With an increase in the mesh size, the contact size between the geogrid and soil reduces, the strength index increases gradually, and the coefficient ratio of the interfacial friction K increases gradually; this is identical to the experiment results. It is unreasonable to calculate the strength index of the contact interface through only the interface friction coefficient or the coefficient ratio of interfacial friction without considering the mesh size.

Through analyzing the stress state of the geogrid in different models, it can be found that the axial force on the geogrid increases gradually with the reduction of the contact area of the geogrid and soil. Figure 11 shows the layout of the axial force when the vertical load is 400kPa. The maximum axial force is 47.93kN for the GSF geogrid and it is 65.59kN for the GSJ. Although the coefficient ratio of interfacial friction is higher for the geogrid with a larger mesh size, the interface of the geogrid and soil can provide higher frictional resistance. Meanwhile, the geogrid with higher strength is needed to satisfy the requirement of tensile strength, shown by $T_i \leq T$, where T_i is the tension on the geogrid and T_a is the permitted tensile strength of the geogrid.



(a)Mechanic state of the geogrid of GSF



(b)Mechanic state of the geogrid of GSJ

Fig. 11 Mechanical state of geogrid under different sizes

The permitted tensile strength T_a is identified according to the Design Standard of Supporting Structure for Railway Foundation of China (TB10025-2006) as $T_a=T/F_i$, where T is the ultimate tensile strength of geogrid and F_i is the influence coefficient. The influence coefficient is 2.5-5.0 which takes into consideration the damage by machines during paving, creeping deformation of material, chemical and biological damage and other factors. The ultimate tensile strength for the geogrid in this paper is 120kN. If F_i is 2.5, the permitted tensile strength T_a=48kN. Therefore, the tension should not be over 48kN in order to satisfy the tensile strength. Figure 12 shows the relationship curve between the coefficient ratio of interfacial friction, the maximum axial force and the ratio of the contact area between the soil and soil under different mesh sizes.

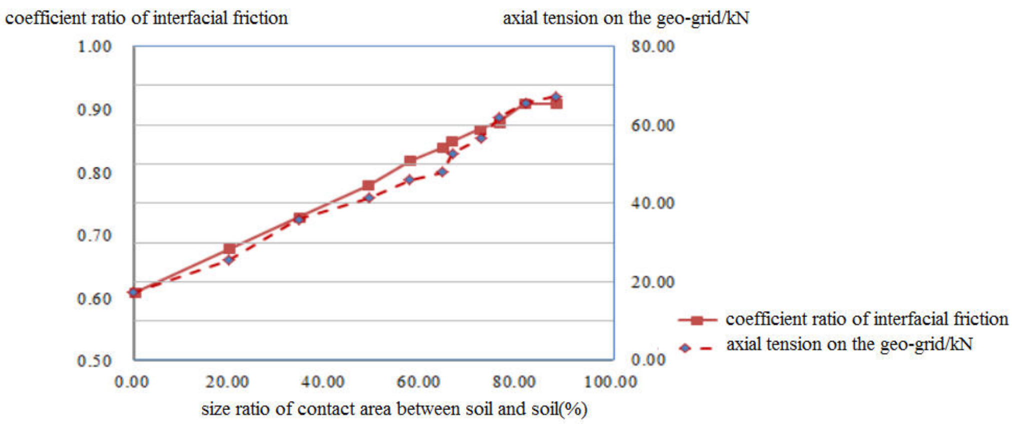


Fig. 12 Relationship curve of the coefficient ratio of interfacial friction and maximum axial tension on the geogrid with the ratio of contact area between soil and soil under different mesh sizes

In Figure 12, the reinforcement effects of the geogrid can be best ensured, and the requirements of tensile strength can be satisfied, when the contact area between geogrid and soil is 0.07m^2 and the ratio of the contact area between soil and soil is 64.34%. When this occurs, the mesh size is optimal. In practical engineering, the permitted tensile strength and the interface parameters should be considered comprehensively to choose the best mesh size of the geogrid.

5 Conclusions

This paper examines the influence of mesh size of the geogrid on interface properties through a large-sized shear experiment and the FEM numerical method. The study reaches the following conclusions:

(1) There is an obvious influence of mesh size on the interface character of the geogrid. However, it is not reasonable to take the same interface friction coefficient or coefficient ratio of interfacial friction to evaluate the interface character between geogrid with different mesh sizes and soil.

(2) In the study of the interface character between the geogrid and soil, shear experiment and pull out experiment should be selected as it relates to the relative deformation between the geogrid and soil for the high embankment reinforced body with geogrid.

(3) The research results of the large-sized indoor shear experiment and numerical simulation show that the interface strength index of a geogrid with a larger mesh size is higher. Meanwhile, the requirement on the geogrid is relatively higher to satisfy the demands of tensile strength.

(4) When the conditions do not allow the implementation of a large-sized shear experiment to obtain the interface strength index between the geogrid and soil, a numerical method can be used to simulate a large-sized shear experiment. The strength of the index of interface with different mesh sizes of the geogrid can be calculated.

(5) In practical engineering, the tensile strength allowed by the geogrid and the interface parameters should be considered comprehensively to choose the most reasonable mesh size.

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