INFLUENCE FACTORS OF GEOGRID-SOIL INTERFACE SHEAR STRENGTH AND CONTRIBUTION OF TRANSVERSE RIBS OF GEOGRID

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ABSTRACT

Based on the large scale direct shear apparatus (Shear box dimension: 500mm × 500mm × 410mm), a series of tests have been completed to investigate the shear strength characteristics of different backfill, compaction, moisture content, geogrid types, and shearing rate. A modified model of geogrid-soil interface shear strength was presented. The results indicate several conclusions: (1) Shear strength between geogrid and soil is smaller than that of soil; (2) For the same backfill material, the triaxial geogrid would be a better choice due to its better interaction performance; (3) With regard to all the geogrid-soil interfaces, higher impaction degree or shearing rate results in larger shear strength; (4) For the same geogrid, sand gravel results in greater interface shear strength than cohesive soil does. For cohesive soil, the strength of geogrid-soil interface is more water content sensitive than soil itself; (5) the contribution of transverse ribs of uniaxial geogrid to the shear strength of geogrid-sandy gravel interface are much more than ones of other geogrids, and the interface shear strength of soil-longitudinal ribs interface follows the friction law well, but it is the smallest among all parts of interface sheer strengths.

Keywords: Geogrid, interface shear strength, model and effect factor

INTRODUCTION

Background

The main function of reinforcement in the soil is to enhance the integrity, and make the discrete soil continuous to some extent (Bao C.G. 2006). The soil-geosynthetic interface behaviors are important for the design and maintenance of the reinforcement structures. For example, an interface of a stronger shearing resistance in a geosynthetic lined slope can reduce the tensile forces mobilized in the geosynthetics, as well as increase the slope inclination (Chia-Nan Liu, 2003). The shear strength of soil-geosynthetic interface is also essential for numerical simulation of the behavior of strip footing on geogrid reinforced soft foundation (Mostafa A, 2007).

Geogrid-soil interface characteristics have been studied by several researchers using direct shear tests or pullout tests under different conditions, such as different dry density, water content of the backfills, type of the geogrids or soils (Wang Mingyuan 2009/2010; Xu Linrong 2004; Yang Guangqing 2006; Zhang Wenhui 2007; Shi Danda 2009; Xu Chao 2011; Yin Guangzhi 2004; Tang Fei 2006; Murad Abu-Farsakh 2007). Though the shear strength of soil-geosynthetic interface has been investigated by conducting other tests, such as tilt table tests, direct shear test is still the most common testing method (Chia-Nan Liu 2009).

Works in this Paper

Although numerous investigations have provided direct shearing test results for interface shear strength along soil-geogrid interfaces, the equipment scale is not large enough. Boundary conditions may affect test results, particularly for small shear boxes (Palmeira 2009). On the other hand, most of the literatures only concentrate on one or two influence factors for the interface strength.

Based on the large scale direct shear apparatus, a series of tests have been conducted to investigate the shearing strength characteristics of different normal stress, backfill, compactness, moisture content, geogrid types, and shearing rate.

TESTING PROGRAM

Material Testing

Four types of geogrids were used for the tests, including RE560 type uniaxial geogrid with short longitudinal ribs, UX1500 type uniaxial geogrid with long longitudinal ribs, SS30 type biaxial geogrid and TX170 type triaxial geogrid (called TriAX). All of these geogrids are manufactured by Tensar Geosynthetics (Wuhan) Ltd. Figure 1 and Table 1 present the sketches and main properties of the geogrids.

The direct shear tests used two different backfill materials: sandy gravel and clay from the foundation of substation building project in Wuhan University.

Table 1 Physical characteristics of four types of geogrids

Geogrids	$\rho_l{}^b$ (%)	$\rho_t{}^c$ (%)	Direction	Ultimate load (kN)	Tensile strength (kPa)
RE560	40.00	2.00	longitudinal	20.91	93.97
UX1500	42.80	1.00	longitudinal	26.63	121.4
SS30	9.95	13.05	transverse	9.56	34.54
			longitudinal	8.86	32.64
TX170	6.53	18.47	90°/270°^{a}	5.6	23.94
			0°/180°^{a}	8.37	31.44
			60°/240°^{a}	6.34	23.12

a------For TX170 triaxial geogrid, the transverse direction was set as 0°and counterclockwise for the positive direction (refer to Fig. 1);
b------ρ_l----the percent of longitudinal ribs area in the overall interface;
c------ρ_t----the percent of transverse ribs area in the overall interface;

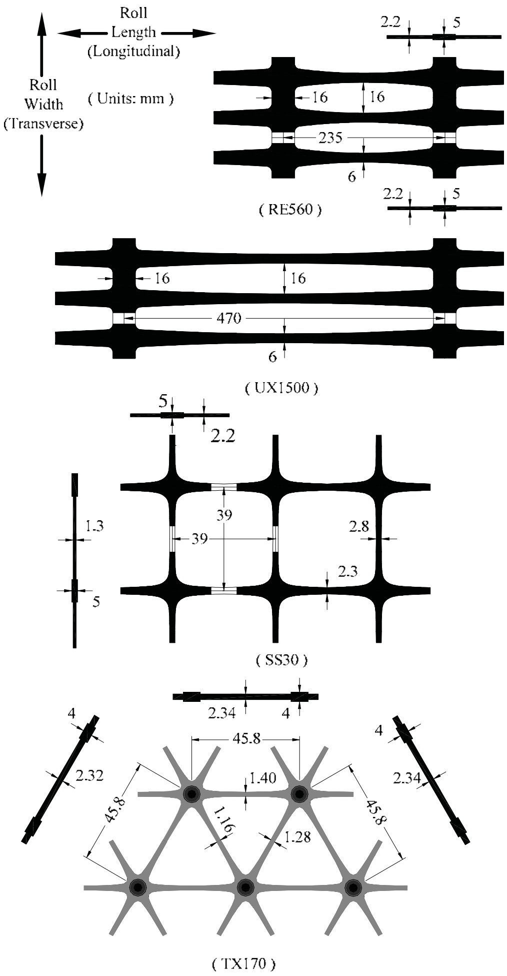

Fig. 1 Sketch of the geogrids used in the tests.

Table 2 Physical characteristics of soils.

Property	Units	Clay	Sandy gravel
Plastic limit	%	42	-
Liquid limit	%	20	-
Maximum dry density	kg/cm^3	1840	2030
Minimum dry density	kg/cm^3	-	1630
Optimum moisture content	%	15.7	-

Fig. 2 Large-scale direct shear apparatus

The coefficient of uniformity and coefficient of curvature of sandy gravel are 23.76 and 0.24, respectively. The physical characteristics of each soil are showed in Table 2.

Test Equipment

Shear tests were carried out on a large-scale direct shear apparatus (Fig. 2) developed by Wuhan Institute of Rock and Soil Mechanics and Hongkong University. Size of the shear box is 500mm(L) ×500mm(W) ×410mm(H). The vertical loading produced by a hydraulic jack is transferred through the rigid reaction frame and applied on a rigid load plate which is placed on top of the soils in the upper shear box. The movement of the lower shear box in the horizontal direction is controlled by a set of gears which are mobilized by an electric motor. The horizontal displacement can be measured by an electric displacement meter.

The geosynthetic specimen (width of 500mm ×length of 700mm) was positioned on top of the lower shear box and was clamped on the front edge of the lower shear box by an anchor force of five aligned bolts and a steel clamping block.

Analysis Method

The peak of the shearing stress on the shear stress –sheer displacement curve was set as the shear strength under each normal stress.

A comparison of the interface shear strength of soil against geosynthetic is quantitatively represented by an interface shear strength coefficient (α), which is the ratio of soil/geosynthetic shear strength ($\tau_{soil/geosynthetic}$) to internal shear strength of soil (τ_{soil}) under the same normal stress, or in other words:

$$\alpha=\left(\tau_{\text{soil/geosynthetic}}\right)/\left(\tau_{\text{soil}}\right) \tag{1}$$

To study the interface characteristics under different conditions, the concept of friction factor ratio K is introduced as.

$$K=\left(\tan\varphi_{sg}\right)/\left(\tan\varphi\right) \tag{2}$$

where φ_{sg} = friction angle of geogrid-soil interface; φ = friction angle of backfills.

TEST RESULTS AND ANALYSIS

Effect of the Type of Geogrid

The tests were conducted with the four types of geogrid: RE560, UX1500, SS30, and TX170. The other conditions of the tests in this section were all the uniform: the backfill is sandy-gravel with compaction degree of 92%. The shearing rate was set as 1mm/min.

Figure 3 presents the shear strength and interface shear strength coefficient (*α*) for different geogrid-soil interface under every preestablished normal stress.

Under the same normal stress, the geogrid-soil interface has smaller shearing strength than internal shear strength of soil. Among these four types of geogrids, the triaxial geogrid (TX170) has the highest interface shear strength coefficient (α) which was approximately equal to 1.0. More over, the sequence of the shear strength coefficient in the test is triaxial geogrid > biaxial geogrid > uniaxial geogrid; and for the uniaxial geogrid, longer longitudinal rib leads to smaller interface shear strength.

Figure 3 shows the Mohr-Coulomb parameters, e.g. cohesion (*c*) and friction angle (*φ*) for different geogrid-soil interface. The test results indicate that the cohesion values of the interfaces are all smaller than that of the backfill. The interface cohesion values are in the sequence of triaxial geogrid> biaxial geogrid >uniaxial geogrid with shorter longitudinal ribs > uniaxial geogrid with longer longitudinal ribs. The friction angle ratio (*K*) of each geogrid-soil interface is greater than 0.9.

Effect of the Compaction Degree of Backfill

The compaction degree of backfills were 86% and 92%, respectively. The other test conditions of the tests in this section were uniform: the backfill was sandy-gravel, and the geogrid was RE560. The shearing rate was set as 1mm/min.

Figure 4 displays the parameters of shear strength of geogrid-soil interfaces with different compaction degree. With the same compaction degree, the geogrid-soil interface has a smaller cohesive and friction angle than the backfill. This result is different from Yan (2010) that the cohesive of the interface is larger than the backfill. It can be seen that the compaction degree increases from 86% to 92%, the difference of cohesion between the geogrid-soil interface and the backfill itself decreases, and the friction angles are approximately equal.

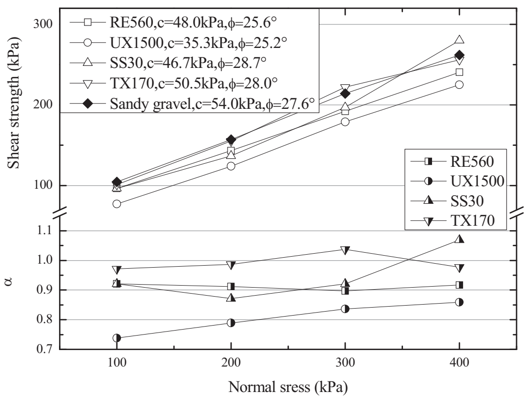

Fig. 3 The interface characteristics under different geogrids

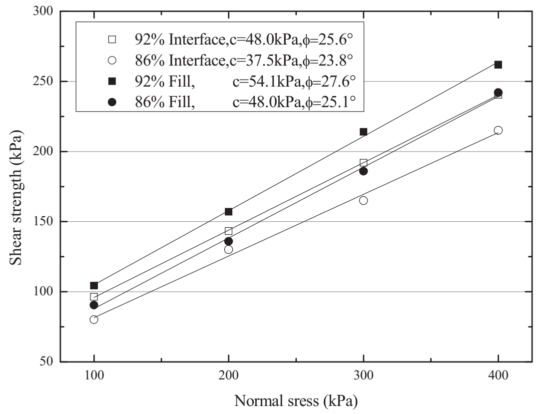

Fig. 4 The interface characteristics under different compaction degree.

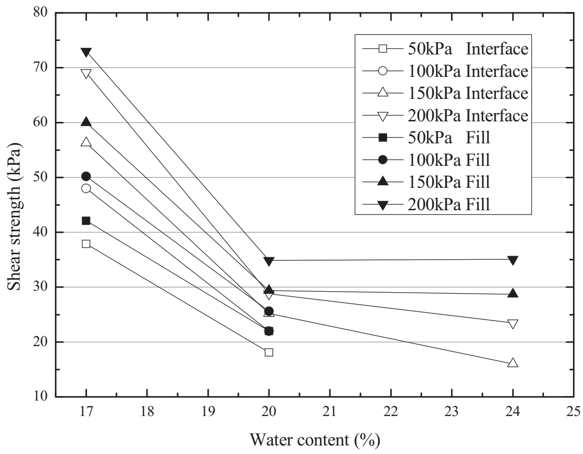

Fig. 5 The shear strength of the geogrid-soil interface and the backfill while water content increase

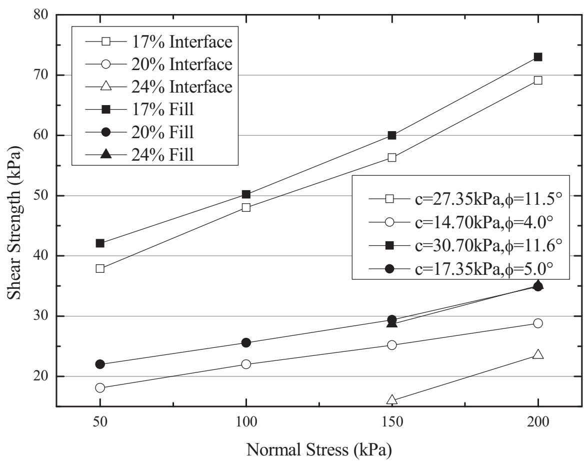

Fig. 6 The geogrid-soil interface and the backfill shear strength characteristics with different water content.

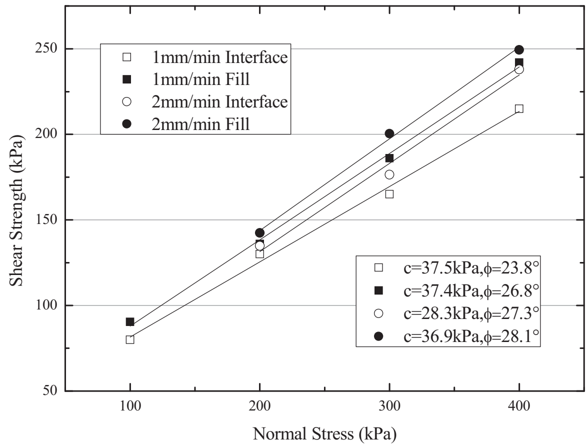

Fig. 7 The geogrid-soil interface and the backfill shear strength characteristics with different shearing rate.

Effect of the Water Content of the Backfill

The tests were conducted with three types of water content of clay: 17%, 20% and 24%. The compaction degree of clay is 93%, the shearing rate is 1mm/min and the geogrid used is RE560.

Figure 5 shows the variations of shearing strength of the geogrid-soil interface and clay with the increment of water content (from 17% to 24%) under different normal stress. For the same normal stress and water content of clay, the shear strength of the geogrid-soil interface is smaller than that of clay. Furthermore, the difference between them is more significantly when the water content increases. On the other hand, the shear strength decreasing rate of both interface and clay decreases significantly as the water content exceeds optimum moisture content.

The cohesion and friction angle for different geogrid-soil interface are presented in Fig. 6. The curves highlight that increment of water content of clay results in significant decrease of the cohesion of both interface and clay. However, friction angle remains approximately equal with different water content. With the same water content, the cohesion of the interface is slightly less than the clay.

On the other hand, when the water content increase from 20% to 24%, the shearing strength of the clay under the same normal stress (150kPa, 200kPa) are almost equal, but that of the geogrid-soil interface show a significant reduction. Test results show that when the water content increased from 20% to 24%, shearing strength of interface decreases slightly while that of clay remained unchanged. This may indicate that the strength of geogrid-clay interface is more sensitive to water content comparing with that of clay.

Effect of the Shearing Rate

Based on the direct shear tests and pullout tests Xu (2010) discovered that the influence of shearing rate on the interface shear strength could be ignored when the rate is smaller than a limited value (such as 7.0 mm/min). On the other hand, Yang (2010) found that the shearing rate increasing from 0.17mm/min to 4.33mm/min resulted in increase of shear strength of geogrid-clay interface.

In our experiment, the shearing rate were 1mm/min and 2mm/min respectively. Sandy gravel and RE560 were set as the backfill and reinforcement respectively, and the compaction degree of backfill was 86%. Figure 7 shows the shear strength of geogrid-soil interfaces and the backfill under different normal stress. As the shearing rate increased from 1mm/min to 2mm/min, the shear strength of both geogrid-soil interface and the backfill slightly increased. The reason is that the rearrange of gravel grain was not completed in instantly, and the slower shearing rate could provide more time for rearranging of gravel grain so as to reduce the dilatancy effect.

Effect of the Type of the Backfill

The compaction degrees were set as 92% and 93% for sandy gravel and clay respectively. The geogrid was RE560, and the shearing rate was set as 1mm/min. Table 3 presents the cohesion and friction angle of the interface between geogrid and different backfills.

Compared with the geogrid-gravel interface, the cohesion difference between geogrid-clay interface and the backfill is more significantly even though the clay was compacted to a higher degree. This indicates that sandy gravel is a priority selection for the backfill.

On the other hand, the fiction angle of the geogrid-soil interface is only slightly smaller than those of both sandy gravel and clay. So the reduction of the shear strength of the geogrid-soil interface compared with the backfill mainly results from the decrease of cohesion.

Table 3 The cohesion and friction angle of the interface between geogrid and different backfills.

Backfill type	Backfill itself		Geogrid-soil interface		Friction factor ratio
	c(kPa)	φ(°)	c(kPa)	φ(°)	K
Sandy gravel	54.1	27.6	48.0	25.6	0.92
clay	30.7	11.6	27.3	11.5	0.99

CONTRIBUTION OF TRANSVERSE RIBS OF GEOGRID TO SHEAR STRENGTH OF INTERFACE

Modified Model of Shear Strength of Interface

Chia-Nan Liu et al. (2009) proposed that the shear strength of geogrid-soil interface composed with three parts: (1) the internal shear resistance of the particles (across the openings, in the case of the geogrid), (2) the shear resistance between soil and the surface of the geosynthetics (surface of the ribs, in the case of the geogrid), (3) the passive resistance developed by transverse ribs of the geogrid appears to contribute to the overall shear resistance at comparatively larger displacements.

Based on direct shear tests, Chia-Nan Liu et al. (2009) developed a model about geogrid-soil interface as follow:

$$\tau_{\text{soil/geogrid}} = (1-\rho)\,\tau_{\text{soil/geosynthetic}} + \rho\tau_{\text{soil}} + \tau_{\text{B}} \qquad (3)$$

where ρ=percent open area of geogrid (i.e., the ratio of overall aperture area to geogrid area); $\tau_{soil/geogrid}$= the overall shear strength of the interface; $\tau_{soil/geosynthetic}$= the shear strength between soil and the surface of the geosynthetics including both the longitudinal and transverse ribs; τ_{soil}= shear strength of soil; τ_B= shear strength contributed by passive resistance of transverse ribs.

In the model showed in Eq. 3, the resistance provided by the transverse ribs was divided into two parts: (*a*) resistance between soil and the surface of transverse ribs which follows the friction law; (*b*) bearing resistance provided by transverse ribs. Consequently, the first part was calculated as one part of $\tau_{soil/geosynthetic}$, and the latter was calculated separately.

It would be more reasonable if the resistance contributed by the transverse ribs could be defined as a single part rather than two parts. There are two reasons for this opinion as follow:

(1) The transverse ribs that under the interlocking (Bao C.G. 2006) and passive resistance impact produce by the particle (Chia-Nan Liu, 2009; CHEN Rong, 2011) would show bending deformation perpendicular to the transverse direction. The mechanism of the transverse ribs doesn't follow friction law and was much more complex than longitudinal and it can't be divided into two parts simply.

(2) It could get more definite evaluation for the contribution made by different geogrid parts (e.g. soil, longitudinal and transverse ribs) to calculate the single resistance of different geometric parts.

A model can be built as Eq. 4:

$$\tau_{\text{soil/geogrid}} = \rho_l\tau_{\text{soil/longitudinal}} + \rho_t\tau_{\text{soil/transverse}} + (1-\rho_l-\rho_t)\,\tau_{\text{soil}} \qquad (4)$$

where $\tau_{soil/longitudinal}$= the shear strength between soil and the surface of longitudinal ribs which follows the fiction law as $\tau_{soil/geosynthetic}$ in Eq. 3; $\tau_{soil/transverse}$= the resistance force provided by transverse ribs per unit area. The meaning of ρ_l and ρ_t were showed in Table 2. The area of node was included in the transverse ribs because its thickness is lager both than the ribs and its mechanism has more similarity with transverse ribs.

The variable of $\tau_{soil/transverse}$ is not a real exist physic stress, and was defined similar to $\tau_{soil/longitudinal}$ as forces (e.g. friction, interlocking, and passive resistance) between soil and transverse ribs per unit area. It's convenient to analysis the resistance provided by different part of geogrid. It's named as shear strength of interface between transverse ribs and soil subsequently.

Bearing Resistance Provided By Transverse Ribs of Uniaxial Geogrid

The only difference between RE560 and UX1500 was the length of the longitudinal ribs. It could be assumed that the main difference of shear strength under the same normal stress between them was resulted from the increased transverse ribs in same length of geogrid. Based on this assumption the interface shear strength provided by longitudinal and transverse ribs can be got according to the overall shear strength and geometric characteristics of the interface respectively.

According to the shear strength of geogrid-soil interface of RE560 and UX1500 under the same normal stress 100kPa and geometric characteristics in Table 1, equation (4) can be expressed as follows:

$$96.4 = 0.4\tau_{soil/longitudinal} + 0.02\tau_{soil/transverse} + (1-0.4-0.02)\times 104.4 \qquad (5)$$

$$77.0 = 0.428\tau_{soil/longitudinal} + 0.01\tau_{soil/transverse} + (1-0.428-0.01)\times 104.4 \qquad (6)$$

Solving equations (5) and (6), the shear strength provided by longitudinal and transverse ribs of RE560 and UX1500 under 100kPa normal stress respectively can be obtained. Similarly, the shear strengths under other 200, 300 and 400kPa normal stress can also be obtained as the preceding procedures.

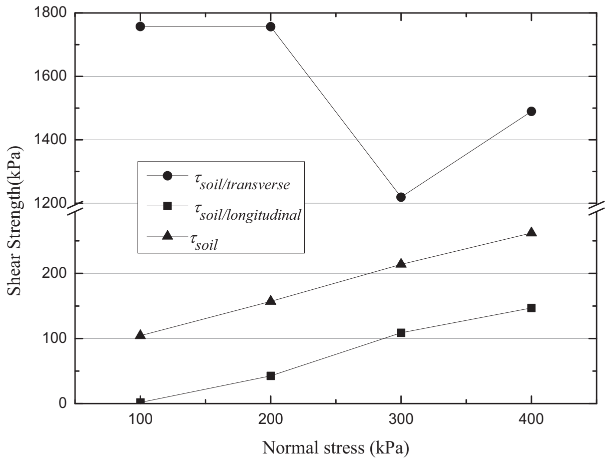

Fig. 8 Shear strength provided by the longitudinal and transverse ribs of uniaxial geogrid under different normal stress

Figure 8 shows the $\tau_{soil/transverse}$ and $\tau_{soil/longitudinal}$ under different normal stress. It indicates that:

(1) The shear strength provided by transverse ribs of uniaxial geogrid (RE560 and UX1500) is significantly bigger than longitudinal ribs ($\tau_{soil/longitudinal}$) and soil (τ_{soil}).

(2) The shear strength of interface between longitudinal ribs and soil shows approximate linear relationship with normal stress and follows friction law well. It also indicates that the assumption about friction law at the beginning of this section is reasonable.

(3) The shear strength of uniaxial geogrid transverse ribs and soil interface shows to be a choppy curve and does not follow the friction law. This also indicates that it's very different to the mechanism of interface between longitudinal ribs and soil.

Bearing Resistance Provided by Transverse Ribs of Different Geogrid

It can be assumed that all the shear strength parameters of longitudinal ribs of different geogrid (include uniaxial, biaxial and triaxial) and soil interface are the same. Based on the value of $\tau_{soil/longitudinal}$ derived from the previous section and model expressed in Eq. 4 and geometric characteristics in Table 1, it can be got that the shear strength provided by transverse ribs.

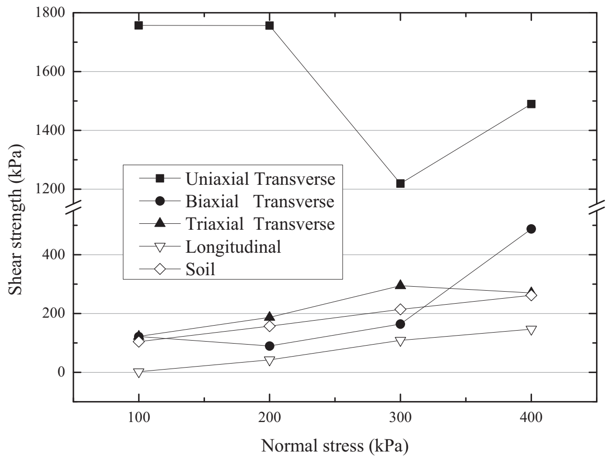

Fig. 9 Shear strength provided by the longitudinal and transverse ribs of different geogrid under different normal stress

Figure 9 shows the shear strength under different normal stress of three types of geogrid. It is observed that the shear strength provided by transverse ribs of uniaxial geogrid (RE560 and UX1500) is significantly bigger than biaxial and triaxial. This is because the transverse ribs of uniaxial are much stronger than others and it could provide much more passive resistance. The curves also indicate that $\tau_{soil/transverse}$ of biaxial and triaxial is about equal to τ_{soil} and follows friction law.

CONCLUSIONS

This research has conducted a series of large scale direct shear tests on geogrid-soil interfaces, where the interfaces of four geogrids against two soils are investigated. The following conclusions can be drawn.

(1)The shear strength of geogrid-soil interface is smaller than that of soil. It indicates that geogrid placed within the soil usually acts as a weak interface in terms of direct sliding.

(2) Regarding the properties of interface shear strength, triaxial geogrid is better than biaxial geogrid and biaxial geogrid is better than uniaxial geogrid; for the uniaxial geogrid, longer longitudinal rib leads to lower interface shear strength.

(3) As the compaction degree increases from 86% to 92%, the difference of cohesive between the geogrid-soil interface and the backfill itself decreases, and the friction angle differences are approximately equal.

(4) For the same geogrid, sand gravel results in greater interface shear strength than cohesive soil does. The strength of geogrid-clay interface is more sensitive to water content change than that of clay.

(5) As the shearing rate increases from 1mm/min to 2mm/min, the shear strength of both geogrid-soil interface and the backfill increases slightly.

(6) Based on the analysis of the modified interface shear strength model, the contribution of transverse ribs of uniaxial geogrid to the shear strength of geogrid-sandy gravel interface are much more than ones of other geogrids, and the interface shear strength of soil-longitudinal ribs interface follows the friction law well, but it is the smallest among all parts of interface sheer strengths.

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