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Study on Geocell-Sand Interface Characteristics Based on Large-Scale Stacked Ring Shear Test

Yicheng Zuo[1], Bo Li[2], Jiangang Dong[3]

[1]School of Civil Engineering and Architecture, China Three Gorges University, Yichang, China
[2]Key Laboratory of Geotechnical Mechanics and Engineering, Ministry of Water Resources, Yangtze River Academy of Sciences, Wuhan, China
[3]Wuhan Construction Engineering Group Co., Ltd., Wuhan, China
Email: auliso2023@163.com

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Abstract

Geocell is a new type of three-dimensional geosynthetics which can provide stronger side limit constraint and friction for the soil, form a flexible structure with the soil, and effectively reduce soil settlement and deformation. It is widely used in engineering construction. At present, there are few studies on the reinforcement mechanism and geocell-sand interface characteristics, and the soil deformation under prototype conditions cannot be fully studied. Through the self-developed DW1280L electro-hydraulic servo direct shear pull-out test system, the interfacial shear characteristics of prototype geocells of different heights under different normal stress conditions were studied. The shear stress, axial displacement and horizontal displacement of stacked rings under different shear conditions were monitored to analyze the influence of geocells of different heights on the reinforcement effect and strain law. The analysis of test results shows that the shear strength parameters of the geocell-sand interface are greater than those of pure sand. With the increase of geocell height, the cohesion of the geocell-sand interface gradually increases, the internal friction angle increases less, and the influence range of reinforcement gradually increases. Under different normal stress conditions, the reinforced soil exhibits a state of first shear shrinkage, then shear expansion, and then tends to stabilize. The change in axial displacement is negatively correlated with the magnitude of normal stress. Comparative analysis shows that the geocells near the horizontal loading position play a reinforcing role first when subjected to load. As the experiment progresses, the geocells at other locations gradually play a reinforcing role. The test results can provide a test basis for the application and theoretical research of geocell in practical engineering.

Keywords

Geocell, Stacked Ring Shear Test, Sandy Interface, Reinforcement of the Area of Influence, Strain

1. Introduction

With the rapid development of China's economy, the demand for important infrastructure such as highways, railways, bridges, airports and substations has gradually increased [1] [2]. At the same time, in response to the national "dual carbon" strategy, a green, environmentally friendly and low-carbon lifestyle is strategically advocated [3]. In this case, as a new three-dimensional geosynthetic, geocell will be widely used in engineering construction because of its characteristics of high tensile strength, large elastic modulus and high overall strength [4]-[6].

The interface characteristics of geosynthetics and soil can directly affect the safety and stability of reinforced soil engineering, and a series of studies have been carried out. Yan Changgen [7] found through triaxial shear tests that under the same working conditions, the reinforcement effect of geocells is superior to that of geogrids. Through the field test of railway foundation bed sinking, it is found that the geocell height and welding distance are reduced, which can effectively increase the dynamic stress attenuation, and the dynamic stress under the geocell reinforcement method is faster and evenly distributed than that of the sand change method [8]. By selecting geocells of different specifications to carry out direct shear tests, it is found that the shear strength of geocell reinforcement increases with the increase of the height of the cell sheet and the decrease of the node spacing, and the influence of strip height on the stiffening strength coefficient is more significant than that of the node spacing [9]. Liu Wei [10] [11] used a large-scale direct shear test to study the shear process of reinforced soil in a geocell, and compared and analyzed the shear stress and shear displacement in a nonlinear manner, and the geocell can significantly improve the cohesion of the reinforced soil, while the increase in internal friction is relatively small. Dash [12] used a large direct shear instrument to study the shear mechanical properties of the geocell-ballast interface, and found that the geocell can effectively constrain the lateral deformation of the ballast under the track and improve the reinforcement effect. Wang Qiang [13] used a small-size geocell model to carry out the drawing test, and found that the geocell can significantly enhance the apparent cohesion of the reinforced soil interface, and the effects of compaction and moisture content on the friction characteristics of the reinforced soil interface are also significant. Wang Yankun [14] used the method of indoor model test to measure and analyze the parameters of foundation settlement, stress distribution, displacement and deformation under different reinforcement conditions, and evaluated the effect of geocell test. Fang Jisheng [15] carried out a number of large-scale direct shear tests to study the interface characteristics of the geocell under different temperature conditions, and found that the shear stress-shear displacement curves of the reinforcement-soil interface under the influence of temperature showed strain softening characteristics.

At present, the conventional shear experiment is too small to simulate the shear process of reinforced soil in geocell, and can't reflect the interaction between geocell and soil. The research on geocell mainly focuses on the comparison of single micro geocell or plane reinforced material, and there are few studies on the stress distribution and shear characteristics of prototype geocell, and there is a lack of systematic research on the reinforcement range of geocell. In this paper, the interfacial shear tests of 6 groups of geocell reinforced sand at prototype size were carried out, the deformation rule and influence range of geocell reinforced sand during shear were analyzed, and the influence of geocell reinforced sand height on reinforcement effect was compared. The experimental basis is provided for the application of geocell in desert area.

2. Test Equipment and Test Design

2.1. Large-Scale Shear Test Protocol

In order to study the effect of a single geocell on the interfacial shear characteristics of reinforced sand, Geocomp Sheear Trac-II was used to conduct direct shear tests on packing materials and geocell with different heights. Multiple groups of strain gauges are pasted in the geocell, and the shear rate is controlled at 1.0 mm/min.

In order to study the influence of monolithic geocells on the interfacial shear characteristics of reinforced sand, the DW1280L Multi-channel large electro-hydraulic servo direct shear pull-out tester was used to carry out shear tests on the packing and prestressed injection molded monolithic geoglery. Three groups of geocell reinforced sand stacked ring shear tests were carried out, strain gauges were glued to the geocell, and the strain values were measured. The displacement of 1, 3, 5, 7, 9, and 11 laminated rings was measured with a laser displacement sensor. The horizontal shear rate is controlled at 1.0 mm/min. Specific test data are shown in **Table 1**.

Table 1. Large stacked ring shear test scheme of geocells.

Numbering	Filling	Geocells specification/mm (Material-weld-height)	Test rate/(mm·min^{-1})	Normal stress/kPa
T1	Fujian standard sand	-	1.0	100, 150, 200
T2		TGLG-PP-330-50		
T3		TGLG-PP-330-100		

2.2. Test Equipment

In this test, the Geocomp Sheear Trac-II Automatic straight shear instrument was used, as shown in **Figure 1**. It is suitable for detecting the interface interaction characteristics of soil filling and geosynthetics, and can automatically run the test and collect data.

The large-scale stacked ring shear test used the DW1280L Multi-channel large electro-hydraulic servo direct shear pull-out tester of the Yangtze River Research Institute, as shown in **Figure 2**. The system can be used to simulate the deformation of soil filling engineering samples under vertical and horizontal load. The advantage of this test system is that the large shear box can reduce the size effect of the sample, and display the whole process of the test, test data and graphics.

Figure 1. Geocomp sheear Trac-II automatic straight shear instrument.

Figure 2. DW1280L multi-channel large electro-hydraulic servo direct shear pull-out tester.

2.3. Test Materials

The test materials mainly include filling materials and reinforcement materials. The filling material is Fujian standard sand, with a maximum particle size of less than 0.5 mm and a relative density of 0.7, as shown in **Table 2**. The reinforced material is the prestressed injection molding integrated geocells, as shown in **Table 3**. The geocell was divided into single geocell and integrated geocells for test, as shown in **Figure 3** and **Figure 4** respectively.

Table 2. Physical characteristics of Fujian Standard sand.

Rate of water content /%	Minimum dry density /(g·cm^{-3})	Maximum dry density /(g·cm^{-3})	Uniformity coefficient /C_u	Coefficient of curvature /C_c
0.13	1.47	1.78	1.36	1.02

Table 3. Physical properties of the geocells.

Model (material-welding distance-height)	Thickness /mm	Extensibility /%	Tensile strength /(kN·m^{-1})	Tensile strength at the junction /(kN·m^{-1})
TGLG-PP-330-50/100	0.64	11.5	223	86

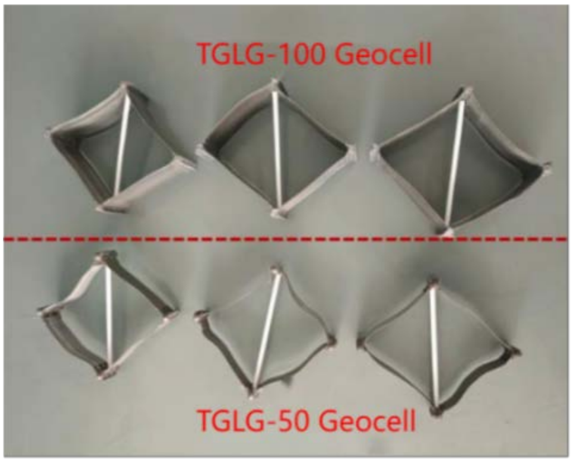


Figure 3. Single geocell at different heights.

Figure 4. Integrated geocells.

3. Analysis of the Direct Shear Test Results of a Single Geocell

3.1. Direct-Shear Test Results

Direct shear tests were performed on pure sand, single geocell TGLG-pp-330-50 and TGLG-pp-330-100 using the Geocomp Sheear Trac-II Automatic straight shear instrument. Select the maximum shear strength corresponding to different normal stress conditions. The specific data are measured in Table 4.

Table 4. Specific results of the direct shear test.

Testing materials	50 kPa	100 kPa	150 kPa	200 kPa	Cohesion /kPa	Internal friction angle /˚
Pure sand	47.8	95.2	138.4	172.0	39.6	9.3
TGLG-PP-330-50	42.3	73.4	103.5	132.2	30.6	13.9
TGLG-PP-330-100	43.7	85.1	108.2	142.2	33.8	20.3

3.2. Analysis of the Shear Intensity

The maximum shear stress value in the shear test of pure sand and geocell at different heights was taken and linearly fitted with the corresponding normal stress, as shown in Figure 5. The shear stress and normal stress of the geocell show a linear relationship, and the fitting coefficients are greater than 0.98. When the height of the geocell is increased from 50 mm to 100 mm, the cohesion increases by 6.4 kPa and the internal friction angle increases by 3.2˚.

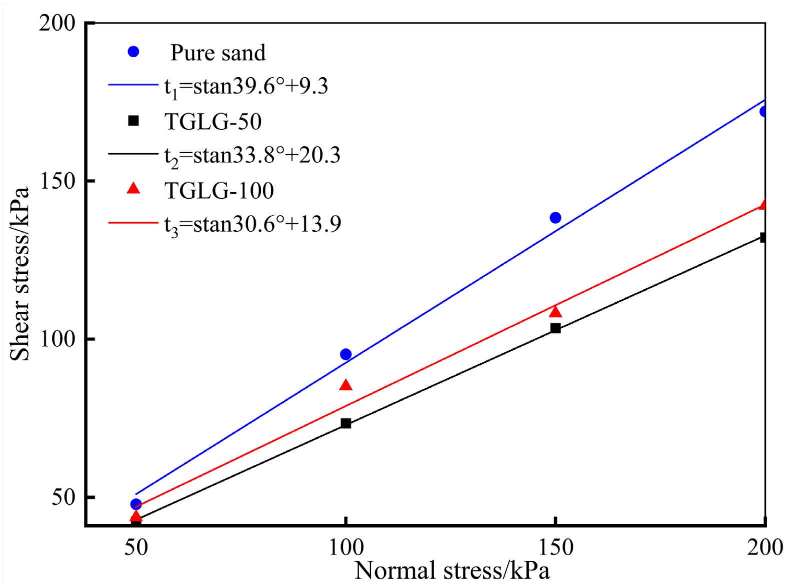


Figure 5. Linear fitting of reinforced sand shear results in a single geocell.

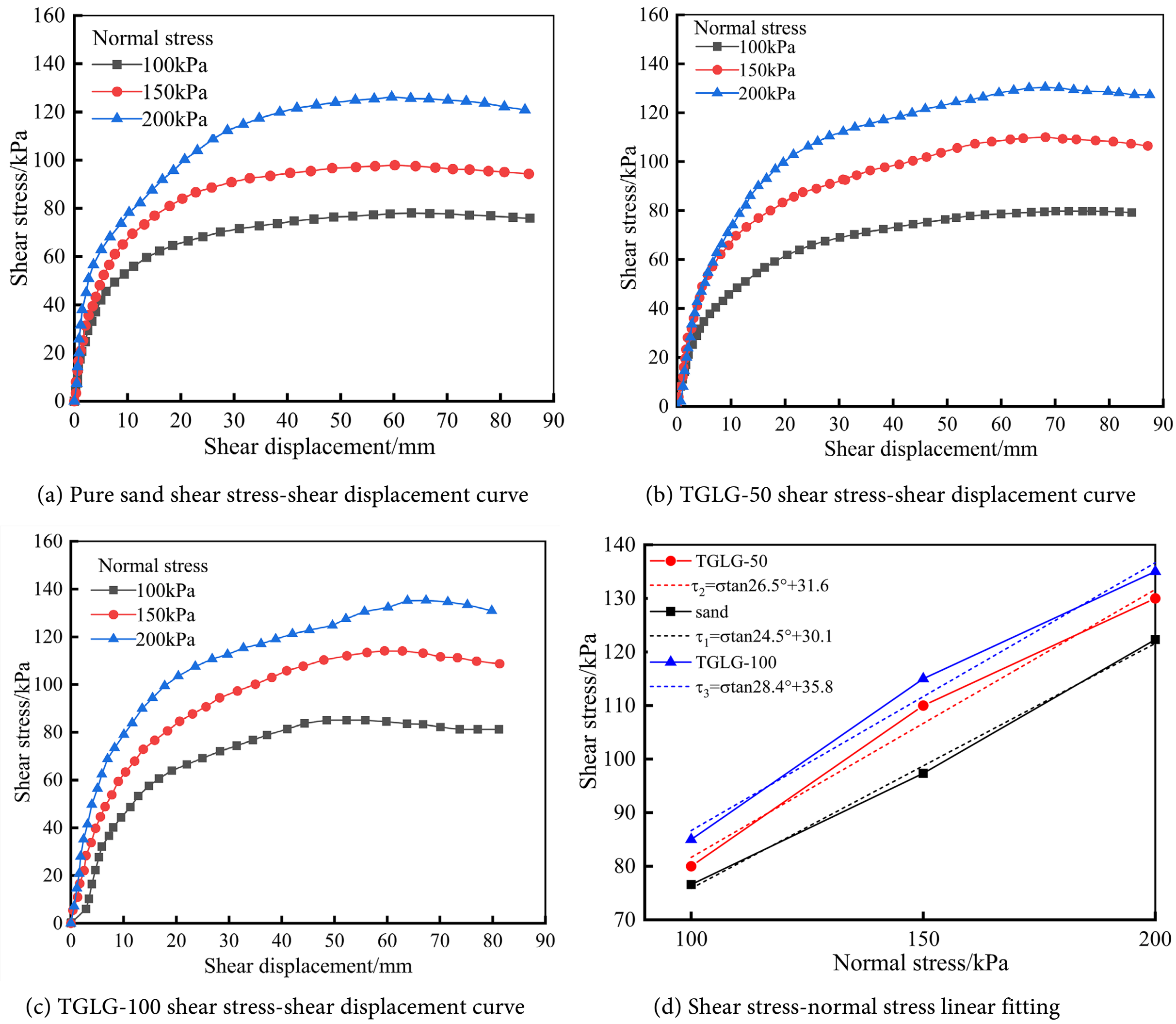
4. Analysis of the Results of the Large-Scale Stacked Ring Shear Test

4.1. Influence of Normal Stress on Shear Mechanical Characteristics

According to the large stacked ring shear test, the shear stress-shear displacement relationship curves of pure sand and geocells of different heights under different normal stresses can be obtained, as shown in Figure 6. The maximum shear stress value in the shear test is taken and linearly fitted with the normal stress under the corresponding working conditions. There is a nonlinear relationship between the interface shear stress and shear displacement of the geocell under different normal stress conditions. The initial stage is a linear growth stage. With the increase of shear displacement, the shear stress quickly reaches its peak strength, and after the peak strength, the shear stress shows a slight decrease or stable trend with the increase of shear displacement. In the normal stress range of the test, the shear stress-shear displacement relationship curve shows a strain softening type.

In the initial stage of the stacked ring shear test, the shear test curves of the geocell reinforced sand at different heights almost coincided. Because the soil medium is first stressed at the beginning of the test, the stress is not transmitted to the reinforcement and interface of the geocell, and the geocell does not play a role in reinforcement. With the increase of shear displacement, the reinforcement effect of the geocell is gradually reflected.

The shear strength parameters of sand and geocell reinforced sand at different heights are shown in Table 5. The cohesion increments were 1.5 and 5.7 kPa, and the internal friction angle increments were 2.0˚ and 3.9˚. When the height of the geocell increases from 50 mm to 100 mm, the height of the geocell has a relatively large influence on the interfacial cohesion.



(a) Pure sand shear stress-shear displacement curve

(b) TGLG-50 shear stress-shear displacement curve

(c) TGLG-100 shear stress-shear displacement curve

(d) Shear stress-normal stress linear fitting

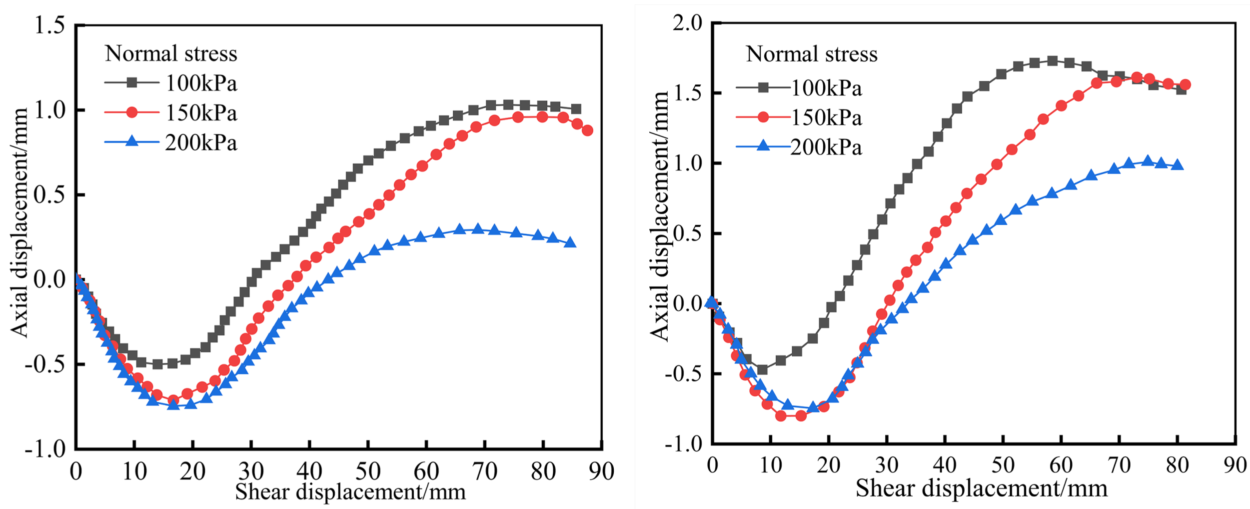
Figure 6. Stacked ring shear test intensity curve and parameter fitting.

Table 5. Comparison of shear strength parameters of sand and reinforced sand with different heights.

Testing materials	Cohesion/kPa	The cohesion increment/kPa	Internal friction angle/°	Internal friction angle increment/°
pure sand	30.1	-	24.5	-
TGLG-50	31.6	1.5	26.5	2.0
TGLG-100	35.8	5.7	28.4	3.9

4.2. Analysis of the Horizontal Displacement Change Law of the Stacked Rings

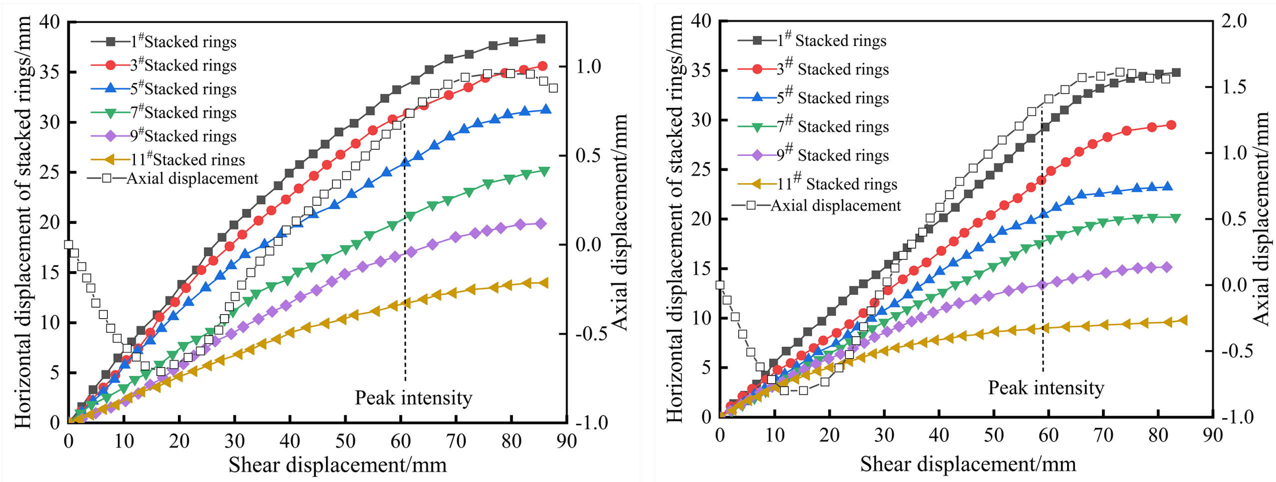
In the stacked ring shear test, the strain of the soil volume can be reflected by the change of axial displacement, so as to obtain the shear expansion change law of the soil [16]. As shown in Figure 7, with the shear test, there were obvious shear volume changes in the reinforced sand of geocells at different heights, and showed the form of first shear contraction and then shear expansion under different normal stress conditions. The change of normal stress will affect the shear body change. The smaller the normal stress, the more obvious the shear. With the increase of the normal stress, the shear expansion weakens. Between the shear displacement of 0 - 17 mm, the sand particles are compressed and compacted due to the normal stress, and the volume of the soil becomes smaller and shows a shear contraction. As the shear test progresses, the soil is compressed to its highest density. With the continuous increase of shear displacement, the sand particles begin to transition from the consolidated and dense state to the loose state, mainly by upward rotation and climbing, and the axial displacement gradually becomes larger, showing strong shear expansion. When the maximum shear strength in the shear test occurs, the sand particles near the shear surface are relatively loose, the particle displacement is mainly horizontal tumbling, and the shear volume change decreases and tends to be stable.



(a) TGLG-50 reinforced sand (b) TGLG-100 reinforced sand

Figure 7. Axial displacement-shear displacement curve.

In the shear test, we divide the stacked rings into $1^{\#}$ - $12^{\#}$ layers. When the shear box is subjected to horizontal load, which produces shear displacement, and drives the stacked ring to produce horizontal slip. As shown in **Figure 8**, in geocells at different heights, when the normal stress is 150 kPa, the horizontal displacement values of $1^{\#}$ stacked ring close to the shear plane are the largest, 38.3 and 34.8 mm, respectively, while the horizontal displacement values of $11^{\#}$ stacked rings away from the shear surface are the smallest, 13.9 and 9.4 mm, respectively. With the shear test, the horizontal displacement of each stacked ring increases gradually. As the height of the stacked ring position from the shear surface increases, its horizontal displacement value gradually decreases. When the peak shear intensity occurs in the shear test, the growth trend of the horizontal displacement of the stacked ring slows down and tends to stabilize.



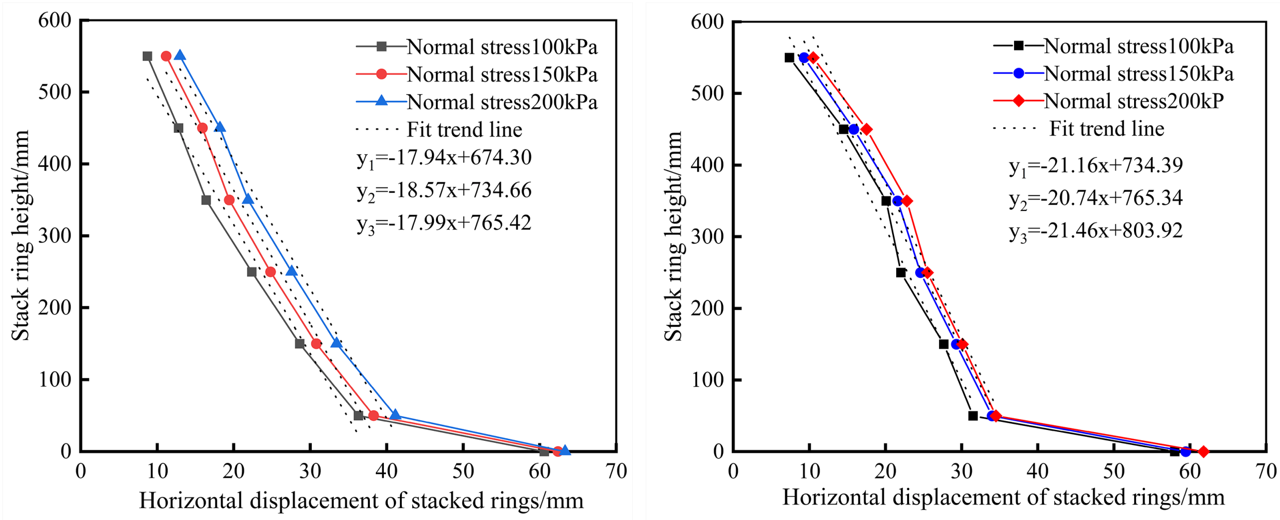
(a) TGLG-50 reinforced sand (b) TGLG-100 reinforced sand

Figure 8. Horizontal displacement of the stacked ring as a function of shear displacement.

4.3. Geocell Reinforcement Area of Influence

Zhu Shunran [17] conducted a study on the interfacial shear characteristics of geotextile-sand using a stacked ring shear apparatus. The results indicate that the shear influence range of reinforced sand is much greater than the thickness, and the influence range of reinforcement during the test exceeds the total thickness of the 7-layer stacked ring. In order to understand the deformation of the geocell-sand interface shear test. A linear fit was performed for the horizontal displacement of the stacked rings, as shown in **Figure 9**. The influence range of the reinforcement of the geocell when the shear strength reaches the peak was studied, and the reinforcement effect of the geocell at different heights was compared.

According to **Table 6**. The influence range of TGLG-100 reinforcement is larger than that of TGLG-50. The increase in the height of the geocell will expand the range of the reinforced layer. It can provide lateral constraints on more soil, thereby improving the integrity of the soil and optimizing the reinforcement effect. And the interaction between the three-dimensional structural reinforcement and the internal filler can provide strong lateral restraint and friction force on the filler.



(a) TGLG-50 reinforced sand (b) TGLG-100 reinforced sand

Figure 9. The influence of horizontal displacement of stacked rings under different normal stresses and parameter fitting.

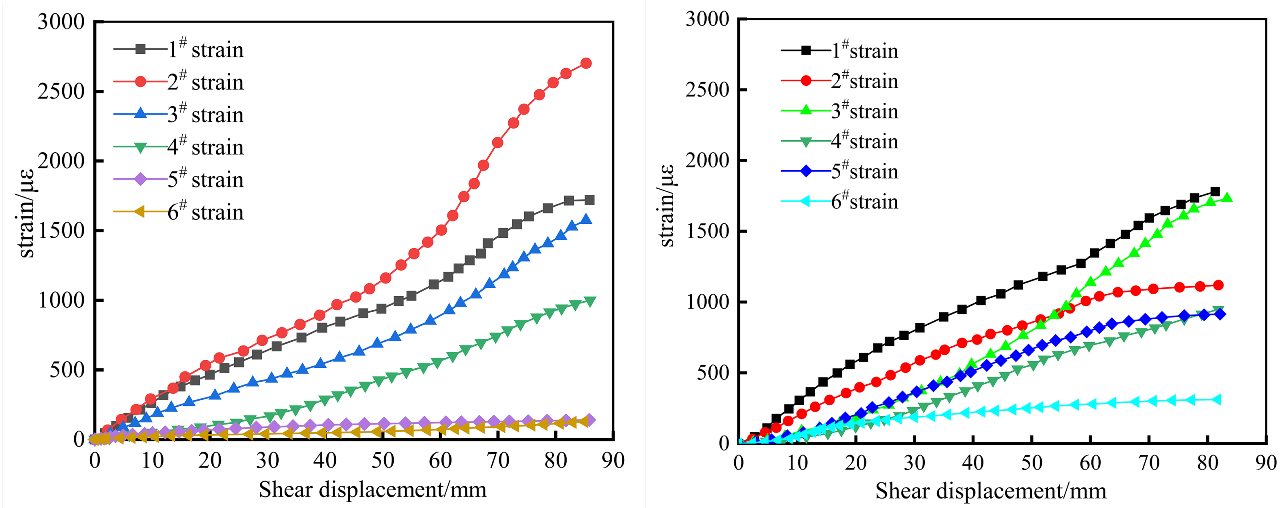
Table 6. The height of the stack ring is affected by geocell.

Geocell height	The height of the ring under normal stress/mm		
	100 kPa	150 kPa	200 kPa
TGLG-50	674.30	734.66	765.42
TGLG-100	734.39	765.34	803.92

4.4. The Law of Change of Geocell Strain

The relationship curve between strain values and shear displacement at 150 kPa collected in the experiment is shown in Figure 10. The deformation of the geocell under stress is non-uniform distribution. As the shear displacement increases, the strain value of the geocell gradually increases, and after reaching the peak shear strength, the growth slows down and tends to stabilize. The strain values of TGLG-50 reinforced sand from $1^{\#}$ - $4^{\#}$ are greater than those of TGLG-100 reinforced sand, while the strain values of $5^{\#}$ - $6^{\#}$ remain almost unchanged. This indicates that during the shear process, the $1^{\#}$ - $4^{\#}$ geocells of TGLG-50 reinforced sand play a reinforcing role. With the progress of the shear test, the strain value of TGLG-100 reinforced sand gradually increased, and the $4^{\#}$ - $6^{\#}$ geocell also gradually played a role in reinforcement.

During the shear process, the deformation of the geocell near the horizontal loading position is the greatest. As the distance to the horizontal loading position increases, the strain value at the corresponding position gradually decreases. Because the reinforcement effect played by the geocell mainly includes horizontal friction, vertical friction, and circumferential restraint force. The geocell near the horizontal loading position will first exert its reinforcement effect when subjected to load, resulting in significant deformation.



(a) TGLG-50 reinforced sand (b) TGLG-50 reinforced sand

Figure 10. Variation curve of cell strain with shear displacement.

5. Conclusions

Under prototype size conditions, Conduct single geocell direct shear tests and large-scale stacked ring shear tests. The following conclusions were drawn, as well as a discussion:

1) The shear strength parameters of geocell reinforced sand at different heights are greater than those of pure sand. The geocell can improve the cohesion and internal friction angle of the sand. With the increase of the height of the geocell, the cohesion increases, while the internal friction angle increases relatively slowly.

2) Through the change of axial displacement and combined with the displacement of sand particles, the shear deformation of sand was analyzed. Under different normal stress conditions, the sand showed a state of first shearing and then dilatation until it tended to be stable. The value of axial displacement change is negatively correlated with the magnitude of normal stress.

3) The horizontal displacement of the stacked ring decreases with the increase of distance from the shear plane, but the influence range of the reinforcement is much larger than the height of the shear zone. In this test, the reinforcement affected area exceeded the total height of the 11-layer stacked rings, and the reinforcement influence range of the TGLG-100 cell was even wider.

4) By collecting the strain values of the geocell, the process of reinforcement effect was studied. The geocell close to the horizontal loading position is first loaded and begins to reinforce. As the shear test progresses, the geocells in other locations are gradually subjected to loads and strengthened.

5) The large-scale laminated shear test of geocell reinforced sand breaks through the influence of size effect, but the filling materials in this test are simple

and lack of universality. Only the height of the geocell was changed, ignoring the influence of environmental factors. The experimental model lacks practical engineering verification.

6) In the follow-up study, shear tests can be carried out under different working conditions, such as material properties, shear rate, environmental conditions and types of fillers of the prototype geocell, and numerical simulation can be used for comparison and verification, and the geocell research system can be improved in combination with engineering practice.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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