



# Article Study on Improvement Characteristics of a Novel Geotextile with Stitched Transverse Ribs

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Abstract: Geotextile is one of the reinforcement materials adopted in many engineering structures. Conventional geotextiles have a limited reinforcement effect due to the insufficient friction strength between geotextiles and soils. This paper proposes a novel type of geotextile with stitched transverse ribs to improve the reinforcement effect. A series of large-scale direct shear tests have been conducted, and the improvement characteristics between conventional geotextiles, geogrids, and the novel geotextiles have been studied. The results show that the novel stitched transverse rib geotextiles can significantly increase the shear strength compared to conventional geotextiles and geogrids. Moreover, due to the restraint and friction effect of ribs on the soils, the reinforcement effect of the novel geotextile is increased with increasing ribs. Insights from this study can provide a new understanding of the novel stitched transverse ribs geotextile's reinforcement mechanism in engineering.

Keywords: geotextiles; stitched ribs; reinforced soil; interface friction characteristics; direct shear test



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# 1. Introduction

Because of being lightweight, having high strength, high flexibility, corrosion resistance, ease of storage, transportation, and construction [1], and due to their costeffectiveness and environmental friendliness [2], geotextiles have been widely used in road, railway [3], airport, port [4], and other major engineering construction fields since the end of the last century. Geotextiles can play the role of isolation, filtration, reinforcement, etc. In reinforced soil engineering, as one of the early and widely used reinforcement materials, the application of a geotextile can reduce displacements and stress values, and increase the bearing capacity [5,6]. However, the reinforcement effect of conventional geotextiles is limited in practice since a geotextile is distributed in a two-dimensional plane and the interface friction between geotextile and soil is not enough [6–8]. Because of the deficiency of geotextiles, geogrids have more applications in engineering, and some scholars have studied geogrid reinforcement [9,10]. Although geogrids can provide a better interlocking effect on soils, the tensile strength of geogrids is still less than that of geotextiles, as the tensile strength of geotextiles can achieve 1000 kN/m, indicating that geotextiles should provide a very good reinforcement effect. Therefore, a new reinforcement form thus needs to be developed to take full advantage of the tensile strength of geotextiles [11].

The passive resistance of the transverse ribs, the frictional resistance of the longitudinal ribs, and the embedded locking and occlusion of the mesh all contribute to the reinforcement effect between geosynthetics and soils. Among them, 60~70% of the resistance comes from the transverse ribs [11–13]. On the basis of existing research results, a novel type of geotextile with stitched transverse ribs is proposed to improve the reinforcement effect between geotextile and soil. The reinforcement effect is determined by the friction characteristics between geotextile and soil, influenced by many properties, such as the types of geotextiles and filled soils, the compaction quality of soils, the test boundary conditions, and so on [14–16]. It is important to obtain an accurate reinforcement effect of geotextiles by carrying out tests [17]. A series of large-scale direct shear tests have investigated the improvement characteristics between conventional geotextiles, geogrids, and the novel geotextile. The reinforcement mechanism of the novel stitched transverse ribs geotextile is also studied. Insights from this study can provide a new understanding of the novel stitched transverse ribs geotextile's reinforcement mechanism in engineering.

# 2. Direct Shear Tests

# 2.1. Test Materials

In this paper, sand was used as the test filler, and four different types of conventional geotextiles and one uniaxial geogrid were selected as the reinforcement materials, as shown in Figure 1. The width and length of the samples were determined by the size and fixing method of the shear box. In order to ensure the fixation of the samples, the length of the cut sample was 400 mm longer than the length of the shear box. The material properties were tested according to the "JTG ESO-2006 Test Methods of Geosynthetics for Highway Engineering". The material properties of the sand are shown in Table 1, and the parameters of the conventional geosynthetics are shown in Table 2.



Figure 1. Comparison of geosynthetics.

Table 1. Material properties of sand.

Characteristic Particle Size			Uniformity	Curvature	
d60/mm	d30/mm	d10/mm	Coefficient Cu	Coefficient Cc	
0.94	0.45	0.18	5.22	1.20	

Reinforcing Material	Mass per Unit Area/(g/m <sup>2</sup> )	Ultimate Tensile Strength/(kN/m)		Ultimate Elongation/%	
		Vertical	Horizontal	Vertical	Horizontal
Geotextile A	460.0	90.20	58.45	15.37%	14.21%
Geotextile B	428.5	99.65	83.45	13.21%	15.66%
Geotextile C	290.0	58.75	46.30	19.14%	14.37%
Geotextile D	200.0	30.30	36.00	11.26%	12.74%
Uniaxial geogrid	-	97.30	-	11.60%	-

Table 2. Material properties of conventional geosynthetics.

The novel stitched transverse ribs geotextile is shown in Figure 2. A 1000 mm  $\times$  1500 mm geotextile was set as the bottom layer of reinforcement, then 400 mm  $\times$  1000 mm ribs were cut out and sewn to the bottom layer of the geotextile at equal intervals of 300 mm. This allowed them to play a similar role as the geogrid horizontal ribs in three dimensions. This enhanced the friction between the ribs and the filler and limited the displacement of the filler. The schematic diagram of the reinforcement is shown in Figure 3.



Figure 2. Novel stitched transverse ribs geotextile.



Figure 3. Schematic diagram of reinforcement.

#### 2.2. Test Equipment

The large drawing and straight shearing instrument used in this test was able to carry out the straight shearing test and pulling test of geosynthetics and soil, as shown in Figure 4. The upper box was pulled through the jack on both sides to achieve the shearing of geosynthetic materials and soil, and the normal load was applied by the reaction force of air pressure on the top steel plate. The horizontal displacement was measured by the displacement sensor, and the shear force was measured by the force sensor. The shear force and the relative displacement on the shear surface were recorded by the computer automatically.



(a) Instrument physical picture



(b) Schematic diagram of the equipment

Figure 4. The large drawing and straight shearing instrument.

The length and width of the removable upper box were 1000 mm and 1000 mm, the length and width of the fixed lower box were 1200 mm and 1000 mm, therefore the boundary effect of the shear box was eliminated and a larger shear displacement could be produced. There was a 10 mm high gap between the upper and lower shear boxes to eliminate the friction between the upper and lower boxes themselves during the shearing process. To ensure that the shear surface remained unchanged during the shear process, a steel plate was placed in the lower box instead of deformable filler, which should have little effect on the interface characteristics of geotextiles and soil since the reinforcement material used in the test is geotextile which can play a good isolation effect on the upper and lower layers of materials. Moreover, the steel plate lower layer can simulate rigid boundary conditions such as the junction of old and new roadbeds.

## 2.3. Test Method

Nine tests were carried out to study the influence of geosynthetics on reinforcement characteristics. The tests were conducted following the "JTGE50-2006 Test Methods of

Geosynthetics for Highway Engineering". To compare the interfacial shear properties of sand itself, sand with geotextile, sand with geogrid, and sand with stitched transverse ribs geotextile, shear tests under different vertical stresses (25, 50, 100, and 150 kPa) on pure sand, four conventional geotextiles, and a uniaxial geogrid reinforced soil were conducted. The same tests were then conducted on the geotextile B with stitched transverse ribs, with better performance. The test conditions are shown in Table 3.

Table 3. Basic physical parameters of geosynthetics.

Groups		Reinforcing Material	Shear Rate (mm/min)	Reinforcement Method	Normal Stress (kPa)
Without reinforcement	Ι	None	1	flattening	25, 50, 100, 150
Conventional geotextiles	Π	Geotextiles A	1	flattening	25, 50, 100, 150
	III	Geotextiles B	1	flattening	25, 50, 100, 150
	IV	Geotextiles C	1	flattening	25, 50, 100, 150
	V	Geotextiles D	1	flattening	25, 50, 100, 150
Geogrid	VI	Uniaxial geogrid	1	flattening	25, 50, 100, 150
Novel geotextiles with stitched transverse ribs	VII	Geotextiles B	1	stitching 1 rib	25, 50, 100, 150
	VIII	Geotextiles B	1	stitching 2 ribs	25, 50, 100, 150
	IX	Geotextiles B	1	stitching 3 ribs	25, 50, 100, 150

## 3. Experimental Results

#### 3.1. Comparison of Reinforcement Effect of Different Reinforcement Materials

The relationship curves between shear stress and displacement of the four geotextiles and geogrids obtained in the tests are shown in Figure 5. It can be seen that the shear stress increases with the increase of shear displacement at the beginning of the test. Generally, the shear stress reaches the maximum value when the shear displacement reaches 5~15 mm. The maximum stress value increases with the increase of vertical stress. The curve is flatter, and the peak point appears earlier when the normal stress is small. The position of the peak point is delayed when the normal stress increases. Under normal stress of 150 kPa, the peak shear stress of woven geotextiles A and B is about 20% higher than that of unreinforced geotextiles, and the uniaxial geogrid improved 28% in shear strength.

The relationship between the maximum shear stress and normal stress obtained from each test is shown in Figure 6. It can be seen that there is an excellent linear relationship between the maximum shear stress and the normal stress, and all of them are in accordance with the Mohr–Coulomb strength criterion. According to Figure 6, the cohesion and friction angle between the interface of the reinforced soil under different reinforcing materials can be obtained, as shown in Table 4.

It can be seen from Table 4 that the cohesion and friction angle of reinforcement materials except Geotextile D increased compared with those of pure sand; the cohesion and friction angle of the geogrid reinforced structure interface is the largest. Among the four kinds of geotextiles, B has the best reinforcement effect, compared with geotextiles C and D. Its surface is rough enough to provide greater friction, forming an interlocking effect with sand. Compared with the woven geotextile A, B is thicker and more robust. Therefore, geotextile B was selected for subsequent tests.



Figure 5. Shear stress-displacement curves for different geosynthetics.



Figure 6. Curves of maximum shear stress and normal stress.

Interface	Cohesion/kPa	Friction Angle/ $^{\circ}$
Steel plate-sand	2.54	20.86
Geotextile A-sand	5.07	22.67
Geotextile B-sand	5.38	23.82
Geotextile C-sand	4.20	22.44
Geotextile D-sand	6.64	20.18
Geogrid-sand	13.86	25.85

 Table 4. Interface strength under different working conditions.

#### 3.2. Comparison of Shear Strength of Stitched Rib Geotextile Reinforcement

The relationship curves between shear stress and displacement of geotextile B stitched one, two, and three transverse ribs are shown in Figure 7. It can be seen that the shear stress increases with the increase of the shear displacement during the test. The positions of the peak points under three working conditions are different; the displacement corresponding to the peak shear stress point is about 60 mm, 50 mm, and 40 mm, when one, two, and three transverse ribs are stitched, respectively. This is mainly because the distance between the transverse ribs will decrease with the number of transverse ribs, resulting in stronger constraints from the soil and faster-achieved peak strength in the shear process. It can be summarized as follows: as the number of transverse ribs increases, the displacement peak value increases gradually, and the peak position advances gradually, which indicates that the structure has a strong ability to limit deformation. In practical application, it can exert its strength earlier, limit the deformation of the reinforced structure, and thus ensure the safety of the overall structure.

Figure 8 shows the picture of the geotextile after damage. It can be seen that the damage occurs mainly at the stitching between the transverse ribs and the bottom geotextile, while a slight tear also appears at the edge of the bottom geotextile. According to the damage degree of the geotextile stitched with three transverse ribs, the damage is most serious at the first transverse rib joint, which is torn almost completely; a slight tear occurs at the second transverse rib joint, while the third transverse rib is intact with no breakage. It can be concluded that the order of the reinforcement effect on the three layers of transverse ribs in the test is: the first layer > the second layer > the third layer, where the first layer is closest to the outer edge, and the second and third layers are more inward sequentially. With the movement of the shear box, the soil on the left side of the transverse rib is squeezed first, so the friction force and the resistance of the transverse rib on the left side of the shear of the shear force on the right side is weak. With the increase of the shear displacement, the strength on the left side of the reinforcement soil interface and the strength of the transverse rib gradually reach the limit value. Then, the right side of the

reinforcement begins to bear more loads, and the shear force gradually shifts to the right side. It can be seen from the shear stress displacement curves of the tiled reinforcement and the stitched rib reinforcement that the shear displacement reaches the stable maximum value before 15 mm when the reinforcement is tiled. The shear displacement of the stitched transverse ribs reinforcement comes to 40~60 mm at the peak value of the shear stress, which is the value required for tensile failure at the fabric joint. At this time, the failure of the main stressed transverse rib (that is, the first transverse rib) reduces the overall shear stress.



Figure 7. Shear stress-displacement curves of sutured ribbed geotextiles with reinforcement.



Figure 8. Geotextile B after destruction.

The shear stress at the shear displacement of 10 mm under various working conditions is shown in Figure 9. It can be seen that the order of the shear stress value is: geotextile stitched with three ribs > geogrid > geotextile stitched with two ribs > geotextile stitched with one rib > flattening geotextile. When the shear displacement is small, the effect of the geotextile stitched with one or two transverse ribs is not obvious compared with that of the tiled reinforcement. The reason is the friction provided by the underlying geotextile increases rapidly, but the transverse ribs need more displacement to play their role. We can see that the reinforcement effect of the bottom geotextile is mainly produced by the friction between the bottom geotextile and the particles. In contrast, that of the geotextile with one stitched transverse rib is not only reflected in the friction with soil particles but also the extrusion on the transverse rib. The geotextile stitched with three transverse ribs has the best reinforcement effect and the most obvious increase in shear stress. The shear stress under four normal loads is greater than the geogrid. It can be seen that the geotextile stitched with three transverse ribs can provide greater shear resistance when the deformation is small.



Figure 9. Comparison of shear stress of different stiffened structures at 10 mm.

The relationship between the maximum shear stress and normal stress obtained from each test is shown in Figure 10. It shows that the shear strength of the structure can be significantly improved by sewing ribs. Under low normal stress (25 kPa), the maximum shear stress of the geotextile structure stitched with one, two, and three transverse ribs are 40 kPa, 55 kPa, and 62 kPa, respectively. Under high normal stress (150 kPa), the maximum shear stress of the geotextile structure stitched with one, two, and three transverse ribs are 100 kPa, 114 kPa, and 140 kPa, respectively. There is a good linear relationship between the maximum shear and the normal stress, and the pseudo-cohesion and friction angle are improved compared with the geogrid. The shear strength of one transverse rib is close to that of the geogrid, and the improved effect is mainly reflected in the pseudo-cohesion, and the improvement of the friction angle of three ribs is more obvious. According to the results shown in Figures 7, 9 and 10, the increase in the number of stitched transverse ribs can greatly improve the shear strength and enhance the constraint effect on the filler, making the structure exert a shear effect earlier. As the filler used in these tests is sand with small particle sizes, the thickness of the influence zone of the geogrid is small. The reinforcement mechanism is changed, and the influence range of the reinforcement is expanded by using the geotextile sewn with ribs, so the strength of the structure is greatly improved.



Figure 10. Relationship between maximum shear stress and normal stress.

## 3.3. Reinforcement Mechanism of the Novel Geotextile with Stitched Transverse Ribs

The reinforcement effect between geosynthetics and soils contains passive resistance of transverse ribs, frictional resistance of longitudinal rib, and the embedded locking and occlusion of mesh.

Geotextiles stitched with transverse ribs can not only restrict the lateral displacement of the fill but also contribute greatly to the whole shear strength due to the friction between sand particles on both sides of the ribs and the geotextile. The shear strength of the geotextile with stitched ribs is mainly composed of three parts, as shown in formula (1) and Figure 11.

$$F = F_1 + F_2 + F_3 \tag{1}$$

where: *F* is the total strength;  $F_1$  is the friction force provided by the underlying geotextile;  $F_2$  is the lateral squeezing force of the soil on the geotextile transverse ribs;  $F_3$  is the component of the friction force provided by the geotextile transverse ribs in the lateral direction. Figure 11 shows a schematic diagram of the reinforcing effect of the stitched transverse ribs geotextile.



Figure 11. Schematic diagram of reinforcement effect of stitched rib geotextile.

According to Figures 10 and 11, the contribution percentage of the underlying layer and the transverse ribs to the overall shear stress can be obtained, as shown in Table 5. It can be seen that when the normal stress is low (25 kPa), the transverse rib  $F_2 + F_3$  plays a greater role, the percentage of which, under the three working conditions, is 57.5%, 69.1%, and 72.6%, respectively. As the normal stress increases, the friction effect between the underlying geotextile and the sand  $F_1$  is enhanced, and the percentage of  $F_1$  in shear stress gradually increases. When the normal stress is 150 kPa,  $F_1$  plays a more significant role, the rate of which is 70%, 61.4%, and 50%, respectively. Taking the geotextile stitched with three transverse ribs, for example, as shown in Figure 12, it can be seen that the reinforcement effect of the geotextile is mainly from the transverse rib at 25 kPa. With the increase of normal stress, shear stress provided by both the underlying geotextile and the transverse rib gradually increases. At 150 kPa, the shear stress provided by both is essentially the same. It can be summarized as follows: transverse ribs play a large role when normal stress is low, but the friction force of the underlying fabric requires a large normal force; therefore, as the number of transverse ribs increases when the normal stress is the same, the fraction of shear stress provided by the transverse ribs gradually increases.

		The Proportion of Each Part (%)		
Reinforcement Method	Normal Stress (kPa)	Friction Force of the Underlying Geotextile F <sub>1</sub>	Stress Force Provided by Transverse Ribs $F_2 + F_3$	
	25	42.5	57.5	
Chitakina 1 vik	50	49.1	50.9	
Stitching I rib	100	62.7	37.3	
	150	70.0	30.0	
	25	30.9	69.1	
Stitching 2 ribs	50	38.2	61.8	
Stitcning 2 ribs	100	52.2	47.8	
	150	61.4	38.6	
	25	27.4	72.6	
Stitching 3 ribs	50	32.5	67.5	
Sutching 5 fibs	100	44.8	55.2	
	150	50.0	50.0	

 Table 5. Comparison of reinforcement effect of each part of geotextile.



Figure 12. Comparison of reinforcement effect of each part of geosynthetics.

# 4. Conclusions

Considering conventional geotextiles have a limited reinforcement effect due to the insufficient friction strength between geotextiles and soils, this paper proposes a novel type of geotextile with stitched transverse ribs. Large-scale direct shear tests have been carried out, and the improvement characteristics between conventional geotextiles, geogrids and the novel geotextiles have been studied. The following conclusions can be drawn.

- (1) Geotextile B exhibits the best reinforcement effect among the four conventional geotextiles, and the shear strength of geotextile B is 20% higher than that of pure sandy soil. Moreover, the surface of geotextile B is rough enough to provide larger friction and form a certain embedded locking effect with sandy soil when geotextile B is compared with geotextiles C and D. Geotextile B has a greater thickness, higher strength and better reinforcement effect compared with the woven geotextile A. However, geogrid shows a better reinforcement effect than the four conventional geotextiles.
- (2) The shear strength of the novel geotextile with stitched transverse ribs is significantly increased. When the number of ribs increases, the magnitude of stress and the

friction angle increase, but the cohesion does not significantly change. When the shear displacement is small, the shear strength of the novel geotextile with three ribs is higher than that of the geogrid. However, when the shear displacement becomes larger, the shear strength of the novel geotextile is higher than that of the geogrid, indicating that the novel geotextile exhibits a very good reinforcement effect.

(3) The frictional resistance from the underlying fabric, the locking effect, the transverse restraint effect, and the frictional effect of ribs contribute to the novel geotextile's shear strength. When normal stress is low, the transverse rib is the key stress part of the geotextile, and the overall reinforcement effect is mainly from the transverse rib while the friction force of the underlying fabric requires a large normal force.

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