

# Investigation on reinforcement-sand-clay layer system using direct-shear test

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**Abstract:** The property of the contact surface between geosynthetics and soil directly affects the whole structure's stability. The interface property is one of the most important indices for the reinforced structure. Systematic direct-shear tests with large direct-shear apparatus are carried out for geobelt reinforced clay under different normal stresses and water content. A reinforcement-sand-clay layer system improving the interface behavior greatly is designed. The stress-strain relationship is investigated on the basis of the experimental results. The results show that with the increase of the normal stress, the shear strength between the clay and the reinforcement increases nonlinearly, and with the increase of the water content, the friction coefficient between the clay and the reinforcement decreases dramatically and the cohesion between the clay and the polypropylene geobelt increases initially, then decreases. There is an optimal value for the water content between the clay and the polypropylene geobelt, which is 2% lower than the optimal water content of clay compaction. This reinforcement-sand-clay layer system improves the shear strength of the interface remarkably. Therefore, the clay-sand-reinforcement layer system is a rather good design for practical use in reinforcement engineering.

**Key words:** high liquid limit clay; direct-shear test; water content; normal stress; reinforcement-sand-clay layer system

The French engineer, Henri Vidal, proposed the concept of reinforcement soil in 1965, and the first reinforced soil wall was constructed in Prageres successfully. Since then reinforced soil structures have been widely accepted in the world because of his effort. At the same time, the technique of reinforced soil has developed rapidly. In the earlier 1970s, geosynthetics was applied in reinforced soil engineering in the USA and in France.

For the geosynthetic reinforced soil structure, the property of the contact surface between the geosynthetics and the soil directly affects the whole structure's stability. So, the interface property is one of the most important indices for the reinforced structure. Some researchers<sup>[1-4]</sup> have studied the interface behavior between geosynthetics and the fills using the direct-shear test and the pullout test, and researchers in China have also studied this issue in recent years, and the fills that they studied are mostly sand, sandy soil and fly-ash<sup>[5-8]</sup>.

In this paper, systematic direct-shear tests were carried out with large direct-shear apparatus to study the interface behavior between high liquid limit clay and the polypropylene geobelt under different normal

stresses and water content. The reinforcement-sand-clay layer system as shown in Fig. 1 is designed to test how the sand improves the interface behavior between the clay and the polypropylene geobelt.

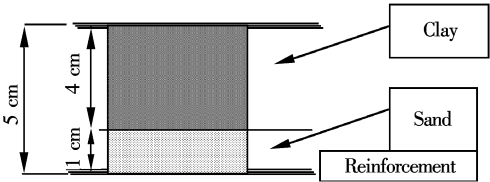


Fig. 1 Reinforcement-sand-clay layer system

## 1 Properties of Clay, Sand and Polypropylene Geobelt

The high liquid limit clay used in the test was sampled from beneath the bridge of the Xin Zhuang cloverleaf junction, a part of the Ning-Zhen Road, 312 National Highway. The physical properties of the sample clay are shown in Tab. 1.

The sand used in the reinforcement-sand-clay layer system is sieved as in Tab. 2. From Tab. 2, we can know that the sand is well graded as coarse sand.

Tab. 1 Physical properties of clay

Liquid limit $W_L$	Plastic limit $W_{pc}$	Plastic index $I_p$	Optimal water content $W_{op}/\%$	Maximum high density $r_{dmax}/(g \cdot m^{-3})$
43.6	19.7	23.9	19.14	1.856

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**Tab.2** Grain-size distribution of sand

Diameter/mm	>2.0	1.0 to 2.0	0.5 to 1.0	<0.5
Percent/%	0.8	50.3	47.5	1.4

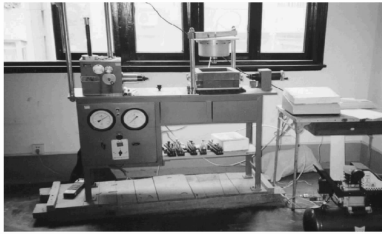
The polypropylene geobelt used in the test was measured by the unconfined tension test at a speed of 30 mm/min, and the tension strengths and tension ratios were obtained. The main physical and mechanical properties of the polypropylene geobelt are shown in Tab.3.

**Tab.3** Physical and mechanical properties of polypropylene geobelt

Width/mm	Thickness/mm	Rib height/mm	Mass/( $\text{kg} \cdot \text{m}^{-2}$ )	Portrait tension strength/( $\text{kN} \cdot \text{m}$ )	Portrait tension ratio/%
23	1.4	0.3	2.4	44.5	11.2

## 2 Test Instrument and Method

The device used in this test as shown in Fig. 2 is the multifunctional reinforcement measurement apparatus, which collects the data ten times per second, picks up the peak value automatically and prints the stress-strain or stress-time curve and data.

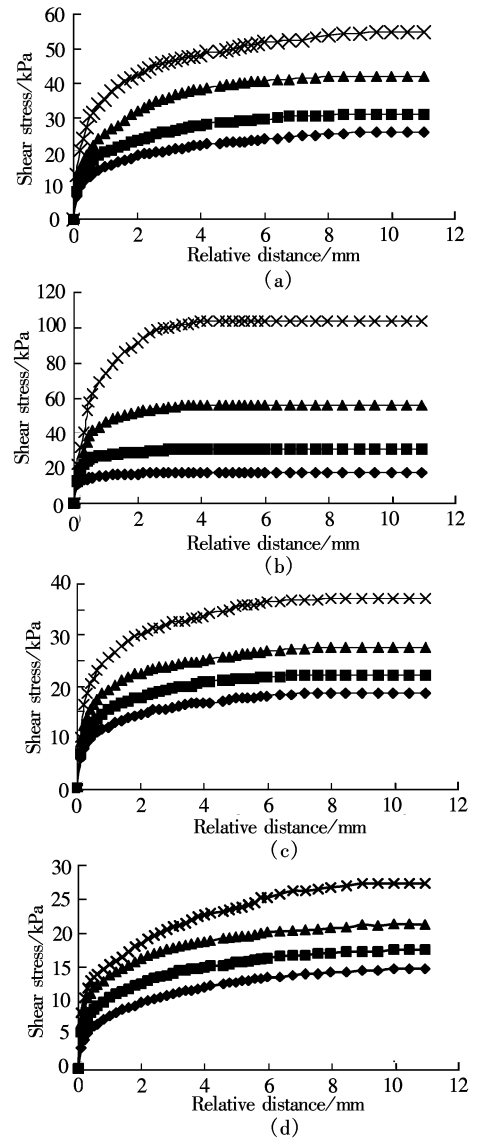
**Fig. 2** Test instrument

The size of the shear box is 20 cm  $\times$  20 cm  $\times$  5 cm. The test is strain controlled and the shear speed employed in the test is 1.60 mm/min. The normal stresses  $p$  applied are 50, 100, 200 and 400 kPa, respectively. The shear strength  $\tau$  obtained in the experiments can be used to plot the  $\tau$ - $p$  curves. As such, the cohesion  $c_a$  and the friction coefficient  $f$  can be obtained.

## 3 Test Results

In the first test series, the polypropylene geobelt was used as the reinforcement and the filled soil used is just the clay under the condition of compaction degree 5%. The water contents of the clay are 15%, 17%, 19%, and 21%, respectively. The relationships between the shear stress and the relative distance are shown in Fig. 3.

In the second test series, the polypropylene geobelt was again used as the reinforcement but in the re-

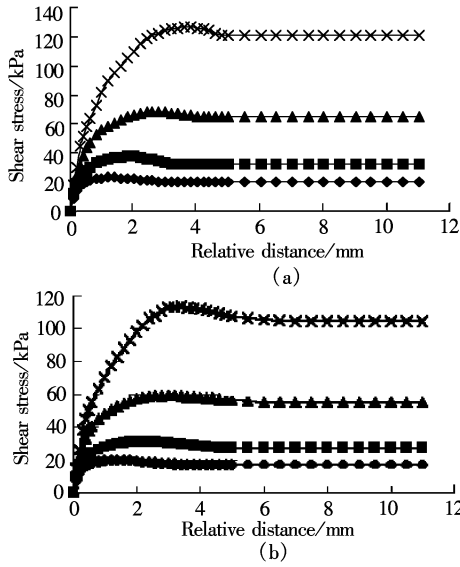
**Fig. 3** Relationships between shear stress and relative distance. (a) Water content of clay 15%; (b) Water content of clay 17%; (c) Water content of clay 19%; (d) Water content of clay 21%

inforcement-sand-clay layer system. In this case, the shear speed is 1.60 mm/min and water contents are 19% and 21%. The relationships between the shear stress and the relative distance are shown in Fig. 4 (a). For comparison, the direct-shear test of sand was also carried out and the results are shown in Fig. 4 (b).

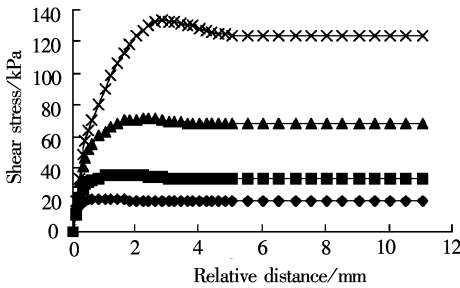
## 4 Analysis

### 4.1 Effect of normal stress

It can be seen from the relationship between the shear stress and the relative distance (Figs. 3 to 5) that with the increase of the normal stress, the shear strength between the clay and the reinforcement increases nonlinearly. For example, the increase of the shear strength, when normal stress increases from 200



**Fig. 4** Relationships between shear stress and relative distance. (a) Clay + sand, water content 19% ; (b) Clay + sand, water content 21%



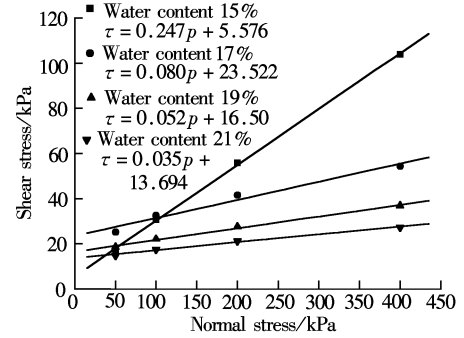
**Fig. 5** Relationships between shear stress and relative distance (sand)

to 400 kPa, is smaller than that when the normal stress increases from 100 to 200 kPa. It can also be seen that the shear strength between the clay and the reinforcement does not increase greatly when normal stress surpasses a certain value. This is very important in the choosing of the shear strength between the lower layer reinforcement and the clay when the high reinforced retaining wall design is adopted.

#### 4.2 Effect of water content

The water content has an important effect on the friction coefficient between the clay and the polypropylene geobelt. Fig. 6 shows that the friction coefficient between the clay and the reinforcement decreases dramatically with the increase of the water content. The friction coefficient decreases by 73% when the water content changes from 15% to 17%. The friction coefficient decreases 34.8% when the water content changes from 17% to 19%, and the friction coefficient decreases 32.1% with the water content changing from 19% to 21%. With the increase of the water content, the cohesion between the clay and the pol-

ypropylene geobelt increases initially, then decreases. There is an optimal value for the water content between the clay and the polypropylene geobelt, which is 2% lower than the optimal water content of the clay compaction.



**Fig. 6** Relationships between normal stress and shear stress

The phenomenon that the cohesion between the clay and the polypropylene geobelt increases initially, then decreases occurs because, with the water increasing, the water content between the clay and the polypropylene geobelt also increases accordingly. Based on the principle of effective stress and the water pressure will increase under the applied load, the effective stress between the clay and the polypropylene geobelt will thus decrease, which will lead to the decrease of the friction coefficient. The shear strength of the system is quite high at low water content but very sensitive to the increase of the water content. Experience shows that when the high liquid limit clay is used as the fills, the water content of the clay after construction is about 5% to 10% higher than that during construction. So for clay, especially for clay with a high liquid limit such as that for the filled materials, we should discount the shear strength between the clay and the reinforcement in designing.

#### 4.3 Effect of structure model

Results and discussions above have demonstrated that the water content has a strong effect on the friction coefficient between the clay and the reinforcement. To solve this problem, the clay-sand-reinforcement layer system is, therefore, designed to improve the interface behavior, and the test results are shown in Fig. 7.

The results from the ordinary model and the clay-sand-reinforcement layer system are both shown in Fig. 8 for comparison. The friction coefficient obtained from the clay-sand-reinforcement layer system improves dramatically. The friction coefficient improved 4.6 times in a water content of 19%, and 6.2

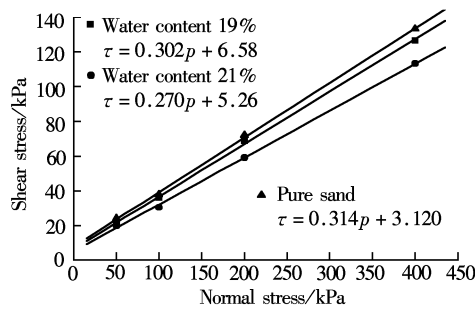


Fig. 7 Clay-sand-reinforcement system

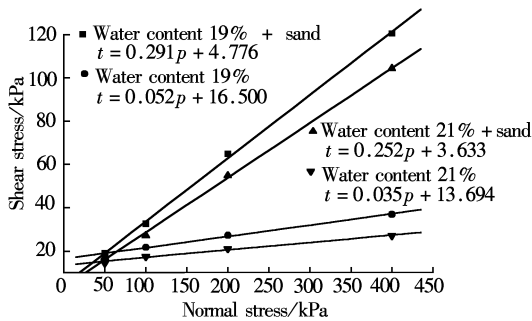


Fig. 8 Comparison between the two models

times in a water content of 21%. The clay-sand-reinforcement layer system has not only a good friction property between the sand and the reinforcement, but also the drainage characteristics of sand. The new system can also greatly improve the shear strength of the interface. Therefore, the new design is appropriate for practical reinforcement engineering.

#### 4.4 Effect of sand dilatancy

Fig. 8 shows that the friction coefficient from the reinforcement-sand-clay layer system is only a little smaller than that from the sand and polypropylene geobelt. The dilatancy will occur during the shearing of the dense sand. While in the reinforcement-sand-clay layer system, due to the “soft” property of clay, sand will be squashed into clay, thus reducing the dilatancy. The higher the water content, the more the reduction. So, the friction coefficient with a water content of 19% is larger than that with a water content of 21%, and they are all smaller than that obtained from pure sand and polypropylene geobelt shearing.

## 5 Conclusion

With the increase of the normal stress, the shear strength between the clay and the reinforcement increases nonlinearly. The shear strength between the clay and the reinforcement cannot increase greatly when the normal stress is up to a certain value. It is very important to choose the value of the shear strength between the lower reinforcement and the clay when the high reinforced soil wall design is adopted.

With the increase of the water content, the cohesion between the clay and the polypropylene geobelt increases initially, then decreases. This indicates that there is an optimal water content between the clay and the polypropylene geobelt, which is 2% lower than the optimal water content of the clay compaction itself.

The friction coefficient decreases greatly with the increase of the water content of the clay. For clay, particularly for clay with a high liquid limit such as that for the filled materials, the shear strength between the clay and the reinforcement should be reduced in designing.

The clay-sand-reinforcement layer system not only has good friction properties between the sand and the reinforcement, but also the drainage characteristics of sand. This system improves the shear strength of the interface remarkably. Therefore the clay-sand-reinforcement layer system is a rather good design for practical use in reinforcement engineering.

Owing to the “soft” property of clay, the dilatancy of sand is reduced in the reinforcement-sand-clay layer system model. The higher the water content, the greater the reduction.

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筋带-砂-粘土层状体系直剪试验研究

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**摘要:**为了研究粘土与加筋材料接触面之间的力学特性,及砂对粘土与筋带接触面力学特性的改善情况,采用直剪试验方法对粘土与聚丙烯土工带 polypropylene 在粘土不同含水量条件下进行了不同法向荷载作用的直剪试验,讨论了法向应力、含水量对高液限粘土与筋带之间剪切特性的影响;设计了筋带-砂-粘土层状布置体系的加筋土结构模型,并根据设计的模型进行直剪试验. 试验结果表明:粘土与筋带接触面之间的剪切强度随着法向应力的增加呈非线性增长;接触面的摩擦系数随着含水量的增加而减小,接触面的粘聚力随含水量的增加先增大后减小,粘土与接触面之间存在一个最佳的含水量,这个值要比粘土压实的最佳含水量低2%左右;筋带-砂-粘土层状布置体系表明砂对粘土与筋带的剪切特性起到明显的改善作用.

**关键词:**高液限粘土;直剪试验;含水量;法向荷载;筋带-砂-粘土层状布置体系

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