

Verification of efficiency of shear test methodology of geosynthetic composite

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Abstract: This research analyzes the effectiveness of different shear testing schemes in determining the most consistent and accurate shear strength results for geosynthetic materials. It also seeks to justify the necessity of implementing shear test methodology in the determination of the shear strength of geosynthetic materials in accordance with state standards. In the course of the research the characteristics of interaction of geosynthetic composite material "KAPLAM" with the soil will also be obtained. A 300×375 mm shear machine was used to perform shear tests at the soil-geomaterial interface with applied normal loads in the range of 100 to 500 kPa. These tests were performed according to the American standard ASTM D5321. Based on the data obtained from the testing the test methodology that provides the most reliable and accurate results for measuring the shear strength of geosynthetics will be determined. It will also identify the main factors affecting the shear strength of the material and establish the mechanisms of their interaction. In addition, the results of the research will show the need for further study of this methodology on the example of other types of geosynthetic materials. In general, the results of this research have an important practical significance for the development of designs of railway embankments and cladding systems of artificial constructions, as well as for testing the shear strength of geosynthetic materials in laboratory conditions. Such tests allow for more accurate modeling of real operating conditions and more objective assessment of the shear strength of composite materials.

1 Introduction

As waterproofing material in railway construction, geosynthetics, which are synthetic materials made of polymeric materials, are often used. Geomaterials interact with soil, sand, stones and any other associated materials, resulting in multiple shear planes in the construction, which can potentially bring about a loss of stability of the soil construction, especially along the slope, ultimately resulting in its collapse. The common boundary between the geosynthetic and the soil has been called the "interface" in foreign literature. Therefore, appropriate geosynthetic interface and internal shear strength should be used in design and construction [1, 2].

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Also, these geosynthetics protect the geo-environment from toxic substance pollution [3, 4]. The research [5, 6] shows the efficiency of using composite geomaterials in the construction of hydraulic structures. The work [7] proved the resistance of composite materials to high temperatures.

Despite the importance of the shear strength of geosynthetics, there is still uncertainty about the test methodology. Many laboratories determine the calculated values of geosynthetic-soil interaction properties using standard air-dry soil test schemes. Researchers have not considered important physical soil parameters such as moisture and density. Increasing/decreasing values of such factors affect dilatancy in soils, which is characterized by the change in volume of the soil mass under shear deformation. The determining factor in shear tests is the surface roughness of the geosynthetic material [8, 9, 10].

However, at present in Russia there is no engineering methodology for determining the characteristics of interaction between geosynthetic materials and soil, which would reflect the changes in strength and deformation properties of soils under the conditions of joint operation of reinforcing elements and soil under the action of various loads. The most complete results of such research were carried out by Ponomarev [11, 12], who obtained friction coefficients of several types of geomaterials on the soil. Among foreign researchers, it is worth noting the works of Muluti [1], L. Li [13], Sh. J. Feng [14], Stark [15], Hossain [16] who considered various interfaces of composite materials.

Due to the lack of Russian regulations on laboratory testing of interaction of geosynthetic materials with soil, it is difficult to choose a standardized test scheme. In order to solve this problem, it is possible to use American ASTM D5821 [17], ASTM D6243 [18] and German DIN EN ISO 12957-1 [19], DIN 60009 [20] standards.

The main objective of this research was to investigate, using a shear machine, the effects of different test methodologies for determining friction coefficients at sand-geosynthetic interfaces [21]. In addition, it was important to identify the soil characteristics that produce the most significant shear strength results and to understand the fundamental mechanisms underlying the interaction at the soil-geosynthetic interface.

2 Experimental materials and methods

Materials

To achieve the objectives of this research, soil and geosynthetic membrane were used to form important components of the embankment slope cover system interface in modern railway construction.

Medium coarse sand was used in the research. Table 1 summarizes the engineering properties of the soils. The particle size distribution was determined according to Russian State Standard GOST 12536-2014 (Table 1). The maximum density and optimum moisture content of the soil according to Russian State Standard GOST 22733-2016 were also determined (Fig. 1).

Table 1 - Particle size distribution of sand

> 10	10-5	5-2	2-1	1-0,5	< 0,5
0	10,65	21,55	63,83	132,44	272
0	2,13	4,31	12,766	26,488	54,4

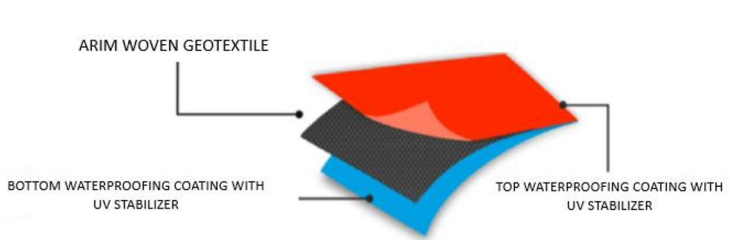


Fig. 1 - Determination of maximum density and maximum moisture content of soil. Source: <https://terratex-geo.uz/geokompozit-gidroizolyaczionnyj-kaplam/>

The geosynthetic material used in this research was geocomposite waterproofing "KAPLAM". It is a waterproofing material, is a geocomposite created from woven polyethylene fabric of different strength and a layer of polyethylene lamination applied on both sides (Fig. 2). Table 2 shows the main characteristics of the geocomposite provided by the manufacturer.

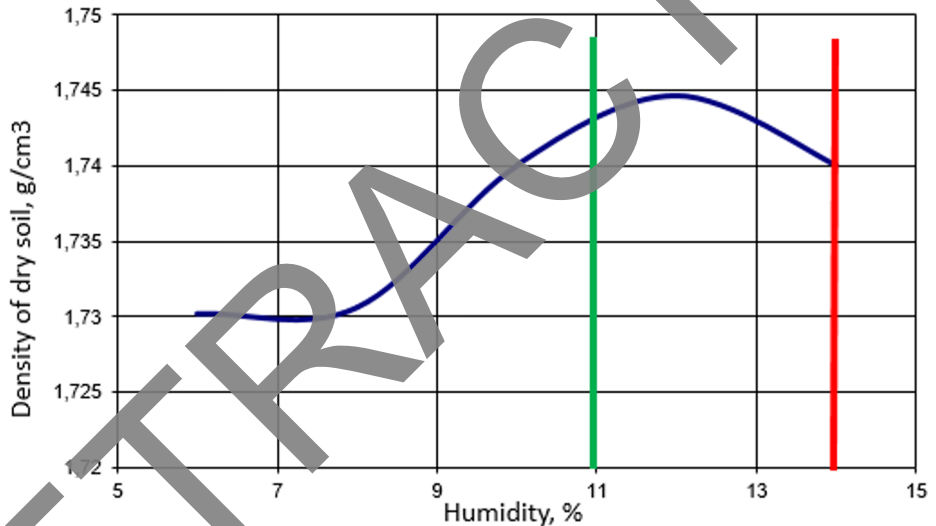


Fig. 2 - Geocomposite waterproofing "KAPLAM"

Table 2 - Physical and mechanical parameters of geocomposite waterproofing "KAPLAM"

Name of parameters	Values
Thickness, microns	1000
Tensile strength, kN/m, not less	60
Tensile strength across, kN/m	900
Resistance to aggressive environments, %	80
UV resistance, %	90
Width, m	До 40 m
Length, m	50, 100

Test equipment

Shear tests at the interface were carried out in the laboratory of the Department "Road Construction of Transport Systems" using a freestanding large direct shear machine Geotech GT 1.2.15, shown in Figure 3. The apparatus consists of a top (static) shear box with plane dimensions of 300x300 mm and depth of 75 mm and a lower (movable) shear box with plane dimensions of 375x300 mm and depth of 75 mm.

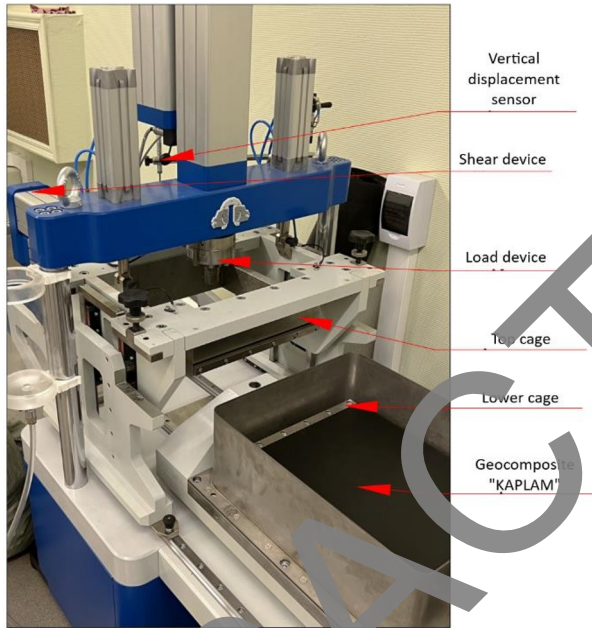


Fig. 3 - Shear machine GT 1.2.15

Test Procedure

The geosynthetic test specimens were randomly cut from the supplied rolls and sized to fit the lower shear zone. The specimens were cut into 300x375 mm dimensions for the bottom box. Tests were conducted at normal stresses of 100, 200, 300, 500 kPa to reflect the different loading conditions.

To determine the shear strength of the soil-geosynthetic interface, the soil sample was consolidated in the bottom box and the geosynthetic sample was fixed on the bottom box. The specimen configuration was assembled according to ASTM D5321 standards [17]. Also, for shear tests of the soil-soil system, the test schemes given in Russian State Standard GOST 12248.1 were applied.

The test sequence was as follows. A porous disk (identical to the one installed in the lower cage) and a top stamp were placed on the top face of the soil sample. The horizontal and vertical displacement sensors are then fixed in the holders with a screw. The tip of the horizontal displacement sensor rests on the support plate of the movable carriage of the shear device, and the tip of the vertical displacement sensor rests on the support plate of the force sensor of the loading device. During testing, the sensor stem extends out of the device housings.

The shear displacement rate (SDR) was set at 1 mm/min [17, 22] and the consolidation period of the soils was 5 minutes. In addition, it was assumed that the consolidation time would be sufficient for the gripping surfaces to fully engage the test specimens. After compaction was completed, a gap of approximately 5-10 mm was created between the upper and lower shear boxes. The shear device was calibrated and the shear test was started.

During the shear test, the lower part of the shear box moved at a speed set by the tester relative to the upper static shear box. Vertical displacements and shear reactions were recorded and saved on the computer during the shear phase using a horizontal displacement sensor and a load sensor, respectively.

The tests were carried out until 10% strain of the specimen was reached.

3 Test results

Figure 4 presents the results of the dry soil tests at applied normal stresses of 100 and 300 kPa, showing the correlation between shear stress and horizontal displacement. The shear stress at a normal load of 100 kPa increased smoothly until the peak value of shear stress was reached. When the normal load was increased by a factor of 2, the behavior of soil particles changed and they began to move in the lower cage opposite to the shear direction, resulting in their rapid accumulation beneath the geotextile and reaching the critical stress at 15 mm of deformation (Fig. 5). This observation describes dilatancy in soils - the movement of soil particles accompanied by an increase in the volume of the soil mass, under shear loading.

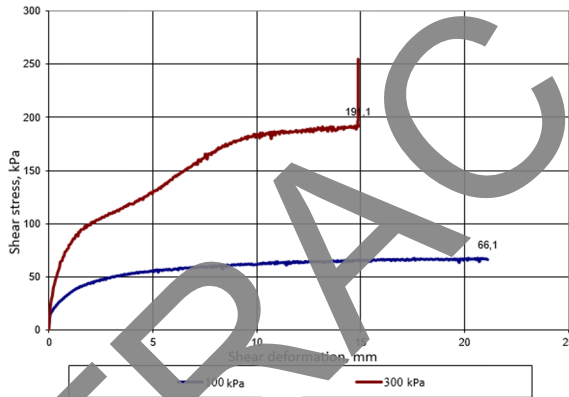


Fig. 4 - Results of shear tests of the system "dry soil - geotextile"

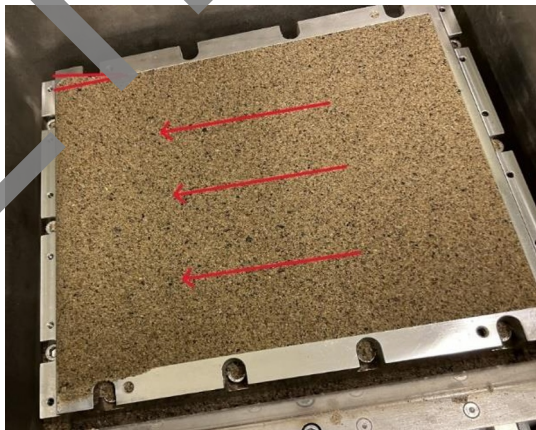


Fig. 5 - Displacement of soil particles

Wetting of soils to the optimum humidity of 11% allowed reducing the velocity of soil particles displacement and testing at normal load values of 300 kPa, 500 kPa. In Figures 6 and 7, at horizontal strain values of 15 - 30 mm and vertical load up to 200 kPa, a minimal increase in shear stress up to 8% was observed. After reaching 30 mm of horizontal

deformation there was a sharp increase in the growth of shear stress - 15 - 20%, which is explained by the beginning of the active phase of soil particles displacement with their further accumulation under the geotextile. At load from 300 kPa this effect starts earlier - from 20 mm of shear.

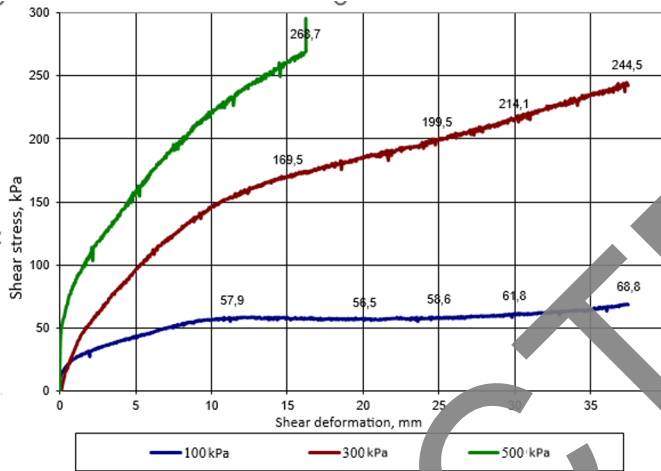


Fig. 6 - Results of shear tests of the system "wet soil - geotextile"

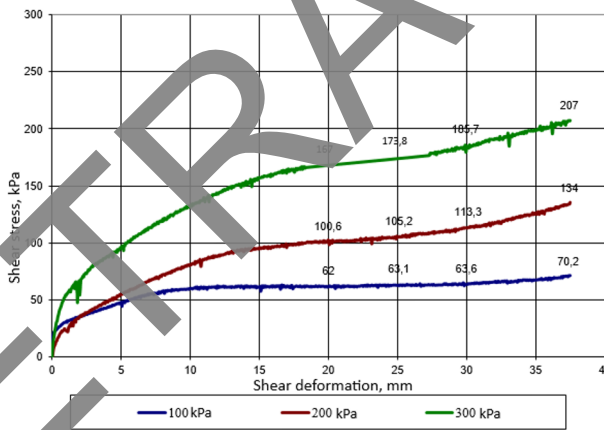


Fig. 7 - Results of shear tests of the system "wet soil - geotextile"

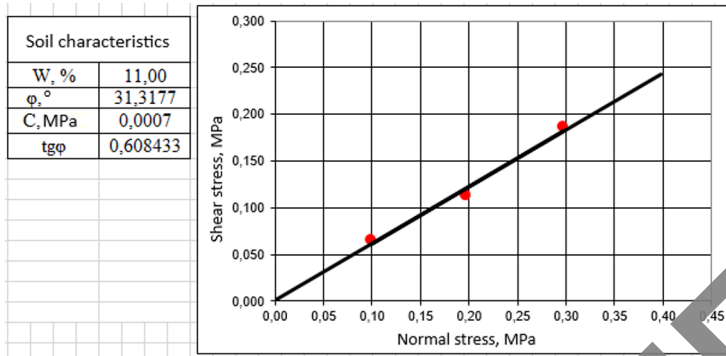


Fig. 8 - Characteristics of the wet soil-geomaterial interface

To further evaluate the interaction between the geosynthetic material and the soil, a soil-soil test was conducted. It was performed at the same facility as the soil-geomaterial system. The test results are shown in Figures 9 and 10.

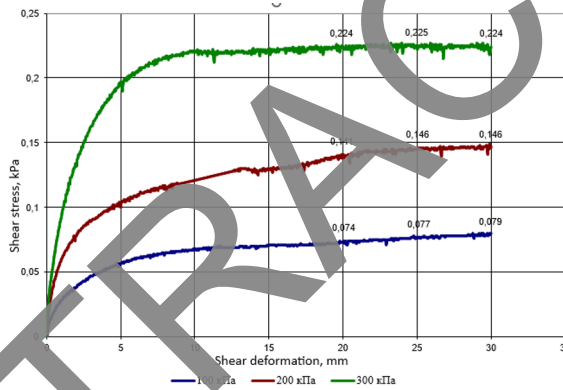


Fig. 9 - Results of shear tests of the "soil-soil" system

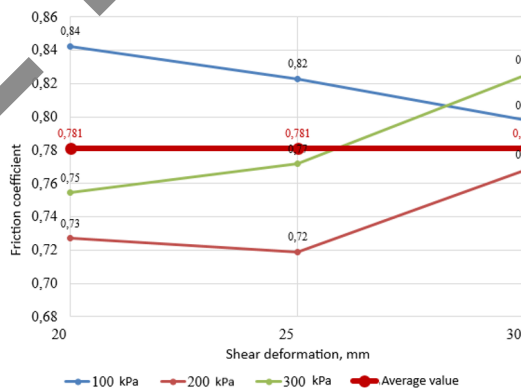


Fig. 10 - Characteristics of the soil-to-soil interface

The interaction of soil with geomaterial is characterized by the friction coefficient for shear [14], which is determined by formula (1)

$$f_g(\sigma) = \frac{\tau^{max}(\sigma)}{\tau_s^{max}(\sigma)}, \quad (1)$$

where $\tau^{max}(\sigma)$ – is the maximum shear stress occurring at the corresponding normal stress σ during shear testing of the soil-geosynthetic material system; $\tau_s^{max}(\sigma)$ – is the maximum shear tangential stress occurring at the corresponding normal stress σ during shear testing of the soil-soil system.

The obtained values of the coefficient of friction at different shear points are shown in Figure 11. With increasing vertical load, the interaction coefficient between soil and geomaterial increases and continues to increase until the critical shear stress is reached. For normal stress values greater than 100 kPa, the coefficient of friction increases with increasing shear deformation.

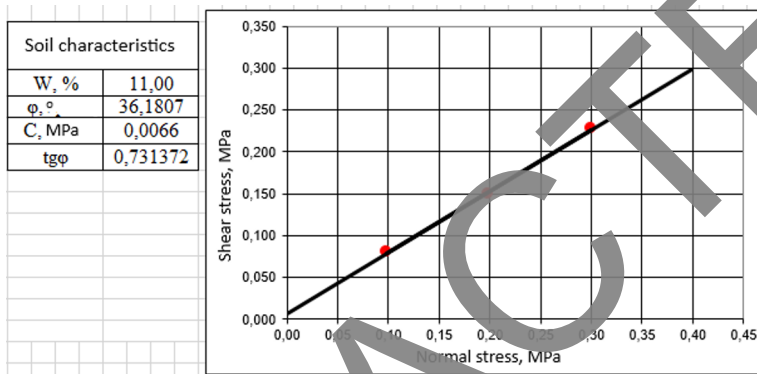


Fig. 11 - Friction coefficient

The coefficient of interaction of geosynthetic material with soil can be calculated as the ratio of the coefficient of friction of the system "soil - geomaterial" to the coefficient of friction of the system "soil - soil". Friction coefficients of two systems are obtained by approximation of test data (Fig. 8, 10). The final formula (2) is as follows:

$$f_g = \frac{tg\phi}{tg\phi_c}, \quad (2)$$

where $tg\phi$ – is the coefficient of friction in the shear test of the soil-geosynthetic material system; $tg\phi_c$ – is the coefficient of friction in the shear test of the soil-soil system.

The value of shear friction coefficient for the studied geomaterial is determined from the expression:

$$f_g = \frac{0,608}{0,731} = 0,832.$$

Comparing the two obtained geosynthetic material-soil interaction coefficients, it can be concluded that the friction coefficient obtained by approximating the shear test data, 0.832, differs from the average value of the friction coefficient for the three shear points, 0.781, by the amount of error in the approximating function.

4 Conclusions

A series of direct shear tests using different test configurations were conducted using a large GT 1.2.15 direct shear machine with a box size of 300x375 mm. The following conclusions were drawn from the test results:

1. The shear displacement rate of soil particles is directly proportional to the normal load and shear strain. But by adjusting the % moisture content, its influence on the test results can be reduced.

2. The optimum point of shear strain for calculating the coefficient of friction is 25 mm.
3. Shear interaction coefficients f_g of geocomposite waterproofing "KAPLAM" and medium coarse sand depends on the normal load - when the normal load increases, the interaction coefficient increases.
4. The angle of internal friction of the soil and the coefficient of friction in shear decreases by 15% with the introduction of geocomposite waterproofing "KAPLAM".

5 Future research

Since one type of geosynthetic specimen was tested, the data from these results are limited to the scope of this research. Therefore, additional tests using other different types of geosynthetic materials are needed to present a complete comparison of the tests. In addition, further tests using soils of different moisture contents should be conducted. The results of these tests should then be compared with the corresponding results obtained in this research.

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