Comparison of pullout test results carried out on steel grid and geosynthetic materials

Sven Schwerdt, Ulrich Turczynski & Danny Ohle
Magdeburg-Stendal University of Applied Sciences, Germany

Andrey Ponomaryov & Daniil Tatiannikov
Perm National Research Polytechnic University, Russia

ABSTRACT: Within an international cooperation between the Perm National Research Polytechnic University, Russia and the Magdeburg-Stendal University of Applied Sciences in Germany the behavior of geogrid and steel grid material during pullout tests were analyzed. The tests were carried out using a pullout test box with several geogrid and geosynthetic materials. Further tests were done with steel grid material. The aim was to verify the pullout characteristic of steel grids in comparison to geogrids.
The tests of the steel grid are significant because in many countries steel grids are used for reinforcement applications and are so in direct competition to geogrids.
The tests were carried out in two ways. First tests were done according to the regulations in EN 13738 and DIN 60009. These tests results were compared with the results of so called “staged pullout tests”. These are tests where the normal stress will be increased in several steps while the geogrid or steel grid material will remain in the box. So the test can be carried out without any influence from removing the fill material, different compaction grades or water contents.
In our tests we could show that steel grids and geosynthetics have different performances on pullout resistance. We could evaluate that the pullout resistance depends on the relationship between the grain size and the mesh grid size of the grid material. And last but not least we were able to evaluate that multi-step tests are suitable to find the pull out resistance of grid materials.

Keywords: pullout tests, geosynthetics, steel grid, multi-level tests, single-level tests

1 INTRODUCTION

The pullout resistance of geosynthetic material is used to determine the behavior of the combination between geosynthetic material and soil in retaining structures and other geotechnical applications. It is quite common to carry out pullout tests to evaluate the amount of pullout force in these structures.

Several alternative products such as steel bars, nets or steel grids were used instead of the geosynthetic reinforcement. The intention of this test series was to compare the behavior of geosynthetic reinforcements during pullout tests with the behavior of steel grids.

In the second part of the tests the behavior of reinforcement elements in different soils and with different spacings between the reinforcement elements should be tested.

And last but not least we were looking for any possibilities to make pullout tests easier to carry out. So we developed a so-called multi-step test and compared the results of these multi-step tests with the results of regular pullout tests.

2 DESCRIPTION OF TEST DEVICE

While the tests with the geosynthetics were carried out by researchers of the Perm National Research Polytechnic University the tests with the steel grid were done by researchers of the Magdeburg-Stendal University of Applied Sciences. Both groups were using the same test equipment.

The tests were carried out in a large test box. This test box is built to carry out large shear tests as well as for pullout tests. In the following figure the test box is shown.

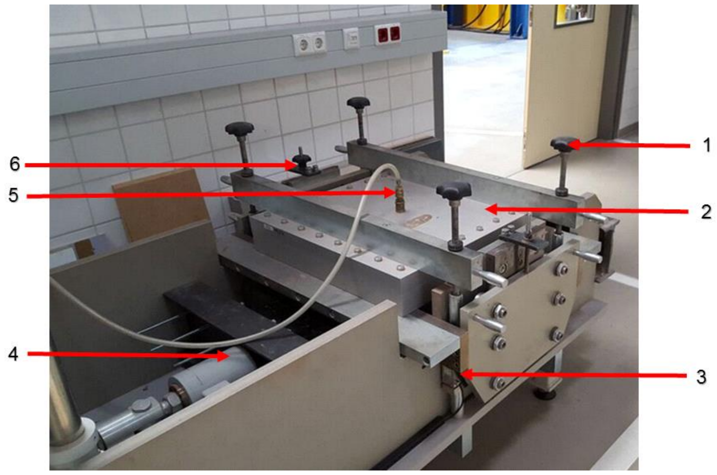


Figure 1: pullout test device
Marks: 1 - Screws for fixing the load-bearing device; 2 – load-bearing device; 3 – vertical load force sensors; 4 – pullout force sensor; 5 – compressed air for vertical load; 6 – device to fix the shear gap

In the table below you can find the technical specifications of the pullout test box.

Table 1. Technical specification of pullout test device

Dimension (L*W)	50*50 cm
Height	2*10 cm
Maximum pullout distance	150 mm
Maximum vertical pressure	800 kPa
Maximum shear force	125 kN

3 TEST PROCEDURE AND TEST RESULTS

3.1 *Tests with steel grids*

3.1.1 *Test procedures*

There were several steel grid tests carried out. The following tasks were investigated:
- Behaviour of steel-grid during pullout tests
- Influence of tranversal bars in pullout tests
- Influence of grain particle size in comparision to mesh size
- Differences between regular pullout tests (single step tests) and multi-step tests (staged pullout tests)

The regular tests were carried out in accordance with DIN 60009 and EN 13738.
The following materials were used during the tests:

Table 1: used materials

Steel grid	*Soil material*
Three different steel grids were used: - Steel bar diameter: 4,5 mm; tensile strength: 450-600 N/mm² - Mesh width: 5x5 cm; 10x10 cm; 10x5 cm - Sample width/length: 30 /50 cm - Some or all transversal bars were removed on several tests .	Two different soils were used: - Crushed stone material (2-32 mm grain size) - Crushed stone material (0-11 mm grain size)

The results of the sieve tests are shown in Figure **2**.

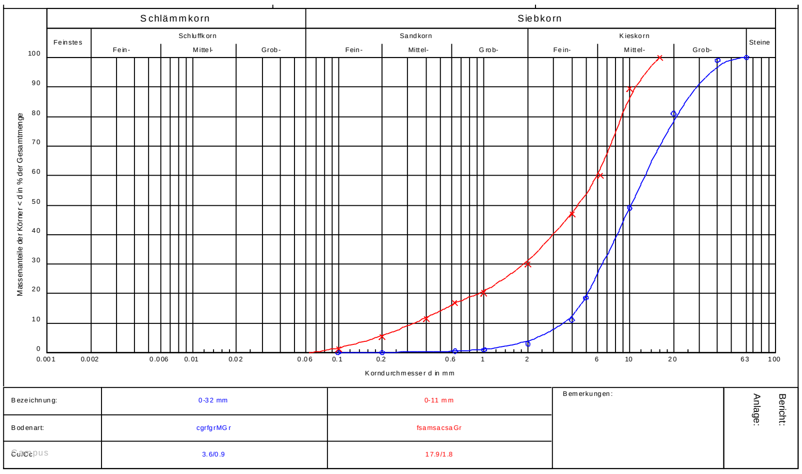


Figure 2: Sieve test results

Additional shear tests without reinforcement material according to (DIN-Deutsches Institut für Normung 2005) were carried out on the crushed stone material. The following figure is showing the results.

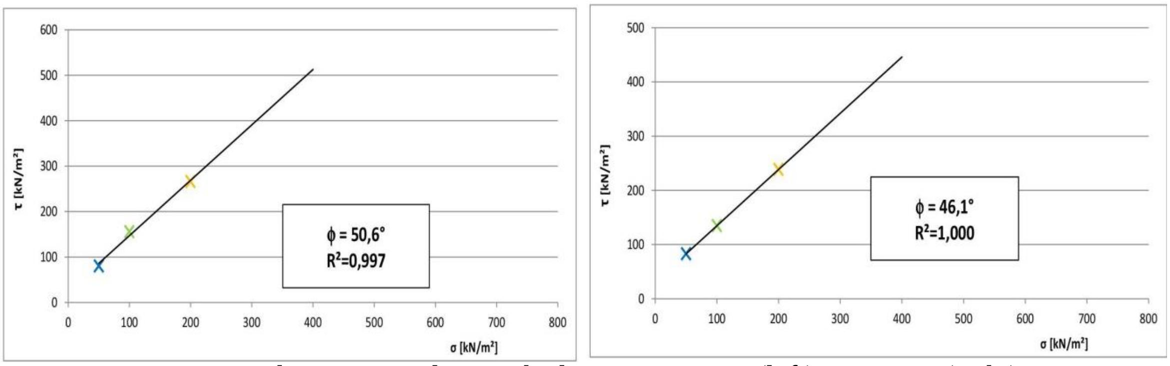


Figure 3: Shear test results: crushed stone 2-32 mm (left), 0-11 mm (right)

3.1.2 *Tests results of regular pullout tests (single step tests) and multi-step tests (staged pullout tests)*

Ju et.al. (2004) describe a method to carry out multi step pullout tests called „staged pullout tests". Several other authors also describe similar test methods (Tamaskovics 2009), (Lajevardi, et al., 2013) and (Althoff, 2015). Outside the regulations in DIN EN 13738 (2005) and DIN 60009 (2011) the geogrid will be placed once in the shear box and afterwards the vertical stress will be increased in several steps. With this method the influence of different installation conditions during the single tests can be avoided, and the temporal and experimental effort can be reduced. But there is one big disadvantage. It has to be confirmed that the reinforcement element remains undamaged throughout the previous load steps.

While multi-step tests have many advantages it was decided to use this test layout for the steel grid tests. To verify the multi-step test results, a comparison between single step tests and multi-step tests was carried out. For the tests the 0-32 mm stone material and a steel grid with 10 cm mesh width were used. The soil was compacted up to 91 %. The following figures show the results:

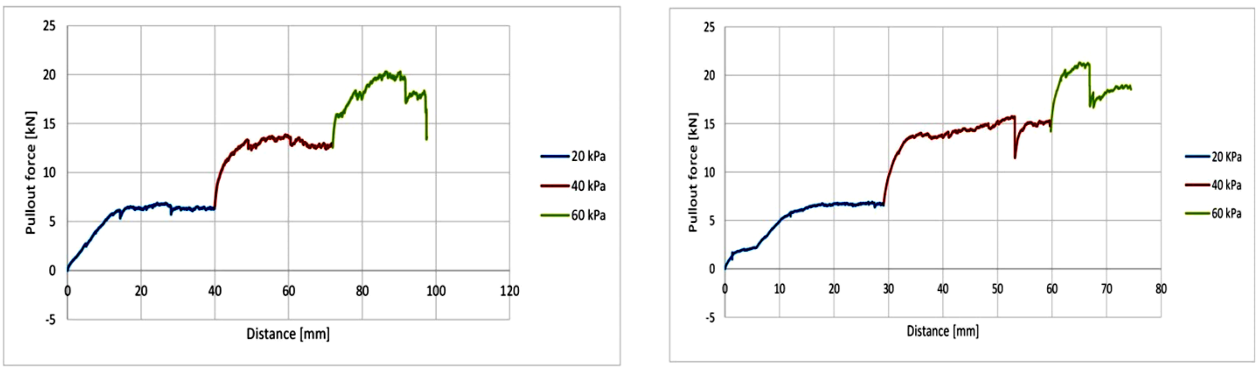
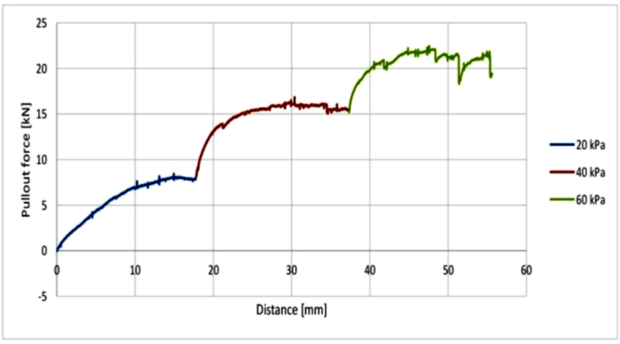


Figure 4: Results of multi-step pullout tests



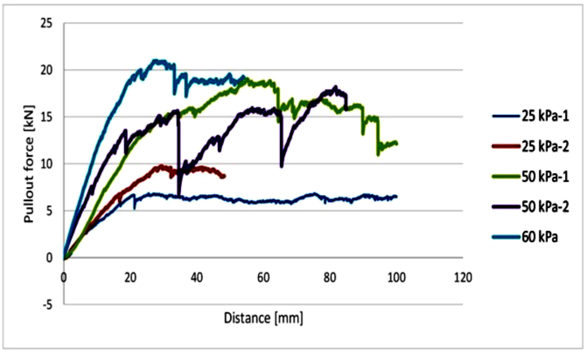


Figure 5: Results of multi-step pullout tests (left) and single step pullout tests (right)

In the following figure the maximum pullout forces of all tests were compared.

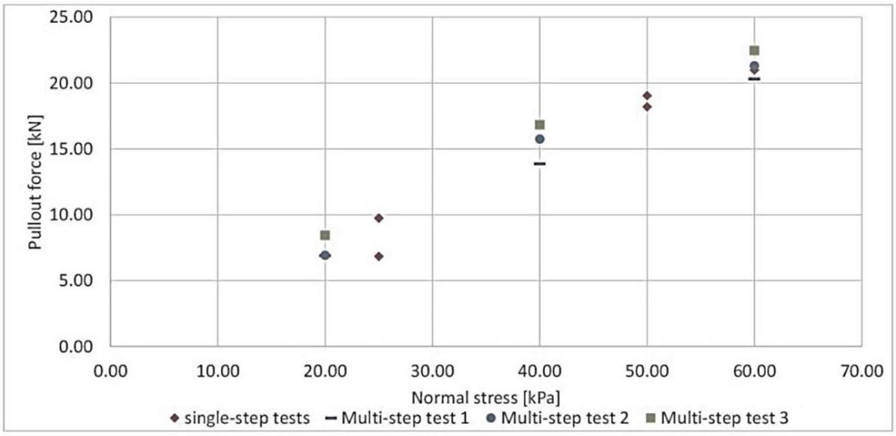


Figure 6: Normal stress vs pullout force for single-step and multi-step tests (stone size 2-32 mm, steel grid 10x10)

According to the results in Figure **6** the pullout forces in the single-step tests and the multi-step tests are comparable. This means the multi-step pullout tests can be used instead of single-step pullout tests. All tests in the following chapter were carried out using multi-step method.

3.1.3 *Multi-step tests*

In the next part tests with several steel grid products were carried out. Steel grids with 5*5 cm, 10*10 und 10*5 cm mesh width were used. The materials were tested in both soil materials (crushed stone 2-32 mm and crushed stone 0-11 mm). All tests were done at least twice. The following figures show the results of the tests.

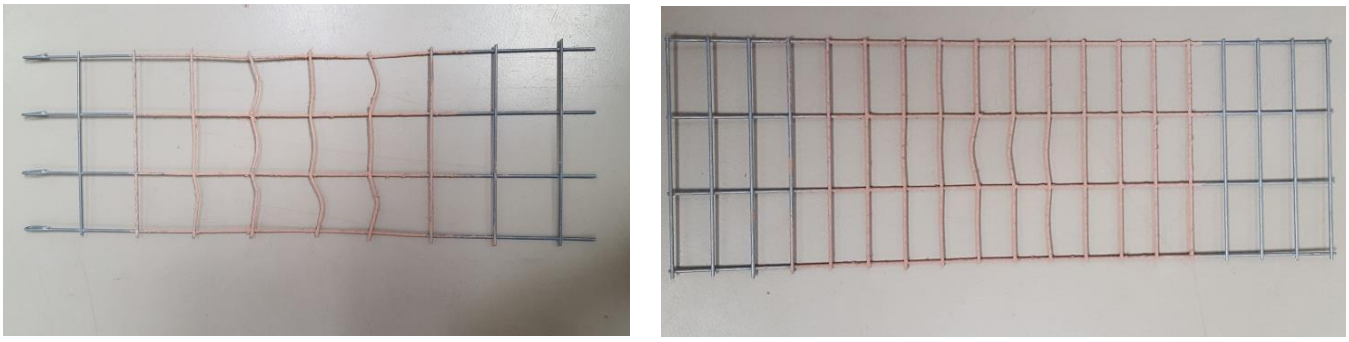


Figure 7: deformed steel grid; left: 10*10 cm; right: 10*5 cm

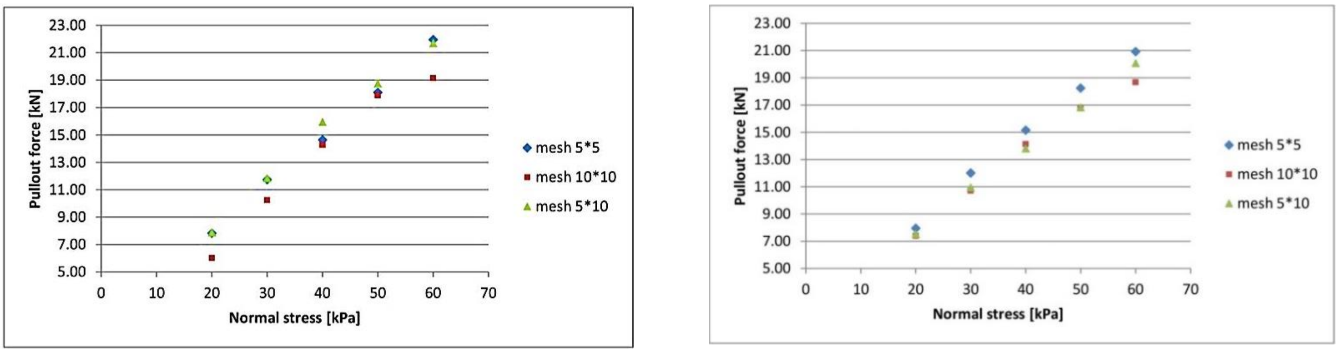


Figure 8: Pullout force for different steel grids; left: crushed stone 2-32 mm; right: crushed stone 0-11 mm

In Figure 8 left the results of the tests using the 2-32 mm crushed stone material are given. It is clearly recognizable that for the 10*10 steel grid the pullout force is lowest. Between the 5*5 mesh and the 5*10 mesh, differences can now be seen. For the tests using the crushed stone material 0-11 mm (Figure 8, right) the results vary more. While on higher normal pressure (60 kPa) the gap between 10*10 and 5*5/10*5 will decrease on lower stress levels. Generally the measured pullout forces reach similar levels on both test rows.

According to DIN 60009 a friction coefficient $f_{s,G}$ can be calculated using the following equation:

$$f_{s,G} = \frac{\tau_{HV,max}(\sigma_n)}{\tau_{s,max}\,(\sigma_n)} \tag{1}$$

where: $\tau_{HV,max}$ – maximum shear stress (one sided) at pullout test; $\tau_{s,max}$ – maximum shear stress at shear test (soil/soil)

The maximum shear stress at pullout test $\tau_{HV,max}$ will be calculated using the following equations:

$$T_{HV,max} = \frac{F_{HV,max} * n_{GGR}}{N_{GGR}} \tag{2}$$

$$\tau_{HV,max} = \frac{T_{HV,max}}{2 * L_a} \tag{3}$$

where: $F_{HV,max}$ – pullout force; n_{GGR} Number of longitudinal reinforcement strips per Meter width; N_{GGR} – Number of longitudinal reinforcement strips in sample; L_a – embedded length of reinforcement sample

The maximum shear stress at shear test will be calculated using the well known equation:

$$\tau_{s,max} = \sigma * \tan \quad \varphi \tag{4}$$

Using eq. 1-4 the friction coefficient could be calculated in the figure beneath.

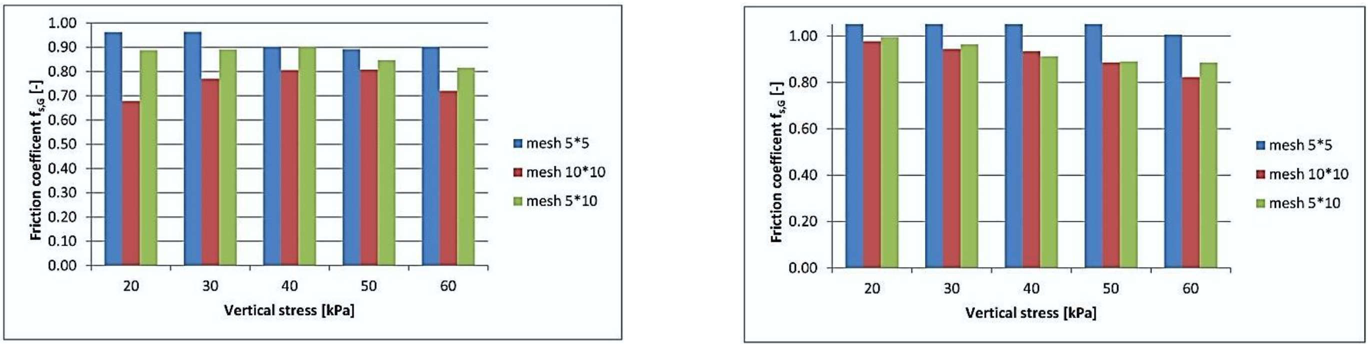


Figure 9: Calculated friction coefficient for different steel grids; left: crushed stone 2-32 mm; right: crushed stone 0-11 mm

The calculated friction coefficients for the tests using crushed stone 2-32 are lower than for the tests with the crushed stone 0-11. The reason can be seen in the lower angle of friction for the 0-11 material and nearly the same pullout force in both test rows. This leads to the conclusion that the mesh width and the maximum grain size are connected. The highest friction coefficients were measured when the maximum mesh size is close to the maximum grain size. The tests with the smaller steel grid mesh (5*5 cm or 5*10 cm) generally show higher friction coefficients than the test with the 10*10 cm grid.

3.2 *Tests with geosynthetics*

3.2.1 *Test procedures*

Pull out tests with two types of geosynthetic materials in sandy ground were carried out. The main goal was to compare geogrid and geotextile work. The tests were carried out in accordance with DIN EN ISO 12957-1 and DIN 60009.

As a primer, uniform, medium-sized sand was used. To study the physico-mechanical characteristics of the soil, laboratory tests and shear tests were carried out, see Figure 10.

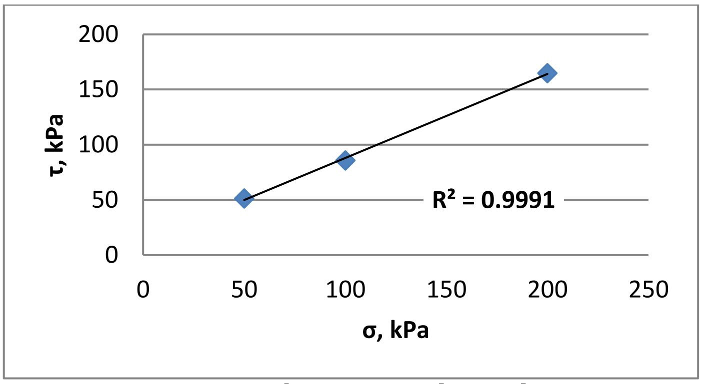


Figure 10: Shear test results sand

Two types of geosynthetics were used in the tests: geogrid and woven geotextiles (Melo, D.L.A. und Santos 2014) (see Figure 11). The physical properties of the materials can be seen in Table 2.

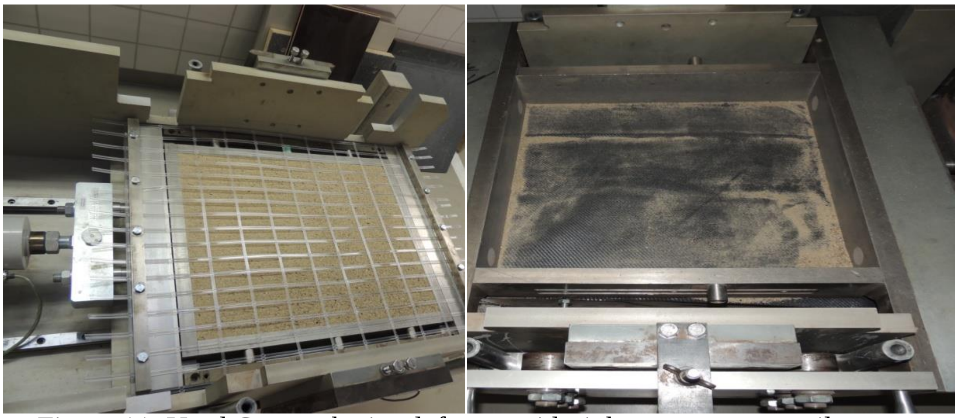


Figure 11: Used Geosynthetics, left: geogrid, right: woven geotextile

Table 2: Physical and mechanical properties of geosynthetic materials

Property	*Value*	
	geogrid	geotextile
The surface density	415 g/m^2	275 g/m^2
The maximum tensile, kN / m along / across	400/400	50/50
Elongation at maximum load, % along / across	9/9	17/15

The methodology for pullout tests is adopted according to the German regulations DIN EN ISO 12957-1 and DIN 60009. The scheme of experimental works is presented in Table **3** (see also: Tatiannikov, Ponomaryov et al., 2014).

Table 3: Test configuration

Normal stress	*pullout test*	
	sand –geogrid	sand – geotextile
20	+	+
40	+	+
50	-	+
60	+	-
100	+	-

3.2.2 *Test results*

One of the main experimental research problems was to establish the patterns of development of shear stress due to the displacement of the material for different types of systems (Tatiannikov, Kleveko 2014). The results of the experiments are shown in the following figures.

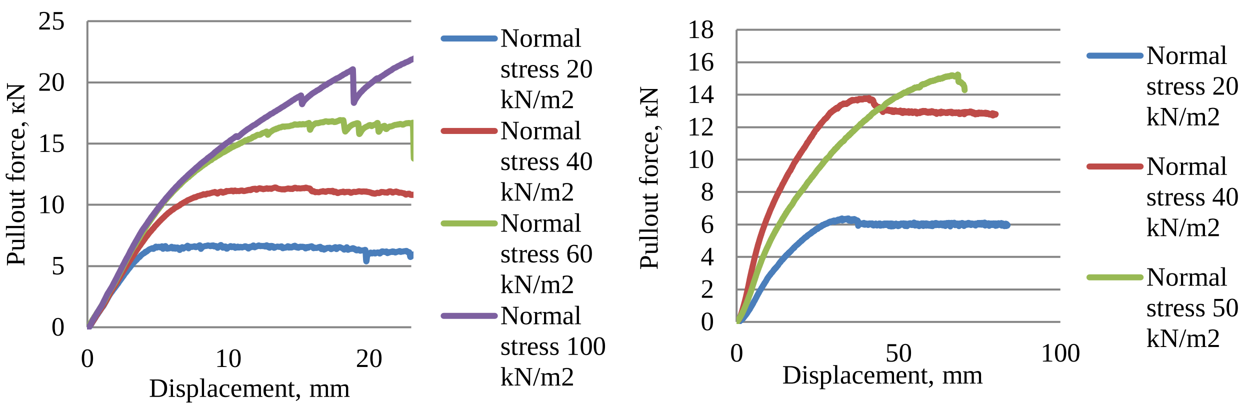


Figure 12: Test results: left: sand-geogrid; right: sand-geotextile

Some irreversible deformation was observed in the process of pullout testing for vertical stress greater than 60 kPa in the geotextile, which led to its rupture, but in the case of geogrid this phenomenon was not observed.

For the most complete comparison of the capabilities of geosynthetic materials and steel mesh, the parameters were determined: friction coefficient ($f_{s,G}$), pulling resistance ($T_{HV,max}$), see formulas (1-4).

The obtained data are summarized in Table 4.

Table 4: Friction coefficents for tests with geogrid and geotextile

Test No.	*σ [kPa]*	*$\tau_{s,max}$[kPa]*	*$\tau_{HV,max}$ [kPa]*	*$f_{s,G}$ [-]*
		Geogrid		
20-1	20	27,62	51,12	1,85
20-2	20	27,62	56,42	2,04
40-1	40	42,75	87,71	2,05
40-2	40	42,75	94,71	2,21
60-1	60	57,87	135	2,33
60-2	60	57,87	135,72	2,34
100-1	100	87,76	179,64	2,04
100-2	100	87,76	173,48	1,98
		Geotextile		
20-1	20	27,62	47,22	1,70
20-2	20	27,62	54,76	1,98
40-1	40	42,75	117	2,74
40-2	40	42,75	103,64	2,42
50-1	50	50,3	120	2,38
50-2	50	50,3	123,68	2,46

According to the results of tests performed, we could make the following conclusions:

In the constructions that entail significant shear forces, the use of geogrids is preferable to the use of geotextiles. This conclusion is confirmed by the coefficients of friction. The values of friction coefficients for tests with a geogrid are, on average, greater than in tests with geotextiles by 11% at similar vertical stresses

The value of the coefficient of friction increases with the normal stress to a peak (2,56) and then it decreases in tests with geotextiles by 6 % (See Table 4.). When testing with a geogrid, the value of the friction coefficient increases, to the assumed maximum at which, in analogy with geotextiles, critical stresses appear in the material and the coefficient of friction begins to decrease.

Based on the obtained values of the friction coefficients, the geosynthetic material (with the example of geotextile) is most fully included in the test work at normal stresses close to critical (50 kPa). This dependence should be taken into account in the design of reinforced structures.

4 CONCLUSIONS

The calculated friction coefficients are showing differences between the tests with the geogrid and the steel grid. While the results for the steel grid are in a range between 0,7 and 1,0 range the results for the tests with the geogrid are showing higher values (1,7 to 2,7). The reason for this differences are not quite clear yet and have to be verified in additional tests.

Beside this results we could show that the pullout resistance is depending on the relationship between the grain size and the mesh grid size of the grid material.

Multi-step pullout tests are suitable to find the pull out resistance of grid materials. The results are very similar to those in single step tests, carried out according to EN 13738.

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