Proceedings of the 8th International Conference on Safety and Durability of Structures
ICOSADOS 2018
May 23 - 25, 2018, LLU, Latvia

INVESTIGATION OF FRICTION BETWEENN GRAVELY SAND OR NON-VOWEN GEOTEXTILE AND TEXTURED HDPE GEOMEMBRANE WITH USAGE OF INCLINED PLANE TEST

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Keywords: textured geomembrane, soil-textured geomembrane friction, geotextile-textured geomembrane friction.

Introduction

Friction is the most important stability factor in every soil-geotextile-geomembrane system placed on a slope. HDPE geomembrane, which is widely used in watertight sealing systems, has relatively low friction coefficient limiting inclination of earth structures planes to ensure enough safety against sliding of covering soil layers. To increase friction forces on the contact planes and thus range of application, different texture patterns increasing geomembrane surface roughness are used. A newly developed pattern of geomembrane surface texture was tested.

Inclined plane test - which is a good model of real condition on a slope - was used to determine friction characteristics between textured geomembrane and soil. The speed of plane platform lifting (rotation) was regulated by multitest-tensile strength testing machine controlled by an individually created computer program. Geomembrane was fixed to the platform plane (Fig. 1, 2). Plane inclination was growing with constant speed 3°/min, as recommended by the standard PN-EN ISO 12957 – 2:2007 [1]. Influence of compaction and of moisture content of the soil on friction coefficient was investigated. Because very often nonvowen geotextiles are used in sealing systems as protection layer, friction coefficient between geotextile and geomembrane was tested, too.

Tests' program and description

Tests were performed on small 60x60x19 mm samples. Usage of programmable strength test machine assured constant angular velocity (3°/min). In tests described in the standard [1] calibrated sand 0,08-2 mm with rounded grains and water content smaller then 0,2 % is to be used. This method is good to compare different products between themselves. For particular projects necessary values should be obtained by testing soils, which are to be applied during realization [2]. According to Bhatia and Kasturi [3] "interface friction is very specific to the soil as well as the membrane". That is why in the reported investigation gravely sand was tested, as a material to be applied in designed realization. Soil sample was placed in square metal frame, which was moved slightly up to ensure, that only soil is in contact with textured geoemebrane. Water content and density index was determined for every soil sample. If friction between non-woven geotextile and textured geomembrane was tested, geotextile was wrapped around box with soil.

In spite of soil material some other changes were introduced adapting the tests to the possibilities of the laboratory. Angle of slipping "δ" is defined in the ISO standard [1], as an angle at which the box's displacement attains 50 mm. Test arrangement (Fig.2) presented in the paper, was prepared not to control sample displacement, but to measure force "V" lifting the plane and to determine displacement of inclined plane free end. When box with soil starts to move changing the position on the plane, sudden drop of lifting force, because of load movement, can be observed. This moment is precisely determined by measuring system of the strength testing machine. Slipping angle δ can be easily determined from the diagram presenting values of lifting force versus vertical displacement of the plane end (Fig. 3).

Fig. 1. Strength testing machine adopted to the inclined plane friction test

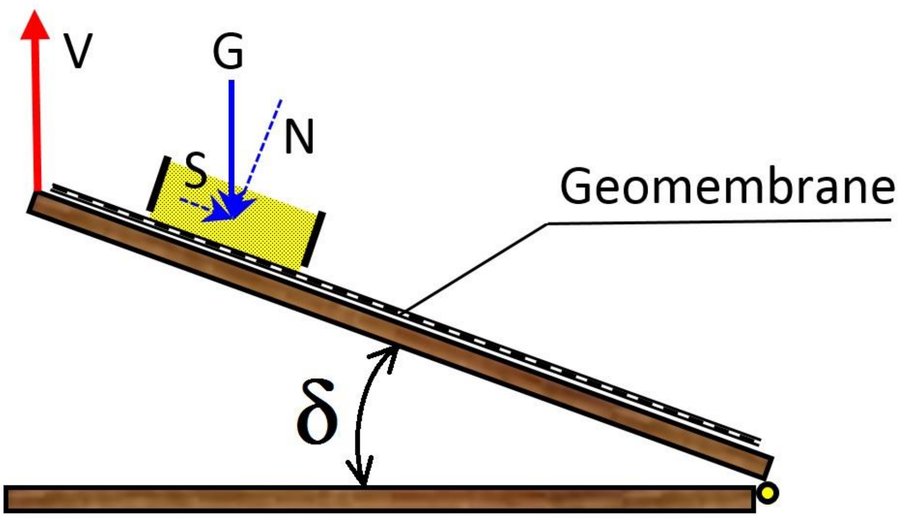

Fig.2. Inclined plane test arrangement

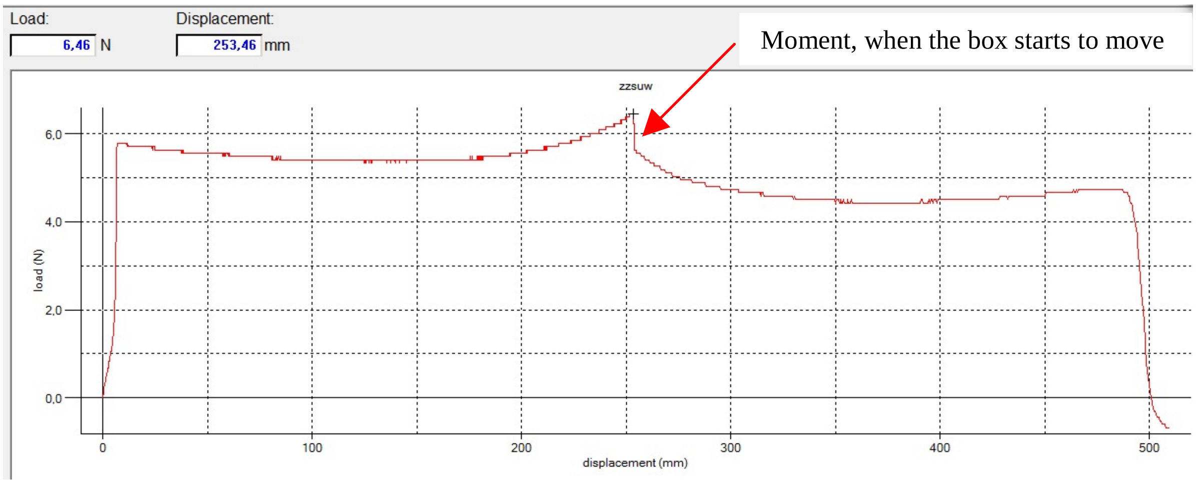

Fig. 3. Example diagram to determinate the moment, when box with soil starts to move

Despite of main tests, some investigation were made to determine soil parameters. The main tested parameters were:

- grain size distribution
- maximal and minimal porosity
- specific weight density
- optimal water content (Proctors test)
- angle of internal friction (in direct shear apparatus)

Average soil's parameters are presented in the table 1.

Table 1. Parameters of soil – gravely sand (grSa) - used in the tests

d_{60}	d_{10}	d_{60}/d_{10}	$\gamma_{max}/\gamma_{min}$	e_{max}	e_{min}	γ_{dmax}	w_{opt}	φ	c
mm	mm	-	kNm^3	-	-	kNm^3	%	deg	kPa
0,9	0,255	3.53	16,39/18,61	0,617	0,424	17,52	6,19	42	0

Textured geomembrane was made of HDPE and was 2 mm thick. Both geomembrane sides were textured. Texture pattern is presented on Fig.3
Non woven (needle punched) geotextile was 2,5. mm thick and its surface density was 175 g/m^2.

Fig. 4. Geomembrane texture pattern

Gravely sand -geomembrane friction on contact plane

The inclination, by which box filled with soil starts to move down, here called angle of slipping, can be taken as equivalent of friction angle between soil and geomembrane. In the highest position plane inclination was ca. 50°. Further movement of the computer controlled lifting arm was impossible, because the machine was reaching its extreme upper position. In some test configuration (moisture content, density) this inclination was too small to reach final slipping position, so further plane movement was continued manually, with much smaller accuracy. Only tests made with air-dry soil have given expected results – angle of slipping δ, based on other, then in the ISO standard criteria – was on the level 45° or less. In other tests, when water content was equal optimal value from Proctor's test or when gravely sand was fully saturated, slipping angels were much bigger than 45° and in extreme cases plane has to reach vertical position to start the box movement. One can suppose, that by so high angels, because of increasing sliding force and the moment it caused on soil – geomembrane contact surface, there was generated some additional suction pressure increasing resisting forces. Probably in real condition such phenomenon would not occurred and is only possible in certain condition of laboratory tests. No reports have been found about similar observation by inclined plane tests made with standard, big dimensions equipment, probably because the ISO standard presume usage of practically dry soil material. So using method described in this article it is recommended to use air dry material too, to eliminate other factors influencing stability of box with soil sample place on inclined plane. Results of the test, which were repeated 3 times for each soil parameters configuration, are brought together in the table 2. Test series 1÷3 were made on loose soil, in tests series 4÷6 soil was compacted.

Table 2. Test parameters and sliding angle δ from inclined plane tests (average values) of friction between geomembrane and gravely sand

Nr. of test series	γ	γ_d	w	I_D	δ	tan δ/tan φ
	kN/m^3	kN/m^3	%			
1	16,84	16,84	~0 (air-dry)	0,23	37,76°	0,86
2	14,10	13,27	6,19 (w_{opt})	<0	73,50°	3,75
3	20,04	16,70	20,05	0,15	45,00°	1,11
4	18,14	18,14	~0 (air-dry)	0,81	45,85°	1,14
5	18,40	17,32	6,19 (w_{opt})	0,45	55,4°	1,61
6	22,21	18,52	20,05	0,96	>90°	

Geotextile-geomembrane friction on contact plane

Geotextile-geomebrane friction was controlled on the same way as for soil samples. Geotextile was wrapped over metal box filled with loose gravely sand. Soil was used only to fill the box and to press geotextile to the surface of geoemebrane. Non vowen geotextile used in this investigation, was or air-dry, or saturated with distilled water. Before the tests, to saturate geotextiles samples, they were submerged in distilled water for at least 24 hours.

Test run was similar to tests made with gravely sand. Geomembrane was fixed to the plane. On it, box filled with soil and wrapped with geotextile, was put carefully and then the plane was pulled up until slipping of the box has occurred. Test results are presented in the table 3.

In the series 7 and 8 average values were calculated on the base of 2 tests only. The results of tests, when the box with geotextile could reach vertical position of the plane (δ = 90°, Fig. 4) and still was connected to the geomembrane, have been rejected.

By testing non-vowen geotextiles - material made of synthetic fibers - and geoemembrane with rough, textured surface formed during production process, it was obvious, that in spite of friction resisting sliding force, there is another resistance component because of mechanical connection between fibers and rough elements of geomembrane texture. The sum of this 2 resistance forces leads to much higher angle of slipping δ, than in standard test with geomebrane and soils, sometimes reaching even 90°. In this case influence of fibers entangled around rough elements of geomembrane surface could be determined with inclined plane tests only if we could use different material filling the box e.g. soil and metal balls, to carry the tests with 2 different loads. The same quantitative determination of other, then friction, factors influencing resistance against sliding forces can be made with direct shear apparatus [4].

Table 2. Test parameters and sliding angle from inclined plane investigation (average values) of textured geomebrane and nonvowen gotextile

Nr. of test series	**G**	**Moisture of geotextile**	**δ**
	G		deg
7	105,91	~0 (air-dry)	81,5°
8	122,12	Water saturated	73,50°

G - weight of the box, filling from gravely sand, and geotextile

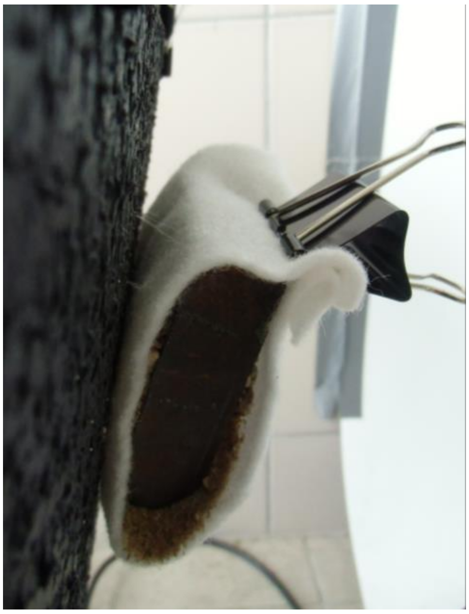

Fig. 5. Box with geotextile wrapped around just before the moment of break off from textured surface of geomembrane.

Conclusions

1. Tests on inclined plane with textured geomembrane and gravely sand have proved, that the geomebrane texture pattern assure very good friction. The smallest values of slipping/friction angle was observed for air-dry soil samples. In extreme cases (when soil is compacted and saturated) plane was lifted almost to vertical position, before sample start to move. It can be supposed that suction forces influenced test results by high water content of the sample.
2. Nonvowen geotextile during the tests exhibited very good connection with textured geomebrane surface. Inspite of friction, fibers from nonvewen geotextiles are tangled with protruding, rough

components of texture pattern increasing this way resistance against sliding. In some extreme cases the sample was detached from the geomembrane only by plane inclination near 90°.

3. To obtain reliable values for design purposes it is recommended to use dry soil, because in air-dry state slipping angle was the smallest. In the case of nonvowen geotextile and textured geoemembrane, there were not so big differences between air-dry and saturated material. Higher values were obtained by bigger moisture content.
4. Laboratory equipment can sometimes be adjusted (like in the example presented in this paper) to realize other tests, then it was primary designed for, using its precise measuring systems and individual programing possibilities to adapt to certain test condition.

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