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SIMPLE PROCEDURE OF GEOGRID-SOIL INTERACTION EFFICIENCY ASSESMENT

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Preliminary notes

Modern geotehnical practice often uses technique of reinforced soil – a composite of soil and reinforcement – mostly geotextiles or geogrids. The efficiency of soil reinforcement depends on soil-reinforcement interaction, which can be determined by testing models in complex laboratory procedures. In this article simple and quick experiment designed to give assistance in determination of most effective geogrid for some granular soil, in lack of complex, expensive and time-consuming test procedures is presented. The idea of proposed test is determination of angle of soil repose, which represents soil friction angle at small vertical stresses and should be higher for reinforced soil than for non-reinforced soil. It is expected that for different grids different angle of soil repose is formed, so comparison of grid efficiency could be made. Tests results show soil-grid interaction, but with limited reliability and with limited application for practical purposes.

Keywords: *grid efficiency, simple tests, soil reinforcement*

Procjena efikasnosti geomreže u tlu jednostavnim postupkom

Prethodno priopćenje

Suvremena geotehnička praksa često koristi tehniku armiranog tla – kompozita tla i armature – najčešće goekstila ili geomreže. Efikasnost ojačanja tla ovisi o interakciji tla i armature, a ona se može utvrditi ispitivanjem modela u skupim laboratorijskim ispitivanjima. U ovom radu predstavljen je brz i jednostavan pokus koji je zamišljen kao pomoć u određivanju najprikladnije geomreže za neko nekoherentno tlo u nemogućnosti korištenja složenijih, skupljih i dugotrajnijih ispitivanja. Ideja predloženog ispitivanja je određivanje kuta rasprostiranja tla, koji predstavlja kut trenja tla pri malim naprezanjima i koji bi trebao biti veći za armirano tlo nego za nearmirano. Za očekivati je da je za različite mreže ovaj kut različit, što omogućuje međusobnu usporedbu efikasnosti geomreža. Provedena ispitivanja oslikavaju interakciju tla i mreže, no s ograničenom pouzdanošću i ograničenom primjenom za praksu.

Ključne riječi: *armirano tlo, efikasnost geomreže, jednostavna ispitivanja*

1 Introduction

Modern building practice in construction of roads, geotechnical constructions of embankments and retaining structures, in improvement of foundation soil and in hydrotechnical works often uses the technique of reinforced soil.

The soil is considered to be reinforced when the plane implants, mostly geosynthetic sheets (geotextiles) or grids (geogrids), are placed in it to create composite with improved mechanical properties (strength and stiffness) [1]. In reinforced soil structures (Fir. 1), poor soil becomes usable and because of overall better properties of this composite (with greater strength and smaller deformability) it is possible to build steeper slopes of embankments often with lower price, save space required for structure, improve structure behavior under earthquake loading and lower cost of construction. The most efficient reinforcement of the soil is geogrids because of nature of their interaction with soil, which depends on rigidity and geometrical properties of grid and properties of soil fill. When grids are used, soil particles enter in grid apertures and effect of interlocking develops due to limited possibility for particles to move. In the same time, grid apertures are deformed and as a reaction grid ribs act with additional lateral stresses to soil particles improving soil strength and stiffness.

There are many types of geogrids which are used in practice that differ in geometry (size and shape of the apertures between grid ribs, thickness and geometry of ribs), way of production (monolithic, welded) and rigidity (rigid and flexible). All these and some other factors affect soil-grid interaction. The efficiency of grid depends of soil-grid interaction, which can be determined using models in complex, time consuming and expensive laboratory procedures [2÷5]. However, these procedures are not precisely defined and fully standardized yet, and one of them mostly used for characterization of some measure of interaction of soil and reinforcement is the pullout test, according to [6].

Figure 1 Reinforced soil embankment [7]

For researchers, designers and contractors the same question is of special importance: how to choose proper grid for available soil, or what type of soil is good for available grid (when non-cohesive soils are used). Some research proved that advanced testing can give answer to this question [8, 9]. However, these tests are complex, time consuming and expensive. Practice requires simple tests, possibly done as classification tests at site that would indicate advantage of certain grid over others. Such an attempt to create a simple test for onsite use that would be able to compare different grid efficiency in reinforcing granular soil was made as a part of a wider research project on reinforced soil at the Civil Engineering Faculty in Osijek. The test to be described is simple, practical and original.

Although results of this research in developing this simple test are not good enough for practical purposes, authors find the attempt inspiring for development of ideas for similar simple procedures in future, based on scientific ideas and empirical knowledge, which are needed in everyday engineering praxis.

The basic idea of the test procedure is determination of angle of repose of soil, without and with grid in it. This angle represents soil friction angle at small vertical stresses and should be higher for reinforced soil than for non-reinforced soil. Also, it is expected that different grids would create different angles of repose. This would enable comparison of grids in terms of their efficiency in improving granular soil properties.

2 Repose angles for granular soil

Shear strength of non-cohesive granular soil depends on normal (vertical) stress and soil friction angle. If granular soil is being poured at horizontal surface the formation of cone of soil occurs and the edges of this cone are inclined to horizontal plane. Maximum possible natural slope angle – repose angle (which can be here expressed as β, Fig. 2) is equal to the internal soil friction angle φ of loose material [10]. Soil friction angle generally depends on soil density, stress state and lateral restraining. Informative values of friction angles for some granular soils are given in Tab. 1.

Figure 2 Formation of cone of soil with natural repose angle β for non-cohesive soil

Table 1 Informative values of friction angle of noncohessive soil [10]

Material	Internal friction angle φ /°			Natural slope angle β /°
	loose	medium	dense	
Sand SU and silty sand SF_s	25-30	28-33	30-35	25-30
Well graded sand SW	29-34	34-40	39-45	29-34
Gravely sand GW	32-35	35-42	42-48	32-35

3 Influence of soil-geogrid interaction on soil friction angle

Interaction between soil and geogrid basically depends on mechanical properties of soil (density, grain size distribution, particle size, shape and orientation) and geometrical and mechanical properties of geosynthetics. Geotextiles in this interaction are characterized by surface roughness and tensile strength. When geogrids are used the aperture size of the grid, thickness and shape of rib cross-section, extensibility of longitudinal ribs, flexibility and shear stiffness of transversal ribs, strength of knots matters [11]. Degree of interaction is influenced by interrelation of soil particles and structure of the grid: ratio between particle size and grid aperture size, ratio between particle size and diameter of transversal ribs of grid [8, 9]. These factors should be considered when intensity of interaction between soil and geogrid is being evaluated.

Interlocking effect develops only with geogrids, and not with geotextiles. Therefore reinforcement of granular soils is today almost exclusively oriented to geogrids. In order to create interlocking, soil needs to be compacted and grid ribs need to be strained. It can be expected that the increased strength and increased stiffness of reinforced soil is the highest around the grid and that it disappears with distance from grid. Fig. 3 shows grid and gravel particles arrangement in reinforced soil and Fig. 4 illustrates the principle of interaction of soil and geogrid through the effect of interlocking.

Figure 3 Grid and gravel particles arrangement in reinforced soil

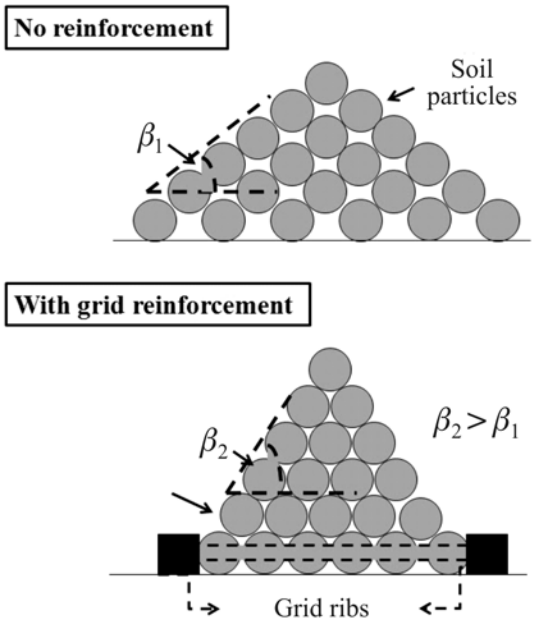

Figure 4 Illustration of soil geogrid interaction through the effect of interlocking: without grid ribs reinforcement particles cannot keep their position (upper fig.), interlocking of soil particles in grid apertures – stabilized bottom layer of soil with particles locked between grid ribs (lower fig.).

Changing the soil grain size distribution and reinforcement properties (shape of cross-section of ribs and grid size aperture) different degree of interaction is expected to develop. This "marriage" of soil and reinforcement is soil type – grid type dependent, which can be seen in the results of some complex laboratory testing [12]. Having that in mind, it can be expected that after soil would be put over the geogrid in a container and compacted, it could have different slope angle upon release of container sides (improved repose angle) depending on type of soil and type of grids used.

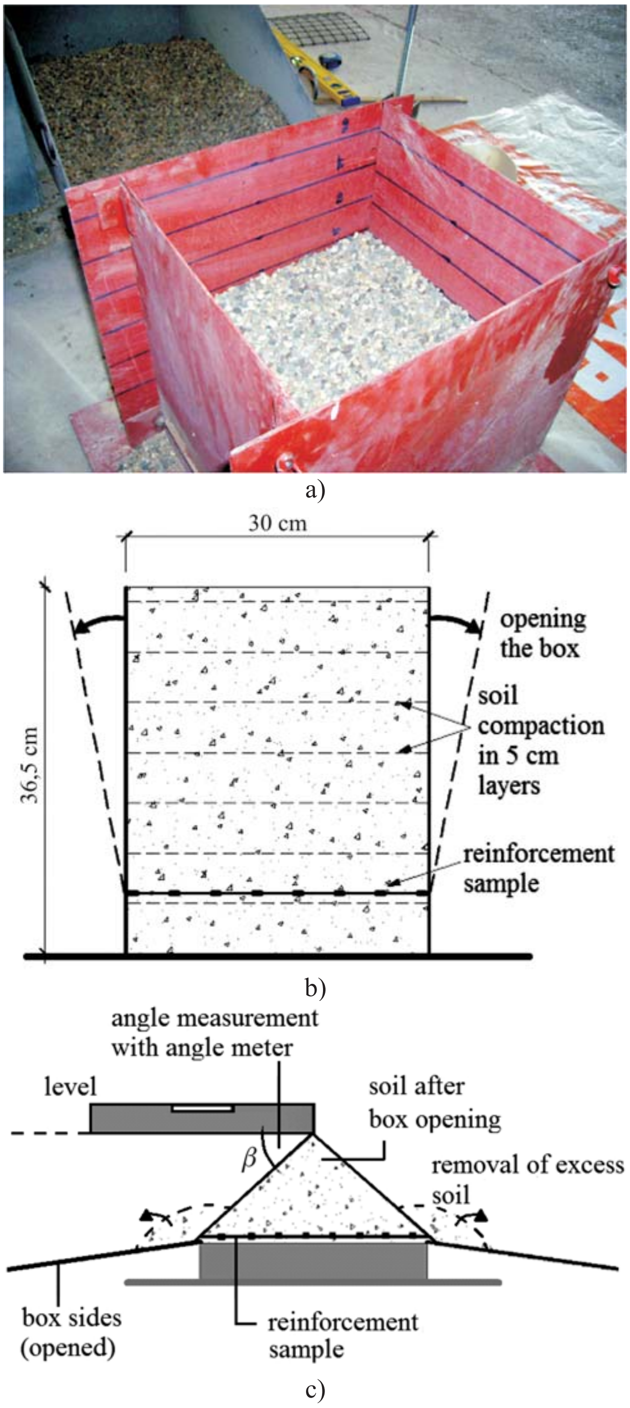

Figure 5 a), b) Testing mould, c) principle of slope angle measurement

4 Description of test procedure

The idea of simple test procedure is to determine natural slope angle of granular soil with grid (or geotextile) at the base and using this procedure, find the difference in efficiency of different types of reinforcement for certain soil. In order to prove this idea tests were conducted for different combinations of reinforcement and soil.

The test procedure is as follows: the soil with reinforcement under the base is placed in metal mould, certain compaction effort is applied, the slope angle is being measured, after the lateral sides of the mould were released causing formation of soil pyramid (before releasing the soil was confined with lateral sides of mould). The cubical testing mould and the principle of slope angle measurement are shown in Fig. 5. The shape of soil pyramid formed after releasing the sides of the mould in case of natural gravel without and with geogrid reinforcement is given in Fig. 6.

5 Tests performed

Tests were performed with geogrid and geotextile reinforcement in five types of granular soil with different grain size distributions and particle shapes: uniform Drava sand with particle sizes 0÷2 mm, natural round shaped gravel "Bilokalnik" with two grain sizes 4÷8 mm and 8÷16 mm and crushed coarse gravel with two grain sizes 2÷4 mm and 8÷18 mm. Tests with Drava sand were conducted for dried samples (w_{dry}) and moist samples with two degrees of moisture content: moisture content (w_0) at room temperature and 14 % moister content (w = 14 %) in order to

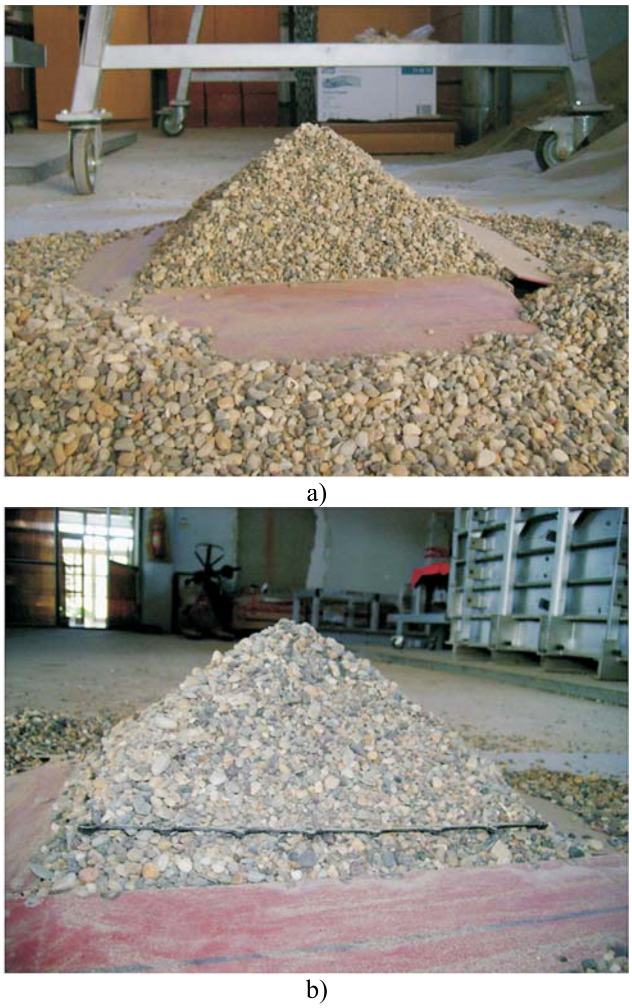

Figure 6 Soil pyramid formed after opening the mould for natural gravel: a) without reinforcement, b) with geogrid reinforcement

determine the influence of apparent cohesion on the natural slope angle.

As reinforcement two types of geogrids (with different geometrical and mechanical properties) were used: Tensar (SS 30 and SS 20), and Secugrid 30/30 Q1 and one type of non-wowen geotextile. Tab. 2 presents properties of geogrids used, with geometrical relations of grid elements.

Testing equipment consisted of a mould, that is metal box with movable sides in which soil and reinforcement were installed. Dimensions of the box were 30 × 30 × 36,5 cm (length × width × height). Soil was poured on prepared bottom, leveled and then compacted with fifteen hand tamper strokes (height of fall was 10 cm) to form layers of 5 cm thickness. This procedure was performed for all subsequent layers till the mould was completely filled. In tests with reinforcement, 6 cm of soil was placed and compacted first, the reinforcement sample positioned, with remaining soil placement following as described above. After compaction was finished the sides of the box were simultaneously opened (outwards, rotating around bottom hinge), the excess soil on the sides was removed carefully, so the proper pyramid shape of soil could be found (Fig. 5).

Table 2 Properties of geogrids used in tests [13, 14]

Geogrid	TENSAR SS 20	TENSAR SS 30	SECUGRID 30/30 Q1
Producer	TENSAR INTERNATIONAL	TENSAR INTERNATIONAL	NAUE FASERTECHNIK
Description	Biaxial polypropilene grid with thickend knots	Biaxial polypropilene grid with thickend knots	Welded biaxial grid from streched glued polypropyplene with flat ribs with welded knots
Nominal tensile strength	≥ 20 kN/m	≥ 30 kN/m	≥ 30 kN/m
Elongation at nominal strength	≤ 5,8 %	≤ 6,1 %	≤ 8 %
Aperture size between grid ribs ($A_L \times A_T$)	39 × 39 mm	39 × 39 mm	32 × 32 mm
Longitudinal rib width (W_{LR})	2,2 mm	2,3 mm	8 mm
Transeversal rib width (W_{TR})	2,4 mm	2,8 mm	9 mm
Longitudinal rib thickness (t_{LR})	1,1 mm	2,2 mm	1 mm
Transversal rib thickness (t_{TR})	0,8 mm	1,3 mm	1 mm
Knot thickness (t_J)	4,1 mm	5,0 mm	2 mm (two welded bands, one over another))

The angle β of pyramid sides (as it is previously established β can represent φ) was measured from horizontal for all four sides of soil pyramid. The mean value (φ_{SR}) from three repetitions of same the experiment was calculated, after one max. and one min. value of slope angle has been dropped out (mean of 10 measurements of slope angle). The value of mean natural slope angle in tests without reinforcement refers as φ_0.

6 Test results and analysis of test results

In the reinforced soil it can be seen that several factors influence the soil reinforcement interaction. These factors include grain size and shape of soil particles, geosynthetic type (geotextile or geogrid), and moister content of soil fill.

Soils with different grain size and shape of soil particles develop different interaction with various geosynthetic types. In this work it is presumed that interaction can be characterized by increase in slope angle from "natural" soil slope angle (without reinforcement at the base) to slope angle of reinforced soil.

Mean values of "natural" slope angles measured for soil without reinforcement and for soils with reinforcement are presented in Tab. 3 and Figs. 7 to 9.

Table 3 Mean values of natural slope angles measured for soil alone, geogrids Tensar SS30 and Secugrid Q30/30 in natural gravel G 4-8, G 8-16 and crushed gravel T 2-4 and T 8-16

Soil type	Angles (degrees), for reinforcement type							
	No reinf. φ_0		φ_{reinf}, Tensar SS30			φ_{reinf}, Secugrid Q 30/30		
	$\bar{x}$	σ	$\bar{x}$	σ	$\varphi_{reinf}-\varphi_0$	$\bar{x}$	σ	$\varphi_{reinf}-\varphi_0$
G 4-8	38,90	0,74	41,95	2,44	3,05	40,30	1,14	1,40
G 8-16	41,60	1,95	43,70	1,27	2,10	42,80	1,93	1,20
T 2-4	42,85	2,06	45,10	2,38	2,25	44,05	1,01	1,20
T 8-16	48,50	1,08	50,60	1,83	2,10	49,85	1,07	1,35

As it is shown in the Tabs. 3 and 4 and at Fig. 7 difference for all measured values of natural slope angle for non-reinforced and reinforced samples does not exceed 4°, but in relation to soil friction angle this could be described as significant increase.

This fact can raise question regarding applicability of the proposed test method. As it can be seen from Tab. 3 values of standard deviations are slightly smaller than measured values of slope angle difference for reinforced and non-reinforced soil. Difference in measured slope angle is present in two almost identical grids: Tensar SS30 and Tensar SS20 (Tab. 4). Obviously, test reliability for prediction of grid effect is within standard deviation of measured values.

Tests showed the highest increase of slope angle for geogrid Tensar SS 30 in gravel with particles 4÷8 mm where increase in friction angle of 3,05° was measured in comparison with the same soil without geogrid. This difference is not large, but it is considered to reflect the effectiveness of a grid.

Regarding the test results several conclusions can be made looking at Figs. 7, 8 and 9:

- calculation of slope angle is subject to some difficulties due to imprecision when taking correct measurements of pyramid slope; that influences interpreted values;

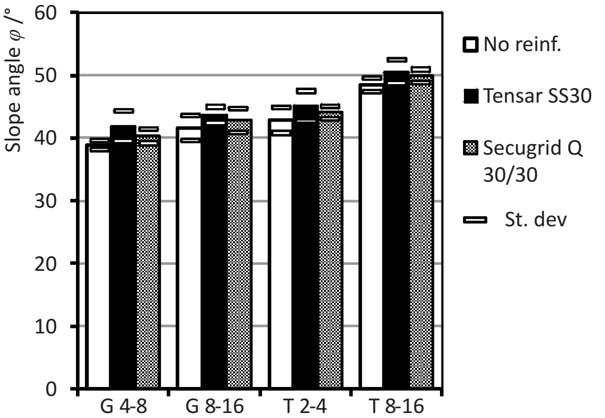

Figure 7 Mean values of natural slope angles with tests standard deviations measured for soil alone, geogrids Tensar SS30 and Secugrid Q30/30 in natural gravel G 4-8, G 8-16 and crushed gravel T 2-4 and T8-16.

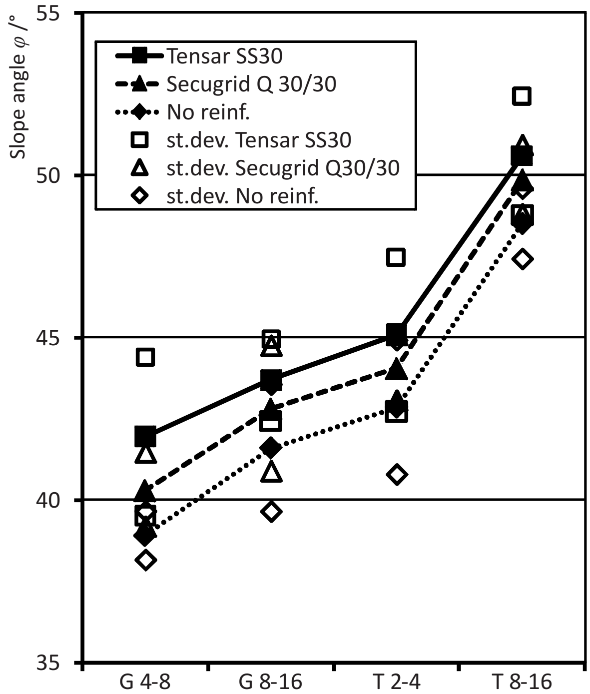

Figure 8 Mean values of slope angles with test standard deviations for nonreinforced soil and for soil reinforced with geogrids Tensar SS30 and Secugrid Q30/30 in natural gravel G 4-8, G 8-16 and crushed gravel T 2-4 and T8-16.

- natural slope angles for non-reinforced soil is generally smaller then for reinforced soil for all soils and all reinforcements;
- natural slope angles rise with particle size and roughness for reinforced and non-reinforced samples (except for dried uniform Drava sand and non-reinforced samples), comparing values for SU, G 4-8, G 8-16 and SU, T 2-4, T 8-16;
- soil particle shape and roughness has greater influence on natural slope angle than soil particle size for soil alone and all geosynthetics, as it can be seen from natural slope angles for natural rounded particle gravel Bilokalnik G 4-8 and G 8-16 which are smaller than for crushed gravel T 2-4 and T 8-16 mm;
- geogrid Tensar SS 30 has the best interaction with crushed gravel T 2-4 and 8-16 in comparison to other reinforcement;
- this simple apparatus and procedure reflects influence of grids present in soil but not to the extent that would enable reliable rating of grids.

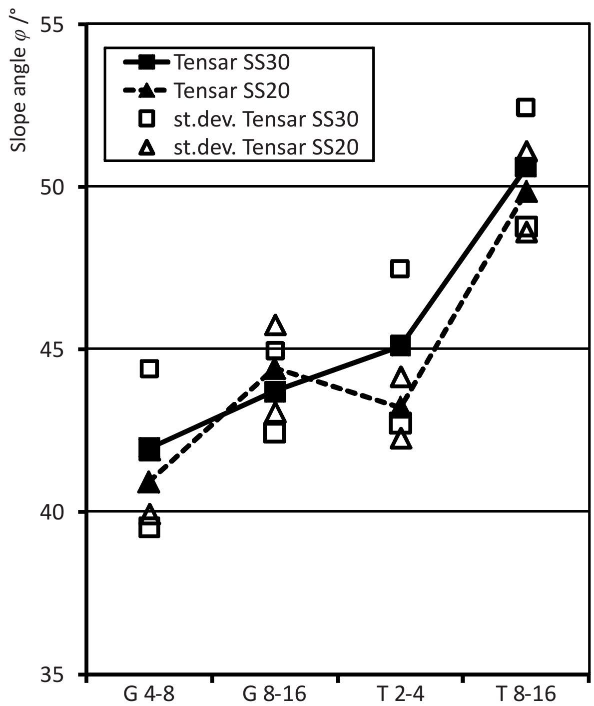

Figure 9 Mean values of slope angles for geogrids Tensar SS30 and Tensar SS20 in natural gravel G 4-8, G 8-16 and crushed gravel T 2-4 and T8-16 with mean standard deviation of tests on both grids.

Table 4 Comparison of difference of mean values of slope angles for geogrids Tensar SS30 and Tensar SS20 in natural gravel G 4-8, G 8-16 and crushed gravel T 2-4 and T8-16 with mean standard deviation of tests on both grids.

Soil type	Angles (degrees), for reinforcement type			
	φ, Tensar SS30	φ, Tensar SS20	Difference φ Tensar SS30 - Tensar SS20	Mean st. dev. Tensar SS30, Tensar SS20
G 4-8	41,95	40,90	1,05	2,22
G 8-16	43,70	44,40	–0,70	2,04
T 2-4	45,10	43,20	1,90	1,37
T 8-16	50,60	49,85	0,75	1,59

Looking at the results for uniform Drava sand (SU), as it can be seen in Fig. 10, following conclusions can be drown:

- moisture in sand has dramatic influence on measured values of slope angle, which is important to know when trying to test effectiveness of different grids in sand;
- this effect can be attributed to apparent cohesion that is developed as a consequence of capillary forces developed upon increased moisture in sand pores;
- nonwoven geotextile acts with its small fibers as a special reinforcement in the very thin zone around its plane, with effectiveness greater than grids produce, since the openings of grids are too big for small sand particles as shown in [15].

Regardless of limited test accuracy undoubtedly it can be stated that for sharper edge aggregates (with coarser particles), particle interlocking in grid apertures is greater and possibility of movement is reduced. This effect, as previously described, can be seen in case of crushed gravel which has coarser particles than natural gravel. Crushed gravel with particle sizes 2÷4 mm has greater slope (friction) angle than natural gravel with particle sizes 4÷8 mm (for example, 45,10° compared with 41,95° for Tensar SS30, see Tab. 3). Best interaction is determined for crushed gravel 8÷16 mm with geogrids, particularly with Tensar SS 30.

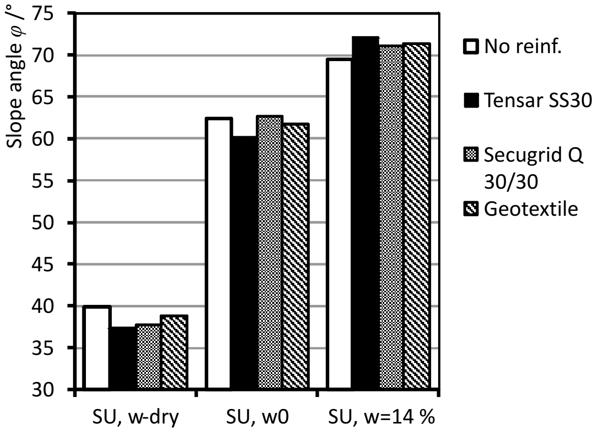

Figure 10 Slope angle *φ* for dry sand, sand with natural moisture content and 14 % moisture content

Finally, the following conclusions can be drawn from test results:

- soil-grid interaction is big issue in today geotechnical engineering; basic behavior is not fully understood neither theories are developed that can predict that behavior of composite material, therefore model testing is of great importance for our practice;
- in this paper an attempt was described that, by using simple device and simple testing procedure, rating of efficiency of different grids in different soils could or could not be reliably established, as for construction site needs;
- tests were conducted on a very simple apparatus, whose purpose was to check if such a simple device could be of help at the construction site in detecting proper match of grid and soil;
- such a simple device and simple procedure showed limited success in rating different grids in different soils in terms of their interaction;
- vertical stresses imposed on soil particles were small and insufficient to strain grid ribs so that real confinement of grid cells wasn't developed, this is consequence of low compaction energy and small soil sample height;
- however, tests clearly demonstrated influence of grid type, size of grains and shape of grain on repose angle in this particular testing type;
- differences of repose angle for different conditions are limited to 2÷4 degrees; having in mind standard deviation and precision of measurement this can be halved;
- this simple device and simple procedure could not, at present, be used for rating grid efficiency in reinforcing different soils;
- however, further efforts in creating similar tests and / or improvement of this one described here might be of interest to practice.

7 Conclusion

In this paper simple and quick experiment designed to give assistance in determination of most effective geogrid for some granular soil in lack of complex, expensive and time-consuming test procedures is presented.

It is shown that with this test, which is intended to be performed at construction site, comparison of efficiency of some grid in reinforced soil, by measuring the increase in "natural" slope angle, in relation to the non-reinforced (natural) soil can be made, but with limited reliability and with limited success for practical purposes. The test is moisture sensitive so it is better to conduct it on dried samples.

Although with limitations, with this test some of expected aspects of improvement of soil with reinforcement can be detected: soils with smaller particle sizes give smaller increase in improvement, soils with larger particle sizes and soils with coarser particles give greater interaction with geogrids.

Having in mind that changes in slope angle are relatively small, and measurement precision is respectively low, the proposed simple test method has limited potential in rating reliably efficiency of different grids in reinforcing granular soil for practical applications. Obviously, density of soil and stress level influences test results. In this paper that aspect has not been specially analyzed (the energy of compaction has not been varied, and stress was low).

This work, which is part of scientific research on reinforced soil conducted at the Civil Engineering Faculty in Osijek, was subject of he final work for baccalaurean degree (coauthor of this paper) [16]. Authors do not recommend this experiment as final and valid solution for selection of geogrid for certain soil. However, this approach should be comprehended as encouragement for development of similar procedures, and confirmation that complex mechanisms can be portrayed by simple procedures, which are suitable for practical applications.

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