Influence of reinforcing geogrids on soil properties

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INFLUENCE OF REINFORCING GEOGRIDS ON SOIL PROPERTIES

Marko Cindric, Krunoslav Minazek, Sanja Dimter

Preliminary notes

As a part of the research project in progress at the Civil Engineering Faculty in Osijek a new large pullout testing device has been developed and specially instrumented for characterisation of interaction between soil and geosynthetic in a pullout box by measuring wave velocity in the soil around the geosynthetic, before and at stops during pullout procedure. This paper presents some of the results of investigation carried out on one geogrid in one type of gravel, in terms of modulus of elasticity *E* and shear modulus *G* developed in the soil around the geogrid, under different vertical stresses and different grid displacements. The results presented are part of a wider range of testing results in the project. When state after compaction was tested, significant influence of the grid on *E* and *G* values compared to non-reinforced soil was not clearly detected. It is expected that after some displacement of geogrid during pullout process, *E* and *G* values for reinforced and non-reinforced soil will be significantly different. Examining this is the next step in the research programme.

Keywords*: geogrid, pullout, reinforcement, soil properties*

Utjecaj geomreža na svojstva tla

Prethodno priopćenje

Za potrebe ispitivanja interakcije tla i geosintetika, u okviru znanstvenog projekta istraživanja učinkovitosti armature na Građevinskom fakultetu u Osijeku, razvijen je posebno instrumentirani veliki uređaj za izvlačenje "pullout box" pomoću kojeg je moguće mjeriti brzinu valova u tlu u blizini geosintetika, prije početka i u prekidima ispitivanja. Ovaj rad iznosi samo dio rezultata ispitivanja modula elastičnosti *E* i modula posmika *G* koji nastaju u tlu oko geomreže, a koji su dio rezultata opsežnijih istraživanja u okviru spomenutog projekta. Predstavljena su ispitivanja na jednom tipu geomreže u šljunku jedne granulacije pri različitim vertikalnim naprezanjima i pomacima mreže. Kod ispitivanja u zbijenom stanju nije bio jasno uočljiv utjecaj mreže na vrijednosti *E* i *G* modula u odnosu na tlo bez mreže. Po ostvarivanju određenog pomaka geomreže za očekivati je da će vrijednosti *E* i *G* modula za armirano i nearmirano tlo biti bitno drugačije. Istraživanje ove pretpostavke je sljedeći korak u programu ispitivanja.

Ključne riječi: *geomreža, pullout, armiranje, svojstva tla*

1 Introduction
Uvod

Reinforced soil is becoming very important technology in road, geotechnical and hydraulic construction work. The present state of knowledge and practice needs several important issues to be solved: developed theoretical background that will be capable of explaining interaction mechanisms between soil and reinforcement element, tests for investigating efficiency of particular reinforcement in particular soil and determination of the controlling parameters of the soil-reinforcement interaction, and methods for quality control of the reinforced soil on site.

Two types of activities are recognised today, their purpose being to give insight into soil-reinforcement interaction so as to serve in design process involving reinforced soil: theoretical approach with numerical simulation of the reinforced soil behaviour, and experimental modelling involving some testing methods that could give better insight into the nature of the composite material behaviour and characterise it by measuring parameters used in numerical modelling.

Evidence of the effectiveness of reinforcement with grids in improving soil mechanical behaviour around grids can be found in many projects. Today's design approaches, however, still treat two materials-soil and reinforcement-separately, without any interaction that could include improved soil properties. Research is very much oriented to improving reinforced soil modelling in both directions: numerical modelling and laboratory testing to provide better description of behaviour of the composite material.

This article deals with the innovative experimental method of testing the soil-reinforcement interaction when geogrids are used. It should be capable of quantifying this interaction in terms of soil improvement around the grid expressed by *E* and *G* modulus, as a consequence of the development of the interlocking effects between soil particles around the grid due to increased lateral stresses between particles close to the grid (lateral confinement of the particles in biaxial grid). Results presented here are a part of the research programme aimed at studying of soil-reinforcement interaction.

2 Theoretical and experimental facts
Teorijske i eksperimentalne činjenice

Two numerical models attracted attention of the authors in regard to their research programme: work by Perkins et al. [1] (2004) is dedicated to the advanced design of reinforced pavements including soil reinforcement, and work by Konietzky et al. [2] (2004) generally aiming to describe geogrid-soil interaction by numerical simulation.

Eiksund et al. [3] (2004) conducted some experimental work on testing reinforced soil in big triaxial cells. Triaxial specimens with reinforcement experienced significant reduction of the axial deformation under cyclic loading compared to non-reinforced specimens, in the zone about 10 cm above and below grid. Different response was noticed for different types of grids. Resilient modulus, however, was not affected by the presence of the reinforcement.

Perkins et al. [1] (2004) performed numerical simulation of the influence of the reinforcement on the soil particles taking into account interlocking effect producing further higher soil stiffness around the grid. Numerical simulation of the soil-grid interaction was performed by including negative temperature gradient in the grid elements that produced shrinkage of the element and additional stresses between grains around the grid. Further simulation confirmed improved pavement behaviour with the grains under increased intergranular forces coming from soil-grid interaction. Resilient interface shear modulus was detected to be dependant on the level of vertical stress on the interface and amount of the applied shear stress. Field observations confirm this finding.

Konietzky et al. [2] (2004) used DEM (discrete element modelling) to investigate interlocking effects of biaxial grids. They clearly showed that interlocking can be numerically modelled and that inter-particle forces increase in the vicinity of the grid. Much more significant increase comes with some displacement (example analysed at a 12-mm displacement when simulating pullout test). The zone where the grid has influence on soil interlocking and inter-particle stresses, was about 20 cm high on each side of the grid. It was also demonstrated that the pullout test could be numerically simulated, as well as tensile strength of the grid ribs and junction.

Based on experimental and in-practice evidence and these two numerical simulations, it is considered there is interlocking effect on the particles coming from interaction with biaxial grids (that can be regarded as soil improvement) which spreads around the grid in the zone of about 15-20 cm in height at each side of the grid.

Other researchers tested experimentally soil-grid interaction. Ziegler and Timmers [4] (2004) studied the role of ribs and junction strength in connection with pullout test resistance and distribution of stresses in the soil around the grid, showing importance of the transversal ribs in creating resistance to pullout, which in turn induced extra stresses in the surrounding soil.

Mulabdić et al. [5] (2005), and Cindric [6] (2005) tested big direct shear improved soil properties of gravel around the grid by changing the position of the shear plane in regard to position of the grid in the reinforced soil. Shear plane was parallel to the grid but at different distances from the grid. They found effects of increased shear resistance of the gravel in the very thin zone around the grid – of about 5 cm in thickness. They also presented results of measurement of the *E* and *G* modulus in the soil around the grid (in the same device as described later in this article). It appears that different displacement of the grid has different effect on the surrounding soil in terms of improved *E* and *G* modulus, inside the zone of about 15 cm in thickness. The shape of the curve of variation of the *E* and *G* modulus in the soil around the grid, illustrating the soil-grid interaction, is expected to be as measured in one of pilot tests shown in Fig. 1 and Fig. 2. *G* modulus (corresponding to G0 - at very low deformations) is expected to be the most important parameter of soil behaviour in the advanced pavement design (Correia [7], 2004).

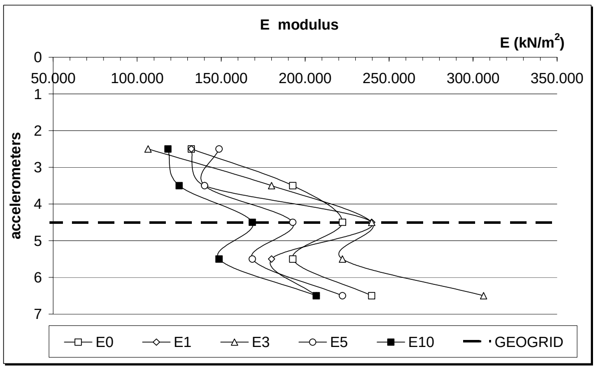


Fig. 1. Measured E modulus distribution around the grid in gravel using P wave propagation method (distance between measuring points is 10 cm, results correspond to zones between them), Ei - E modulus at different displacement (i - displacement of the grid in millimeters)

Slika 1. Mjerena distribucija modula E u okolini mreže u šljunku, dobivena mjerenjem rasprostiranja P valova (udaljenost mjernih točaka je 10 cm, rezultati odgovaraju zonama između njih), Ei – E moduli pri različitim pomacima (i – pomak mreže u milimetrima)

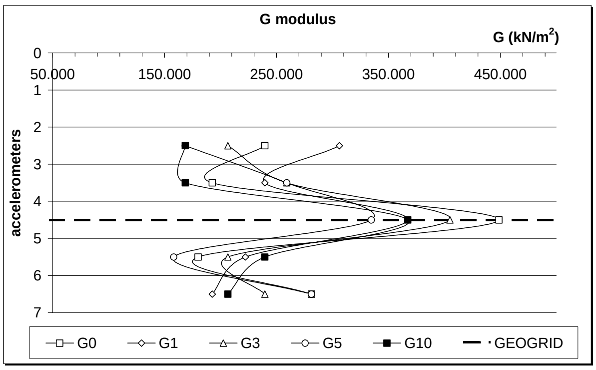


Fig. 2. Measured G modulus distribution around the grid in gravel using S wave propagation method (distance between measuring points is 10 cm, results correspond to zones between them), Gi - G modulus at different displacement (i - displacement of the grid in millimeters)

Slika 2. Mjerena distribucija modula G u okolini mreže u šljunku, dobivena mjerenjem rasprostiranja P valova (udaljenost mjernih točaka je 10 cm, rezultati odgovaraju zonama između njih), Gi – G moduli pri različitim pomacima (i – pomak mreže u milimetrima)

Results presented here are obtained by the tests oriented to measurement of the *E* and *G* modulus of the reinforced soil at small deformations, since that parameter is often used in different models for calculation of deformations in reinforced soils. The testing was performed as a part of the broader research programme aimed at determination of the soil-grid interaction, using specially developed equipment adapted to a big pullout testing device.

3 Testing device

Uređaj za ispitivanje

There are several standards that refer to the pullout testing: ASTM D6706-01, GRI Test Method GT6 and Draft prEN 13738. These standards set the requirements on the device, testing procedure and interpretation procedure. Based on these demands and measurements intended to be performed in the research, as a part of a wider research project, a special pullout device was constructed at the Faculty of Civil Engineering at University in Osijek, Croatia (GFOS device), see Fig. 3.

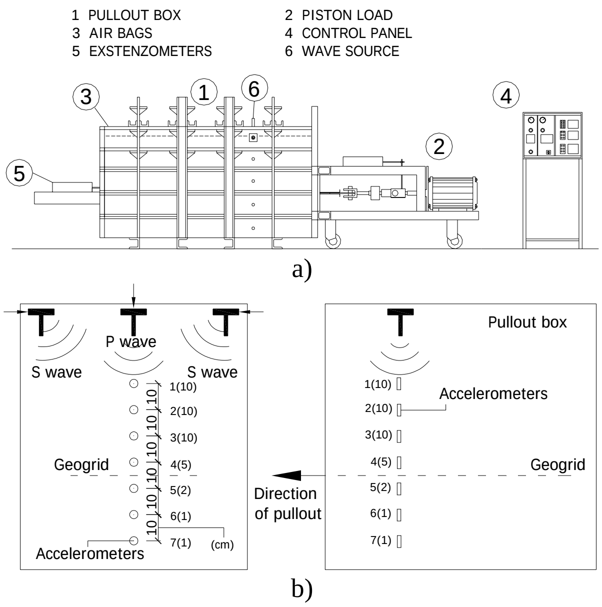


Fig. 3. a) Specially instrumented GFOS pullout device, b) set up for measurement of wave velocity in the soil (accelerometer sensitivity in (g) is given in brackets)

Slika 3. a) Posebno instrumentiran GFOS uređaj za ispitivanje, b) Postav sustava za mjerenje brzine širenja valova u tlu (u zagradama je dana osjetljivost akcelerometara)

The size of the pullout box is L x B x H = 1,9 x 0,9 x 1,2 m. It consists of six, 20 cm high, horizontally set rectangular steel elements, put one over another and firmly framed, enabling work with specimens of different height, the maximum being 120 cm. For special testing, the pulling force can be applied on two levels. Vertical pressure is generated by air pressure from airbags placed under the top cover pressed by steel beams connected to the vertical frames fixing the horizontal elements. Maximum pullout force is 80 kN, and it is generated by the air-pressure piston mounted at the front of the box. Five displacements are measured by the extensometers: piston movement and four points on the grid. Maximum extension is 200 mm and sensitivity is 0,01 mm.

A special device was developed for measurement of wave propagation through the soil, installed in vertical direction, above and below the grid at different distances. It is possible to generate two types of waves: compressive (P) waves and shear (S) waves at the surface of the soil bellow the air bags, using directed impact on the soil. Small two-component accelerometers (for P and S waves) were used for measuring the wave velocity in the zones of soil between the accelerometers. They were spaced at different distances around the grid (Fig. 3.). Their acceleration capacity is 1, 2, 5 and 10 g, sensitivity is 10, 20, 50 and 100 mV/g. Having these accelerometers around the grid, and producing P or S waves, it is possible to measure arriving times of the waves at different positions at points where accelerometers were installed. The velocities of compressive waves are used for calculation of E values, and the velocities of the shear waves are used for calculation of G values. With density of the soil, distance between the accelerometers and travelling time from any pair of accelerometers being known the modulus E ($E = v_p^2 \times \rho$) and G can be determined. Since the deformations induced in the soil with this wave propagation technique are very small the values of G and E modulus are high.

4 Testing programme

Program ispitivanja

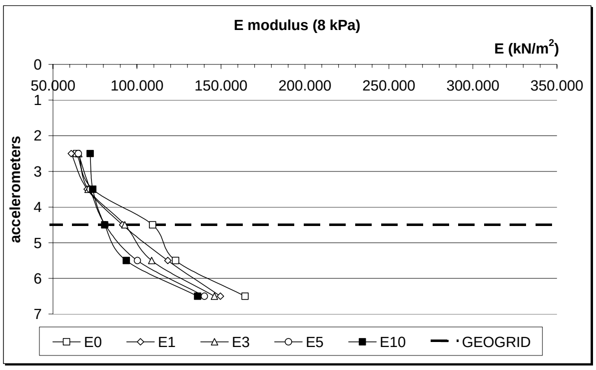
General testing programme on pullout resistance and soil interaction of the research project includes testing of three unbound materials and three different geogrids, at three vertical stresses. Before the pullout and at some displacements during pullout, measurements of the G and E modulus will be performed using wave propagation technique inside the soil body. The results of testing on two vertical stresses with one soil material and one geogrid, presented and discussed here are only a part of the recently realized programme. Measurements of the E and G modulus were performed on compacted soil (soil was compacted in layers at different displacements of the grid in pullout test).

One uniform gravel type soil was tested: with the particles ranging 4-8 mm obtained by sieving natural gravel to different size fractions. The grid type was Tensar SS 30. Two vertical stresses were applied in two pullout tests.

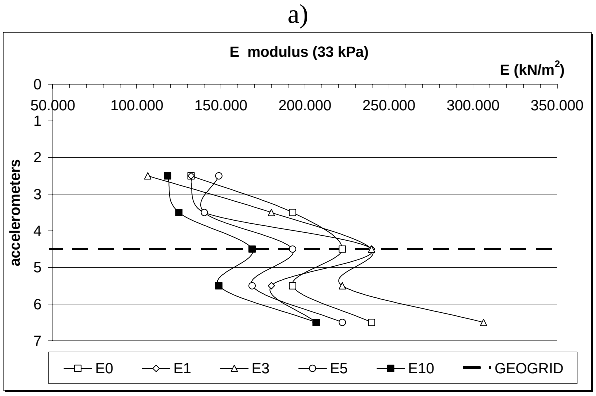
Soil was placed and compacted in layers of 10 cm in thickness, since this was the distance between accelerometers. Accelerometers were installed after soil compaction in one vertical line bellow the point of impact device used to generate waves. After compacting the soil, vertical pressure of 0 kPa (corresponding to soil overburden pressure of 50 cm, which means about 8 kPa in the grid plane) were applied in first test, and

25 kPa (33 kPa) in second test. In each pullout test, P and S waves were generated at different displacement of the grid (0, 1, 3, 5 and 10 mm). Arriving times of these waves were measured at six different positions of accelerometers. These six accelerometers were used for interpretation of the *E* and *G* modulus of the soil between pairs of two adjacent accelerometers, spaced at distance of 10 cm. Four accelerometers were put above the grid and three below it. With this disposition of accelerometers it was possible to interpret *E* and *G* values in the level of the grid and 20 cm above and 20 cm below this level. Average soil density value of 1620 kg/m^3 was used.

The results of measurements are presented in Fig. 4 and Fig. 5. Higher value of vertical pressure (33 kPa) induces significant modulus differences at different displacements (0, 1, 3, 5 and 10 mm) of the grid in relation to the case of lower vertical stress (8 kPa). Most of the tests showed increase of *E* and *G* with depth, probably due to increased density of the soil coming from successive compaction of the layers above it.



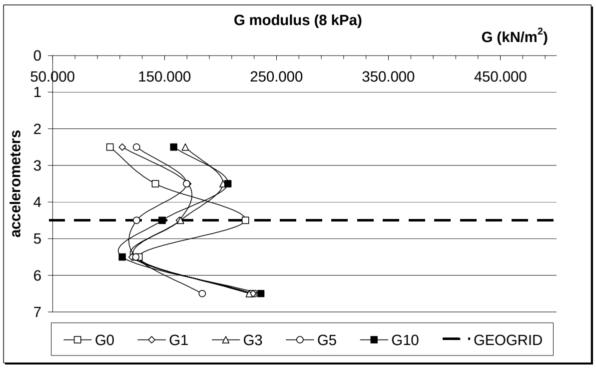
a)



b)

Fig. 4. Development of the E modulus in the soil around the grid (Tensar SS30, gravel 4-8 mm) at different grid displacement (0, 1, 3, 5 and 10 mm) for two vertical pressures; a) vertical pressure 8 kPa; b) vertical pressure 33 kPa

Slika 4. Raspodjela E modula u tlu oko mreže (Tensar SS30, šljunak 4-8 mm) pri različitim pomacima mreže (0, 1, 3, 5 i 10 mm) za dva vertikalna pritiska; a) vertikalni pritisak 8 kPa; b) vertikalni pritisak 33 kPa



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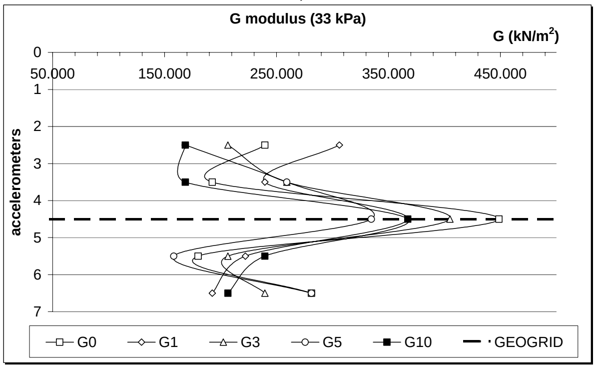

b)

Fig. 5. Development of the G modulus in the soil around the grid (Tensar SS30, gravel 4-8 mm) at different grid displacement (0, 1, 3, 5 and 10 mm) for two vertical pressures; a) vertical pressure 8 kPa; b) vertical pressure 33 kPa

Slika 5. Raspodjela G modula u tlu oko mreže (Tensar SS30, šljunak 4-8 mm) pri različitim pomacima mreže (0, 1, 3, 5 i 10 mm) za dva vertikalna pritiska; a) vertikalni pritisak 8 kPa; b) vertikalni pritisak 33 kPa

5
Discussion of results
Komentar rezultata

One uniform aggregate (unbound material) was tested with one grid to detect possible soil-grid interaction in terms of change of *E* and *G* modulus in the soil due to extra confinement provided by the grid after compaction. Uniform soil material was difficult to compact and achieve constant homogeneity in density.

Generally, results show difference in *E* and *G* modulus for different vertical pressures and different grid displacements for the same soil. With the higher values of vertical pressure in the soil, the higher values of the *E* and *G* for all the conditions are determined, as expected. Values of E modulus ranged from 50 MPa to 300 MPa, and *G* values ranged from 70 MPa to 440 MPa (small deformation values). Values of measured velocities for P waves were between 190 - 380 m/s and for S waves between 250 - 500 m/s for all tests. It is considered to be within the expected range, taking into account type, gradation and very low humidity of the soil. Discrepancy of the expected ratio of *E* and *G* moduli could be interpreted taking into account different amount of strain developed in generation of P and

S waves. Lesser energy input for generation of S waves than for P waves (wave source for the generation of S wave is shifted aside of vertical axis of accelerometers, and P waves are generated directly above the accelerometers with different energies) produces very small shear deformation and therefore the values of *G* modulus are higher (corresponding to *G*max), than in the case of E modulus where axial deformations are larger. This interpretation has to be confirmed by additional investigation and further steps and results in continuation of the preliminary phase (where the wave source is in the same vertical axis for P and G waves generation) are giving the justification for such interpretation. The exact determination of wave velocity and thereby the *E* and *G* determination is somewhat difficult because of small accelerometer distances and relatively large accelerometer diameter with respect to soil grain diameter of soil tested. Also, determination of P and S wave arrival time is difficult to determine unambiguously and there are few alternative approaches with difference in results.

The methodology of investigation is experimental in character and it is in the process of evaluation of adequacy and reliability for application in this kind of investigation. In this sense further testing to determine deformation in wave generation is needed. Also alternative method of *E* and *G* determination is required to verify acquired values. The results of the testing presented showed accordance with expected appearance in the soil (the soil is stiffer in the vicinity of the grid, stiffness decreases with distance of grid) for *E* and *G* modules (acquired values correspond to usual values for small deformation) without respect to relative E and G ratio which still has to be determined with certainty.

The results of testing are not entirely satisfactory; nevertheless the insight is given in the methodology of solving these problems in order to get expected results. This could be gained by better density control and improved measurement technique (additional analysis of signals from which wave velocity is obtained).

6 Conclusion
Zaključak

Soil-grid interaction is very important for reinforced soil behaviour in terms of improved soil properties and positive effects on inter-particle stresses and lower permanent deformation of structures.

This interaction can be modelled numerically, but the crucial elements have to be measured on the models in the laboratory or in site.

A new measuring technique for detection of soil-grid interaction was presented. It is based on measurement of wave velocities in soil. It enables measurement of the values of the *E* modulus and the *G* modulus (at small strains) and their distribution around the grid at different distances from it. A special device has been adapted for this measurement, which is still being improved, as well as is the technique for producing an impact in the soil that generates P and S waves.

The E modulus in reinforced soil was shown to be sensitive to presence of grids in uniformly graded unbound gravel. Influence of vertical stress in the soil was clearly detected, *E* and *G* values being 2-3 times higher for 33 kPa vertical pressure compared to values at low (8 kPa) vertical pressure.

The next step in research is improvement of technology for measurement of the modulus, which will bring information that is closer to real behaviour of the composite material. Following tests will include more grid types and soil materials. More precise answers about soil-geogrid interaction through pullout tests and *E* and *G* measurements are expected.

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