Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering

doi:10.3233/978-1-61499-656-9-1393

Influence of reinforcing grids on soil properties

Influence du réseau dans la terre armée sur les caractéristique du sol

M. Mulabdic, K. Minazek & D. Mrackovski
Department of Geotechnics and Transportation
Civil Engineering Faculty, University in Osijek, Croatia

ABSTRACT
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. The paper presents some results of investigation carried out on two grids in two types of gravel, in terms of E modulus developed in the soil around the grid, under different vertical stresses. There is no significant influence of the grid on E value compared to non-reinforced soil, when state after compaction is tested. It is expected that after some displacement during pullout process E values might differ more, and that is next step in the research program.

RÉSUMÉ
Un nouveau dispositif de grande taille pour les essais à l'arrachement a été développé, équipé d'instruments spécifiques pour l'étude du mécanisme d'intéraction entre le sol et le géosynthétique dans une boîte d'arrachement par la mesure de la vitesse des ondes dans le sol autour du géosynthétique, avant et aux arrêts pendent la procédure d'arrachement. L'article décrit quelques résultats des essais qui ont été faits sur deux réseaux dans deux types de gravier en matière de modulus E développé dans la terre autour du réseau, sous pressions verticaux differents . Il n'y a pas d'influence significante du réseau sur le valeur E en comparaison avec la terre non-armée, quand les essais sont faits de la condition immédiatement après la compaction . On attend qu'après certain déplacement au cours de l'arrachement, les valuers E puissent différer en plus, ce qui est l'étape suivante du programme de recherche.

1 INTRODUCTION

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 as to better describe 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 moduli, 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 program aimed at studying of soil-reinforcement interaction.

2 THEORETICAL AND EXPERIMENTAL FACTS

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

Eiksund et al (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 bellow 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 (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 inter-granular 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 (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 in which the grid influenced soil interlocking and inter-particle stresses was found to be of thickness of about 20 cm on each side of the grid. They 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 one could say that there is interlocking effect on the particles coming from interaction with biaxial grids that can be regarded as soil improvement and which spreads around the grid in the zone of about 15-20 cm in thickness at each side of the grid.

Other researchers tested experimentally soil-grid interaction. Ziegler and Timmers (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.

Mulabdic et al (2003) tested in 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 G modulus in the soil around the grid (in the same device as described later in this article). It appears that different grid has different effect on the surrounding soil in terms of improved G modulus, inside the zone of about 15 cm in thickness. The shape of the curve of variation of the G modulus in the soil around the grid, illustrating the soil-grid interaction, is expected to be as measured in one of pilot tests showed in Fig.1, and is expected to reflect soil-grid interaction and be used as a guide in selecting proper grid for particular soil and for additional design considerations. G modulus (corresponding to G_0 - at very low deformations) is expected to be the most important parameter of soil behaviour in the advanced pavement design (Correia, 2004).

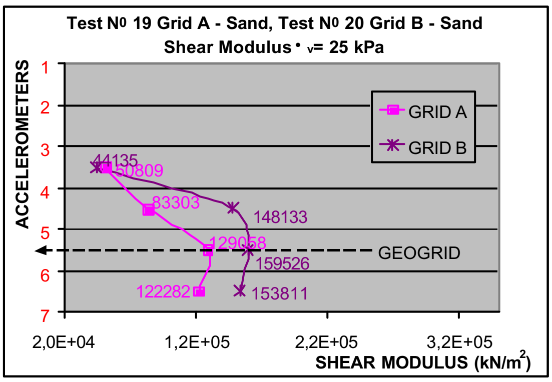

Fig.1. Measured G modulus distribution around two types of grid in sand using shear wave propagation method (distance between measuring points is 10 cm, results correspond to zones between them, Mulabdic et al, 2003)

Results presented here are obtained by the tests oriented to measurement of the E 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 program aimed at determination of the soil-grid interaction, using specially developed equipment adapted to a big pullout testing device.

3 TESTING DEVICE

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, a special pullout device was constructed at the Civil Engineering Faculty at University in Osijek, Croatia (GFOS device), see Fig. 2.

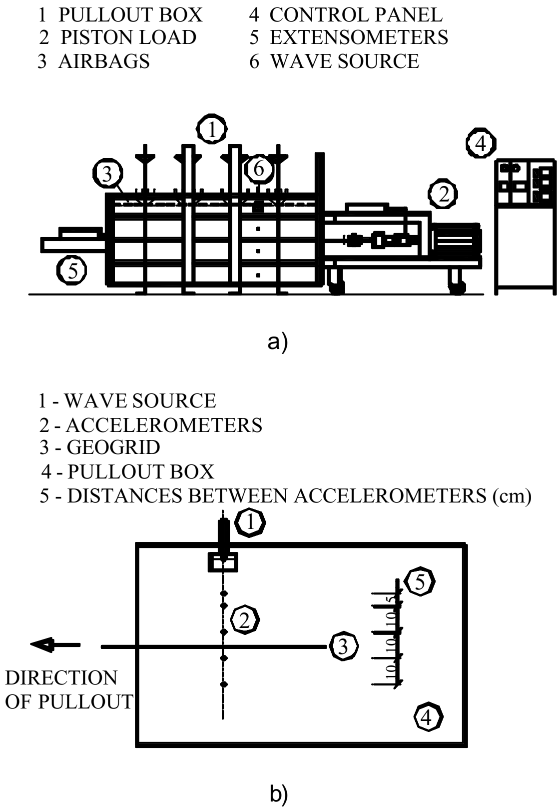

Fig. 2 a) specially instrumented GFOS pullout device, b) set up for measurement of wave velocity in the soil.

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 110 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 extensiometers : 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, in vertical direction, to be installed 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, by using directed impact on the soil. Small two-component accelerometers (for *P* and *S* waves) are used for measuring the wave velocity in the zones of soil between the accelerometers. They were spaced at different distances around the grid (Fig.2.). Their acceleration capacity is 10 g and sensitivity is 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 where accelerometers were installed. Compressive waves are used for calculation of E values, and shear waves are used for calculation of G values, density of the soil, distance between the accelerometers and travelling time from any pair of accelerometers being known ($E = v_p^2 \times \rho$). 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 PROGRAM

General testing program of the research project includes testing of three unbound materials and three different grids, at three vertical stresses on pullout resistance and soil interaction. 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. Here will be presented and discussed a part of the recently realised program only. This comprises two types of soil material and two grids under different vertical stresses. Measurement of the E modulus was performed on compacted soil (soil was compacted in shifts) and no pulling out was applied.

Two uniform gravel type soils were tested: with the particles ranging 4-8 mm and 16-32 mm in diameter, obtained by sieving natural gravel to different size fractions.

The two grids were of type Secugrid 30/30 and Tensar SS 30.

Soil was placed and compacted at the water content of about 2.5 % (Proctor values were difficult to define), in shifts of 10 cm in thickness, since this was the distance between accelerometers. These were installed after soil compaction in one vertical line bellow the point of impact force used to generate waves. After compacting all the soil, vertical pressures of 0 kPa (only corresponding to soil overburden pressure of 30 cm, which means about 5 kPa), 25 kPa and 50 kPa were applied, successively. With each vertical stress, vertical impact was generated resulting in a compressive wave was generated. Arriving time of this wave was measured at four different positions of accelerometers. These four accelerometers were used for interpretation of the E modulus of the soil in-between two adjacent accelerometers, spaced at distance of 10 cm. Two accelerometers were put above the grid and two bellow it. With this disposition of accelerometers it was possible to interpret E value on the level of the grid and 10 cm above and 10 cm bellow this level.

Densities of the soil were low, and somewhat different for different tests. Fig.3. shows densities of soil for different tests and conditions, achieved after compaction. Average value of density is 1.7 kg/m^3, having the spread of about ± 2.8% for 16-32 mm aggregate, and ± 4 % for 4-6 mm aggregate, which can be considered as significant.

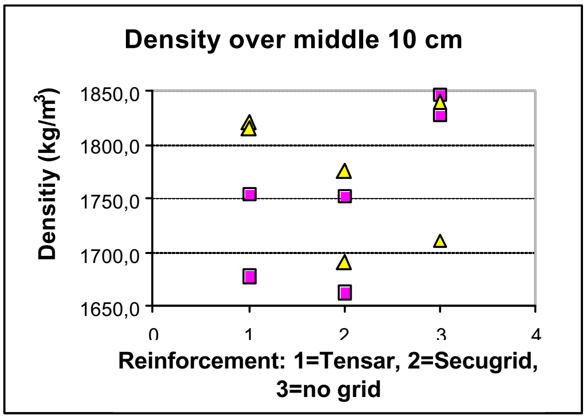

Fig.3. Densities of soil in different tests measured for the soil shift in which geogrid was installed corresponding to the middle position of the accelerometers (triangles are for 16-32-mm aggregate, and squares for 4-8-mm aggregate)

Measurements of the wave arriving times were made on two fresh specimens for each condition. Several impacts for each specimen were conducted and average values were used in interpretation for a single test. In terms of vertical stresses, they were applied on the same specimen, one after another, starting with zero kPa and ending with 50 kPa.

All the measurements are presented in Fig.4 and Fig.5. The E values are interpreted at three zones: (1) middle zone, defined as ± 5 cm around the grid, (2) upper zone – 10-cm-thick zone on top of the middle zone, and (3) lower zone - 10-cm-thick zone bellow the middle zone. Most of the tests showed increase of E with depth, probably due to increased density of the soil coming from successive compaction of the shifts above it. E values very close to grid, valid for the middle zone, are shown in Fig.5. and an average value for all three zones is shown in Fig 4. It can be seen from two figures that there is no significant difference in E values for the zone of 10 and 30 cm around the grid, saying that on the grid level E values were higher than those in upper zone but smaller than those in lower zone.

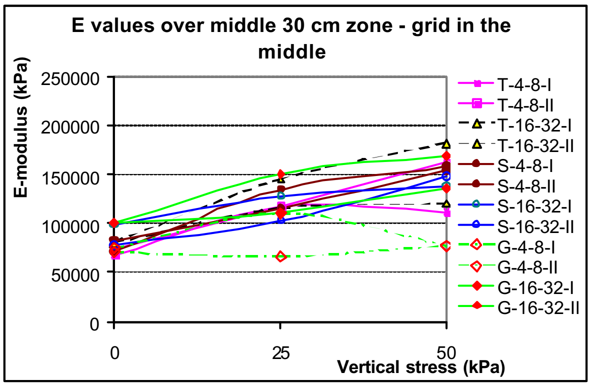

Fig.4. Development of the E modulus in the region of 30 cm around grid (T = Tensar SS30 grid, S = Secugrid 30/30 , G = gravel, no grid, 4-8 mm = aggregate, 16-32 = aggregate, I, II = 1st and 2nd test)

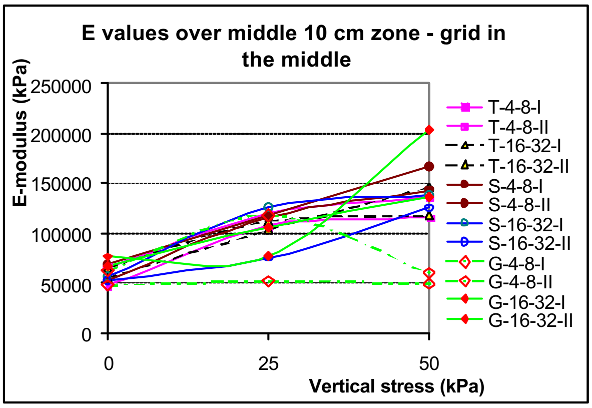

Fig.5. Development of the E modulus in the region of 10 cm around grid (T = Tensar SS30 grid, S = Secugrid 30/30, G = gravel, no grid, 4-8 mm = aggregate, 16-32 = aggregate, I, II = 1st and 2nd test)

5 DISCUSSION OF RESULTS

Two uniform aggregates (unbound materials) were tested with two grids with the aim to detect possible soil-grid interaction in terms of change of E modulus in the soil due to extra confinement provided by the grid after compaction. Uniform soil material was difficult to compact and to achieve constant homogeneity in density.

Generally, results didn't show difference in E modulus for different grids and for the soil without grid in the same conditions. This is in accordance with findings by Eiksund et al (2004) regarding resilient modulus that was insensitive to presence of grid reinforcement.

Tensar grid has similar effects on both aggregates and Secugrid has somewhat better effect on 48 mm aggregate. Highest soil densities were achieved in soil with no grid, which can be the reason for high E values measured in these conditions. On the other hand, while the higher E values were measured in non-reinforced soil for zero vertical pressure, E values under increased vertical stresses become generally equalised for reinforced and non-reinforced soil.

The higher the vertical pressure in the soil, the higher the E value, for all the conditions, as expected. E values ranged from 40 MPa to 200 MPa (small deformation values). Measured velocities for P waves were in the range 150 - 380 m/s for all the tests, which is considered to be within the expected range taking in account type, gradation and very low density of the soil.

6 CONCLUSION

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 situ.

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 not to be sensitive to presence of grids in uniformly graded unbound gravel. Influence of vertical stress in the soil, however, was clearly detected, E value being 2-3 times higher for 50 kPa vertical pressure compared to E values at zero vertical pressure.

Next step in research should include measurement of the modulus after some displacement in pullout test has been reached, which will bring information that is closer to real behaviour of the composite material.

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