Effect of transverse ribs of geogrids on pullout resistance

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ABSTRACT: A specially equipped pullout apparatus, having dimensions of 1.9 x 0.9 x 1.2 m, has been developed to measure the soil-grid interaction during pullout. The purpose of the testing is to explore the nature of the soil-grid interaction in a way that will enable a more efficient design of reinforced soil in unbound materials. Transversal ribs are of special importance in transferring loads from grid to soil. This phenomenon is in this paper investigated in two ways: a) testing of bearing capacity of a grid in a simple pullout test, using grids with and without transversal ribs, and b) measuring soil grid interaction for the grid with and without transversal ribs, by measuring velocity of waves travelling through the reinforced soil in perpendicular direction towards the grid. Specially adopted accelerometers were used to determine the arriving time of compressive and shear waves when propagating through reinforced soil, at different vertical distances from the reinforcing grid - higher wave velocity means stiffer material and that indicates better soil-grid interaction). Two geosynthetic grids and one metal grid were tested in pullout in sand and middle gravel, at vertical stresses of 25 and 50 kPa. Although testing program was only partly finished at the time, the results show significant contribution of transversal ribs and flexural stiffness of a grid to pullout force. Limited tests with wave velocity measurements show potential of this new method in characterizing soil – grid interaction.

1 INTRODUCTION

Reinforced soil is important technology in road, geotechnical and hydraulic construction work. Geogrids offer great reinforcement potential, although the understanding of the interaction mechanism is not completed yet. Design solution of any project with reinforced soil using geogrids will have to consider two aspects: 1) bearing capacity, where soil-grid interaction arises from the confinement of soil particles inside the grid cell (so called interlocking effect), and 2) anchoring of grid, were pullout resistance depends much on transversal ribs effect. This article focuses on the latter aspect, important in slope reinforcement and retaining walls. Two approaches are used in practice for calculation of pullout force when designing anchoring length of a grid in soil: either simple friction over the surface of the grid or combination of friction and passive resistance in soil in front of the transversal ribs of a grid. BS 8006:1995 suggests the first approach, and there is no widely accepted method for the second approach. Jewell (1990) suggests that normal stresses in soil in front of the rib should be calculated as bearing stress problem, with different modes of failure.

Still the question remains: what friction angle should be used in expressions? The author's opinion is that it should be friction angle of the soil, as a lower but safe value. This is because interlocking effect that is created in soil around grid, as a consequence of confinement of soil particles inside the grid ribs, produces dilatant behaviour of soil in shear increasing peak angle of internal friction in soil. This effect is recognised long ago (Dayer, 1985), but was not measured or characterised for design purpose.

At the Civil Engineering Faculty - University of Osijek, a study of an interaction between soil and geosynthetic has been undertaken, with the innovative experimental method of testing the soil - reinforcement interaction. Using this method, it should be possible to quantify soil-grid interaction in terms of soil improvement around the grid expressed by increase in G and E soil moduli, as a result of the development of the interlocking effects between the grid and soil particles around the grid. Special technique of measuring velocity of shear (S) and compressive (P) waves propagating through the reinforced soil was used in this research. The idea is that grid cells produce confinement, which in turn increases soil stiffness and therefore increases wave velocity in soil. When transversal ribs are removed this confinement cannot be fully activated, and stiffness of the soil and wave velocity should correspond to non-reinforced soil. This kind of testing ribs efficiency using wave velocity is presented in this paper. Results presented here are a part of the wider study of soil-reinforcement interaction still active.

2 TESTING PROGRAM

Study of the ribs efficiency in geogrids was based on pullout testing of different grids in different soils, and on measurement of wave velocity in reinforced soil by using innovative method described in next section.

Three types of grids were used:
Grid 1: biaxial rigid polypropylene grid, extruded as a monolith, tensile strength of 40 kN/m', height of the longitudinal and transversal ribs 2,5 mm (in – plane ribs), openings size 39x39 mm,
Grid 2: rigid biaxial polypropylene grid with longitudinal and transversal ribs glued, tensile strength 60 kN/m', height of the longitudinal and transversal ribs 1,5 mm (out of plane ribs), opening size 32x32
Steel grid: diameter of longitudinal and transversal ribs 5 mm (in-plane ribs), opening size 45x45 mm.

Also, plate of steel and plate of HDPE geomembrane were tested in pullout as to demonstrate pure frictional behavior of soil in contact with reinforcement.

The tests were performed on grid samples with transversal ribs and without transversal ribs (the ribs were cut out) under different confining pressure (25 kPa and 50 kPa). Dimensions of the grids and plates were 40 x 40 cm.

The pullout tests were conducted on two unbound soil types: well to uniform graded gravel (max. particle size 16 mm) and uniform fine sand (max. particle size 2 mm).

Measurement of wave velocity was conducted in tests with and without transversal ribs.

3 TESTING EQUIPMENT AND PROCEDURE

Testing was performed in a special large GFOS pullout device that was constructed for the research project related to soil – grid interaction at Civil Engineering Faculty in Osijek, Croatia, Figure 1.

The dimensions of the box are 1.9 x 0.9 x 1.2 m. It consists of four to six 20 cm high horizontally placed rectangular steel frames, fixed one over another, enabling different heights of the box and work with maximum height of soil in the box of 110 cm. Overburden stresses are generated with 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 electrically driven reducing gear mounted at the box front. The displacement on the grid sample can be measured in five points by the extensometers: one at the point of pullout force appliance and in four points on the grid. Maximum extension is 200 mm and sensitivity is 0.01 mm. The pullout process is computer controlled; the basic setup of the apparatus is shown in Figure 2.

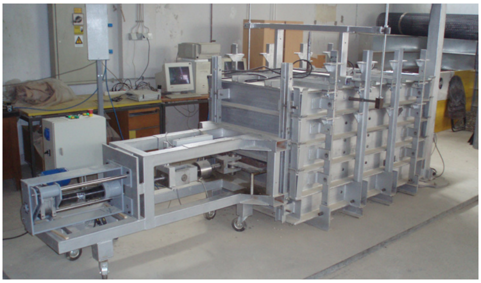


Figure 1. Large pull-out apparatus of GFOS type.

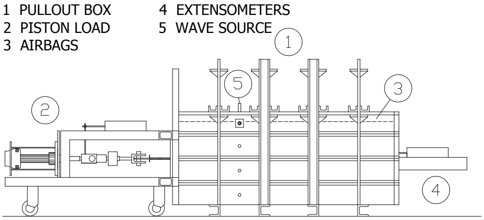


Figure 2. Lateral view of the pullout apparatus.

Special device mounted on top of the pullout apparatus is used for mechanical generation of shear and compressive waves at the surface of the soil in the pullout box (number 5 in Fig.2). In order to be able to calculate wave velocity of the wave propagating from top to bottom of the soil specimen, special instruments were needed to register travelling time of the wave over certain distance. Small accelerometers were used for this purpose, having acceleration 1-10 g and sensitivity of 100 mV/g. The accelerometers were used to record arriving time of the wave at their elevation. They were put at different distances above and below the grid level. Wave velocity is determined in the zones between two accelerometers in order to interpret modulus of the soil and influence of the soil-reinforcement interaction on its value. Knowing wave velocity and density of soil it is possible to calculate G modulus (from shear waves) and E modulus (from compressive waves). Both moduli are associated with very small deformations and are considered to be of maximum value.

Wave velocities are measured before and during pullout of the grid, so that pullout can be stopped at some displacement of the grid and measurement of the wave velocity can be performed. In the Figure 3 the schematic cross-section of the accelerometer placement in the pullout box can be seen.

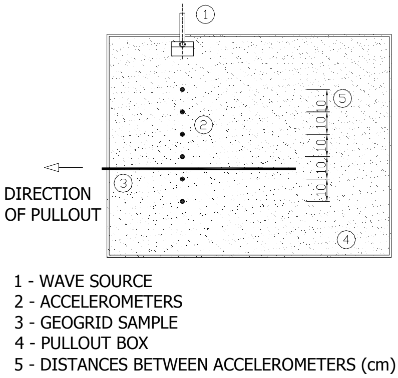


Figure 3. Accelerometer positions in pullout box.

Wave records were obtained using 16 channel digital oscilloscope and velocities were calculated form known distance between accelerometers and time differences of wave arrival between adjacent accelerometers obtained using cross-correlation method.

4 TESTING RESULTS AND ANALYSIS

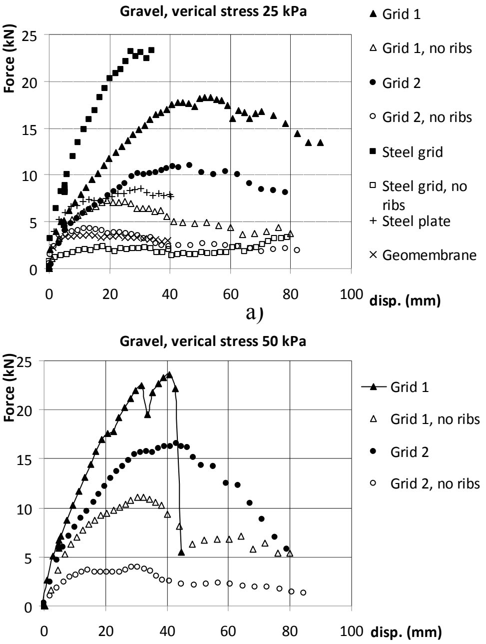
The testing program was only partly finished in the time of finishing this paper. Here, the intention is to compare influence of transversal ribs (grid with and without transversal ribs vs. plate), stiffness of grid and form and material of reinforcing element (grid vs. plate, steel plate vs. geomembrane) on pullout force development. Density of the soil was lower than maximum according to Proctor test, in order to avoid possible damage of the accelerometers by compaction process.

The results of testing are given in figures 4 to 9. It should be mentioned that forces are for grid of the size 0, 4 x 0,4 m.

From Fig. 4. and 6. it follows that contribution of transversal ribs in total pullout force in gravel increases with vertical stress and grid flexural rigidity, and is about 50% at 25 kPa to more than several times at 50 kPa, compared to grid without ribs.

Interesting comparison was made in Fig. 7, were pullout forces are expressed in terms of shear stresses over the total surface of the implantant. The smallest friction is over geomembrane, equaling only 20% of the friction in gravel itself. Somewhat higher friction is registered over metal plate.

On Fig. 7 it can be seen that in gravel for metal grid and grid 1, and for grid 2 shear resistance is in-between values for gravel itself and geomembrane in gravel.



a)

b)

Figure 4. (a) Pullout force – displacement dependence, Grid 1 tests with and without transversal ribs, b) development of pullout forces for Grids 1 and 2 at different vertical stresses /steel grid limited in pullout deformation for technical reasons/

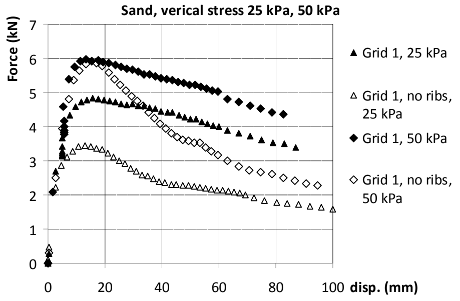


Figure 5. Pullout force – displacement dependence, Grid 1, tests with and without transversal ribs, at different vertical stresses.

Some tests in sand showed inconsistency in regard to role of ribs (Fig.5). More testing is needed to verify these results. Previous tests showed that in sand transversal ribs are of much less importance to sand then to gravel. This is confirmed in Fig.8.

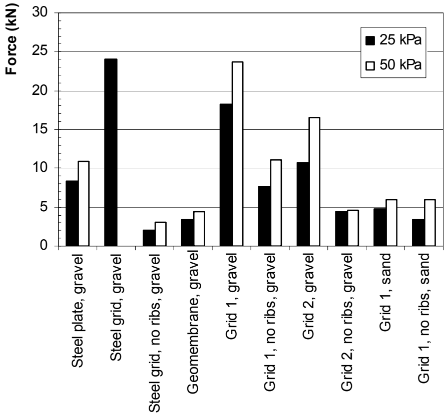


Figure 6. Comparison of pullout forces in gravel under confining stress of 25 and 50 kPa.

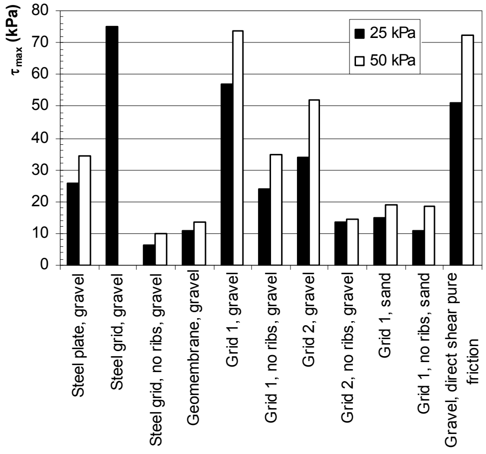


Figure 7. Shear stress around grid, calculated from pullout forces over total grid area (0,4 x 0,4 m); shear stresses in gravel obtained in direct shear box at confining stresses 25 and 50 kPa.

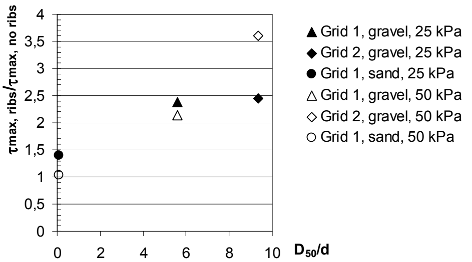


Figure 8. Influence of grain size and grid structure on pullout stresses, D_{50}- particle diameter at 50% passage, d – height of transversal rib on grid).

The improvement of soil-geogrid composite characteristics can be shown in terms of ascendency of G or E modulus near the grid sample, which is determined from wave velocity. Modulus can be calculated as $G=v_s^2/\rho$ or $E=v_p^2/\rho$, on the basis of the measured wave velocities and known soil density. Figure 9. shows increase in velocity/modulus with presence of grid (interlocking effect). In case of sand, where interlocking effect is not present, the wave velocity doesn't change much around the grid.

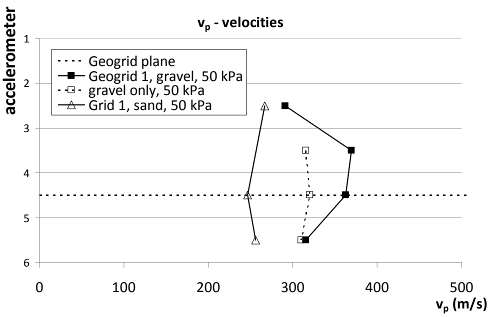


Figure 9. V_p velocity values in the grid vicinity for tests of grid 1 in sand gravel.

4 CONCLUSION

Based on limited number of tests obtained in a complex program of testing soil-grid interaction, one can conclude that transversal ribs play significant role in transferring pullout forces to soil, reflecting grid geometry and its stiffness, and grain size of soil. This was proved by pullout testing and partly by special innovative measurement of wave propagation through reinforced soil. This new method requires further development in technique in order to be used with confidence. Further testing will clarify and quantify the effects mentioned here.

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