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Characterization of Soil-grid Interaction by Shear Wave Velocity

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ABSTRACT

A specially equipped pullout apparatus, measuring 1.9 x 0.9 x 1.2 m, has been developed to measure the soil-grid interaction during pullout. The method used to evaluate the soil-grid interaction is a veritable novelty as the velocity of shear waves passing through the specimen is measured from top to bottom. This measurement is performed at different levels around the grid in order to obtain a velocity profile in the soil adjacent to the grid. Specially adapted accelerometers, positioned at different distances above and below the grid, are used to measure the arriving time of compressive and shear waves propagating through the reinforced soil. Once the wave velocity is known, the shear (Go) and elastic (Eo) moduli (at small strains) are calculated for these depth intervals. Some results of this study are presented, and the testing apparatus and technology are described.

1. INTRODUCTION

The geotechnical practice related to the use of geosynthetics in reinforced soil is today well established (BS 8006:1995). Impressive structures with very high retaining walls and embankments are nowadays built, and smart engineering structures such as platforms, and foundation improvements based on reinforced soil, are routinely realized. Present day roads perform better thanks to the effects geosynthetics produce in composite material known as the reinforced soil.

However, our ability to build has exceeded our capacity to understand and explain the real mechanism of soil-grid interaction (Palmeira, 2008). Research has been focusing for many years on measuring performance of these structures, rather than on characterising interaction between grid and soil in order to detect improvement of composite material that is responsible for the stress-strain behaviour of such structures. In other words, the soil-grid interaction needs to be investigated in the fundamental manner, at the level of change in material properties, so that the true nature of the so called “interlocking effects” can be explained in the manner enabling cost-effective design of reinforced soil structures.

The first significant experimental study of the soil–grid interaction was presented by Dyer (1985) in his photoelastic characterisation of stress field in glass particles surrounding the grid in case of pullout. The effect the ribs perpendicular to the direction of force have on the increase of stress in the mass of glass particles is quite obvious (Fig.1.). A similar mechanism can also be noted in the unbound soil–grid reinforcement. We are interested in the intensity of interaction in terms of the extent of zone influenced by the interaction, effect of soil particle size and grid rigidity, and the type and form of the ribs.

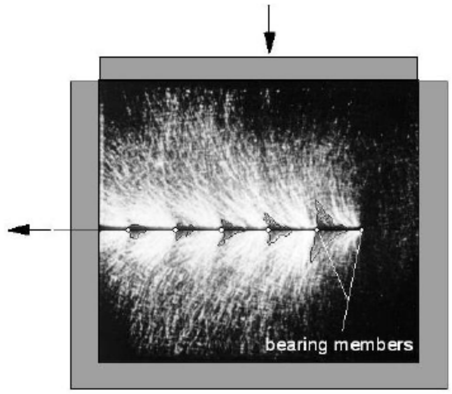

Figure 1. Photo-elastic results of the pull-out test conducted on a steel grid (after Dyer, 1985).

Some authors, such as Aydogmus et al. (2003), succeeded in performing a numerical simulation of the process of pullout of the grid from the soil, and showed the extent of soil influenced by the interaction (Fig.2.). These analyses are based on parameters that should be determined in model tests, which presently can not characterise the soil-grid interaction at the required level.

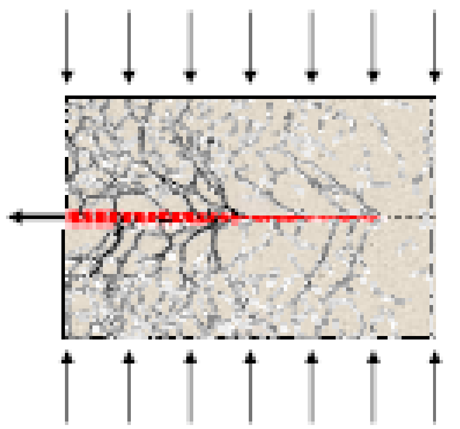

Figure 2. Results of the numerical simulation of pullout test according to the programme system PFC (after Aydogmus et al., 2003).

Some interesting and encouraging results are described in the papers presented by Bussert (2008) and Bussert and Naciri (2008). They confirm, based on model testing and an actual wall, that factors of safety used in the reinforced soil structure design are very high, that grid deformations are very low at working stresses, and that we must acquire additional fundamental data on the soil-grid interaction in order to produce a cost-effective design.

An original approach to the characterisation of soil-grid interaction is presented in this paper. It involves measuring basic properties of the unbound soil around the grid, and this at different grid displacement/strain values as applied in the course of a standard pullout test. This concept is based on the velocity of propagation of waves through the soil, in order to define the stiffness and shear strength of the soil. The basic apparatus setup and some testing results are also presented.

2. TEST SETUP

In the scope of a research project related to the study of reinforced soil, the research team formed at the Civil Engineering Faculty of the University of Osijek, Croatia, constructed a large and specially equipped pullout testing device (Mulabdic at al., 2003, 2005). This apparatus enables generation of shear and compressive waves at the surface of reinforced soil in the pullout box, as well as measurement of wave velocity at different depths. This is done by accelerometers positioned around the grid in the unbound soil, at specified vertical distances from the grid.

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, placed one above another and firmly framed, enabling work with specimens of different height, the maximum being 110 cm. For special testing, the pulling force is applied at two levels. The vertical pressure is generated by air coming from airbags placed under the top cover compressed by steel beams connected to the vertical frames fixing the horizontal elements. The maximum pullout force of 80 kN is generated by the air-pressure piston mounted at the front side of the box. Five displacements are measured by the extensometers: piston movement at four points along the grid. The maximum extension is 200 mm, and the sensitivity is 0.01 mm. A special device was developed and installed to measure vertical wave propagation through the soil, above and below the grid. The device is based on small accelerometers, accurate to 100 mV/g, and suitable for accelerations ranging from 1 to 10 g. It can measure wave velocities in the zones between individual accelerometers which are placed at different distances above and below the grid level. The measurement results are used to interpret the shear modulus of the soil and the influence of the soil-reinforcement interaction on this value. The maximum displacement is 200 mm, while the readability is 0.01 mm. The pullout process is computer controlled, and grid displacements are measured at four points in the soil, and at the force piston. The basic setup of the device is shown in Figure 4.

Wave velocities are measured before and during pullout of the grid, i.e. the pullout process is stopped at a chosen displacement of the grid, and the wave velocity is measured.

Figure 3. Large pull-out apparatus of GFOS type.

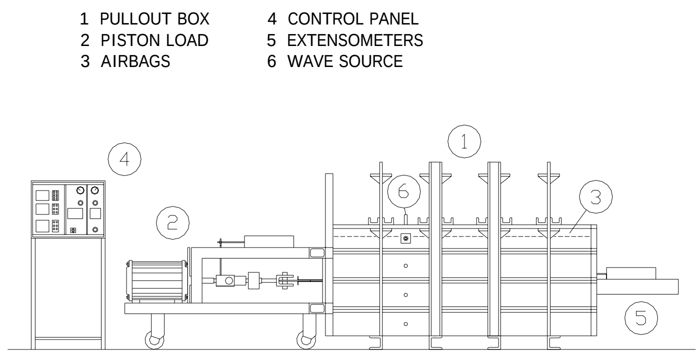

Figure 4. Lateral view of the pullout apparatus.

Accelerometers are sensitive to both shear and compressive waves. Only one type of waves is generated at one time, and all accelerometers record the arriving time of the waves. Taking into account the known distance between any two of the accelerometers, and the difference in arriving times of the waves to their respective positions, we can calculate wave velocity and the corresponding modulus as an average value for the distance travelled by the waves (G_0 for shear waves and E_0 for compressive waves).

The position of accelerometers and the setup of the system is presented in Figure 5. One accelerometer viewed in its position in the soil is shown in Figure 6.

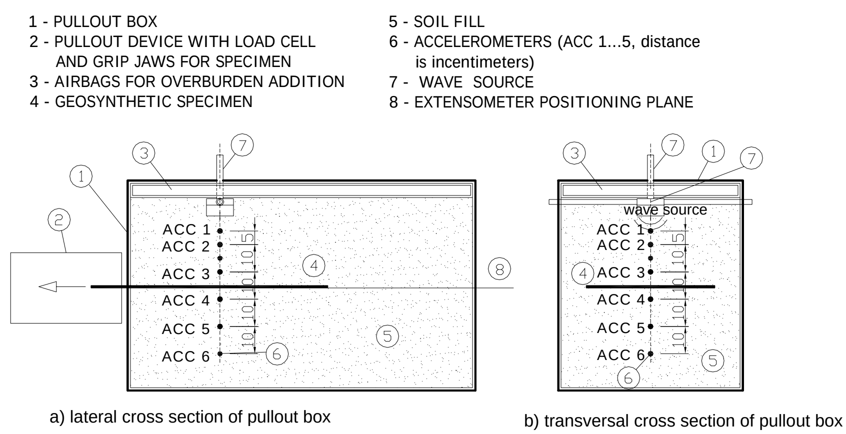

Figure 5. Test setup of pullout device for wave velocity measurement.

Figure 6. Accelerometer positioning in pullout box.

A considerable amount of time was spent to adequately define the accelerometer sensitivity, the wave type and the wave energy control, and also the technique to be used to analyse the wave arriving time.

3. ANALYSIS OF TEST RESULTS

Wave records were obtained using the 16-channel digital oscilloscope, and the wave velocities registering procedure included the use of the cross-correlation method for determining the difference in wave arrival times for adjacent accelerometers. Wave velocities are calculated from time differences obtained, and from known distances between accelerometers. Some of the results obtained by the p wave velocity measurement are presented in the following figures. Wave records before and after the use of the cross-correlation method for determining the time difference are presented in Figure 7 for the 6-accelerometer setup, while the wave velocity profile along the depth is given in Figure 8. It can be seen that in tests with geogrid the wave velocities are higher in the vicinity of the geogrid, especially in tests with higher normal stress values.

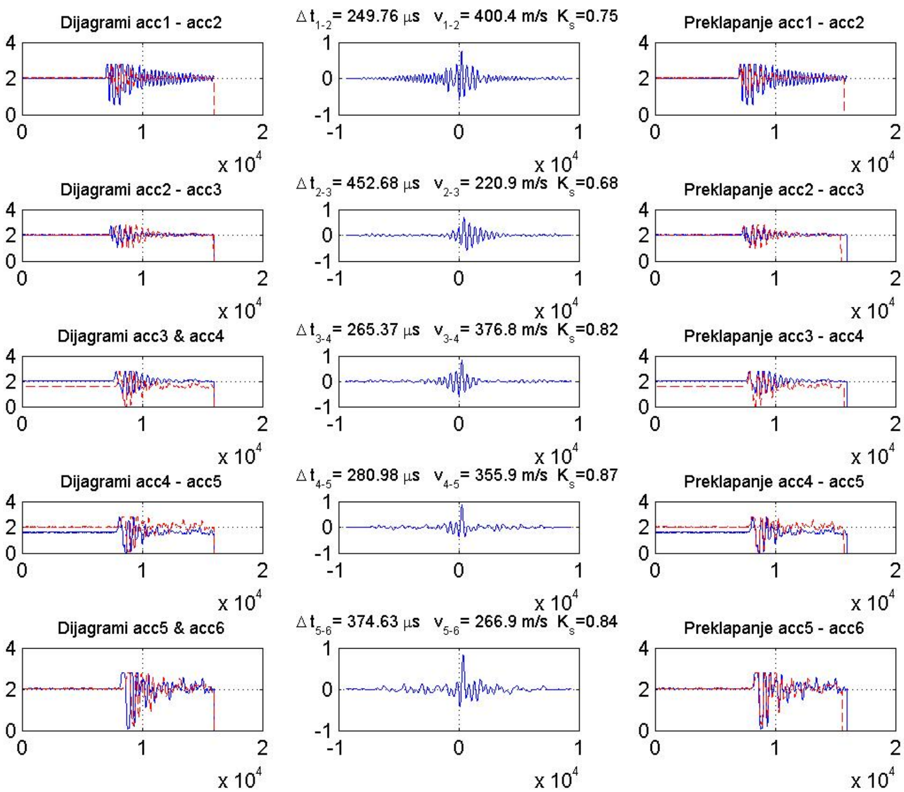

Figure 7. Wave velocity determination by cross-correlation for adjacent accelerometers (from surface downwards). Diagrams to the left show wave records for two adjacent accelerometers, diagrams in the centre show the cross-correlation level, and the diagrams to the right present shifted wave records used for determining difference in arriving times). The first accelerometer is used as the trigger .

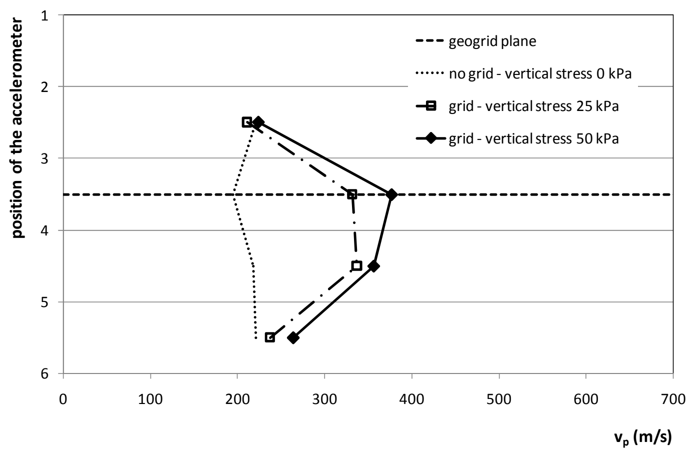

Figure 8. Wave v_p velocities measured in tests with/without grid.

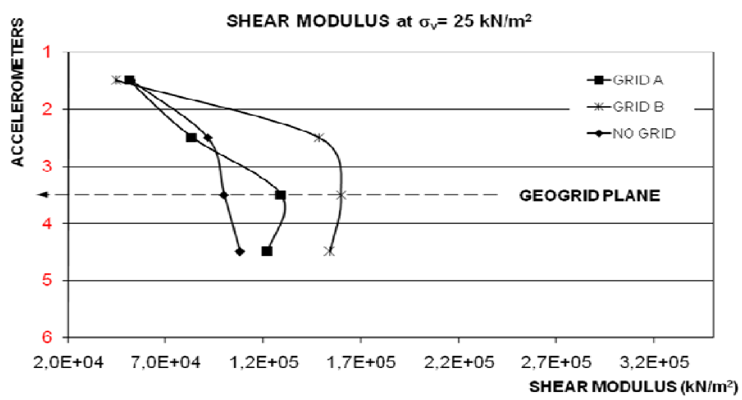

Figure 9. Shear modulus G interpreted from shear wave velocities measured from the first accelerometer arriving time for tests with and without grid (Mulabdic et al., 2003)

An example of comparison of shear modulus developed in the soil at different distances from different grids is presented in Figure 9. It is obvious that different types of grids generate different interactions with soil, which results in different velocities of wave propagation along in depth, with highest values in the vicinity of the grid. The values of G modulus are calculated using known soil density values. This fact is used in the definition of grid efficiency for individual materials, and possibly for defining the proper distance of grids in reinforced soil.

It should be noted that the measurement of wave velocities is influenced by the quality of impulse, by the position of accelerometers (higher energy is required for lower-lying accelerometers), by the stability of the accelerometer in the soil, and by the size of the accelerometer compared to the size of grains.
So far, we have been working with one accelerometer size only, and so the influence of the size of accelerometer on measured values still remains to be determined. The soil was dry and not very dense, as the denser soil does not permit pullout of the grid (grid fails in tension). The use of stronger grids, possibly made of steel, is planned, so that the grid pullout can be realized under moderate and high vertical stresses.

4. CONCLUSION

A new method has been developed in order to characterise the soil-grid interaction in reinforced soil. It relies on measurement of the velocity of wave propagation through reinforced soil, from the top position downwards. Since velocity is dependant on soil stiffness, and as the latter is in turn influenced by the interlocking effect generated in soil by the grid, the velocity profile describes the level of grid & soil interaction developed at different distances from the grid. When velocities of shear waves and compressive waves are known, it is possible to interpret the G and E moduli in soil from the measured velocity and density of soil. The comparison of velocities over depth intervals in soil for different grids is valuable in the determination of most efficient grids for particular soil types, and the information about the soil stiffness (G, E) enables us to analyse deformation characteristics of the material known as the reinforced soil. Further developments of the method will undoubtedly lead to better understanding of the interaction between the soil and grid, and will also enable improvements in the use of cost-effective design methods involving reinforced soil.

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