Deformation properties of geosynthetic reinforced gravel at small strain range

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ABSTRACT: Granular material being used at road and railway embankments are subjected to specific stress conditions with confining stresses much lower than stresses applied in vertical direction. To improve strength characteristics geosynthetic reinforcement is often applied. A series of large-scale triaxial tests on dense gravel, prismatic specimens with dimensions of 50 cm in height and 23 cm times 23 cm in cross-section was conducted to investigate the contribution of confining effect of reinforcement to the strength and particularly the impact upon the deformation properties of reinforced gravel from very small to large strain range. Two kinds of geosynthetics have been used as a reinforcement: geogrid and geocomposite. Deformations were measured locally using vertical and horizontal local deformation transducers. Unsaturated specimen were tested in drained triaxial compression, using monotonic loading. Confining pressure of 25 kPa has been applied by vacuum. Besides strength characteristics, particularly the stiffness properties were subject of research interests. Stiffness at different stress states was evaluated by using very small strain load cycles.

Keywords: reinforced soil, large-scale triaxial tests, deformation properties, small strain range

1 INTRODUCTION

As a tensile strength of soil is relatively low, an additional reinforcing element is appreciated to transfer tensile forces arised within the earth structure when it is loaded. Different kind of geosynthetics, most commonly geogrids, can be used for that purpose. High internal friction, generated between soil and embedded geosynthetic, allows the transfer of tensile stresses from the soil into the geosynthetic and thus inhibits extension strains within the soil. An overall strength of the composite material increases thereby.

Alternating layers of reinforcement (e.g. woven geotextile, geogrid or geocomposite) and fill material (e.g. gravel) are often placed beneath foundations to improve load-bearing capacity of foundation soil and settlement characteristics. So called confining effect (Ling and Tatsuoka, 1994) caused by embedded reinforcement has been identified in such vertically loaded composites. A significant improvements of mechanical properties of soil, such as increased peak and postpeak strength, have been proven by several authors (Ruiken et al., 2010; Xiaobin et al., 2014; Latha and Murthy, 2007) and through different design approaches accepted also in the industry (Demir et al., 2013; Lenart and Klompmaker, 2014; TenCate, 2017). However, to mobilize sufficient reinforcement contribution in the geosynthetics, large deformations have to occurre in the soil structure.

There exists extremely little information on the behaviour of reinforced soil at very small to medium strain range. Heineck et al. (2005) found no influence of microreinforcement (i.e. polypropylene fibers) upon the initial stiffness of fine grained soils, like silty sands, while Choo et al. (2017) report that presence of fibers disrupt the direct contact between sand grains, leading to decrease in small strain stiffness of fiber reinforced sands. Lower initial stiffness of geogrid reinforced sand compared to unreinforced sand was observed by Kongkitkul et al. (2007) and explained with direct bedding error related to the surface roughness of reinforcement and to the loose zone in the grid aperture.

Reinforced gravel materials, as it is known to authors, have not been studied at small strain range yet. Furthermore, deformation properties of layered reinforced sand and coarse grained material has been studied mainly by plane-strain (Ling and Tatsuoka, 1994) and triaxial (Ruiken et al., 2010; Xiaobin et al., 2014) tests, generally restricted to medium to large strain magnitudes.

Thus, granular material, reinforced with two kinds of reinforcement – geogrid and geocomposite, at stress conditions similar to road and railway applications has been tested in this research. Particular attention was paid to small strain behavior, i.e. initial stiffness, which was evaluated by using static and dynamic methods.

2 EXPERIMENTAL PROGRAM

Considering the road and railway applications of geosynthetic reinforced gravel, rather low confining pressure of 25 kPa was used in triaxial tests to simulate in-situ stress conditions (Lenart et al., 2014). Particularities of large scale triaxial tests at low confining pressure and sensors used for local strain measurements are described more into details elsewhere (Lenart et al., 2014), whereas this paper focus more into small strain stiffness measurements issue.

2.1 *Large-scale triaxial apparatus*

A series of tests on prismatic specimen with dimensions of 50 cm in height and 23 cm times 23 cm in cross-section was conducted at large-scale triaxial apparatus at Institute of Industrial Science, the University of Tokyo (AnhDan and Koseki, 2004; Lenart et al., 2014). The axial loading device employs an electro-hydraulic actuator having a capacity of 490 kN. A load cell attached at the top cap to eliminate the effects of piston friction is used to measure the axial load. As the confining pressure was rather low, it has been applied by means of partial vacuum as the back pressure.

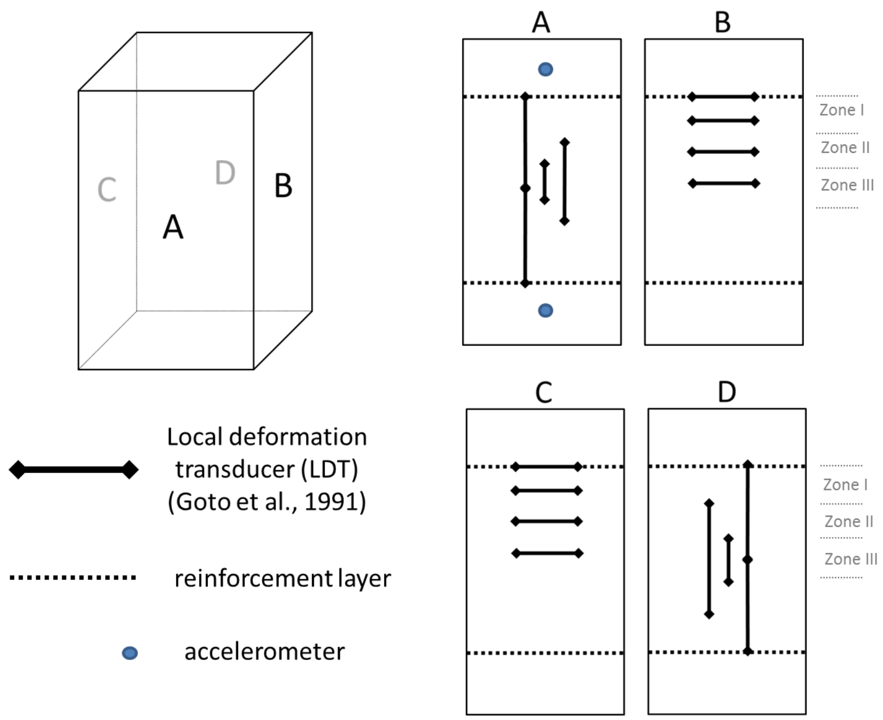

Figure 1. Prismatic specimen in large-scale triaxial apparatus with position of local deformation transducers (LDT) and denoted three confinement zones.

Axial strains (ε_1) were measured by four pairs of vertical local deformation transducers (LDTs) (Goto et al., 1991), placed at four heights of specimen between two layers of reinforcement. Combining their measurements, local axial strain was evaluated in three zones (denoted as I, II and III on Figure 1) between the reinforcement layer and the middle of the specimen. Lateral strains (ε_3) were measured by another four pairs of horizontal LDTs, three of them placed in the middle of three zones of specimen and fourth placed in the position of reinforcement layer. Position of all LDTs on the test specimen and position of reinforcement layer are shown in Figure 1.

To reduce friction between the specimen and rigid plates of top cap and pedestal a lubrication layer was inserted between them. Recommendations of previous researchers (Goto et al., 1993; AnhDan and

Koseki, 2004) were modified (Lenart et al., 2014) in the way that one lubrication layer consisted of two 0.8 mm thick rubber membranes and two layers of 125 μm (equivalent to two layers of Scotch tape) thick silicone grease. No correction for the effect of membrane force was applied in the analysis of test results.

2.2 *Testing material and specimen preparation*

The testing material was a well-graded crushed stone, called Tochigi gravel. Its gradation is within the boundary gradation curves for unbound granular base course materials used in Slovenia (Figure 2). It consists of angular to sub-angular particles with a coefficient of uniformity C_u=32 and specific gravity G_s=2.68 g/cm3. The optimum moisture content and the maximum dry density were defined by modified Proctor compaction test as w_{opt}=4.0 % and ρ_d=2.168 g/cm^3, respectively.

Dense specimens were prepared by manual compaction by falling hammer at nearly optimum moisture content (Table 1). Specimens were compacted in 10 layers with a thickness of 5 cm for each layer. Before placing the material for the next layer, the surface of the previously compacted layer was scrapped to a depth of about 2 cm to ensure a good interlocking between vertically adjacent layers. The compaction was applied with an aim to reach dry density of specimen as close as possible to the one defined by Proctor test. In reality approximately 95% of the maximum density was reached on average.

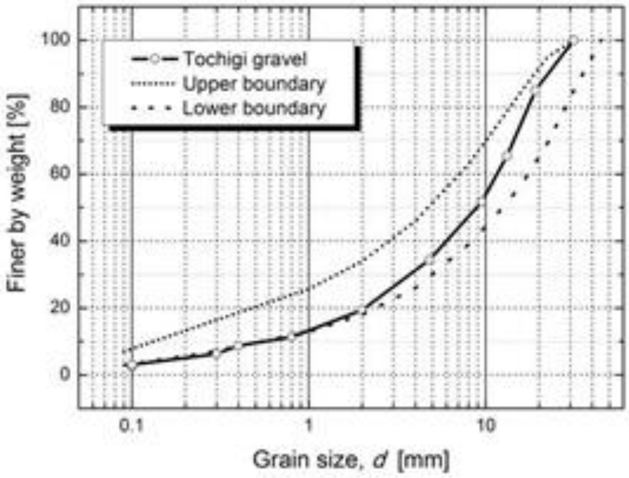

Figure 2. Gradation curve of tested Tochigi gravel (Lenart et al., 2014)

Table 1. Details about specimens

Specimen	IIS-0E	IIS-2A	IIS-COM-A
Dry density, (g/cm^3)	2.053	2.063	2.065
% of ρ_d by Proctor	94.7	95.1	95.2
Void ratio, (-)	0.31	0.30	0.30
Moisture content, (%)	3.73	3.86	4.09
Type of reinforcement	-	horizontal geogrid	horizontal geo-composite

The first specimen (specimen IIS-0E) was reference specimen without reinforcement, while other two specimens consisted also of different kind of reinforcing material. Two kinds of reinforcement were used (Figure 3), namely horizontal geogrid reinforcement (specimen IIS-2A) consisted of stretched, monolithic polypropilene (PP) flat bars with welded junctions and horizontal geo-composite reinforcement (specimen IIS-COM-A), which is a composite of the same geogrid and mechanical bonded filter geotextile welded within the geogrid structure. Their major characteristics are presented in Table 2.

Geogrid and geo-composite were installed horizontaly within the specimen in two layers. After two layers of compacted gravel, the first layer of horizontal reinforcement was installed. The second layer of horizontal reinforcement was installed after eighth layer of gravel. Set up of local deformation transducers shown on Figure 1 allowed us to observe local strain development in vicinity of reinforcing layer and to analyze expected confining effect caused by two different kinds of reinforcement. Due to the neglectable effect of geotextile bonded on the geogrid, stiffness of geogrid and geo-composite are assumed to be the same, while friction characteristics significantly differ due to the presence of geotextile.

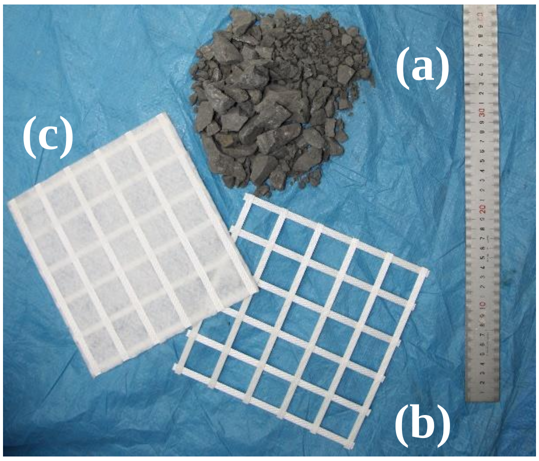

Figure 3. Tochigi gravel (a) and two kinds of reinforcement: geogrid (b) and geo-composite (c).

Table 2. Geosynthetic reinforcement characteristics as declared by manufacturer

Geogrid, white polypropylene (PP)	
Aperture size, md x cmd*, [mm x mm]	31 x 31
Mass per unit area, [g/m^2]	240
Maximum tensile strength, md/cmd*, [kN/m]	>40 / >40
Elongation at nominal strength, md/cmd*, [%]	<8 / <8
Tensile strength at 2% elongation, md/cmd*, [kN/m]	16/16
Tensile strength at 5% elongation, md/cmd*, [kN/m]	32/32
Geotextile, non-woven white polypropene (PP)	
Mass per unit area, [g/m^2]	150
Maximum tensile strength, md/cmd*, [kN/m]	6 / 10
Elongation at nominal strength, md/cmd*, [%]	60 / 40

2.3 *Testing procedure*

Test results of three specimens are presented in this paper. All tests were drained triaxial compression tests at constant confining pressure σ_3=25 kPa. The first part of loading was stress controlled monotonic loading and consisted from six stages. Each of them characterized with certain final deviatoric stress q = σ_1 - σ_3 equal to 20, 40, 80, 125, 180 and 230 kPa, individually. Small strain cyclic loadings were performed at the end of every stage, followed with unloading to zero deviatoric stress. When finally 230 kPa deviatoric stress was reached, strain controlled loading up to the failure was applied.

At the end of every loading stage, many very small vertical unloading/reloading cycles were conducted for the purpose of evaluating quasi-elastic properties as shown on Figure 6. At the end of the series of small cycle loadings, specimen was unloaded to zero deviator stress and then reloaded back again.

3 TEST RESULTS AND DISCUSSION

Figure 1 presents general stress-strain response of three specimens. During loading in stress controlled mode (loading/unloading cycles, small-strain cyclic loadings) one can hardly observe any difference, although specimen with geogrid reinforcement exhibits slightly stiffer behavior in middle strain range. When approaching to the strain controlled loading part of the test, geo-composite seems more efficient reinforcement. Specimen reinforced with geo-composite reached larger strength than specimen reinforced with geogrid, while unreinforced specimen was the weakest as expected.

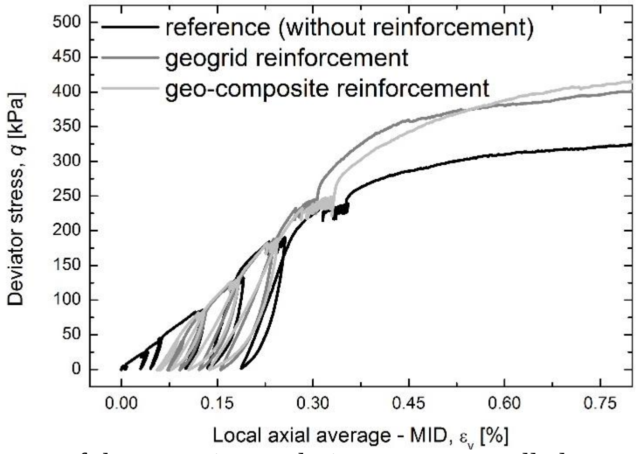

Figure 4. Loading history of three specimens during stress controlled monotonic part of loading

3.1 *The effect of confinement*

Development of strain in three distinguished zones at various distance from reinforcement layer has been studied by unique arrangement of local deformation transducers. Figure 5 presents difference in development of local strain regarding the type of reinforcement being used. As expected following the reports of other researchers (Kongkitkul et al., 2007; Choo et al., 2017) zone I has been proven as the most deformable. The loose zone nearby the reinforcement seems thicker in case of geo-composite, means better interlocking is achieved in case of "open" apertures of geogrid, but also slightly lower strength compared to geo-composite reinforced gravel. Figure 5 compares also the results of external and local measurement of strain. It is obvious that external measurements are useless for this kind of analysis.

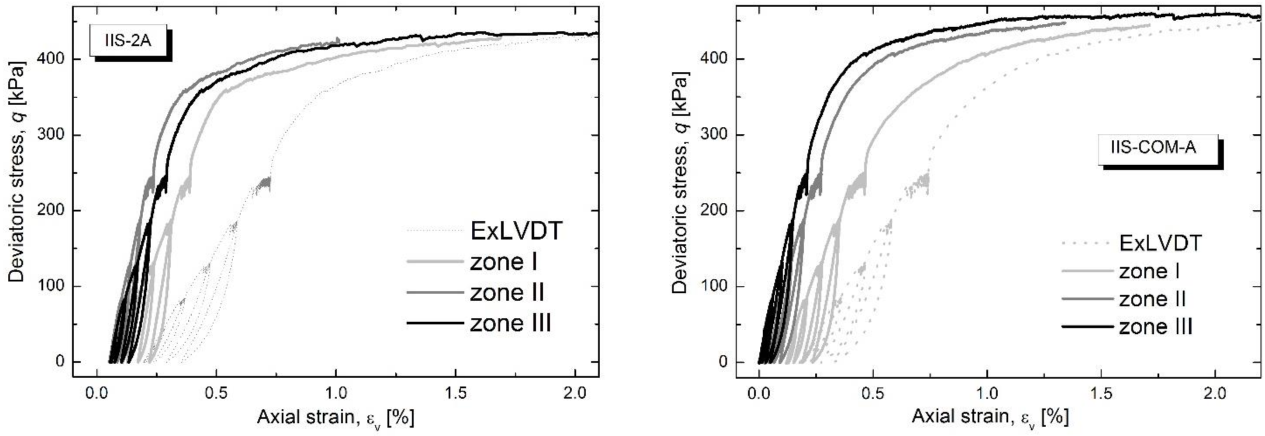

Figure 5. The effect of reinforcement upon the stress-strain relationship in case of geogrid (left) and geo-composite (right)

3.2 *Small-strain load cycles*

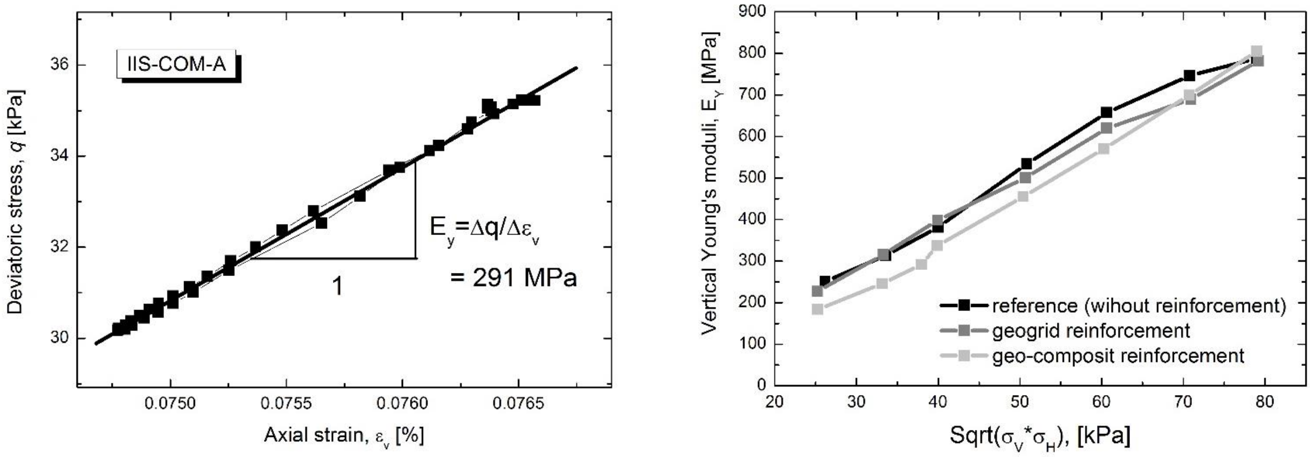

Figure 6. Typical stress-strain relationship during small-strain vertical load cycle (left) and the effect of stress level upon the vertical Young modulus

Finally, quasi-elastic vertical Young's moduli were evaluated during small strain loading cycles (Figure 6). In accordance with researches conducted on sand and with microreinforcement (Kongkitkul et al., 2007; Choo et al., 2017), geosynthetic reinforced gravel exhibits slightly lower initial small strain stiffness also in the present research. This is more pronounced in case of geo-composite than in case of geogrid. Referring to Figure 5, one can observe similarity between appearance of decreased initial small strain stiffness and thickness of loose zone nearby the reinforcement. Thus the decrease of initial stiffness is assumed to be caused by bedding error at the interface between gravel and reinforcement.

4 CONCLUSIONS

Large-scale triaxial tests on dense gravel reinforced with two different types (geogrid and geo-composite) but of the same stiffness of reinforcement have been conducted. Local strain measurements are essential in this kind of tests. Results prove that reinforcement increases the strength of specimen, while it also slightly decreases its initial stiffness, presumably due to the formation of loose zone nearby the reinforcement layer. This zone is thinner in case of geogrid as aperture enables better bedding of gravel within the reinforcement structure..

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