LABORATORY TESTING ON GEOSYNTHETICS OF REINFORCED FOUNDATION GROUND

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ABSTRACT: The paper describes results of experimental observation of axial strain mobilization process in geogrids used as reinforcement of soil base layers or foundation subsoil layers situated generally on a main body of weak and soft soil which are vertically loaded by a static pressure concentrated on a part of their top surface. The experiments were carried out in the form of conventional static foundation load tests on two Test Models different in geometrical arrangement, type of foundation, soils and loading scheme. In both Test Models an instrumented geogrid was installed between an upper thin layer of a strong and stiff soil and a lower thick layer of a week and compressible soil. The geogrid instrumentation was based on strain gauges installed on five locations of the geogrid central rib and in the 2nd Test Model on pressure transducers placed in the soil mass below the reinforcement in the same plan locations as the strain gauges. Before constructing the Test Models a suitable method of strain gauges installation on polypropylene geogrid had to be successfully resolved. The loading phase was carried out either according to the appropriate Czech Technical Standard or by statically increasing the foundation bearing pressure until onset of soil failure. Foundation settlement, reinforcement axial strain and soil normal vertical stress (Second Test Model only) were recorded as a function of the applied soil-foundation stress. The main observation result was that only small axial strains and hence normal forces mobilized at ultimate vertical loads.

1 INTRODUCTION

The contribution's focus belongs to the area of techniques of mechanical improvement of soil base layers or foundation subsoil layers via geosynthetic reinforcement. Although this type of soil reinforcement practice involves a high number of square meters of geosynthetics installed, from the research point of view it is still quite behind techniques of slope or retaining structures reinforcement. The situation can be illustrated by the Nice Conference proceedings where approximately 38 contributions focused on reinforced slopes or retaining walls compared to only 8 contributions dealing with subsoil or base layers reinforcement were presented.

The first insight into this way of soil reinforcement was presented by Binquet and Lee (1975), who were examining the influence of reinforcement (aluminium stripes) on bearing capacity of soils. These authors were followed by a succession of scientists investigating this area either theoretically or experimentally. The experimental research continued in two directions. Firstly, experiments in laboratory conditions were carried out using sand to model the soil (e.g. Fragaszy and Lawton, 1984; Guido et al 1985, 1987). The main objective of these experiments was to estimate the degree of influence of reinforcement on the bearing capacity of soils which was usually quantified by a bearing capacity ratio BCR. The second direction of research proceeded by full-scale tests represented e.g. by those carried out in the US in 1990s. Their objective was to examine the mechanical behaviour of different types of geosynthetics used as a reinforcement of light airplane courses (Webster, 1992). The output of these tests was not only how much each of the geosynthetic products influenced the depth of a groove left by a testing wheel but also discussion on the cause of the difference in reinforcing ability of the tested products. The important conclusion was that the geosynthetic reinforcement structure (i.e. rib robustness, spacing or shape) rather than its tensile strength is important in order to increase the soil bearing capacity. Such conclusions led the authors of this paper to investigate how the reinforcement strain is mobilised with external foundation loading.

The topic was examined via laboratory experiments in the form of conventional static foundation load tests on reinforced soil system with reinforcement instrumented by strain gauges.

2 EXPERIMENTS

Strain gauges were chosen to measure strain in the reinforcement member and pressure transducers were appointed to measure stress in a soil mass (both working on the electric resistance principle). Before the strain gauges could be used the method of their installation on polypropylene reinforcement had to be satisfactorily resolved. The foundation load tests were carried out in two different laboratories and hence on two different models – First Test Model and Second Test Model. The models differed in geometrical shape and dimensions of their stand, in sequence, type and depth of soil layers filling the stand, in type of foundation used for loading and in loading sequence. A strictly static foundation load was applied on the reinforced soil layer in chosen increments; effects of dynamic loading were out of the scope of this research.

2.1 *Transducers*

After initial discussion and after consultations with specialists and agents of the strain gauges distribution firms the transducers' installation (especially glueing) problem seemed nearly unsolvable because the geosynthetic reinforcement appointed for the experiment was made of polypropylene (PP) based material. PP belongs to polymers called polyolefins i.e. to non-polar plastics that are difficult to glue using cyano-acrylate pastes. The problem was overcome by preparing the reinforcement surface using either UV-rays or advantageously low-viscous fluid before transducers' pasting. The applicability of the chosen strain gauges installation method was verified by a set of reinforcement tensile load tests with the transducers installed. These tests were also used to determine the force-strain diagram of the reinforcement from the measured quantities and hence to establish the standard (i.e. calibration) curves of the strain gauges. An illustrative example of a transducer standard curve determined for one of the tested welded geogrids is depicted in Fig. 1 where the first load cycle can be compared to the corresponding part of the force-strain diagram presented by the geogrid fabricator.

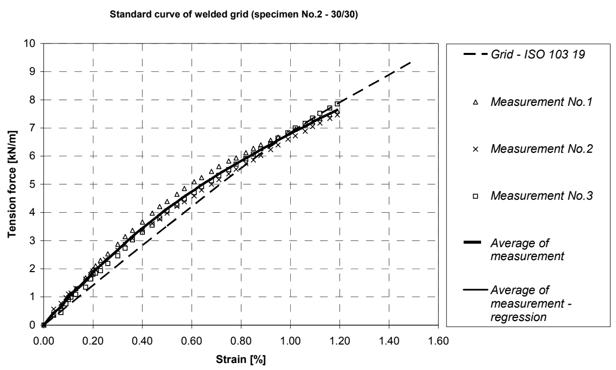

Figure 1: Example of a determined strain gauge standard curve

Together with the reinforcement strain mobilization measurement the normal vertical stress in the soil situated under the reinforcement grid was measured by pressure transducers PDA – 200kPa and PDA – 500kPa (made by firm TML Tokyo Sokki Kenkyujo Co., Ltd) in the Second Tests Model. In this case the problem to overcome was careful installation of the pressure transducers into the soil mass.

2.2 *First Test Model*

The experiments were carried out in so called "laboratory geotechnical testing field" where conditions of routine tests on real soil bodies of transport (highway or railway) structures are simulated. The part of the testing field used for the experiments had dimensions 3.0m x 3.0m in plan and 2.0m depth. In the bottom of this space a soft subsoil was represented by a clay layer (LL=57%, w=26%, PI=34%, γ=15 kN/m^{-3}) 750mm deep. A welded geogrid of tensile strength 60/60 kN/m (ISO EN 10319) was installed on the top of the clay layer. Full technical parameters of the geogrid used are summarized in Tab. 1.

Table 1: Parameters of welded grid

Property	description
Polymer type	polypropylene
Aperture size [mm]	
Machine direction	29
Cross-machine direction	28
Tensile strength at 2% elongation	
Machine direction [kNm^{-1}]	21
Cross-machine direction [kNm^{-1}]	21
Max. tensile strength	
Machine direction [kNm^{-1}]	≥60
Cross-machine direction [kNm^{-1}]	≥60
Elongation at nominal strength	
Machine direction [%]	8≥
Cross-machine direction [%]	8≥

A 0-32mm fraction gravel layer 150mm (Test 1, see below) or 300mm (Test 2) deep was compacted over the initially stressed reinforcement. The load was applied by a static pressure of rigid circular foundation of 300mm diameter.

The reinforcement strain magnitude was observed in two distinct cases. "Test 1" was carried out using standard static foundation load test loading scheme according to Czech Standard ČSN 72 1006 (Soil Compaction Control). In this case an ultimate load could not be reached. Therefore a different load scheme was tested in the second case (Test 2) where the bearing pressure was statically increased until the onset of subsoil failure. Only the "Test 2" results are presented in this paper.

2.2.1 *Loading until Subsoil Failure*

During the test the vertical settlement of the foundation plate was observed as a function of the bearing pressure applied in 20kPa increments (Fig. 2). In each load step the reinforcement geogrid strain was measured under the foundation plate centre (L1=0.0m), under the edges of the foundation plate (L2=0.5B) and in distances L3=1.5B from the plate centre. The strain in the instrumented geogrid rib is depicted in Fig. 3.

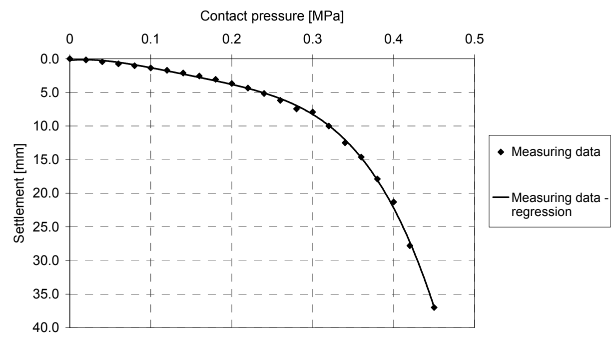

Figure 2: Load-settlement curve

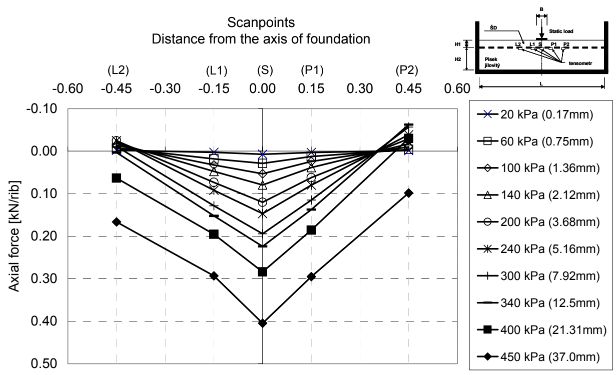

Figure 3: Strain measured in geogrid rib

2.2.2 *Results summary (1st Test Model)*

The loading scheme of Test 2 was realized on the basis of Test 1 results that presented a very low level of strain in the reinforcement. The objective of Test 2 was to determine whether a significant increase in reinforcement strain would have been achieved if the load limitations of Test 1 (i.e. either maximum settlement or maximum bearing pressure) had been overreached.

The most important results of the First Test Model are summarized in the following points:

- To mobilize as little as 0.5% strain in the reinforcement grid a 450kPa foundation bearing stress resulting into 37mm vertical settlement had to be applied. This strain measured in the most loaded location of the most loaded geogrid rib can be diverted to a corresponding 10.1 kN/m "hypothetical" plane strain reinforcement normal force which represents only a 16.8% of the geogrid short-time tensile strength. The word hypothetical stands for the fact that axisymmetrical rather than plane strain conditions are applicable to this test and therefore a force calculated on the basis of one rib force and the number of ribs per meter can be used only for comparison.
- A noticeable amount of compressive force was mobilised in the measuring locations furthest from the foundation centre.

2.3 *Second Test Model*

The test was carried out in a stand of 1.28m x 0.45m in plan and 1.00m in depth. The front wall of the stand had been constructed from glass and the other walls had been made of timber with metal or laminated plastic surfacing to reduce friction on their faces. The space created was then filled from the bottom with a 0.4m deep silica sand layer, 0.25m deep clayey sand layer (w=21%; LL=32%, PL=18%) and 0.1m deep gravel layer. A welded PP geogrid of plan dimensions 0.96m x 0.45m was installed between the gravel and the clayey sand layer. The technical parameters of the reinforcement are stated in Tab. 2.

Table 2: Parameters of welded grid

Property	description
Polymer type	polypropylene
Aperture size [mm]	
Machine direction	44
Cross-machine direction	43
Tensile strength at 2% elongation	
Machine direction [kNm^{-1}]	12
Cross-machine direction [kNm^{-1}]	12
Max. tensile strength	
Machine direction [kNm^{-1}]	30
Cross-machine direction [kNm^{-1}]	30
Elongation at nominal strength	
Machine direction [%]	10
Cross-machine direction [%]	10

The model geometry is visualized in Fig. 4.

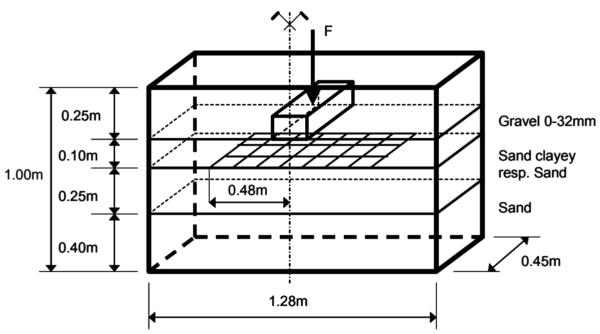

Figure 4: Geometry of the stand

The reinforcement had been instrumented by strain gauges GFLA-6.350-70 situated on the central rib (transversal direction) under the foundation centre (L1=0.0m), under the foundation edges (L2=0.5B) and in distances L3=1.5B from the foundation centre (longitudinal direction). The strain gauges were glued both to the bottom and the top surface of the reinforcement rib to allow for elimination of bending if necessary.

Furthermore PDA strain transducers were installed in the sandy clay layer in a horizontal level 30mm below the reinforcement in the same plan position (both transversally and longitudinally) as the strain gauges. Next set of pressure transducers was installed in a horizontal level 100mm below the reinforcement in longitudinal distances L1=0.0m and L2=0.5B. Last transducer was placed under the foundation centre 200m below the reinforcement. The previously described subsoil was loaded statically by a rigid plane strain foundation represented by steel RHS of 100x100mm in profile and 0.45m length installed transversally in the longitudinal centre of the stand. The ratio of the reinforcement length to the foundation width was circa 10. The soil-foundation pressure was increased continuously.

2.3.1 *Measured Quantities*

During the loading phase the impulses from all the transducers were recorded in chosen load increments. In the same increments the foundation settlement and bearing pressure were collected as well. The maximum soil-foundation stress reached during the test was 245kPa with a corresponding 45mm vertical settlement. The load - settlement curve of the test is depicted in Fig. 5.

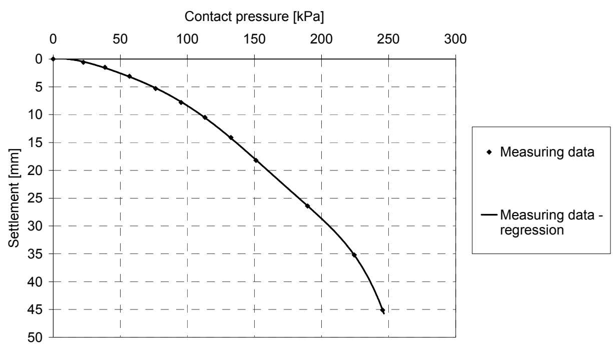

Figure 5: Load – Settlement curve of Second Test Model

The plots of the measured rib strain (Fig. 6), corresponding reinforcement plane strain normal force (Fig. 7) and soil normal vertical stress distribution below the reinforcement level (Fig. 8) were evaluated from the measured quantities.

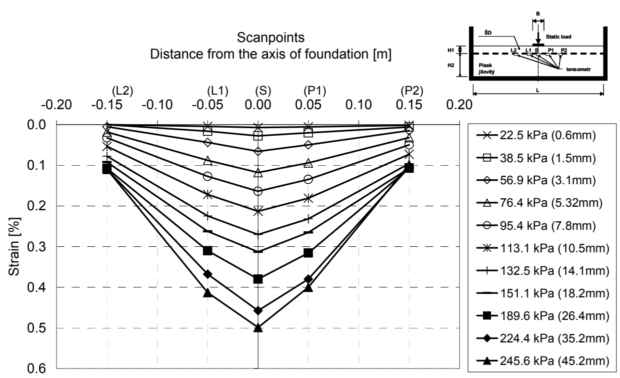

Figure 6: Geogrid strain distribution for different load levels

The reinforcement plane strain normal force was determined by multiplying the force in the measured rib obtained using the recorded strain from the previously prepared transducer standard curve by the number of ribs per unit width of the geogrid. This approach was appropriate due to plane strain conditions of this foundation load test where only the longitudinal geogrid ribs carrying (transferring) the load whereas the transversal ribs were functioning as anchorage points and their load carrying function could be neglected.

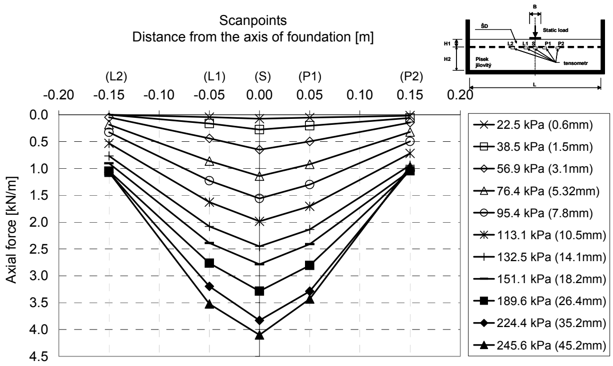

Figure 7: Geogrid normal force distribution for different load levels

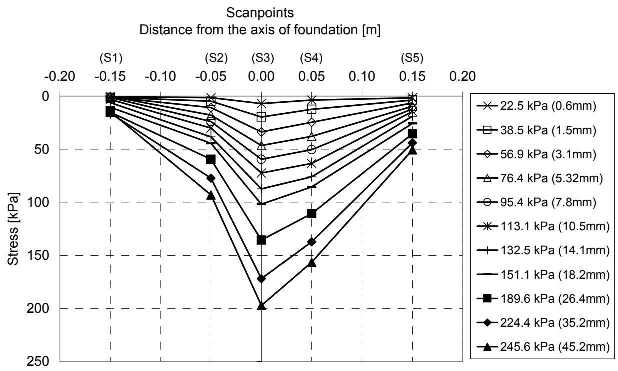

Figure 8: Soil normal vertical stress distribution 30mm below the reinforcement for different load levels

2.3.2 *Results Summary (2nd Test Model)*

The most important results of the Second Test Model can be summarized in the following points:

- The measured strain magnitude was in tenths of per cent and the maximum strain measured was 0.5% (under the foundation centre) at the ultimate bearing pressure 245kPa. It can be further seen from the graphs (Fig. 6 and 7) that as the loading progressed the strain in the outer measuring points increased as well until the load reached 150kPa level since which no significant change in strain took place. This could be explained by the assumption that the limiting anchorage stress was overreached in the outlying areas and reinforcement slippage took place.
- The maximum plane strain axial reinforcement force reached at ultimate load was 4.10kN/m which corresponds to 13.6% utilization of the geogrid short-time tensile strength of 30kN/m.

3 CONCLUSION

The realized experiments showed that if a reinforced foundation subsoil layer (or soil base layer) constructed over a main body of weak and compressible soil is vertically loaded by a shallow foundation only a small strain and hence axial force is mobilized in the reinforcing geosynthetic member. The maximum strain reached during the tests was 0.5%. Transforming the axial strain into a plane strain reinforcement normal force only (10-15)% of the geogrid short-time uniaxial tensile strength (ISO EN 10319) was mobilized at maximum vertical load. This result confirms the conclusions of the full-scale tests from the US (Webster, 1992) that the reinforcing ability of geosynthetics used in the previously mentioned way is not governed by their strength.

Preparation of the experiments added also some information to the problem of strain gauges' installation on PP-based geosynthetics. To glue the strain gauges on non-polar plastic material it is useful to prepare its surface either by UV-ray or low-viscous fluid.

4 ACKNOWLEDGMENT

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