Recent findings about the confining effect of geogrids from large scale laboratory testing

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ABSTRACT: To investigate the contribution of geogrids to the strength of reinforced soil large scale laboratory triaxial and plane strain testing has been carried out at RWTH Aachen University. The outcomes of the triaxial tests clearly show the development of an additional confining effect of the reinforcement. The contribution of this effect to the development of the horizontal earth pressure on the facing of reinforced retaining walls has then been investigated with plane strain model tests. The significant reduction of the earth pressure, that has been assumed and reported various times during the past two decades, could be confirmed with these tests.
However, analysing displacements and rotations of the soil particles during retraction of the facing, the development of shear zones within the reinforced soil body has been identified. The results clearly show an arching effect of the soil between the stabilizing geogrid layers.

1 INTRODUCTION

The immense contribution of geogrids to the strength of reinforced soil is well known in science and nowadays also increasingly accepted in the industry. This is reflected in design approaches that have been updated recently, e.g. the German design standard EBGEO (2009). The earth pressure acting on the facing of geogrid reinforced retaining walls is assumed herein to be far less as it used to be in the former version and as suggested by other standards, such as BS 8006 (1995).

The mechanism of the geogrids leading to the increased strength of the soil has been identified as confining effect (Ling and Tatsuoka (1994), Tsukamoto et al. (1999)). However, further large scale triaxial and plane strain laboratory testing has been done to investigate this effect in principle, especially in order to visualize the confining effect.

2 TRIAXIAL TESTING

Large scale triaxial tests have been carried out to investigate the relation of the stress level, the type of filling soil and the vertical reinforcement spacing to the reinforcing effect of geogrids.

2.1 *Test Set-up*

The soil specimen were 500 mm in diameter and approximately 1100 mm high (Fig. 1). The confining pressure has been applied by vacuum. Two types of soil have been tested, i.e. a crushed base course material (d_{50} = 12 mm) and a medium sand (d_{50} = 0.5 mm) that have been compacted to both 95% and 100% proctor density.

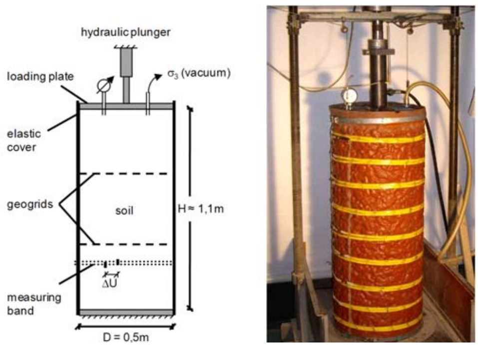

Figure 1. Principal sketch and photograph of triaxial cell.

Tests have been conducted with a constant strain rate of 0.1 %/min, while plunger load, geogrid strains and average radial strains have been recorded.

The geogrid used for the work presented in this paper was a biaxial polypropylene geogrid with 30 kN/m nominal strength made of welded pre-stretched flat bars. The aperture size was 32 mm x 32 mm and the tensile force at 2 % strain was 12 kN/m as stated by the manufacturer.

2.2 *Test Results*

As reported earlier by Ruiken and Ziegler (2008) the test results indicate a significant increase of the bearing capacity and reduction of deformations due to the geogrid reinforcement. The results of the measuring bands on the outside of the elastic cover of the triaxial cell given in Figure 2 show the distribution of average radial strains over the height for tests with a varying number of reinforcement layers at the same load level. The development of radial strains is reduced significantly due to the geogrids, even without attaching the geogrids to the elastic cover.

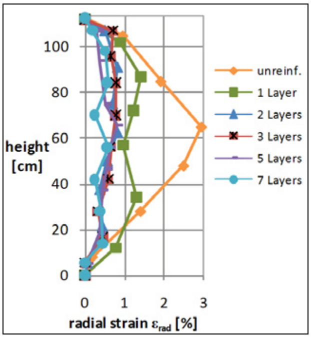

Figure 2. Comparison of average radial strains for a varying number of reinforcement layers.

This confining effect of the geogrids, that has been observed also by Moghaddas-Nejad and Small (2003) and Eiksund et al. (2004), can be explained with the mechanical model given in Figure 3. The effect is similar to an additional confining pressure $\Delta\sigma_3$ acting homogeneously over the whole height of the specimen if the vertical spacing between the reinforcement layers is small enough. The magnitude depends on the degree of activation of the geogrids. Corresponding stress paths that take the additional confinement into account have been determined and drawn for the reinforced triaxial tests in Ruiken and Ziegler (2008).

In Figure 4 the development of the volumetric strains ε_v can be seen for triaxial tests with base course material. The increase in bearing capacity is accompanied with reduced dilatancy effects. This is consistent for both soils tested, i.e. sand and gravel and has been observed also by Peng et al. (2000) from plane strain compression testing.

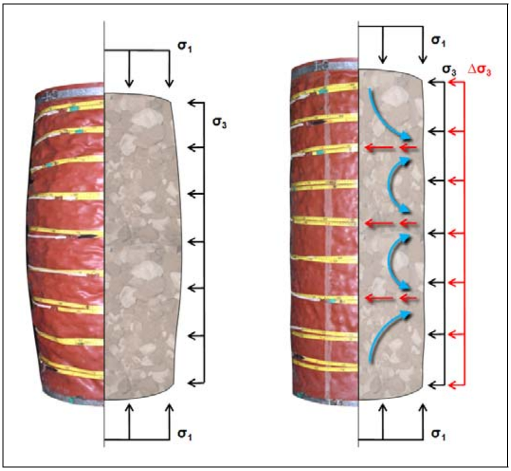

Figure 3. Comparison of unreinforced and reinforced triaxial specimen at the same load level.

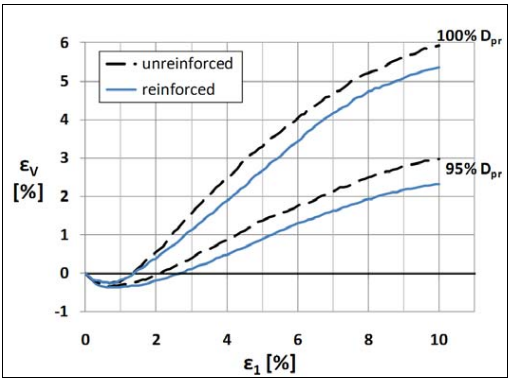

Figure 4. Volumetric strains of unreinforced and reinforced gravel compacted with 95% and 100% proctor density.

3 PLANE STRAIN TESTING

Additional large scale plane strain testing of geogrid reinforced soil has been carried out to investigate the advantageous reinforcement effect of reducing the lateral earth pressure on the facing, which has been suggested various times, e.g. Clayton et al. (1993) and Soong and Koerner (1997), and has recently been measured by Yang et al. (2009).

The basic mechanism suggested in Soong and Koerner (1997) for the stress condition of the backfill soil directly behind the facing corresponds with the effect that has been observed during triaxial testing, i.e. a zone of unconfined soil between the geogrid layers, which is therefore not restricted in deformation.

3.1 *Test Set-up*

The apparatus shown in Fig. 5 has been constructed to carry out reinforced soil wall model testing under plane strain conditions as well as plane strain element testing under a constant confining pressure. The maximum dimensions of the soil specimen are (H-W-D) 1m x 1m x 0.45m. Front and back facing can be retracted independently, whereas the fixed sidewalls provide the plane strain conditions. The 106 mm thick glass sidewall is designed for a maximum deflection of 0.1 mm under surcharge loads up to 50 kPa that are applied uniformly with a compressed air cushion.

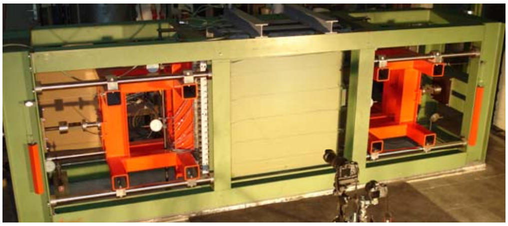

Figure 5. Apparatus for plain strain testing of reinforced soil.

The above described sand has been deposited with a rainfall technique to more than 100 % proctor density. Friction parameters have been determined with direct shear tests to 7° between sand and glass at the sidewalls and to less than 2° between the facing elements and a thin latex membrane lubricated with silicone grease.

3.2 *Test Results*

3.2.1 *Horizontal earth pressure development*

The horizontal earth pressure distribution over the height of the facing has been obtained from 20 elements (each 5 cm high). Redundancy was achieved by comparing the sum with the result of one large load cell supporting the whole facing.

The earth pressures given in Figure 6 start with a huge difference in the initial values. This is due to slight movement (up to 0.7 mm) of the facing elements during loading, which allows the geogrids to get activated already during the loading sequence.

The results indicate a reduction of the active earth pressure down to 40% compared to those of the unreinforced soil, even without connecting the geogrids to the facing. The effect increases with an increasing number of reinforcement layers.

3.2.2 *Particle displacements and rotations*

Using a remote-controlled digital reflex camera with a fixed focal length pictures of the specimens have been taken during testing. The pictures have been processed afterwards evaluating particle displacements and rotations (PIV-method) to visualize the confining effect of the geogrids and the development of shear zones.

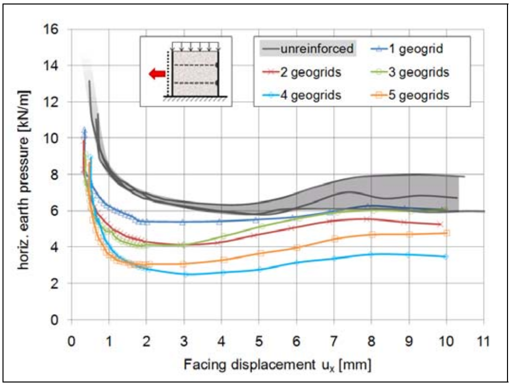

Figure 6. Development of the horizontal earth pressure (grids not connected to the facing).

Results given in Fig. 7 show the particle displacements during retraction of the front facing. The arching effect that has been assumed from the presented results of the triaxial testing and from FE-calculations for reinforced plane strain compression tests (Peng et al., 2000) and reinforced retaining structures (Pachomov et al., 2007) can be seen perfectly for the soil between the two geogrid layers.

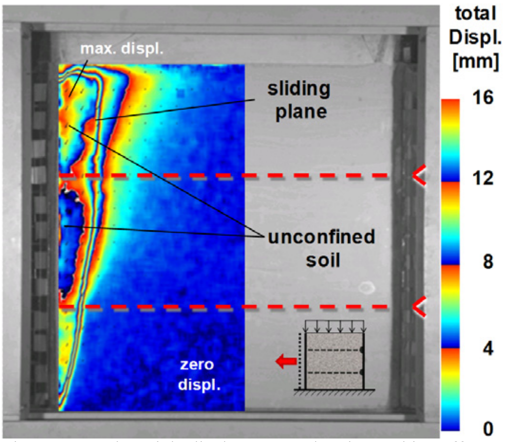

Figure 7. Total particle displacements showing arching effects during facing retraction.

The interaction mechanism between soil and reinforcements is of major concern in this study. Therefore, high resolution photographs of the sand were taken by focusing on a detail section of the specimen, i.e. at the height of the upper geogrid at the facing.

The comparison of displacements (Fig. 8) and rotations of the sand particles (Fig. 9) within the detail section clearly indicates that in contrast to the development of a single failure plane in the unreinforced soil, various failure planes have been developed in this case due to the geogrid reinforcements. Especially remarkable is the slip surface (B) leading from the free end of the geogrid down- and inwards. The different colours of the slip surfaces indicate a different sense of rotation of the soil particles at the shear zones. This indicates relative downward movement of the soil between the pink (A) and the orange (B) shear zone (Fig. 9). Due to this, the soil in the unconfined zone is pushed towards the facing.

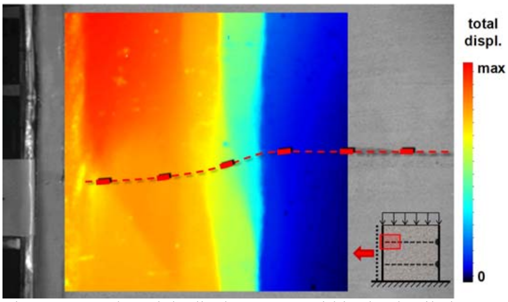

Figure 8. Total particle displacements within the detailed section at the facing.

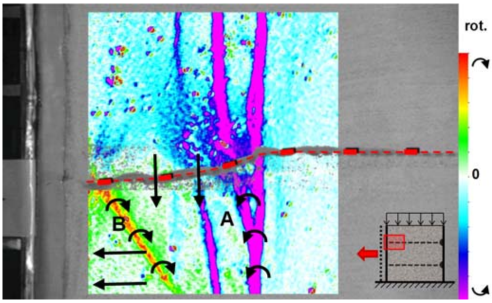

Figure 9. Particle rotations within the detailed section at the facing.

4 SUMMARY AND DISCUSSION

The confining effect of the geogrids has been visualized in large scale triaxial testing as well as in plane strain model wall testing. It is responsible for an increased bearing capacity and for reduced deformations in the triaxial tests, especially at the height of the geogrids.

During plane strain model wall testing, the horizontal earth pressure on the facing has been reduced significantly by the geogrids. An arching effect and the corresponding zone of the soil between the geogrids that cannot be supported has been identified.

The assumption of a very low to moderate horizontal earth pressure on the facing of reinforced retaining structures is therefore justified.

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