LABORATORY TESTING OF INTERACTION PERFORMANCE OF PVA GEOGRIDS EMBEDDED IN STABILIZED COHESIVE SOILS

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Abstract: Geogrid-reinforced soil structures have become increasingly very popular in geotechnical engineering. The use of local cohesive soils as a fill creates additional ecological and economical advantages. This paper presents and discusses the results of a laboratory investigation of the interface shear-strength and pullout behaviour of a PVA-geogrid embedded in a typical cohesive soil with and without additional stabilization. Two types of stabilizers were used, lime and cement. The investigation was conducted in a recently developed novel shear- and pullout testing device with negligible influence of device configuration constraints on test results. The focal point is the behaviour of the combination of stabilized soil-geogrid because of the lack of knowledge for such cases, combined with doubts about the shear strength, shear stiffness etc. in the interface zone of the geogrid/soil. It was found that for the specific geogrid used: the shear as well as the pullout behaviour in the interface was better regarding both strength and strain. A positive synergetic effect seems to take place.

Preliminary results of the laboratory testing programme were presented in 2006. In the meantime, further investigations have been conducted and the experimental investigations completed. In this paper the authors present the outcomes of the experimental work.

The results gained will provide an important contribution to the efficient use of geosynthetics in innovative civil engineering applications.

Keywords: Reinforced clay, soil improvement, PVA, interaction, direct shear test, pull-out test.

INTRODUCTION

Since the last decades, there is an increasing shortage of traditional ‘good’ non-cohesive soils as construction material. On the other hand, locally available cohesive soils often cannot be used as construction fill material without additional engineering measures, thus they have been ignored or avoided for a long time. Today this is practically no longer possible due to economic and environmental reasons. Cohesive soils have to be used with increasing tendency as a structural fill for embankments, bearing layers for roads and railroads, slope retaining systems etc.

Generally, there are two main possibilities to improve the mechanical behaviour of cohesive soils to use them as fill material for construction purposes: ‘chemical’ improvement or stabilization (e.g. by cement/lime) or ‘mechanical’ stabilization using appropriate geosynthetics.

It can be very useful to combine these techniques looking for a synergetic effect, i.e. to reinforce cement/lime stabilized cohesive soils with appropriate geosynthetic reinforcement.

For that purpose it is important to gain knowledge of the interaction between soil and reinforcement in the shear- and pullout mode. This knowledge is essential for the stability analysis of geosynthetic structures. There is a lot of experience in this regard for non-cohesive fills and some experience with cohesive fills, but unfortunately there is a lack of experience with lime- and/or cement-stabilized cohesive soils.

For the aforementioned reasons, a comprehensive laboratory testing programme was carried out in order to study the interaction between PVA-geogrid-reinforcements and lime/cement-stabilized typical cohesive soils. The tests focussed on the shear- and pullout resistance and on the interface shear stiffness.

Due to the lack of space, only the results believed to be more important are presented and discussed herein.

MATERIALS TESTED

Soil

The soil used in the present study was obtained from the region of Chemnitz, Germany. It is one of the most common local poor cohesive soils. The soil is classified as inorganic clay of high plasticity. It has a maximum dry specific density of 1.695 kN/m³ and an optimum moisture content of 18.3 %. Some engineering properties of the clay are summarized in Table 1.

Geogrid (GG)

The reinforcement used in this study was a FORTRAC® geogrid R 750/50-30 M of PVA yarns. This type of Fortrac® geogrid seems to be an efficient solution due to a high tensile modulus and a very low creep tendency combined with high alkaline resistance (Alexiew et al., 2000) in the case for cement-stabilized soils with a pH >12. A summary of some properties of this geogrid is presented in Table 2.

Stabilizer

For this study Portland-limestone Cement ‘CEM II/A-LL 32.5 R (EN 197-1)’ with rapid early strength and hydrated lime ‘CL 60 S’ were chosen as two best suited additives for stabilisation.

Table 1. Properties of the cohesive soil used

Property	Unit	Value
Initial water content w	(%)	24.10
Specific density ρ_s	(g/cm^3)	2.757
Liquid limit w_L	(%)	53
Plastic limit w_P	(%)	24
Plasticity $I_P = w_L - w_P$	(%)	29
Cohesion c’	(kN/m^2)	46
Angle of internal friction φ’	(º)	29.70
Organic content	(%)	3.2

Table 2. Geogrid parameters

Property	Unit	Value
Type / mesh size	flexible / 30 mm	
Ultimate Tensile Strength (UTS)	(kN/m)	≥ 750
Ultimate strain	(%)	≤ 6
Tensile force at 2% strain	(kN/m)	≥ 230
Tensile force at 3% strain	(kN/m)	≥ 330
Chemical and biological durability	(-)	very high

EXPERIMENTAL PROGRAMME

Engineering properties of Soil-Cement and Soil-Lime mixture

A range of laboratory tests were carried out on the treated cohesive soil, both on specimens prepared with lime and cement. The proportions of soil and stabilizer were varied to find the appropriate lime/cement content for the upcoming GG interaction tests. The specimens were examined with 3 different lime/cement contents, 3%, 6% and 9% by dry weight of soil.

Typical engineering properties of the untreated and cement treated soil including the sample preparation and test procedure are described and discussed in Aydogmus et al. (2006). Under consideration of the gained test results as well as costs and environmental conditions for real structures, the option with 6% lime and 6% cement was chosen for the interaction tests.

Experimental investigation of interaction behaviour – Laboratory testing program

The laboratory testing program was carried out to study the interface shear-strength and pullout behaviour of a PVA-GG-reinforcement embedded in a typical cohesive soil with and without lime and cement stabilization. It consists of 6 shear- and 3 pullout test series in following constellations:

- untreated soil (US)
- cement stabilised soil (CSS)
- lime stabilised soil (LSS)

Each test series consist of three tests with each test conducted at a different level of normal stress ranging from 50 to 200 kN/m². In total 27 tests were carried out.

The shear and pullout test were carried out according to the European and German standards DIN 18137-3, EN ISO 12957-1 and EN 13738, respectively. The test apparatus, specimen preparation and procedure related to these tests are fully described in Aydogmus et al. (2004, 2008) and Aydogmus (2007), respectively.

RESULTS AND DISCUSSION OF THE PERFORMED SHEAR AND PULLOUT TESTS

The obtained results show very interesting mechanical properties without and with GG reinforcement for US, CSS and LSS. Note that the following results represent the strength of the soil-cement-mixture in a relatively early age (~14 hrs.). Some additional tests show that with increasing hydration time the positive effects regarding the geogrid stabilized soil interaction (see below) are even better.

The shear and pullout behaviour of PVA-GG-reinforcements embedded in US, CSS and LSS are shown for the normal pressure σ = 200 kN/m² as a representative for each series in Figure 1 and 2, respectively.

The shear stress – displacement behaviour of cement/lime stabilized and reinforced soil is quite different from that of untreated and unreinforced soil (Figure 1). For untreated and unreinforced cohesive soils the well known curve shows (as expected) a maximum strength at large displacements followed by a smooth decrease to a residual value. For the untreated soil with GG the peak value is higher and takes place at smaller displacements. The highest peak shear strength is registered for the CSS and LSS with the GG at even smaller displacements. Correspondingly, a higher decrease back to a residual value takes place.

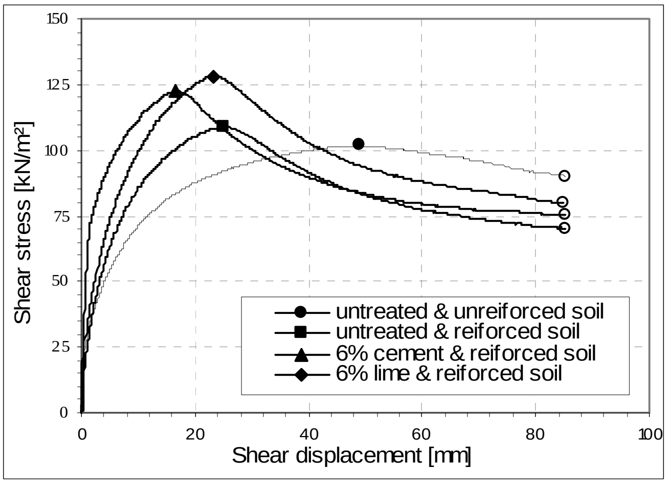

Figure 1. Shear stress vs. shear displacement (σ = 200 kN/m²)

A possible interface softening due to the implemented GG does not occur. The data seem to confirm a synergetic effect of cement/lime stabilization and GG inclusion for the materials tested in the sense of increasing both strength and stiffness in the shear mode.

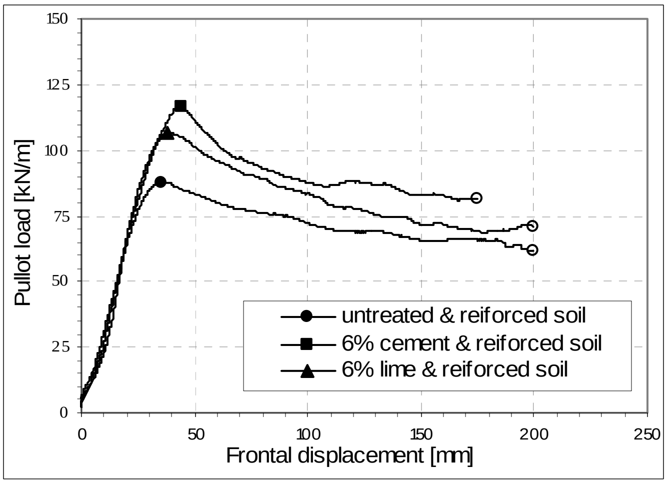

Figure 2. Pullout load vs. displacement (σ = 200 kN/m²)

An analogous positive synergetic effect as mentioned above for GG and stabilized soil occurs in the pullout tests, increasing the peak pullout load by 20-30 % (Figure 2).

Soil-geogrid coefficients of interaction

To compare the values obtained from the different test carried out to characterize the interface shear-strength and pullout behaviour, the interface coefficient was calculated for each case.

For shear tests, the soil-geosynthetic interface, let us define 'shear strength ratio' f_g (σ) at peak shear strength is determined for different normal stresses using equation

$$f_g(\sigma) = \tau^{max}(\sigma) / \tau_s^{max}(\sigma)$$

where $\tau^{max}(\sigma)$ is the soil-geogrid peak shear strength and $\tau_s^{max}(\sigma)$ is the soil-soil peak shear strength.

As far as pullout tests are concerned, the 'pullout strength ratio' can be determined by using equation

$$\tau^{max}(\sigma) = F_{max} / 2 \cdot L$$

where F_{max} is the pullout load per unit of width obtained from the test and L is the length of geogrid embedment.

Using above equations, the strength ratio of the soil-geogrid interface was determined. These values are presented in Figure 3 and 4 for the cases US, CSS and LSS. In all cases the value is about 1. Especially in the case of stabilised soil, which is the main issue herein, the values are >1.0 for the full range of normal stresses, indicating the suitability of the geogrid used for reinforcement of stabilized cohesive soils.

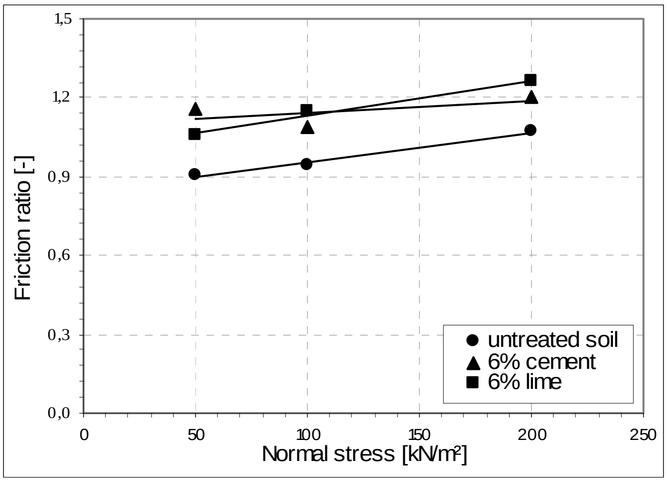

Figure 3. Friction ratio envelopes (test modus: shear test)

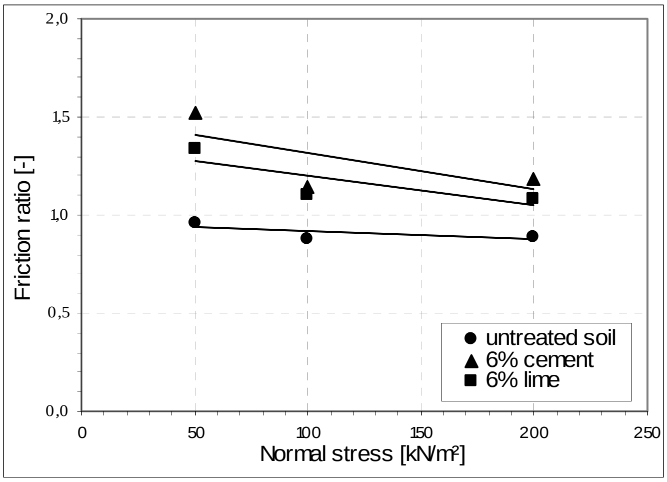

Figure 4. Friction ratio envelopes (test modus: pullout test)

Comparing the results for GG reinforced and stabilized soils obtained from the shear- and pullout tests, it is clear that the interface coefficient is higher in the case of the pullout test. This phenomenon could be explained with the specific favourable geometry in the stabilized soil generated by the geogrid used (Figure 5).

Generally shear (and similarly: pullout) tests for geosynthetic-soil combinations are a priori of phenomenological nature. Internal mechanisms and the influences of different factors as soil and geogrid parameters and structure, surface-roughness of geosynthetic, polymers used, mesh size etc. are hardly clarified and not really obvious. Thus, the authors prefer to avoid any further hypothesis at present. In any case, the interaction GG-CSS/LSS is even better than the 'interaction' of GG-US.

CONCLUSION

In this paper, the results of a laboratory investigation of the interface shear-strength and pullout behaviour of a PVA-geogrid-reinforcement embedded in a typical cohesive soil with and without additional stabilization were presented and discussed.

Results from both shear- and pullout-tests were presented showing interesting mechanical properties for a 6% cement and 6% lime content in a typical cohesive soil with and without GG reinforcement. The results seem to confirm a synergetic effect of cement/lime stabilization and Fortrac® M (PVA) geogrid inclusion for the materials tested, in the sense of increasing both strength and stiffness in the shear and pullout mode. For both shear and pullout-modes the coefficients of interaction between the PVA-geogrids tested and the cemented/limed soil are equal to 1.0 or even higher demonstrating the so-called 'perfect bond'. This positive interaction behaviour can open the way for a more intensive use of such geogrids in combination with stabilized cohesive fills.

The results gained will provide an important contribution to the efficient use of geosynthetics in innovative civil engineering applications.

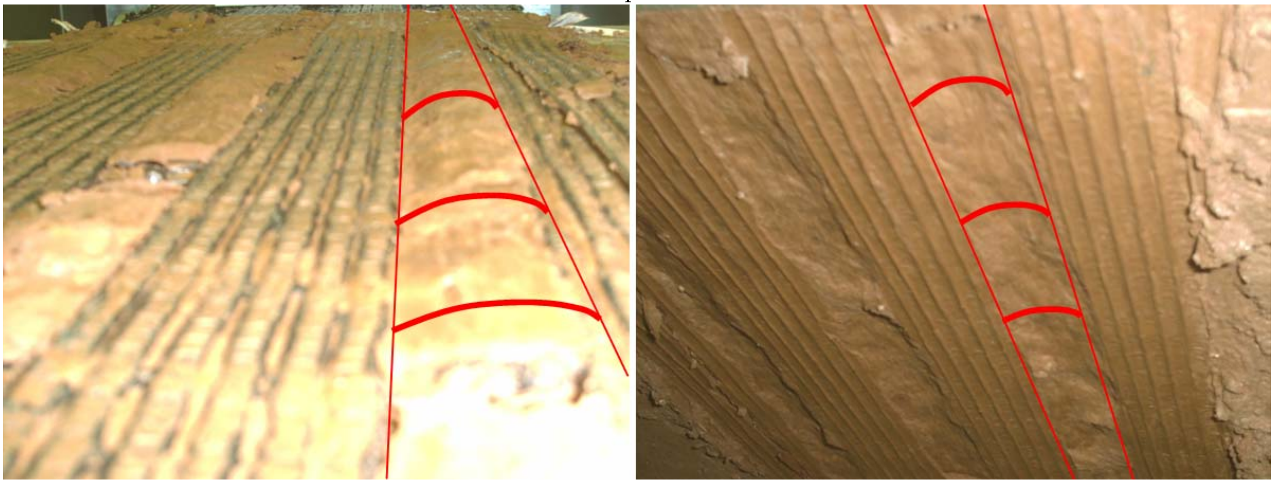

Figure 5. Pullout plane after the test – left: lower sample part with geogrid; right: upper sample part with copy of the longitudinal geogrid elements and arc-shaped failure of the soil

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