Interaction behaviour of geosynthetics in cohesive soils

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ABSTRACT: In a unique, systematic and extensive experimental study applying a large shear frame testing device, the interaction between different geosynthetics and cohesive soils both with and without stabilizing additives has been observed. In order to reach an efficient experimental schedule, multi-stage tests have been successfully applied both in shear, friction and pull-out tests in the large shear frame device. The comparison with single-stage experiments under identical soil mechanics conditions has shown that multi-stage tests yield nearly identical experimental results slightly on the safe side. The interaction behaviour of different geosynthetics in cohesive soils has demonstrated, that a perfect bond with interface friction factors of one is rarely reached. The interface friction factors showed higher values for friction failure than for pull-out failure of the examined geosynthetics. The use of stabilizing additives in the soil lead to the deterioration of the interface interaction performance. At the testing of cohesive materials, further issues regarding the sample installation procedure arise, leading to interesting additional information on geosynthetics interface behaviour.

1 INTRODUCTION

In the practical application of geosynthetics, the requirement for soils mostly with high shear strength as construction material is an important economic factor. In many occasions, the use of the soil encountered on the construction site would be economically very advantageous, even if the soil is cohesive and has relatively low shear strength. With the use of stabilizing additives like lime or cement, the shear strength can be significantly increased. However, the available knowledge on the interface properties of geosynthetics in cohesive soils with and without additives is quite limited as far. During project development, the quantitative evaluation of the interface properties of geosynthetics in the soils on site is complicated by the required high experimental effort, as in order to examine the interaction characteristics between geosynthetics with large structure and soils, experiments in a special large shear-frame device (interaction test device) are required.

In a unique, systematic and extensive experimental study applying a large shear frame testing device, the interaction between different geosynthetics and cohesive soils both with and without stabilizing additives has systematically been observed.

The systematic study of the interface behaviour of different geosynthetics and a cohesive soil with lime and cement additives has been carried out with a high strength uniaxial geogrid (short name HUG) and a high strength uniaxial geotextile (short name HUT) embedded into a slightly cohesive soil termed red silt I from the region of the city Chemnitz in Germany, where it is encountered over large areas.

In order to reach an efficient experimental schedule, multi-stage tests have been successfully applied both in shear, friction and pull-out tests in the large shear frame device. The comparison with single-stage experiments under identical soil mechanics conditions has shown, that multi-stage tests yield nearly identical experimental results for the determined shear strengths slightly on the safe side.

Test material:	ρ_s= [kg/m³]	w_P= [1]	w_L= [1]	I_P= [1]	w_{opt}= [1]	ρ_{Pr}= [kg/m³]
Red silt I without additive:						
Red silt I	2757	0.2916	0.5313	0.2397	0.1830	1695
Red silt I with 6% lime additive:						
Red silt I	-	-	-	-	0.2040	1571
Red silt I with 6% cement additive:						
Red silt I	-	-	-	-	0.2050	1612

Legend:
ρ_s : Grain density, [kg/m³]
w_P : Plastic limit, [1]
w_L : Liquid limit, [1]
I_P : Plasticity index, [1]
w_{opt} : Optimum water content, [1]
ρ_{Pr} : Proctor density at optimum compaction, [kg/m³]

Table 1: Soil physical test results

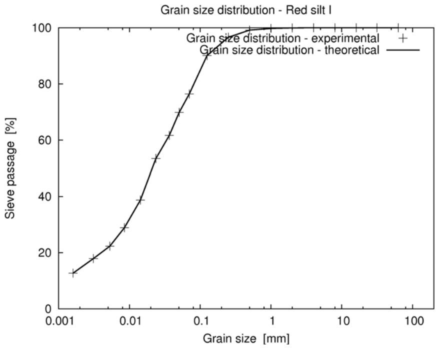

Figure 1: Grain size distribution of the tested soil

2 TEST MATERIAL

In preparation of the tests in the large shear frame device, soil physical tests were carried out on the cohesive material red silt I (abbreviation RLI). The test results are presented in the table 1. The grain size distribution of the soil is shown in the figure 1. The grain size distribution and the consistency parameters of the red silt I show that it is a strongly clayey and sandy silt with high plasticity. In preparative tests it has also been shown, that with 6% lime (abbreviation K6) and 6% cement (abbreviation Z6) additives a significant but also economically optimum shear strength improvement can be obtained.

The table 1 also shows the results of dynamic compaction tests on the densification characteristics of the examined soils. With stabilizing additives, higher optimum water contents with lower maximum densities have been observed. At the installation of the samples in the large shear frame tests, the dry density could not reach the level of optimum densification due to the lower available compaction energy. In the large shear frame tests on the red silt I without additives, an initial dry density of ρ_d=1600 [kg/m³] could be reached. With 6% lime additive, the initial dry density dropped to ρ_d=1400 [kg/m³] and with 6% cement additive to ρ_d=1500 [kg/m³]. The optimum water content w=0.1830 [1] of the untreated red silt I material has been held constant over the test series both with and without additives.

3 TEST DEVICE

The present study has been carried out with the large shear frame device (the geosynthetics-soil interaction testing device, short IPG) of the Geotechnical Institute at the Freiberg University of Mining and Technology. The figure 3 gives an overview and the table 2 shows the technical parameters of the large shear frame device.

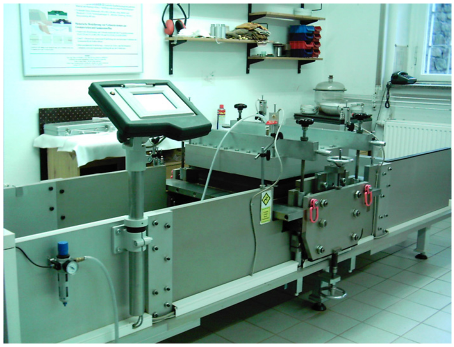

Figure 3: Overview of the test device

The lower and upper shear frame of the test device has a volume of V=50 [dm³] and for each test a soil mass of m=80...120 [kg] has to be installed depending on the required density. Before the tests, the examined soil sample is homogenized and its water content is regulated with an appropriate mixing device. The soil sample is installed into the large frame shear device stepwise in individual compacted layers of prescribed volume and weight in order to control the initial density.

Size of shear frame:	L = 500, B = 500, H = 200 [mm]
Normal stress range:	σ = 0 ... 600 [kN/m²]
Shear stress range:	τ = 0 ... 500 [kN/m²]
Maximum shear and pull-out force:	F_{max}= 125 [kN]
Shear velocity:	v= ± 0 ... 12,5 [mm/sec]
Maximum shear displacement:	u= 400 [mm]

Table 2: Test device parameters

With the large shear frame device, different test types can be carried out. In shear tests (abbreviation ISV), the shear strength of a soil sample is determined. Especially with cohesive soils, special attention should be paid to the sample installation in the region of the shear gap. Representative shear strength values for the tested soil material can be obtained only, if in the region of the shear gap a compact and adequately thick soil layer is installed.

In friction tests (abbreviation IRV), the shear strength between the tested soil and a geosynthetic material is examined for the failure mechanism, that the soil moves relatively to the geosynthetic material. In this test method, the geosynthetic material is installed into the shear gap level and fixed to the lower shear frame.

In pull-out tests (abbreviation IPV), the shear strength between the tested soil and a geosynthetic material is examined for the failure mechanism, that the geosynthetic material moves relatively to the tested soil. In this test method, the upper and lower shear frames of the large shear frame device are fixed to each other and the tested geosynthetic material embedded into the soil on the shear gap level is pulled out with a suitable roll or flat clamp.

The mechanical construction of the large shear frame device allows for the vertical movement of the upper shear frame during a conducted test. This offers the special advantage, that the shear gap can adjust itself to the volume deformation characteristics of the tested material during the experiment. Alternatively, the shear gap size can also be constrained to a fixed value.

In spite of the extensive experimental effort, large shear frame tests remain the only practical method to the determination of the interface characteristics between geosynthetics and soils that are required for engineering design purposes.

4 TEST METHOD

During the experimental analysis of the interface characteristics of geosynthetics and soils in large shear frame tests, the examined samples are usually installed with a high initial dry density and also reach a significantly high stiffness. Thus, the shear displacement at shear strength is usually very low. At the low shear velocity usually applied in large shear frame tests, the ductility of the soil sample allows for the observation of the pre-failure development of shear stresses approaching the shear strength and for stopping the experiment before the sample can suffer significant shear strain damage. Based on these observations, a multi-stage testing procedure has been developed in order to improve the experimental method of large shear frame tests, basically consisting of the following procedure:

1. Consecutive consolidation and reconsolidation of the sample under different increasing or decreasing normal stress load levels
2. Consecutive shear loading of the sample until the shear stresses approximately reach the shear strength level corresponding to the normal stresses in the pre-failure shear load range or a prescribed level of the shear displacement is reached in the post-failure shear load range

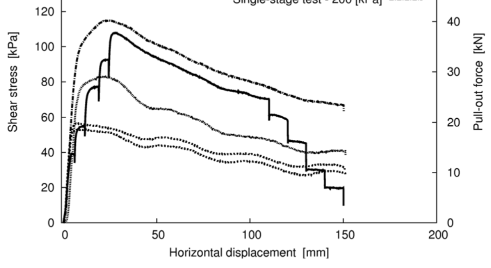

Figure 4: Verification pull-out test

In order to validate the results of multi-stage experiments, an extensive series of comparative tests with conventional single-stage experiments has been carried out under identical soil physical and mechanical conditions, including all the large shear frame test types introduced above. In figure 4 the comparison of single-stage and multi-stage pull-out tests show an acceptable correspondence of results.

Test number:	Test results:					
	φ_f'	c_f'	λ_φ	λ_c	λ_φ'	λ_c'
	[°]	[kPa]	[1]	[1]	[1]	[1]
ISV – Shear tests:						
ISV-00-RLI-OPT-200-00-V1	**25,6**	**32,7**	REF	REF	1,01	1,46
ISV-00-RLI-OPT-200-00-X1	26,0	21,8	1,02	0,67	REF	REF
ISV-00-RLI-OPT-200-00-X2	24,8	23,0	0,97	0,70	REF	REF
ISV-00-RLI-OPT-200-K6-V1	**32,5**	**39,6**	REF	REF	1,02	1,53
ISV-00-RLI-OPT-200-K6-V2	**34,1**	**39,9**	REF	REF	1,08	1,54
ISV-00-RLI-OPT-200-K6-X1	32,1	25,9	0,95	0,65	REF	REF
ISV-00-RLI-OPT-200-Z6-V1	**31,9**	**57,7**	REF	REF	1,12	1,58
ISV-00-RLI-OPT-200-Z6-X1	29,0	36,5	0,89	0,63	REF	REF
IRV – Friction tests:						
IRV-HUG-RLI-OPT-200-00-V1	**25,9**	**23,1**	1,01	0,71	1,02	1,03
IRV-HUG-RLI-OPT-200-K6-V1	**30,8**	**27,3**	0,91	0,69	0,95	1,05
IRV-HUG-RLI-OPT-200-Z6-V1	**28,9**	**24,8**	0,89	0,43	1,00	0,68
IRV-HUT-RLI-OPT-200-00-V1	**31,8**	**8,7**	1,30	0,27	1,31	0,39
IRV-HUT-RLI-OPT-200-00-V2	**29,4**	**17,4**	1,18	0,53	1,19	0,78
IRV-HUT-RLI-OPT-200-K6-V1	**28,4**	**27,3**	0,82	0,69	0,86	1,05
IRV-HUT-RLI-OPT-200-K6-V2	**29,5**	**19,5**	0,86	0,49	0,90	0,75
IRV-HUT-RLI-OPT-200-Z6-V1	**31,2**	**13,3**	0,97	0,23	1,09	0,36
IRV-HUT-RLI-OPT-200-Z6-V2	**28,6**	**17,7**	0,88	0,31	0,98	0,49
IPV – Pull-out tests:						
IPV-HUG-RLI-OPT-200-00-V1	**21,0**	**34,2**	0,80	1,05	0,81	1,53
IPV-HUG-RLI-OPT-200-K6-V1	**21,9**	**30,5**	0,61	0,77	0,64	1,18
IPV-HUG-RLI-OPT-200-Z6-V1	**27,0**	**31,3**	0,82	0,54	0,92	0,86
IPV-HUT-RLI-OPT-200-00-V1	**23,3**	**8,6**	0,90	0,26	0,91	0,38
IPV-HUT-RLI-OPT-200-00-V2	**22,6**	**12,6**	0,87	0,38	0,88	0,56
IPV-HUT-RLI-OPT-200-K6-V1	**23,3**	**13,1**	0,66	0,33	0,69	0,50
IPV-HUT-RLI-OPT-200-Z6-V1	**16,8**	**17,2**	0,49	0,30	0,54	0,47
IPV-HUT-RLI-OPT-200-Z6-V2	**21,1**	**17,7**	0,62	0,31	0,69	0,48
IPV-HUT-RLI-OPT-200-Z6-V3	**19,5**	**15,9**	0,57	0,28	0,64	0,44

Legend:
ISV: Shear test, IRV: Friction test, IPV: Pull-out test
00: without geotextile
HUG: high strength unaxial geogrid
HUT: high strength uniaxial geotextile
RLI: test material red silt I
OPT: sample installation with optimum water content
200: normal stress range of the tests 0 ... 200 [kN/m²]
00: without additive, K6: with 6% lime additive, Z6: with 6% cement additive
V1, V2, V3: Test number, installation of the sample with compact shear zone in shear tests (ISV)
X1: Test number, installation of the sample with divided shear zone in shear tests (ISV)
φ_f'. Peak angle of internal friction, c_f': Peak cohesion
λ_φ: Interface factor for the angle of internal friction derived from tests with compact shear zone
λ_c: Interface factor for the cohesion derived from tests with compact shear zone
λ_φ': Interface factor for the angle of internal friction derived from tests with divided shear zone with weak plane
λ_c': Interface factor for the cohesion derived from tests with divided shear zone with weak plane
REF: reference value of the shear strength parameters to the derivation of interface factors

Table 3: Test results

5 TEST RESULTS AND CONCLUSIONS

In order to study the interface behaviour of a high tensile strength uniaxial geogrid and geotextile in cohesive soils with and without additives, a systematic test series has been carried out. The test results are presented in table 3 in detail. The partial interface factors λ_φ, λ_c, λ_φ' and λ_c' have been derived from the ratio of the obtained peak shear strength parameters in the individual tests respectively, the tangent of the friction angle tan(φ_f') and the cohesion

c_f', and their counterparts from reference shear tests on the test soil marked with REF in table 3. The lower valued interface factors λ_φ and λ_c have been calculated from shear tests with a compact soil zone in the shear gap level. The higher valued interface factors λ_φ' and λ_c' have been determined from shear tests with a divided soil zone and a weak plane in the shear gap level, better indicating the real interaction effects between geosynthetics and the tested soil.

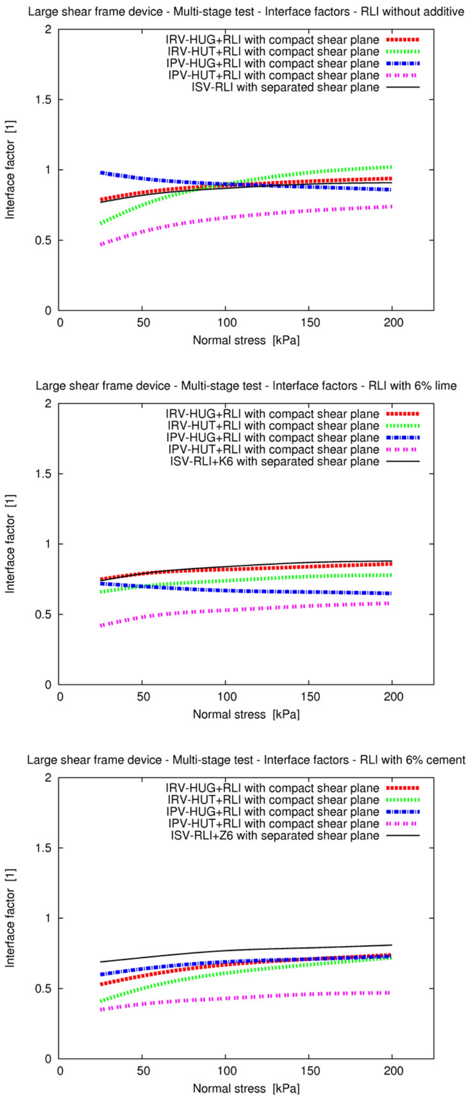

Figure 5: Derived stress dependent interface factors

Additionally, from the comparison of the shear stresses at failure, stress dependent interface factors have been derived and presented in figure 5. With a thin straight line, virtual interface factors have additionally been plotted that have been determined from shear tests on the test soil red silt I (RLI) with compact and divided shear zone. The comparison between the stress dependent interface factors clearly demonstrates the interaction behaviour of the examined different geosynthetics types in cohesive soils with and without soil additives. In general, the examined geogrid (HUG) has mostly reached significantly higher interface factors than the examined geotextile (HUT).

From the obtained results, the following conclusions can be drawn for the interface behaviour of the examined different geosynthetics types and cohesive soils with or without additives:

- **Experimental procedure:** in the usual experimental procedure for the derivation of interface factors, a compact soil zone in the shear gap level is used, underestimating the real geosynthetic soil interface interaction performance.
- **Lower interface factors at the use of additives in the cohesive soil:** due to the significant increase in the soil strength, the resulting interface factors are systematically lower for the tests, where additives have been used for soil improvement.
- **Stronger reduction of the cohesion with geotextiles:** the cohesion is significantly reduced due to the complete separation of the soil by the geotextile in the shear plane.
- **Better interaction effects with geogrids:** the open structure of geogrids does not lead to full separation of the soil in the shear plane. Additionally, a higher friction effect can mostly be observed in the interface shear strength results.

Multi-stage large shear frame tests yield a shear strength for soils with our without reinforcement on the safe side within the tolerance for engineering calculations and can be recommended as an economic and very time efficient alternative to single-stage tests at the determination of interface factors for geosynthetics required for project development.

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