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Interface friction between geosynthetics and soils and between different geosynthetics

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ABSTRACT: The friction parameters in contact areas of geosynthetics and soils are important for stability analyses of liner systems. In Germany no standardized experimental procedure for friction tests is available. The Working Group 5.1 of the German Geotechnical Society is preparing recommendations concerning friction tests and initiated interlaboratory tests. This paper presents some results of the first part of the interlaboratory tests and some results of supplementary tests performed by the Institut für Grundbau, Bodenmechanik und Energiewasserbau (IGBE) of the University of Hannover. The aims of the second part of interlaboratory tests and the idea and headlines of the recommendations in preparation are pointed out.

1 INTRODUCTION

Nowadays it is usual to build liner systems of different soils and geosynthetics. Landfill liner systems are often inclined in slope areas. The stability of the slopes has to be analysed using the methods of soil mechanics and foundation engineering. The friction parameters of the contact areas between soils and geosynthetics and between different geosynthetics are required for the stability analyses.

The friction parameters have to be determined experimentally. Mainly direct shear laboratory equipment is used to investigate the friction between geosynthetics and soils and between different geosynthetics. In Germany friction test methods for site specific conditions are still discussed (e.g. Saathoff 1991, Düllmann and Seppelfricke 1993, Blümel and Brummermann 1994, Fillibeck and Heyer 1995). The testing institutes use different test procedures and obtain different results for the same test cases. Therefore it is necessary to improve and standardize the test procedure. With this aim the Working Group 5.1 of the German Geotechnical Society initiated interlaboratory friction tests with direct shear equipment and is preparing recommendations on "Friction between different geosynthetics and between geosynthetics and soils".

The intention of this paper is to show the problems and to give a short report about the first results of interlaboratory tests, about some results of own supplementary tests and about the German recommendations in preparation.

2 PROBLEMS

2.1 *New field of application*

The use of geosynthetics in geotechnical engineering is new in relation to soil materials. Often the design and construction procedures for landfills including the liner systems are not approved. Analytical and experimental investigations are required. A lack of coordination and communication between many different engineers responsible for design, construction, production etc. and authorities might lead to problems. Part of these organizational problems is the determination of friction parameters treated in this paper.

In addition to the organizational problems experimental investigation of friction in contact areas between geosynthetics and soils is difficult. Already with the determination of shear strength of cohesive soils there may arise problems. Friction tests in contact areas between geosynthetics and soils are even more complex. Soil and geosynthetic material aspects have to be considered. Often the test institutions have experience only on soils or on geosynthetics due to their former field of working.

2.2 *Complex cases*

Liner systems are very variable. We may have contact areas between:
- geomembrane and geotextile,
- geomembrane and cohesive soil,
- geomembrane and non - cohesive soil,
- geotextile and cohesive soil and
- geotextile and non - cohesive soil.

There are only direct neighbours listed. A geotextile can be an external component of a geosynthetic composit. The friction in contact areas is often influenced by the surrounding liner components. If we have to consider the surrounding liner system components we multiply the possibilities of variations. Moreover soils have varying soil mechanical properties and geosynthetics are made of different materials with different structures.

2.3 *Multiple experimental choice*

Friction tests for a single contact area can be performed in different ways concerning:
- the test procedure (e.g. direct shear apparatus or tilt table, regulation of displacement or force),
- the apparatus (e.g. guidance of the frame or not),
- the testing system and the fixing of the geosynthetics (e.g. soil in the upper or lower frame, clamping or gluing of the geosynthetics),
- the handling (installation method, consolidation, velocity etc.) and
- the determination of friction parameters (e.g. different definition of the limit states).

3 GERMAN INTERLABORATORY TESTS AND OWN SUPPLEMENTARY TESTS

3.1 *First part of interlaboratory tests and own supplementary tests*

Caused by the problems with site specific friction tests the German Geotechnical Society initiated and the Institut für Grundbau, Bodenmechanik und Energiewasserbau (IGBE) at the University of Hannover organized interlaboratory tests with 20 different participants. Three cases had to be investigated using direct shear equipment with a minimum friction area of 30 * 30 cm²:
- case A: Geomembrane (GM)/Geotextile (GT),
- case B: Geomembrane (GM)/Clay (C) and
- case C: Geotextile (GT)/Sand (S).

Table 1 gives information about the test materials and the test instructions. The instructions still allow free determination of several test conditions by the participants, but are more detailed as usually given for commercial performance tests in Germany up to now.

It is impossible to describe all interlaboratory friction test results in this paper. Some basic results and evaluations are given and some selected aspects are discussed.

Table 1. Interlaboratory test materials and instructions.

case	A: GM/GT	B: GM/C	C: GT/S
material 1	HDPE - geomembrane (2.5 mm thick, rough)	HDPE - geomembrane (2.5 mm thick, textured with squares and knubs)	mechanically bonded HDPE - nonwoven (300 g/m²)
material 2	mechanically bonded PP - nonwoven (1200 g/m²)	medium plastic clay (dry density 1.61 g/m³, water content 24 %)	standard sand according to DIN EN 196 (0/2 mm, dry)
normal stress	20, 50, 100 and 200 kN/m²	ditto	ditto
shear velocity	10 mm/h	≤ 1 mm/h (drained condition)	10 mm/h
preconsolidation	no	up to the end of consolidation/settlements	no
further instructions	application of an internal draft of the German recommendations and collection of proposals to improve the recommendations		

In general the range of the interlaboratory test results is great. Figure 1 shows the friction stress vs. displacement for some tests with a normal stress of 100 kN/m² of case A, B and C. The type of the curves and the friction values are different. It is difficult to analyse the differences because more than one test condition vary between the tests of different participants and it is therefore impossible to separate their effects.

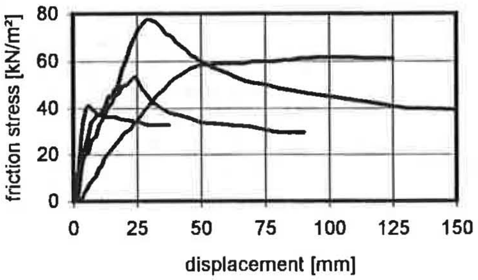
The test reports of the participants showed a great variance of test conditions. This was not only because of the use of different equipment. Tests performed with the same equipment led to a great range of results, caused by variations of the test conditions.

Figure 2 explains the definitions given by the IGBE to interpret the friction stress - displacement - curves of interlaboratory and supplementary tests. The abbreviation F is used for peak or failure friction stress and R for residual friction stress. The study of the interlaboratory test reports shows that the participants themselves used different definitions to interpret their test results.

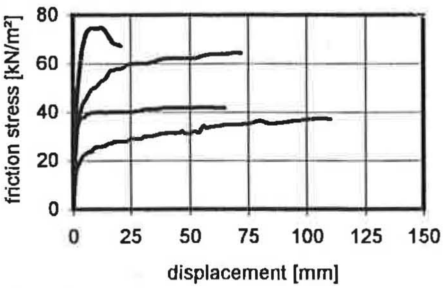
The following figures with selected results of the interlaboratory tests show some trends concerning single test conditions although other conditions may vary as explained above.

Figure 3 shows the peak friction stress vs. normal stress for tests of case A with varied geosynthetic fixing. The effect of fixing can not be evaluated clearly due to the effects of other varying test conditions.

a) Case A.



b) Case B.



c) Case C.

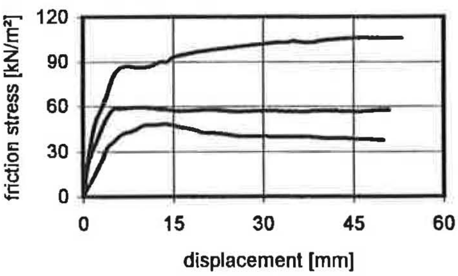
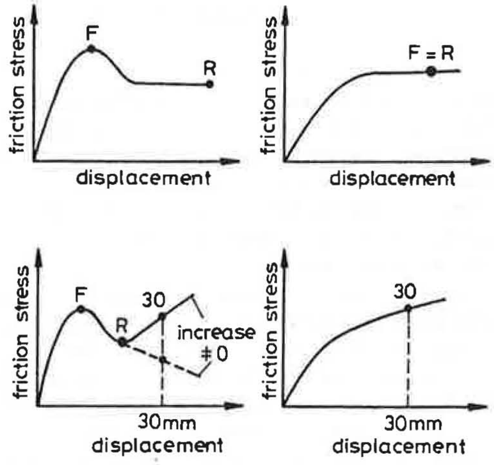


Figure 1. Friction stress vs. displacement for some tests with a normal stress of 100 kN/m².



F: peak or failure friction stress
R: residual friction stress
30: friction stress according to a certain displacement, e.g. 30 mm

Figure 2. Peak and residual friction stress definitions used by the IGBE.

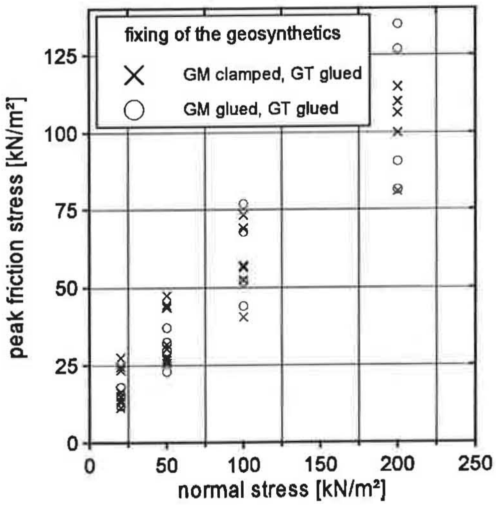


Figure 3. Peak friction stress vs. normal stress for some tests of case A with varied fixing of geosynthetics.

Figure 4 shows the peak friction stress vs. normal stress for tests of case B with varied geomembrane fixing and varied initial water content of the clay. The effects can not be separated clearly. An increase of water content seems to decrease the peak friction stress as expected from the soil mechanical point of view. There seems to be a tendency that the friction stresses of tests with glued geomembranes are smaller than those of tests with clamped geomembranes.

Figure 5 shows the peak friction stress vs. normal stress for tests of case C with varied geotextile fixing. The friction stresses of tests with clamped geotextiles are smaller than those of tests with glued geotextiles, but there are outliers out of this trend.

Figure 6 shows the peak friction stress vs. clay initial water content for tests of case B with varied normal stress. There seems to be the tendency that the friction stress increases with decreasing water content for higher normal stresses.

Figure 7 shows the peak friction stress vs. initial sand density for tests of case C with varied normal stress. No clear tendency is to be recognized.

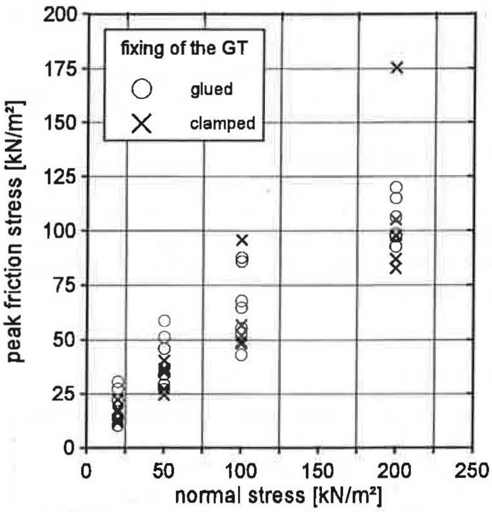


Figure 5. Peak friction stress vs. normal stress for some tests of case C with varied fixing of the geotextile.

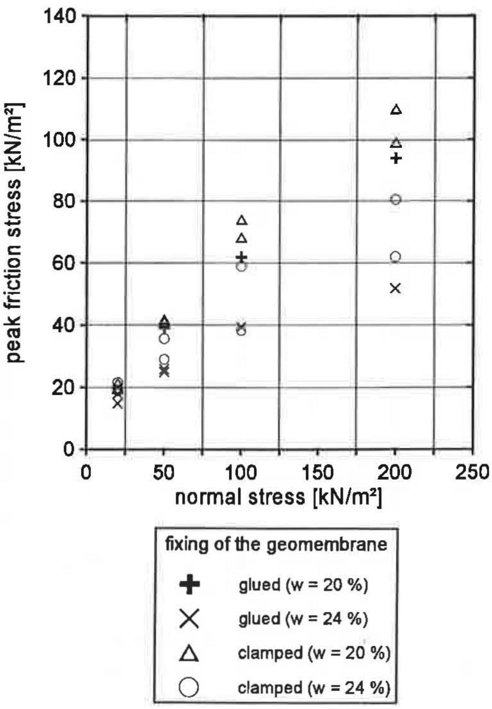


Figure 4. Peak friction stress vs. normal stress for some tests of case B with varied geomembrane fixing and initial water content of the clay.

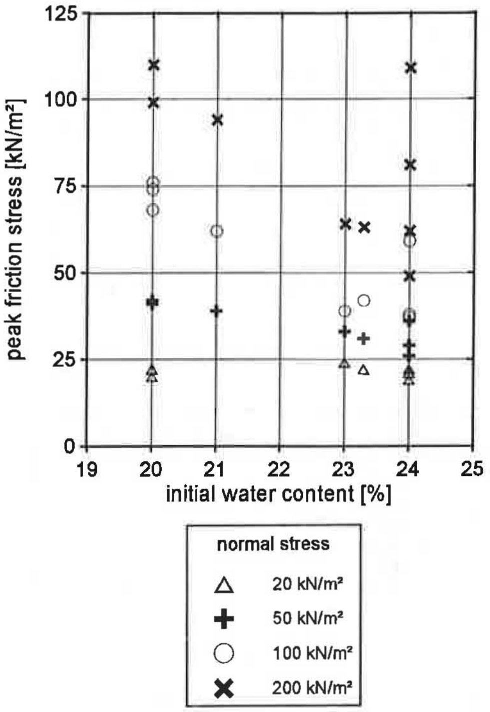


Figure 6. Peak friction stress vs. clay water content for some tests of case B with varied normal stress.

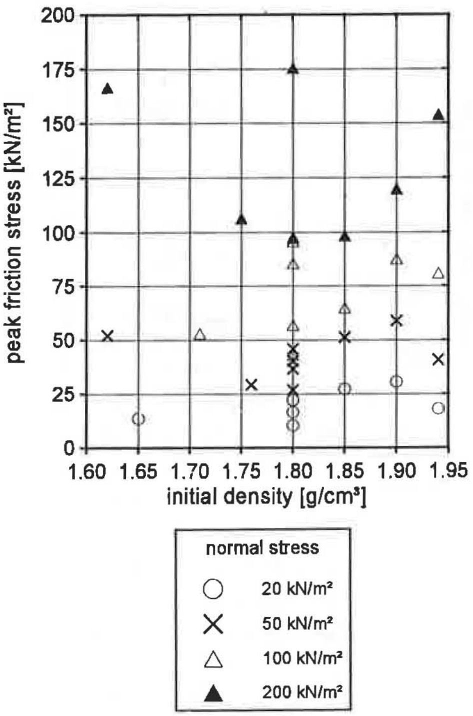


Figure 7. Peak friction stress vs. sand density for some tests of case C with varied normal stress.

During the analyses of the first part of interlaboratory test results several supplementary tests were performed at the IGBE. The aim of these tests was to investigate the effect of some selected test conditions varying only one condition within each set of tests.

A direct shear apparatus with an upper and lower shear frame and a constant area of 30 * 30 cm² was used to perform supplementary tests for case A. The upper shear frame is fixed to the base of the apparatus. So the upper frame can not move in vertical and horizontal direction. The lower frame can move in horizontal direction. The system is loaded pneumaticly using a rubber pad below a steel plate fixed to the upper frame. The upper frame, the steel plate and the base of the apparatus form the support for vertical loading.

The geomembrane was glued to a rigid support in the lower frame. The nonwoven geotextile was either clamped to the upper frame and the frame was filled with sand using a sheet to reduce the side wall friction or the geotextile was glued to a rigid plate inside the upper frame.

The results are scattering within a wide range. The pneumatic loading system of rubber pad, the upper shear frame, the steel plate and the base of the apparatus seem to contribute to the scattering of the test results. The normal stress at the underside of the upper shear frame and its distribution are unknown. Therefore additional load measurement or modifications of the upper part of the test apparatus are required.

A direct shear apparatus with a constant friction area of 10 * 10 cm² was used to perform supplementary tests for case B and C (Lottmann 1996). The system is loaded mechanically. The upper frame is fixed in horizontal direction but vertical movement is possible. Therefore the amount of the normal force acting in the friction area is known, but the stress distribution within the area may be affected by side wall friction or by tilting of the upper frame.

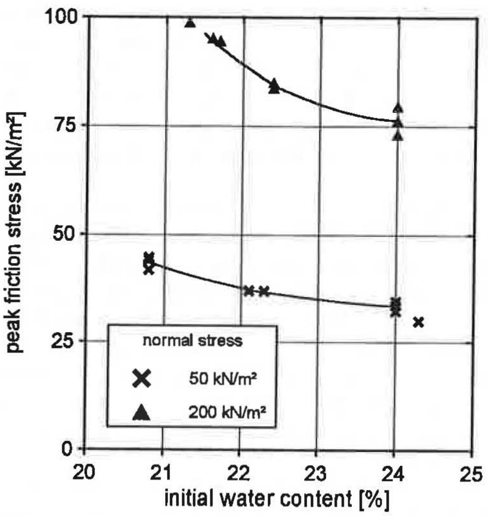
Figure 8a shows the peak friction stress vs. initial water content of supplementary tests for case B with varied normal stress. The correlation between friction stress and water content is better than in the interlaboratory test results. The peak friction stress decreases with increasing water content. With increasing normal stress the influence of water content increases. Figure 8b shows the friction stress vs. displacement for the tests with a normal stress of 200 kN/m². Only the curves of the tests with the low water content of about 21 % have a significant peak.

Figure 9a shows the peak friction stress vs. initial sand density of supplementary tests for case C with varied geotextile fixing. With increasing sand density the friction stress increases a little. The interlaboratory test results do not show this tendency due to the superposition with the influences of other test conditions. Figure 9b shows the friction stress vs. displacement for the tests with a normal stress of 200 kN/m². In tests with glued geotextiles the friction stress decreases after reaching a peak. The type of the curves of tests with clamped geotextiles is different. No peak friction stress is obtained for tests with clamped geotextiles, but the values of the residual friction stresses are approximately equal.

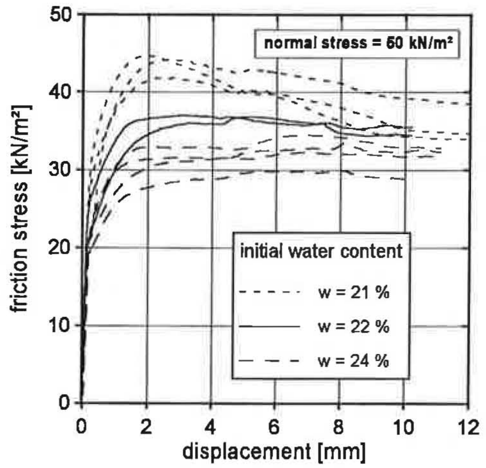
One important result of the first part of interlaboratory tests is that some test conditions which seemed to be unimportant up to now have a significant influence on the test results.

The first conclusions of the Working Group 5.1 are:

- The recommendations must give more detailed instructions especially concerning the loading equipment and procedure, the composition of the testing system including the surrounding components, the fixing of the geosynthetics, the distan-



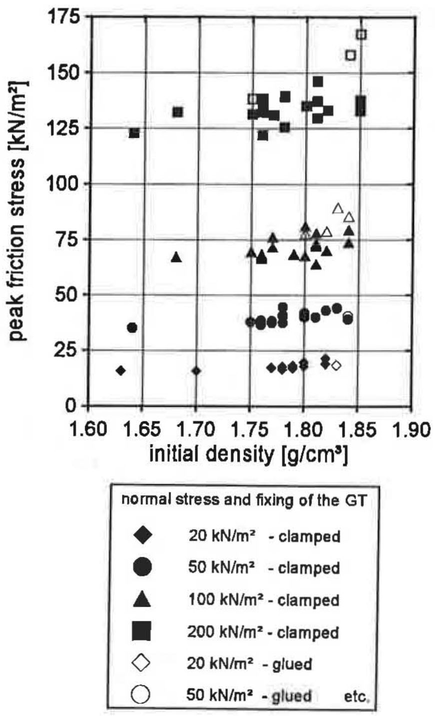
a) Peak friction stress vs. initial water content of the clay.



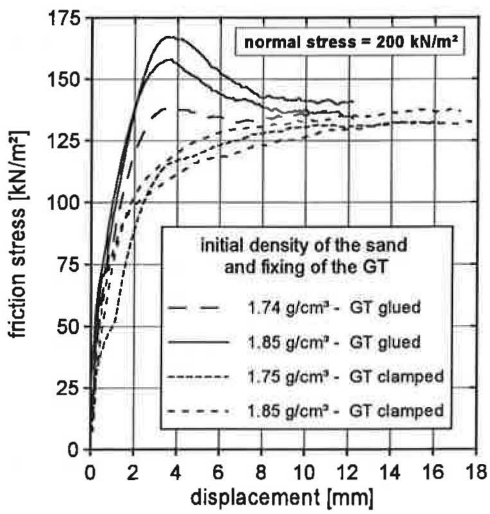
b) Friction stress vs. displacement for the tests with a normal stress of 50 kN/m².

Figure 8. Supplementary tests for case B with varied initial clay water content.

ce between upper and lower shear frame, the installation conditions of soils and the preconsolidation time. The instructions have to take into account the load - settlement - time relation of geotextiles. The suitablity of the proposed detailed instructions has to be checked carefully by tests.



a) Peak friction stress vs. initial density of the sand.



b) Friction stress vs. displacement for the tests with a normal stress of 200 kN/m².

Figure 9. Supplementary tests for case C with varied initial sand density and fixing of the geotextile.

- As it is impossible to cover every specific case or in situ condition, the recommendations shall focus attention on the important and critical points and help to solve the problems.
- Guidelines for the use of test results in stability analyses are necessary. Therefore additional investigation and evaluation about the transferability of test results to site specific conditions need to be done. A compromise between standardization aspects and the aspects related to site specific conditions is necessary.

3.2 *Second part of interlaboratory tests*

The Working Group 5.1 has started a second part of interlaboratory tests in Germany. Case A and C of the first part of interlaboratory tests are repeated with more detailed instructions. The additional instructions mainly concern the structure of the testing system including the indirect components, the fixing of the geosynthetics and the initial density of the sand.

The following supplementary instructions are given to the participants:

case A:

- gluing of the geomembrane using a rigid support within the lower frame
- possibility 1: clamping of the geotextile to the upper frame, installation of a 2 cm thick sand layer beyond the geotextile and of a load plate beyond the sand and adjusting a distance of the geotextile thickness at a load of 2 kPa + 1 mm between the underside of the upper frame and the geomembrane top edge
- possibility 2: gluing of the geotextile to a rigid plate using a double - sided splicing tape and adjusting the distance between the underside of the upper frame and the top edge of the geomembrane so that the geotextile is situated within the split

case C: holohedral fixing of the geotextile to a rigid support in the lower frame, installation of dry sand in the upper frame with a density of 1.8 g/cm^3 and adjusting a distance of 1 mm between the top edge of the compressed geotextile and the underside of the upper frame.

Also the participants are asked to check their loading systems and procedures if possible, e.g. by repeating tests.

The general aim of the second interlaboratory test programme is to reduce the scattering of the test results by further improved recommendations on test equipment and procedures.

4 GERMAN RECOMMENDATIONS IN PREPARATION

Caused by the problems explained in chapter 1 and 2 the Working Group 5.1 of the German Geotechnical Society is preparing recommendations on "Friction between geosynthetics and between geosynthetics and soils". Existing standards (e.g. ASTM D 5321 1992 and BS 6906 1991) deal with index tests. These geotechnical recommendations are related to performance tests. They are not addressed to test institutes only but also to design engineers, to geotechnical and other consulting engineers, to contractors, to producers of geosynthetics etc. Not only friction test procedures itselves are explained but also basic definitions and amendments concerning the use of the test results for stability analyses. As it is impossible to recommend standard test conditions for all site specific cases, it is also intended to give decision criteria and to focus the engineering sense on critical points. Because of the topical need the working group has at first concentrated its activity on friction tests with direct shear equipment and wants to publish a draft of the recommendations as soon as possible after closing the second part of interlaboratory tests.

The proposed content ot the recommendation shall cover:

- Definitions
  - Friction between the even surfaces of rigid bodies
  - Shear strength of soils
  - Friction between geosynthetics and soils
- Friction tests with direct shear equipment
- Use of experimental test results
  - Judgement of transferability from the test to the site specific conditions
  - Determination of design values
  - Use of the friction parameters in stability analyses

5 CONCLUSIONS

The experimental determination of friction parameters between geosynthetics and between geosynthetics and soils has to be improved, because site specific friction tests performed by different institutes often lead to different results. Usually there exist only few comparable site specific tests which makes it impossible to find out the reasons of the differences. Therefore interlaboratory tests assist to improve the test procedures. The attention of the interlaboratory test participants is directed to the test method only and not influenced by other interests.

A working group of the German Geotechnical Society initiated interlaboratory tests and is preparing recommendations. Due to about twenty different participants the diversity of direct shear equipment and the manifold variants of test conditions have been obtained. The data of the first part of interlaboratory test results give essential information to recognize critical points of friction tests, e.g. the effective load and the stress distribution in the friction area, the fixing of the geosynthetics, the initial water content and density of soils etc. Further interlaboratory and supplementary tests have been started. The test results shall improve and check the recommendations and shall help to solve the critical points. The interlaboratory test results also give basic information for the determination of partial safety factors for friction parameters between soils and geosynthetics and the use of peak or residual friction stresses in stability analyses. In addition field tests and investigations are needed to improve the transferability of standardized laboratory test results to site specific conditions.

In any case it is necessary that reports about site specific performance tests give detailed information about the test conditions and procedures. Otherwise it is impossible to evaluate the test results.

All important aspects of the tests and the specific civil engineering work have to be checked before using the friction parameters in stability analyses. Therefore the engineers responsible for the project must know the critical points of experimental friction tests, the behaviour of soil and geosynthetic materials, the aspects of stability analyses and the details of the specific civil engineering work. Otherwise they can not check the transferability of the test results to the site specific conditions and can not determine suitable, safe and economical design values of the friction parameters.

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