British-German cooperative research on geosynthetic friction testing methods

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ABSTRACT: For the stability analysis of geosynthetic constructions knowledge of the friction behaviour in the geosynthetic interfaces is essential. Usually direct shear tests are performed to investigate these interface friction characteristics. European and German intercomparision testing programmes have shown large scattering of the results. A cooperative research programme between Loughborough University, Leicestershire, UK, and Hanover University, Germany, was initiated in 1999 in order to improve British and German testing procedures. In this paper some results of friction tests for a nonwoven geotextile-textured geomembrane interface are presented. Different designs of shear boxes were used for testing in order to investigate the influence of test device configurations on friction test results. Based on the data from the cooperative testing programme preliminary recommendations on the test setup for geosynthetic friction testing, especially regarding the support of the top shear box, are given.

1 INTRODUCTION

Landfill lining systems usually comprise of different geosynthetic and mineral components, such as geomembranes, geotextiles or geocomposites and soils. Knowledge of the friction behaviour of the interfaces between the geosynthetic components and soils is essential for an assessment of the stability of inclined sealing systems.

Friction parameters for geosynthetic interfaces are commonly determined using a modified direct shear test known from soil mechanics. Although this test method is longstanding and well known for testing granular materials, the modification of testing devices creates some problems in the performance of friction tests with geosynthetics. In particular, each laboratory has developed its own testing procedures and hence the results from different laboratories might not necessarily be comparable. The lack of uniform testing procedures leads to uncertainty and insecurity in evaluation of test data and therefore in analysing the stability of lining systems.

Until now there is no European standard on friction testing, although one is in preparation. National standards or recommendations on testing procedures exist in the UK (BS 6906, Part 8) and in Germany (GDA, E3-8). A comparative testing programme for a geosynthetic-geosynthetic and a soil-geosynthetic interface has been performed at Hanover University, Germany, and Loughborough University, UK. In this paper only friction between a geotextile and a geomembrane is discussed. The friction behaviour of this interface is commonly considered to be investigated without major problems because soil mechanical aspects can be excluded.

2 SCATTERING OF FRICTION TEST RESULTS

Friction between textured geomembranes and nonwoven geotextiles is affected by the surface roughness of the geomembranes, by anisotropy in the texture, by the polymers of both friction partners, by effects due the production process of the nonwoven and by effects due to soil either above or below the geosynthetics e. g. drainage gravel. Nevertheless, attempts can be made to derive generic friction parameters for some geotextile-geomembrane interfaces for preliminary design purposes. Jones (1999) presents such a set of data compiled from a literature review, and also from his own tests for interfaces between textured geomembranes and nonwovens. The same evaluation was done by the Institute for Soil Mechanics and Foundation Engineering (IGBE) of Hanover University from different performance tests carried out at its laboratory.

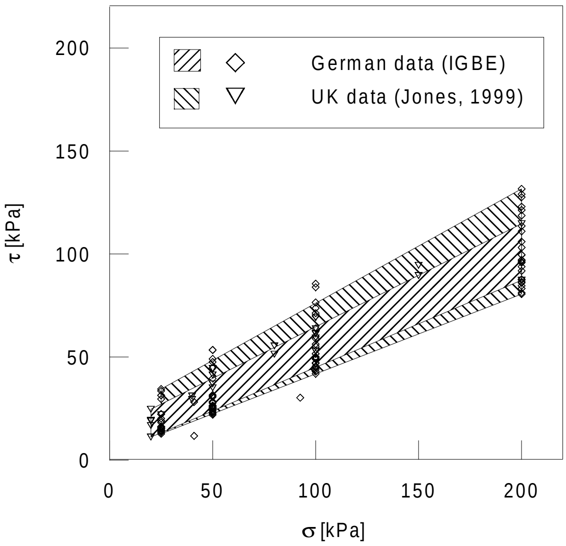

Figure 1: Peak friction stress τ vs. normal stress σ plots for different nonwoven - textured geomembrane interfaces under varying testing conditions (data from IGBE and Jones, 1999)

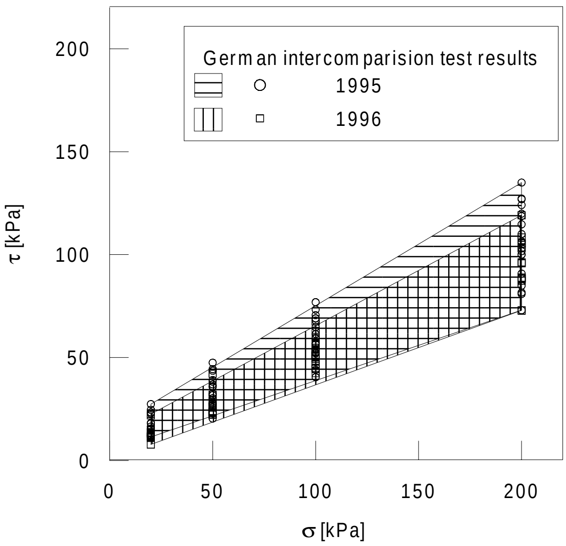

Figure 2: Peak friction stress τ vs. normal stress σ plots for a nonwoven - textured geomembrane interface; tests performed in different German laboratories under “condition of comparison”

Figure 1 shows the results of these evaluations. It has to be regarded that the data are gathered from tests performed with varying materials and testing conditions. In this context it should be noticed that external friction on interfaces between different materials, e. g. soil-geosynthetic or geosynthetic-geosynthetic, are described by the term friction stress. Whereas the term shear stress is solely used for the internal friction in soils.

In order get more information about the scattering of test data, that can be expected for tests conducted on different soil and geosynthetic combinations and to evaluate influences of testing procedures, comparative testing programmes were organized by an EC Measurement and Testing Programme (Gourc and Lalarakotoson, 1997) and also by the German Geotechnical Society. Both intercomparison testing programmes showed large scattering of test data. This could not be reduced significantly by a second attempt within the frame of the German testing programme. The European testing programme concentrated on sand geotextile interfaces. In the two German intercomparison testing programmes in 1995 and 1996 (Blümel *et al.*, 1997) the interface between a rough geomembrane and a nonwoven was investigated. The tests were performed under "conditions of comparison". The testing procedures were prescribed in more detail in the 1996 test series but scattering of the test data was still significant (Figure 2).

The intercomparison tests showed also that the variation of the test data increases with decreasing normal stresses applied. The coefficient of variation, defined as the ratio of standard deviation divided and mean, reaches from about 20 % at 200 kPa normal stress up to 30 % at 20 kPa normal stress for tests conducted in different laboratories. However, the coefficient of variation does not exceed the value of about 10 % for repetitive test performed at the IGBE and at Loughborough University. In Figure 3 the coefficients of variation for peak friction stresses are plotted vs. normal stress. Data are taken from the German intercomparison test series and from tests performed by the authors. Generally similar findings are reported by Philipp (1991), who evaluated direct shear tests on a clay under conditions of comparison. The coefficient of variation of shear strength for a normal stress of 100 kPa was 17 % and about 10 % for a normal stress of 600 kPa. Criley and Saint John (1997) analysed friction test results for different cohesive soil-geomembrane interfaces and found similar relationsships.

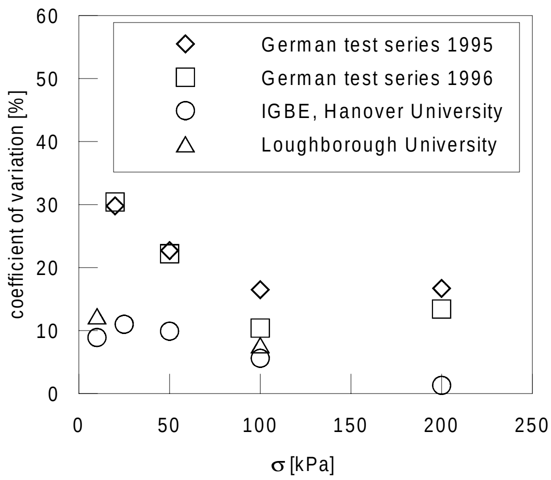

Figure 3: Coefficient of variation for peak friction stresses τ vs. normal stress σ for a nonwoven - rough geomembrane interface

At Loughborough University an additional research programme has been started to investigate geosynthetic friction behaviour at very low normal stresses, which are typical for cover sealing systems. The main aim is to quantify the scattering of friction data and define the required safety factors to be considered in landfill design. Preliminary results from this study are presented by Dixon *et al.* (2000). Essentially the results confirm the magnitude of variability found in previous studies even though using materials from one source, one shear box device (type 1), a detailed test specification and one operator.

3 EFFECTS OF TESTING DEVICES

3.1 *Testing devices*

The data scattering described above implies that the construction of the testing devices might affect the results of friction tests. At the Institute of Soil Mechanics and Foundations Engineering at Hanover University and the Geotechnics Group of the Department of Civil Engineering at Loughborough University different test equipment is available that represents most of the commonly used test configurations for friction testing.

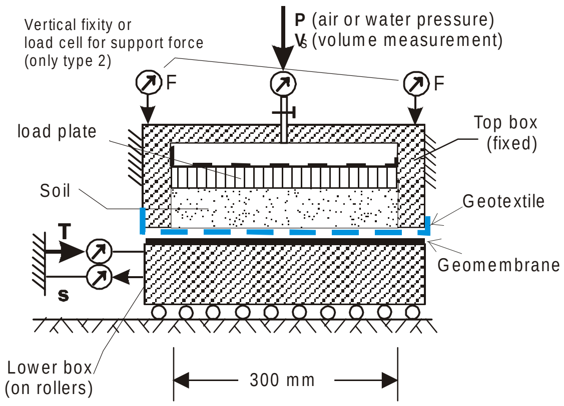

Figure 4: : Sketch of the fixed top box device (type 1 and 2) and the test setup for friction tests at Hanover and Loughborough University

All shear boxes have a top box of 300 mm x 300 mm. The lower box is 100 mm longer than the upper one so that the contact area is constant during the test. Normal stresses are applied by air or water pressure via a membrane.

The testing devices can be differentiated by the kinematic degrees of freedom of the top box. Type 1 has a fixed top box with no kinematic freedom. This type is available in both laboratories. A general sketch of these testing devices and the test setup is shown in Figure 4. The device at Loughborough University was manufactured by Durham Geo-Enterprises, Inc., Stone Mountain, Georgia, USA. The device at Hanover University was produced by Wille Geotechnik GmbH, Göttingen, Germany.

The latter device was further modified by the authors at Hanover University and the manufacturer as follows. For devices with a fixed upper box it is questionable whether a constant vertical stress, derived from the load applied to the top of the sample, is acting on the interface. Friction between the test material and the walls of the upper box, and other effects, must be considered.

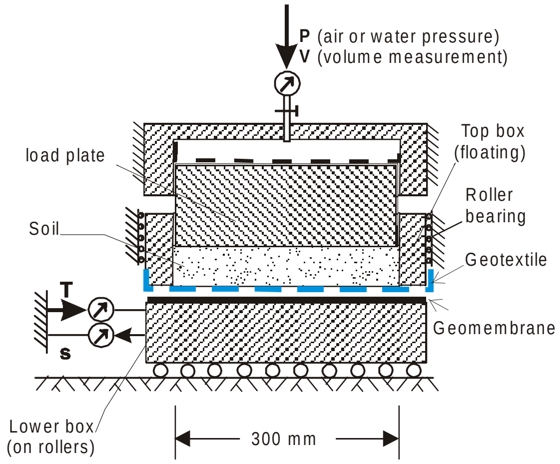

Figure 5: Sketch of the vertically movable top box device (type 3) and the test setup for friction tests at Hanover University

In a modified test device named type 2 the average vertical stress acting on the friction interface is determined by measuring the vertical forces at the corners of the fixed upper box. By summarizing the values of the vertical support forces the resulting vertical force acting on the interface can be obtained. The pressure applied to the top of the sample is regulated during horizontal displacement of the lower box in order to keep the resulting vertical force and average vertical stress acting on the friction interface at a constant value. This test setup is characterized in this paper by the term “normal load controlled”.

In both devices (type 1 and 2) the top box is fixed and vertical displacement is impossible or restricted by the elongation of the force transducers. So constraint forces may also act when the horizontal displacement is applied. These effects are well known from direct shear tests on sand but also from friction test for interfaces between granular soils and geosynthetics (Stoewahse, 2000, Blümel and Stoewahse, 1998). In order to prevent such constraint forces the testing device was modified furthermore. The loading system was separated from the upper box which was then able to move vertically. This testing device, called type 3, is shown in Figure 5. Side friction losses during consolidation are eliminated by the normal load control unit, which is not shown in the sketch.

Table 1: Types of testing devices used

Type	top box	Loughborough University	Hanover University
1	fixed	yes	yes
2	fixed, normal load control	no	yes
3	vertically movable	no	yes

3.2 *Materials tested and general test setup*

A 2,5 mm HDPE geomembrane with an impingement of approximately 55 ± 5 g/m² was used. No significant anisotropy of the impingement was visible. The geomembrane was fixed to a rigid substrate and was also clamped on its tension side.

A PP nonwoven geotextile with an area weight of 1200 g/m² and a thickness of 8 mm at 2 kPa normal stress was used. It was clamped to the top box which was filled with a standard sand according to EN 196-1. The sand was compacted to a density of 1.8 g/cm³.

The friction tests were performed with dry materials. Both geosynthetics were tested in direction of production at nominal normal stresses of 10/25/50/100/200 kPa, and with a shear velocity of 1 mm/min. For the fixed top box device (type 1) the normal stress applied to the top of the sample is defined as the nominal normal stress. For the normal load controlled device (type 2) and for the vertically movable top box (type 3) the nominal normal stress was obtained from the transducer measurement and hence is related to the interface. These data discussed in detail below.

3.3 *Test results*

All test results are plotted as friction stress vs. displacement curves. In Figures 6 and 7 the results obtained with the fixed top boxes (type 1) at Loughborough and Hanover University are shown. At all nominal normal stresses the friction stresses measured with the device at Loughborough University are somewhat lower than the comparable values from Hanover University, especially for small normal stresses.

In Figres 8 and 9 the results obtained with the type 2 and 3 devices are displayed. The peak friction stress values differ from the fixed box (type 1) results and they also do not match each other.

In all fixed top box devices (type 1 as well as type 2) stretching of the geotextile seems to affect the stress-displacement behaviour in some tests (see Figures 7 and 8). These effects are discussed in section 3.4.

The shear device with the vertically movable top box produces a good performance, i. e. concerning the scattering of test data as well as the shape of the stress-displacement curves (Figure 9)

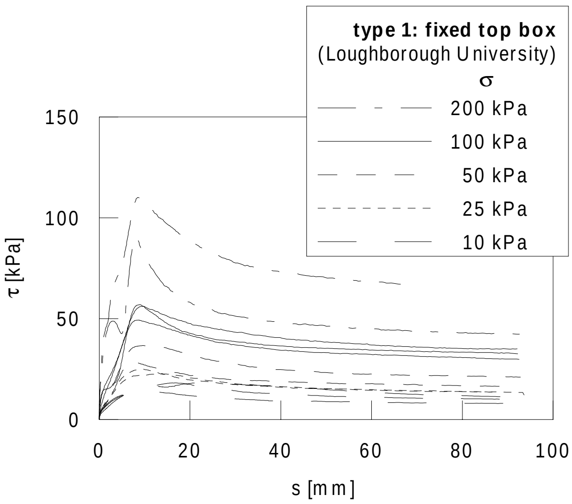

Figure 6: Friction stress τ vs. displacement s; fixed top box device (type 1) at Loughborough University

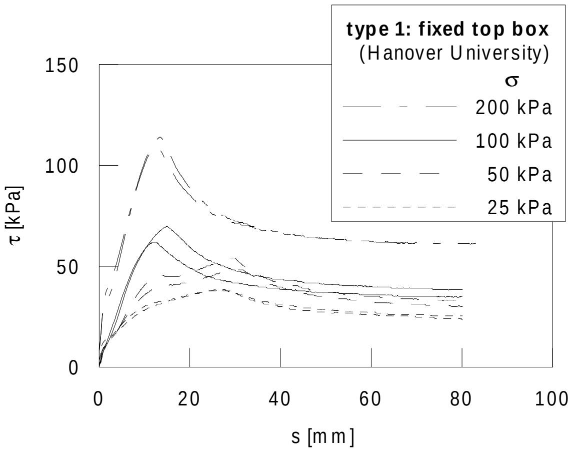

Figure 7: Friction stress τ vs. displacement s; fixed top box device (type 1) at Hanover University

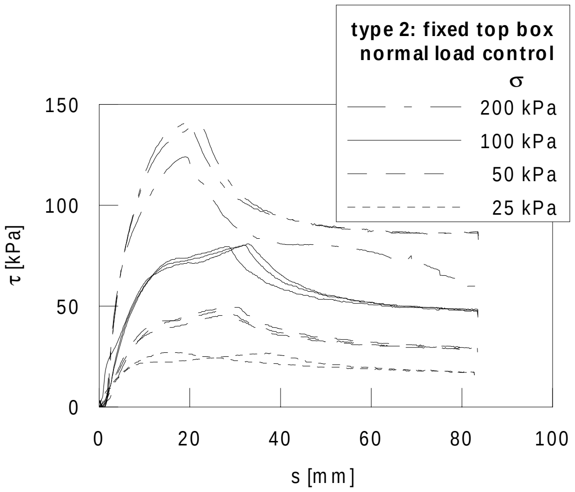

Figure 8: Friction stress τ vs. displacement s; normal load controlled fixed top box device (type 2)

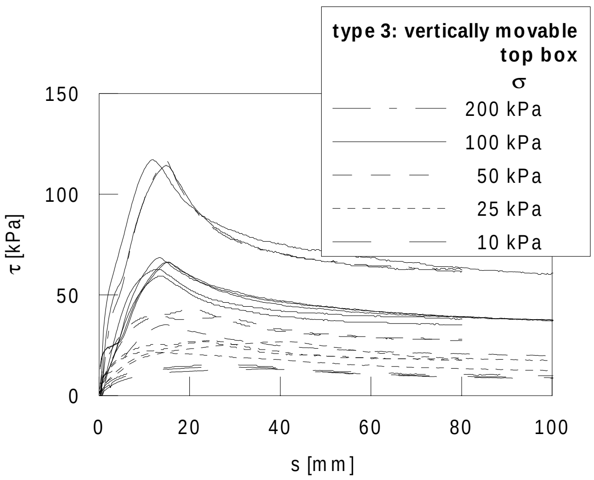

Figure 9: Friction stress τ vs. displacement s; vertically movable top box device (type 3)

3.4 *Shape of stress-displacement curves*

Friction stress-displacement curves for materials described in section 3.2 normally show a significant peak at displacements less than approximately 20 mm. With further displacement the friction stresses decrease and approach asymptotically a residual friction stress value.

In some tests maximum friction stresses are found at larger displacements. After a steep first part, the slope of the friction stress-displacement curves decrease significantly at displacements corresponding to those at which normally the peak is reached. This might be due to some slack in the system or stretching of the geotextile. If the friction forces between the sand fill in the top box and the geotextile is in the range of the horizontal forces acting in the geotextile-geomembrane interface then tensile forces may act in the geotextile. It will be stretched and failure can occur progressively starting from the mainly tensioned section of the geotextile.

The sand was filled into the top box with a relative density of about 0.6. For such a medium density of the sand the interface angle of friction between this sand and the geotextile is not larger than 30°. So contact forces between fill sand and geotextile might be lower than the geotextile-geomembrane friction especially at small normal stress levels. Under these conditions a slip surface may partly develop on the top side of the geotextile.

3.5 *Friction parameters*

In Figure 10 the peak friction stresses measured with the different devices are plotted versus normal stress. In Table 2 the friction parameters derived from these tests are listed. The friction parameters are defined in the same way as soil mechanical parameters according to the Coulomb yield condition. The friction parameters were determined by linear regression. The coefficients of determination R^2 are shown in Table 2 and found to be in the same level. Both fixed top box tests gave nearly the same friction angles, but different intercept values. The highest friction angle was obtained from the data measured with the normal load controlled fixed top box device.

One reason for the large differences between the results from the three fixed top box designs might be side friction effects caused by the soil above the geotextile. In the normal load controlled device the nominal normal stress is measured on the interface. The pressure applied via the membrane to the sand fill was logged separately and was up to 50 % higher than the normal stress on the interface. On the other hand, with the Hanover fixed top box device (type 1) at low normal stresses higher friction stresses were measured than in the normal load controlled device (type 2).

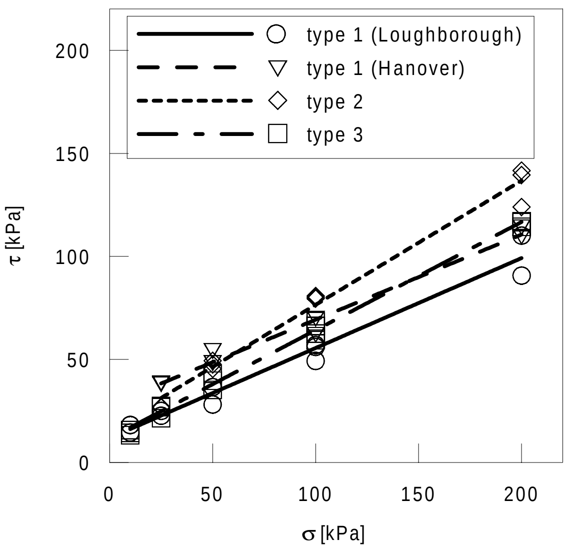

Figure 10: Peak friction stress τ vs. normal stress σ for a nonwoven geotextile – textured geomembrane interface; tests performed with different supports for top boxes

Table 2: Coulomb friction parameters for the geotextile-geomembrane interface obtained with different testing devices

device	δ [°]	a [kPa]	R^2 [-]
type 1			
(Loughborough)	23,6	11,8	0,97
(Hanover)	22,3	28,0	0,98
type 2	31,0	16,3	0,98
type 3	27,5	11,7	0,99

If the friction stress values measured with the fixed top box device (type 1) are related to normal stresses reduced by the ratio of measured interface stress to applied stress, the data would fit better to the data obtained with the normal load controlled devices (type 2).

Is the data shown in Figure 10 compared in general terms with the results given in Figures 1 and 2, it can be seen that the data are of the same order of magnitude, and that scattering is still significant if data obtained with different devices are compared. The repeatability of the tests in each device is good for most normal stress levels investigated.

4 PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

The determination of friction properties between different geosynthetics and between soil and geosynthetic in direct shear devices is complicated due to high scattering of data. Test equipment, boundary conditions, test procedures and the mechanical properties of soil affect the characteristics of the friction stress vs. displacement curves, and the magnitude of the peak friction stresses. Therefore, the experimental investigations, test setups and boundary conditions should reflect the expected situations at the site as closely as possible.

In the tests described in this paper a test setup according to the German GDA 3-8 was used. This test setup is similar to those documented in ASTM D 5321 and BS 6906, Part 8, and is recommended as a standard testing procedure as it also allows investigation of material effects, both above or below the geosynthetics (e. g. drainage gravel) on the interface friction behaviour. As shown in section 3.4, attention must be given to the friction characteristics between fill soil and geotextile. During the test stretching of the geotextile can occur and affect the friction-displacement behaviour of the investigated interface.

Interface friction properties of geosynthetics are usually tested in shear boxes developed for soil mechanics testing. As shown in Figure 10 the type of testing equipment and method of load application can affect the results of friction tests. Their effect has to be regarded and the kinematic conditions of the two boxes of the test device must be reported together with the results of the friction tests and other boundary conditions.

Effects of testing device construction on friction tests and direct shear tests results are being investigated experimentally and numerically at Hanover University (Stoewahse, 2000). According to current research, devices with a vertically movable top box show a good performance for shear tests on soils and for soil-geosynthetic friction tests. Therefore, this device can also be recommended for use with geosynthetic- geosynthetic interfaces.

To cover the data scattering observed and to obtain a sufficient data base for design purposes, it is recommended to carry out a sufficient number of tests by two different institutions for each project. The institutions that perform the friction tests, have to be provided with detailed information about the type of construction and about the construction materials. The properties of the tested soils have to be considered. The determination of test conditions, data evaluation and derivation of friction parameters for design calculations must be done in close cooperation with the engineers responsible for design and stability calculations.

At the low normal stresses acting in landfill covers data scattering of friction tests is still very high, and material variability, test setups or testing device have a greater impact on the test results. Recommendations are expected from the results of the investigation on geosynthetic friction behaviour at low normal stresses, which is part of a research project running at Loughborough University.

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