DESIGN AND EVALUATION OF AN ENHANCED SHEAR AND PULL-OUT TESTING DEVICE

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Abstract: Considering practical aspects of the use of geosynthetics as reinforcement element or as construction material with complex functions in innovative civil engineering applications, a new testing apparatus for direct shear- and pullout-tests has been developed and built for the examination of the interaction behaviour of soil-geosynthetic-compound-systems.

Within the frame of this paper, the newly developed device, called Geosynthetic-Soil-Interaction-Testing-Device is introduced first. In comparison with known geosynthetic testing practice, the novel testing apparatus offers the special advantage that a wide range of innovative shear and pullout test procedures can be carried out in the same device with negligible influence of test device configuration on friction test results. This device can be used for determination of all required parameters for the stability analysis of geosynthetic constructions at mechanically correct kinematic and kinetic boundary conditions.

The interaction behaviour between commonly used geosynthetics and soils are examined in an extensive series of shear and pullout tests. In order to develop device configurations with mechanically correct kinematic and kinetic boundary conditions, the experimental work emphasises the investigation of influence factors from the test boundary conditions on the test results.

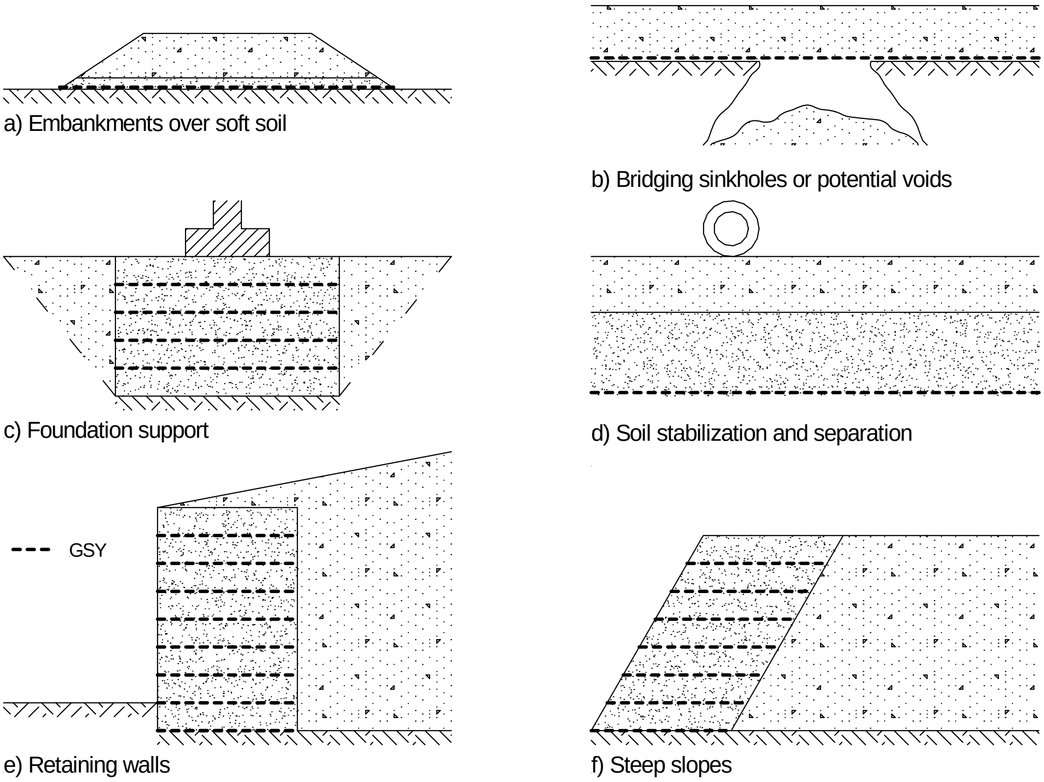
From the obtained results, a recommendation is given for a suitable device configuration regarding mechanically correct boundary conditions for the determination of the interaction parameters.

Keywords: Laboratory test, direct shear test, pull-out test, boundary friction, interaction.

INTRODUCTION

Today geosynthetics are used in a large range of civil and geotechnical engineering applications. Geosynthetics are products such as geotextiles, geogrids, geomembranes etc. They have been used successfully for separation, filtration, draining, reinforcing, protection, sealing and further specific functions for over 30 years. Employing geosynthetics instead of using conventional methods offers significant technical and cost advantages.

Being economic and ecological, there is a growing global tendency towards geosynthetic use in innovative civil engineering, especially as reinforcing elements in a wide variety of structures. Nowadays it is not uncommon to see their application on reinforced slopes and walls, embankments on soft soils, reinforcement in the base layers of railroad- and roadconstructions, reinforced foundation mattresses, or even the bridging of sinkholes or reinforced abutments (Figure 1).



a) Embankments over soft soil

b) Bridging sinkholes or potential voids

c) Foundation support

d) Soil stabilization and separation

e) Retaining walls

f) Steep slopes

Figure 1. Range of applications of geosynthetic reinforced soil (Aydogmus, 2007)

For the stability analysis of geosynthetic constructions knowledge of the friction behaviour in the geosynthetic interfaces is essential. For the assessment of the main failure mechanisms of a geosynthetic-reinforced-soil construction shear- and friction tests are usually performed, as well as now also pullout tests. In the following, a novel experimental apparatus for the examination of the interaction behaviour of soil-geosynthetic-compound-systems capable of performing both pullout and direct shear tests is described.

The interaction behaviour between commonly used geosynthetics and soils are examined in an extensive series of shear and pullout tests. In order to develop device configurations with mechanically correct kinematic and kinetic boundary conditions, the experimental work emphasises the investigation of influence factors from the test boundary conditions on the test results.

From the obtained results, a recommendation is given for a suitable device configuration regarding mechanically correct boundary conditions for the determination of the interaction parameters.

GEOSYNTHETIC-SOIL-INTERACTION-TESTING-DEVICE

Apparatus Specification

For the examination of the interaction behaviour of soil-geosynthetic-compound-systems a new test device, called the Geosynthetic-Interaction-Testing-Device (GITD), has been developed. This device is capable of performing both pullout and direct shear tests. A schematic cross section and a photo of the GITD is shown in Figure 2 and Figure 4 respectively.

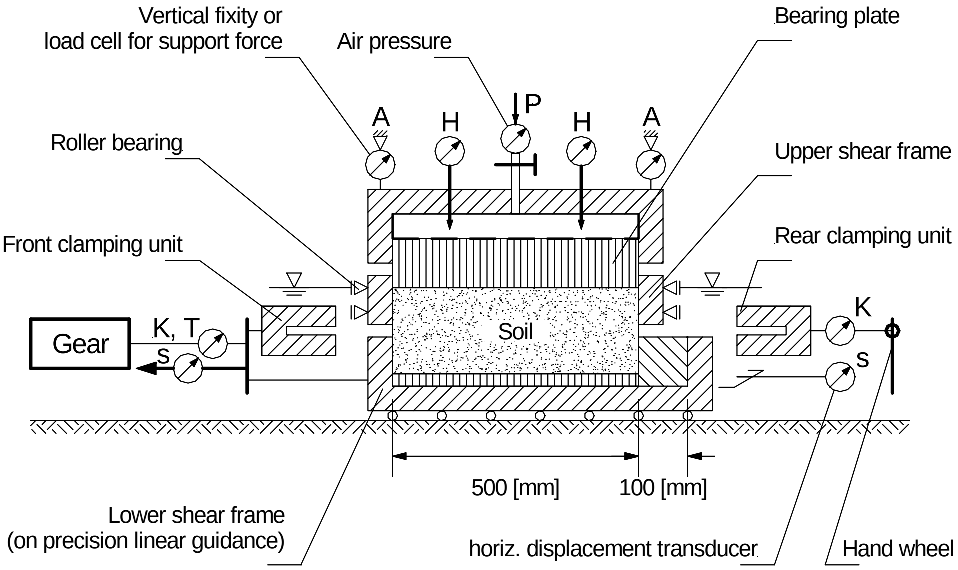


Figure 2. Cross section of the Geosynthetic-Interaction-Testing-Device

As seen in figures 2 and 4, the GITD exists basically of two main units:

- shear unit with an optional vertically arrangable upper shear frame (fixed or floating shear gap) and
- the newly developed clamp units on both ends of the device.

The modular construction of the GITD allows the execution of different types of tests (Figure 3):

- Direct shear tests
- Friction tests
- Pullout tests
- Overlapping tests
- Tensile strength tests

There is flexibility within these tests, enabling a multitude of test versions through the alteration of boundary conditions.

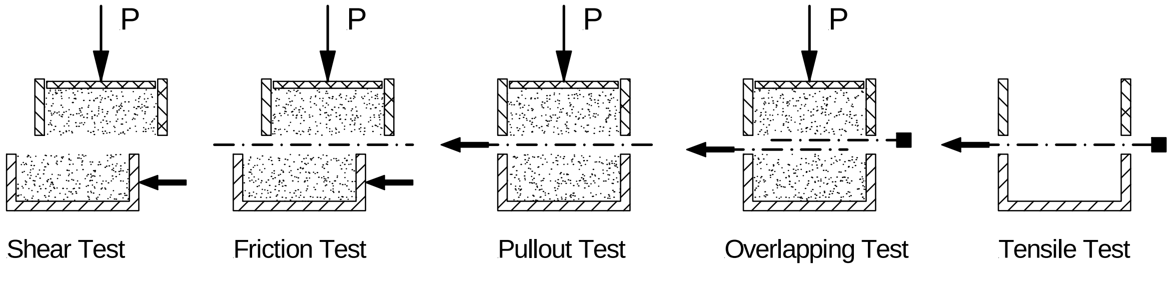


Figure 3. Tests which are executable by the Geosynthetic-Interaction-Testing-Device

Figure 4. Geosynthetic-Interaction-Testing-Device of Geotechnical Institute of the TU Bergakademie Freiberg

The main advantage of the GITD over other current devices is the simple transition from shear to pullout mode and vice versa. A single soil-geosynthetic compound can undergo different tests on one device, making a thorough investigation of all compound components and a direct comparison between the test results possible.

The modular construction of the GITD provides versatile, reproducible mechanically clean kinematic and kinetic boundary conditions in the material/composite to be tested. Furthermore, the newly developed modular clamps allow for a hold of a broad spectrum of geosynthetics without diluting, rupturing and/or degrading the material.

The GITD has been developed at the Geotechnical Institute of TU Bergakademie Freiberg (Aydogmus, 2007).

Technical Data

The parameters of apparatus and sample are as follows:

- shear plane area: 500 (600) x 500 x 200 mm,
- normal pressure: 0 - 600 kPa
- max. pull- and shear force: 125 kN
- rate of displacement: 0.000001 to 12 mm/min
- max. shear way: 160 mm
- max. pullout way: 400 mm
- shear gap: 0 - 50 mm
- variant: shear plane below water

The dimensions of the apparatus permit tests with coarse grained geomaterials and coarse meshed geogrids.

Bearing System of Upper Shear Frame

The GITD upper frame can be conducted in three modes (Figure 5):

- The fixed shear gap mode (fix)
- The floating shear gap mode (floating)
- The floating shear gap mode with dead load compensation by means of springs (compensated)

The influence of the bearing of the upper shear frame on the test results is discussed below.

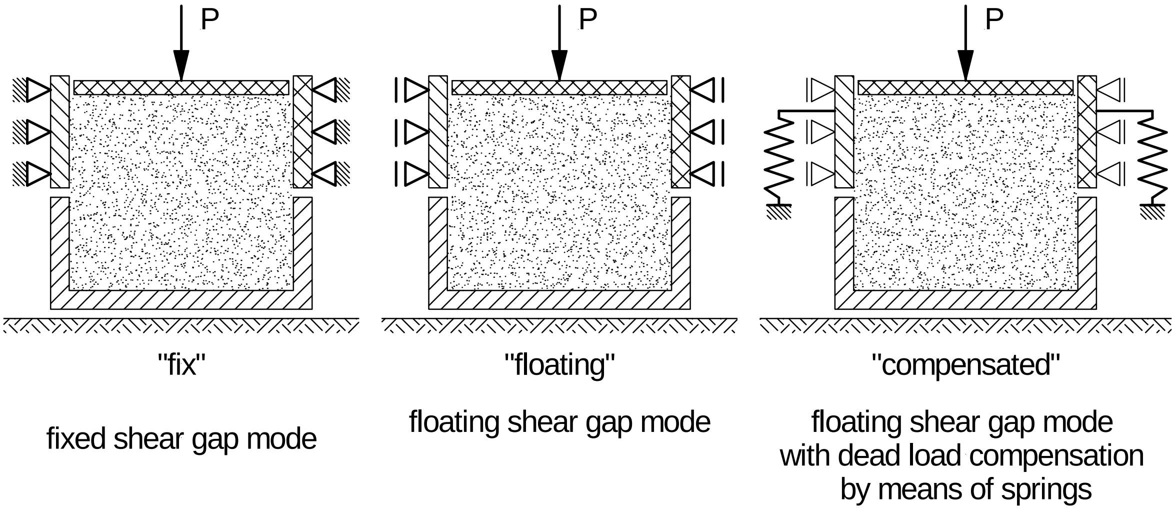


Figure 5. Bearing system of upper shear frame

Technology of Measurement

The device is equipped with a standard set-up of force and displacement transducers. The electronic system of the apparatus provides the infrastructure for extended measuring tasks with special technical equipment. The acquisition of data is conducted with a separate data collector and is fed into a computer for monitoring, calculation and evaluation.

Software

The software for controlling and regulation the GITD and the measurement program for acquisition and processing of measured data were developed at the Geotechnical Institute with the programme system LabVIEW from National Instruments. LabVIEW is a graphical programming language using graphic symbols/objects, which send or collect data and execute specific tasks. The objects, wired to each other, represent the source code of a programme. LabVIEW is not a text-based programming language. The self-development of the software has the special advantage that within certain framework space for individual requirements is created, which is significant for research purposes. The evaluation of the measurement results is carried out by the Microsoft programme EXCEL. The layout of the experiment evaluation can be adjusted for individual needs.

The collection of the measurements is selectively operated with the aid of the controlling computer or manually on the LCD control station.

EXPERIMENTAL ANALYSIS

Reliability and Reproducibility of Measurement Results

The reliability and the reproducibility of the measurement results were examined for different geomaterials and geosynthetics in different test variants under identical boundary conditions. The shear test results with a medium-grained sand under a normal pressure of σ = 100 kN/m² are exemplary shown in Figure 6. The results show, like in all conducted tests, an excellent reproducibility (Aydogmus, 2007).

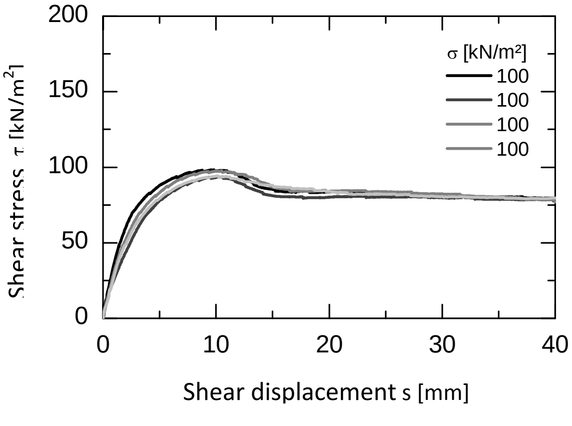


Figure 6. Reproducibility of the test results

Influence of the Apparatus Configuration Constrains on the Measurement Results

Friction parameters for geosynthetic interfaces are commonly determined by 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. The type of testing-equipment and method of load application can affect the result of the shear test.

To eliminate one of the known problems - the friction influence between the sample and the side walls of the shear frames - the GITD was constructed in such a way, that the upper shear frame can freely move during the test in vertical direction, and the size of the shear gap automatically and optimally adjusts itself according to the actual testing conditions.

The interaction behaviour between commonly used geosynthetics and soils are examined in an extensive series of shear and pullout tests. In order to develop device configurations with mechanically correct kinematic and kinetic boundary conditions, the experimental work emphasises the investigation of influence factors from the test boundary conditions on the test results.

Representative for all conducted experimental investigations the outcomes of one series is shown and discussed hereafter. For comprehensive test series along with detailed evaluation and discussion refer to Aydogmus (2007).

The outcomes of the series in Figure 7 demonstrate the influence of the upper shear frame bearing on the test results under otherwise identical boundary conditions, but the kinematic degree of freedom of the upper shear frame. The shear tests were conducted with dry standard sand (CEN sand 0/2). All shear tests were performed at normal stresses of 50 kN/m², 100 kN/m² and 200 kN/m² at a constant shear displacement rate of 1 mm/min.

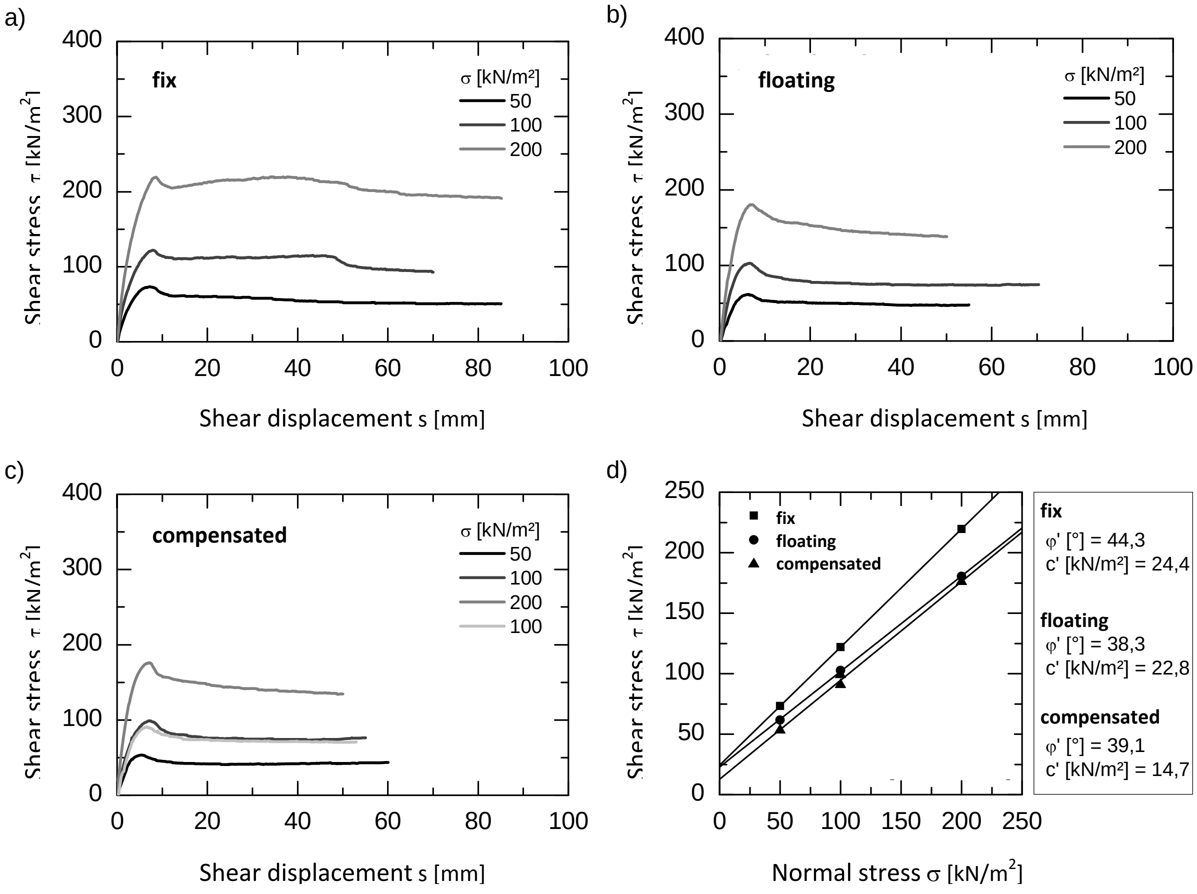


Figure 7. Influence of the shear frame bearing on the shear parameter in the test mode: direct shear test

All test results are plotted as shear stress versus shear displacement curves. Figure 7d summarizes the results obtained in the fixed shear gap mode (Figure 7a), floating shear gap mode (Figure 7b), and floating shear gap mode with dead load compensation by means of springs (Figure8b) as Mohr-Coulomb failure envelopes.

As it can be seen from Figure 7d the shear parameters are inversely proportional to the kinematic degree of freedom of the upper shear frame. In other words the shear parameters obtained in the fixed shear gap mode are always higher then those in the floating shear gap mode (with or without dead load compensation). The lowest values for cohesion and friction angel were obtained from the data measured with floating shear gap mode with dead load compensation by means of springs.

The high cohesion values in the fixed shear gap mode are not justified for the examined non-cohesive sand. One reason for the fictitious cohesion values might be the side friction effects, resulting in higher normal stresses in the shear plane. Similar observations were made in other test series.

CONCUSIONS AND RECOMMANDATONS

Recent developments in the technology, which is related to the manufacturing of new and enhanced high-quality geosynthetic materials, indicate the fact, that the use of the reinforcement function of geosynthetics will be increasingly applied in new geotechnical structures.

However, as with all construction materials, the advantageous application of geosynthetic reinforcement requires a better understanding of the mechanical behaviour of reinforced soil, especially in such new applications. Usually direct shear and pullout tests are performed to investigate the friction characteristics (the interaction soil-reinforcement), which are used for stability analysis.

Innovative testing devices with negligible influence of device configuration constraints on test results are also needed, allowing the exact determination of the representative material specific parameters.

Based on the state-of-the-art of testing methods and considering practical aspects of the use of geosynthetics as reinforcement element or as construction material in complex functions, a new testing device, called ‘Geosynthetic-Soil-Interaction-Testing-Device’ (GITD), has been developed for the examination of the interaction behaviour of soil-soil-geosynthetic-compound-systems. The construction of GITD insures mechanically correct kinematic and kinetic boundary conditions in the sample of the tested material or material composite. The construction of GITD offers the special advantages that the negative effects from wall friction on the test results can be mostly eliminated, and – in opposite to the today’s geosynthetic testing practice – a wide variety of innovative shear and pullout test procedures can be carried out with one single device.

The interaction behaviour between commonly used geosynthetics and soils are examined in an extensive series of shear and pullout tests. In order to develop device configurations with mechanically correct kinematic and kinetic boundary conditions, the experimental work emphasises the investigation of influence factors from the test boundary conditions on the test results.

Based on the obtained results, a device with vertically movable upper shear frame with dead load compensation is recommended for the performance of shear and interaction test.

The Geotechnical Institute at the TU Bergakademie Freiberg is targeting of expanding and developing new innovative ranges of application of geosynthetics for various geotechnical construction projects through the development of advanced experimental facilities, measurement systems, theoretic approaches and analysis with numerical methods.

In this context, the presented ‘Geosynthetic-Interaction-Testing-Device’ (GITD) will also execute further research programmes to gain statistical secured information to the interface interaction of soil-geosynthetic compound systems. It will be accomplished with multiple parallel test series of numerous composite constructions with a variation of boundary conditions, followed by two and three-dimensional modelling with different numerical programme systems. The results should lead to a more precise, effective and economic dimensioning of geosynthetic reinforced constructions (Aydogmus & Klapperich, 2008).

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