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Enhanced shear-pullout-testing device for the examination of the interaction behaviour of soil-geosynthetic-compound-systems

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ABSTRACT: A novel experimental apparatus for the examination of the interaction behaviour of soil-geosynthetic-compound-systems – called the Geosynthetic-Interaction-Testing-Device (GITD) – capable of performing both pullout and direct shear tests is described. The construction of the testing device enforces mechanically correct kinematic and kinetic boundary conditions in the sample of the tested material or material composite. The influence of side friction conditions at the vertical and horizontal boundaries of the shear frame on the kinematics in the tested material have been numerically examined with the program FLAC 2d (v.3.40).

1 INTRODUCTION

The use of the building material "geosynthetic", like geotextiles and geomembranes, plays a rapidly increasing role in a variety of civil engineering applications. Their functions reach from the separation of adjacent soil types and fill materials, preventing them from being intermixed, over their protection against mechanical damage, up to the improvement of mechanical properties of geomaterials as means of special reinforcement (DGGT 1997, Jones 1996). Their combination also enables a variety of parallel functions, as for example in the GEOsafe-System at the reclamation of previously used land (Klapperich & Azzam 2000, Hogrebe & Klapperich 2000, Klapperich 2001, Klapperich & Aydogmus 2002). In comparison with alternative solutions, the application of geosynthetics often offers the joint advantage of lower technical effort and economical benefit. Besides, the potential for the application of geosynthetics is still growing and they are more and more becoming a modern tool in structural engineering.

Recent developments in the technology 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 civil engineering constructions (Jones 2000).

However, as with all construction materials, the advantageous application of geosynthetic reinforcement requires better understanding of the mechanical behaviour of reinforced soil, the use of innovative theoretical models and the exact determination of representative material properties.

In the following, a novel experimental apparatus for the examination of the interaction behaviour of soil-geosynthetic-compound-systems – called the Geosynthetic-Interaction-Testing-Device (GITD) – capable of performing both pullout and direct shear tests is described. The construction of the testing device enforces mechanically correct kinematic and kinetic boundary conditions in the sample of the tested material or material composite. The influence of side friction conditions at the vertical and horizontal boundaries of the shear frame on the kinematics in the tested material have been numerically examined with the program FLAC 2d (v.3.40).

The GITD has been developed at the Geotechnical Institute of Freiberg University of Mining and Technology and is pending for a patent at the German Patent and Trade Mark Office (Aydogmus, Tamaskovics, Klapperich & Schick 2001, unpubl.).

2 GEOSYNTHETIC-INTERACTION-TESTING-DEVICE (GITD)

2.1 *General*

For the determination of the interface parameters within the layer boundaries between geosynthetics and soils or between geosynthetics and geosynthetics, translational shear devices with different shear box size and torsional shear devices are commonly used. Furthermore pullout devices and tilt tables are applied in small scale experiments. An outline of different test devices, -types, -methods, and in addition the advantages and disadvantages of each type and configuration have been pointed out by Blümel et al.1994, Stoewahse 2001 and Takasumi et al. 1991.

In conventional shear devices, the soil sample is usually placed into a shear box, consisting of an upper and a lower shear frame. For consolidation, normal stresses are applied using a "platen" placed on the soil sample. Shear stresses are introduced by relative horizontal movement between a fixed and a movable shear frame part of the box, while normal stresses in the sample are kept constant.

Following conventional applications it is unfavourable, that the side friction on the vertical boundaries of the shear frames, mobilized by the relative displacement between soil sample and the shear box, cannot be reduced completely. As substantial disadvantage remains, that the geosynthetic specimens embedded between two-soil layers are not located accurately in the shear plane during the test, as the normal stresses are only applied on one side of the sample and the geosynthetic is usually forced to move into the other shear frame (Takasumi et al. 1991). Thus, an accurately linear movement of the shear frames in horizontal direction and the exact size of the gap between the shear frames can rarely be guaranteed. Furthermore, the introduction of the shear force often cannot avoid momentums acting in the shear plane of conventional shear devices.

In many known testing devices, the installation and required compaction of the tested soil is carried out in a non-removable shear frame, leading to a disadvantageous loading of the shear frame bearings. In order to avoid this, the installation of the tested sample into the shear frames can be carried out on an external table, making a lifting device for handling heavy shear frames necessary. At the development of a novel experimental device, all this drawbacks have to be taken into account.

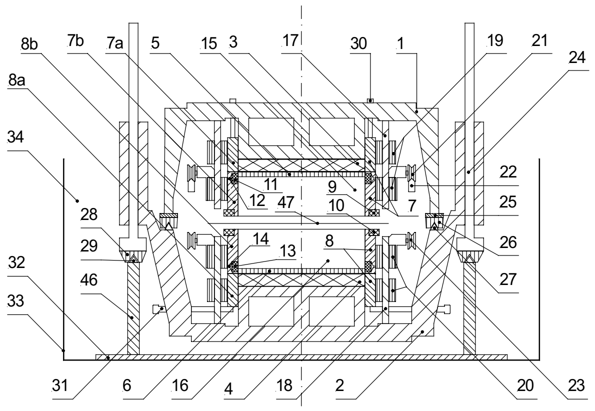

Figure 1. Cross section of the Geosynthetic-Interaction-Testing-Device

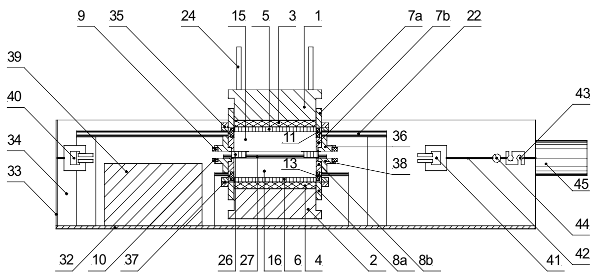

Figure 2. Longitudinal section of the Geosynthetic-Interaction-Testing-Device

2.2 *Test setup*

For the observation of the interaction behaviour in soil-geosynthetic-compound-systems, a new test device has been developed.

A schematic diagram of the Geosynthetic-Interaction-Testing-Device is shown in cross section in Figure 1 and in longitudinal section in Figure 2.

As it can be seen in the figures above, the GITD consists of a working chamber (34), mounted on a rigid steel base plate (32) and surrounded by a water tub (33). Outside the working-chamber, the gear (45) is fastened to the base plate (32), being able to apply a pulling or pressing force. The device also comprises a compressor for the production and regulation of the pressure in the load units (3, 4) and a computer based data acquisition system for recording and evaluation of measured data, both of them not depicted here.

Within the working chamber (34), a fixed clamp (40) is fastened to the base plate (32) of the testing equipment. The sample installation into the sample sections (7b, 8b) of the shear frames can be carried out on the worktable (39). The pulling rod (42) is connected to the gear (45) over a load cell (43) for measurement of the resulting tangential force in the shear plane (or the pullout force). Additionally, a displacement transducer (44) is used for measuring the pullout/shear displacement. To the end of the pulling rod, a mobile clamp (41) or a device for pulling or pressing the load frames (1, 2) is mounted, depending of the applied test regime.

In the working chamber (34), an upper and a lower load frame (1,2) is installed tilt-free. The load frames are lead horizontally and are displaceable against each other. Their height can be adjusted with a lifting gear (24). The displacement of each of the shear frames can be prevented by locking them with bolts (30, 31) to the base plate (32) of the test device. For the registration of the normal stresses in the shear plane (47), the resulting force normal to the shear plane is measured at the bearing points between the upper and lower load frame with four load cells (25). In the upper and lower load frame, a shear frame unit is installed. They comprise an upper and a lower, vertically movable and floating shear frame (7, 8), consisting of a load and a sample section (7a, 8a & 7b, 8b) respectively. Each shear frame unit includes a load unit (3, 4) being operated with a separate pressure regulating system, a shear-abutment (5, 6), filter stones (11, 13), lateral normal stress bearings (36, 38), linear units of the vertical and transport guide (19, 21, 20, 23), and in addition a geosynthetic clamping frame (9, 10).

Relative displacement between the upper and lower load frames (1, 2) or between the base plate of the testing equipment and lower load frame during the test is allowed using a precision linear guidance (26, 27, 28, 29), that can restrain all force components, except in thrust direction. The complex from the upper and lower load frames and the installed upper and lower shear frame units are provided with lifting gears (24) for adjusting the height by raising or lowering. By raising the shear frames, they can be individually or pair wise removed from the sample sections (7b, 8b) of the load frames. The shear frames can be rolled over the attached bearing rails (21, 23) and transport guide (22) to the installation table, where sample installation and removal can be carried out. An auxiliary plate is used to the transport of the shear frames with an installed soil sample into the load frame.

Regulating the vertical position of the load frame complex, the acting point of the pull or press force can be optimally adjusted to the position of the shear plane and desired momentums in the shear plane during the shear test can be avoided.

For the reduction of the friction influences between the sample and the side walls of the shear frames, the upper and lower shear frames can freely move during the test in vertical direction,

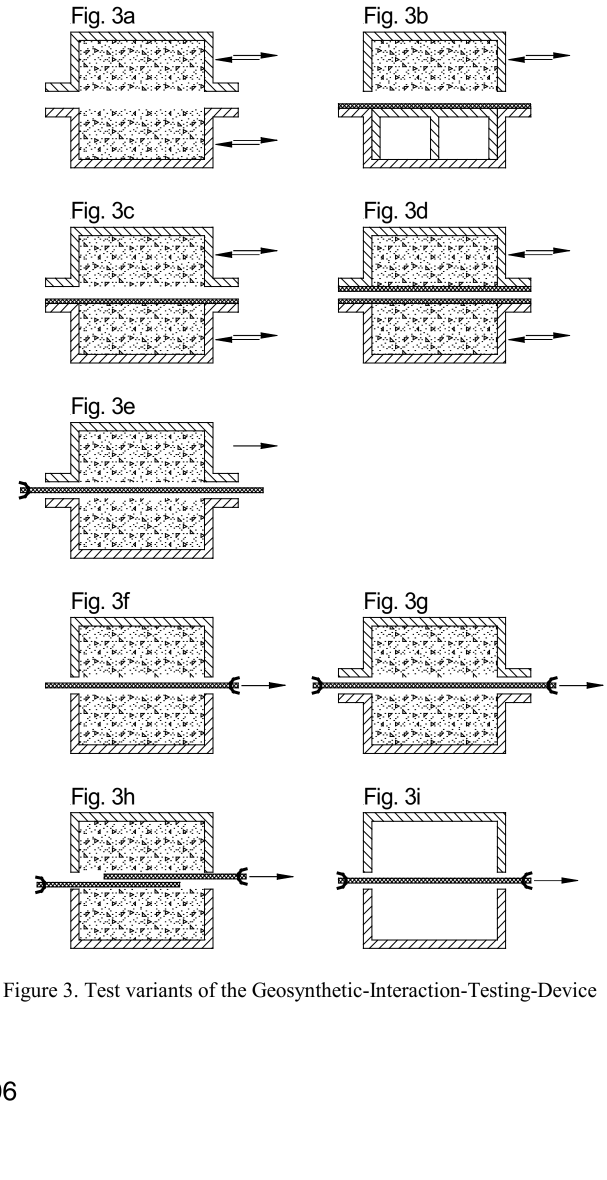

Figure 3. Test variants of the Geosynthetic-Interaction-Testing-Device

and the size of the shear gap automatically and optimally adjusts itself according to the actual experimental conditions. Using bolts, the lower and upper shear frames can also be locked to the lower and upper load frames respectively, leading to a controlled and accurate adjusting of the shear gap to a prescribed aperture during the entire testing procedure. The effect from the self weight of the shear frames is compensated by counterweights. Homogeneous load conditions in the examined geosynthetic-soil compound are generated with the parallel use of two load units, consisting of a rubber bag filled with a pressurized liquid, also offering the opportunity to measure volume changes of the sample during testing. The load units are directly attached to the upper and lower load frames respectively, avoiding disturbances of vertical displacements in the sample during consolidation phase in great extent and thus leading to favourable initial conditions for the soil-geosynthetic-soil interaction and pullout tests.

2.3 *Test variants*

In comparison with known geosynthetic testing practice, the construction of the presented new test device (GITD) offers the special advantage, that a wide range of innovative shear and pullout test procedures (Fig. 3) can be carried out in the same device and with negligible influence of test device configurations on friction test results.

Individual testing procedures for test variants follow from the test set-up and only variant names are given in the following list.

Shear tests: (Fig. 3a-3e)
- Variant A: soil-soil – shear test
- Variant B: soil-geosynthetic – shear test
- Variant C: soil-geosynthetic-soil – shear test
- Variant D: soil-geosynthetic-geosynthetic-soil – interaction test
- Variant E: soil-geosynthetic-soil – 'free' shear test

Pullout tests: (Fig. 3f-3i)
- Variant F: soil-geosynthetic-soil – pullout test
- Variant G: soil-geosynthetic-soil – interaction 'tension' test
- Variant H: soil-geosynthetic-soil – overlapping test
- Variant I: geosynthetic – tension test

With minor modifications in boundary conditions, also other test variants and test regimes are possible to be carried out without significant technical rearrangement of the device.

3 NUMERICAL INVESTIGATIONS OF THE BOUNDARY CONDITIONS ON THE KINEMATIC BEHAVIOUR OF THE TESTED MATERIAL

The influences of friction conditions at the vertical boundaries and at the load faces of the shear frames on the kinematics in the tested material has been numerically examined with the program FLAC 2d (v.3.40). Different influences from device specific constraints have been considered with the formulation of appropriate boundary conditions. In the analysis, the introduction of interfaces has been avoided in order to eliminate their influence on the calculation results. With this, the modelling effort has been significantly reduced also. For rough walls, displacements of the soil adjacent to the walls have been prohibited. For smooth walls, frictionless sliding of the material adjacent to the walls has been allowed. The simulation of floating shear frames with variable shear gap has also been strongly simplified to the case of perfectly smooth vertical walls. Thus, the shear gap has remained constant and could not automatically adjust itself during the test like in the case with really floating shear frames. Vertical stresses have been introduced into the tested sample with the application of constant normal stress boundary conditions at one or two shear frame faces, respectively. In spite of these simplifications, the calculation results have clearly pointed out the advantages and drawbacks of different test configurations.

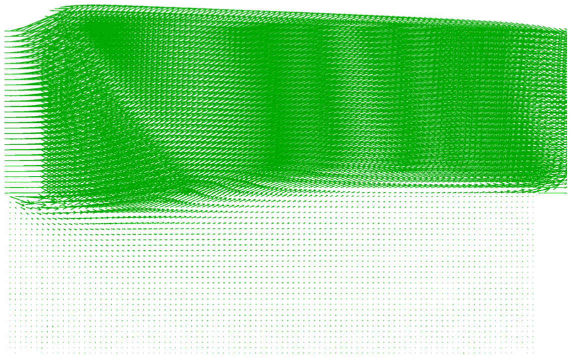

Figure 4. Displacement vectors of the type of device R-I

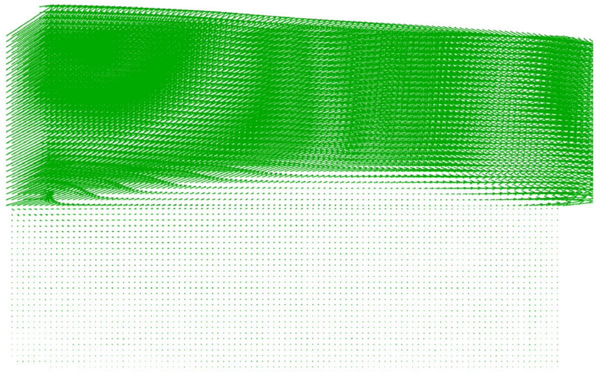

Figure 5. Displacement vectors of the type of device S-I

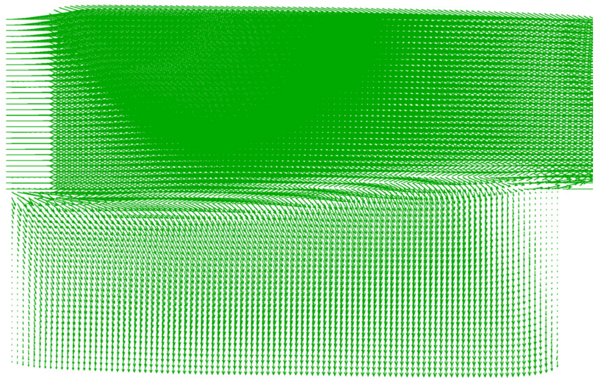

Figure 6. Displacement vectors of the type of device R-II

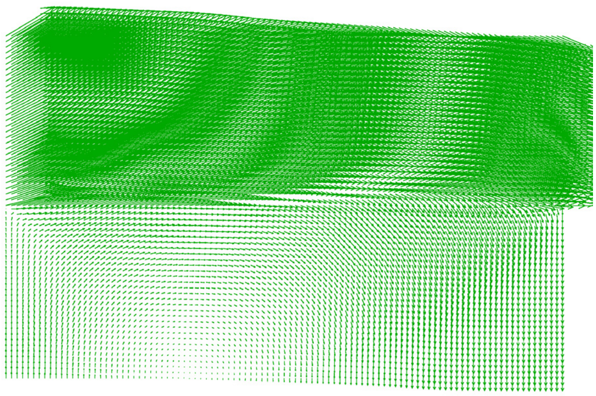

Figure 7. Displacement vectors of the type of device S-II

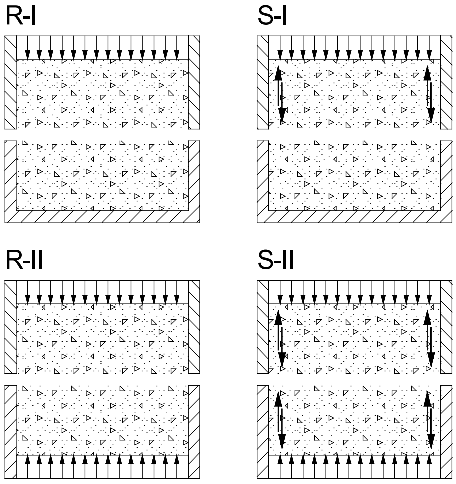

Figure 8. Numerical simulated test set-up types

In the modelling, two general constructive device classes and two specific device types in each constructive class have been modelled with the formulation of adequate device specific boundary conditions, respectively:

Device classes I - One load face:

- Device type R-I: Upper and lower shear frames with rough wall, one-side vertical stress load from above
- Device type S-I: Upper (floating) shear frame with smooth wall, lower shear frame with rough wall, one-side vertical stress load from above

Device classes II - Two load faces:

- Device type R-II: Upper and lower shear frames with rough walls, vertical stress load from above and below
- Device type S-II: Upper and lower (floating) shear frames with smooth walls, vertical stress load from above and below

Figure 8 shows the configuration of the examined device types. The device type R-I corresponds to a conventional direct shear box test with fixed shear frame and one load face. The device type S-II corresponds to the innovative constructive concept described in chapter 2, where the examined sample is loaded from above and below and both shear frames are allowed to float vertically during the test.

The analysis results for the different device types are represented in the Figures 4-7. In all devices, a significant localization of strong displacement differences can be observed in the region between the shear frames moving relative to each other, being identified as the preferential shear zone. However, depending on the particular load conditions in the respective device, the form of the shear zone is clearly different. In the device types R-I and S-I, a less or more strongly pronounced curvature appears in the shear zone caused by the effect of one-side loading from above. Side friction conditions at the shear frame resulted in an arc-shaped form of the shear zone in the device type S-I, and in a wavelike form of the shear zone in the device type R-I. In the device types R-II and S-II with two-side load on the sample, an almost plane shear zone is formed. The shear zone in the device R-II suffers a light inclination in shear direction. The shear zone in the device S-II is almost horizontal, evenly distributed and ideally shaped.

4 CONCLUSION

A safe and economic design of soil reinforcement with geosynthetics requires better understanding of the fundamental mechanisms of reinforced soil deformation. Innovative testing devices with negligible influence of device configuration constraints on test results are also needed, allowing the exact determination 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 elements or as construction materials in complex functions, a new shear-testing device (Fig. 1-2) has been developed for the examination of the interaction behaviour of soils and geosynthetics in soil-geosynthetic-compound-systems. The construction of the testing device insures mechanically correct kinematic and kinetic boundary conditions in the sample of the tested material or material composite. The construction of the shear device offers the special advantages, that the position of geosynthetic layer(s) is only slightly influenced by the consolidation process during the preparation of shear tests in soil-geosynthetic-compound-systems, negative effects from wall friction on the test results can be mostly eliminated, an accurately linear movement of the shear frames in horizontal direction can be guaranteed, 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 thorough analysis of different known testing device configurations with different and slightly simplified device specific boundary conditions shows, that the double-sided vertical load on the tested sample and the reduction of the friction at the vertical sides of shear frames or equivalently, allowing the shear frames to vertically float during the test lead to favourable mechanical testing conditions and an almost horizontal, evenly distributed and ideally shaped shear zone is enforced in the sample.

The test device briefly presented here is able to satisfy requirements for mechanically ideal test conditions, providing an important contribution to the development of the safe use of geosynthetics in innovative civil engineering applications.

5 REFERENCES

Aydogmus, T., Tamaskovics, N., Klapperich, H. & Schick, R. 2001 (unpubl.). Geosynthetik - Geomaterial - Prüfgerät. *Patent Specification, German Patent and Trade Mark Office, 15. March 2001*.

Blümel, W. & Brummermann, K. 1994. Reibung zwischen Geokunststoffen und Erdstoffen in Deponiedichtungen. *Müll und Abfall*, No. 4: 242-259. (in German)

Deutsche Gesellschaft für Geotechnik (DGGT) 1997. *Empfehlungen für Bewehrungen mit Geokunststoffen*. Essen: Ernst & Sohn. (in German)

Hogrebe, C. & Klapperich, H. 2000. *Innovative Concepts in Reuse of Brownfields*. Green Brownfields: Innovative Concepts in Remediation for successful Redevelopment. 19.-23. March 2000, Salt Lake City.

Jewell, R.A. 1996. *Soil reinforcement with geotextiles*. Construction Industry Research and Information Association, CIRA Special Publication 132. London: Thomas Telford Publishing.

Jones, C.J.F.P. 1996. *Earth reinforcement and soil structures*. London: Thomas Telford Publishing.

Jones, C.J.F.P. 2000. Recent developments in geosynthetic soil reinforcement materials. *Geosynthetics in Geotechnical and Geoenvironmental engineering; Proc. of an international symposium on geosynthetics held in association with GEOeng2000, Melbourne, 18. November 2000*: 42-51.

Klapperich, H & Aydogmus, T. 2002. Flächenrecycling mit Geosynthetics – Brachflächen und Bergbaufolgelandschaft. *5. Sächsisches Bautextilien - Symposium „Bautex 2002", Chemnitz, Germany, 24. January 2002.* (in German)

Klapperich, H. & Azzam, R. 2000. Rehabilitation of industrial sites – innovative concepts for geotechnical and engineering geological approaches. *Proc. of an international Conference on Geotechnical & Geological Engineering, GeoEng2000, Melbourne, Australia, 19-24 November 2000.*

Klapperich, H. 2001. Flächenrecycling von Industrie- und Bergbauflächen - Innovative Konzepte. *Österreichische Baugrundtagung 2001, Wien*. (in German)

Stoewahse, C. 2001. Ermittlung des Reibungsverhaltens von Geokunststoffen und Erdstoffen im Rahmenschergerät. *Mitteilungen Institut für Grundbau, Bodenmechanik und Energiewasserbau, Universität Hannover, Heft 57, Eigenverlag*. (in German)

Takasumi, D. L., Green, K. R. & Holtz, R. D. 1991. Soil-Geosynthetics Interface Strength Characteristics: A Review of State-of-the-Art Testing Procedures. *Geosynthetics '91 Conference, Atlanta, USA*: 87-100.