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# Investigation of kinematic behavior and earth pressure development of geogrid reinforced soil walls

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ABSTRACT

Geogrid reinforced soil is an advanced composite material that is widely used for the construction of retaining walls as frequently needed in transportation structures. Most standards and proposed design methods have included a beneficial effect of geogrid reinforcement on the earth pressure that acts on the facing of a retaining wall. However, field measurements at applications often show much lower deformations and stresses as estimated from the design. This indicates a certain improvement potential for the design of geogrid reinforced soil structures and thereby for the general acceptance of geogrid reinforced soil. Therefore, at RWTH Aachen University model tests with geogrid reinforced soil retaining walls have been carried out. The design of the developed test apparatus allows the determination of various parameters, such as the determination of the earth pressure distribution at the facing, geogrid connection loads at the facing and specimen deformations throughout the whole cross section of the test wall.

This article deals with the results of parametric studies focusing on the reduction of the active earth pressure in geogrid reinforced retaining structures due to geogrids with varying reinforcement ratio, i.e. number of reinforcement layers per specimen height, and reinforcement stiffness. A reduction of the earth pressure due to a surface load was apparent already underneath the topmost reinforcement layer. This effect was observed for both, structures with and without a facing connection of the reinforcement. With increasing reinforcement ratio, the sliding soil wedges decreased in size and only an unconfined soil area, beneath a developing soil arch in between two reinforcement layers, caused a horizontal earth pressure on the facing. All observations were merged to formulate a mechanical model idea that is presented at the end of this article.



## Introduction

Geogrids as reinforcement in soil generally create an advanced compound material with increased strength and stiffness in comparison to the unreinforced soil. When applied in mechanically stabilized earth (MSE) walls, which are often used for transportation geotechnical structures, geogrid reinforced soil creates a "reinforced soil block" that is very stable in itself and requires only little support by a wall facing construction. It is well known that geogrid reinforced soil can lead to a reduced earth pressure on the wall facing, depending on its stiffness. This is already reflected in some standards, e.g. the German EBGEO (Deutsche Gesellschaft für Geotechnik, 2011), where the

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earth pressure on the facing may be reduced as a function of the facing stiffness, or the K-stiffness method introduced by Allen et al. (2003) and Bathurst et al. (2005) based on measurements of instrumented walls. The internationally strongly varying assumptions regarding the earth pressure acting on the back of a facing of geogrid reinforced retaining walls are rather empirical than based on mechanical models. This shows the need for further research in this area to enable more realistic and economic design.

Geogrid reinforced soil for transportation purposes is usually employed in line structures, i.e. retaining walls or foundations of roads and railway tracks, where it can be assumed that no deformation occurs in the direction of the structure's main axis. The prevailing stress–strain conditions can therefore be described appropriately as plane strain conditions. The plane strain state does not only constitute a mechanical simplification, but also allows horizontal deformation only in one direction. This has to be the primary direction of the tensile members of the biaxial geogrids employed. In contrast to a triaxial or radial symmetric deformation state, in this case, measured reinforcement strains can be linked directly to reduced specimen deformations or increased bearing capacities. Additionally, plane strain as a model test condition allows the use of advanced measurement techniques such as optical deformation measurements, when transparent sidewalls are being used.

At RWTH Aachen University a laboratory apparatus has been developed that allows testing of large samples of geogrid reinforced soil ($H \times W \times D = 1\ \mathrm{m} \times 1\ \mathrm{m} \times 0.45\ \mathrm{m}$) under the mentioned plane strain condition. Special feature of the test device is its transparent sidewall through which the entire cross section of the specimen can be observed. With the help of digital photographs and a subsequent evaluation with the Digital Image Correlation (DIC) method, the kinematic behavior can be visualized by the distribution of specimen deformations and soil particle rotations.

In this article, the results of geogrid reinforced soil retaining wall model tests with a variation of reinforcement ratio and reinforcement tensile stiffness are described. Test results presented in this paper include specimen kinematics, the development of the earth pressure as a function of the facing displacement and its distribution over the height of the facing. Additionally, connection loads of geogrids to the facing are given. The laboratory device with its boundary conditions and instrumentation, as well as the test set-up and procedure is presented in detail in the following Section 'Laboratory device'. The materials used and the presented test program are described in the Section 'Materials & test program', before the various test results are given in the Section 'Test results'. Finally, taking into account the sidewall friction effect within model tests, earth pressure coefficients are calculated and a mechanical model idea is presented in the Section 'Analysis'.

## Laboratory device

The laboratory apparatus shown in Fig. 1 has been developed at RWTH Aachen University to carry out tests with geogrid reinforced soil under plane strain conditions. It was used for biaxial compression tests by Ruiken (2013) as sort of element tests to investigate the compound material *geogrid reinforced soil* in principle as well as the interaction behavior of geogrid and soil as described by Jacobs et al. (2013) and Jacobs and Ziegler (2015). Additionally, model tests were carried out using this device. These types of tests include a geogrid reinforced bearing layer under a rigid footing as shown in Ziegler (2013) and secondly, geogrid reinforced soil retaining wall, which is described in this article.

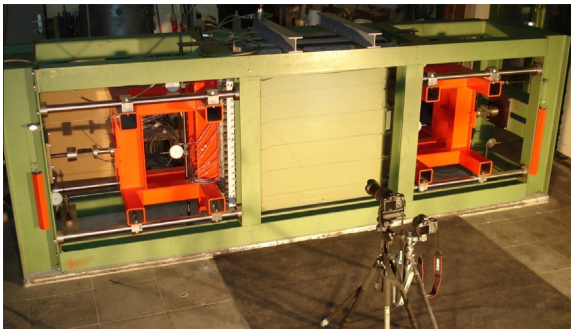

**Fig. 1.** Apparatus for plane strain model tests of geogrid reinforced soil retaining walls (Ruiken et al., 2010).

In the wall model tests, the stiff front and back facings of the apparatus could be retracted independently on (red) linear slide bearings that allowed only translational movement. The stiffness of the facings has a strong impact on the test results, as described in detail by Tatsuoka (1993). Transverse to the paper plane, the specimen was encased by two rigid sidewalls; a steel wall of 40 mm at the rear side and a transparent glass wall of 106 mm thickness towards the camera, as can be seen in Fig. 1. This transparent sidewall allowed the observation of the specimen throughout the tests and to evaluate its deformation (see Chapter 'Instrumentation'). The thickness of 106 mm of the glass sidewall ensured that a deflection of less than 0.1 mm occurred during the tests so that the plane strain condition was preserved. Additionally, 6 mm inner glass walls were attached to the outer sidewalls to ensure the same boundary conditions on both sides of the specimen.

### *Boundary conditions*

In experimental studies, the boundary conditions generally play an important role for the quality of the test results. The materials in contact with the soil specimen were load cushion, a lubricated bottom plate, lubricated facing elements and rigid glass sidewalls.

Specimen deformations parallel to any sidewall lead to resisting shear stresses. For ideal test conditions, those should be reduced as much as possible by reducing the wall roughness. E.g. Gäßler (1987) who carried out field tests achieved reduced side wall friction with 4 cm wide trenches filled with bentonite slurry, which however was not applicable here. Tatsuoka and Haibara (1985) and Goto et al. (1993) used silicone grease and a thin latex

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