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Static & dynamic loading on different geogrids: Recent German Experiences

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ABSTRACT

Due to the globalization of the world economy and the global increase of trade, there is an increasing shipment of goods which creates high demands on the maintenance and development of an efficient infrastructure (road, railway & waterway). The development of infrastructural projects will be a booming sector of the construction industry around the world with highest demands in Asia and Europe. Sustainability concepts for the construction activities and funding problems of the contracting authorities are current boundary conditions which can be accommodated optimally with geosynthetic construction methods. At the same time, besides the technical advantages, the economical and ecological advantages can be used too - saving construction costs and taking care of building materials resources. This paper will give a state-of-the-art report about the performance of different geogrids.

1 GENERAL

Soil alone is only able to carry compressive and shear forces. However, through the use of geosynthetics as reinforcing elements, soil structures can be built to carry tensile forces. In road or railway applications the insertion of horizontal geogrid layers in granular base courses provide an increased modulus, hence a lateral confinement to the system. This lateral confinement resists the tendency for base courses to create large deformations (rutting) under the anticipated dynamic loads.

Geogrid reinforced soil structures as flexible alternative to conventional construction methods, as e.g. concrete retaining walls, allow the preparation of land for building even under difficult topographic conditions. Geogrid reinforced steep slopes enable the development of building land on limited space, which is extremely beneficial in case of expensive land prices. From an economical viewpoint a reduction in the overall construction costs of at least 30% can be achieved compared to conventional methods.

Although this concept is appreciated by many engineers, it is difficult for them to ensure that the best type of geogrid is used on their project.

2 STATIC LOADED GEOGRIDS

Presently designs with geogrids are made using results of tests carried out on the geogrid in contact with air and not in contact with soil. Recent research has studied the load transfer mechanism by soil/geogrid interaction with "in-soil" testing. The test setup uses a metal container with a movable front wall and the test introduces forces from the soil into the reinforcing geogrids. Such testing shows future guiding results for designers (Bussert 2006). Fig. 2 shows the test setup.

The test results show that the interaction of soil and geogrid mainly depends on the geosynthetic layer spacing, soil grain size, geosynthetic aperture size as well as showing how the strength of shape and extensional stiffness of the geogrid product influences these results. It showed that stiff geogrids absorb the imposed forces with less movement than flexible grids. Opposite to the presently used design methods no correlation between geosynthetic tensile strength and serviceability of the geosynthetic reinforced soil structure can be accomplished. The stress reduction at the front wall by moving the front wall in x-direction (Fig. 2) caused by different geogrid products are compared with each other and with the results where no reinforcement is used, are shown in Fig. 3. With "stiff", welded and extruded geogrids a reduction of the stress level

is already given before any front of wall movement is initiated. A reinforcing effect occurs immediately without any deformation of the front wall whereas the "textile-style" woven geogrids need an initial deformation to activate the reinforcing effect. When fully activated the soil/geogrid composite material is characterised by significant smaller effective horizontal stress than the un-reinforced soil.

This current report on recent research results shows the promising development to a better understanding of soil/geogrid interaction for the design of even more effective geogrid reinforced soil structures.

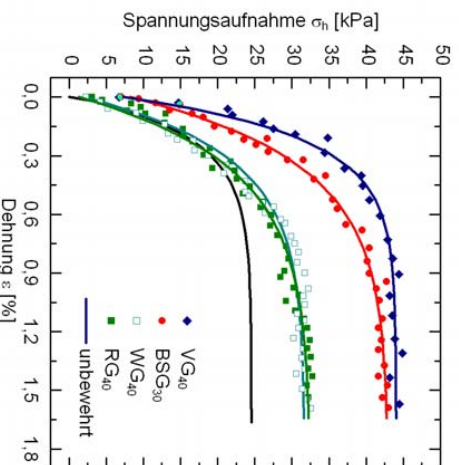
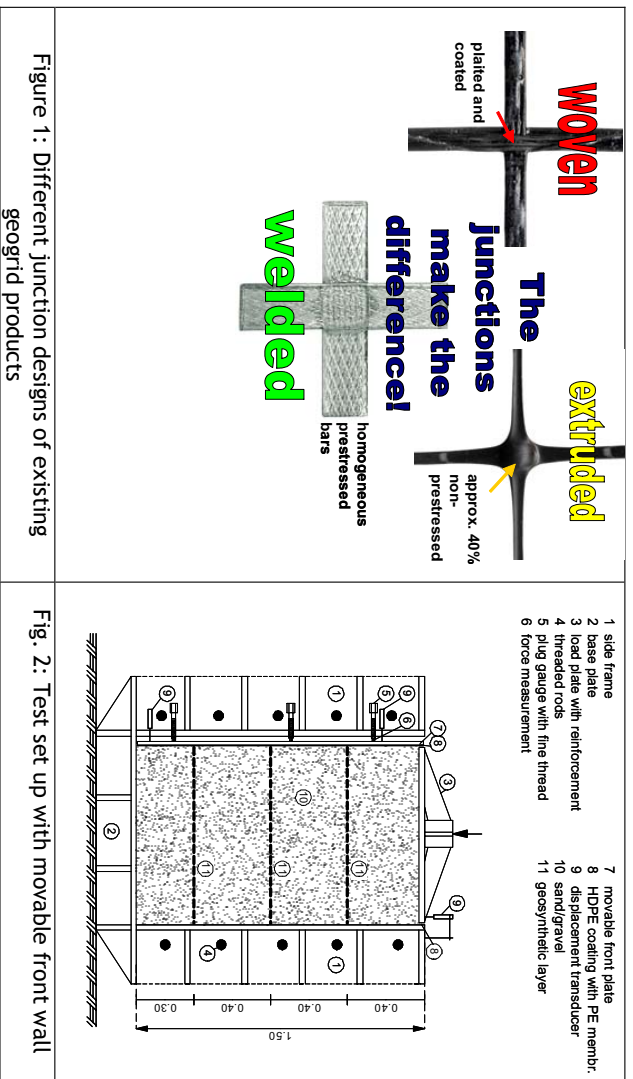


Figure 3: Earth pressure/stress reduction at the movable front wall with different /no reinforcement of soil body. The blue line represent the results of a laid geogrid, the red one those from an extruded geogrid and the green line the results from a woven geogrid. The black line shows the results with no reinforcement. Initially there are no differences between the un-reinforced soil and those measurements made with the woven grid reinforced soil. The results from the laid (the blue line) and extruded geogrids (the red line) show that high joint strengths (like those in the extruded geogrids) are not required to achieve a superior reinforcement of the soil.

Depending on the manufacturing technique (laid, stretched, woven & knitted) of the used geogrid a different effectiveness in relation to the maximum stress absorption can be determined.

In general it can be noticed that the laid geogrid shows the highest effectiveness in gravel as well as in sand. Due to a much higher flexibility of the woven geogrid in comparison to the stretched and laid geogrids, no effective fixed support of the soil is given, which allows a higher deformation capability of the compound material. A higher stiffness of the geogrid also leads to a higher stiffness of the compound material which encourages the stress absorption and low deformations.

Further tests within the investigation also document that woven and knitted products need an initial deformation before a reinforcing effect can be measured compared to an un-reinforced system.

Due to the production related pre-stressing of laid and stretched geogrids, immediate stress absorption without primary deformations of the compound material takes place. Dimensionally stable and high-modulus geogrids assure an immediate frictional connection with the surrounding fill and increase already the stress absorption capacity of the compound material prior to the movement of the facing.

The achievable maximum stress absorption of woven and knitted geogrids is much lower due to a missing stabilising effect in the beginning and the resultant soil movement within the compound material.

Whereas the overall bearing effect of compound materials reinforced with stretched and laid geogrids consists of a stabilising and reinforcing part, only a reinforcing bearing effect can be achieved with woven or knitted products.

The activation of the reinforcing effect is further a result of the stress-strain behaviour of the geosynthetic product. Due to the fact that a higher modulus of the used geogrid normally results in an increase of the dimensional stability, it is incidental that an influence on the bearing strength of the compound material is also given.

3 DYNAMIC TESTING ON A LAID GEOGRID

There is still a need for clarification concerning the behaviour of reinforced soil structures under constant dynamic loads, as they are typical e.g. in the safety-relevant field of railway traffic loads.

To monitor the behaviour of geosynthetic reinforced soil structures under such dynamic loads, extensive large scale tests have been carried out at the University for Engineering and Economy Dresden in a 1:1 scale (Göbel, Großmann; 2006).

The reinforced soil structure consisted of 4 geogrid layers, which were installed with a vertical spacing of 0.4 m. The embedment length of the installed geogrids was 1.75 m and the width of the reinforced slope was 3m. The slope was built with an inclination of 70° (Figure 4). As fill material sandy gravel (0/32 mm) has been used.

As reinforcing element Secugrid 60/60 Q6, a laid and welded, solid PET geogrid with a tensile strength of 60 kN/m in both directions, was used (Figure 5).

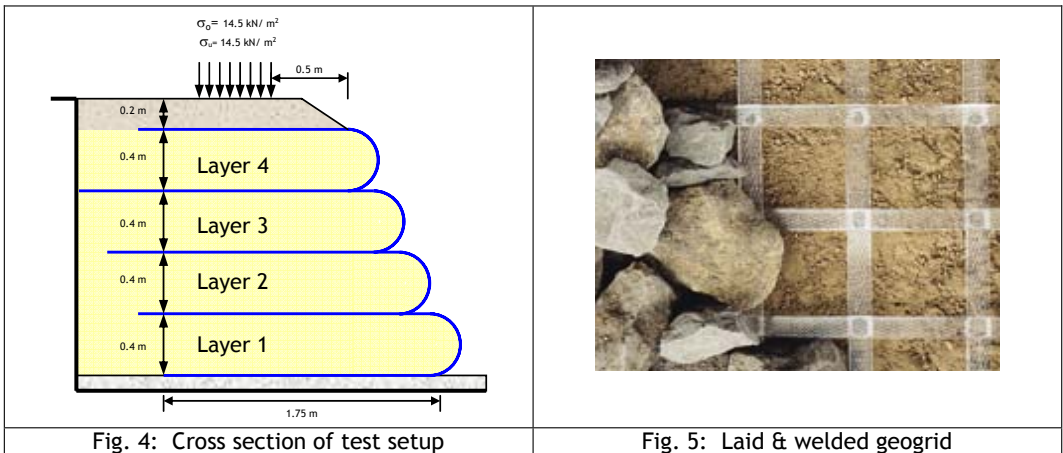


Fig. 4: Cross section of test setup

Fig. 5: Laid & welded geogrid

To be able to monitor the dynamic stability of the reinforced soil structure under realistic railway traffic loads, extensive devices for the measurement of the deformation as well as for the oscillating rates have been installed inside the structure.

As dynamic load an alternating load with a lower load level of $\sigma_u = 14.5 \text{ kN/m}^2$ and an upper load level of $\sigma_o = 94.5 \text{ kN/m}^2$ at a frequency of 7 Hz was applied to the structure with a hydraulic loading device. These loads typically represent a train with a speed of 200 km/h. In addition to those typical loads, also extreme dynamic loads (frequency of 28 Hz & 40 Hz), which rarely occur in practice, have been applied to the reinforced soil structure.

As a result of 12.8 million applied load cycles, maximum vertical deformations of 0.1 mm were measured, whereas the measured horizontal deformations were within the accuracy of measurement.

At applied vibration rates of 15mm/s, remaining values of < 5mm/s have been measured already at a depth of 0.50 m underneath the load plate. The magnitude of dynamic impacts on the geogrid directly depends on the depth. It is thus of great importance, at which depth underneath the dynamic load level the first geogrid level is installed.

In German railway regulations the minimum depths at which geosynthetics can be installed is prescribed. It is considered that these depths are conservative. So for this test series the top layer was installed only 600 mm beneath the level where the dynamic load was applied. Even under these extreme test conditions, the reinforced soil structure has proven sufficient load carrying capacity and serviceability.

After the test the top geogrid layer has been excavated. The results of the visual inspection can be summarized as follows:

- No damages of the geogrid could be recognized
- Between geogrid and fill soil a good interlocking has been detected
- Abrasion of the geogrid due to high dynamic loads could not be registered

To investigate the mechanical properties of the top geogrid layer after applying 12.8 Mio dynamic load cycles, samples have been tested to measure the remaining tensile strength of the geogrid. Based on the carried out tensile test according to ISO 10319 a 3 % lower tensile strength of the installed geogrid was measured, in comparison to a sample from the same production lot that was tested during quality control.

Based on this results, a safety factor for installation damage and dynamic loads of $SF_{\text{Inst+Dyn}} = 1.03$ can be derived. According to Hubal (2000), a safety factor SF_{Dyn} for the determination of the long-term design strength of the reinforcing element, considering dynamic effects resulting from railway

traffic, have to be considered. Recommended values of $SF_{D_{yn}}$ are defined according to the depth of the geogrid layer underneath load level:

≤ 1.5 m below load level : $SF_{D_{yn}} = 1.5$

≥ 4.0 m below load level : $SF_{D_{yn}} = 1.0$

Interim values can be interpolated.

Based on the gained test results from the large scale laboratory test it can be concluded that the current standards underestimate the resistance of the tested geogrid against dynamic loads, of overestimate the propagation of vibrations over depth and thus have to be reconsidered to allow even more economic geosynthetic alternative solutions in comparison to conventional construction methods.

4 PULL OUT TESTING.

At breaking load reinforcing products show elongation values of $\varepsilon \gg 5\%$ whereas the serviceability of reinforced earth structures is limited to deformations of $\varepsilon < 2\%$. Several in-situ measurements in reinforced earth structures even document that the elongation of the reinforcing geogrids is even more less with $\varepsilon < 0.5\%$ (Pachomow et al., 2007). Even being confident that the actual design practice of geogrid reinforced earth structures is a very safe approach, a lot of future research is needed to fully understand and describe the geogrid/soil interaction as composite material structure.

The very high bearing capacity of geogrid reinforced soil structures cannot merely be explained by friction interaction of soil and reinforcing elements, but additional interlocking effects with forces mobilized in front of the cross bars have to be considered.

In a special research program at the RWTH Aachen (University of Technology, Germany) the influence of geogrid cross bars has been studied. Fig. 6 shows the mobilisation of drag forces as friction and soil resistance in front of the cross bars (Ziegler et al., 2007).

In grids with more than one cross bar, the rear cross bars cause smaller drag force decreases than the ones in the front as the continuous strain of the grid diminishes the displacement of the cross bars. Thus, the cross bars' loads decrease continuously towards the rear area (Fig. 6).

This effect, which is not considered by the common design procedure, transfers decreasing forces up to the point x_0 from which on the grid is no longer subject to significant displacement since no more loads are transferred by the cross bars. Not taking any safety factors into consideration, the distance from the place of pull-out force induction to the point x_0 equals the required anchor length of the reinforcement.

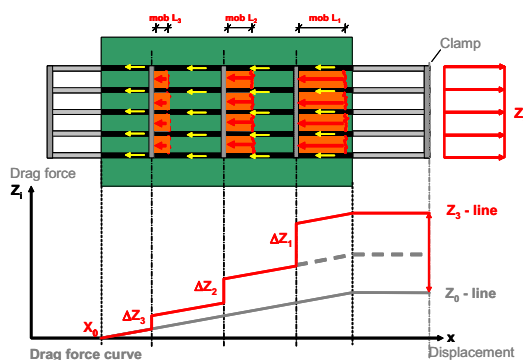


Figure 6: Mobilization of friction and soil resistance of a geogrid in a pull-out test

Based on this approach it is also possible to deal with actual loads to the geogrid junctions. The ladder-shaped drag force line also clearly shows that the maximum stress at the junctions can correspond to the first drag force leap only. It is obvious that this drag force decrease ΔZ_1 , particularly with a full grid, is much lower than the force Z_3 introduced at the start of the grid.

An upper estimate for the stress at the junction results when one calculates the drag force difference between a corresponding pull-out test with pulling out the longitudinal bars only (test

with no cross bars) and a pull-out test with only one cross bar. This difference in pull-out force has to be transmitted in the junctions of the sample. In a real grid, however, the stress at the junction would be even much smaller since the mobilised area is restricted by the subsequent cross bar. To make full use of the soil/geogrid interaction the junctions of a geogrid have to transmit forces from cross bars to length bars and the junctions have to be strong enough to carry the ΔZ forces shown in Fig. 6. A different junction design of geogrid products as shown in Fig. 1 will clearly show different soil/geogrid interaction behaviour.

5 CONCLUSIONS

This paper describes three test series.

In the first, static loads were applied in a special container where the front wall was moved. Different laid, extruded and woven geogrids were placed with different granular fill material and the resulting stress strain relationships were recorded and compared to each other and to the similar set but without any synthetic reinforcement. The results showed that the performance of a geogrid is also dependent upon the manufacturing process as well on the strength and aperture relationship to the fill material. Stiff laid geogrids provided the least amount of movement of the reinforced soil body. Woven, flexible geogrids did not improve the soil performance until the grids had undergone some movement.

In the second test series dynamic loadings were applied to a geogrid reinforced steep slope using laid geogrids. The performance of the structure showed that such reinforced steep slopes perform well with dynamic loadings. The dynamic loadings were chosen to represent trains travelling over such a slope at about 200 km/h. The damage expected did not occur suggesting that such geogrids can be used closer to the rails than presently allowed in German regulations.

The third testing series also showed the performance of soil/geogrid compositions under pull out testing conditions. It showed that that the forces on the grid joints decreases the further the joints are from the applied force. Presently the designs of reinforced soils do not take this into consideration.

In all three testing situations, the results showed that the current methods of designing soil geogrid interactions are conservative. Presently the design is based mostly on test results where the geogrid has been tested in air only, not in contact with the soil. By better understanding how the geogrid soil compositions work, more economical designs can be made. More research is necessary.

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