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The effect of geogrids under unbound sub base layers

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ABSTRACT: Geogrids in unbound sub base layers and on top of the sub grade may improve the performance of road constructions. It has been proven with large scale tests that the elongation in the geogrid is a suitable kick-off to predict the behaviour of reinforced aggregate layers. Independently from the caused deformations at the surface of the reinforced sub base layer the elongation of the geogrid is limited to $\varepsilon < 2\%$. Therefore the interaction resistance which occurs instantly at very small deformations in the geogrid layer is more important than its ultimate tensile strength. The measured improvements have been divided in the ones related to deformations respectively rutting and the ones which are measurable in terms of an increasing bearing capacity. Under appropriate conditions for the use of geogrids these improvements have resulted in 30% less rutting and 40% higher bearing capacity. The optimum circumstances are described in the paper. To forge a link between this research project and the daily design practice a dimensioning chart for the use of the investigated geogrid under unbound sub base layers has been developed.

1 INTRODUCTION

From a today's view geosynthetics have become an integral part of road constructions. Amongst others geogrids have been established in that connection as a part to reinforce or stabilize layers in these structures. While geogrids have been used in temporary and unpaved roads at the beginning, they are nowadays used in nearly every layer of paved road constructions too. That has led conclusively to a change in the dimensioning of the geogrids. Building haul and country roads (unpaved roads) is based on the allowable rut depth which may occur during the service life. The rutting is related to the number of load cycles. But in the field of road constructions with a paved capping rutting is not acceptable. Because everything will be done to prevent rutting in such a situation the rut depth isn't a measurement to predict the performed bearing capacity of the sub grade or base. Here are measurements required which indicate the bearing capacity of the structure by using the modulus or CBR-value.

2 BACKGROUND

Based on the fact that the reinforcing effect of the geogrid in haul and country roads over soft soil can be assessed by a decreasing rut depth or an increased number of load cycles, it has to be taken into account that this will not be a sufficient way to estimate the performance of paved roads. The deformations caused by the rutting on unpaved roads are partly reflected in the geogrid. This activates tensile stresses in the geogrid up to a certain rate of elongation. Even low deformations are an indication for tensile stress in the geogrid which can be determined by using the stress-strain graph of a wide-width tensile test. That's a so-called membrane effect and shown in Figure 1.

The purpose of this research work was to find a relation between the loading of the geogrid, the thickness of the aggregate layer and its bearing capacity. This would normally lead to an investigation

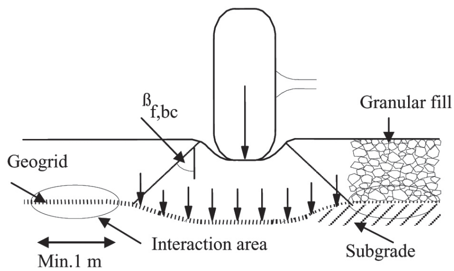

Figure 1. Membrane effect.

on the lateral restrain behaviour of a geogrid. Figure 2 gives an idea of this mechanism. The effect is comparable with a stabilizing mattress which provides an improved load distribution.

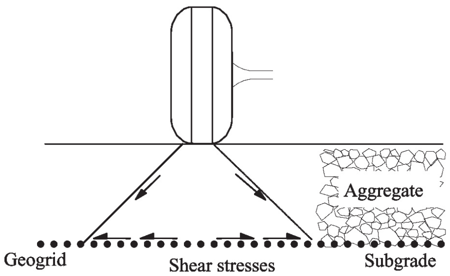

Figure 2. Lateral restrain effect.

3 LARGE SCALE TESTING

3.1 *Test model*

A test series was launched at the University of Applied Sciences in Dessau, Germany to have a closer look into this subject with (Turczynski & Schwerdt 2004) and (Boettger 2005). Both the test site as well as the load and measurement facilities have been made available for these 1:1 scale tests by this university. The layer thickness and the grain size have been chosen according to the test cylinder to prevent effects of the limited diameter. Control measurements have shown that this has been done successfully.

The road structures have been built in a circular steel cylinder with a diameter of 1.6 m and a height of 1.3 m (Figure 3). A cohesive soil with varying water contents was used as sub grade at three different bearing capacity stages. The range covered CBR-values of 1.1%, 2.2% and 5%. Several layer combinations of crushed gravel 0/32 mm and Enkagrid MAX 40 have been investigated to estimate the effect of the geogrid in unbound sub base layers. The biaxial polypropylene geogrid has an ultimate tensile strength of 47 kN/m at a strain at break of 10%. For single layer situations the geogrid was placed directly on the sub grade. In case of a multi-layer system the second layer was placed on top of 30 cm of aggregate. The gravel of the sub base has been compacted to Proctor densities between 0.85 and 1.02 depending on the bearing capacity of the sub grade and the use of geogrids.

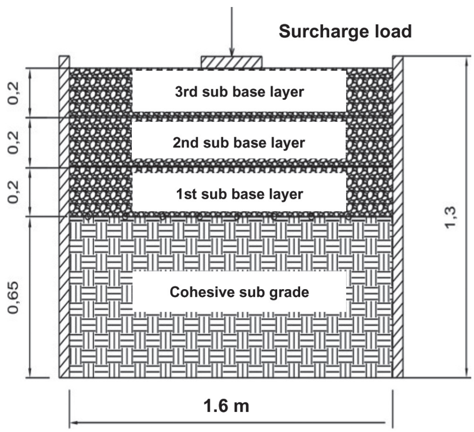

Figure 3. Layer structure in the test cylinder.

A dynamic load has been applied in each test set up by using a circular steel stamp. The diameter of the load stamp was 0.3 m and is comparable with the contact area of a two wheeler. Depending on the test combinations a load of 30 kN respectively 50 kN was applied to the load stamp. The number of load cycles at a frequency of f = 2 Hz ranged from 10,000 to 50,000. To prevent effects of the steel cylinder its walls have been covered by a slip foil. Refer to Figure 4 for a photo.

Figure 4. Test facility.

3.2 *Discussion of measurements*

3.2.1 *Proctor density*

The inclusion of geogrids supports the compaction of granular fill on soft foundations. From comparisons between unreinforced and reinforced sections on a sub grade with CBR = 1.1% the conclusion could be drawn that the Proctor density has been increased by 5 to 10% while using geogrids. A Proctor density $D_{PR} \geq 0.9$ was only be achieved in case a geogrid was applied. This effect reduces by an increasing bearing capacity of the foundation soil. There is nearly no effect regarding This effect wasn't present with an CBR > 5%, because a Proctor density of $D_{PR} = 1.0$ could be easily achieved.

The tests have shown that a Proctor density of $D_{PR} \geq 0.98$ is needed to get consistent results to predict the performance of the construction.

3.2.2 *Rutting*

During the tests sink hole depths of the load stamp between 50 mm and 200 mm for the unreinforced and between 20 mm and 105 mm for the reinforced situations have been measured. The test was stopped when a bulge of soil developed at the edges of the load stamp.

As expected an increasing bearing capacity of the sub grade and an increasing layer thickness of the sub base goes with a reduction of the sink hole depth.

But the most essential effect for the decreased rutting was provided by the geogrid. Compared to the various layer structures the reduction caused by a single layer of geogrid reached 40% on top of 0.2 m reinforced aggregate and for the use of two geogrid layers 60% after two times 0.3 m aggregate. The percentage rate is based on original rut depth for the reference sections without a geogrid but the same aggregate layer thickness. The bearing capacity of the sub grade was in both situations CBR = 1.1%.

A reduction of the rutting due to a second geogrid layer was only been measured at CBR = 1.1% of the sub grade. Already on a sub grade having CBR = 2.2% an influence on the sink hole of the second geogrid layer wasn't verifiable compared to a single geogrid layer system.

Compared to the geogrid the effect of the layer thickness as well as the one of the bearing capacity of the sub grade was much less.

3.2.3 *Elongation measurements*

The measurements of the occurred elongations in the geogrid have drawn a similar picture as evaluated from the rutting. The largest deformations have been determined exactly underneath the load stamp where a strain gauge and a pressure measurement device have been placed. They reached from $0.65\% \le \varepsilon < 1.42\%$ in the single layer situation. At the edges of the steel cylinder the elongation converged to $\varepsilon = 0\%$. The elongations caused in the second geogrid layer have been even smaller and between $0.4\% \le \varepsilon < 0.55\%$. Figure 5 contains a sketch where the pressure and strain gauges have been placed during the tests. Due to the radial symmetric shape of the test facilities only one radius was used to measure the strain respectively the pressure.

A general correlation between the rutting on the surface and the elongation in geogrid couldn't be obtained. Internal failures and bulge mechanisms of the sub base, while the load has been applied, might have been reasons for that. The maximum elongation of $\varepsilon = 1.25\%$ has been reached at 105 mm sink hole depth for reinforced situation.

3.2.4 *Stress distribution in the sub grade*

The internal stress distribution in the sub grade was measured with a flat jack and earth-pressure gauges. The stress gauges have been installed approximately 0.05 m under the sub grade surface and covered with soil to provide continuous friction behaviour in the interface between the different soil and geogrid layers.

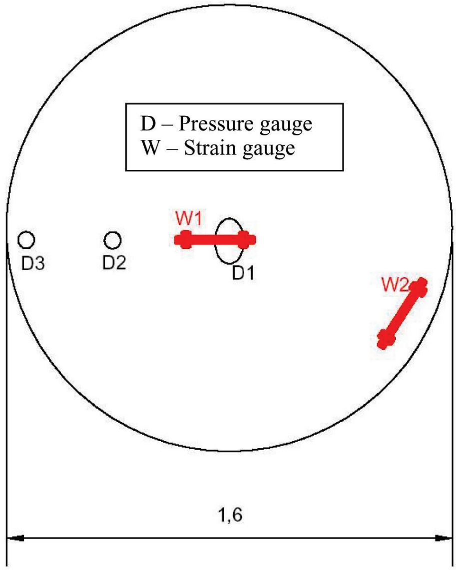

Figure 5. Pressure and strain gauges.

Figure 6 shows such a measurement for the effect of the sub base layer thickness of an unreinforced situation on a sub grade with CBR = 1.1% and layer thicknesses of 0.2 m and 0.6 m. It is clearly visible that a thicker sub base (0.6 m) led to an improved load distribution over a larger area with a lower peak value directly underneath the load stamp. The curve of the 0.2 m sub base layer situation might back up the conclusion that a bearing or deep-seated failure occurred during the loading. That's in line with the observed rutting and the cracks at the surface of the sub base as shown in Figure 7.

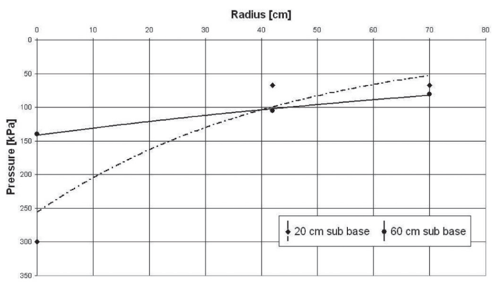

Figure 6. Stress distribution in the sub grade (CBR = 1.1%) depending on the layer thickness without a geogrid.

Figure 8 gives an indication of the effect of a geogrid compared to the unreinforced situations at CBR =1.1% and CBR = 5% of the sub grade. There are clear signs that the effect of the geogrid is the

Figure 7. Cracks at the sub base surface.

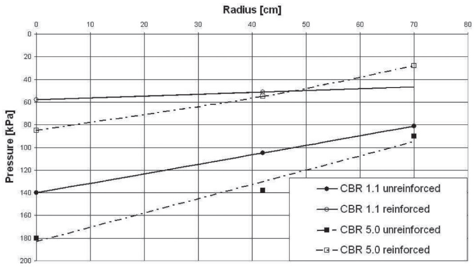

Figure 8. Stress distribution improvement in the sub grade layer underneath a 0.6 m of aggregate.

decisive element in the structure and the influence of the bearing capacity is of lesser extend.

3.2.5 *Bearing capacity*

To determine the bearing capacity of the sub grade as well as of the sub base at several test stages the following measurements have been carried out:

- Static plate load tests
- Dynamic plate load tests using a light falling weight
- Static CBR-tests
- Dynamic CBR-tests
- Undrained shear strength tests

The above described observations have been confirmed by these measurements. It can be stated that the various measurements correlated well to each other for the investigated tests. For example the quotients of the first and the second load processes of the plate load tests allow estimates about the compaction ratios. These results have been in correlation to the densitometer measurements. The effect of the geogrid on the compaction ratio was significantly higher on low bearing capacities and reached its maximum at CBR = 1.1% and an aggregate layer thickness of 0.4 m with an improvement of 30% for the bearing capacity. This was also visible in the inclination and the shape of the curves determined in static plate loading tests.

The outcome of the tests based on the bearing capacity improvements resulted in minimum thickness requirements for the aggregate layer depending on the sub grade conditions. The results of the tests based on the rut depth haven't led to a minimum thickness requirement. In this case an improvement is achieved by simply installing a geogrid independently from the actual layer thickness. Table 1 contains an overview of the optimum layer thickness to improve the bearing capacity by the use of a geogrid compared to the unreinforced situation.

The measurements lead to the conclusion that the influence of the geogrid on the bearing capacity decreases while the bearing capacity of the sub grade increases. Furthermore is an appropriate layer thickness essential for the effect of the geogrid.

Table 1. Optimum layer thickness to improve the bearing capacity.

CBR sub grade	Thickness sub base layer	Improvement of the bearing capacity
1.1%	60 cm	35%
2.2%	40 cm	40%
5.0%	40 cm	17%

4 DESIGN TOOL

The measurements of the evaluated tests gave highly consistence results. The outcome has been summarized in Figure 9 to make them available for the practical use. So far as the in the following sections mentioned circumstances are valid on site the chart can be used to predict the behaviour of unbound layers in road constructions.

4.1 *Area (I) – green*

This area of the chart covers the standard situations. It can be chosen if the bearing capacity of the sub grade is between $2.0\% < CBR \leq 5.5\%$. The use of one geogrid layer provides an economical solution. The layer thickness of the sub base depends on the target of the bearing capacity on top of it. The sub base layer must be sufficiently compacted which has been achieved with $D_{PR} \geq 0.98$. Special attention must be paid to a sufficient angle of internal friction cal. $\phi \geq 42°$.The installation of the sub base material should be close to its optimum water content.

The area between CBR 2.0% and CBR 2.5% is a kind of a transitional phase where the requirements for the sub base material and the installation process are even higher.

4.2 *Area (II) – white*

On sites where the bearing capacity of the sub grade is $1\% < CBR \leq 2\%$ a first layer of a geogrid in connection with a nonwoven should be installed to achieve a $CBR \geq 2\%$ on top of the first sub base layer. Due to this step the site will be passable and

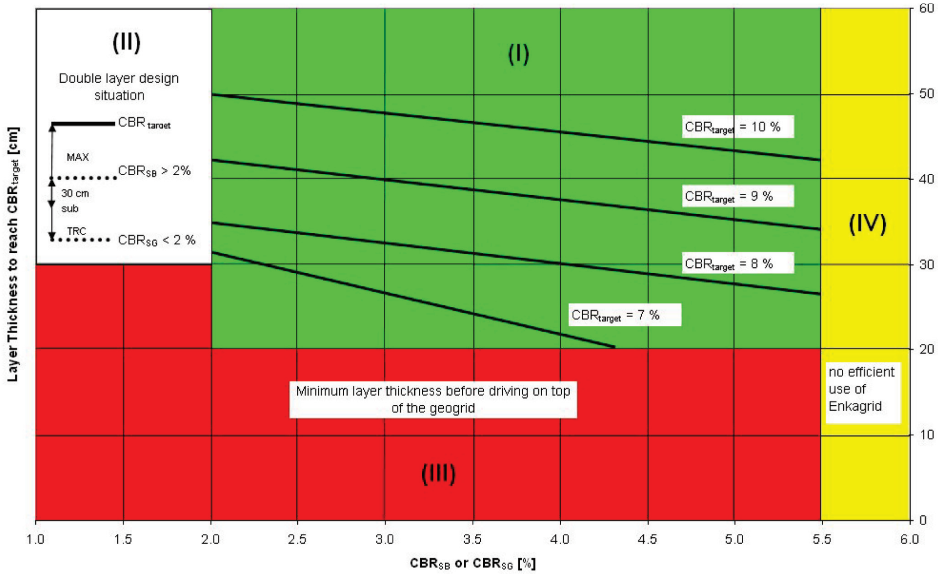

Figure 9. Design chart.

the needed bearing capacity can be created to proceed with area (I).

That the first 0.3 m of sub base material act as a temporary construction situation with a limited load cycle capacity of approximately 2,500 axle loads with 10-t-axles. It is difficult to give a general prediction for that range. Continuous observations on site are recommended. In case extreme rutting occurs the ruts must be refilled with additional sub base material before the 2nd geogrid layer will be installed.

4.3 *Area (III) – red*

This area marks the minimum required thickness to prevent the geogrid against damage during the installation process according to the front-spread method and the driving on top of it. The standard thickness for the protection layer is 0.2 m and on soft sub grade at least 0.3 m.

4.4 *Area (IV) – yellow*

Based on experiences on several construction sites and the described large scale tests it can be stated that a bearing capacity CBR > 5.5% makes the use of a geogrid inefficient. The bearing capacity of the sub grade is sufficient to carry the load and the geogrid won't have any reinforcing or stabilizing effect. The systems bearing capacity depends on the quality of the sub base material in that case. In some cases it can be useful to include a geogrid into the construction to ensure the quality of the aggregate over the service life of the construction.

5 ANALYTICAL CHECK

To evaluate the measurements and the design charts based on the pasts experiences calculations according to (Giruoud & Noiray 1981) have been done with EnkaRoad 3.1. The results confirmed the validity of the test results. The difference between the tests and the computation was in every case smaller than 0.05 m and normally between 0.02 m and 0.03 m applying the same number of load cycles.

With the results between the tests and the calculation a relation between the acceptable rutting by (Giroud & Noiray 1981) and the bearing capacities of the test range can be drawn. Furthermore it can be said that the strength of the geogrid is of minor importance so long as the structure of the geogrid provide a good interaction in the interface to the neighbouring soil at low deformations.

6 CONCLUSIONS

It has been proven with the explained 1:1 scale tests that geogrids have a measurable positive effect on the bearing capacity and on the rutting of unbound layers in road constructions. That's even the case where only very small elongations of $\varepsilon \leq 0.5\%$ occur. Because of this the deformations are much smaller than the generally accepted 1.5% to 2% for the membrane effect of geogrids in unbound layers. How far the working mechanisms have changed from reinforcing to stabilizing effects, depending on the caused elongation, couldn't be evaluated.

The limited number of double layer tests where very small elongations have been observed in the geogrid indicate such a change but don't allow any general statement. This needs some further investigations on thin multi-layer reinforced structures.

The facts stated in this paper have been done based on the used aggregate and the provided geogrid. The evaluation is mainly based on the stress-strain behaviour of the used geogrid, which differ for other materials. Therefore the conclusions drawn in this paper have to be seen in conjunction with the used materials.

Regarding the rutting a maximum reduction of the rut depth of 40% compared to the unreinforced situation has been observed while using a geogrid.

Improvements of up to 30% have been noticed for the bearing capacity on top of a reinforced sub base layer.

The validity of the determined design chart and the predicted effect of the geogrids under unbound sub grade layers have been proven on site and in the belonging recalculations.

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