Comparison of designs based on standard tests with on site measurements of the reinforcement effect of geogrids in executed road projects

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ABSTRACT: A variety of measurements has been taken into consideration to get an impression how reliable the theoretical dimensioning of reinforced road structures compared to the practical realization on construction sites is. The focus has been set on the effect of the geogrid in terms of rutting reduction and raising the bearing capacity. While this was done several circumstances have been discovered which may influence the mechanisms of the interaction between the geogrid and the surrounding soil. Some conditions have to be fixed to be able to transfer the design idea to the construction site.

1 INTRODUCTION

Geogrids in road constructions in this connection are used to reinforce and to stabilize the unbound sub base layers over soft sub grades.
Though geogrids have been used in this manner for decades the mechanism of their effect is only vaguely known. The theoretical background which is mostly used for the dimensioning of road constructions is (Giroud & Noiray 1981) and newly (Giroud & Han 2004). It is based on the rut depth which may occur during the service life. Therefore this theory fits most for temporary roads.

But the practical use of geogrids in road constructions has been driven faster than its technical background in the last 25 years. Geogrids are now also commonly used as an inlay of unbound sub base layers covered by bound and paved top layers. That means that rutting is not acceptable for this kind of high demanding road constructions. For these applications the dimensioning has to be changed from a rutting based to a bearing capacity related system. The question may be raised how the stress will be initiated in the geogrid without noticeable deformations. In general this gap will be closed by building test sections on a construction site.

Two opportunities may used to design a road construction. To check the suitability of these two procedures where one is rutting related and the other based on the bearing capacity field and laboratory measurements have been carried out. The measurements have been divided in three groups which provide general information, records to assess the rutting and tests which consider the bearing capacity.

2 GENERAL SETTINGS

2.1 *Undrained shear strength*

In general the undrained shear strength is an important design factor for both mechanisms, the design based on rutting as well as the design based on bearing capacities. It is a good basis to carry on with further investigations on the sub grade improvements.

In the range footings with a very low as well as a low bearing capacity the undrained shear stress correlates with the CBR-values as well as with the modulus E_{V1}. This can be seen in Figure 1 and Figure 2

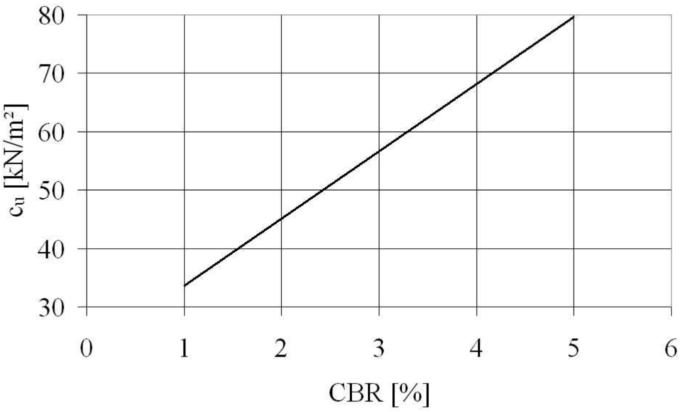

Figure 1: Correlation c_u vs. CBR

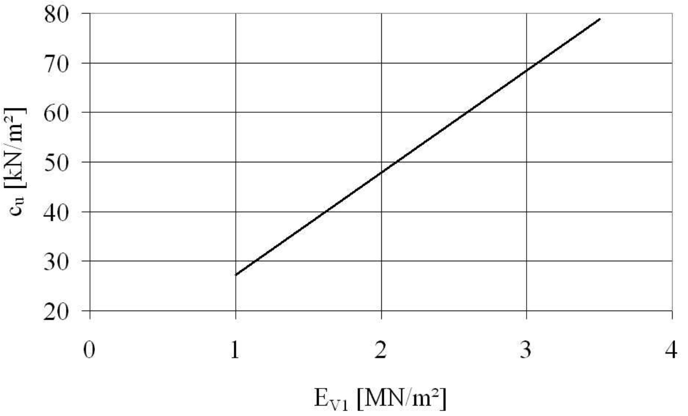

Figure 2: Correlation c_u vs. E_{V1}

2.2 *Water content*

On site measurements by (Retzlaff 2000) have shown that the water content of the sub base has an influence on the relative density of the granular fill and therefore a direct influence on the constructions bearing capacity. The circumstances of that are explained in a more detailed way in (Retzlaff et al. 2006). This negative influence has obtained for both either higher or lower water content divergent from the optimum. While using fresh concrete recycling an overlapping of the reinforcement effect of the geogrid and the hydration of the cement fines in the uppermost recycling layer may occur. Especially in that case the use of dynamic plate load devices with a light falling weight isn't feasible.

2.3 *Grain size distribution*

To achieve an optimum load spreading angle of the sub base layer a wide grain size distribution will be helpful. The share of fines (< 0.063 mm) should be significantly below the 5 weight -% limit. Already a slight move to middle and fine sand in a gravel 0/45 mm distribution may lead to poorer mechanical properties of the aggregate. This had led to the varying rut depths of the rutting in Figure 3. It has assumed that the sandy gravel may have been remixed while unloading and installing the sub base material. The final failure has occurred due to an insufficient overlapping of two geogrid lanes. These areas of weakness in structures are easily to discover by evaluating the rutting on a construction site.

3 RUTTING RELATED PROCEDURES

(Giroud & Noiray 1981) are using simplified mechanisms for their approach. They have been focussed on the rut depths and the loading spread angle of the reinforced layer above the geosynthetic. However properties which describe the sub base material or the geosynthetic are not explicit mentioned. Regarding the geosynthetics a further differentiation is available by (Giroud & Han 2004).


Figure 3: Rutting on a construction site

A real advantage of a rutting related design procedure is that the reinforcing effect by the strain in the geogrid is understandable.

Nevertheless it can't be assumed that the volume of the rut, which is pressed into the sub base, will be transferred constantly to the geogrid layer. A computation based on this includes some uncertainties. The uncertainties are larger with smaller rut widths and deeper ruts. A reason for that are bulging effects at the edges of the rutting where the soil will become looser.

The measurements at several Enkagrid types with various ultimate tensile strengths on site and in lab tests have led to a maximum elongation e < 2 % of the geogrid.

With Figure 4 in mind it can be concluded that the rutting on its own doesn't allow any clear estimate about the caused elongation in the geogrid. A general division depending on the bearing capacity of the sub grade may be drawn. That would allow the conclusion that a larger elongation occurs in the geogrid while it has been laid on a sub grade with a lower bearing capacity. But unfortunately this doesn't correlate with the rutting depth. Therefore it is questionable which supporting effect the bearing capacity of the aggregate underneath the geogrid has. In particular a comparison of the caused rutting between CBR = 1.1 % and CBR = 5 % shows that a comparable rut depth is of lesser effect to the geogrid while the bearing capacity is higher.

To clarify that observation it would be interesting to investigate on the mechanisms of possible load transfers into the geogrid. It might be that the mechanism to activate the work has changed.

Regarding the maximum deformations carried out at different densities of the reinforced sub base the picture as shown in Figure 5 has been determined.

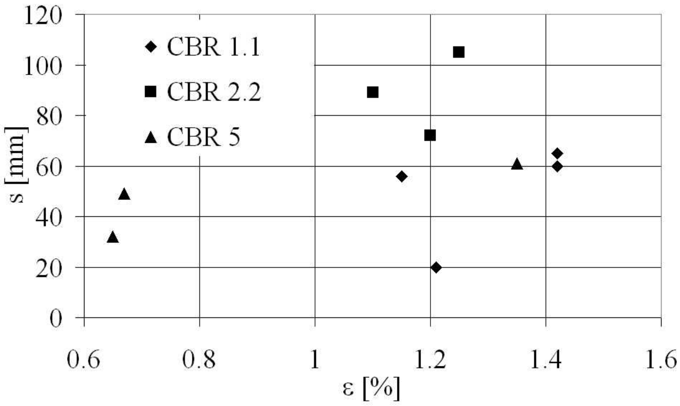

Figure 4: Relation between rutting and elongation in the geogrid

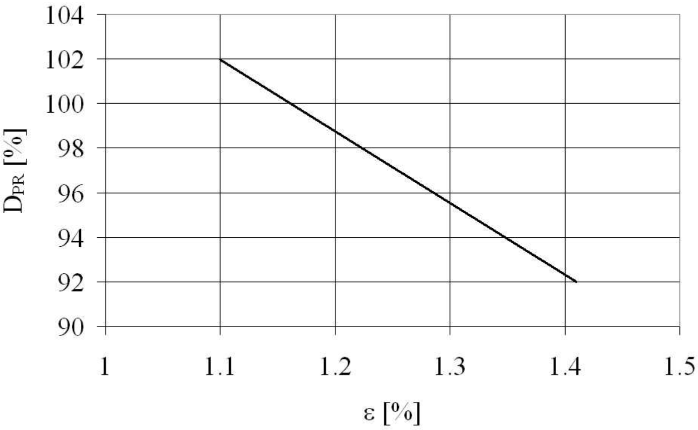

Figure 5: Relation between density and elongation

Though an extrapolation beyond the measurements isn't secured the tendency is surely given. It may be expected that the compaction of the used crushed gravel 0/32 mm has an influence of the elongation in the geogrid. To reach an elongation of e = 1.5 % the Proctor density of the aggregate must be $D_{PR} < 0.9$ and even $D_{PR} < 0.75$ before elongations e of approximately 2 % will occur. In particular the last case won't provide a stable situation of the reinforced structure and is therefore not acceptable in every respect. This leads to a remarkable change of the soil properties which depend on the Proctor density. The commonly required Proctor density for road constructions of at least $D_{PR} \geq 0.95$ may cause an elongation in the geogrid of $e \leq 1.5$ % by the applied stress.

This can be verified also by analytical methods because the interaction resistance at the interface between the geogrid and the surrounding soil depends on the normal stress applied to the system. This force is limited in road constructions due to the relatively thin layer system. The wheel load of a truck will affect only a small part on the surface which doesn't cover the whole area of the influenced geogrid section.

4 BEARING CAPACITY RELATED PROCEDURES

With an increasing successful use of geogrids in haul and country roads a market for the use in road construction with bound top layers has been developed. With this step forward the requests on each single layer in the structure have been increased compared to unpaved roads. In general no or only very small deformations can be accepted. Deformations are a warning for lower bearing capacities. The bearing capacity can be evaluated in several ways. Commonly used are the CBR-value and the modulus of the aggregate which can be determined with plate load tests. While CBR tests provide only percentage rates for the structural resistance the plate load tests give results of the actual bearing capacity in terms of stress. Therefore it has been decided to determine the effect of a geogrid with the help of plate load tests. This has been done on several construction sites. While doing this it has been discovered that already big differences on a single test field have to be taken into account. That made a direct comparison between the single measurements difficult and sometimes impossible. This let to the conclusion that general inferences can't be made from a few in situ tests on site, because they are not repeatable or applicable to other sites due to different circumstances. That should also be kept in mind for the design of road constructions. The more data about the construction site available are, the better the prediction for the performance of the design will be.

As already mentioned plate load tests offer one opportunity to determine the bearing capacity of soil. For this evaluation a circular load stamp will be installed on the surface of the soil layer. The vertical load will be applied to this load stamp in steps until it reaches a certain level or the settlements extend given limits. During this process the load stamp will be pressed into the surface of the aggregate layer. Based on the settlements and the applied load a verification of the bearing capacity is possible.

If that has been done twice in a measurement cycle the relation between the first and the second loading allows conclusions about the bedding conditions of the soil. Different load stamp diameters are available: 300 mm, 600 mm and 762 mm. The diameter of the load stamp has an effect on the depth below the surface which may be affected by the test. Common to all diameters is that the deformations caused on the surface and therefore also in the reinforcement layer are very small. That's challenges the proof of the reinforcing or stabilizing effect of the geogrid. This is only possible if a direct comparison between a dummy and reinforced section is available on a construction site. But it will be still questionable if the geogrid has a reinforcing or stabilizing effect.

In case of a reinforcing mechanism the effect will be achieved with deformations in the geogrid layer where tensile stress is applied to the geogrid. That's in line with the above described situation for rutting procedures.

A stabilization of the sub base layer has been realized if the load spreading angle of the aggregate layer on top of the geogrid has been improved due to the geogrid inlay without any noticeable deformations. An enlargement of the load spreading angle could be proven by pressure measurements in the sub grade respectively in the aggregate layer below the geogrid. Because the measurement devices need a sufficient embedding this isn't appropriate on construction sites. This has let to extensive 1:1 scale laboratory tests (Retzlaff et al. 2006)

During these tests it has been determined that there is an effect of the geogrid on the bearing capacity at even very small deformations.

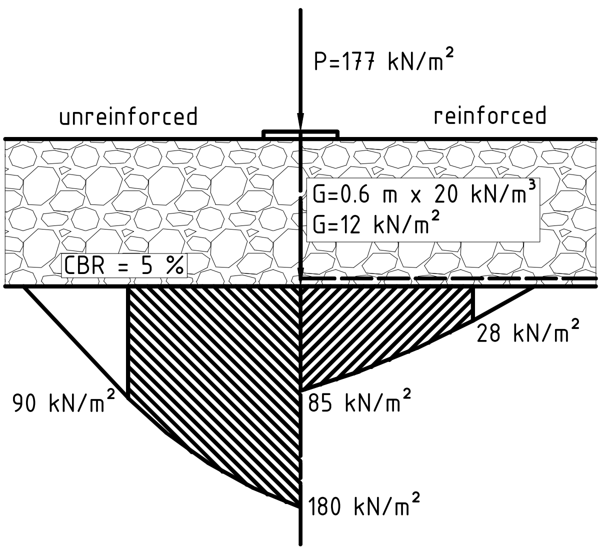

Figure 6: Stress distribution below the sub base in an unreinforced and a reinforced situation

Figure 6 shows that for the unreinforced situation the loads have caused a punching failure because the measured stress directly under the surface of the sub grade equals the sum of the applied stress to the load stamp and the stress caused by the gravity of the aggregate In case a geogrid was applied the load distribution has improved and the load stamp has been prevented from punching through the base layer. The difference can be explained with the reinforcing effect of the geogrid.

Measurements on site by (Banjac 1998) have shown that the effect of the geogrid depends also on the location of the geogrid in the system. This has been confirmed by the testing of (Turczynski & Schwerdt 2004). Therefore the layer thickness above the geogrid should be taken into account while using it in road constructions.

5 CONCLUSIONS

The effect of the inclusion of a geogrid in road constructions has been demonstrated in executed projects and in theory.
It is very important that the procedure is carefully described. It has been shown that for example the density of the reinforced sub base layer has a decisive influence on the reinforcement mechanism. The accompanying elongation in the geogrid is related to the density of the aggregate. The maximum elongation of the geogrid which has been observed was in any case less than 2.0 %. The use of a geogrid enables a road construction to carry much higher loads before a failure may arise.

6 NOTATIONS

CBR	California Bearing Ratio [%]
c_u	Undrained shear strength [kN/m²]
D_{PR}	Proctor Density [%]
E_{V1}	1st modulus of plate loading test [MN/m²]
G	Gravity pressure [kN/m²]
P	Load Pressure [kN/m²]
s	Rutting [mm]
e	Elongation [%]

REFERENCES

Giroud, J.P.; Noiray, L. 1981. Geotextile reinforced unpaved road design. ASCE, Journal of the Geotechnical Engineering Division, vol. 107, n. GT 9, 1233-1254

Giroud, J.P.; Han, J. 2004. Design method for geogrid-reinforced unpaved roads – Part I theoretical development. ASCE Journal of Geotechnical and Geoenvironmental Engineering, vol. 130, n. 8, 776-786

Giroud, J.P.; Han, J. 2004. Design method for geogrid-reinforced unpaved roads – Part II calibration and verification. ASCE Journal of Geotechnical and Geoenvironmental Engineering, vol. 130, n. 8, 787-797

Retzlaff, J. 2000. Einsatz von Geogittern im Straßenbau unter ungebundenen Tragschichten bei besonderer Berücksichtigung zeitabhängiger Faktoren. Master thesis, University of Applied Sciences Wismar, Germany

Retzlaff, J, Turczynski, U., Schwerdt, S. 2006. The effect of geogrids under unbound sub grade layers. Proceedings of the 8th International Conference on Geosynthetics, 18.-22. September 2006, Yokohama, Japan

Turczynski, U.; Schwerdt, S. 2004. Prüfbericht über Untersuchungen zum Einsatz von Geogittern in ungebundenen Tragschichten – Teil 1: Ergebnis der Versuche mit Geogitterbewehrung. Gropius Institut als An-Institut der Hochschule Anhalt in Dessau, Germany. Unpublished

Boettger, J. 2005. Geogitter in ungebundenen Tragschichten. Master thesis, University of Applied Sciences Anhalt, Dessau, Germany. Unpublished

Banjac, R. 1998. Dimensionierung von Oberbauten von Verkehrsflächen unter Einsatz von Geokunststoffen zur Stabilisierung des Untergrundes. Master thesis, University of Applied Sciences Frankfurt, Germany. Unpublished