Design methods for roads reinforced with multifunctional geogrid composites for subbase stabilization.

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This article is a direct translation from the published paper 'Dimensionierung von Oberbauten von Verkehrsflächen unter Einsatz von multifunktionalen Geogrids zur Stabilisierung des Untergrundes' presented at the German conference on geosynthetics 'Kunststoffe in der Geotechnik', Technical University Munich, March 1999

1 Introduction

During construction of roads on soft soils a certain bearing capacity of the subbase is required to prevent unnecessary differential settlements of the roadstructure. For a subsoil with insufficient bearing capacity, measured with ZTVE StB 94, stabilization is necessary. The bearing capacity can be increased by excavation of the soft material, chemical stabilization by using chalk or by using geosynthetics.
For several years geosynthetics are used to stabilize the subbase for unpaved roads like haulroads or access roads.
For paved roads till now the use of geosynthetic reinforcement is not discussed due to the very small displacements of the surface and due to the poor long term tensile strength of geosynthetics used in roads. For paved roads geosynthetics should be used which have a very positive stress-strain behavior and good long term behavior.

2 Functioning of geosynthetics in roadstructures

Geosynthetics in roadstructures can have a reinforcement, separation and filtration function. Because of the reinforcement function significant higher shear stresses can be observed at the interface subbase - geosynthetic - subsoil (Figure 1). The separation function prevents contamination of the gravel with the small particles of the soft subsoil.

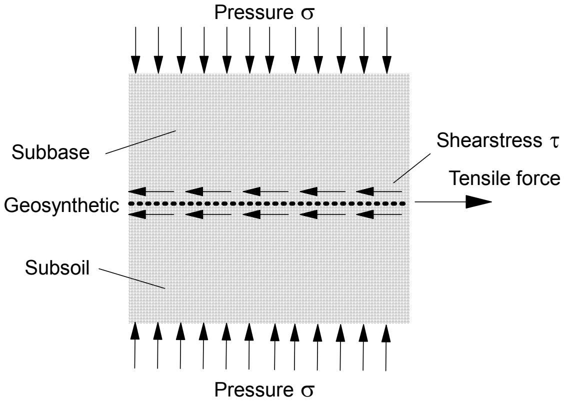
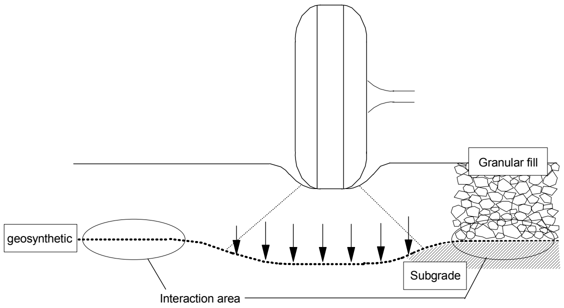


Figure 1: Reinforcement function of geosynthetics

The tensile force is only created when displacement occurs below the geosynthetic. A membrane effect will then be developed when enough interaction between soil and grid is developed (Figure 2). This mechanism creates an extra stiffness in the roadstructure and prevents further settlement.
When a geosynthetic develops high tensile strength at very low elongation (i.e. a high modulus), less settlements will occur at the (unpaved) surface of the road structure.



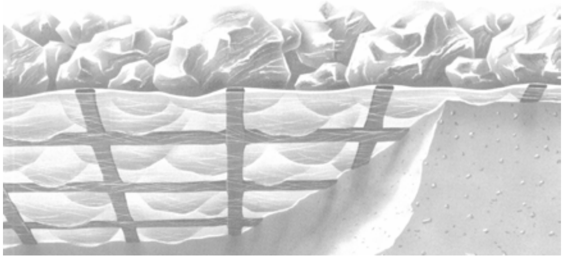
Picture 2: Membrane-effect after *Giroud and Noiray* [1]

The increase of bearing capacity is mainly attributed to the reinforcement function. As the separation effect substantially contributes to the long term stabilization, it is useful to combine both functions in one product.
An other important issue is that the stresses should be taken up by the geosynthetic also for a longer period without significant strain. During the construction of the unpaved road the geosynthetic will be pretensioned according to the Membrane-effect theory [1]. With this pretensioning effect the foundation of the road possesses a higher stiffness which has a positive effect on the lifetime of the road. Geosynthetics for permanent unpaved and paved roads should possess good long term performance to act as a reinforcement and/or as a separator during the total road life..

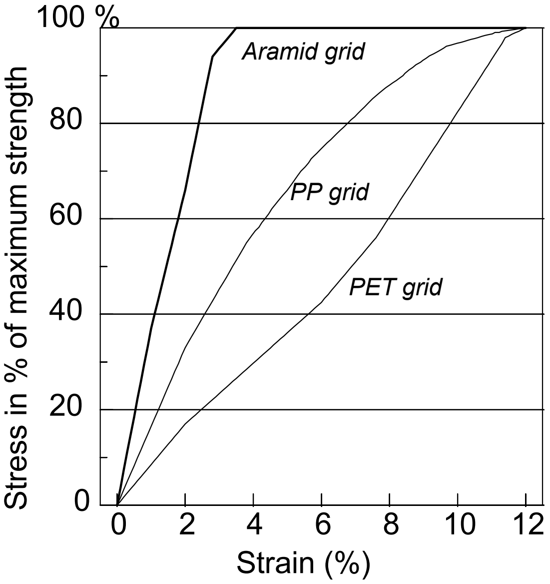
3 Multifunctional geogrid

At several road construction sites a multifunctional geogrid has been installed which, based on its properties, fulfills all mentioned functions (reinforcement, separation and filtration). The product is constructed from a coated aramid grid embedded in Colback, a polyester nonwoven

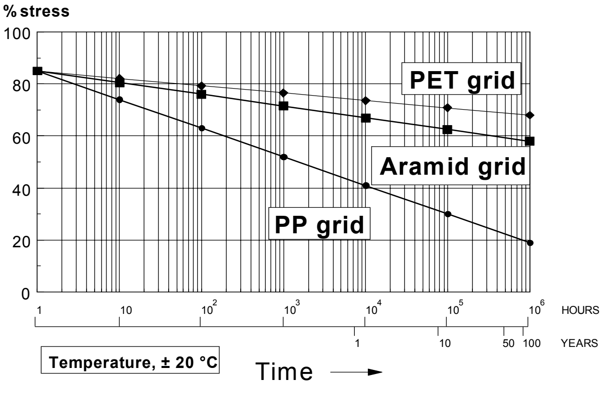
(Picture 3, TRC-Grid).
Aramid possesses a very high Elasticity-modulus which activates high tensile forces at low strains compared to other polymeric products (Picture 4). Besides, aramid has a low creep behavior resulting in a long structure lifetime with a very small reduction of tensile strength or no increase of displacement (Picture 5).



Picture 3: Multifunctional-geogrid



Picture 4: Stress-strain curves of different geogrids



Picture 5: Creep rupture data of different geogrids

4 Fieldtests

In roadwork's the necessary bearing capacity of the subsoil and the subbase is measured by plate bearing tests. The allowable displacements are presented in the RStO 86/89, a guideline for the standardization of the total road structure.
In several existing roadprojects fieldtrials were executed at the first phase of the road construction to assess the properties of a multifunctional-geogrid and to establish the minimum thickness of the base when incorporating a multifunctional-geogrid.

In this paper the fieldtest near the B26 Südspange Goldbach is presented as example. The subsoil before the construction existed of soft to stiff clay.
A testfield of ca. 10 x 30 m has been installed. With static and dynamic plate bearing test the bearing capacity has been measured. After excavation of the top-layer of the subsoil a uniform area was created with a equal bearing capacity of Ev2 = 20 MN/m² and a relation Ev2 / Ev1 = 3,0 to 4,0 was measured. With the dynamic plate bearing test Evd-values from 8 to 10 MN/m² obtained.[1]

The testarea was divided in 10 sections. On the subsoil several different heights of base were placed. The granular material was a mixture of sharp broken gravel 0/32 mm (measured with the ZTVT StB 95 standard).
The test sections were installed in such a way that the bearing capacity with and without geosynthetic could be measured. The geosynthetic used had a short term strength of 30 kN/m at a strain at break of 3.5 % (TRC-Grid 30). At each section 5 static and 3 dynamic plate bearing tests were executed. The location of each plate test was such that it did not influence other test locations (Picture 6). The base thickness varied between 30 cm and 60 cm (Picture 7).

The results (average values of the executed trials) of the static plate bearing tests showed an increase to 76 % bearing capacity compared to a structure without a geogrid. The maximum increase for the static plate bearing tests was for 40 cm base thickness, for the dynamic plate bearing tests this was 30 cm (Picture 8).

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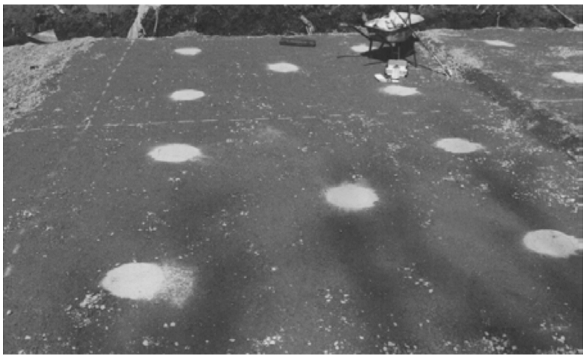
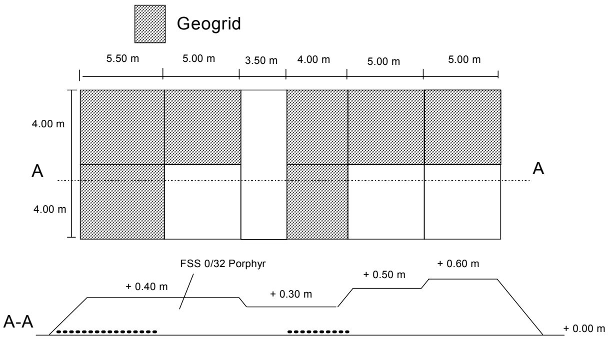
[1] Additional information: the Ev1 and Ev2 are the messured elasticity moduli on top of either the subsoil or the base. The Ev1 is measured when a plate is pushed into the soil. The relation between the force and the displacement is the E-modulus. After relaxation the plate is pushed for the second time in the soil at the same location which gives the Ev2. In Germany a certain Ev2 should be reached before placing the next layer, e.g. the surface layer.



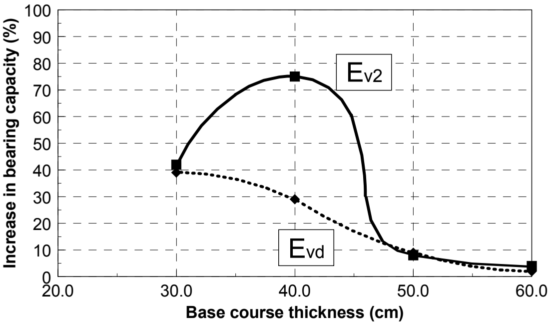
Picture 6: Test area with locations of the plate bearing tests clearly visible.



Picture 7: Testfield Goldbach with the lay-out of the sections and the thickness of the base.

The increase of bearing capacity reduces at higher base course thickness due to the limited depth influence on the plate bearing test. Combining the results of different testsites, the maximum and minimum increase of bearing capacity depends on the quality of aggregate and the bearing capacity of the subsoil.

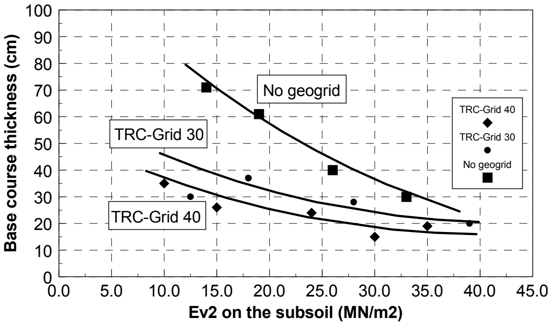
For a bearing capacity of the subsoil of $E_{v2} < 10$ MN/m² (not possible to measure with a static plate bearing test) e.g. $E_{vd} = 2 - 4$ MN/m² or CBR = 2 % the maximum bearing capacity increase was obtained at 300 mm. Similar testsites with different subsoil and subbase conditions have been carried out [2].



Picture 8: Increase of bearing capacity by the use of geogrids

In Picture 9 the results of the plate bearing test are presented on a road and bicycle path between Schneppenbach and Westerngrund. The base course material was a well graded recycling aggregate 0/45 mm.

In general, the increase of bearing capacity by the use of multifunctional-geogrids can be measured by the test methods like the plate bearing tests.



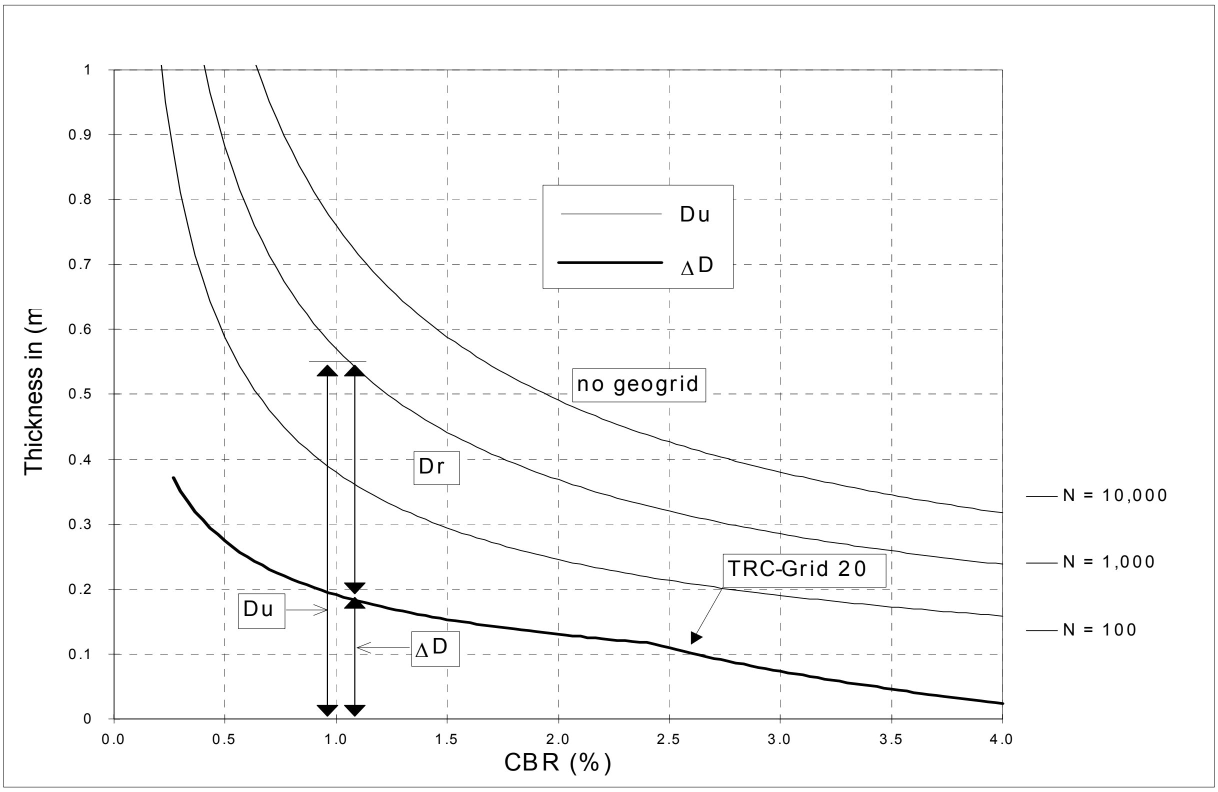
Picture 9: Base course thickness needed to achieve the bearing capacity of 80 MN/m^2 on top of the base course.

Furthermore tests with passing trucks were executed to measure the rut depth after several wheel passes. After these tests the geosynthetic was extracted to determine possible damage. It showed that a minimum base course thickness of 200 mm should be used to have no reduction of the behavior of the geosynthetic.

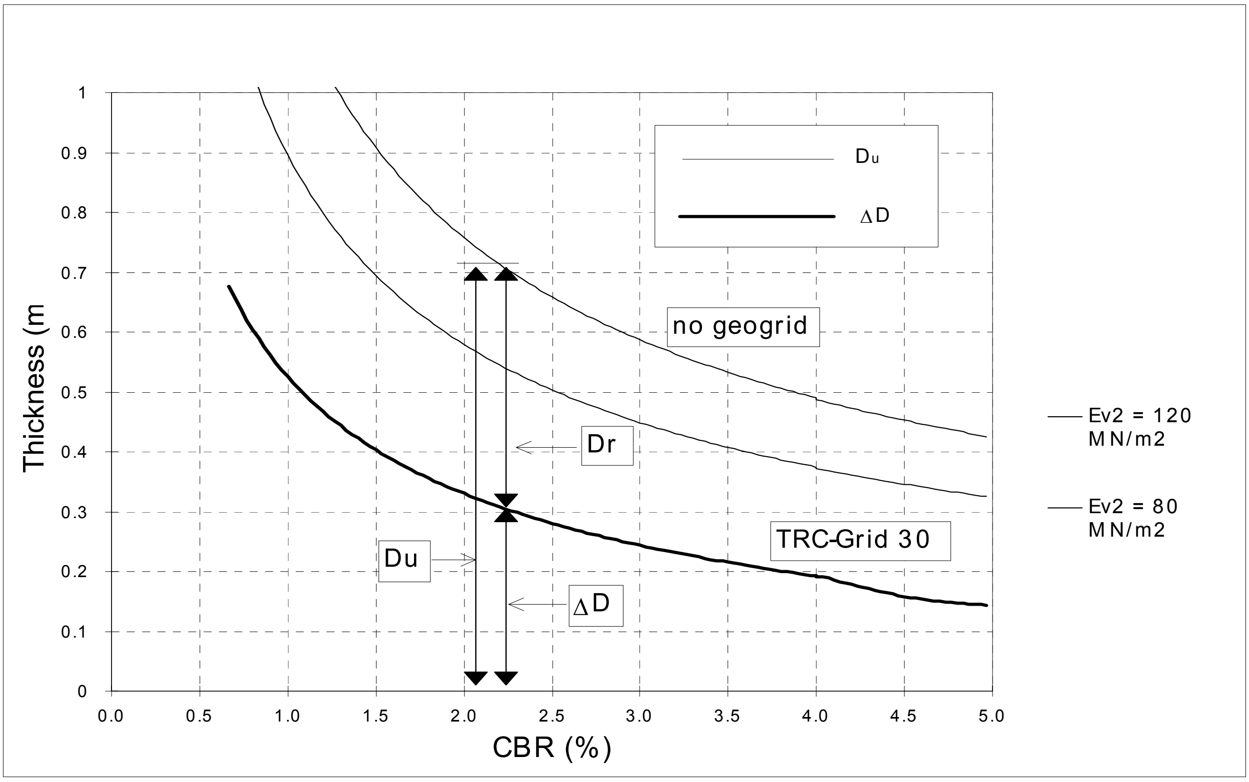
The measured rut depths are strongly related, as expected, to the conditions of the subsoil, the base course thickness and the quality of the aggregate. It was recorded that the rut depths reduced by half due to the incorporation of the multifunctional-geogrid.

5 Unpaved roads

Based on the results of the trials and the membrane theory of *Giroud and Noiray* [1] design graphs are developed for multifunctional-geogrids in unpaved and temporary roads which are also presented by *Jaecklin and Floss* [3]. Boundary conditions are the allowable rut depth, the axle load, the number of axle passes, the conditions of the subsoil and the quality of the aggregate. From the graphs the designer can read the thickness of the base without geosynthetic (Du), the reduced thickness when using a geosynthetic (Dr) and the reduction (ΔD). Picture 10 shows the design graph based on a rut depth of 75 mm and a geogrid with an ultimate tensile strength of 20 kN/m (TRC-Grid 20). The minimum thickness as described in [3] is not taken into account. Other details can be found in [4].



Picture 10: Designing the base thickness for unpaved roads based on the allowable rut depth (75 mm), axle load (80 kN) and axle passes according to the membrane theory [1].



Picture 11: Designing the base thickness for unpaved roads based on the bearing capacity on the top of the base (in this case crushed gravel 0/56 mm).

The rut depth is just one indication for the load and deformation taken up by the reinforcing element (geosynthetic). On trafficked areas other then temporary roads the bearing capacity is normally measured by plate bearing test where a plotted graph shows the relation between the applied pressure and the deformation; the deformations are often very small (< 5mm).

A design graph (Picture 11) presents design curves for the thickness of the base course (crushed aggregate 0/56 mm) to achieve a required Ev2 value on top of the layer (often a frost protection layer). The bearing capacity of the subsoil is given as a CBR value (California-Bearing-Ratio) as the plate bearing test on soft soil is very hard to perform. The investigation for the thickness of that layer was based on these very small deformation. The design curves are based on normal loads due to construction traffic and compaction which induce tension forces in the geogrid.

The results of the plate bearing tests reflects only short term behavior of the geosynthetic interlayer. When an unpaved road is build for a longer period the long term behavior of the geosynthetic (during the life time of the road) should be taken into account. The tensile strength will be reduced due to creep, mechanical damage and other mechanisms as described in EBGEO.

6 Paved roads

6.1 General

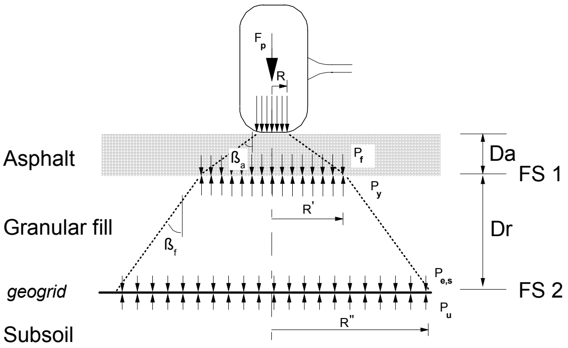
For using geosynthetics in paved road structures (surface layer existing of asphalt or concrete) the long term behavior has to be taken into account. The measures bearing capacity on top of the base should be maintained during the total service life of the road.
As mentioned before, to consider the long term behavior of a geosynthetic the reduction factors as described in the EBGEO should be taken into account. For example, the strength of the high modulus geogrid is based on the aramid yarns, which have a reduction factor A1 of 1.58 for a 100 years design life.
The special configuration of the multifunctional-geogrid provides a permanent separation to prevent contamination of the subbase and preventing losses of the bearing capacity on the long term.

For the design of the construction phase (unpaved situation) design graphs are presented in [4] to find the reinforced thickness. An example is presented in Picture 11.
For paved roads the calculated thickness of the unpaved situation is checked for spreading the load in such a way that the vertical pressure on the subsoil is not exceeding the bearing capacity of the subsoil.
The total stability of both the base and the subsoil is checked according to modified theory of Houlsby and Jewell [5]. This new theory and the design steps as presented in section 6.2 and are also described in [4].

6.2 Design philosophy

The design for a paved road starts with the unpaved situation during construction and only then goes on to consider the paved situation. It therefore integrates the results of calculation for the unpaved road with those for the paved structure (with asphalt or concrete).
Calculation for the unpaved situation gives the thickness of granular fill when using a reinforcement. Before placing the asphalt layer the granular fill should be compacted to project specifications. This compaction is usually given as a Proctor Density (%).
To design the surface layer general accepted design charts or standard programs are available. In Germany the design method according to the RStO 86/89 is available. While the usual pavement designs have some layers of different asphalt types, the total surface layer thickness is used in this design method. Note that the surface layer has no influence on bearing capacity and only functions to spread the load. Picture 12 illustrates the mechanism.

The top-layer of the total pavement structure is considered to be elastic and isotropic and only spreads the wheel load. It has no influence on the road's total bearing capacity. Instead of using asphalt, it is also possible to calculate with a concrete pavement. In this case the load spreading angle of the top layer and the density should increase.



Picture 12: Forces and pressures in the paved situation

To check whether the complete structure is stable for its entire life, the maximum bearing capacity of the granular fill and the subsoil should be calculated and these should be compared to the actual stresses. The factors of safety (FS) for a stable structure are:

$$\frac{P_y}{P_f} > 1.1 \qquad \text{(FS 1)}$$

$$\frac{P_u}{P_{e,s}} > 2.0 \qquad \text{(FS 2)}$$

in which:
P_f = pressure on the fill
P_y = bearing capacity of the fill
$P_{e,s}$ = equivalent pressure on the subsoil
P_u = bearing capacity of the subsoil

FS 1

- The design method assumes a completely elastic surface layer that has no effect on the rigidity of the total structure. In practice, of course, the surfacing does impart additional rigidity.
- Compaction of the granular fill is likely to raise the bearing capacity of the fill to a certain maximum, and limited or no differential settlement in the fill will therefore take place.

FS 2

During the life of the structure, differential settlements may occur in the subsoil due to its low CBR value and to dynamic wheel loads. The geogrid raises the bearing capacity of the subsoil and reduces the chances of differential settlement, the most critical failure mechanism. Hence the higher safety factor.
Note:
The values given for FS 1 and FS 2 are default values. While they reflect the experiences of the authors and may serve as a guideline for design, designers may choose to adopt other safety factors more closely in line with standards applicable in their country[2].

6.3 Design procedure

STEP 1
Calculate the thickness of granular fill for the unpaved situation (D_r) as described in section 5. The selection of the geogrid type depends mainly on the CBR-value of the subsoil but can also be done in relation with the expected traffic.
STEP 2
The contact area between the tire and the road surface is considered to be circular (with radius R). R is being calculated as $R = \sqrt{\{F_p / (\pi\ P_t)\}}$ with F_d the wheel load and P_t wheel pressure. R' and R'' determined:

$$R' = R + D_a \times \tan \beta_a \qquad \text{(eq. 1)}$$
$$R'' = R' + D_r \times \tan \beta_f \qquad \text{(eq. 2)}$$

in which:
R = radius of area of contact between tire and road surface
R' = radius of distributed load between tire asphalt and granular fill (Picture 12)
R'' = radius of distributed load between granular fill, TRC-Grid and subgrade (Picture 12)
D_a = thickness of surface layer (e.g. asphalt)
D_r = thickness of granular fill using a geogrid (Section 5)
β_a = load spreading angle of the surface layer
β_f = load spreading angle of the granular fill (after compaction)

When using two or more layers of different granular fill types in the road foundation, keep in mind that the different load angles and densities may have an influence on the outcome.

STEP 3
Determine the pressure on the granular fill (P_f) from:

$$P_f = \frac{F_p}{\pi\ (R')^2} + \gamma_a \times D_a \qquad \text{(eq. 3)}$$

in which:
F_p = maximum wheel load for the paved situation
γ_a = density of the surface layer

STEP 4
Calculate the maximum bearing capacity of the granular fill (P_y) using the following formula *Houlsby and Jewell* [5]:

$$P_y = 0.6\ R' \times \gamma_f \times N_\gamma \qquad \text{(eq. 4)}$$

This expression uses a shape factor of 0.6 for an axial symmetry together with the theory of Vesic [8]. The bearing capacity factor N_γ for a rough based footing can be expressed approximately as $N\gamma = 2(N_q+1)\tan\phi'$, and finally the bearing capacity factor N_q us given by the exact expression $N_q = \{(1+\sin\phi')/(1-\sin\phi')\}e^{\pi\tan\phi'}$.
ϕ' is the internal angle of friction.

CHECK 1
The stability of the fill can be checked by calculation the ratio

$$\frac{P_y}{P_f} > 1.1 \qquad \text{(FS 1)}$$

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[2] Additional information: for the German standards the FS 2 has been set to 2.0.

If it exceeds 1.1, the bearing capacity of the fill is sufficient. If the ratio is less than 1.1:

- increase the thickness of the surface layer, *or*
- use a different type of surface layer to increase the load spreading angle, *or*
- increase the compaction of granular fill to obtain a higher angle of friction, *or*
- use a different granular fill with a higher angle of friction.

STEP 5
Estimate the number of loaded wheel passes for the life of the paved road (N_p). This is equal to the number of loaded axles passes during the road life. Two load carrying axles per truck is assumed.

For the German situation this number can be obtained from the existing standards.

STEP 6
Calculate the equivalent wheel load F_e. The dynamic loadings during the road life may have an influence on the differential settlements in the subsoil. To take these repetitive loading patterns into account for the bearing capacity check of the subsoil, calculate an equivalent wheel load (F_e). This F_e will replace the single wheel load F_p.
Using the number of passes for the life of the paved structure (N_p) (STEP 5), the F_e is derived from the equation (*De Groot et al.*, [6]):

$$F_e = F_p \,({}^{6.2}\sqrt{}\, N_p) \qquad \text{(eq. 5)}$$

STEP 7
Calculate the equivalent pressure on the subsoil ($P_{e,s}$) using the formula:

$$P_{e,s} = \frac{F_e}{\pi\,(R'')^2} + \gamma_a \text{ x } D_a + \gamma_f \text{ x } D_r \qquad \text{(eq. 6)}$$

This equivalent pressure is the result of the equivalent wheel load (STEP 6) and the weight of the surface layer and the granular fill.

STEP 8
Calculate the maximum bearing capacity of the subsoil (P_u) using the formula [5]:

$$P_u = N_c \text{ x CBR x } 30 \left[\frac{R''}{R}\right]^2 \qquad \text{(eq. 7)}$$

N_c is the bearing capacity factor of the subsoil. For axial symmetry the N_c value for a reinforced structure is 5.69. For an unreinforced structure this value is 3.14.

CHECK 2
Check the subsoil stability by calculation the ratio:

$$\frac{P_u}{P_{e,s}} > 2.0 \qquad \text{(FS 2)}$$

If this ratio is higher than 2.0, the mechanical stability of the subgrade is guaranteed. If the safety factor is less than 2.0:

- increase the thickness of the granular fill, *or*
- increase the compaction of the granular fill to achieve a higher load spreading angle, *or*
- use different granular fill with a higher load spreading angle, *or*
- increase the CBR value of the subsoil by artificial consolidation.

7 Conclusions

- A design method for unpaved and paved roads has been presented.
- Extensive static and dynamic plate bearing tests on different conditions have been executed which showed an significant increase of bearing capacity when using a multifunctional-geogrid.
- The new design philosophy for paved roads is based on the lateral restraint theory [5].
- For paved roads both short ànd long term properties of the geosynthetics are critical. Reduction factors for installation damage and creep should be used as described in the EBGEO.[3]
- Several paved roads have already been designed and executed according to the presented design method. A computer program which is based on the presented design method is available at the authors.
- Further fieldtests and monitored roadprojects should be executed to verify and calibrate the new design method for paved roads.

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[3] Additional information: the use of reduction factors should be in line with the standards applicable in your country.

8 Literature

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Questions raised during the Geosynthetic Conference in March 1999 at the Technical University of Munich.

Q: 'Is there a relationship between Picture 10 and Picture 11? And why is the outcome different?'

A: 'Both pictures show a design graph which can be used to calculate the thickness of the granular fill when using a reinforcement. Picture 10 is based on the membrane effect of Giroud and Noiray which uses a deformation at the top of the fill and in the subsoil to develop this membrane (see Picture 2). Picture 11 is based on the E-modulus of the subsoil and the granular fill. The thickness of the fill the derived from the acquired E-modulus on top of the fill. As these are two different principles the two graphs cannot be compared with each other.
Further research should be done to find a proper relation between the membrane theory of Giroud and Noiray and the plate bearing tests.'

Q: 'On which method is the computerprogram based?'
A: 'The software is based on the Membrane effect of Giroud and Noiray for the unpaved road and uses the same philosophy as presented in section 6 for the paved road design.'