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Safe and economical soil reinforcement using a new style geogrid

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ABSTRACT: It's a vision of today that in future the soil reinforcement with synthetic geogrids will be as common as traditional measures. This trend is supported by economical and ecological advantages. By developing this technology also new products are entering the market. This paper will give the background of the development of a "new style geogrid" and is presenting test results from pull-out tests, miniature steep slope tests and first field application experience.

1 INTRODUCTION

The reinforcement of soils and the construction of soil reinforced structures is a big challenge for the future of earth construction activities. Different products with different properties are offered on the market. All these products have to reinforce soil structures and therefore to fulfill some basic requirements which are explained below.

2 THE GEOGRID-SOIL-INTERACTION

If geogrids with mesh sizes exceeding 10 mm are used as reinforcing elements, immediate interlocking interaction can take place between the reinforcement and the filling. The interaction can be intensified the higher the form stability and the modulus of the used geogrid and the better the geogrid matches the filling related to geometry and grain size. Depending on the selected geogrid type – woven, extruded, laid – considerable differences can occur regarding deformations of constructions in use. For this reason, product properties have to be defined which help to distinguish products related to their reinforcing efficiency with deformations as low as possible.

According to Lopes et al. 1999, optimum interlocking is given if at least 20 % of the filling's grain size ranges between the thickness of the geogrid bars and the geogrid mesh size. The interlocking results in transfering strengths from the geogrid's crossbars to the longitudinal bars and requires strong, rigid junctions.

3 DIFFERENT GEOGRIDS

Stretched, woven and laid geogrids can be distinguished (FGSV 1994). Up to now stretched geogrids are made of extruded synthetic sheets (polyolefine raw material). Holes are punched into these membrane sheets which are then stretched in machine direction or in machine direction and cross direction at the same time. Through this process the polymer molecules are orientated in direction of yield. This increases the strength of the material and reduces elongation. Stretched geogrids are made of polypropylene (PP) or high density polyethylene (HDPE) resulting in homogeneous integrated joints, which cannot be displaced, which are torsionally rigid in and vertical to the geogrid plain and which are normally 1.5 to 3 times as thick as the bars are. The manufacturer cannot directly influence the junction strength, it is always as solid as allowed by the production techniques.

Disadvantages of stretched geogrids are the limited strength (subject to raw material), which means that the short term strength is limited right now to about 150 kN/m, and the different degree of stretching in the bar and junction area, that there is hardly no stretching at the joints (due to production). Due to the strongly developed creep characteristics of polyolefine raw materials the short-term strength can only be used to a low degree as long-term strength.

Woven geogrids are wovens with openings exceeding 10 mm. They are flexible due to cross-laid warp and weft threads usually made of polyester filament yarns. The filaments are often less than 0.1

mm thick and have a large specific surface. Thus they are possibly more susceptible to installation stresses and environmental influences than for example monolithic stretched and laid geogrids (BMBV 1990 and Bräu 1999). As protective measure they are often equipped with a PVC or PVA coating. For all flexible and not pre-stressed reinforcing products, especially all woven geogrids, a so-called structional elongation occurs with the initial stress. The product elongates by the product specific structural elongation before carrying any reinforcing load. This leads to an inefficient utilisation of the strength of the reinforcing elements and results in unnecessary deformation at site within the geosynthetic soil composite.

Laid geogrids are made of coated strips respectively strip-like elements (FGSV 1994). Products of different manufacturers are offered in this product group. There are flexible products, for example bundled polyester or aramide yarns which are fixed at the junctions by polymer coating. These products are less significant on the market than woven or extruded/stretched geogrids.

Looking at the given market situation, the main challenge for the development of a more effective soil reinforcing synthetic geogrid is the best combination of highest long-term design strength and highest initial modulus to achieve the highest reinforcing success. Parallelly, the geogrid structure has to be as rigid as possible to withstand installation stresses with limited and little damages and all environmental influences of the application.

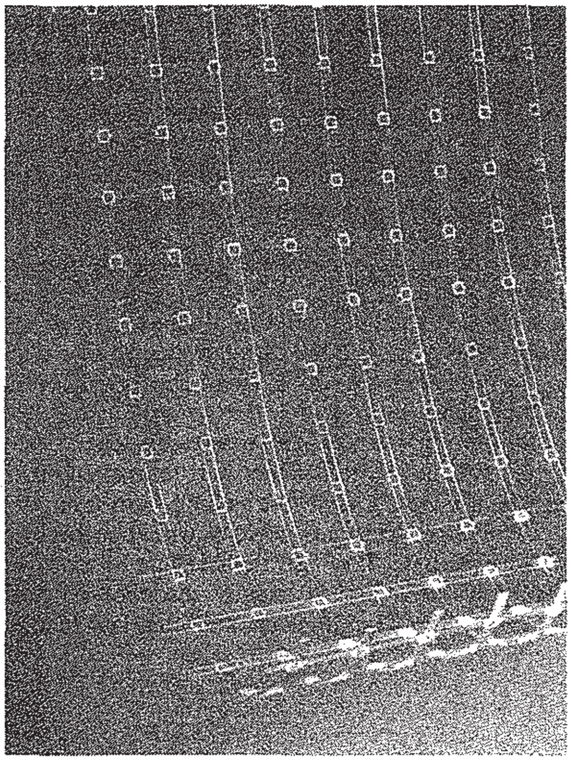

Figure 1. The new style geogrid.

Based on this approach, Naue Fasertechnik GmbH & Co. KG, a leading manufacturer of geosynthetics in Germany, has developed a new style geogrid. It is made of pre-stressed monolithic flat bars (raw material polyester / PET) with welded joints. It provides very low elongation at high strength and has very low creep characteristics.

Figure 1 shows this new style geogrid which is available as Q type with the same strength/strain characteristics in machine and cross direction (biaxial grid) and as R type with higher strength in machine direction (uniaxial grid) with short-term strength up to 600 kN/m.

As a result of the monolithic bar geometry (cross section some mm²) the geogrid has a high resistance to mechanical and chemical/biological damage. Figure 2 is showing the success of this development with the welded PET grid having the highest initial modulus compared to other products (woven grids from PET, PVA or even aramide yarns, extruded stretched grids, woven fabrics).

4 COMPARISON OF PULL-OUT BEHAVIOUR

As pull-out tests and the interpretation of the results are topic of discussions for many years up to now, the following results are not intended to be used for calculations, but for the comparison of different products under the same conditions.

A shear box with the dimensions l/b = 50 cm / 50 cm was used. The box consists of two soil containers with a height of h = 25 cm each. In the tests, always a rate of displacement of v = 10 mm/h was used.

For the pull-out tests three different geogrid types (Table 1) and two different soil types (sand and crushed stones) were used. More details of the soil parameters are given by Floss et al. 2000.

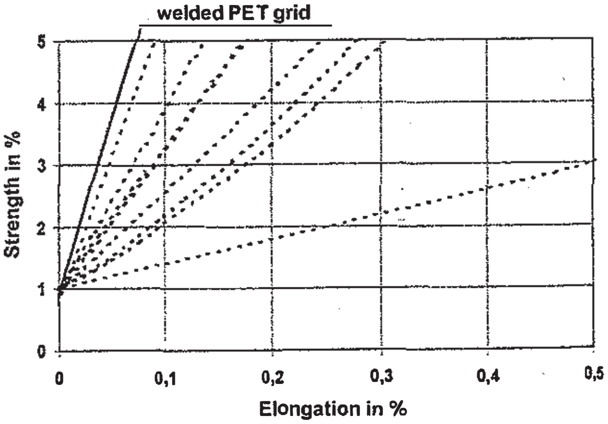

Figure 2. Different initial modulus of various geosynthetic reinforcement products (measured with a pre-load of 1% of the max. tensile strength and shown with standardized max. tensile strength = 100%) (Heerten, 2000).

Table 1. Characteristic values of geogrids for pull-out test.

product	raw material	mesh size (mm)	tensile strength (MD, kN/m)	tensile strength (CD, kN/m)
extruded geogrid (EG1)	PP	39	30	30
laid geogrid (LG1)	PET	40	40	40
woven geogrid (WG1)	PET yarns, PVC coating	20	35	30

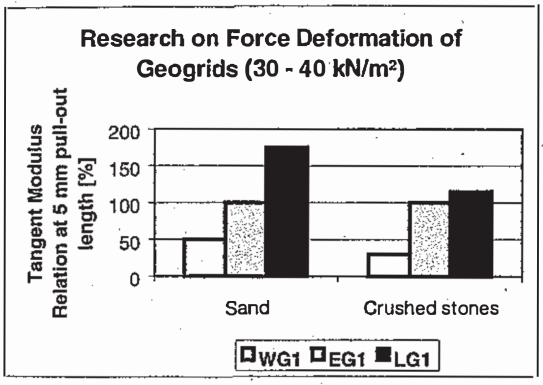

Figure 3. Relation of the tangent modulus at 5 mm pull-out length of three different geogrid types in two different soil environments.

All 3 products are biaxial geogrids.

From the numerous tests the following results are obtained from product specimens which always have two longitudinal bars (l = 70 cm) in the distance of the grid aperture and all transverse bars with a length up to the middle of the grid aperture following the longitudinal bars.

The results show that under the same conditions the EG1 reaches the highest values of the maximum pull-out force. WG1 only reaches about 50 %, LG1 about 90 % of these values for sand and crushed stone.

But LG1 has 90 % of the maximum pull-out force of EG1 at only half the pull-out length and therefore a much higher initial modulus as shown in Figure 3, where the relation of the initial modulus at 5 mm pull-out length is presented with the EG1 value being set to 100%.

5 FULL-SCALE MODEL TESTS

For studying the geosynthetic/soil interaction in a full-scale model test, several two-layered "miniature steep slopes" (MSS) were built and loaded. Although it is no direct simulation of a real steep slope, using the same conditions for all the products gives clear advice on the different behaviours.

Figure 4 shows a cross section of the MSS construction.

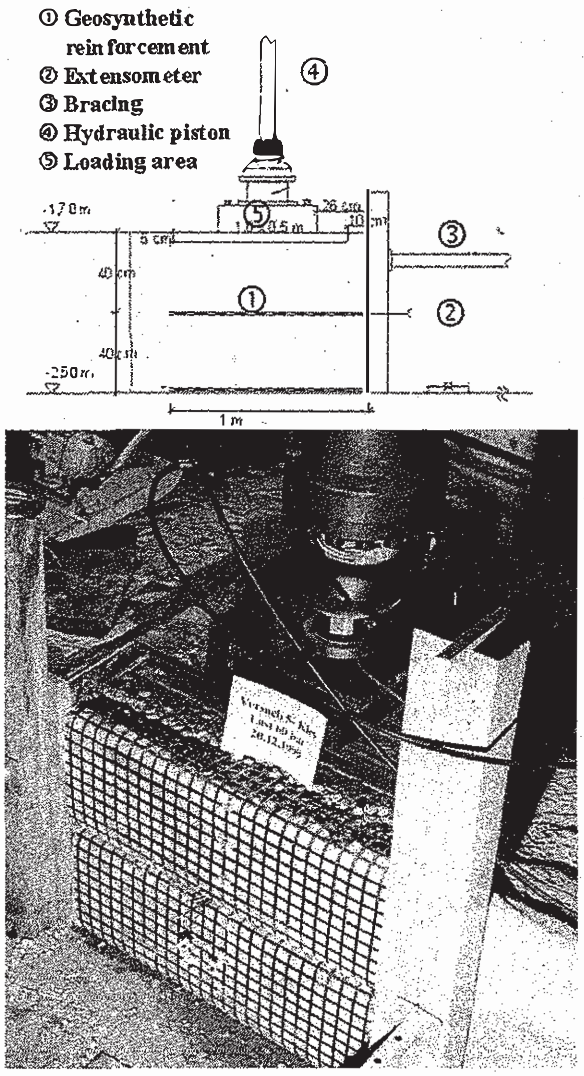

Figure 4. Cross section and picture of MSS.

The construction consists of two soil layers (h = 40 cm each), where the geosynthetics were wrapped around at the front. Between the two soil layers the products are in direct contact without connection. The reinforcement length is 1 m.

The loading area consists of a rigid steel construction with 1 m width (same as MSS) and 0.5 m in length direction. The loading is done by a hydraulic piston. The loading is done in several steps each documented with measuring results. When the deformations increased too much or when it was not possible to raise the load anymore, the test was stopped. It was difficult to fix a definite maximum bearing capacity, because usually there was no clear failure of the MSS. This was a problem for the test, but is of course an advantage of those constructions in practice.

The series of tests again was carried out with two coarse-grained soil types, a poor-graded sand and a well-graded gravel.

For the MSS tests three different geogrid types, one mechanically bonded nonwoven and one thermally bonded nonwoven were used. The relevant characteristic values are shown in Table 2. For more details of the test set-up and soils used in the test see Floss 2000.

EG2 is an uniaxial geogrid. The LG2 is assembled from flat bars made of PET black with a cross section of 8 mm x 0,95 mm.

The following Table 3 shows the maximum loads of the tests carried out.

MNW and TNW have not been tested with sand because of the expected very high deformations and settlements.

These results show that MSS with gravel have higher failure loads and less settlement than those with sand. Within the gravel tests the effect of reinforcement is quite obvious comparing No. 7 (unreinforced gravel) with the other tests. Slightly surprising are the failure loads for MNW and TNW in the same range as with geogrids, but with higher deformations, especially in horizontal direction.

Table 2. Characteristic values of geogrids for MSS test.

product	raw material	mesh size (mm)	tensile strength (MD/CD, kN/m)	strain at failure (MD, %)
extruded geogrid (EG2)	PP	115	55	11
laid geogrid (LG2)	PET	40/40	60/60	7
woven geogrid (WG2)	PET yarns, PVC coating	23/23	55/30	12.5
mechan. bonded nonwoven (MNW)	PET	---	18	65
thermally bonded nonwoven (TNW)	PP	---	12/12	70

Table 3. Maximum loads and vertical deformations of MSS.

No.	soil	geosynthetic	test final state max. load (kPa)	max. settlement (cm)	geosynthetic was
1	sand	WG2	830	28.3	
2	sand	LG2	960	26.3	
3	sand	EG2	1080	25.9	
4	gravel	WG2	1330	10.35	ruptured
5	gravel	LG2	1580	8.65	
6	gravel	EG2	1600	11	ruptured
7	gravel	---	330	1.2	
8	gravel	MNW	1460	11.5	ruptured
9	gravel	TNW	1710	24.6	ruptured

The horizontal deformations are measured along a vertical line in the middle of the construction. Following the loading steps it was found in the gravel tests that WG2 had already great deformations at lower load levels, which occurred from one step to the other. The absolute deformations were within the range of the MNW. The deformations of EG2 and LG2 tests had a continuous and similar development at lower and medium load levels. At higher load levels the EG2 has higher values of deformation than LG2. For all products the deformations with sand are 5 to 6 times higher than those with gravel.

There are results for all loading steps (Floss et al. 2000), but for comparison it seems best to look at the horizontal deformations at a certain high load for all tests. For loading $\sigma = 850$ kPa, Figure 5 shows the results for MSS tests with sand and Figure 6 those with gravel.

For MSS tests with sand the horizontal deformations are similar for all 3 products with the smallest deformations at the LG2.

For MSS with gravel great differences are between the LG2 and EG2 tests and the tests with the other products. While LG2 and EG2 tests show a parallel movement of the front, the WG2 and the nonwovens have great deformations at the lower layer. The range of deformations at WG2 is the same as with MNW.

For sand and gravel tests the horizontal deformations are in following order: LG2 < EG2 < WG2.

The tests with gravel show according to the very small deformations at the front also low values of strain. Only the TNW has significant values that increase to values of more than 30 %.

The LG2 and EG2 have values of 2 to 3 % even at the highest load level, whereas WG2 has values similar to the MNW.

At maximum loads for most products the strains reached failure states which led to ruptures that were found at excavation. Only with LG2 strain values of about 3 % at $\sigma = 1600$ kPa were measured and a visually undamaged product was found on excavation.

All test results show clear differences depending on the soil type and the production method of the geosynthetics with best results for the LG type, the new style laid geogrid.

Finally, a comparison test with a non-reinforced slope (gravel) is showing the high reserves of bearing capacity of geosynthetic reinforced systems with announcing failure mechanism instead of sudden crashes of systems with soil only. The very high levels of loadings (up to 1500 kPa) and bearing capacity in the MSS tests are in congruence with the experience of field loading tests (Bräu et al. 2000).

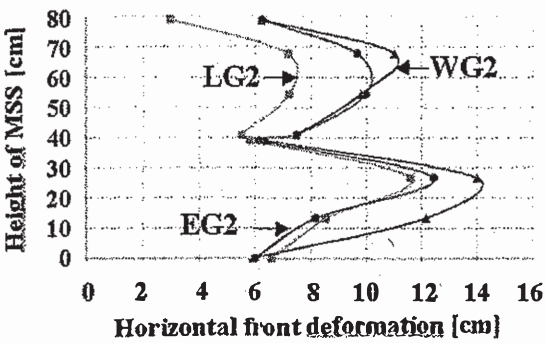

Figure 5. Horizontal deformations of MSS tests (sand, σ = 850

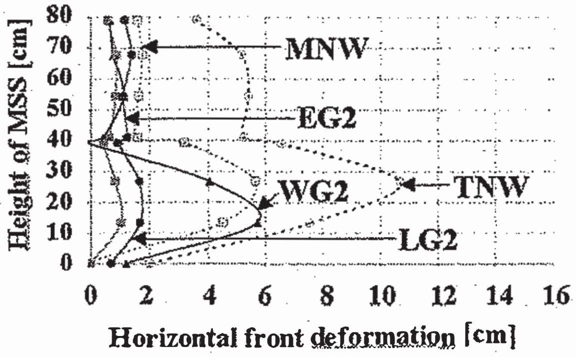

Figure 6. Horizontal deformations of MSS tests (gravel, σ

6 APPLICATION EXAMPLES OF THE "NEW STYLE GEOGRID"

Since production started in summer 1999, already more than 1.5 million m² of the laid PET geogrids have been delivered to construction sites and have been successfully used and installed.

Among others, some projects should be mentioned to show the variety of already existing experience.

6.1 *Federal motorway A31 (Germany)*

The Road Construction Agency Aurich in North West Germany extended the existing city highway by adding two lanes to the federal motorway A31. However, the route of this motorway section led over soft soil layers which have a low bearing capacity up to 7 m below the road.

After the investigation of the Federal Agency for Road Engineering (BAST) which also included the assessment of the costs, the owner decided upon a reinforced road construction which showed cost savings of approx. 5 million DM compared to a bridge. Due to the stability calculations, a geosynthetic with a short-term tensile strength of 400 kN/m was required to prevent base failure. The Road Construction Agency Aurich and the BAST supported the use of a geogrid made of welded PET flat bars (400 kN/m MD, 60 kN/m CD) for in-situ tests to determine the consolidation and deformation behaviour.

In order to gain suitable soil stability, the highway route over the soft ground requires both compaction and consolidation treatment. This is to be done by placing an overburden soil layer of approx. 4 m in height on the geogrid until the required settlement is achieved (vertical drains are additionally installed to accelerate this process). The overburden soil will then be lowered to a height of approx. 2.5 m and the road will be constructed on top of this base. Since mid September 1999 the overburden soil layer has been placed to a height of 2.00 m. Final results of the elongation, consolidation and deformation behaviour will be available only after a longer period of loading. But the deformation measuring devices already show the expected activation of tensile forces in the geogrid.

6.2 *Heightening of a railway dam*

First Certificates of Approval have been granted by the Eisenbahnbundesamt, Bonn, for the newly developed geogrids made of welded PET flat bars. Therefore, geogrids of this type can be generally used for reinforcing applications in railway construction. The first application of these new products in 1999 at the Deutsche Bahn AG is described in the following.

In the city of Hanover, the raise of a railway dam was necessary due to the multitrack extension of the railway section Hanover-Berlin. Since an additional purchase of land for the broadening of the dam was not possible, the existing railway dam had to be raised. To stabilize the railway dam, a geogrid made of welded PET flat bars (400 kN/m MD, 60 kN/m CD) was installed over the whole crest width, thus ensuring safety against slope failure.

The use of geosynthetics was very advantageous for the realization of the construction work. First, one line was removed and the existing layer of crushed stone excavated. The geogrid was laid on the formation level at right angles to the dam's centre line, rolled up and stored in the area between the two lines, and then the first line was set up again. After excavation and construction of the second line, the geogrid stored between the two lines could be carried on. Thus, a continuously laid geogrid reinforces the dam safely and provides tensile interlocking.

6.3 *Noise barrier application motorway A12, Netherlands*

To reduce traffic noise levels in a new housing development, the city of Vleuten/De Meern planned a 10 m high noise barrier with an additional, approx. 3 m high wall on the wall crest at the motorway A12. The noise barrier runs parallel to the motorway and is approx. 1500 m long.

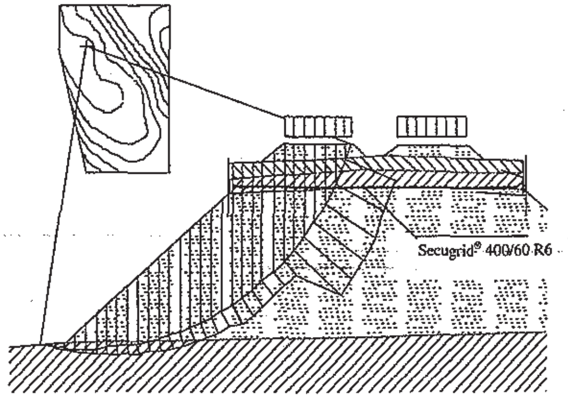

Figure 7. Raised railway dam near Hanover with geogrid reinforcement.

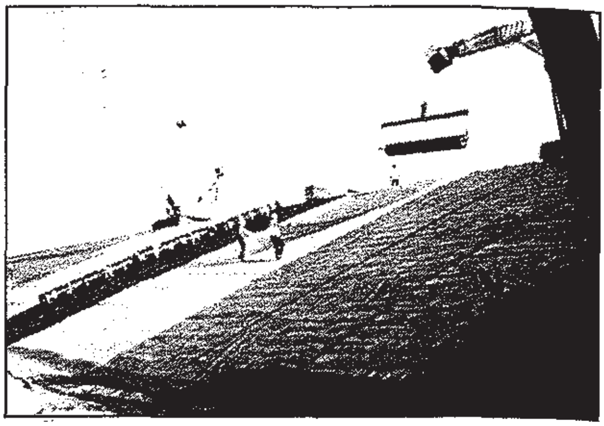

Figure 8. Installation of the laid PET geogrid as toplayer of the capping system.

The barrier was built with approx. 650,000 tons of cinder from incineration plants. According to the Dutch Guideline for Construction Materials the cinders may be considered as a secondary construction material. When using it, various requirements for the protection of the environment must be fulfilled, e.g.:

- The stability of the construction must be ensured in the long term.
- After final consolidation, the secondary construction material must be at least 0.5 m above the average highest groundwater level.
- No precipitation may get into the noise barrier.
- An expert company certified according to ISO 9001 should carry out the sealing with approved materials and in accordance with the quality control measures.

Against precipitation, a composite seal, comprising a geosynthetic clay liner and a 2 mm thick structured geomembrane made of chemically resistant high-density polyethylene, was installed directly on the compacted cinders. The structure on both sides of the geomembrane ensures the necessary friction performance in the shear plain.

The polypropylene nonwoven protection geotextile (installed on the sealing system) has two functions. Primarily, it serves to safely protect the underlying geomembrane against mechanical damage. Secondarily, it enables seepage water to discharge from the topsoil layer.

To ensure the stability of the 1.5 m thick top-soil layer and to take up the forces directed down the slope, a polyester (PET) geogrid with welded flat bars (120 kN/m MD, 40 kN/m CD) was installed (Fig. 8). For anchoring, the geogrid was embedded into the fill crest. Approx. 1000 m²/day of the capping system were installed.

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