Research data and field performance for a geogrid

Résultats de recherche sur les géogrilles, en laboratoire et *in situ*

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ABSTRACT: Recent surveys have shown that the use of reinforcing geogrids in retaining wall applications is an economical and technically equivalent alternative to conventional systems, also in other reinforcing applications. A new geogrid with low elongation properties and a higher initial modulus than most commercially available geogrids has therefore been developed. This paper presents first research results and applications.

RÉSUMÉ: Des sondages récents ont démontré que l'emploi des géogrilles renforçants les murs de soutènement est une alternative économique et techniquement équivalente aux systèmes conventionels, qui peut aussi être appliqué pour d'autres travaux de renforcement. C'est pour cette raison qu'une nouvelle géogrille avec des charactéristiques de basse élongation et un module initial plus haut que la plupart des autres géogrilles a été développée. Cet article comprend les premiers résultats de recherche et des exemples d'application.

1 INTRODUCTION

In a 1998 report issued by the Geosynthetic Institute, all 50 US Departments of Transportation were surveyed as to the installed costs of more than 1,000 public-sector retaining wall systems. Costs were requested for four wall types:

- reinforced concrete gravity walls,
- various types of crib/bin walls,
- mechanically stabilised earth (MSE) walls – metallic reinforcement,
- MSE walls – geosynthetic reinforcement.

Insofar as general findings are concerned, the following applies:

- Comparing the mean value of wall costs for all wall heights; gravity walls are the most expensive, followed by crib/bin walls and MSE metal walls, and then MSE geosynthetic walls, in that order.
- For the highest walls, the difference in mean value vosts between MSE-metal and MSE geosynthetic is quite small and considering the variation in the data may be statistically insignificant.
- The standard deviation in wall costs of the four types of walls surveyed is high, which is to be expected for a national survey of this type.

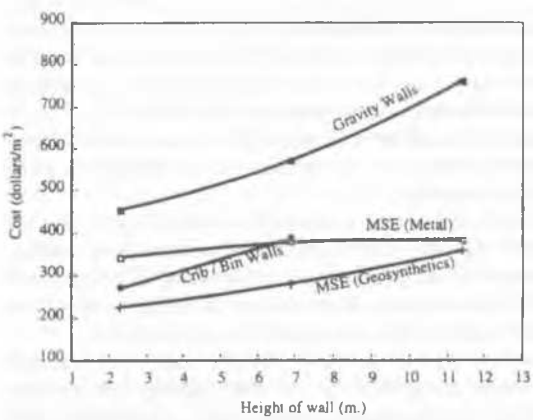


Figure 1: Cost comparison of different types of retaining walls.

This report clearly shows that geosynthetic reinforcing systems are an economic alternative to conventional systems and are increasingly being added to regulations and recommendations.

Geogrids are not only being used in MSE wall applications, but also in many other soil reinforcement applications such as:

- reinforced embankments,
- reinforced support structures,
- railway engineering
- soil veneer reinforcement,
- earth subsidence protection,
- building over sludge lagoons,
- reinforcement foundation pads.

Recent earthquakes in several earthquake endangered environments have shown that geosynthetic reinforced structures have been able to withstand the severe stress occurring during the earthquake and have proven to be sufficient even in these critical environments.

2 NEW GEOGRID DEVELOPMENT

To improve the current geogrid reinforcement, a German manufacturer developed a new geogrid. It is made from pre-stressed monolithic flat bars (raw material polyester PET) with welded joints, provides low elongation at high strength and has low creep characteristics.

The monolithic bars used in the geogrid production are prestressed during manufacture so that the absorption of high tensile forces is possible with very low elongation (higher initial modulus). As a result of the monolithic bar geometry, the geogrid has a high resistance to mechanical and chemical/biological damage.

3 CALCULATION METHODS

A generic example of the basics of a soil reinforcement calculation with geogrids is shown in the following equation.

Table 1: Recommended reduction coefficient.

Secugrid® R6 and Q6 (PET)						
A_1 ① [-]	A_2 [-]		A_3 ② [-]	A_4 ③ [-]		
	$d_{max} < 32$ mm	$d_{max} < 63$ mm		pH 4.1 – pH 8.9	pH 9.0 – pH 9.4	pH 9.5 - pH 12.5
1.56	1.02	1.1	1.0	1.0	1.15	2.0

The permissible load F_d of a reinforcement element can be calculated according to EBGEO (1997) as follows:

$$\text{permissible load } F_d = \frac{F_k}{A_1 \times A_2 \times A_3 \times A_4 \times \gamma}$$

F_d = Design strength of the geogrid [kN/m] (Must be determined for the elongation)
A_1 = Reduction factor for creep [-]
A_2 = Reduction factor for damage caused by transport, installation and compression [-]
A_3 = Reduction factor for processing (connections, connecting to elements) [-]
A_4 = Reduction factor for environmental influences (weather resistance, resistance to chemicals, micro-organisms and animals [-]
γ = Partial safety coefficient for the consideration of possible deviations.

A dynamic reduction factor A_{dyn} should be considered for e.g. applications in railway engineering.

① Reduction factor A_1 determined for 95 % confidence limit, extrapolated to 120 years
② no connection or overlapping in main direction of tension
③ With high concentrations of chemical compounds in the soil, stability must be evaluated individually.

The mechanical requirements of the soil depend on the application and must be fulfilled on site.

Both internal and external stability must be achieved. For the design for external stability, the reinforced earth embankment is assumed to be monolithic. Retaining walls are subjected to stress by soil pressure.

The calculation of earth pressure can be carried out as per DIN 4085. To calculate active earth pressure E_a with non-cohesive soil for example COULOMB's earth pressure theory is employed. This is only applicable with the assumption of an even slip surface, when the failure plane runs parallel to the ground (RANKINE case). Determination of eccentricity with earth pressure formula as per DIN 1054 is only valid with an angle at the rear of the earth embankment of $\beta_{rear} \geq 70°$ (EBGEO (1997)). The same applies to both sliding and piping conditions.

The sum of the forces provided by each reinforcement layer (Σ T) must provide the determined retaining force (T_{ai}) within the permissible working load of the geogrid (F_d). The smaller value of T_{ai} (removal of reinforcement) and F_d (breach of reinforcement is definitive for proving the internal stability: internal stability is produced when $\sum (T_{ai} \text{ or } F_d) \geq \Sigma T$. Permissible anchoring force (T_{ai}) in the geogrid is determined from the length (L_{ai}) of the reinforcement behind the shear plane:

$$T_{ai} = \frac{2 \times L_{ai} \times (\gamma \times h_i + p) \times \tan\varphi'}{\text{safety factor}}$$

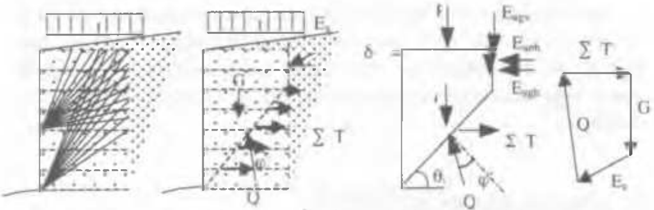


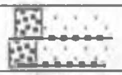
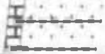
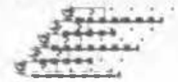
Figure 2: Calculation of forces causing internal failure to retaining structure.

4 COMBINATION CONSTRUCTION METHODS

For MSE (geogrid reinforced) walls, the facing of embankments should be designed appropriately to match the landscape and also serve as erosion protection (Table 2). Embankments with slope angles of > 1:1.5 or $\beta > \varphi_0'$, will require additional detailing to secure the slope from failure.

Where facing blocks are to be used to cover the slope surface, static equilibrium may be determined from both the friction between the soil and the grid and the support provided by the 'facing wall'.

Table 2: External skin types and application possibilities

System	Angle 87°	Angle 70°	Angle 60°	Planting Complete	Planting Partial	Diagram
Gabions	○	○			○	
Rock Armour	○	○			○	
Facing Blocks	○	○			○	
Concrete Panels	○	○			○	
Steel Grid with Spray-on planting		[○]	○	○		
Grass			○	○		

5 RESEARCH ON PULL-OUT BEHAVIOUR

For soil reinforcement with geosynthetics the comparison of the stress-strain behaviour of the soil and the geosynthetics is of great importance. As the influence of the soil decreases using wovens or grids for reinforcement, it is important to use products with high modulus shown at the tensile test results even at low strains. Most of the known products show a great difference between the stress-strain behaviour of the reinforcing elements (fibres, yarns) and the final product. Furtheron product specific construction deformation is utilised after installation and creates additional deformation without load transfer. 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.

Pull-out tests and full-scale model tests of a two layer miniature steep slope (MSS) were conducted under the same testing conditions for different geogrids and nonwovens for comparison purpose. The results show clear differences depending on the soil type and the production method of the geosynthetics.

At the pull-out tests it is shown that the maximum pull-out forces for woven geogrid (WG1) are only approx. half as large as for the newly developed laid geogrid (LG1), although the products have nearly the same tensile strength.

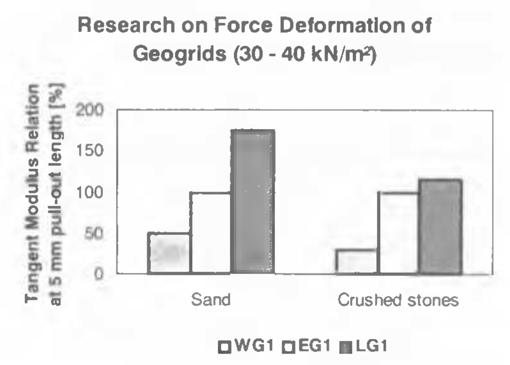


Figure 3: Relation of the tangent modulus at 5 mm pull-out length of three different geogrid types in two different soil environments. (LG1 = laid geogrid, WG1 = woven geogrid, EG1 = extruded geogrid)

Especially in the beginning of the pull-out test, i.e. at small displacements up to 10 mm, there were partially significantly steeper rises of the pull-out force/displacement curve for LG1 in comparison to WG1. For comparable lengths there were higher tangent modules and thus accordingly also higher pull-out forces. This shows clear advantage on the soil interaction with LG1 at usage states of loading.

The tendencies of the pull-out tests are also to be found at the MSS tests. The products with higher tangent modulus (LG1) at the pull-out test show the smallest, the woven grid (WG2) the highest deformation at the model slope.

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

6 REINFORCEMENT APPLICATIONS

6.1 *Embankment*

Constructing earth embankments on soils with a very low bearing capacity (or with greatly differing bearing capacities over a relatively small area) can often lead to failure of the structure by shear forces induced by both the self-weight of the embankment and imposed loading. By introducing geogrid reinforcement with high tensile strength (high initial modulus), lateral (horizontal) deformations are absorbed by the reinforcement, reducing the risk of the embankment toe from failing. Construction periods can be reduced since consolidation of the subsoil is less critical and local stressing is avoided. Relatively large deformations will always occur with these soil types, and this must be considered in the design of the geosynthetic reinforcement to prevent a progressive failure mechanism.

The Road Construction Agency Aurich in North West Germany extended the existing city highway by adding two lanes to the Federal Motorway A 31. However, the route of this section of motorway lead 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 Secugrid® 400/60 R6 geogrids 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 Secugrid® 400/60 R6 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 possible only after a longer period of loading. The deformation measuring devices already show the expected activation.

6.2 *Reinforced road sub-base*

The old road joining Tessin with Wesselsdorf, Eastern Germany, consisted of cobble stones overlaid with asphalt and was badly deformed. It was not longer capable of carrying the increased traffic and vehicle weights that were now using the road. The local community Selpin and the consultants Merkel Ing. Consult decided to completely rebuild the road according to current German standards.

A 500 to 1,000 mm thick sand layer covered the peat subgrade. It was not possible to carry out a plate bearing load test because of the weakness of the ground.

The pavement design consisted of:
- 100 mm aspaltic layers
- 200 mm aggregate layer
- 300 mm sand frost protection layer
- geogrid reinforcement

The design calculations showed that the geogrid should have a short-term strength of 60 kN/m in machine and cross machine directions. It was planned that the 500 mm geogrid at the edge of the road should be folded back over first 150 mm of sand. The design was based on the assumption that the plate bearing load value $E_{V2} \geq 120$ MN/m^2 would be achieved when measured on top of the aggregate layer. After the formation was formed by a tracted excavator using a wide shovel, the geogrid was unrolled across the width of the road pavement with sufficient extra length to form the edge envelopes. The 150 mm sand layer was installed with the trucks supplying the sand driving over the uncompacted 150 mm sand layer as it was pushed out by a tracked bulldozer. The wheels of the trucks did not penetrate more than 20 mm into the sand. Once installed, the sand layer was compacted. After the 500 mm overlaps were formed at the road edge, the second 150 mm sand layer was installed and compacted, followed by the aggregate. The tests on the compacted aggregate layer showed results well above the required minimum 120 MN/m^2.

7 CONCLUSION

First presented data show a technical advantage of a newly developed geogrid manufactured from pre-stressed monolithic flat bars with welded joints, especially due to low elongation properties and a high initial modulus. It allows an overall reduction of the permissible reduction factors and makes the use of this geogrid a technically and economically interesting alternative. These advantages are not only shown in the calculation methods but also in pull-out tests . This product has successfully been used in various applications, such as a reinforced embankment and a reinforced road sub-base.

8 REFERENCES

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