EBGEO 2010 – EXPERIENCE WITH GERMAN DESIGN PROCEDURES FOR GEOSYNTHETIC REINFORCED STRUCTURES

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ABSTRACT

The German Geotechnical Society (DGGT) has publishing a second edition of "EBGEO - Recommendation for Reinforcement with Geosynthetics" in 2010 that covers updates of already published applications like reinforced steep slopes, waste disposals and embankments over weak subsoil as well as newer topics as reinforced embankments over pile-similar elements, covered columns, overbridging systems and systems under dynamic loadings. This paper gives a short introduction to EBGEO and shows some practical application.

Keywords: Reinforced walls, reinforced steep slopes, load transfer platforms, design codes

INTRODUCTION

The German Geotechnical Society (DGGT) had published the first edition of "EBGEO – Recommendation for Reinforcement with Geosynthetics" in 1997, which was prepared by its working group AK 5.2. Meanwhile a lot of new experience with reinforcement applications of geosynthetics are available that are incorporated in the new edition published 2010 in German and 2011 in English.

INTRODUCTION TO EBGEO

Content

The more than 40 members and guests of the working group AK 5.2 come from university, governmental departments, consultants, manufacturers and contractors, which form a wide spread and experienced group to look at the specific problems from different points of view.

The work of the group was organized within several subgroups dealing with the different chapters of the recommendations, the construction and materials. The following topics were discussed and formed the chapters of the new edition:

- General recommendations
- Design principles
- Embankment over weak subsoil
- Layers for improved bearing capacity in road constructions
- Reinforced foundation cushions
- Steep slopes
- Waste disposals
- Reinforced embankments on pile-similar elements (punctual/linetype)
- Geosynthetic encased columns
- Overbridging systems in areas prone to subsidence
- Dynamic loadings

Design Principles

In Germany the fundamental standard for all soil mechanics work is DIN 1054. This standard was published in 1976 and is based on a global safety concept. For the preparation of EBGEO 2010 the DIN 1054 version of January 2005 was used. In this edition the partial safety concept is fixed and also the necessary partial factors for permanent and variable actions as well as for resistance are given. Also the principles for the design calculation are shown mostly in accordance with EN 1997-1, the so called Eurocode EC 7.

The actual version of the EBGEO 2010 is based on this new partial safety concept of DIN 1054:2005-01 and uses those specifications. This means a simplification and harmonization of the design work and a better attraction for the geosynthetic way of reinforcement in Germany.

There are two fundamental approaches in design: Calculations with the ultimate limit state (GZ 1) ensure the construction against failure and the serviceability limit state (GZ 2) leads to suitable and usable constructions. Within GZ 1 mainly used are the limit states GZ 1B, where the failures of the components of the construction are looked at, and GZ 1C where the overall stability of the structure is calculated. Problems occur, where geosynthetics are touched or cut, because the assignment of failure mechanism (GZ 1B and/or GZ 1C) is not clarified within DIN 1054. Finally it has now been fixed in EBGEO to ensure safe, easy and certain use by the designer.

Within GZ 1B characteristic values for the determination of characteristic actions E_k and resistance R_k are used. The characteristic actions E_k are multiplied by the partial factors for actions to receive the design values for the actions E_d. The same is done for the resistance by dividing the characteristic values by the appropriate partial factors to receive the design value R_d. The limit state is fulfilled with the equation $E_d < R_d$.

The calculation of GZ 1C applies the partial factors to the parameters of the soil strength and takes these design values of the soil strength to calculate the limit state conditions.

Geosynthetics

For the calculation of the design strength of the geosynthetics the meanwhile widely accepted procedure is used. The short term strength $R_{Bi,k0}$ retrieved by tests with DIN EN ISO 10319 is divided by several reduction factors (A_1 to A_5) to get the characteristic value of the long term strength $R_{Bi,k}$. The design strength $R_{Bi,d}$ results by dividing $R_{Bi,k}$ by the partial factor of safety γ_M.

$$R_{Bi,d} = \frac{R_{Bi,k0}}{A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot A_5} \cdot \frac{1}{\gamma_M}$$

The partial safety factor for the geosynthetic materials is actually fixed to $\gamma_M = 1.4 / 1.3 / 1.2$ for the three load cases LF1 (permanent) / LF2 (temporary) / LF3 (extraordinary).

The reduction factors (not: factors of safety!) are dealing with the following topics:

A_1 long term behaviour
A_2 installation damage, compaction
A_3 connection and overlapping
A_4 environment
A_5 dynamic influence

Within EBGEO the reduction factors shall be certified by laboratory or field tests otherwise certain fixed minimum values have to be used for the calculation (Table 1).

For the calculation the shear parameters have to be considered. If there are no appropriate test results, the interaction parameters have to be reduced as follows:

geosynthetic / soil $f_{sg,k} = 0.50 \tan \varphi_k'$
geosynthetic / geosynthetic $f_{gg,k} = 0.20$

Table 1 Reduction factors without special investigations

A_1	long term behaviour for permanent structures	PP / PE	6.0
		PES / PA	3.5
A_2	installation damage, compaction	mixed/coarse round material	2.0
		fine grained round material	1.5
A_4	environmental conditions (permanent structures with lifetime < 100 years)	DIN EN 13249 ff annex B4 only new polymers proved by tests for 25 years PES/PVA: AR/PP/PE:	2.0 3.3

The values for the reduction factors derived from tests are usually much lower than the values given in the table. It is always worth to ask producers for specific values of their product.

Soil

In EBGEO there are very few restrictions for the soil that can be used for reinforced constructions. The idea behind this is that taking the values for the strength of the soil to the calculation and getting sufficient terms of safety from it, is the important point to be obeyed.

Restrictions for the soils are only given to ensure that they will reach and keep these values for the life time of the construction:

- compactability,
- maximum grain size according to layer height,
- drainage conditions
- pH value in respect of the reinforcement used.

This approach allows the use of soils available at site according to the standard regulations for earthwork and ensures that reinforcing with geosynthetics provides a high cost efficient construction.

Execution

For the execution of the constructions in Germany the DIN EN 14475 “Execution of special geotechnical works – Reinforced fill” is used. For road, railway and waterway application special recommendations are used.

DESIGN CONSIDERATIONS FOR CERTAIN APPLICATIONS

Steep Sand Walls

For steep slopes and walls there is no longer a differentiation in EBGEO doing the calculation due to the inclination of the front as the search for a failure mechanism is the same. Only the different types of facing systems lead to different calculations at this part of the system.

The calculation method for steep slopes and walls is shown in the old EBGEO 1997 with a clear distinction between "internal" and "external" stability. This distinction of the calculations led to problems, as not all possible failure mechanisms were found. The designer has to think about all mechanisms with failures of the whole structure, failure mechanisms crossing the reinforced structure or not and sliding mechanisms along the geosynthetics at each layers (Fig. 1). This led to the actual state for the new edition of EBGEO to urge the calculation for all mechanisms without distinction in "internal / external stability". The calculation are done by using the limit state GZ 1C mainly.

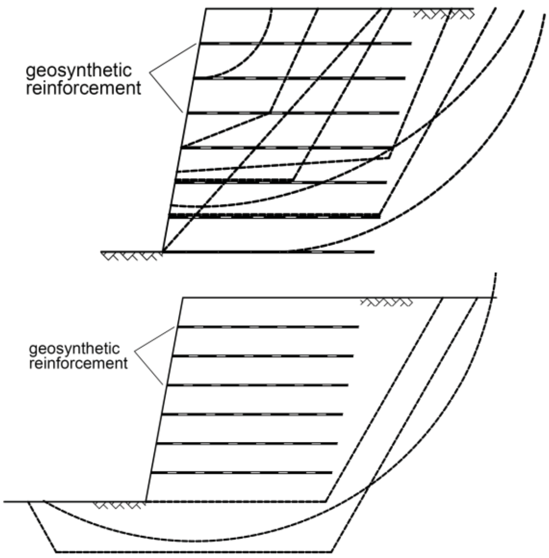


Fig. 1 Potential failure mechanism for steep slopes

For the serviceability (GZ 2) of those structures there are hints for possible calculations given. These procedures are still under discussion and cover the possibility of the observational method and learned experience from former sites. The parameters of in-soil-tests may be taken into account. The possible deformations that should be calculated are shown in Fig. 2.

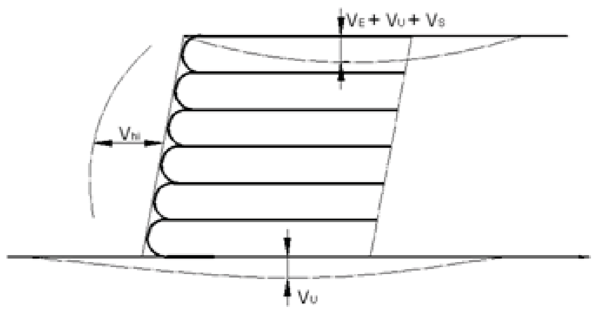


Fig. 2 Possible deformations (GZ 2)
v_U settlement of subsoil
v_E settlement of fill material
v_{hi} horizontal deformations at reinforcement layer i
v_S shear deformation

Reinforced Embankments on Pile-Similar Elements

For the construction of embankments over weak subsoil sometimes the standard procedure with one single layer beneath the embankment is not sufficient to get a low deformable earthwork with high bearing capacity. To solve this problem, in the recent years reinforced embankments with a pile-similar support were developed. The system consists of pile-similar elements in a regular distance in the weak subsoil. Over these elements at least one reinforcement layer is placed, followed by the rest of the embankment Fig. 3.

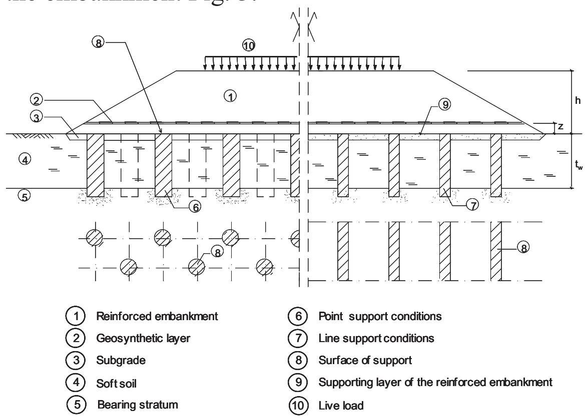


Fig. 3 Geosynthetic-reinforced pile-supported embankments

Meanwhile several applications, especially for highway and railroad embankments showed the practicability and performed well regarding both bearing capacity and serviceability.

The design method is based on the arching effect in the reinforced embankment over the pile heads and a membrane effect of the geosynthetic reinforcement, taking into account also the support of the soft soil between the pile-similar elements.

The design method is based on field and laboratory tests and further investigations that are presented in in Kempfert et.al. (2004), Zaeske & Kempfert (2002) and Heitz (2006).

Columns Encased with Geosynthetics

Sand or stone columns are used to improve the bearing capacity of soft soil. Without a geosynthetic encasement the material of the columns and the surrounding soil will mix and a regular behaviour is not possible. With the use of geosynthetic coated columns the absolute and relative settlements can be reduced, the reduction of pore water pressure and the resulting settlement is accelerated and the safety during construction and in the final state is increased.

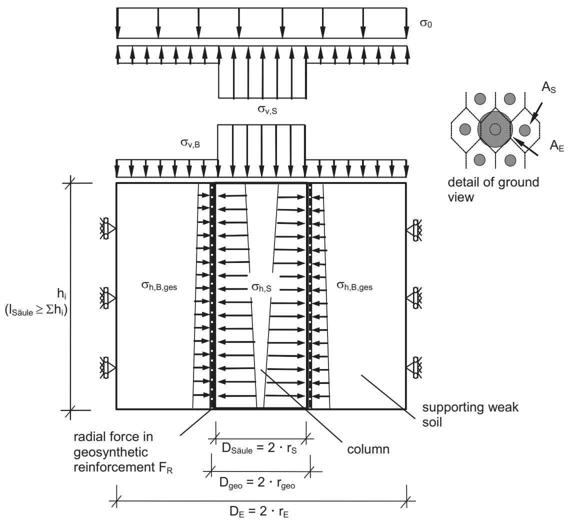


Fig. 4 Scheme of calculation model for geosynthetic coated columns

The design principle used in EBGEO is shown in Fig. 4 for a simplified system with one soil layer (for more complex systems see Raithel 1999). The calculation results in values for the maximum radial strain and force in the geosynthetic reinforcement and shows the primary settlement of the head of the columns.

Overbridging Systems in Areas Prone to Subsidence

Another new topic in EBGEO is the design of overbridging systems with geosynthetics in areas prone to subsidence and sinkholes (Fig. 5).

The systems are used to preemptively secure highways, motorways and railway constructions at least for a short period until the rehabilitation could take place. As the geosynthetics are not in service for most of their time installed and only necessary for that short time, special design considerations are given in EBGEO to find cost-effective solutions.

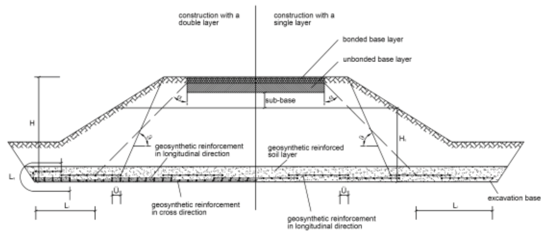


Fig. 5 Schematic views of possible reinforcement systems for overbridging systems

PRACTICAL EXAMPLES

The EBGEO is since 2010 the latest design recommendation in Germany. There are now a lot of constructions using geosynthetics as reinforcement and designed by EBGEO 2010. Some examples will be shown in the following. Bridge abutments are one major topic. Figure 6 shows carried out bridge abutments with different kinds of facing.

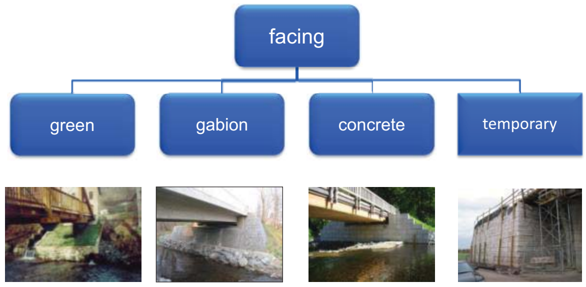


Fig. 6 Bridge abutments with different kinds of facing

The range of possible facings is very wide and allows taking care optical, as well as constructive issues. All these geosynthetic reinforced abutments are much cheaper than an equivalent concrete solution. They are faster to build and at the end much more economically.

Fig. 7 Bridge abutment “K1355 near Ilsenburg”

Fig. 8 Bridge abutment "Mandelholz "

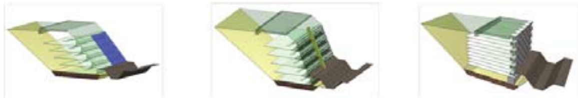
As shown in paragraph 3.4 overbridging systems in areas prone to subsidence are a special new topic of the EBGEO. All over the world there a lot of such areas, that's why alternative solutions are so important. Using geosynthetics is one option to solve these problems in an economically way. In Germany, a lot of practical experience has been gained in this field and with the design method in the EBGEO 2010. The practice shows that the design methods are nearby the reality. Following Fig. 9 shows one example of such a solution.

Fig. 9 Overbridging system "Hohenmölsen"

A very interesting and innovative solution is in the case of soft soil reinforced embankments on pile similar elements. The next figure shows one example of a reinforced embankment over vibrated stone columns. The economic benefit is much more than 10 to 20 % in comparison with conventional solutions without geosynthetics.

Fig. 10 Reinforced embankment one pile- similar elements "B6n near Bernburg"

For reinforced steep slopes and embankments the recommendations of the EBGEO 2010 for dimensioning of the forces on the facing area are very important. As shown in Fig. 11 the EBGEO 2010 divides in non-deformable, partially-deformable and deformable systems front systems.



	Calibration factor			Earth pressure angle
	η_G		η_Q	δ
	$0 < h \leq 0{,}4\,H$	$0{,}4\,H < h \leq H$		
Non-deformable facing elements	1.0	1.0	1.0	Analogous to DIN 4085
Partially deformable facing elements	1.0	0.7	1.0	1/3 φ' to 1.0 φ' (see [11])
Deformable facing elements	1.0	0.5	1.0	0

Fig. 11 Calculation of forces at the facing

That allows the calculation depending on the stiffness of the facing. These design approaches caused by a lot of measurement results gathered on practical examples in the last 15 years. This theoretical formulation enables constructions with a height between 20 m and 30 m.

Fig. 12 Reinforced slope "Iserlohn I"

CONCLUSIONS

The EBGEO 2010 are in this context recommendations which permit and consistently working from production over design, planning and preparing tenders and constructions as well as quality control. This is shown in Fig. 13 with the link to other German guidelines, rules and recommendations (i.e. M Geok 2005, TL Geok E-StB 05).

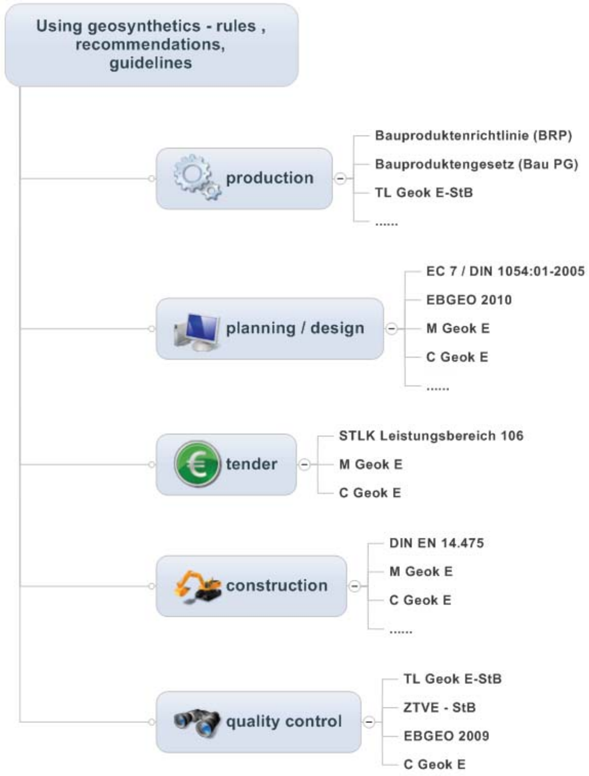


Fig. 13 From production to quality control with geosynthetics

The EBGEO 2010 is also prepared for the European code EC 7. The revision for full adaption is under progress. The English version will be adopted as soon as possible. The EBGEO 2010 represents 10 years of experience, influenced by producers, designers and universities. Theory and praxis are going hand in hand in this recommendation. The EBGEO is the most actual and innovative recommendation in Europe.

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