ACTUAL DESIGN CONSIDERATIONS FOR GEOSYNTHETIC REINFORCED EARTH STRUCTURES
Gerhard Bräu, Technische Universität München · Zentrum Geotechnik, Germany
Kent von Maubeuge, Naue GmbH & Co. KG, Germany

ABSTRACT
In Europe the fundamental design principle for geotechnical works has changed from a global safety concept to a partial safety concept. The according standard is EC 7 - EN 1997-1 which will be obligatory starting from 2010. Meanwhile national standards have to adopt the principles and make the regulations applicable. In Germany the regulations for reinforced earth works are on the way (DIN 1054:2005, EBGEO). Besides the ultimate limit state, considerations about the serviceability are incorporated for standard constructions (e.g. embankment on weak soil, steep slopes) as well as for new techniques for the use of geosynthetics (e.g. embankments on column, overbridging of sinkholes).

RÉSUMÉ
In Europe the fundamental design principle for geotechnical works has changed from a global safety concept to a partial safety concept. The according standard is EC 7 - EN 1997-1 which will be obligatory starting from 2010. Meanwhile national standards have to adopt the principles and make the regulations applicable. In Germany the regulations for reinforced earth works are on the way (DIN 1054:2005, EBGEO). Besides the ultimate limit state, considerations about the serviceability are incorporated for standard constructions (e.g. embankment on weak soil, steep slopes) as well as for new techniques for the use of geosynthetics (e.g. embankments on column, overbridging of sinkholes).

1. 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 will be involved in the new edition that is planned to be published in 2006.

2. HISTORY AND MEMBERSHIP OF WORKING GROUP
The work for the EBGE0 started in the early 1990s under the leadership of Dr.-Ing. B. Thamm and led to the publication of the booklet EBGE0 - Recommendation for Reinforcement with Geosynthetics” in 1997. The working group AK 5.2 of the German Society for Geotechnical Engineering (DGGT) is now under the chairmanship of G. Bräu with his co-chair A. Herold.
The members of the working group come from university, governmental departments, consult-ants, manufacturers and contractors, which form a wide spread and experienced group to look at the specific problems from different points of view. Meanwhile there are 29 members (1997: 19 members) within the group and additionally about 15 guests in different subgroups for the discussion of special topics.
The work of the group is organized within several sub-groups dealing with the different chapters of the recommendations, the construction and materials. Actually the following subgroups are under work:
5. General recommendations
6.1 Design principles
6.2 Embankment over weak subsoil
6.4 Layers for improved bearing capacity in road constructions
6.5 Reinforced foundation cushions
6.6 Steep slopes
6.8 Waste disposals
6.9 Reinforced embankments on pile-similar elements (punctual/linetype)
6.10 Geosynthetic covered columns
6.11 Dynamic loadings
6.12 Overbridging systems in areas prone to subsidence

3. ACTUAL STATE OF DISCUSSION
3.1 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. In the 1990s the first drafts of a new DIN 1054 ("part 100") were discussed, which were based on the partial safety concept. When the EBGEO were published in 1997, these drafts were taken as basis for the design concepts. Unfortunately the "part 100"-series were not finalized, leading to an uncertain status of EBGEO with the need to calculate each problem with the global and the partial safety concept regularly.

Meanwhile the DIN 1054 is published with its edition January 2005, which has been officially acknowledged in several states of Germany during the year 2005. 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, the so called Eurocode EC 7. The actual drafts and working papers for the new edition of EBGEO are based on this new concept of DIN 1054-2005 and will use those specifications. This means a simplification and harmonization of the design work and a better attraction for the geosynthetic way of reinforcement in Germany (Floss 2004).

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 there are mainly used the limit states GZ 1B, where the failures of the components of the construction are looked at, whereas GZ 1C is responsible for the overall stability of the structure. Problems occur, because the assignment of failure mechanism, where geosynthetics are involved, touched or cut, to GZ 1B and/or GZ 1C is not clarified within DIN 1054 and is still under discussion in EBGEO. Finally it will be fixed in EBGEO to ensure safe, easy and certain use by the designer.

Within GZ 1B the calculation uses characteristic values for the determination of characteristic actions $E_i$ and resistance $R_i$. Finally the characteristic actions $E_i$ are multiplied by the partial factors for actions to receive the design values for the actions $E_i$. The same is done for the resistance by dividing the characteristic values by the appropriate partial factors to receive the design value $R_i$. The limit state is fulfilled with the equation $E_i < R_i$. 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.

For the calculation of the design strength of the geosynthetics the meanwhile widely accepted procedure is used. The short term strength $R_{Bi,k}$ 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 $R_{Bi,d}$. The design strength $R_{Bi,d}$ results by dividing $R_{Bi,k}$ by the partial factor of safety $\gamma_M$: $$ R_{Bi,d} = \frac{R_{Bi,k}}{A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot A_5} \cdot \gamma_M $$

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 (transient) / LF3 (extraordinary). The reduction factors (not: factors of safety!) are dealing with the following topics:

- A1 long term behaviour
- A2 installation damage, compaction
- A3 connection and overlapping
- A4 environment
- A5 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. The following table gives an overview showing the actual state of discussion.

| Table 1 Reduction factors without special investigations |
|-----------|-------------|----------|
| $A_1$     | long term behaviour for permanent structures | PP / PE |
|           |                                                      | 5.0      |
| $A_2$     | installation damage, compaction                     | mixed/coarse round material |
|           |                                                      | 2.0      |
The discussion about reduction factor A₅ has to be to continued. Several laboratory and field tests are under evaluation indicating minor problems than expected. For the calculation the shear parameters have to be considered. If there are no test results, the interaction parameters have to be reduced as follows:

- geosynthetic / soil $f_{tg,s} = 0.50 \tan \varphi'$
- geosynthetic / geosynthetic $f_{tg,d} = 0.20$

This restrictive approach in EB GEO urges the parties to do tests with the real soil and geosynthetic for the site, which is the only way to get realistic values for the design. Results from index testing are not worthwhile.

All the applications, tests and recommendation for the geosynthetic products are in strict coordination with the other German regulations for geosynthetics in earthworks (M Geok 2005, TL Geok E-StB 2005).

3.2 Embankment over weak subsoil

The EB GEO 1997 already presented a design method for embankments over weak subsoil that was proofed in several sites equipped with measuring devices Blume et al. (2004). For the new edition some additional aspects will be considered. It was found, that the reinforcing effect of the geosynthetics at the toe of the slope (anchorage) could be taken into account.

On the other hand the squeezing out of the subsoil beneath the embankment is a potential failure mechanism which should be incorporated according to BS 8006.

3.3 Steep slopes

The calculation method for steep slopes is shown in EB GEO 1997 with a clear distinction between "internal" and "external" stability. This division of the calculations led to problems, as not all possible failure mechanisms were found and makes no longer sense as the way of the calculation is the same for both. 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. This led to the actual state for the new edition of EB GEO to urge the calculation for all mechanisms without distinction in "internal / external". The calculation will be done using the limit state GZ 1C mainly. A comparison of different design methods (DIN, BS, CUR) is given in Thurwell et. al. (2004).
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.

A more detailed description of the design method and the field tests and investigations is given in Kempfert et.al. (2004) and Zaeske & Kempfert (2002). The draft of this chapter from EBGEO is presented since 2004 to the public on the website of the “Special section Geosynthetics” of DGfT.

3.5 Columns coated with Geosynthetics

Sand or stone columns are used to improve the bearing capacity of soft soil. Without a geosynthetic coating the material of the columns and the surrounding soil will mix and a regular behaviour is not possible. There are several types of coated columns which are different in the construction procedure and the kind of improvement of the soil. Systems with small diameters (d < 30 cm) are used to accelerate the consolidation of the soft soil by giving an open structure for the reduction of pore water pressure (Geuder et. al. 1997, Figure 4). The reinforcing effect of these columns usually is neglected.

Systems with greater diameters (d > 80 cm) besides the drainage effect are installed due to their reinforcing effect (Kempfert & Wallis 1997). They can be built by excavating the soil protected by a piling equipment or by repressing the soil with an additional compaction effect for the subsoil.

For the above mentioned types usually woven geotextiles are used. In the recent years also systems with geogrids were developed that are able to give sufficient support for embankments even if the support of the subsoil is very low (i.e. organic soils) (Paul & Ponomarjow 2004, Trunk et. al. 2004).

For the several types of application of geosynthetic coated columns design methods are developed and will be presented in the new edition of EBGEO.

3.6 Overbridging systems in areas prone to subsidence

Another new topic in EBGEO will be the design of overbridging systems with geosynthetics in areas prone to subsidence and sinkholes. The systems are used to secure highways, motorways and railway constructions at least for a short period until the rehabilitation could take place.

Actually the national and international experience is studied and the design methods for EBGEO prepared due to the different needs of full and partly secured systems, with isotropic and anisotropic reinforcement. Actual considerations are shown in Paul (2004).

4. PERSPECTIVE

The 1997 edition of EBGEO is no longer available, the final version of the new EBGEO is planned to be published as draft for public discussion in late 2006. Besides the recommendations there will be typical calculations for all samples.

To give information about actual design considerations and bring the practical experience back to EBGEO during its development, the working group decided to present drafts in the internet:

http://www.gb.bv.tum.de/fachsektion/b_ak/ak52.htm.

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