EBGEO - GERMAN RECOMMENDATION FOR REINFORCEMENT WITH GEOSYNTHETICS

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Abstract: The German Geotechnical Society (DGGT) had published the first edition of "EBGEO - Recommendation for Reinforcement with Geosynthetics" in 1997. Meanwhile a lot of new experience with reinforcement applications of geosynthetics are available and will be included in the new edition to be published as a draft for public review in the beginning of 2008. This new draft is also prepared by the working group AK 5.2 of DGGT (chairman: G. Bräu).

The paper shows the actual state of the re-work and the discussions of the different chapters:
- embankment over weak subsoil
- steep slopes
- base courses for roads
- landfill
- reinforced embankments on pile-similar-elements
- soil columns covered with geosynthetics
- spanning systems in areas prone to subsidence
- reinforcement under dynamic loadings

Further more, actual knowledge of long term behaviour, durability, damage during installation and soil-reinforcement-interaction are included in the new edition of EBGEO.

Keywords: reinforcement, design method, recommendation, safety factor, reduction factor, cyclic load.

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 geo-synthetics are available that will be involved in the new edition that is planned to be published in 2006.

HISTORY AND MEMBERSHIP OF WORKING GROUP

The work for the EBGEO started in the early 1990s under the leadership of Dr.-Ing. B. Thamm and led to the publication of the booklet EBGEO - 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 subgroups dealing with the different chapters of the recommendations, the construction and materials. Actually the following subgroups are under work:

- 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 covered columns
- Dynamic loadings
- Overbridging systems in areas prone to subsidence

ACTUAL STATE OF DISCUSSION

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 most states of Germany meanwhile. 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, Eurocode EC 7 Part 1.

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_k and resistance R_k. Finally 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.

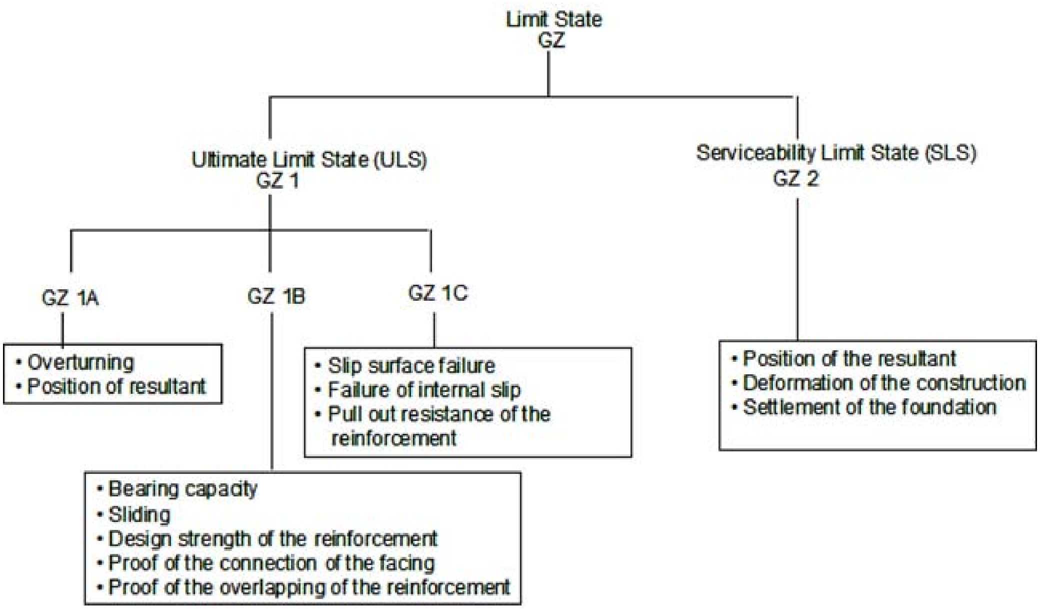


Figure 1. Limit states according DIN 1054 / EC7

Figure 1 shows the several limit states realised in DIN 1054 and the actual associated failure mechanisms (Thurwell et. al. 2004).

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 γ_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:

- 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. 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	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 discussion about reduction factor A_5 has to be to continued. Several laboratory and field tests are under evaluation indicating minor problems than expected (Retzlaff 2007).

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 $f_{sg,d} = 0{,}50 \tan \varphi_d'$
- geosynthetic / geosynthetic $f_{gg,d} = 0{,}20$

The conservative approach in EBGEO is intended to encourage the parties to do tests with the real soil and geosynthetic for the site, which is the correct way to determine values for the design. Results from index testing can be misleading and of dubious value.

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).

Embankment over weak subsoil

The EBGEO 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). In 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 (Figure 2).

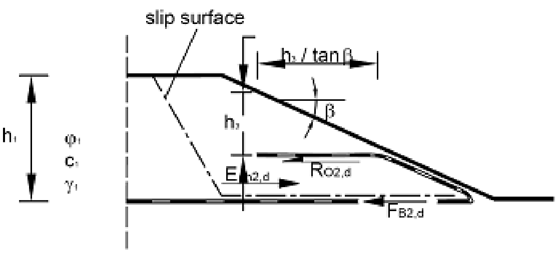


Figure 2. Anchorage at slope edge

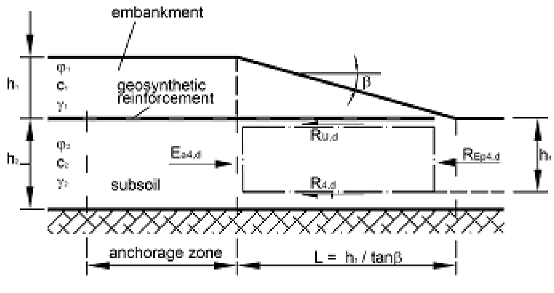


Figure 3. Squeezing out of subsoil

On the other hand the squeezing out of the subsoil beneath the embankment (Figure 3) is a potential failure mechanism which will be incorporated according to BS 8006 (1995).

Steep slopes

The calculation method for steep slopes is shown in EBGEO 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 EBGEO to urge the calculation for all mechanisms without distinction in "internal / external".

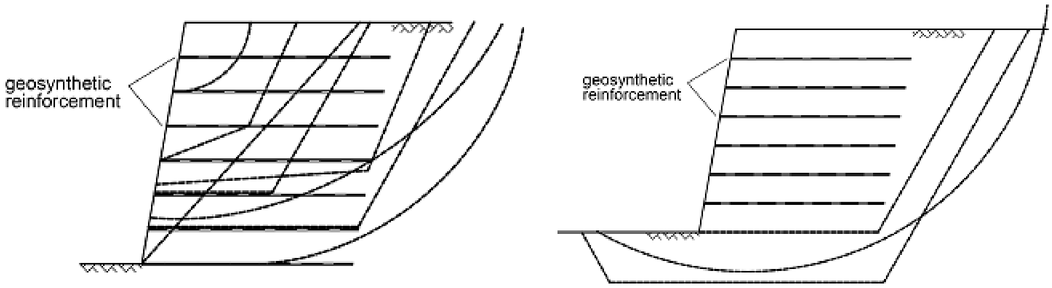


Figure 4. Potential failure mechanism for a steep slopes

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).

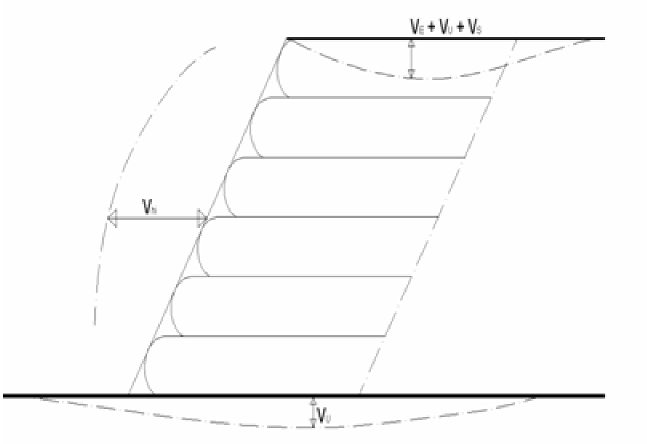
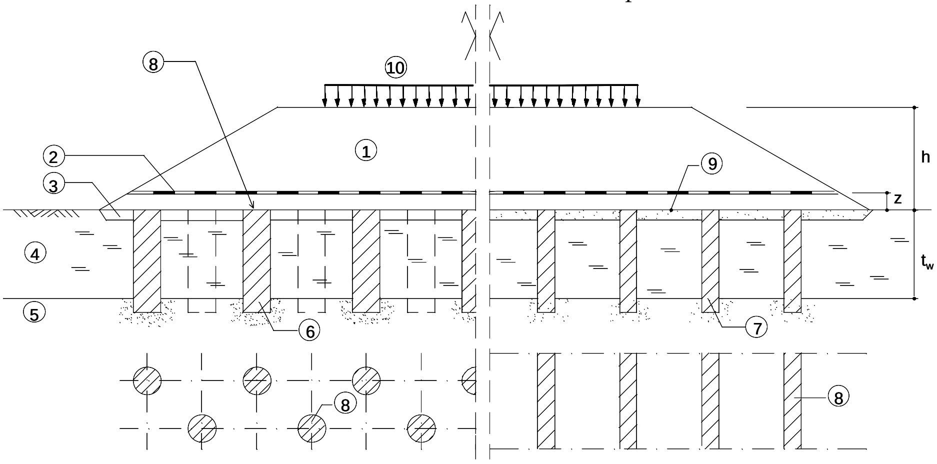


Figure 5. Calculation of possible deformations (GZ 2)

For the serviceability (GZ 2) of those structures there will be hints for calculations. The procedures are still under discussion and will cover the possibility of the observational method and experience collected from sites. The parameters of in-soil-tests will be taken into account, as it is possible to reinforce structures also with non-woven geotextiles using these parameters Bauer & Bräu (1996), rather than high strength, stiff materials only. The possible deformations that should be calculated are shown in Figure 5.

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 year's reinforced embankments with a pile supports or other ground improvement systems have been designed. The systems consist of pile elements in a regular pattern in the weak subsoil. A load distribution system with least one reinforcement layer is placed, followed by the rest of the embankment Figure 6.



1 Reinforced embankment
2 Geosynthetic layer
3 Subgrade
4 Soft soil
5 Bearing stratum
6 Point support conditions
7 Line support conditions
8 Surface of support
9 Supporting layer of the reinforced embankment
10 Live load

Figure 6. Reinforced embankment on pile-similar elements

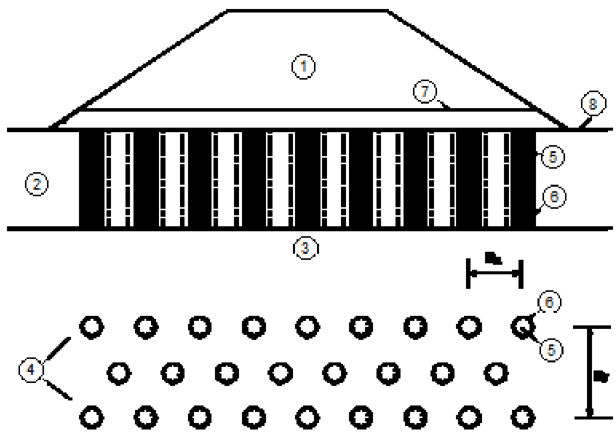
A number of applications, especially for highway and railroad embankments have shown the practicability of this concept and most have performed well in both bearing capacity and serviceability.

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 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 has been presented since 2004 to the public on the website of the "Special section Geosynthetics" of DGGT. An updated version based on new site experience and research work (Heitz 2006) is actually discussed and will be published soon.

Columns Encapsulated with Geosynthetics

Sand or stone columns can be used to improve the bearing capacity of soft and loose soils. Without a geosynthetic coating the material of the columns and the surrounding soil can mix and a coherent behaviour is not possible. Using geosynthetic coated columns (GCC) ensures that the absolute and relative settlements can be reduced, the reduction of pore water pressure and the resulting settlement is accelerated and the factor of safety during construction and in the final state is increased.



1 Embankment
2 weak subsoil
3 sustainable subgrade
4 grid of columns
5 column packing (non cohesive)
6 radial geosynthetic reinforcement (coating)
7 horizontal geosynthetic reinforcement
8 horizon of column capping

Figure 7. Schema of construction with geosynthetic coated columns

There are several types of GCCs which are different in the construction procedure and the kind of improvement of the soil. Systems with small diameter columns (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 8). The reinforcing effect of these columns usually is neglected.

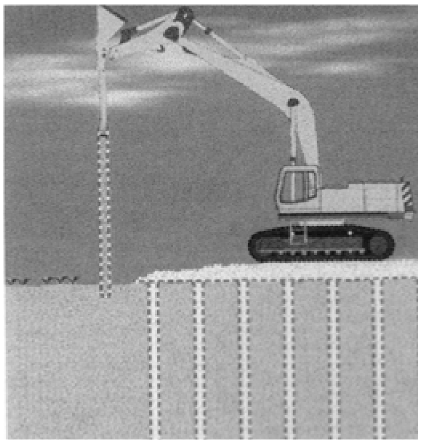


Figure 8. Geosynthetics coated columns with small diameter and minor reinforcing effect

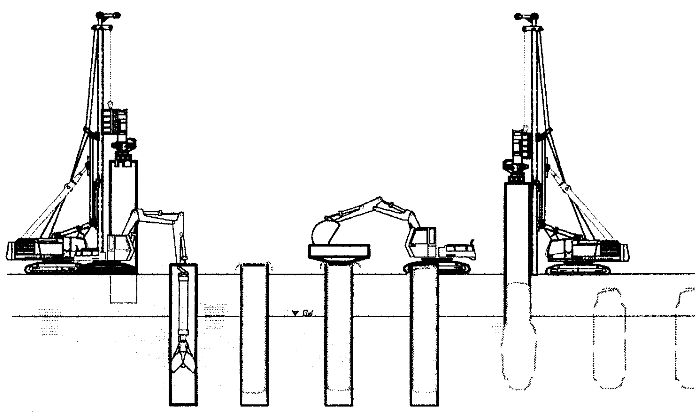


Figure 9. Geosynthetic coated columns (soil replacement, d > 80 cm) (Kempfert & Wallis 1997)

Systems with larger diameters (d > 80 cm, Figure 9) will in addition to the drainage effect introduce a reinforcing effect (Kempfert & Wallis 1997). The GCCs can be constructed by excavating the soil within temporary casings or by compacting or replacing the soil with an additional compaction of the soils.

The large GCCs are usually formed using woven geotextiles. In the recent years some systems with geogrids have been developed. The geogrid reinforced GCCs are able to give sufficient support for embankments even where the support of the subsoil is very low (i.e. organic soils) (Paul & Ponomarjow 2004, Trunk et. al. 2004).

Figure 10. Geogrid coated stone columns (Trunk et.al. 2004)

For the several types of application of GCCs design methods have been developed (Raithel 1999) and will be included in the new edition of EBGEO. The design method is shown in figure 11 for a simplified system with one soil layer (for more complex systems see Raithel 1999). The calculations result in maximum radial strain and force in the geosynthetic reinforcement and shows the primary settlement of the head of the columns.

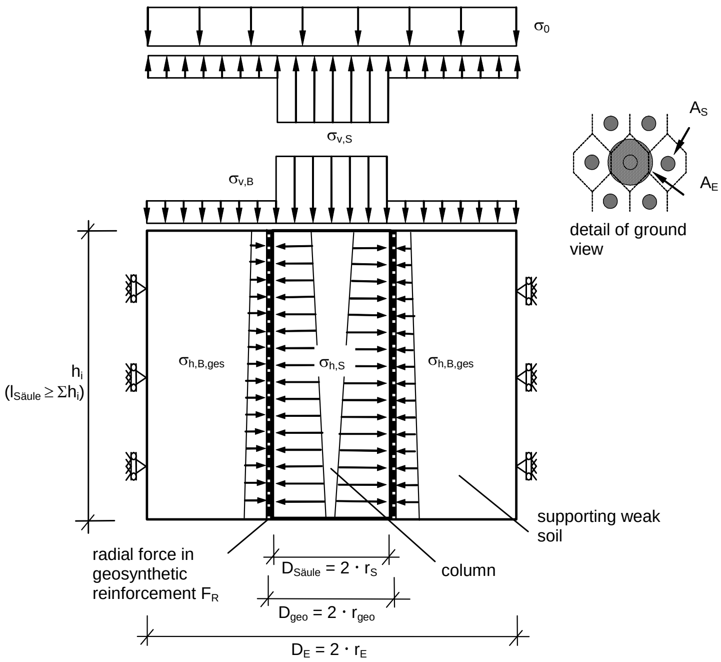


Figure 11. Scheme of calculation model for geosynthetic coated columns

Spanning systems in areas prone to subsidence

Another new topic in EBGEO will be the design of spanning 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 repair can take place.

Figure 12. Sinkholes in free field, caused by previous mining, near Wansleben (Germany) (Paul 2004)

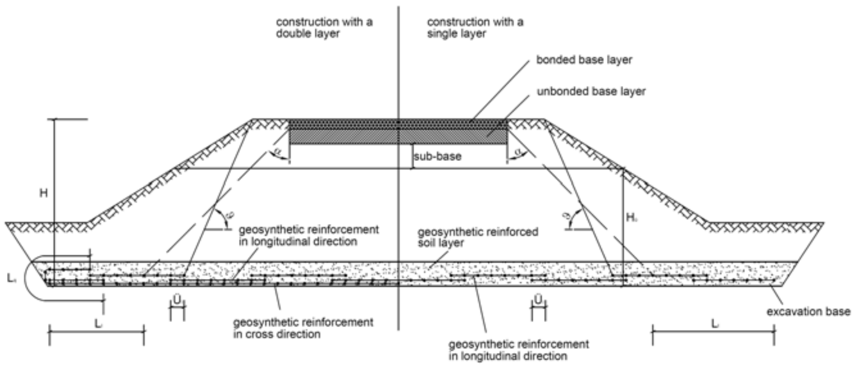


Figure 13. Schematic view of possible reinforcement systems for spanning systems

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).

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 2008. 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:

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