1 Introduction to the Recommendations and their Application Principles

Note: The following paragraphs are taken in part from the EAB (2006) or are based on them.

1.1 National and International Regulations

In Germany the analysis and design of reinforced fill structures, as well as the required safety stipulations, are controlled by DIN 1054 and other relevant standards. These Recommendations are based on DIN 1054:2005-01 'Subsoil – Verification of the Safety of Earthworks and Foundations' and analyses are performed using the partial safety factor approach. In addition, the European design standard EN 1997-1 (EC 7-1) 'Eurocode 7: Draft, Geotechnical Design' is also referenced; it too deals with reinforced structures. See Section 1.2 for details of the formal and planning control use of these two standards.

The following manufacturing standard is used for the individual reinforcement systems:

– DIN EN 14475: 'Execution of Special Geotechnical Work – Reinforced Fill'.

The following standards and regulations apply to quality assurance:

– DIN EN 13251: 'Geotextiles and Geotextile-related Products – Required Characteristics for use in Earthworks, Foundations and Retaining Structures',
– DIN EN 13249: 'Geotextiles and Geotextile-related Products – Required Characteristics for use in the Construction of Roads and other Trafficked Areas',
– *Merkblatt über die Anwendung von Geokunststoffen im Erdbau des Straßenbaus*, M-Geok E 05, FGSV 535, Forschungsgesellschaft für Straßen- und Verkehrswesen,
– *Technische Lieferbedingungen für Geokunststoffe im Erdbau des Straßenbaus*, TL Geok E-StB 05, FGSV 549, Forschungsgesellschaft für Straßen- und Verkehrswesen,
– Guidelines for Determining the Long-term Strength of Geosynthetics for Soil Reinforcement, English Edition ISO/TR 20432.

Inasmuch as no information to the contrary is given in these Recommendations, the respective current editions of the relevant technical regulations (e.g. standards, guidelines, codes of practice and recommendations) shall be observed. They are named in the appropriate sections.

A summary can be found at: http://www.gb.bv.tum.de/fachsektion/index.htm.

Hereinafter, references to standards are given without the publication date. If a certain paragraph is referred to directly the edition is also given.

Recommendations for Design and Analysis of Earth Structures using Geosynthetic Reinforcements (EBGEO). German Geotechnical Society.

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Details of reference literature are given at the end of each respective section of these Recommendations.

1.2 Types of Analysis and Limit States using the Partial Safety Factor Approach

1.2.1 New Standards Generation and Transitional Regulations

A European Commission decision aims to replace the governing national building design and execution standards by European standards. Numerous European design and execution standards now exist for special geotechnical engineering.

The governing European execution standard for manufacturing reinforced fill structures is given in Section 1.1.

Analysis and design of reinforced fill structures in Europe are dealt with in EN 1997-1: 'Draft, Geotechnical Design' (Eurocode EC 7-1 (EC 7)). The German edition is published with the title DIN EN 1997-1:2005-10 and triggers a transition period within which a National Annex to Eurocode EC 7-1 shall be compiled to comply with European agreements. The National Annex (NA DIN EN 1997-1) will contain national specifications on those sections defined for this purpose in Eurocode EC 7-1. Simultaneously, another transition period begins, by the end of which Eurocode EC 7-1 will be introduced into building regulations in conjunction with the National Annex and all contradictory national regulations are withdrawn. A collateral DIN 1054:2010 standard to be compiled by 2009 may then only include non-contradictory supplements to Eurocode EC 7-1 in conjunction with the National Annex. The National Annex and the DIN 1054:2010 collateral standard have now been compiled in NA 005-05-01-01 and will be published in draft form in 2009. To simplify use of the three parallel standards they will be published together in a standards manual accompanying DIN EN 1997-1:2005 and DIN 1054:2009 'Draft, Geotechnical Design'. The regulations in the National Annex and the collateral standard have been adopted in the text of EC 7-1, and are specially marked.

Until the introduction of the Eurocodes a temporary generation of national standards using the partial safety factor approach meets the needs of all fields of structural engineering.

The following regulations, in particular, govern the construction of geosynthetic-reinforced structures:

– DIN 1055: 'Actions on Structures', in conjunction with DIN Fachbericht (*Technical Report*) 101,
– DIN 1054:2005-01: 'Verification of the Safety of Earthworks and Foundations'.

1.2.2 Effects and Resistances

The foundation for stability analyses is represented by the characteristic values for actions and resistances. The characteristic value, characterised by the index 'k', is a value with an assumed probability neither exceeded nor fallen short of during the reference period, taking the design working life or the corresponding design situation of the civil engineering structure into consideration. Characteristic values are generally specified on the basis of test results, measurements, analyses and/or empiricism.

The characteristic values of effects are multiplied by partial safety factors, those of resistances are divided. The variables acquired in this way are known as the design values of effects or resistances respectively and are characterised by the index 'd'. Different limit states are differentiated for stability analyses.

1.2.3 Limit States

The following limit states are differentiated in the partial safety factor approach:

- The ultimate limit state is a condition of the structure which, if exceeded, immediately leads to a numerical collapse or another form of failure. It is known as the ultimate limit state (ULS) in DIN 1054. Three cases of ultimate limit state are differentiated.
- The serviceability limit state (SLS) is a condition of the structure which, if exceeded, no longer fulfils the conditions specified for its use. It is known as the serviceability limit state (SLS) in DIN 1054.

The EQU limit state describes the loss of static equilibrium. It includes:

- analysis of safety against overturning,
- analysis of heave or uplift safety,
- analysis of hydraulic heave safety.

The EQU limit state incorporates favourable and unfavourable actions only, but no resistances.

The governing limit state condition is:

$$F_d = F_k \cdot \gamma_{dst} \leq G_k \cdot \gamma_{stb} = G_d \,, \qquad \text{Eq. (1.1)}$$

i.e. the destabilising actions F_k, multiplied by the partial safety factor $\gamma_{dst} > 1.0$, may only be as large as the stabilising action G_k, multiplied by the partial safety factor $\gamma_{stb} < 1.0$.

The STR limit state describes the failure of structures and structural elements or failure of the ground. It includes:

- analysis of the bearing capacity of structures and structural elements subjected to ground loads or supported by the ground,

– analysis of the bearing capacity of the ground, e.g. provided by passive earth pressure or bearing resistance, to ensure it is not exceeded.

Analysis of the bearing capacity of the ground to ensure it is not exceeded is performed in exactly the same way as for any other construction material. The limit state condition is always the governing condition:

$$E_d = E_k \cdot \gamma_F \le R_d \,, \qquad \text{Eq. (1.2)}$$

$$R_d = \frac{R_k}{\gamma_R} \,, \qquad \text{Eq. (1.3)}$$

i.e. the characteristic action or effect E_k, multiplied by the partial safety factor γ_F, may only be as large as the characteristic resistance R_k, divided by the partial safety factor γ_R. A characteristic of the STR limit state is that the effects and resistances are determined using characteristic values. The partial safety factors do not come into play until applying the limit state equation.

The GEO limit state is peculiar to geotechnical engineering. It describes the loss of overall stability. It includes:

– analysis of slope stability,
– analysis of global stability.

The governing limit state condition is:

$$E_d \le R_d \,, \qquad \text{Eq. (1.4)}$$

i.e. the design value E_d of the effects may only be as large as the design value of the resistances R_d. The geotechnical actions and resistances are determined using the design values for shear strength:

$$\tan\varphi'_d = \frac{\tan\varphi'_k}{\gamma_\varphi} \quad \text{and} \quad c'_d = \frac{c'_k}{\gamma_c} \,, \qquad \text{Eq. (1.5)}$$

and

$$\tan\varphi_{u,d} = \frac{\tan\varphi_{u,k}}{\gamma_{\varphi u}} \quad \text{and} \quad c_{u,d} = \frac{c_{u,k}}{\gamma_{cu}} \qquad \text{Eq. (1.6)}$$

i.e. the friction $\tan\varphi$ and cohesion c values adopted in the calculations are reduced from the outset using the partial safety factors γ_φ, $\gamma_{\varphi u}$, γ_c and γ_{cu}. An analogous procedure applies to the interface friction angle and adhesion.

The serviceability limit state describes the state of a structure or structural element at which the conditions specified for its use are no longer met, but without loss of bearing capacity. It is based on a serviceability analysis, i.e. that the anticipated displacements and deformations are compatible with the purpose of the structure. Analysis uses characteristic values, where all partial safety factors are generally 1.0.

1.2.4 Applying EBGEO in Conjunction with DIN EN 1997-1

This edition of EBGEO is based on the stipulations made in DIN 1054. This in turn was closely harmonised with DIN EN 1997-1, Eurocode EC 7-1. DIN 1054 is not identical to Eurocode 7-1 in all details. At the transition to Eurocode 7-1/NA EC 7-1 (see 1.2.1) DIN 1054:2005-01 will be replaced by the collateral standard DIN 1054:2010. The consequences associated with this for applying the present edition of the Recommendations are related below, as well as a preview will allow.

Legally binding rules in terms of the applicability of the individual regulations are specified by the respective controlling authorities. The controlling agencies are deemed to be:

- the building regulations control authorities of the federal German states for building measures subject to the respective state building code; at regular intervals the upper building regulations control authorities of the respective federal states publish a list of technical building regulations applicable to that state.
- the departments of the Federal Ministry of Transport, Building and Urban Affairs responsible for inland waterways, federal roads and road bridges, and the Federal Railway Authority responsible for rail traffic.

Stability analyses as described in Section 1.2.3, Eurocode EC 7-1, provide three options in terms of the STR limit state. DIN 1054 is based on analysis procedure 2 to Eurocode EC 7-1, inasmuch as the partial safety factors are applied to both the effects and the resistances. To differentiate between this and the other permitted scenario, in which the partial safety factors are not applied to the effects but to the actions, this procedure is known as analysis method 2* in the Commentary to Eurocode EC 7-1.

The National Annex represents the link between Eurocode EC 7-1 and national standards. It states which of the possible analysis methods and partial safety factors are applicable in the respective national domains. Remarks, clarifications or supplements to Eurocode EC 7-1 are not permitted. However, the applicable, complementary national codes may be given. The complementary national codes may not, however, contradict Eurocode EC 7-1. Moreover, the National Annex may not repeat information already given in Eurocode EC 7-1.

The revised DIN 1054 will be paramount in the complementary national code; it has the working title ‘DIN 1054:2010’ and is the application rule to Eurocode EC 7-1.

The supplements, improvements and modifications included shall be adhered to inasmuch as they affect the regulations of the EBGEO, if the respective geosynthetic-reinforced structure is designed to Eurocode EC 7-1. However, they may also be utilised accordingly if design is based on DIN 1054.

In the current edition Eurocode EC 7-1 defines the following limit states instead of the limit states GZ 1A, GZ 1B and GZ 1C to DIN 1054:

- EQU: loss of equilibrium of the structure or the ground, which is regarded as rigid. The designation is derived from ‘equilibrium’.
- STR: internal failure or very large deformation of the structure or its components, where the strength of the materials governs resistance. The designation is derived from ‘structural failure’.
- GEO: failure or very large deformation of the structure or the ground, where the strength of the soil or rock governs resistance. The designation is derived from ‘geotechnical failure’.
- UPL: loss of equilibrium of the structure or ground due to buoyancy or water pressure. The designation is derived from ‘uplift’.
- HYD: hydraulic failure, internal erosion or piping in the ground, caused by a flow gradient. The designation is derived from ‘hydraulic failure’.

In order to convey the GZ 1B und GZ 1C (STR and GEO) limit states from DIN 1054 to the terminology used in Eurocode EC 7-1 the GEO limit state is divided into GEO-2 and GEO-3:

- GEO-2: failure or very large deformation of the ground in conjunction with determining the action effects and dimensions; i.e. when utilising the shear strength for passive earth pressure or bearing resistance. The GEO-2 limit state comprises analysis method 2* to Eurocode EC 7-1.
- GEO-3: failure or very large deformation of the ground in conjunction with analysis of overall stability, i.e. when utilising the shear strength for analysis of slope stability and global stability and, generally, when analysing the stability of engineered slope stabilisation measures, including that of structural elements. The GEO-3 limit state comprises analysis method 3 to Eurocode EC 7-1.

The previous limit states are replaced as follows:

- The previous limit state GZ 1A to DIN 1054 now corresponds without restrictions to the EQU, UPL and HYD limit states to Eurocode EC 7-1.
- The previous GZ 1B limit state to DIN 1054 now corresponds in all facets to the Eurocode EC 7-1 STR limit state. The GEO-2 limit state to Eurocode EC 7-1 is also used in conjunction with the design dimensions for foundation elements.
- The previous GZ 1C limit state to DIN 1054 corresponds to the GEO-3 limit state to Eurocode EC 7-1 in conjunction with analysis of overall stability.

Analyses of the stability of engineered slope stabilisation measures are always allocated to the GEO limit state. Depending on the engineering design and function (see DIN 1054) they may be dealt with either according to the previous GZ 1B limit state or the GEO-2 limit state, or according to the previous GZ 1C limit state or the GEO-3 limit state. The geosynthetic material is designed for the STR limit state.

1.3 Examples of Reinforced Earth Structures

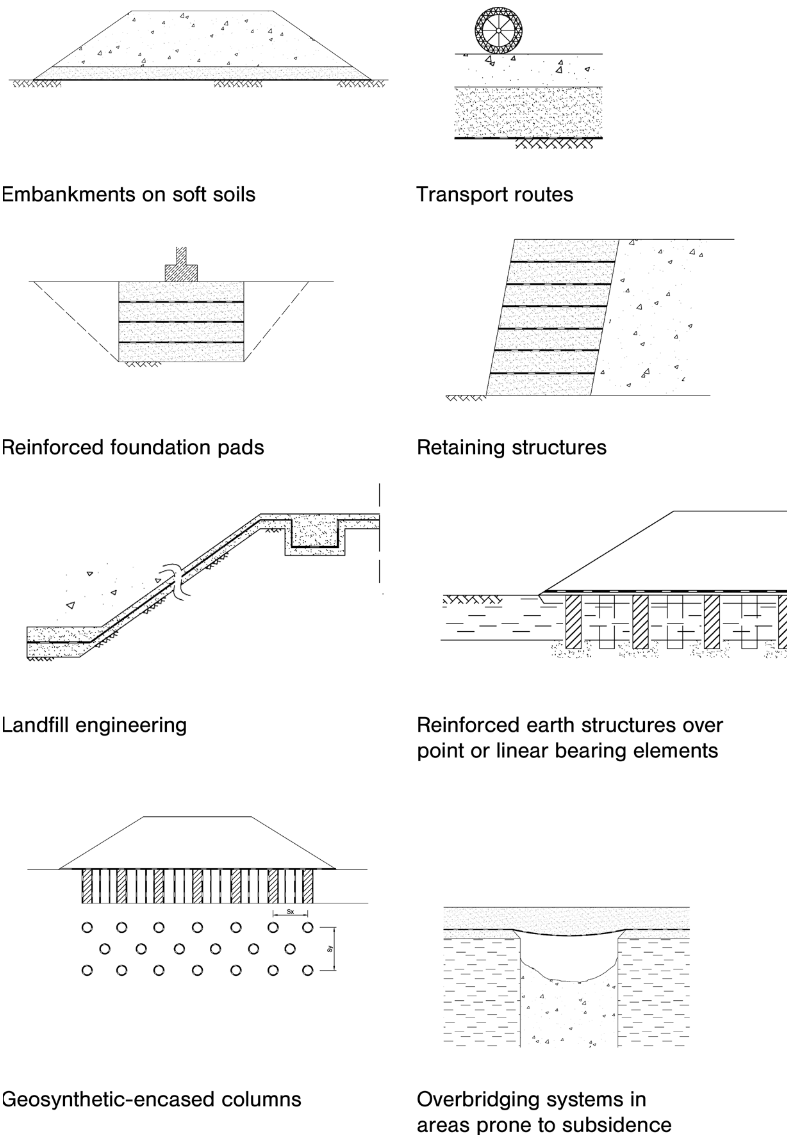

Figure 1.1 Examples of reinforced earth structures

1.4 General Definitions

Reinforced fill or reinforced earth structures are engineered earthworks where the bearing capacity is increased by introducing geosynthetics.

Reinforcement in earth structures in the terms of these Recommendations comprises oriented geosynthetics installed in layers, which may form either continuous surfaces or grids. The stiffness, limiting strain and tensile strength of isotropic geosynthetics are the same in both directions (machine and cross-machine directions); in anisotropic geosynthetics they are different.

Fill soil is the soil within the reinforced earth structure.

Facing is the frontage on the visible surface of a reinforced earth structure; it retains the fill material between the reinforcing layers and protects against erosion.

Backfill area is the ground outside the reinforced earth structure extending to the top of the structure.

Cover fill zone is the ground above the reinforced earth structure.