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RETAINING STRUCTURES MADE OF EARTH REINFORCED WITH TEXTILES
STÜTZBAUWERKE AUS TEXTILBEWEHRTER ERDE
OUVRAGES DE SOUTENEMENT EN TERRE AVEC ARMATURES TEXTILES

In this paper the design and erection of retaining structures made of textile-reinforced earth are described and the main features of indicating the inner and outer stability are outlined. To ensure stability in the erection phase, stabilizing elements are required which are generally used as erection aids. For maintaining the strengh of the geotextiles at the external wall of the retaining structure, it is necessary to use UV-protected material which is empervious to light. Further specifications for the design, dimensioning and erection of retaining structures are contained in a specific building regulation. The first major structure was a very steep embankment 6.5 m in height made of geotextile-reinforced earth the construction of which is described in the following.

1. DESIGN AND ERECTION

Retaining structures made of earth reinforced with textiles consist of the following constructional elements: external wall, reinforcements and backfill material (fig.1). The external wall and the reinforcements are made up of geotextiles. The geotextiles take up the tensile forces which arise from the earth pressure acting on the external wall and transmit them to the backfill material by friction. A certain roughness, high tensile strength at minimum expansion as well as good long-term behaviour are the prerequisites for the suitability of geotextiles as reinforcing material. The backfill material should consist of non-cohesive earth the grain size of which is required to comply with particular specifications (1).

Due to the fact that geotextiles are only able to take up tensile forces, but not any compressive forces or bending moments, stability problems arise in the erection phase of structures. Therefore rigid stabilizing elements are required which temporarily take up the active earth pressure from the earth layer to be placed, until the friction mechanism begins to become effective. These stabilizing elements are called stabilizers. They help to erect retaining structures made of textile-reinforced earth without any shoring on the outside (fig.1).

The stabilizers may be left in the structure and are designed in this case as edged rigid metal lengths (fig.2). But it is also possible to use them only temporarily as erection aids, then to extract them after the layer has been finished, and to reuse them for the erection of the following layer (fig.3).

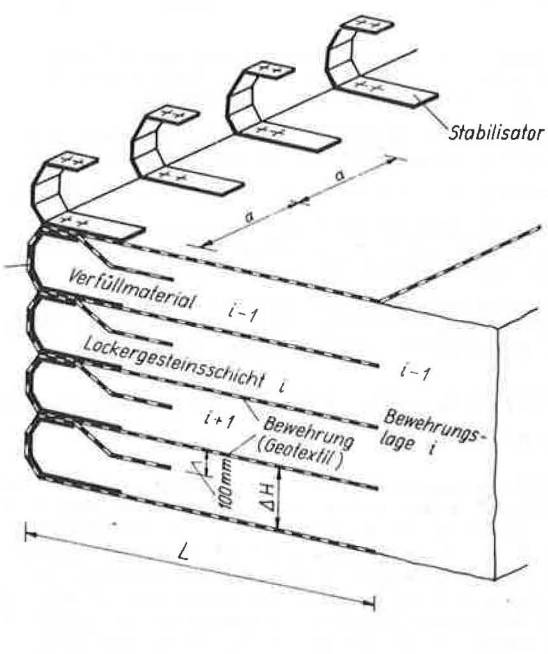

Fig.1 Schematic representation of the design of retaining walls made of textile-reinforced earth

Between the angular stabilizers which will not remain in the structure and the external wall, shuttering boards can be used as additional erection aids. Through the temporary installation of shuttering boards, the dimensional stability and overall quality of the structure increase considerably.

Retaining structures reinforced by textiles are erected layer by layer. Generally the thickness of the earth layer and hence the vertical spacing of the reinforcing layers ΔH are 330 m. After preparation of the foundation soil and, if necessary, installation of a drainage system,

Fig.2 Edged rigid metal lengths used as stabilizers which remain in the structure

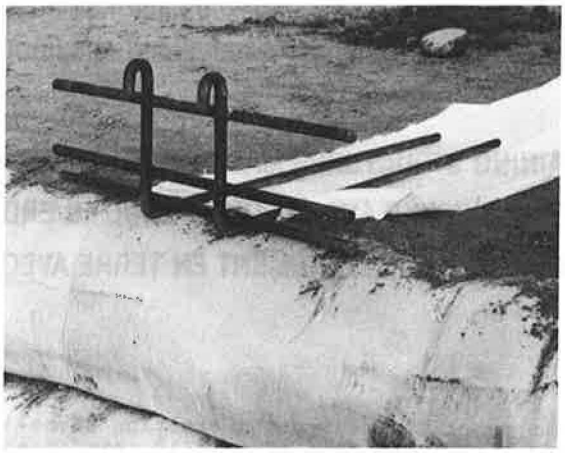

Fig. 3 Angular rigid stabilizers which are only used temporarily as erection aids

the following procedure is repeated in each layer (fig. 1):

- Laying the reinforcement strips of reinforcement layer i on earth layer i + 1 and installation of the stabilizers;
- Forming the external wall by pulling the reinforcement strips up by the stabilizers;
- Placing and compacting the earth layer i;
- Turning the geotextile strips over in the direction of the structure and covering them with backfill material;
- Placing and compacting the complete earth layer i and laying the reinforcement strips of the reinforcement layer i-1.

2.EXPERIMENTAL STRUCTURE MADE OF TEXTILE-REINFORCED EARTH

In 1981 an experimental structure made of textile-reinforced earth was erected in the GDR (2). The structure is H = 3.26 m in height and L = 9.0 m in length. As reinforcement and external wall element a polyamide texture was used with ultimate tensile strength of 44 kN/m and a breaking value at extension in longitudinal direction of 40 percent. With vertical spacings of flat-spread geotextile reinforcements of $\Delta H = 0.33$ m, a reinforcement length of L = 3.50 m was required. The subsoil consisted of glacial loam with $\emptyset = 28^o$, $\gamma = 21$ kN/m^3 and c = 5 kN/m^2. As backfill material a medium sand with $\emptyset = 32.5^o$ and $\gamma = 18$ kN/m^3 was used.

The finished structure is shown in fig. 4. Half of the structure was erected without UV-protection and the other half with UV-protection through corrugated asbestos sheets, so that it was possible to carry out long-term investigations into the influence of the ultraviolet

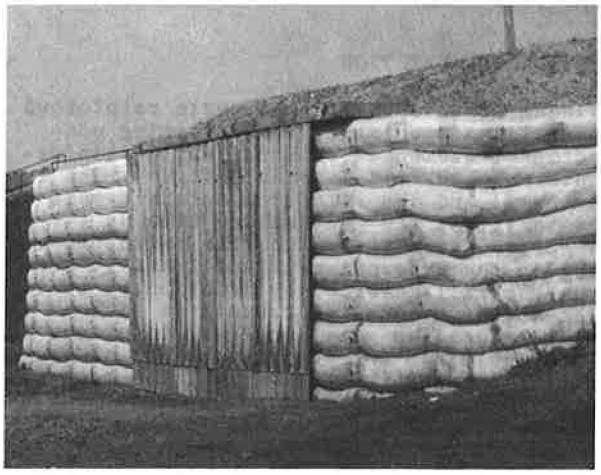

Fig. 4 Completed experimental structure with partly UV-protected external wall

radiation of the sunlight in the change of geotextile strength. For 3 years geotextile samples are taken at regular intervals from the external wall with and without UV-protection and tested in the laboratory. The results of the investigations obtained to date are represented in fig.5 as a function of the global solar radiation. Fig. 5 shows that the strength of geotextiles without UV-protection is reduced in proportion to the global solar radiation to about 30 percent of the initial strength up to the 2nd year. Subsequently strength remains constant for a short time, to show a further reduction in the 4th year. The affected surface of the textile seems to form a certain protection, at least for a short time, for the underlying texture. The reduction of strength is considerably slower in the UV-protected material. Thus after a period of 3 years the residual strength sill amounts to 93.5 percent of the initial strength. Therefore, the UV-protection must be considered the decisive structural measure for maintaining the strength of geotextiles. For that reason textile-reinforced retaining structures must always be erected with UV-protection at the external wall.

stress the breaking strength $\sigma_{Br.}$ of UV-protected geotextiles is reduced by a time-dependent factor k as a function of the planned service life of the structure and the basic material of the geotextile. For the dimensioning of reinforcements the reduced strength $\sigma^*_{Br.} = k \cdot \sigma_{Br.}$ is used. The values of k are given in fig. 6.

The time-dependent factor k sets a time limit for the application of retaining structures made of textile-reinforced earth. These k-values, however, still include broad confidence intervals, and it can be expected that further investigations of the long-term behaviour of geotextiles will help to indrease the reduction factor k.

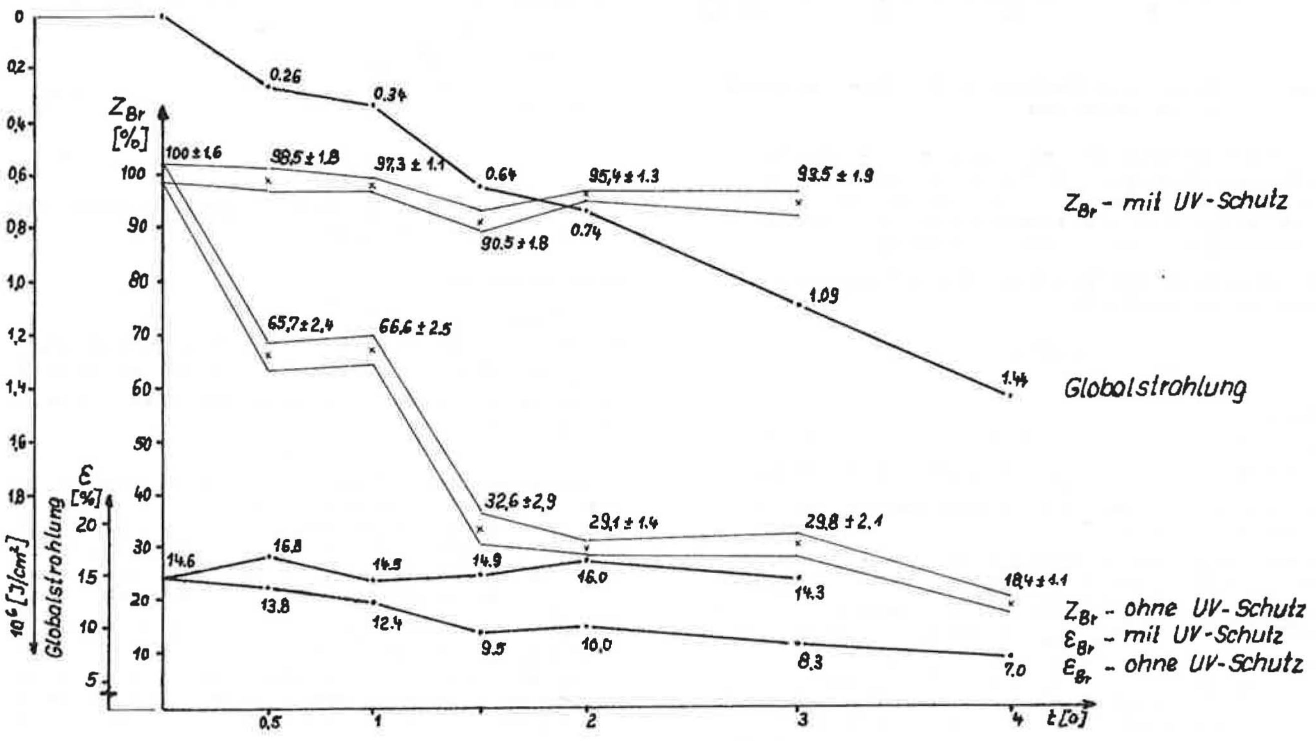

Fig. 5 Time-dependent change of the strength of geotextiles in the external wall with and without UV-protection

3. BUILDING REGULATION "REINFORCED EARTH - REINFORCEMENT WITH GEOTEXTILES"

For the design, dimensioning and erection of retaining structures made of textile-reinforced earth the regulation "Reinforced Earth-Reinforcement with Geotextiles" is valid in the GDR since 1983 (1).

This regulation is obligatory for statically and dynamically (i.e. by road vehicles) loaded retaining structures in civil engineering for building and traffic structures.

As it is still difficult to predict the long-term behaviour of geotextiles under tensile

For the dimensioning of retaining structures made of textile-reinforced earth a distinction must be made between inner and outer stability. Inner stability is realized if it is impossible to extract the reinforcements from the backfill material (dimensioning of reinforcements with regard to extraction) and if the reinforcements do not break (dimensioning of reinforcements with regard to failure). If these requirements are fulfilled the retaining textile-reinforced structure can be regarded as a massive body which is stable in itself. For this body the outer stability must be indicated.

With a view indicating the inner stability, the active earth pressure on the external wall is calculated according to the conventional earth pressure theory by means of the frictional angle of the wall $\delta_a = 0$. In order to in-

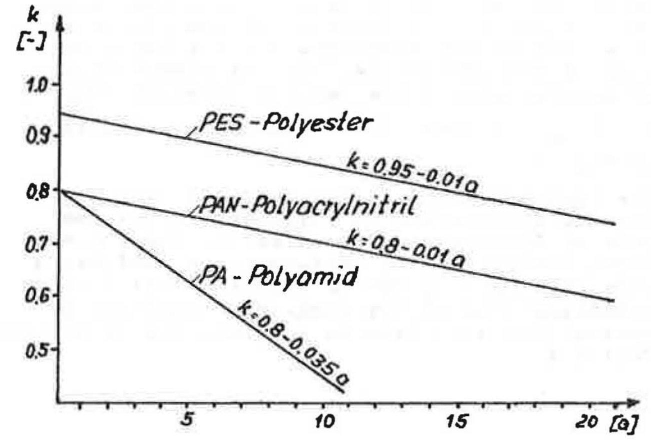

Fig. 6 Reduction factors k for the strength of geotextiles

dicate breaking of reinforcements the reduced breaking strength of the given geotextile is compared with the maximum partial earth pressure which must be transmitted from the reinforcement to the backfill material.

Hence safety against breaking of area reinforcements is given by

$$\sigma_{Br.} = \frac{Z^*_{Br.}}{Z_i} = \frac{Z_{Br.} \cdot k}{e_{ah,max} \cdot \Delta H} \qquad (1)$$

where
Z_i is the maximum tensile force in the reinforcements and $e_{ah,max}$ the greatest ordinate of the active earth pressure taking into account all loads (fig. 7).

Safety against extraction of the reinforcements is not indicated for each particular reinforcing layer but for the whole system. The total earth pressure $E_{ah,max}$ acting on the external wall is compared with the sum of all frictional forces $Z_{r,ges.}$ between the backfill material and the geotextile reinforcements. For the determination of $Z_{r,ges.}$ one should only set up the reinforcing lengths L_{ai} outside the active sliding wedge according to fig. 7. Then the safety against extraction becomes

$$\eta_{HC} = \frac{Z_{r,ges.}}{E_{ah,max}} \qquad (2)$$

It should be noted that the maximum frictional force acting in a reinforcement layer can only be at the most the breaking force of the geotextile. If there are problems of indicating the safety against breaking, the reinforcement strips can also be double-laid. In the case of static load the safety factors $\eta_{Br.} = \eta_{HC} = 2.5$ must be indicated and in the case of dynamic load $\eta_{HC} = \eta_{HC} = 3.0$ for the uppermost 2 meters of the structure. Independent of dimensioning, the minimum lengths of the reinforcements must

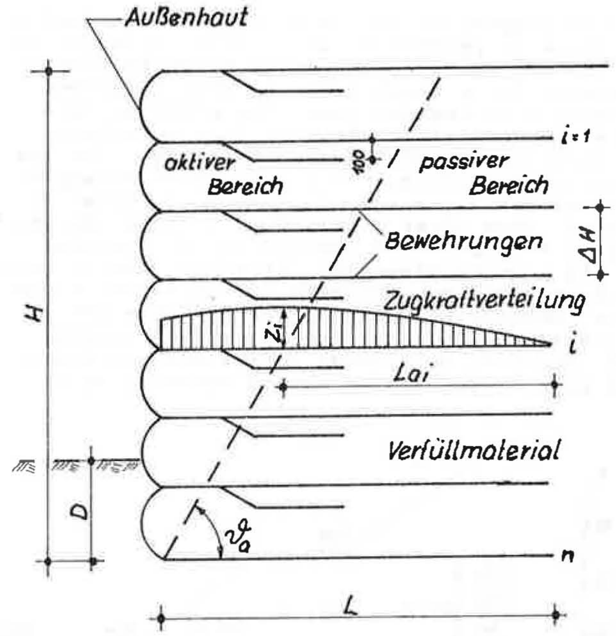

Fig. 7 Designations for indicating inner and outer stability

be assumed to be

$$L_{min.} = H \cdot \cot \vartheta_a = 1{,}50 \text{ m} \qquad (3)$$

As regards the degree of the frictional angle δ_s between geotextile and earth, extensive tests were carried out with different materials (3) giving

$$\delta_s = 0.8\ \emptyset$$

Considering outer stability the active earth pressure acting on the imaginary back wall of the retaining structure (connecting line formed by the ends of the reinforcement strips) must be calculated with a wall friction angle of $\delta_s = \emptyset$. Outer stability is ensured if there is sufficient safety against base failure, sliding and ground failure. Sliding safety indications are based on the idea that the structure slides on a reinforcement layer. Therefore the frictional angle δ_s must be again set up with

$$\delta_s = 0.8\ \emptyset$$

4. ERECTION OF A VERY STEEP EMBANKMENT SLOPE MADE OF TEXTILE-REINFORCED EARTH

For the construction of an industrial plant a ground fill of ca 7 m in height was necessary. On space grounds it was planned in the first design phase to erect an angular retaining wall of prefabricated units. At the same time alternative light-weight construction methods were studied, and as a result of these investigations, a very steep slope of textile-reinforced earth was built up. This is the first larger structure in the GDR made of textile-reinforced earth. It is 140 m in length and 6.5 m in height. The construction of the textile-reinforced slope is shown in fig. 8.

At a vertical distance of every 2 meters a 0.5m

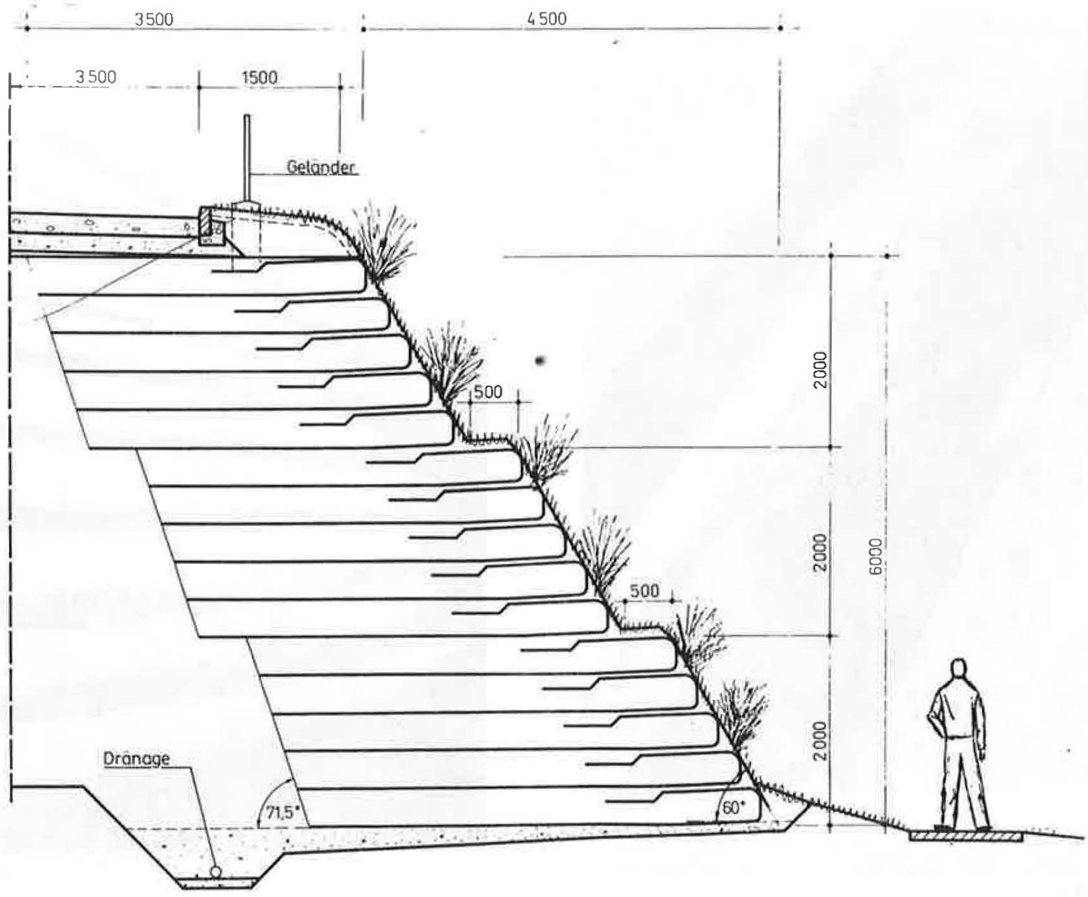

Fig. 8 Variant of a very steep slope made of textile-reinforced earth

wide bench was built to allow subsequent walking along the slope. Each earth layer is 0.4m in thickness. The length of the reinforcement strips in the bottom layer is 5.0 m and that in the top layer 3.5 m.

A permanent protection of the geotextile against UV-radiation was reached by covering it over with agricultural soil, sowing with wild grass and planting bushes. To improve the stability of the agricultural soil and to speed up the growth of grass and bushes the agricultural soil is covered with a rottable geotextile in which grass seeds are contained. Due to previous experience gained with this vegetation we came to the conslusion that an inclination of 60° represents a maximum. Therefore, with a protection of the external wall just described, 50° should not be exceeded.

As the reinforcing element, a polyester texture of 155 g/m^2 mass per unit area was used with a breaking strength of 26 kN/m lengthwise and 30 kN/m crosswise, and a breaking extension of 20 percent langthwise and 15 percent crosswise. The ageing resistance of this geotextile is indicated to be 50 years. The earth filled in is a gravel sand with a finegrained fraction of 10 to 15 percent.

The total mass of earth is machine-filled layer after layer. The laying of the geotextile and the construction of the auxiliary shutters are done manually. For shuttering wooden planks 40 mm thick were taken held by special stabilizers (fig. 9). The shuttering construction is only used temporarily and moves upwards with the erection of the structure. The auxiliary shutters have to take up the active earth pressure due to compaction. Earth layer compaction is effected by means of vibrating plates which are moved up to the shutters thus obtaining a standard (Proctor) density of 90 percent. By compaction and auxiliary shuttering a uniform external wall is formed (fig. 10).

After the agricultural soil has been mechanically distributed, pressed and graded, the grassing mat containing the grass seeds is unrolled. The mat is fixed to the slope sur-

Fig. 9 Arrangement of the stabilizers and auxiliary shutters on the external wall

face with earth nails. Subsequently the slope should be sprinkled for about one month to ensure rapid rooting and growth of the vegetation. In summary it can be said that the building contractors were able to build up a very steep slope reinforced with textiles at a constant rate and without any problems. When comparing this type of slope with the variant of an angular retaining wall it was possible to prove savings in cost, material and transport services. Moreover the time of construction was much shorter than the comparative period required for the other variant.

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(3) Piesker, F.: Untersuchungen zur Konstruktion und Berechnung von Stützbauwerken aus textilbewehrter Erde. Dissertation A, Hochschule für Verkehrswesen "Friedrich List" Dresden, 1983.

Fig. 10 View of the external wall of a very steep slope during the state of construction