DURABLE GREEN VEGETATION AND FIRE PROTECTION OF GRE-STRUCTURES

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ABSTRACT: The method of geo-synthetic reinforced earth (GRE) is becoming increasingly common for building supporting structures. An important advantage of this method of construction is the ease of adding vegetation to the embankment facing. Using this method, one can take landscape designing into consideration. In the case of the projects which have been built to date, a number of problems have occurred with respect to the quality and durability of the vegetation and the necessary fire protection. Following inspections of 40 existing GRE-constructions, the vegetation and the success of this were analysed from the point of view of a biological-engineer in /1/ and /5/. On this basis, sources of mistakes and possibilities for solutions are found. In /5/ and /6/ the problematic of fire protection is discussed at length. Here, these points are drawn together in one article. Possible methods are shown for the construction of a fire-proof GRE-structure with permanent green-facing.

1 PERMANENT VEGETATION

1.1 *General*

Samples of vegetation were taken and analysed from completed GRE-structures. This is shown in /1/. The current flora and the changes of this during the existence of the building were analysed. Apart from being inspected visually, the vitality of the vegetation and the spread of particular plant species was considered. Additionally an analysis of the nutrient content and make up of the soil was also carried out. The usual construction methods for inclined fronts with green-facing at present were considered.

1.2 *Composition of GRE-systems where green-facing is possible*

Figures 1 and 2 show the two common principle methods of building a green facing. Basically, the following elements are parts of these constructions:

1 Filling soil
2 Topsoil
3 Necessary geo-synthetic reinforcement
4 Layer of matting for protection against erosion and soil loss and protection of the vegetation
5 Framework/structural elements

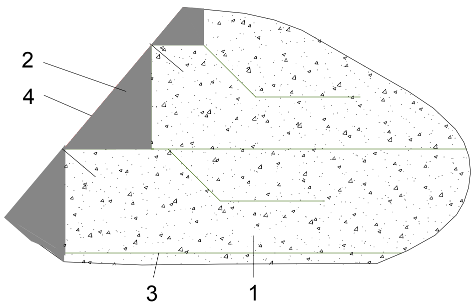

Figure 1: System 1 External topsoil wedge n. /5/

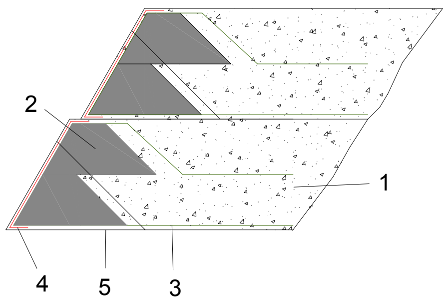

Figure 2: System 2 Internal topsoil wedge n. /5/

In **system 1**, a non-permanent supporting structure is used during construction. This gives the structure a stepped front. Topsoil is added to the resulting steps or wedges and protected with erosion and vegetation protection layer. This is kept in place with earth pins.

In **system 2**, the topsoil is contained in the whole system. A structural element, usually consisting of steel grids is used. These remain in the structure and carry out either constructive or static roles. The topsoil is added at the same time as the filling soil in the front of the construction. The erosion protection, vegetation and soil loss protection layer is installed between the structural framework elements and the necessary geosynthetic reinforcement.

1.3 *Encountered problems with the green-facing*

The biological engineering analysis in /1/ was carried out with the aim of finding the constraining conditions for vegetation growth and, where possible, to draw conclusions as to which constraining conditions need to be considered when designing GRE-constructions. The assessment was based on measurements by Ellenberg and the classification according to the Braun-Blanquet scale. To do this, the embankments were inspected once in the vegetation phase and again in late summer. Figures 3 and 4 show examples of the embankment front of a building project according to /2/ early in the year and in late summer.

Figure 3: Embankment early in the year /2/

Figure 4: Embankment in late summer /2/

These are the results:

- In many cases there is no covering vegetation present – ‚bald-patches'
- Emergence of dominant species of plants on the embankment
- Variable levels of success in the vegetation dependant upon the exposure of the embankment surface
- In the applied standardised seed mixture, some of the species have died out
- In dry periods, the surfaces which are only covered with grass dry out – resulting in fire danger!
- Larger bald-patches are found in those areas where the protection matting does not cover the surface
- Embankments near roads show bald-patches from coming in contact with salt spraying.
- In many cases nitrogen indicating plants are predominantly found
- In all embankments natural succession and changes in the vegetation are to be noted
- Emergence of a 'plant pot effect' – filling soil not suitable for the root network with the result that roots only grow in the topsoil wedge
- Areas which are exposed to wind clearly lag behind the areas protected from wind regarding vegetation
- Embankments which aren't maintained (e.g. with hydration, dung) tend to dry out fully and more sensitive species (first and foremost herbs) are not to be found
- All embankments are to be considered as dry locations with strong changes in temperature
- The water balance of the embankments is extremely unfavourable

1.4 *Influences on the success of the green-facing*

Based upon the examination in /1/, it is possible to list the following factors which have a strong influence on a properly functioning green-facing on a GRE-structure:

- Exposure of the front of the embankment
- Water balance of the embankment
- Inclination of the embankment
- Surrounding conditions / climate zone
- Condition of soil / supply of nutrients
- Degree of compression of filling soil and top soil
- Composition of seeds used / choice of plants
- Maintenance of embankment after completion
- Time and duration of building project
- Surface form of embankment

These factors have varying degrees of influence on the success of the vegetation. The heat cycle varies according to the exposure of the embankment surface. In the case of south facing embankments one must reckon with extreme temperature variations on the surface of the structure. Figure 5 shows an example of the changing temperate of a south facing embankment in the course of a summer day /3/. From this it becomes clear, that in the critical phase the germinating seed is exposed to an enormous range of temperatures. In addition, the south facing embankments thaw more quickly in the winter months which results appreciably earlier in frost-thaw changes. On north facing embankments one can see the opposite phenomenon.

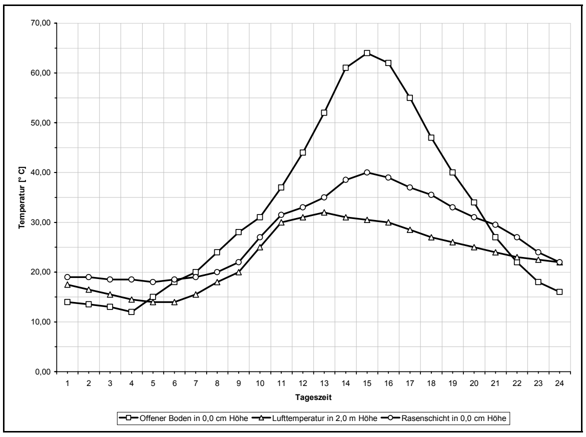

Figure 5: Temperature changes on a south facing embankment in summer according to /3/

Next to the exposure of the embankment, the water balance also has a determinative influence on plant growth. The topsoil takes the role of a storage element for moisture. For this to happen however, surface water must be able to penetrate into the topsoil. The types of filling soil used can generally be regarded as permeable and poor absorbers of moisture, i.e. no water can be expected to enter the topsoil from behind. In the case of embankments with a steep, even surface and too thick overhanging vegetation, it is possible that no water can enter the structure. A non-functional water balance can result in the loss of the entire green-facing. The inclination of the embankment is, together with the exposure, one of the most important influencing factors. The steeper the embankment and the more even its surface, the greater the erosion forces on the embankment due to wind and water and the more unfavourable the water balance and the temperature cycle become. The natural succession which occurs has a long-term influence on the vegetation. Climatic differences due to the local topography also affect the vegetation strongly. In the construction of the geo-synthetic structure, filling soil is used, compacted to D_{pr} 97-100% (proctor density) to keep the deformation of the structure to a minimum. Firstly, the filling soil consists mostly of loose soil with good permeability and poor water absorption properties. Secondly, the necessary degree of compression makes it more difficult for the plants to take root in the filling soil. In contrast to this, the degree of density in the topsoil wedge is greatly lower in order to provide the plants with a favourable growing area. This results in a ‘plant-pot effect’. Root networks are laid almost exclusively in the topsoil wedge. The plants are not enticed to take root in the filling soil as well. This effect is compounded by the good availability of nutrients in the topsoil and the very poor level in the filling soil. With respect to the composition of the seed mixture one can determine that the employment of the standardised seed mixture according to /4/ (usually RSM 7.2.1. or 7.2.2.) without altering the composition does not achieve the required results. The large percentage of grasses (Lolium / Festuca) found in this mixture do admittedly lead to a seemingly good green facing. The long stalks do however prevent the rain water from trickling into the surface. The competitive pressure amongst the species is influenced negatively causing the probable loss of herbs and shrubs in favour of grass types. To ensure the stability of the construction and its durability, vegetation over the entire surface is urgently necessary. Without regular maintenance of the embankment i.e. mowing, new seeding, weeding/removal of unwanted growths, hydration and dung, (in short, development and maintenance in accordance with DIN 18919), no satisfactory green-facing can be expected. Building phases and vegetation phases do not as a rule coincide. During germination, which usually occurs during building, a functioning water balance is essential. On a number of occasions, a part of the seed mixture was destroyed due to improper storage or absence of hydration during construction. To make construction appreciably easier, the surface of the embankment is built level and with a steady slope. This however restricts the possibility of maintaining the embankment and accelerates the rate of draining of the water. In addition, structures of this type offer large arrears for erosion by wind and weather.

2 RECOMMENDATIONS FOR DESIGNING GRE-CONSTRUCTIONS WITH DURABLE GREEN-FACING

2.1 *General Recommendations*

The applicability of GRE-structures with green-facing is primarily decided upon due to static considerations. Here, the inclination of the embankment is the most important factor, due to its influence on the building materials used and on the type of vegetation. Figure 6 shows a suggestion for classifying the embankment inclinations, with subsequent explanation.

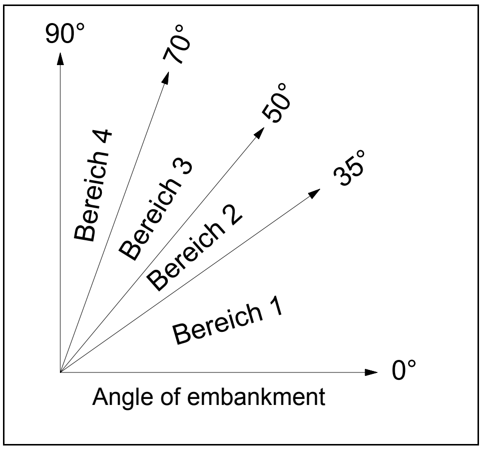

Figure 6: Suggested classification of embankment inclination according to /5/

RANGE 1 0° - 35°

- Loose stone embankment
- Erosion protection necessary
- Maintenance without berms possible
- Maintenance of the embankment in accordance with DIN 18919 with little to moderate effort

RANGE 2 35° - 50°

- Geo-synthetic reinforcement required according to static calculations
- Design of facing according to figure 1 with external topsoil wedge
- Geo-mesh preferable, however textiles, non woven fabrics and combinations also possible
- Application of maintenance berms from 3m elevation and inclination greater than 45° recommended
- Installation of permanent hydration systems at inclination greater than 45° recommended
- Division of surface recommended
- Primary and secondary vegetation recommended
- Maintenance of the embankment according to DIN 18919 possible with little to moderate effort

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RANGE 3 50° - 70°

- Geo-synthetic reinforcement required according to static calculations
- Design of facing according to figure 2 with internal topsoil wedge and geo-meshes exclusively as reinforcing elements
- Embankments of 3 meters of higher require maintenance berms or alternative maintenance methods
- Application of steps (see paragraph 2.2)
- Installation of permanent hydration systems recommended
- Division of surface recommended
- Primary and secondary vegetation necessary
- Maintenance according to DIN 18919 possible with moderate to high effort
- Vegetation trials on location beforehand recommended

RANGE 4 70° - 90°

- Geo-synthetic reinforcement required
- Green-facing only in individual cases (max. 80°) with suitability tests and vegetation trials
- Design of facing according to figure 2 with internal topsoil wedge and geo-meshes exclusively as reinforcing elements
- Separate maintenance methods mandatory
- Application of steps (see paragraph 2.2)
- Installation of permanent hydration systems recommended
- Division of surface recommended
- Primary and secondary vegetation necessary
- Maintenance according to DIN 18919 possible with extremely high effort
- Vegetation trials on location beforehand necessary
- In the case of inclinations greater than 80° green-facing not to be used

2.2 *Recommendation for the Construction*

In order to offer the green-facing optimal support engineering considerations are to be implemented during design. The aim being to tune the design and geometrical form of the embankment to allow for optimal success of the vegetation. Summarizing, the following considerations during designing are recommended:

- Creation of a non-constant geometrical form for the construction
- Installation of berms or alternative methods to allow maintenance of the structure
- Installation of steps to increase the distance water has to flow down the structure
- Selection of method of green-facing (system 1 or 2) depending upon the inclination of the embankment
- Selection of plants and seeds based upon location
- Type of geo-synthetic reinforcement according to paragraph 2.1
- Replacement of topsoil wedge with reduced topsoil/filling soil mixture
- Hydration systems to be used during construction, afterwards installation of permanent hydration systems according to paragraph 2.1
- The layer for protection against erosion and soil loss and protection of the vegetation must have contact over the whole surface with the topsoil
- Insertion of seeds between the layer for protection against erosion and soil loss and protection of the vegetation recommended
- Seeds to be fixed to the reverse side of this layer just before installation
- Fire protection to be considered together with hydration systems!
- In the case of burrowing rodents, a protecting mesh is to be added

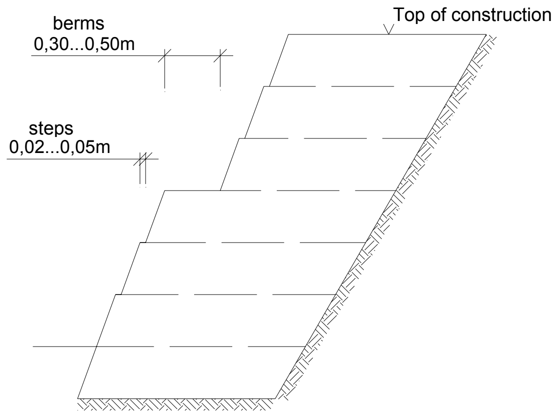

Figure 7: Constructive elements berms/steps

2.3 *Recommendations for the green-facing*

Due to the variety of influences, a biological engineering local profile is to be made for every location where a geo-synthetic reinforced structure with green-facing is to be built. Together with a biological engineer and based upon this local profile, the optimal vegetation method (seed mixture/plant selection/maintenance) for the embankment can be selected. Provisions are also to be made during planning for the maintenance of the embankment after building is completed. A two-stage method of vegetation is to be recommended.

Primary vegetation
(wide-area short-stalked grass)
Secondary vegetation
(local shrubs, bushes, climbing plants)

The **primary vegetation** must germinate shortly after the construction of the embankment had finished and ensure as thick as possible a covering for the embankment. Through this, a micro climate can be provided for on the surface of the embankment, which is of great importance for further growth of the plants. Through the vegetation, the water balance and the temperature cycle of the embankment are changed greatly. Additionally, the front of the embankment is stabilized by the root networks and the UV-protection for the geo-synthetic reinforcement is improved. The erosion forces on the surface of the embankment are reduced. As a basic mix of seeds for the primary vegetation, the standardised seed mixture RSM 7.2.2. is to be used /4/. This must however be modified to fit the location and construction. In /1/ further recommendations to this theme can be found.

The **secondary vegetation** should allow a balance in the total vegetation. Constant vegetation throughout the whole year is to be strived for. In addition to this, shrubs and climbing plants should be envisaged, taking the competition between species into consideration. The secondary vegetation is to be added locally. Deep root systems improve the stability of the embankment front. Unevenness in the embankment front can be supported (local wind and sun protection). A recipe for the secondary vegetation can not be generated. It is recommended to decide upon type and range of secondary vegetation with a biological engineer during design.

Figure 8: Close-up of vegetation 4 weeks after assembly with primary and secondary vegetation in accordance with /2/

3 FIRE PROTECTION

3.1 General

Experience of large constructions /8/ shows that fire protection is of great importance in structures with green-facings. Firstly, all polymer geo-synthetics are combustible and inflammable. Secondly, the whole surface of the embankment dries out in the course of the seasons. This means that the following questions must be answered during design:

- How would the structural stability of the constructional be compromised in the case of a fire?
- How can a GRE-construction with green-facing be made resistant to fire?

3.1 *Design/examination*

No rules and regulations exist for fire protection and prevention in GRE-constructions. In /5/ exhaustive tests on this subject were carried out and in /6/ compiled and presented. The purpose of these tests was to measure the combustibility and inflammability of materials used in the construction of GRE-structures, for example geo-grids and erosion protection matting. These were examined with and without soil. The test arrangements were in compliance with DIN EN ISO 6941 (1995). For the first test arrangement (geo-synthetic alone without soil), a special fixture based upon DIN EN ISO 6941 (1995) was built. For these examinations, samples measuring 300x210 mm were cut and inserted in to the holding clamps of the mounting support. This having been done, the samples were exposed to fire from a small burner at 17mm intervals.

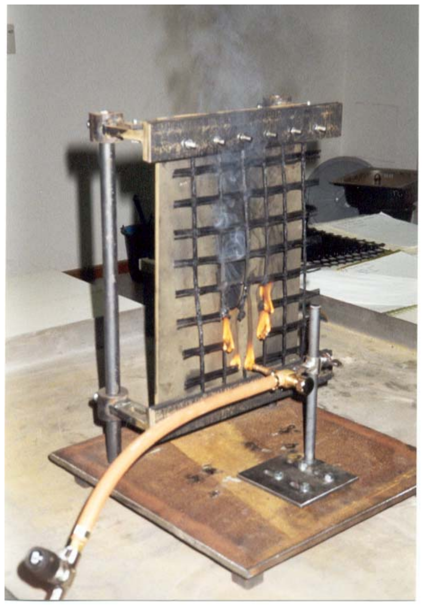

Figure 9: Test arrangement 1 (burning test without soil)

For the second test arrangement (built into the ground) boxes were used, open to the top and to the front of size 90 x 50 x 40 cm (depth x width x height). In these boxes, the front of the designed embankment was built. Water was added to the test arrangement every day, and the whole was exposed to normal daylight, in order to ensure the most even and expansive green-facing possible. After the vegetation was ready, the sample was exposed to fire in accordance with DIN EN ISO 6941 (1995).

Figure 10: test arrangement 2 (burning test built into soil)

Based on the experiments carried out and their evaluation, a formula for the fire load can be given following the DIN-standard 18230 /5/. The coefficients necessary for this were derived from the examinations described above.

$$q_R = \frac{\Sigma\left(M_i \cdot H_{ui} \cdot m_i \cdot \psi_i \cdot \xi_i\right)}{A}$$

Mi	Mass of individual combustible material/kg
Hui	Calorific value of the individual material /kWh/kg
A	calculated area subjected to fire (plan area) /m²
mi	Combustion factor of the individual materials
ψi	Combination coefficient for protected materials (ψi = 1 in the case of unprotected materials)
ξi	Factor added to take inclination into account

Using this formula, the specific fire load for the construction in consideration of the materials used can be calculated. In the case of a safe construction:

$$\textbf{vorh } q_R \leq \textbf{max } q_R$$

The maximum value applied is determined after repeated test calculations and subject to the geotechnical risk:

- **GK 1** **max $q_R \leq$ 10 kWh/m²**
- **GK 2** **max $q_R \leq$ 7 kWh/m²**
- **GK 3** **max $q_R \leq$ 5 kWh/m²**

Subject to the specific fire load of the construction, the fire risk can now be defined and evaluated.

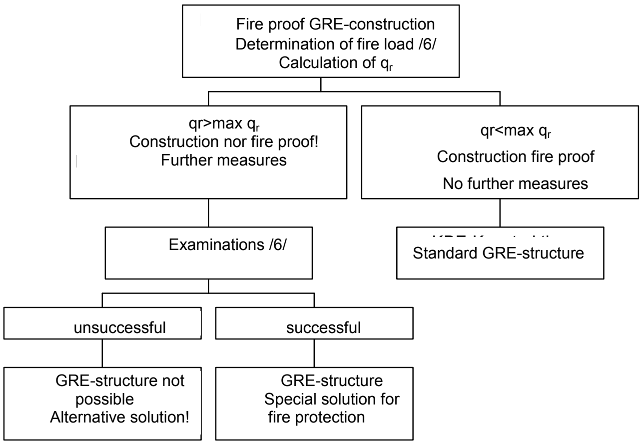

Figure 11: Determination of fire load

3.2 *Measures to increase resistance to fire*

Provided that the required fire resistance of the construction does not suffice, there exist a number of constructive possibilities for the reduction of the fire load q_R.

- Installation of glass-fibre erosion protection grids
- Hydration systems

Hydration systems make sense in combination with steep green-faced embankments, because they can be used as a sprinkler system as well as for hydration /2/, /9/. These systems are however difficult to maintain and cost-intensive. The installation of close meshed glass-fibre grids as a replacement for conventional erosion protection and vegetation layers has proven to be advantageous and inexpensive /5/ /8/. The non-flammable glass-fibre structures reduce the fire load considerably and allow for optimal green-facing.

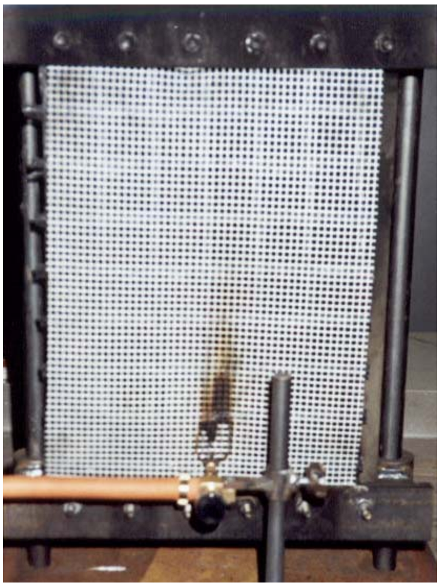

Figure 12: Determination of fire load for a PES-grid made out of glass-fibres

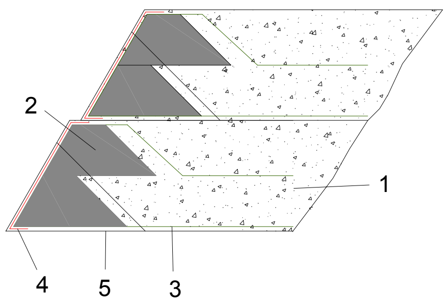

Figure 13: Installation of glass-fibre grids –4 (glass-fibre grids)

4 CONCLUDING REMARKS

With the help of the approaches shown here, the vegetation of GRE-constructions can be made much more successful, and a permanent green-faced structure can be achieved. The methods for determining the fire load of this sort of construction allow a risk appraisal for this case. Vegetation and fire protection are two essential parts of design. The co-operation with biological engineers and landscape architects is therefore necessary for the overall performance of the project The concluding pictures show the practical implementation of these recommendations and the following success:

Figure 14: GRE-Erfurt Galgenberghang/at date of commissioning

Figure 15: GRE-Erfurt Galgenberghang / after 4 years

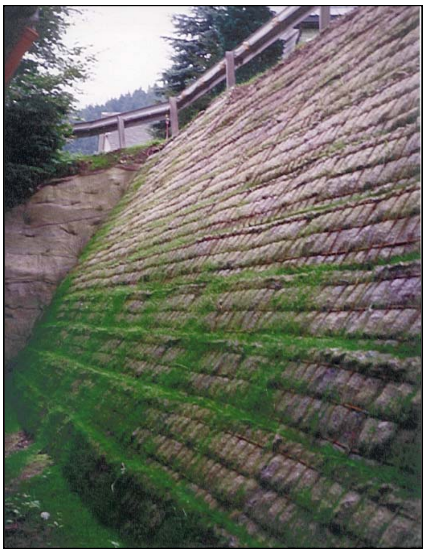

Figure 16: GRE-Manebach / at date of commissioning

Figure 17: GRE-Manebach / after 5 years

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