ONE OF EUROPE'S TALLEST GREEN FACED GEOSYNTHETIC REINFORCED RETAINING STRUCTURES

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ABSTRACT: At Iserlohn a 19 m high, 215 m long, geosynthetic reinforced earth structure was built for Lobbe Holding GmbH & Co. The construction is located adjacent to the A46 motorway and has a maximum free height of 16.70 m with a width of 11.20 m at the base. Both planning and the design calculations were carried out by Geokunststoff GbR Herold & Köhler, located in Weimar, Germany. The design is strictly in accordance with the „Empfehlungen für Bewehrungen aus Geokunststoffen – EBGEO“. The completed wall has a slope angle of 80° without berms whilst the slope face has been completely vegetated. This paper describes both the design approach and the construction details including construction time, installation sequence and details of the face vegetation. The results of deformation measurements over a period of 2 years are also included

Keywords: Case study, Embankments, Facing, Geogrids, Monitoring

1 INTRODUCTION

In 1997 Lobbe Holding GmbH & Co. planned a new head office building in Iserlohn. The construction site is characterised by terrain which slopes strongly towards the North. The construction site is bounded on the West by a railway line and on the North by the motorway A46. The difference in elevation between North and South boundaries is 17.00 m. The aim of the construction was to protect the new building from the noise of the A46 and to allow a park area to be placed in front of the building. This is shown in figure 1.

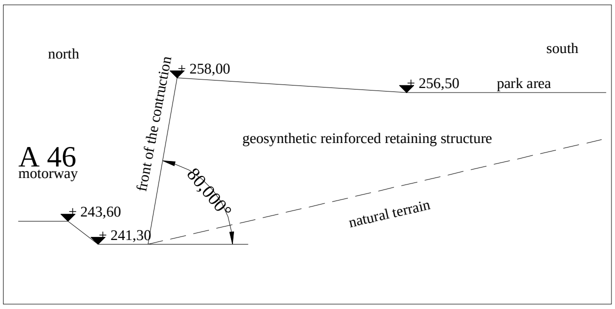

Figure 1: Natural terrain in North-South-section and basic idea for the construction

The new terrain resulted in a 3500 m² park area in front of the head office building. The construction functions as a noise shield. For this reason the line along the top of the geosynthetic reinforced construction was fixed. The line along the foot of the embankment was fixed by the ground boundaries. These conditions resulted in an inclination of 80° of the construction face and a maximum free height of 16.70 m. The total length of the embankment measured along the top line is 215.00 m. In immediate proximity disused barracks were located. These were to be demolished and used as fill for the construction. This provided a large amount of brick and concrete material of grain size 0/32 and 0/45. The landscape architect commissioned the complete vegetation of the face of the embankment.

2 DESIGNING OF GEOSYNTHETIC- REINFORCED EARTH CONSTRUCTION

2.1 *Method of construction*

The author of this article suggested the method of construction known as geosynthetic-reinforced earth for this embankment (GRE). The method offers the possibility of designing a green faced surface and the advantage of using recycled building materials. The GRE is built up in layers, allowing the shaping of the front surface and depositing of backfill soil at the same time. Figure 2 shows the cross section of the construction. The construction has the following properties:

- height of construction: 19,70 m
- maximum free height: 16,70 m
- average angle of inclination : 80,00 °
- maximum breadth at base : 11,20 m
- total length: 215,00 m

The base of the construction was dictated by the plot boundary taking into account a 3.5 m wide path between the construction and the plot boundary for maintenance, access and control purposes. At the south-west end of the construction, a spiral-shaped tower was to be built.

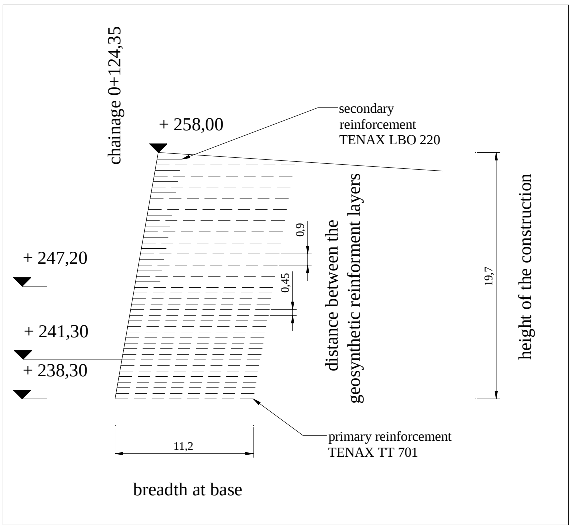

Figure 2: Cross section at chainage 0+124,34

2.2 *Materials used in the construction*

In the construction materials were used in accordance to the designing results. These were:

filling soil:	recycled soil	0/32 to 0/45
	specific gravity	γ_k/γ'_k = 21/11 kN/m³
	angle of friction	φ'_k = 35°
	cohesion	$c'_{u,k}$ = 0,00 kN/m²

The fill soil was compacted to 100 % Proctor density. The compaction was monitored using the German guideline ZTVE-StB 94 (edition 1997). The following geosynthetic reinforcements were used:

primary reinforcement:

product:	TENAX TT 701
tensile strength	$F_{B,k0}$ = 110 kN/m
failure strain	ε = 13 %

secondary reinforcement (structural reinforcement):

product:	TENAX LBO 220
tensile strength	$F_{B,k0}$ = 20 kN/m
failure strain	ε = 10 %

As static reinforcement (primary reinforcement), a monodirectionally stretched geogrid made of high density polyethylene (HDPE) was used. The geogrids had a width of 1.0 m. In the direction of force, no overlapping was allowed. In the horizontal plane, the grids were laid next to each other, with some constructive overlapping of adjacent geogrids in curves. Because it is difficult to fold the monodirectionally stretched grids at the front, an additional flexible grid was used. In accordance with the design calculations, the distance between the geosynthetic layers was 0.45m for the lower half of the construction, and for the rest, 0.9m. To simplify the working procedure, and to achieve a more stable facing, an additional structural reinforcement (secondary reinforcement) was built into the upper half. As a result of the two kinds of reinforcement being used interchangeably, the effective distance between the geogrid layers is also 0.45m in the upper half. Figure 2 shows the design cross-section at chainage 0+124.34. The primary reinforcement is represented by slashes, and the secondary reinforcement by lines.

2.3 *Construction of the facing / Details of vegetation*

The top line was fixed by the need to provide noise protection. This resulted in a surface with an inclination of 80°. It was not possible to use berms in this case, since they would have resulted in an inclination of less than 80°, and a resulting lack of noise protection. However, an inclination of 80° causes a lot of problems with the green facing required. The green facing was therefore conceived in 2 stages.

stage 1: initial green facing
stage 2: secondary green facing

The first stage had to stabilise the facing as quickly as possible with a thick root network. These plants had to be fertile on a slope of 80°, but were not allowed to dominate the secondary vegetation. A specially composed selection of lawn grasses was used for the first stage. This was introduced into the topsoil during construction and integrated in the erosion control textile on the front of the facing (see figure 5). The secondary vegetation was built in after the building work was completed. Various climbing plants were used. As formwork, a reinforcing wire mesh with cross braces at a distance of 0.50m was used. Behind this mesh are the vegetation and erosion control textile and geosynthetic reinforcement, which surround the wedges of topsoil. The primary reinforcement ends at the front of the structure. The topsoil wedges are 0.30m thick in the middle and joined without boundary element into the filling material. The vegetation and erosion control textiles are made of a polymer support fabric, with a mat made of recycled cotton fibres sewn on to it. An important detail of the structure are the 2cm wide ridges at the top of each layer on the front. These enable rain water flowing over the front of the structure to pond and irrigate the topsoil wedges. Because this was the first construction with an inclination of 80° and full green-facing, there were no precedent cases, so an additional water supply system was designed for the structure.

Figure 3: Detail of work on the facing

3 DESIGNING

The dimensioning of the geosynthetic reinforced construction was done in accordance with the EBGEO /1/ (partial safety concept). The external and internal stability of the construction were calculated. This was calculated at 3 different cross-sections.

The reduction factors A_1-A_4 and the friction coefficient were provided by the manufacturer. The values were:

A_1 = 2,62
A_2 = 1,10
A_3 = 1,00
A_4 = 1,00
γ_B = 1,40

The maximum useable long-term tensile strength of the geosynthetic reinforcement was calculated to be 25% of the short time characteristic tensile strength. While designing, it was also necessary to predict the deformation of the construction. This is normally relatively straightforward for the base deformation of the construction, but the horizontal deformation of the facing cannot be exactly predicted at this time. For these calculations, FEM methods are a possible solution. In practice, they are not normally used because they require expensive programs and too many man-hours work. The results are also dependant on the input. A practical way around the problem is to observe the deformation of the construction during the building process and afterwards. This enables the input values of the calculation to be checked while monitoring the construction for possible problems. It was agreed that the building would be monitored during construction and for 2 years after completion. Deformation measurement points were built into the surface at heights of 3, 6, 9, 12, and 16.70m at 8 cross-sections. The deformation was measured 3 dimensionally.

4 CONSTRUCTION

4.1 *Building process*

The construction work was carried out by Lobbe Holding GmbH & Co. The employees had had no experience of this building method up to this time. An introduction to geosynthetic- reinforced earth was therefore taken into account. The introduction included a two-day on-site control with practical assistance for the first steps, followed by the monitoring of the entire building process. Regular visits and unannounced checks helped to ensure the high quality of the construction work. The building process showed the following problems:

- Difficulties in keeping to the desired inclination.
- Constant work assuring safety at the work place, in particular danger of falling.
- achieving the required degree of compaction of the filling soil
- Deviations from the intended technology of compaction, according to the design calculations.

The first problem was to maintain the intended inclination of the surface. For this reason, special moulds were used. This system could be applied without problem up to the maximum height. The advantage of this system is the combination of a safety railing while providing a guide for the desired inclination. This system is shown in figure 4. The inclination system consisted of conventional formwork beams, which were anchored with steel elements in the construction. These steel elements, shaped like a horseshoe, were built in at every third layer and were connected with the formwork beams. Two formwork beams each 4.0 m long were used. When the construction work had reached a height above the first beam, a second beam was used. A third beam was avoided by using the now redundant first beam again. This proved to be a practical and efficient method. The next problem which occurred during construction was to achieve the required homogenous degree of compaction of the whole filling soil. The contracted geotechnical institute - Baugrundingenieure Dr. Schäfer & Dipl.-Ing Giljohan supplied the necessary soil properties, for example Proctor compaction curve, optimal water content and grading of the filling soil. A test field was carried out to acquire correlation between the different methods of checking soil density; direct and indirect methods, for example, plate-bearing test and dynamic plate-bearing tests. The dynamic plate-bearing test was used because of the ease and speed of application. This test was calibrated with a direct testing method for the degree of compaction. The control tests were carried out in accordance with the ZTVE-StB 94 /2/. By the application of a statistical control plan and using the direct and indirect checking methods, it was possible to reach the required degree of compaction homogeneously in the whole consruction. The following figures show details of the construction work.

Figure 4: Safety railing and inclination guides

Figure 5: Surface of the construction site in original condition.

Figure 6: North side of the construction during building

Figure 7: Installation of a wedge of topsoil

Figure 8: West surface during construction, half complete

4.2 *Deformation measurements*

On the front side of the construction 40 different measurement points were installed. Figure 11 shows one measurement point. The deformation of each of these points has been controlled at regular intervals since the close of the construction work in 1998. Deformations in 3- dimensional space are measured with a precision of ± 1 mm. Figure 12 shows the cross-section at the highest point with measurement point numbers. Table 1 shows measurements taken at these points one year after completion. In the calculation these deformations were predicted:

- Predicted vertical maximum settlement ca. 4.0 - 5.0 cm
- Predicted horizontal maximum elongation ca. 6.0 - 8.0 cm

As table 1 shows the practical values after one year are a lot smaller than expected.

- Measured vertical maximum settlement ca. 2.0 - 3.0 cm
- Measured horizontal maximum elongation not measurable

The answer for this is in fact simple. The first measurement was taken when the construction was completed. This was 6 months after commencement. A large part of the settlement had already occurred during the building process and had been immediately corrected. For this reason the maximum settlement value one year after construction was measured at the top point. It can be seen that the elongation after one year is negligible. This shows that the construction method of geosynthetic-reinforced earth is remarkably stable with respect to deformation. The measurements will be carried out for a further few years.

measurement point	Height above the base of construction	elongation after 1 year (x)	elongation after 1 year (y)	settlement after 1 year (z)
17	15 m	not measurable	not measurable	-0,03 m
16	12m	not measurable	not measurable	-0,02 m
15	9 m	not measurable	not measurable	-0,02 m
14	6 m	not measurable	not measurable	-0,01 m

Table 1: Results of the deformation measurements after one year

Figure 9: Circular building at the south end of the construction

5 CONCLUSIONS

In this project, a lot of experience was gathered. The building showed that large green-faced geosynthetic-reinforced embankments can be built practically. Be that as it may, this is only possible under strict control and painstaking design and planning . Some of the most important conclusions are:

- The construction of geosynthetic reinforced earth embankments with an inclination of 80° and green facing is fundamentally possible.
- When the inclination is between 60° and 80°, special steps have to be taken so that the green facing is durable. A sensible solution is a division between primary and secondary green facing. The green facing must be carefully planned.
- In order to take into account the climatic conditions specific to the natural environment in this place with respect to the

selection of plants and design of the green facing, the advice of a biological engineer is to be recommended

- Analogous to conventional concrete retaining constructions, geosynthetic earth constructions must be carefully designed and planned. Because of a lack of long-term experience with this method at this time, and the resulting difficulty in predicting the deformation of systems of this sort, a programme of deformation measurements is to be recommended.
- From an economical point of view, it is necessary to design with the product-specific reduction factors taking into account the intended fill soil.
- The calculation of this building was worked out in accordance with DIN V 1054-100 (partial safety concept). A comparative calculation in accordance with the summation security concept provided the same results.

Figure 10: West side, completed

Figure 11: View of measurement point

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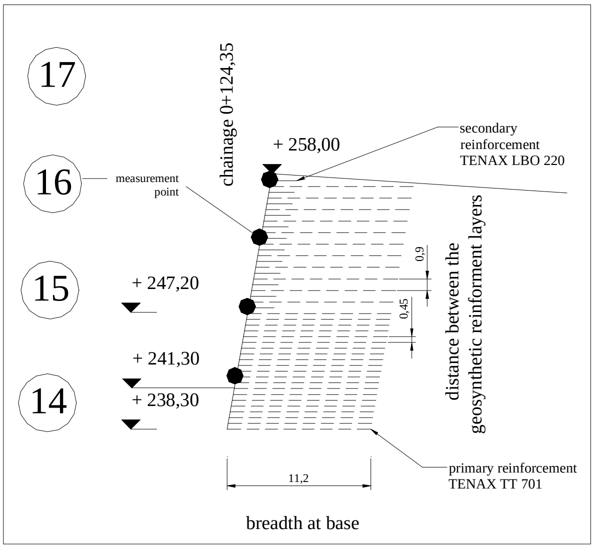

Figure 12: Cross section with measurement points

Figure 13: The whole construction

LITERATURE

/1/ Empfehlungen Bewehrungen aus Geokunststoffen – EBGEO; Verlag Ernst & Sohn, Berlin 1997

/2/ ZTVE-StB 94 (Fassung 1997), BMV, Bonn 1997