Large-scale investigation on a geosynthetic reinforced earth structure

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ABSTRACT: In this paper the author will show how a 13 m high geogrid reinforced earth structure with extensive instrumentation proved the technical benefits of this construction method. Deformations were within acceptable limits, design can be carried out using simple design procedures, and geosynthetic strains below 3% gave an additional “hidden” factor of safety to the system. Centrifuge model tests and back calculation using Finite Element methods yielded a good correlation between calculated and recorded values.

1 INTRODUCTION

In Kaltenleutgeben south of Vienna a 10 m high experimental wall reinforced with 20 layers of high strength geogrid was constructed. In order to evaluate the stability and deformation performance, extensive instrumentation was applied to the wall. The project was carried out by Polyfelt Ges.m.b.H. in collaboration with the Institute for Geotechnics of the University for Agriculture in Vienna. In Summer 1997, the height of the wall was increased by another 3 m.

The projects had the following objectives:

- Verification of design methods
- Investigation of the performance soil / geogrid in combination
- Evaluation of the economic efficiency of the construction method
- Checking the technical and safety limits of the method
- Optimization of installation and construction

2 CONFIGURATION OF THE WALL

The height of the wall in the first construction stage was 10 m, with a slope inclination of 70°. As fill material, recycled building waste material with a wide-spread grain size distribution (between 0 and 63 mm) was used. The fine material content (< 0.06 mm) ranged between 15 and 50%, the Proctor density between 18.8 and 22.8 kN/m³, and the friction angle was determined with 33.6° with very low variations.

The reinforcement consisted of 20 layers of high tenacity polyester geogrid, having an ultimate tensile strength acc. EN ISO 10319 of 45 kN/m and an elongation at break of 15%. The layers were installed at a vertical spacing of 50 cm. The anchor length of 6.5 m was chosen to be at the lower acceptable limit (L/H = 0.65).

The second construction stage, with additional 3 m height, was constructed with the same fill material, geogrid and vertical spacing, but with a berm of 1.5 m and a slope angle of 75°. The cross section of the wall is illustrated in Figure 1.

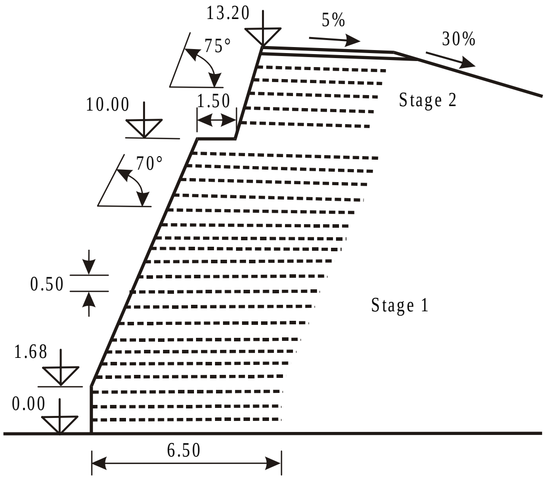

Figure 1. Schematic cross section of the test wall.

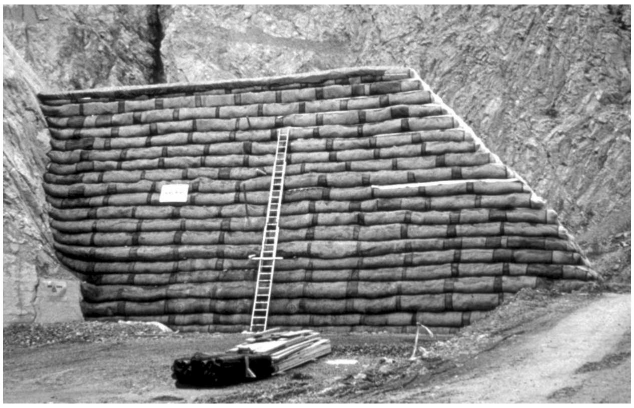

Figure 2. Front view of the instrumented test wall (stage 1).

3 PRELIMINARY DESIGN

The preliminary design of the first stage was carried out using the „earth pressure method" by calculating the active earth pressure on the wall, and dividing it by the number of layers. The resulting design force was then multiplied by an adequate reduction factor to achieve the required ultimate tensile strength of the reinforcing layers. Measurements have shown that the earth pressure distribution over the height of the wall is not linear but parabolic. In order to simplify the calculations, it was assumed that the earth pressure is evenly distributed over the whole height of the wall.

In order to evaluate the limits of this construction method, this reduction factor was chosen with 3,0, a value being at the lower acceptable limit. The design parameters are summarized in Table 1.

Table 1. Design parameters for the preliminary design

Slope geometry:	Fill material:
Wall height H = 10 m	Friction angle φ = 30°
Slope inclination β = 70°	Cohesion c = 0
Reinforcement:	Safety factors:
High strength geogrid (Polyfelt Rock)	for soil parameters = 1,0
Ultimate tensile strength 45 kN/m	for tensile strength = 3,0

4 INSTRUMENTATION

The extensive instrumentation consisted of vertical and horizontal inclinometers covering the deformations, and extensometers recording the strain in the reinforcing layers. Additionally, the surface was surveyed geodetically in regular intervals. The horizontal inclinometers were installed between layers no. 6 and 7, and 12 and 13 respectively (for stage 1) and between layers no. 20 and 21 (for stage 2). The extensometers were installed in layers no. 5, 11 (for stage 1) and 21 (for stage 2).

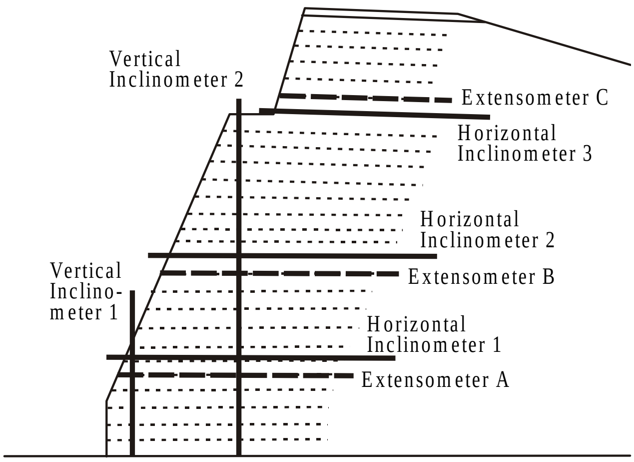

Figure 3. Location of instrumentation

5 CONSTRUCTION

The layers were filled utilising of a special formwork. This formwork comprised steel angles and wooden boards, with 1 m distance between the steel angles. The installation was carried out by three personal, using a crawler-type loader, a 10 to single-drum vibration compactor (min. 5 passes) and a small vibration compaction plate (for the compaction of the front area). At the end of the construction after sufficient experience had been achieved, 2 layers of 15 m length could be installed per working day. As surface finishing a shotcrete covering was applied.

Comparative cost calculations yielded a possible cost reduction of 30 to 60% compared to a conventional concrete gravity retaining wall.

Figures 4 and 5. Construction using steel angles and wooden boards as temporary formwork

6 OBSERVATIONS AND RESULTS

6.1 *Geodetic survey*

In the first year, relatively large deformations at the surface were observed which were mainly caused by the inadequate compaction of the front area. At this time, the shotcrete surface was not yet applied. Until November 1998 (i.e. after 800 days), the maximum deformation was 48 cm (in a height of 5.5 m), from which 44 cm occurred during construction.

6.2 *Extensometers*

The extensometers measured the strains in the geogrid. The maximum measured elongation amounted to only 3%, very low compared to the elongation at break of 15% of the grids. This shows that there still was plenty of „hidden" safety. Typical strains of extensometer A are illustrated in Figure 6.

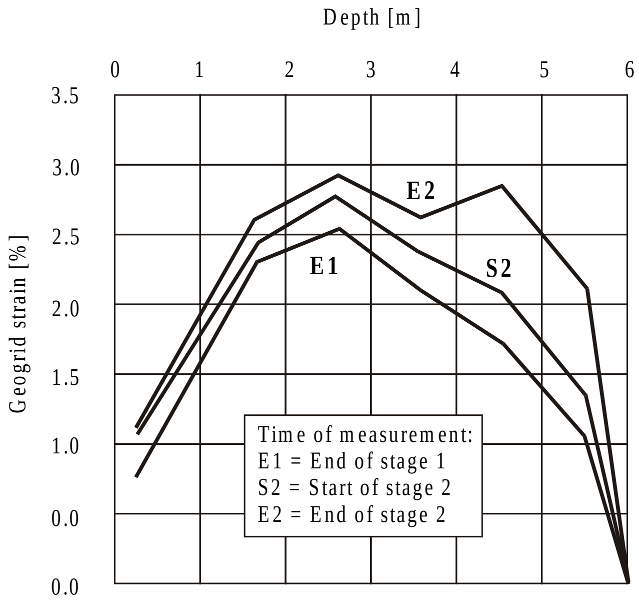

Figure 6. Strains of geogrid (extensometer A)

6.3 *Horizontal inclinometers*

The horizontal inclinometers allowed the control of the vertical deformations (settlements) of the wall. The maximum deformation measured was 25 cm in the back area of the wall, and 40 cm near the surface. Settlements near the surface are partly caused by sagging due to frost during the first winter. Settlements measured with inclinometer 2 are illustrated in Figure 7.

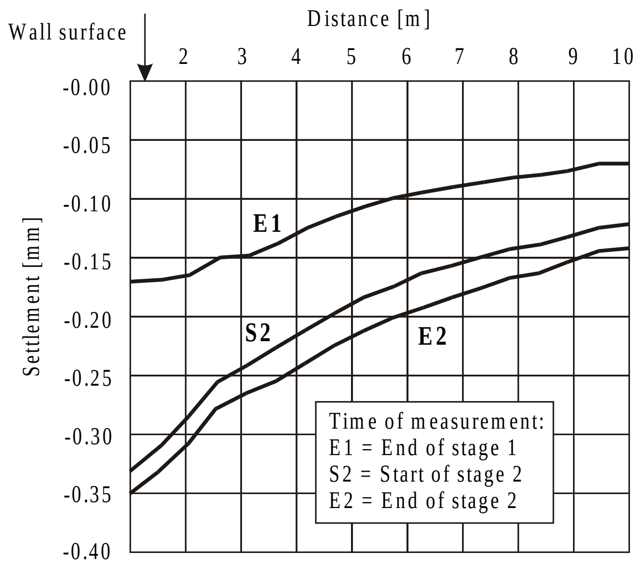

Figure 7. Settlements measured with horizontal inclinometer 2

6.4 *Vertical inclinometers*

The vertical inclinometer allowed the control of the horizontal deformations of the wall during construction and after completion. The maximum measured deformation (during stage 1) amounted to 24 cm. Deformations of this magnitude were expected. For conventional retaining walls, this value would have been unacceptably high. For a flexible wall like the experiment one however it could be accepted, as the largest part appeared during construction, and the deformation had no influence on the stability.

7 CENTRIFUGE MODEL TESTS

Additional comparative model tests were carried out with a centrifuge. The model was reinforced with a mechanically bonded continuous filament nonwoven, with an ultimate tensile strength of 7,3 kN/m. As fill material, two types of soil were used: sand and silt. The load was applied after the installation of every 3rd layer. The schematic cross section of the model is illustrated in Figure 8.

Table 2 summarizes the measured wall deformations for both soils after the installation of the final (20th) layer. These values were then calculated to the original size to simulate site scale conditions by means of conventional model laws. The results corresponded well to the actually measured values.

For both soil types there was no evidence of any tearing in the reinforcement. In the case of the silt, at the back of the reinforced soil structure (where the reinforcing ended) cracks were observed which indicate that the reinforced soil mass can be seen as rigid mass (similar to a gravity retaining wall). This confirms the assumptions usually taken for the design.

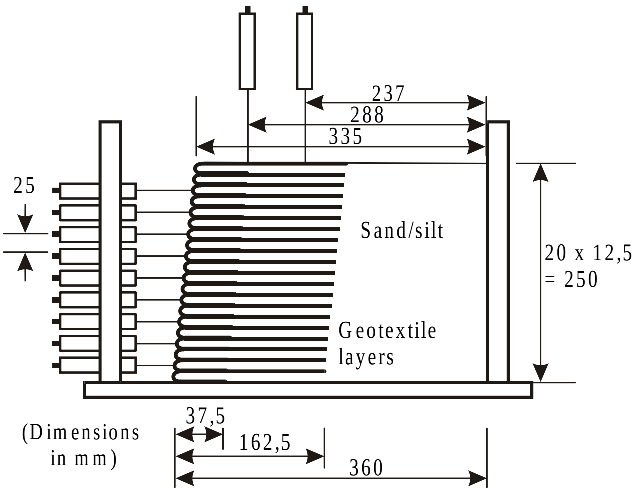

Figure 8. Cross section of the centrifuge model

Table 2. Results of the centrifuge model tests

Fill material silt:			
Acceleration	20g	40g	60g
Maximum deformation [mm]	4.10	6.58	9.90
corresponding to [cm] in nature	16.4	26.3	59.4
Fill material sand:			
Acceleration	20g	40g	60g
Maximum deformation [mm]	4.08	4.56	5.16
corresponding to [cm] in nature	16.3	18.2	31.0

8 FINITE ELEMENTS CALCULATIONS

Finally, a back calculation using a finite element program (PLAXIS) was carried out, using the following input parameters:
- Soil (front area): γ_d = 17.0 kN/m³, γ = 18.4 kN/m³, E = 2.0 MN/m², c = 1 kN/m², φ = 33.5°, ν = 0.2
- Soil (back area): γ_d = 20.0 kN/m³, γ = 21.3 kN/m³, E = 8.5 MN/m², c = 1 kN/m², φ = 33.5°, ν = 0.2
- Geogrid: K = 333 kN/m

The following results were realised:

- The calculated vertical deformations at the surface were lower than the actual values measured at the wall. This can be explained by the sagging which could not be taken into account in the calculations.
- The calculated horizontal deformations at the surface were slightly higher than the measured ones.
- The calculated geogrid elongations corresponded well to the measurements of the extensometers.

9 SUMMARY AND CONCLUSION

- The deformations of geosynthetic reinforced earth structures lies in an acceptable limit even with „narrow“ design, using a relatively low factor of safety.
- Conventional design methods, such as the earth pressure method, are sufficiently accurate.
- The reinforced soil mass can be seen as a rigid mass, similar to a gravity retaining wall.
- The actual elongations in the reinforcing layers were only 3%. Compared to the elongation at break of 15%, this means that enough additional „hidden“ safety is available.
- Compared to conventional concrete retaining walls, cost reductions up to 60% can be achieved.