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DESIGN, CONSRTUCTION AND PERFORMANCE OF HIGH GEOGRID EMBANKMENTS IN A COMPLEX GEOLOGICAL SURROUNDING

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ABSTRACT

This paper presents the case study B114 Trieben-Sunk and is dealing with conventional, analytical calculation methods and numerical simulations of geosynthetic reinforced embankments. Two and three-dimensional analysis are performed. For conventional calculations GGU Software is used and for numerical simulations Plaxis V.8 and Plaxis 3D Tunnel is employed. The goal is to simulate respectively to evaluate the behavior of geosynthetic reinforced embankments. The differences between conventional and numerical calculations are shown and the results are compared. An important aspect is the determination of the global safety factor and the failure mechanism. With Plaxis the deformations of the embankment and the resulting forces in geosynthetics and anchors are calculated. Variation of the ground stiffness and the road roller compaction force shows the influence on the forces in geosynthetics. The settlements of the embankment are calculated and a comparison with measurements at the project Trieben–Sunk is provided. Finally advantages and disadvantages of each, conventional and numerical method of calculation, are shown. Further the actual performance of the road under traffic is presented.

Keywords: geogrid, FEM, reinforced soil, Trieben-Sunk

INTRODUCTION

More and more geosynthetic reinforced embankments find their acceptance in modern building design as an economic solution. In Trieben–Sunk, Upper Styria, Austria, such a construction has been built up. In this area a continuous creeping of the slopes of the valley is measured up to three cm per year. Therefore a “soft” structure that is able to sustain the deformations without stress concentrations has been designed. Up to 30 m high, 60° sloped, geosynthetic reinforced embankments have been planed to lead the road B 114 from Trieben to Hohentauern.

Conventional analysis is often not sufficient to design such geosynthetic reinforced embankments. Nowadays numerical simulations give a better understanding of the behavior of the construction and the occurring deformations. The objective of the paper is to investigate the behavior of geosynthetic reinforced embankments and to show the differences between conventional analysis and numerical simulation related to such constructions.

PROJEKT TRIEBEN – SUNK

The “B114 Triebener Bundesstraße” is an important connection between highway A9 in Upper and the motorway S36 in Lower Styria. On the average 2000 vehicles per day pass the road, nine percent trucks are counted. During construction of the new B114 the daily traffic flow must not be handicapped. Therefore, the new road was planed on the opposite side of the valley in “Wolfsgraben”. Date 06.06.2006 was defined for the commencement of construction. In October 2008 the approval for traffic was given. In June 2009 the whole construction was finished. The building costs have been calculated with 21 million Euros.

The 2.9 km long road is divided in seven geotechnical zones. This paper is dealing with zone three, the geologically most endangered area. A geological cross section for profile 46 in geotechnical zone three is shown in Fig. 1. Geologically the cross section is composed of coarse grain dominated slope debris (1), which is interrupted by aquiferous fine grain dominated slope debris (2).

The constructive design of the geosynthetic reinforced embankment and the stabilising procedures were based on the excavation of the slope and the construction of the embankment. Shotcrete and 12 m long IBO anchors, were used to cover the excavation due to the embankment´s footing. A reinforced concrete plate was planed as a footing of the embankment. To prevent a slip failure two 16 m long GEWI anchors were installed.

CONVENTIONAL ANALYSIS

For conventional analysis two approaches, Bishop and Janbu, after DIN 4084 are used. To make the comparison between conventional analysis and numerical simulation possible, the factor of safety is calculated as a global factor (Lackner 2008).

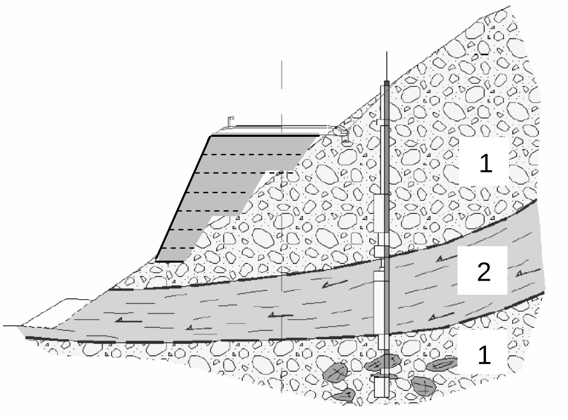

Fig. 1 Schematic sketch of the 3D overview on the Discrete Element model.

The model for conventional analysis was based on the geological and constructive cross section shown in Fig. 1. Four calculations are performed.

In the first analysis, the factor of safety for the inventory slope was determined. In addition an analysis for the construction step, excavation, covering with shotcrete and anchoring the slope was performed. In the next step, calculation three, the geosynthetic reinforced embankment was implemented and the global safety factor again was estimated. Finally, the embankment's safety itself was determined.

The inner safety was specified by the long-time tensile strength of the geogrid. The long-time tensile strength was calculated with equ.(1)

$$z_{Rd} = \frac{r}{A_1 * A_2 * A_3 * A_4 * \gamma} = \left[kN/m\right] \quad (1)$$

z_{Rd}...Minimal value of long time tensile strength
r… Minimal value for short time tensile strength
A_1... Reduction ratio concerning creeping
A_2... Reduction ratio concerning damage (transport, compaction)
A_3... Reduction ratio concerning converting
A_4…Reduction ratio concerning environmental conditions
g… Material safety factor

The results of the conventional analysis are given in Tab. 1.

Table 1. Global factor of safety of conventional analysis Bishop/Janbu

Slope	Excavation	Embankment	Inner stability
1.21/1.18	1.32/1.29	1.33/1.28	1.84/1.78

NUMERICAL SIMULATION

The numerical simulations include the calculation of the factor of safety by phi-c reduction, the forces in geogrids and anchors and the deformation of the embankment during the construction process.

In addition the numerical simulation is calibrated related to the factor of safety, see Fig. 2. Three-dimensional effects are also implemented in the two-dimensional model. A comparison between the maximum expanse of excavation in 3D, shortly before failure, and the maximum percentage of excavation in 2D (m_{stage}) has been performed.

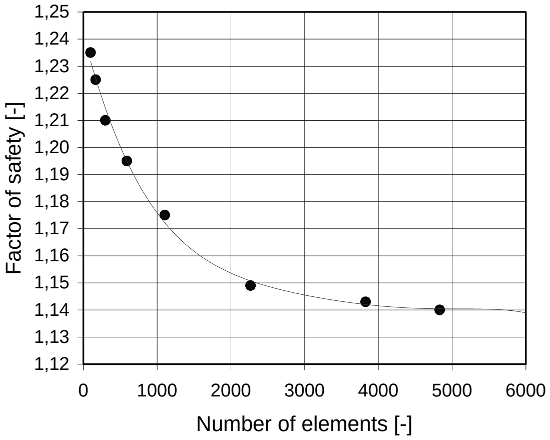

Fig. 2 Factor of safety vs. number of elements.

Therefore the calibrated two-dimensional model runs with 4015 elements and a mstage of 0.4 is implemented in the calculation to simulate the finite, uncovered excavation in 3D. The results for the factor of safety are given in Tab.2 and the numerical failure mechanism is shown in Fig. 3.

Table 2. Global factor of safety (Plaxis V8 2D)

Slope	Excavation	Embankment	Inner stability
1.14	1.21	1.22	1.72

The forces in the geogrids are additionally calculated

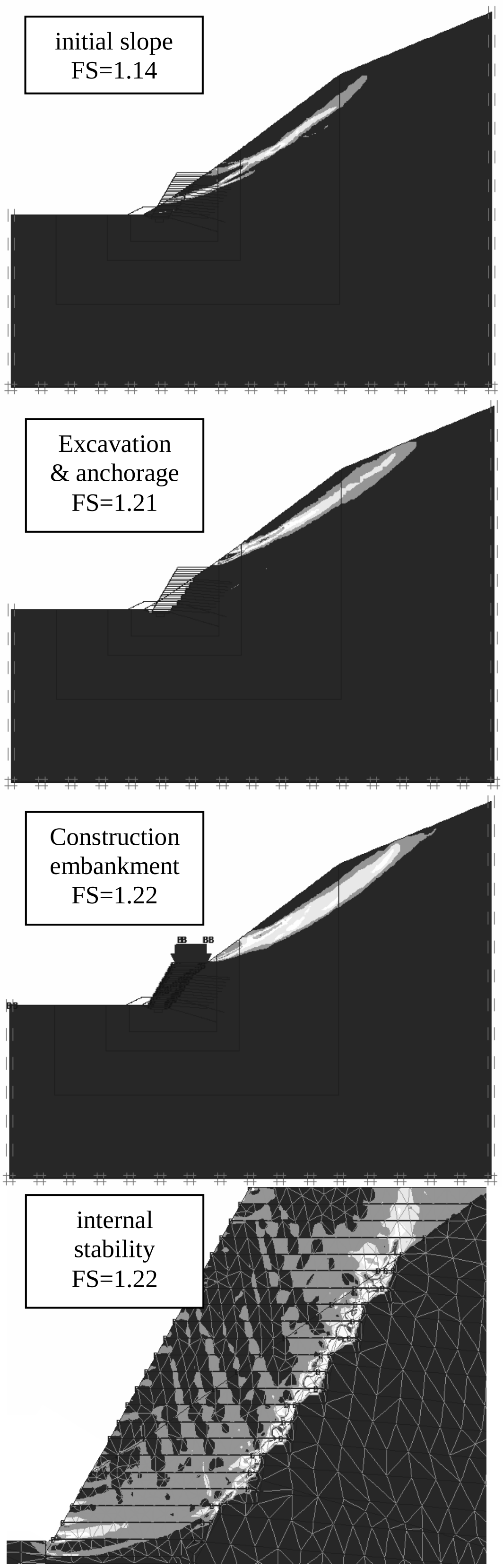

Fig. 3 Failure surface FEM (shear shadings).

The maximum force in the geogrids amounts to 15.5 kN/m and is dependent on the ground`s stiffness and the road roller's compaction force. The forces in the IBO and GEWI – anchors are additionally calculated. The amount of the maximum IBO anchor force is 55 kN/m, the maximum force of the GEWI anchor amounts to 105 kN/m.

Additionally the deformations of the embankment during the construction process are calculated. In the last calculation step, activating traffic load on the finished embankment, the maximum settlements amount to 10.4 cm. After excavating the slope until foundation a heaving up to 2.2 cm occurs. Therefore, total settlements from 12.6 cm can be calculated. 13 cm loss of cubature is measured for a 13 m high embankment at the building site.

PERFORMANCE OF THE EMBANKMENTS

Since 2009 the road is under traffic and is performing very well.

Fig. 3 Final stage of the road.

In June 2012 hard rainfalls led to huge landslides over the constructed embankment.

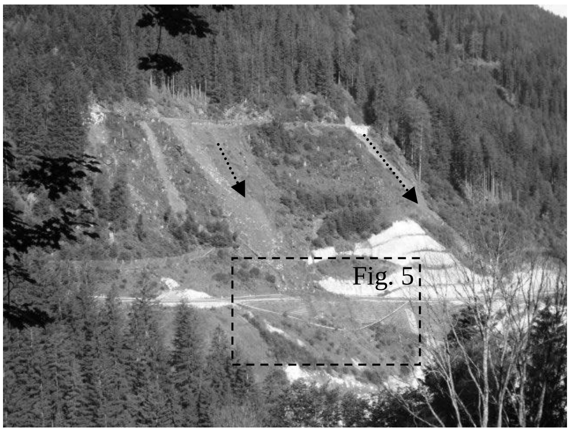

Fig. 4 Road after landslide.

Although the road has been totally over rolled from the landslide, the geogrid reinforced embankment still performed well (Fig. 4 and Fig. 5).

Measurements have shown that the deformations on the embankment are equal to the initial deformation of the slope mass.

Fig. 5 Detail: road after landslide.

CONCLUSIONS

The comparison of the analytically calculated factors of safety and those from the phi–c reduction of the numerical simulation shows related results. The failure mechanism is also comparable, although, Plaxis V8 2D itself detects the more critical failure function, which can be seen in the lower factor of safety.

The time economy of the conventional analysis faces the flexibility of numerical simulations. In one single simulation, it is possible to calculate on the one hand the factor of safety (Ultimate Limit State) and on the other hand the deformations of the embankment (Serviceability Limit State) including the resulting forces in geogrids and anchors.

It can finally be concluded that the geogrid reinforced road structure performs well during traffic and even resists hard attacks such as the landslides from June 2012.

In every case, modeling a numerical simulation of a geosynthetic reinforced embankment is essential to get a deeper insight into the behavior of the interaction between embankment and geogrid.

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