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Sensitive infrastructures in instable slope conditions

Infrastructures sensibles en domaine des versants instables

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ABSTRACT
The report presents an open cut for the construction of a railway line in a landslide area. Before the construction an extensive ground exploration programme was carried out. The landslide is secured with piles. The design of the piles is based on analytical calculations. To predict the ground deformations of the secured landslide and the planned track and to proof the serviceability, two- and three-dimensional finite-element models were developed. The observational method including a large variety of measurements was installed to observe the predicted ground deformations.

RÉSUMÉ
L'exposé décrit une tranchée ouverte dans un versant instable pour la construction d'une ligne ferroviaire. Avant de commencer l'excavation un programme étendu d'exploration du sol a été effectué. En suite les versants de la tranchée a été stabilisé par des pieux forés dont le dimensionnement fût effectué à base des calculs analytiques. Pour déterminer préalablement la déformation de la tranchée et du tracé prévu, des modèles des éléments finis bi- et tridimensionnels furent développés. De façon à pouvoir observer les déformations prévues du sol une méthode d'observation comprenant une grande variété de mesures fût développé et installée.

1 INTRODUCTION

For the construction of a new high speed railway line an open cut with a length of approximately 300 m has to be built in an instable mountain slope (Fig. 1). The depth of the excavation reaches up to 10 m. The angle of the mountain slope is about 10°.

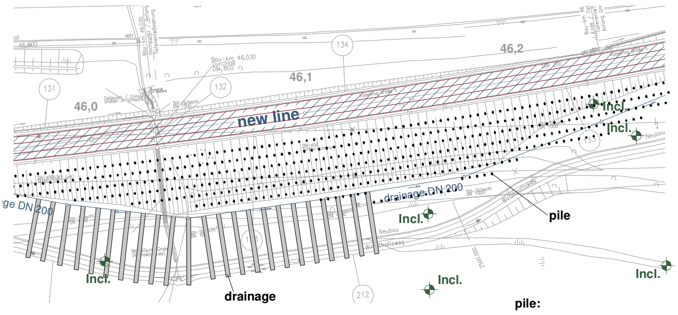

Figure 1. Geometrical situation – plan view

To prevent further instabilities the slope is secured by large diameter bored piles before the excavation of the open cut. Due to the soft soil conditions, additional foundation piles below the track had to be installed to reduce the vertical displacements (Fig. 2). The new line will be equipped with rigid track.

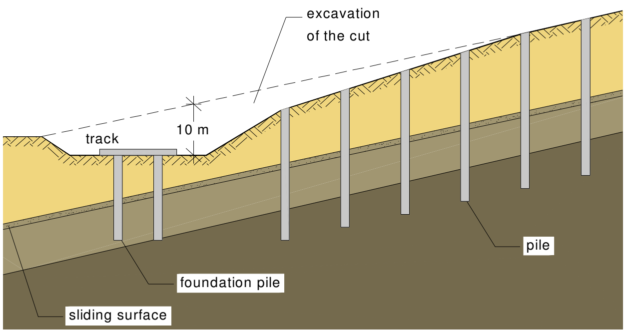

Figure 2. Geometrical situation – cross view

For the geotechnical proof of the ultimate limit state of the slope and the serviceability of the track analytical and numerical calculations were carried out. These calculations regard the results of the ground exploration and the in-situ measurements. To observe the landslide numerous inclinometer had been installed (Fig. 4).

Figure 3. Project site

To design the piles in the slope analytical studies were carried out. The analytical study, however, is not capable to determine strain and deformation of the ground. Therefore 2D and 3D finite-element models were developed to predict these ground deformation of the secured slope. In order to obtain realistic deformation back-analysis of the slope numerous variations of significant ground parameters on the basis of the geotechnical report were carried out.

2 GROUND AND GROUNDWATER CONDITIONS

Several ground exploration programmes in the years 1998 and 2001 were conducted with altogether 28 drillings. The drillings reached a depth from up to 30 m. Ten of these drillings were installed with inclinometers. Furthermore 10 measure points of the groundwater table in different layers were put in. To prognosticate the surface of each layer along the axis of the line more precisely pressure soundings within a distance of 50 m were used.

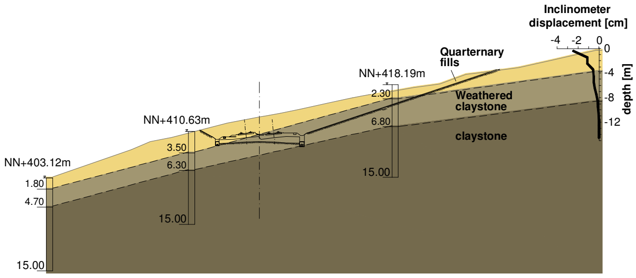

Figure 4. Geometrical situation – cross view

These field investigations were supported by an extensive laboratory testing programme, which included the determination of the:

- consistency limits
- grain-size distributions
- density of solid
- density of soil
- unconfined compression
- shear strength
- swelling pressure

As a result of the exploration and laboratory testing programme the ground conditions can be characterized by quaternary fills and soft weathered claystone respectively claystone (Fig. 4). With regard to the geological documentation and the in-situ measurements a sliding plane (layer 2) with only little shear resistance between the quaternary fills (layer 1) and weathered claystone (layer 3) was found. The groundwater conditions are represented by two groundwater levels: A quaternary groundwater level close to the surface and a confined aquifer in the claystone underneath the weathered soft clay (Fig. 5).

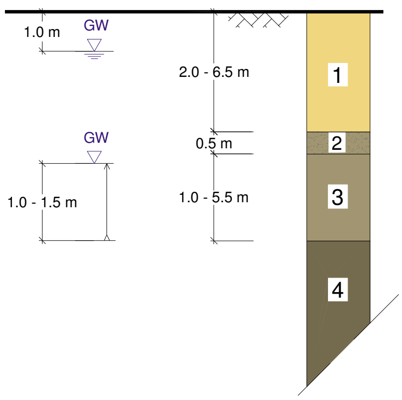

Figure 5. Ground model

The characteristic values of each layer are shown in Table 1.

Table 1: Characteristic values

Layer	Unit weight γ [kN/m³]	Friction angle φ' [°]	Cohesion c' [kN/m²]	Young's modulus E_s [kN/m²]
1 Quarternary fills	20	22,5	2	13
2 Sliding surface	20	12,5	0	10
3 Weathered claystone	20	20	10	10
4 claystone	20	22,5	20	40

The characteristic values for the sliding surface (layer 2) are based on the assumption that the residual shear parameters are decisive. Therefore, the cohesion was set to zero and the friction angle was evaluated by analytical and numerical back-analysis (Fig. 6). The back-analysis of the mountain slope in the original situation determined the value of the friction angle of the sliding surface for a factor of safety of SF = 1.0, which was a presumption for the nearly stable slope. The 2D numerical mesh for the back-analysis considers the realistic ground model without the piles. The back analysis produced a friction angel of $\varphi = 14°$, which is comparable to the angle of the analytical method. Since the slope is known for movements, it had to be safely designed for a friction angle of $\varphi = 12.5°$.

3 CALCULATIONS

For the geotechnical proof of the ultimate limit state and the serviceability a calculation strategy of analytical and numerical models was developed (fig. 6).

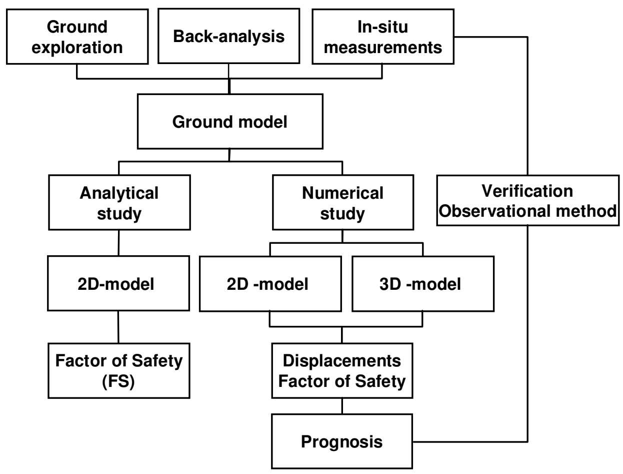

Figure 6. Calculation strategy

4 ANALYTICAL CALCULATIONS

To design the piles as well as to secure the slope two analytical calculation steps were needed. First step: the wedge failure model was used (Fig. 7). A factor of safety of SF = 1.2 for the construction phase and SF = 1.3 for the final state are required (DIN 4084). The slope was subdivided into homogenous sections with consideration to the geological, hydrogeological and geometrical situation. The piles were not considered in this first step. In this step the slope without the piles reached a smaller factor of safety than required. Therefore a deficit force was implemented to increase the resistant forces and to insure the required factor of safety for all construction phases.

In the second step, the method of subgrade reaction was used (Fig. 8). The calculated required deficit force was conducted into the ground via piles underneath the sliding surface. The assumed horizontal subgrade reaction of the claystone (layer 3, 4) was a linear distribution.

By means of these two calculation steps all required parameters to design the piles (grid distance, length and diameter of piles etc.) could be chosen. The geometrical data of the securing piles are listed below:

- Grid distance: 3,0 m
- Length of pile: 10 -16 m
- Diameter of pile: 0,9 m

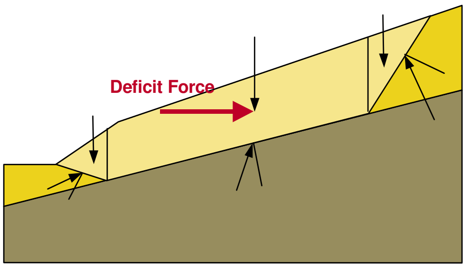

Figure 7.-Analytical study –wedge failure method (DIN 4084)

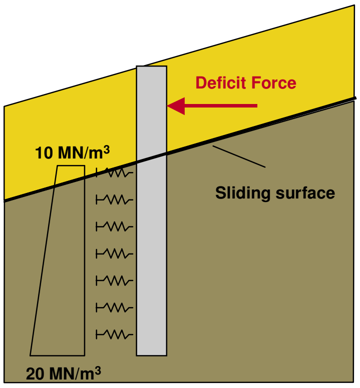

Figure 8. Analytical study–method of subgrade reaction

5 NUMERICAL STUDY

5.1 *2D numerical study*

The 2D numerical study for the construction of the cut regards the initial stress condition, the construction of the piles and the excavation of the cut. The reduction of the friction angle in the sliding surface from φ = 14° to 12.5° was simulated between the different construction phases.

The aim of the numerical study was to evaluate the residual displacements of the slope and more important the displacements of the ground underneath the planned track. In addition a safety analysis by means of the so called Phi-c-reduction was carried out. The factor of safety for slope secured by piles was comparable to the result of the analytical calculations (SF = 1.4).

The horizontal displacements of the slope were analyzed in different cross sections. Underneath the track these displacements amount to < 5 mm. The maximum displacement of the slope is located just above the track and ads up to 20 mm. On the downhill side of the track the horizontal displacements turn slightly negative, which means up the hill. This is caused by unloading (excavation) the ground.

5.2 *3D numerical study*

For a more realistic consideration of the slope secured by bored piles, it is indispensable to create a supplementing 3D model. Because of the longer calculation time and more complicated mesh, the influencing parameters should be evaluated with the 2D numerical study.

All obtained information and results of the preliminary and the 2D study were taken into account to generate the mesh of the 3D study. In the 3D model the realistic positioning and geometry of the piles in the direction of the track (Fig. 9) was considered. Altogether three rows of piles in the z-plane were simulated. The ground layers and the piles are represented by 15-node-wedge elements with 6 stress points. The model consisted of 4,000 elements.

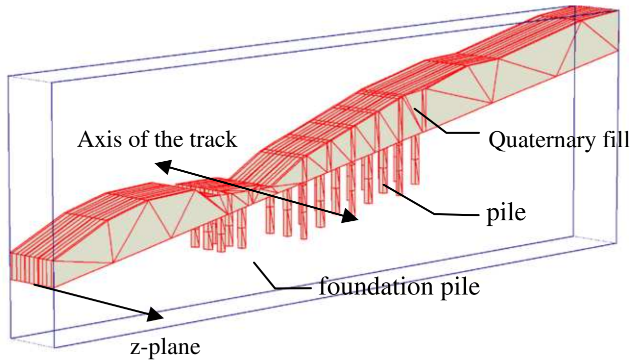

Figure 9. 3D numerical study – upper part of the 3D model

The results of the 3D study are comparable to the 2D study, the maximum horizontal displacements of 26 mm occur at the bottom of the slope. The displacements underneath the track add up to a maximum of 5 mm on the uphill side. On the downhill side of the track, the displacements are superposed by the unloading of the excavation, so the displacements are more or less zero. Below the sliding surface only little deformation take place. The horizontal displacements are illustrated in Fig. 10.

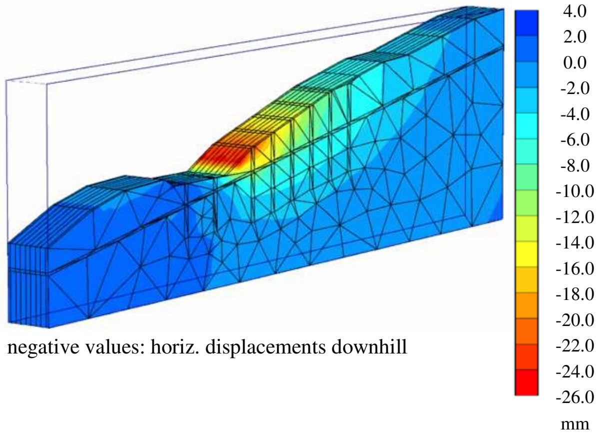

Figure 10. 3D numerical study – horizontal displacements

Figure 11 pictures the deformation of the piles. The soil layers except the sliding surface are switched off. The piles in the slope directly above the track receive, as expected, the most deformation. However, a flow of the ground around the piles could not be noticed.

The foundation piles underneath the track receive only little forces from the mountain slope and therefore only little horizontal deformation.

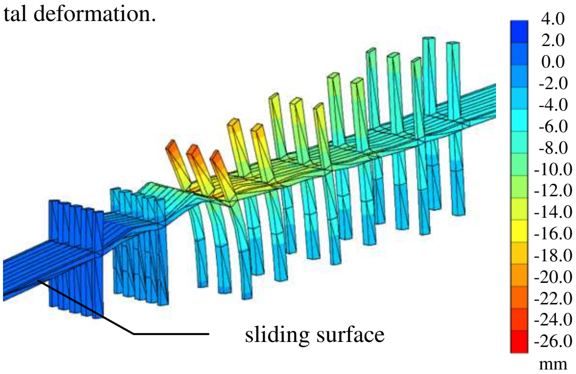

Figure 11. 3D numerical study – deformed piles

6 OBSERVATIONAL METHOD

In cases where the prognosis of deformations is not sufficient reliable, although an extensive ground exploration and complex calculations were carried out, the German technical rule recommends the observational method. Even with the best possible exploration and calculation procedure the observational method is an essential element of the geotechnical approval strategy.

Therefore the presented slope will be installed with a monitoring system consisting of hydrogeological, geodetical and geotechnical (e.g. inclinometer) measurements in certain cross sections.

6.1 *Measurement Results*

The open cut has just been excavated. The up to now measured horizontal displacements are smaller than calculated. The max. measured versus the calculated horizontal displacements of the piles are shown in figure 12.

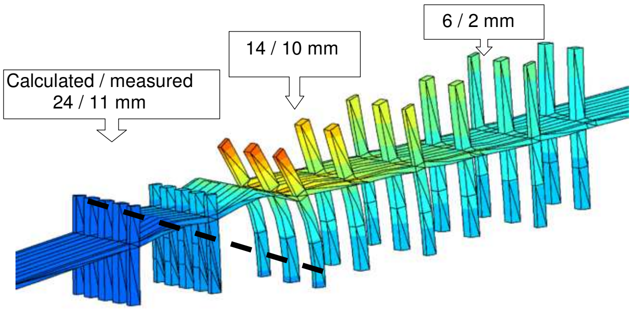

Figure 12. Horiz. displacements – calculated vs measured

7 CONCLUSION

Analytical calculations are an essential tool to proof the required factor of safety. Besides this proof it is often necessary to obtain deformation data to evaluate the serviceability of the construction or neighbouring construction. For a 3D situation an evaluation of the actual deformation is possible with numerical simulations for example with the used finite element method (FEM). The difficulty is to define all ground parameters for chosen material models. In this case a 2D back-analysis of the present mountain slope was carried out to determine all necessary parameters.

Before calculating and even more important interpreting a difficult 3D simulation it is recommended to carry out elementary 2D simulations to study all influencing parameters.

With the help of the finite element method it is possible to determine deformation to proof the serviceability of constructions. In the case of the presented instable mountain slope the calculated deformation can be used as a prognosis. Later on this deformation has to be compared with the real one (in-situ). To observe these deformations an extensive monitoring system must be installed. For difficult geotechnical situation numerical simulations can not replace the observational method.

REFERENCES

Anforderungskatalog zum Bau der Festen Fahrbahn (2002), 4. Auflage

DIN 1054-100 1996. Standsicherheitsnachweise im Erd- und Grundbau

DIN 4084 1981. Gelände- und Böschungsbruchberechnungen

Meißner, H. 1991. Empfehlung des Arbeitskreises "Numerik in der Geotechnik" der deutschen Gesellschaft für Erd- und Grundbau e.V., *Geotechnik 14, S.1-10*

Meißner, H. 1996. Empfehlung des Arbeitskreises "Numerik in der Geotechnik" der deutschen Gesellschaft für Erd- und Grundbau e.V, *Geotechnik 19, S.99-108*

Plaxis B.V. Finite Element Code for Soil and Rock Analyses 1998. Version 7

Plaxis B.V. Finite Element Code for Soil and Rock Analyses 2001. 3D Tunnel Version 1