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Causes and reconstruction of a landslide in lower triassic sandstone by excavation of a cut on motorway A38

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1 Introduction

As a connection between the motorway A7 near Göttingen and the motorway A9 south of Halle/Leipzig, the new motorway A38 is been build as Verkehrsprojekt Deutsche Einheit Nr. 13. Between the connection points of Rossla and Wallhausen, north of Hohlstedt, the new A38 has been planned in cuts with depths up to approximately 20 m, whereby the slopes are situated in the Lower Triassic Sandstone. Although during the exploration the stability of the slopes was found to be critical – in particular concerning the angle of incidence of the intact rock layers – and has been improved by structural engineering measures, there was a landslide with the length of approximately 100 m in spring 2003.

After the landslide additional analyses and calculations were made in order to get to know the causes of the damage (report Kempfert + Partner Geotechnik 2003). The presentation of the conclusions of the examinations makes up the major part of the following article, in which the reconstruction concept and the measures as well as the geological and geotechnical conditions are described.

2 Project and General Geological Situation

The cut near Hohlstedt from about km 14+650 to about km 15+700 is characterised by slope inclinations of approximately 1:1.75 (angle of slope about 30°) and a maximum depth of about 20 m on the northern side of the motorway A 38. The maximum depth is been achieved from about km 15+380 to km 15+480 on a length of approximate 100 m. The present site inclination behind the top of the slope constitutes still approximately 5° to 10°.

The motorway runs in east-west direction on the northern edge of the „Goldenen Aue“, a morphological depressed area between the southern edge of the lower Harz and the northern edge of the Kyffhäuser mountains. In the region northwest of the location Hohlstedt three regional eminent tectonic perturbations are crossing each other. They are the Hohlstedter Störungszone (direction circa E-W), the Kirchbergstörung (direction circa NW-SE) and the Wallhäuser Störzone (direction circa WNW-ESE). A request to the State Office for Geology and Mining Sachsen-Anhalt (LAGB) didn't give any hints of a geogenic danger for the motorway.

The subsoil in the considered area is formed by minor thick layers of quarternary loose soils on top of sediments of the Lower Triassic Sandstone, which are made up of a change of patelled-platy clay and silt stone and platy-stratified sandstone resp. limestone with a thickness of more than 100 m. The groundwater level is situated under the plane of the cut base. Due to subterranean leaching – karst formation - of the in former times existing water soluble layers of Zechstein below the Lower Triasic sandstone layers, there was a laminar descent of the overhanging layers in geological past, which lead to a distortion of the Lower Triassic Sandstone layers and in some areas, they were adjusted steeply.

During the subsoil exploration, core drillings and trial holes, in which the geotechnical structure was documented, were carried out in a distance of about 150 m. In order to calculate the stability of the slopes, the shear strength of the southeast to southwest running strata joint was estimated to φ_{SS} = 17° with c_{SS} = 0 kN/m² on basis of experiences and literature. Based on first calculations, an extensive bolting on a length of approximately 650 m would be necessary to guarantee the slope stability. Therefore additional trial pits with sampling of rock layers were carried out.

Tests on this samples were made to obtain the shear strength, which yield to a friction angle of φ_{SS} = 22° (at c_{SS} = 0 kN/m²) for the bedding plane as base for the planning. The necessary stability of the slopes could finally be guarantied flattening the slope inclination to 30° in connection with bolting in areas of local distortions (for further information: see Hecht, Mittag 2002).

3 Description of the Damage

The excavation of the cut, where the landslide occurred, began on 27th November 2002. Since then, the cut was excavated efficient and almost continuously. The bolting and the monitoring through three long inclinometers should be effected at the same time. The installation of the inclinometer cases and the bolting was delayed due to several circumstances, in particular by open questions concerning he protection against corrosion of the bolting.

- The inclinometer number 1 was bored and installed from the 28th January 2003 to the 06th February 2003 at km 15+500 outside the body of the slide.
- The cut had been excavated for the most part on the 11th of February 2003 but no bolting had been installed yet.
- The drilling for inclinometer number 2 started on the 11th of February 2003. On February, the 17th, at the depth of approximately 20 m, it was detected that the core barrel couldn't be moved any more. It had to be retrieved.
- At the 18.02.2003, a heave was recognized on the surface of the slope.
- The drilling for inclinometer number 3 started at the 20.02.2003. The depth of 16m was reached at the 24.02.2003.
- During the night from the 24th to the 25th of February big deformations between about km 15+360 and km 15+400 occured, which lead in the end to a landslide in the area from about km 15+360 to km 15+460. Smaller landslides could be noticed earlier in a proximate area with a depth of the cut of about 14 m from km 15+100 to km 15+160.

The big slide-body is shown in top view in Fig. 1 with the detected fissuration. The body can be evidently described as a prismatic tetrahedron or wedge-shaped body with a synclinal floor area (Fig. 2).

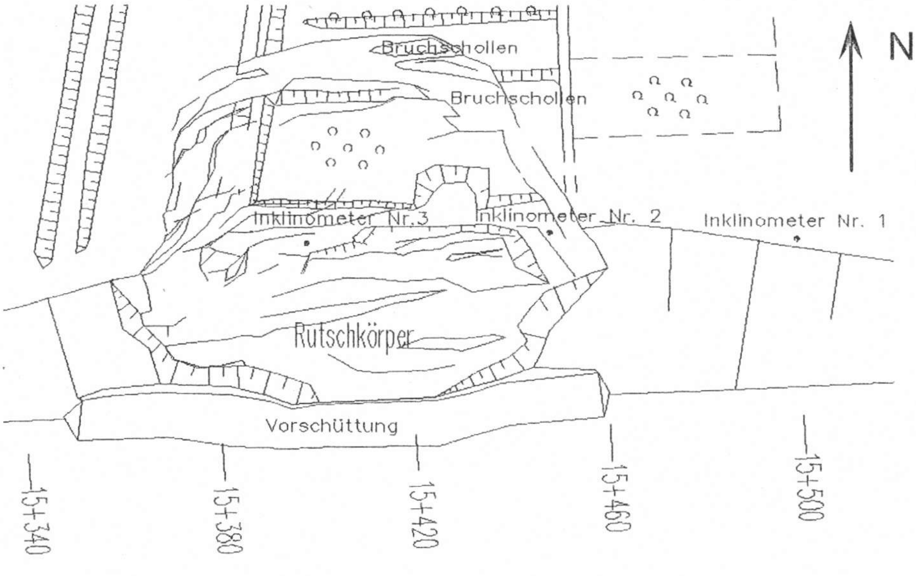


Fig. 1 „Big landslide" with fissurration in top view

Fig. 2 Overview „big landslide"

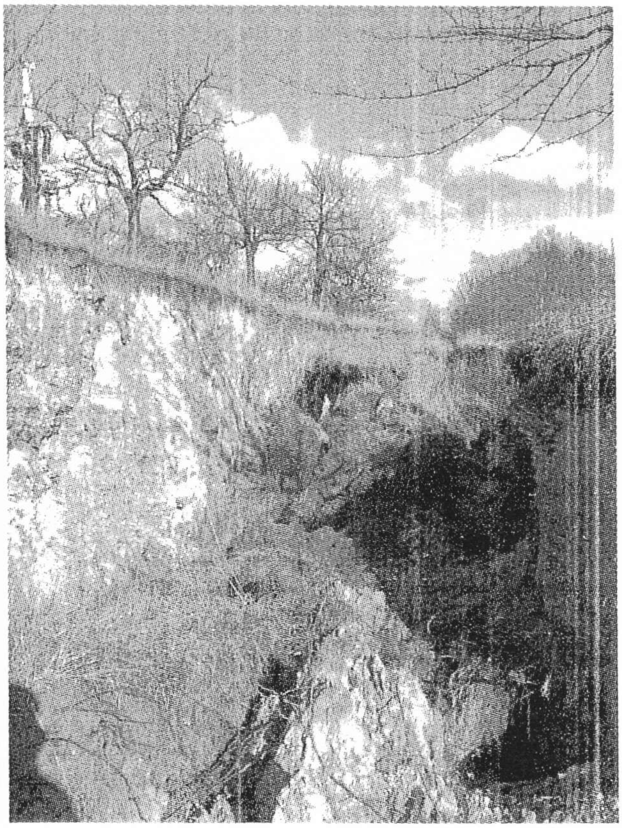


Fig. 3 (left) Area of the former top of the slope
Fig. 4 (right) Rear tear-off edge of the slide-body, about 40 to 45 m behind the former top of the slope

In the lower area of the rock slide a hog was visible, which was up to 2 m higher than the soil surface and was stabilised in the meantime with a preload (Fig. 1) in the lower part of the slope and at the toe. In the area of the former top of the slope, multiple wide fissures and terraces were present, which basically ran parallel to the former top of the slope. A several meters high, almost vertical tear-off edge was detected behind the top of the slope, in front of a neighbouring tree population, whereby a several meters high, almost horizontal notch was accumulated in front of the tear-off edge (Fig. 3). With a distance of about 40 to 45 m to the original top of the slope, in the neighbouring tree population, a mighty fissure with a width of more than 5 m and several different clods of earth was found. The rear limit consisted of a vertical tear-off edge with a height of more than 4 m (Fig. 4).

4 Soil Investigation after the Landslide

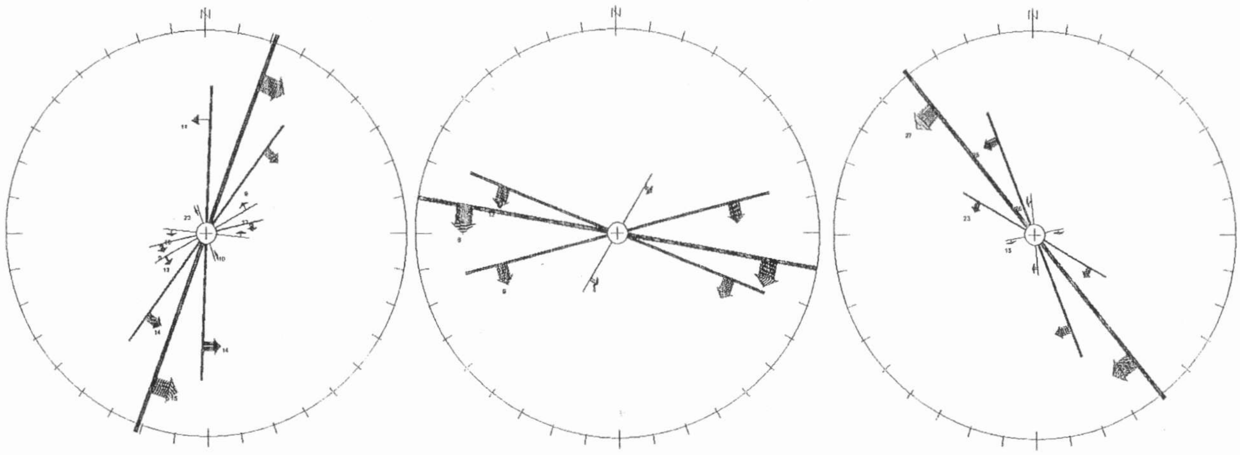
4.1 Borings and Visual Inspection of the Slide

During the installation of two more inclinometers outside the apparent body, the soil type of the cores was classified by a geologist. The profound weathered rock of the Lower Triassic Sandstone, which can be seen as an irregular, strong alternating sequence of mostly petalled to thin platy silt-, clay- and sandstone-layers with thin stratified to stratified, obviously firmer resp. harder calcareous sandstone formations in between, follows underneath the zone of weathering. A various number of micaceous strata joints filled with soil and with an average thickness of 1 cm was found within the clay-, silt- and sandstone-layers. The first centimetres of the clay- / silt-stone layers were partially totally weathered to clay/silt.

During the geological survey and the inspection of the front and rear tear-off edge of the slide, it was detected in particular, that strata joints filled with clay / silt and a thickness of several centimetres were present in the clay-, silt- and sandstone-layers resp. - stratums and in parts between these layers and the calcareous sandstone (see Fig. 6).

Disturbed samples were taken from these bigger strata joints in order to carry out classification tests. The taken samples are a plastic clay resp. silt (TM, UM according to DIN 18196) according to the classification. Also a mineralogical analysis of the clay was realised by two independent institutes. Intra-crystalline swellable clay minerals with 17 to 20 percent by weight and 40 to 43 percent by weight of clay with $d < 2$ µm were found in these analyses. A formative interaction of the soil-physical properties was adopted according to the high quantitative fraction of swellable clay minerals.

The geological model could be completed using the inspection of the landslide on the surface of the slope and the geological survey of the close-to-surface areas of the tear-off edge and the measurements on the surface of the slope during the excavation of the cut. The course of the strata joints in the area of the slide-body results from the evidently wedge shaped resp. synclinal run, whereas strata joints could be detected in the middle of the slide-body over a limited length, which are even heading in nearly southern direction and as consequences at right angle to the trace of the motorway, which show an angle of incidence of approximately 10° (Fig. 5).



western area	middle	eastern area
15+330 to 15+415	15+415 to 15+420	15+420 to 15+490
EFR/EFW: 111/13	EFR/EFW: 190/6 resp. 200/11	EFR/EFW: 230/24

Fig. 5 Lagekugeldarstellung of the strata joints (biggest frequency of occurance) direction of incidence EFR; angle of incidence EFW

4.2 Cognitions during the removal and exploration of the slide-plane

The reconstruction of the damage (see section 6) was carried out by removing the sled rock masses in the area of the big slide. The removal was supervised by geotechnical engineers and geologists to verify the geological model and in particular to document the position of the slip joint. To investigate the accurate depth and run of the slip joint as well as the tectonic circumstances and the circumstances of the stratification, 6 trial holes with depths up to 10 m below ground surface were excavated in different working orders of the removal. In summary the following can be conducted to define the slide-body:

- The landslide was limited in the east, north and west by tectonic disturbances with east-western resp. north-southern course, whereas the tear-off edges follow the course of these disturbances. North of the disturbance limit the typology changes from low grounds into saddles.
- The sliding zone normally could be described as an about 50 cm thick area with a main slip joint in terms of a several cm thick strata joint made of silt/clay (Fig. 6).
- The slip joint resp. sliding zone shows in the core area an average gradient of approximately 12° at right angle to the slope, reaches in the area of the planned motorway and runs approximately 1 to 1,5 m below the toe of slope.

- The sliding zone shows a stepped trend in north-south direction. The main step was probably a disturbance with east-west direction circa in the middle of the slide-body.

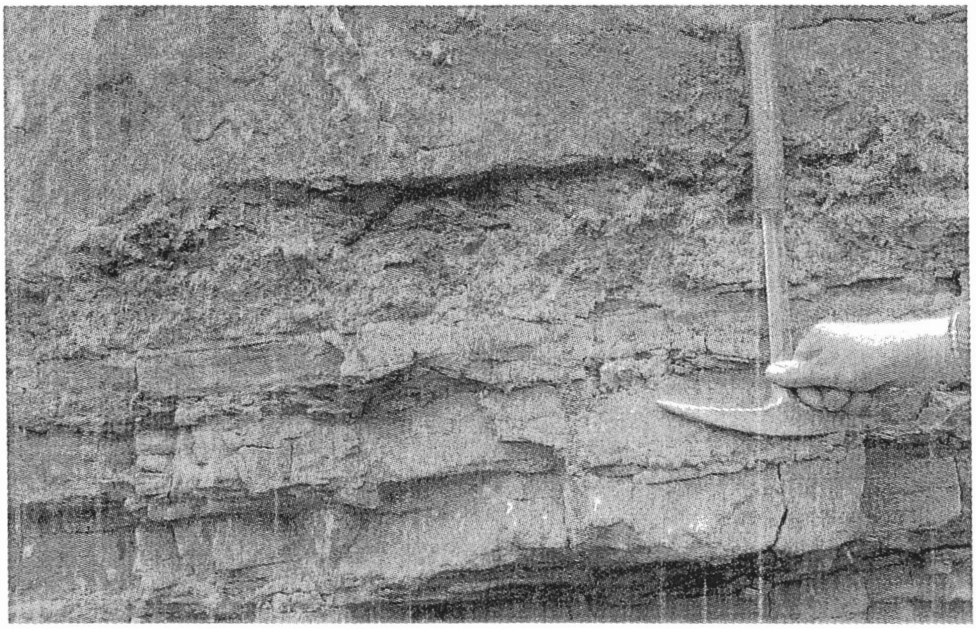


Fig. 6 Slip joint in trial hole number 6

5 Geotechnical Model and Analysis of the Slide

5.1 Mathematical Analysis

After the definition of the leading strata joints, a statistical evaluation of the geotechnical survey and the survey of the slide-body, several different, simplified geotechnical models were analysed (program SOLIDROCK; see table 1). At first, plane slide-bodies were tested. This examination requires that the individual bodies are sliding in a row. Because minor stabilities had been calculated particularly in the eastern area, the eastern and middle part should have sled first of all and then, according to the lacking lateral support, the western part. This examination can't be adequate for the analysis of the landslide, because it is premised that there is a certain blocking among the bodies at the beginning of the slide. As expected, higher stabilities were calculated by consideration of three dimensional slide-bodies. A stability of $\eta \approx 1,1$ was calculated by using an adapted, wedge shaped body and setting the angle of shear friction to an unfavourable value of $\varphi_{SS} = 10°$. Due to the slip planes parallel to the slope in the middle of the slide-body, which had not been considered in the calculation, it was assumed that the in situ stability was smaller than the calculated. In comparison to other calculation, it could be considered for sure, that the slope stability of the situation was below $\eta = 1{,}0$.

model	**bedding plane direction of incidence/angle of incidence [°]**	**angle of friction φ_{SS} [°]**	**stability η [-]**
plane body	190/6 (middle)	20 10	3,5 1,7[1)]
	200/11 (middle)	20 10	1,9 1,0[1)]
	230/24 (east)	20 10	0,8 0,7[1)]
	111/13 (west)	20 10	1,6 0,8[2)]
three dimensional body (Fig. 7)	111/13 (west) und 224/24 (east)	20 10	2,3 1,1[1)]

[1)] with slide plane to the motorway [2)] without slide plane to the motorway

Table 1 Results of the stability analysis for the big slide

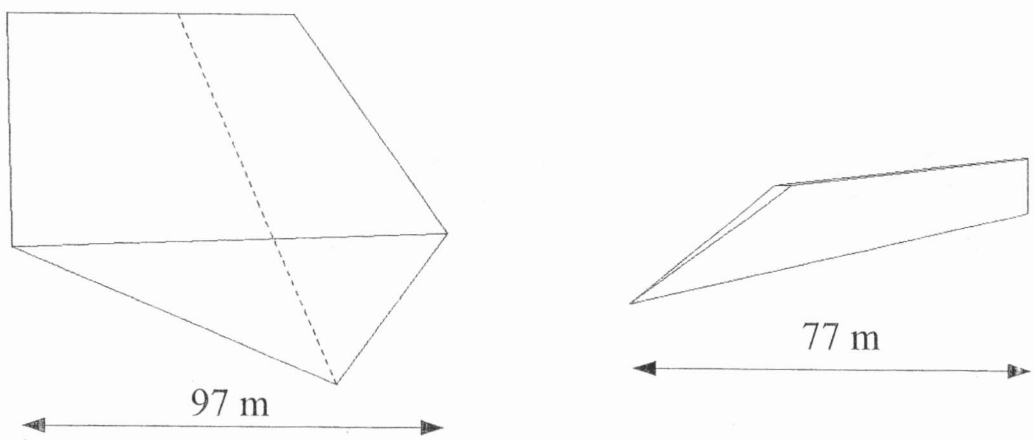


Fig. 7 Three dimensional body (schematically)

5.2 Conclusion for the shear strength of the strata joints

The samples, which were taken for shear tests during the original soil investigation, could only be taken from trial holes near the surface, whereas deeper lying strata joints were not reached. It was shown after the soil investigation during the reconstruction, that the shear tests made during the planning of $\varphi_{SS} = 22°$ were only valid for the thin strata joints within the clay-, silt- and sandstone layers. Between the single clay-, silt- and sandstone-layers resp. limestone banks, there were also thicker strata joints filled with swellable silt / clay and a thickness of several centimetres present, which were found in greater depths after the land slide. Due to the change of the state of stress, a certain swelling of the strata joints was possibly connected with a great decrease of the shear strength. According to experiences and the calculations, an angle of shear friction $\varphi_{SS} = 10°$ to $15°$ ($c_{SS} = 0$ kN/m²) had to be assumed, taking into account all existing cognitions, for example the swelling, structure of the rock mass, the existing tectonic loading. Concerning the geotechnical survey of the slip joint, an average friction angle of about $\varphi_{SS} = 12°$ was available in core of the slide. Insofar has the leading shear strength been overestimated during the planning.

6 Reconstruction

The fundamental plan for the reconstruction of the big slide was to flatten the slope till the slip plane, because the sufficient surface was available. The sled material in the central area of the synclinal damage was totally cleared above the slip joint (Fig. 8), so that no extra safeguards were necessary.

Fig. 8 Reconstruction a) flattened slope b) bolting

An additional bolting was planned in the border area north of the former tear-off edge and in the eastern transition area with an approximately 1:3 tended slope to the normal slope. The geometry of the slope and the conception of the bolting was defined during the reconstruction, that is to say during the clearing of the rock masses on the basis of the existing cognitions concerning the depth of the slip plane, of the height of the new slope and of the additional survey of the structure of the undisturbed Lower Triassic Sandstone. About 500 bolts (system GEWI) with a length between 6 and 12 m were installed in the area of the big slide in a grid space from 1.5 to 2.5 m (Fig. 8).

7 Conclusion

A landslide appeared in spring 2003 on the motorway A38 Halle - Göttingen, which is under construction, in an approximately 20m deep cut north of Hohlstedt (Sachsen-Anhalt). The synclinal course of the strata joint as well as the small shear strength of $\varphi_{SS} = 10 - 15°$ of the strata joints and the leading slip joints were detected as the leading cause. This small shear strength wasn't recognized during the planning, because the leading strata joint wasn't detected within the normal soil investigation. These strata joints were filled with swellable material in addition, so that the shear strength was further reduced by excavating the cut. This phenomenon was never been recognised in the regional geology before.

In spite of a professional soil investigation the landslide could not be avoided in fact, the landslide would have been accured during the bolting of the cut. The damage has to be essentially situated in the area of the „Soil Risk“. It can be assumed, that the magnitude of the damage would have been smaller, if the inclinometers had been installed in time before excavating the cut, so that after a small excavation unscheduled deformations would have been recognised.

References

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