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USE OF GEOTECHNICAL MONITORING IN REMEDIATION PROJECT OF AN UNSTABLE SLOPE

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RESUMÉ

The road connecting Chur with the alpine villages Tschiertschen and Praden passes at Ricaldei an active landslide area. In the last decades the road was partially reconstructed and extended. To pass the landslide area, it was planned to build a 500m long tunnel. An extensive geotechnical and geological survey included 3D displacement measurements with TRIVEC in an instrumented borehole to characterise the landslide. Based on the results of the geotechnical investigation and the Trivec readings, which indicated large slope movements, the tunnel could not be built. The slope was partly excavated to unload the slide. The extents and effect of slope formation is assessed by TRIVEC measurements. The principals and some results are presented. In coming years, other measures will be studied to enable uninterrupted access to the villages.

INTRODUCTION

An alpine road connecting the town of Chur with villages Tschiertschen and Praden is endangered by unstable slope. The slope movements of 5 to 20 mm, maximally 90mm per year have been observed since the end of 70’s. /1/ Lardelli, Zwahian.

The road had to be secured because of slides and falling stones. One possibility was to build a tunnel 500 to 800 long in the rock massif. The tunnel construction was rejected due to large rock deformations and high building costs in 1993, after evaluation of first geotechnical measurements in a borehore with special casing. Other possible solution – realignment of the road was refused as well. The chosen solution was rehabilitation – excavation and dewatering of the unstable slope. The extents and the efficiency of the slope formation could be assessed with use of long-term geotechnical monitoring of slope movements - 3D displacement measurements in a borehole with special casing. I (M. Záleský) participated at the measurement during my summer fellowship at Solexperts AG.

GEOLOGICAL CONDITIONS

Woody hillside belongs to region of Bündner shales, which were named after canton Graubünden. Monotonous flysh bedding of tough carboneous sandstone stratified in thick beds with interbeds of carboneous coarse sands with dark clayey shales adjoins to Sassaun series of Prättigaus.

The layers and cleavage are steeply inclined into the mountain. The rock massif is pervaded and weakened by carbonated discontinuities which are inclined into the mountain too. Loosened steep cracks in North-South direction can be seen in the whole area of interest. Therefore, rock formations are well situated from the slope stability point of view. Slides along predisposed slip surfaces cannot be found here, although they are common in the clayey shales of the canton Graubünden.

The results of geological and seismic investigation show, that the area of interest is highly aquiferous. Bending of strata occurs accompanied with pushed rock banks. Slope detritus lays on the rock subsoil and West moraine in the area. /1/ Lardelli, Zwahian.

PRINCIPAL OF GEOTECHNICAL MONITORING OF SLOPE MOVEMENTS

A boring with inclinometer casing was instrumented at first. Reliability of the results was continuously reduced by settlement of 35 cm since 1993. Inclinometer (Slope Indicator) is during the measurement inserted to the casing of the borehole with cable. The measurement can be done in 0,5 or 1 meter intervals according to the probe length. The depth of the measurement points is related to the top edge of the casing. Significant settlement progressively moves the location of measurement points in vertical direction, which leads to distortion of measurement results. Therefore, measurements with the TRIVEC probe, which is described bellow, were proposed and carried out.

Vertical deformation z and horizontal displacements x and y can be obtained with the TRIVEC probe (Fig. 1). It is a combination of a high precision extensometer and inclinometer. Resolution of the extensometer is 0,001 mm/m, its accuracy (mean error) is ± 0,003 mm/m. Both inclinometer sensors work with resolution 0,005 mm/m and accuracy (mean error) 0,05 mm/m. The borehole is instrumented with telescopic casing TRIVEC. The casing is manufactured in 1 meter long pieces made of PVC tubes fitted with telescopic coupling - brass measuring marks. The tubing pieces are connected with screws. Flexible casing grouted in the borehole with cement-bentonite grout is connected with the surrounding massif and follows all its vertical and horizontal deformations. The borehole should be deep enough in order to reach the stabile rock or subsoil with the casing toe, which should be at least 3 meters deep in the stabile subsoil. Then the bottom of the boring can be a reference point - in the case of measurement with "fixed toe".

Fig. 1 Equipment for measurement.

During a measurement, the probe is fitted to reinforced data cable is moved through the casing with guide chain at the lower end of the probe and with guide rods attached to its top. So is the position of the probe between each couple of measuring marks precisely ensured.

High reproducibility of measurements is guaranteed by quality measurement marks with cone-shaped contact surfaces, to which fit spherical measuring heads of the probe. Each measuring mark has a bolt, which ensures always the same orientation of x and y inclinometer sensors.

The measurement equipment consists of the TRIVEC probe, which is lowered into the casing by a winch with Kevlar fibres reinforced data cable. The probe is connected to the readout unit Solexperts Data Controller, from which the measured data are transferred to a palmtop (i. e. HP Jornada), Fig. 1. Continuous registration and control of results is done by programme TRIVEC. The massif deformation is measured in 1meter intervals, always between two measurement marks. The guide rods are used to operate the probe and rotate between the measurement and sliding position. The measurement is taken twice in the same couple of measuring marks in order to assure and check its accuracy. In the measurement position is at first measured the vertical deformation z, then x and y in the "first location". Afterwards is the probe 180° rotated to the "second location" and deformations x, y are measured once more. Thereafter the probe is rotated back to the first location and moved to the following measurement position. At the first time, the measurement is taken in the downward direction – from the top to the bottom of the borehole and second time upwards. In order to maintain the accuracy of measurements, the probe should be calibrated in a calibration device prior and past a field measurement. The factors gained from the calibration measurement are used for evaluation of field measurements.
/4/ Naterop.

MEASUREMENT EVALUATION

First measurement in the borehole is called "reference measurement", to which are related the following ones. The development of deformations along the borehole can be monitored in time. The interval between measurements depends mainly on the velocity of massif deformation. The data gathered at the site are evaluated in the programme TRICAL, which enables also to archive the data from all measurements together with the corresponding calibrations. Values of each deformation components are plotted in two graphs: differential displacements - for each couple of measurement marks in the first graph and summation graph in the second plot. (Fig. 5, 6, 7). The results of more measurement episodes can give information about:

- location of the slip surface
- volume of the sliding mass
- rate of movement and its changes
- potential development of sliding before movement appears on the surface
- probable future development of the slope movements

/3/ Thut.

DEVELOPMENT OF MEASUREMENTS AND SLOPE REMEDIATON

The first borehole for measurements of 3D deformations with TRIVEC probe was instrumented in 1993 at this site. The measurement results confirmed large deformations up to 60 meter depth from the surface of the former slope. The second 93m deep borehole was instrumented in 1997 for additional monitoring of the massif movements and to determine the efficiency of the slope remediation. Continuous stopping of the slide should be reached after excavation of a part of the slope – unloading of the unstable area.
First of all, a dense forest had to be cut down (Fig. 2). Because the slope is almost inaccessible, a temporary cableway was constructed to transport the excavated material. Temporary paths and irrigation channels running into concrete sumps were built during

continuous lowering of the slope height. After finishing the terrain formation, the new surface of the slope was reinforced with coconut geo-mesh fitted by steel fasteners (Fig. 3). Later on, the slope was seeded with grass.

Fig. 2 Slope prior to excavation, May 2001. After /2/ Frodl.

Fig. 3 New shape of the slope with coconut geo-mesh. After /2/ Frodl.

Fig. 4 Measurement in August 2002. After /2/ Frodl.

The graphs (Fig. 5, 6, 7) show the results of measurements since the year 1997. Large deformations were developed until May 2001, when the slope remediation began. During the years 1997 – 2001 the total horizontal displacement of the slope reached about 42cm accompanied by settlement of 35 cm (/2/ Frodl). Significant slow-down of sliding appeared after partial unloading of the slope, which is proved by the measurement in October 2001. During the following excavation of 12 meters of height of the slope was also the casing 12 meters shortened. Afterwards, the casing was cleaned and at this time last measurement was done in August 2002 (Fig. 4). The results of the last measurement (Fig. 5, 6, 7) show the shortened borehole and the effect of unloading of the slope and its springing back. The efficiency of the extents of remediation could be assessed based on future measurements. The monitoring of the area should go on in order to prove sufficient slow down of the slope movements in long-time period.

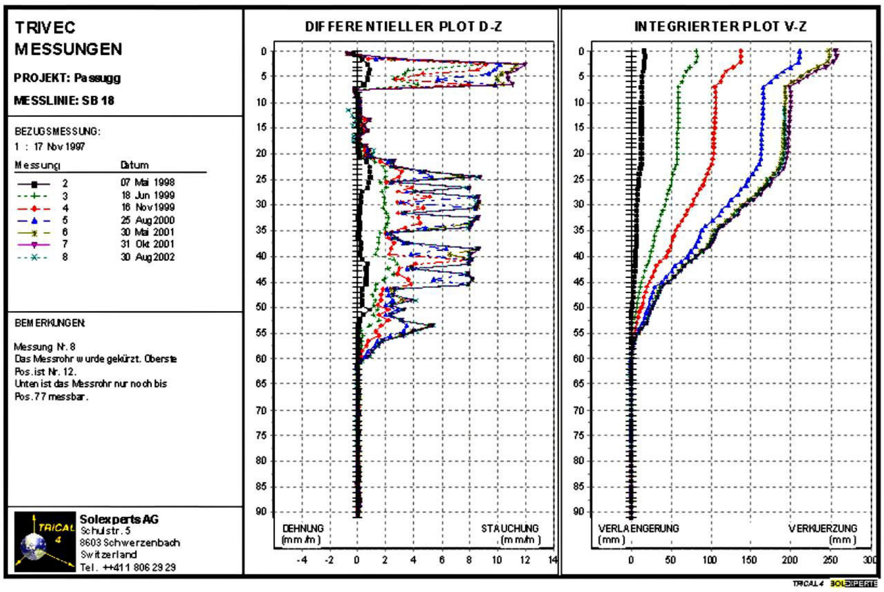

Fig. 5 Results of measurement in the sliding area, evaluated in programme TRICAL. Plots of vertical deformations z. Each curve corresponds with one measurement episode. The last curve displays the borehole which was 12 m shortened. After /2/ Frodl.

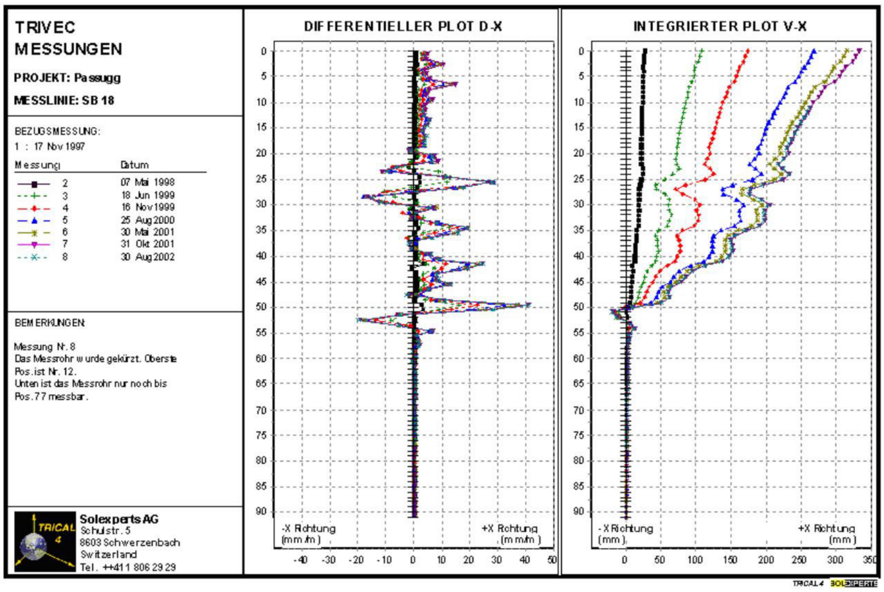

Fig. 6 Results of measurement in the sliding area, evaluated in programme TRICAL. Plots of horizontal deformations x. Each curve corresponds with one measurement episode. The last curve displays the borehole which was 12 m shortened. After /2/ Frodl.

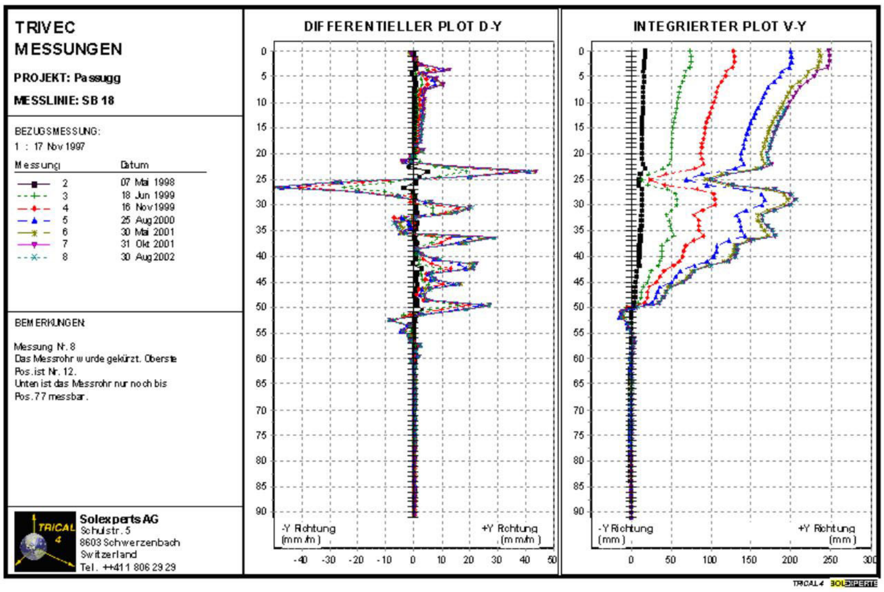

Fig. 7 Results of measurement in the sliding area, evaluated in programme TRICAL. Plots of horizontal deformations y. Each curve corresponds with one measurement episode. The last curve displays the borehole which was 12 m shortened. After /2/ Frodl.

CONCLUSION

Geotechnical monitoring is a very important part of problems solution and remediation of unstable slopes. Measurement of 3D deformations with the probe TRIVEC in instrumented boreholes helped to select the adequate remediation measures. Thanks to continued monitoring of slope movements development he necessary extents of excavation can be determined. The consequence is reduction of costs spent on the unstable area remediation.

GEOTECHNICAL MONITORING AT THE FACULTY OF CIVIL ENGINEERING OF CTU IN PRAGUE

The Department of Geotechnics at the Faculty of Civil Engineering provides monitoring of subsoil deformations of the St. Vitus Cathedral and of so called “Mathey’s Pillar” (at the corner of the West part of the North Wing of the Prague Castle) in two boreholes with combined casing. It is a grant project. The measurements are done with Sliding Micrometer (extensometer equivalent with TRIVEC probe) and with inclinometer by Solexperts.

Combined measurement of 3D deformations is also used to monitor movements of the slope Rabenov in an open pit mine Chabařovice and a slope slide Čertovka in Vaňov, North Bohemia. As a student of Faculty of Civil Engineering I have the possibility to participate at those projects.

LITERATURE

/1/ LARDELLI, Tomaso; ZWAHIAN, Peter: Ricaldei – Probleme im Randbereich einer grossen Rutschung. Strasse und Werkehr Nr. 5, May 1994

/2/ FRODL, Heribert: Bericht – Trivec Messung in SB 18 Tschiertschenstrasse / Ricaldei. Schwerzenbach, Schweiz, Solexperts, A. G. 2002

/3/ THUT, Arno: Slope Displacement: Geotechnical Measurement and Monitoring. Schwerzenbach, Switzerland, Solexperts, A. G. 1999

/4/ NATEROP, Daniel: Linewise Deformation Measurements for Solving Geotechnical Problems. Development of Geotechnical Tests, Chinese Assoc. of Geotechnical Investigation, Seminar Beijing 1998

Brochures of Solexperts, A. G.
Figures: Heri Frodl, Laurent Moser

/5/ ZÁLESKÝ, Marek: Accuracy Verification of Line-wise Measurements of Subsoil Deformations of Buildings. Student Workshop 2001/2002, section Geotechnics.

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