Subsurface Investigation and Landslide Monitoring as a Basis for Planning Protection Measures
- Case Study Doren Landslide -

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INTRODUCTION

Large or widespread slope movements are often characterised by a very complex interplay of various mass movement processes which are in turn caused by saturated water conductivity regimes in the underground that are difficult to assess or model. The planning of protection measures is therefore often met with great challenges. The importance of monitoring measures for determining protection measures is to be demonstrated using the example of the Doren landslide.

GENERAL INFORMATION

The oral tradition about a landslide area on the orographic righthand side of the Weißach river in close vicinity to the town center of Doren/Austria reach back to the year 1847. Mass movements in 1927, 1935, 1988 and 2007 in each case involved the movement of 2 – 3 million m³ of material. In 1935 and 2007 the Weißach was completely dammed up by this material, causing a lake of approximately 500 m in length behind the landslide deposit. Following the mass movement of 1935, the first geological investigations were carried out and drainage tunnels of circa 700 m length were mechanically bored and filled with coarse boulders for stability.
The geological subsurface in the landslide area consists of rocks of the so-called Weißach layers of the Lower Freshwater Molasse. The landslide area is divided into various sections (see **Fig. 1**):

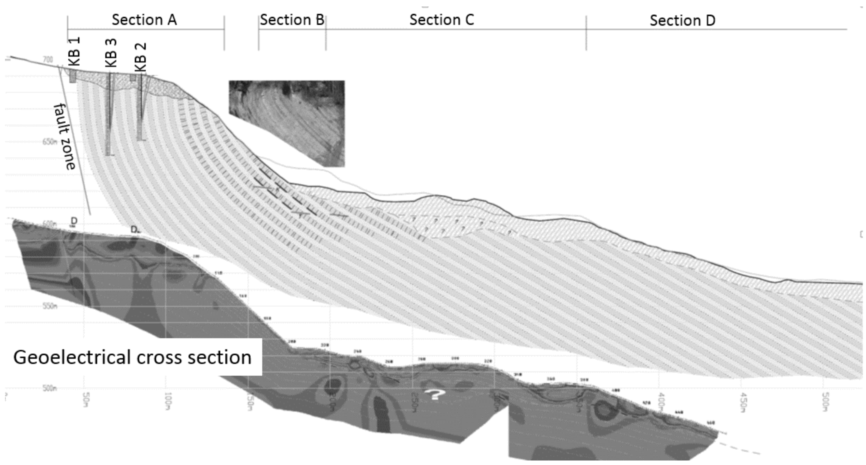

Fig. 1: Schematical geotechnical cross section of the landslide with the different sections A, B, C and D.

Section A: terrace covered with quaternary sediments

Section B: a scarp face of up to 70 m height with slope parallel marlstone and sandstone layers of the Lower Freshwater Molasse. The marl layers contain up to 45% swellable clay minerals

Section C: Rotational slips in the slope debris at the foot of the scarp face.
Section D: a 600 m long earth and rock waste stream to the tributary Weißach.

The layers of marl weather very rapidly into their components. Spring outlets at the interface between the Weißach layers and moraine deposits continuously supply water so that weathering products are soon eroded. Weathering along with the three landslide processes (bedrock slipage in the scarp, rotational slides at the foot of the scarp face, as well as the immediately adjoining earth and rock waste stream) which interact with one another lead to a retrogressive erosion of the scarp face on the order of 1 m per annum.

MONITORING AND PROTECTION MEASURES

Protection measures in the form of boreholes drilled into the marl subsoil date back to the aftermath of the mass movement event of 1935. As a result of these investigations, drainage pipes as well as rubble drains and supporting structures were constructed to stabilise the scarp. The quantities of the water thus discharged was measured; such measurements are also being made in the present. In the 1950s seismic surveys were carried out with the objective of quantifying the thickness of moraine deposits as well as obtaining information about the composition of the Weißach layers. Seismic surveys were repeated after the 1988 event and complemented by vertical and horizontal drillings for the purpose of calibrating the seismic data and investigating the hydrologic budget of the landslide. Two of the boreholes were equiped with inclinometers. The subsurface data supplied by these inclinometers, later supplemented by geoelectrical measurements as well as information from dye tests, were used to develop a concept for draining the surface water, which was implemented from 2002 to 2004. In 2003 a deep drainage system was constructed and the water discharge from it continually measured, amounting to approximately 13.000 m³ of water per annum. The very large mass movements of 2007 necessitated new investigations in order to adapt the protection and mitigation concept. As a result, the existing boreholes above the main scarp were augmented with 4 additional boreholes. In addition, 2 boreholes were drilled in the rock waste stream at the foot of the slope and equiped with inclinometers and piezometers. Further water gauges and piezometers have since provided very interesting data about the landslide's highly complex hydrologic budget. Since 2010 the entire earth and rock waste stream has regularly been surveyed by the provincial land surveying office of Vorarlberg and the rates of movement documented.

The comparison of orthophotos taken since 1950 in conjuntion with numerous laserscans since 2003 has provided information about the landslide's mass balance, whose head scarp has over the past 65 years moved an average of 1 m in the direction of the town center, and it has furthermore shown the importance of securing the scarp face. Since 2014, two slope stabilization systems are being tested for their functionality in the eastern section of the scarp face, namely the KRISMER mesh System and TECCO nets.

CONCLUSION

For complex landslides, monitoring measures over a long period of time are indispensable for providing an overview of the relavent processes taking place, for determining and evaluating protection measures as well as for adapting the technical construction measures to changing conditions.

Keywords: landslide, monitoring, protection measures