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Dynamic fluid electric conductivity logging for identification and characterization of preferential groundwater flow in the Åknes rockslide (Norway)

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The Åknes rockslide in western Norway is situated in crystalline rocks along the shore line of the Sunnylvsfjorden. The unstable rockslope is ranging in elevation between about 900 and 100 m asl, and has a main upper scarp with a length of about 600 m. It consists of highly fractured orthogneissic rocks with the main foliation dipping on average downslope. The Åknes rockslide shows an annual downhill creep of 4 to 5 cm and has an estimated thickness of 15 to 45 meters. In the worst case a volume of 70 to 90 million cubic meters of rock could be released from this slope, generating a large rock avalanche and a subsequent tsunami wave in the fjord area. In order to design and setup an early warning system a large national project (Åknes-Tafjord Project) has been established (Blikra 2008). The Engineering Geology Chair of ETH is a scientific partner of this project and supports borehole investigations and studies of the hydrogeological conditions at the Åknes site.

It has to be assumed that the stability and future evolution (eventually catastrophic failure) of the Åknes rockslide is strongly influenced by pore pressures and groundwater flow within the unstable rock mass. The distribution of groundwater pressure and flow within fractured crystalline rock masses is very heterogeneous and difficult to predict. Pore pressure can dramatically change across faults and affect slope stability and slide velocity. Therefore, for the understanding of hydrodynamic processes within the Åknes rockslide, the knowledge of the locations of conductive fractures and their hydraulic heads and transmissivities is essential. To obtain such knowledge, a total of seven 150 to 200 meters deep boreholes have been cored in 2005 and 2006. Two boreholes have been drilled at an “upper” and “lower” drill site of 658 m and 236 m asl, and three boreholes have been drilled at a “middle” drill site with an elevation of 565 m asl. These boreholes have been investigated with standard and novel testing methods.

Preliminary impeller flowmeter logs have shown that very high ambient flow rates of up to 5 l/min occur within all monitored boreholes. These high ambient flow rates from multiple inflowing and outflowing fractures are indicative of strong vertical hydraulic gradients. In this paper we present a hydraulic borehole testing approach that has been designed to observe and measure such preferential groundwater flows and vertical head gradients in detail using a new protocol for dynamic fluid electric conductivity logging in conjunction with heatpulse flowmeter logging.

In dynamic fluid electric conductivity logging (DFEC) experiments, formation water is first replaced by water of a higher salinity. This is done by controlled injection of saltwater at the bottom of the hole through a tube or hose. After removing the injection tube, a downhole pump is operated and borehole fluid electric conductivity logs are recorded at different times after flushing. At depth locations where fresh formation water enters the borehole, the fluid conductivity profile develops peaks. These peaks grow with time and become skewed in the direction of advective and dispersive borehole flow. By quantitatively analyzing the electric conductivity profiles at successive times, it is possible to obtain the flow rate (or transmissivity and head), as well as the salinity of individual inflows from hydraulically active fractures.

Until now DFEC logging was only used in boreholes with low ambient flow rates, typical for plains and smoothly dipping slopes. In these experiments constant low rate borehole and fracture flow was induced by pumping. At Åknes ambient borehole flow is very high and conductivity peaks after borehole fluid exchange are quickly flushed away. Therefore an appropriate fluid exchange method with a hose that could be quickly taken out of the borehole had to be developed and implemented. In addition several low-head fractures create flow from the borehole to the formation and require special data analysis approaches.

The successfully measured fluid conductivity profiles imply a very complex groundwater flow regime in the rockslide with up and downward directed flows in the same boreholes. In spite of the high fluid velocities, the conductivity profiles show the initiation and growth of many conductivity peaks. For example, 12 conductivity peaks in a 100 m section between xx and yy meters in borehole xxx, situated at an elevation of xx masl. In combination with the results from detailed heatpulse flowmeter logs it is possible to simulate the measured electrical conductivity profiles with a numerical model called VHBORE. By optimizing the match between the simulation results and the observed DFEC logs, the fracture hydraulic properties could finally be determined.

BLIKRA, L.H., 2008, The Åknes rockslide; monitoring, threshold values and early-warning, 10^{th} International Symposium on Landslides ISL: Xi'an China.