THE LANDSLIDE EVENT

One of the largest landslides in Austria over the last years occurred near Sibratsgfäll in the federal state of Vorarlberg (Austria), where about 70 million m^3 of soft rocks and an area of 1,6 km^2 was involved in a hazardous mass movement, destroying 17 buildings completely. A short period of heavy precipitation and the rapid melting of snow in spring of 1999 initiated this catastrophic landslide on the South-flank of the Rubach Valley. The movement rates of rock- and debris bodies involved exceeded up to 1m per day.

THE STRATEGY

As a follow up of this catastrophic landslide a strategy (an overview is displayed in fig.1) to deal with similar events was worked out based on the evaluation of applied measures. It turned out that airborne geophysical measurements are a valuable tool to get a quick overview of the geological situation, to detect areas susceptible to a high sliding probability, to assist the follow up geological and hydrological mapping program and to optimise planning of further (ground)-geophysical surveys. Within a second step ground geoelectrical surveys were used for advanced understanding of the internal structure of the landslide. The location of survey lines was planned according to the resistivity pattern derived from the airborne electromagnetic survey. Based on these findings and on the results of a geohydrological mapping program (Jaritz, et. al., 2004), boreholes were drilled to calibrate the geoelectrical results and to determine the geotechnical parameters of soil samples. Additionally geophysical logging and hydrophysical logs were performed (Pedler, et. al, 1992). Based on all of these results a geotechnical subsurface model was set up and parameters and conditions of safety and failure were calculated. Finally a multi parameter monitoring network was set up and maintained now for four years.

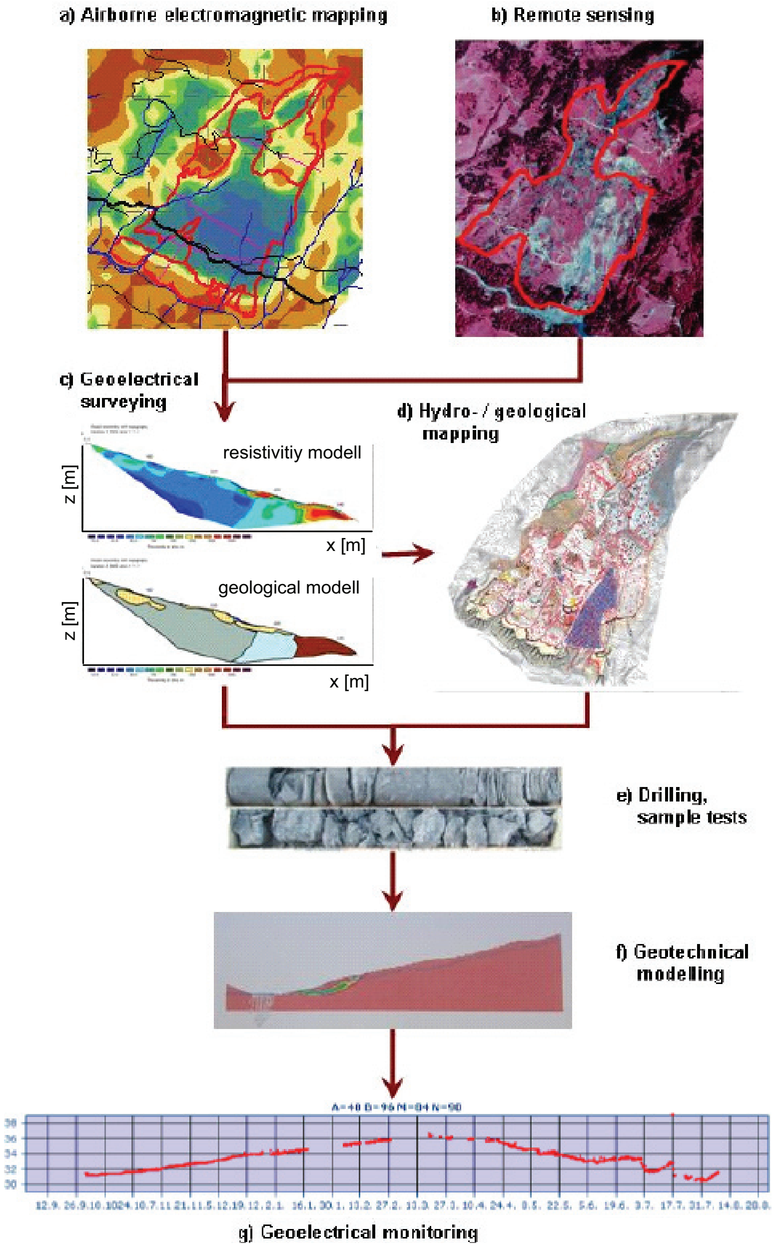

Fig 1: Overall scheme of applied research strategy

AIRBORNE GEOPHYSICAL SURVEY AND REMOTE SENSING

A high resolution, multi-parameter airborne survey was performed, using electromagnetics, magnetics, gamma ray measurements, soil humidity and infra red sensors (Motschka, et. al., 2001). Electromagnetics turned out to be the most important parameter to investigate the structure of large scale landslide areas. Using this method a conceptual model of the subsurface structure could be derived. The results were very valuable for mapping geologists as they helped to optimise mapping procedures and to minimise actual field work, which is often very difficult and time demanding in the rugged terrain of sliding slopes. Fig.2 shows the results of the homogenous halfspace inversion of airborne electromagnetic data (Ahl, et. al, 2007). The area affected by movement shows lower resistivities than surrounding structures.

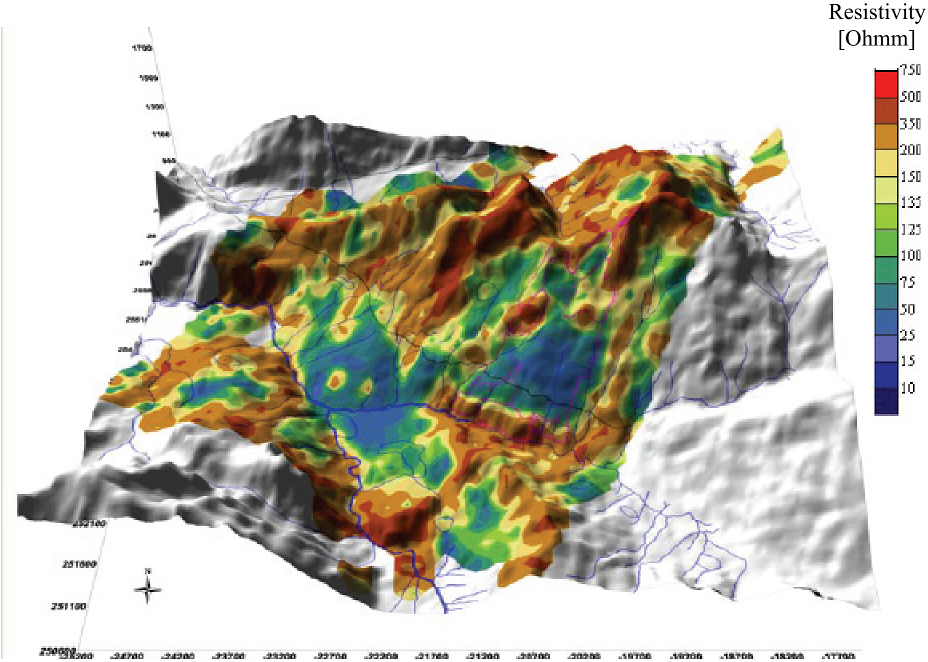

Fig.2: Results of airborne electromagnetic mapping – Resistivities [Ohmm] of homogenous halfspace inversion are draped on digital terrain model

GROUND GEOELECTRICAL SURVEY AND GEOTECHNICAL MODEL

The outcome of the airborne survey furthermore helped to optimise the location of a ground based geoelectrical campaign. Several km of multielectrode profiles were carried out to constrain the inversion of the airborne electromagnetic data and to determine the detailed internal structure of the sliding area. Fig.3 shows the geoelectric results of one profile crossing a mudflow structure. The geoelectric results could be calibrated after drilling of several deep boreholes and the application of borehole electromagnetic logging.
Based on the subsurface model derived from the geoelectrical results, geotechnical calculations (fig.4, fig.5) proved that soil water content is the driving factor for movement of this landslide. According to situations of high or low water level different scenarios of failure resulted, thus underlining the importance of monitoring the subsurface water regime for the design of future early-warning systems.

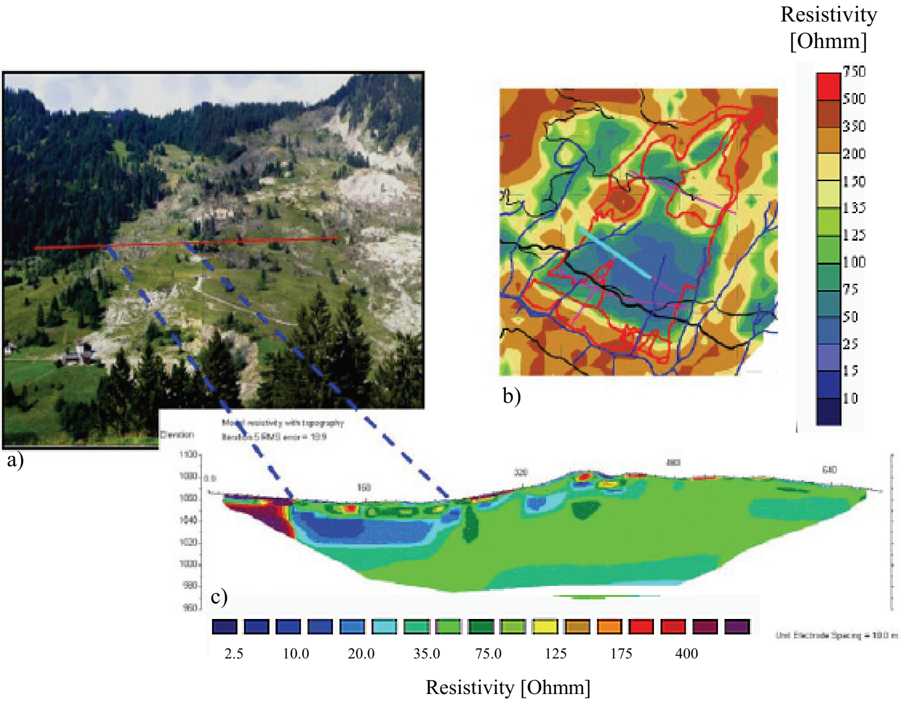

Fig.3: Results of geoelectric profile crossing a recent mudflow area; a) shows location of profile, b) shows location of profile within resistivity pattern of airborne mapping, c) geoelectric result

THE MONITORING SYSTEM

As changing hydrological conditions are reflected mainly in a variation of saturation, the geoelectric method, whose determining parameter Resistivity mainly depends on porosity, saturation, pore fluid conductivity and clay content, could be a reliable tool for observing such changes. Consequently a multi-parameter monitoring system was designed Supper, et al, 2002, 2003, 2004). The core part of the development was focused on the design of an innovative geoelectrical monitoring system.

The monitoring system has now been in operation since 2002. The data is sent daily by email to the central data base in Vienna. The geoelectrical system is supported by meteorological monitoring instruments, soil temperature and soil humidity measurements at different depths, inclinometric measurements, GPS time lapse positioning and hydrological monitoring. The results of four years of monitoring show a correlation of resistivity and self potential anomalies with phases of increased movement. However, due to financial reasons and as the focus of the project was centred on system development and not data interpretation, permanent movement observation could not be performed. Fig.6 give a selected results from 2003. Fig. 7 shows the result of repeated GPS measurements. Points 141 and 142 are close to the monitoring site.

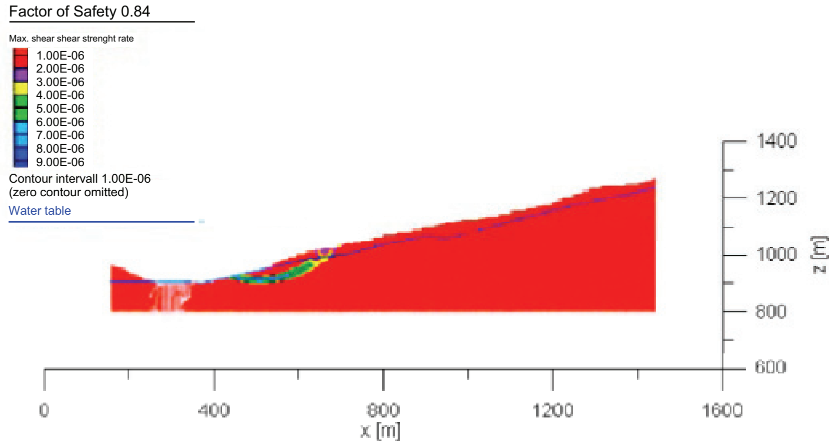

Fig.4: Determination of sliding surface using geotechnical simulations. Calculations are based on the subsurface model derived from geoelectric measurements and core probing: results at low groundwater table (after Hofmann, 2005)

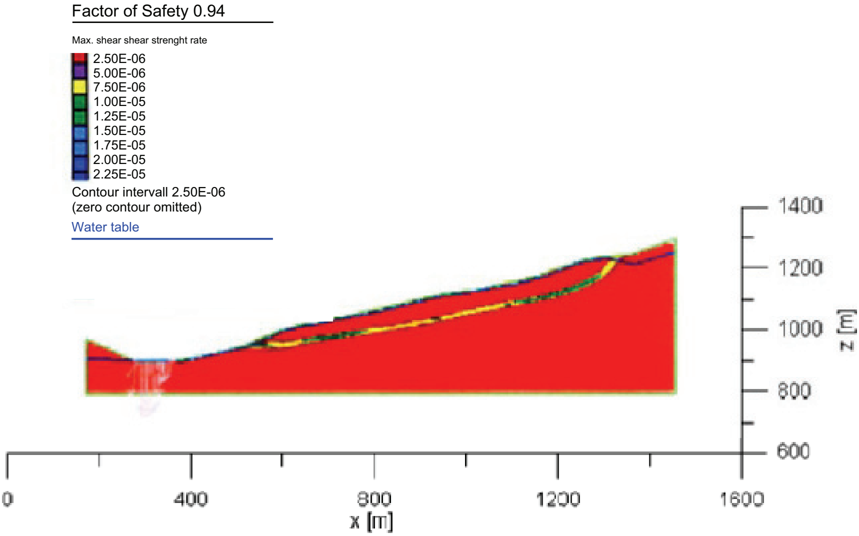

Fig.5: Determination of sliding surface using geotechnical simulations. Calculations are based on the subsurface model derived from geoelectric measurements and core probing: results at high groundwater table (after Hofmann, 2005)

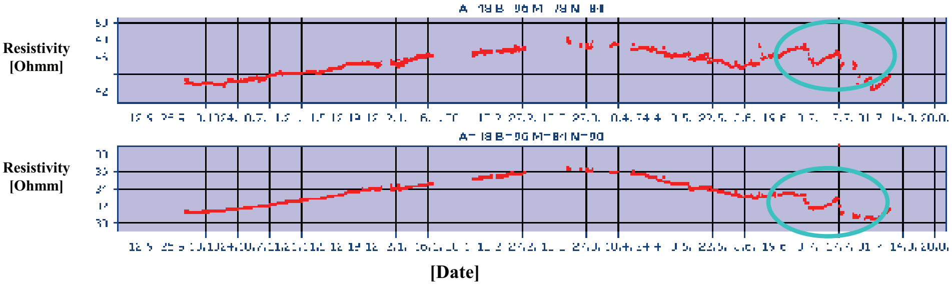

Fig. 6: Selected result of geoelectric monitoring; circle indicates anomalous behaviour of resistivity measurements [Ohmm] at times of increased slope movements

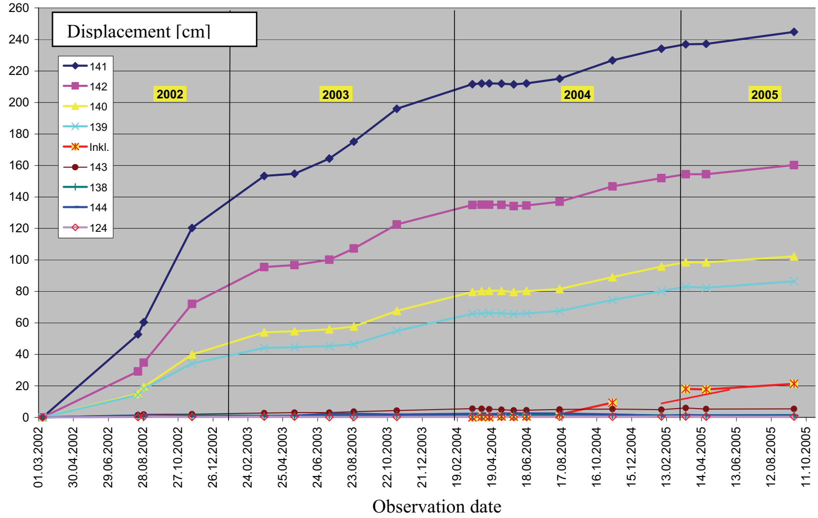

Fig.7: Displacement observation based on GPS data at the monitoring site Rindberg

CONCLUSIONS

Several methods were evaluated to design an improved interdisciplinary strategy for immediate measures to be applied in case of future landslide events. The strategy allows to quickly assess the prevailing hazard situation and to develop and recommend effective mitigation measures. The resulting optimise approach consists of the application of airborne electromagnetics, ground geoelectrical measurements and geoelectrical monitoring combined with hydrological and geological mapping and geotechnical modelling. Interdisciplinary communication and discussion was the primary key to access this complicated hazard situation in the case of the large-scale landslide event evaluated at Rindberg.

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