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3D structure of a large complex rockslide as determined from integrated geological and geophysical investigations (Randa, Switzerland)

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The Randa *in-situ* laboratory is a high-altitude research facility in the Swiss Alps, where ETH has established a long term monitoring and testing program for the study of rockslope failure processes. The laboratory was established in the year 2001 in a slowly moving rock mass located above the main scarp of the 1991 Randa rockslide failure. Since 2001, a large amount of monitoring data (displacements, pore pressure, micoseismicity, climate) was acquired that gave us a unique insight into the structure, kinematics and mechanics of in the unstable rock mass. This contribution presents the 3D structure as determined from integrated analysis of geological mapping, geophysical borehole measurements and 3D radar and refraction seismics.

Detailed surface and borehole televiewer mapping revealed that the foliation of the ortho- and para-gneisses dips primarily to the west, and hence into the slope. Several fracture sets cut the foliation and compositional banding and break the rock mass into blocks. Based on surface mapping, two scales of discontinuity networks were recognized: a small-scale network consisting of fractures with lengths of up to 5 m, and a large-scale network of faults and fracture zones. The large-scale fracture network (trace lengths longer than 10 m) includes fracture zones, brittle faults and brittle-ductile shear zones that dip either parallel to foliation to the W or steeply inclined to the E and NW. Similar to the small-scale fracture network, no faults and fracture zones dip at favorable degrees out of the slope. Detailed analysis of

inclinometer/extensometer monitoring carried out at ground surface and in the 3 deep research boreholes clearly showed that only some of the large-scale fractures are active and key elements for the current rockslide kinematics. No evidence of active displacement was found for the small-scale fractures.

Useful information on the large scale fracture network was gained by geophysical logs and singe-hole georadar experiments that were conducted in the three boreholes. A consistent pattern of spalling, displacements and radar velocity/amplitude anomalies was observed at 16 of the 46 major discontinuities identified in borehole televiewer images. Radar reflections suggested possible connections between 6 surface and 4 borehole fractures and led to the discovery of 5 additional near-surface fracture zones that have no surface expression. The successful connection of these steeply dipping fractures demonstrated that depths extended at least 40-60 m into the subsurface.

Steeply dipping fracture zones are generally difficult to detect using traditional surface-based ground-penetrating radar techniques. Evidence for their presence in standard georadar images may be either completely absent or limited to diffractions and/or chaotic reflection patterns that are often difficult to interpret after applying standard processing techniques. To address this issue, a novel 3-D migration scheme based on computation of semblance values has been developed. This new approach, named semblance-based topographic migration (SBTM), emphasizes diffractors while markedly reducing the effects of specular reflectors. The scheme also accounts for the effects of undulating surface topography.

Since the SBTM only emphasizes rough surfaces and discontinuities but not specular reflection, the results from the SBTM were combined with the results from a relatively conventional topographic-migration scheme to extract maximum information from a 3-D georadar dataset. Both methods provide different but complementary pieces of information for the 3D structure of the mesoscale fracture set as defined by borehole and surface mapping.

Also a new 3-D tomographic seismic refraction technique was developed in the framework of the project to determine the P-wave velocity structure in the unstable and adjacent parts of the Randa *in-situ* laboratory. The used field array consisted of eight seismic lines and of a pattern of shots located apart from the lines. This configuration allowed for the recording of a dense 3-D seismic data set. Comparison of 2-D tomograms along the seismic profiles with a 3-D tomogram demonstrated that only 3-D tomography can be used to detect reliably the elongated complex velocity anomalies relating to the rock fracturing.

Inversion of first-arrival travel time picks revealed a broad zone of remarkably low seismic velocities (smaller than 1500 m/s). This ultra-low velocity zone extended to a depth of at least 25 m over a 200 x 100 m area significantly beyond the limits of rock mass that is known to be currently moving. To explain such low velocities requires 17 % of the investigated volume to be air-filled voids. Several fracture zones and faults transect the ultra-low velocity region, the trend of which paralleled part of the scarp generated by the 1991 rockslide events. Several prominent linear velocity anomalies within this region are oriented in the same direction. Ubiquitous dry cracks, fracture zones and faults are the likely cause of the anomalously low velocities. Such deeply reaching unsaturated conditions are also supported by the pore pressure monitoring system.