Geol. Paläont. Mitt. Innsbruck, ISSN 0378–6870, Band 25, S. 1–242, 2001

INTERRELATIONSHIP BETWEEN BRITTLE DEFORMATION STRUCTURES AND GROUND SETTLEMENTS ABOVE TUNNELS IN FRACTURED CRYSTALLINE ROCKS

C. Zangerl, S. Löw, E. Eberhardt

Recent measurements of surface displacements above the Gotthard highway tunnel in central Switzerland have shown up to 12 cm of subsidence over approximately 800 meters of overburden. Subsidence of this magnitude in a fractured crystalline rock mass is unexpected and appears to be related to large-scale consolidation resulting from fluid drainage and a reduction in the water table level. These displacements are of notable concern since they could adversely affect the integrity of surface structures (e.g. dams) above the underground opening.

Construction of the Gotthard highway tunnel occurred between 1970 and 1980 and was driven through the fractured polymetamorphic, crystalline rocks of the Aar and Gotthard massifs. During construction initial water inflows of up to 150 litres per second were measured in an area where several brittle fault zones with steeply dipping joint sets occurred. Analysis of the hydrological data from the tunnel revealed spatial relationships between the water inflow from these large-scale fractures and the settlements observed on surface. A study was therefore initiated to investigate the apparent relationship between the tunnel construction and the measured subsidence. This study incorporates the use of geodetic measurements, surface and underground discontinuity mapping, and numerical modelling techniques.

Brittle discontinuities, i.e. brittle fault zones and joints, play a major role in geotechnical engineering problems in crystalline rock masses. Ground water flow in low-permeability rock masses (e.g. granitic gneiss), is predominantly controlled by brittle structures which form a connected fracture network. If a tunnel then intersects this water-filled pressurized, fracture network, the rock mass will drain. Several examples from recent and previous tunnel construction sites have shown that high water inflow rates often lead to serious technical problems. Another effect related to tunnel drainage is the change in pore pressure within the rock mass. This hydro-mechanical coupled process affects the mechanical behaviour of discontinuities and also the low-porosity intact rock matrix. Thus, the knowledge of fracture-orientation, -spacing, -frequency and -length is essential to construct a 3-D fracture network, which in turn provides the basis for subsequent hydro-mechanical numerical modelling.

The first stage of this investigation involved the mapping of existing joints and brittle fault zones on a regional scale. The diverse behaviour exhibited by brittle fault zones relative to joints, especially with respect to hydro-mechanical behaviour, required that these structures be treated and evaluated independently. Geological and topographical data were collected and managed through a GIS database, which was subsequently programed to resolve the orientations and spatial relationships between dominant joint sets. Results presented in this talk show that the jointing system can be characterised by three to four main joint set orientations depending on the rock type: two steeply dipping sets sub-parallel and perpendicular to the foliation; and one to two sets with a medium to flat dip angle. The number of joint sets and orientations vary with rock type and region. One major joint set, with respect to frequency and length, is sub-parallel in orientation to the strike of the main brittle fault zones.

The full brittle fault zone pattern shows two major sets striking SW-NE and NNE-SSW, and one minor set with a W-E strike. The structural composition of the brittle fault zones can be characterised as a heavily fractured cataclastic zone with layers of mm to dm thick sand-clay bearing fault gouges. These fault zones dip steeply and form, together with the sub-parallel joint set, a 'fan-like' structure with a NE-SW striking axis. Most of the fault zones can be described as strike-slip faults with right-handed shear.

Findings from the second stage of this investigation are also presented and involve the detailed mapping of joints through the use of scanlines along surface outcrops above the Gotthard-road tunnel. A high degree of correlation, with respect to the number of joint sets and orientations, was found between both regional and local scale analyses and between surface and tunnel measurements. Whereas outcrop measurements in general produce only discontinuity orientation data, the more systematic scanline technique allows for measurements of joint-spacing, -frequency and -length. These geometrical parameters, when represented by different probability distributions (negative-Exponential-, Weibull- or Log-normal-distributions), form the input for the 2-D or 3-D network generation.

An example is provided using the 2-D distinct-element code UDEC, used to model discrete block displacements induced through the opening and closing of discontinuity apertures as a function of changing fluid pressure and normal stress due to tunnel drainage.

Authors' address:
Mag. Christian Zangerl, Dr. Erik Eberhardt, Prof. Dr. Simon Löw, Institute of Geology, Engineering Geology, ETH-Hoenggerberg, HIL D 21.3, CH-8093 Zurich, Switzerland