Physics and Chemistry of the Earth 33 (2008) S374–S387

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Influence of bedding planes to EDZ-evolution and the coupled HM properties of Opalinus Clay

Till Popp, Klaus Salzer, Wolfgang Minkley

Institut für Gebirgsmechanik GmbH, 02479 Leipzig, Germany

ARTICLE INFO

Article history:
Available online 15 October 2008

Keywords:
EDZ
Permeability
Indurated clay
Rock mechanical modelling
Ultrasonic wave velocities

ABSTRACT

Field observations at the Mont Terri site demonstrate an excavation damage zone (EDZ) around tunnels consisting of a complex crack network related to the bedding and the existing stress field. To separate the different impacts of the rock mass and bedding planes laboratory investigations were performed on Opalinus Clay samples including triaxial strength and direct shear tests. During the deformation tests monitoring of ultrasonic wave velocities, permeability and volumetric strain measurements facilitates the detection of stress induced onset of damage. Two stress dependent criteria were estimated, referring to various damage states, i.e. (1) to initial onset of damage and (2) occurrence of dilatancy. Based on the experimental results a new modelling approach for a prognosis of the evolution of the EDZ is developed consisting of two parts: (1) a (visco-)elasto-plastic constitutive model, comprising the hardening/softening behaviour and dilatancy effects of the rock mass, and (2) a specific friction model, which described displacement- and velocity-dependent shear strength softening for the bedding planes. The capability of the new approach is demonstrated by recalculating the spatial development of EDZ around a drift at the Mont Terri site.

1. Introduction

In the assessment of a multi-barrier system the geological and hydrogeological features of the repository site are crucial as the safe confinement of the radioactive waste and its isolation from the biosphere has to be guaranteed for a period of up to one million years. Due to their favourable transport and geochemical properties different argillaceous rocks are being under investigation as potential host rock formations for an underground repository, e.g. the Opalinus Clay as an indurated clay in the Swiss waste disposal program (Nagra, 2002) or the Callovo-Oxfordian argillite in the Meuse-Haute-Marne region (Andra, 2005).

Mining of underground galleries and cavities generally results in development of an excavation disturbed (EdZ), respectively, damaged zone (EDZ), which affects the efficiency of geological barrier systems at least while operation and closing phases (e.g. Tsang et al., 2005). However, a prognosis of the mechanical evolution of the EDZ is only possible if the relevant processes are captured by the used constitutive models. Exemplarily the various characteristics of the EDZ identified around the Mont Terri New Gallery are schematically depicted in Fig. 1 (for details see Bossart et al. (2004)):

- Extension brittle failure: Extension-induced fractures extend to approximately 0.5 m in the sidewalls,
- bedding plane slip is expected in the floor and roof to extend to less than 1 m,
- swelling and softening: change in moisture content can result in significant swelling pressures resulting in time-dependent deformations (this process is not considered in our investigations).

Thus, it can be anticipated that initiation of inelastic deformation and the relative dilatation are clearly a function of the spatial stress geometry and bedding plane properties. Because the latter can act as preferential flow paths and weakness planes understanding of its contribution is essential for a prognosis of the EDZ creation. Following a material science approach this study consists of a combination of appropriate laboratory experiments including triaxial and direct shear tests. The rock-mechanical investigations deliver a base for parameter determination for subsequent numerical modelling to enlarge the scale of investigation.

Since the transport properties of the clay are responsible for the demanded integrity of a radioactive waste repository, knowledge about the relationship between development of damage (dilatancy) and hydraulical properties is of utmost importance. In the lab the amount of damage of rocks is generally described by the parameter dilatancy, i.e. the development of micro-fractures depending on the state of stress (stress field geometry and deviator). The determination of the stress dependent onset of dilatancy is, therefore, of predominant importance for an appraisal of barrier properties of solid rocks. In extension of former investigations

E-mail address: till.popp@ifg-leipzig.de (T. Popp).

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doi:10.1016/j.pce.2008.10.018

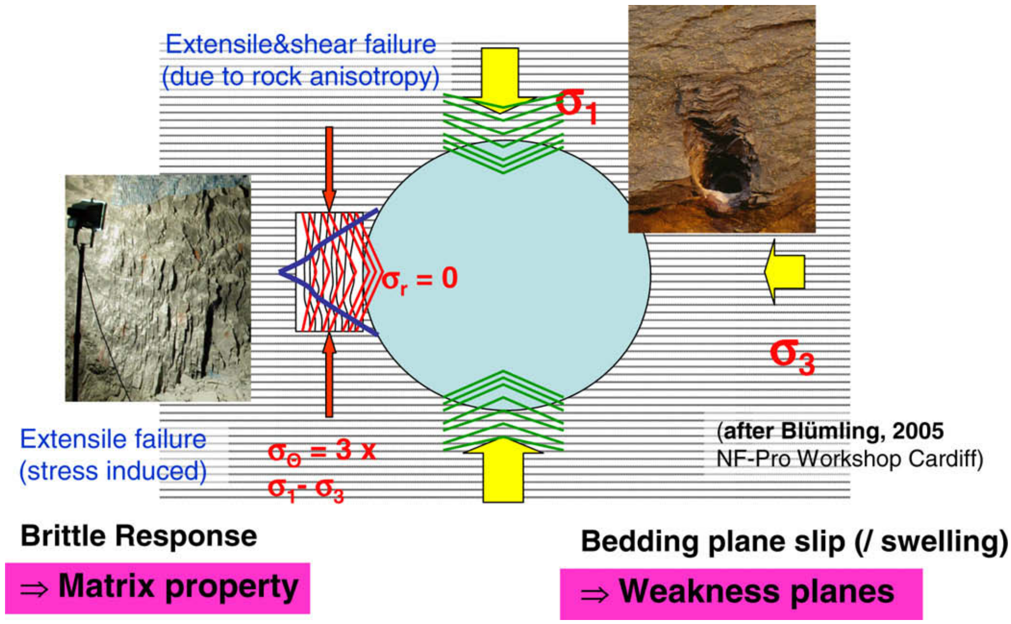

Fig. 1. Failure mechanism and anisotropy phenomena observed at the Mont Terri site (modified after Blümling (2005)).

(Popp and Salzer, 2007) new results will be presented obtained with a conventional triaxial Kármán cell, that allow detection of onset of microcracking by monitoring ultrasonic wave velocities and, coevally, measurements of the gas permeability parallel to the sample axis.

In addition direct shear tests were performed on large sample blocks (of approximately 100 mm × 100 mm × 200 mm). The obtained experimental results cover a wide range of applied confining, respectively, normal stresses and displacement rates and delivered a reliable estimate of rock mechanical properties (i.e. strength and dilatancy angle).

Based on the experimental data base a new modelling approach has been developed consisting of two parts, i.e. of a (visco-)elasto-plastic constitutive model comprising the hardening/softening behaviour and dilatancy effects of the rock mass and a specific shear friction model, which describes displacement- and velocity-dependent shear strength softening for the bedding planes. Its usability is demonstrated simulating a simple 2D-drift situation at the Mont Terri site.

2. Sampling and material description

The central heater borehole (BHE-D0) of the HE-D Experiment was used for core recovery which is located in homogeneous shaly layers of the sandy facies (Mont Terri Project, 2004). The borehole was drilled by the French drilling company COREIS with the double core barrel techniques, using compressed air as drilling medium in spring 2004. The technical borehole data are summarized in Table 1.

Finally 10 core segments with a total core length of around 4 m were sampled between 2 and 7 m depth and immediately sealed with aluminium foil to avoid humidity loss (before sealing the foil tubes were evacuated). At the IfG in Leipzig the sealed samples were stored at average conditions of 16 °C and around 80% r.h.

From the large cores (Ø ≈ 26 cm) cylindrical samples were drilled carefully with a special core drilling set (tube end equipped with hard metal crumble) in a modified lathe (automatic slow transmission of the drilling tube) with continuous extraction of the drilling dust by an integrated vacuum cleaner. Because the cylinder surfaces are sufficiently smooth, only the cylinder ends were flattened and polished in a lathe.

Tectonic and artificial stressing during core recovery and sample preparation sometimes result in fracture development mostly parallel the bedding. Samples showing these failure features were rejected. The prepared samples show thin bedded dark grey clay minerals with a typical anisotropic texture of clay particles parallel the bedding surface. A detailed description of the textural and mineralogical characteristics of the rock is given in Popp and Salzer (2007).

3. Coupled hydraulical and mechanical properties during triaxial loading

In this section, results from triaxial testing of cylindrical clay samples (four parallel and two perpendicular to the bedding) are reported with simultaneous monitoring of ultrasonic wave velocities (Vp, Vs), dilatancy and gas permeability to characterize the coupled hydraulic-mechanical behaviour of Opalinus material. Each test consists of (1) a hydrostatic and (2) a deviatoric loading cycle to separate effects of pre-damage due to sample recovery from deformation-induced micro cracking.

Table 1
Technical data of the BHE-D0 borehole (taken from Mont Terri project (2004)).

Borehole	Drilling technique	Drilling fluid	Tunnel metre NG	Length (m)	Azimuth of dip (°)	Dip angle* (°)	Diameter hole/core (mm)	Location Bm*	Remarks
BHE-D0	DC*	Air	HE-D niche	13	240	0	300/260	Front wall	Heater borehole

* Abbrevations: *DC* – Double core drilling: Bm – borehole mouth (m) at tunnel wall; dip angle: + up – down.