Impact of Tensile Stresses and Tensile Fractures in Rock Salt on the evolution of the EDZ – capability of numerical modelling

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Abstract:

Around underground openings in salt tensile strength and tensile damage processes play dominant roles for development of micro-cracks and progressive damage, usually described by the term “Excavated Damage Zone” (EDZ). In addition to pure mechanical effects, i.e. due to rock convergence, tensile stresses may also generated by thermal processes, e.g. due to a temperature drop if high compressed gases are stored out from a gas cavern or if temperature changes occur in a heat generating radioactive waste repository.

When the in situ stress field is disturbed by underground excavation or temperature impacts, deformation and, possibly, dilatancy take place, as it is also documented by the stress-strain curve obtained from laboratory testing of rock samples. Due to stress redistribution processes in the rock contour, tensile crack initiation and propagation is the dominating damage process, forming with progressive deformation localized shear bands (with an internal tensile fracture structure). In the pre-failure area generated micro damages cause initially an increase of the permeability but by accumulation of such micro damages also arise macroscopic fractures, which may lead to instabilities such as spalling. Therefore, the tensile failure mechanism is relevant for the assessment of the mining safety as well as for a reliable estimation of hydraulic properties of the EDZ.

For the assessment of the stability of the rock contour or for the prediction of the time-dependent development of EDZ, especially in the vicinity of geotechnical barriers, numerical methods are essential. Thus, it follows, that appropriate constitutive models are needed to simulate the complex mechanical behavior of the salt rocks.

However, as already mentioned, in the most cases tensile failures occur together with shear deformations or shear failures. Both processes influence each other, so that the formation of micro damages or fractures and shells cannot be explained only with one of these both processes. Therefore for the modelling of damages, fractures and collapses constitutive models are needed with implemented formulations both failure mechanisms.

The IfG in Leipzig, Germany, has developed two constitutive models which were already validated in a lot of projects, i.e. the visco-plastic Minkley approach (Minkley et al., 2001, 2007) and the advanced strain hardening approach by Günther-Salzer (Günther & Salzer, 2010, Günther et al., 2012). Both approaches are applied in the "Joint project III on the comparison of constitutive models for the mechanical behavior of rock salt", i.e. a US-German collaboration project, where different models are systematically compared to each other.

Our both constitutive models are able to describe the characteristic of the three creep-phases in combination with the strength and dilatancy behavior. However, they base on different model strategies:

- The visco-elasto-plastic model uses for the creep behavior a rheological approach basing on a Burgers model. Material strength and the dilatancy are implemented via an advanced nonlinear Mohr-Coulomb formulation with a non-associated flow-rule. A separate strain-dependent failure boundary for the tensile strength can be used.
- The advanced stain hardening approach, describes the mechanical behavior of rock salt comprehensively within the scope of an unified creep approach. The model viscosity is dependent on an inner state variable which characterize the present state of the effective material hardening. The formulation of the state variable is basically related to the creep strain and the dilatancy. For the formulation of the tensile strength a dilatancy dependent failure boundary is used.

In this article both constitutive models will be systematically characterized, focusing on the different approaches to handle tensile stresses in relationship to the other model parts. Then, the capability of both modelling approaches is demonstrated by back analysis of laboratory tests and in-situ situations. Based on the gained experiences, final conclusions will be made on the importance of tensile stresses for solving underground problems in salt formations.

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