Stability and integrity of salt caverns und consideration of hydro-mechanical loading

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Conventional assessments for the dimensioning of salt rock caverns are generally prohibiting the occurrence of damage at the cavern contour, i.e. the strength limit must not be exceeded by tensile or shear stresses. However, this concept is unrealistic with respect to real caverns and can only be maintained for ideal caverns without considering hydro-mechanical interactions. This is confirmed by the observation of spalling and contour breakage during the operation of caverns. There will always be a limited damaging occurring at the cavern contour as a result of the applied modes of operation and unfavorably leached cavern configurations, since these factors may lead to stress states which violate the effective tensile stress criterion at the cavern wall. In this case, the pressure within the cavern is greater than the minimum principal stress, leading to a pressure-driven percolation into the polycrystalline salt rock and subsequent spalling at the contour.

Based on a discontinuum-mechanical modeling approach for salt rocks, these hydro-mechanical coupling effects such as the pressure-driven percolation of fluids, intergranular microcracking and hydraulic fracturing can be analyzed. Within conventional geomechanical simulation approaches, salt rocks have been predominantly regarded as a continuum and the mechanical effect of micro- and macroscopic discontinuities have been widely neglected. In the grain scale however, polycrystalline salt represents a discontinuum constituted of intergrown crystals, whose grain boundaries are micro-mechanical weakness planes that preferably fail under mechanical and hydraulic/pneumatic loading. Constitutive models developed at the IfG for the visco-elasto-plastic behavior of the salt grains themselves and an adhesive frictional shear model for the intergranular interaction are used to describe the mechanical behavior, while the hydraulic description of fluid percolation is realized using the cubic law for laminar flow. Only after overcoming a percolation threshold (minimum principal stress) the pressure-driven opening and interconnection of flow paths along grain boundaries is initiated in the salt rock and induces a directional percolation in the direction of the maximum principal stress.

Practical applications of this modeling approach are presented, e.g. the investigation of damage and percolation processes in a cavern contour during cyclic storage or long-term abandonment. For the operational phase it has to be shown, that the accumulated crack development due to the hydro-mechanical interactions is limited in its penetration depth, in order to guarantee the stability and integrity of the cavern. It is also discussed that healing effects at high cavern pressures are not to be expected after the contour has been dilatantly damaged due to shear stresses and/or hydro-mechanical loading. The violation of the

effective tensile stress criterion may be even stronger under consideration of additional thermo-mechanical effects during fast injection or withdrawal. The results obtained by investigating these coupled THM-processes are incorporated in the advanced cavern design concepts of the IfG for salt caverns.

Keywords: numerical modeling, discontinuum mechanics, fracture mechanics, hydro-mechanical coupling, pressure-driven percolation