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Interactive evolution concept for analyzing a rock salt cavern under cyclic thermo-mechanical loading

Diethard König, Elham Mahmoudi, Kavan Khaledi, Achim von Blumenthal, and Tom Schanz
Chair of Foundation Engineering, Soil and Rock Mechanics, Ruhr-Universität Bochum, Bochum (bi-gbf@rub.de)

The excess electricity produced by renewable energy sources available during off-peak periods of consumption can be used e.g. to produce and compress hydrogen or to compress air. Afterwards the pressurized gas is stored in the rock salt cavities. During this process, thermo-mechanical cyclic loading is applied to the rock salt surrounding the cavern. Compared to the operation of conventional storage caverns in rock salt the frequencies of filling and discharging cycles and therefore the thermo-mechanical loading cycles are much higher, e.g. daily or weekly compared to seasonally or yearly. The stress strain behavior of rock salt as well as the deformation behavior and the stability of caverns in rock salt under such loading conditions are unknown.

To overcome this, existing experimental studies have to be supplemented by exploring the behavior of rock salt under combined thermo-mechanical cyclic loading. Existing constitutive relations have to be extended to cover degradation of rock salt under thermo-mechanical cyclic loading. At least the complex system of a cavern in rock salt under these loading conditions has to be analyzed by numerical modeling taking into account the uncertainties due to limited access in large depth to investigate material composition and properties. An interactive evolution concept is presented to link the different components of such a study – experimental modeling, constitutive modeling and numerical modeling.

A triaxial experimental setup is designed to characterize the cyclic thermo-mechanical behavior of rock salt. The imposed boundary conditions in the experimental setup are assumed to be similar to the stress state obtained from a full-scale numerical simulation. The computational model relies primarily on the governing constitutive model for predicting the behavior of rock salt cavity. Hence, a sophisticated elasto-viscoplastic creep constitutive model is developed to take into account the dilatancy and damage progress, as well as the temperature effects. The contributed input parameters in the constitutive model are calibrated using the experimental measurements. In the following, the initial numerical simulation is modified based on the introduced constitutive model implemented in a finite element code. However, because of the significant levels of uncertainties involved in the design procedure of such structures, a reliable design can be achieved by employing probabilistic approaches. Therefore, the numerical calculation is extended by statistical tools such as sensitivity analysis, probabilistic analysis and robust reliability-based design. Uncertainties e.g. due to limited site investigation, which is always fragmentary within these depths, can be compensated by using data sets of field measurements for back calculation of input parameters with the developed numerical model. Monitoring concepts can be optimized by identifying sensor localizations e.g. using sensitivity analyses.