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Simulation of cyclic storage of hydrogen in salt caverns based on laboratory-benchmarked modeling of creep

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Salt caverns provide promising storage capacities for safe cyclic storage of hydrogen. With a few caverns worldwide in operation for (monotone) hydrogen storage as feedstock to chemical factories, scaling up their utilization for energy transition requires quantification of the rock salt mechanical behavior under cyclic loading. Not only the mechanics of the rock salt specimen, but also the deformation and stability of the entire cavern structure, considering the heterogeneities and uncertainties, under cyclic loading needs to be quantified [7]. Rock salts are known to have complex inelastic and time-dependent deformation mechanisms under different stress regimes, temperatures, and loading frequencies. For hydrogen operations, in which the period of injection/production scales in the order of days, transient creep (i.e. primary creep stage) is expected to play a major role, while the impact of steady-state and accelerated creep stages take place in much longer time scales.

The existing models for salt rock mechanics assume the transient creep is either fully recoverable [3,5,9] or fully plastic and permanent [6]. However, our recently obtained experimental results suggest that the transient creep stage is actually composed of both viscoelastic and viscoplastic contributions. Based on this observation, we propose a new concept to model the rock salt mechanics specifically for hydrogen storage applications, which is based on incorporating both elastic and plastic deformations. More precisely, the proposed model utilizes the Kelvin-Voigt model [3] for the viscoelastic response and Perzyna's model with a non-associated flow rule [4] for the viscoplastic deformation. In addition, for the steady-state creep, pressure solution [10] and dislocation [1] creep deformations are both considered, as in our recent publication [8]. Finally, the accelerated creep stage is described by a damage evolution model [2]. The constitutive model is implemented in a finite element framework using the FEniCS package.

We show that this model is able to improve predictions of the salt rock mechanical behavior, using the laboratory experimental data as the benchmarking reference. Built on this new modeling approach, we investigate the impacts of the transient creep on the deformation of the salt cavern structures, in the presence of the heterogeneity and complex geometrical features.

Participation

In-Person

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