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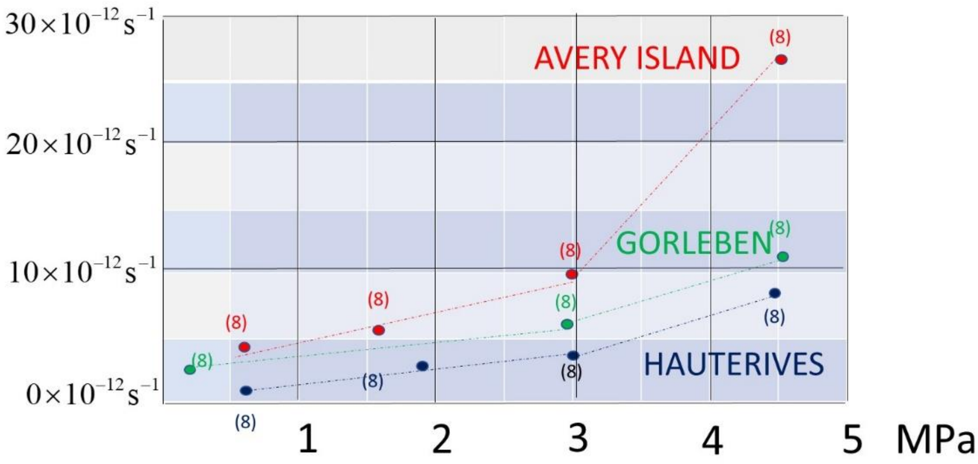
Research
Report
2020-1

SMRI Research Report RR2020-1:

Very Slow Creep Tests
As a Basis for Cavern Stability Analysis
–
PHASE 2

April 2020

EXECUTIVE SUMMARY



Strain-rates at the end of the tests versus applied axial stress during Phase 1 and Phase 2 of the SMRI Program (2015-2019). The number between brackets is the test duration (in months).

In 2014-2016, an experimental program, supported by the SMRI, proved that, in the 0.2 - 1 MPa deviatoric stress range, creep rate of natural salt sample was much faster – by several orders of magnitude – than the creep rate extrapolated from what is currently observed during standard creep tests performed in the 5 – 20 MPa range at the laboratory. Theoretical considerations suggested that pressure-solution, a mechanism in which grain size and brine content play an eminent role, is especially active in the small stress domain. Taking into account the significance of this result for the computation of the mechanical behavior of salt caverns, the SMRI supported a follow-up experimental program whose objective was to confirm these findings. This new program included a total of ten tests, eight of them ranging from 8 months to 24 months and performed in the Altaussee Mine, where temperature and humidity experience exceedingly small fluctuations. The two other tests were performed in laboratories at Leipzig (IfG) and Rapid City (RESPEC). In addition, Ecole Polytechnique supported four additional creep tests, also described in this Report.

Loads of 1.5, 3 and 4.5 MPa were applied successively during 8 months to three samples from the Hauterives, Avery Island and Gorleben sites, which had been tested during the 2014-2016 “Phase 1” program under loads smaller than 1 MPa. They proved that, in the 0.2 - 3 MPa range, in sharp contrast with what is currently observed in the 5 – 20 MPa stress range, in the case of the Hauterives and Avery Island salt samples, the relation between strain rate and applied stress is linear, a characteristic feature of pressure solution; the associated viscosity is $\eta = 3\times10^{16}$ Pa.s in the case of Avery Island salt. Linearity is lost when the applied load is 4.5 MPa. As during earlier tests, the Gorleben sample experienced apparent swelling, the origin of which remains poorly understood.

The role of brine content was explored by performing 1-year long tests on 4 samples cored from Avery Island and Leine_Na3 salt. Two samples were tested “Wet” (no special insulation from mine drift humidity) and two were tested “Dry” (they were set in a tight vessel). Wet samples behavior was similar to the behavior observed during the 2014-2016 program, as expected. In sharp contrast, after several months, Dry samples experienced oscillating additional strains whose average value was close to zero, suggesting that creep is nil or very small when the sample contains no brine, a second characteristic feature of pressure-solution.

In order to check that tests performed in the mine provide results similar to those observed during standard creep tests performed at the laboratory, a salt sample from the Avery Island salt mine was tested in Altaussee during 6 months under a 3-MPa deviatoric stress, and shipped back to RESPEC testing facilities at Rapid City, SD, where it was tested for a shorter period in the same temperature conditions (8°C) and under the same deviatoric stress (3 MPa), both in uniaxial and triaxial stress conditions. The observed creep rates were consistent with those observed in the mine. At the same time, 3-year long creep tests were performed at the IfG facility at Leipzig, Germany, under small loads (2 MPa, typically). The creep curves obtained during these tests were slightly less smooth than in the Altaussee mine; however, here again, strain rates were consistent with what was observed in the mine.

Additional long creep tests were performed under 0.2 and 0.6 MPa on salt samples cored from a salt formation in Les Landes, in southwestern France. After one year, steady-state creep rates were faster than what was observed for the Gorleben, Avery Island and Hauterives samples when the same stresses were applied, suggesting that creep rate is faster when grain size is smaller – a third characteristic feature of pressure-solution creep mechanism.

A creep test was performed on an Avery Island salt sample under a 0.02-MPa stress – the smallest ever load applied on a sample. Creep rate was very small but somewhat erratic, and such a load might be the lower bound of what can be reasonably applied using this testing set-up.

A creep test was performed on a salt monocrystal. After a several months transient period, strain rate oscillated around a zero value, indirectly supporting the idea that grain boundaries are needed for activation of the pressure-solution mechanism.

The tests performed during this “Phase 2” of the SMRI program strongly support two notions: in the 0.2 – 3 MPa range, creep rates are much faster than what can be extrapolated from current creep tests (performed at low temperature in the 5 – 20 MPa range); and this transition can be explained by the pre-eminent role played by pressure-solution in this stress range (Spiers et al., 1990, Urai et al.,1986, Ter Heege et al.,2005, Urai and Spiers, 2007, Urai et al., 2008; see also Conclusions of this Report.)