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"High Frequency Cavern Cycling – Phase 2: Cyclical Loading Effects on the Dilation and Creep Properties of Salt"

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5.0 SUMMARY and CONCLUSIONS

Cyclic loading tests were performed on cylindrical specimens of Avery Island domal salt at two stress state conditions: one where dilation should not occur and one where dilation was expected. The tests were performed at a single temperature of 30°C. Replicate tests were performed by two different laboratories (RESPEC and TUC) using similar test protocols but different test systems. To aid in reducing the specimen-to-specimen variability in results, all test specimens were recovered from the same borehole at the Avery Island Mine in Louisiana, USA. All specimens were preconditioned using an isostatic stress of 20 MPa for 2 weeks before cyclic testing commenced.

The test results for the same test conditions were highly reproducible between the two laboratories and the specimen-to-specimen variability was minimal. The same test conditions were used by both RESPEC and TUC and test results matched. Thus the variability between laboratories was judged to be minimal. The specimen-to-specimen variability was judged by comparing two identical tests performed at the TUC laboratory; both specimens yielded similar results, so variability within the salt core was judged to be minimal. With this low level of variability between laboratories and between specimens, the experimental results were considered to be robust.

The cyclic testing was performed by sequentially applying a 30-day-long series of stress cycles under high mean stress (where dilation was not expected) followed by a second 30-day-long sequence of stress cycles under a low mean stress condition (where dilation was expected). The occurrence (or lack thereof) of dilational behavior was determined by measuring changes in specimen volume (RESPEC) and by changes in ultrasonic velocity through the specimen (TUC). Both approaches led to the same conclusion that dilation occurred only at the lower mean stress where it was expected. While the axial strain increased during the dilational phase, it was not uncontrolled, so the creep deformation from cyclic loading did not appear to be significantly different than that from conventional static loading.

The cyclic creep test data generated in these tests were compared to static creep tests performed at similar test conditions. The comparison was made by removing the low stress difference segments of the cyclic tests (representing an unloading condition) and concatenating the high stress difference segments of the cyclic tests to create a continuous series similar to a conventional static loading creep test. The comparison indicated that the cycling of the applied stress did not have a dramatic effect on the specimen creep rate as long as the applied stress was not in the dilational regime. The concatenated cyclic test was also compared to a numerically simulated creep test at the same stress and temperature conditions of the cyclic test. The simulation used Avery Island properties in the M-D constitutive model and the comparison matched closely for the nondilational loading segment (Phase 1).

To check whether or not the cyclic loading had induced significant damage in the specimen, a third phase of cyclic loading was applied at the same test conditions used in the first non-dilational phase. The specimen response in Phase 3 replicated the behavior observed in the first phase of loading (Phase 1). Thus it was presumed that the intervening second phase of loading at dilational stress conditions, while causing some microfracturing, did not damage the specimen so significantly that recovery processes were not viable.

The observations that the first and third phases of cyclic loading at nondilational stress states were very similar to static tests and behavior predicted by an Avery Island constitutive model for creep led to the conclusion that cyclic loading is not significantly more hazardous than static loading (at least for these durations at these stress and temperature conditions).

The testing presented here is limited and should be supplemented by additional investigations. Three suggestions are:

1. The possible impacts of thermal cycling should be investigated to assess the significance of thermally induced stresses. Temperatures greater than the 30°C used in this study might reduce brittle behavior and promote more ductility in the salt, which could reduce the risk of dilation in the salt.
2. The role of changes in the intermediate principal stress should also be investigated because a common stress state in the cavern walls is one of extension rather than compression. The tests reported here are compression tests (axial stress > confining pressure) that cause shortening of the specimen; whereas, extension tests (axial stress < confining pressure) result in an elongation of the specimen. Dilation is more likely in extensional states of stress, but there is a need for data to assess if cyclic loading worsens this condition.
3. There is still the issue of how the frequency of cyclic loading affects the salt. The current results indicate that if cyclic loading continued at dilational stress states, the damage would continue to accumulate and ultimate failure would result. However, if the frequency were reduced, perhaps the recovery processes during the unloading condition would retard or eliminate the damage induced during the hardening phase of the cycle. The recovery processes during the unloaded state of a cyclic load are not well understood and could play a significant role in reducing dilation risk. Additional lower frequency cyclic tests should be performed (perhaps 2 weeks per cycle) that could be compared to the 2-day frequency reported here (and the much higher frequency testing reported in the literature).