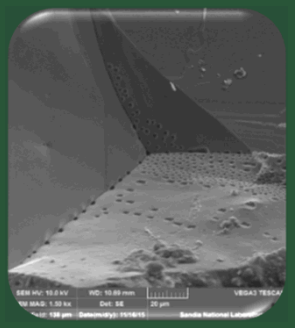
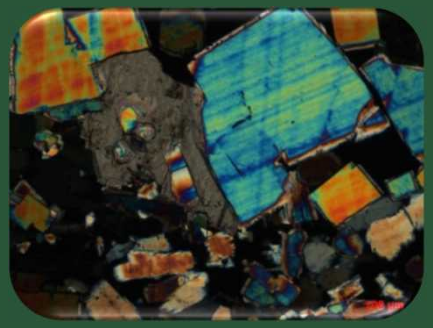



Testing Shear Strength and Deformation along Discontinuities in Salt

8th US/German Workshop on Salt Repository Research, Design, and Operation

Steven R. Sobolik, Sandia National Laboratories, Albuquerque, New Mexico, USA
Stuart Buchholz, RESPEC, Rapid City, South Dakota, USA

Middelburg, The Netherlands

September 5-7, 2017

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND2017-XXXX.

Test Proposal

Purpose:

- To measure, evaluate and quantify effects of shear displacement along a bedding interface or clay seam on shear and fracture strength of the interface and accompanying salt.
- Evaluate bedded salt modeling concerning deformation, failure at seams, and bedding planes.

Expected outcome:

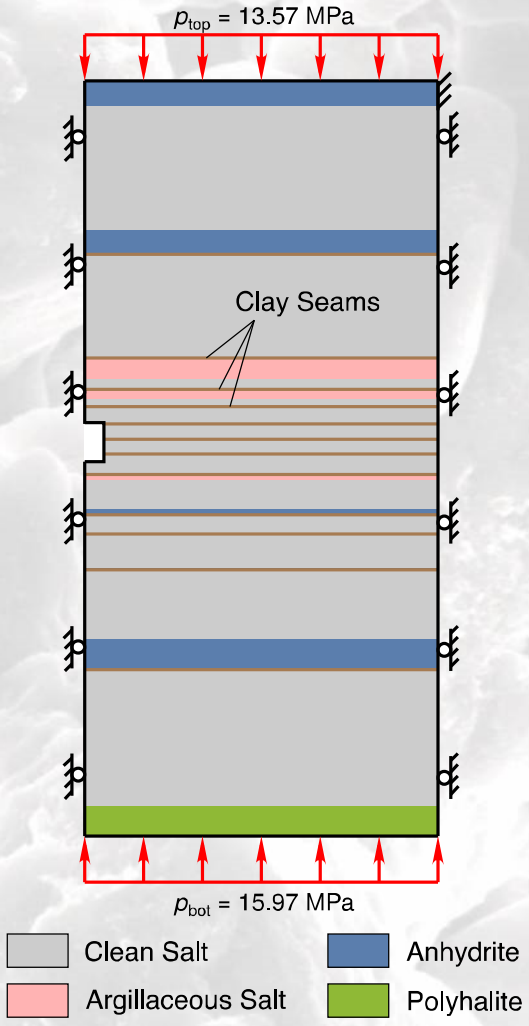
- Improve understanding of shear stresses and strains on bedding interfaces that can be translated to current geomechanical and performance assessment models.
- Reduce uncertainty.

Test Phases

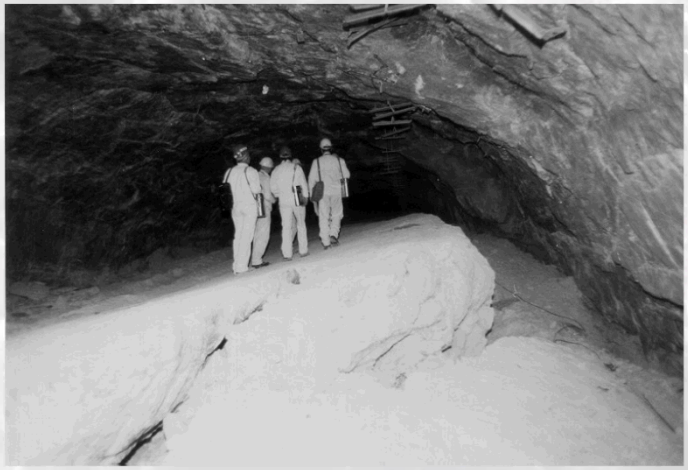
- Scoping laboratory tests of shear across interfaces using controlled samples (blocks of different materials such as anhydrite and halite) and samples obtained from the field (halite with included clay seam) – Autumn 2017.
- Numerical modeling of laboratory results to develop appropriate shear friction/fracture models – 2017-2018.
- Underground tests in alcove wall with clay seam or similar interface – 2018 (maybe).

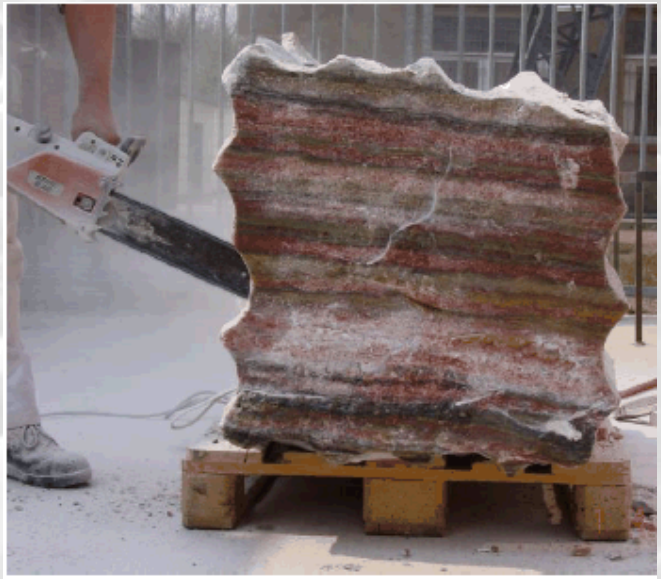
Discontinuities in salt

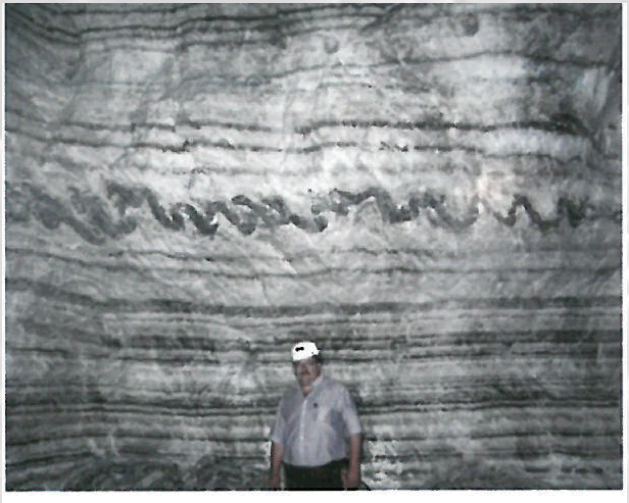
- Influence of nonhomogeneities in repository performance identified as 1 of 4 key areas of the research agenda
- Examples include bedding interfaces, boundary shear planes, joints, and seams of non-halite material such as anhydrite
- Does shear strain create a permeable flow path along an interface or premature salt failure?
- Little existing lab or *in situ* data to characterize shear strength of salt interface and effects of shear on interface displacement and permeability

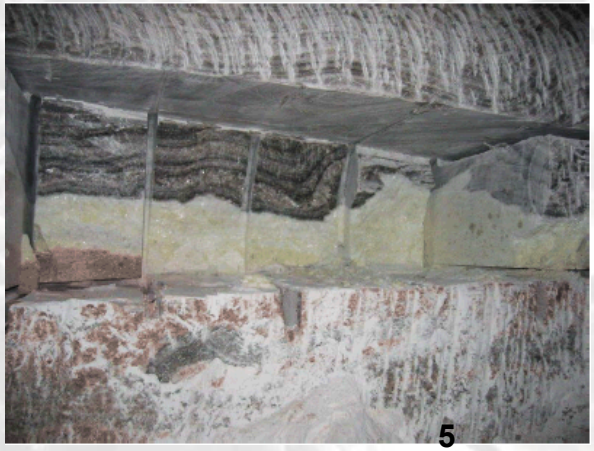


Discontinuities in salt (Popp, Van Sambeek)



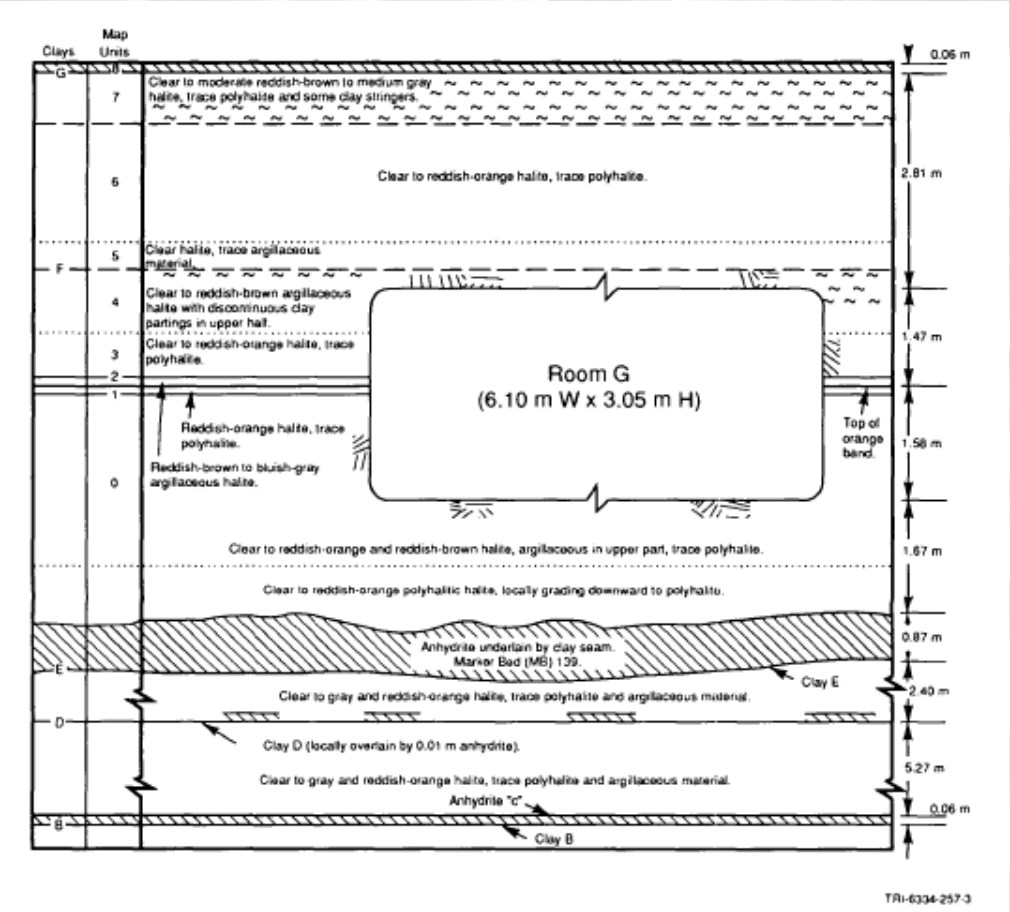






Early test proposed for WIPP

- Munson & Matalucci (1983) proposed in situ test with direct shear across clay seam.
- 1 X 1-m block in wall containing representative clay seam would be isolated by cutting around it in place in one of the drifts.
- Flatjacks installed in slots cut around the block to apply shear and normal stresses.
- Displacements along and across the seam would be measured as function of applied stress.
- This proposed test never occurred.



Laboratory testing in 2017

Test description: Series of laboratory tests to begin in late 2017 to be used in conjunction with WIPP, WEIMOS modeling exercises.

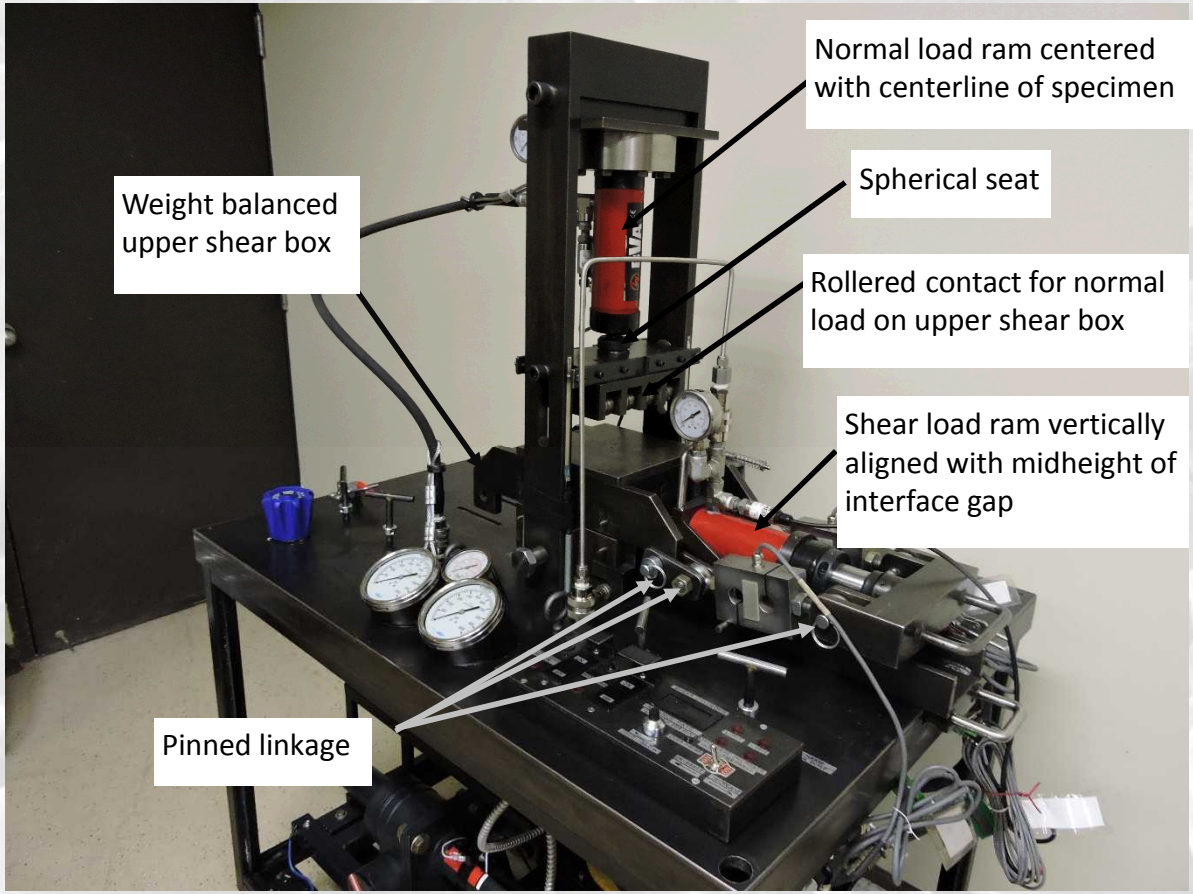
- Test plan written, completed WIPP QA reviews 7/27/2017.
- Contract modification between SNL, RESPEC in process, pending DOE requirements for WIPP; NEPA checklist completed 8/7/2017
- Plan to obtain cores for up to 33 test samples from Intrepid potash/salt mines:
  - 30 cm diameter, 56 cm length cores cut vertically from floor
  - Cores to contain clay seam identified from further uphill in drift
  - Test samples cut from cores will be 10-cm cylinders or square blocks
  - Seam size no greater than 2.5 cm; or interface between distinct layers
  - Material next to seam/interface – halite, polyhalite, anhydrite
  - Asperity characteristics?

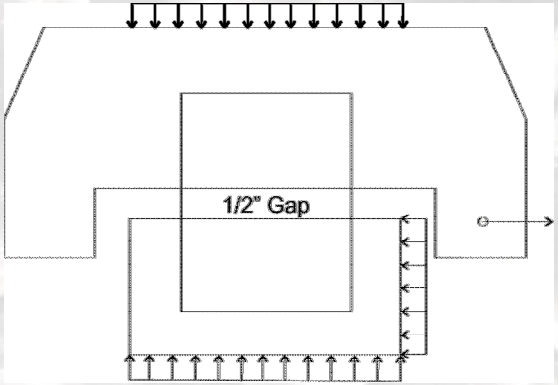
Laboratory testing goals

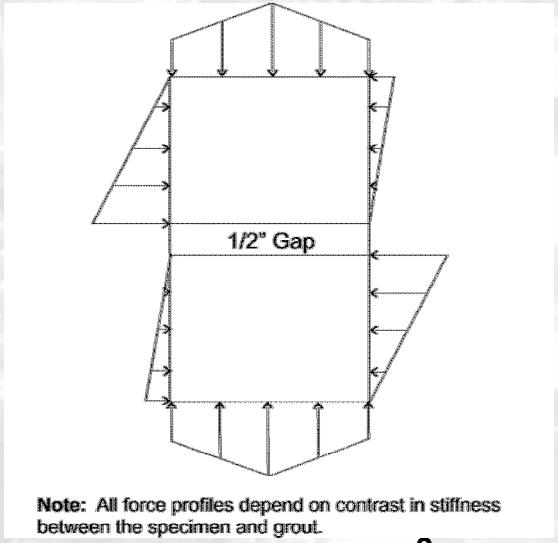
- Laboratory shear tests similar to those on carnalite and salt performed in 2007 (Minkley & Mühlbauer); test results were used for model development.
- 2017 laboratory tests require following:
  - 10-cm samples, with existing or fabricated interface
  - 6.9-20.7 MPa stress capacity both in axial (compression) and shear loading
  - Fixed normal stress for most tests; fixed normal displacement another option
  - Variable shear velocity to evaluate onset of fracture/slip
  - RESPEC direct shear machine (Capacity for up to 15-cm cube samples, 130 kN capacity, shear velocities 0.25-5 mm/min.)
- Analysis plan in process (Reedlunn) to develop constitutive, numerical model for shear slip in seams from results of 2017 lab tests.

Shear Test Setup

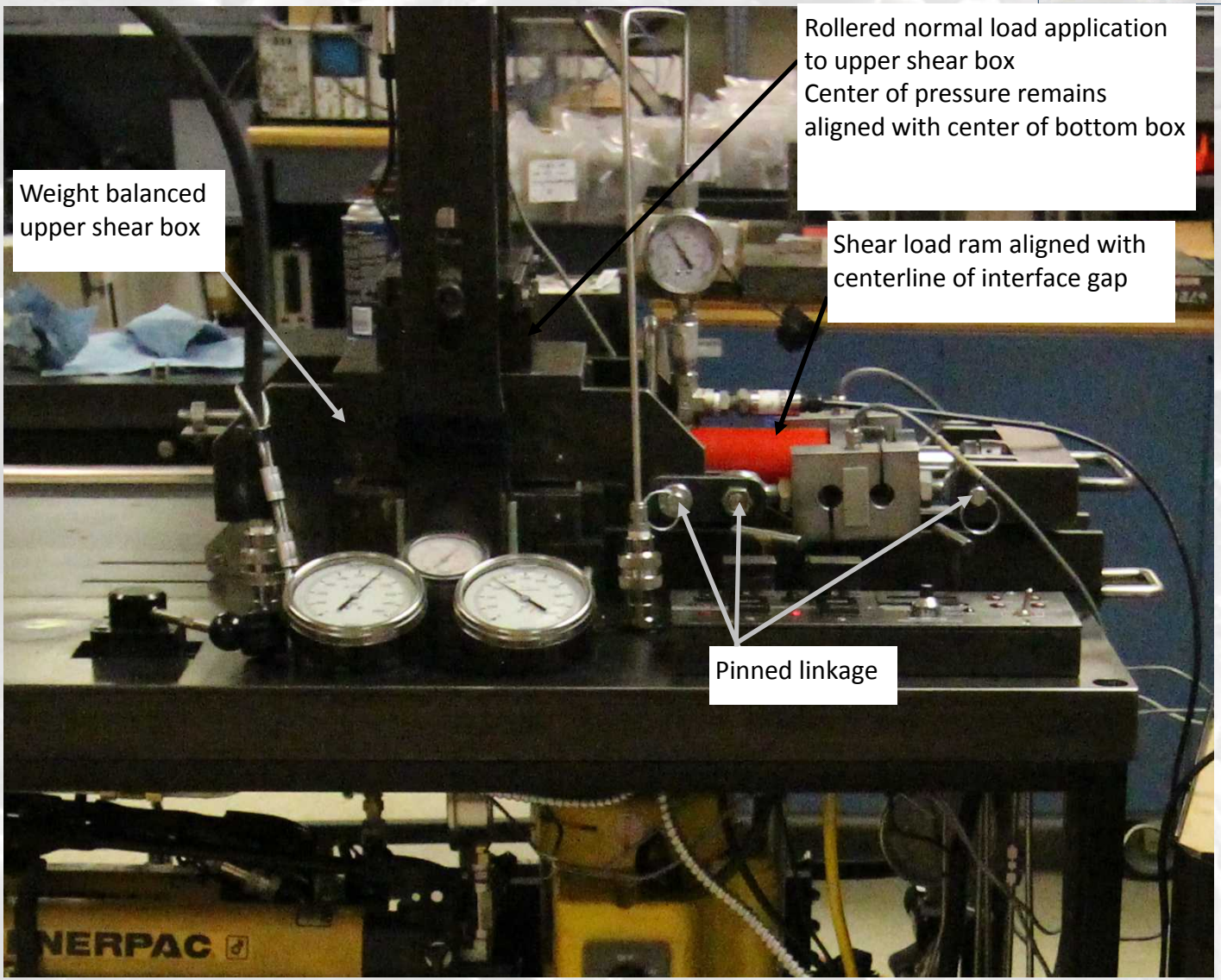
- Similar to Minkley test setup
- RESPEC direct shear machine
- Eliminates bending force due to shear (box that holds specimen)



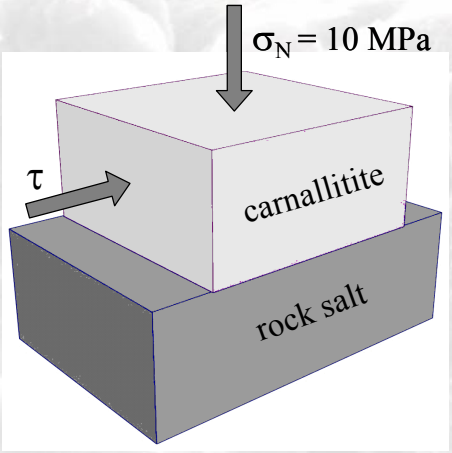




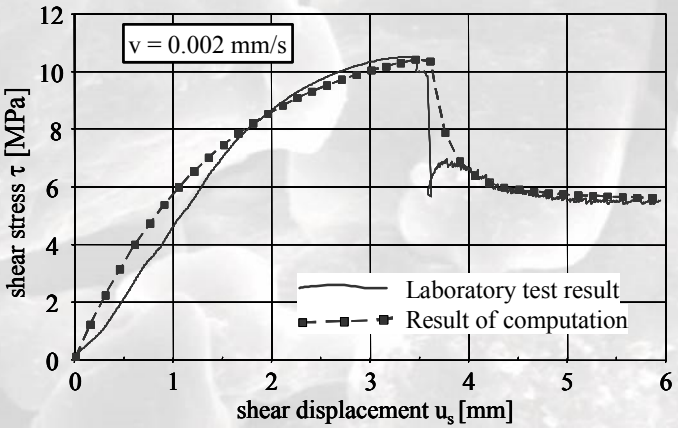
Shear Test Setup (Actual Test)

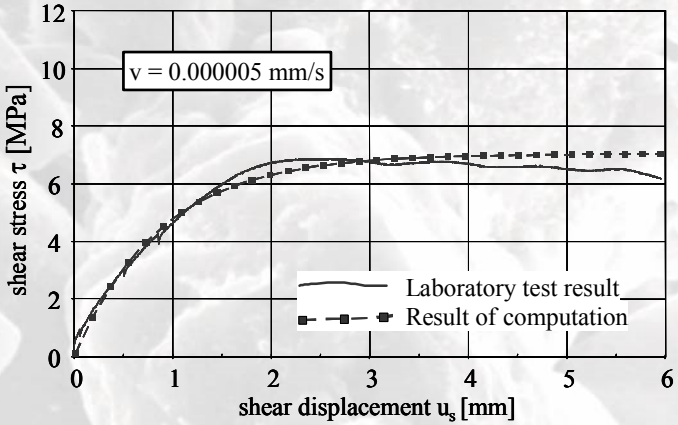


German shear test - velocity



- Dependence of the friction on the velocity of the running shear process is plotted here.
- At high shear velocities, adhesive friction resistance must be overcome before a loss of strength appears. Under such conditions a significant drop in shear stress occurs.
- At low shear velocities, no additional resistance of adhesive friction develops as in the case of a quick movement and, thus, cohesion is maintained.

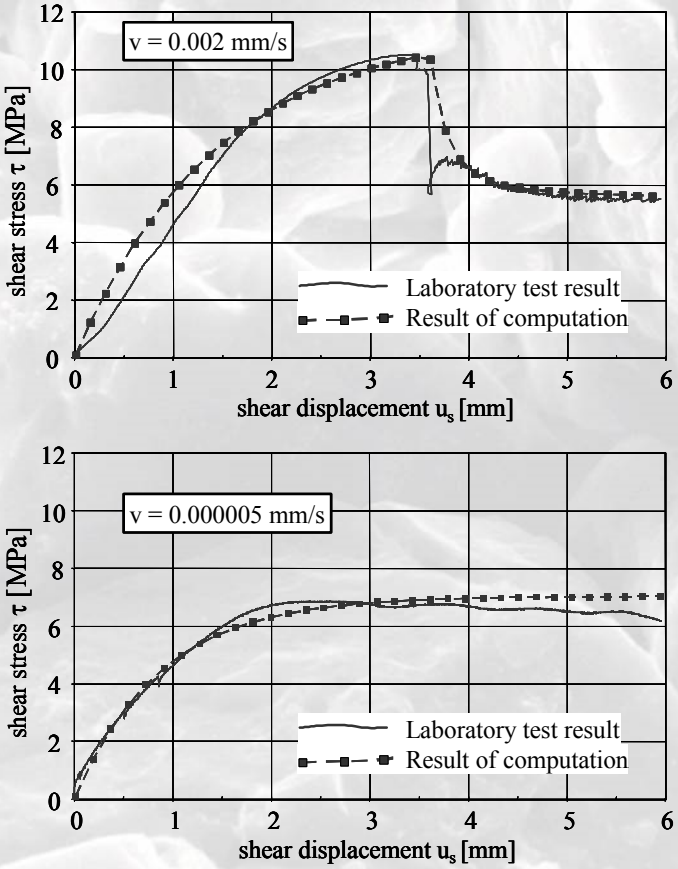




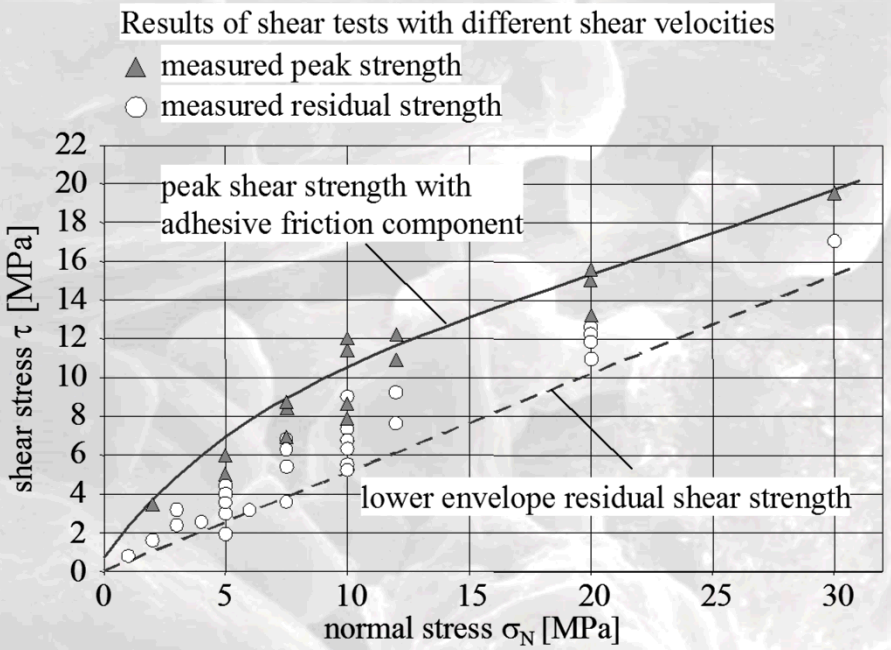
σ_N=10 MPa

Minkley & Mühlbauer (2007) Test Results (Carnallite on salt)

Test Results at Two Different Shear Velocities



Summary of Test Results

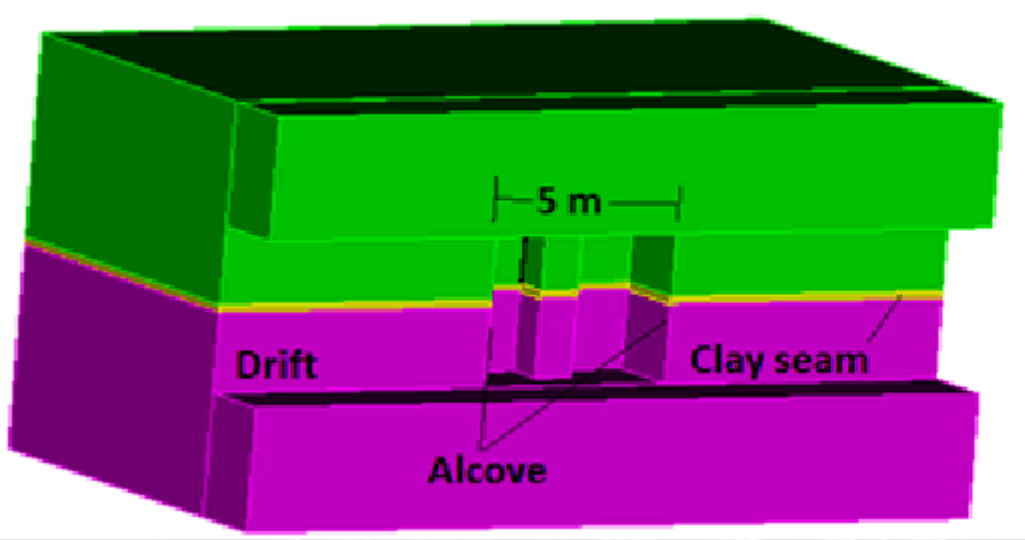


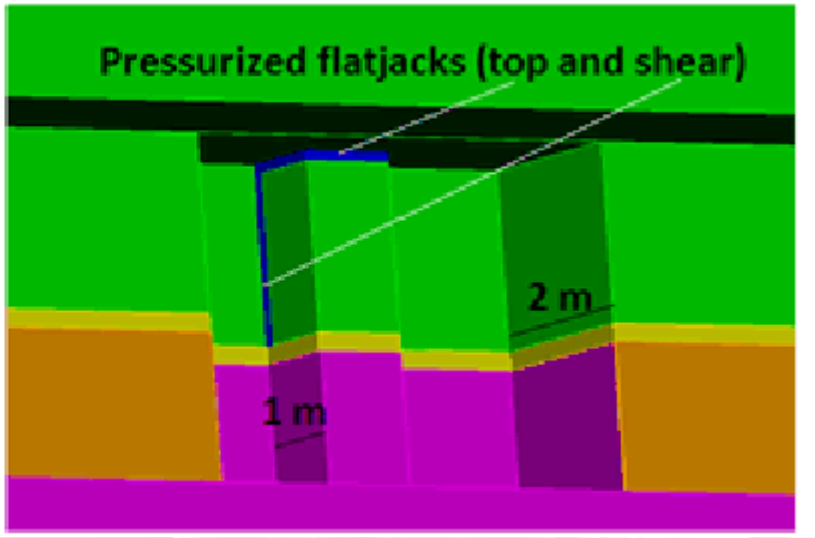
Testing/modeling options that can be considered

- Measure composition of interface
- Seam/interface may be modeled as contact surface, or as thin layer or one of more materials
- Simple Mohr-Coulomb static/dynamic friction coefficient may be first approach
- Select material models, parameters for shear stiffness & strength
- Compare predictions of displacement along interface, change in aperture thickness, based on design, actual pressure application to measured values
- Also consider including long-duration constant pressure, to collect measurements for transient, steady-state creep parameters
- Measure permeability or flow in interface (and changes during test), if feasible
- Ambient test required; additional heated test should be considered

Proposed Slot Test in Salt (2018)

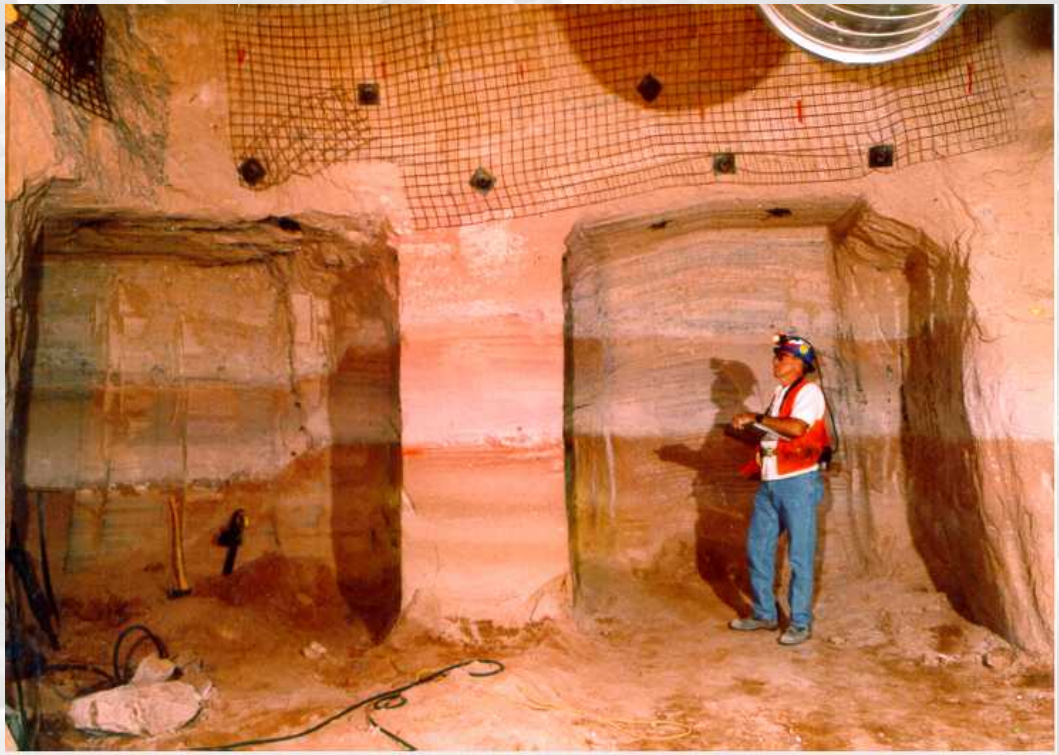
- Alcove with horizontal clay seam, with “room divider” pillar created for test.
- Slots cut in top, back of pillar; pressurized flatjacks installed to produced controlled normal, shear loading.
- Measurements of applied pressure and displacement will capture the evolution of shear-induced characteristics of the inhomogeneity and neighboring salt during the test.
- Pre-test analyses to predict changes to interface.
- Other test configurations considered to eliminate bending moment.



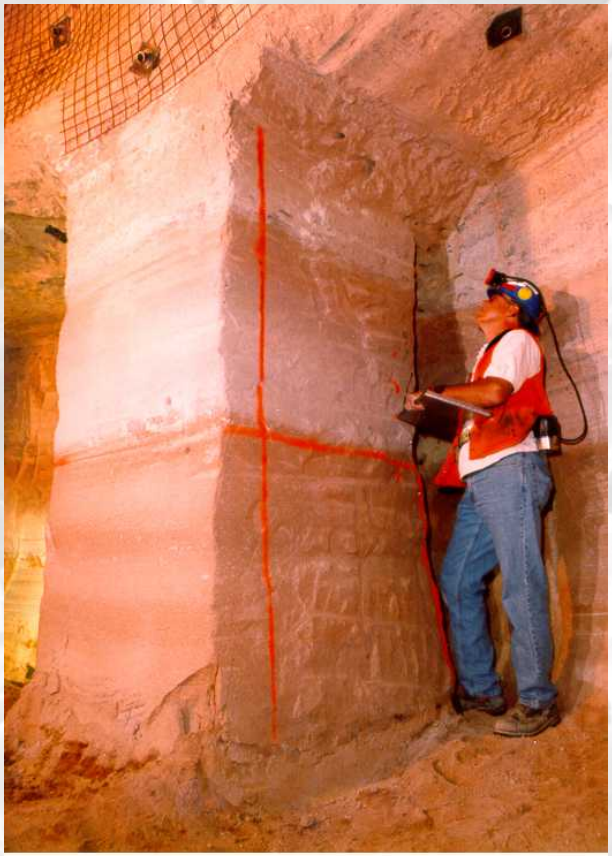


Proposed Slot Test in Salt

- Proposed test alcove will look similar to YMP Busted Butte test shown below (pictures supplied by Los Alamos National Labs)



YM-19894 1 METER BLOCK EXCAVATION ACTIVITIES AT BUSTED BUTTE.



YM-19899- 1 METER BLOCK EXCAVATION ACTIVITIES AT BUSTED BUTTE.

Conclusion

Thank you!