Sandia National Laboratories

DBE TECHNOLOGY GmbH

PTKA Project Management Agency Karlsruhe
Karlsruhe Institute of Technology

5th US-German Workshop
on Salt Repository Research, Design and Operation

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Update on the "Joint Project on the Comparison of Constitutive Models for Rock Salt"

Dr. Andreas Hampel

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Joint Project III on the Comparison of Constitutive Models for Rock Salt

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Managed by

PTKA Project Management Agency Karlsruhe
Karlsruhe Institute of Technology

Project Partners

From Germany (since 2004):

Dr. Andreas Hampel, Scientific Consultant, Mainz

Institut für Gebirgsmechanik (IfG), Leipzig

Karlsruher Institut für Technologie (KIT), Karlsruhe

Leibniz Universität Hannover (LUH), Hannover

Technische Universität Clausthal (TUC), Clausthal-Zellerfeld

Technische Universität Braunschweig (TUBS), Braunschweig (since 2010)

From the United States (since 2010):

Sandia National Laboratories, Albuquerque & Carlsbad, New Mexico

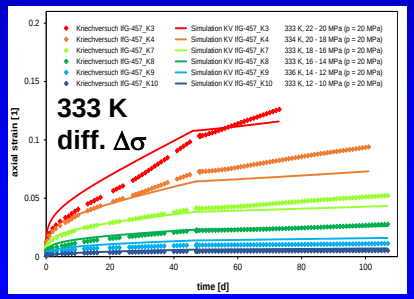
Three Joint Projects on the Comparison of Constitutive Models for Rock Salt

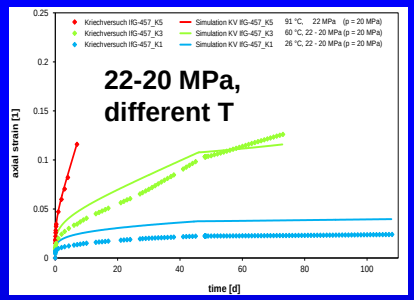
Project	Period	Main Objectives: Document, check and compare ...
I	2004 – 2006	... capabilities of the models to describe reliably the relevant deformation phenomena in rock salt
II	2007 – 2010	... the suitability of the models to perform 3-D simulations, predictions of the future behavior, calculations of permeability
III	2010 – 2016	... the modeling of temperature influence on deformation (part I): • performance of many creep & strength tests with Asse-Speisesalz (IfG) ➢ back-calculations of the lab tests, determination of parameter values • simulations of in-situ borehole tests IFC (isothermal) & HFCP (heated) ... the modeling of damage reduction & healing of rock salt • performance of high-precision healing tests with Asse-Speisesalz (TUC) ➢ back-calculations of the healing tests, determination of par. values ➢ simulation of the “Dammjoch” (bulkhead) in the Asse mine ... the modeling of temperature influence on deformation (part II): o performance & back-calculations of many creep & strength tests with clean salt & argillaceous salt from WIPP (IfG & TUC) o simulations of Rooms D (isothermal) & B (heated) at WIPP

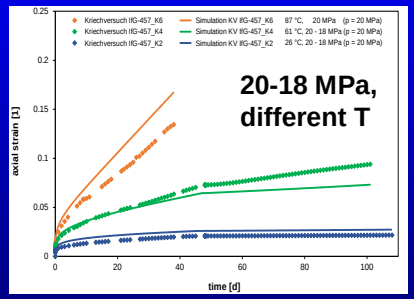
Back-Calculations of Laboratory Deformation Tests with one Salt Type

1. Check the ability of the models to describe the relevant deformation phenomena & dependencies.
2. Determine a <u>unique</u> salt-type-specific set of parameter values for each constitutive model.

transient creep
different T, different Δσ

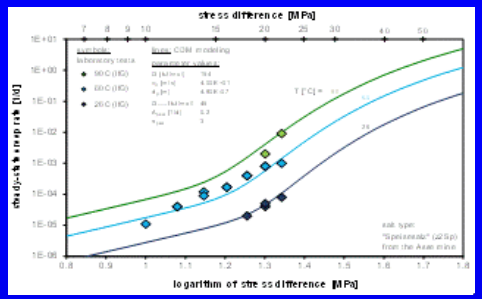






Creep tests and strength tests with Asse-Speisesalz (IfG)

steady-state creep rates
different T, different Δσ



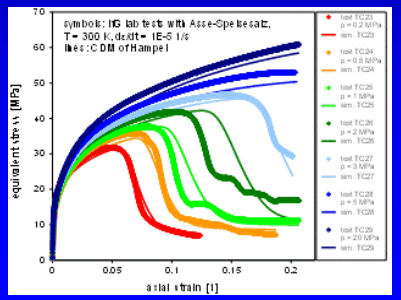
All tests were calculated with the same parameter values

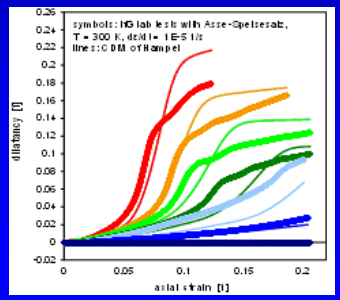
(this example: CDM of Hampel)

stress – strain
different T, different p

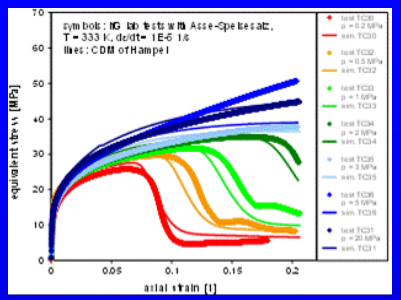
dilatancy – strain

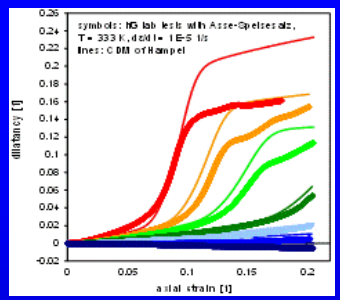
300 K



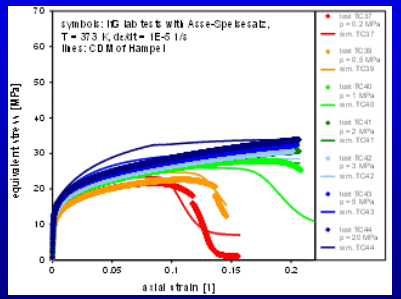


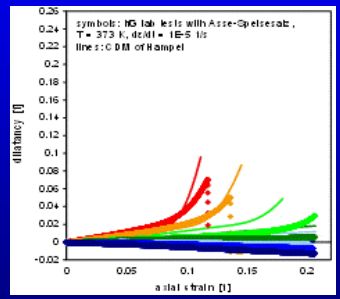
333 K





373 K





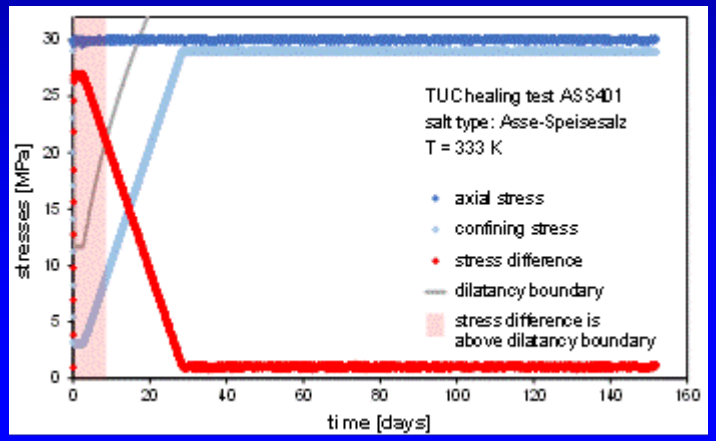
Back-Calculation of Laboratory Healing Tests

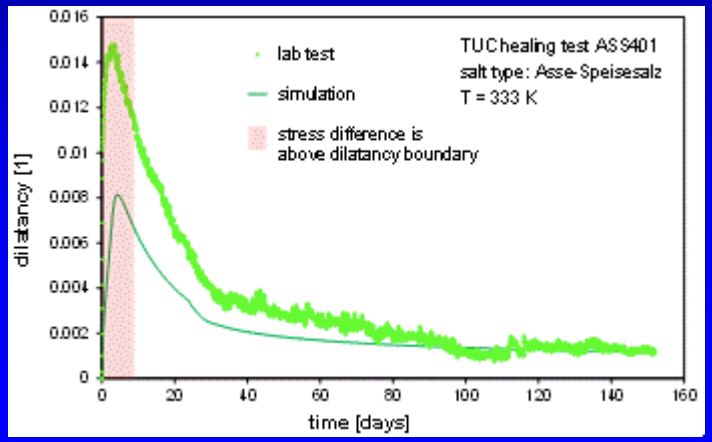
applied stresses

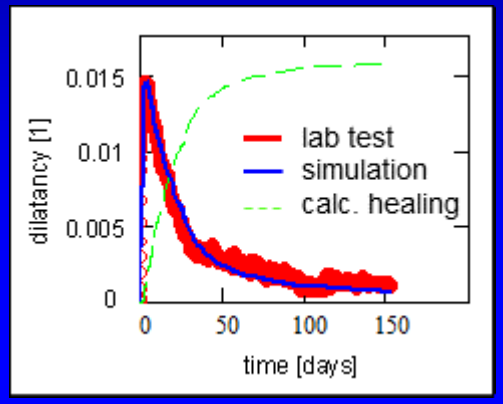
dilatancy calculated with the unique set of parameter values

dilatancy calculated with individual parameter values

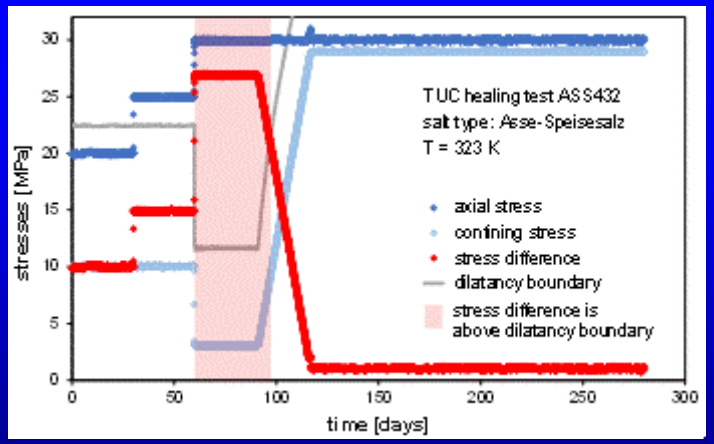
1)

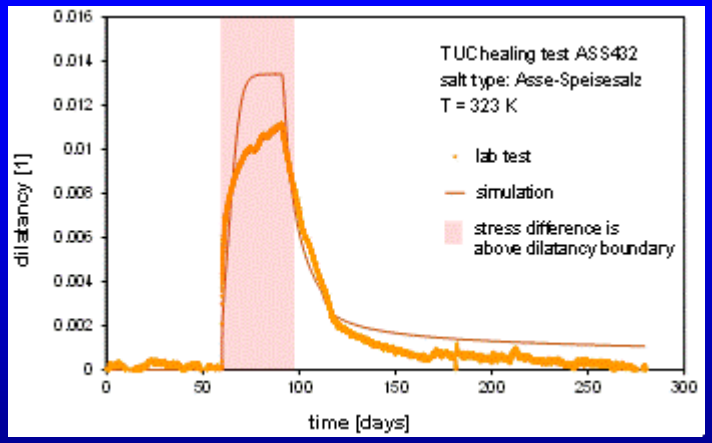


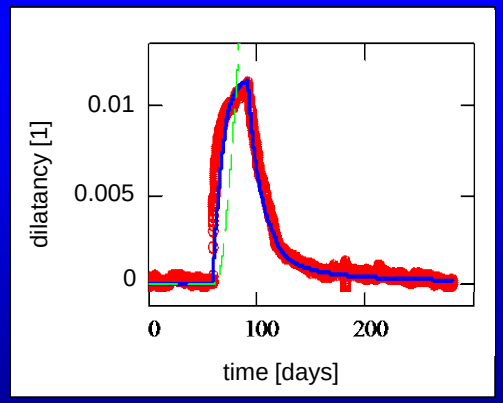




2)





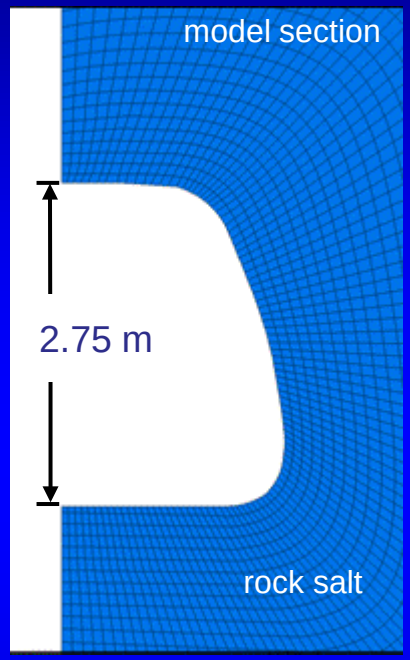


Back-calculations of Hampel (model: CDM, salt type: Asse-Speisesalz)

“Dammjoch” (bulkhead) in a drift at 700 m depth in the Asse Mine

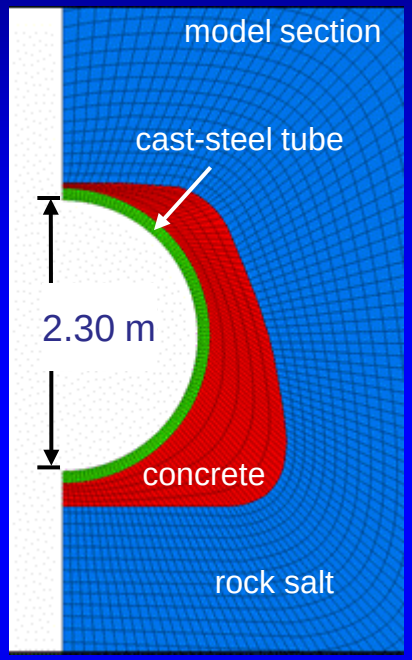
1911: drift excavated, 1914: 25 m long section lined

Photo by Janosch Gruschczyk,
“Asse Einblicke” Nr. 25 (07/2014) BfS, Remlingen, DUMMY Verlag GmbH



Simulation 1:

0 ... 88 a: open drift



Simulation 2:

0 ... 3 a: open drift

3 ... 88 a: drift with bulkhead

drift size: h_{max} = 2.75 m, w_{max} = 3.80 m

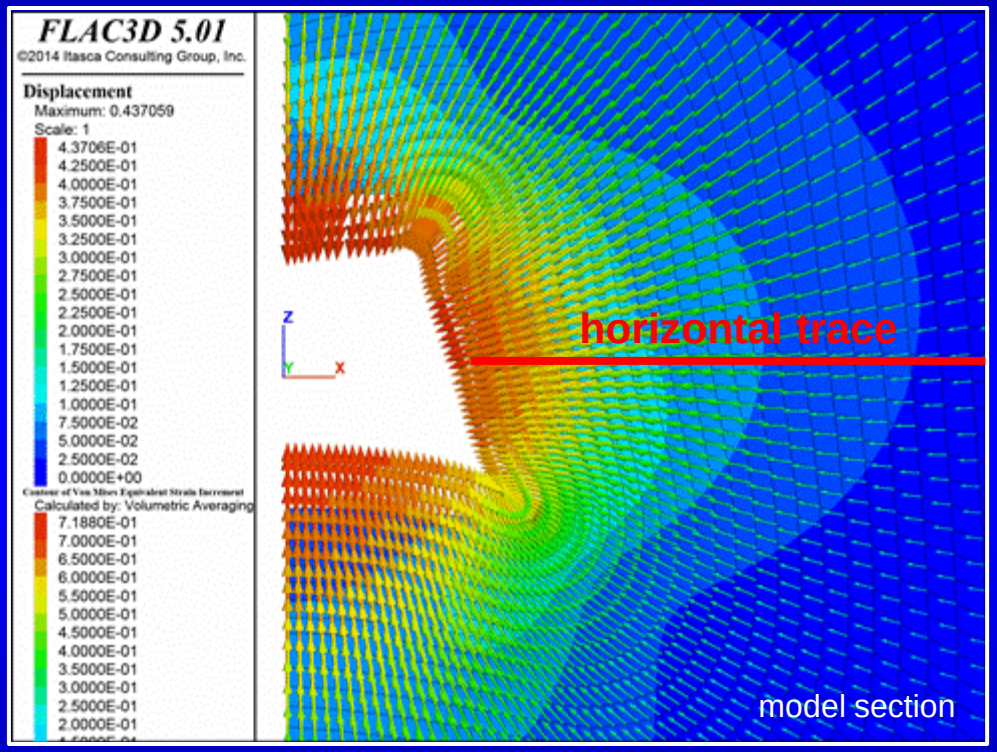
cast-steel tube: $Ø_{in}$ = 2.30 m, wall thickness = 10 cm

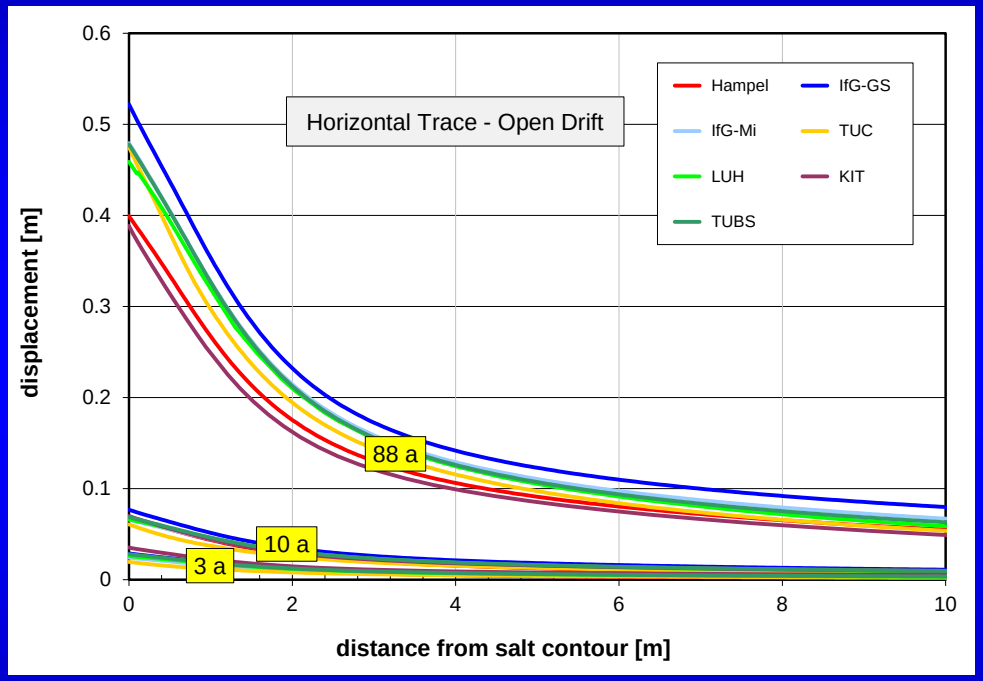
residual gap: concrete

total model size (h x w x d)

100 m x 50 m x 0.05 m

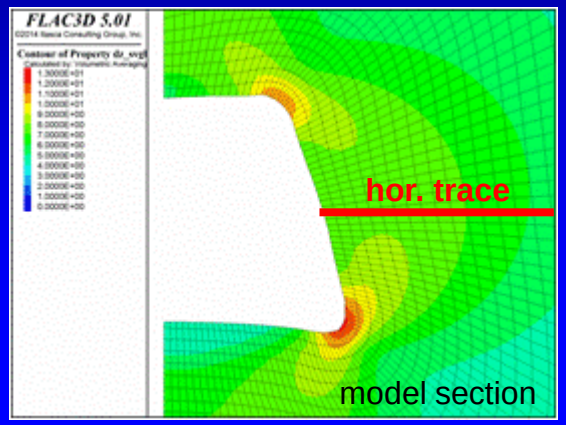
Deformation (Displacements) of the open drift 88 years after excavation



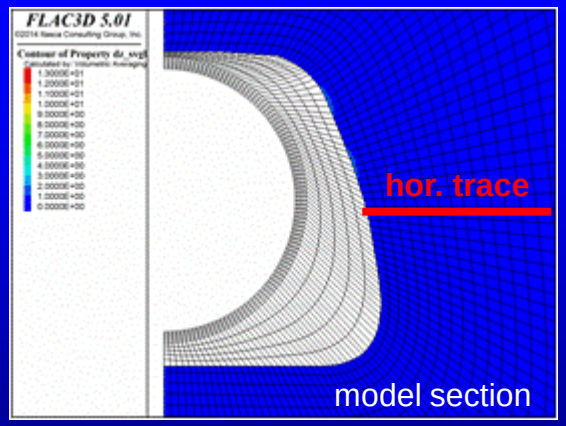


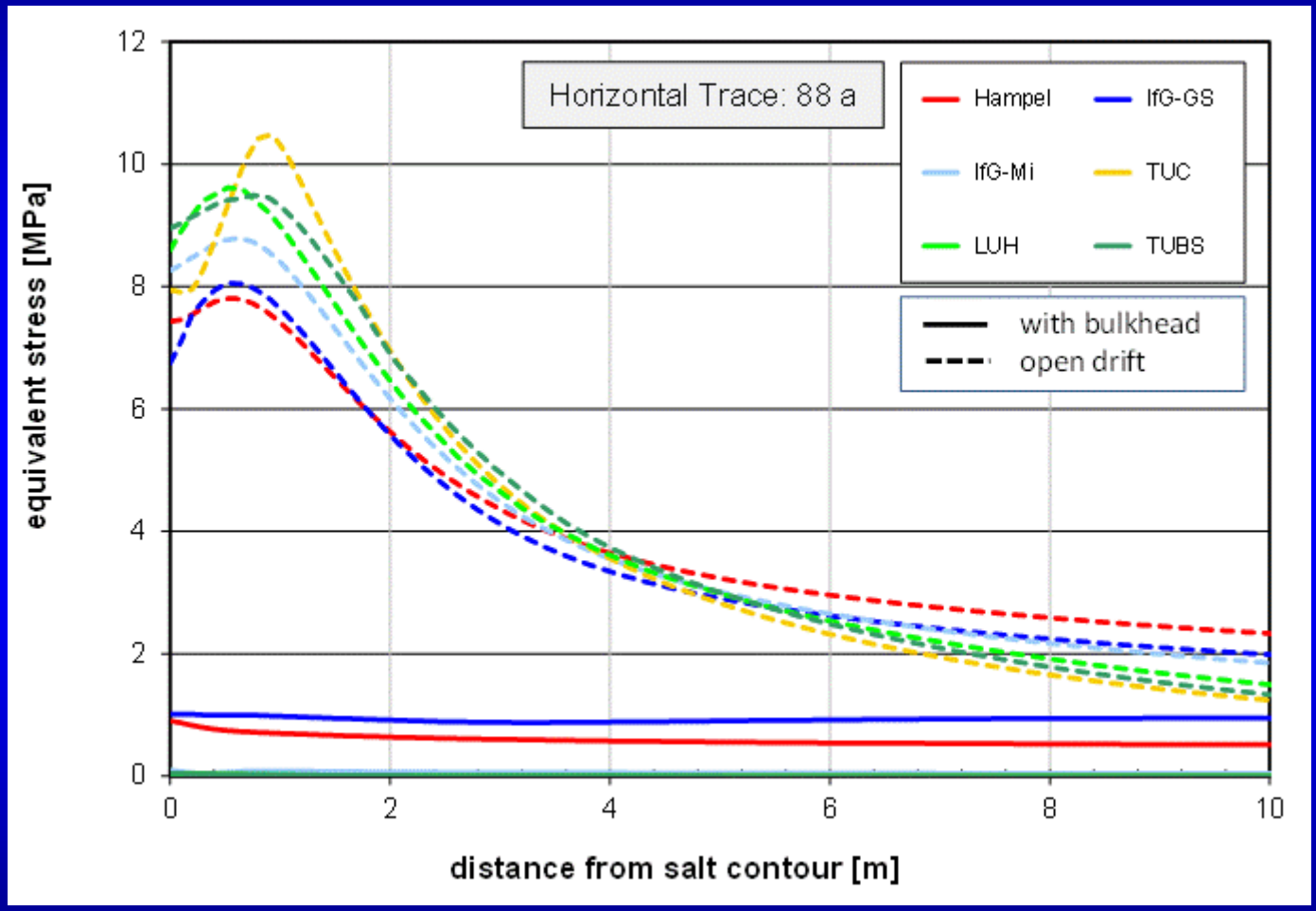
Equivalent Stress 88 years after excavation

open drift



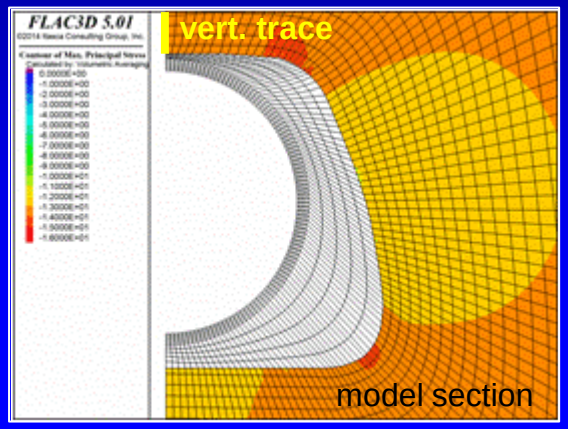
after 3 a with bulkhead



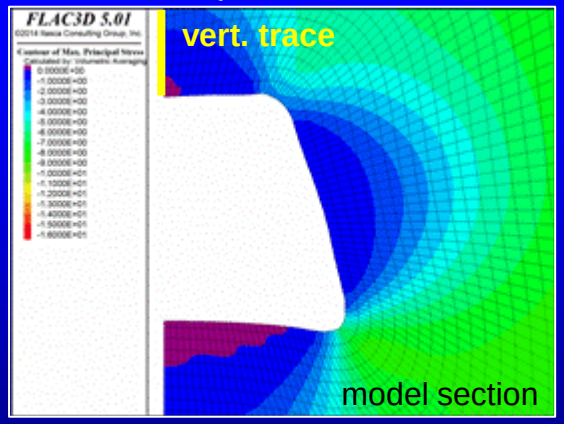


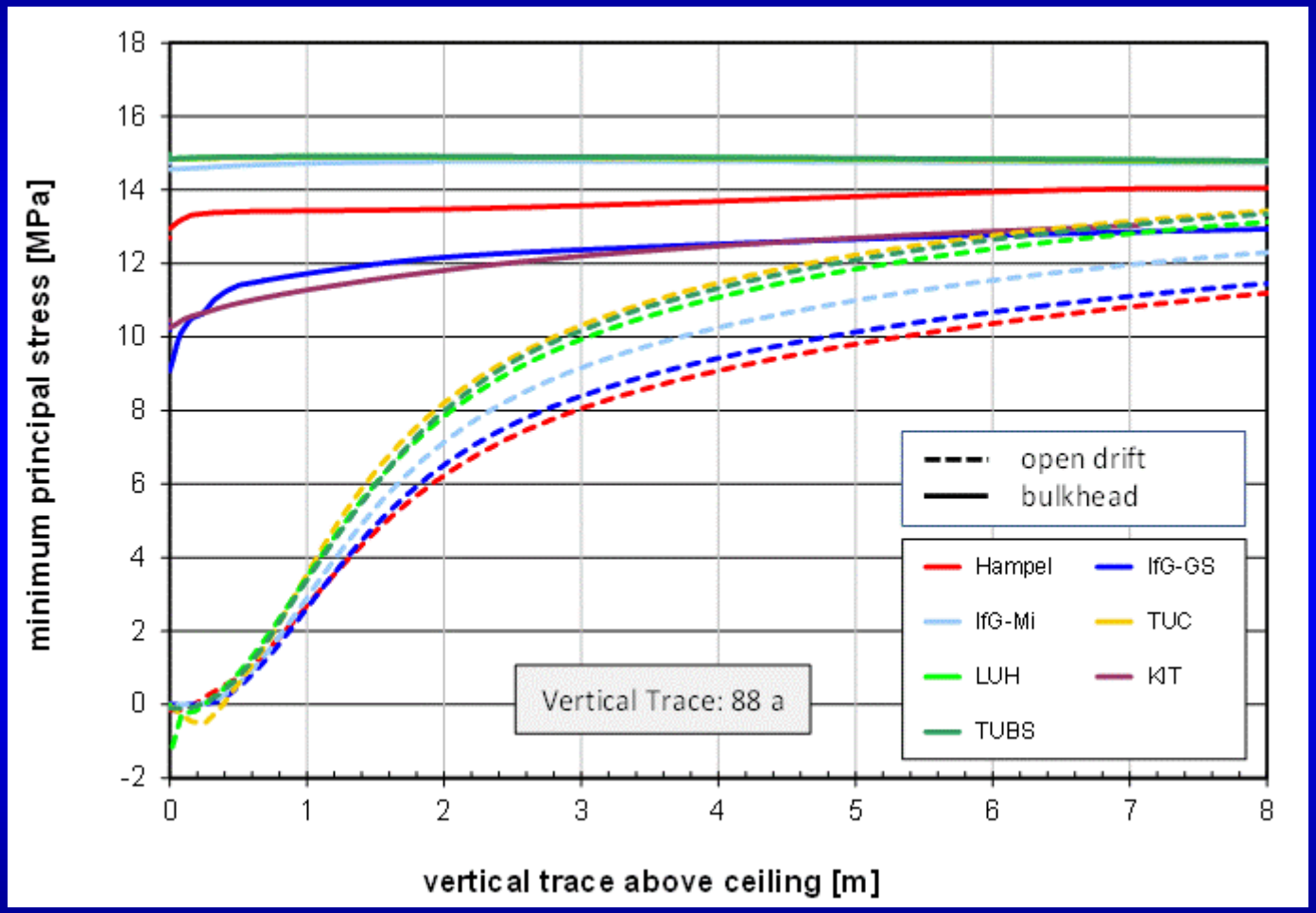
Minimum Principal Stress 88 years after excavation

after 3 a with bulkhead



open drift



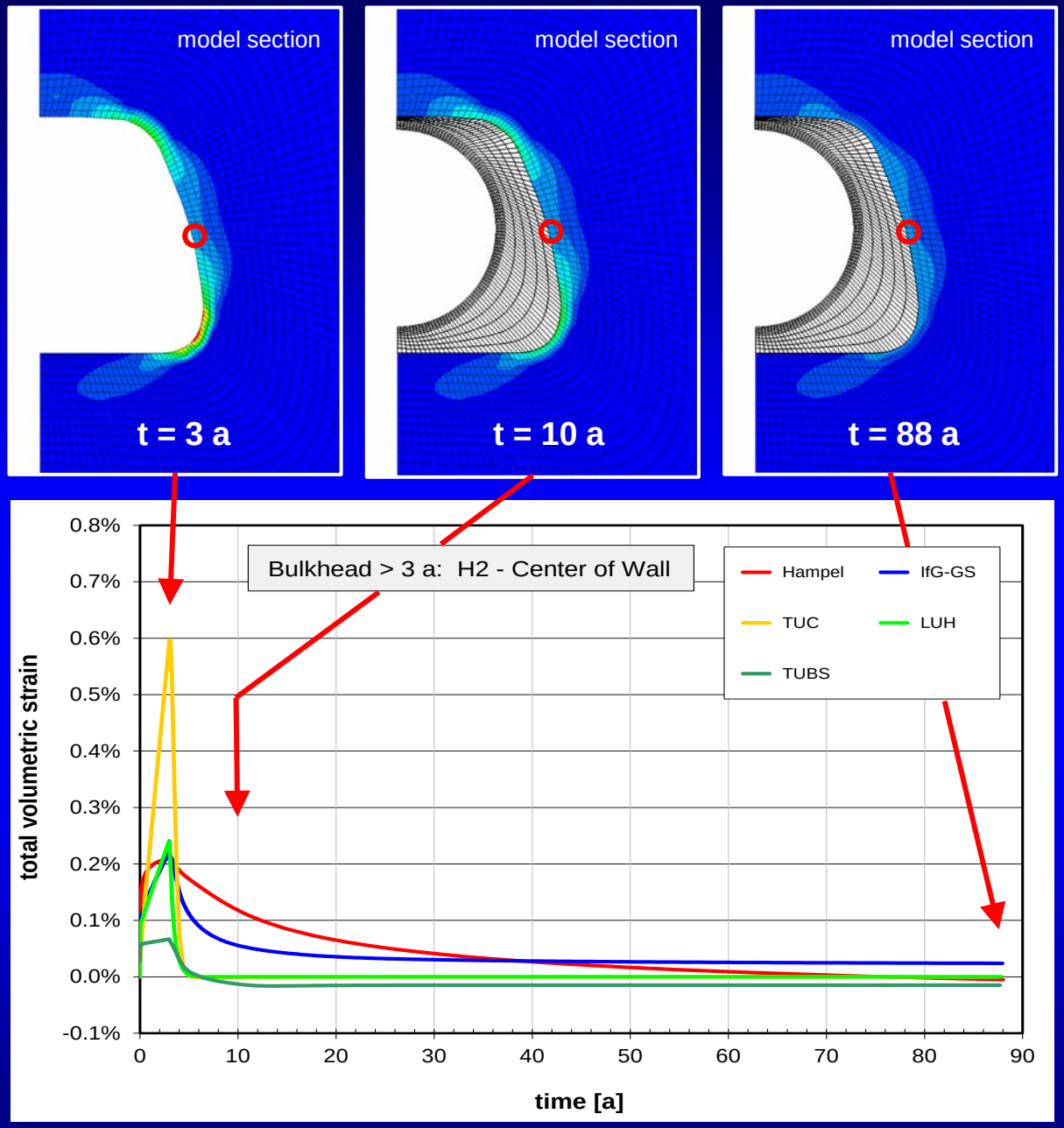


Volumetric Strains (Dilatancy)

Simulation 2:

0...3 a: open drift

3...85 a: with bulkhead



Summary

Joint Project III on the Comparison of Constitutive Models for Rock Salt

Part 2: Modeling of damage reduction and healing of rock salt

Investigations: High-precision laboratory creep & strength tests (IfG Leipzig)

High-precision laboratory healing tests (TU Clausthal)

Benchmarking:

1. Back-calculations of laboratory creep, strength, and healing tests, determination of a unique set of model parameter values

2. Simulations of the “Dammjoch” (bulkhead) in the Asse Mine (88 a)
   1) open drift, 2) drift with bulkhead after 3 years

→ Considered constitutive models are appropriate to model the healing of rock salt.

→ More high-precision experiments and further developments of the models are required.

Open Questions – Subjects for Future Collaborations

~> Joint Project IV on the Thermo-Mechanical Behavior of Rock Salt

- Investigation and modeling of the deformation at small stress differences
- Investigation and further development of the modeling of healing
- Investigation and modeling of the humidity influence on deformation
- Treatment of tensile stresses in model calculations
- Investigation and modeling of contact surfaces (e.g. salt/clay)
- Deeper and more detailed analysis of the bandwidth of modeling results

→ More high-precision laboratory tests and new in-situ underground experiments

→ Joint collaboration on the further development of constitutive modeling