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Numerical Simulation Evaluating the Structural Stability of SPR in the Bayou Choctaw Salt Dome
(ARMA 08-150)

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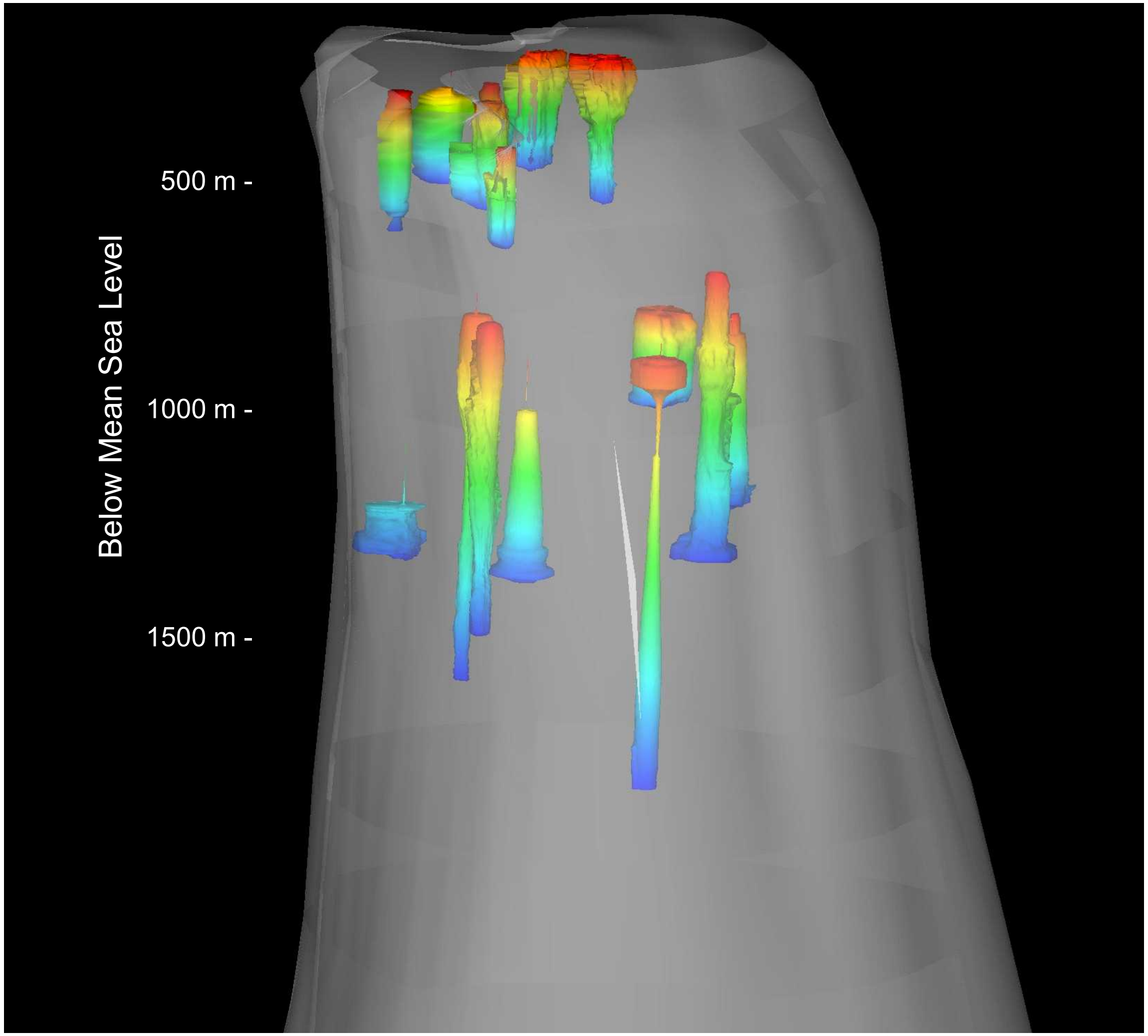
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

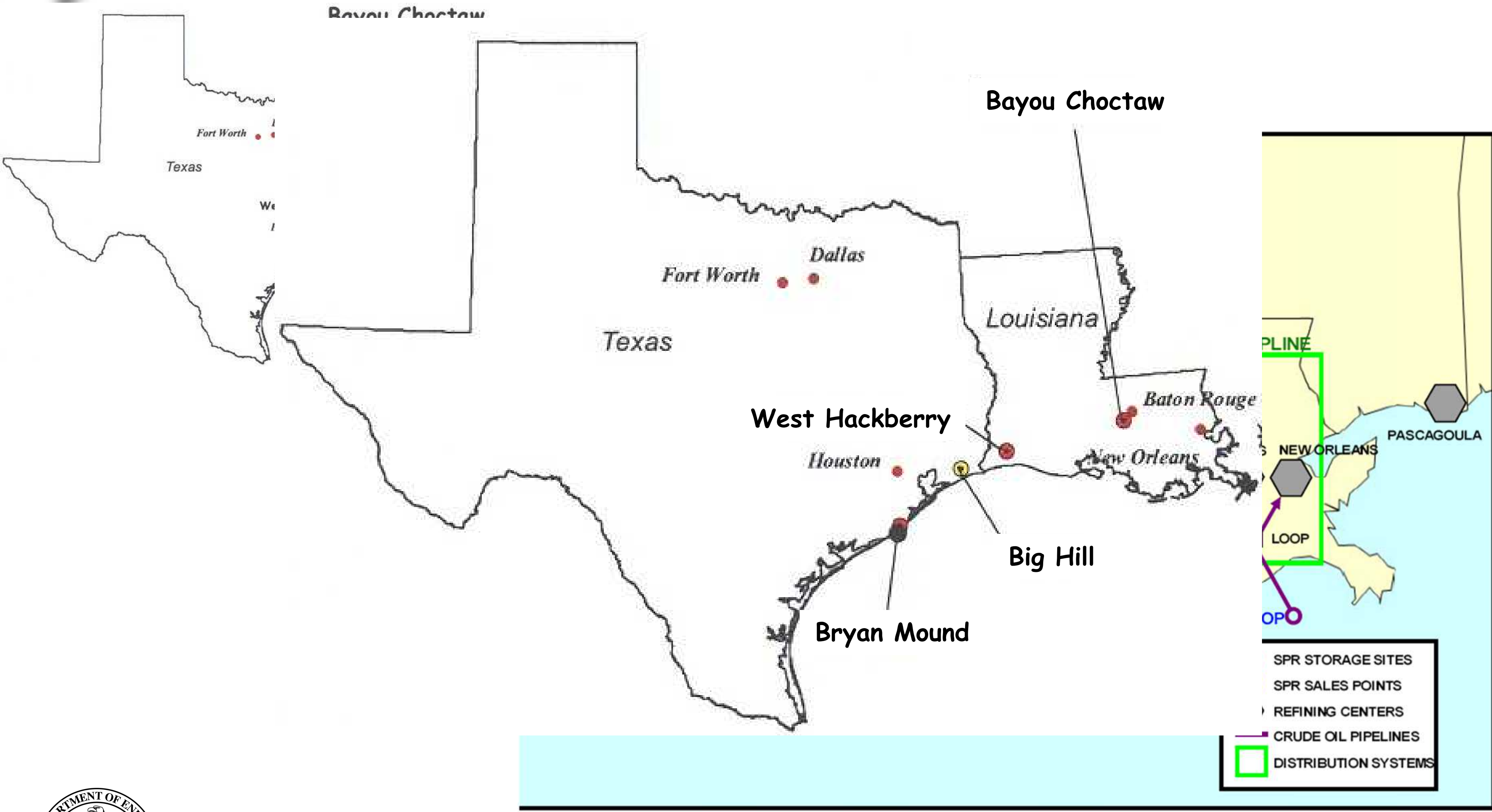
Strategic Petroleum Reserve (SPR)

- A typical SPR cavern holds 10 MMB and is cylindrical in shape with a diameter of 60 meters and a height of 600 meters.
- America's emergency crude oil is stored in salt caverns created deep within the massive salt domes
- These caverns offer a secure and affordable means of storage, costing up to 10 times less than aboveground tanks and 20 times less than hard rock mines



Caverns within Bayou Choctaw Salt Dome

Storage Sites and Distribution System



SPR by the numbers

- 62 SPR caverns at four different site
- Current storage capacity = 727 MMB
- Current days of import protection in SPR = 59 days
- Average price paid for oil in the reserve = $27.73 per barrel
- Time for oil to enter US market = 13 days from presidential decision
- Investment to date = $22 billion ($5 billion in facilities; $17 billion for crude oil)
- Past emergency sales:
  - 1991 Desert Shield (Gulf war) = 17 MMB
  - 2005 Hurricane Katrina sale = 11 MMB

Background

- The Energy Policy Act of 2005 directed the Secretary of Energy to fill the SPR to its authorized one billion barrel capacity.
- At a typical 10 MMB barrels per salt cavern, this means another 27 caverns need to be added to the existing complex.
- If shown to be feasible, the current capacity of Bayou Choctaw (76 MMB) may be expanded to 109 MMB.

Necessity of 3D Modeling

- Most of SPR caverns can be typified as cylindrical in shape and were solution mined at approximately the same depth.
- The exceptions to this are the 24 caverns at Bayou Choctaw. The geometry, spacing, and depths of the caverns are irregular.
- A 3D FEM model allowing analysis of each cavern individually needed to be constructed.

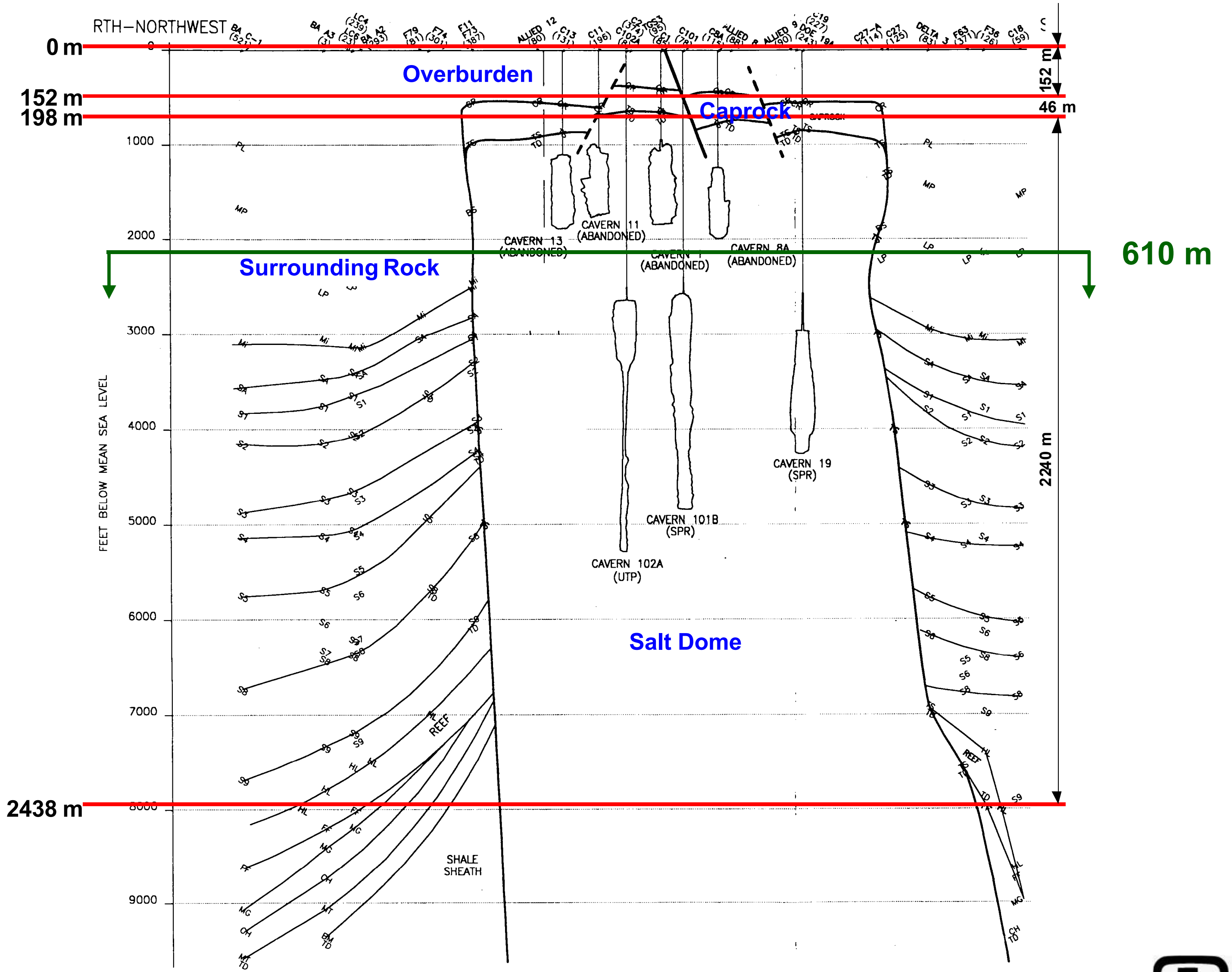
Objectives

- This study attempts to model this geometric condition and addresses the resulting performance and stability issues:
  - Geotechnical concerns arise due to the close proximity of the some of the caverns to each other (e.g., Caverns 15 and 17)
  - Or to the edge of salt dome (e.g., Cavern 20).
  - The salt volume beneath Cavern 4 is being considered as a location of new SPR cavern.
  - Cavern 7 was leached in 1942 and collapsed 12 years afterwards. Cavern 4 in the similar condition is believed to be in a quasi-stable condition.

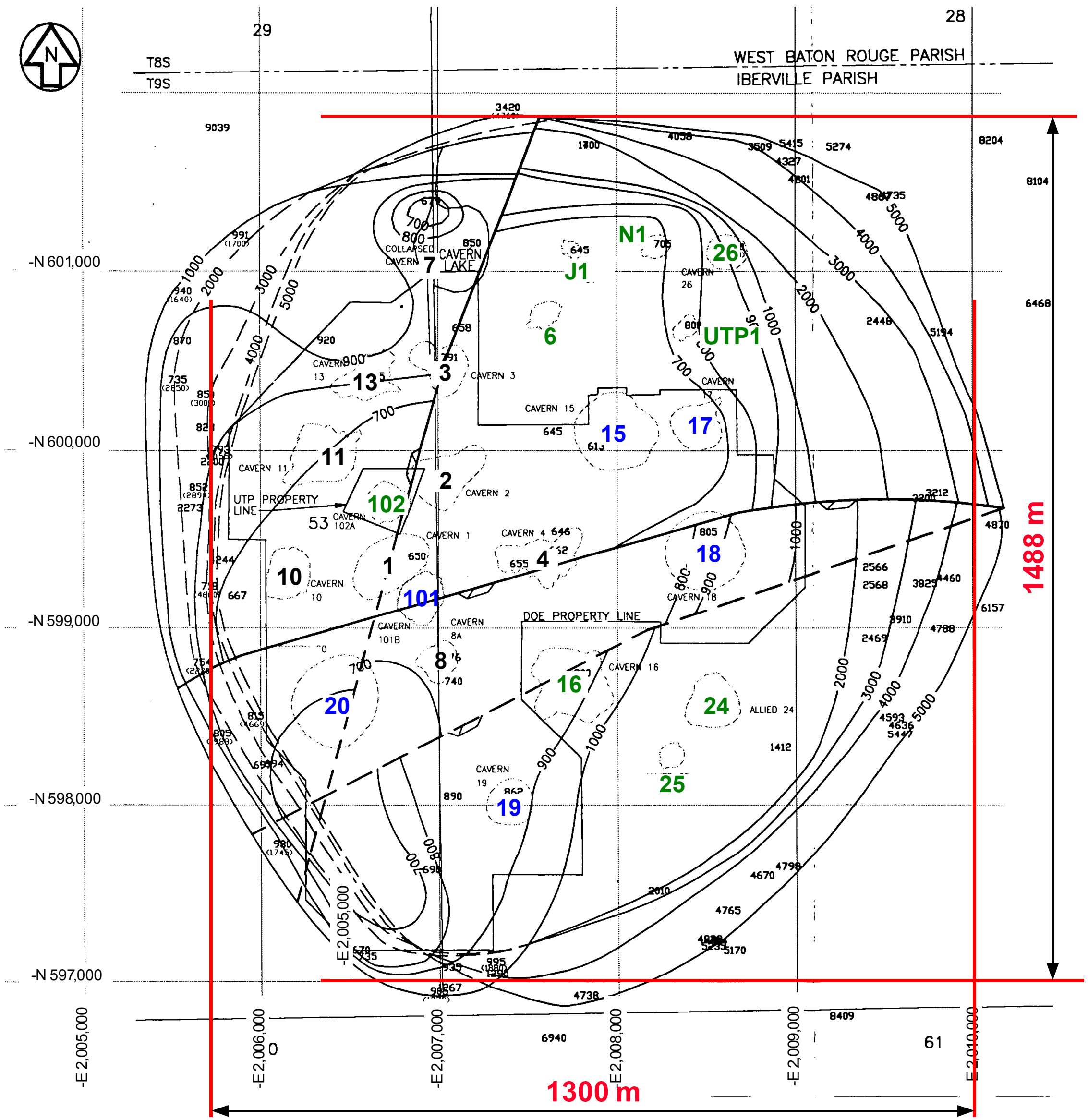
Approach

- Consider the stratigraphy of Bayou Choctaw
- Construct the FEM mesh for the entire salt dome containing all caverns and surrounding lithologies.
- Simplify all caverns using cylindrical shapes
- Consider workover every five years for each SPR cavern during analysis period
- After 21 years, include five drawdown leach cycles for each SPR cavern occurring every five years

Stratigraphy

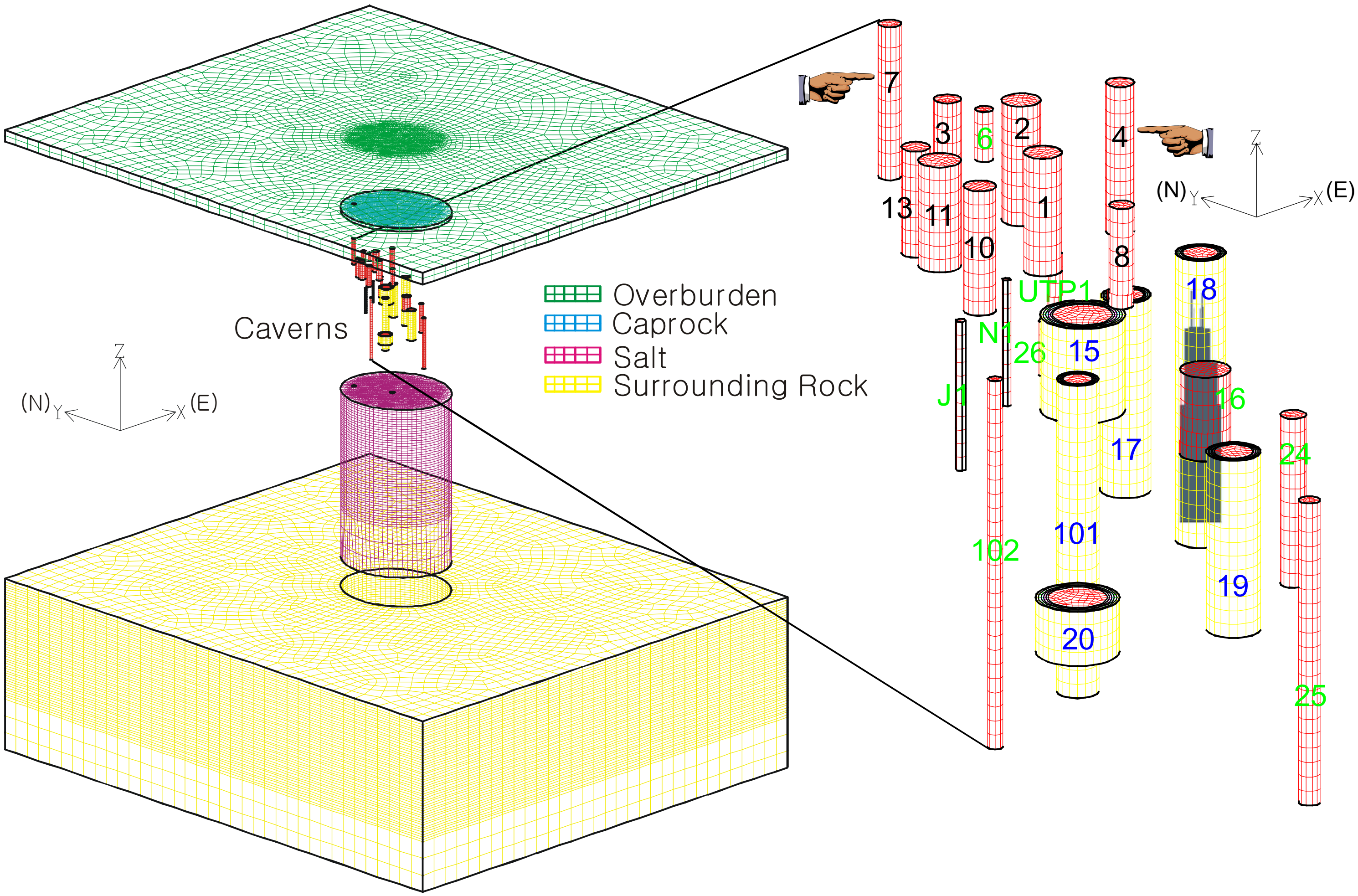


Shape of Salt Dome in Plan View

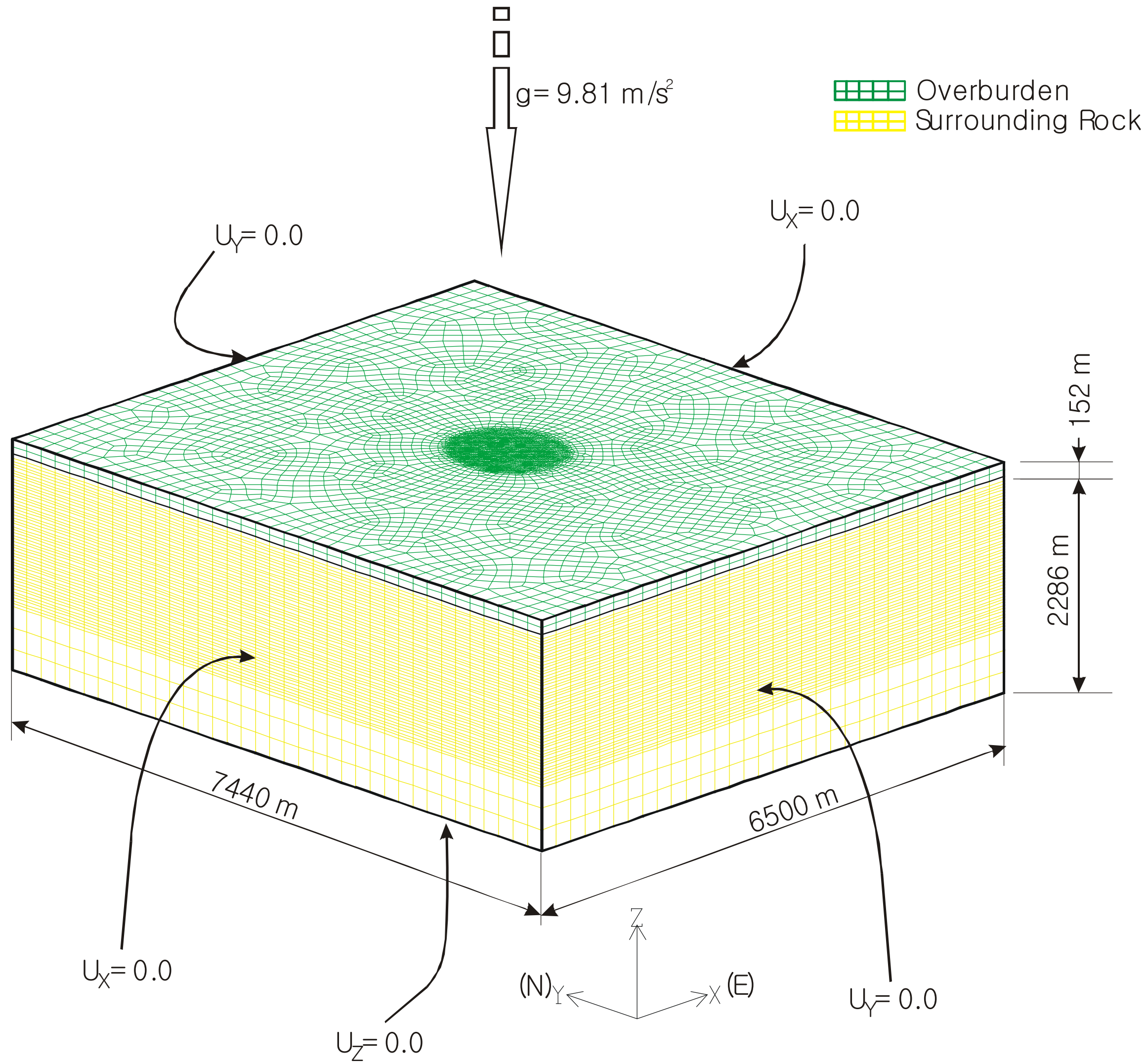


Overview of the Mesh

(6 SPR, 9 Abandoned and 9 UTP Caverns)



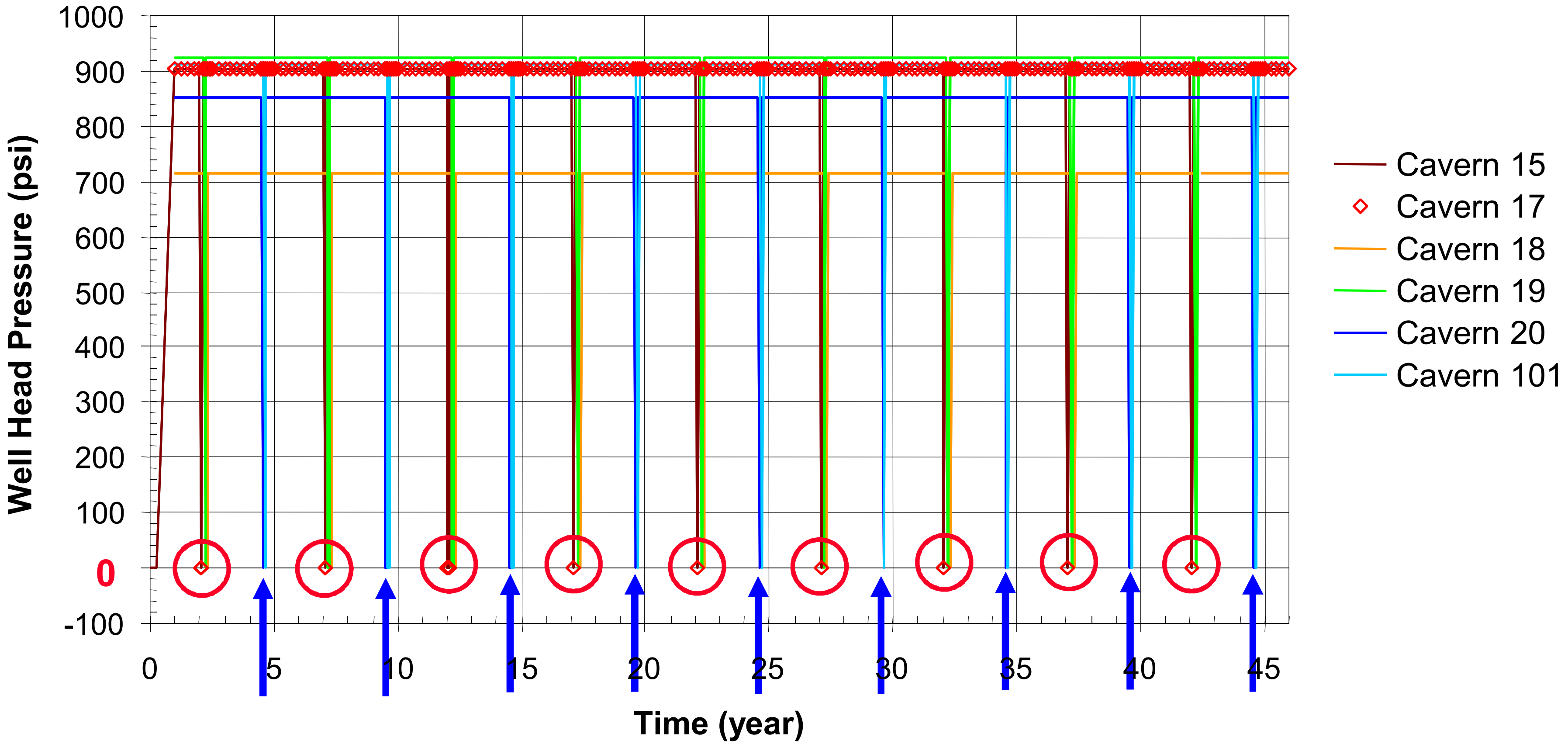
Boundary Conditions



Tools

- Cubit 10.0A for 3D mesh generation
- JAS3D for 3D FEM structural analysis solver
- "Power Law Creep Model" is used for the salt dome
- "Elastic Model" is used for overburden (sand), caprock (gypsum and sand), and far field (sandstone)

Internal pressure changes in SPR Caverns



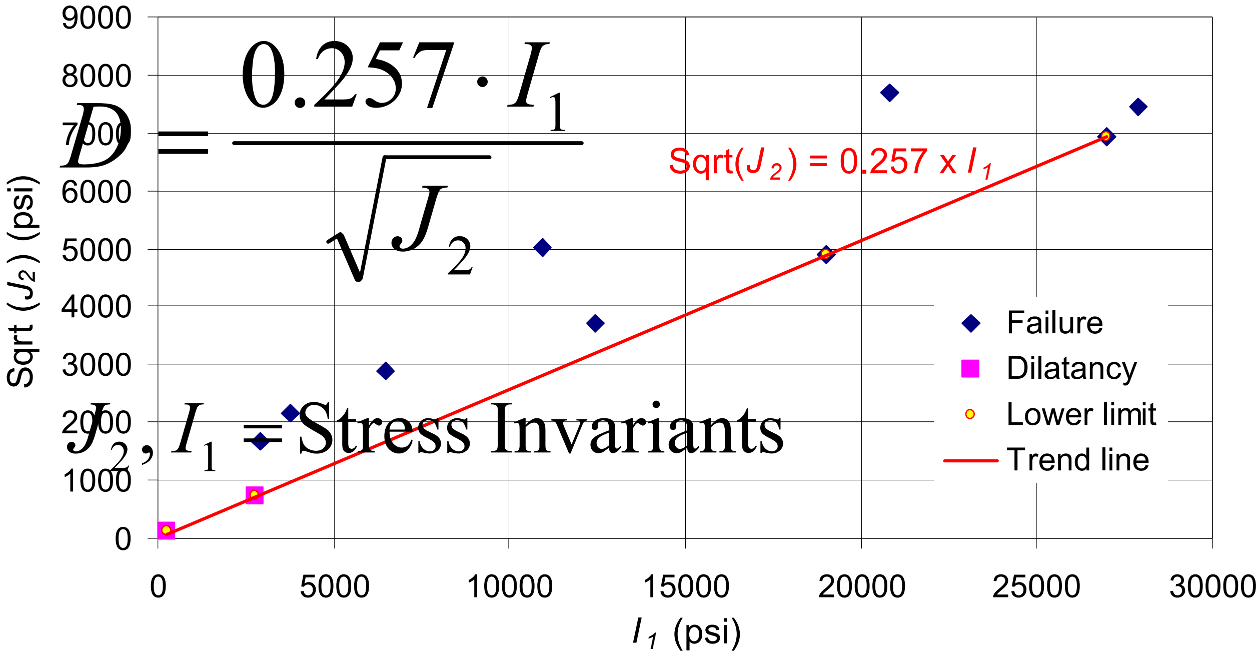
Thermal Condition

- **The FEM model includes a depth-dependent temperature gradient which starts at 29ºC at the surface and increases at 0.025ºC per meter of depth (Ballard and Ehgartner, 2000).**

Failure Criteria

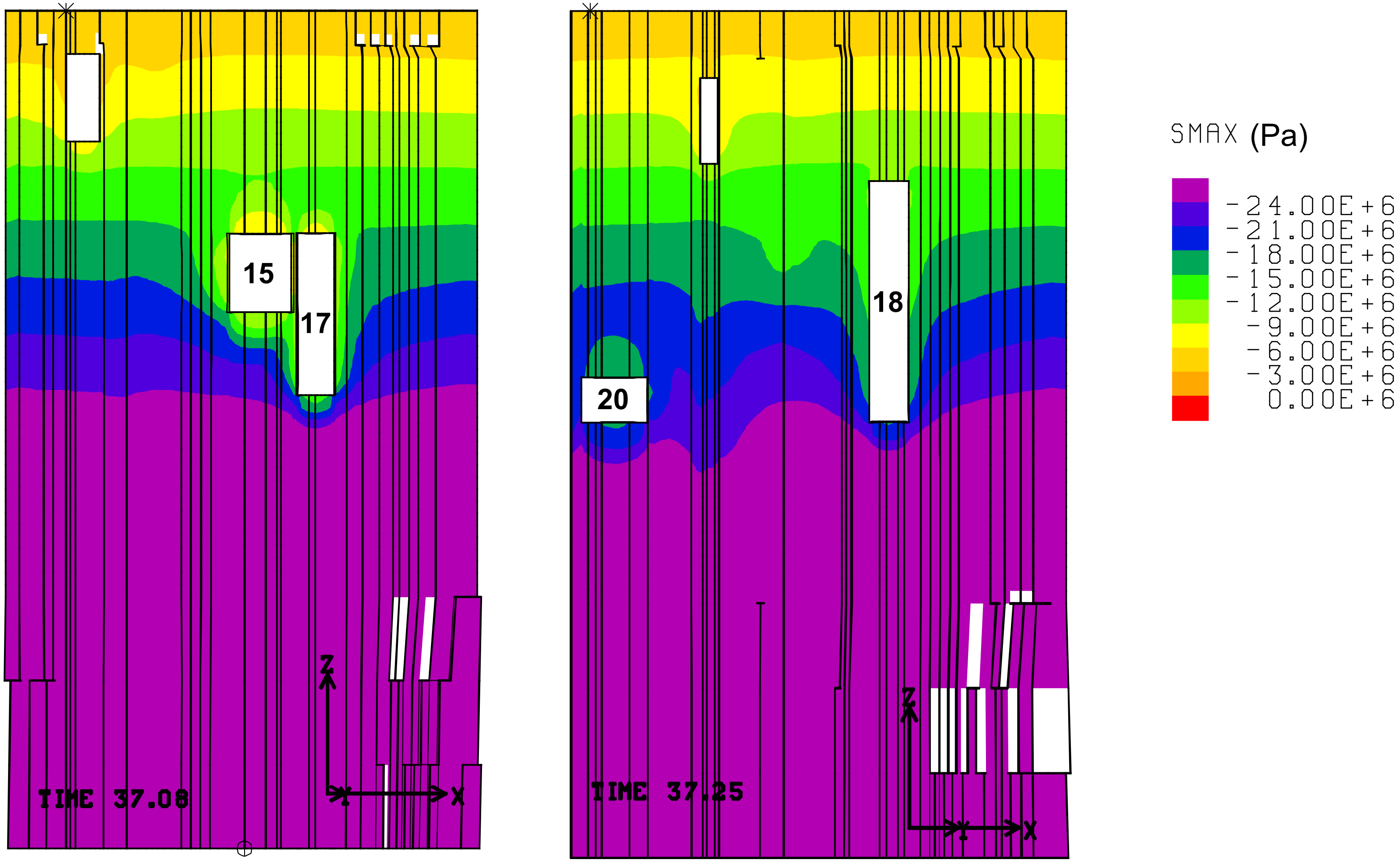
- **Structural Stability of Salt Dome:**
  - **Tensile failure**
  - **Dilatant damage**

$$D = \frac{0.257 \cdot I_1}{\sqrt{J_2}}$$

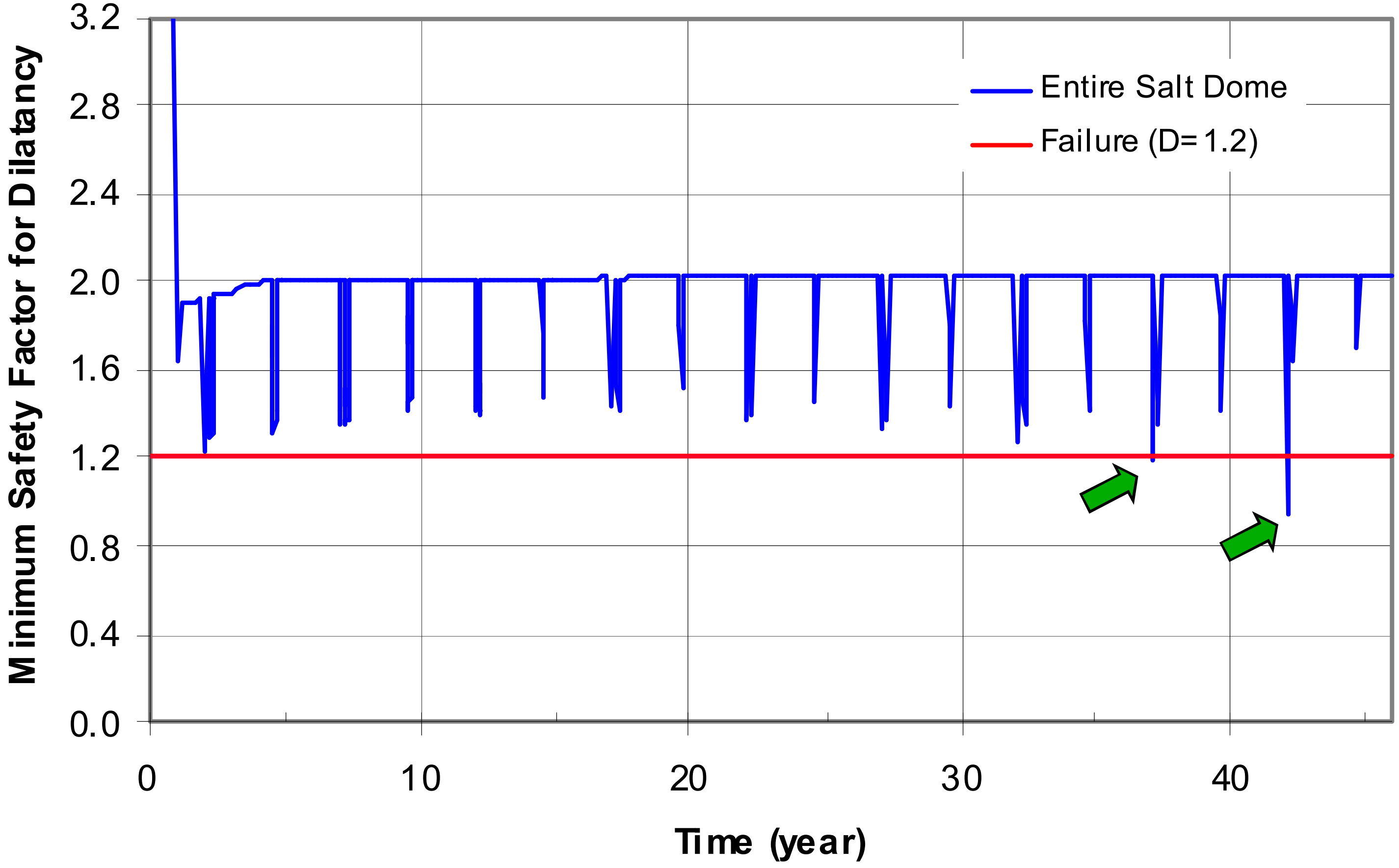


J_2, I_1 = Stress Invariants

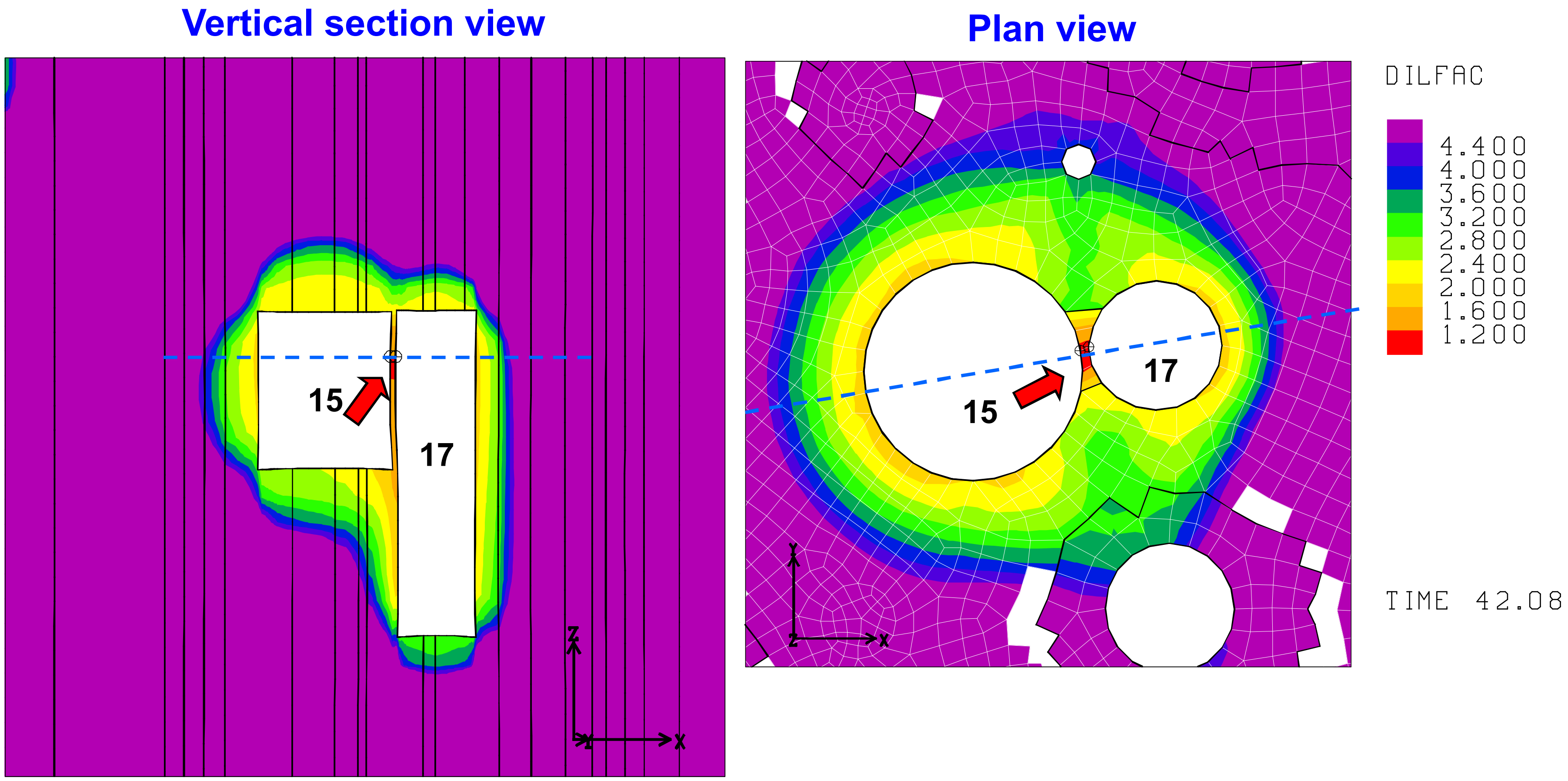
Minimum Compressive Stress in Dome



Minimum Safety Factor Change against Dilatant Damage

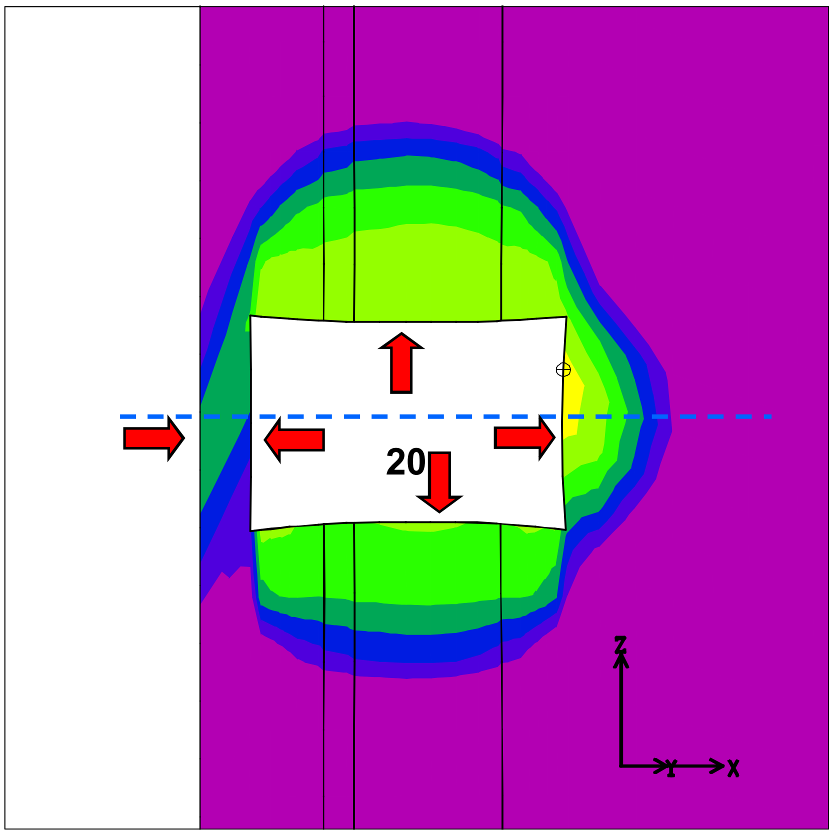


Dilatant Safety Factor Contours during Workover of Cavern 15 and 17 at 42 years

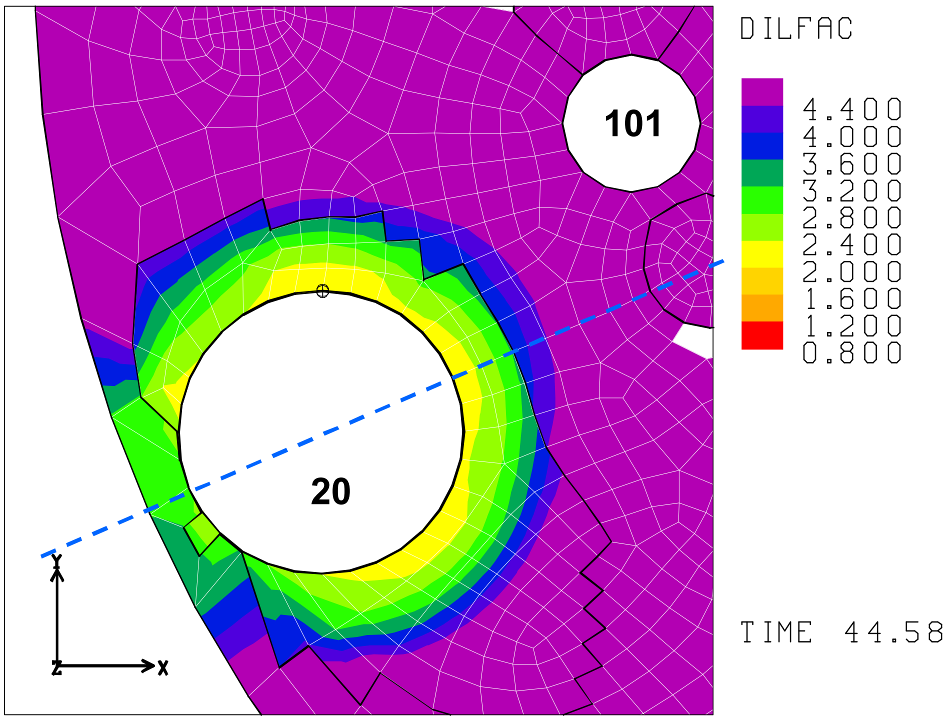


Dilatant Safety Factor Contours during Workover of Cavern 20 at 45 years

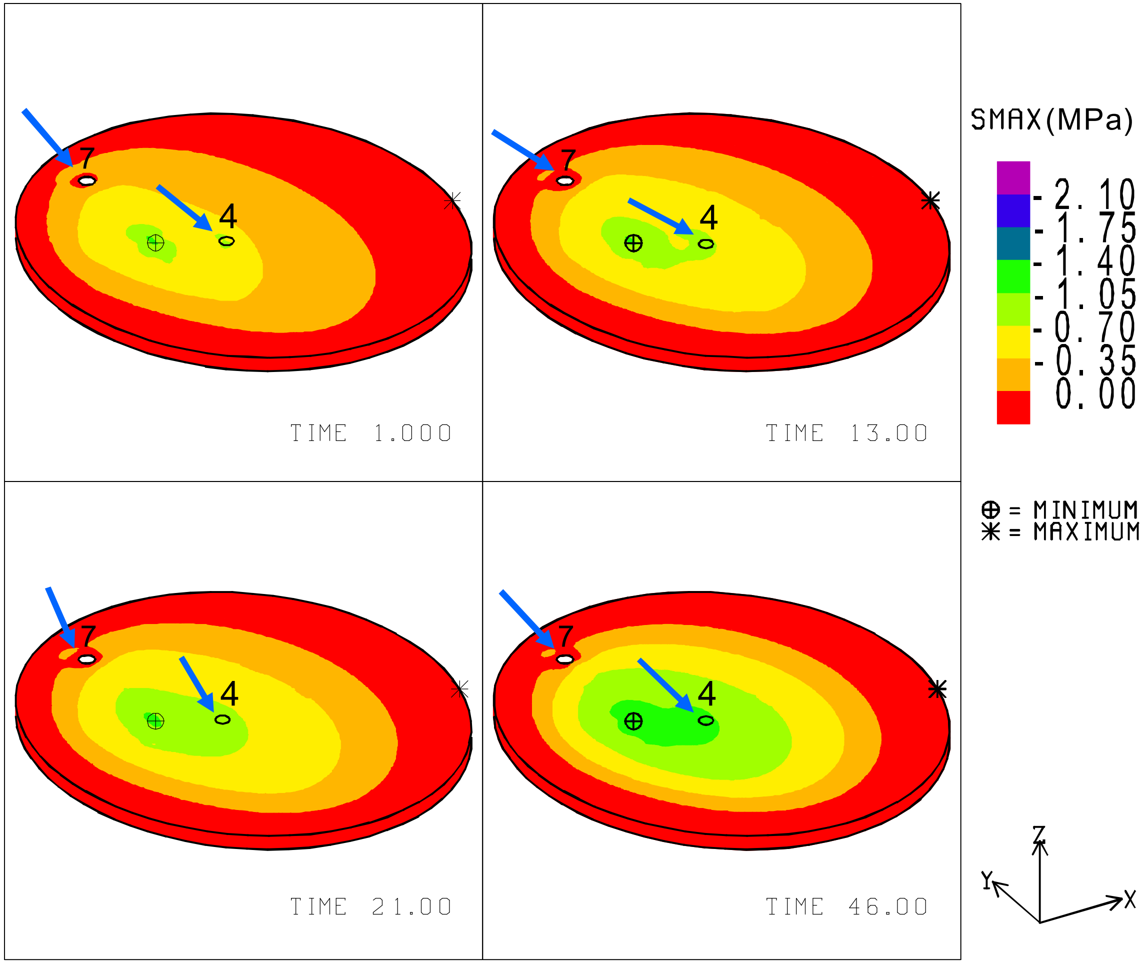
Vertical section view



Plan view



Contour plots of the minimum compressive stress in the caprock layer



Concluding Remarks

- A three dimensional FEM model allowing analysis of each cavern individually was constructed.
- All SPR caverns are predicted to be structurally stable against tensile failure.
- The results show that from a structural view point, the existing caverns can be safely drawdown, but limitations exist as to the number of drawdowns.
- Cavern 4 should not collapse into the salt dome, thus the salt volume beneath the cavern can be a candidate for the expansion.

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