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Assessing Risk of Loss in Integrity of Sidewall of Cavern Located near Dome Edge

PA43G-1412 Byoung Yoon Park, Ph.D.

Sandia National Laboratories, Geotechnology & Engineering Department, Albuquerque, NM 87185, USA, bypark@sandia.gov

Sandia National Laboratories

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Introduction

The U.S. Strategic Petroleum Reserve (SPR) stores crude oil in 60 caverns located at four sites located along the Gulf Coast. Most of the caverns were solution mined by the U.S. Department of Energy (DOE). Bayou Choctaw Cavern 20 (BC-20) is located near the edge of the salt dome (Fig.4). Its proximity close to the edge of the dome raises concerns about potential tensile failure in the surrounding rock near BC-20 induced by the cavern volume closure due to salt creep. The location of BC-20 in the salt dome is similar to the cavern involved in the Bayou Corne Sinkhole shown in Fig.5 admonishing us that a risk of loss integrity of the sidewall of BC-20 should be investigated. Due to the Bayou Corne cavern collapse, 150 homes had been evacuated for nine months since August 2012. This paper evaluates the structural instability in the salt between the dome edge and the cavern (call 'edge pillar', indicated by yellow ovals in Fig.4) through a geomechanical analysis using a newly developed numerical model (Fig.6).

Fig.1. Bayou Choctaw SPR site location map

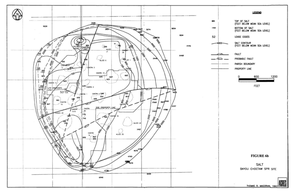


Fig.2. Bayou Choctaw site plan view

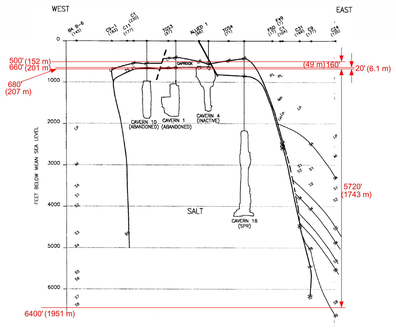


Fig.3. Stratigraphy near the Bayou Choctaw salt dome and the thickness of each layer used for modeling

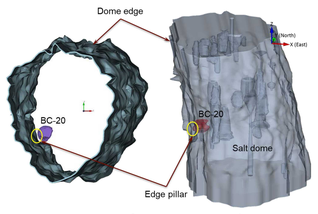
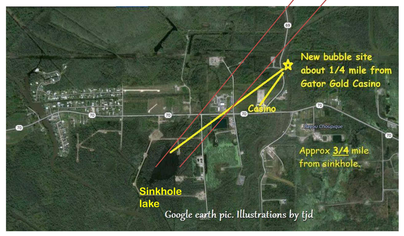


Fig.4. Location of Cavern 20 with respect to the edge of the salt dome



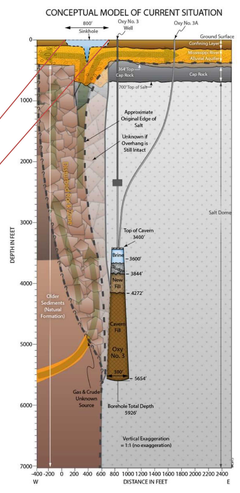
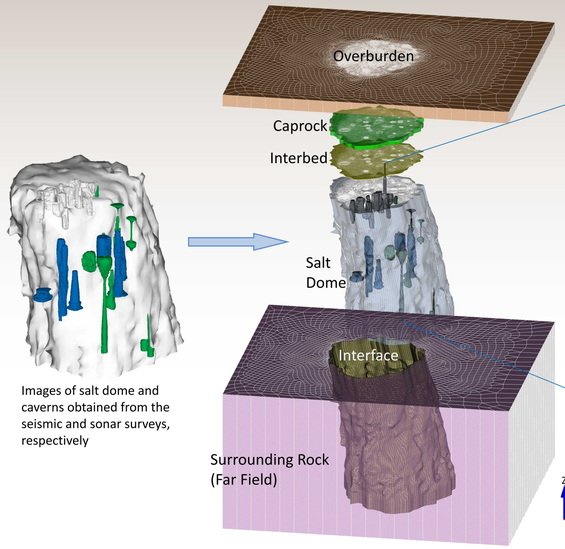


Fig.5. Photo of the sinkhole lake (left) and conceptual diagram of failure/collapse of sidewall of brine-mined Oxy No. 3 salt cavern in the Napoleonville salt dome. Formation of the Bayou Corne sinkhole occurred in August 2012 [LSU, 2013]

Finite Element Model



Images of salt dome and caverns obtained from the seismic and sonar surveys, respectively

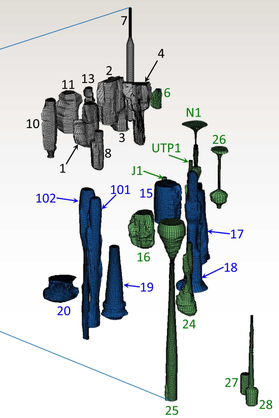


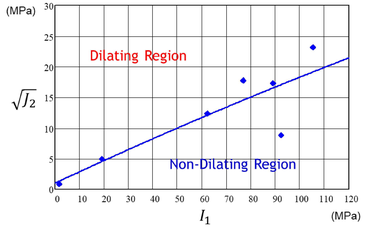
Fig.6. The images of salt dome and caverns obtained from the seismic and sonar surveys, respectively (left) and overview of the hexahedral finite element meshes of the stratigraphy and cavern field at Bayou Choctaw. The U.S. Strategic Petroleum Reserve stores crude oil in the seven blue caverns. The other caverns are the Boardwalk caverns (green) and abandoned caverns (gray). The cavern ID numbers are also shown [Park et al., 2017]

Salt Damage Criteria

Potential damage to/around the SPR caverns was evaluated based on two failure criteria:

- Tensile failure
- Dilatant damage

The potential for tensile failure exists if the maximum principal stress (σ_1) is numerically zero or positive value



Dilatant damage factor (*DF*):

$$DF = \frac{a \cdot e^{n \cdot I_1} + c}{\sqrt{J_2}}$$

a = -118.8 MPa

n = -1.574 x 10^{-3} (1/MPa)

c = 119.8 MPa

If, *DF*≤*1* the shear stresses in the salt ($\sqrt{J_1}$) are large compared to the mean stress (I_1) and dilatant behavior is expected. If, *DF*>1 the shear stresses are small compared to the mean stress and dilatancy is not expected.

I_1 = First invariant of Cauchy stress tensor

J_2 = Second invariant of deviatoric stress tensor

Fig.7. Dilatant damage criterion for Bayou Choctaw salt (Dots indicate experimental data)

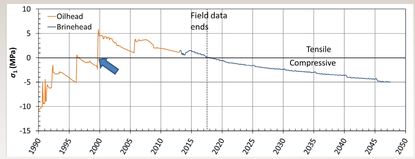
References

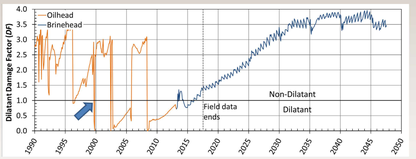
LSU. (2013) *Blue Ribbon Commission Initial Technical Briefing*, Presentation slides dated April 5, 2013.

Park, B. Y., B.L. Roberts, and S.R. Sobolik. (2017) Construction of hexahedral finite element mesh capturing realistic geometries of a petroleum reserve. *Journal of Finite Elements in Analysis and Design*, 135, 68–78. https://doi.org/10.1016/j.finel.2017.07.007

Analysis Results

σ_1 and *DF* in Edge Pillar





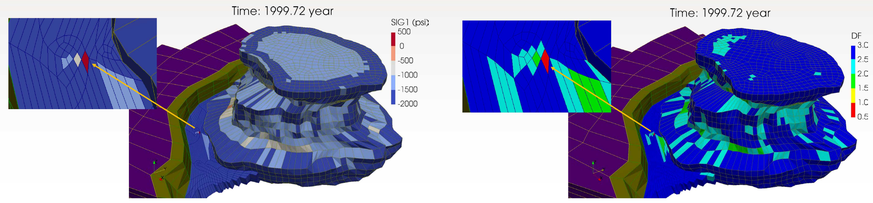
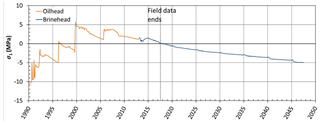


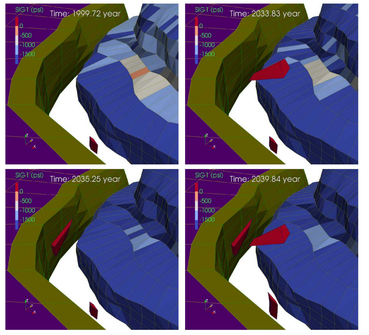
Fig.8. The critical element, which is in both a tensile and dilatant damage stress condition, is predicted to locate in the salt between dome edge and BC-20 at -1244 m depth in 1999

Contour Plots of σ_1



The tensile stressed area is predicted to be created in 1999 and then disappear in 2018 because we filled fully the cavern and wellbore with brine since 2013

If BC-20 is Still Used for SPR



- If BC-20 is still used for SPR without filling brine, structural failure may occur at the edge pillar
- Predicted contour plots of σ_1 in 1999, 2033, 2035, and 2039 to show the area in tension (red) in the edge pillar
- Tensile stressed areas have continued to develop and grow since 1999
- High possibility of salt fracture and crack propagation
- Once a crack is created, the crack will continue to propagate with time because it is in tensile state.

Summary and Conclusions

- The possibility of a loss in integrity of BC-20 is examined in the salt between the dome edge and the cavern.
- The edge pillar is predicted to have experienced tensile but the tensile stressed area disappears in 2018, because BC-20 has been emptied of oil and filled fully with brine since February 2013.
- If BC-20 is still used as a SPR, structural failure may occur at the edge pillar like Bayou Corne case.
- This paper proves the decision to stop the use of BC-20 is effective and necessary.

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