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Finite Element Analysis of Tilt Behavior during the First Eugenie 1 Re-entry

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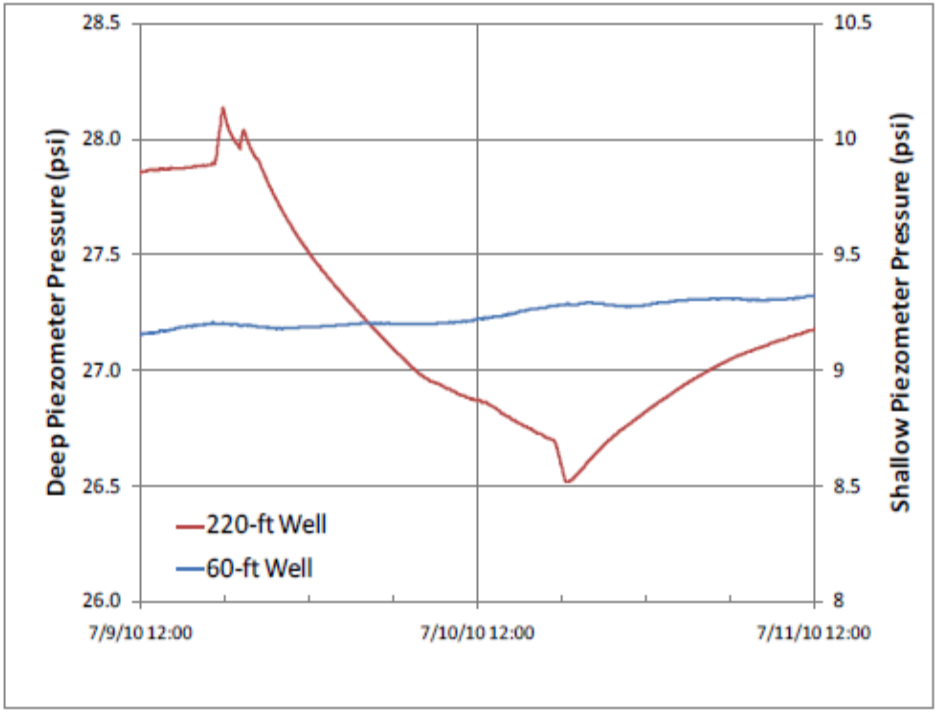
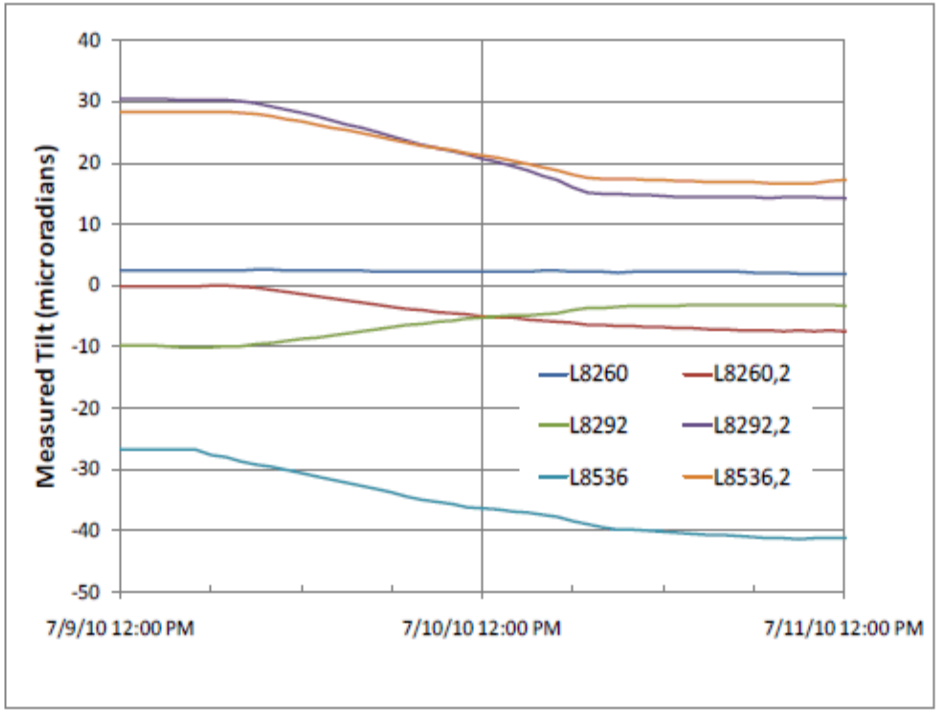
Outline

1. Re-entry history
2. Site Stratigraphy and Finite Element Model Setup
3. Analysis Methodology
4. Results and Comparisons to Field Data
5. Extrapolation of results
6. Conclusions

Eugenie 1 Re-entry July 9-10, 2010

- Proposed to perform a sonar survey to characterize the size and shape of the cavity
- Cavern re-entered at wellhead pressure of 30 psi
- Cavern leaked-off at 1 bbl/min for 21 hrs, then at 3 bbl/min for 1 hr
- In general, the pressure in the deep monitoring well dropped and the measured tilts increased





Site Stratigraphy and Finite Element Model Setup

- The stratigraphy is based primarily on Goodman et al. (2009)
  - Alluvium, Rustler formation, a salt layer, and an underlying layer
  - Salado formation is absent in most places west of the Pecos River (Hendrickson and Jones, 1952)
  - The stratigraphy is not well understood

Alluvium

- Alluvium consists of gravel, sand, clay, and silt with beds of caliche and limestone/conglomerate
- Modeled using two material descriptions
  - dense sand and gravel mixture
  - weak limestone

	E (MPa)	Poisson's ratio	Density (kg/m^3)
Dense sand / gravel mixture	145	0.35	1920
Weak limestone	15,000	0.25	2150

Other Formations

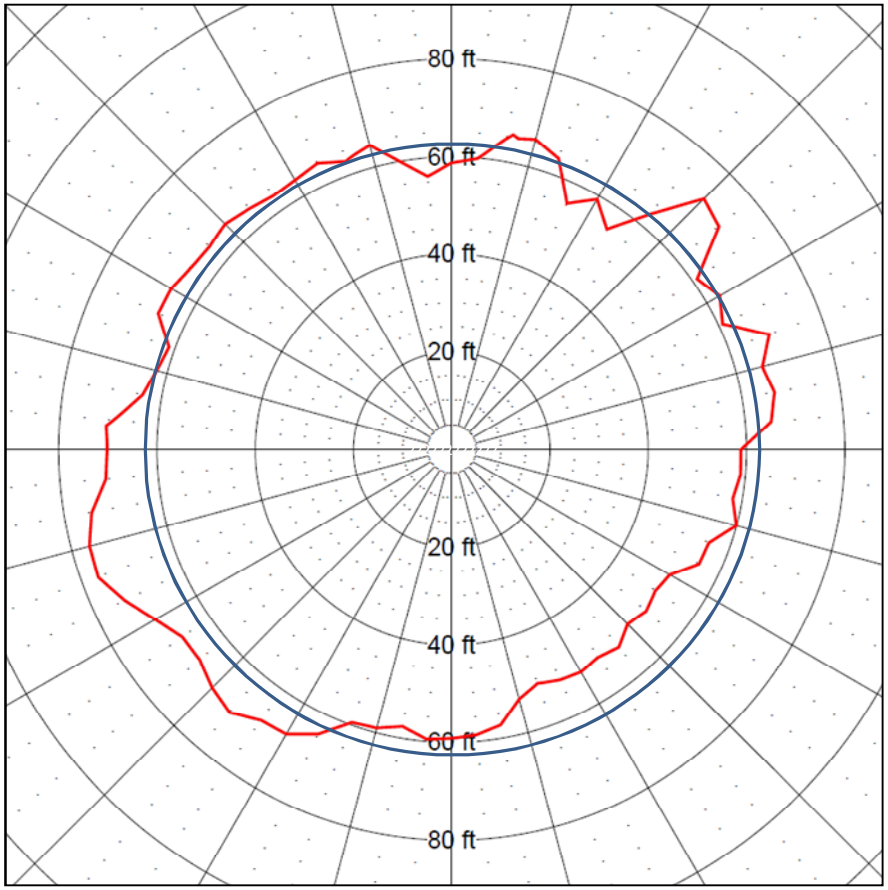
- Rustler and Lower formations
  - Assumed identical
  - Rustler data from Argüello et al. (2009)

	E (MPa)	Poisson's ratio	Density (kg/m^3)
Rustler Formation	20,000	0.30	2160

- Salt
  - Assumed similar to WIPP salt
  - Multi-mechanism deformation (M-D) model
  - Viscoplastic model with 16 parameters

Circular Cavern Geometry Assumed

- Similar to the shape of the upper cavern
- Dissolution of a salt cavern in a horizontally isotropic, homogeneous bedded salt formation should occur equally in all directions – even in a two well operation (John Plosz and Peter Jackson, The Mosaic Company, pers. comm.)
- Consistent with other solution mining activities



Radii and Centers Used

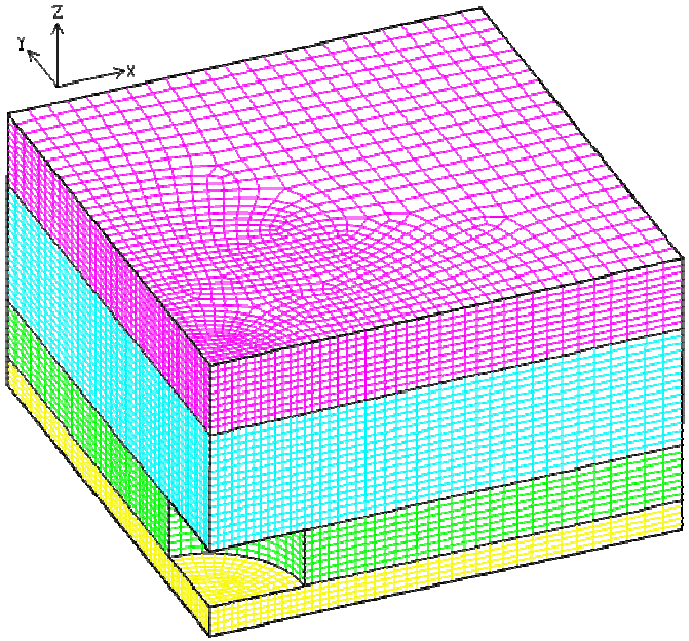
Radii

Designation	Radius (ft)	Radius (m)
R1	62.5	19.1
R2	213	64.9
R3	350	106.7

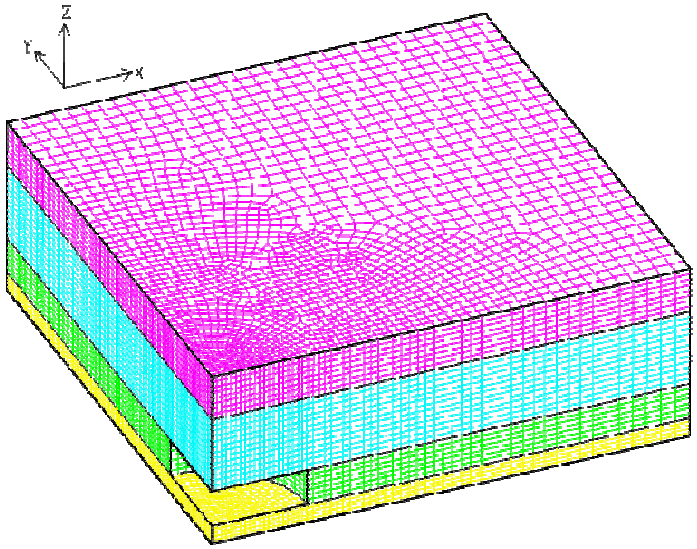
Centers

Center
Eugenie 1
Midpoint between E1 and E2

Mesh Example 1 – 213 ft radius, Center at E1

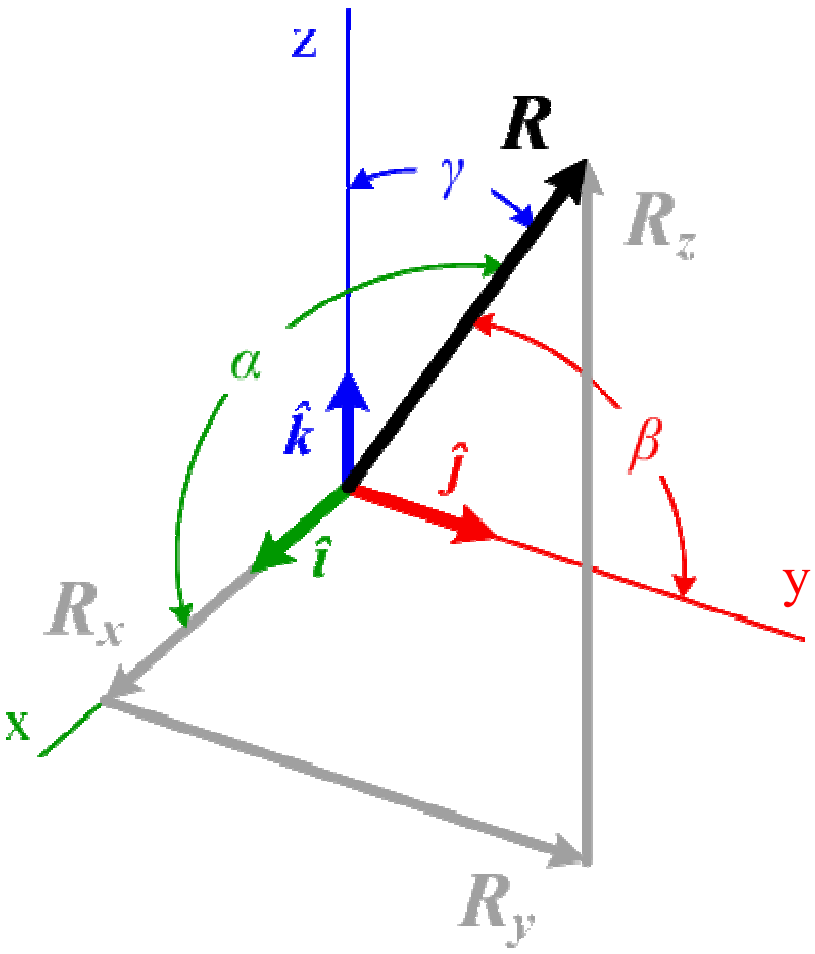


Mesh Example 2 – 350 ft radius, Center at E1-E2 Midpoint

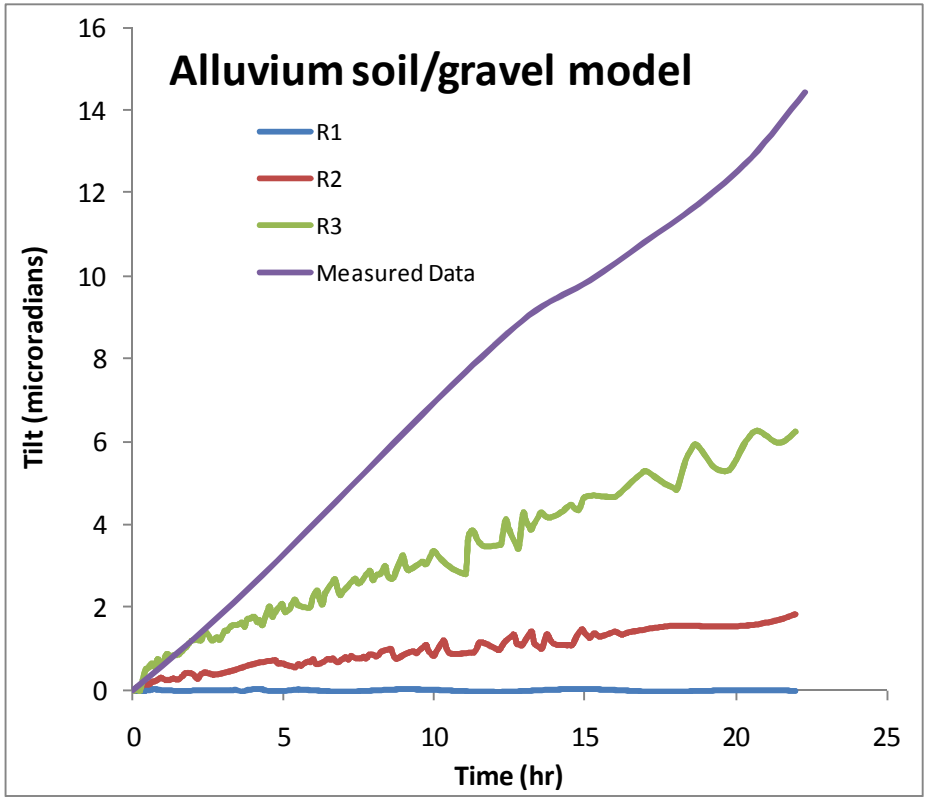


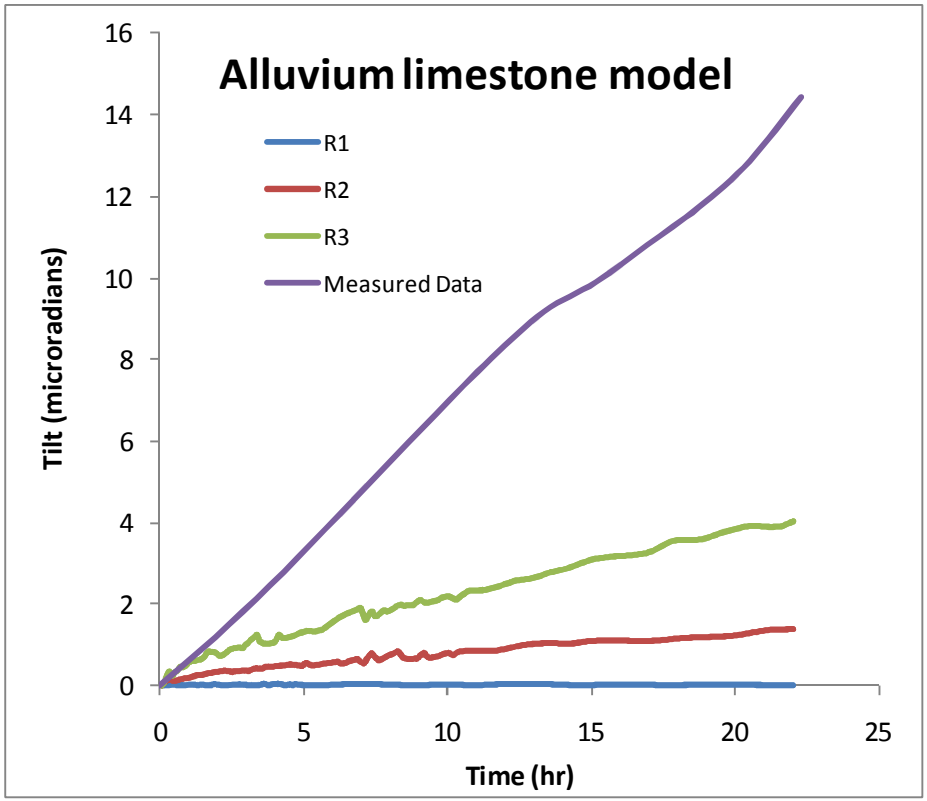
Methodology

- Wellhead pressure was decreased linearly from 30 to 14 psi over 22 hrs
  - Brine density = 10 lbs/gal ("ten pound brine")
- Considered only the tilt magnitudes
  - locations of tiltmeters were projected onto the mesh
  - compared change in tilts at mesh locations with field data during bleed off period

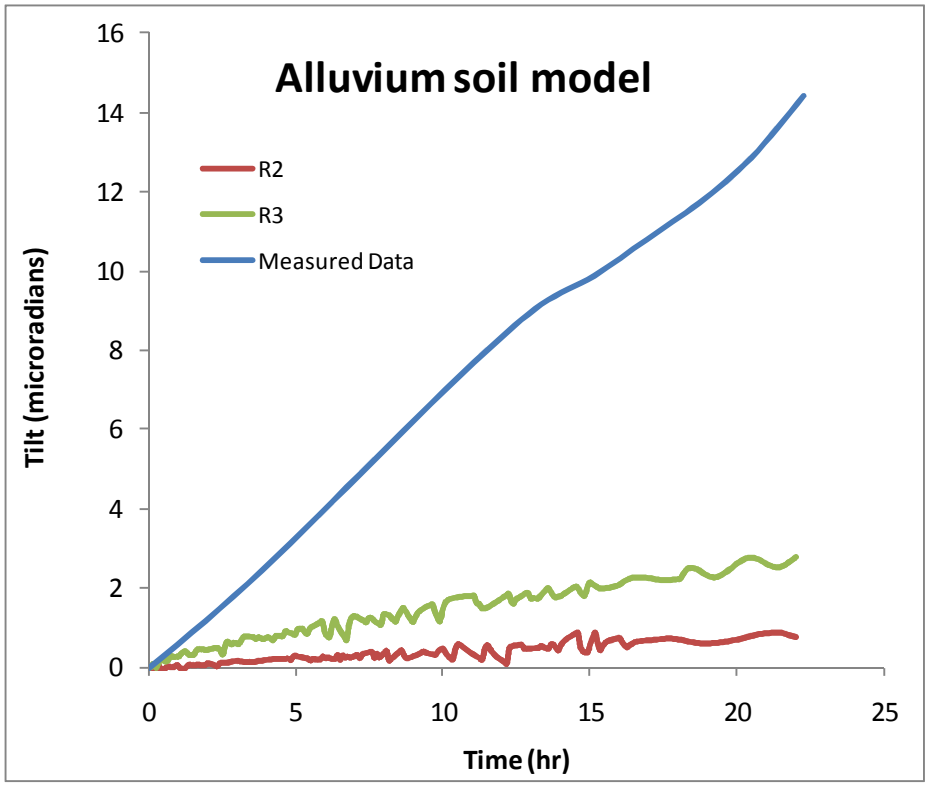


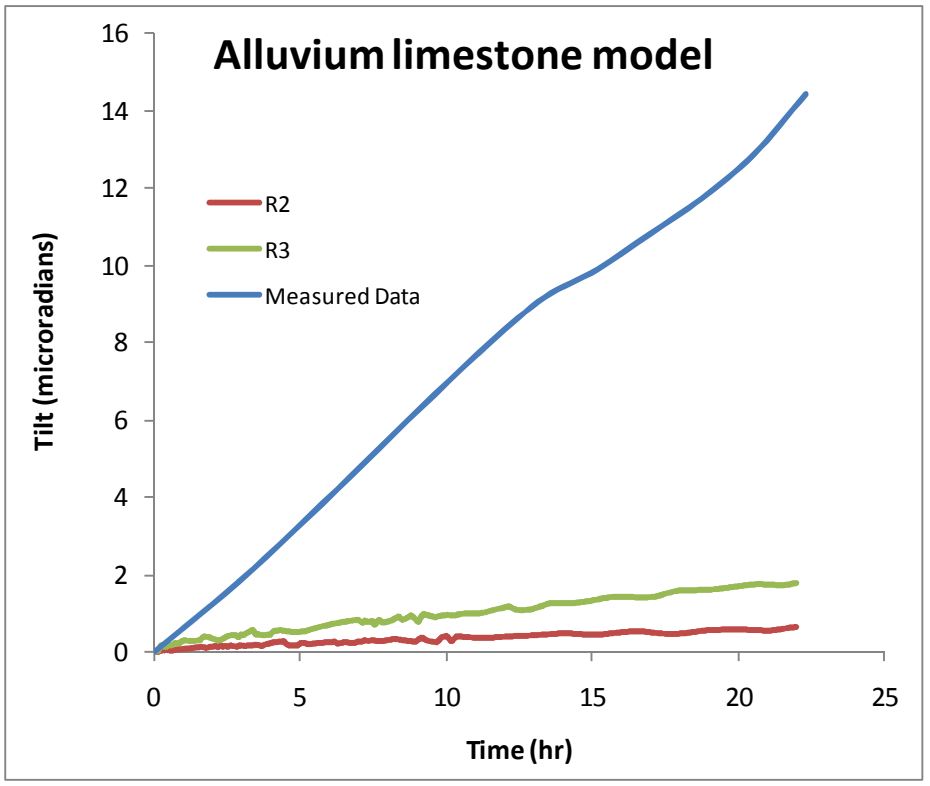
Comparison of Field Measurements with Predicted Values – Tiltmeter 8536, Center at E1





Comparison of Field Measurements with Predicted Values – Tiltmeter 8536, Center at E1-E2 Midpoint

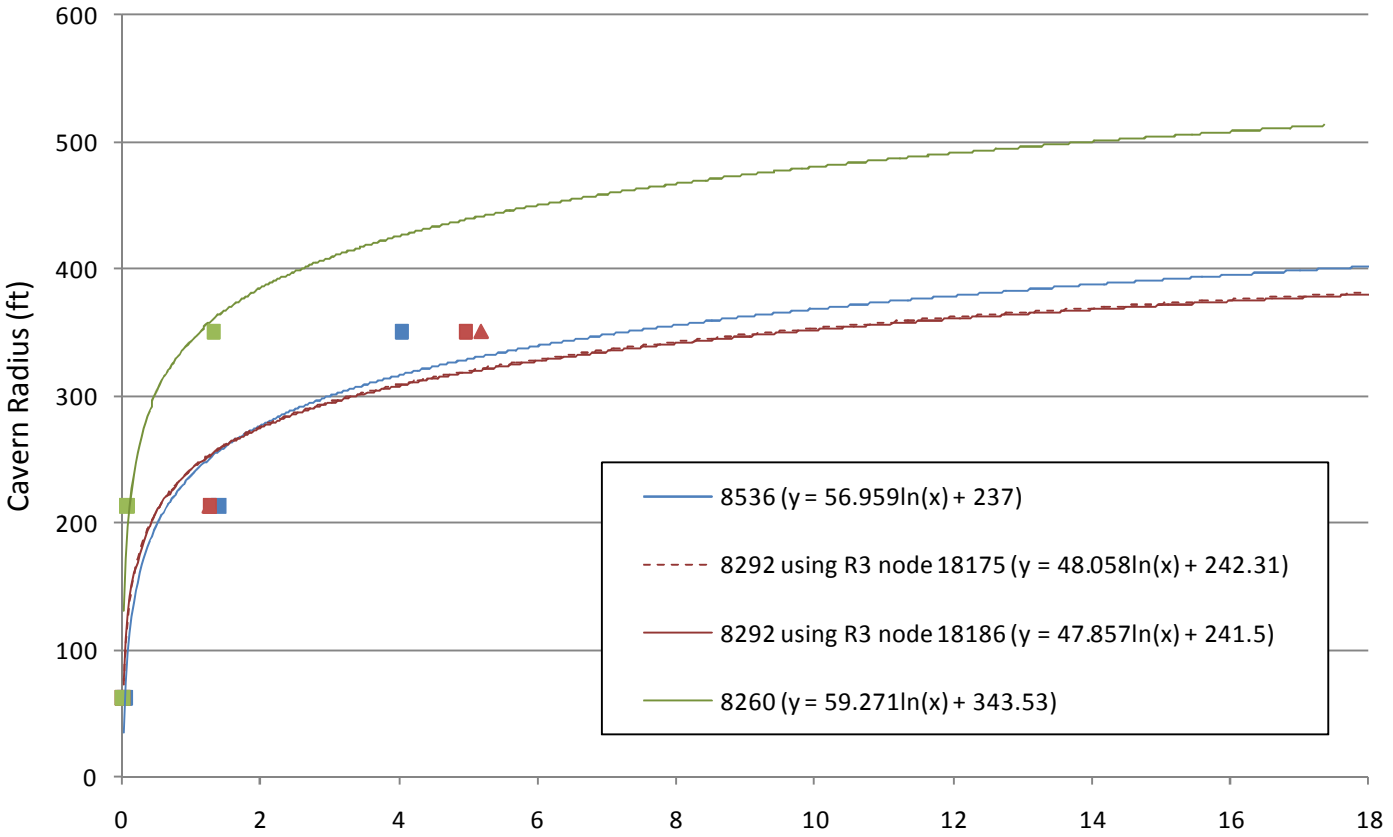




Extrapolation of Numerical Results

- In general, field data tilt magnitudes were larger than numerical model results
- Presented linear and logarithmic fits to the data trends (tried every method in Excel)
  - A logarithmic fit seemed to be the best match based on the response of the models centered about Eugenie 1
- Can extrapolate trend to match the measured field tilt changes to obtain an estimate of the cavern size (assumed circular)

Alluvium Limestone Model – Center at E1

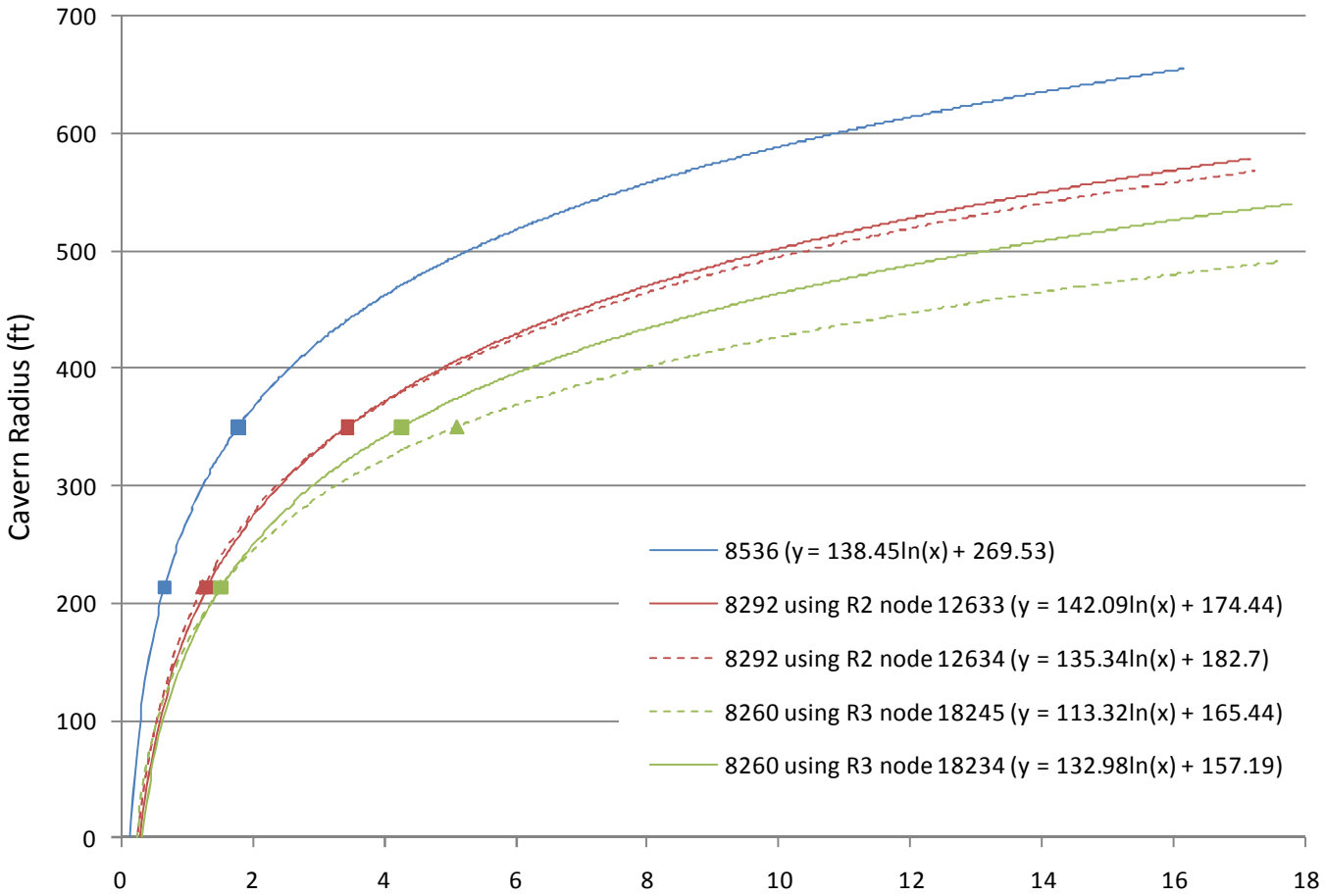


Tiltmeter	*Measured Tilt, μ rad*	*Cavern Radius, ft*	
8536	14.422	389	
8292	15.726	375	(R3 node 18175)
		373	(R3 node 18186)
8260	6.048	450	

Alluvium Limestone Model

Cavern centered at E1

Alluvium Limestone Model – Center at E1-E2 midpoint



Tiltmeter	*Measured Tilt, μ rad*	*Cavern Radius, ft*
8536	14.422	639
8292	15.726	566 (R2 node 12633)
		556 (R2 node 12634)
8260	6.048	397 (R3 node 18234)
		369 (R3 node 18245)

Alluvium Limestone Model

Cavern centered at midpoint between E1 and E2

Predicted Range of Radii (ft) using Logarithmic Fit

Center	Alluvium Model	
	Sand/Gravel Mix	Weak Limestone
Eugenie 1	360 – 430	375 – 450
E1-E2 midpoint	330 – 545	370 – 640

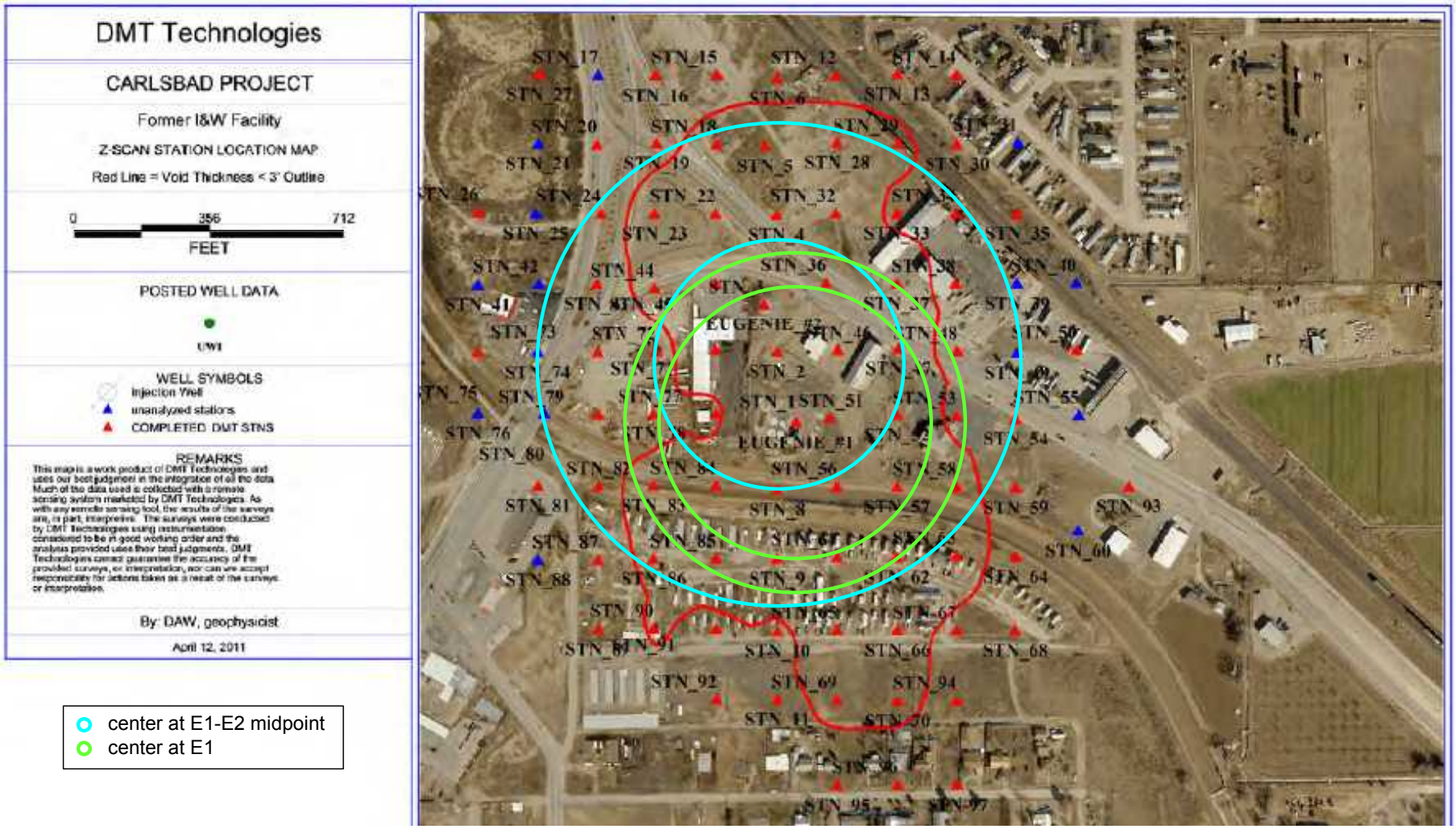
Conclusions

- A finite element analyses with a simplified geometry was used to evaluate the response of the rock mass above the I&W cavern during the 22 hr bleed off event
- The range of modeled cavern radii was not sufficient to capture the changes in tilts recorded by the three tiltmeters
  - The actual cavern must be larger than the modeled caverns
- A logarithmic extrapolation fit the calculated data better than a linear fit (and all others)

Conclusions (cont'd)

- Surface deformation is controlled by the short axis of the cavern
  - Radius of circular hole gives estimate for short axis of an oblong shape
- Results consistent with DMT Technologies magnetotelluric results

Superposition of FE results on DMT survey



DMT Technologies. 2011. Final Report for EMNRD/OIL Conservation Division: Z-SCAN Review Former I&W Facility Carlsbad, New Mexico. April 11, 2011. Available at http://www.emnrd.state.nm.us/ocd/documents/IWMagnetotelluricReport.pdf