From: Tieszen, Sheldon R [srtiesz@sandia.gov]
Sent: Tuesday, June 01, 2010 6:07 PM
To: Hunter, Tom (Sandia); 'Slocum42@gmail.com'; 'slocum42@MIT.edu'; Majumdar, Arun; 'RLG2@us.ibm.com'; 'RGarwin@ostp.eop.gov'; 'gcooper@berkeley.edu'; 'jholdren@ostp.eop.gov'; 'mcnutt@usgs.gov'; 'Ray_Merewether@seektech.com'; OConnor, Rod; SCHU
CC: 'hunsaker61@comcast.net'; Keese, David; Hurst, Kathy; O'Sullivan, Donald Q. (LANL); jack.bullman@nasa.gov; Perfect, Scott A (Lawrence Livermore National Laboratory); Edwards, Michael L; McDonald, W Leith; galkowski1@llnl.gov; Burns, Michael J. (LANL); Tieszen, Sheldon R; O'Sullivan, Donald Q. (LANL); Tatro, Marjorie; Bickel, Thomas
Subject: 1 June Report from Houston
Attachments: 1 June Report.pdf; gulf_draft.pdf; Summary.pdf

All,

Attached you will find the Houston daily brief and two technical products from the lab team. Cutting operations are taking longer than expected but making progress.

Thank you,

Sheldon

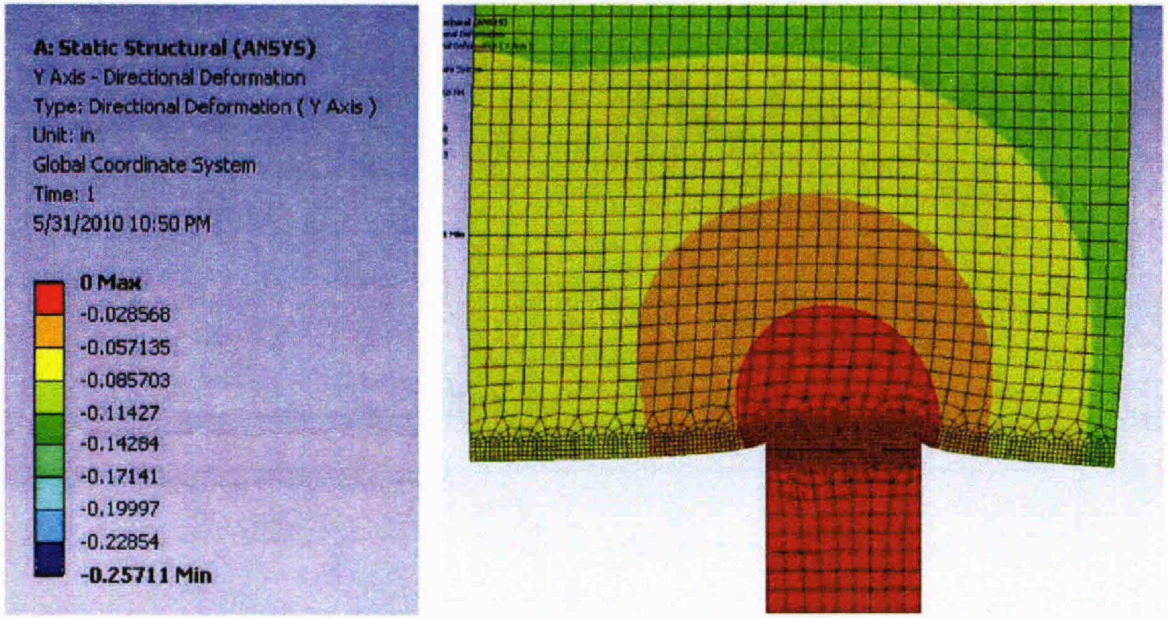
11620
Exhibit No.
Worldwide Court Reporters, Inc.

1 June Report

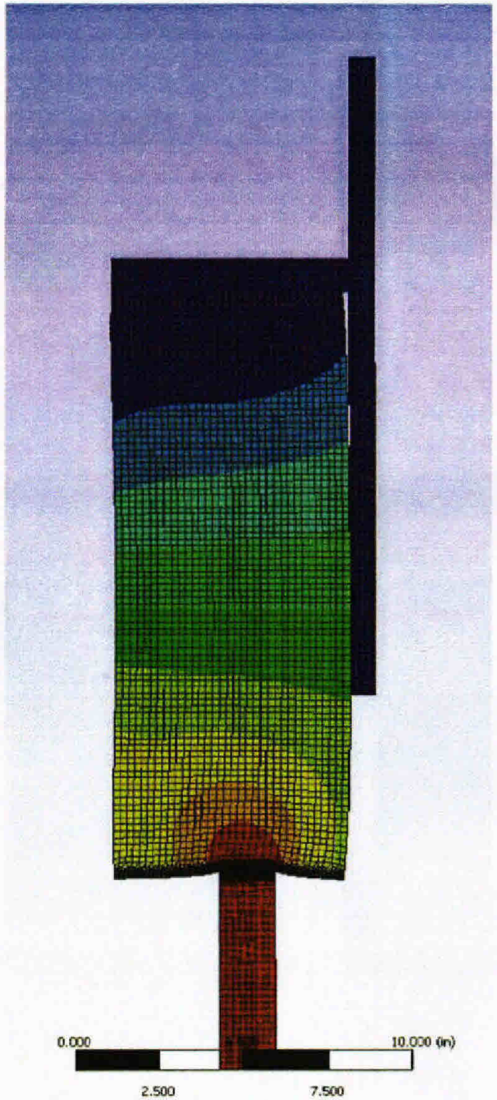
Cut & Cap Operations

- A) Seal Analysis: Gretchen Ellis - FEA Analysis
  - 83 Durometer rubber may be too stiff to seal on surfaces with ½ inch roughness
  - Softer rubber and 3-D calculations are underway
  - See separate attachment for more details

Axial Deflection in Inches



A: Static Structural (ANSYS)
Y Axis - Directional Deformation
Type: Directional Deformation (Y Axis)
Unit: in
Global Coordinate System
Time: 1
5/31/2010 10:50 PM



Cut & Cap Operations

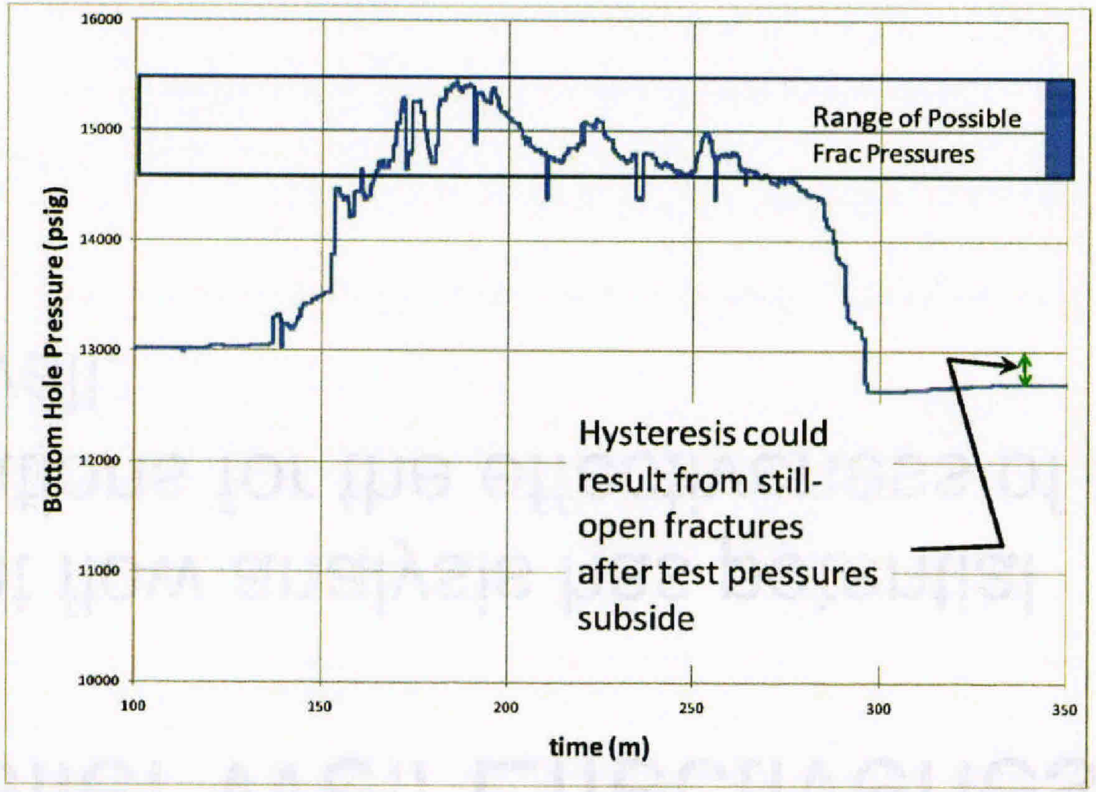
- Sea Bed Operations
  - Had to remove choke and kill lines to allow shear to get the right bite on the riser pipe.
  - As of 5 pm, this removal operations were still going on
  - Expect shearing operation shortly after choke and kill line removal
  - Diamond saw in position upstream of kink

Long Term Containment

- Labs & USGS began initial engagement late this afternoon with long term containment team
- Scope – final containment through hand off to the relief well (August/September)
- BP asked for
  - support on Slocum sleeve (labs) and hydrates (USGS)
    - Labs supporting design review today
  - Unattended dispersal agent injection system (for 3-5 days)

Analysis of Flow

- Dykhuizen & Morrow Analysis
  - Several plausible scenarios analyzed
  - Two hour technical consultation with BP flow analyst/geomechanics personnel
  - See separate attachment for details



Range of Possible Frac Pressures

Hysteresis could result from still-open fractures after test pressures subside

- This result shows that the pressure level might be controlled by the fracture pressure at the bottom of the well

Relief Well Effectiveness

- Current flow analysis has potential implications for the effectiveness of the relief well.

Mud Flow During Kill
Ron Dykhuizen & Charlie Morrow

June 1, 2010

OFFICIAL USE ONLY
May be exempt from public release under the Freedom of Information Act (5 U.S.C. 552), exemption number and category: #4 Commercial Property.

Department of Energy review required before public release
Reviewer Name/Org: Larry Shipers, 6471 Date: 14 July 2009
Guidance (if applicable): N/A

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

Where did the mud flow?

- **We were provided data for a single kill operation on 5/28/2010**
  - We desire to determine where the 9800 barrels of mud went
    - Based on transient pressures measurements
    - Consistent with visual observations
- **Unknowns complicate the analysis**
  - What was the initial condition of the well
    - What fluid initially resides in each well bore volume (especially important for transient kill analysis)
  - What flow paths are available to the mud
    - What is the condition of the various (Hanger, BOP, cement, etc.) seals
- **Calculations will assume a 50 barrel per minute mud flow which is NOT equal to the maximum flow of almost 80 barrels per minute**
  - Friction results scale approximately with the square of the flow
  - Head results are independent of the flow
  - Assume a Newtonian mud with viscosity of 0.2 poise (results are slightly sensitive to this value)

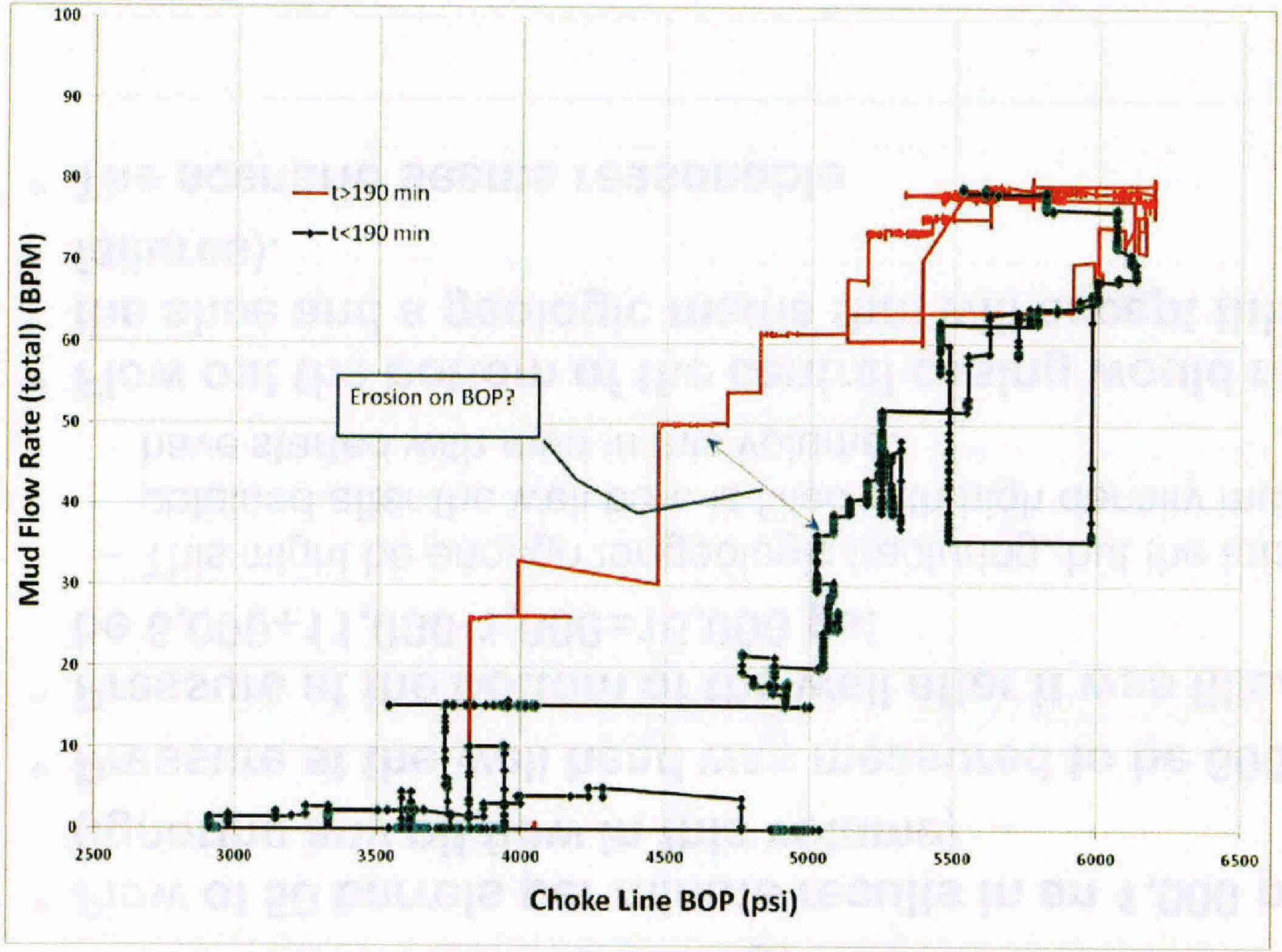
Mud Volume Considerations

- **9800 barrels of mud pumped**
  - Volume of central casing is 739 barrels (correction of BP estimate of 943 barrels)
  - 16 inch annular volume is 1039 barrels
- **Mud could have gone up past BOP seals**
- **Mud could have gone down central casing and out past the shoe into a geologic formation**
- **Mud could have gone down the central casing and out up the drill string**
- **Mud could have gone down the 16 inch annulus and out into a geologic formation**
- **Mud could have gone down the 16 inch annulus, out burst discs, and into a geologic formation**

Up past BOP seals

- **The drill string was determined to be in place, and likely a reasonably obstruction free flow path.**
- **Testing on May 25 indicated that each BOP seal provided some seal (pressure drop), but flow did exist in annular space around the drill string.**
- **It was thought that injection into the lowest BOP elevation would flow down into the well since the test RAM would be open and the upper seals would remain (possibly improved by bridging material and added hydraulic pressure).**
- **BP concludes that if a large amount of mud flowed passed the BOP seals, they would exhibit a large erosion; However, the final pressure drops were near the initial pressure drops indicating little erosion (a qualitative conclusion).**
- **A counter argument: the BOP is a failed component**
  - The BOP pressure flow characteristics may be highly nonlinear
  - Seals may have eroded away, but maybe the bridging material added more resistance and masked this change.

Hysteresis or Erosion: 5/28 test



The cross plot of flow vs. pressure indicates either a hysteresis or an erosion of the flow path resulting in less pressure required later in the test.

BP initially explained this may be an indication of formation opening and closing due to geologic fracturing.

Flow down the central well casing

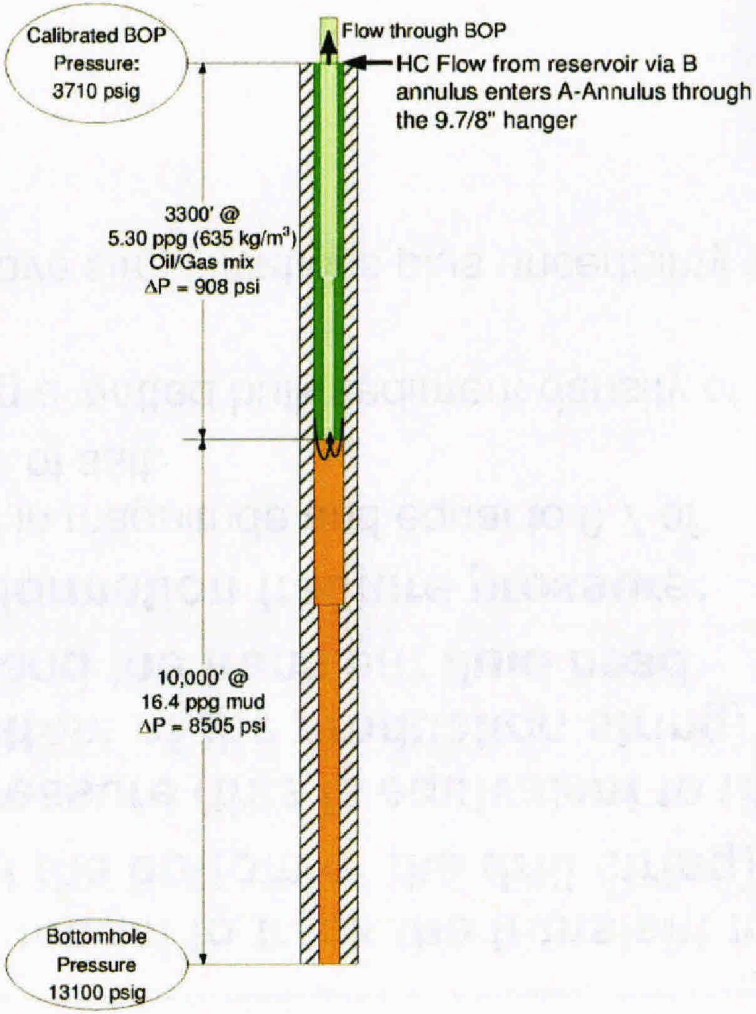
- **If mud fills the central casing, it would exhibit an 11,000 psi head**
- **Flow of 50 barrels per minute results in an 1,000 psi friction loss (ignoring any oil flow in this volume)**
- **Pressure at the well head was measured to be 6000 psi**
- **Pressure at the bottom of the well after it was filled with mud would be 6,000+11,000-1,000=16,000 psi**
  - This might be enough for geologic fracturing, but the total pressure is only obtained after the well bore is filled with high density mud. All kill tests may have started with mud in this volume.
- **Flow out the bottom of the central casing would require a failure of the shoe and a geologic media that will accept this mud flow (two failures).**
- **The scenario seems reasonable**

Simple Fracture Model

- **We developed a simple fracture model to track the transient mud level (from an initial condition at the bottom of the drill string)**
- **We calculate the bottom hole pressure (this is equivalent to the bottom of the annulus or the bottom of the production string) due to the measured BOP pressure and the transient fluid head**
- **We plot this with the estimated formation fracture pressure:**
  - Horizontal principle stresses equal in magnitude and equal to 0.7 of overburden stress. Ignored effects of salt.
  - Overburden stress calculated using a wetted bulk sediment density of 2200 kg/m^3
  - Uncertainty range derived from above simplifications plus uncertainty in rock tensile strength (500 psi assumed)

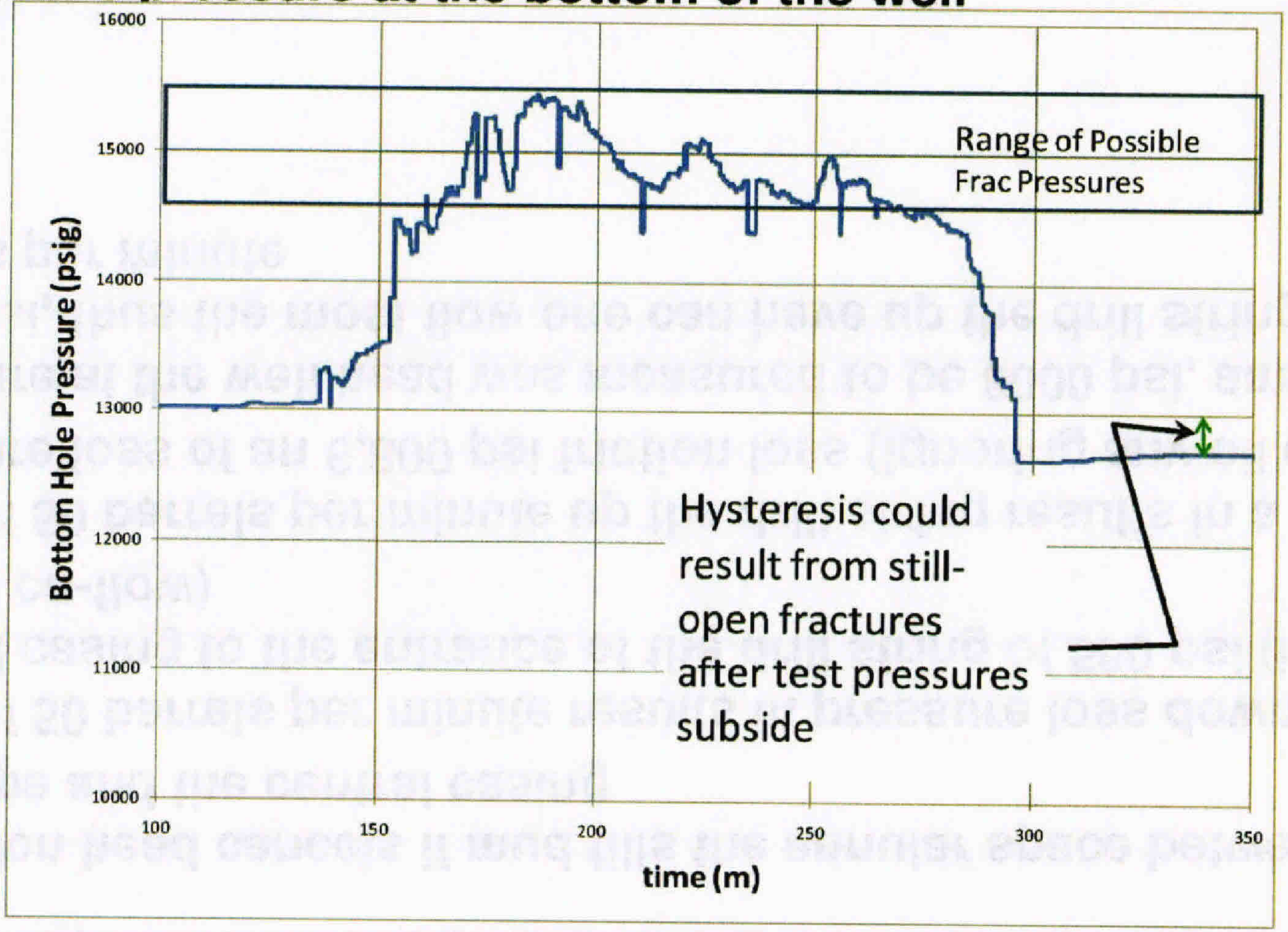
Simple Fracture Model – Initial Condition

- **The initial condition includes a short head of organics and a longer head of mud.**



Simple Fracture Model

- **This result shows that the pressure level might be controlled by the fracture pressure at the bottom of the well**



Range of Possible Frac Pressures

Hysteresis could result from still-open fractures after test pressures subside

Down the central well /up the drill pipe

- Elevation head cancels if mud fills the annular space between the drill pipe and the central casing
- Flow of 50 barrels per minute results in pressure loss down the central casing to the entrance of the drill string of 500 psi (ignoring any oil co-flow)
- Flow of 50 barrels per minute up the drill string results in a pressure loss of an 6,800 psi friction loss (ignoring any oil co-flow)
- Pressure at the well head was measured to be 6000 psi, ambient is 2250 psi, thus the most flow one can have up the drill string is 35 barrels per minute

Flow down the 16 inch annular

- **If mud fills the 16 inch annulus, it would exhibit an 11,000 psi head**
- **Flow of 50 barrels per minute results in an 3,000 psi friction loss**
  - assumes no loss past the failed hanger
  - the friction is concentrated below a depth of 15,000 ft where the flow area is the smallest
- **Pressure at the well head was measured to be 6000 psi**
- **Pressure at the bottom of the well after it was filled with mud would be 6,000+11,000-3,000=14,000 psi**
  - This might be enough for geologic fracturing, but the total pressure is only obtained after the well bore is filled with mud. Leakage into the formation is required before complete filling.
- **Flow out the bottom of the 16 inch annulus would require a failure of the cement and flow into the oil formation, or flow into the geologic formation above the top of cement**
- **A possible conclusion**

Down the 16 inch annular/ out burst discs

- The burst discs may have failed due to heating up of the mud left in this space by flow of hot oil in the central well bore (if the hanger did not fail first)
- If mud fills the 16 inch annulus to the first burst disc, it would exhibit an 800 psi head
- Annular flow of 50 barrels per minute results in an 15 psi friction loss (assuming no loss past the failed hanger)
- Pressure at the well head was measured to be 6000 psi
- Pressure at the highest burst discs is 6000+800-15 psi
- The back pressure is estimated at 3000 psi
- Flow out the two burst discs would result a flow of 11.8 barrels per minute
- The condition at the lowest burst discs is not significantly different: 12.4 barrels per minute through the two discs
- Thus, for all 6 burst discs, the total flow is less than 40 barrels per minute (0.433 inch diameter flow area)

Counter Current Flow Scaling Analysis

Is counter current flow of mud down and oil up possible?

- **This seems reasonable in the 16 inch annulus where the flow area is approximately 50 inches by 1 inch. Oil could occupy a portion of the perimeter. The following momentum balances on the two individual phases can be written:**

$$0 = -\alpha \frac{dP}{dz} - WallFriction_{mud} + \alpha \rho_{mud} g + Drag$$

$$0 = -(1-\alpha) \frac{dP}{dz} - WallFriction_{oil} + (1-\alpha) \rho_{oil} g - Drag$$

- **To maximize mud flow Drag is zero (no friction between mud down and oil up)**
- **To maximize mud flow α (the mud volume fraction) approaches unity**
- **To maximize mud flow gas velocity approaches zero (only slightly negative)**

Counter Current Continued

Counter current flow of mud down and oil is possible!

- **This results in the following requirement**

$$WallFriction_{mud} < (\rho_{mud} - \rho_{oil})g$$

- **As long as the mud flow is slow enough to generate a flowing friction less than above, counter current flow is possible**
- **Examples presented in this talk allow counter current flow**
  - 16 inch annular flow 50 barrels per minute
  - Above 15,000 ft depth counter current flow is possible:

    Wall friction is 0.03 psi/ft < 0.6 psi/ft head difference
  - However, below the 15000 ft depth the requirement is not satisfied:

    Wall friction is 1.1 psi/ft > 0.6 psi/ft head difference

Other visual observations

- **It was stated that oil reappeared at the kink quickly after the mud flow was stopped**
  - This is consistent with flow of oil up the annulus and mud down the center
- **It was stated that the well condition returned to a steady operation quickly after mud flow was stopped**
  - This is consistent with flow of oil up the annulus and mud down the center
  - Implies that the inventory of the well is unchanged from the beginning of each kill (mud below the drill pipe in center, and no mud in annulus)
  - Hard to make mud flow down the annulus consistent with this unless we have counter current flow
- **Mud flow down the annulus and oil up the center seems unlikely also because:**
  - Mud would prefer to at least initially flow down the center (which would be all gas above the drill string end)

Conclusions

- It is only possible to flow 35 barrels per minute of oil up the drill string under the conditions of 5/28 (this cannot be the major path for the total mud flow)
- It is only possible to flow 40 barrels per minute out of the burst discs (this cannot be the major path for the total mud flow)
  - Change in area due to erosion could increase flow
- There is no clear indication that mud flows up past the BOP seals, but this is still possible.
- Without a major failure of the well casing, the flow must be out the bottom of either the annulus or the center casing. This requires a failure of a seal, however, we already know that at least one seal failure has occurred due to the current flowing oil (unless the source of the oil is a different formation).
- Counter current flow within the 16 inch annulus seems possible
- A likely scenario is flow of oil up 16 inch the annulus and mud down the center bore. This requires both cement seals at the bottom of the well to be broken (double failure).

Gretchen Ellis
May 31, 2010

Assumptions for Gasket Compression Analysis

Shape Factor: from www.moldeddimensions.com/urethane scompression.html

For disks and cylinders: Shape factor = d/(4h)

D = 26", h = 18"

S = 0.36

Compression Stress-Strain plots from www.moldeddimensions.com/urethane scompression.html

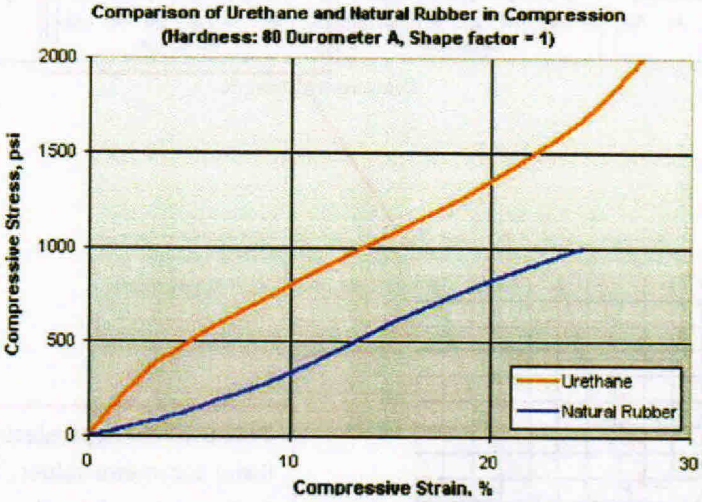

Comparison of Urethane and Natural Rubber in Compression
(Hardness: 80 Durometer A, Shape factor = 1)

Figure 1.

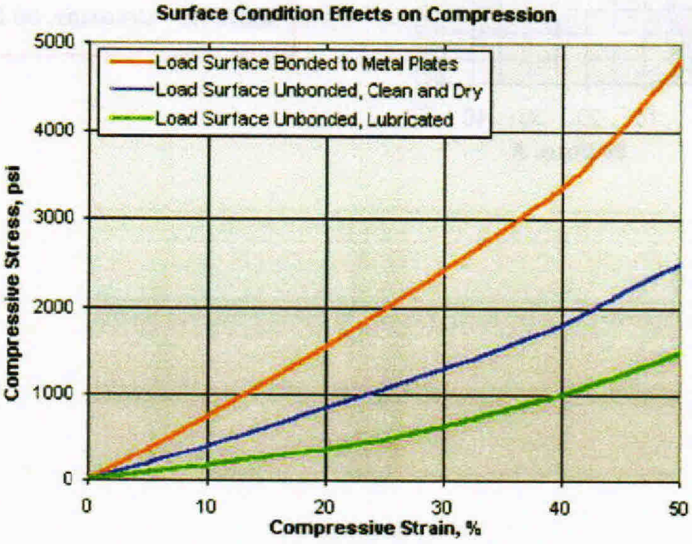
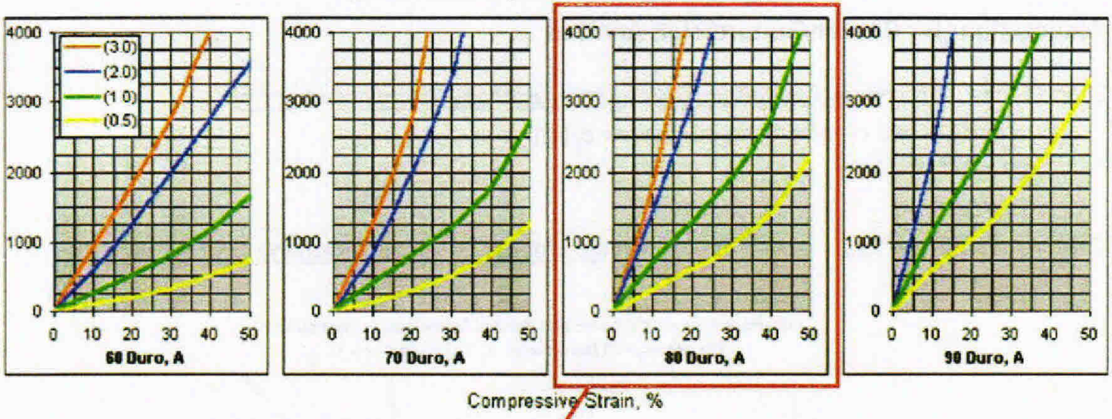
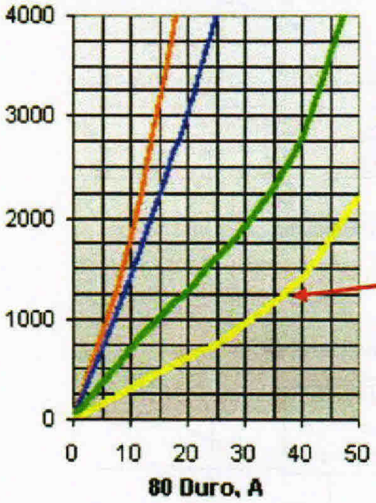

Surface Condition Effects on Compression

Figure 2.

FIG 3
Compression-Deflection Characteristics
Of Soft Urethanes (With different Shape Factors)

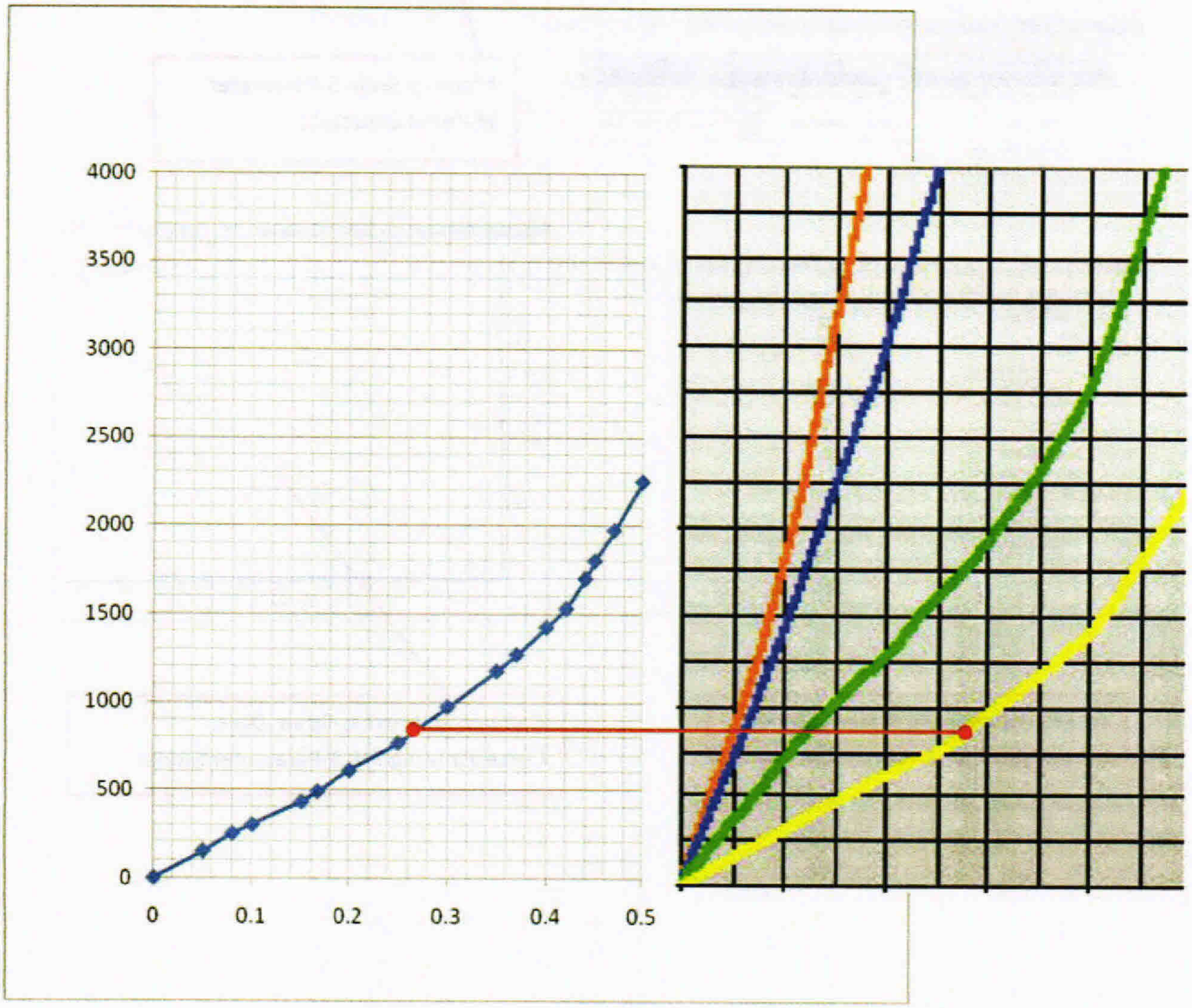


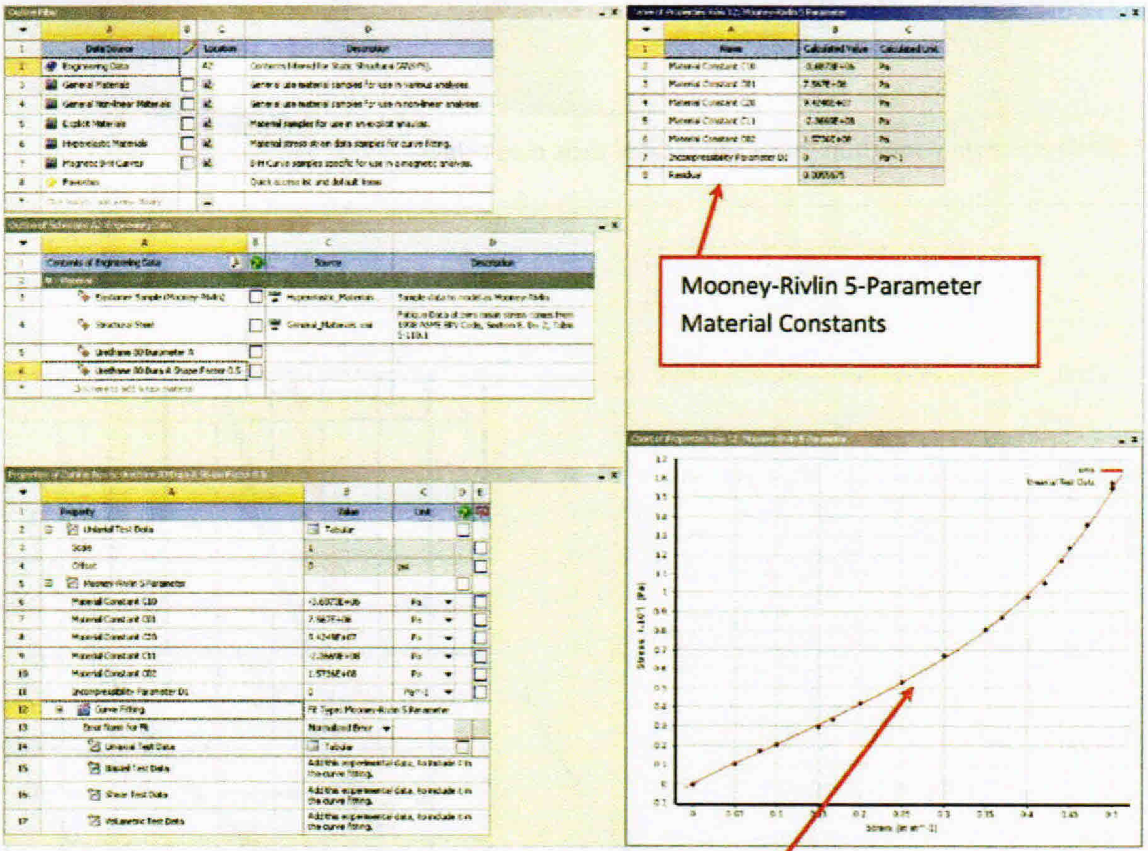


Data used for hyperelastic Mooney-Rivlin parameter values. Curve-fit performed on these data.

Shape Factor = 0.5
Material = Urethane, 80 Durometer A

Took stress-strain values from curve and created excel data below.





	A	B	C	D
1	Data Source		Location	Description
2	Engineering Data		A2	Contents filtered for Static Structural (ANSYS).
3	General Materials	☐		General use material samples for use in various analyses.
4	General Non-linear Materials	☐		General use material samples for use in non-linear analyses.
5	Explicit Materials	☐		Material samples for use in an explicit analysis.
6	Hyperelastic Materials	☐		Material stress strain data samples for curve fitting.
7	Magnetic B-H Curves	☐		B-H Curve samples specific for use in a magnetic analysis.
8	Favorites			Quick access list and default items

	A	B	C	D
1	Contents of Engineering Data		Source	Description
2	Material			
3	Elastomer Sample (Mooney-Rivlin)	☐	Hyperelastic_Materials	Sample data to model as Mooney-Rivlin
4	Structural Steel	☐	General_Materials.xml	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
5	Urethane 30 Durometer A	☐		
6	Urethane 30 Duro A Shape Factor 0.5	☐		

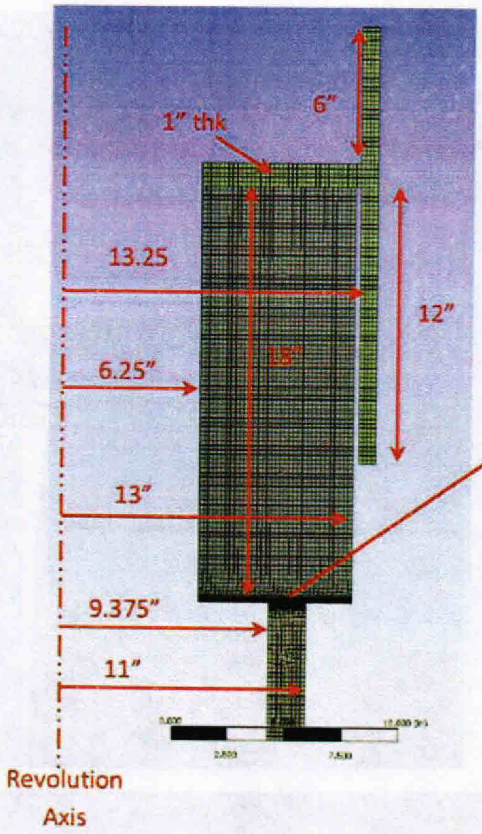
	A	B	C
1	Name	Calculated Value	Calculated Unit
2	Material Constant C10	-3.6873E+06	Pa
3	Material Constant C01	7.5677E+06	Pa
4	Material Constant C20	9.4248E+07	Pa
5	Material Constant C11	-2.3660E+08	Pa
6	Material Constant C02	1.5736E+08	Pa
7	Incompressibility Parameter D1	0	Pa^-1
8	Residual	0.005675	

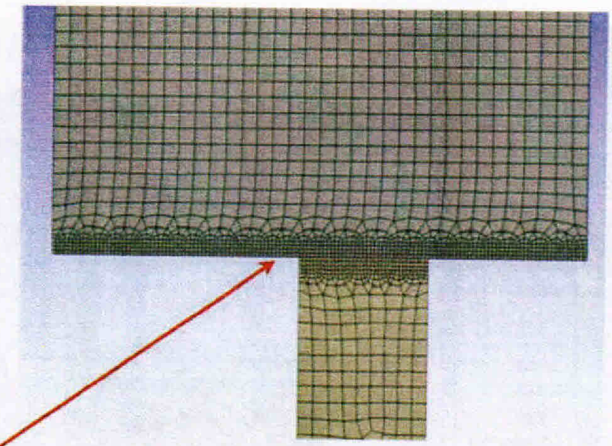
	A	B	C	D	E
1	Property	Value	Unit		
2	Uniaxial Test Data	Tabular		☐	
3	Scale	1			☐
4	Offset	0	psi		☐
5	Mooney-Rivlin 5 Parameter			☐	
6	Material Constant C10	-3.6873E+06	Pa		☐
7	Material Constant C01	7.5677E+06	Pa		☐
8	Material Constant C20	9.4248E+07	Pa		☐
9	Material Constant C11	-2.3660E+08	Pa		☐
10	Material Constant C02	1.5736E+08	Pa		☐
11	Incompressibility Parameter D1	0	Pa^-1		☐
12	Curve Fitting	Fit Type: Mooney-Rivlin 5 Parameter			
13	Error Norm for Fit	Normalized Error			
14	Uniaxial Test Data	Tabular		☐	
15	Biaxial Test Data	Add the experimental data, to include it in the curve fitting.			
16	Shear Test Data	Add the experimental data, to include it in the curve fitting.			
17	Volumetric Test Data	Add the experimental data, to include it in the curve fitting.			

Mooney-Rivlin 5-Parameter
Material Constants

ANSYS Hyperelastic Material Model

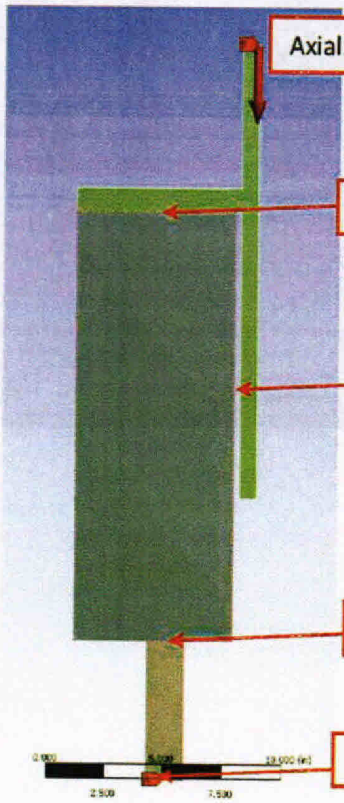
Compression Stress-Strain Data,
Curve-Fit using MR 5-Parameter Model





Axisymmetric FE model of Cut Riser, Gasket, and Steel Annular Gasket Support

MODEL DETAILS



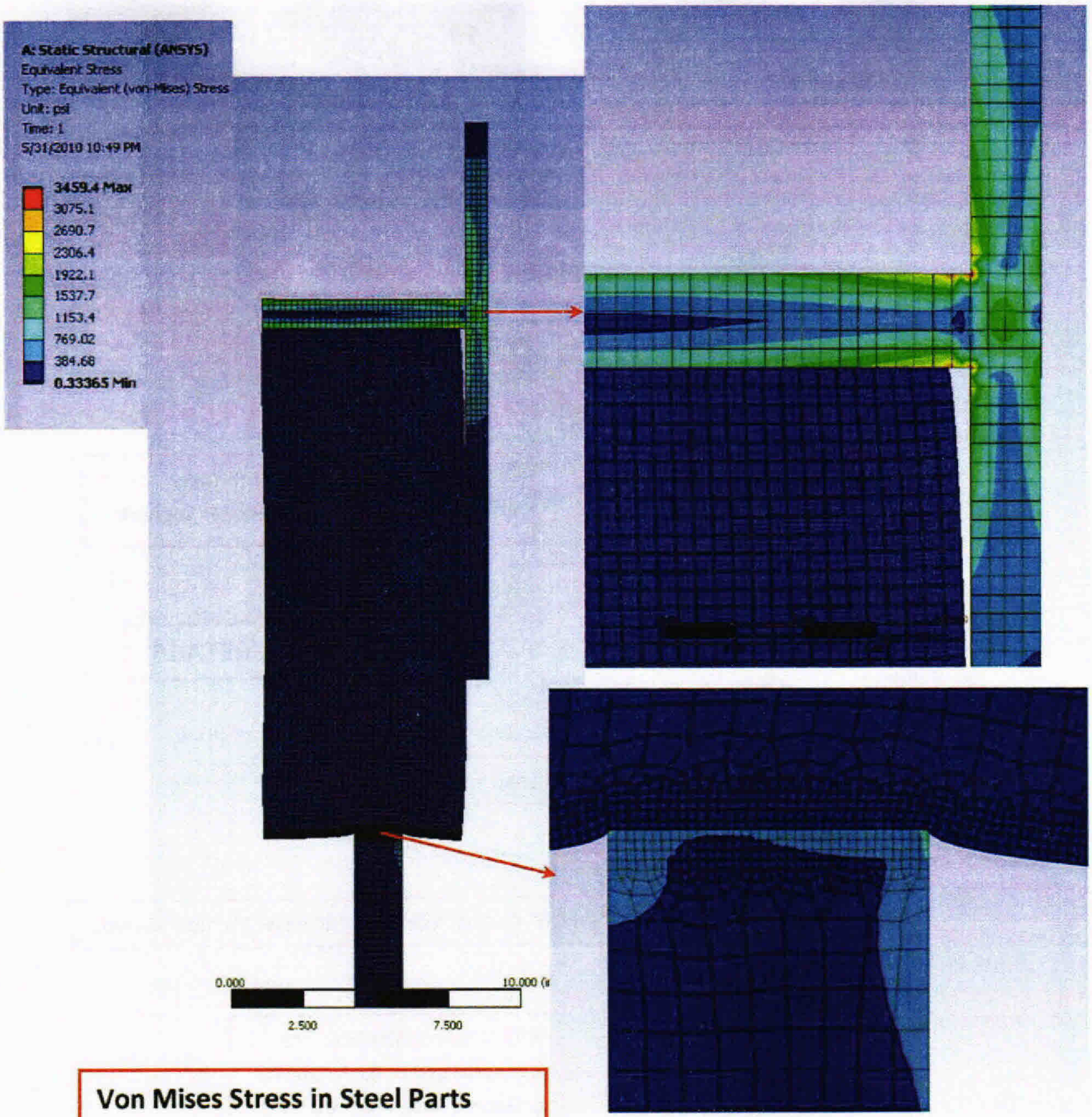
Axial Applied Load = 20,000 lbf

"Rough" Contact Interface (frictional, but not Bonded)

Frictionless sliding interface. Has initial gap of 0.025", but if gasket expands more than that radially, it cannot pass through steel ring wall

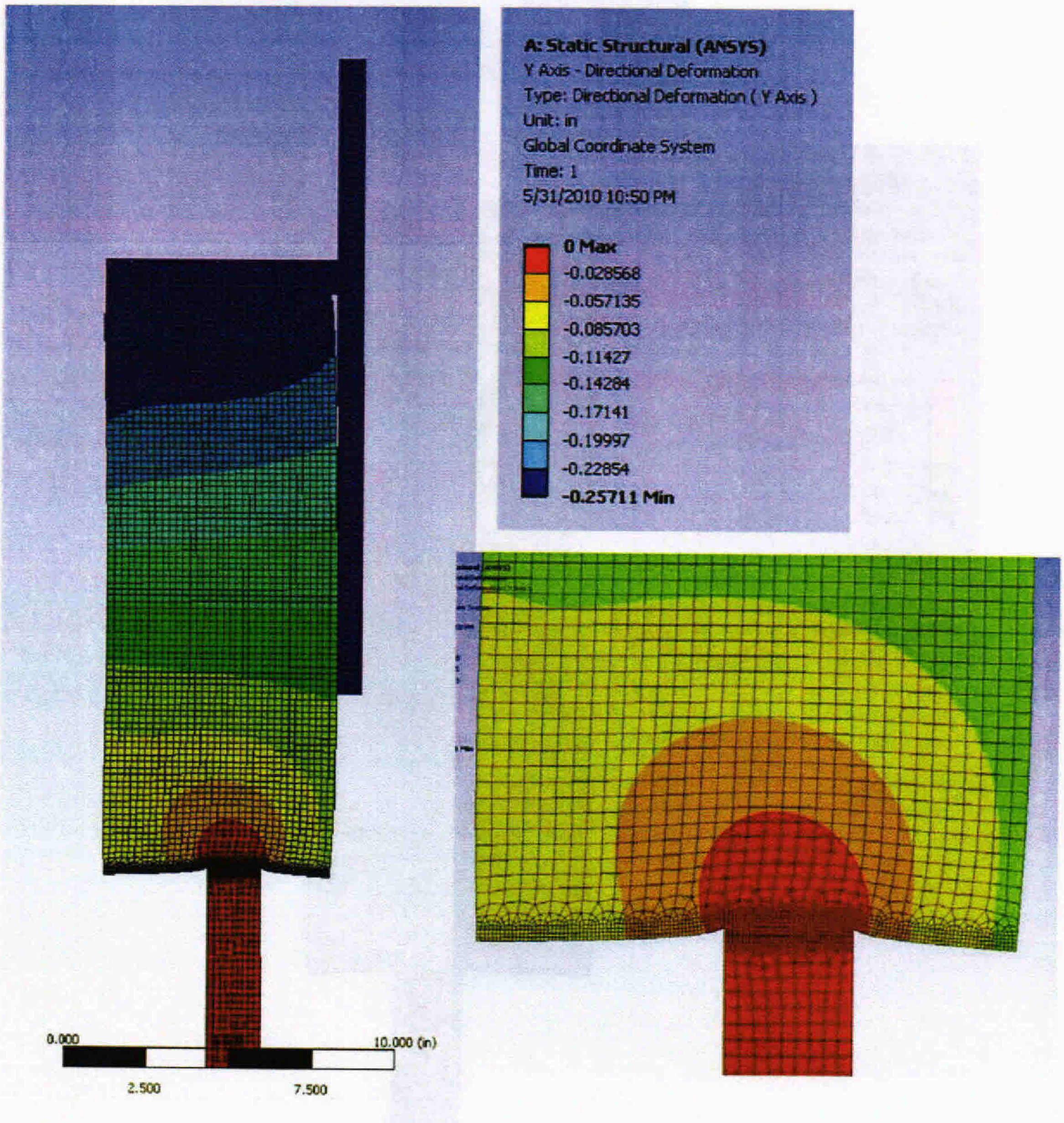
"Rough" Contact Interface (frictional, but not Bonded)

Axial Displacement Fixed

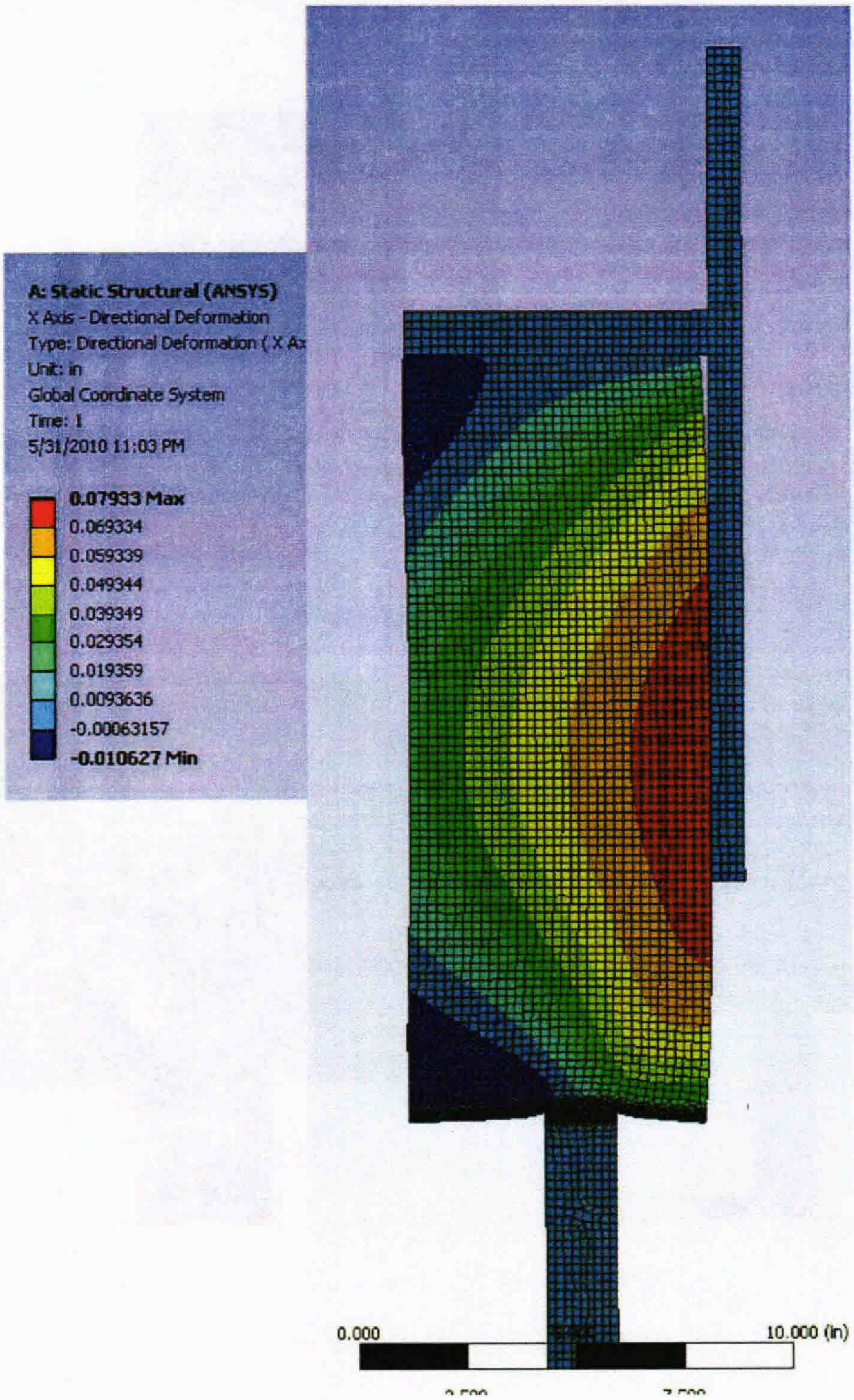


Von Mises Stress in Steel Parts Max (bending) in annular ring/plate weldment is ~3500 psi

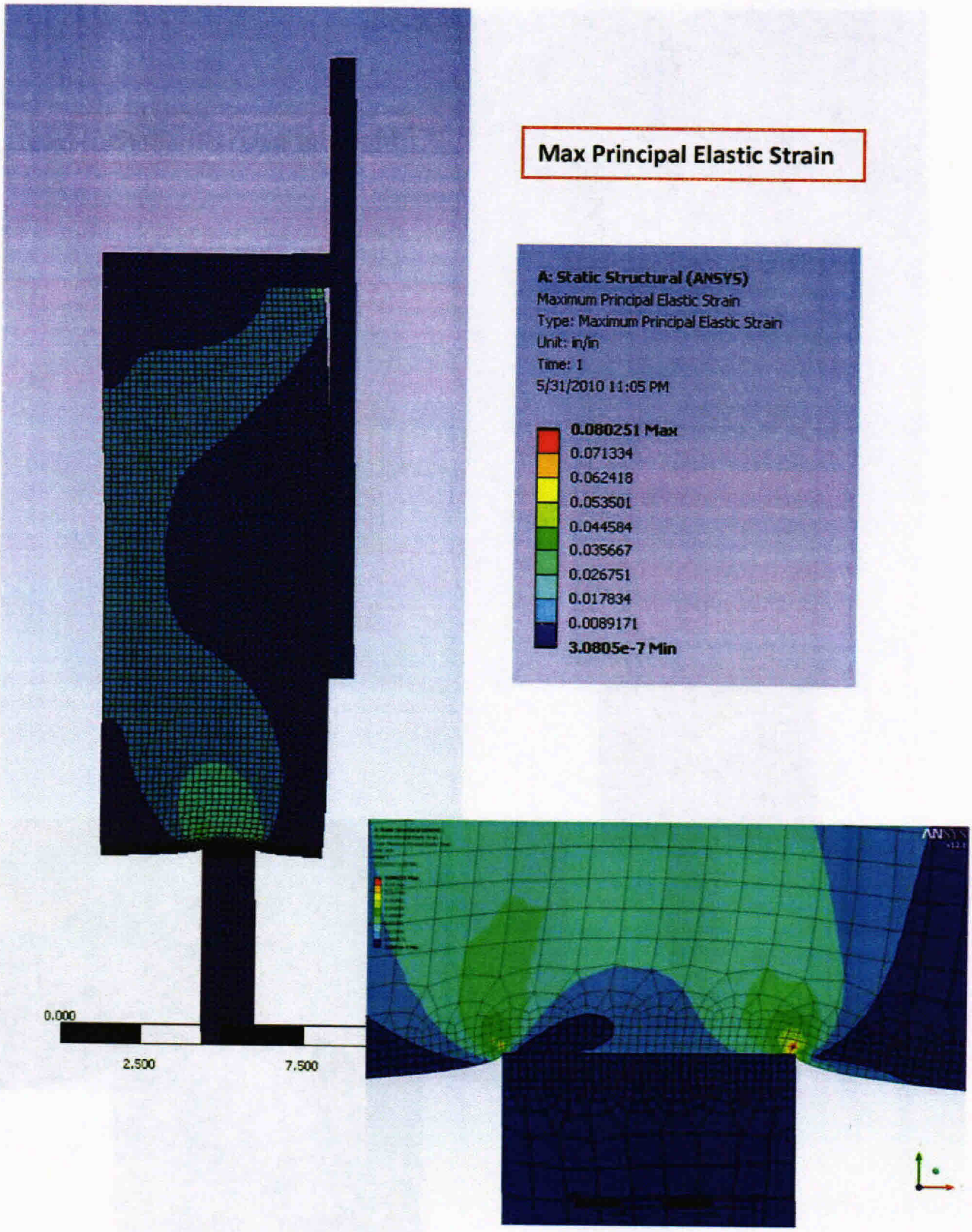
Axial Deflection in Inches

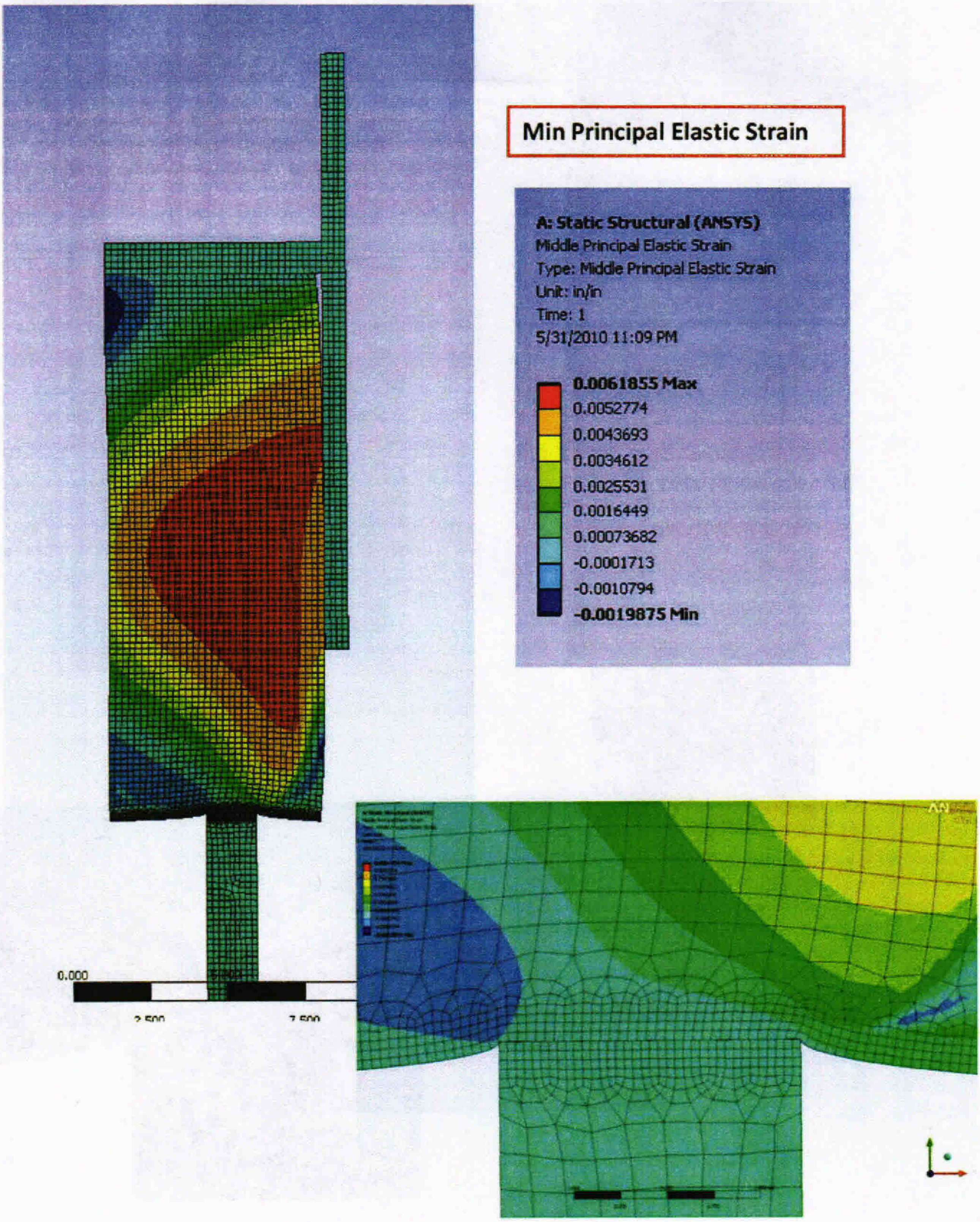


Radial Deflection in Inches



Max Principal Elastic Strain





Min Principal Elastic Strain

A: Static Structural (ANSYS)
Middle Principal Elastic Strain
Type: Middle Principal Elastic Strain
Unit: in/in
Time: 1
5/31/2010 11:09 PM

- 🟥 **0.0061855 Max**
- 🟥 0.0052774
- 🟧 0.0043693
- 🟨 0.0034612
- 🟩 0.0025531
- 🟩 0.0016449
- 🟩 0.00073682
- 🟦 -0.0001713
- 🟦 -0.0010794
- 🟦 **-0.0019875 Min**