9th European Formation Damage Conference

SPE 14391 - Formation Loading & Deformation of ESS

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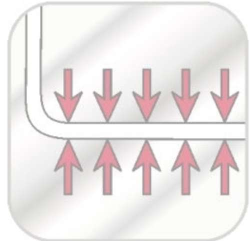
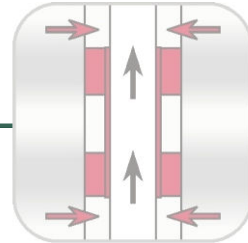
June 2011

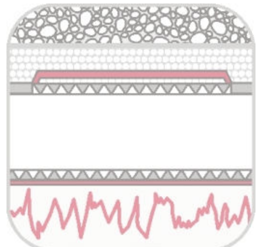
Solving your sand control challenges.


High Productivity


Optimum Drainage


Effective Isolation


Application Versatility


Integrated Function

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- Hydraulic Collapse Testing
- Large Scale Triaxial TWC Compression Testing
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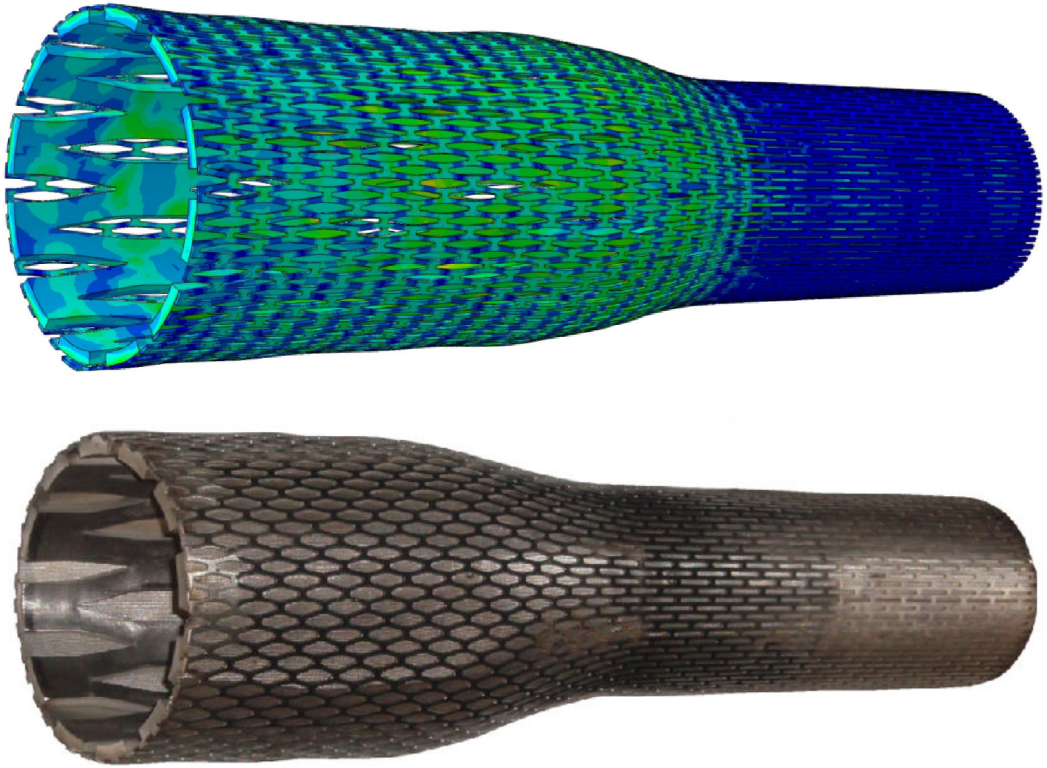
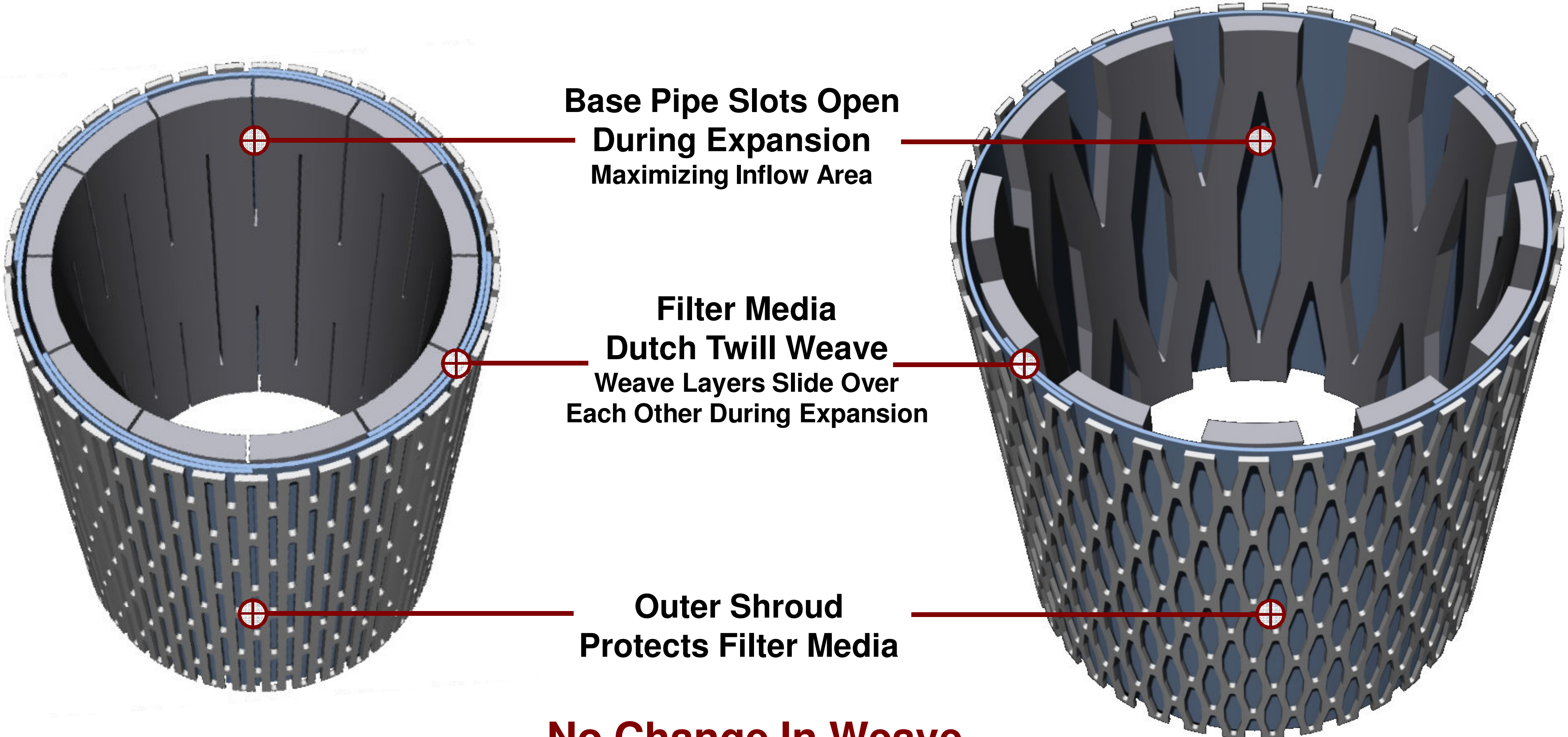
  - Analytical Solution
  - Numerical Solution
- Application Screening
- Conclusions



Introduction: ESS Design

Product sizes; 4”, 4-1/2”, 5-1/2” and 7”



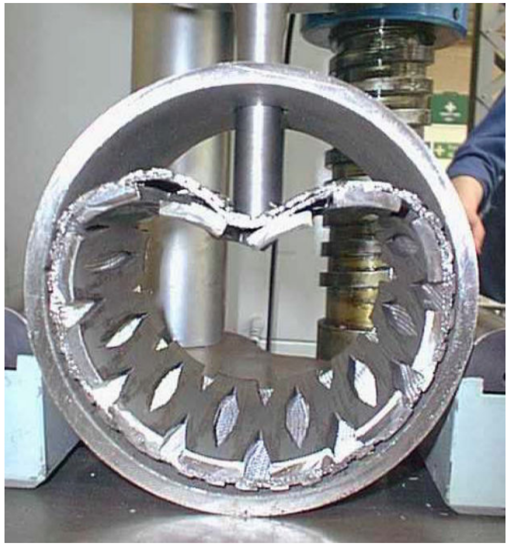
Unexpanded

No Change In Weave Aperture Size

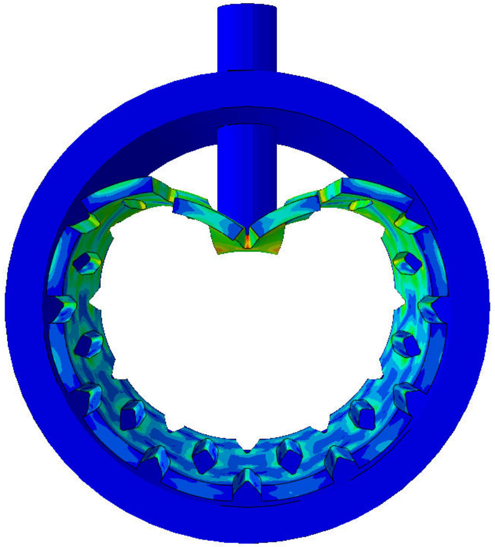
Expanded

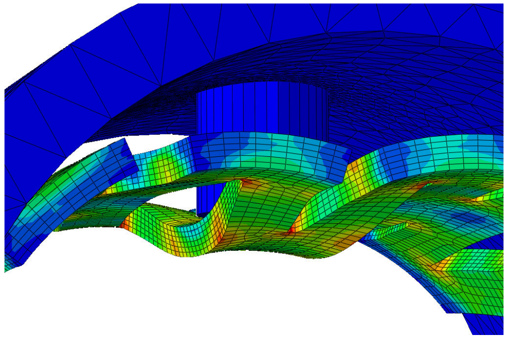
Axial & Radial Compression Testing

Radial Point Loading



Experimental Results

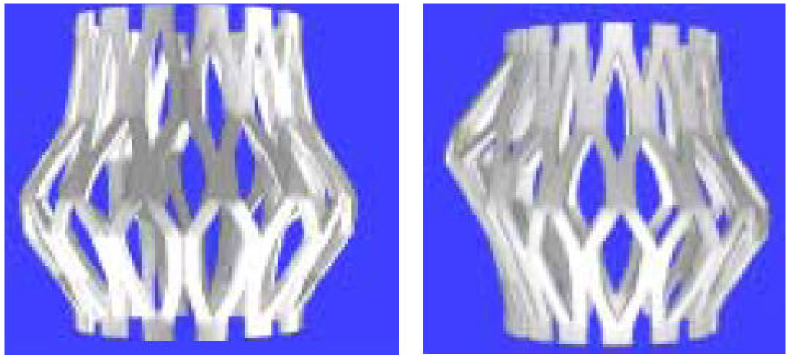




Numerical Predictions

Axial Platen Loading

Experimental Results



Numerical Predictions

Reproduced from OTC 14314 – Ensuring the Mechanical Integrity of Expandable Sand Screens (May 2002)

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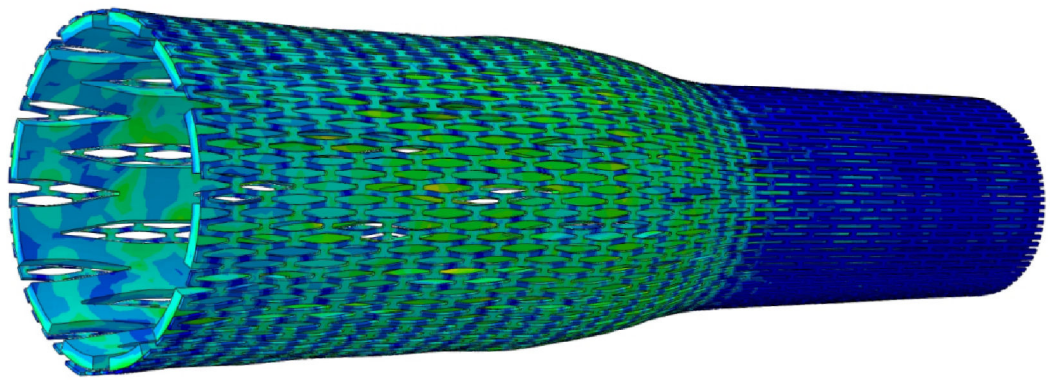
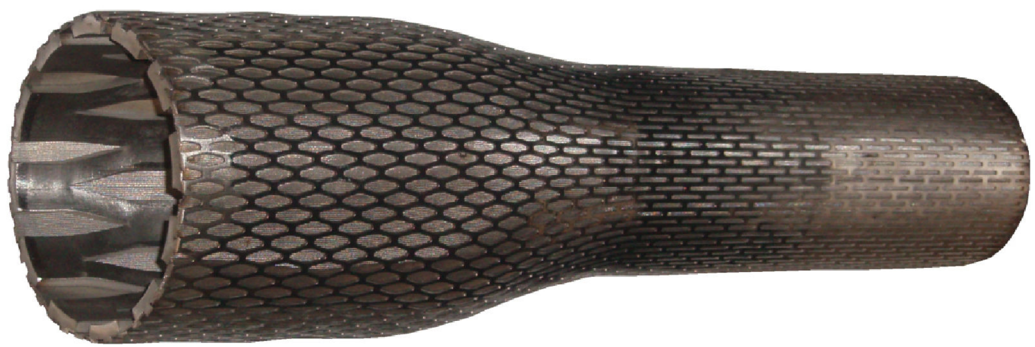
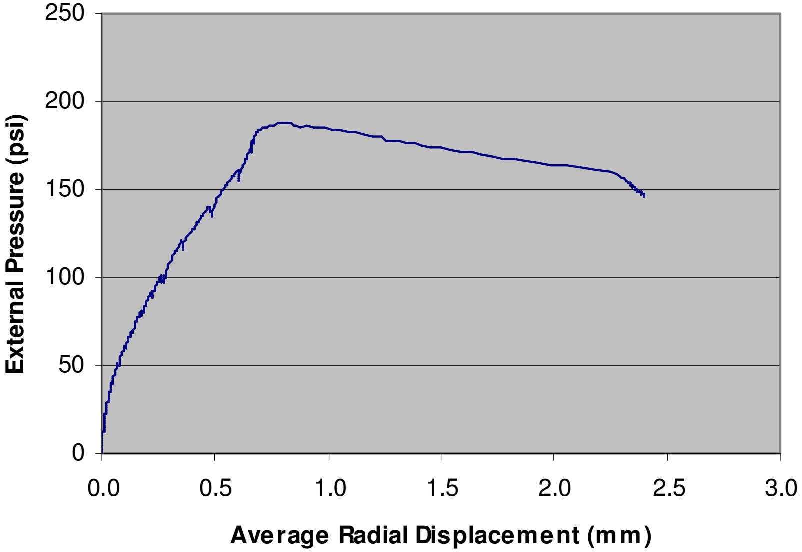




Hydraulic Collapse Testing

- Tests performed in a pressure vessel, with ESS plugging with impermeable membrane or fluid loss pill.
- ESS deformation measured using displacement transducers
- Tests show ESS deforms in linearly to a peak, after which the structure buckles and the load bearing capacity drops slowly



ESS Size	Hydraulic Collapse
4" 316L	170psi
4 ½" 316L	180psi
5 ½" 316L	123psi
7" 316L	350psi

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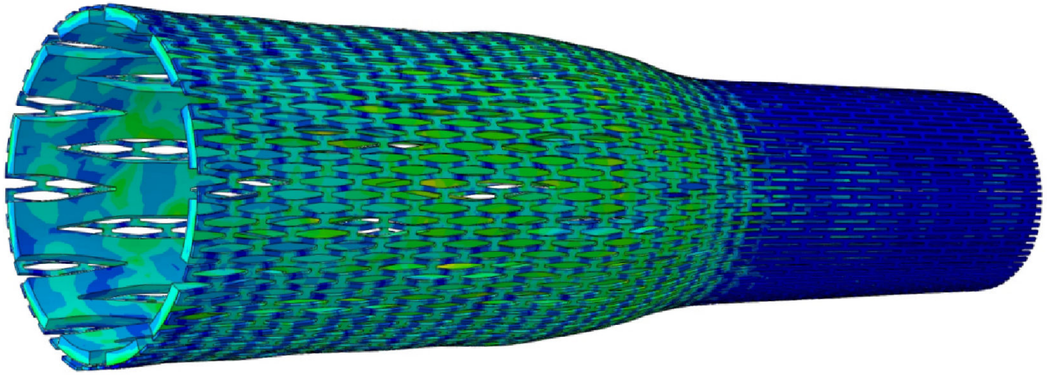
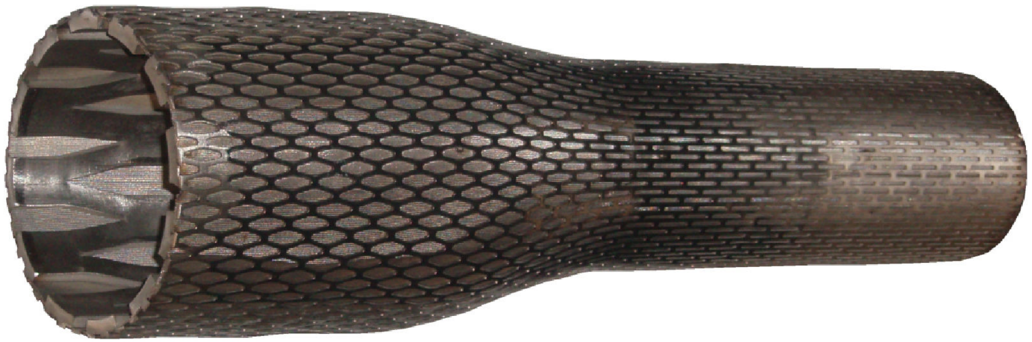
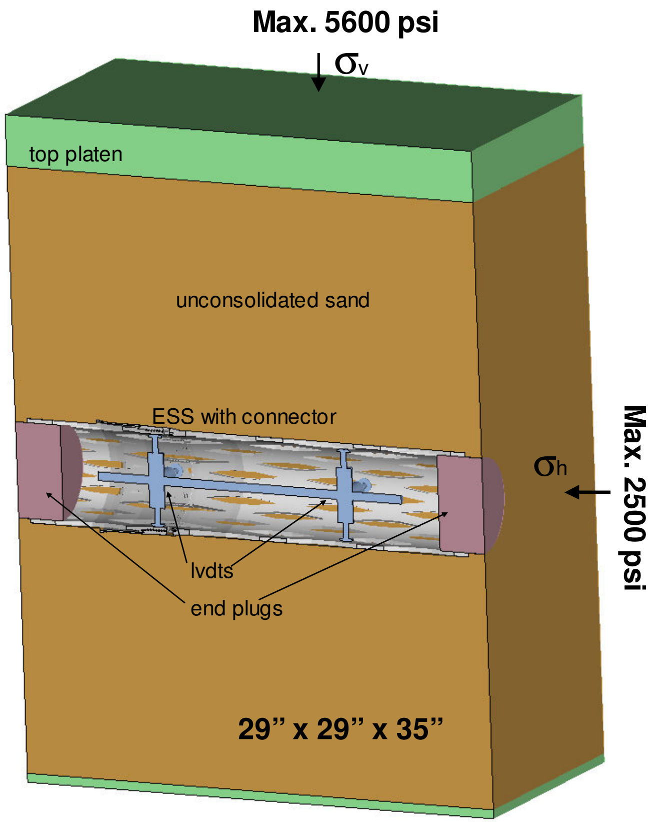


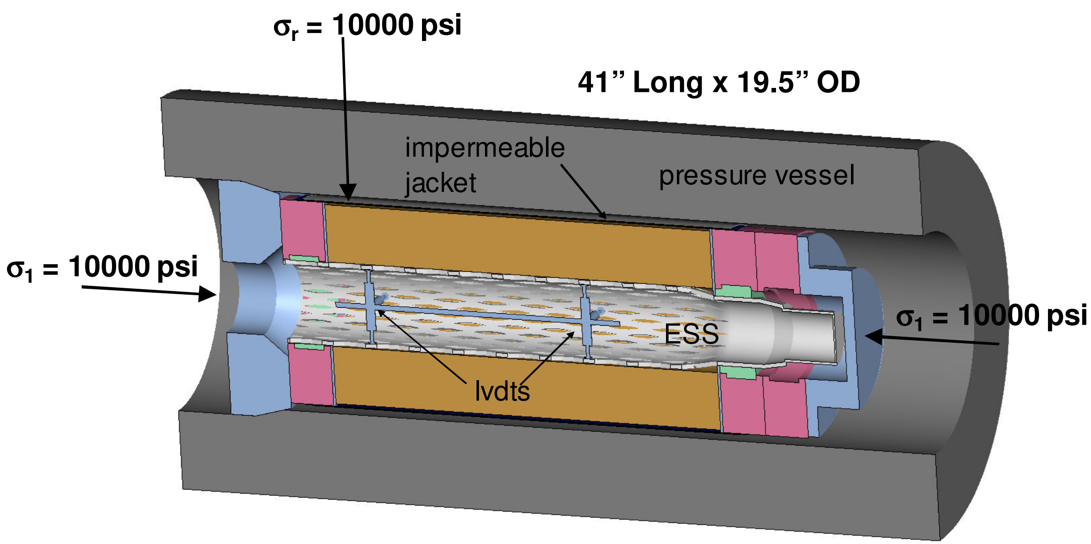


PEA 182 – Large Scale Triaxial Deformation Tests

- Multi-Operator JIP project to study ESS-formation interaction
- Total of 11 tests conducted, 9 on ESS, 1 on alternative expandable screen design with pre-drilled base pipe and 1 SAS.
- Sand Box (SB) and Pressure Vessel (PV) tests performed on ESS

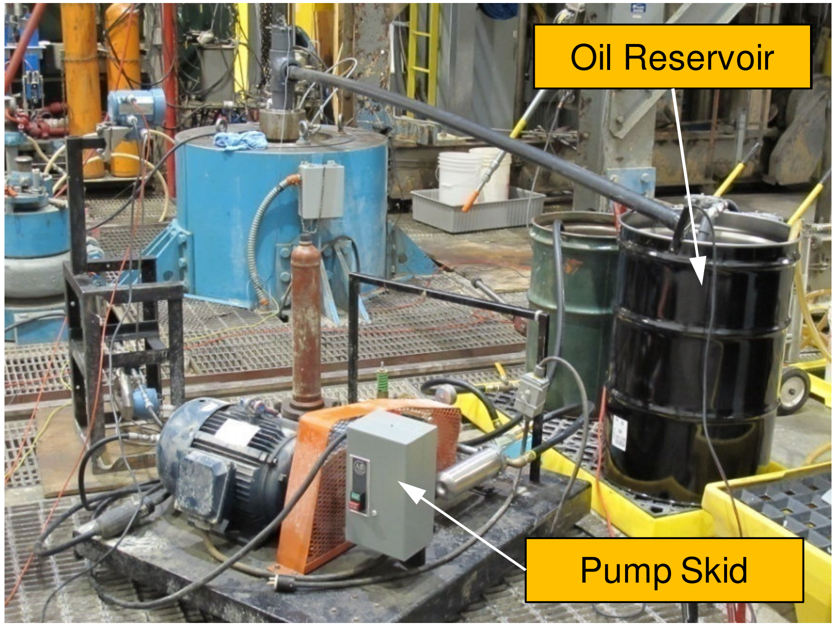


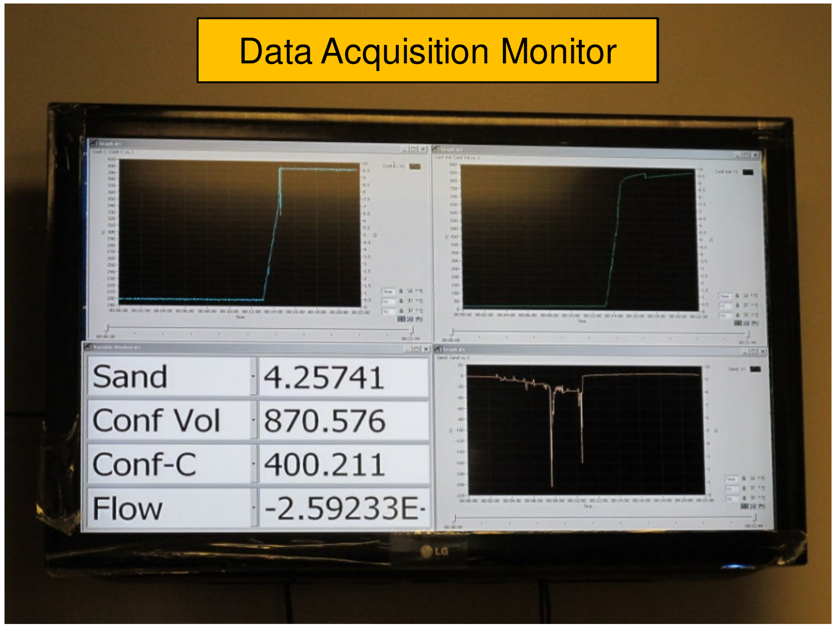
Sand Box (SB) Test Fixture

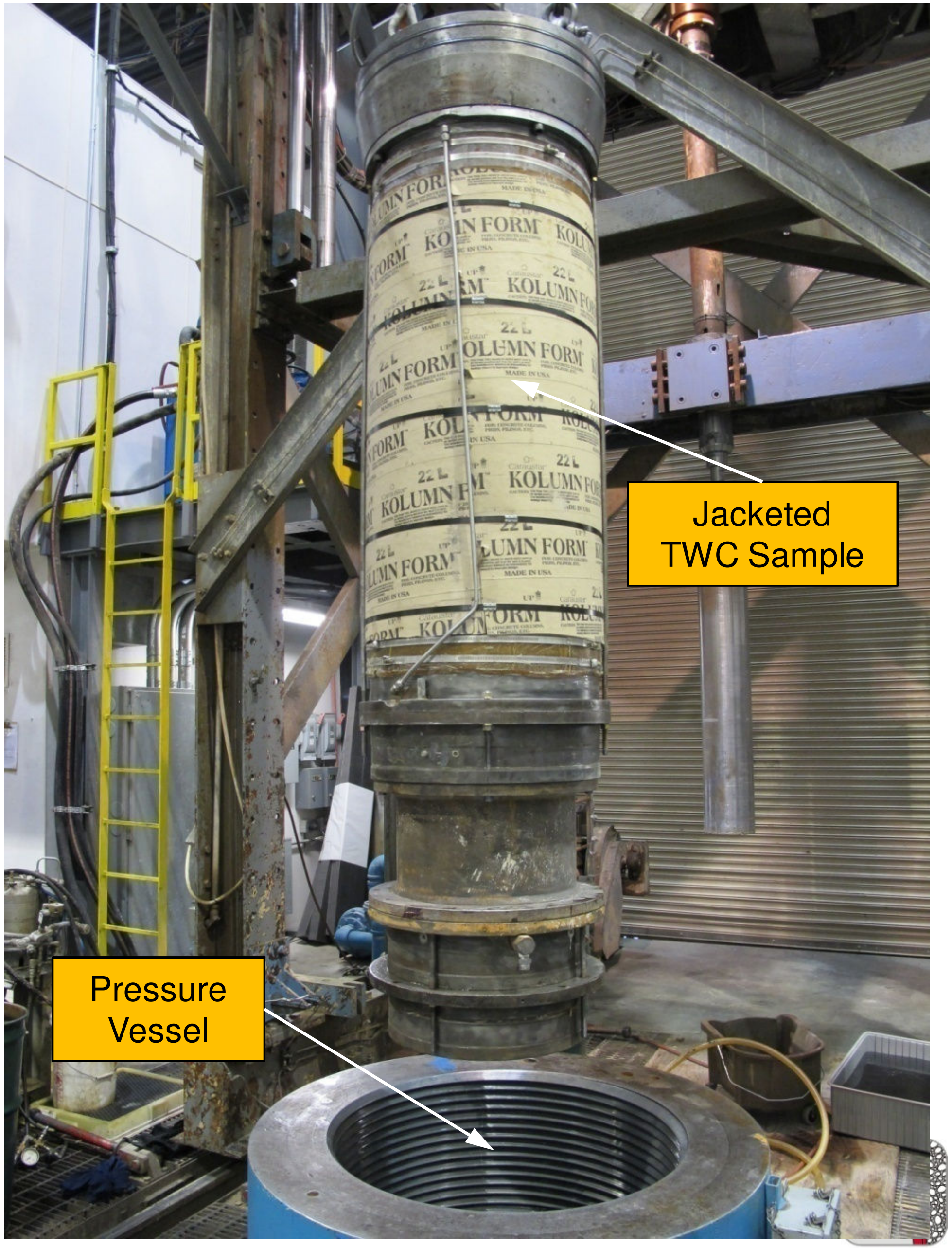


Pressure Vessel (PV) Test Fixture

PV Test Apparatus







PEA 192 ESS Test Matrix

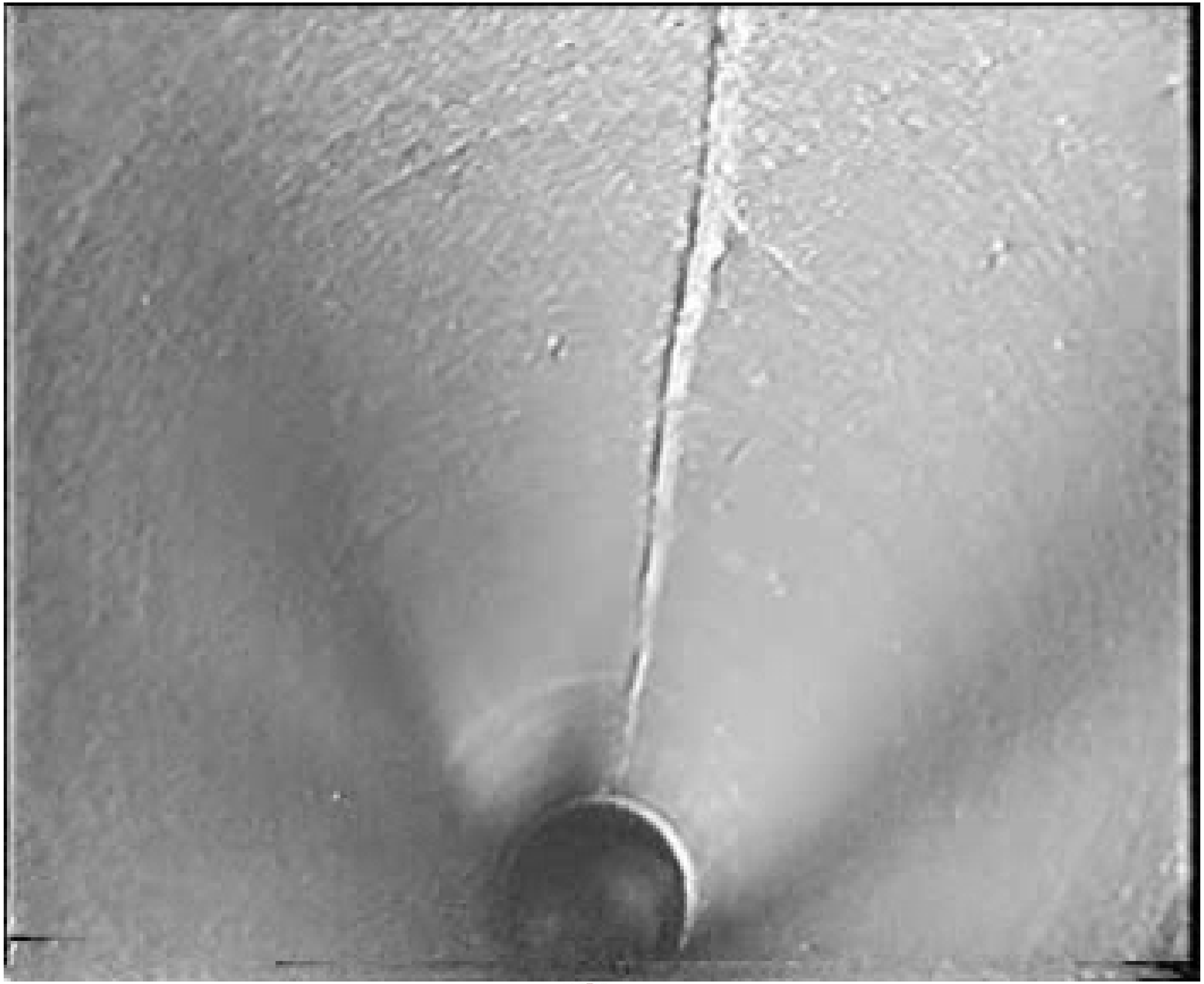
Rock	Test	Properties	Comments
Unconsolidated 1 (UC1)	1,8	UCS=0, FA~30°	TerraTek standard U/C sand
Unconsolidated 2 (UC2)	7	UCS=0, FA high	Designed to be a high friction angle
Unconsolidated 3 (UC3)	6	UCS=0, FA low	Sand clay mixture 60/40 , low friction angle
Castlegate SS (CSS)	2,3,4,5	UCS=1500psi	Weak to medium strength sandstone
Saltwash South SS (SWSSS)	8, 11	UCS=400psi	Weak sandstone
Pierre Shale (PS)	6, 11	UCS=350psi, FA 0-34°	Surface shale

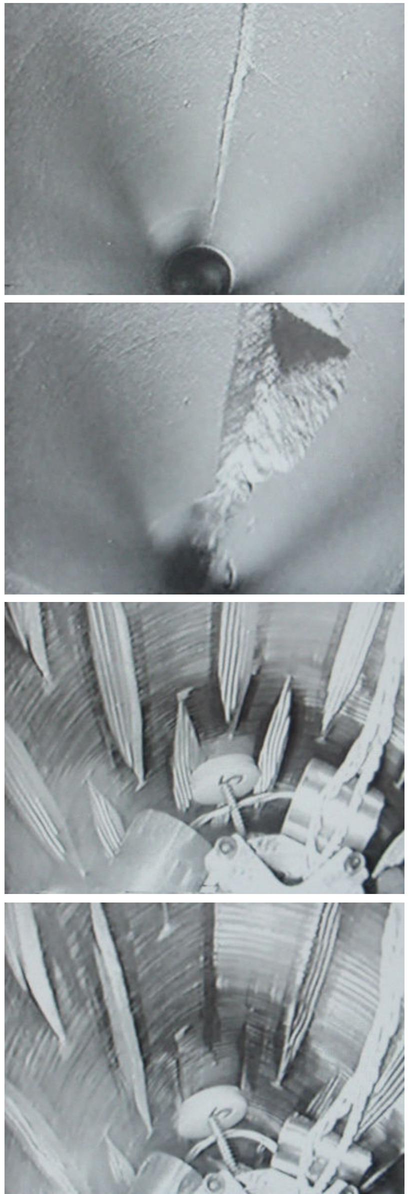
Table 1: Rock Types Used

Test	Objective	ESS Size	Test Type, Rock Type	Borehole	Maximum Stress (psi)	Maximum Deformation	Maximum Decrease in ID
1	Evaluate MKI connector design	5 ½" c/w connector	SB, UC1		5600	1.07"	15%
2	Benchmark ESS deformation under fully compliant conditions	4"	PV, CSS	6.1"	9000	0.3"	6%
3	Assess impact of non-compliancy	4"	PV, CSS	6.1" + 6.6"	10000	0.75"	15%
4	Quantify increase in borehole strength through ESS confinement	4"	PV, CSS	6.1" c/w Breakouts	10000	1.03"	21%
5	Repeat of Test 3 with MKI connector included	4" c/w connector	PV, CSS	6.1" + 6.6"	10000	0.95"	19%
6	Evaluate impact of sand-shale interface on ESS deformation	4"	PV, PS,UC3	6.1"	3000	0.7"	14%
7	Assess impact of stronger metallurgy	4" Incolloy	SB, UC2		1500	1"	20%
8	Assess impact of unconsolidated sand-weak sandstone interface	5 ½" (8.44" OD)	PV,SWSSS,UC1	8.73"	5000	2.5"	34%
11	Evaluate impact of sand-shale interface on ESS deformation	7" 25Cr (8.6" OD)	PV, PS, SWSSS	8.7"	1600	2.5"	32%

Table 2: Summary of Test Results

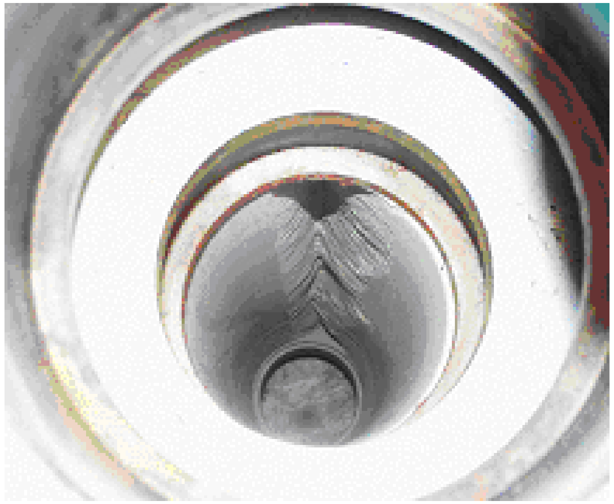
Large Scale Triaxial TWC Compression Test 4





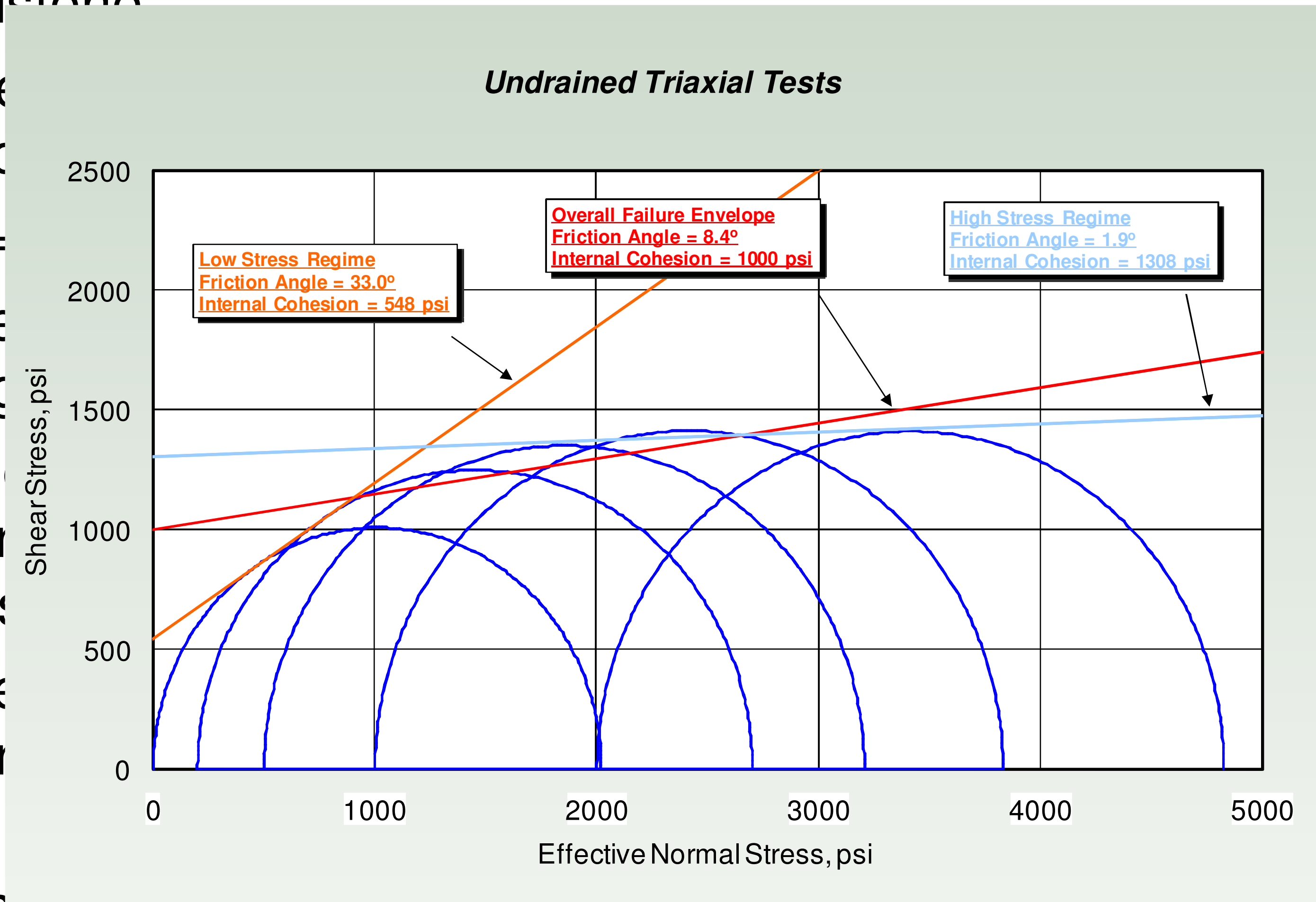
Large Scale Triaxial TWC Compression Test 4

- As a precursor to Test 4 the CSS TWC sample was stressed in PV to induce borehole breakout
- Breakout occurred at 2500 psi confining pressure, equating to strength of unsupported borehole
- ESS was then expanded to achieve full compliant contact with the borehole except across the breakout
- Rock sample was then re-stressed, with confining pressure increased to 10,000 psi limit of PV vessel
- ESS sample was still and sand-tight, and boosting borehole strength fourfold.



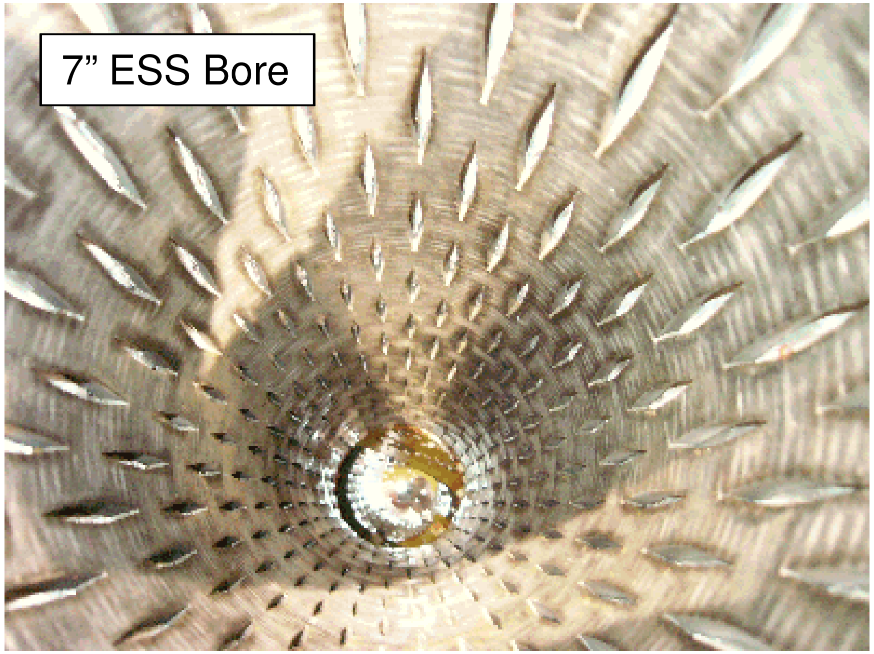
Large Scale Triaxial TWC Compression Test 11

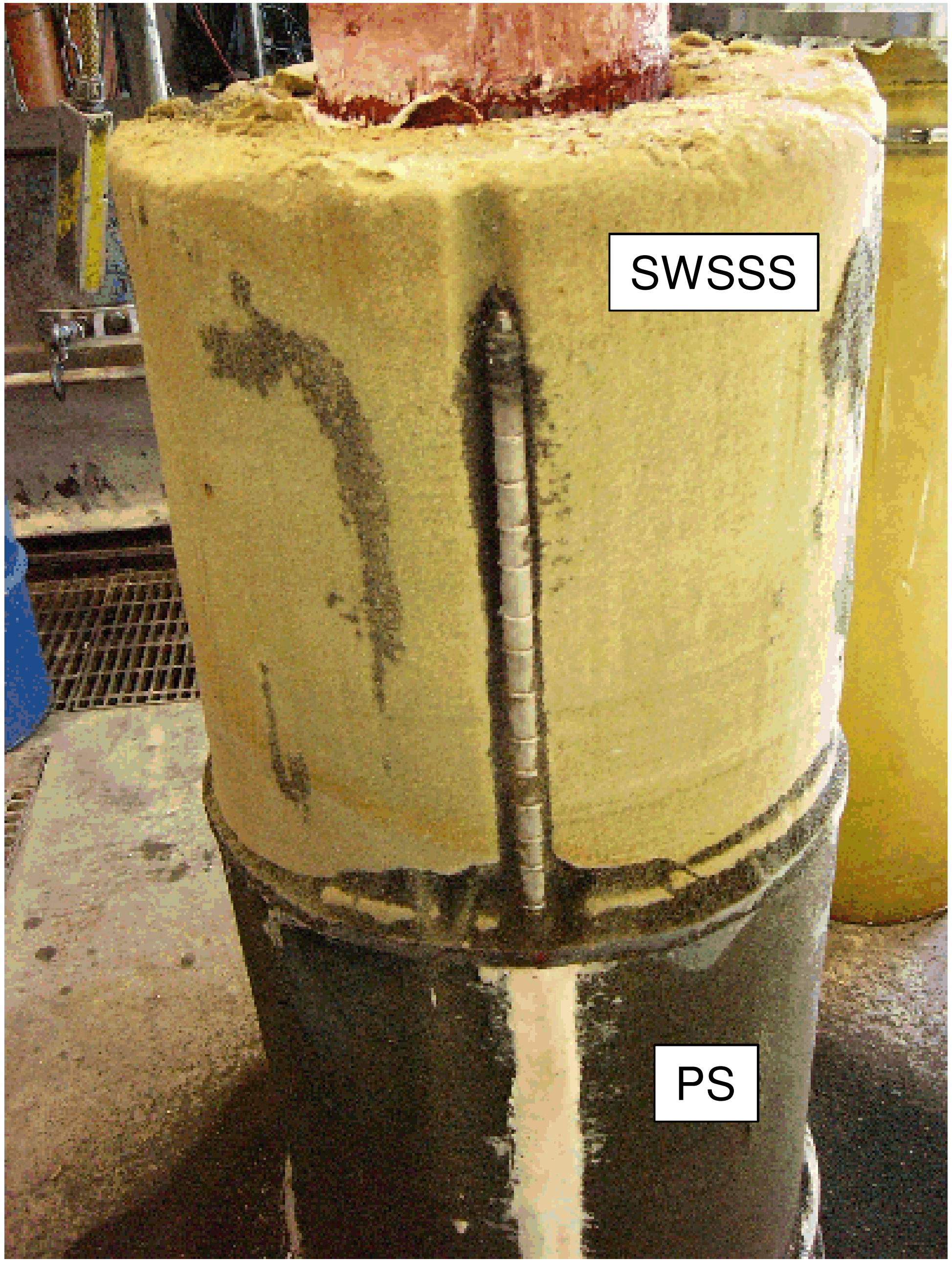
- TWC sample comprised layer of Pierre Shale and Saltwash South Sandstone
- Pierre ... with 40% clay c...
- UCS= ... s
- Value ... samples, owing ...
- As a ... cation of confi... ld a sands...
- There ... effective confi... ction angle
- If the ... gle would be much higher. However this would take years for the 19.5" OD sample



- The undrained conditon is therefore elevant to the PV tests.

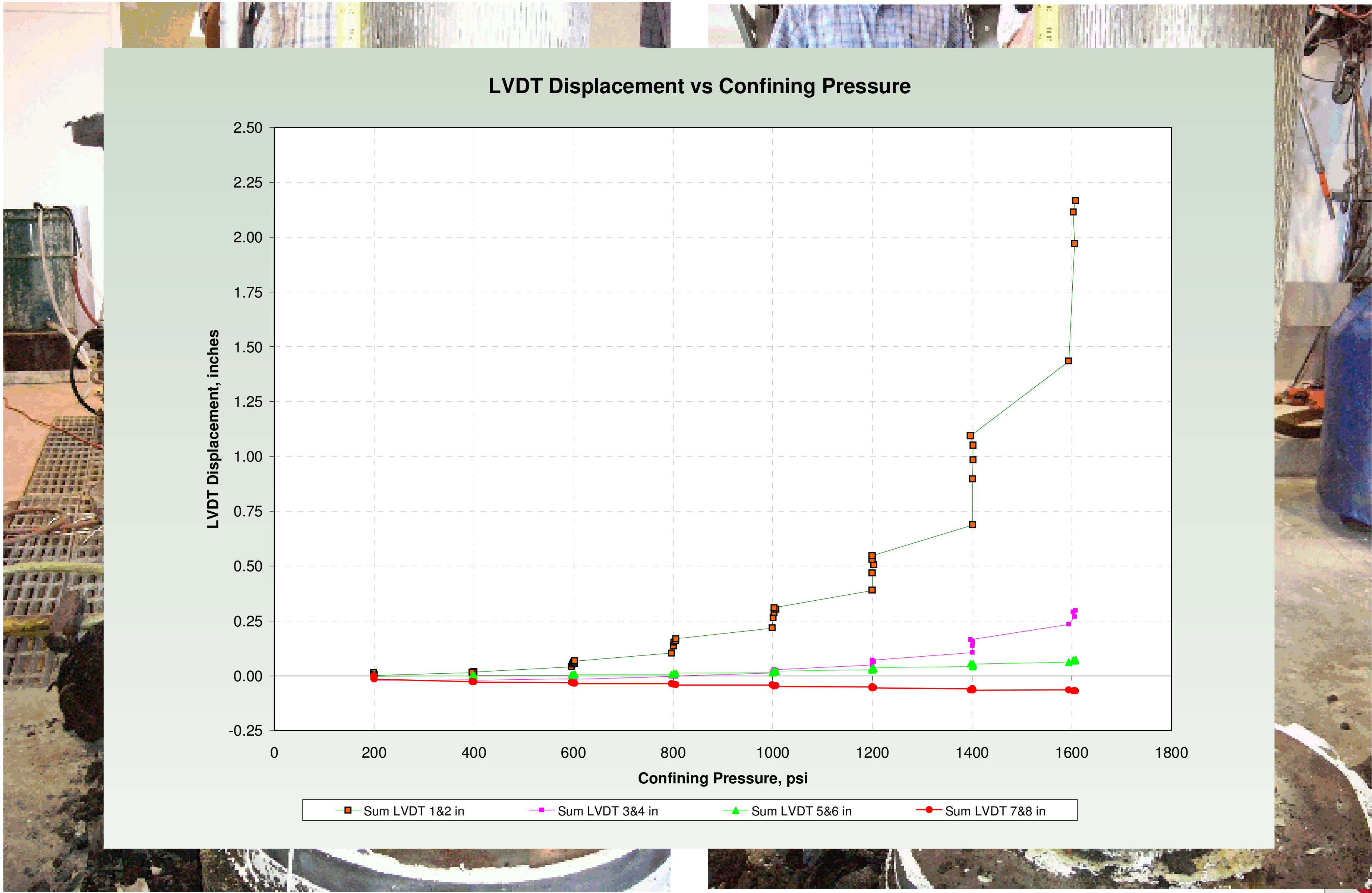
Test 11 Sample – Post Deformation





Test 11 Shale Shear Banding & Faulting

Test 11 Elliptical Deformation of 7" ESS



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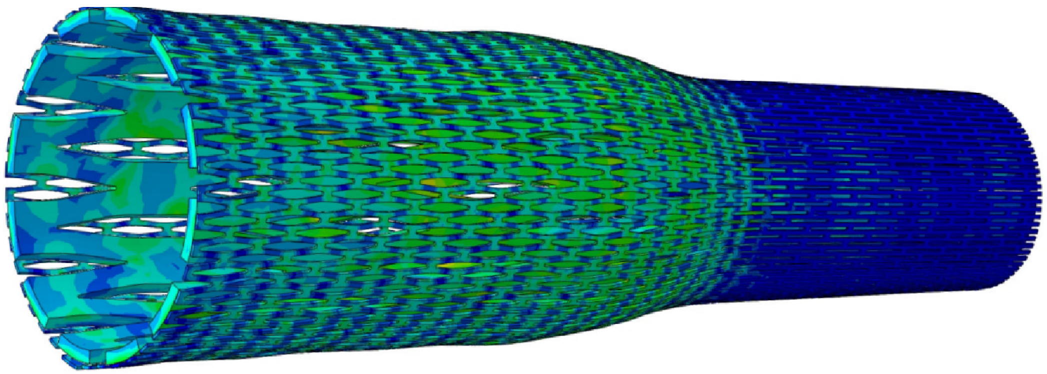
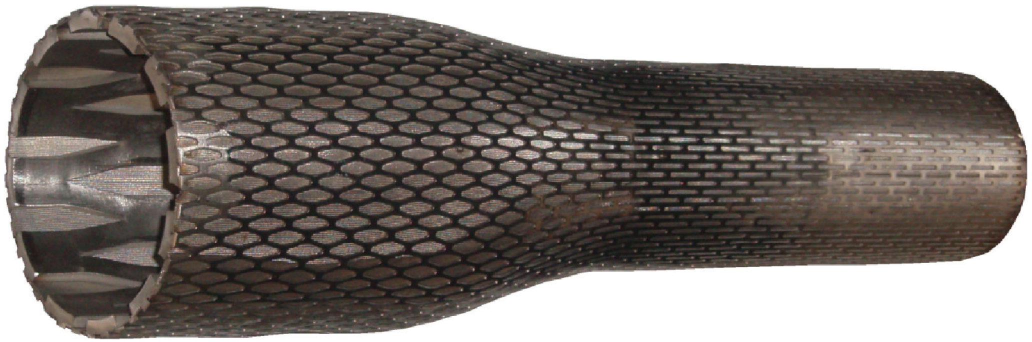




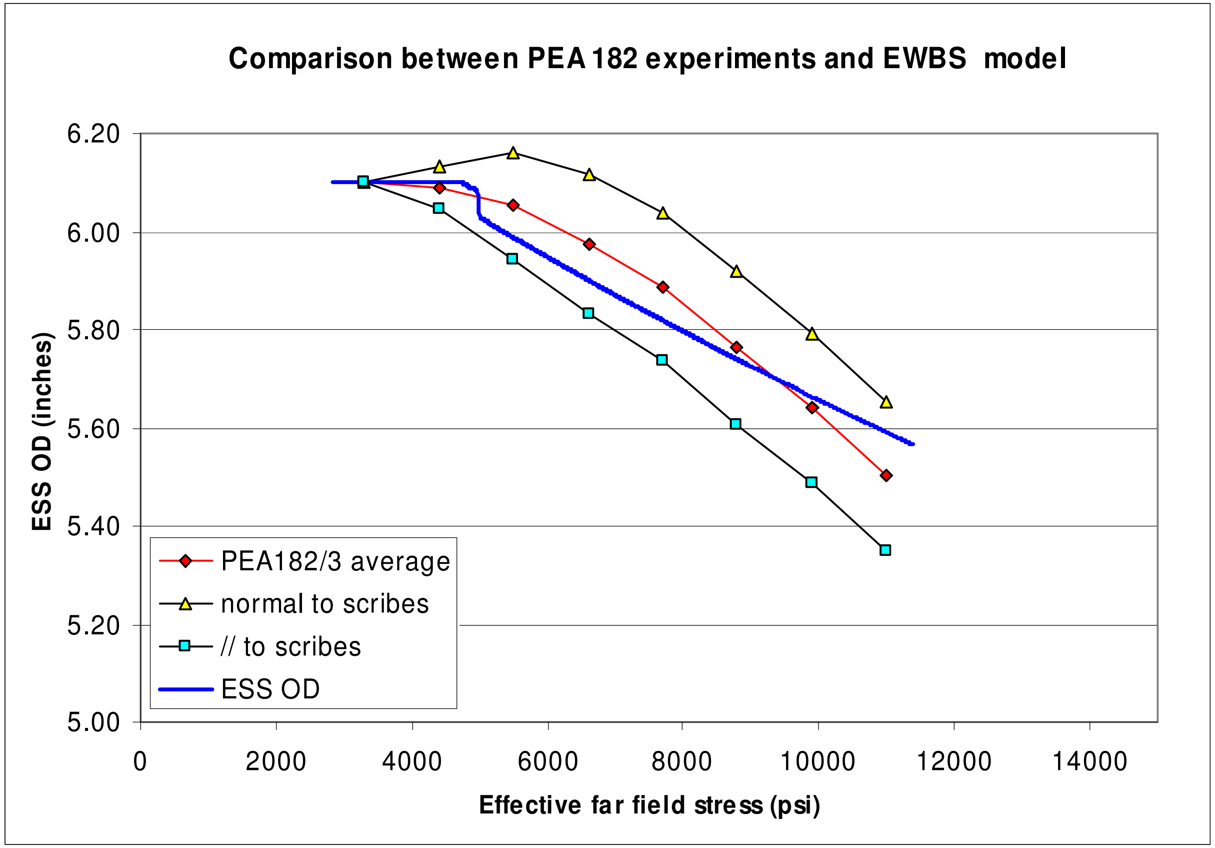
Analytical Model – Based on Yield Zone Theory

- Simple equations
- Straight forward assumptions
- Predicts depth of yielded or failed zone
- Calculates reduction in wellbore diameter as a result of dilatancy

Assumptions

- Homogeneous isotropic rock
- Plane strain
- Equal stress
- Linear failure envelope
- Circular opening
- No pressure gradients
- Constant dilatancy in yield zone
- Simplified stress-strain relationship for any screen
- Uniform homogeneous deformation

Model and experiment comparison



- Good fit is possible with realistic input data
- Model predictions are low but this is consistent with sample boundary conditions

EWBS Calculates ESS ID

Weatherford Expandables Wellbore Stability Model (EWBS)

Well Properties

Depth	8602	ft
Overburden	8602	psi
Max Horizontal Stress	5000	psi
Min Horizontal Stress	5000	psi
Initial Pore Pressure	3536	psi
Final Pore Pressure	2500	psi
Azimuth (SHmax)	0	degs
Inclination	90	degs
Hole size	8.50	inch

ESS Properties

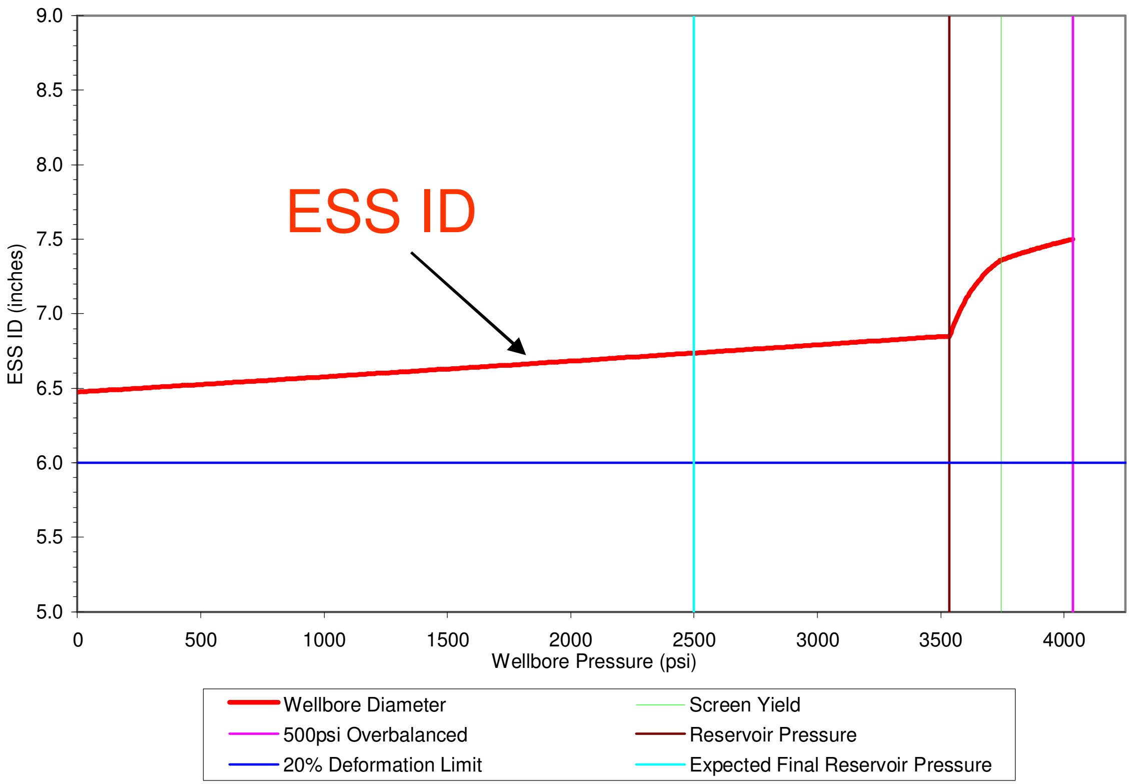
ESS Size	5 1/2 (316L)	inch
Nominal OD	8.50	inch
ESS Eff. Mod	7500	psi
ESS Yield	123	psi
ESS Hardening Modulus	375	psi

Formation Properties

Unconfined Compressive Strength	100	psi
Triaxial Stress Factor	3	psi/psi
Friction angle	30.0	degs
Cohesion	28.9	psi
Dilatancy	0.01	dV/V
Yielded Material Cohesion	15	psi
Initial Reservoir Permeability	n/a	mD
Yielded Reservoir Permeability	n/a	mD

Deformation & Depletion

Yield Zone at Installation	10.96	inch
Deformation Limit	20	%
Wellbore Pressure @ Limit	0	psi
Maximum Depletion/Drawdown	3536	psi



Mud Calculations

Over Balance	500	psi
Wellbore Pressure	4036	psi
Mud Weight	9.0	ppg
Yield Zone	2.58	radii
Yield Depth	10.96	inch
Volume Increase	3.20	cu inch
Hole ID bef ream	8.26	inch

Well Details

Client	
Well	
Field	
Region	
Comments:	

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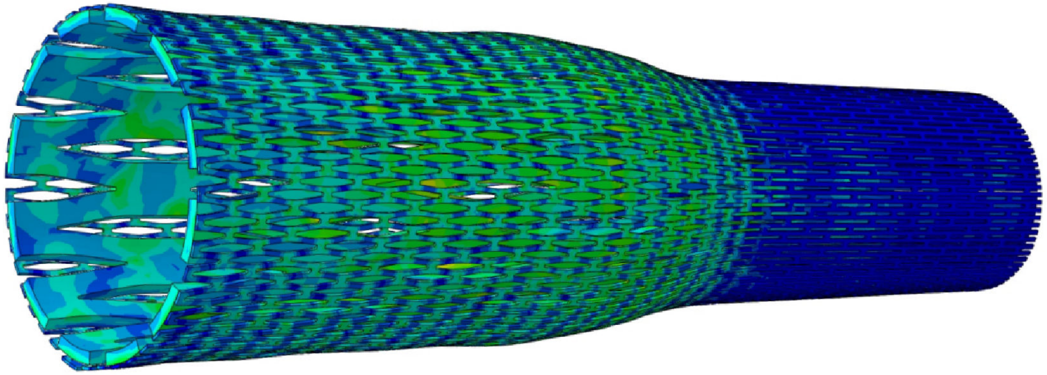
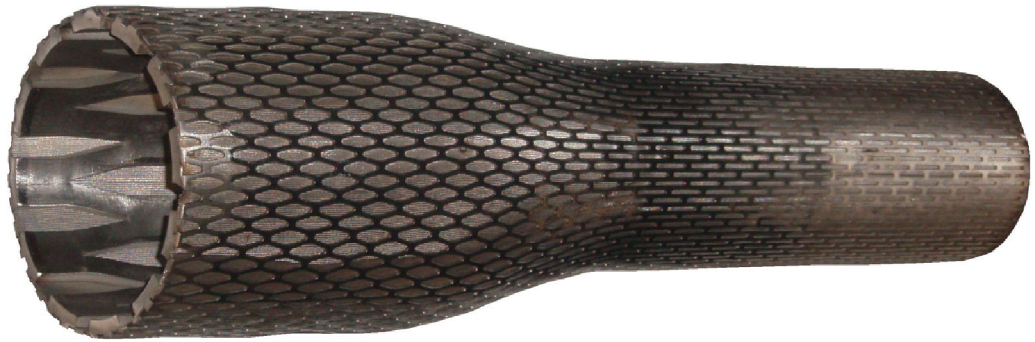
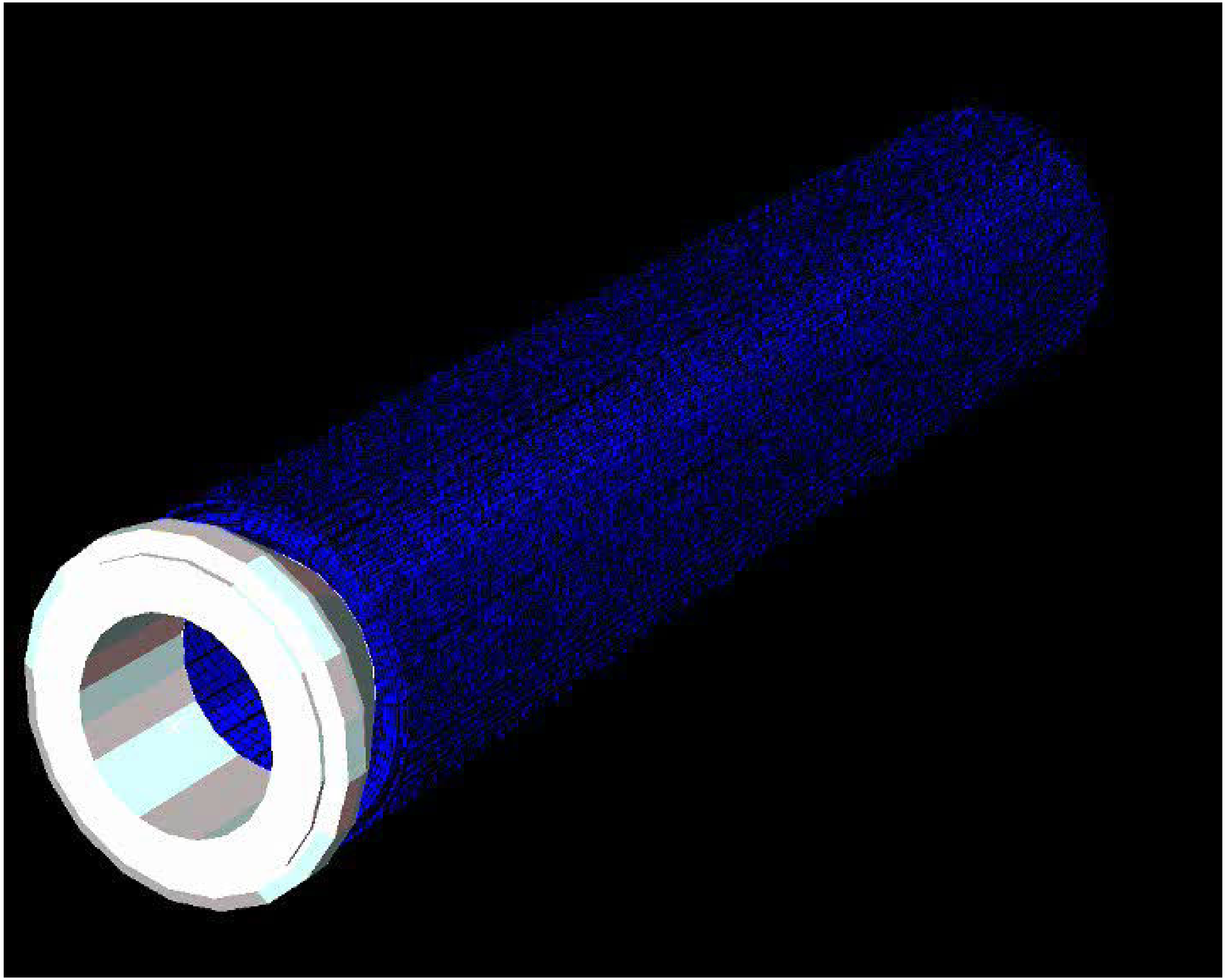
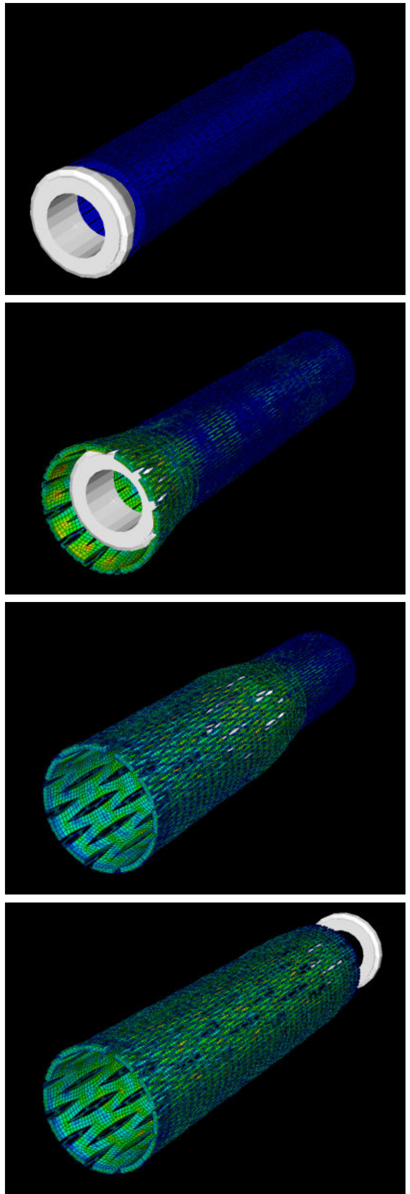




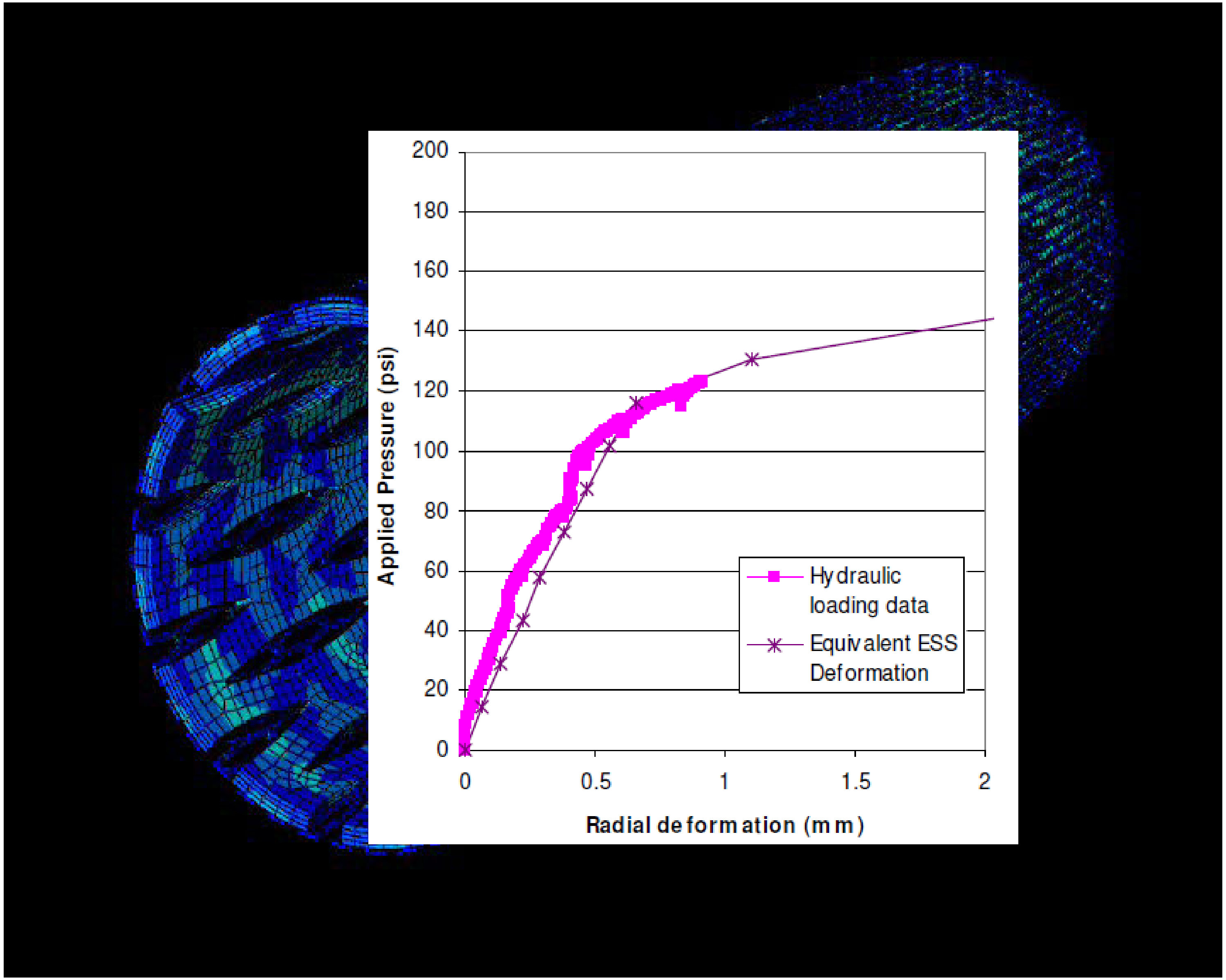
Stage 1 – Construct FEA Model of ESS

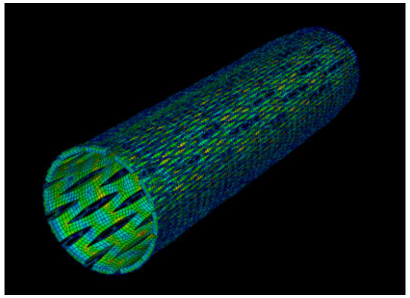


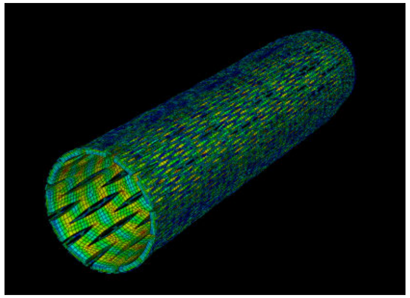


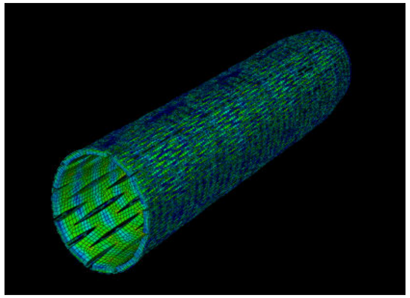
Simulated Cone Expansion

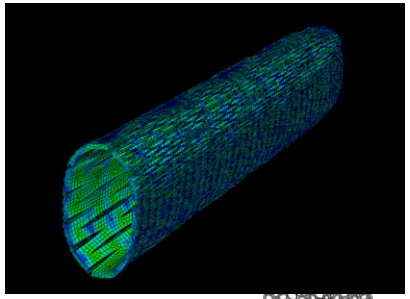
Stage 1 – Construct FEA Model of ESS







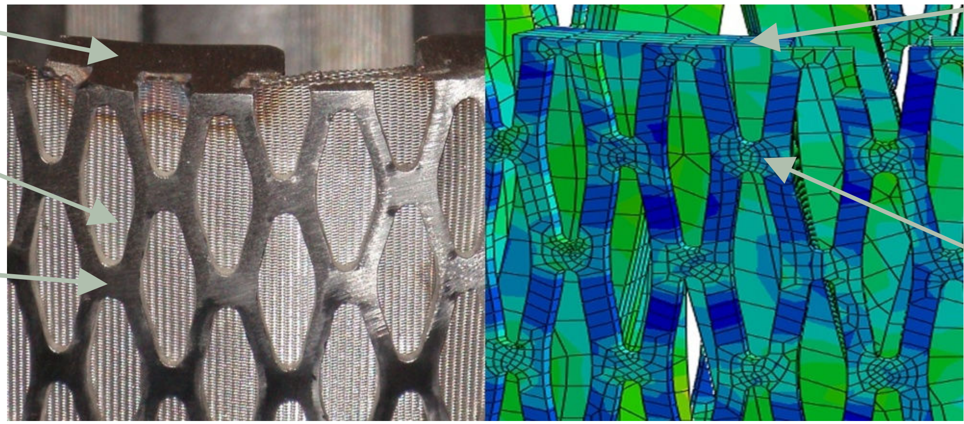




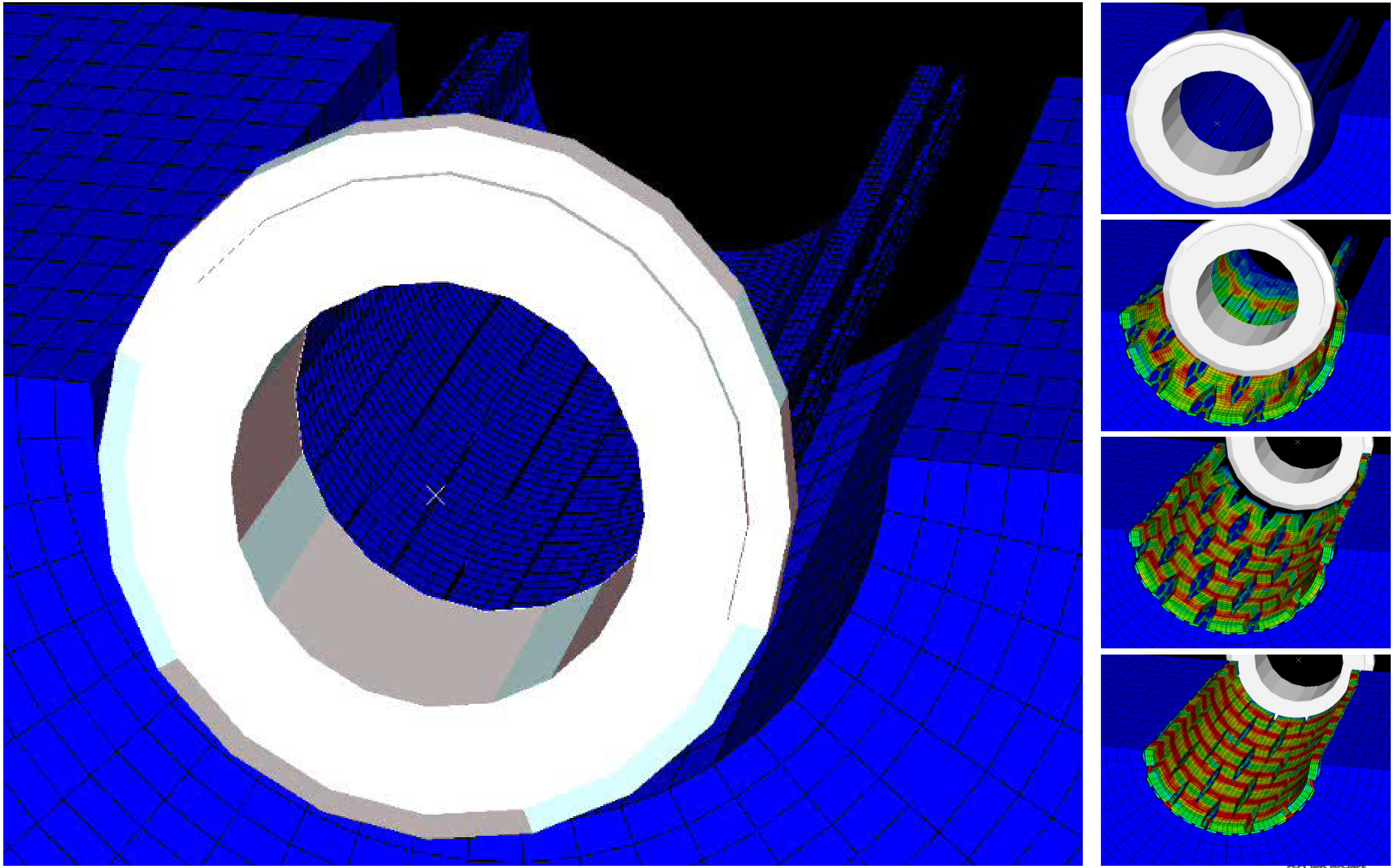
Simulated Hydraulic Collapse

Veracity of FEA Model

- FEA model matches the observed behaviour
  - The models give predicted surplus expansion ~ 4%
  - The required force to expand; tested = 16,000 lbs, model = 14,400 lbs
  - Hydraulic deformation is consistent with measured results. Slight differences due to sample heterogeneities and method of sample loading
- A reasonable comparison; the filter weave isn't currently modelled, which would give a slight increase in the forces
- All sizes have been modelled and compared to previous tests, with a good match achieved in all cases

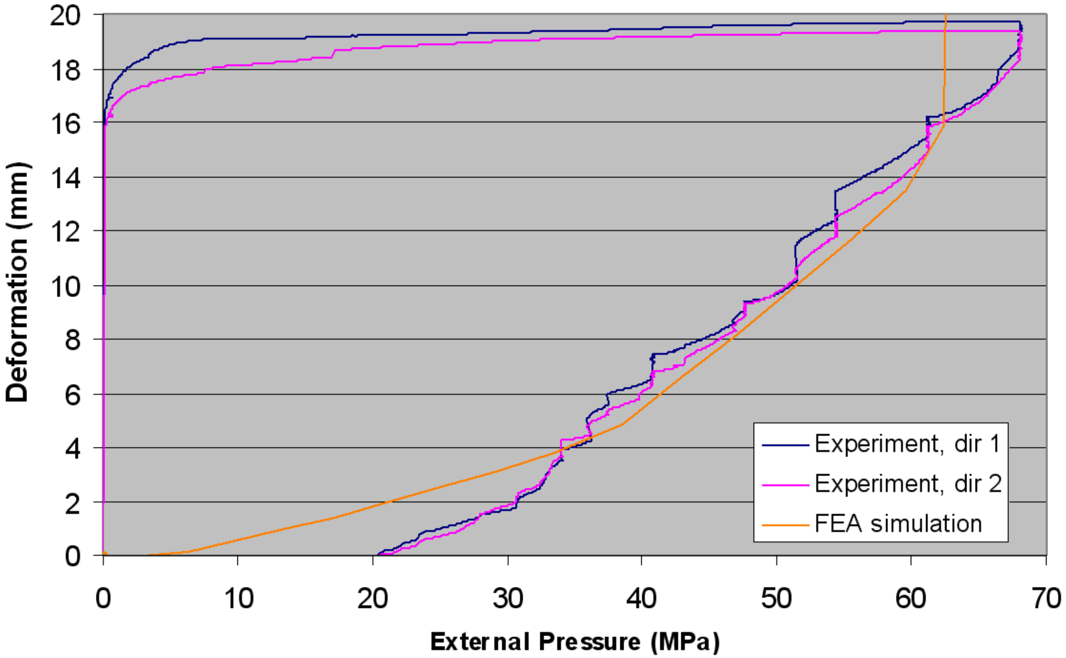


Stage 2 – Simulate PEA 182 TWC Tests



Veracity of FEA model of ESS-Formation Interaction

- Reasonable fit to data
- Complicated rock failure modes can be accounted for
  - Shear bands
  - Compaction
  - Dilatancy
  - Creep
  - Anisotropic (planes of weakness)



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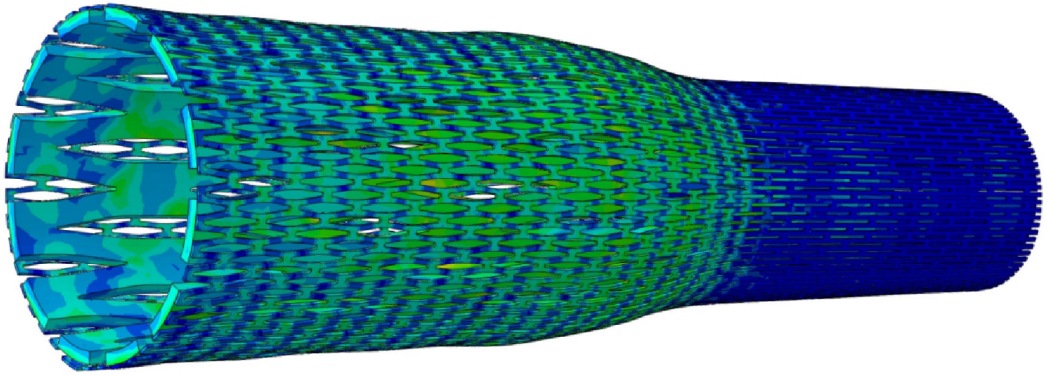
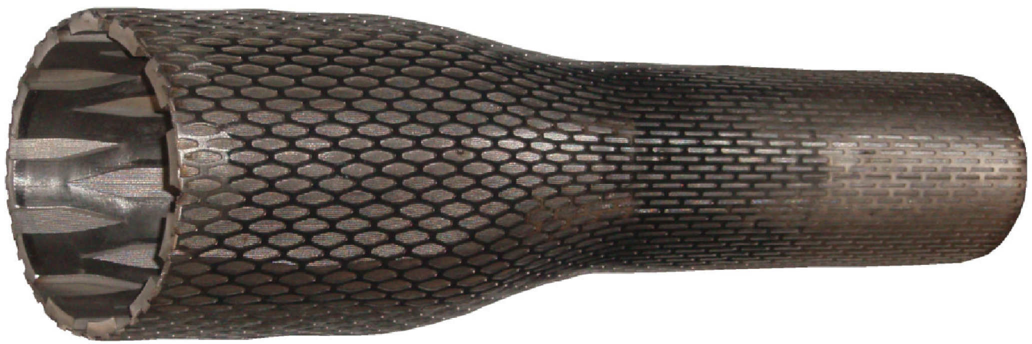
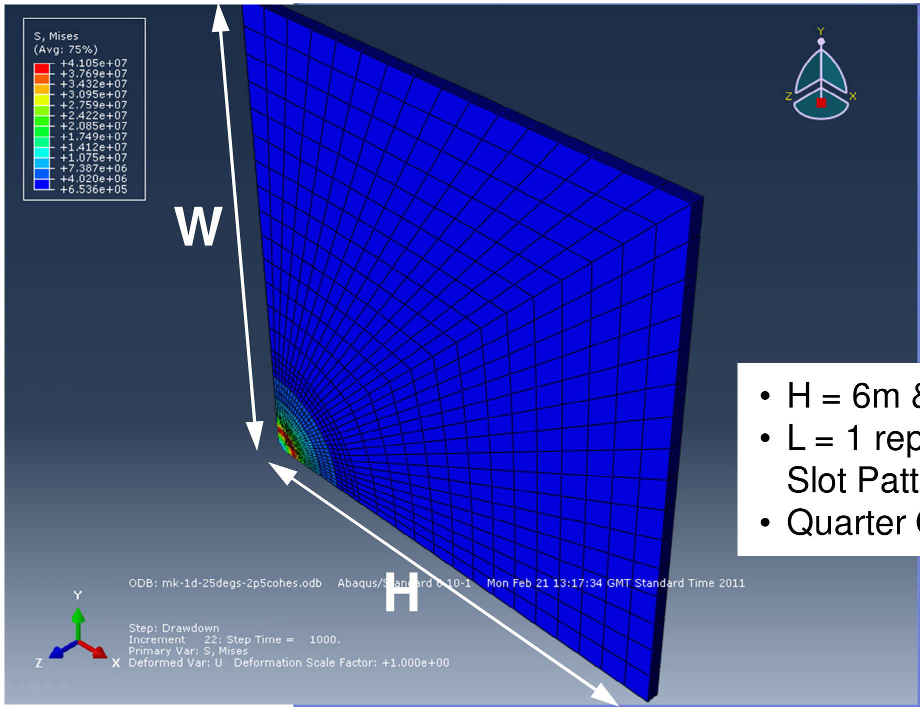


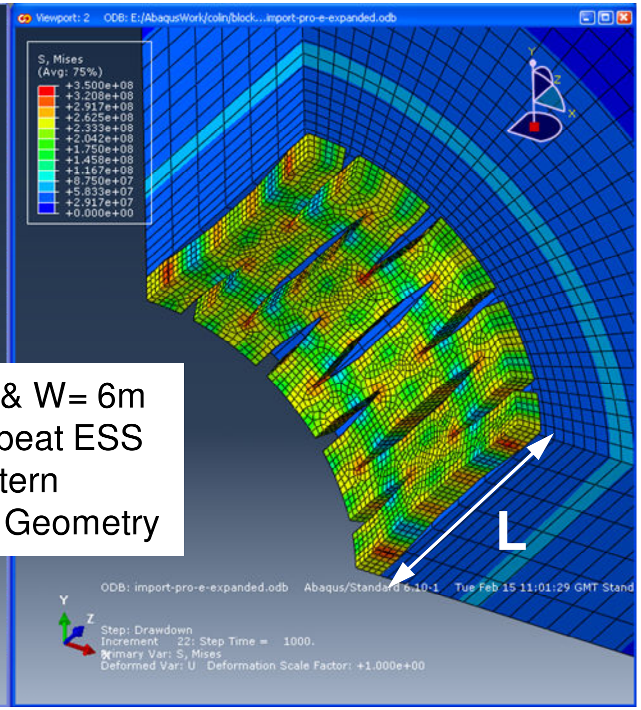


Oilwell Lifecycle & Re-Circularization

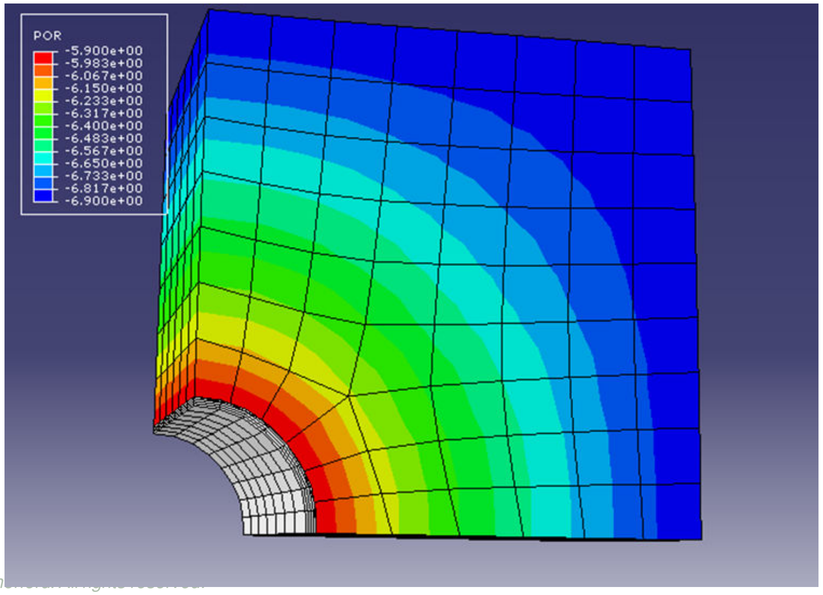
- Wellbore is drilled through rock at depth, the removal of material causes a concentration of stress in the formations close to the wellbore
- Failure of near wellbore if the formations are weak. Any wellbore movement needs to be reamed off to allow drillbit removal and the later installation of the sand screen completion
- In the FEA simulations, two separate models are used:-
  - 1st model with the correct geometry has the initial stresses applied. This causes change in the wellbore shape.
  - 2nd model identical to the first has the stresses mapped over it. This allows for an undeformed model carrying the loaded/stressed state.

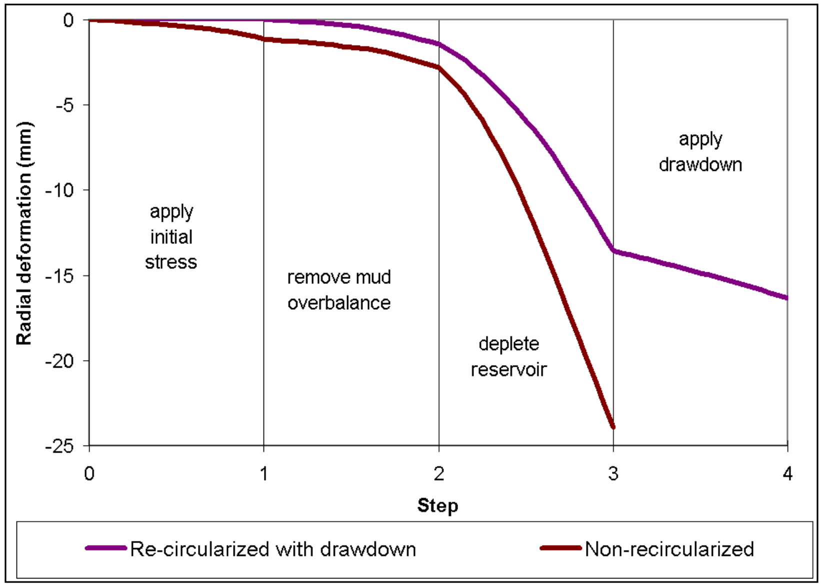
Vertical-Horizontal Well Application Screening Tool



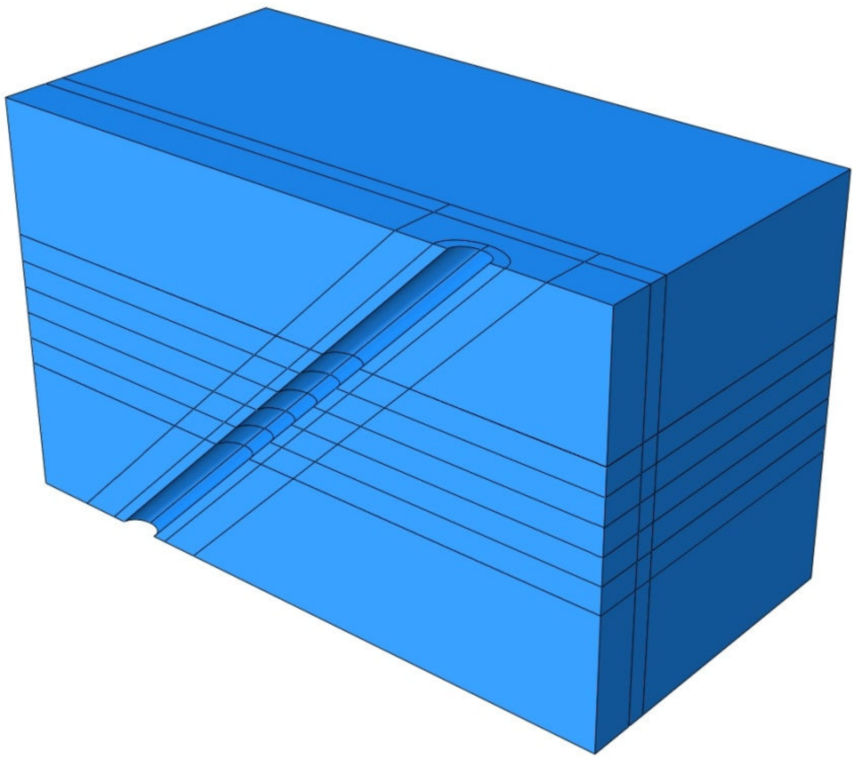


- H = 6m & W= 6m
- L = 1 repeat ESS Slot Pattern
- Quarter Geometry





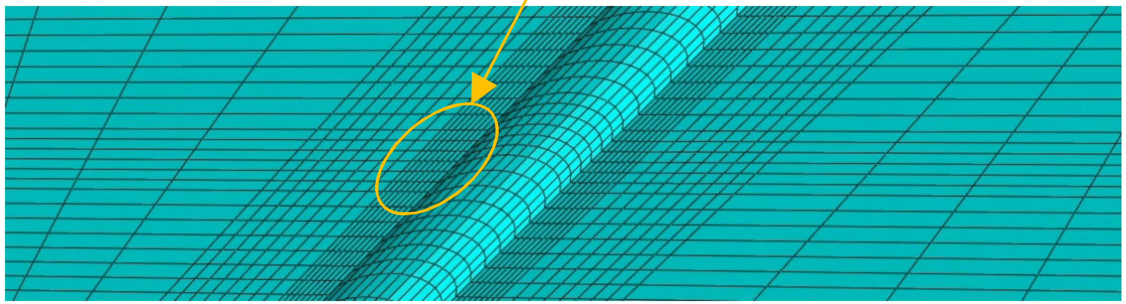
Inclined Well In a Sandstone-Shale Sequence



Inclined wellbore in a 5m x 5m x 3m block

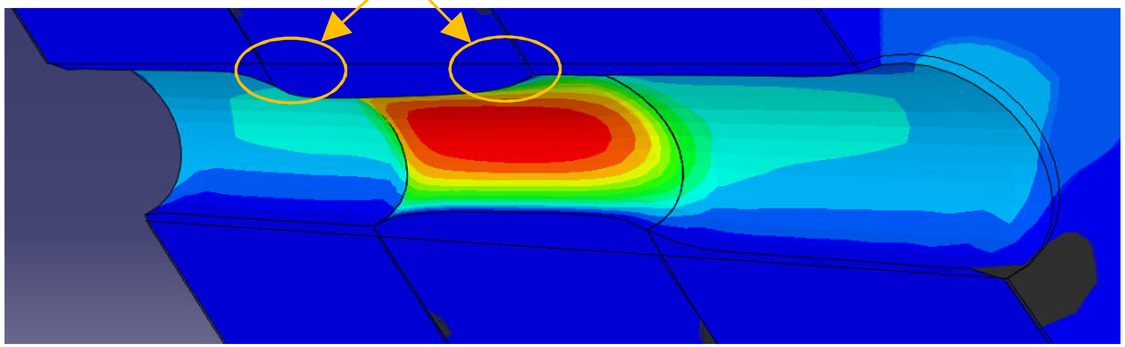
- Block partitioned to allow for finer meshing closer to the wellbore.
- The central section is split into 5 sections which allowed shale layers from 0.2m to 3m to be modelled.

Very fine mesh at middle of block



Detail of applied finer mesh close to the wellbore

Sand appears to support the shale at the interfaces



Detail of the deformation in the Sandstone and Shale

ESS Deformation in Central Shale vs Thickness

Three sets of simulations were run:-

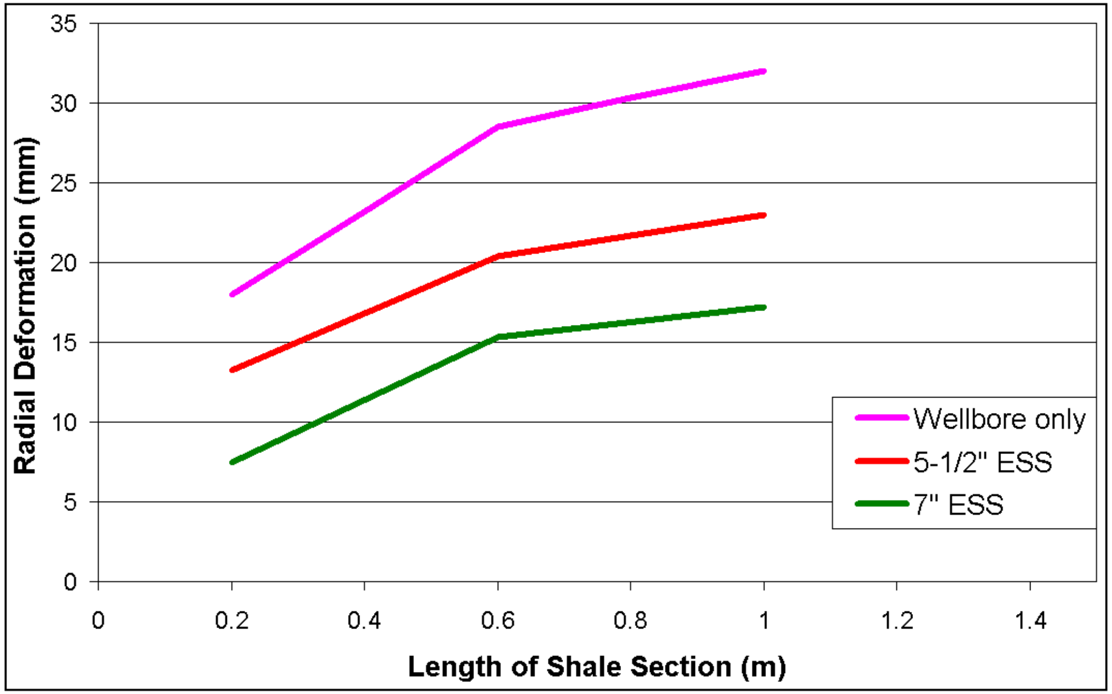
- Bare 8-1/2” wellbore with 0.2 – 1m shale layer.
- 8-1/2” wellbore + 5-1/2” ESS with 0.2 – 1m shale layer
- 8-1/2” wellbore + 7” ESS with 0.2 – 1m shale layer

Depth	1900m
Vertical Stress	35MPa
Horizontal stress	32MPa
Initial reservoir pressure	19.2MPa
Mud overbalance	3.5MPa

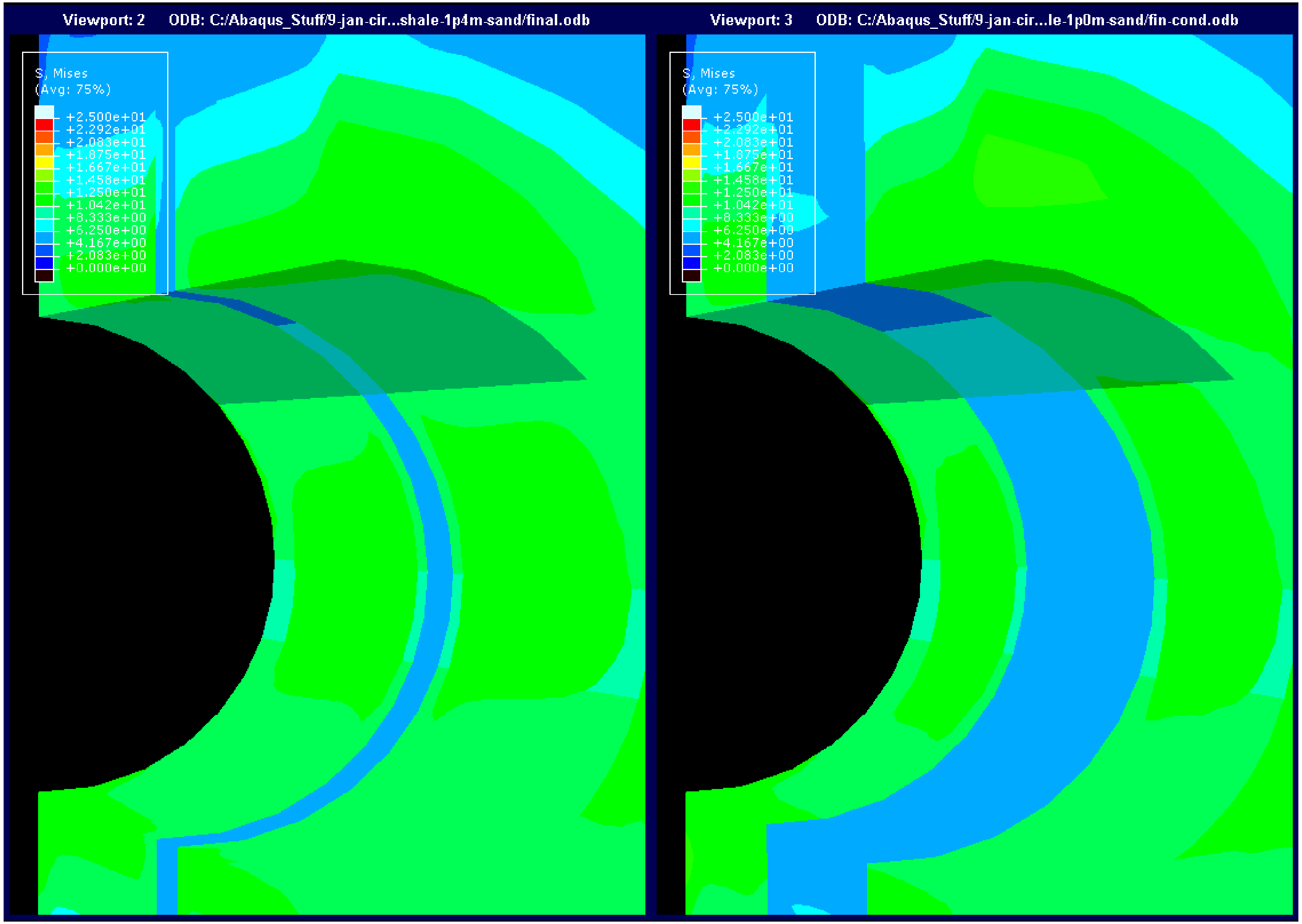
Table 1Well parameters

Rock	Sandstone	Shale
Density	2500kg/m3	2500kg/m3
Young’s Modulus	2069MPa	1379MPa
Poisson’s Ratio	0.16	0.16
Friction Angle	20 degrees	13 degrees
Dilatancy Angle	0 degrees	0 degrees

Table 2 Material properties of the sandstone and shale used in the simulations



ESS Deformation in Central Shale vs Thickness

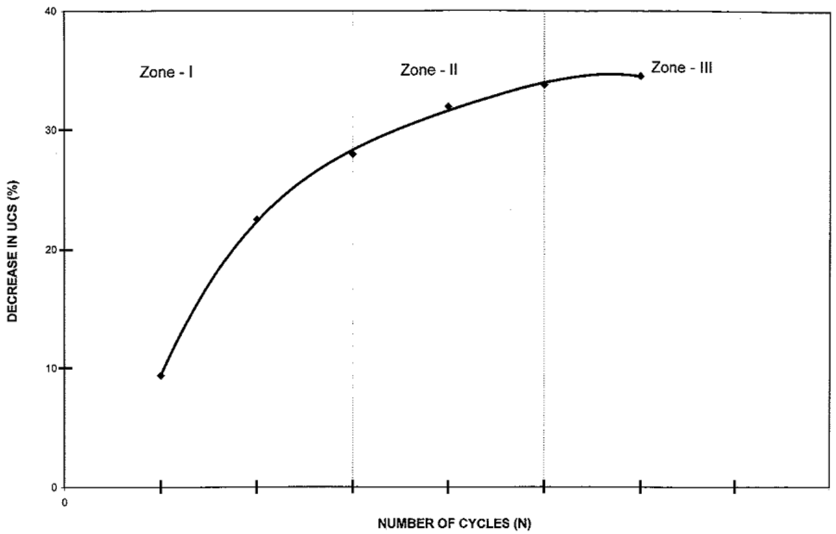


0.2 metre shale section

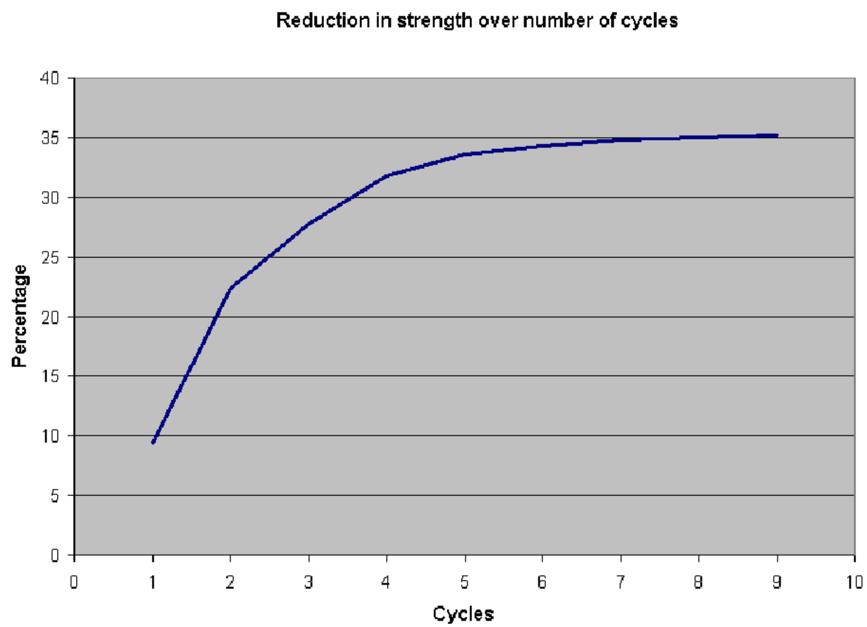
1 metre shale section

Simulation of UGS Applications

- *S.K. Ray et al 1998* showed that a cycling load will initially cause a decline in material strength that levels off after a number of cycles.
- The UCS of the given rock will also decrease with cyclic loading that also stabilizes after a number of cycles
- This diminishing strength is incorporated into the FEA simulations



Showing the decrease in UCS versus number of cycles (Ray et al 1998)

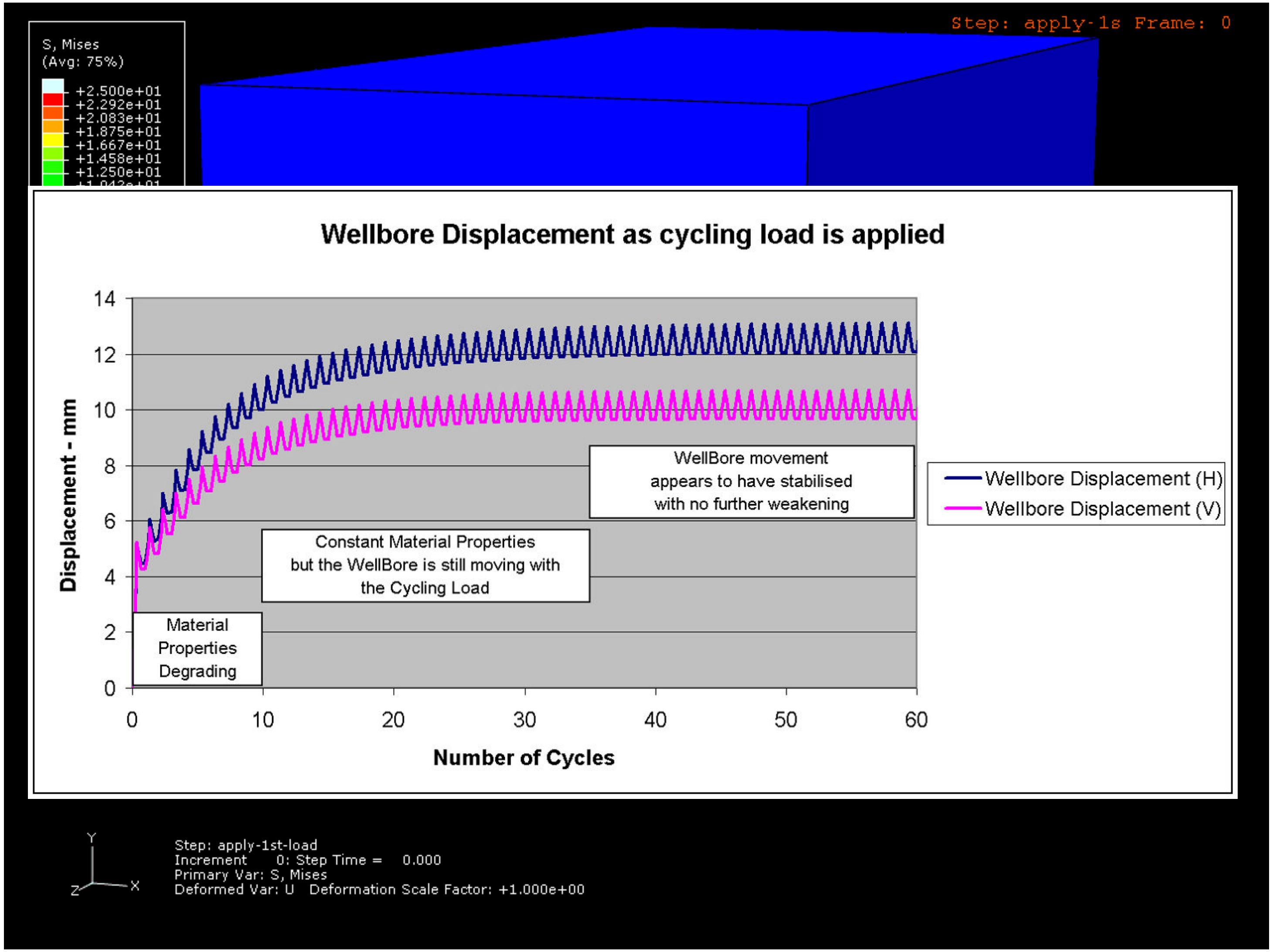


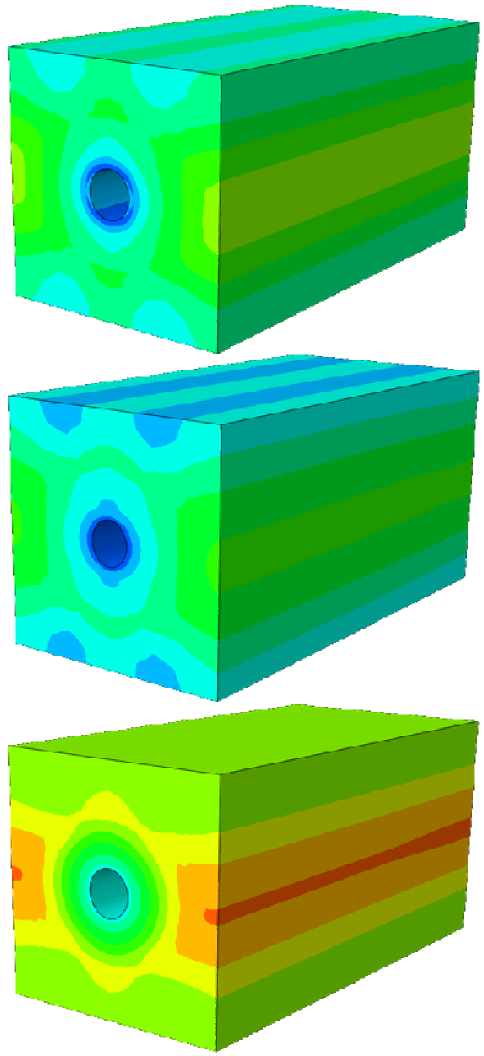
Showing the percentage decrease in Cohesion Yield Stress (for use in FEA)

FEA model construction and configuration

- A model was built to simulate an annual winter/summer cycling UGS application.
- The rock mass was set up with the dimensions 1m x 1m x 2m deep, complete with an 8.5" diameter wellbore running through the centre.
- A cycling load schedule was created:-
  - for the *vertical sides*, the load varied between 13 and 25MPa (1885 and 3625psi)
  - for the *top and bottom* the load varied between 16 and 28MPa (2320 and 4060psi).
- These load changes can be viewed as changes in UGS reservoir pressure of 12 MPa (1740 psi) due to injection and production.
- The front and back faces had no load, they were held in such a manner (with a simple boundary condition) to limit the rock extruding out.
- The stress values are typical of a reservoir at 4000-5000ft vertical depth.

UGS Simulation Results

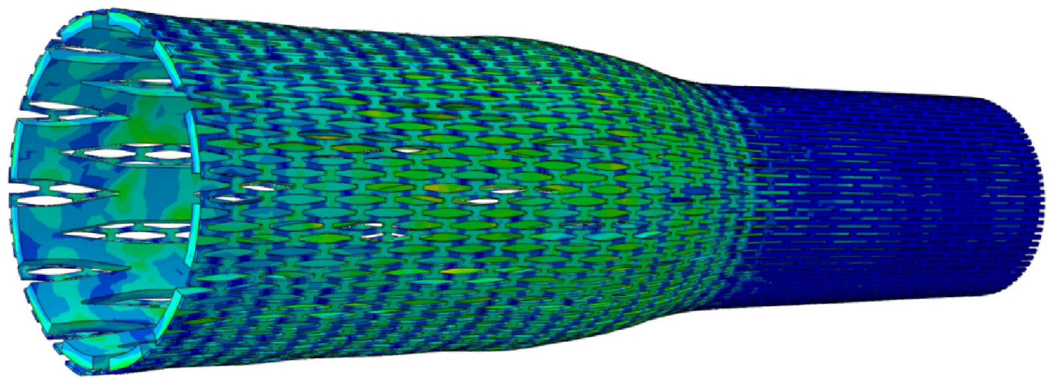


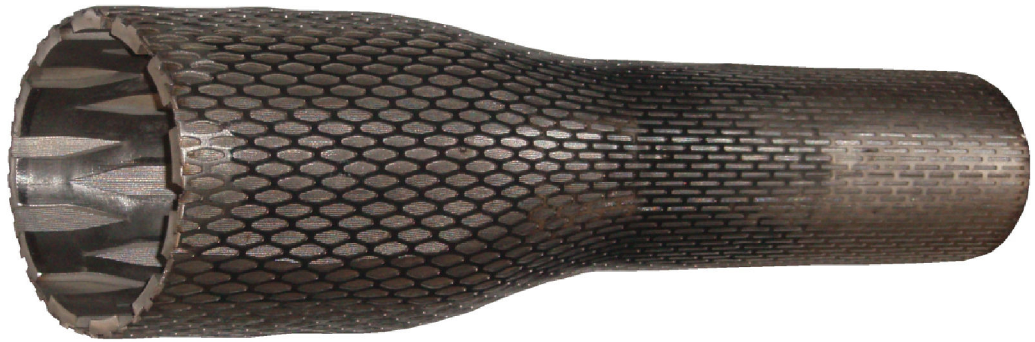


Animation shows the rock mass (ESS not shown) with a very low Friction Angle of 15 degrees to show the deformation better.

Presentation Contents

- Introduction
- Hydraulic Collapse Testing
- Large Scale Triaxial TWC Compression Testing
- Deformation Modeling
  - Analytical Solution
  - Numerical Solution
- Application Screening
- Conclusions





Conclusions

9th European Formation Damage Conference

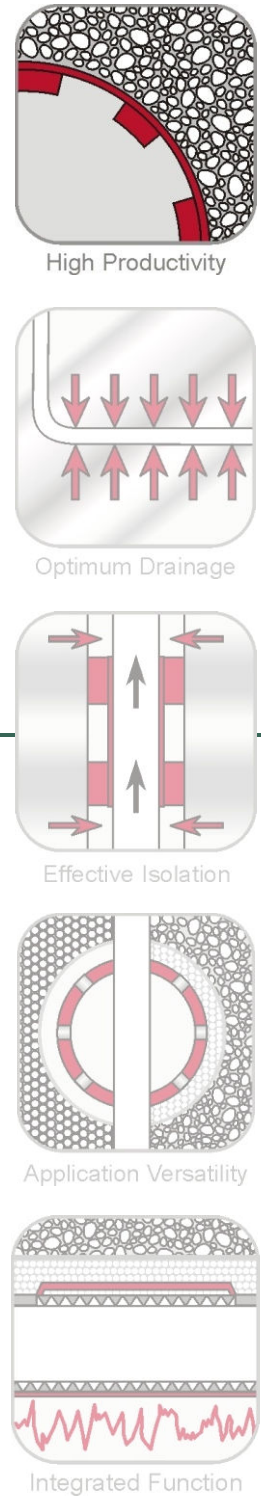
SPE 14391 - Formation Loading & Deformation of ESS

Colin Jones, Ken Watson, Quentin Morgan

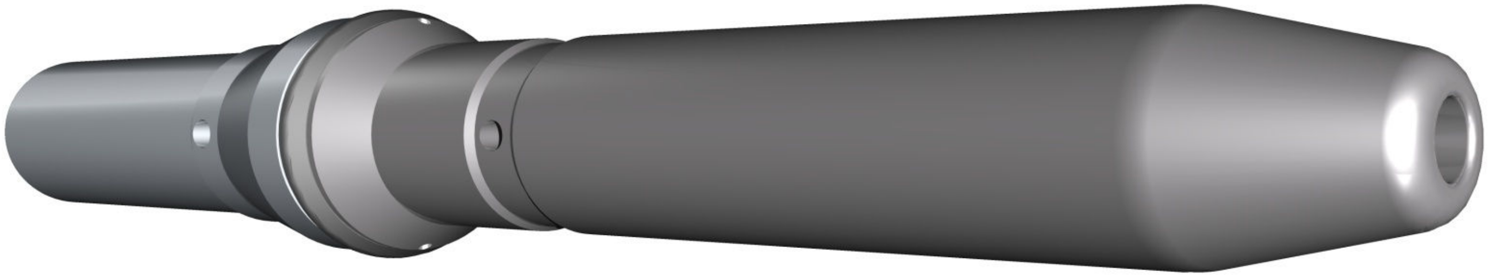
June 2011

Q & A

Solving your sand control challenges.



Introduction: ESS Expansion Methods

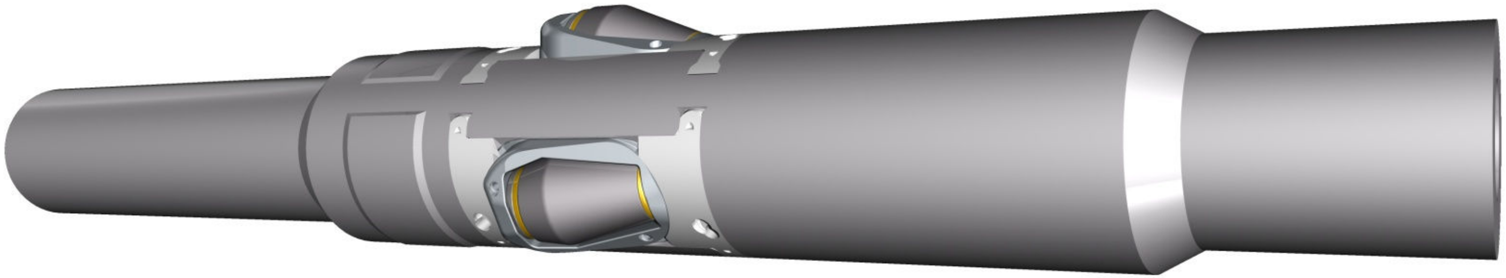


Solid Cone Expansion

- Results in 4% surplus expansion
- Requires 20-40 klbs setdown weight

Axial Compliant Expansion

- 1500 psi operating pressure
- Requires 15-30 klbs setdown weight
- 10ft/min expansion rate



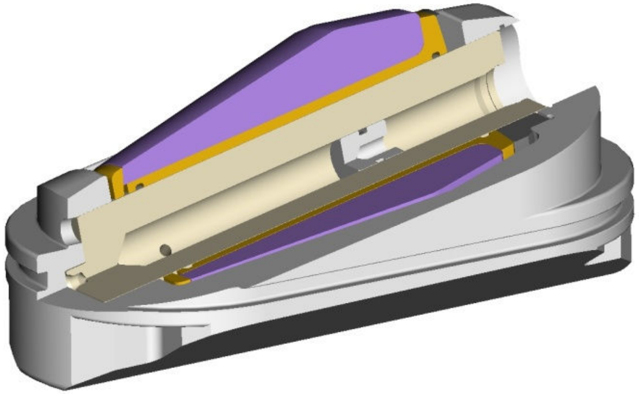
Rotary Compliant Expansion

- 800-1200 psi operating pressure
- Requires 20-30 klbs setdown weight
- Requires 50 RPM rotation
- 4-8ft/min expansion rate

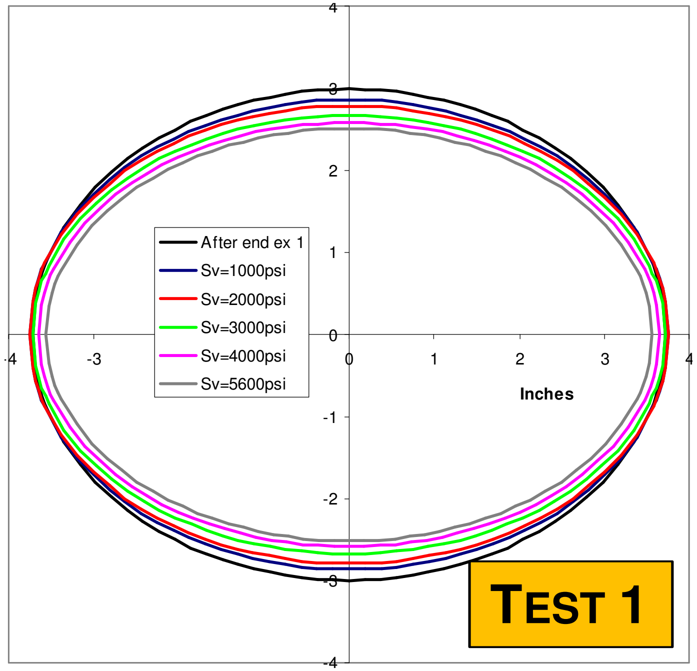
What is Tribology?

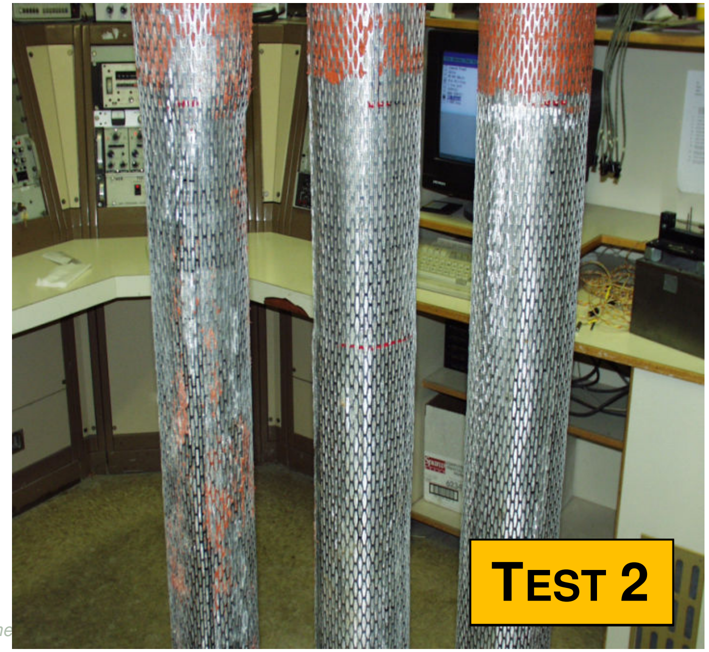
Tribology

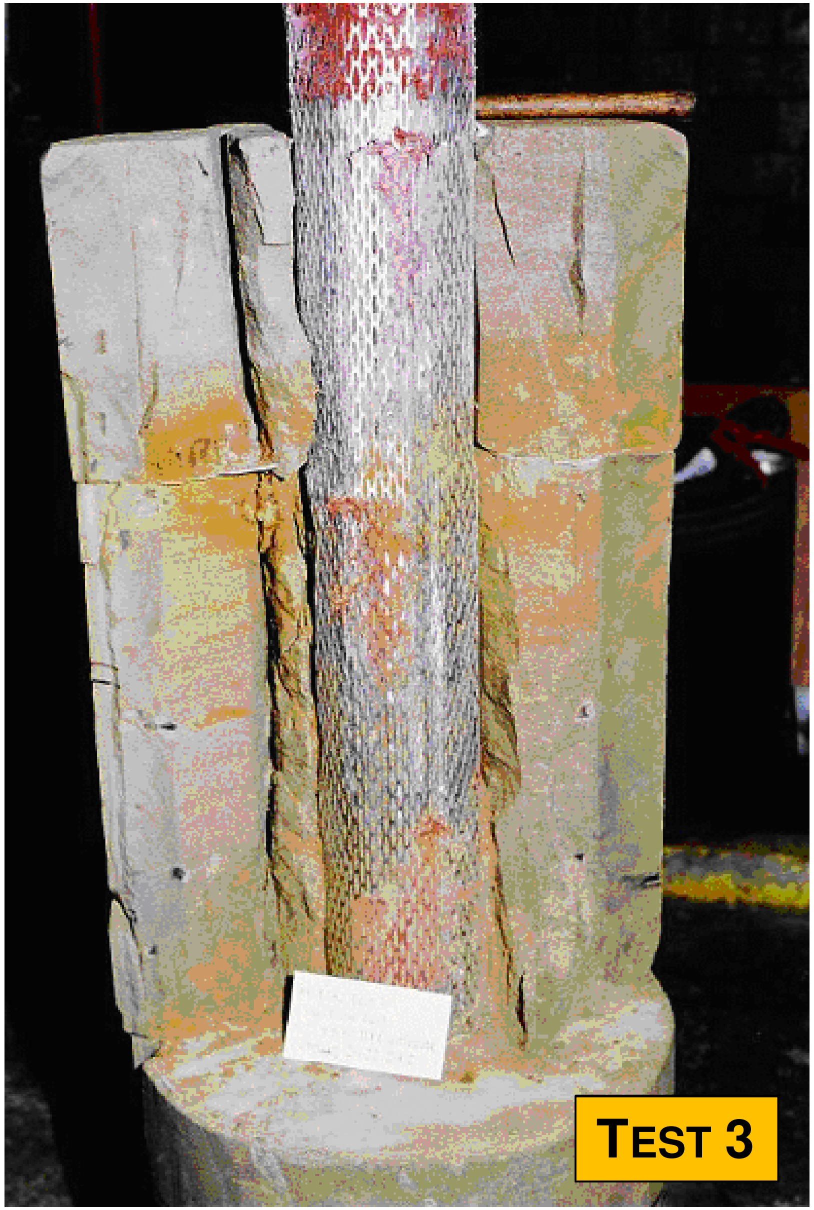
Tribology is the science and technology of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication, and wear



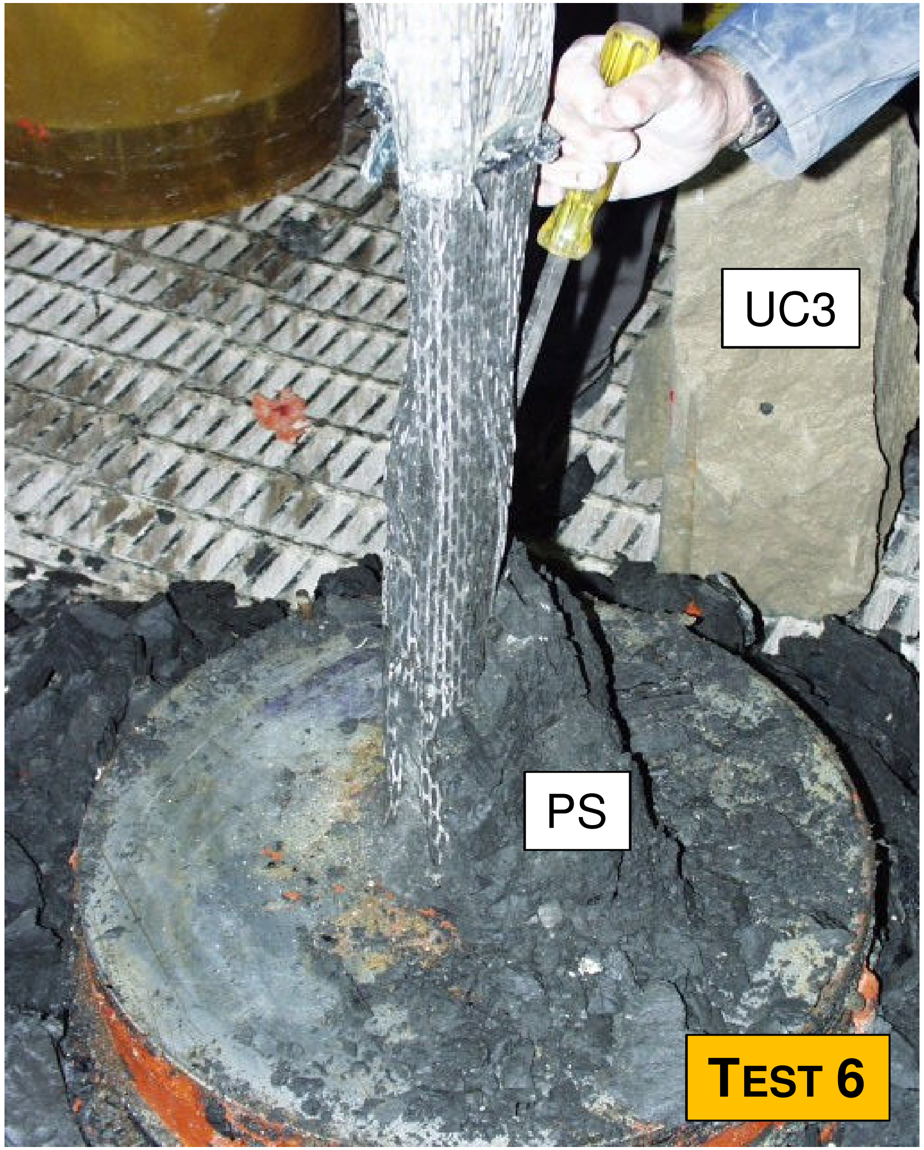
SB Test 1 and PV Tests 2&3







It is horrible if we get it wrong!!!



Yield depth

- Analysis of stress in the yielded and elastic zone led to following formula for depth of yield zone

$$\bar{r} = r_0 \left(\frac{2q - \sigma_0 + p'(k+1)}{(p+p')(k+1)} \right)^{\frac{1}{k-1}}$$

- Where:-
  - q = isotropic effective stress
  - p = the support pressure, from the ESS
  - σ = UCS
  - K = tri-axial stress factor (related to friction angle)
  - P’ = cohesion of broken rock
- Directly analogous to mud support or borehole support by an ESS