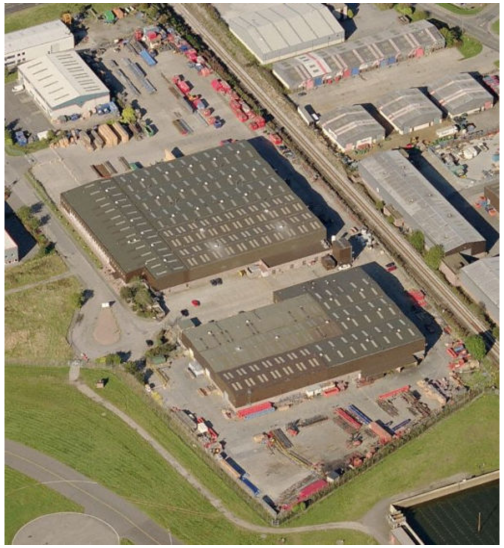
Weatherford®

Well Completion Technologies

Our Abaqus use and experiences: 2007 onwards

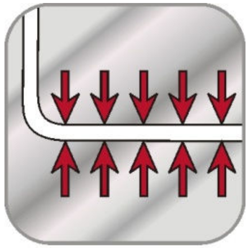
Ken Watson, 3D Specialist, Weatherford International Ltd



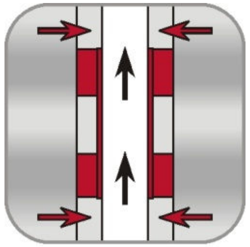
Spencer Road, Houston, Texas

22nd February 2011

High Productivity



Optimum Drainage



Effective Isolation

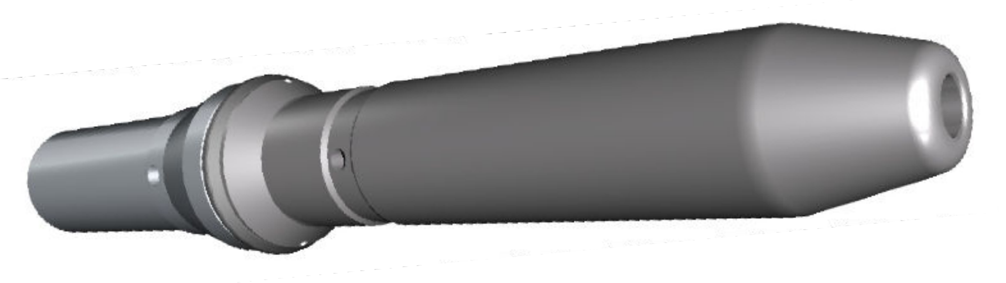
Application Versatility

Integrated Function

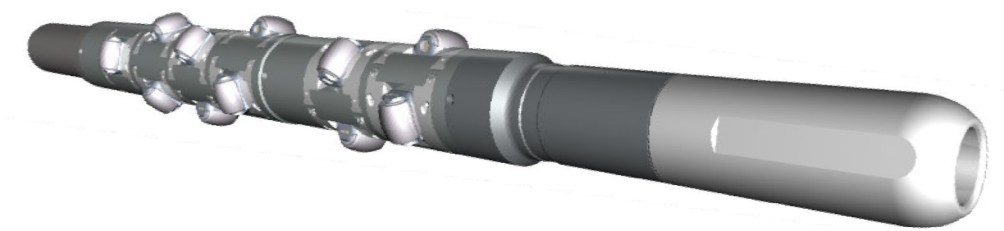
Solving your sand control challenges.

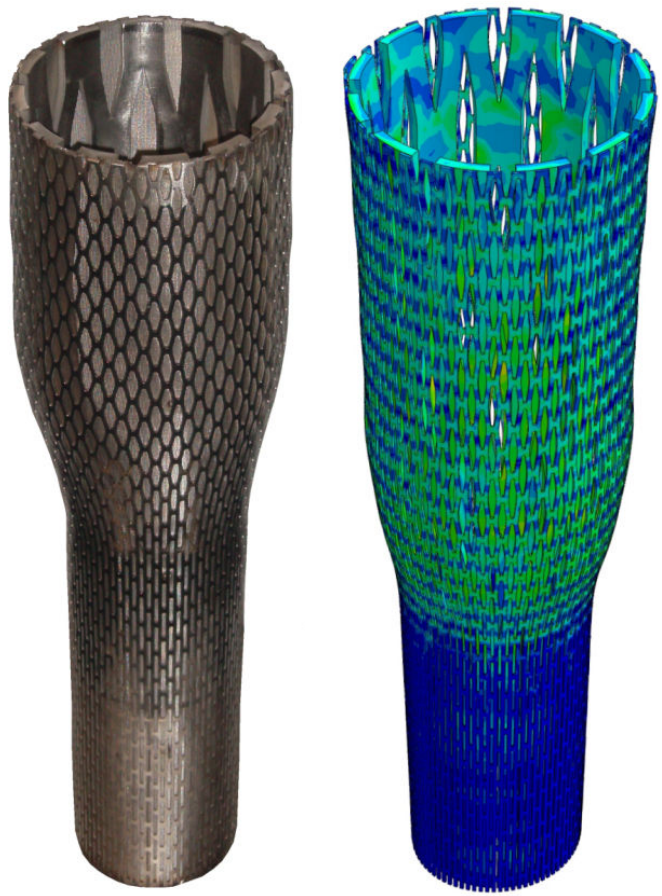
Presentation Overview

- Our ESS® product - Existing then R&D for strength improvements Abaqus/Explicit
- Developing an Equivalent *ESS* Representation (for rapid application screening) Abaqus/Standard
- Well Application Screening Tool (Geomechanics + Equivalent *ESS*) Abaqus/Standard
- Underground Gas Storage (Geomechanics + Equivalent *ESS*) Abaqus/Standard
- More E*SS* R&D for a specific client requirement Abaqus/Explicit
- Simple day-to-day analysis work Abaqus/Standard
- Investigations for Tooling issues Abaqus/Explicit
- Pressures and Velocities Abaqus/CFD
- Conclusions / Q and A



Examples of the Tools used to expand ESS, Cone and ACE



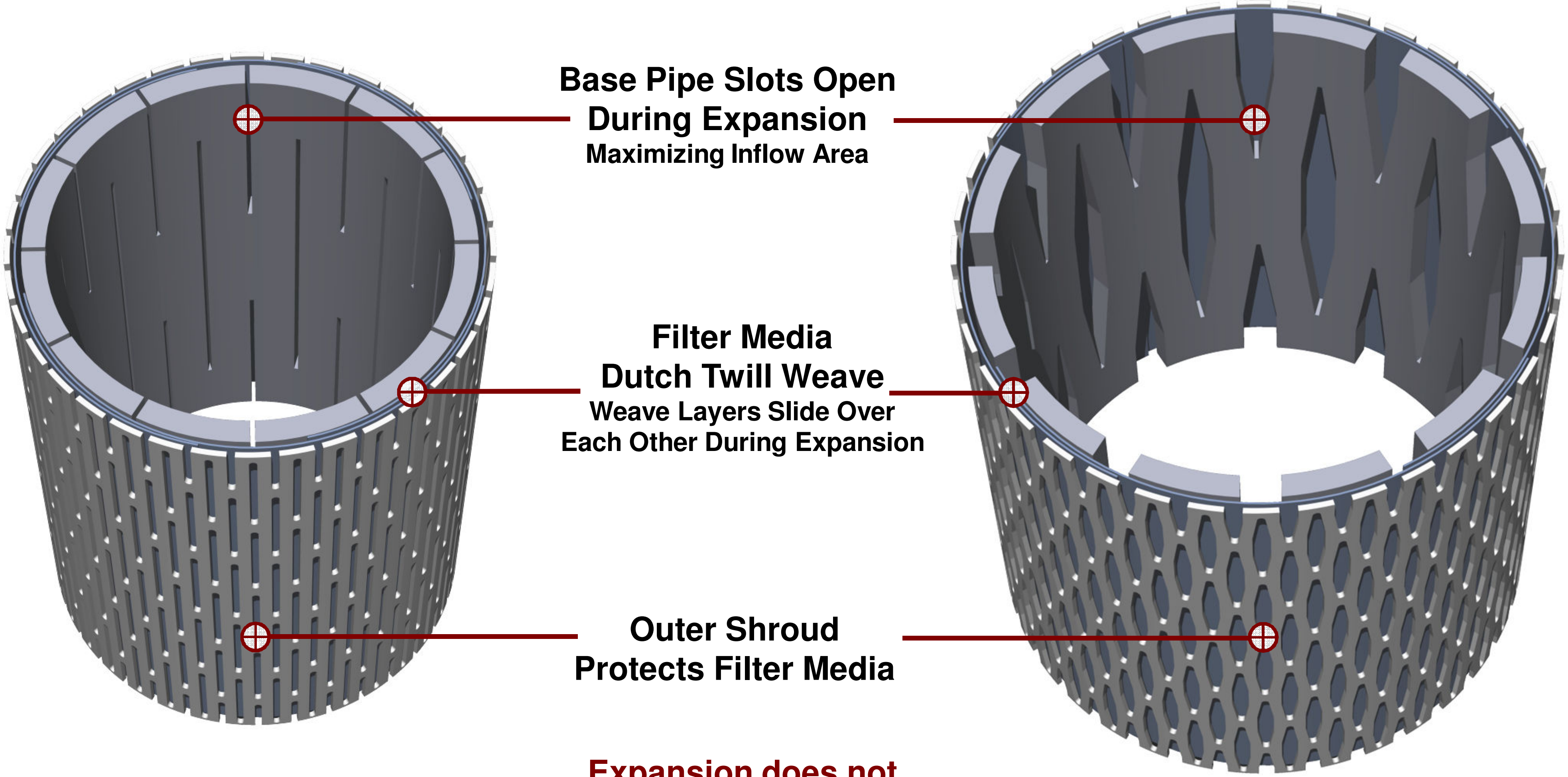


ESS® = Expandable Sand Screen

ESS® Product – Design / Background

ESS is a product that controls the ingress of solids in oil and gas reservoirs with weak and unconsolidated formations. *ESS* improves well production and significantly reduces well costs when compared with other systems.

Product sizes; 4”, 4-1/2”, 5-1/2” and 7”
There are also a variety of Weave aperture sizes / ratings

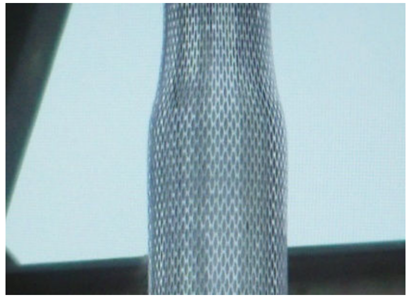


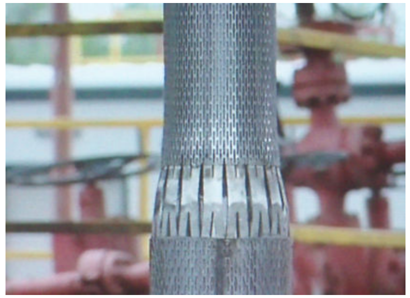
Unexpanded

Expanded

Expansion does not change the Weave aperture size / rating

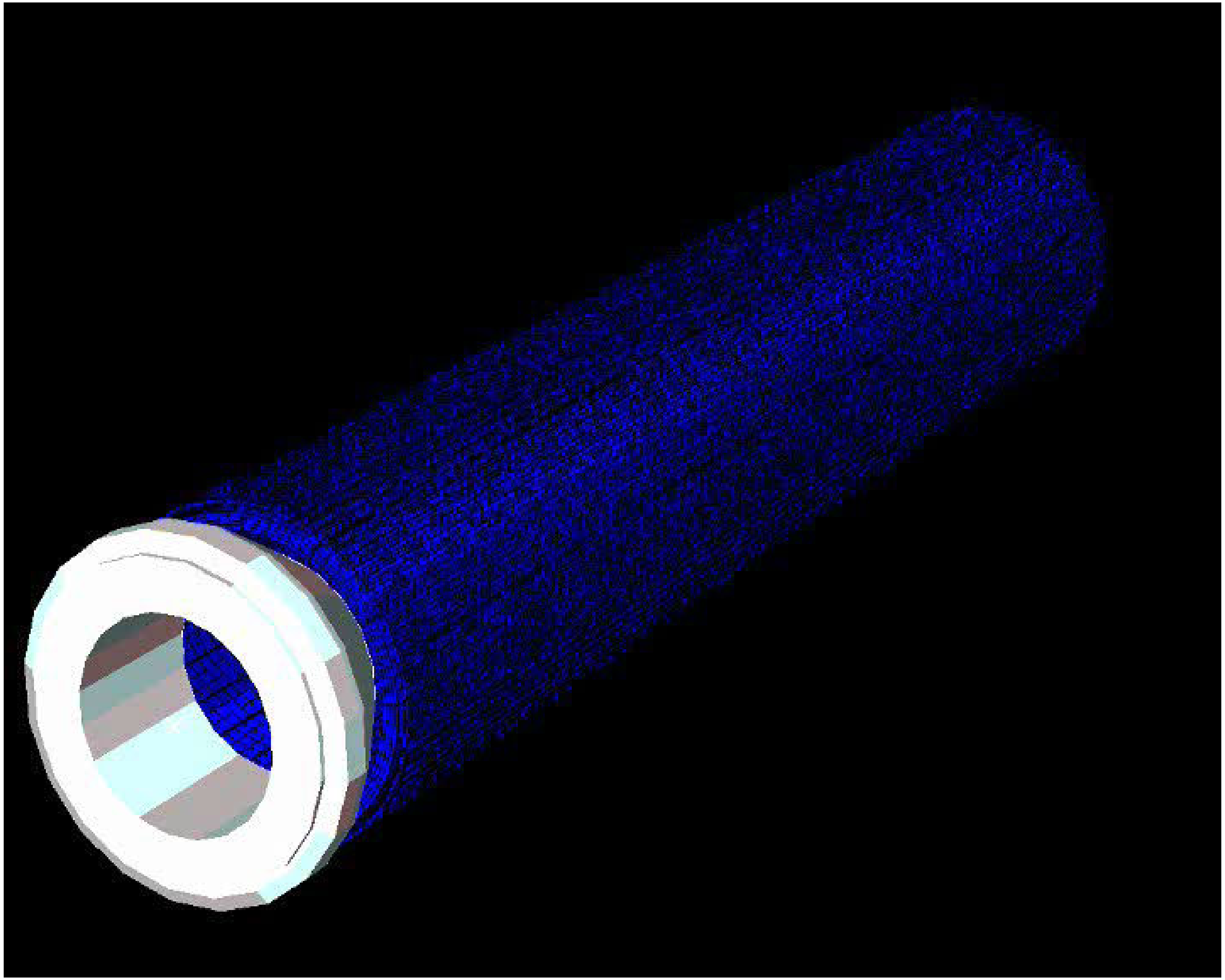
ESS® Product - Example

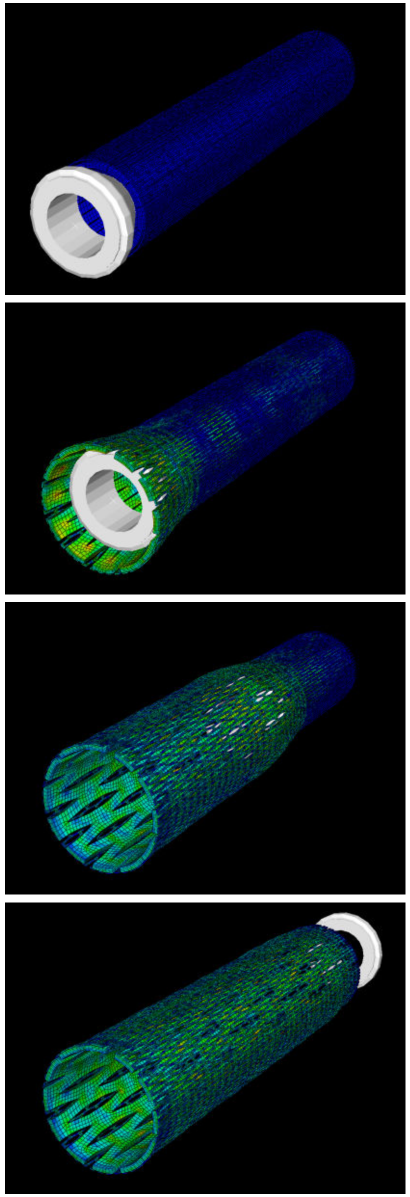




ESS® Product – Expansion using Abaqus/Explicit

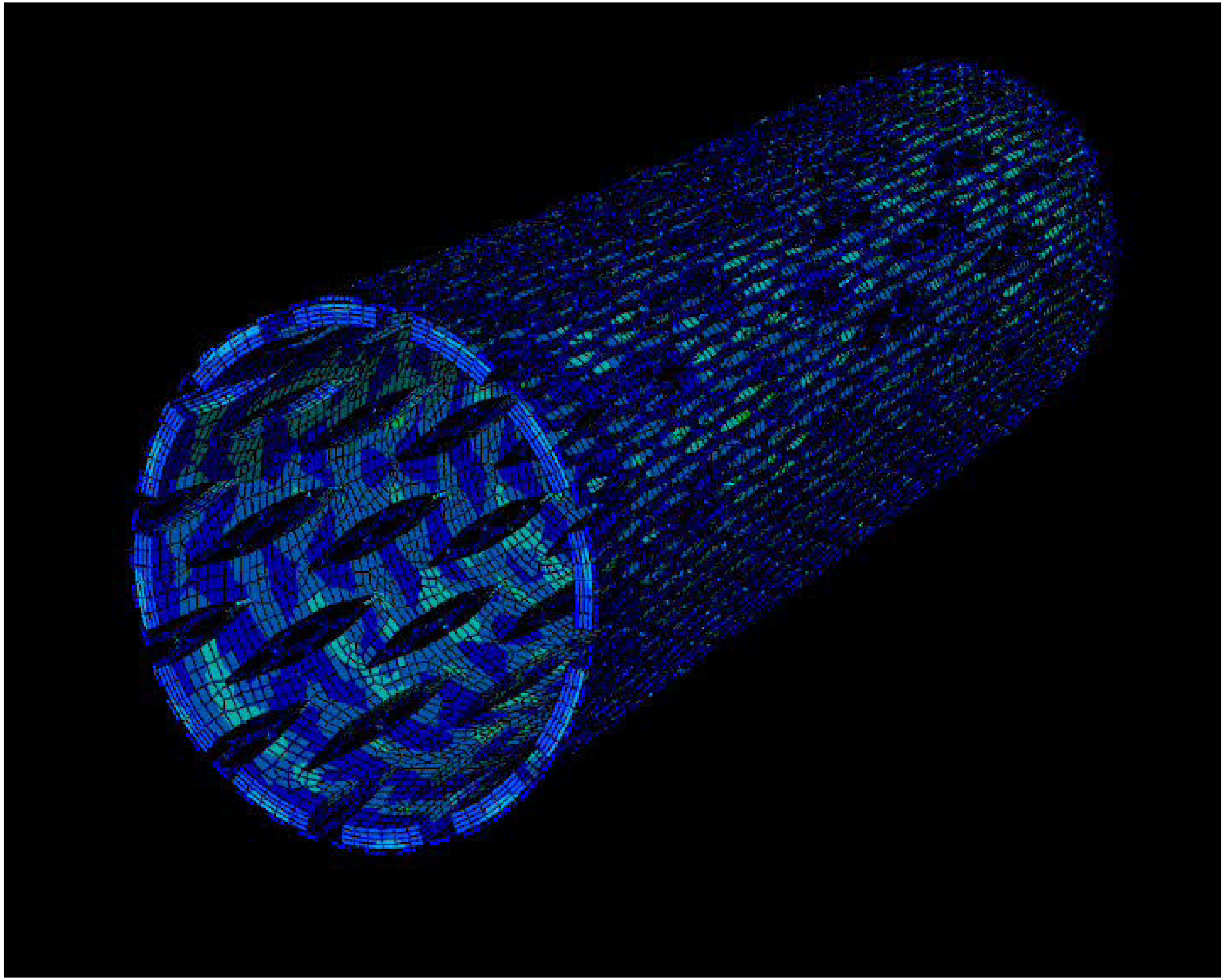
Elements; **C3D8R**   Complex 3D parts modelled in Pro-Engineer then imported into **Abaqus/CAE**

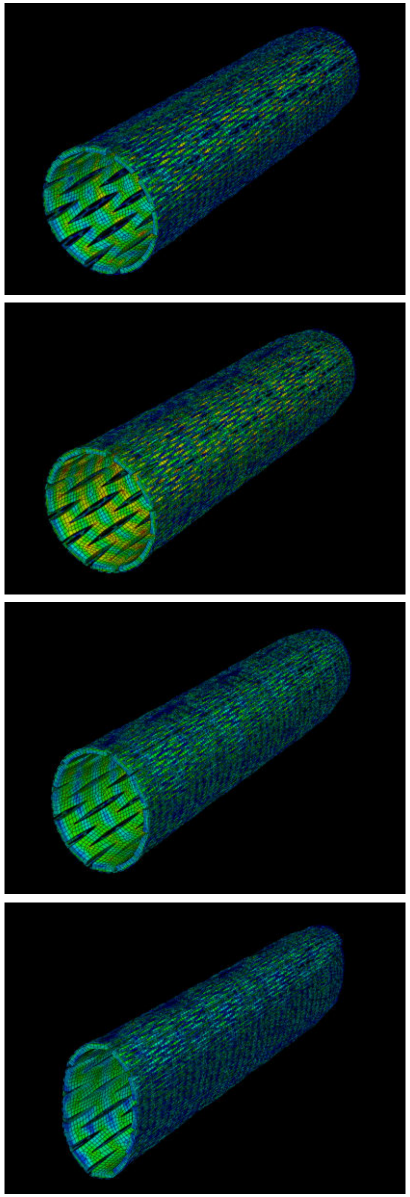




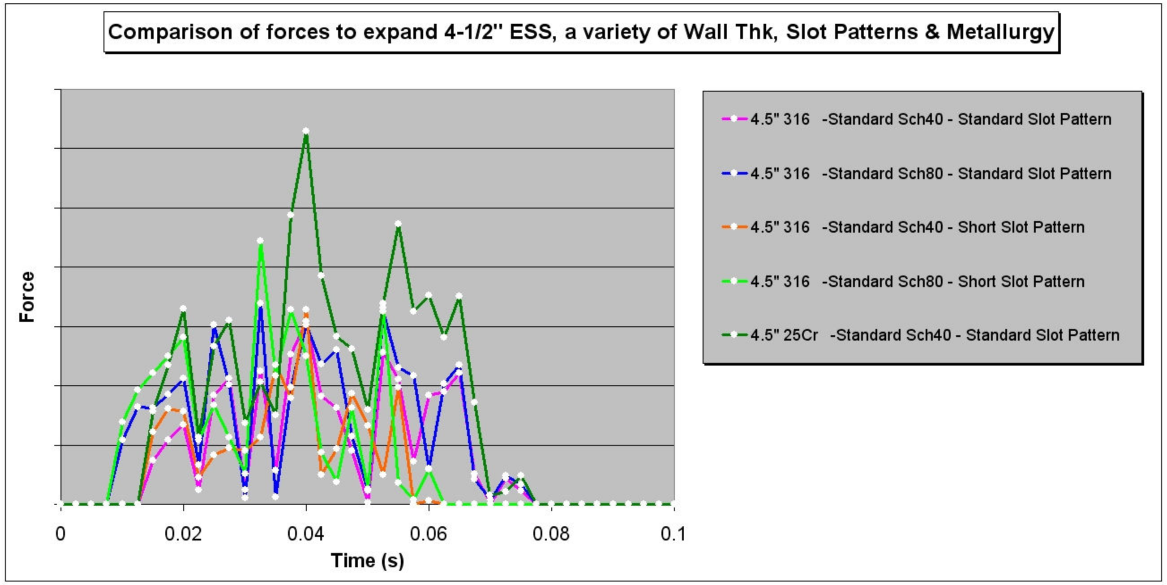
ESS® Product – Collapse using Abaqus/Explicit

Expanded test piece now subjected to **Hydraulic Collapse**





ESS® Product – Forces to Expand and Collapse Resistance



Case Study

Recent R&D study into strength improvements

Proposed designs – 4 off

New test pieces – 1 off

Weatherford benefited by **saving** a huge amount of **time** and **costs** by using **Abaqus/Explicit** in this series of tests

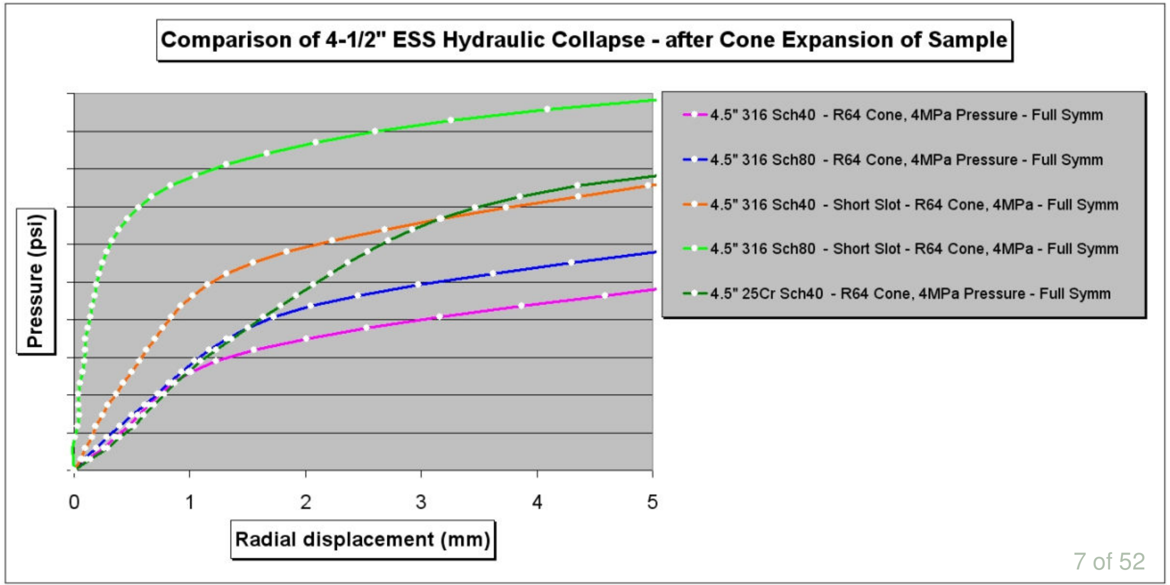
Five analysis runs; (1) current design, *to verify the material model* (2) changing the basepipe wall thickness (3) changing the basepipe metallurgy (4) changing the slot pattern (5) a mixture of wall thickness and slot pattern

The required force to expand (push tool through) could not increase too much due to *ESS* connection capability

FEA model matches the observed behaviour.

The models give predicted expansion forces and collapse resistance

All sizes have been modelled and compared to previous tests; there is a good fit to the results.



Papers and Presentations - 2008

Most papers and presentations are available on both *Exchange* and *Sharepoint*

The Exchange
One Weatherford.
One Source.

Weatherford SharePoint

FEA Modelling of Expandable Sand Screens

C. Jones and K. Watson

Weatherford International Ltd.

Abstract: Expandable sand screens are a relatively novel sand control system, which are used to control the ingress of solids in oil and gas reservoirs with weak
They combine the ease of installation of conventional screens w
gravel pack.

There are two different variations of expandable screens; a syst
which are easy to expand but relatively low in strength and a sy
which are very strong but difficult to expand.

FEA has been used to model the slotted basepipe type to better
expanded screen with the rock formations. This type of analysi
analytical, models based on tunneling theory. There are many
allows a better choice of material models for the rock such as D
also allows the investigation of a wider range of configurations,
or the interfaces between different formations.

The results from the FEA modeling compares favorably with da
experiments. This satisfactory outcome increases confidence i
to design models for field applications.

Keywords: Constitutive Model, Critical State Plasticity, Desig
Verification, Geomechanics, Wellbore.

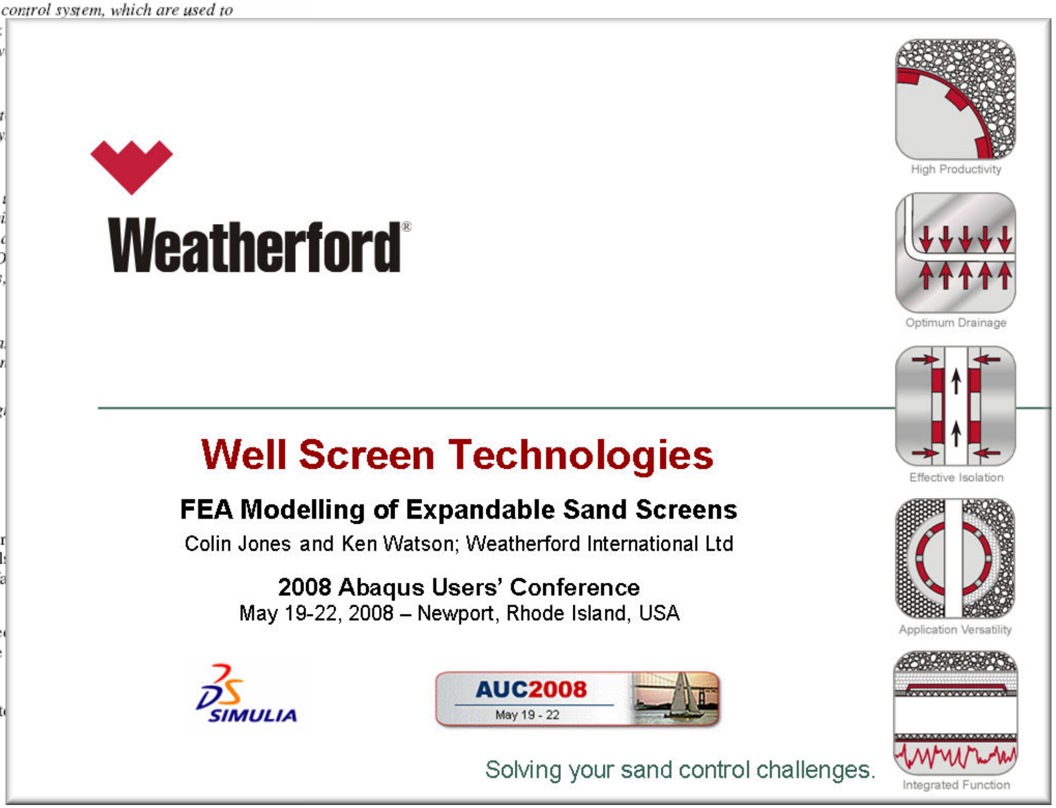
1. Introduction

Expandable sand screens (ESS®) are a relatively new sand contr
are used to control the ingress of sand in oil, gas and water well
unconsolidated formations. The sand is produced due to rock fa
changes in in-situ stress over the life cycle of the well.

There are many different strategies available to control produce
from the very simple, such as reducing production rate, to more

® ESS is a registered trademark of Weatherford International Lt

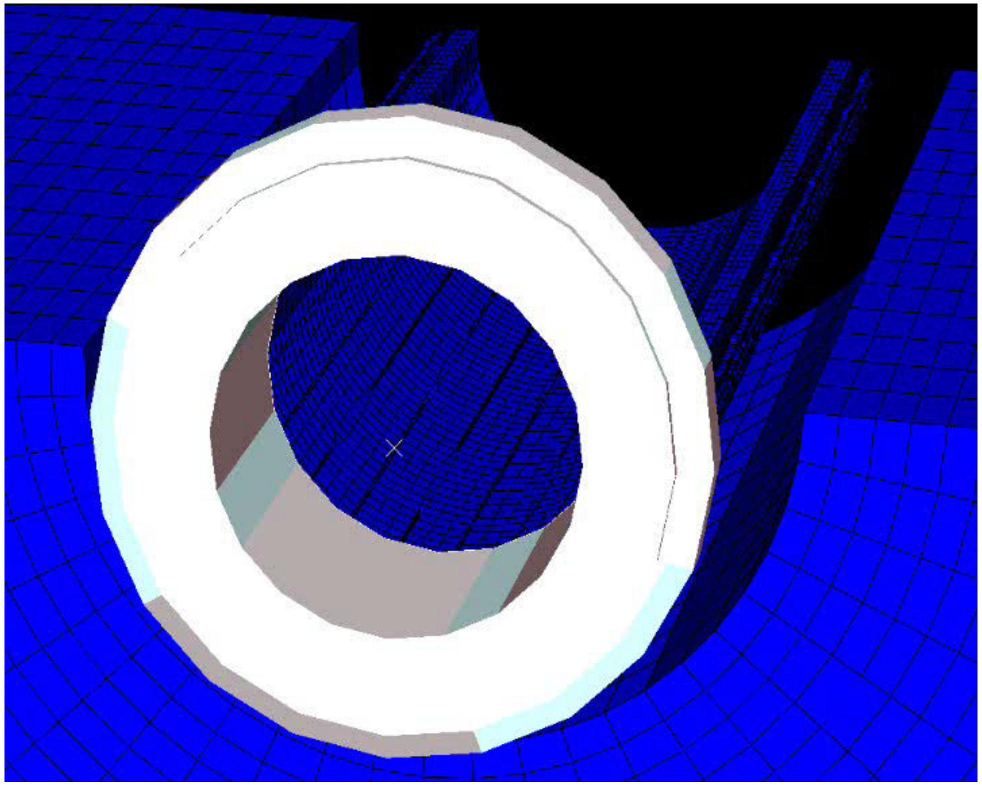
2008 Abaqus Users' Conference

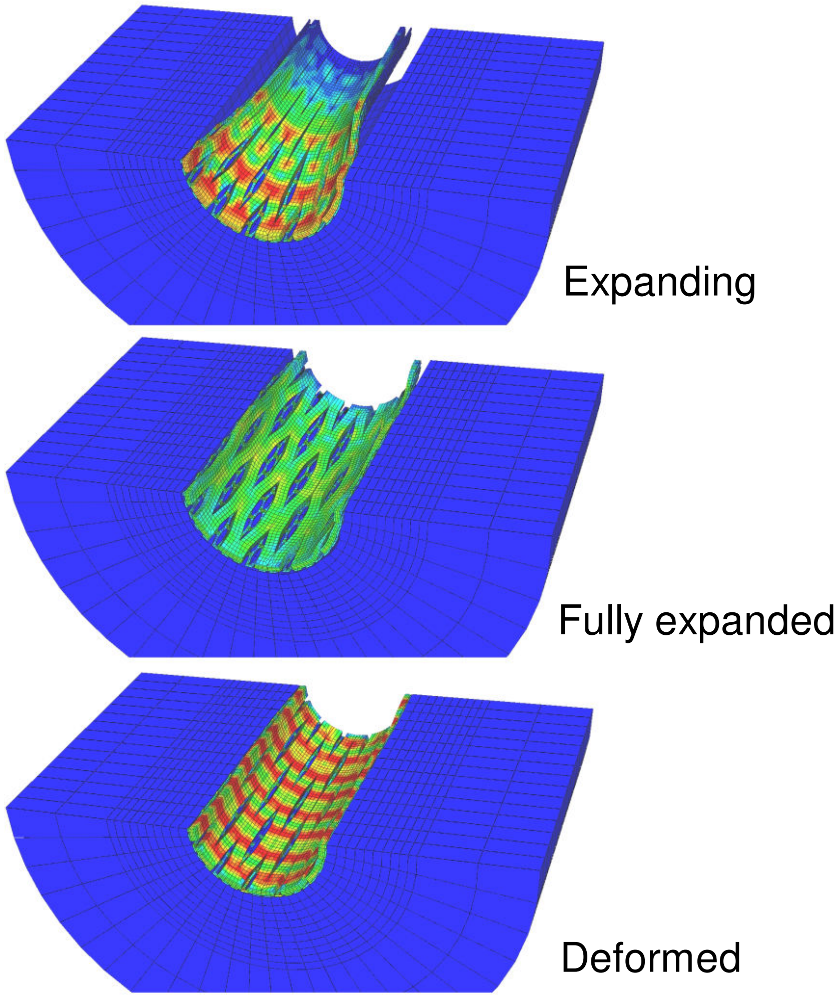


Paper and Presentation at Abaqus Users Conference, May 2008

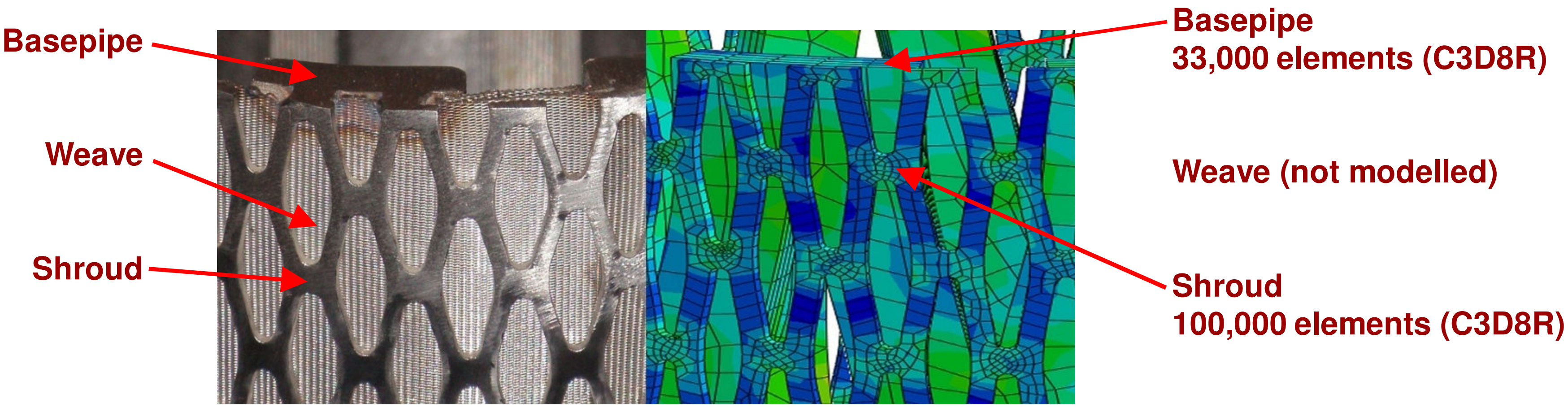
Thick Wall Cylinder experiments

Deformation simulations that include expansion of the ESS followed by collapse due to rock screen interactions have also been performed; this demonstrates the greater deformation resistance of the combined ESS/well bore with a huge increase in system collapse strength. These compare favourably to large scale testing on the ESS in rock cylinders. The predicted and measured deformations are comparable, within the uncertainties of the inputs.





Meshing of Slotted ESS and developing an Equivalent ESS®

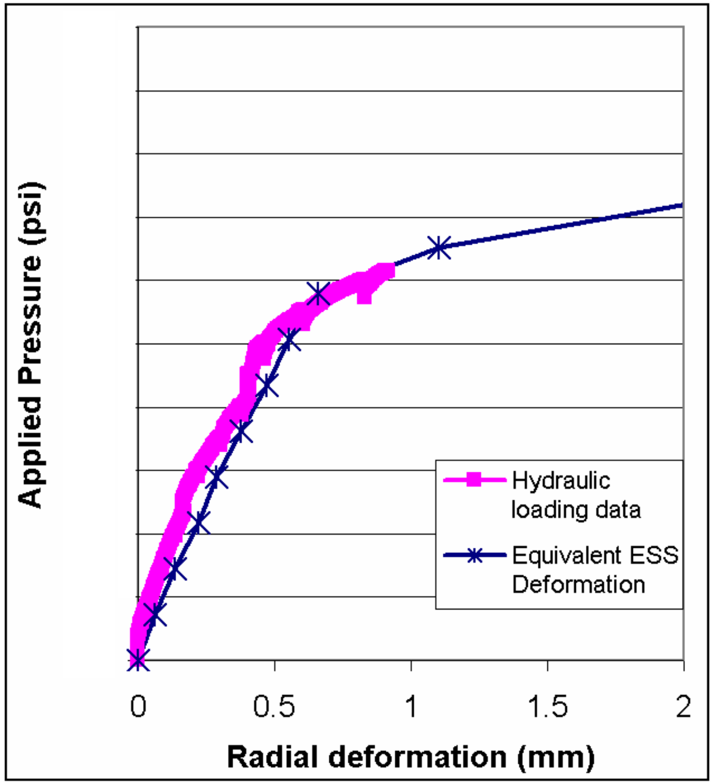


Detail of ESS construction showing complexity of the meshing on the shroud

Earlier models that were analysed and compared to physical tests were adequate as a design tool but rather slow (due to the huge number of Elements) for an analysis tool for screening multiple application scenarios.

Therefore a simple representation of the ESS was developed. This equivalent ESS was a plain pipe with the ID/OD dimensions of expanded ESS. The Elastic and Plastic properties were adjusted to fit hydraulic collapse data and FEA models of the whole slotted system

The method developed was very computationally efficient.



Comparison of the measured deformation;
(1) the full scale simulation and
(2) the equivalent (simple representation) simulation

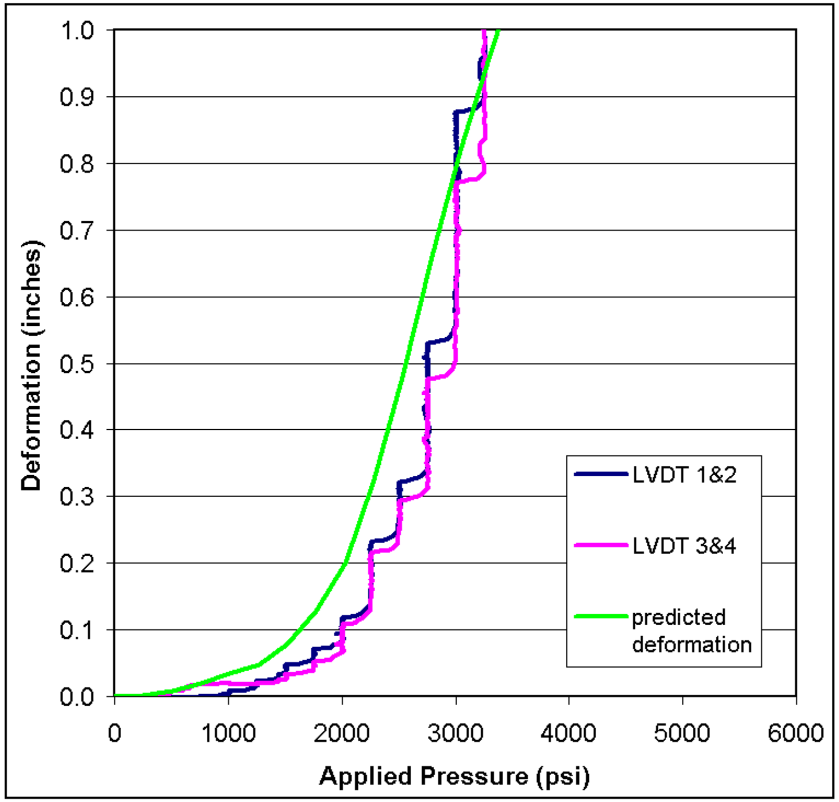
Verifying the Equivalent ESS®

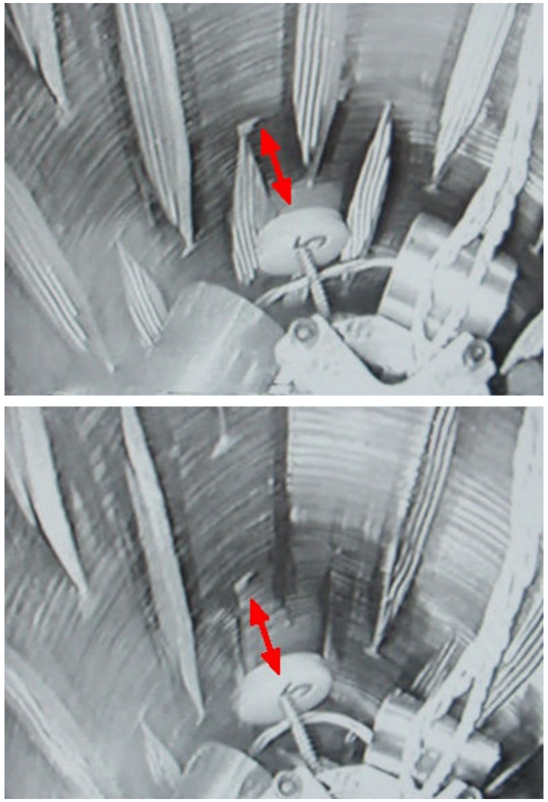
Confirming the Equivalent *ESS* does match existing data;

Thick Walled Cylinder (weak sandstone), stresses applied to simulate burial of between 15,000 and 20,000ft.

Deformation starts around 500psi, accelerates rapidly, attaining 1" deformation around 3000psi.

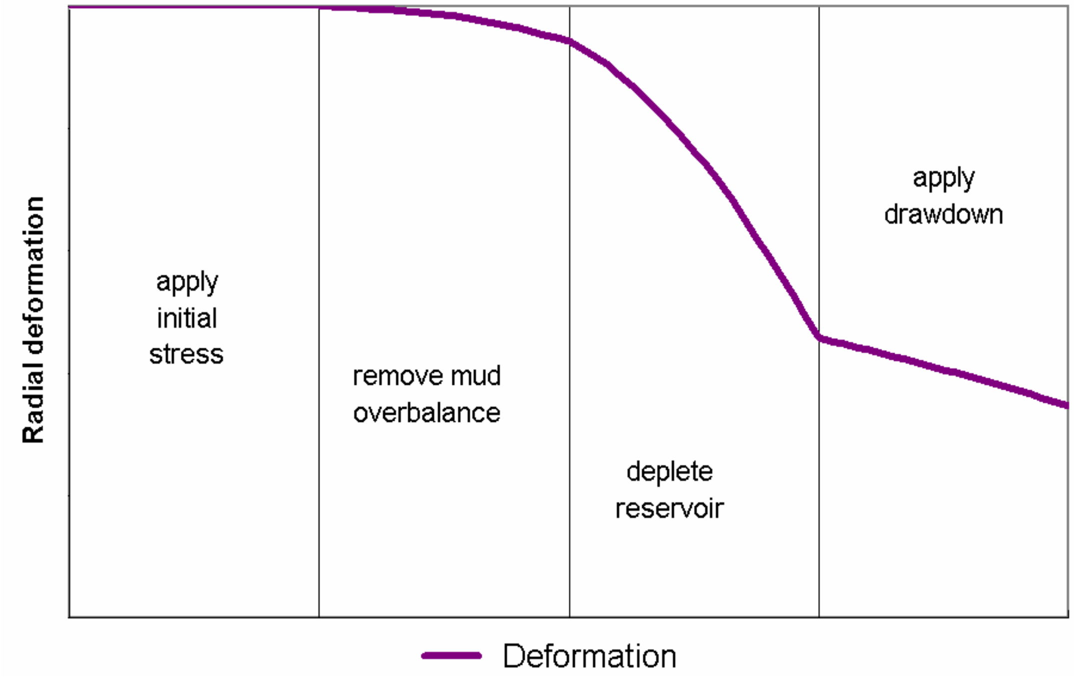
The FEA Equivalent *ESS* plain pipe gives a good match

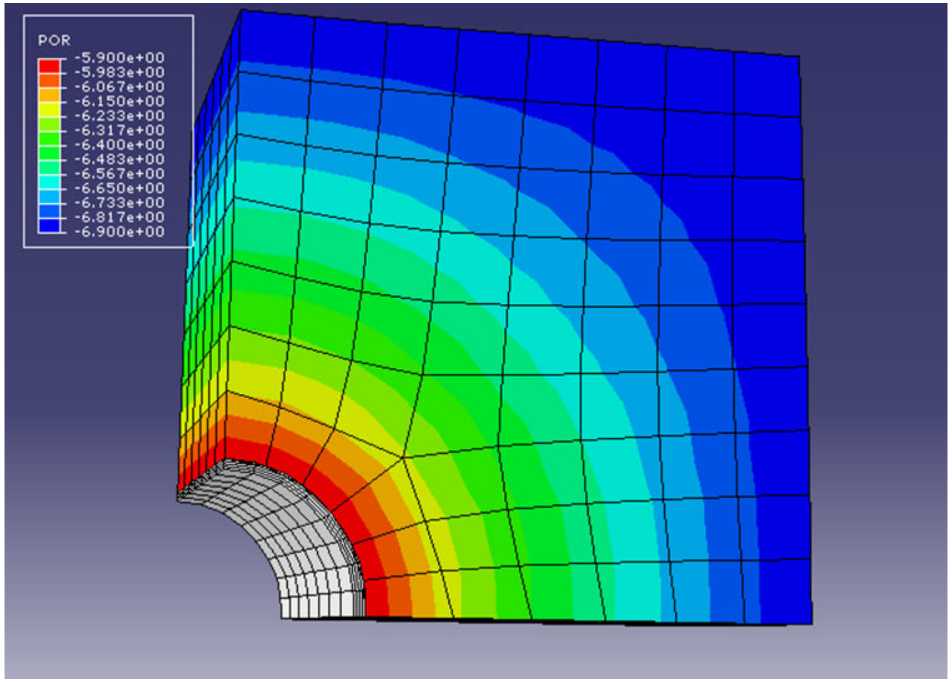




Vertical-Horizontal Well Application Screening Tool – Abaqus/Standard

A tool for screening potential applications for excessive deformation; simple enough to be run on a **basic laptop**!





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

Table 1 Well parameters

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

Table 2 Material properties of the sandstone used in the simulations

Weatherford now has a **tool** for quickly screening applications by using **Abaqus/Standard**

Formation Screen Evaluation "Lite" – W Magazine


magazine VOL. 11 NO. 4

Renewed Focus on Global Compliance

Simplified Modeling Speeds Sand Screen Candidate Selection

Formation Screen Evaluation 'Lite'

The interaction between the formation and the screen is central to successful installation of an openhole expandable sand screen (ESS®) system. To understand this interaction, finite element analysis (FEA) is often used to model complex downhole stress conditions, formation strength and the projected production history of the well.

While this complex model is appropriate for design, it is too cumbersome for field analysis. To streamline the process, a simplified equivalent of the *ESS* model has been developed that is computationally efficient and enables rapid investigation of formation/screen interactions.

The model is being used to study the effects of formation/screen interactions at various wellbore inclinations and through multiple rock layers. It is also routinely used to study new applications for potential, problems.

FEA is commonly used to model slotted base-pipe *ESS*. Initially, the entire screen structure was modeled and the results were compared to physical test data. But with this full model, simulating *ESS* expansion and loading it to collapse takes several hours on a powerful quad-core desktop computer.

FEA modeling is used extensively within Weatherford as a design and research tool. For these purposes, the performance is more than adequate. But it is rather slow for an analysis tool being used to review multiple application scenarios. In addition, much of this analysis needs to be done quickly on a laptop in remote locations around the world.

To simplify the simulation for use in routine field applications, an equivalent representation of the *ESS* was developed to match the gross behavior of the screen in terms of stiffness and yield. This approach was very computationally efficient and enabled rapid investigation of formation screen interactions.

september09

Euronext Welcomes Weatherford

The French *Autorité des marchés financiers* (AMF) approved Weatherford's prospectus for admission of its registered shares to listing and trading on the Professional Segment of NYSE Euronext Paris. Weatherford's registered shares now trade on Euronext and the New York Stock Exchange under the symbol WFT.

NYSE Euronext offers Weatherford a truly global cross-market listing enabling convenient, cost-effective access to business partners in the USA and in Europe, while enhancing its global profile.

...modeling of slotted-base expandable sand screens is making well candidate selection a faster process.

...S consists of a plain pipe with the ID/ ... the expanded screen. The elastic and ... of the material were adjusted to fit the ... data and FEA models of the whole ... results of the fit were very good.

...eracity of the equivalent *ESS* ... was built to simulate some large-scale ... a thick-walled cylinder (TWC) of rock.

The large stresses were applied to the outside and end surfaces of the TWC to simulate deep burial in the earth. The vessel is able to apply stresses that simulate depths of 15,000 and 20,000 feet (4,572 and 6,096 meters). The FEA was a very good fit with the experimental data.

In addition to screening future applications, the equivalent *ESS* representation has been used to model more complex well architectures, such as an inclined well, crossing multiple layers. This model shows many interesting features and has answered such questions as what happens at sand/shale interfaces and how the deformation varies with shale-layer thickness.

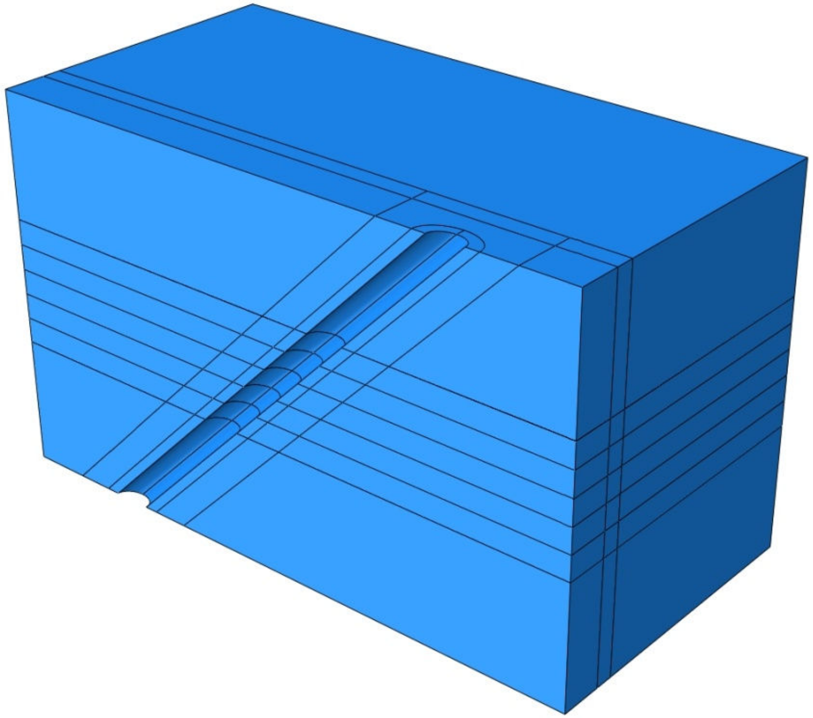
This synopsis is derived from a presentation at the SIMULIA Customer Conference, London (May 2009), *FEA Modelling of Expandable Sand Screens Interactions with Rock Formations*, authored by Ken Watson and Colin Jones, Weatherford International LTD. The referenced Weatherford technology includes expandable sand screen (ESS®) systems.

22 magazine

year in review 23

Inclined Wellbore in a Sand Shale Sequence - Abaqus/Standard

Investigation into more complex well geometries; inclined wellbore with more than one rock type

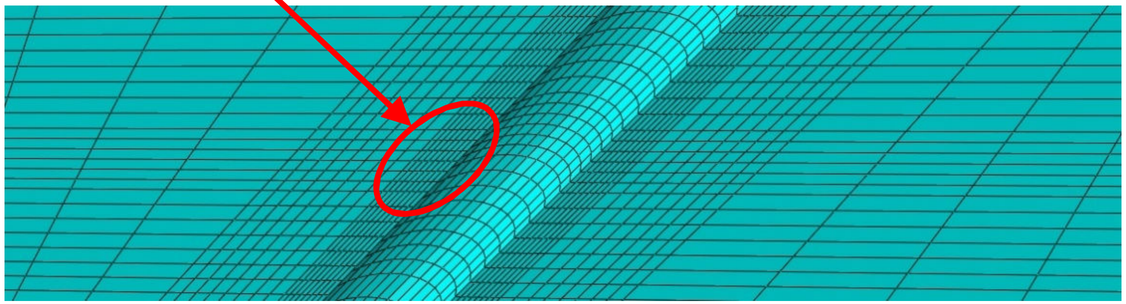


8.5” Diameter, 45º Inclined wellbore in a 5m x 5m x 3m block

Block was partitioned to allow for finer meshing closer to the wellbore.

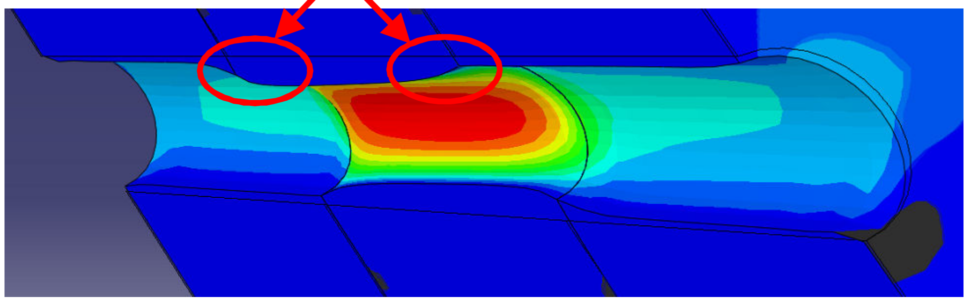
The central section is split into 5 sections which allowed shale layers as thin as 0.2m to be modelled.

Very fine mesh at middle of block



Detail of applied finer mesh close to the wellbore

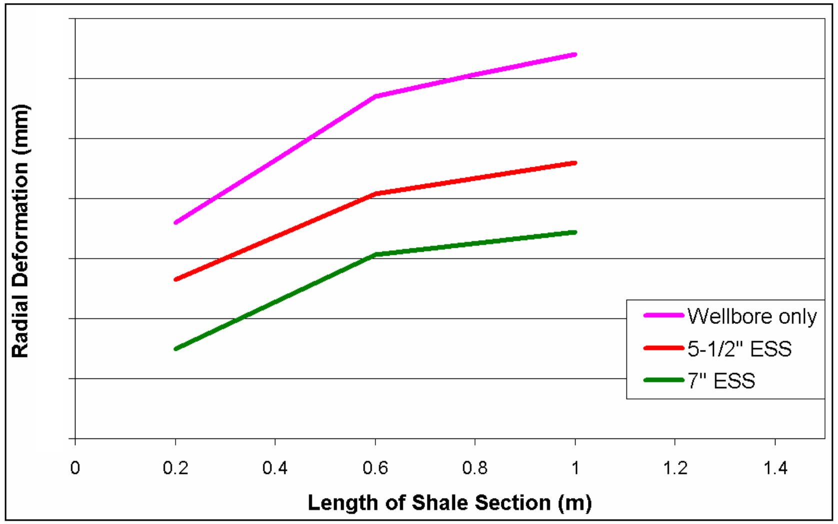
Sand appears to support the shale at the interfaces



Detail of the deformation in the Sandstone and Shale

Weatherford gets an **understanding** of complex issues by using **Abaqus/Standard**

Deformation in the central shale as a function of shale layer thickness.



Three sets of simulations were run.

(1) A bare 8-1/2" wellbore with 0.2 – 1m layers of shale.

(2) A 8-1/2" wellbore with 5-1/2" ESS installed, expanded out to 8-1/2" OD (with 0.2 – 1m shale)

(3) A 8-1/2" wellbore with 7" ESS installed, expanded out to 8-1/2" OD (with 0.2 – 1m shale)

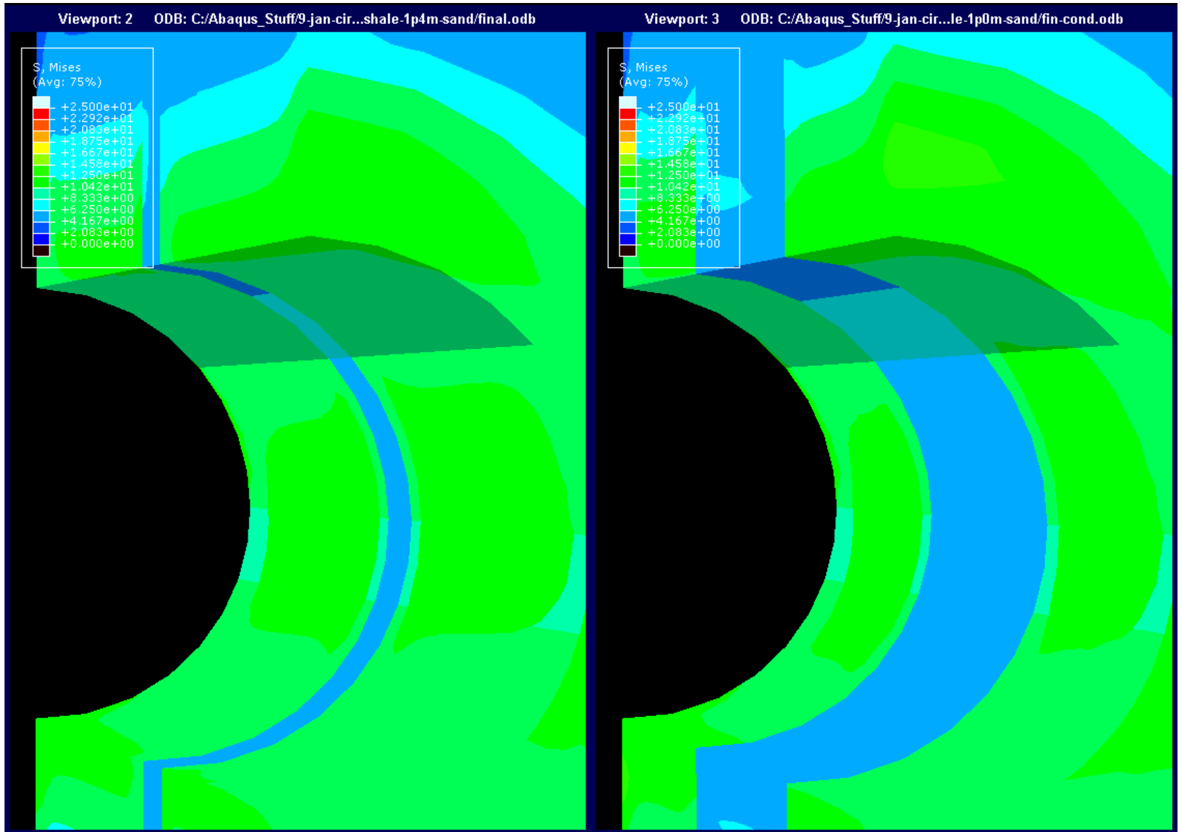
Depth	1900m
Vertical Stress	35MPa
Horizontal stress	32MPa
Initial reservoir pressure	19.2MPa
Mud overbalance	3.5MPa

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

0.2 metre shale section **1 metre shale section**



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FEA Modelling of Expandable Sand Screens Interactions with Rock Formations

Ken Watson & Colin Jones

Weatherford International

Abstract: Expandable sand screens are a sand control system, which is used to control the ingress of solids in oil and gas reservoirs with weak and unconsolidat different variations of expandable screens; a system based on expand compliant to the formation but is relatively low in stre basepipe which is very strong but is more difficult to expand c

FEA has been used to model the slotted basepipe type to be expanded screen with the rock formations. Initially the modelled and the results compared to physical test data. The well, with run times of the order of a few hours depending o simulations were adequate for research purposes but for r models were simplified. An equivalent representation of the gross behaviour of the screen in terms of stiffness an computationally efficient and allowed rapid investigation of f

The model was used to study the effects of formation scree through multiple rock layers. The model is also routinely potential problems.

Keywords: include Geomechanics, Soil-Structure Interaction

1. Introduction

Expandable sand screens (ESS™) are a relatively new sand co installations worldwide over all vendors. They come in 2 diff a slotted basepipe or a system based on a drilled basepipe. Th common, with around 600 installations since 1997. The adva is that it is relatively easy to expand into full contact with shape and diameter, to give a truly compliant system. productivity, sand retention capability and reliability (Hembl

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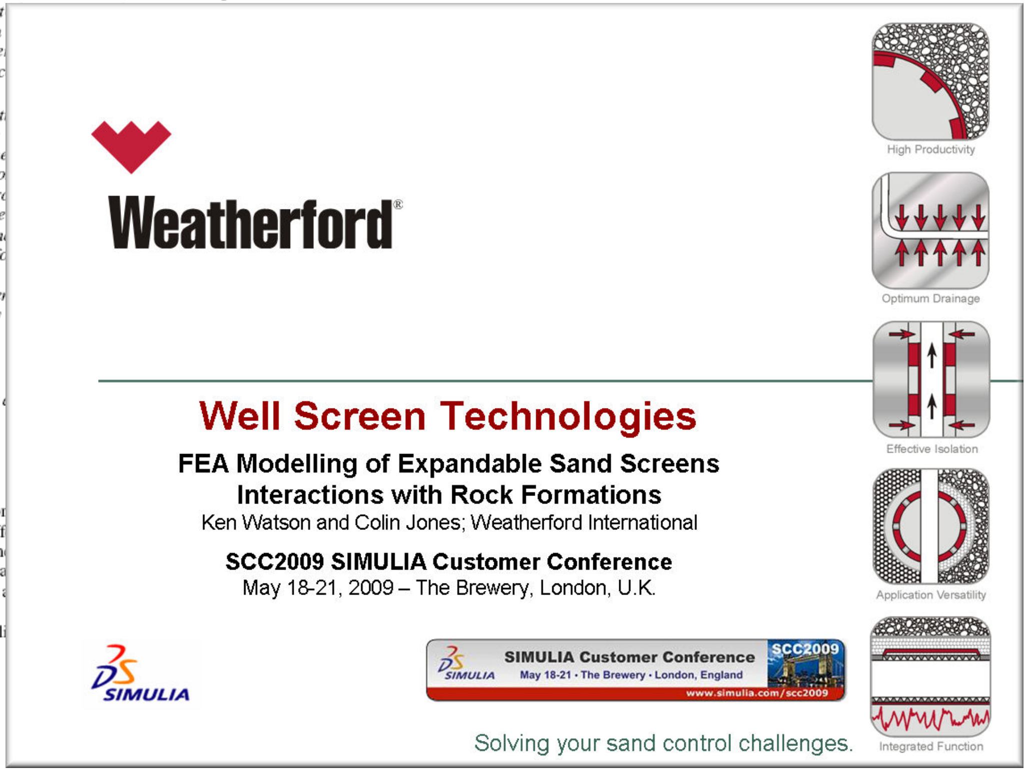
2009 SIMULIA Customer Conference

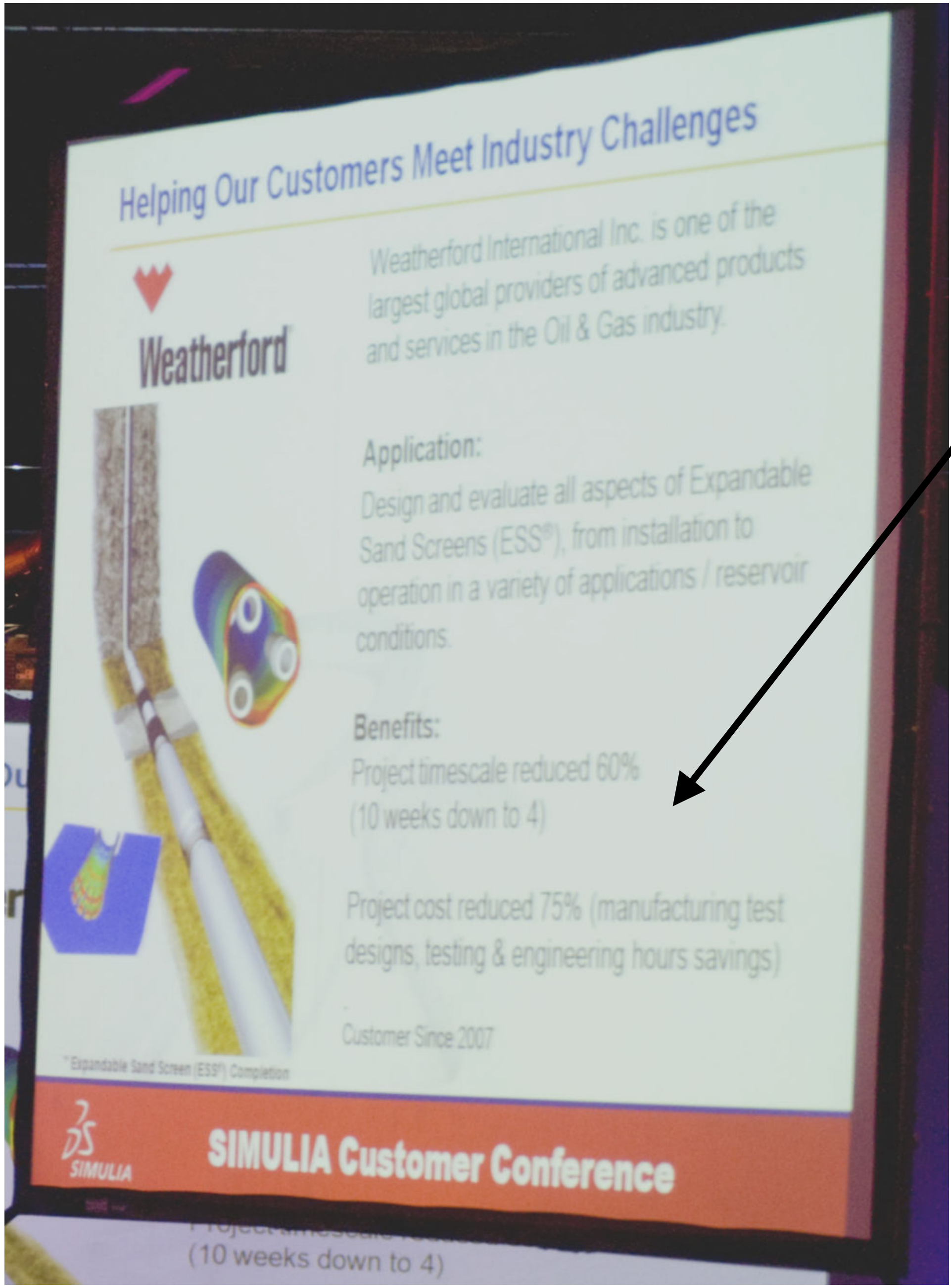


Paper and Presentation at Simulia Customer Conference, May 2009

Simulia Customer Conference; London 2009

2009 Simulia Customer Conference; the opening speech for the conference, Scott Berkey, CEO of Simulia

Simulia Customer Conference; London 2009



At the **2009 Customer Conference**, in the opening speech for the conference, **Scott Berkey, CEO of Simulia**, spoke of **Weatherford** being a **success story**, having saved **considerable time and money whilst using Abaqus**;

FEA of Plate Designs for 7" ESS Transition Areas

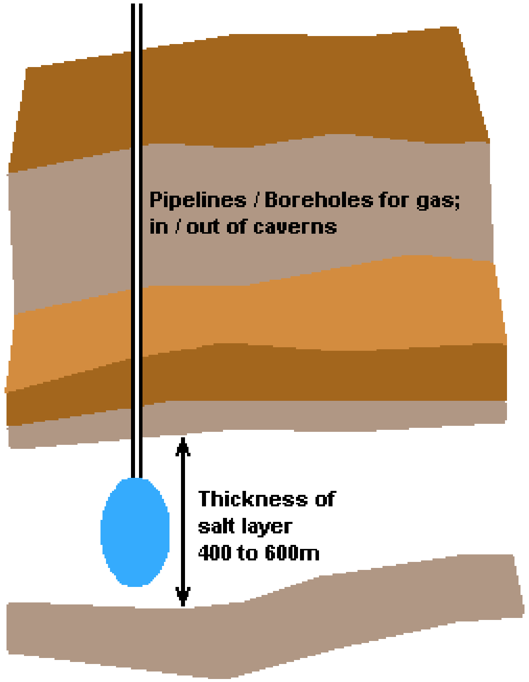
Reduce ten different Plate Designs down to just two physically tested designs

Weatherford engineers get rapid turn-around for different designs using **Abaqus** products

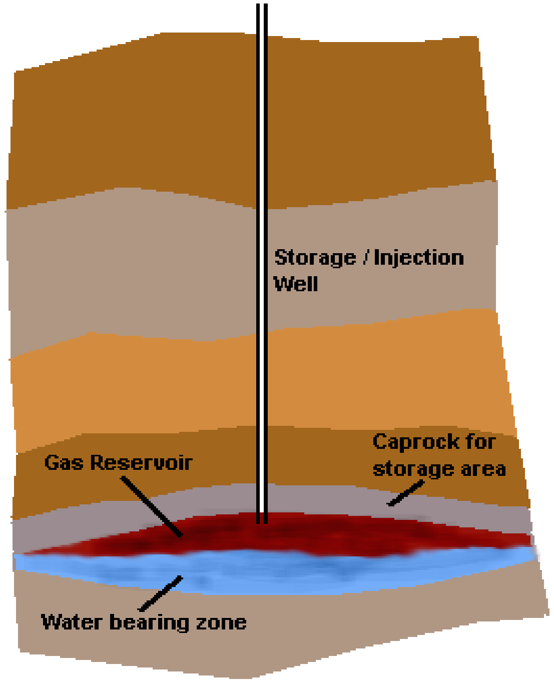
But of course, conferences aren't all about listening to papers and presentations – here's Colin and myself letting our hair down (such that it is) with Chris Smith, General Manager, Simulia U.K.

Underground Gas Storage; the geological structure types

- The use of Underground Gas Storage (UGS) is expected to increase considerably in the near future,
  due to a variety of factors;
  including security of supply (whether due to technical or political issues).
- There are several geological structure types for storing gas underground;
  - salt caverns (either natural or manmade),
  - porous rock in depleted gas or oil reservoirs,
  - aquifers (not shown), where there would be an impermeable cap rock, with water filled rock strata below, with the injected gas displacing the water.



Salt cavern UGS

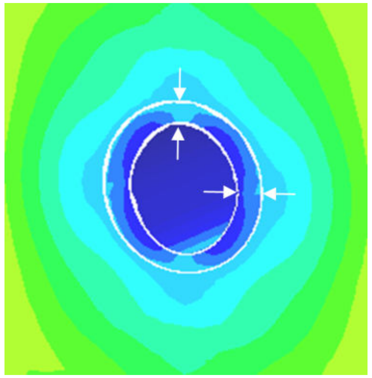


Depleted gas reservoir UGS

Analysis; results

Annual winter/summer cycling using a depleted gas reservoir

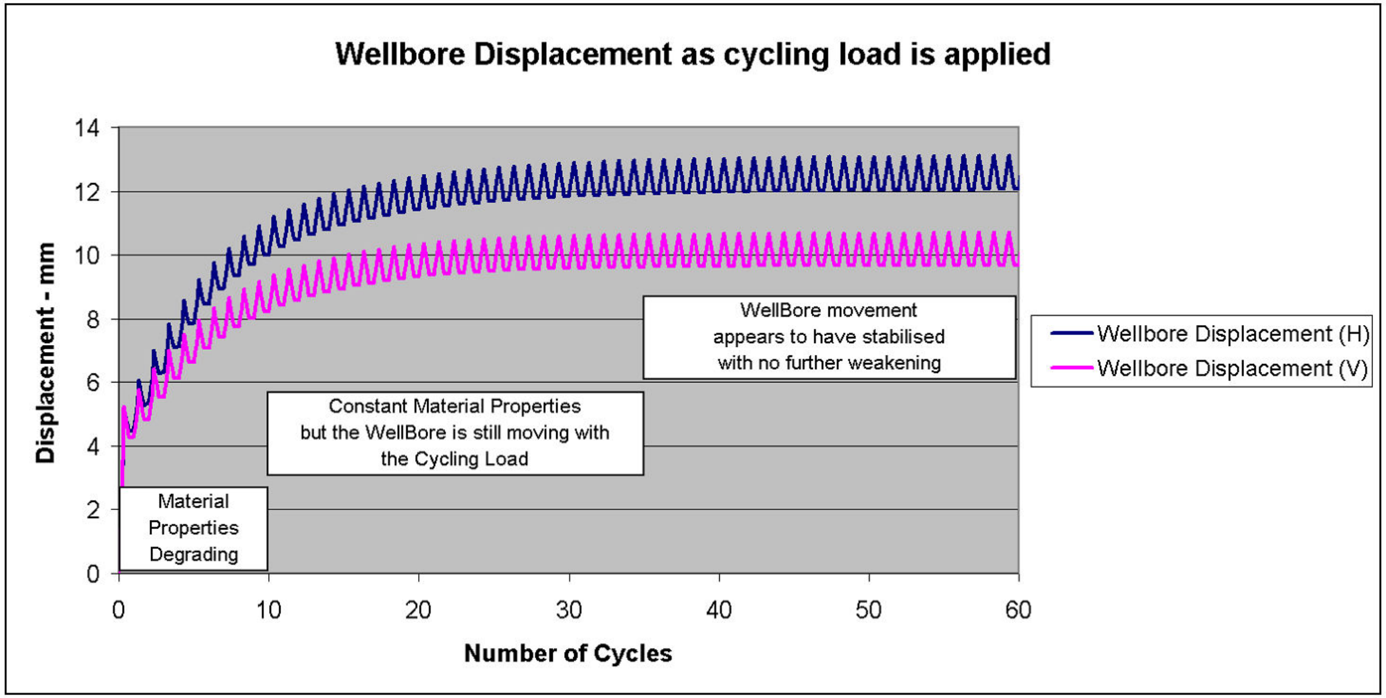
- Strength degraded over the first 10 cycles, but takes 35 cycles to stabilise.
- It is important that the deformation stabilises, since excessive formation induced deformation of ESS could restrict access to the well and may ultimately cause a loss of sand control.
- Extensive testing in a joint industry project showed that ESS could withstand large deformations without collapsing or losing the ability to control the sand.
- A limit of 20% deformation was set based on the results of the joint industry project. The 20% value includes a large safety factor.
- For the weak sandstone used in this analysis, the extent of deformation prior to stabilisation is seen to be around 12%, which is well within the acceptable limit of 20%.



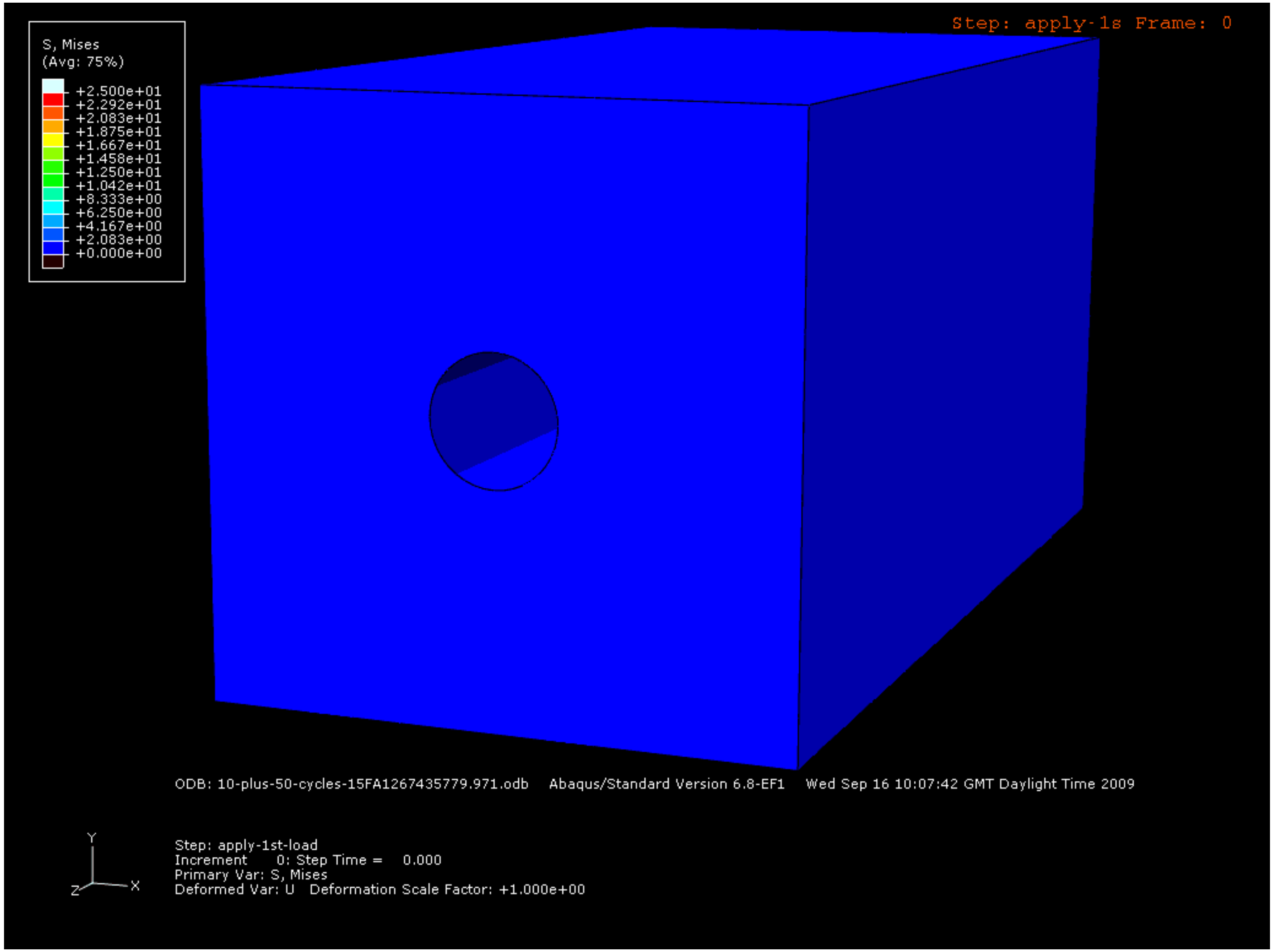
Wellbore movement with an artificially weak sandstone

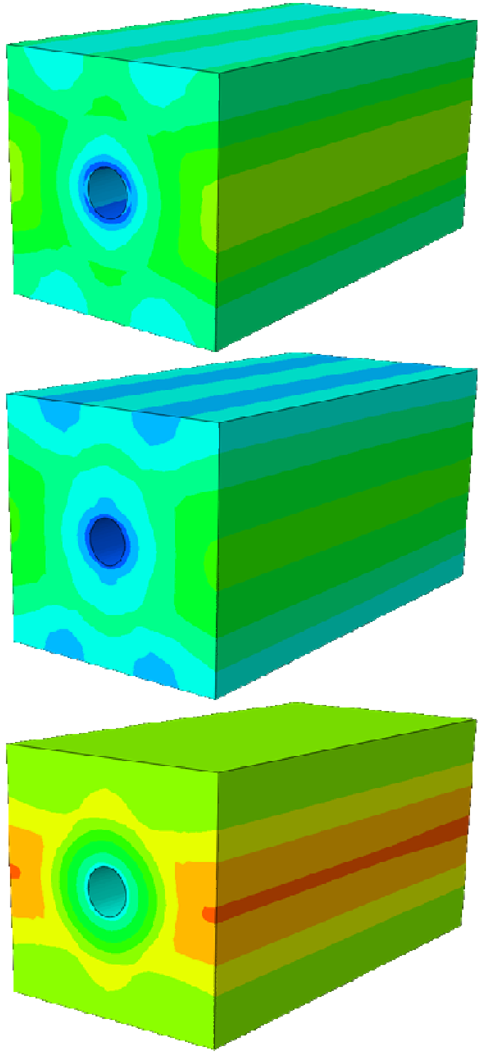
Radial wellbore displacement as cycling load is applied showing both Horizontal and Vertical movement

Friction Angle = 25

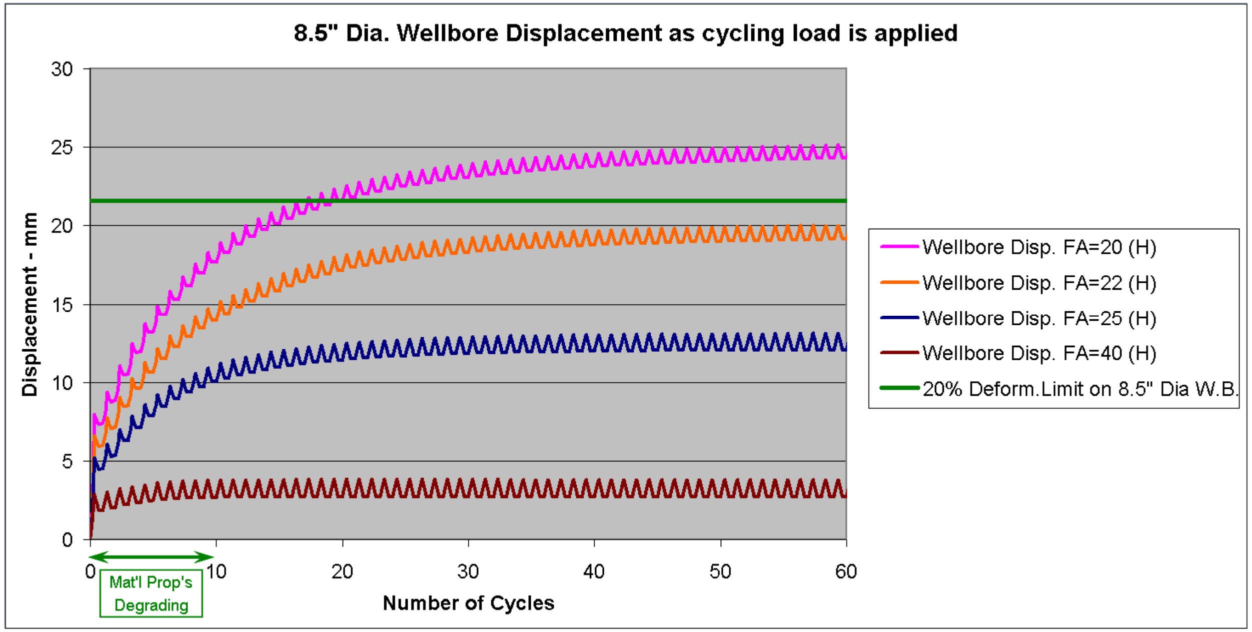


The video below shows the rock mass (Equivalent ESS not shown), with a very low Friction Angle of 15 (low value chosen as it shows the deformation better).

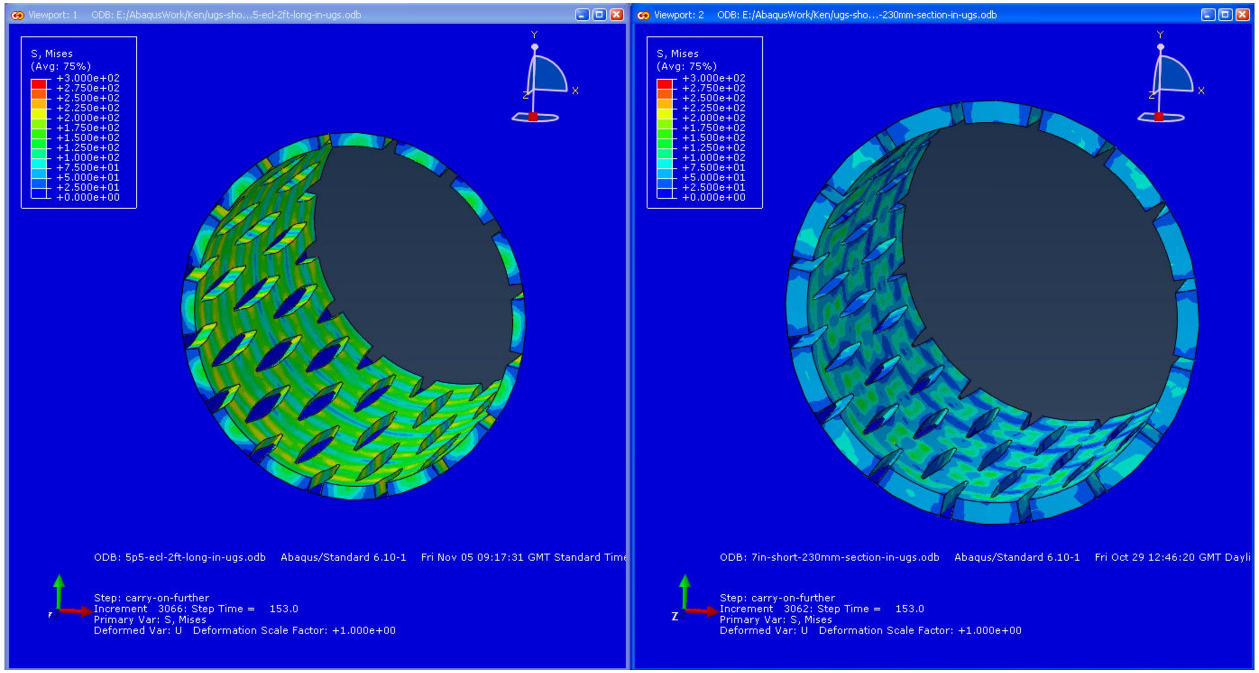




Analysis; results



Changing parameters within Abaqus is a simple process – in this case varying the Friction Angle



In this case both 5-1/2" and 7" slotted basepipe is shown at the end of the 60 cycles
(both started at the same O.D.)

Papers and Presentations - 2010

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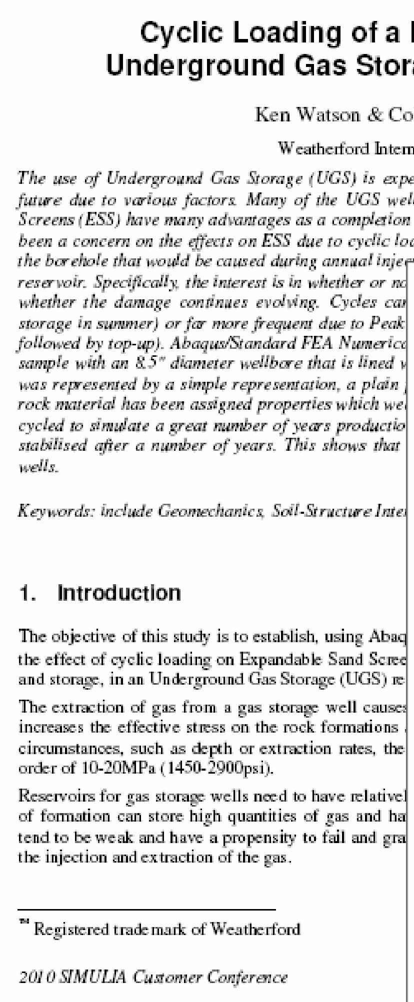

Cyclic Loading of a Rock Mass for Underground Gas Storage Applications

Ken Watson & Colin Jones

Weatherford International

The use of Underground Gas Storage (UGS) is expected to increase considerably in the near future due to various factors. Many of the UGS wells require sand control. Expandable Sand Screens (ESS) have many advantages as a completion option in UGS wells. But there has always been a concern on the effects on ESS due to cyclic loading. The paper deals with the changes in the borehole that would be caused during annual inje... reservoir. Specifically, the interest is in whether or no... whether the damage continues evolving. Cycles can... storage in summer) or far more frequent due to Peak... followed by top-up). Abaqus/Standard FEA Numeric... sample with an 8.5" diameter wellbore that is lined ... was represented by a simple representation, a plain ... rock material has been assigned properties which we... cycled to simulate a great number of years productio... stabilised after a number of years. This shows that ... wells.

Keywords: include Geomechanics, Soil-Structure Inte...

1. Introduction

The objective of this study is to establish, using Abaq... the effect of cyclic loading on Expandable Sand Scree... and storage, in an Underground Gas Storage (UGS) re...

The extraction of gas from a gas storage well causes... increases the effective stress on the rock formations ... circumstances, such as depth or extraction rates, the... order of 10-20MPa (1450-2900psi).

Reservoirs for gas storage wells need to have relativel... of formation can store high quantities of gas and ha... tend to be weak and have a propensity to fail and gra... the injection and extraction of the gas.

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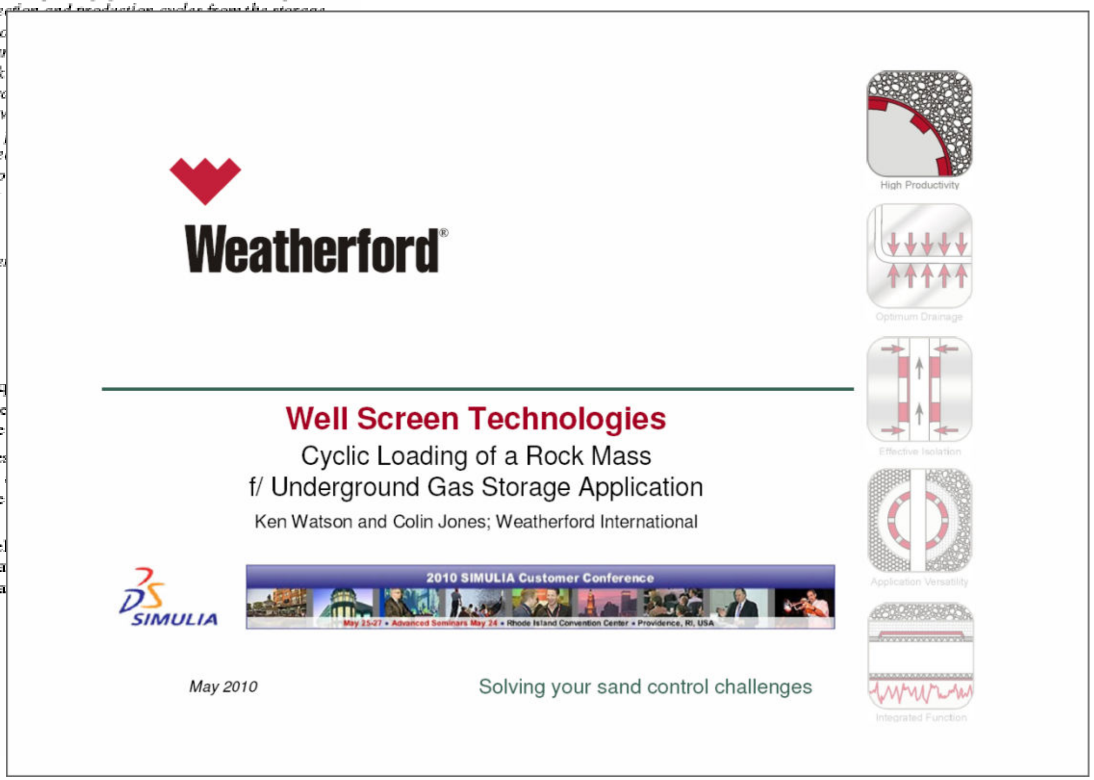
2010 SIMULIA Customer Conference



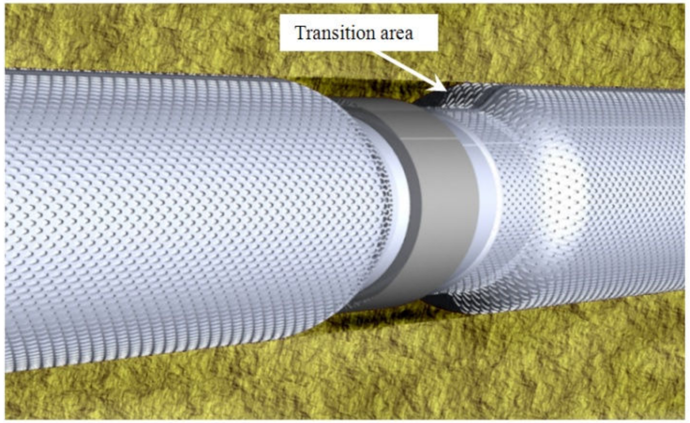
Paper and Presentation at Simulia Customer Conference, May 2010

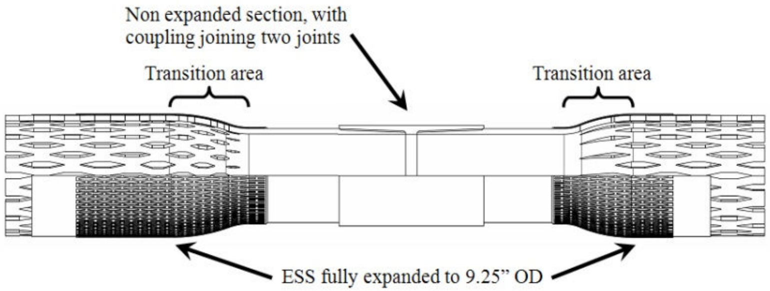
SPE International — Society of Petroleum Engineers

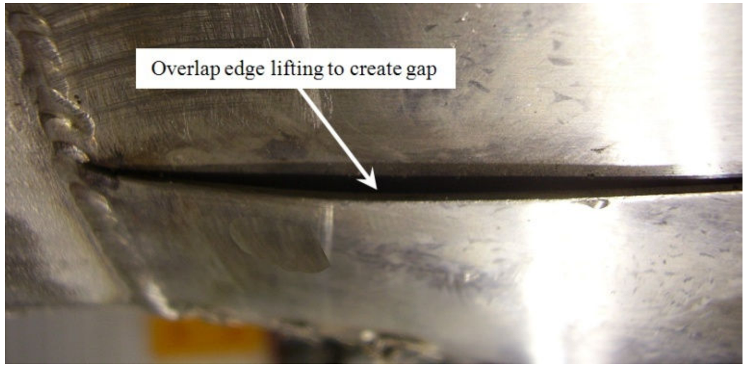
A version of this presentation was also made at the SPE organised Sand Management Forum, March 2010

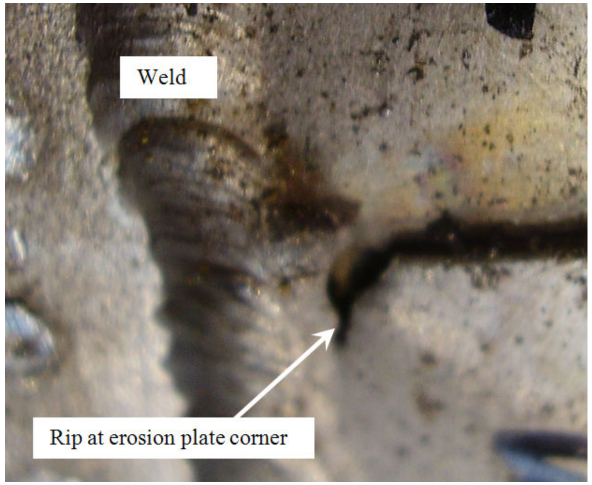
4th SPE/SMN European Sand Management Forum
10th & 11th March 2010
Aberdeen Exhibition & Conference Centre

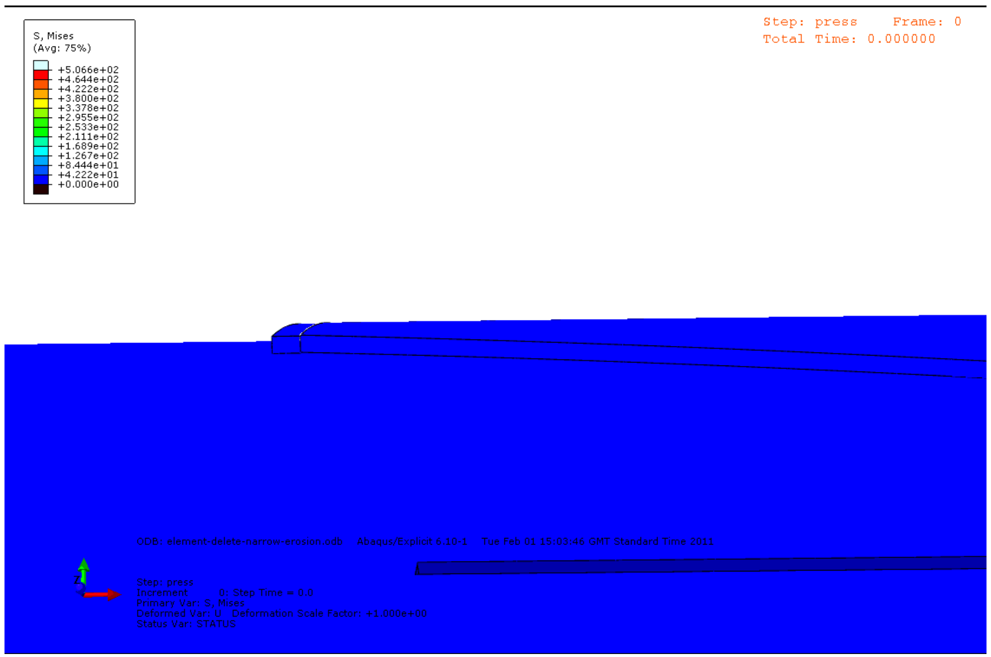
R&D on the ESS Product, Erosion Plates- Abaqus/Explicit











Background to the Erosion Plates studies

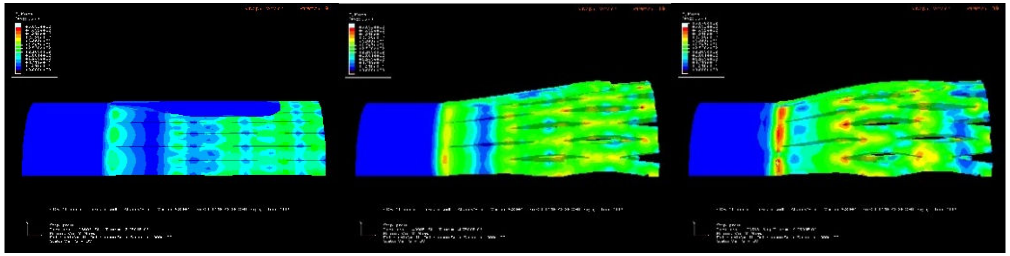
To create a non-flowing transition area between the expanded and non-expanded section on 7" ESS. Erosion of the weave could occur in the transition area in especially high-rate wells.

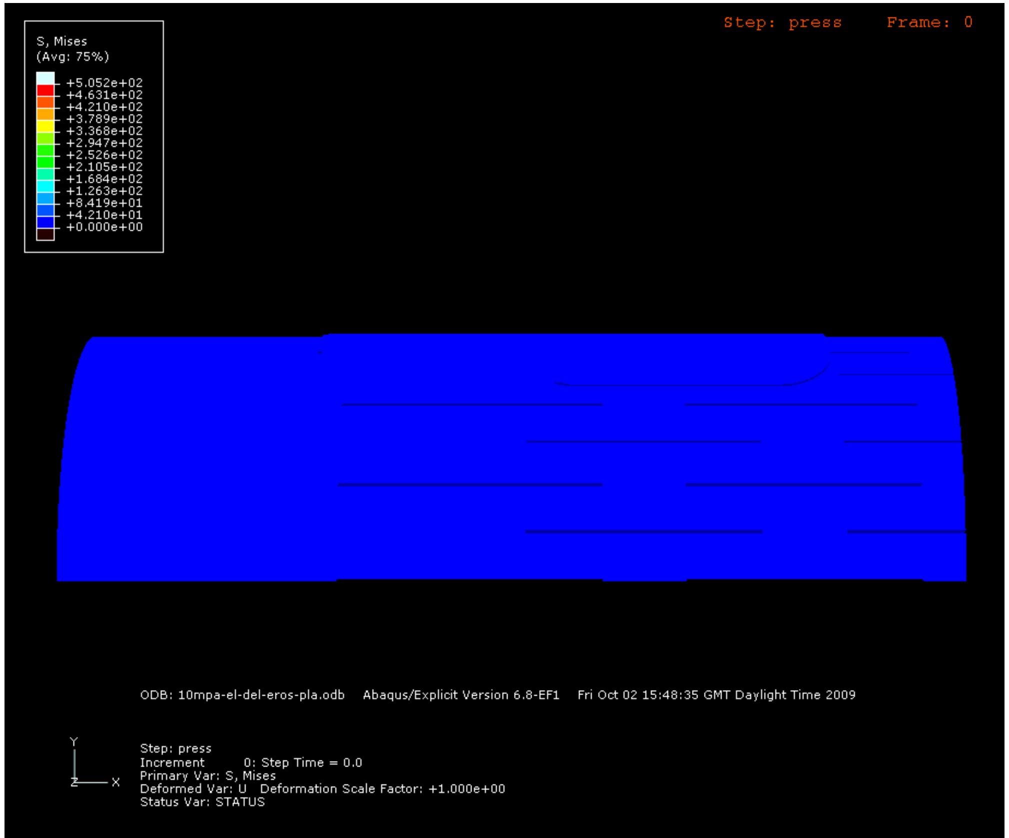
Erosion Plates - Abaqus/Explicit

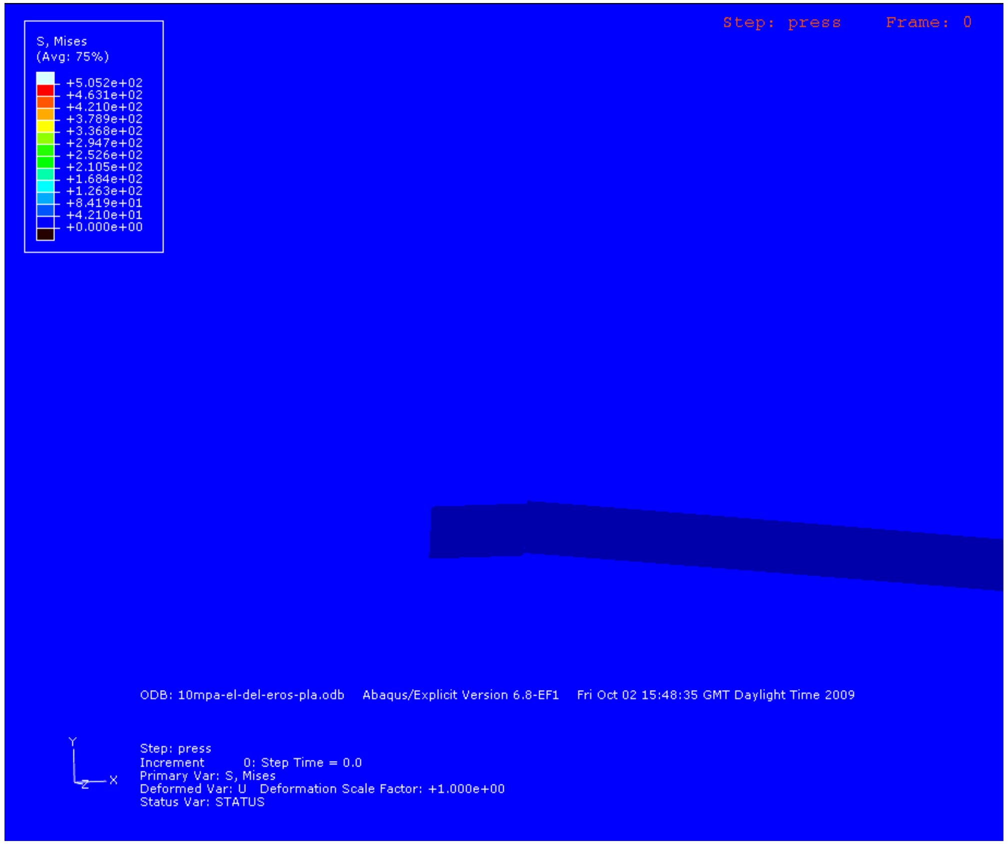
Case Study, for a specific Client requirement

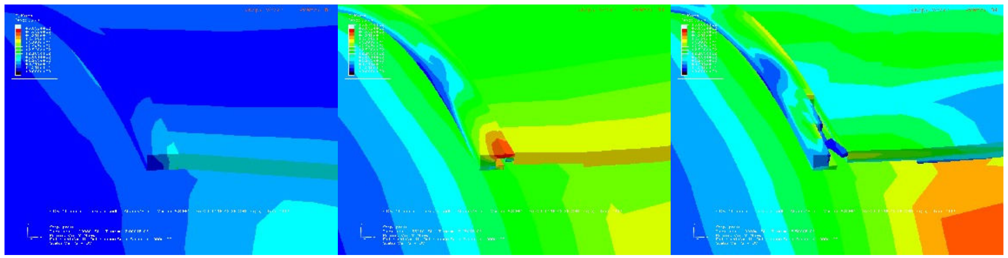
New Plate designs – 10 off

Physical test pieces – 2 off









Weatherford benefited by **saving time; 60%** and **costs; 75%** by using **Abaqus/Explicit** in this study

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The use of FEA in sand screen design cuts costs and accelerates development

Ken Watson and Colin Jones

Weatherford International

Expandable sand screens are a sand control system which is used to control the ingress of solids, in oil and gas reservoirs in weak and unconsolidated formations. The filtration media is typically sized to the largest 10% of the formation grain size distribution. As a consequence of this some fine solids are often produced. This has a beneficial effect in that it cleans the near wellbore of fine solids which have a tendency to plug the formations. However, in high rate gas wells there may be the possibility of erosion on the inside of the filter media part of the ESS in the transition area between expanded and non-expanded sections of the screen. To reduce the chances of this happening, the addition of thin sacrificial plates were installed over the critical area. These erosion plates would cover, and therefore blank off, the transition areas, so preventing any damaging flow through the filter. Several designs were proposed with varying number and shape of plates and the details of the welding. Ten different scenarios were modelled and subjected to analysis in FEA. The two best variations, showing the least stress at the welded corners as the ESS system changed diameter due to expansion forces, were taken forward to be physical test pieces. One of these designs was chosen for production. Using FEA for this project allowed our engineering group to discount eight of the original ten designs leaving just two to be fully manufactured and tested extensively. This helped reduce both the project time by 60% and the overall costs by 75%.

Keywords: Damage, Design Optimization, Experimental Verification, Failure, Forming, Pipeline, Tube Expansion and Visualization.

1. Introduction

The objective of this study using Finite Element Analysis (FEA) was to establish a suitable erosion plate design and configuration capable of withstanding diametrical change across the transition areas of a 7" Expandable Sand Screen (ESS™) joint, shown in Figures 1a and 1b. Solid metal erosion plates have previously been established as a suitable method of providing this non-flowing transition area between the expanded and unexpanded sections. A non-flowing area is required to ensure that there is no flow through the transition sections which could, potentially, lead to erosion of the filter weave in applications where very high flow rates are expected. The erosion could take place from the inside out due to the small quantities of solids entrained in the production fluids.
An example of ESS construction is shown in Figure 2, typically the ESS consists of three parts, **1. the slotted basepipe** or expandable slotted tubular (EST), **2. the woven filter mesh** (weave) which retains the sand and **3. the outer shroud** which protects the mesh during deployment.

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Paper and Presentation at Simulia Customer Conference, May 2011

SPE 122847

A Successful Expandable Sand Screen Case History in a Deep, Corrosive Gas Well Application

Noel Ginest, Abdulaziz Al-Sagr, Bandar Al-Malki, Muhammad Al-Khawajah, Saudi Aramco, Colin Jones, Quentin Morgan and Keith Parry, Weatherford International

Abstract

K Field is a gas field located in Saudi Arabia, with production from the Unayzah A reservoir, an unconsolidated sandstone reservoir notable for its comparative depth. The high corresponding bottomhole temperature combined with corrosive gas properties manifests in aggressive in-situ corrosion conditions. Sand control is needed in this reservoir due to the weak rocks and high tectonic stresses. Frac-pack completions have been used successfully for a number of years and typically manifest in a low positive skin. They tend to suffer from condensate banking and flow related skin.

A number of years ago it was decided to use the then novel expandable sand screen (ESS) technology in a long horizontal well to maximise reservoir drainage. This presented many challenges in terms of the metallurgy, the interaction with high stresses and the deployment in a deep hot well. In April 2004 Well K-3 was drilled as a horizontal open hole well and completed with ESS, setting three world records at that time for the hottest and deepest ESS installation and first ever Incoloy ESS system.

The well was shut-in almost immediately after clean-up operations began due to a mechanical failure in the upper completion, and remained shut-in for nearly 3 years. The well was successfully restarted after an upper completion workover.

This paper describes assessment of well performance from a multi-rate production test conducted following successful workover of Well K-3, and benchmarks key performance indices with those derived from analysis of neighbouring wells equipped with alternative sand control techniques.

Introduction

The K field is an Aolean sandstone reservoir with strong sanding tendencies. The field is in the Greater Ghawar area, south east of the super giant Ghawar Field. The reservoir is in the early Permian age (c280My) Unayzah A formation, which underlies the Pre-Khuff carbonates[1]. The reservoir is deep at 14800' TVD, with an average porosity of 18%, but with permeabilities ranging up to several Darcies.[2] The field was discovered in 1982 and developed in (2000-2004).

The Unayzah formations consist of well developed Aeolean sandstones with associated inter dune deposits. Geological analysis has divided the reservoir into four discrete facies: dune, sand sheet, paleosol and playa. The dune and sand sheets are the main productive reservoir units, while the paleosols and the playa have low porosity and permeability (<1mD) and act as flow barriers. The reservoir has been completed with sub-vertical frac-packs. These provide excellent productivity and sand control, but suffer from relatively rapid depletion due to intersecting only one reservoir unit.

The main challenges to drilling and completing the wells were the relative depth (the K-3 well was at 15100' TVD), relatively high temperature of 320F and the non-hydrocarbon content in the gas composition. Additionally the high horizontal stresses gradient of up to 1.5psi/ft due to Arabian plate tectonics and the nearby subduction zone can cause wellbore stability problems, especially in the shales.

The K-3 well was originally drilled into the Unayzah reservoir on 1997 as a gas producer to a depth of 16,149ftMD. The well was then perforated and tested, before being suspended with cement plugs. In October 2002, the cement plugs were drilled out, and the 7" casing was then perforated. After frac-pack pumping operations were completed, the rig was unable to pull the gravel pack service tools out of the gravel pack packer and after numerous unsuccessful fishing attempts, the well was again suspended. The well was eventually sidetracked and fitted with an ESS in 2004.

SPE 122847 5

Depth (TVD)	15,176 Ft
Vertical stress	16,694 psi
Greatest horizontal stress	22,764 psi
Least horizontal stress	10,471 psi
Initial reservoir pressure	8,650 psi
Final reservoir pressure	4,000 psi

Table 1 In-situ stress and reservoir pressures

Sample	UCS (psi)	Friction Angle (degrees)
RM12	4,887	30.8
RM13	4,336	28.3
RM27	5,771	27.4
RM28	4,394	24.3
RM46B	3,002	26.4
RM46C	4,843	23.2

Table 2 Rock strength

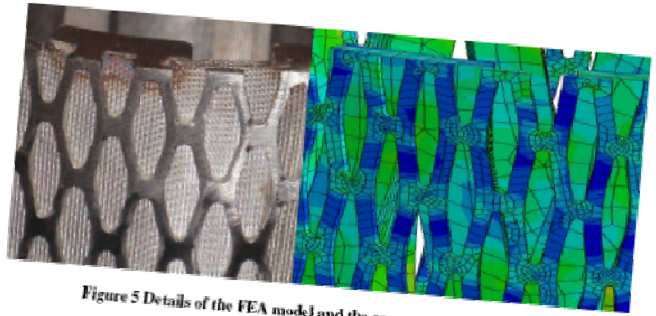


Figure 5 Details of the FEA model and the corresponding actual ESS

Installation

The objective of installing ESS in the K-3 work-over was to provide a drainage point in the Unayzah reservoir, and to prevent sand production. The Unayzah reservoir was completed with 4" 230µm ESS compliantly expanded in the 5-7/8" hole.

A window was milled in the original 9 5/8" casing from 13,390 ft to 14,012 ft and a sidetrack performed with 7" liner set at the top of Unayzah reservoir at 15,191 ft MD (14,889 ft TVD). After running and cementing the 7" 32# liner, the 9 5/8" and 7" were cleaned and the cement drilled down to the float shoe. The 5-7/8" section was drilled to TD at 16,747 ftMD (15,125 ftTVD) at a maximum ROP of 25ft per hour, holding inclination at 86.87 degrees and azimuth at 270 degrees through the reservoir sand, using a 90 pcf Na/K Formate brine based DIF system, weighted with Calcium Carbonate. Check trips were performed every 300ft of hole drilled or as hole conditions dictated. After reaching TD a wiper trip was performed to check hole conditions. Prior to installation a suite of logging tools were run on drill pipe.

After logging the 5-7/8" hole, a bit and scraper was run to TD to check the integrity of the hole. While at TD the well was displaced to solids free Na/K Formate brine. The filter cake was removed and the hole cleaned using 310-ft/min annular velocity and high vis pills. The returns were conditioned using 325 mesh shakers and centrifuges. This process was continued until three samples of the mud passed a production screen test (PST).

The 4" Incoloy 825 ESS screens with 230µm filtration media was deployed into the 5-7/8" open hole section and suspended from a Weatherford EXP 5 ½" x 7" hanger packer. The packer was hydraulically set by dropping a ball. Packer setting was confirmed by an annulus pressure test to 500 psi.

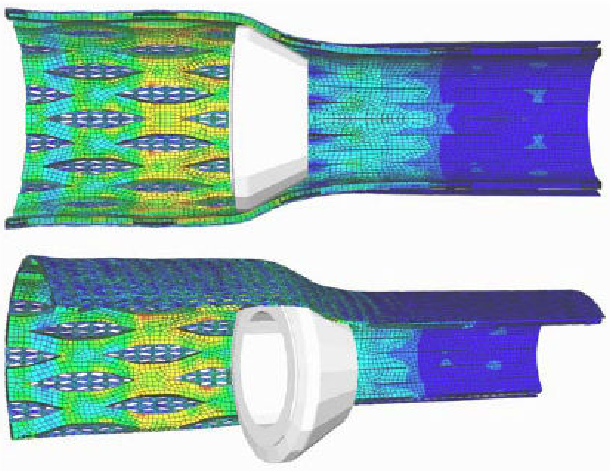
After retrieving the hanger setting tool the ESS was compliantly expanded against the borehole wall in two separate planned Axial Compliant Expansion (ACE) runs. The screen expansion was completed without incident and in accordance with hook loads predicted from extensive torque & drag (T&D) modeling. T&D modeling was considered to be the most

Finite Element Analysis of Weatherford Expandable Sand Screen Products

K. Watson, Weatherford International Ltd

Expandable sand screens (ESS) are a relatively novel sand control system, which are used to control the ingress of solids in oil and gas reservoirs with weak and unconsolidated formations. They combine the ease of installation of conventional screens with the borehole support of a gravel pack.
FEA has been used to model slotted basepipe ESS to better understand the interaction of the expanded screen with the rock formations. This type of analysis will eventually replace earlier, simple analytical, models based on tunneling theory. There are many advantages to using FEA. It allows a better choice of material models for the rock such as Drucker Prager and Cap models. It also allows the investigation of a wider range of configurations, such as the effect of an annulus or the interfaces between different formations.
This work is ongoing, recent results are presented below.

Cone expansion showing surplus expansion



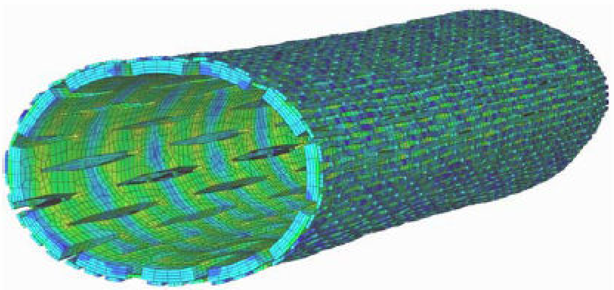
A cone style expansion tool is currently used within FEA, this gives good results when compared with empirical testing. A long term goal will be to also model the compliant expansion tools.

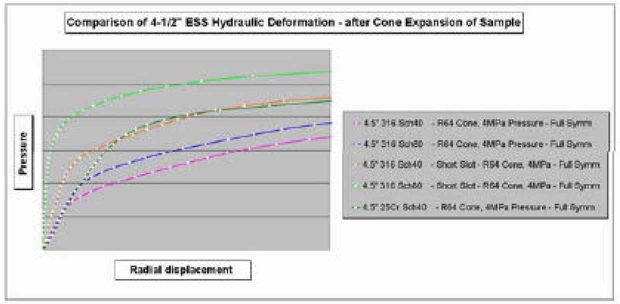
Prediction of hydraulic collapse strength

Using FEA gives greater understanding of required expansion forces and deformation resistance.

It gives the ability to quickly assess various slot patterns, wall thicknesses and different metallurgies.

The prime consideration being ability to expand and resistance to deformation. This can be quickly established with FEA and the designs optimised prior to verification by testing.

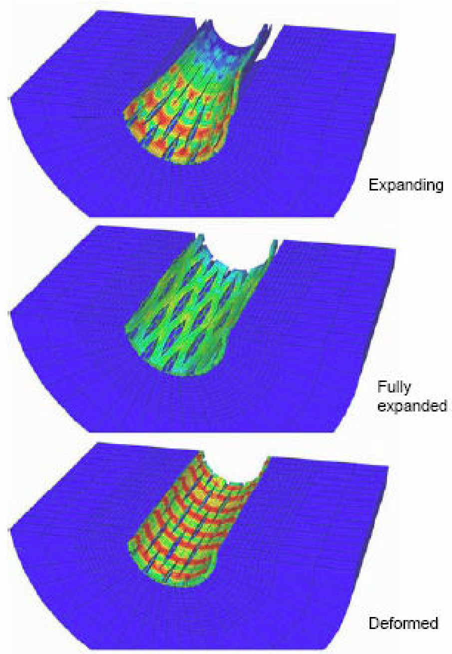




From the graph above, it can be seen that a 25Cr version of ESS would give the best deformation resistance, followed by the standard metallurgy, standard basepipe but with shorter slots. However, the required expansion forces for the 25Cr version are too high. The next strongest variation has an expansion force that is similar to the current ESS design.

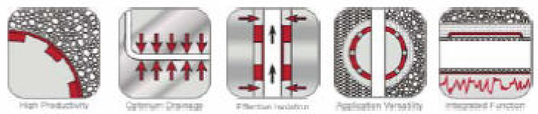
Large scale TWC experiments

Deformation simulations that include expansion of the ESS followed by collapse due to rock screen interactions have also been performed; this demonstrates the greater deformation resistance of the combined ESS/well bore with a huge increase in system collapse strength. These compare favourably to large scale testing on the ESS in rock cylinders. The predicted and measured deformations are comparable, within the uncertainties of the inputs.



Future work;

The next stage of the development is to use the FEA modelling for field qualification of ESS applications



Numerical Modelling capabilities within Weatherford International Ltd.

F. Bahrini & K. Watson, Weatherford International Ltd

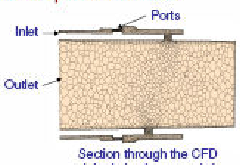
Computational Fluid Dynamics (CFD)

CFD can simulate: single and multiphase, erosion, reservoir modelling, chemical reaction, heat and mass transfer…
CFD allows you to access parts and observe phenomenon that you would not be able to see in the lab.
CFD can save money, time and helps you to design better, because CFD can predict the results for any initial conditions without carrying out several lab tests.
Although CFD can reduce the cost, it does not replace a lab test

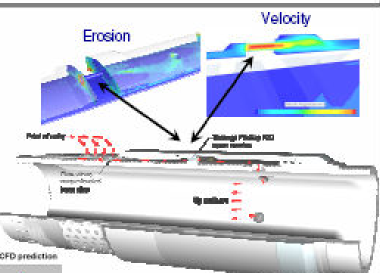
FloReg™ *ICD;* Velocities, pressure drops and erosion

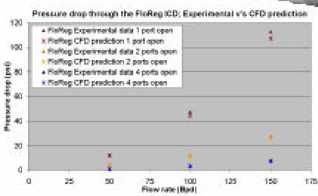
Floreg ICD completion systems provide a uniform inflow through a wellbore. Early water breakthrough, hot spots, are reduced by adjusting the numbers of open ports.

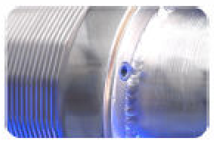
In this example, CFD simulations were used to check the experimental data: three configurations were studied: 4 ,2 and 1 open port for each case. Three flow rates were applied: 50,100 and 150 Bpd. Based on CFD results, the major pressure drop is located in the port zone, moreover the pressure drop predicted by CFD matches with existing experimental data



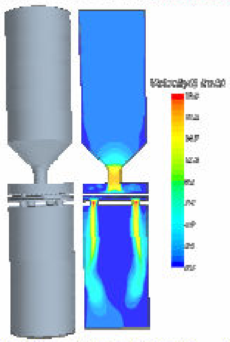
Section through the CFD polyhedral volume mesh for the *FloReg* ICD



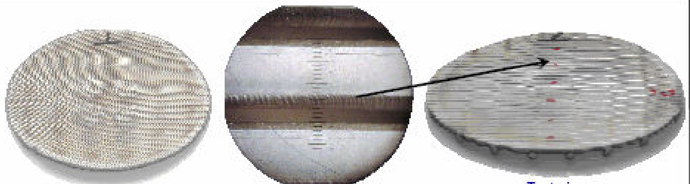




WWS Erosion; Prediction

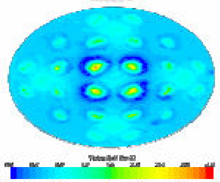


Velocity – flow passing through restriction (casing perforation), shroud and basepipe

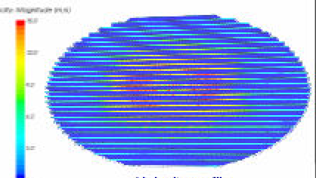


Erosion

Test piece

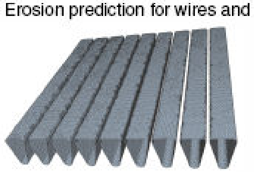


Velocity – flow passing through Maxflo® Shroud "image" can clearly be seen

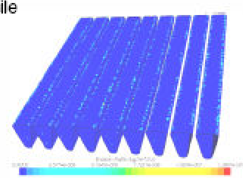


Velocity profile

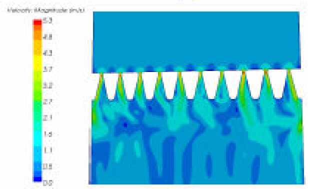
Erosion prediction for wires and velocity profile



CFD surface mesh for wires



Erosion rate prediction



Velocity profile

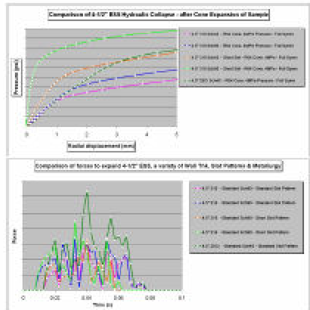
Finite Element Analysis (FEA)

Expandable Sand Screen (ESS®) Expansion; Forces to Expand and Hyd.Collapse

FEA gives a greater understanding of required expansion forces and deformation resistance (whether by hydraulic collapse or point loading) on a fully slotted *ESS* part.

Favourable comparisons between existing, empirical, results and new FEA analyses can be observed.

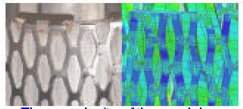
This has allowed for rapid testing of new *ESS* designs, saving considerable time and expense



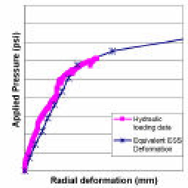
Graphs from rapid testing of new ESS designs

Short length of expanded ESS

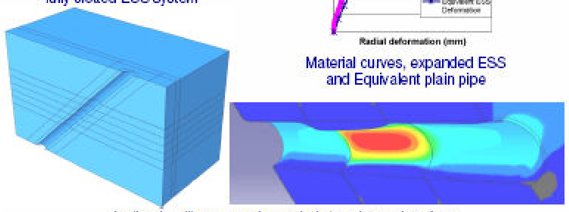
Well Application Screening Tool; Vertical / Horizontal / Inclined wellbore



The complexity of the mesh in a fully slotted *ESS* system



Material curves, expanded ESS and Equivalent plain pipe



Inclined wellbore crossing a shale/sandstone interface

For new *ESS* designs, fully slotted systems are analysed, but for rapid screening of well applications an equivalent pipe had to be developed. This non-slotted plain pipe was given the same material properties as the gross behaviour of a fully slotted and expanded system.

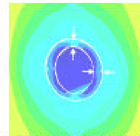
The number of elements in the equivalent *ESS* system reduced by an order of magnitude.

This now allowed for rapid analysis of vertical, horizontal and inclined wellbore systems. It also gave the chance to investigate, in an inclined wellbore, a shale/sandstone interface.

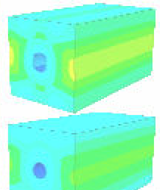
Underground Gas Storage (UGS); Cyclic Loading on a Rock Mass / *ESS* withstanding collapse forces

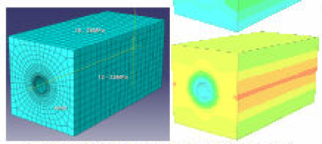
Using the equivalent plain pipe, FEA quickly provides answers to how *ESS* behaves under a cycling load, such as the situation for an injection/withdrawal scenario in a UGS. UGS can typically be salt caverns or depleted gas/oil reservoirs.

Varying reservoir material models can be applied, depending on data received. If the deformation of the *ESS* is within acceptable limits, for the given material, confidence can be assured for reliable sand control over the feasible life of the UGS well.

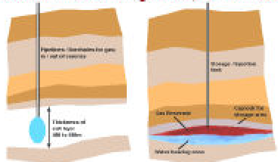


Wellbore deformation in an artificially weak material

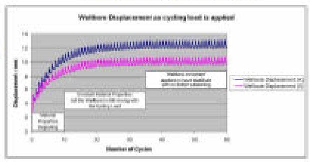




Model set-up for a horizontal wellbore and showing equivalent stresses



Two typical UGS scenarios



Wellbore displacement as cycling load is applied

Day-to-day analysis work – Abaqus/Explicit

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ENTERPRISE EXCELLENCE FORM

FORM NUMBER: EED-015	REV: 1	PAGE: 1 of 4	ORIGINAL ISSUE DATE: 09/JUN/2003	REVISION DATE: DD/MMM/YYYY
PREPARED BY: M. CLARK	REVIEWED BY: D. ROBERTS		APPROVED BY: D. GRANT	APPROVED BY:
TITLE:	ENGINEERING TEST REPORT			

Subject:	Localized loading and deformation of ESS - all current sizes		
Report No:	ESS/0000/002R	**Date:**	1st February 2010
Author:	Ken Watson	**Approved:**	Colin Jones / Mike Clark

Summary

This study examines the deformation of expanded ESS (constrained in casing) due to localized loading, specifically due to a 1" diameter piston moving in a radial manner to press in on the outer surface. All current sizes of ESS were investigated, as was the proposed, new, slotting pattern for the 4.5" ESS.

The FEA study was performed using Abaqus/Explicit. A short section containing one repeat of the slot pattern was performed. The casing sizes for each analysis were based upon information taken from the Expandable Completion Selection Guide.

The results were both as expected and as previously witnessed in empirical testing; the 7" proved the strongest (6,200psi, *thickest wall section*), followed by 4.5" ESS (3,100psi, *new slot pattern*), then 4.5" ESS (2,700 psi, *standard slot*), then 5.5" ESS (2,400psi), and finally the 4" ESS (2,200psi, *thinnest wall section*).

Background

This report is a follow on from the recent Subsurface Engineering Research Report; *SSE/ESS/003 - ESS Point Load Deformation*, which solely investigated the 5.5" ESS size. In that report, many different piston diameters were used (0.5" up to 3"). Essentially, a small piston size has a large pressure capability (10,000psi) but a large piston size has a very small pressure capability and in fact this low capability, for a large enough piston, can be extrapolated out to becoming equivalent to the hydraulic collapse figure of 123psi

This point loading set-up can be used as a rapid test to model the effects of plugging in ESS close to a casing perforation.

Analysis and Model set-up

The FEA study was designed to replicate the testing shown in Figure 1. Models were created for each current ESS size and slot pattern, with the proposed slot pattern for the 4.5" size also investigated (all dimensions are nominal). The lengths for the short sections of ESS were;

152.4mm length for 110.6mm slots (standard 4" / 4.5" / 5.5")
115mm length for 85mm slots (standard 7")
120.08mm length for 87.5mm slots (proposed 4.5")

The wall thickness for each ESS size are;

4" = 5.74mm / 4.5" = 6mm / 5.5" = 6.55mm / 7" = 10.35mm

The casing sizes were all based on the Expandable Completion Selection Guide which is stored on "The Exchange" (Intranet). For the 4.5" ESS, two casing sizes were considered, to check if expanded diameter has an affect on collapse. The casing inner diameters were;

6" diameter for 4" ESS (standard slots)
6" and 6.5" diameters for 4.5" ESS (standard slots)
6" diameter for 4.5" ESS (proposed slots)
8.5" diameter for 5.5" ESS (standard slots)
8.5" diameter for 7" ESS (standard slots)

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The material data (ESS basepipe is 316 Stainless Steel) was as per previous analysis jobs, with minimum yield figures.

As a matter of course, there would normally be four elements through the wall thickness. For the new analysis runs, six elements were used and, further to that, the mesh seeding was fixed at a far finer setting (3 / 0.1 as opposed to ≈5 / 0.1). In this instance, the mesh could be made particularly fine as there was no time constraint. This resulted in models, Figure 4, with a mesh quantity ranging from 30,000 to 44,000. A coarse mesh could be stiffer in nature, whereas a finer mesh should be more flexible, thereby providing results with greater accuracy. A typical model would normally have had 10,000 to 15,000 mesh elements. The jobs took approximately 24 hours each on a powerful quad core computer. For the coarser mesh setting, the jobs would have taken approximately 8 hours.

A further consideration is the fact that an ECL system (slotted basepipe) was modeled, rather than a full ESS system, which would have been complete with perforated shroud. Although the 1.5mm thick shroud adds to strength in a hydraulic collapse scenario, it has been demonstrated previously that in a point loading simulation (which these are), the shroud adds no strength, it would have simply added more complexity to the model, thereby increasing job run times. Each slotted basepipe sample was hydraulically expanded out to the inner surface of the casing. This method, rather than swaging, also helps reduce the analysis time. Each sample was oriented such that the piston would strike the centre of one node.

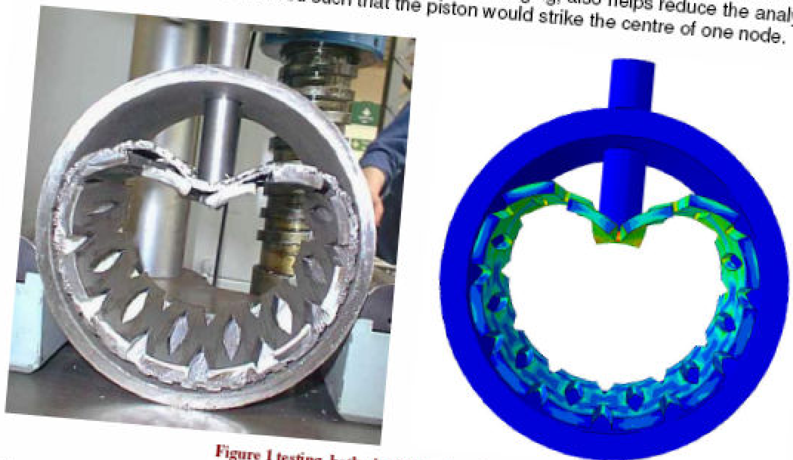

Figure 1 testing, both physical and modeled (typical)

The force applied to displace each size of ESS is shown in Figure 2 and the pressures are shown in Figure 3. Within the two standard 4.5" ESS simulations (at different casing sizes), there was a slight variation in the results, but the peak values are very similar.

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Day-to-day analysis work – Abaqus/Explicit

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ENTERPRISE EXCELLENCE FORM

FORM NUMBER: EED-049	REV: 0	PAGE: 1 of 5	ORIGINAL ISSUE DATE: 02/OCT/2009	REVISION DATE: DD/MMM/YYYY
PREPARED BY: J. Paw	REVIEWED BY: G. Rowans		APPROVED BY: G. Watson	APPROVED BY:
TITLE:	SUBSURFACE ENGINEERING RESEARCH REPORT			

Subject:	Localized loading and deformation of ESS		
Report No.:	SSE/ESS/003	**Date:**	16 December 2009
Author:	K. Watson, C. Jones	**Approved:**	M. Geddess

Summary

This study examines the feasibility of localized hydraulic load causing extensive deformation of the ESS. The study was stimulated by observations of restrictions in cased hole water injectors opposite the perforations. The FEA study was performed using ABAQUS. A short section containing one repeat of the slot pattern of 5 ½" ESS was deformed using various diameter pistons, while confined in a 9 5/8" casing. The results showed that as the loading diameter increased the required loading pressure decreased and would probably attain the hydraulic collapse pressure of 123psi around 5" loading diameter.

This confirms it is feasible to generate sufficient pressure to collapse the ESS in cased hole as long as the loading diameter is around 5".

Background

Restrictions have been noted in two cased hole water injectors fitted with ESS for sand control. The collapses were noted after a relatively long period of injection. The injectivity of the wells had been declining. The injection was into multiple zones and there were numerous shutdowns.

At first it was thought that thermal cycling and buckling was a potential cause of the restriction. However a detailed analysis found this to be unlikely.

A mechanism which may be feasible is loading of the ESS by fluid exiting the perforation tunnels during shut-in and possible cross-flow. The ESS has a high open area and the pressure drop across it is very small unless it is substantially plugged or acted upon by a piston force. In cased hole environments this piston force could also arise from the pressure drop generated across sand fill accumulating inside the perforation tunnels over time following geomechanical failure. Samsuri et al[1] show that this pressure drop is quantified by Forchheimer's equation outside of the casing and Saucier's equation inside the casing.

Any mixing of formation sand in the perforation tunnels with clays, material from the crushed zone, perforation gun debris, or injected solids, can result in a pack permeability substantially lower than the formation matrix, resulting in substantial pressure drops through the pack acting on the ESS. It is also possible to envisage the gradual accumulation of solids in the perforation tunnels from the injection fluid, obviously subject to injection water quality.

When injection stopped, cross-flow or transients may cause any loose solids to flood out quickly, plugging the weave. Alternatively, sand fill in any failed perforation tunnels could exert localized piston load on the ESS due to high pressure drop through the pack. In both scenarios, sufficient force could conceivably be generated to deform the ESS basepipe, allowing solids to migrate into the casing-screen annulus. When injection recommences the solids would be cleaned off the weave opposite the perforation tunnel and injection would proceed as before.

The ESS should spring back elastically, potentially leaving some plastic deformation. However, any solids that have accumulated in the casing-screen annulus would stop it springing back completely. This process would be repeated during each shutin and the ESS would be slowly ratcheted into the center of the well.

[1] Samsuri, A., Sim, S.H., Tan, C.H.: "An Integrated Sand Control method Evaluation" SPE 80444 presented at APOGC, Jakarta, Indonesia, 15-17 April 2003

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ENTERPRISE EXCELLENCE FORM

FORM NUMBER: EED-049	REV: 0	PAGE: 5 of 5	ORIGINAL ISSUE DATE: 02/OCT/2009	REVISION DATE: DD/MMM/YYYY
TITLE:	SUBSURFACE ENGINEERING RESEARCH REPORT			

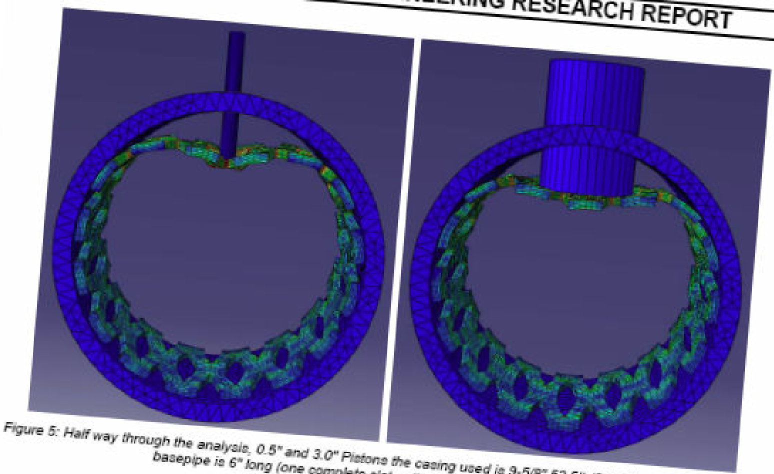

Figure 5: Half way through the analysis, 0.5" and 3.0" Pistons the casing used is 9-5/8" 53.5# (8.535" ID), the 5.5" slotted basepipe is 6" long (one complete slot pattern) after 50mm displacement

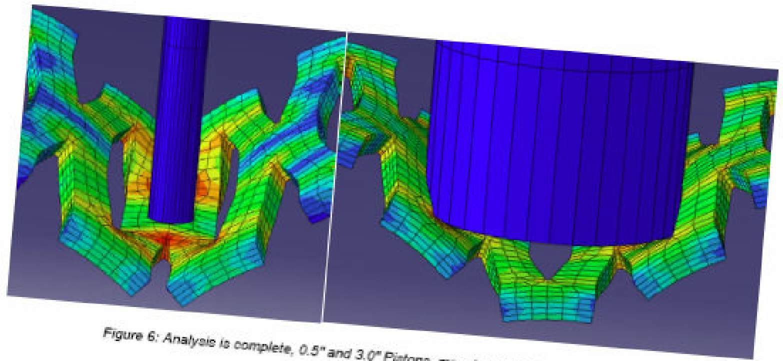

Figure 6: Analysis is complete, 0.5" and 3.0" Pistons, max. travel, 100mm displacement

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Day-to-day analysis work – Abaqus/Explicit

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FORM NUMBER: EED-015	REV: 1	PAGE: 1 of 4	ORIGINAL ISSUE DATE: 09/JUN/2003	REVISION DATE: DD/MMM/YYYY
PREPARED BY: M. Clark	REVIEWED BY: D. Roberts		APPROVED BY: D. Grant	APPROVED BY:
TITLE:	ENGINEERING TEST REPORT			

Subject:	Collapse of unexpanded ESS (4" / 4.5" / 5.5" / 7")		
Report No:	ESS/0000/001R	**Date:**	4th December 2009
Author:	Ken Watson	**Approved:**	Mike Clark

Summary

The objective of this report is to establish, using Finite Element Analysis (FEA), the collapse values for unexpanded Expandable Sand Screens (ESS). The four common sizes of 4", 4.5", 5.5" (slots are 110.6mm long x 1.2mm wide) and 7" (slots are 85mm long x 1.2mm wide) are all examined.

Based on the four FEA simulations, the unexpanded ESS can withstand a reasonable external pressure application (Fig.1) and this is due to the slots closing up shortly after the pressure applications commences. The pipe then behaves in a similar manner to a solid tubular as the pressure rises until, ultimately, there is buckling

	Collapse Values		
	Solid Tubular Calculator (Lame's)	Slotted Basepipe (FEA)	
	MPa / psi	Initial Yield MPa / psi	Ultimate Yield MPa / psi
7.0"	22.68 / 3290	13.0 / 1885	16.5 / 2393
4.0"	22.05 / 3198	12.5 / 1813	16.0 / 2320
4.5"	20.56 / 2982	11.5 / 1668	14.3 / 2074
5.5"	18.30 / 2654	9.6 / 1392	12.5 / 1813

Figure 1. Collapse Values for four sizes of ESS (for info. - Lame's for solid tubulars is also shown)

Compared to the Lame's Stress Collapse Value for solid tubulars, the Initial Yield of the slotted pipe is approximately 55% and the Ultimate Yield is approximately 70%.

Background

For ease of computational time, six inch long samples for 4", 4.5" and 5.5" ESS were used (one complete slot in the centre, axially) and a nine inch long sample of 7" ESS was used (two complete slots in the centre, axially). The perforated shroud [1] and weave were ignored for these simulations, it was purely the basepipe that was studied. The 3D model was created to nominal sizes, with no imperfections and the material data used was as per other FEA analysis runs, stainless steel 316L, with the minimum yield of 30ksi.

[1] In reality, the perforated shroud would have a reasonable contribution to the overall strength of an ESS test piece, in a purely hydraulic collapse scenario, but adding this to the model would have considerably increased the computational time of the analysis runs.

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Observations and Analysis - continued

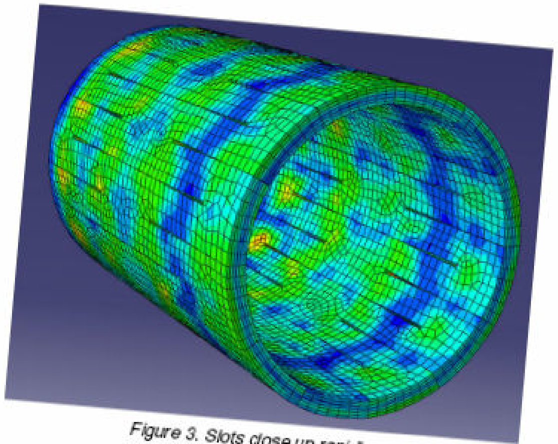


Figure 3. Slots close up rapidly

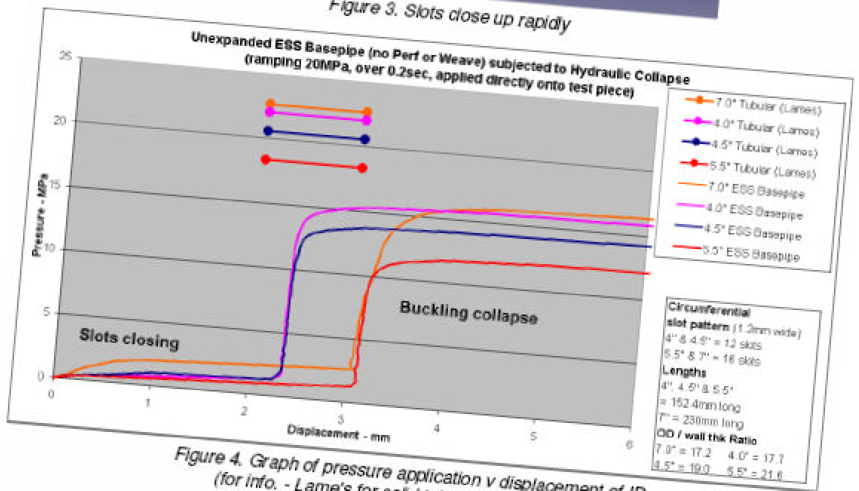
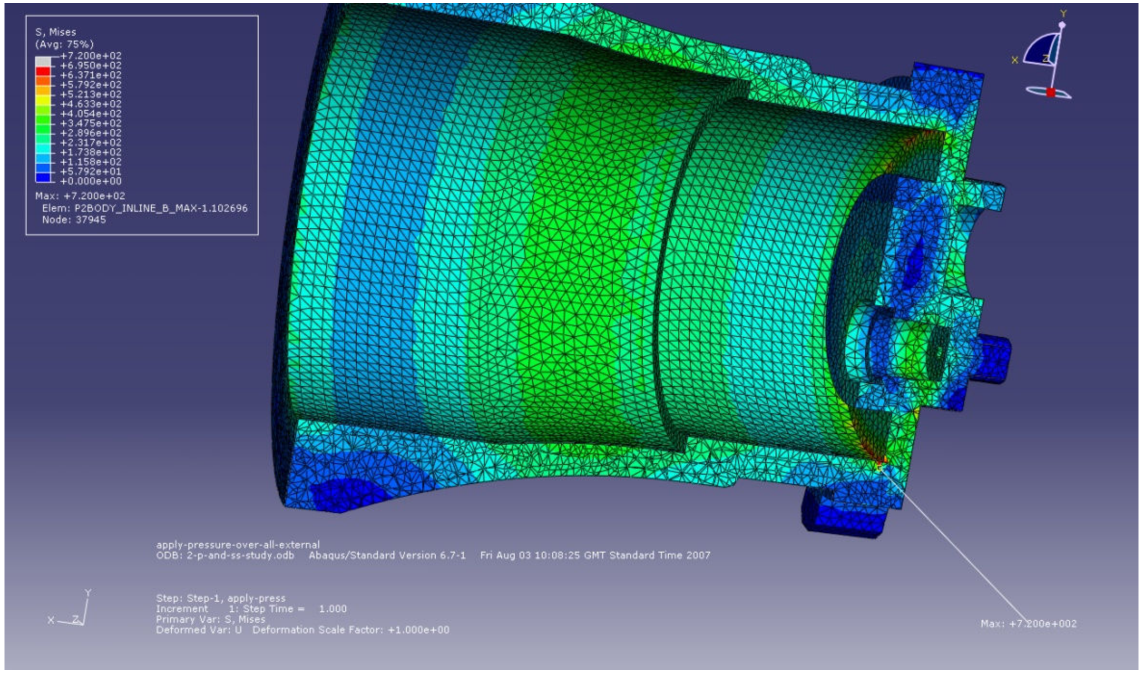
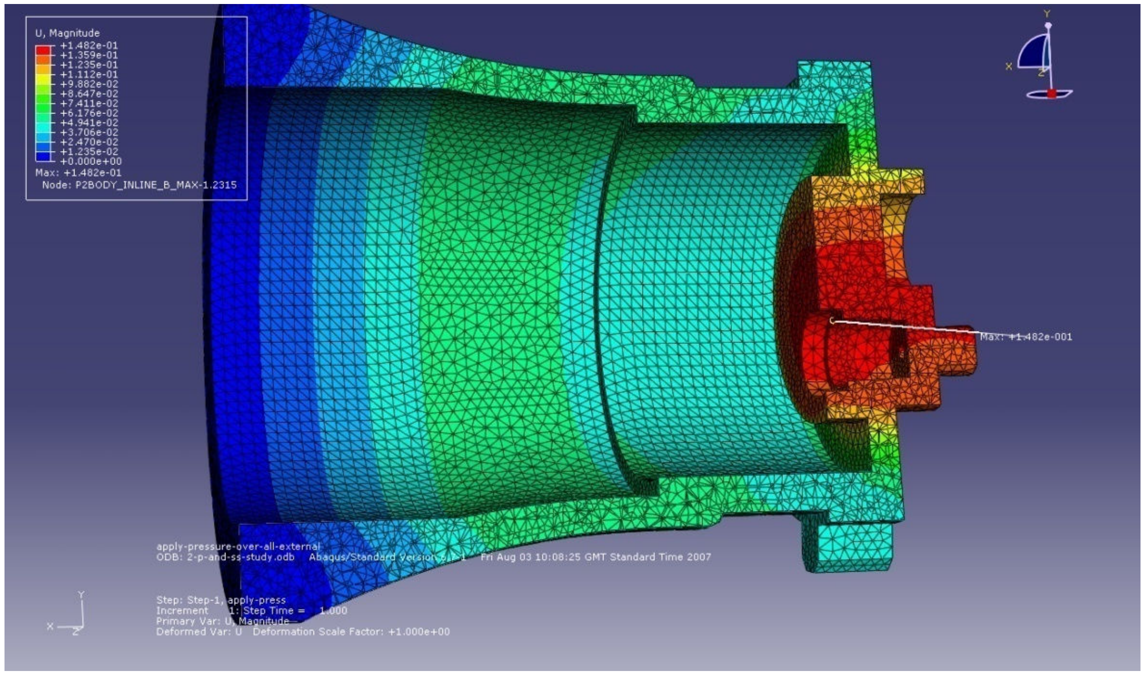


Figure 4. Graph of pressure application v displacement of ID (for info. - Lame's for solid tubulars is also shown)

P&SS had a Pressure Vessel (part of a Pipeline Inspection Pig) containing electronics. They needed to check that the end plate was thick enough (pressure rating).

Abaqus showed that there was a problem, but a small design change would solve it.





Simple day-to-day analysis work - Abaqus/Standard

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ENGINEERING / TEST REPORT			
Subject: FEA on 4.0" 9.5# and 5.5" 20# Well Screen Tubulars with perforations	Report No.: GEN-5500-002R Rev 1, 1st Sep 08	Date: 21st Aug 08	
Author: Ken Watson	Approved: Dave S. Grant		

Summary

The objective of the analysis is to establish, using Finite Element Analysis (FEA), safe working values for collapse and tensile rating of non-standard screen basepipe design for BPTT. Two sizes of L80 13Cr Well Screen Tubulars were included in the analysis representing;

- 4.0" 9.5# with 8 x12mm diameter perforations at a 25mm axial offset pitch
- 5.5" 20# with 9 x 12mm diameter perforation at 25mm axial offset pitch

The perforation size and spacing provide an approximate inflow area of 10% in both cases.

The FEA simulations provide figures based on nominal pipe dimensions and minimum yield. From analysis of the FEA simulation, several key points in the yield of the pipe can be observed. This starts from the very first location of exceeding pipe yield to complete yield through pipe wall forming a continuous path of yield around the circumference. It is towards the latter defined stage that complete pipe collapse would likely occur. The collapse figures quoted in this report are therefore a range between which full plastic deformation of the pipe could be expected.

A safety factor of 0.875 has also been applied to account for any variations in wall thickness and ovality. Figures for collapse and tensile can therefore be quoted as:

4" 9.5# Basepipe c/w perforations

(1) 4.0" 9.5# Tensile value - **127,674 lbf**
(2) 4.0" 9.5# Collapse range - **4,695 psi – 5,583 psi**

5 ½" 20# Basepipe c/w perforations

(3) 5.5" 20# Tensile value - **300,476 lbf**
(4) 5.5" 20# Collapse value - **5,456 psi – 6,598 psi**

Background

BPTT have requested Well Screens with an increased basepipe perforation pattern which increases the open area from 5% to 10%. This increase in open area results in decreases in both the Collapse and Tensile ratings of the Screens.

Some of the variables that have been investigated for Conventional Well Screens (perforated Basepipe);

Tensile and Compression, Burst and Collapse and Torque

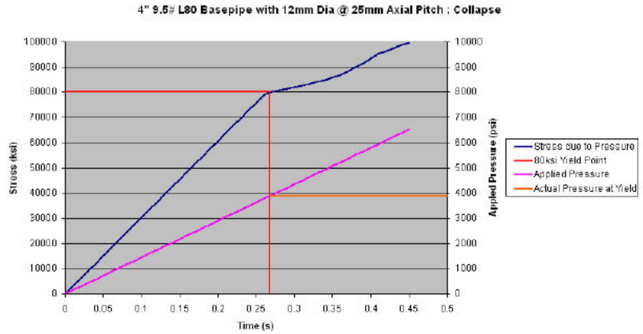

Figure 5

Collapse Stages of 5 1/2" 20# Perforated Basepipe

The following figures are taken from various stages of the FEA analysis conducted on the 5 1/2" 20# perforated basepipe. The analysis was conducted on basepipe with an 9 off 12mm dia perforations per plane at a 25mm axial offset pitch.

Each figure is a section taken through the pipe so as the inner bore can be seen.

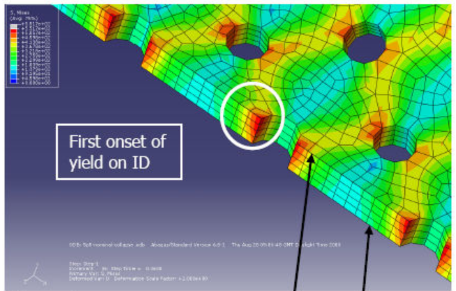

Figure 6

ID of BasePipe

OD of BasePipe

Figure 6 identifies the point during the analysis at which the yield point (80 ksi) is exceeded for the first time. This occurs on the ID of the base pipe at the inner edge of a perforation.

This occurs at a pressure of 5,250psi

It should be noted that this is the first breech of yield and is localised at one perforation so actual collapse of the point would not occur.

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ENGINEERING TEST REPORT

Subject:	Collapse Ratings for 6.625" 24# Tubular; a variety of perforation patterns
Report No:	**Date:** 7 October 2010
Author: K. Watson	**Approved:**

Summary

This report examines the collapse rating of a 120 holes per foot conventional well screen product and then double the number of perforations to 240 holes per foot (for higher flow). This further examination has been made as it was highlighted that the **"Perforated Tubulars Mechanical Properties"** calculator spreadsheet makes no allowance for the changing number of perforations per cross-section; the collapse pressure rating result remains constant, no matter the quantity of holes around the circumference, which appears counter-intuitive. Specifically, the original request stated that the overall screen (6-5/8" UGHD) rating would be 3,960psi, so would the proposed new 240 holes per foot version of the screen be approaching this collapse rating? It was already known that 120 holes per foot version was satisfactory.

The FEA results show that the calculator spreadsheet is reasonably close, especially for the lower and more "common" holes per foot count, but the calculator diverges as the hole count increases. In this new set of analyses, the 120 h/ft rating was 32.1MPa (4,656psi) and the 240 h/ft rating was 29.2MPa (4,235psi). The calculator states the collapse rating is 32.4MPa (4,695psi) no matter the hole per foot count.
The results have also shown that the deflection, or displacement, of the basepipe increases with the number of holes, as expected, but it is a relatively small increase, so may not be a problem.
The 120 h/ft radial deflection was 0.1394mm [0.0055"] and the 240 h/ft radial deflection was 0.147mm [0.0058"].

Background

One of the common FEA requests from Conventional Well Screens group is for Burst and Collapse for their perforated basepipes. These perforated basepipes are the main structural element for the Conventional Sand Screen product, where there would be a set of wires arranged around the outer surface of the basepipe and these act as the sand screen/filter.
Other requirements can be for Axial Tension and Compression and, more infrequently, Torque.
The Conventional Sand Screen product can be bespoke, different customers may ask for different open-areas for the screen and this will lead to different hole counts and patterns on the basepipe.
There are three general patterns used for the perforations; Linear, Hatch and Spiral.
Linear is where each bank of holes around the circumference are aligned with each other.
Hatch is where every second bank of holes is offset from the preceding set by half the angle between the holes.
Spiral is where each hole has an axial distance and an angle difference from the preceding hole.
Generally Hatch is the most common pattern as there can be a greater open area supplied without too great a degradation of Burst, Collapse, Tensile and Compression.

A commonly used calculator spreadsheet is available:
"Perforated Tubulars Mechanical Properties" and this is used for establishing most outputs for a perforated tubular; Burst, Collapse and Tensile. The inputs for this spreadsheet include,
O.D., Wall thickness, Minimum Yield Stress, Hole Size, Perf. per cross-section and Axial Perf. Pitch

A further commonly used calculator spreadsheet is:
"Burst and Collapse with Axial Loading". This spreadsheet deals with a non-perforated tubular and is a good starting point for establishing loading within Abaqus. Inputs here include,
O.D., I.D., Yield Strength, Modulus of Elasticity and Poisson's Ratio.

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Analysis (cont'd)

Figures 1 to 3 show the typical graphical output for three of the analyses; the plain tubular, the 120 holes per foot and the 240 holes per foot variations.
Figures 4 to 6 show how the raw output data from Abaqus/Standard is used. Specifically a point is monitored for Stress and a graph is produced. A further trace is generated that shows the ramping collapse load. The period of time where Stress breaches Yield (551.7MPa / 80,000psi) is used to ascertain what the pressure application is at that precise time; this therefore gives the collapse rating (with no safety factor).
Note, Fig's 5 and 6 have not had their collapse ratings normalized to account for surface area.
The period of time has a secondary use; a further Abaqus output is used for radial displacement/deflection. It can now be shown what the deflection is for the basepipe at the time of yield.

6.625" 24# Tubular - undergoing an FEA collapse simulation

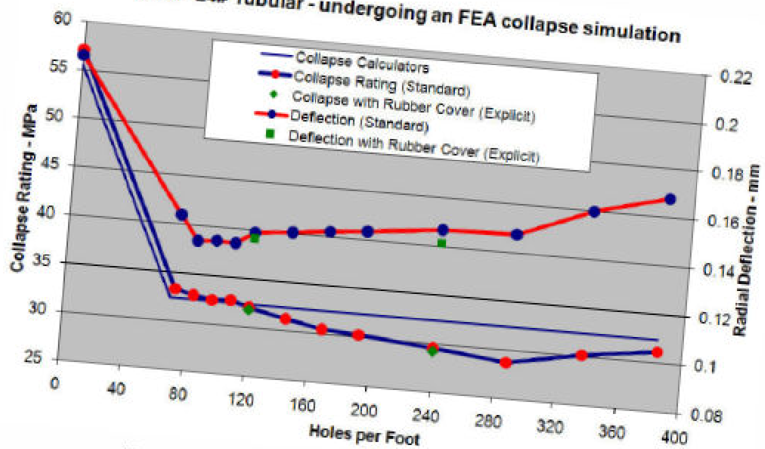
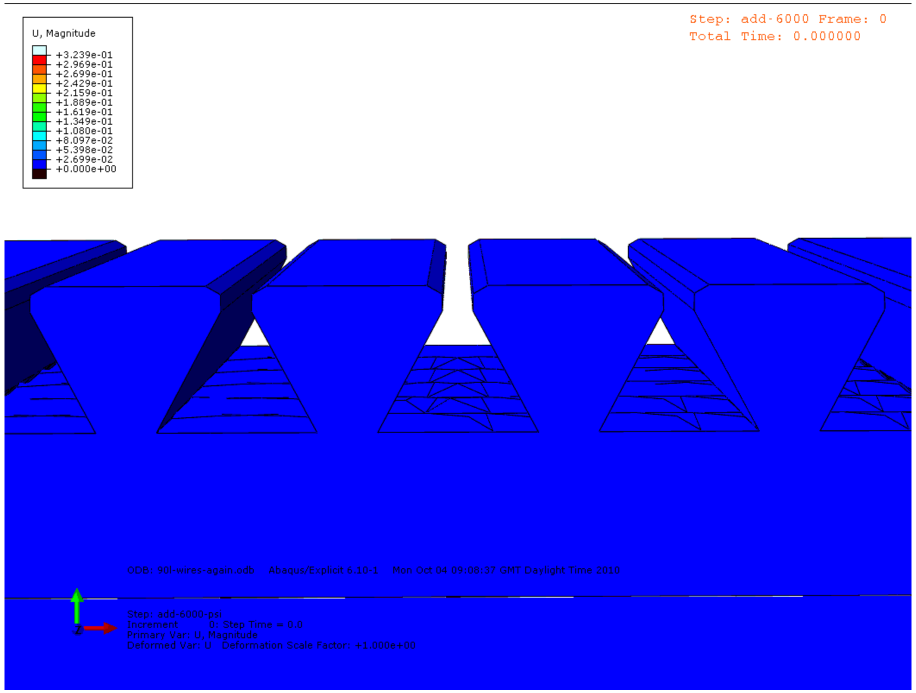


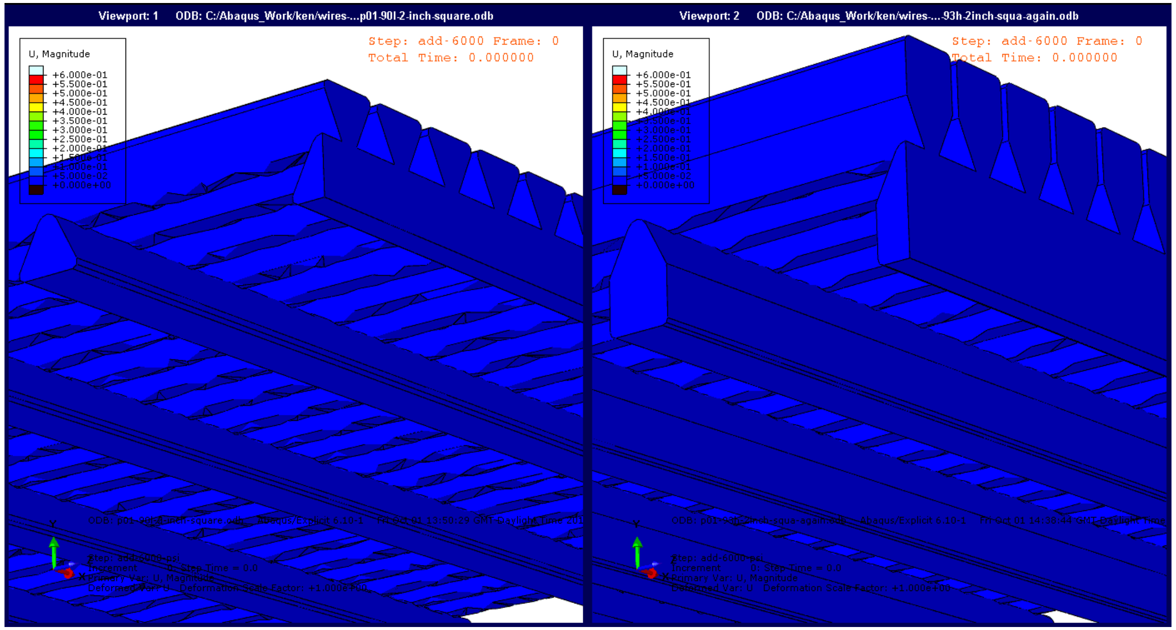
Fig. 7; the consolidation of all the collapse ratings and radial deflections

Figure 7 shows all the analysis outputs consolidated into one graph. The collapse ratings (Standard) have now been normalized to account for the difference in surface area (perforated pipe to plain tubular).
It can be seen that the collapse rating does decrease as the hole count increases, and it can also be seen that for a very high (unrealistic value) hole count the rating shows an improbable increase. This behaviour will be due to the fact there is very little material between the holes (on each circumferential bank of holes) and the distinct rings of material, between each bank of holes is increasingly supporting all the stress, in fact becoming more like a plain tubular, albeit a very short length. The banks of perforations are de-coupled from the areas carrying the pressure loading.
Also shown are the results from the Abaqus/Explicit analyses for 120 and 240 holes per foot. As discussed, this is where the pressure is applied to a rubber "sock" as opposed to directly onto the perforated basepipe, so these values are directly from Abaqus (with no factoring). The "Explicit" collapse ratings are almost identical to that for the normalized "Standard" collapse rating. The "Explicit" deflection for 240 holed per foot is slightly different, but still within 0.01mm of the "Standard" result

CWS – Wires and Rods analysis work - Abaqus/Explicit

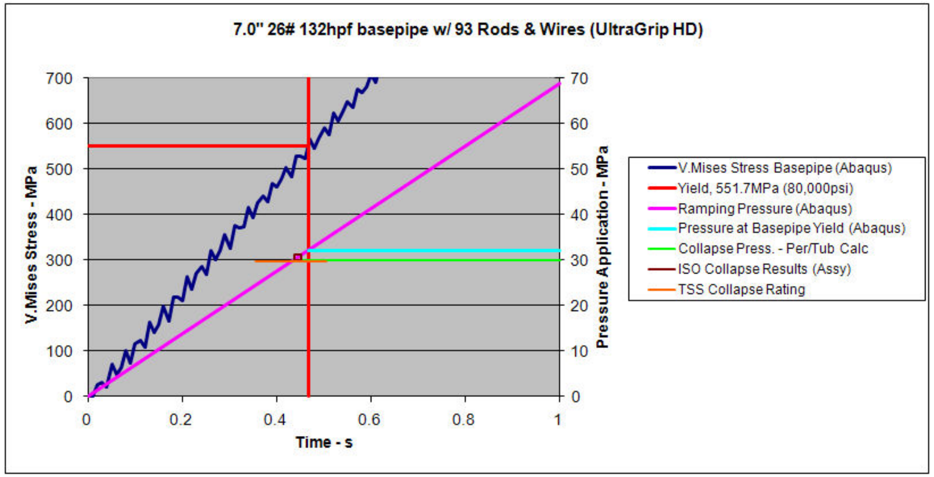


Some extra work that has been touched upon; how the wires and rods react as an external pressure is applied – and the effect of laying the rod over a perforation in the basepipe.

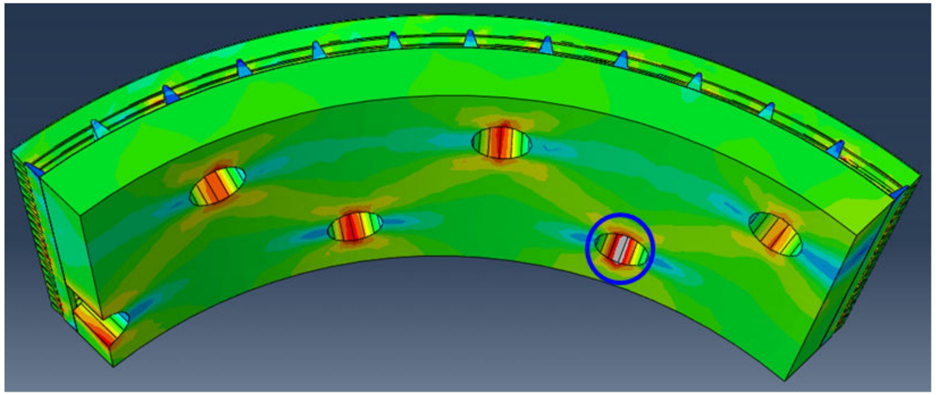


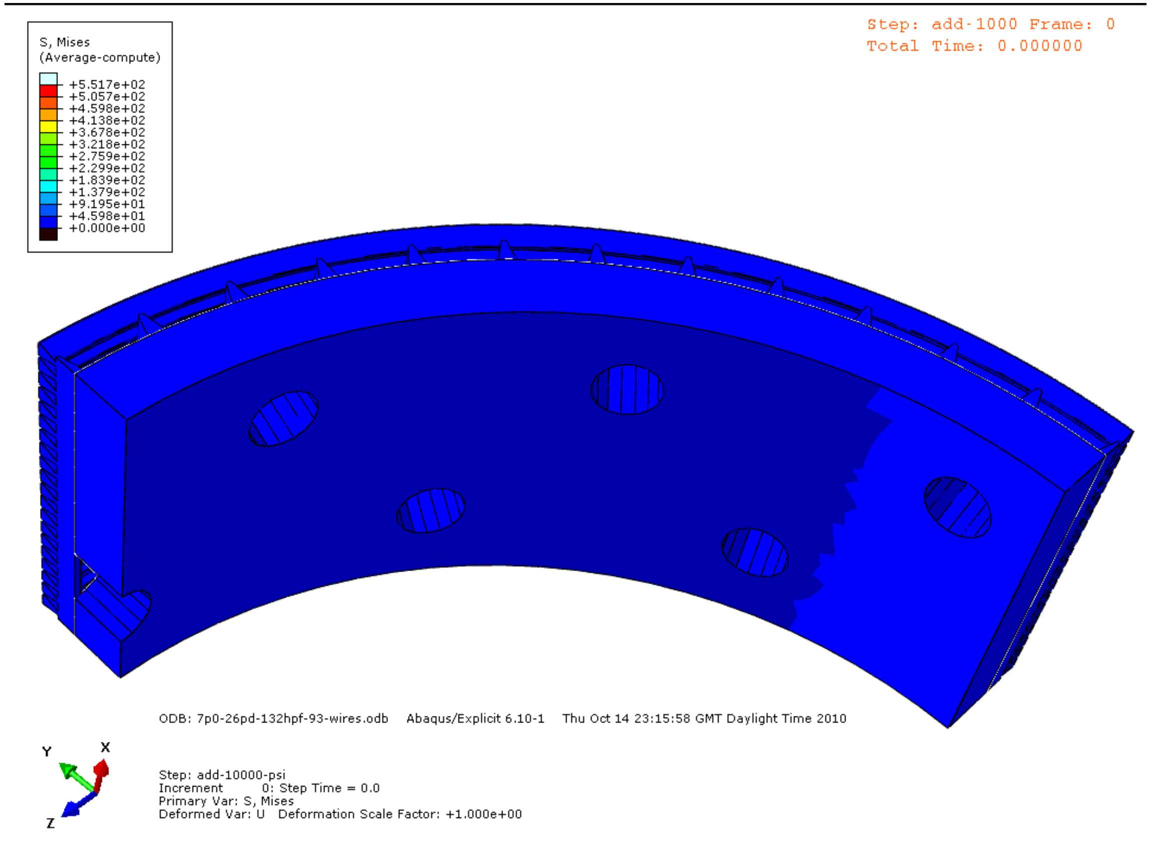
More work needs to be done, using actual metallurgy properties – but first impressions show that having rods passing over perforations is a bad thing; the rod can “fall” into the perforation and this in turn can open up the gap between the wires.

CWS – Wires and Rods analysis work - Abaqus/Explicit



This version was done as quarter-symmetry, rather than flat, coupon, format





Monitor the point that goes through yield first. The applied pressure at that time is the rating.

Compare this value to the Calculator, ISO Collapse Results and the Joint TSS.

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ENGINEERING / TEST REPORT

Subject:	FEA on CRQ Lock Mandrel Main Body (TSR 08-03/008)	Report No.:	GEN-3500-001-R	Date:	1st Apr'08
Author:	Ken Watson	Approved:	Abdur R. Masood		

Summary

The objective of this report is to establish, using Finite Element Analysis (FEA), the effect of Pressure Loading (12,000psi / 82MPa) on the Lock-Out Key Windows and the No-Go Key Windows.

Based on these FEA simulations, the Compressive loading scenario is well within the yield of the material (SS304, 95ksi / 655MPa); a max value of 198 MPa was observed. As was expected, the Tensile loading scenario developed a higher max value; 466 MPa, but again, this is within yield of the given material.

Background

For ease of computational time (and as per the model/set-up supplied previously), the CRQ Lock Mandrel Main Body (Fig.1) was quartered (Fig.2). The loading and constraints (Figs 3 & 4) were also set-up as per previously supplied. Both simulation runs were done within Abaqus/Standard and they took less than a minute to complete.

Figure 1. CRQ Lock Mandrel Main Body - 01192061 (within Pro-E)

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Results and Conclusions (Cont'd)

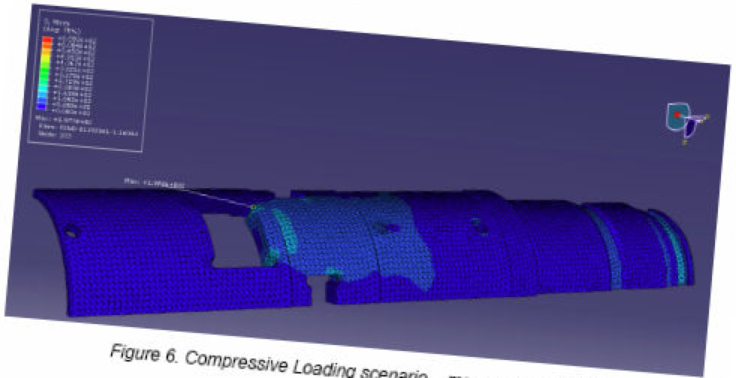


Figure 6. Compressive Loading scenario – max value = 198MPa

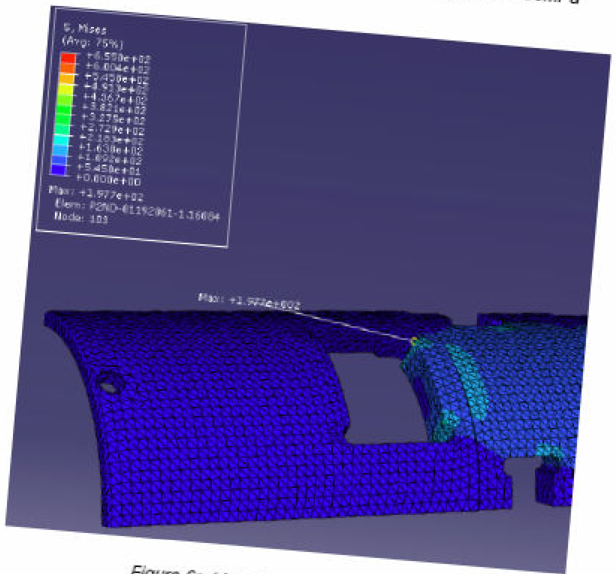
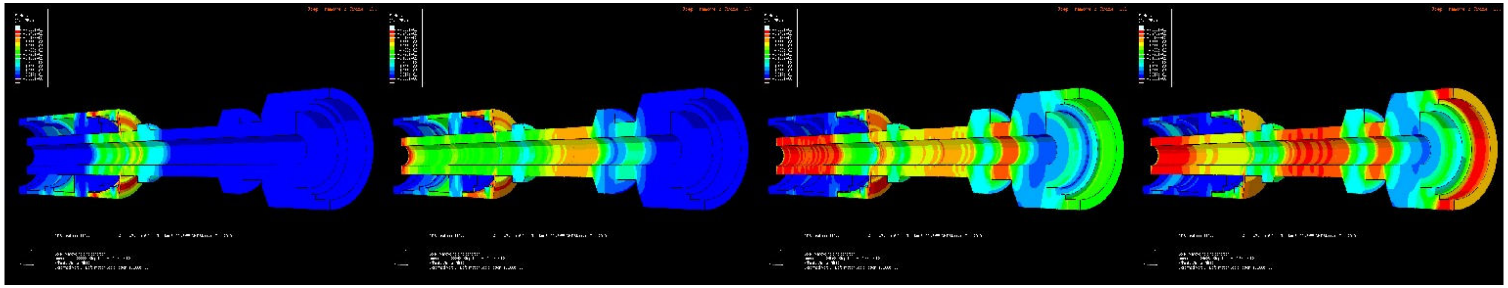


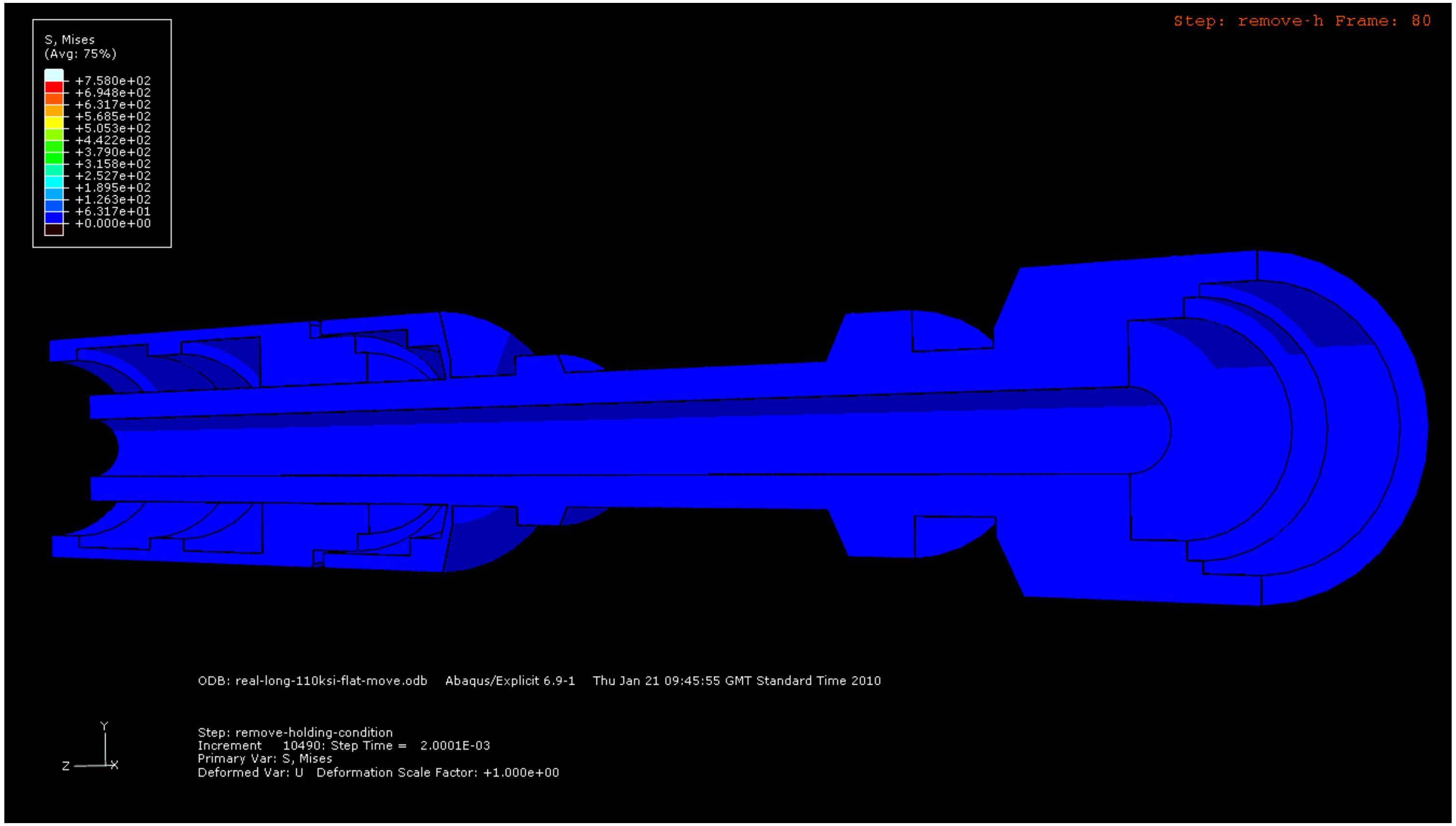
Figure 6a (detail). Max value location

Investigations for Tooling Issues - Abaqus/Explicit

Weatherford gets an **insight** into problems by using **Abaqus/Explicit**

Case Study – tool shearing too early

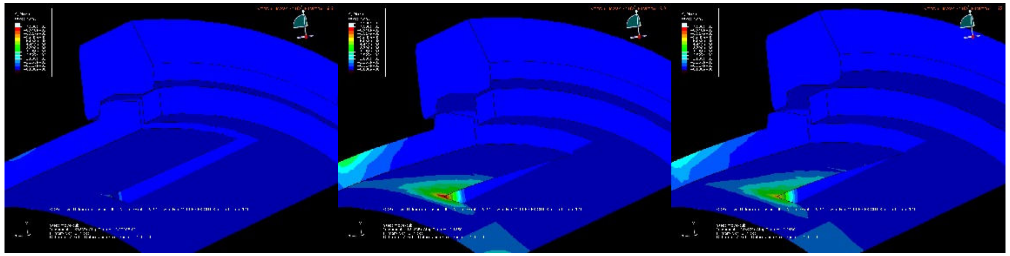


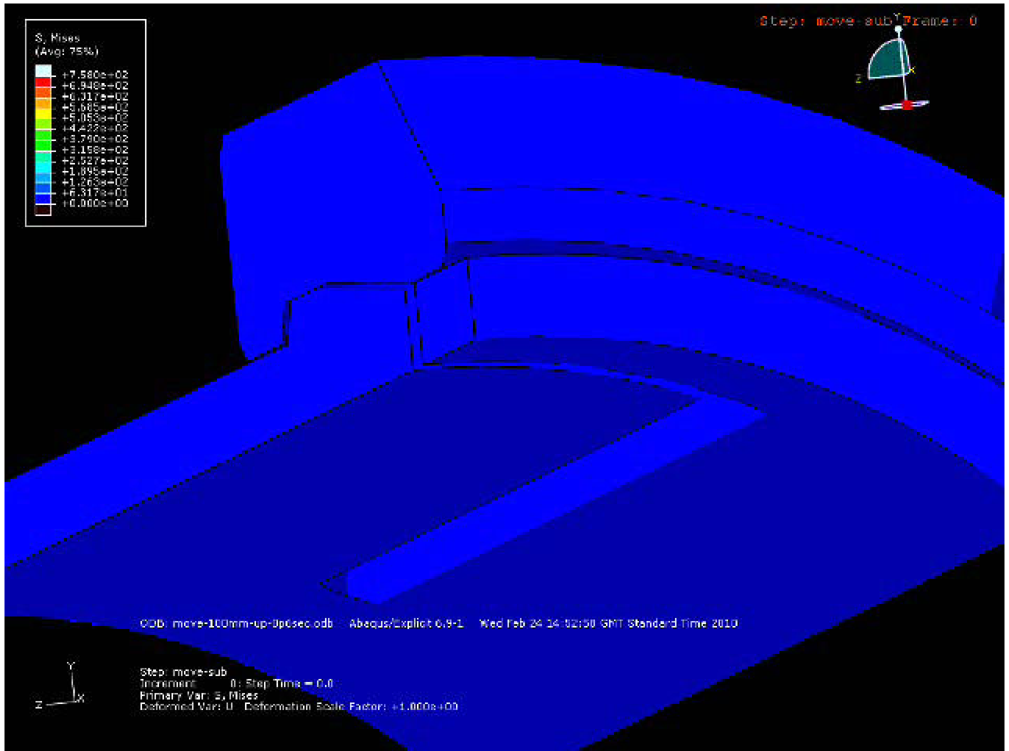


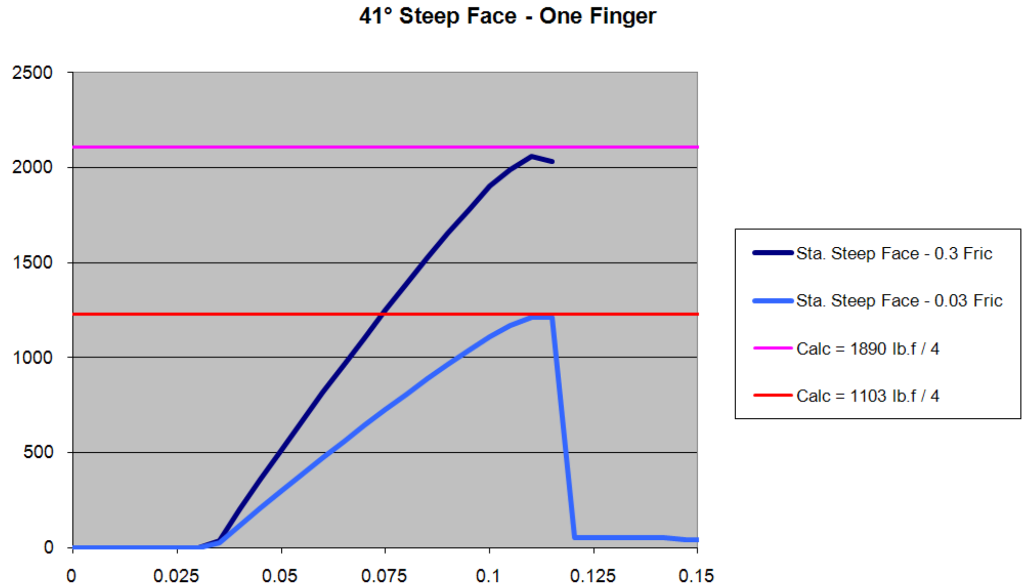
Investigations for Tooling Issues - Abaqus/Standard

Case Study – a new feature in a tool

Investigating required forces to overcome Collett Finger profiles, both directions



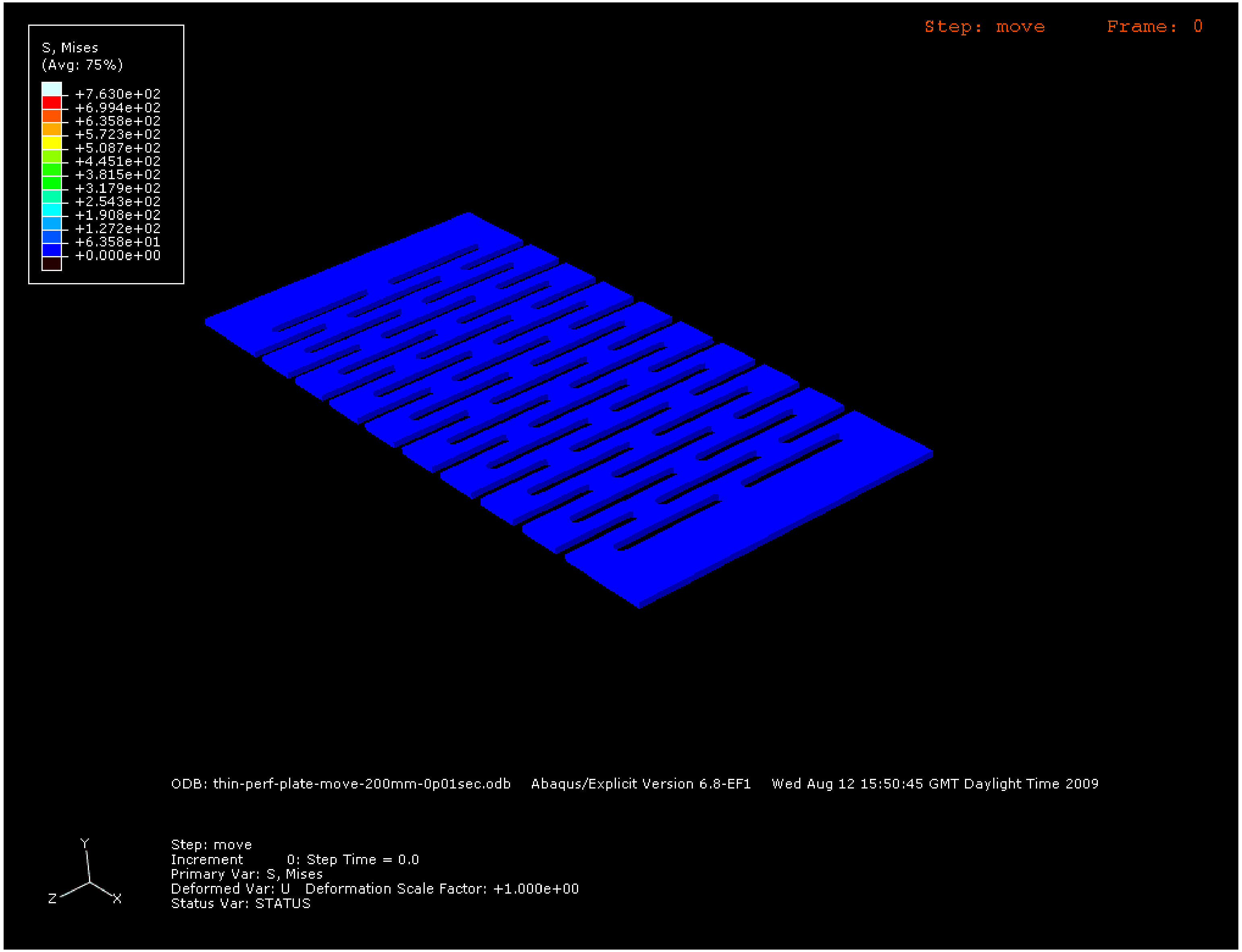


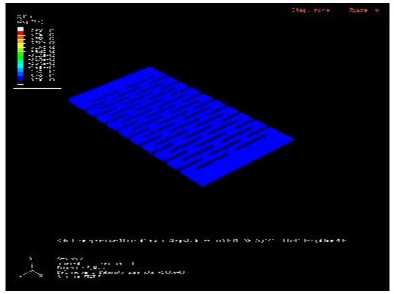


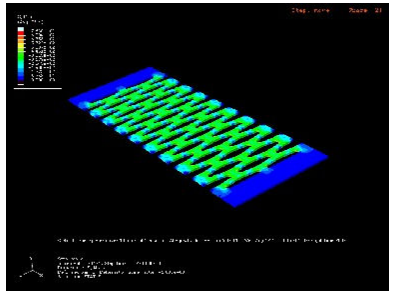
Different contact friction values can be investigated rapidly – and in this case the outputs were very similar to the calculated values

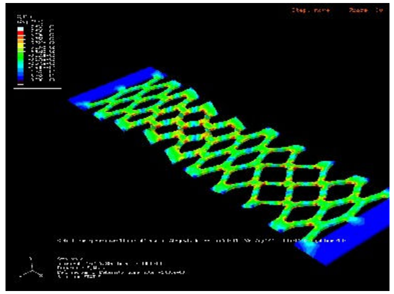
Weatherford can quickly get **design improvements** by using **Abaqus/Explicit**

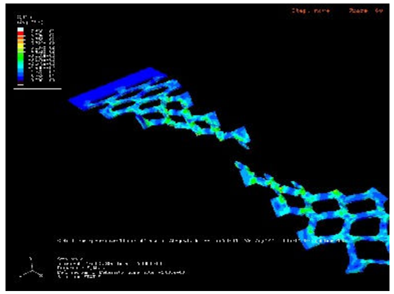
Trying out new functions; element deletion - Abaqus/Explicit



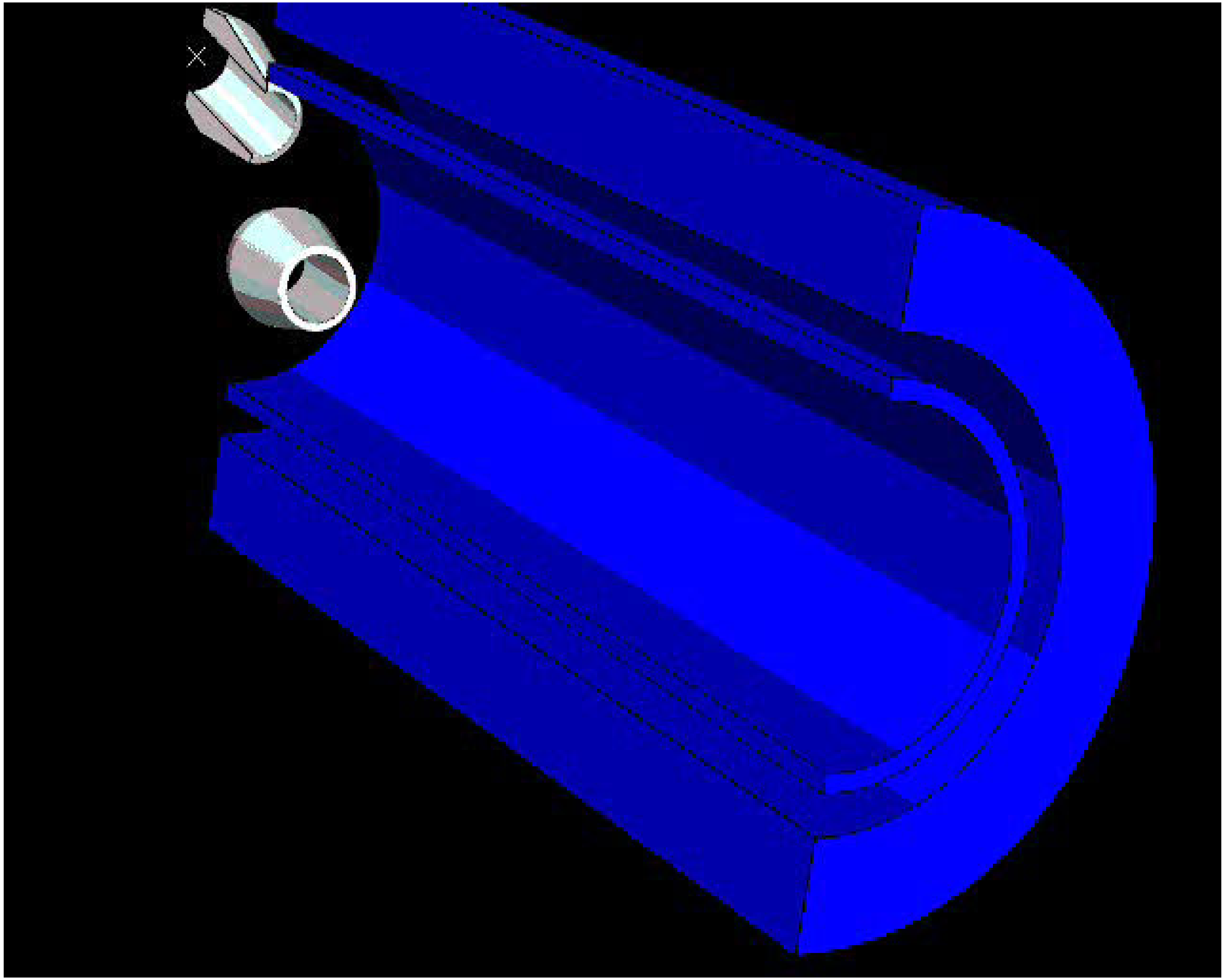


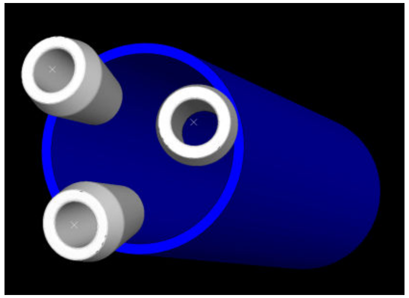


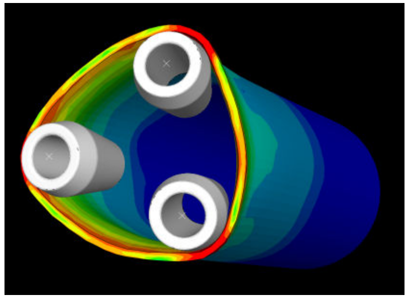


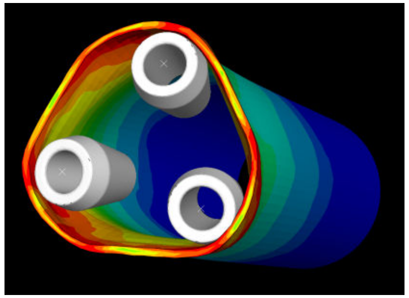


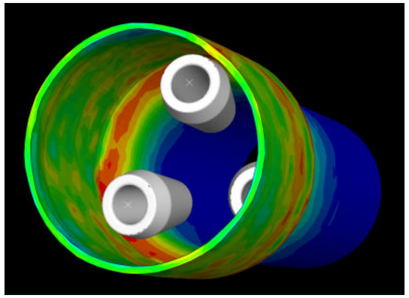
Solid tubular analysis - Abaqus/Explicit



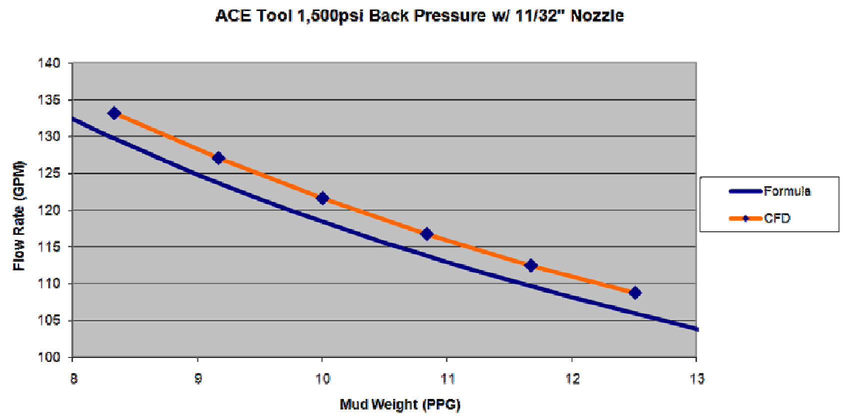


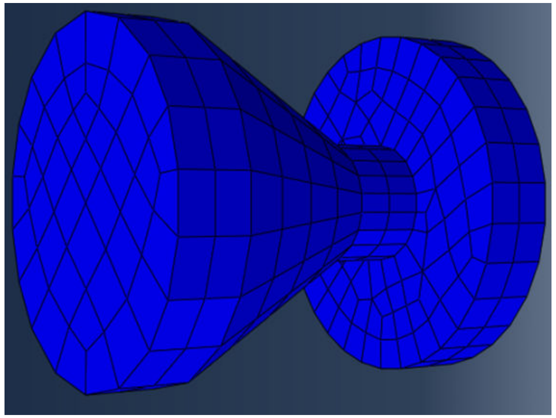






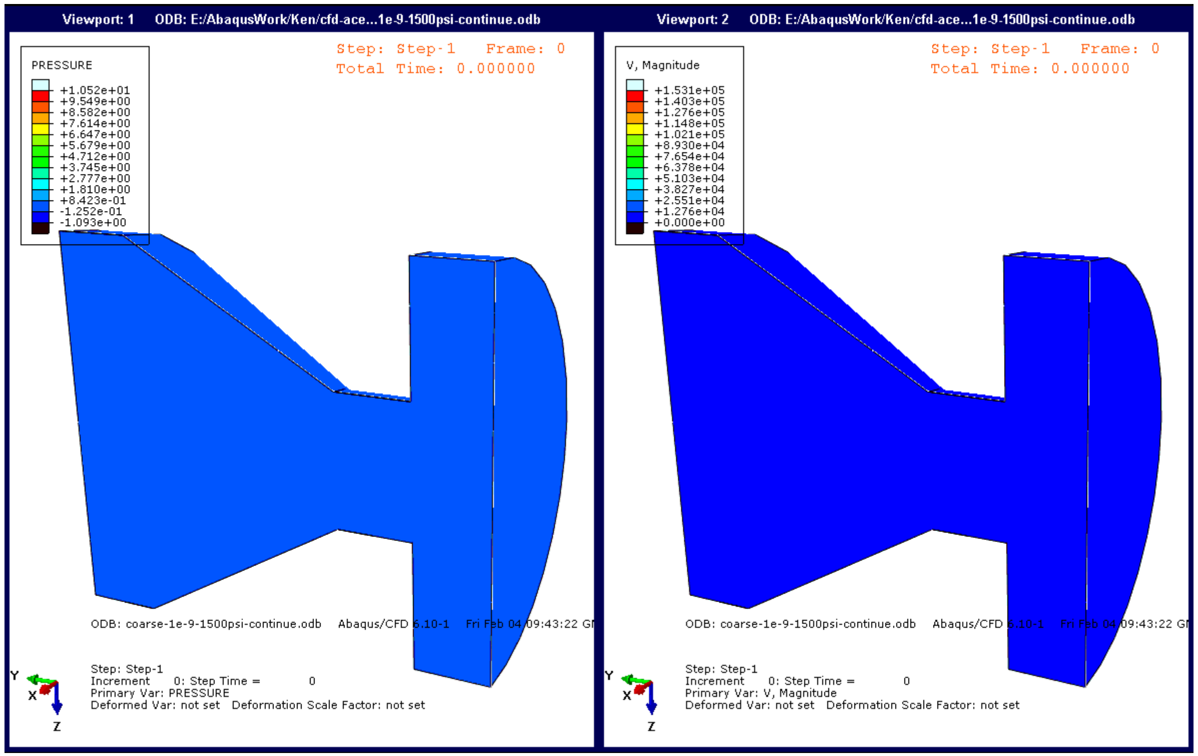
Abaqus/CFD





Pressure and **Velocity** as a ramping Flow is applied to the Inlet (simple geometry / coarse mesh)

15 minutes to run - Results are within 3% of Formula



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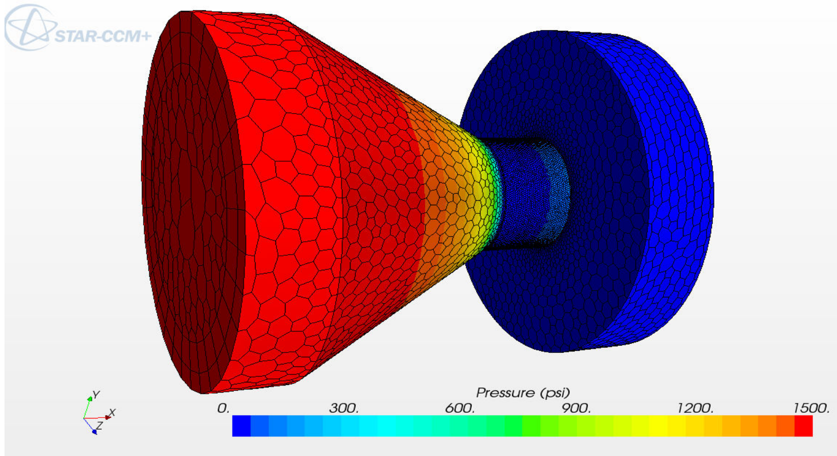
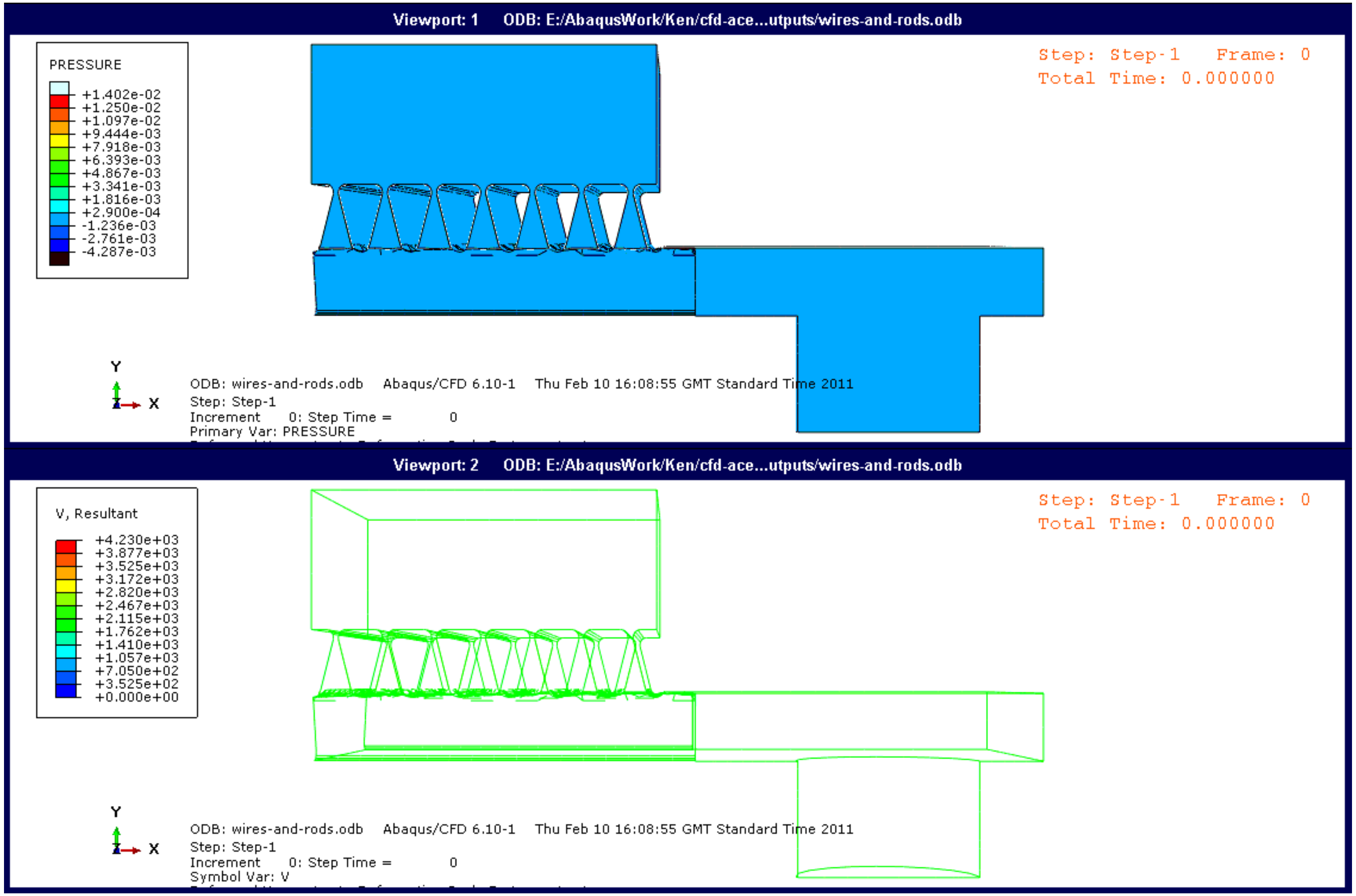
Finer mesh than Abaqus/CFD

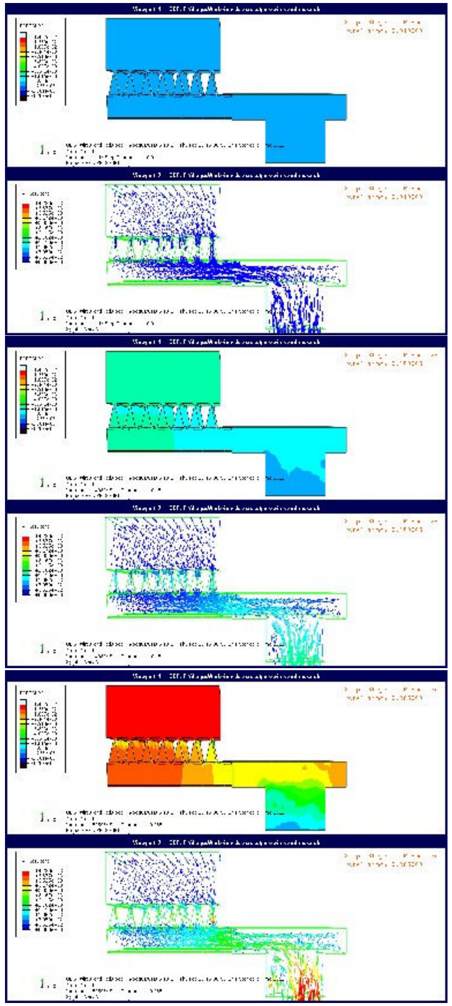
15 minutes to run - Results are within 0.07% of Abaqus/CFD



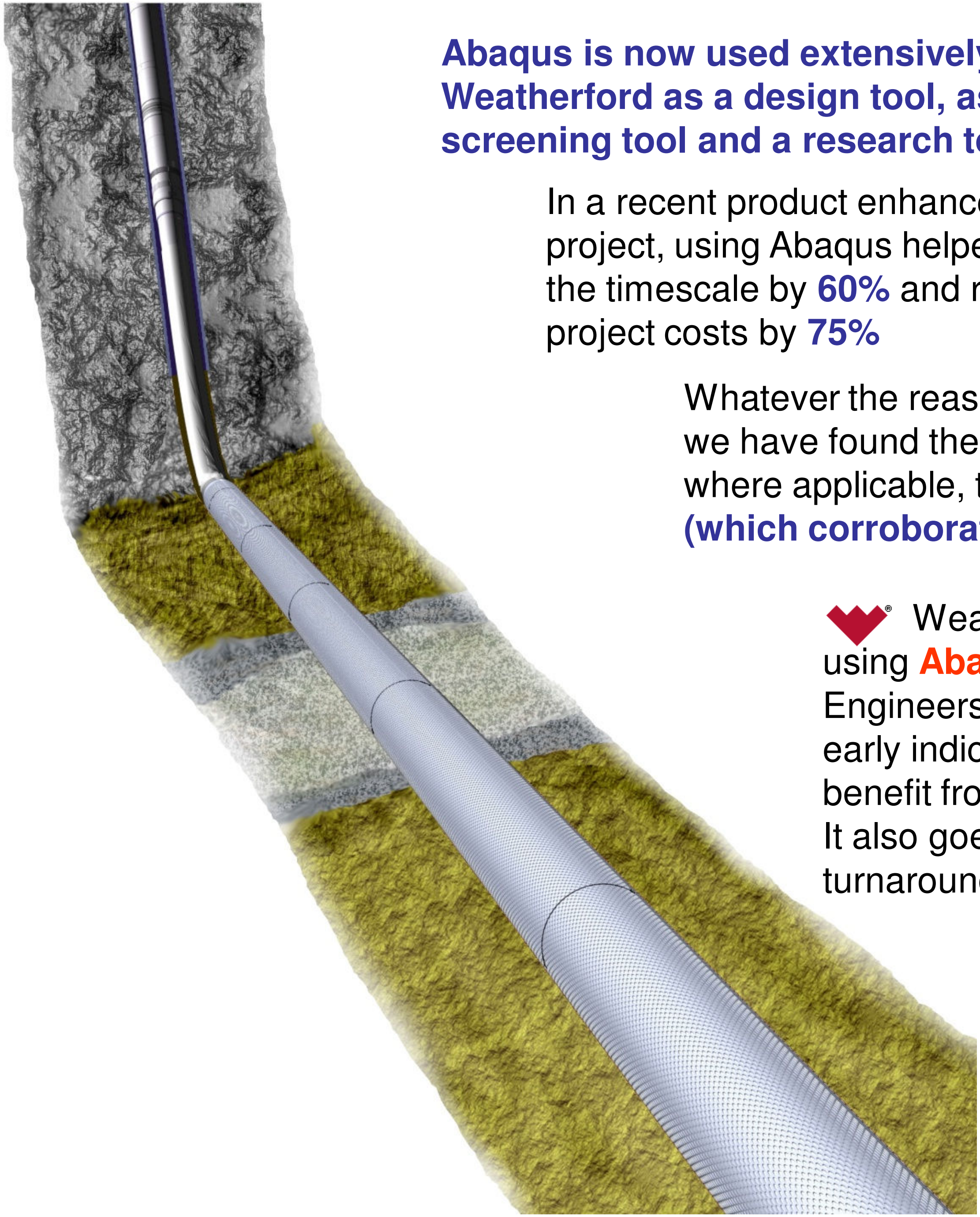
Pressure and **Velocity** as a ramping Flow is applied.

Inlet thru' Wires and Rods – Outlet thru' a 3/8" perf'





Conclusions



Abaqus is now used extensively within Weatherford as a design tool, as an application screening tool and a research tool.

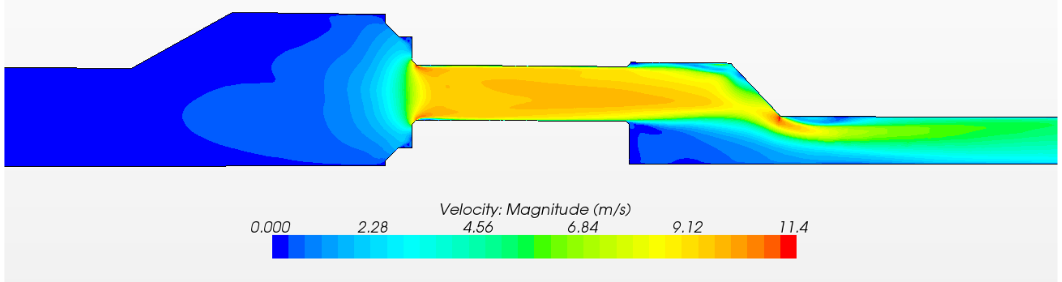
In a recent product enhancement project, using Abaqus helped reduce the timescale by **60%** and reduced project costs by **75%**

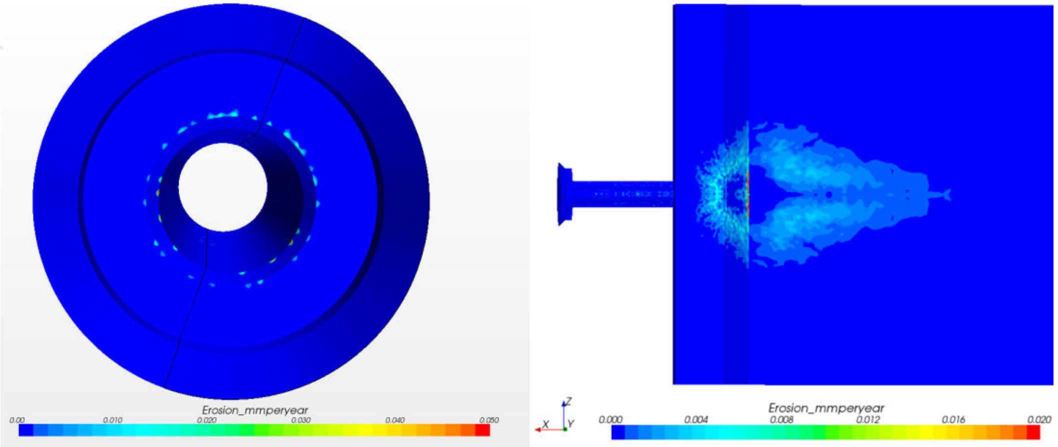
Whatever the reason for performing the analysis, we have found the results to be reliable and, where applicable, to match existing empirical test data **(which corroborates methodology and materials)**

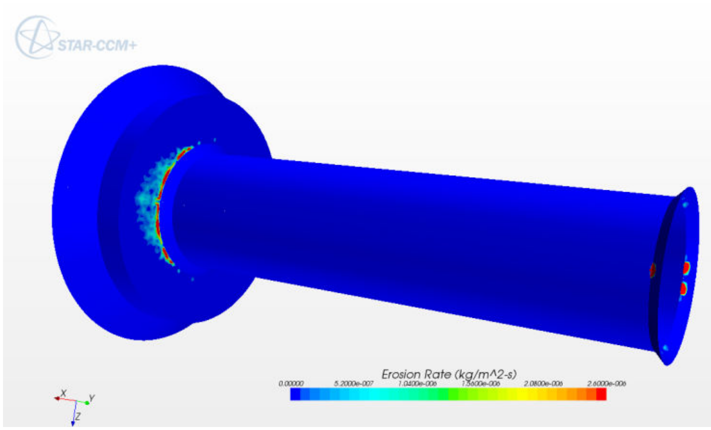
Weatherford has benefited enormously by using **Abaqus** products.
Engineers get insight into problems, they get early indicators for design improvements and benefit from reduced costs for testing.
It also goes without saying that faster R&D turnaround is essential – and is now possible!

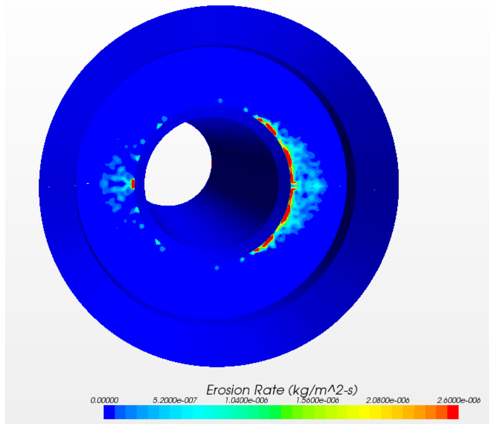
CD-adapco **STAR-CCM+**

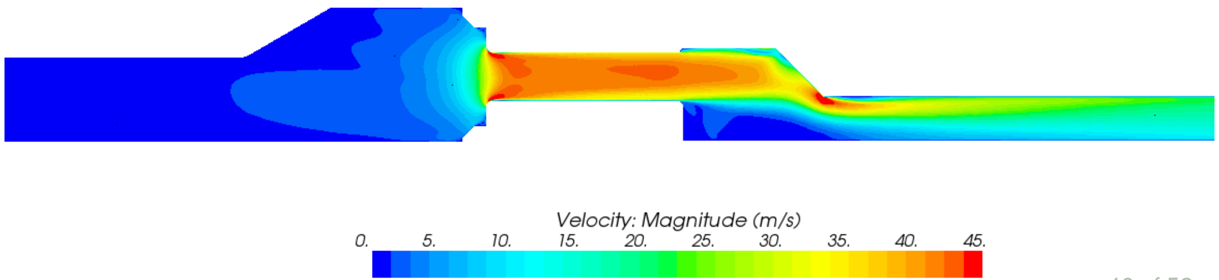
Velocities / Erosion Rates











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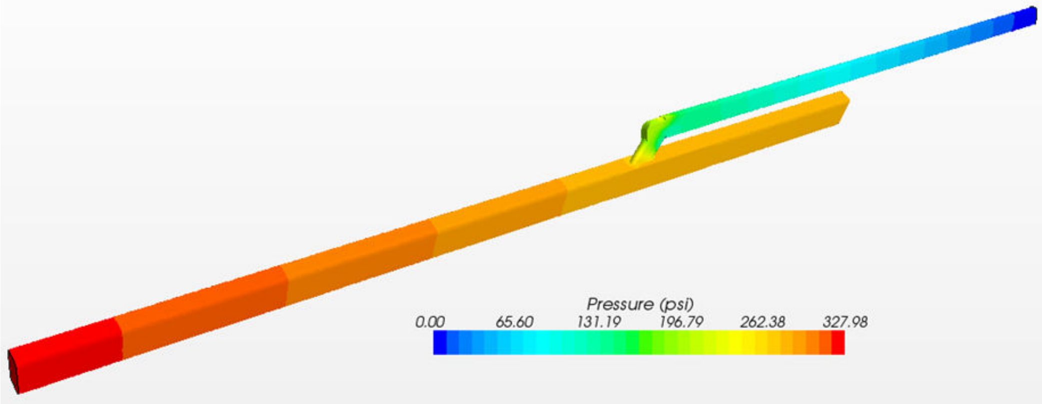
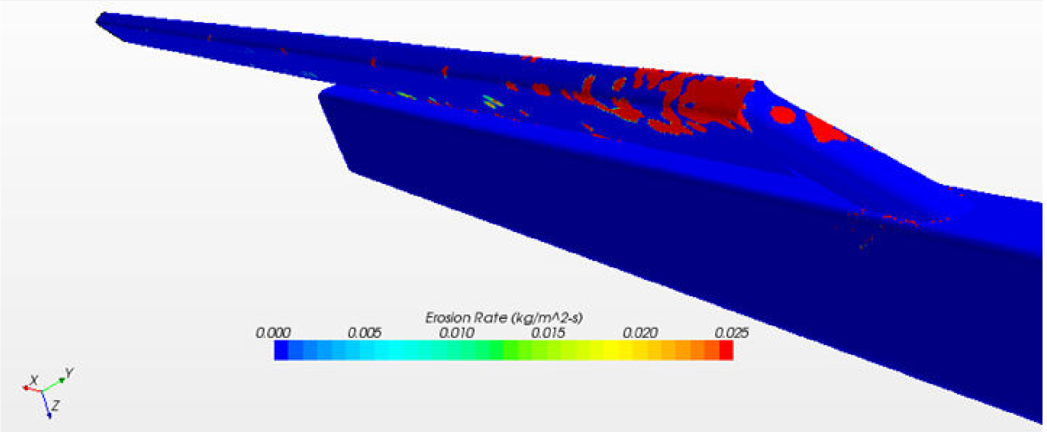
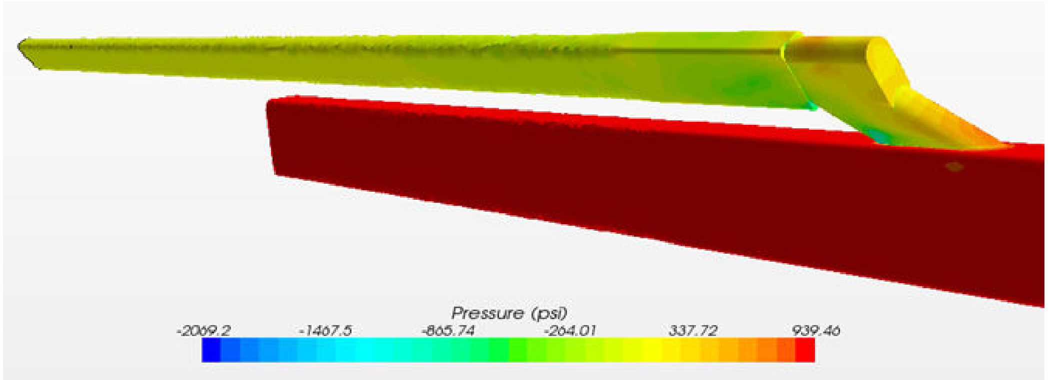
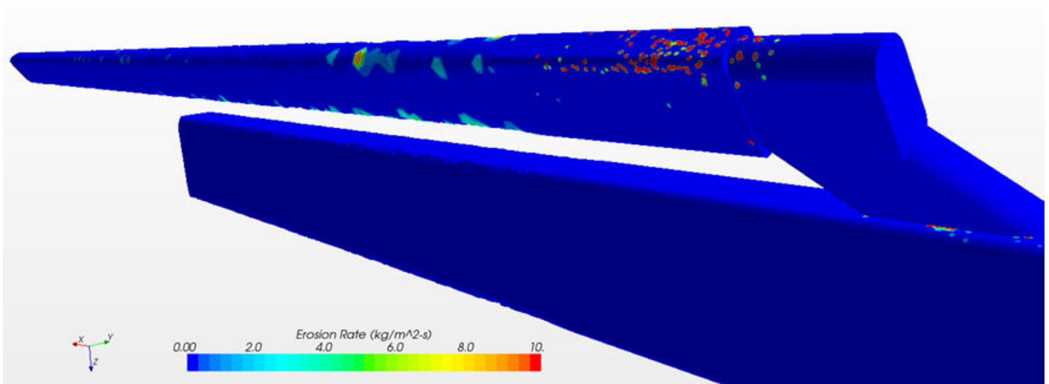
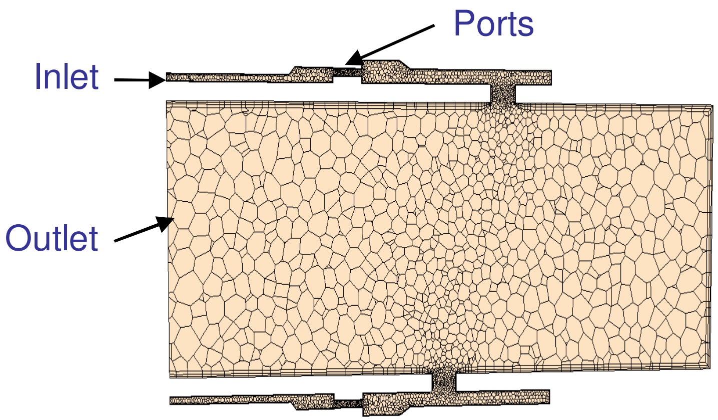
Pressure Drops / Erosion Rates



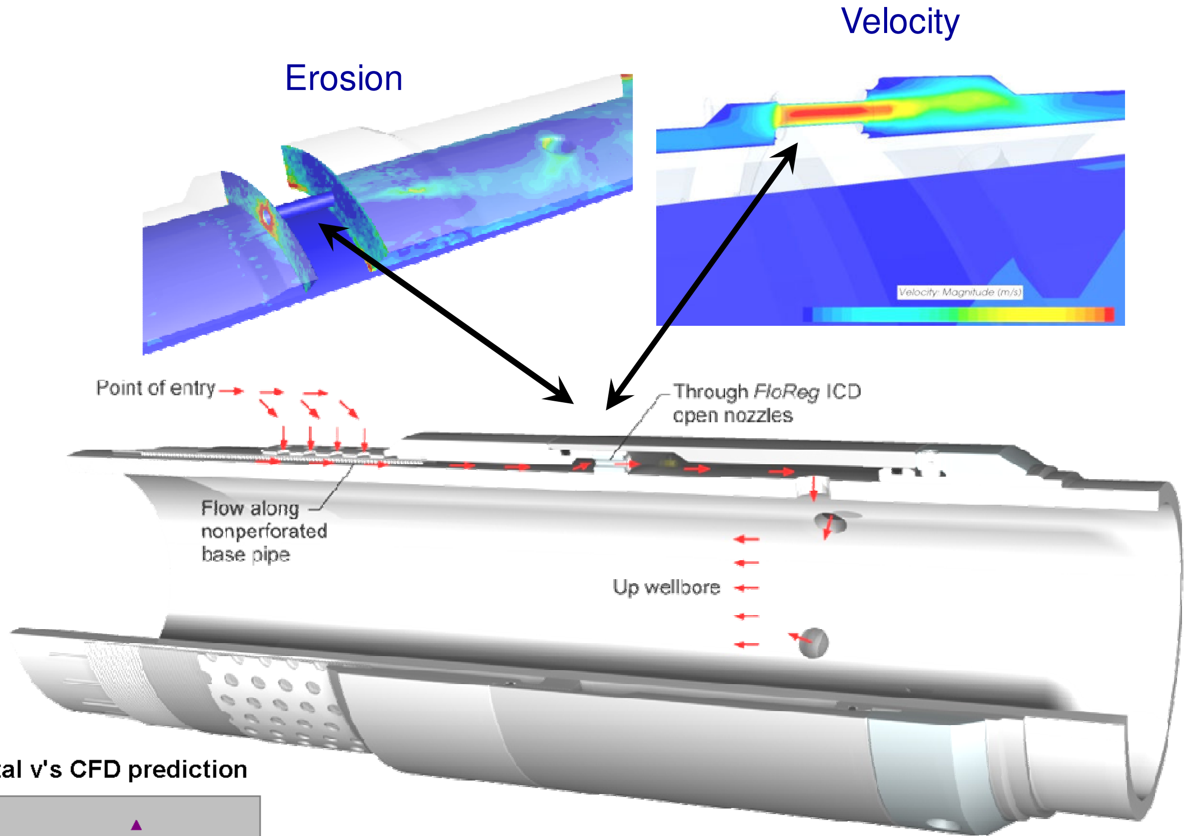


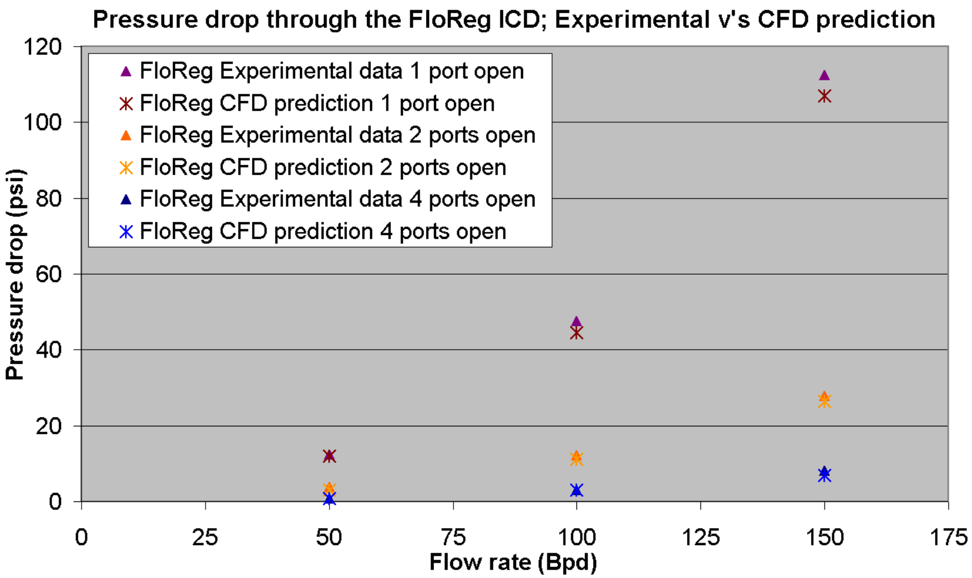


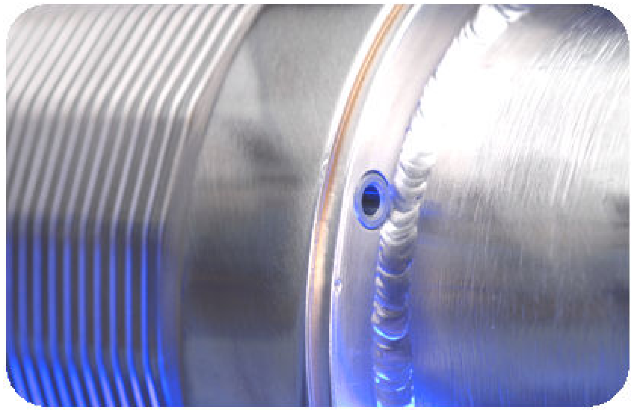




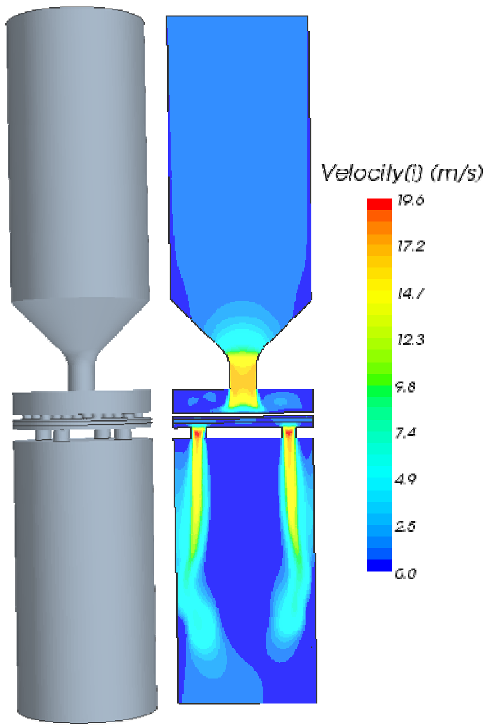
Section through the CFD polyhedral volume mesh for the *FloReg* ICD



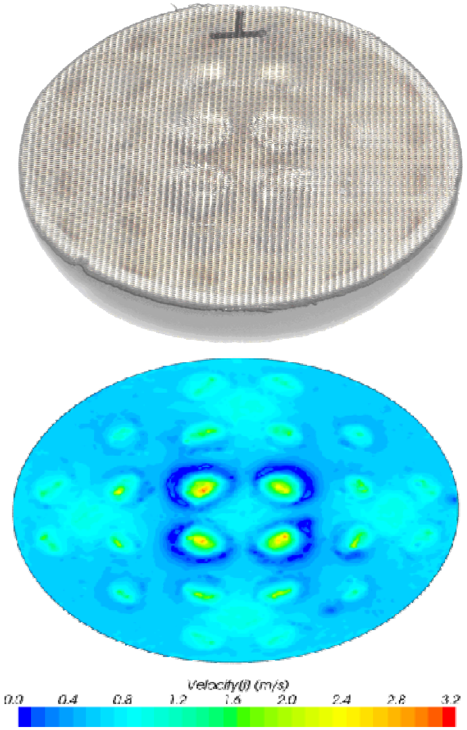




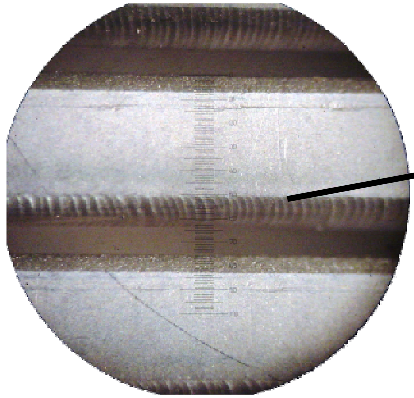
CFD has been proven by comparison with Experimental Data



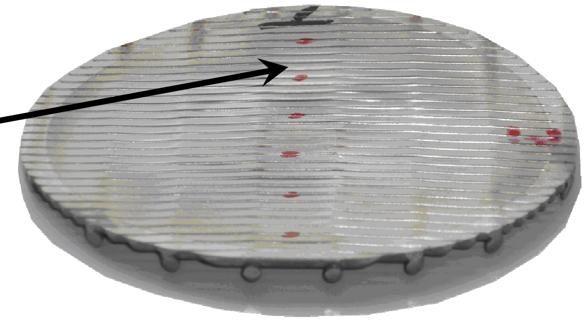
Velocity – flow passing through restriction (casing perforation), shroud and basepipe



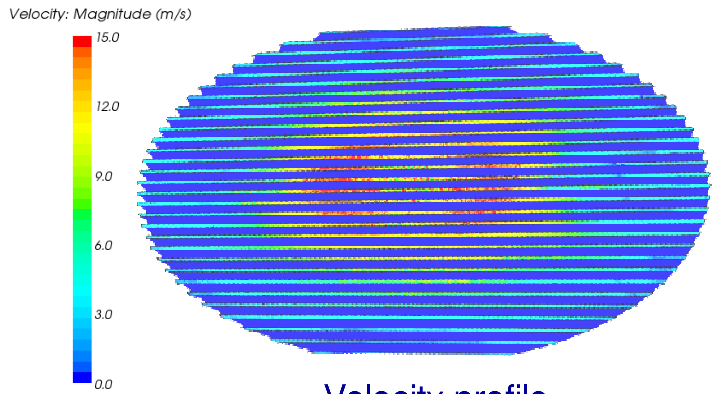
Velocity – flow passing through Maxflo® Shroud "image" can clearly be seen



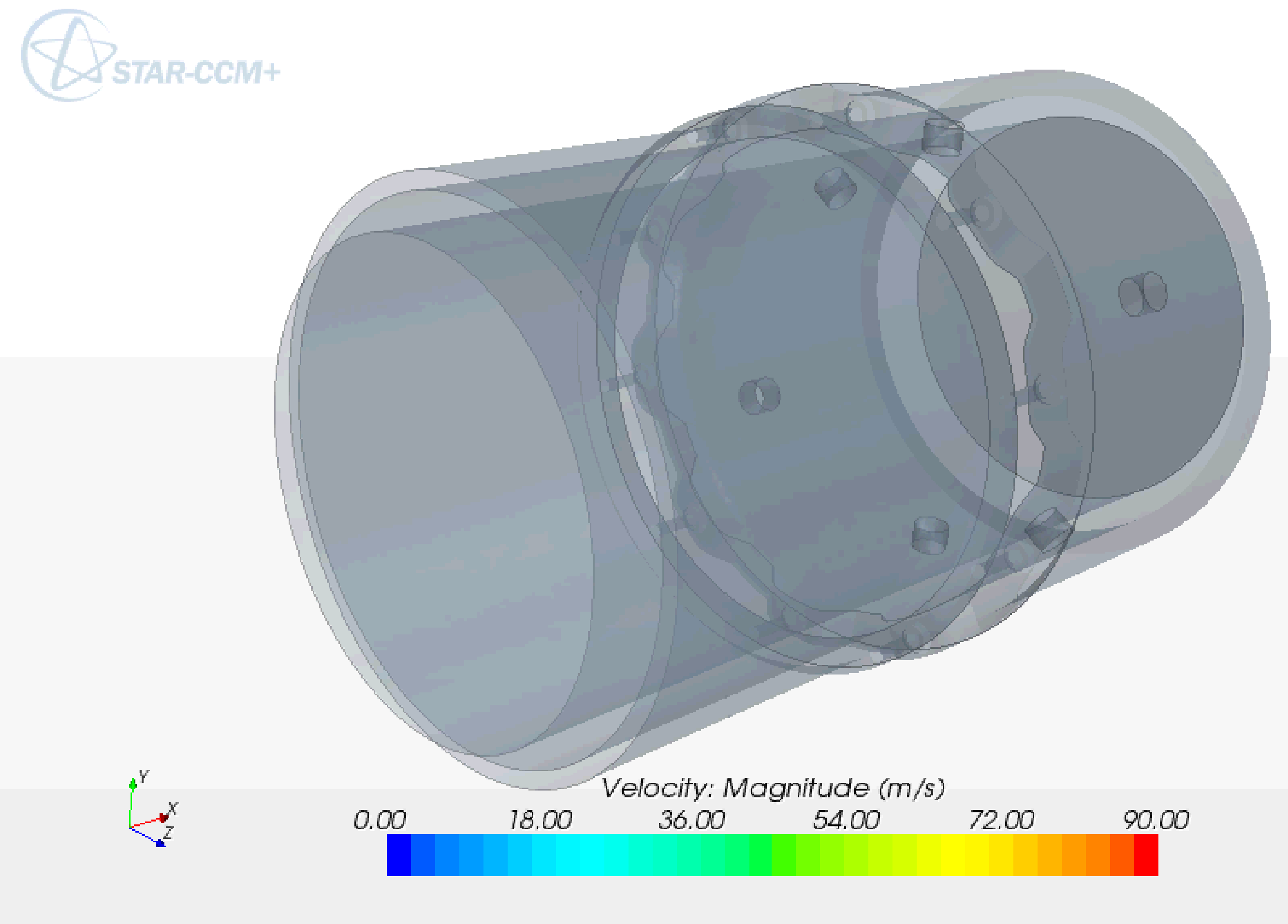
Erosion

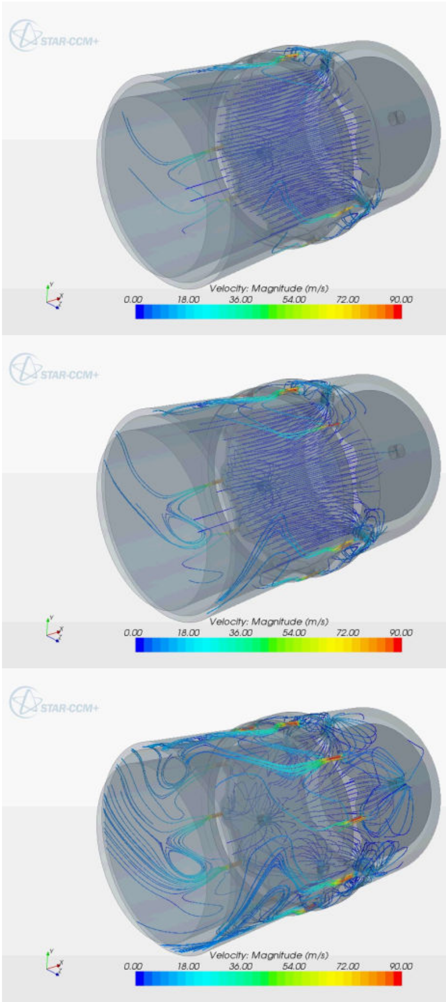


Test piece



Velocity profile


STAR-CCM+
Velocity: Magnitude (m/s)
0.00
18.00
36.00
54.00
72.00
90.00
Y
X
Z


STAR-CCM+
Velocity: Magnitude (m/s)
0.00
18.00
36.00
54.00
72.00
90.00

Ken Watson is the 3D Specialist for the Engineering Group within Well Completion Technologies, Weatherford International.

He joined Weatherford in 2000 as a 3D Modeller and CAD draughtsman and has since embraced other 3D design tools such as FEA and CFD.

He has written various FEA related Technical Papers which he has subsequently presented. He has also produced many rendered 3D graphics (from CAD) for papers, presentations and magazines.

He has been involved in many aspects of oil industry draughting and design since 1985.

Thank you for your attention

Please feel free to ask any questions