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 and unconsolidated formations. They combine the ease of installation of conventional screens with the borehole support of a gravel pack.

There are two different variations of expandable screens; a system based on a slotted basepipe which are easy to expand but relatively low in strength and a system based on a drilled basepipe which are very strong but difficult to expand.

FEA has been used to model the slotted basepipe type to better understand the interaction of the expanded screen with the rock formations. This type of analysis has replaced 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.

The results from the FEA modeling compares favorably with data from earlier, large scale, experiments. This satisfactory outcome increases confidence in the modeling and has allowed us to design models for field applications.

Keywords: Constitutive Model, Critical State Plasticity, Design Optimization, Experimental Verification, Geomechanics, Wellbore.

1. Introduction

Expandable sand screens (ESS®) are a relatively new sand control system (Metcalfe, 1999). They are used to control the ingress of sand in oil, gas and water wells in reservoirs with weak and unconsolidated formations. The sand is produced due to rock failure as a consequence of the changes in in-situ stress over the life cycle of the well.

There are many different strategies available to control produced sand downhole. They range from the very simple, such as reducing production rate, to more complex mechanical restraint of

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the sand. Two mechanical sand control methods are sand screens and gravel packs. A sand screen is a metal filter which filters the sand out of the produced fluids in the reservoir. A gravel pack is a common addition to a sand screen where a sand pack fills the annulus between a sand screen and the formation; this supports the wellbore and retains the formation sand. There are many advantages to the gravel pack in terms of solids retention and system reliability. However, the gravel is pumped into place as slurry. This is a complicated and expensive process which can also give rise to severe production impairment.

Expandable sand screens are a system which combines the ease of installation of the normal sand screen with the wellbore support and sand retention of a gravel pack. In an expandable sand screen installation the screen is run in-hole to depth in an unexpanded form. An expansion tool is then passed through the screen to swage it onto the wall of the wellbore.

There are two types of expandable screen, a type based on a slotted basepipe and a type based a drilled basepipe. This paper is concerned with the slotted basepipe type system. An example of the construction of the slotted basepipe ESS is showed in Figure 1. The ESS consists of three parts, 1. the slotted basepipe or expandable slotted tubular (EST), 2. the woven metal mesh which retains the sand and 3. an outer shroud which protects the mesh during deployment.

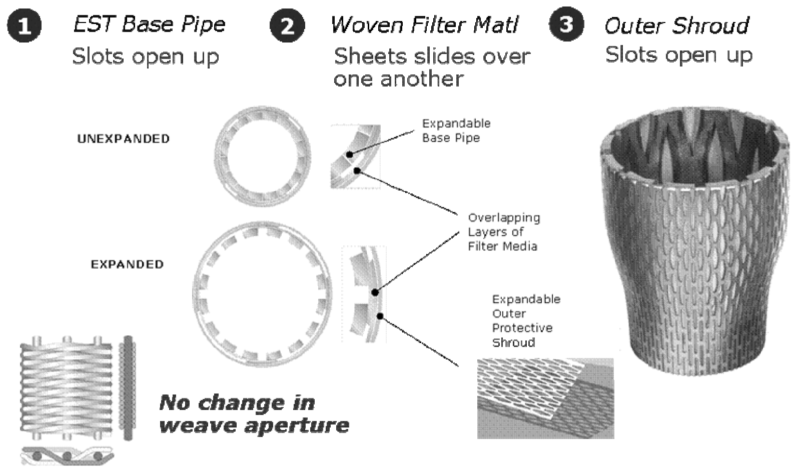

Figure 1 Details of the construction of the ESS

The advantage of the slotted basepipe system is that it is comparatively easy to expand, it can be expanded out to large expansion ratios, and it can be expanded to follow a non uniform wellbore. The disadvantage of the slotted basepipe system is that it has a comparatively low strength.

Although the ESS has a comparatively low strength, numerous experiments have shown that this is not an issue since the interaction of the screen with the rock formation allows the system to withstand huge changes in stress with only minimal deformation. However in a very weak rock the screen will potentially undergo large deformations. A simple analytical model has been developed to act as an application screening tool (Jones, 2005). The model is based on tunnel support concepts and uses a Mohr Coulomb representation of the formation materials. The model has been used extensively to decide which applications are feasible based on the rock strength and the in-situ stresses.

The simple analytical model has been very successful, but it is also limited. It is limited in the types of material it can deal with and it is essentially a one dimensional model. To overcome these limitations an FEA model was developed using Abaqus/CAE. This allowed the study of more realistic rock material models and structural interactions to be investigated, such as the effects of an open annulus between the ESS and the rock formations and the interaction with multiple formations. FEA investigations have been done in the past on the ESS by the oil companies who use the product (Willson 2002). We have also contracted out numerous FEA studies on the ESS, but this is the first time we have developed an in-house FEA capability.

2. Work flow and model

The basic work flow was firstly to develop a model representing testing which had already been done on the ESS. This allowed verification of the model with the test data. Secondly the model was used to predict the deformation of the ESS in an ESS/rock deformation experiment. In each case Abaqus/Explicit was used because of its advantages in dealing with multiple, changing contact surfaces and the large scale plasticity in the systems modeled.

The initial simulations were performed on the 4 1/2” version of the ESS. The model verification was an extensive set of tests performed to measure the hydraulic collapse resistance.

The parts for analysis in Abaqus/CAE are generally created with Pro-Engineer Wildfire 2.0. This is because the parts are generally complex in that they have a large number of slots, or perforations, around their circumference and along the length. ACIS SAT files are then simply imported to Abaqus/CAE. Figure 2 shows a ¼ symmetry section of basepipe exported into Abaqus/CAE.

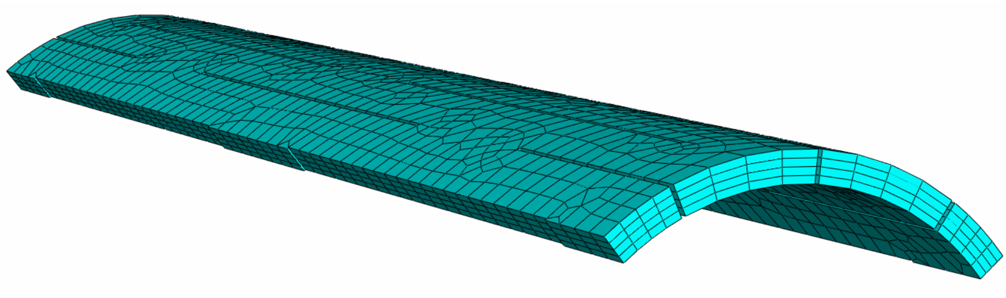

Figure 2 Section of basepipe withC3D8R mesh

Once successfully imported into Abaqus/CAE the part is then meshed. Generally C3D8R elements are used. For the EST shown (quarter symmetry) mesh four deep (from outside to inner bore) are used. The perforated shroud is generally meshed with a single layer of tet elements. Hex elements have been tried but they become too small and too numerous for realistic computation times. In these simulations the metal filtration weave is ignored. The reason for this is its complex structure and its small contribution to strength. However the deformation of the weave during expansion and production is a crucial aspect and will be investigated in the future.

For the full symmetry simulations, one end was held by constraining U1 = 0. The co-efficient of friction for all interactions was set to 0.5. The basepipe and the outer shroud were made from stainless steel 316L, with a yield of 206MPa, with a Young's modulus of 210GPa and a Poisson's ratio of 0.3.

Typical run times for the quarter symmetry models were 2-3hrs and 6-8hrs for the full symmetry versions.

3. Model Results

In the actual application of this technology in the field expansion is accomplished by a cone or a variable expansion tool. Only cone expansions were simulated due to the relative simplicity of the models. Full representations of the tooling are under development but require very long run times on the available computers. An example of the cone expansion within Abaqus/CAE is shown in Figure 3 and a partially expanded piece of real ESS is shown in Figure 4.
Typically it takes 25-35klbs to push a cone through a 4 ½" ESS, the modeled reaction force was 31klbs. This represents a good match between the experimentally measured values and the FEA.

3.1 Hydrostatic collapse experiments

The distribution of stress and plastic strain is very similar to what has been observed in actual samples. The plastic strain is localized at the ends of the slots where there is a stress concentration and the metal is acting like a plastic hinge.

Once the sample had been expanded the next step was to apply a hydraulic pressure to the outside of the sample. This gradually deformed the expanded ESS. Initially the deformation is linear and elastic up to a radial displacement of approximately 1.2mm and an external pressure of 170psi. Above this pressure the structure appears to yield and deforms plastically. An image of the partially collapse ESS in shown in Figure 5. This shows some localized buckling of the structure. As the applied pressure is increased still further the sample eventually flattens completely and the inside surfaces come into contact.

Figure 6 shows the radial deformation plotted against applied pressure for the numerical and actual hydraulic collapse test. There is a very good correspondence up to a radial displacement of 2mm. The initial slopes of the experimental and numerical pressure displacement curves are virtually identical. After yield the experimental and numerical behaviors depart slightly. In the actual experiment once a peak pressure was reached the sample slowly loses its load bearing capacity and gradually collapses. The numerical pressure displacement curve increases after yield.

The reason for the difference is probably to do with either the way the samples are loaded or heterogeneities in the structure. In the experiment the ESS is fitted with a rubber membrane and mounted inside a pressure vessel. Pressure is applied by a small volume piston pump. The sample ID is measured using a set of extensometers. As volume is added to the pressure vessel the pressure on the sample increases and it deforms. If there is some movement of the sample the change in volume will cause a pressure drop. Also in the actual sample there are some departures from an ideal structure. The slotting process is not exact and the pipe is not perfectly round and concentric. All these factors may lead to plastic strain localization and a drop in pressure. In the simulation the pressure is ramped up to a given maximum. The pressure must continue to increase and the sample rapidly flattens at an ever increasing pressure.

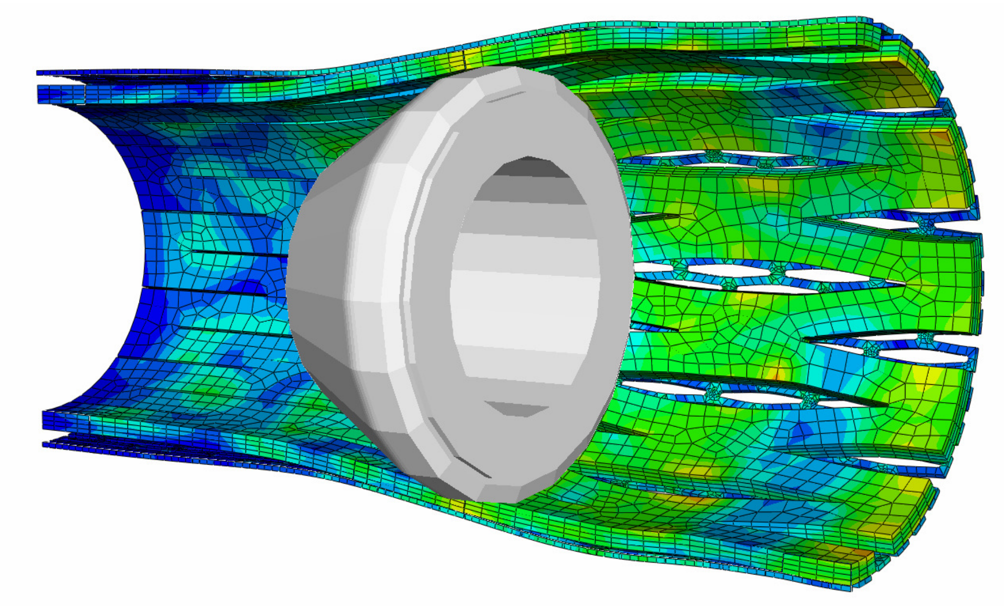

Figure 3 ODB output of cone expansion of the ESS

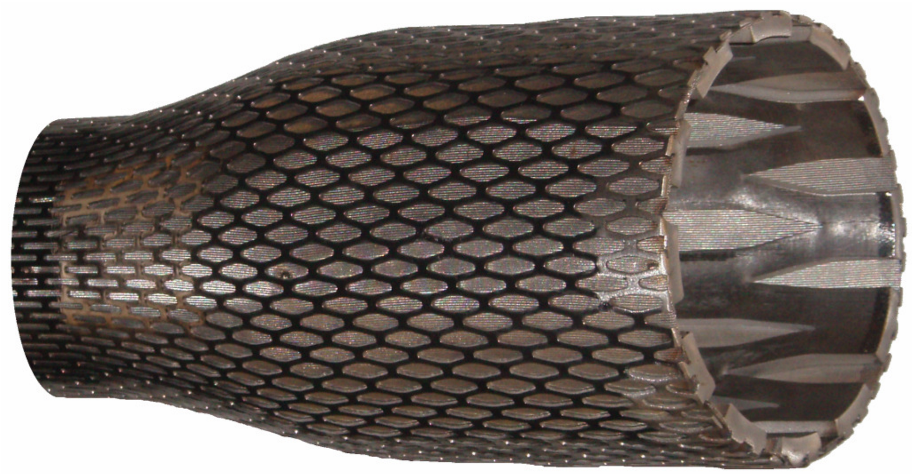

Figure 4 Example of partially expanded ESS

In the simulation the pressure is increased monotonically through the time step. Once the sample yields it deforms ever more quickly as the load bearing capacity diminishes. This can be seen on Figure 6 as the data points are ever further apart. If the internal and kinetic energy of the system is plotted (Figure 7), in the first half of the graph up to approximately 0.1 time represents the expansion part of the simulation. Here the internal energy is 2 orders of magnitude higher than the kinetic energy. In the second half of the graph which represents the collapse of the ESS, initially the internal energy is almost 3 orders of magnitude higher than the kinetic energy. As the application of pressure continues the kinetic energy rises as dynamic effects become more important as the structure loses its load bearing capacity. At the end of the loading step the kinetic energy drops again as the structure is crushed flat.

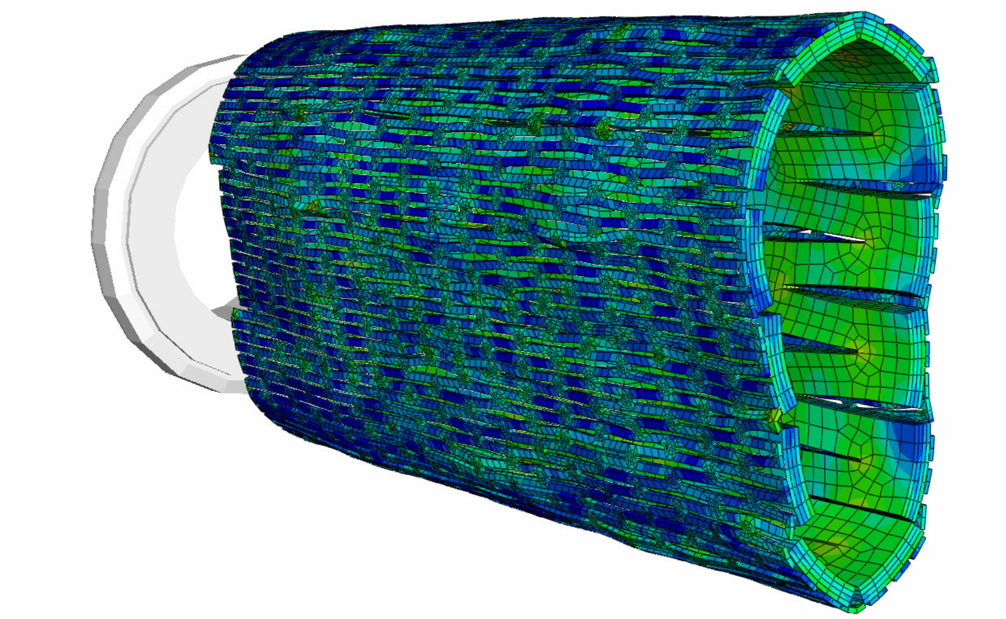

Figure 5 Hydraulically collapsed ESS sample

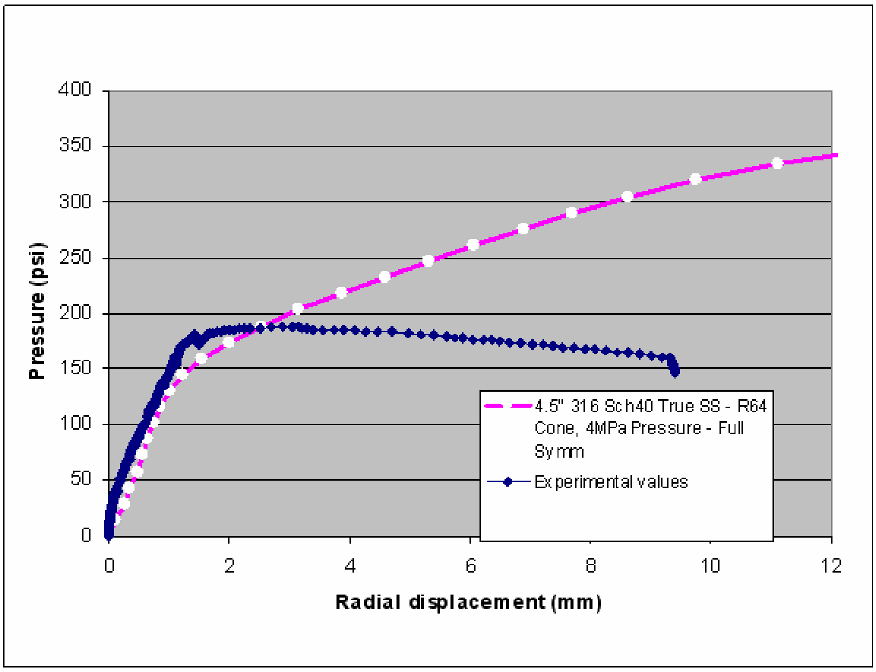

Figure 6 Comparison of applied pressure vs radial displacement for ESS.

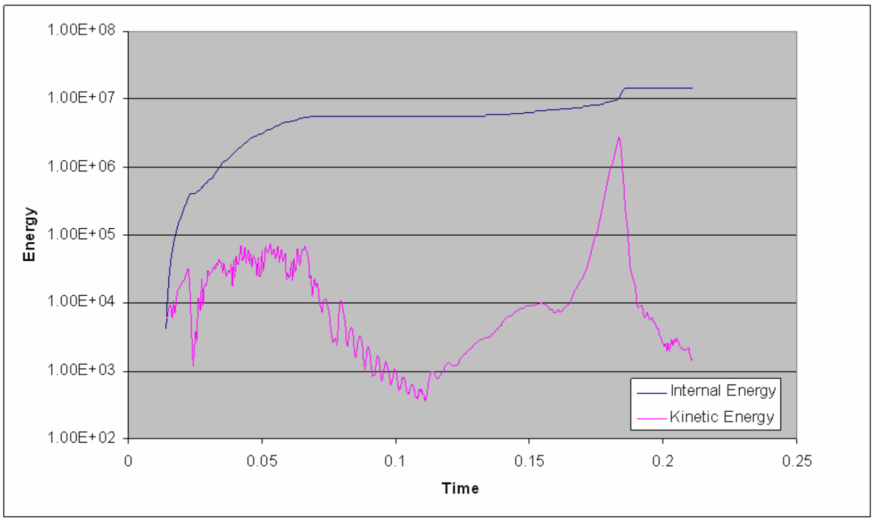

Figure 7 Plot of internal and kinetic energy during the expansion and collapse of the ESS

3.2 Thick walled cylinder experiment simulations

Another type of experimental test has been used extensively to determine how the ESS will deform in a rock formation. In this type of test the ESS was compliantly expanded into a 152.4mm (6”) wellbore in a thick wall cylinder rock sample. The sample dimensions are 495mm (19.5”) outside diameter, 152mm inside diameter by 1041mm (41”) long. The sample assembly is then jacketed and mounted on steel platens and placed in a large pressure vessel. Stresses of up to 70MPa are applied to the cylinder of rock via the platens and the impermeable jacket. The sample assembly has flow ports to allow fluid flow from the outside of the cylinder to the inner wellbore, to simulate oil production in a well. Sets of extensometers measure the deformation of the ESS.

Figure 8 shows a picture of the partially dismantled sample assembly showing the upper platen, the failed rock sample and the ESS inside. The rock is failed close to the wellbore/ESS and relatively intact on the outside. The rock exhibits obvious shear bands and compaction close to the wellbore.

The sandstone used in the test was a weak sandstone from the USA known as Castlegate Sandstone. The Castlegate sandstone has a UCS of approximately 1500psi and a friction angle of 30 degrees. Several different test have been performed using this configuration, either with some version of ESS expanded into the wellbore or just the bare unsupported wellbore. All commonly used sizes of ESS have been used, as well as the expandable connectors which are used to join together 10m sections of ESS. The test on the unsupported wellbore in Castlegate sandstone showed that sample could withstand approximately 17MPa before total collapse. With an ESS expanded into the same rock sample the composite ESS/rock sample can withstand 70MPa applied external stress and remain stable. The ESS has a collapse resistance as shown in 3.1 above of <2MPa, but the combination of the weak ESS and the weak sandstone combine to give great strength.

The mechanism for this dramatic increase in strength is that the ESS keeps the failed material in place and applies a radial stress to the broken rock at the wellbore. Due to its frictional properties the broken rock near the wellbore is strengthened by the applied radial stress from the ESS. The radial stress builds up through the rock sample strengthening the broken rock until it reaches a level where the rock material can withstand the stresses without failure. This stress arching phenomena shields the ESS from the large applied stresses. During this process the ESS deforms. The level of deformation is a function of the friction angle of the rock in which the ESS is deployed. For a high friction angle the deformation is minimal, for a low friction angle the deformation can be significant. It is the final purpose of this work to predict the deformation of the ESS for a given set of rock properties under in-situ conditions.

In the simulations the Castlegate sand stone was represented by a cap plasticity model with cap hardening with data matched from a suite of triaxial tests. The simulation was in two parts, firstly the ESS was expanded into contact with the inside of the wellbore, secondly stress was applied to the outside surface and ends of the rock sample to simulate loading.

Figure 8 Partially dismantled rock sample showing ESS inside failed rock

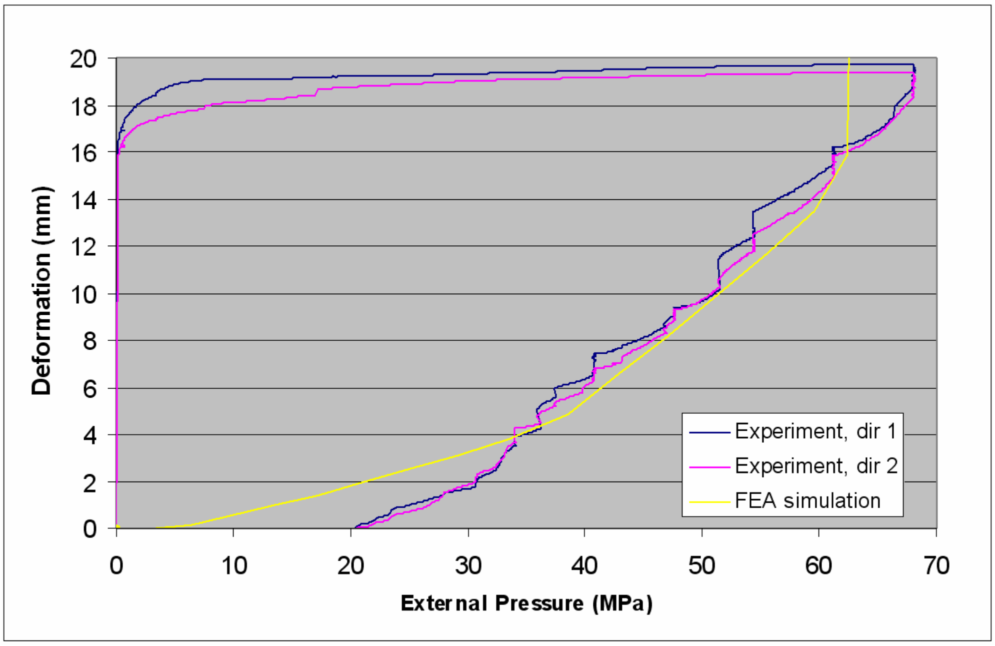

Figure 9 Measured and predicted ESS deformation in large scale TWC test

The results of the experiment and the simulation are plotted in Figure 9. The graph shows external pressure on the x-axis and internal deformation on the y-axis. The fit between the simulations is very good. Initially deformation starts sooner on the simulation and appears to accelerate slightly at the end of the loading. The reason that there is a lag in deformation for the experimental measurements is that there may be an annulus between the rock and the ESS and there is some slight initial compliance in the ESS weave and shroud. This could cause the experimentally measured internal deformation to lag behind initially. The slopes of the pressure deformation curves are identical.

4. Conclusions and further work

This work represents our first attempt at using FEA modeling to better understand how the ESS will respond to applied stresses. It is clear that there is a great deal of further work that could be done to improve the modeling but the simulations agree very well with both the hydraulic collapse testing and the large scale thick walled cylinder tests.

Abaqus/Explicit can be applied to many aspects of product testing. It can and is currently being used for a rapid evaluation of different designs of ESS such as slot patterns, pipe thickness and metallurgy. In the past, test pieces were used for these types of evaluation which is expensive and time consuming. Tooling design and optimization is already being developed, again at a great potential saving.

The most important future application is the simulation of how an ESS deforms in an actual formation. Models are currently being built to perform these simulations.

5. References

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