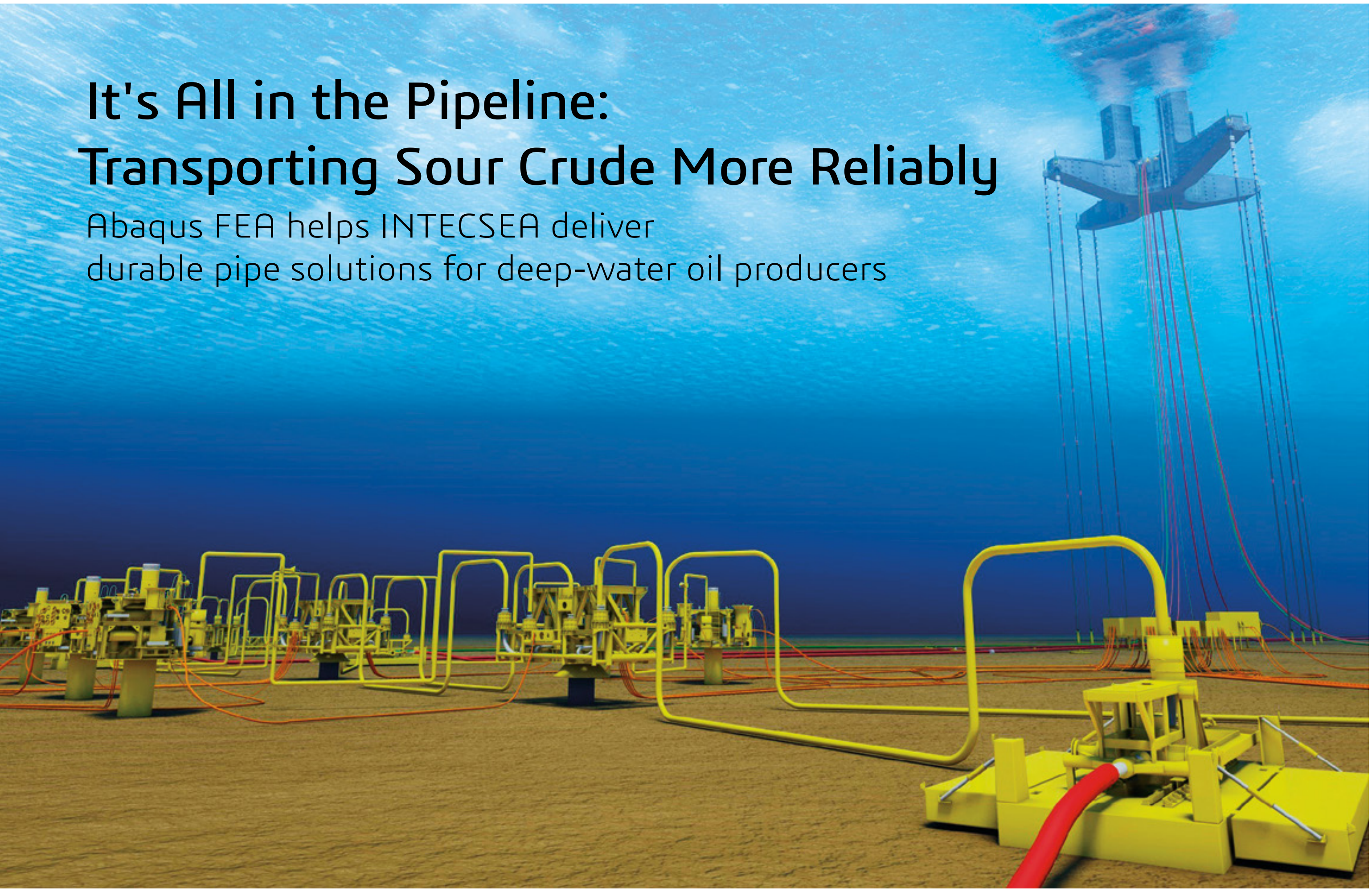


It's All in the Pipeline: Transporting Sour Crude More Reliably

Abaqus FEA helps INTECSEA deliver durable pipe solutions for deep-water oil producers

It's not that the world is running out of oil. The problem is getting to what remains of it, at a price that consumers can swallow. A September 2013 Oil Market report from the International Energy Agency (IEA) said global demand for oil and liquid fuels will rise to 93 million barrels per day in 2014, an increase of more than 2 percent. This comes at a time when most experts agree the days of "easy" oil are over. Petroleum companies are now forced to drill in areas deeper and more remote than ever before.

In the case of deep-water production, this means very high and unpredictable pressures coupled with severe temperature gradients both inside the pipe and out. Worse, the crude oil coming from these depths is increasingly "sour," a corrosive witch's brew containing high levels of hydrogen sulfide, CO_2, and volatile organic compounds that make short work of regular carbon steel pipe. The oil industry has responded with calls for better pipeline material.

> "Oil production wouldn't be practical without simulation tools like Abaqus. It's a real enabler."
>
> **Philip Cooper, INTECSEA Global Technology Director**

Clad pipe has been used in high-strain environments for decades. By metallurgically bonding a thin layer of Corrosion Resistant Alloy (CRA), typically 316L or Alloy 625, to the inside of C-Mn structural steel pipe, a robust combination of strength and corrosion resistance is formed.

However, clad pipe suffers from long lead times and high cost. Sherif El-Gebaly, lead pipeline engineer at INTECSEA, a global company within the WorleyParsons Group and a leader in subsea production systems, says clad pipe can cost 10 times that of regular C-Mn Steel. "An alternative is CRA mechanically lined pipe using a weld overlay at the ends," he says. "This is both easier and quicker to manufacture, presenting cost savings of 30 percent over clad pipe."

However, concerns over the weld overlay to liner interface joint have prevented wide use of CRA mechanically lined pipes due to the technology readiness level (TRL) not meeting operator requirements. INTECSEA has been working to resolve and increase the TRL confidence in CRA mechanically lined pipe for use in harsh environments.

Making the weld stronger than the pipe

Pipe sections are manufactured in lengths of about 12 meters, called pipe joints. These joints are then "girth" welded together end-to-end to create a pipeline. For mechanically lined pipe, each CRA joint is slid inside a carbon steel joint and plastically expanded in the radial direction to ensure tight fit between the carbon steel and the liner. The fitted CRA joint is shorter in length, leaving a distance of about 50 mm to 150 mm at each end; this gap is filled with a weld overlay of a CRA material, bonding the CRA layer to the carbon steel pipe and enabling the joint-to-joint girth weld to be performed.

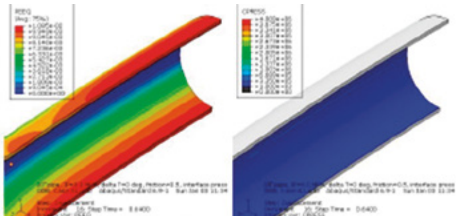
"Girth welds are very critical," says INTECSEA Global Technology Director Philip Cooper. "Some of these ships are running $1 million a day. The weld joints are inspected prior to lowering the pipe into the sea, and if repairs have to be made at this point, it can seriously impact production quota."

Regardless of how much pipe gets laid in a day, environmental and safety considerations mandate zero tolerance for failure once the pipeline is in the water. This is because deep-sea flow lines are subject to tremendous stress as they transport a gloppy mix of oil, gas and sand from the wellhead to the offshore storage facility (FPSO) or onshore processing terminal. This fluid alternately heats and cools the pipeline, causing expansion, bending and potential buckling. High velocity "slugs" of water and gas within the pipe create vibration, leading to fatigue. Even the weight of the pipe itself as it crosses the uneven terrain of the seafloor is a cause for concern.

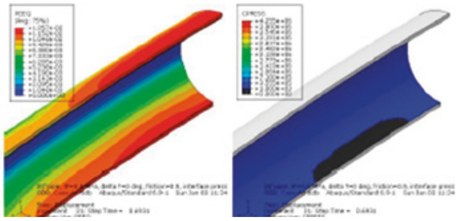
"The movement of the pipeline under production conditions is similar to your garden hose when you turn on the tap," says Cooper. "You'll get wiggling and sideways motion due to the pressure. This is why fatigue performance and strain capacity in this environment is so important."

The oil industry demands thorough testing of any component used in deep-sea oil production, and CRA-lined pipe is no exception. Because of its two-layer design, some experts were concerned over the possibility of "ripples" forming in the liner material under bending stress which presents a risk of premature failure (Figure 1). Equally important was ensuring the integrity of the girth welds used for the weld-overlay-style pipe.

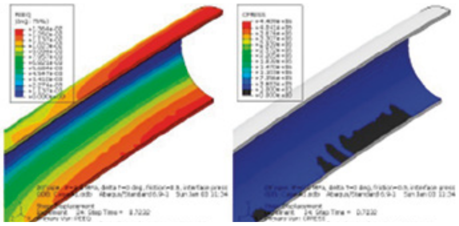
But since sticking your head inside a 12" diameter pipe one mile under the ocean is clearly not an option, INTECSEA design engineers have been employing realistic simulation with SIMULIA Abaqus finite element analysis (FEA) software from Dassault Systèmes, the **3D**EXPERIENCE Company.



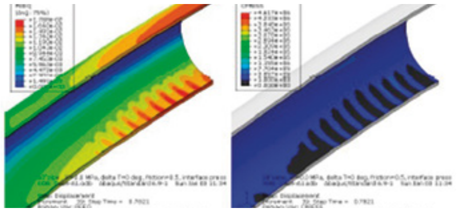
Prior to initiation



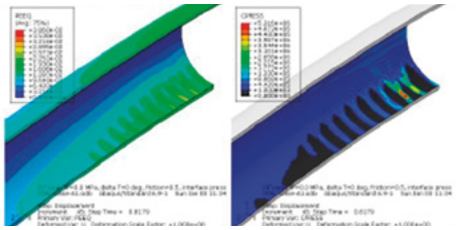
Contact pressure zero



Initiation of rippling



Growth of rippling



Start of final buckling shape

Figure 1. FEA analysis of pipe response to stress. The diagram at the top shows the pipe at rest. As bending force is gradually applied, ripples begin to grow in the CRA liner. At the bottom, the pipe is beginning to buckle.

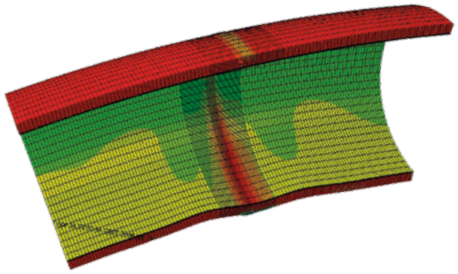


Figure 2. Abaqus FEA model of pipe girth weld.

Visualizing deep-sea conditions with Abaqus

FEA lets the team query the geometry and behavior of computer models of their pipe designs, simulating every condition from production to performance thousands of feet below the ocean surface. "We've been using Abaqus for the past decade or so," says Cooper. "Over the last few years it's really become our preferred tool for pipeline design. On top of that, many of our customers show a preference for Abaqus. It's more or less a standard in this industry."

El-Gebaly's team had a number of factors to consider when setting up their Abaqus FEA models to predict lined pipe and weld behavior. "One challenge was a potential problem with under-matching," he says. "Imagine that you have two 12-meter long pieces of pipe and you're welding them together (Figure 2). The weld is basically just a ring, one that is stronger than the pipe on either side. Normally when you bend the whole system, you don't have to worry about this small ring, you're concerned more with the pipe materials. But if at some point the yield strength of that ring becomes less than that of the pipe on either side—for example, under certain high temperature operating conditions or where the consumable selected for welding exhibits a lower yield strength at certain temperature than the base material—the joint will actually become more flexible than the pipe and then all the stress flows into it. FEA helped us investigate such cases."

There were other scenarios to check within the assembled pipeline itself. Aside from the garden-hose phenomena described by Cooper, El-Gebaly was concerned with the development of ripple-type deformations induced in the liner layer during spooling and subsequent installation. "You have to understand the behavior of liner under bending moment, the wrinkling onset conditions, as well as the fatigue performance of the girth weld during the installation and design life," he says.

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