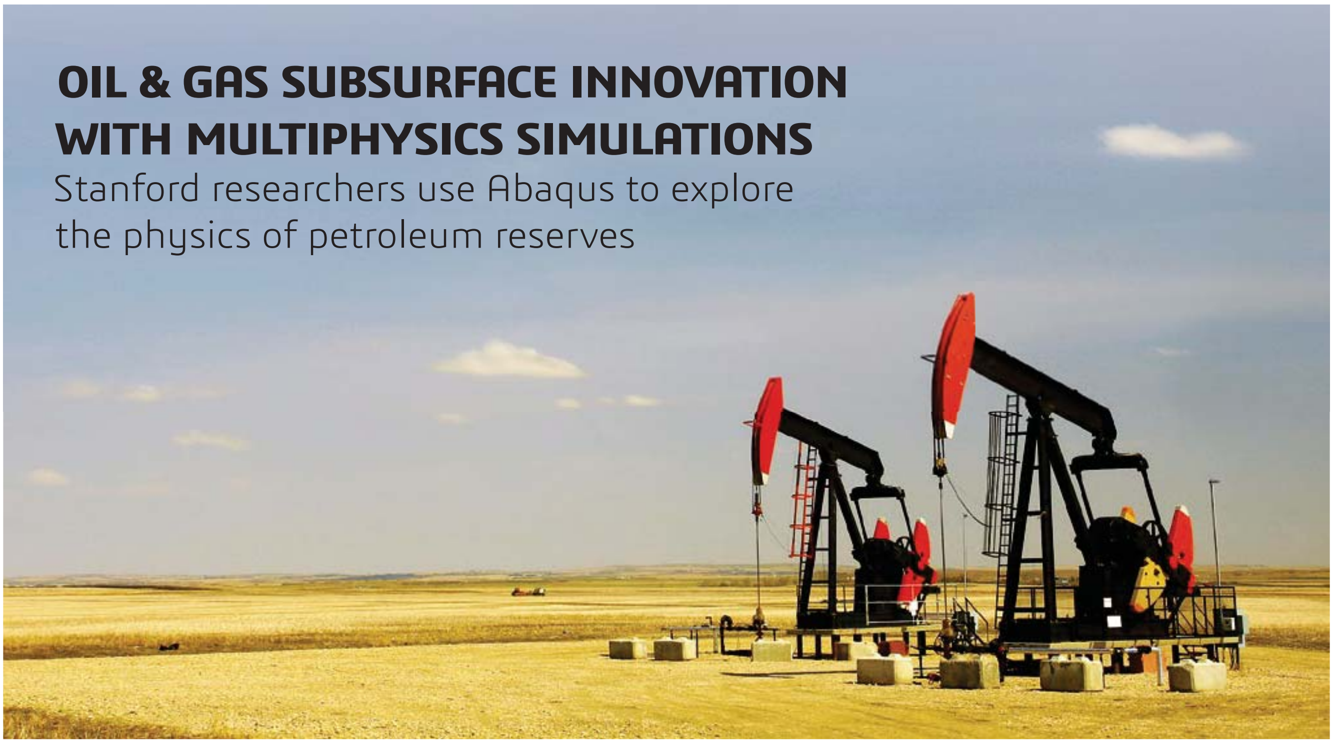
OIL & GAS SUBSURFACE INNOVATION WITH MULTIPHYSICS SIMULATIONS

Stanford researchers use Abaqus to explore the physics of petroleum reserves



Recent reports indicate that the United States is poised to become the biggest producer of oil & gas in the world, thanks in large part to extraction from shale rock resources. Alternative energy is gradually contributing more to the world's energy supply but, given current global demand, there will continue to be significant focus on the development of both conventional and unconventional oil & gas reserves for the foreseeable future.

With safety and efficiency of paramount importance, there is an urgent need to better understand the physics and the connection between oil & gas extraction practices—such as hydraulic fracturing and water reinjection—to seismic activity and production declines. Realistic multiphysics simulation of subsurface formations provides a powerful method to understand the behavior of oil & gas fields, both from production efficiency and safety points of view, over the entire lifecycle of the fields, from initial development to continued operations over years or even decades.

At Stanford University, Ph.D. candidates Jeremy Brown and Randi Jean Walters, under the guidance of Prof. Mark Zoback of the Stanford School of Earth Sciences, have been using Abaqus to understand and develop potential methods and solutions for some of these challenges. Brown and Walters are both working on their doctorates in geophysics in the Stress and Crustal Mechanics Group at Stanford. He holds an M.Sc. in geophysics from Stanford and a B.Sc. in geophysical engineering from the Colorado School of Mines. She also holds an M.S. in geophysics from Stanford and has a B.S. in geosciences from Boise State University with a minor in Applied Mathematics.

"Our group is working to better understand how changes in situ stress can lead to triggered and induced earthquakes, fault reactivation, wellbore stability issues when drilling, reservoir compaction and subsidence, and production from both conventional and unconventional reservoirs," says Brown.

The Stanford Group works in collaboration with commercial oil & gas companies, which often provide the researchers with high-quality data from the field that can be used to better understand geomechanical processes. Brown specifically works with rock mechanics data from BP. The company acquires rock core when drilling into a reservoir and sends it to the Stanford lab for testing. Walters uses data provided by ExxonMobil that includes well-log information as well as injection, microseismic, and tilt data. She compares her Abaqus/CAE simulations of deformation to the real-world tilt data and microseismic event locations to determine whether her simulations are reasonable.

SIMULATING STRESS PATHS OF RESERVOIR FAULTS

Up to now there have been few geomechanical studies of Paleogene reservoirs in the Gulf of Mexico—studies that could help determine reservoirs' fault re-activation potential during initial depletion of the reservoirs or during subsequent re-pressurization of the reservoirs. Research into such scenarios could aid with optimal placement of wells and facilities or help to anticipate and prevent problems during production.

For such studies, Brown has adopted a multiphysics approach that couples a commercial reservoir simulator (for flow of the oil & gas) with Abaqus finite element simulations (for geomechanics)—a scheme that allows the stress path taken at several production wells in a Paleogene-type field to be determined more accurately. The quantification of these nonlinear stress paths helps determine the potential for production-induced fault re-activation on reservoir boundary faults.

In recent work, Brown was able to determine that faults in the Paleogene are closest to failure at the initial stress state within the reservoir rather than during reservoir depletion. However, the simulations also indicated that failure is more likely during the re-pressurization phase of production—information that could allow operators to adopt appropriate mitigation strategies. Another interesting aspect of this study is that it was carried out using a streamlined workflow that allows efficient progression from structural and geologic modeling all the way to coupled multiphysics reservoir simulations, which lays the foundation for more thorough assessments based on probabilistic methods.

Jeremy Brown, Professor Mark Zoback and Randi Jean Walters

> "Abaqus is a powerful tool that has allowed me to do some great simulation work."
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> —Jeremy Brown, Ph.D. candidate, Stanford University

STUDYING DEFORMATION DUE TO STEAM INJECTION

One of Walters' research topics at Stanford uses Abaqus simulations to help understand how a heavy oil reservoir undergoing cyclic steam stimulation (CSS) responds to stress perturbations in the form of deformation. "Our insights could lead to a safer production environment, enhanced well casing integrity and improved production," she says.

Walters collected borehole microseismic, surface tilt, and steam injection data at a heavy oil production site during the first instance of steam injection and, after spatial and temporal analyses, found a complex deformation environment. The goal of her ongoing research is to create a calibrated multiphysics simulation model that can first match the observed initial deformation patterns and then potentially predict future behavior as production continues.

Walters' simplified Abaqus model, developed to simulate the subsurface deformation occurring as the result of steam injection at the pad, did not match the more complex deformation patterns, suggesting that a more-sophisticated model, incorporating various failure mechanisms, might be more appropriate. The failure models could be somewhat simplistic—such as homogenous inflation of the reservoir as if it were disk-shaped or a homogenous inflation of small disk shapes centered at the steam injection locations—or more complex, including the activation of shear slip on pre-existing natural fractures and hydraulic fracturing. "Advanced fracture and failure modeling and simulation capabilities in Abaqus will likely be critical in this research to understand the complex and evolving deformation patterns and their effects during CSS and other extraction methods," says Walters.

ABAQUS HELPS SUPPORT SAFER AND MORE EFFICIENT OIL & GAS FIELD DEVELOPMENT

Such research at Stanford and many other academic and commercial institutions worldwide, based on Abaqus multiphysics simulations, will continue to play a key role in contributing to safer and more efficient oil & gas field development and production operations.

"Abaqus is a powerful tool that has allowed me to do some great simulation work," says Brown. "My research will hopefully provide some insight for oil and gas companies about the geomechanics in the Gulf of Mexico and will aid in better reservoir management. I am thankful to BP for providing financial support and technical guidance to allow me to do this exciting work."

"SIMULIA's software is clearly applicable to many different problem types," says Walters. "The end goal of my research is to allow operators to limit the damage that occurs to their wells due to deformation in the reservoir and overburden as well as mitigate seismic hazard and risk. This work also provides an understanding of fluid propagation through the subsurface and how to identify that propagation via micro-seismic and deformation information."

OnePetro.org (search for Abaqus for over 1,000 research papers) is a very useful resource for researchers interested in learning more about the use of multiphysics simulations in oil & gas.

References:

Understanding Deformation Due to Steam Injection at a Heavy Oil Reservoir through Tilt Data, Microseismic Data, and Geomechanical Modeling. Randi Jean Walters and Mark Zoback, Stanford Borehole Geophysics Laboratory.

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https://earth.stanford.edu/