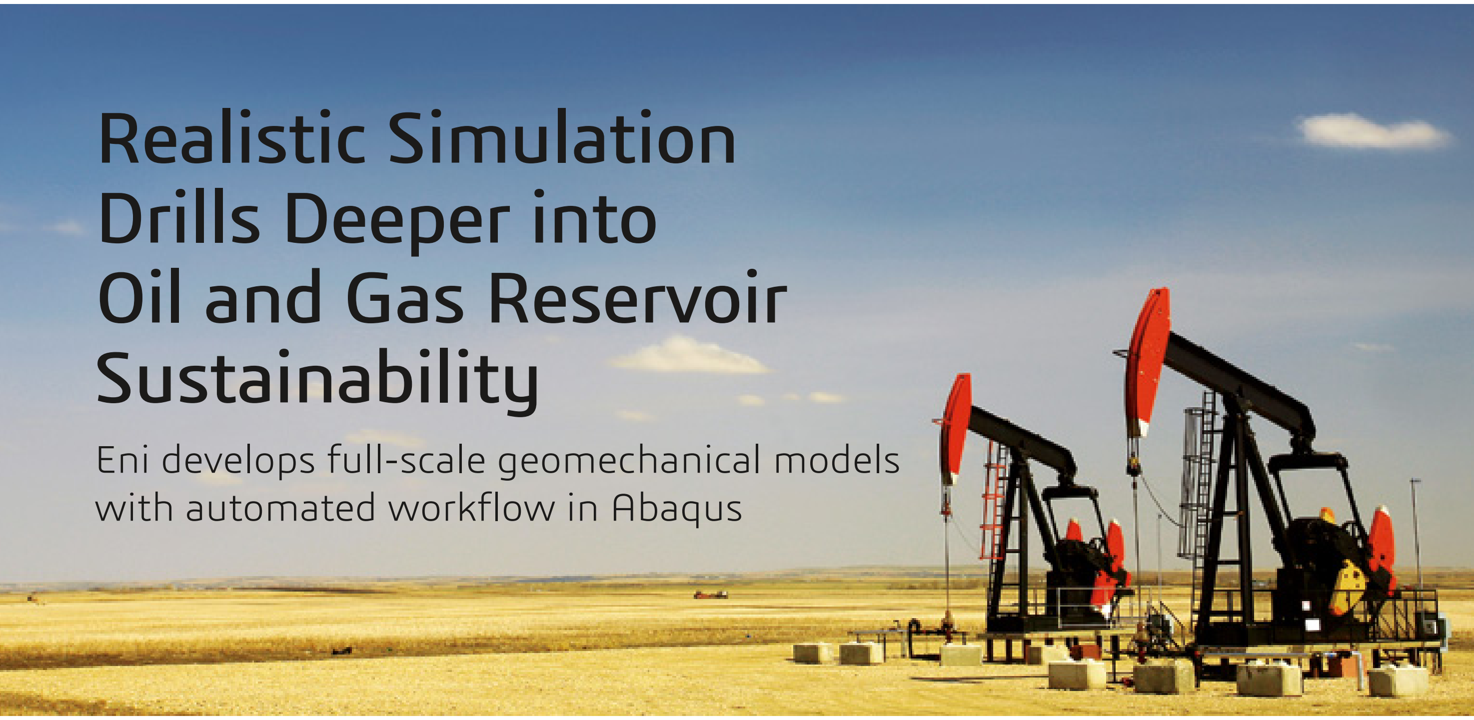

Realistic Simulation Drills Deeper into Oil and Gas Reservoir Sustainability

Eni develops full-scale geomechanical models with automated workflow in Abaqus

Managing the lifespan of an oil or gas field is an ongoing, big-picture concern for energy companies. With huge investments needed just to start the flow of hydrocarbons from a well, keeping production levels at optimum rates for as long as possible is a necessity: the world still relies heavily on petroleum.

The challenge of such reservoir "sustainability" has been partially met with flow-predicting software and on-site monitoring tools. When flow rates drop, the injection of fluids can boost production higher again. But there is more to the puzzle than how fast the oil or gas will come out, and for how long. As petroleum is pumped from its original bed, subsidence and compaction of the soils surrounding the reservoir can affect rock permeability, the integrity of boreholes, equipment function, and even the geology of the land around the production sites.

This happens because the extraction of petroleum from underground reservoirs leads to a reduction in pore fluid pressure within the reservoir, which results in a redistribution of stress in the rock formation. Since rock deformations are often plastic, this produces subsidence of the ground around the reservoir that expands over time as extraction continues. As the rock deforms, the permeability of the rock itself changes, which then affects the flow of fluid within the reservoir. The phenomena of fluid flow and mechanical deformations are thus inexorably coupled to each other (see Figure 1).

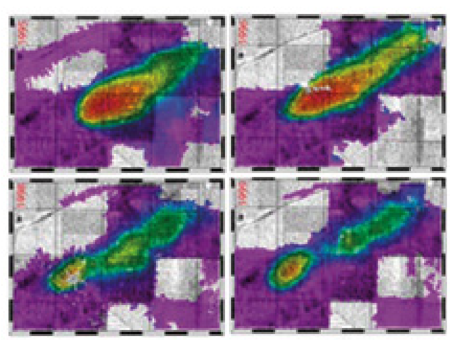

Figure 1. The NASA images above show the rapid rate of subsidence (in red) of over 3 cm/month during active production in the Lost Hills area of California. Note that production occurs over several years and so easily results in several feet of subsidence.

Subsidence challenges petroleum industry both on and offshore

Reservoir compaction has been extensively investigated to determine its impact on both hydrocarbon field production and environmental stability, onshore or offshore. The effects can be cumulative. For example, in the Netherlands, subsidence at the large Groningen gas field, though only on the order of tens of centimeters to date, poses significant long-term challenges since large portions of the Netherlands are below sea level and protected by dikes. Some important, much-documented lessons from the past clearly demonstrate the negative impact of the phenomenon over time. The city of Long Beach, California, experienced subsidence of some 20 square miles of land, with a surface dip of 29 feet near the center, due to extraction from the huge Wilmington oilfield. Subsidence from the Goose Creek oilfield in Texas affected over four square miles, with up to five feet of surface drop. Remediation in both cases cost millions of dollars. Offshore, the Ekofisk field in the North Sea suffered seafloor subsidence that required highly expensive interventions to re-establish the safety of the producing platforms.

While the majority of oil and gas projects don't encounter challenges at such a large scale, petroleum engineers now clearly understand the value of starting with deeper knowledge of the terrain at the earliest stages of reservoir development.

A more realistic view of what lies beneath

As an integrated energy company operating in engineering, construction, and drilling both off- and onshore for customers around the world, Italy's Eni S.p.A. devotes considerable manpower and resources to research into reservoir management. Their work helps clients close to home as well: Gas fields in the Adriatic Sea have become a major source of energy for the country. Due to the particular morphology of the shoreline in that area, it is of paramount importance for Eni to be able to correctly predict the land subsidence that may be induced by hydrocarbon production in order to guarantee the sustainable development of the offshore fields.

Eni has for some time been developing advanced methodologies for studying the problem of reservoir subsidence and compaction with the help of Abaqus finite element analysis (FEA). "Abaqus is our main stress/strain simulator for studying the geomechanical behavior of reservoirs at both field and well scale," says Silvia Monaco, geomechanical engineer in the petroleum engineering department of Eni E&P headquarters in San Donato, Milan, Italy.

The ability of Abaqus Unified FEA to realistically simulate complex structural and material behavior makes it well suited to the task. Although the study of subsidence in petroleum fields has been slowly advancing since the 1950s, earlier approaches were based on an assumption of homogeneity of the whole system, i.e. they described the side-, over-, and under-burdens of rock and soil with mechanical properties identical to those of the reservoir. But soil and rock are in fact very non-homogeneous and show highly nonlinear behavior that is strongly influenced by previous stress paths. Incorporating FEA into a computer model of a reservoir provides a much more realistic simulation of this truth. Different types of finite elements, a large variety of material properties, coarser or finer element meshes, and data-based boundary conditions can all be woven into a prediction that much more accurately reflects the full effects of the geomechanical complexities unfolding beneath the surface.

Coupling Abaqus with the leading flow simulator

Of course it's the start of oil or gas flow out of the reservoir that gives rise to the effects that FEA models anticipate. So the Eni group links their Abaqus FEA models to the leading flow simulator ECLIPSE (from Schlumberger). "Fluid-flow analysis is essential in order to forecast production and manage field development," says Monaco. "But the geomechanical processes at work in the rock and the fluid contained in its pore space are also of primary interest since they can affect the behavior of the reservoir itself. By transferring pore pressure depletion data from ECLIPSE into Abaqus, we can more fully understand the mechanisms involved in surface subsidence in order to forecast and prevent well failures and adverse environmental impact." (see Figure 2)

Running a computer model of the large-scale dynamics of an entire oilfield is becoming much more efficient these days, thanks to huge leaps in parallel processing and high-performance computing that can handle FEA models with millions of degrees of freedom (DOF). And for Eni, creating those kind of models in the first place has recently become much easier.

When the Eni team first began coupling Abaqus with their ECLIPSE models several years ago, there was still considerable effort involved in creating the complex workflow needed to produce simulations that behaved realistically and correlated well with real-world measurements. "Previously, we had a number of non-automated procedures as well as simplifications related to the geometry description, such as the smearing of faults and simplified treatment of collapsing layers," says Monaco. "It used to take almost two months to complete a single model suitable for running."

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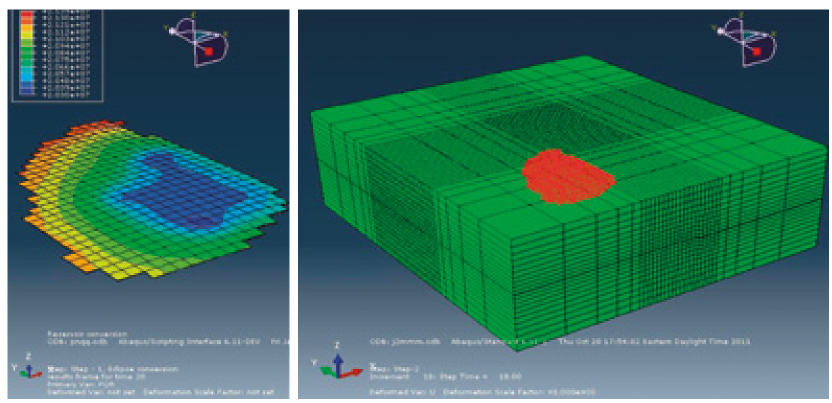

Figure 2. (Left) Active region generated from the flow simulation solution. (Right) Abaqus mesh showing the active region within a reservoir. Linking ECLIPSE with Abaqus incorporates the geomechanical effects of extraction for a more realistic simulation of full-site development over time.

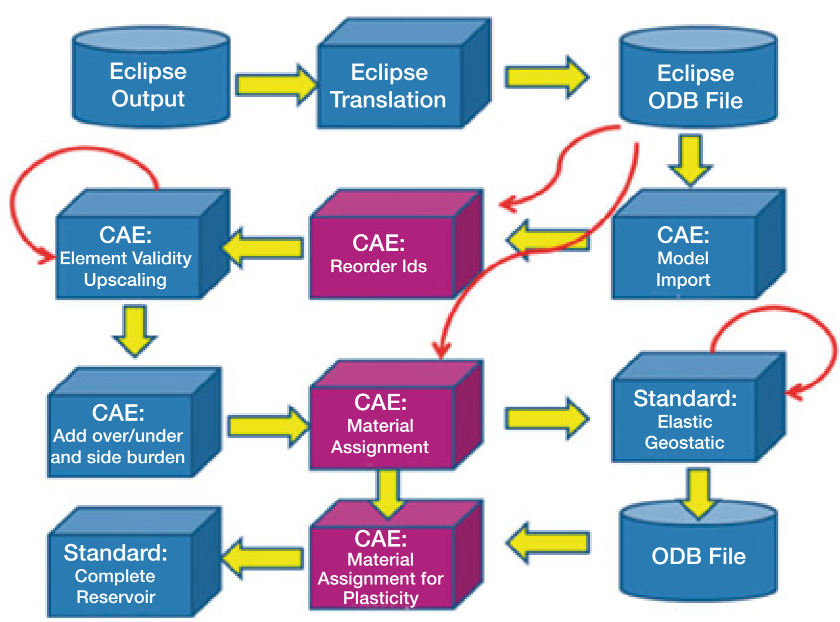

Figure 3. Reservoir geomechanics workflow. An output database file (ODB) is created from ECLIPSE and imported into Abaqus/CAE for creation of an FEA geomechanical model from which the stress distribution over a reservoir can be derived. A plastic analysis then predicts the geomechanical deformations (subsidence) in the surrounding terrain that will result from this stress.

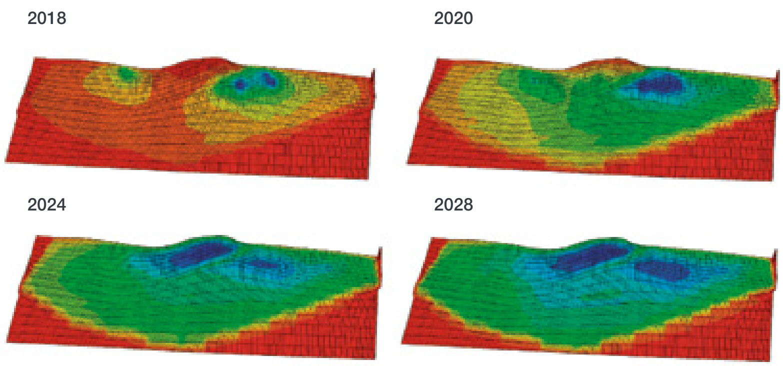

Figure 4. Four increments in an Abaqus FEA simulation of subsidence in a hypothetical oilfield, displayed over ten years. Blue areas denote greatest downward displacement of the surface. This particular example from Eni contains just 300,000 degrees of freedom; enhancements in model setup and automation now allow the running of huge full-scale models with millions of DOF in just a few hours. Rock faults (not pictured here) can be included in simulations.

Geomechanics group at Eni: (left to right) Caterina Topini, Gaia Capasso, Anna Corradi, Stefano Mantica, Marco Brignoli, Giorgio Volontè, Silvia Monaco, and Francesca Bottazzi.

With the goal of streamlining this process, Eni teamed with SIMULIA in a two-year R&D collaboration, the results of which were presented at the 2011 SIMULIA Customer Conference in Barcelona, Spain. "SIMULIA worked closely with us to develop new features in Abaqus that definitely change the approach to geomechanical reservoir simulation by allowing a completely automated workflow," says Monaco. "Now we can build a geomechanical model in only four weeks: We obtained an improved efficiency compared to the previous process in terms of elapsed time needed to set up an analysis. Moreover, the new iterative solver implementation provides a strong reduction in computational times and memory usage that further speeds up the execution of the study."

The new workflow (see Figure 3) automates the transfer of data from ECLIPSE into Abaqus and speeds the subsequent FEA model set-up, expanding the flow-centric view of a field-scale reservoir into a much richer 3D profile of flow-plus-subsidence over time. This involves the following steps:

- A translator establishes a link between ECLIPSE and Abaqus. All the information from the reservoir model (grid, properties, and pressure) is automatically populated into the FEA model in the form of data that can be used for the geomechanical analysis. For example, ECLIPSE cells are designated either as gas, oil, or water according to the percentage of fluid saturation they hold; in the Abaqus model the elements that are automatically derived from these cells can be assigned as many as 300 different material property definitions. ECLIPSE pressure history descriptions are also translated into Abaqus pore pressure values. These values are essential for calculating the change in the effective stress in the reservoir. Abaqus meshing tools automatically adjust the elements and nodes as needed and perform upscaling, a process that condenses the size of the FEA model by merging horizontal rows of elements while maintaining the vertical zones (where drill data has already been collected), which are more relevant to subsidence prediction.
- Burden regions over, under, and to the sides of the oil reservoir are created in Abaqus to extend the analysis to the terrain beyond the reservoir as the petroleum is pumped out.
- Once the model is set up, results from an initial elastic run are used to update the plasticity values (since rock behavior is elasto-plastic) to make the models more realistic. The simulations are then run over time increments so predictions can extend over many years (from the year 2018 to 2020 to 2024 to 2028, as seen in Figure 4).

New geomechanical models provide greater predictability

"We now have a logical scheme for easily and automatically executing all the steps required for creating and running our geomechanical models," says Monaco. "This significantly improves our efficiency in terms of user time in the preprocessing stage. Our analyses are now measurably more precise."

Such precision is helping Eni better serve their energy customers in developing strategies for ensuring sustainable oil and gas production for the long term.

"The increased quality of the results we've obtained with the new Abaqus implementations allows for a highly accurate and predictive environmental analysis," says Monaco. "This is a key point for a sustainable development of Italy's hydrocarbon reservoirs. Moreover, as a result of the cutback in computational times, a larger number of studies can also be performed internally, thus strengthening the link between geomechanical engineers and the team in charge of the geological and reservoir model construction."

In the near future, the Eni team plans to turn its attention to a comprehensive integration of the huge quantities of deformation measurements they've acquired at different scales and through different methodologies. "The automatic calibration of the rock properties of a geomechanical model will allow for this," says Monaco. "Isight process automation and optimization software from SIMULIA could be a proper tool for obtaining results."

For More Information

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