Pre-drill planning saves money

Modeling geomechanical stresses can reduce operational headaches.

AUTHORS
Andrew D. K. Brehm and ***Chris D. Ward***,
GeoMechanics International Inc.

Stuck drill pipe. Lost circulation. Everybody wants to avoid the millions of dollars and hundreds of manhours that can be lost as a result of wellbore instability and lost circulation problems. Fortunately, today's operators are increasingly recognizing that they have a weapon for controlling these issues and keeping budget and unforeseen problems under control by using comprehensive geomechanical models for effective pre-drill planning and superior casing design.

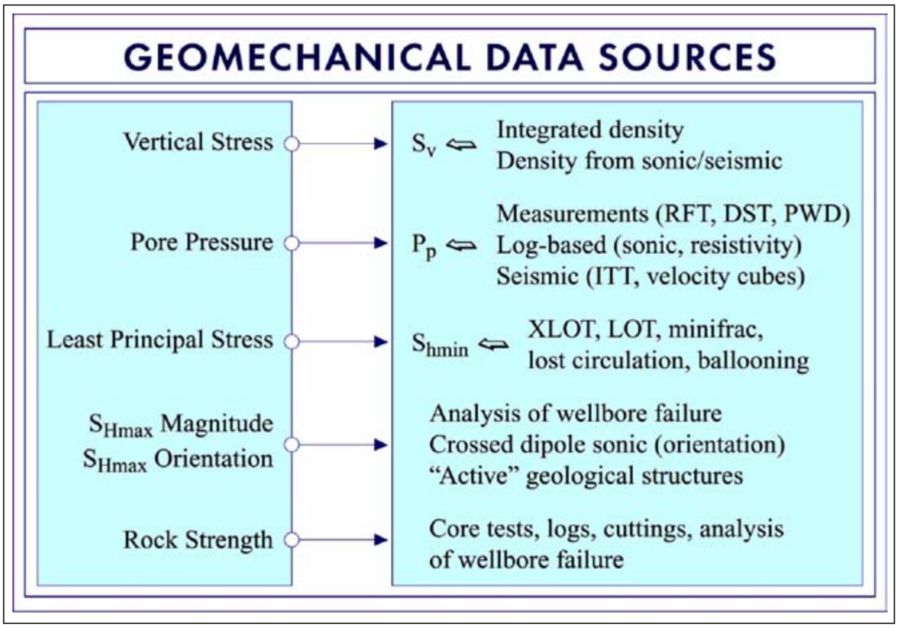

Figure 1. Core model components are essential to responsible geomechanical modeling. (Image courtesy of GeoMechanics International Inc.)

Traditional or optimal?

Traditional casing design and mud weight selection relies upon predicted pore pressures and empirically determined fracture gradients. Adjustments to the resulting mud weights and casing points come solely from offset well experience — necessary because the mud weights required to prevent both wellbore failure and lost circulation rely on wellbore trajectory and regional stress state. But today's marketplace and management demand more than a passive look at what's worked in the past. It's critical to establish limits of a safe operating mud window using a geomechanical model incorporating pore pressure, stress magnitudes and orientations, rock strength, and well trajectory.

Geomechanical model construction

Responsible geomechanical modeling starts with core model components, then refines as data permits. Core components are shown in Figure 1.

These components ultimately lead to guidance regarding mud weights needed to prevent borehole failure and lost circulation. Common data sources can include anything from seismic to core tests. Before using any model to predict mud weights needed to prevent wellbore failure in a planned well, the model must first be able to predict failure, or lack of failure, in offset wells where failure actually did or did not occur. This demands a detailed drilling history.

Borehole instability and lost circulation are both highly dependent on the stress state around the borehole. The three principal stresses are the vertical stress (S_v) or "overburden," maximum horizontal stress (S_{Hmax}), and minimum horizontal stress (S_{hmin}). The relative magnitude of each of these three principal stresses determines the type of geomechanical faulting stress regime.

The orientation of these stresses also has an impact on the position of the wellbore failure on the wellbore wall as well as implications for optimal drilling directions. The effective rock strength and other rock mechanical properties play a significant role in an effective geomechanical model. Laboratory core tests are the best source. This information is not often available, however, warranting the use of empirical methods.

Model verification

By inserting the mud weights used to drill an offset well into the model, one obtains the amount of failure that should have occurred under those stress, pore pressure and rock property conditions. Then, by comparing the predicted failure to the drilling experience, it is possible to verify the

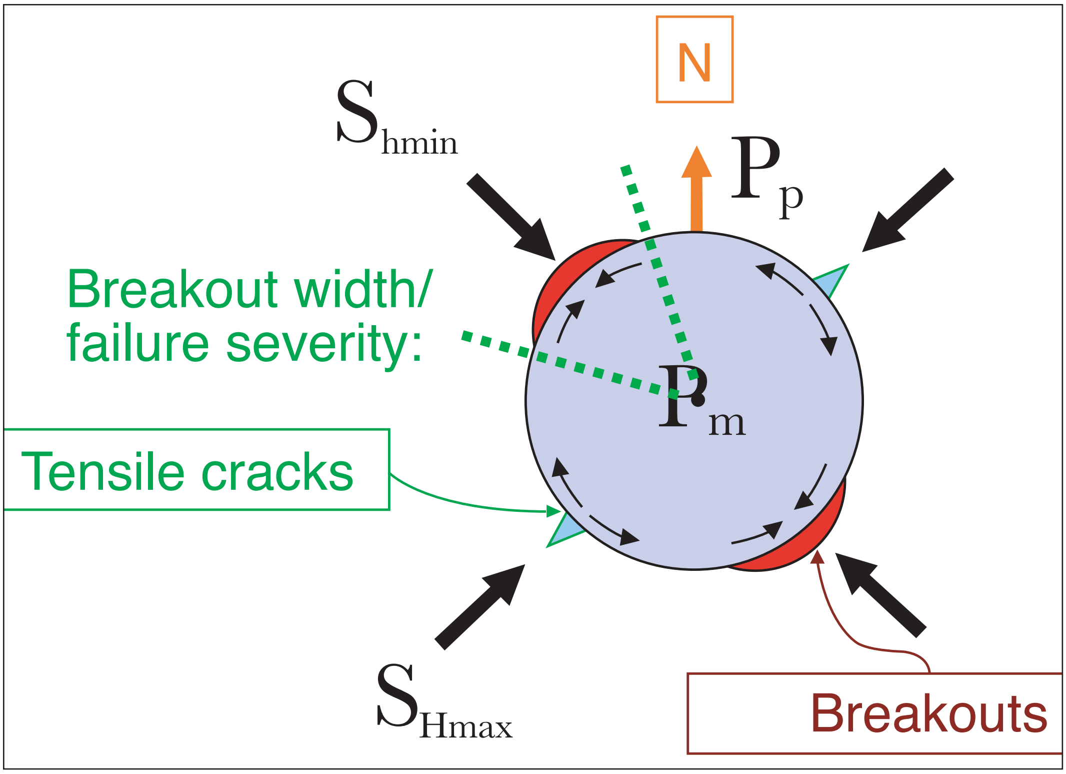

Figure 2. This illustration shows how wellbore breakouts form under the right stress, rock and mud conditions. (Image courtesy of GeoMechanics International Inc.)

model is sufficient for predicting wellbore failure in future wells. But what is wellbore failure?

In geomechanical terms, wellbore failure is defined by wellbore breakouts: part of the borehole wall caving in due to stress concentrations at the wall itself that result in shear failure. The breakout width depends on stress conditions, rock properties and drilling fluid pressure. If the breakout width exceeds approximately 90° to 100°, it is likely the rest of the borehole wall will collapse (washout). Similarly, if the stress and mud conditions are right, tensile cracks can be created at the points along the wall that are in tension (Figure 2).

When designing mud weights the point is not to select values which prevent breakouts all together. We're trying to keep them to an acceptable limit. This limit, the critical breakout width (CBW), is dependent on borehole deviation. Vertical holes are easier to clean, so we can withstand higher failures. A CBW of 90° is acceptable in vertical holes. Cleaning horizontal holes is harder, however, and, in these cases, acceptable CBW is reduced to 30°. CBW for any deviation between vertical and horizontal can be calculated by linear interpolation between 90° and 30°.

Putting it all together

Once the geomechanical model is developed and calibrated, different casing and mud weight plans should be tested against the safe operating mud window. Furthermore, determination of how much borehole azimuth and inclination are affecting the operating mud window should be made. It is also possible to quantify the sensitivity of wellbore failure to small changes in mud weight. After a casing plan has been selected, additional analysis should be made to identify the drilling risk based on the uncertainty in the model inputs.

Historically, casing points have been selected so that operating equivalent mud weights can be kept between the pore pressure and an empirically derived fracture gradient. However, it is possible to further define the bounds of the operating mud window by calculating a mud pressure needed to prevent wellbore failure beyond the CBW and the magnitude of S_{hmin}. By defining the lower bound of the operating mud window as the higher value of either the pore pressure or collapse pressure, mud weights will prevent any excess wellbore failure as well as preventing any formation kicks or flows. By using Shmin as the upper bound of the mud window, mud weights will be less than the pressure needed to propagate a hydraulic fracture using an oil-based mud system.

The borehole collapse pressure depends on the wellbore trajectory at a particular depth. In some cases, changing the well trajectory can improve the operating mud window and increase the chances of successful drilling.

Not only is it important to identify the mud weights needed to prevent borehole collapse beyond an allowable limit, but also it is critical to understand how sensitive the borehole failure is to changes in the mud weight. Often, due to swab events, well bores experience pressures less than the static mud weight. The sensitivity of failure to small changes in the mud weight determines the impact of swabbing in terms of borehole instability. Small swab pressures in a well bore can cause it to go from stable to unstable quickly.

Before completing the pre-drill plan, one must decide how much risk is associated with the desired casing plan. One method is to use a quantitative risk assessment (QRA) utilizing a Monte Carlo approach; this will generate a probability of success for a particular mud weight. Each input parameter used to make both borehole collapse and fracture calculations is assigned a most likely value as well as range of possible values. A bell curve is then fit to each of the ranges, and 10,000 simulations are performed within these bell curves. QRA also allows for identification of the most sensitive uncertainty parameters.

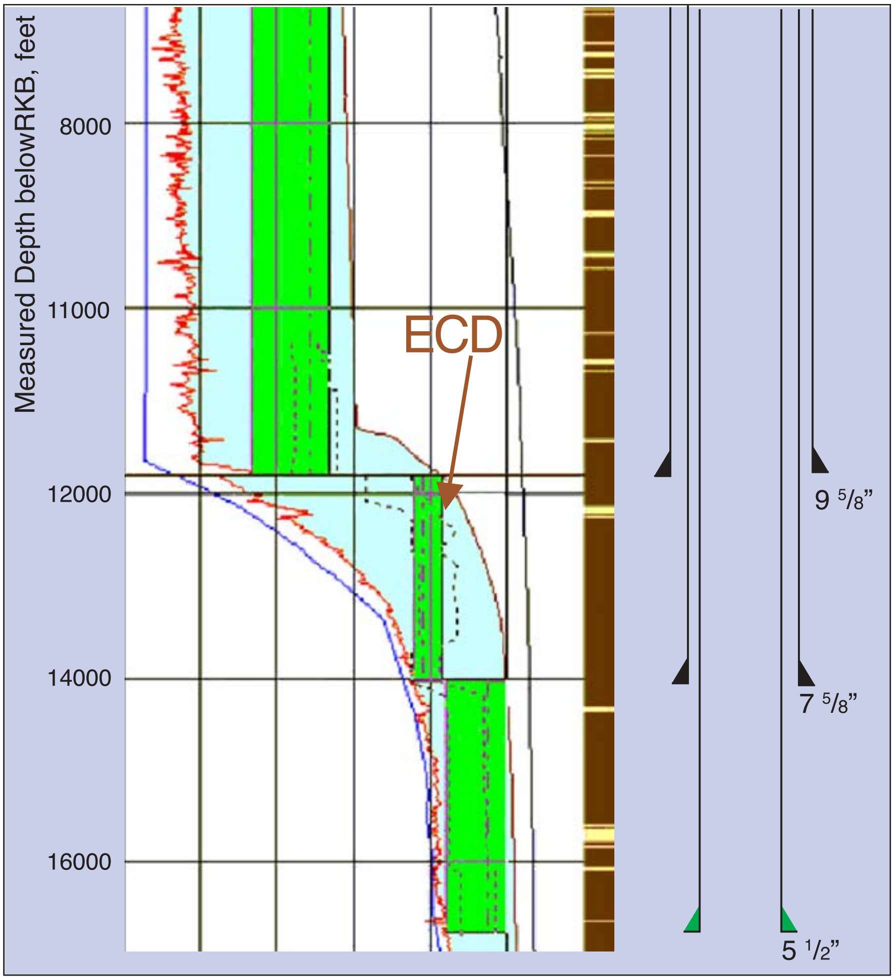

Figure 3. The actual casing points, equivalent circulating densities and static mud weights are displayed here against the pre-drill geomechanical model. (Image courtesy of GeoMechanics International Inc.)

Post-drill verification

The pre-drill geomechanical model should be verified based on the actual experience of the planned well. Lost circulation events will be used to verify the upper bound of the mud window. One of the best tools for evaluating lost circulation events is a pressure-while-drilling tool. Its data, preferably time-based, gives accurate determination of equivalent mud weights when losses start and stop. Drilling events potentially associated with the lower bound of the mud window (i.e. pore pressure and collapse pressure) such as stuck pipe, kicks, tight hole and hole enlargements are also used to verify the model.

Gulf of Mexico case study

For a planned well in **West Delta block 83**, Goodrich Petroleum Company and GeoMechanics International Inc. (GMI) teamed up to study the use of a geomechanical model to optimize the casing design of a deviated well bore and prevent problems which had occurred in offset wells. Data from two offset wells were used to develop and validate the geomechanical model, with resulting casing points and mud weights adjusted to meet well challenges. Least principal stress determined upper bound mud weight, while both the pore pressure and the mud pressure determined the lower bound mud weight.

Uncertainties in the geomechanical model were then evaluated using quantitative risk assessment to determine the confidence level in different casing plans; this allowed the operator to make a risk-based decision on the final casing design. Based on the results, the operator chose an aggressive casing design in order to reach the target sands with the optimum borehole size and a minimum number of casing strings. The greatest uncertainty in the geomechanical model occurred within the overpressure zone. To mitigate the risk, a 7-in. contingency liner was added to the drilling plan and authority for expenditure (Figure 3).

The result? Successfully drilling the well without major wellbore stability issues. No stuck logging tools. No flows and kicks. No excessive reaming. The project team could not have made such informed decisions without such pre-drill geomechanical modeling. In an environment where operating costs and marketplace pressures make unprecedented demands on performance, such detailed pre-drill modeling will soon become a prerequisite for competitive operators.