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Process of integrating Geomechanics with well design and drilling operation

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Abstract

Wellbore stability can have a major effect on well design. Traditional drilling engineering envisions the pressure window between pore pressure and fracture gradient. However, wellbore stability can control both the lower and upper bounds of the mud weight window. The pressure controlling excessive formation breakout can exceed one to control formation fluids and may be the most significant design parameter in choosing mud weight and operational practices. In addition, the maximum mud weight is often controlled by formations with micro fractures that destabilize at a lower mud weight then what is required for hydraulic fracturing resulting in excessive fluid losses.

The benefits of considering wellbore stability follow not only from pre-drill planning, but real-time monitoring, updating and calibration of the living model.

This paper will present examples of how wellbore stability parameters were used in well design, including casing seat selection and benefits of verifying actual wellbore stability while drilling.

Introduction

Oil and gas industry spends over one billion dollars a year for non-productive time and lost in hole costs. Significant part of it is taken by the kicks, mud losses, excessive circulations, stuck pipe and other instability related events. Some events occur due to lack of planning, which makes it unavoidable. Some events occur due to lack of execution that makes the events impossible to prevent and difficult to control.

A major concern of drillers is pore pressure. However, even normally pressured formations do not imply trouble free drilling. In many cases there is a problem of keeping the wellbore stable, at which point the mud weight is constrained by the minimum stable and fracture gradients. This minimizes the permissible safe mud weight window and unawareness could cause overpulls, hole-cleaning problems, pack offs, lost in hole equipment and loss of circulation. This could lead to costly sidetracks or the loss of the wellbore. To avoid and manage the unstable borehole a good geomechanics well bore stability model must be incorporated into the drilling plan with the means for monitoring and updating.

This paper emphasizes the process of integrating geomechanics with both well design and drilling operations and presents the positive results of implementing this process with an example from an extended reach (ERD) well.

Well bore stability modeling [2]

Modeling borehole stability is a complex problem[2]. The instabilities are subdivided into two main types: chemical and mechanical. In the first case the instability is caused by formation reaction to the drilling fluids and is controlled with the mud type and its properties. Where in the second case it is a function of in-situ stresses, pore pressure, rock strength and are controlled by the annulus pressure or mud weight. Most of the time there is a composition of the two. In many cases oil based mud handles the chemical instability well. The main discussion point of this paper will be the mechanical type.

To minimize the mechanical instability mud of the right density should be determined in the pre-drill well bore stability analysis. The analysis contains: study of the mechanical and elastic rock properties, rock strength, identifying principal stress magnitudes and directions, and building a pore pressure model. Image and caliper logs in conjunction with cavings morphology are used to identify the failure mechanism. Combined with results of core analysis, along with geological and basin knowledge, a deformation model can be chosen. This model will best represent the rock behavior once the hole is drilled. Using the well inclination and azimuth the far-field principal stresses are converted into the stresses around the wellbore (Hoop stresses). This is used to gain an understanding of the principal stresses at each point around the circumference of the borehole with depth. A preferred failure criterion is then applied. This calculation gives an indication of the minimum required mud weight to avoid certain modes of failure. The two types of the rock failure presented on Figure 1 are tensile and compressional (or shear) failure. For these failures to occur certain criteria should be met.

Different modes of the failure are presented on Figure 2. The modes of failure highly depend on the mud weight pressure.

Geomechanics consideration within the drilling program

After the well has been drilled, the well bore stability analysis can give ideas on improving future operations. To achieve this, a 3D Mechanical Earth Model (MEM) [4] should be built.

A full 3D MEM must encompass physical properties of the rock, pore pressures, in-situ stresses, drilling mechanics and other parameters. Based on the3D MEM a well bore stability forecast for the planned well trajectory can be developed. It helps to identify the most efficient path to the targets. This includes the identification of a stable trajectory, casing point optimization, BHA and drill string design, mud weight and hydraulics optimization. Knowledge of unstable depth intervals, and failure severity facilitates in establishing proper drilling practices and procedures. Understanding stability provides additional information to analyze drilling events, which allow the alteration of drilling and completion operations.

Real time WBS Management Process

The real time WBS Management Process has been developed for drilling. This combines interpretation of drilling mechanics and down hole measurements with the WBS model. Refer to Figure 3.

WBS Model

All models have assumptions, which inherently cause uncertainty. The WBS Model is no exception. The information gained from the correct interpretation of surface and down hole measurements is invaluable when reducing model uncertainty. The pre-drill model must be combined with all possible information while drilling to realize its full power of predictability in front of the bit.

Interpretation of Drilling Mechanics

All drilling mechanics measurements must be correctly interpreted. The following is a common list of drilling mechanics parameters that need to be interpreted while drilling:

- On bottom torque/Off bottom torque
- Pick up weight/Slack off weight/Rotating weights
- ROP
- Cutting Removal Index, Cuttings/Cavings morphology

Vibration from surface measurements (best from high speed frequency data)

Experience has shown that correct interpretation of these parameters give important clues on the stability of the well bore.

Interpretation of Down hole Measurements

Measurements from MWD/LWD tools provide invaluable information of actual down hole conditions. The following down hole parameters are essential when identifying WBS issues:

- DTOR/DWOB
- ESD/ECD
- Downhole vibrations (axial, lateral, torsional)
- Collar RPM
- LWD Data (Resistivity, Sonic, Density, GR, Caliper)

It has been shown that these and other down hole parameters provide a full picture of events occurring down hole.

Decision Point

After correctly interpreting all drilling mechanics and down hole parameters in conjunction with the real time WBS model, the information must be compared to the pre-drill model. Compliance between models assures predictability ahead of the bit. The drill team can continue drilling with confidence. However, if the models disagree, calibrations must be applied.

Calibration of Models

The models are calibrated with interpreted real time data time to reduce uncertainty. Each calibration reliably provides predictability in front of the bit.

Knowledge Capture, Change Drilling Program, Alter Drilling Practices

A host of interpretations, drilling events and data points are utilized for each calibration. This information is very powerful and should be captured as lessons learned for future projects.

At this point, the WBS model has been calibrated using actual drilling data, which then provides predictability ahead of the bit. However, if the Drilling Program and Drilling Practices do not change, the WBS model's power has been lost. The information provided by the calibrated WBS model can be used to push casing seats, eliminate casing strings, extend reservoir drainage, and ultimately increase production.

The Real Time WBS Management Process is very effective if each step is followed. The step which is most ignored is the Knowledge Capture, Change Drilling Program, Alter Drilling Practices step. The principal cause of failure is linked to drilling culture. Company men, drilling engineers, and drilling superintendents must be willing to change drilling programs and drilling practices based upon interpretation of while drilling data. Communications with the entire drill team (G&G, Drilling Department, Company Men and Rig Crew) is also essential for this process to be successful.

Evaluation

After the completion of the drilling phase, all events and results are carefully analyzed and summarized. Lessons learned and good practices are captured into a database for further development.

The model can be brought to the next level for completion optimization. This can include optimization of perforations, reservoir fracturing, and sand control.

Case Study [6]

The Petronius field located in the Gulf of Mexico Viosca Knoll 786 has been under development since 2000. One vertical and several deviated wells have been drilled in different directions from the platform. As the reach became longer at the same vertical depth (TVD), the wells have become increasingly difficult to drill and the need for wellbore stability modeling and management became necessary. The "No Drilling Surprises" (NDS) [1,3] service provided by Schlumberger was applied. This solution provides pre-drill modeling, real-time model updating and implementation of the resultant changes at the rig site to lower and manage the risks and reduce non-productive time.

As a result of the open collaboration and integration of many disciplines in one process, six (to date) extended reach wells have been successfully drilled with significant time (of up to 30%) and money savings for the operator.

This case study is related to the sixth ERD and its geological sidetrack in the field A-21 and A-21 ST1.

Well design

Petronius ERD wells have common design parameters:

- Previously set 20" conductor pipe
- 17 ½" hole with 13 3/8" casing (the build up section)
- 12 ¼" hole (the tangent section) with 9 5/8" casing, inclination varies for a maximum of 79 degrees and
- 8 ½" hole with 7" liner (the reservoir section)

As the development progressed some modifications were applied such as drilling 8 ½" by 9 ¼" hole using bi-centered bit on the rotary steerable.

Objectives and challenges

Petronius platform is one of the world deepest fixed structures positioned in over 1,750 ft of water. It is located at the frontier of shelf and deep water. Water depth varies around the platform from 700 ft to 3400 ft depending on the azimuth. On the way to the reservoir dipping formations and low-pressure sands had to be drilled.

Predrill analysis identified hole cleaning, excessive circulation time, tight hole, over-pulls, pack offs, tools lost-in-hole and sidetracks as the main drilling problems. These issues are exasperated as inclination increased. The increase in inclination narrows the safe mud weight window.

The main objectives were to:

- Avoid high over pulls, stuck pipes, lost-in-hole, loss circulations
- Place 9 5/8" casing past the unstable zone before drilling into lower fracture gradient formations with higher mud weight
- Monitor ECD and ESD within the limitations established and, constrain in real time
- Monitor hole conditions, and drill within rig limitations

Modeling

A three dimensional approach was taken in order to model the stresses and account for the changes along the well path

A full 3D Mechanical Earth Model (MEM) [4] was built using 3D seismic, logs and tests information and incorporated drilling experience from all the wells previously drilled in the area.

Figure 4 shows in blue a comparison of the overburden estimated *with (red)* and *without (blue)* taking into account water depth variation.

New safe margins had to be established due to the narrow stable mud weight window. The acceptable magnitude of the failure that could be handled by the rig hydraulics was estimated at 60 degrees. This means allowing failure of 60 degrees along the circumference of the borehole symmetrically on each side. This limit is represented as MW60 on Figure 5. Please note that once the failure of the borehole wall is initiated, there is no predictive answer of how the breakout is going to behave. Therefore emphasis was made on realtime ESD/ECDto be greater than failure initiation pressure.

Drilling mechanics response was modeled and optimized upon the stability prediction.

Torque and Drag analysis was conducted and theoretical profiles calibrated with the real time of pick up and slack off weights data (Figure 6).

Limitations of the most essential rig equipment were considered in the modeling for preventing and eliminating potential failure.

For this particular well it was identified that instability will be met shallower due to trajectory and structural features. This drove the decision for the placement of the 13 3/8" casing. This avoided the risk of setting it shallow, leaving a big interval of 17 ½" hole open. This could have jeopardized the cement job and circulation efficiencies of the next hole section.

It was established that A-21 original hole could be completed with 12 ¼" size hole. In case the reserves will not be proven the sidetrack option will be exercised and 8 ½" by 9 ¼" hole drilled with the lower mud weight to avoid losses in the weaker zones. The mud weights and initial drilling parameters were identified for the both original well and the sidetrack.

Real time updating

Based on the pre-drill analysis certain degree of the hole instability had to be allowed. To successfully manage drilling in such conditions close monitoring[5] must be applied.

The following log measurements were used to update the geomechanics model: gamma ray, resistivity, sonic, density and porosity from the neutron tool.

The main challenge was to keep borehole stabile, in terms of both collapsing and fracturing the formation. ECD magnitude is sensitive to the hole condition and, due to a little tolerance, it had to be managed within 0.1 ppg of the established limits.

Understanding the possible processes occurring in the borehole permitted real time interpretation of the log and drilling parameters response. Pick up, slack off and rotating weights of the drill string calibrated and compared with the actual measurements while drilling and on every trip (Figure 6). This provided an overall understanding of the well condition. The correct interpretation of this information together with ECD and drilling parameters provided actionable information.

After drilling the first 1,500 ft of the 12 ¼" hole losses were experienced. Using APWD interpreted data, new safe limits for the ECD were established. During the trip out at around 15,000 ft MD operations were suspended due to rough weather. . As a result, overpulls and formation packing off were experienced. These events compelled the drill team to set the contingency casing at this depth to isolate the trouble zone. However, the updated WBS model along with real time drilling observations provided strong evidence not to exercise the contingency option. The drill team debated this information and collectively decided to continue drilling. As a result, the original hole successfully reached TD.

The sidetrack was started from 19,000 ft MD of the original hole. Using real time data the 9 5/8" casing point was adjusted. This prevented drilling into the loss circulation zone with the higher mud weight.

The minimum horizontal stress was used as the safe upper bound. However utilizing a full wellbore stability prediction allowed calculations of formation breakdown pressure gradient based on the hoop stress theory. The mud weight was adjusted for the 8 ½" by 9 ¼" section. No losses were observed in further drilling.

Results and Conclusions

The fifth ERD well and its geological sidetrack were successfully drilled applying Real Time WBS Management Process and integrating across various disciplines. The client and service companies communicated and debated information based on real time information. Drilling plans and practices were alter which ultimately resulted with a well bore which was drilled safely and efficiently.

There were no stuck pipe incidences, lost-in-hole or costly sidetracks. Losses and instabilities were successfully managed. All the targets were reached and all of the casings went to the planned depth.

The drilling of the original hole was on the AFE plan (excluding the waiting on weather and time spent on installing equipment). The sidetrack was drilled 16 days under AFE.

Predrill mechanical earth model with the means for real time updating and monitoring, along with proper communication are crucial to success of the drilling operation. It is especially critical to the cases of unstable formations and changing environment of ERD wells.

Nomenclature

AFE = Authorisation For Expenditure
APWD = Annular pressure while drilling
BHA = Bottomhole assembly
DTOR/DWOB = Downhole torque and weight on bit
ECD = equivalent circulation density
ESD = equivalent static density
ERD = Extended reach drillng
LWD = Logging While Drilling
MEM = Mechanical Earth Model
MWD = Measuraments While Drilling
NDS = No Drilling urprises
RKB=rig floor kelly bushing elevation
RPM = Revolutions per minute
ROP = drilling rate of penetration
TD=total depth
TVD=true vertical depth
WBS = Well Bore Stability
WOB = weight on bit

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References

1. Bratton, T., Edwards, S., Fuller, J.: *"Avoiding Drilling Problems,"* Oilfield Review (Summer 2001) 32-51.
2. Addis, T., Boulter, D., Last, N., Plumb, R.A.: "*The Quest for Borehole Stability in the Cusiana Feld, Colombia*," Oilfield Review (Summer 1999) 33-43.
3. Aldred, W., Plumb, R.A., Cousins, L.: *"Managing Drilling Risk,"* Oilfield Review (April/July 1993) 2-19.
4. Plumb, R.A., Edwards, S., Pidcock, G., Lee, D*.: The Mechanical Earth Model Concept and Its Application to High-Risk Well Construction Projects"*, IADC/SPE 59128
5. Bradford, I.D.R., Aldred, W.A., Cook, J.M.: *"When Rock Mechanics Met Drilling: Effective Implementation of Real-Time Wellbore Stability Control"* IADC/SPE 59121
6. Smirnov, N.Y., Tomlinson, J.C., Brady, S.D, Rau, W.E.: "Advanced Modeling Techniques with Real-time Updating and Managing the Par

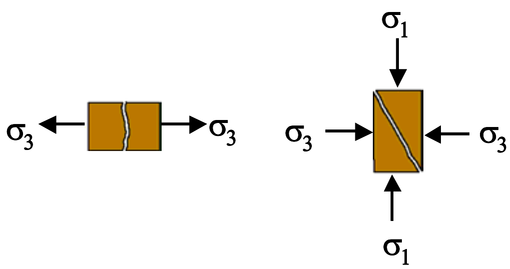

Figure 1 Rock Failure: Tensile (left) and Compressional or shear (right)

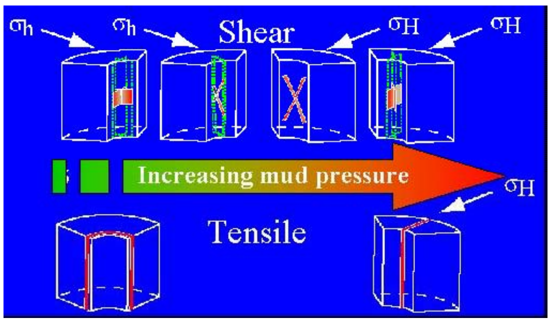

Figure 2 Modes of failure. Shear failure from left to right: wide breakout, shallow knock out, high angle echelon and narrow breakout. Tensile failure: circumferential failure and fracturing.

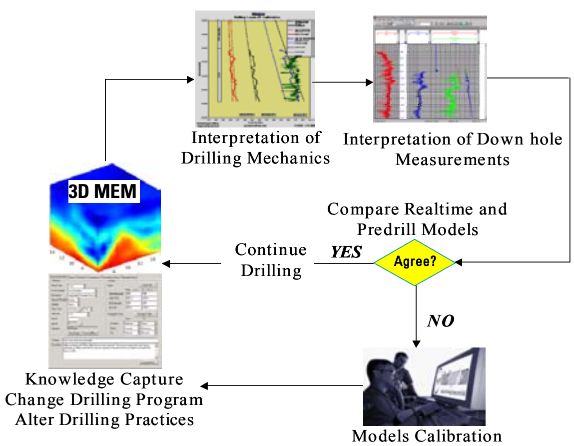

Figure 3 Real time WBS Management Process

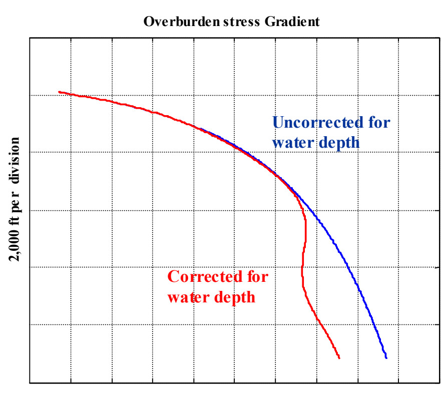

Figure 4 Overburden stress comparison

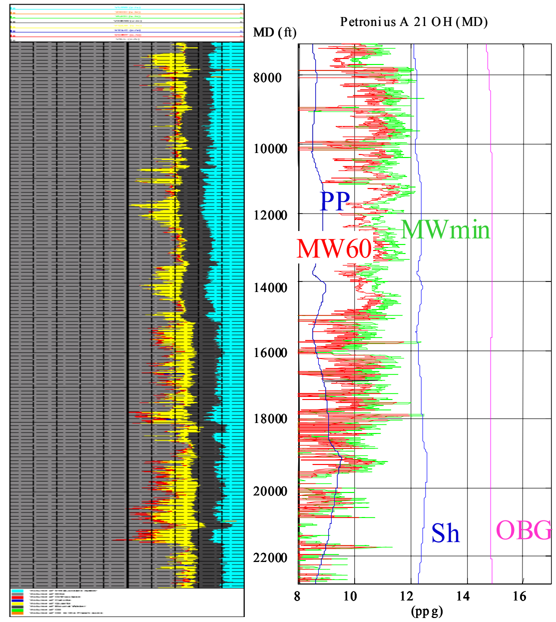

Figure 5 Well bore stability modeling results

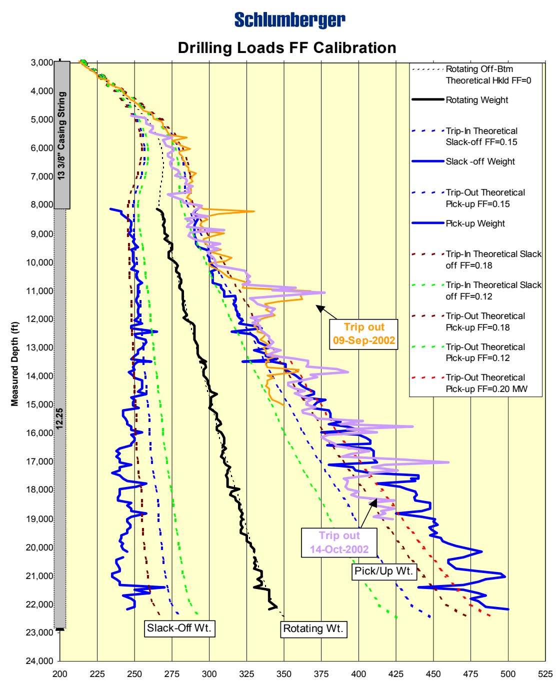

Figure 6 Tripping Loads