

BHA Selection and Drilling Practices to Successfully Drill and Underream Difficult Deepwater GOM Salt Section, a Case History

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Abstract

A recent well drilled in the Green Canyon field in GOM deepwater required drilling through more than 15,000 ft of salt formations. Offset wells in this area with BHAs (Bottom Hole Assemblies) including hole opening devices were challenged by excessive vibrations resulting in drillstring twist-offs and subsequent fishing operations. In addition, episodes of low rate of penetration were observed, most likely due to weight transfer problems between reamer and bit.

These challenges were addressed by careful BHA engineering in the planning phase plus the integration of a downhole measurement and dynamic diagnosis system into the drilling system. In the execution phase, the tool provided key information in real-time, allowing informed decisions to be made to ensure a safe and efficient drilling environment. In particular, the downhole weight measurement was instrumental to properly identify the weight taken by the reamer versus the weight transferred to the bit.

The paper/presentation describes the detailed planning and BHA selection and presents the lessons learned in the execution phase of the well. Some log examples document the effect of changes in drilling parameter and practices on the downhole dynamics response and the drilling performance results achieved.

Introduction

Green Canyon field is located in south-southwest of New Orleans in the Gulf of Mexico, United States as shown in Fig. 1. Several deepwater discoveries have been found since 2000 to date, with appraisal, development and more new exploratory wells under construction.

The deepwater prospects blocks in Green Canyon, Gulf of Mexico consist of major and minor anticlinal structures with trapped salt formations, some clean and others with inclusions. The depth of salt formation in some of the blocks discovered and explored to date ranges from 10,000 – 17,000 ft TVD depending on the

sedimentation and formation dip. The area has produced significant quantities of oil and gas per day from the pay sands of Miocene and Oligocene formations. The move into deeper waters has provided new opportunities for petroleum production, but it has also provided new challenges as different reservoir problems are encountered.¹ In this field, the sedimentations are heterogeneous, thus making it difficult to predict the interaction of formation layers as earth movements may have created impurities or inclusions. Reference 1 describes detailed integrated characterization of beds in the Green Canyon field.

The drilling of the heterogeneous layers and transition zones of halite, sandstone and calcite usually pose drilling challenges due to vibrations, in particular, when entering the salt with inclusions in the top part or when transitioning into another formation. Destructive vibrations have also been observed when exiting the salt. In reference to the applications discussed in this paper, two earlier wells drilled in the same field with approximately the same formation characteristics exhibited catastrophic failures after drilling about 500 – 2000 ft into the salt formation.

In both wells, different vendor rotary steerable tools (RSS) with concentric reaming devices were utilized to simultaneously drill and underream. Due to the principle of operation, concentric reamers are inherently more stable in design than eccentric reamers.² This has proven advantageous in reducing non-productive time (NPT) and cost with the deepwater applications. Unfortunately, in the two offset wells twist-offs occurred in the drill stem due to heavy downhole vibrations. The subsequent fishing operations resulted in significant delays with respect to planned AFE drilling days. In addition to the twist-offs, the offset wells exhibited also periods of lower than expected rate of penetration (ROP), most likely due to problems of transferring sufficient weight to the bit.

The drilling program for the subject well of this case history was engineered to minimize the risk of twist-offs. The industry's most advanced real-time drilling dynamics and optimization tool was integrated into the BHA in order to identify critical situations and mitigate them

through active intervention of an onsite drilling optimization engineer. The execution phase of the well showed that BHA selection as well as parameter management was the key to success in the difficult well intervals. As demonstrated in similar applications in the past, accurate information about the downhole weight on bit compared to the weight on the reamer, actual downhole torque, dynamic diagnostics, and actual downhole rotary speed (RPM) provided critical insight into downhole conditions while drilling. Figure 2 shows the planned BHA to drill the trouble interval. This will be further discussed in the planning phase.

The main focus of this case history is the design and execution of the planned strategies, interpretation, and communication of the data sent uphole by the drilling optimization tool included in the drillstring.

Project Interval Objectives

Figure 3 shows a typical casing program for the ultra deep wells in the field. The top section below the mud line was planned and executed as a 26" jet-in with a drill-ahead assembly consisting of a 9 1/2" positive displacement motor with 0° bent sub, to a 22" surface casing point. The 18 1/8" x 22" section below the 22" casing includes the salt formation and is the interval of interest for this case history.

The drilling objectives for this section were as follows

- Successfully drill pilot hole while underreaming the section in same pass
- Avoidance of twist-offs encountered in offset wells
- Minimize ECD changes by applying good hole cleaning and drilling practices to minimize risk of losses and kicks

BHA Planning

Real-time drilling dynamic information was essential to make necessary adjustment to drilling operations. A rotary steerable assembly with concentric hole opener as a one pass drilling solution was selected to deliver a smooth wellbore with low tortuosity, precise directional control and supreme hole cleaning capability. A bi-center bit solution was originally considered, but was dropped due to disadvantages compared to the concentric reamer in terms of poor directional control, high vibrations and high risk of creating an irregular spiral hole due to the eccentric design.³

Limited information was available about the offset failure scenarios, as both wells were still in tight-hole condition, and were drilled by different service providers for different operators. As a result, a lot of focus was given to real-time drilling dynamic information in order to be able to make necessary adjustments to drilling parameters to ensure safe and efficient drilling. As such,

a state-of-the-art drilling dynamics sub was placed between the 18" stabilizer and the 22" underreamer.

In order to minimize the BHA radial movement in the borehole, careful attention was given to the placement and spacing of stabilizers in the BHA. In order to select the optimum drilling assembly for the subject well, various designed BHAs were mathematically modeled to simulate the natural frequency of the BHA. Graphical presentation of the related mode shapes (radial movement vs. of distance from bottom) allowed for a quick interpretation of trouble spots and associated frequencies. The modeling predicted a safe rotary speed and weight-on-bit operating range for simulated conditions based on surface parameters, mud properties, and wellbore geometry.

Problem Identification Challenges

Providing accurate information about downhole drilling conditions in real-time to surface via MWD technology is challenging. Destructive drilling dynamic events typically lie in the 0 – 75 Hz frequency range, thus the standard sensor readings in the MWD tool cannot be observed in real-time on surface due to the transmission bottleneck with mud pulse telemetry. This challenge has been solved by analyzing sensor data downhole and transmitting processed data in the form of diagnostic flags to surface. The downhole drilling dynamics tool used on this project was programmed to simultaneously acquire high rate measurements data (1000Hz) from a total of 14 sensor channels, and further diagnose the occurrence and severity of various drilling dynamics phenomena.^{4,5} This may be in form of bit bounce, stick-slip, whirl, or lateral vibration. A real-time display placed in key offices on the rig and the rigfloor shows the vibration conditions in a way that allows an optimization engineer to communicate effectively to the driller to mitigate an occurring event. Figure 4 shows a real-time capture showing drilling salt with inclusions with minimal vibration.

It needs to be emphasized that downhole problem identification in real-time is important for instant reaction at surface. This process was obviously absent in the offset wells, as problems were not easy to identify, hence were difficult to mitigate.

Execution Phase and Lessons Learned

The 18 1/8" x 22" BHA including 18 1/8" pilot PDC bit, 9 1/2" rotary steerable system including the 9 1/2" drilling dynamics and optimization tool, and a 22" concentric reamer⁶ was picked to drill the float of the earlier set 22" casing about the top of the salt.

Drilling sand-shale interbedded formations resumed, after a successful formation integrity test (FIT) was performed. The reamer was mechanically activated by dropping a ball through the center of the drillstring. Upon

successful activation, the particular reamer used in this deployment diverts some mud flow through the drillpipe through nozzles to clean the reamer cutting elements.

The successful activation of the reamer was confirmed by the differential pressure information from the drilling dynamics tool in the BHA. As less flow was circulated through the bit, the differential pressure dropped after activation of the reamer - visible on the rig site on a surface display in real-time. The log excerpt in Figure 5 shows the decrease in differential pressure while maintaining the same flow rate. With this confirmation, drilling of the section resumed.

As the reamer entered the salt, strong oscillations were noticed up to severity levels 4-6, equating lateral vibration signals of 5-15 g_{RMS} amplitudes. At about 200ft below the top of salt, severe torsional oscillations up to full stick-slip developed. In most drilling operations, a decrease in weight-on bit and increase in rotary speed would mitigate this problem. However, the depth-based log in Figure 8 shows that despite the fact that the rotary speed was increased from 90 to 135 RPM, while the weight was backed off to about 30 klbs, the torsional oscillation could not be eliminated. Based on the real-time diagnostic feedback, the onsite optimization engineer identified a stable operating window at 120 RPM and about a constant weight on bit of about 40klbs. About 300ft below this point, the bit drilled into an inclusion, and the downhole torque measured by the dynamics tool increased. When the reamer got to the same spot, it reacted to the change in formation by taking a lot of weight, slowing down the rate of penetration. At this point, a strong lateral vibration in the form of BHA whirl developed. The action of stopping drillpipe rotation for some time and gradual restarting of drillstring rotation did help to overcome the weight transfer problem, however, it failed to eliminate the whirl of the BHA. It was not until further dropping the downhole RPM to 100 and maintaining 40klbs WOB, that a smoother drilling environment could be established. The time log in Figure 6 documents the efforts undertaken by the onsite engineer to improve the rate of penetration over the rest of the run by reducing lateral vibration by decreasing rpm from 120 to 99. Parameter management to reduce or eliminate drilling dysfunctions in this type of situation was successful due to the accurate and true downhole information and relied heavily on proper communication with the entire drilling team. In the subject well, the rotary speed and the weight had to be controlled within ± 20 RPM in some intervals without inclusions and up to ± 51 RPM with inclusions and within ± 35 klbs WOB adjustments in most cases in real-time to mitigate possible catastrophic whirl, lateral and torsional vibration.

The downhole weight on bit measurement was valuable to determine the weight taken by the reamer in the drilling process. The difference between the surface and downhole weight in the logs presented in this paper

is actually the weight taken by the reamer. This insight into the downhole environment helped to identify situations where the bit is out-drilling the reamer, i.e., the reamer tends to accumulate more weight while trying to establish its cutting pattern, thus reducing penetration rate. Figure 7 shows an increase in the weight on the reamer as the overall weight applied to the system increased. The diagram also shows an almost linear increase in ROP while reducing the RPM at the same time. The high variations show that there was no one single solution to effective drilling as long as environmental factors change constantly, emphasizing the need for timely, accurate downhole feedback from the drilling optimization tool.

Whirl Diagnostics and Bending Moment

When drilling this vertical well with an underreamer, several events of severe whirl were observed, especially below the hole opener. Whirl is caused by off-center rotation of the components with mass imbalance in the drillstring. In some cases, forward whirl develops, which causes eccentric component wear as the drillstring rotates clockwise in the direction of bit rotation. Backward whirl causes excessive cyclic stress reversal leading to fatigue as the center of the drillstring moves around the borehole faster than the applied rotary speed. This phenomenon was observed in many occasions. In the log excerpt in figure 8, several attempts to increase rpm resulted in backward whirl, causing the driller at surface to back off the rotary speed immediately in order to prevent failures of the downhole BHA.

The bending moment describes the bending stresses that drillstring components are exposed to. The bending stresses can be a result of direction changes in the wellbore, or, as in Figure 8, a result of the whirl motion of the string causing high dynamic bending stress changes.

Conclusions

The main achievement of this interval is that it was drilled with no twist-off or any other catastrophic drillstring failures that would have elongated the interval drilling time and probably the entire project. It also enabled the drilling operator to improve the downhole drilling environment by optimizing several surface drilling parameters.

The downhole weight measurement successfully identified the weight taken by the reamer which can't be recognized by the standard WOB measurement at surface. The downhole dynamics tool also confirmed that the reamer was activated, therefore eliminating another hole opening trip before the casing was run.

Loss of stabilization was also seen as a cause of whirl that could have been detrimental to the entire drillstring; therefore drilling parameters were aggressively managed to mitigate whirl situations.

The real-time update and the intervention by an experienced dedicated onsite engineer were found crucial for the successful drilling of this section. The presence of the engineer helped to establish the required focus on mitigating critical situations.

The experience gained in this vibration prone zone has been valuable to subsequent BHA designs and drilling activities in other planned sections in this field by the operator.

The interval was finished nearly vertical, with maximum inclination of 2.8°, a dogleg created when the reamer engaged a formation stringer.

The drilling practices established on this section will be used as a standard in this field, where all prior drilling attempts encountered at least one major failure with other equipment, including subsequent fishing operations.

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Nomenclature

<i>AFE</i>	= <i>Authorization for expenditure</i>
<i>BHA</i>	= <i>Bottomhole assembly</i>
<i>FIT</i>	= <i>Formation integrity test</i>
<i>MWD</i>	= <i>Measurement while drilling</i>
<i>NPT</i>	= <i>Non productive time</i>
<i>RMS</i>	= <i>Root mean square</i>
<i>ROP</i>	= <i>Rate of penetration</i>
<i>RPM</i>	= <i>Revolutions per minute</i>
<i>RSS</i>	= <i>Rotary steerable system</i>
<i>WOB</i>	= <i>Weight on bit</i>

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Figures

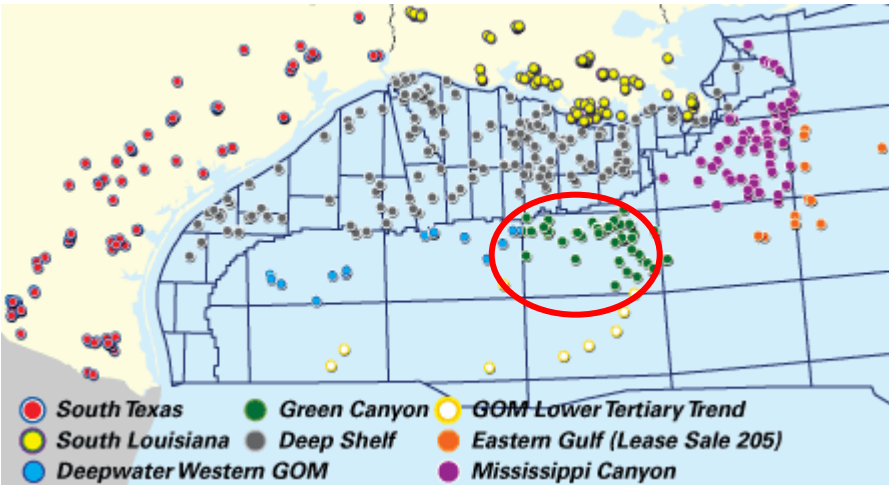


Figure 1: Outlook of Green Canyon Deepwater Blocks, courtesy of Rock Solid Images (Rock Physics Atlas and AVO Atlases website; www.rocksolidimages.com)

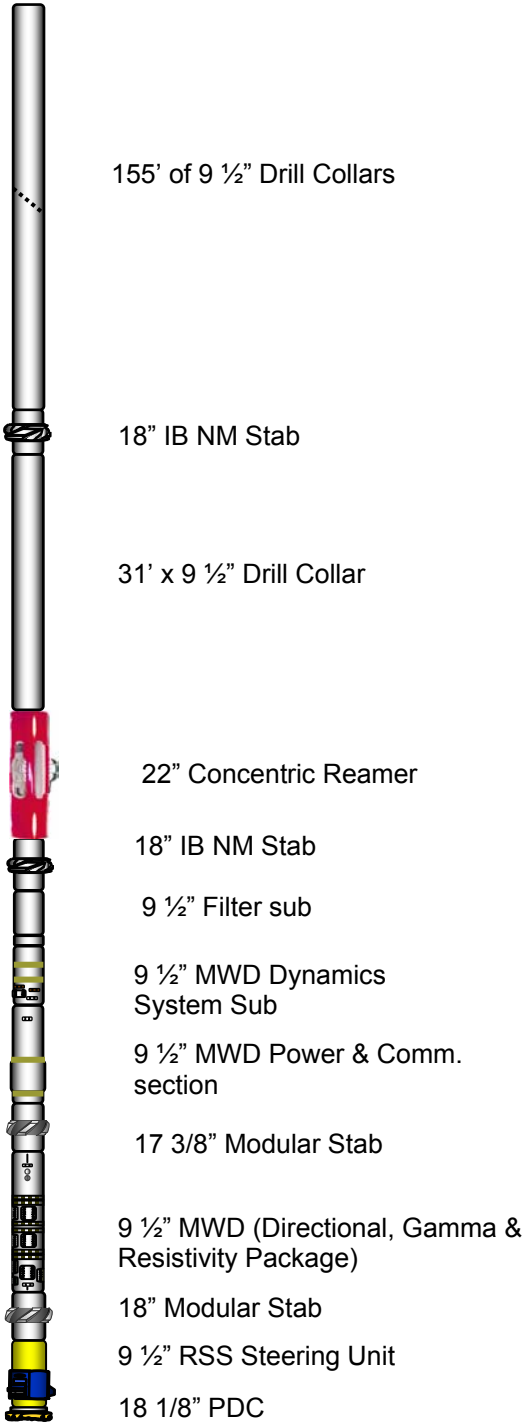


Figure 2: The BHA designed to drill the 18 1/8" x 22" interval. This assembly was modeled with proprietary software to show the contact forces and natural vibrations.

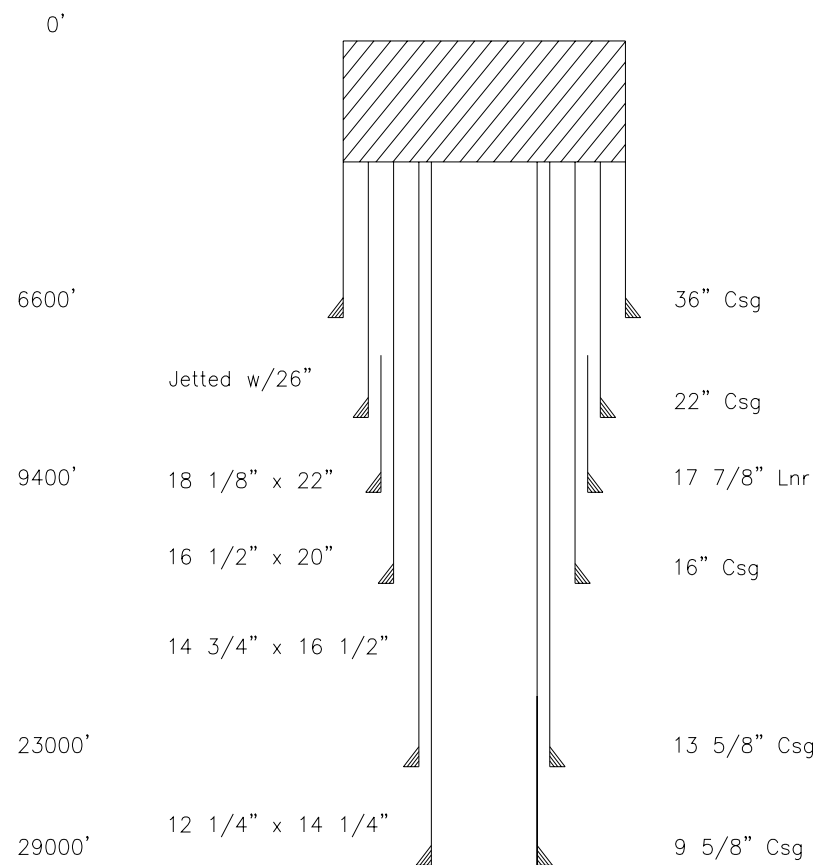


Figure 3: An illustration of a sample casing program for a typical GoM deepwater well with hole openers.

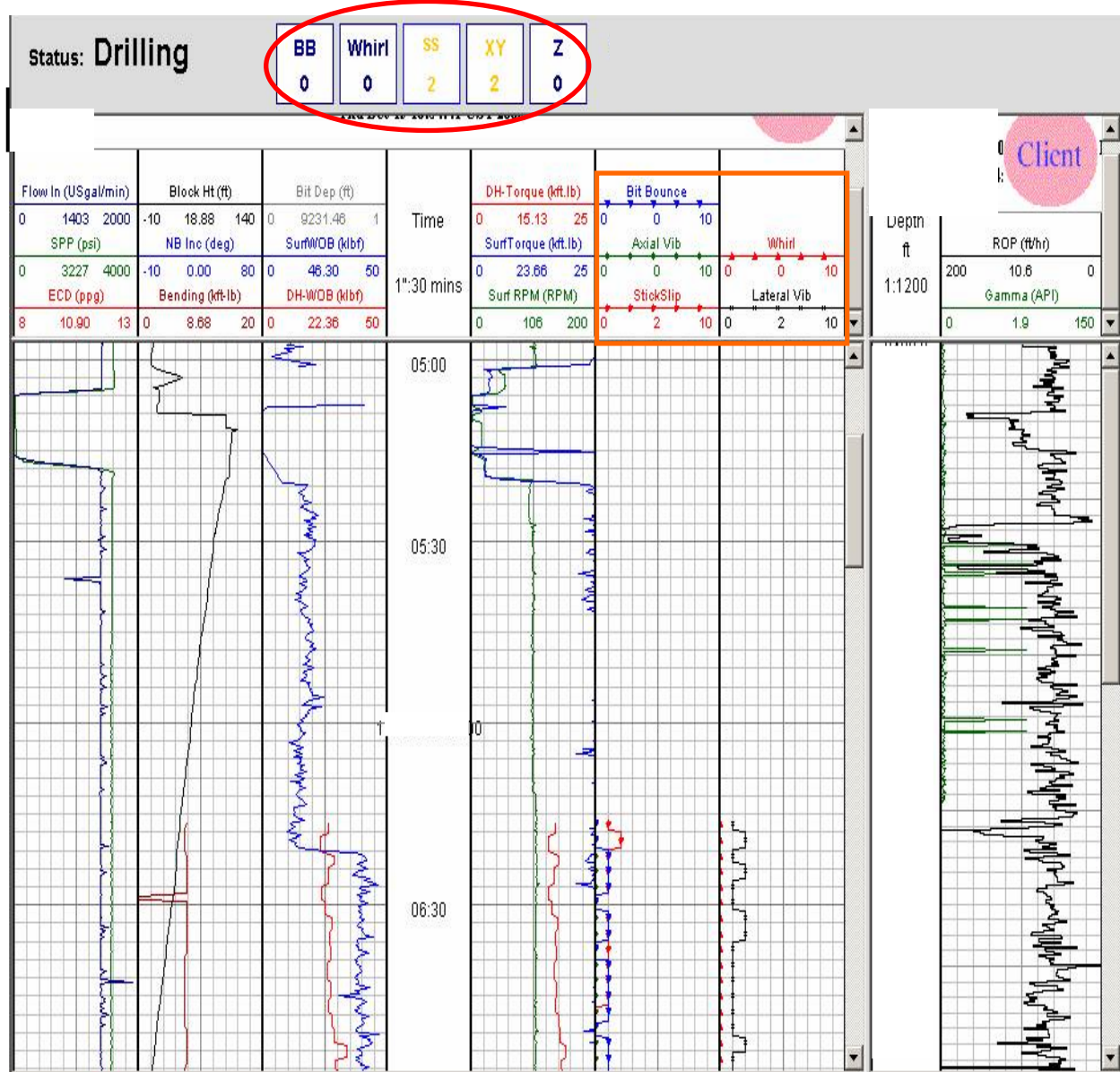


Figure 4: Real-time capture of drilling activities simultaneously transmitted from the rigsite to the office. In addition to the real-time analysis on the rig, the data are used by engineers in the office to evaluate drilling activities to further update models and simulations.

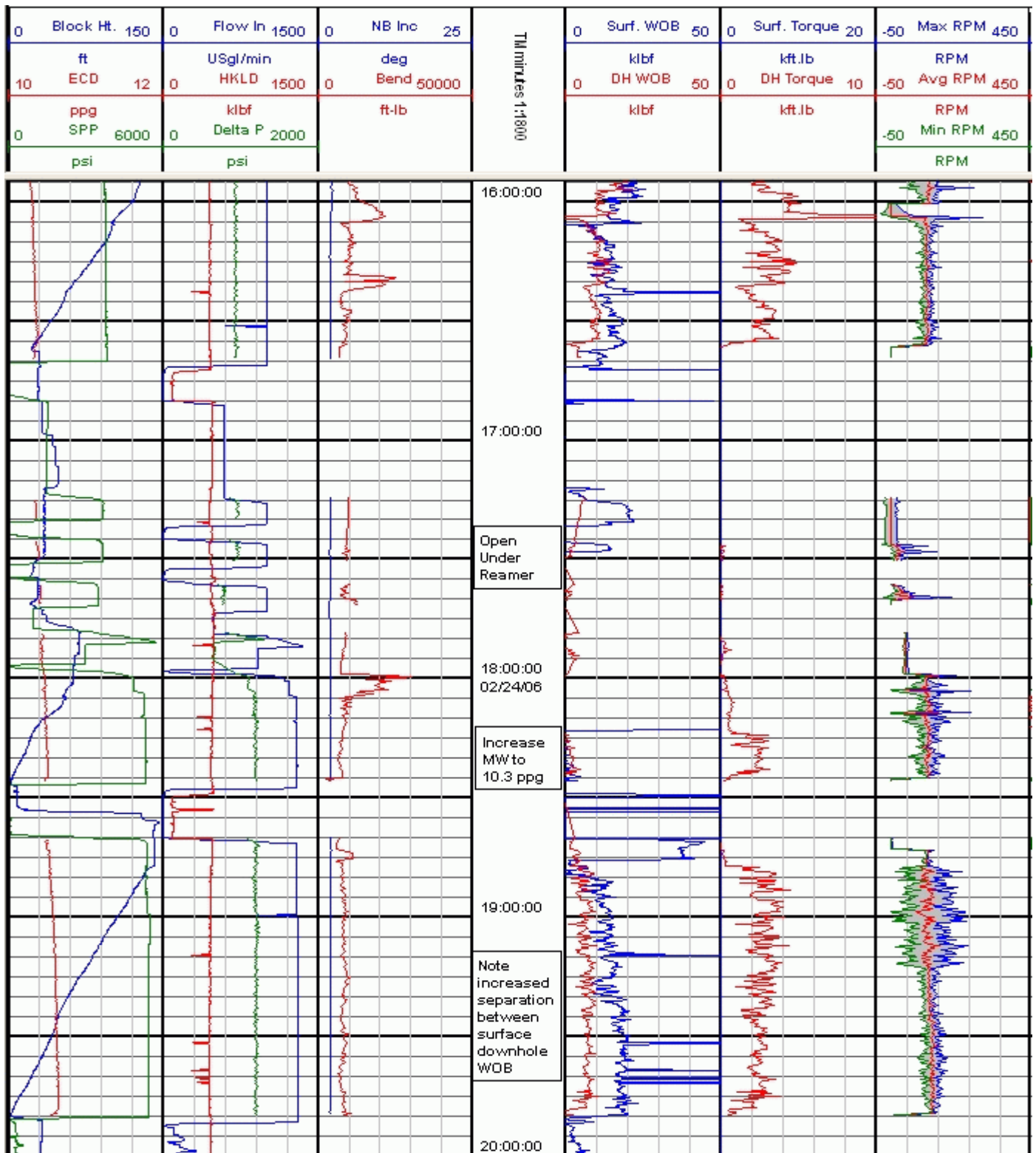


Figure 5: A time-based log sequence showing the successful activation of the reamer in the BHA. Downhole delta pressure displays about 18% at the same flow rate after engaging the hole opener cutting blades. The drilling dynamics and optimization tool confirms an increase in weight on bit separation between surface and downhole.

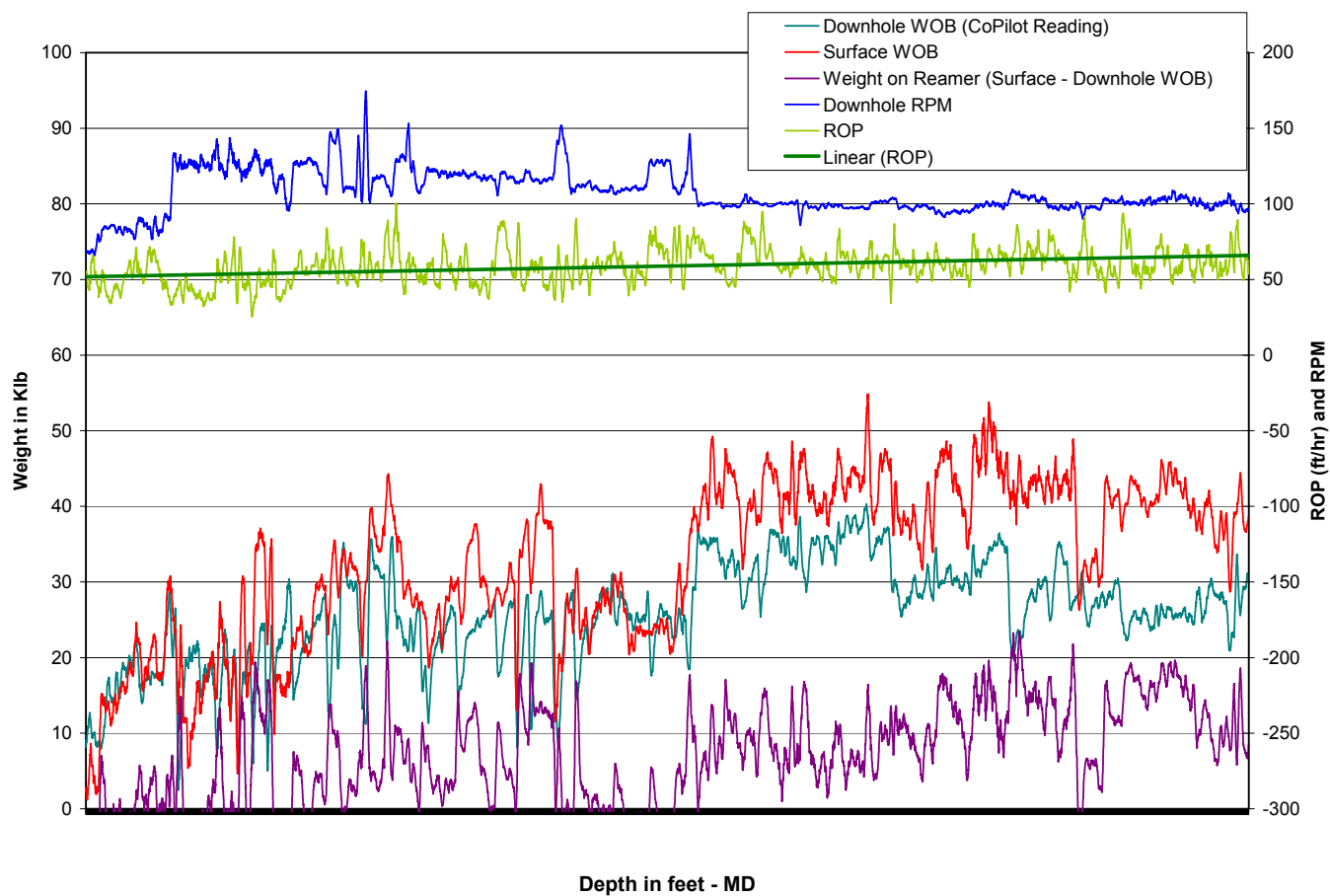


Figure 7: Illustration of net weight taken by reamer and the effective increase in rate of penetration as rotary speed is reduced.

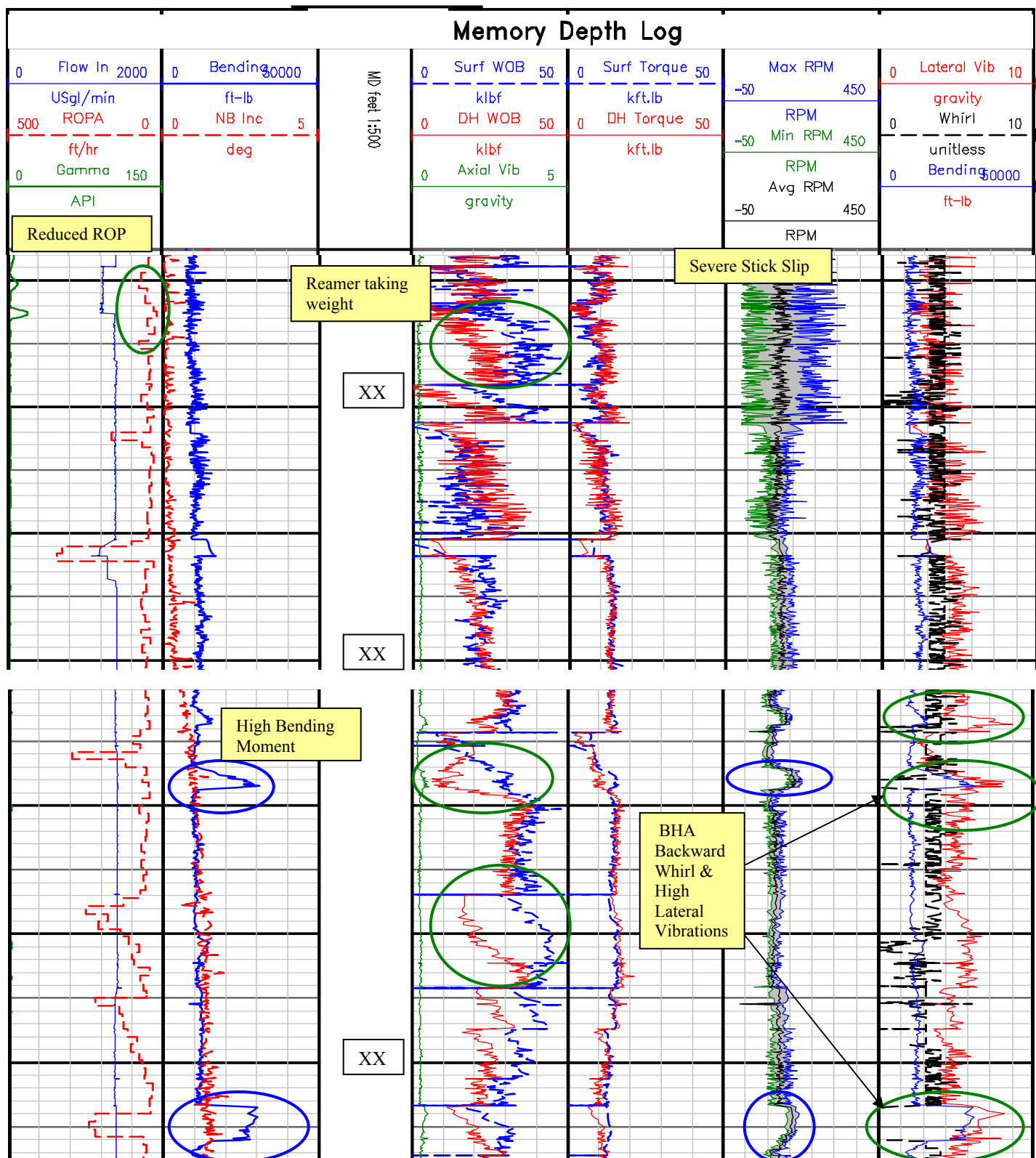


Figure 8: A depth-based log excerpt log showing increase in bending moment due to backward whirl events triggered by attempts to increase the rotary speed. The log excerpt also shows good examples of weight transfer problems from surface to bit