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First GoM Deepwater Well Deploying an Integrated Rotary Steerable Drilling System Drills 18 ¼ -inch Section

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Abstract

This paper describes a project conducted by Schlumberger and a GoM Deep water Operator concerning the development and application of a Rotary Steerable System (RSS) for 18-¼ inch hole size. The project was focused on reducing drilling costs in deepwater drilling projects and was driven by opportunities in a deep-water project in the Gulf of Mexico (GoM). The intention was to prove that a step change in performance could be achieved by application of Rotary Steerable technology in this large hole size.

The 18-¼ -inch hole section objectives included: drilling out the 20 inch casing shoe, drilling vertically through the salt interval, and then building angle to TD. The worlds first 18-¼ inch RSS drilling system, comprising a 9 ½ -inch OD Rotary Steerable Tool, combined with a Rotary Steerable PDC bit, and specially designed BHA to mitigate shock & vibration, achieved the longest distance drilled in a large hole size by this type of system in the GoM. The well drilled vertically through the salt, kicked off and built to an inclination of 27° (averaging a DLS of 2.6°/100 ft). The salt section was drilled with an average ROP (including connections) of 97.6 ft/hr. The system drilled the entire interval of 4,859 ft in 44 hrs. The complete section, including salt and interbedded sand/shale, was drilled without any difficulties and with minimal bit wear.

Introduction

Recognizing both a general need and the near-term objectives of this deepwater project application, Schlumberger and the Operator created and deployed this new RSS. Together they focused on the rapid development, construction and field-testing of the 18¼-inch. RSS. Over a period of 9 months, the RSS was designed, tested and deployed by teams working in the USA and the UK. Experience gained with smaller tool sizes was used to design the system, including the bit and the steering unit. The approach taken by Operator Asset teams in the GoM and Schlumberger contributed to accelerated field-testing of the RSS in January 2002. Initial field trials proved successful with the system achieving the required kick off from vertical of more than 3°/100 ft build up rate. The system has since proved to be beneficial to other deepwater projects, and the value of the collaboration has been clearly demonstrated.

The Challenge

The team challenged the drilling performance of the field discovery well and used the Technical Limit process to identify opportunities for performance improvement.

The original well had taken 5 days to drill the salt interval and a further 14 days to under-ream the hole to 20 inches to accommodate 16-inch casing. Improving on this performance was the focus of this collaborative development effort. The desire to develop a solution to drill salt as fast as possible with system reliability and directional control led to the development of the 18 ¼-inch RSS and the Rotary Steerable PDC bit.

Salt drilling is typically associated with four challenges. They are:

1. Low Rate of Penetration (ROP)
2. Directional Control - which can involve strong walk tendencies
3. Poor Hole Quality - including washouts depending on the type of drilling fluid
4. BHA Reliability - excessive downhole vibrations and bit bounce can damage BHA components that result in mechanical and electrical tool failures and twist-offs

Each of these challenges was addressed in the planning process.

Well Planning

The Drilling Engineering team began by looking at offset well and drilling data to develop an understanding of the baseline performance achieved with current drilling technologies.

The design team chose goals of:

1. Drilling a 2,000 ft vertical section of salt in 24 hrs

2. Finding a way to dispense with the need to open the salt before setting 16-inch casing. The well plan called for a vertical 18¼-inch hole in the salt, with strict DLS limits to ensure that the 16-inch casing went to bottom first time

3. Performing directional work in the interval below the salt, where the hole would be drilled and opened at the same time, while building angle.

Technical Approach

Among the processes that had to be addressed in order to reach the goal were shock and vibration mitigation planning, hydraulics and cuttings disposal.

The BHA was designed after a comprehensive review of salt drilling technical literature had been researched. Nodal analysis on the BHA was used to separate bit induced shock & vibration and stick-slip from the rest of the drillstring and the top drive.

Shock and vibration downhole measurements (lateral, torsional, stick/slip, overall shock) were augmented with surface measures of slip/stick. The drilling crew was trained to understand the process that initiates bit whirl, slip/stick, torsional and lateral vibrations, and what can be done to overcome this problem. The understanding of this problem and the training of personnel was taken to a new level of awareness by the team. Data was transmitted in real-time over the Internet allowing engineering teams onshore to be involved in the optimization process.

With this approach, instantaneous ROPs in 18¼-inch hole of up to 180 ft/hr were achieved with minimum shock & vibration and no stick-slip.

Total System Approach

A systems approach was taken in optimizing the implementation of the RSS solution. Among the issues addressed were:

a. The drill string design,

b. Circulating system capabilities and hole cleaning requirements and

c. Cuttings management and disposal.

A 6 5/8-inch drill string was selected to allow higher flow rates with the RSS. Additionally, the pressure drop in the BHA was greatly reduced by using RSS instead of Mud Motors, allowing for a higher flow rate with the same stand pipe pressure. This ensured improved hole cleaning, critical for the faster drill rates (thus higher cuttings volume) anticipated with the use of the RSS.

As for the cuttings management and disposal, new shale shakers had just been installed on the rig being used. However, the team decided to ensure that all equipment was in top working order prior to spudding the hole by conducting a solids removal equipment audit. Of note, given the chosen drilling technique, the cuttings generated would not need to be cleaned or dried prior to disposal overboard. Specifically, the RSS would produce large-sized cuttings with less total surface area to retain oils, versus those produced by a faster spinning yet slower drilling mud motor. Further, the cuttings would stay in the annulus a shorter period of time, due to the high flow rates and great annular velocities. This eliminated the need for cuttings dryers and the reclaimed synthetic mud product could be reused during drilling. In the end, the cuttings handling system would be able to perform well with a drilling ROP of 140 ft/hr and up to 300 ft/hr instantaneous, sufficient to reach the stated goals. At this point, the team was confident with its decisions and ability to carry out the established plan.

Development of Functional Specifications

A critical part of the rapid development process is to carefully specify the functional specifications of the tool. For the development project to remain on schedule, these specifications should be robust and not subject to change. The operating conditions for the particular well and other deepwater wells were identified early in the project by the development team.

BHA Design Overview

Two major aspects were considered for the drilling system: the theoretical Dogleg capability of the RSS tool and the PDC bit design for the planned BHA.

These aspects are important to counter the strong walk tendencies seen in the salt without introducing kinks in the wellbore. This would reduce the risk that the casing could be run to bottom with the inherent tight tolerances seen in salt drilling.

The strength and direction of the walk changed with depth on the offset wells and so it was important to be able to change the DLS capability and direction of the well bore from surface. The initial part of the salt used conventional RSS techniques. Deeper sections used a total closed loop vertical drilling mode for drilling the salt.

The tool is capable of always knowing which way is down and adjusting itself to drive the BHA in that direction. On subsequent wells this technique was perfected allowing 6,132 ft to be drilled with an overall displacement from start to finish of approximately 3.2 ft.

RSS Tool design overview

The basic steering principal used by the system is that of a synchronous dynamic bias. Close behind the bit, a fully rotating bias unit is used to apply a side force to the bit. The hydraulics power of the mudflow is harnessed and directed by an electronic control unit, located above the bias unit, in such a way that it results in directional control of the system (Figure 1a).

Theoretical Dogleg capability of the RSS:

The maximum theoretical dogleg of this directional system is based on the three points of contact on a curve, which in this case, is bit face, bias pad, and first stabiliser (located after the control unit of the tool). The resultant dogleg is defined as the sector angle (created by the three touch points), divided by the distance between the two outermost touch points (bit and stabiliser). A visual schematic of this set-up can be viewed in Figure 1b.

This is a very simplistic model and it is based on geometric points of contact, which in real drilling circumstances, are actually indeterminate and does not take account of external influences such as bit behaviour, dynamic effects of bias pad travel, hydraulics, well bore geometry, and pad / formation interaction. However, it is a valid method for benchmarking potential trends in the BHA from altering the assembly configuration.

Initial mass and stiffness calculations for this large size rotary steerable tool indicated that the output hydraulics force at the bias pads was sufficient to produce 4-deg/100 ft curvature, based on the string being in a horizontal position. Applying this force in the three-point analysis provided a theoretical capability in the range of 5.5 to 6 deg/100ft, dependant on the actual length of the BHA components used, with 100% bias.

On review of Figure 1b, it can be seen that potential borehole curvature can be increased via one of three methods: Increased bias pad travel distance, decrease distance between bias pad and bit face, or reduce distance between bit and stabiliser. With this assembly, the bias pad travel and length of bias unit and control unit are fixed. Thus, without re-engineering the tool, the only possible dogleg improvement that can be made, other than the use of clamp-on stabilisers (with the potential for problems with deformation of the tool collars) is to decrease bit length. This is a key design feature of the PDC bit that was actually created as an integral part of this drilling system. This aspect is more critical with this new tool due to the reduction in theoretical maximum dogleg capability with increasing tool size.

The actual results achieved in the initial field trial run with the new large tool (using the BHA configuration depicted in Figure 2b) was a maximum of 2.6 deg/100ft: A figure greater than the 50% of theoretical DLS ratio observed with smaller size tools. Note that this was achieved at relatively low inclinations (hole angles of 0 to 27 degrees), high ROP, no sliding, continuous control, smooth wellbore and no spiralling.

Bit design for Rotary Steerable system:

In order to capitalise on the drilling benefits achievable with the use of RSS, it was necessary to specifically design the drill bit as an integral part of the system. As such, it was necessary to understand the operating mechanism of the tool in order to assure compatibility of each of the system parts. It is important to note that the operating principles of the commercially available RSS tools differ considerably from each other, highlighting the need for an integrated approach involving the normally separate RSS and bit engineering groups.

Bit design characteristics:

There are three key qualities required for a successful PDC bit design for use on RSS tool: Steerability, Stability, and Durability. The key focus of the Bit engineering group was to produce a range of PDC bit designs with maximum steerability in order to reduce the magnitude of steering force required from the RSS, thus reducing mechanical wear of the tool.

The engineering concept behind the profile and cutting structure is outlined by Barton [1] in SPE 62779. That paper details the following considerations:

1. Cutter positioning and backrake to maximise potential penetration rates

2. Secondary cutter positioning to eliminate preferential wear

3. Gauge geometry and cutting structure to maximise sidecutting ability (active gauge)

4. Short bit length to reduce the distance between bit and bias unit to improve theoretical dogleg

5. Bit body and hydraulic requirements

Development of new gauge geometry:

The development of the gauge geometry of PDC designs was created to match the operating mode of a specific RSS. The SPE paper 77531 [2] outlines the development of the bit design guidelines to achieve optimum steerability. The modelling was used to determine critical contact points between the bit and borehole when the RST was both biasing and in neutral modes (Figure 3). This analysis allowed the correct cutter placement (back angle of gauge pad) and geometry of gauge pads (recessed) so that efficient transfer of bias force from the tool could be converted through the bit into borehole deviation when the bit was tilted in the hole via the bias pads.

Bit design consideration for larger RSS size:

Lateral stability was addressed by significantly increasing bit to borehole contact via use of a steel ring, measuring approximately ½" thick with a height of 2 ½". The concept behind the ring technology was developed by Roberts [3] in 1998. Initially, the concept of a full circumferential gauge ring was added to the body of a PDC bit design so that all the junk slots were enclosed. Later testing revealed that limited detriment to lateral stability was achieved by switching to a partial ring design (180 degree circumferential coverage) using alternate open and enclosed junk slots (Figure 4).

The partial steering wheel design was selected for its benefits of lateral stability and hole quality.

Figure 5a depicts the positioning of 13mm diameter, active gauge cutters along the entire leading face of the open sections of the gauge ring, set at low backrakes. This combination of aggressive set cutters with exposure provides sidecutting ability whilst maintaining good gauge ring coverage for stability. Additional cutters are set in the back angle of the gauge ring on all blades (Figure 5b) to ensure maximum sidecutting coverage when the bit is tilted in hole (DAG concept).

The Execution and Results

According to plan, after the 20-inch casing was set at 9,089 ft MD, a combination of 18¼-inch PDC bit with the Rotary Steerable system (11" OD tool) and its associated BHA began drilling a vertical 18¼-inch section.

The team's ability to meet its objectives would be determined by the crew's ability to maximize the Rotary Steerable system's performance (Bit and Rotary Steerable tool) while drilling from 9,150 ft to 14,009 ft a 4,859 ft-long section.

A total of 2,196 ft of salt was drilled in 22.5 hrs (a GoM record for this hole size), which was an 80% improvement over the previous best well. The well was then kicked off from vertical and built at 1.5°/100 ft to a planned tangent section inclination of 27°, through a section composed by shale and sand. The complete section was drilled in 44 hrs, average ROP 117 ft/hr (Maximum ROP 300 ft/hr).

A synthetic mud system was used with a Mud Weight of 11.2 ppg,

The RSS system demonstrated that this type of technology can be used to improve performance of drilling sub-salt deepwater wells. See Figure 6.

Conclusions

The introduction of the RSS and Rotary Steerable PDC bit, with a specially designed BHA and extensive shock and vibration mitigation processes, set the record in GoM for drilling in an 18¼-inch hole size in a salt environment. The lessons learned from this well were then applied to the next sub-salt well, breaking the salt drilling record again.

The current BHA System Design can be implemented for drilling salt and will continue to be optimized for overall cost reduction.

The 18¼-inch section was drilled with the maximum allowable surface torque for the drillstring and maximum RPM for the top drive, which defined and limited the WOB. Combinations of these drilling parameters were used to mitigate shock & vibration issues. A vertical closed loop mode was also run for the first time in GoM, which resulted in minimum walk and DLS while drilling the salt. No wiper trip was required prior to run 16-in casing.

With improved ROP, overall field development costs can be reduced significantly.

Although great results were achieved with the first applications of the new technology, the Drilling Team continues to reach for additional performance gains in Deepwater drilling programs. The team believes that it is possible to double the ROPs in the salt above the performance already obtained.

On subsequent wells the vertical closed loop mode was perfected allowing 6,132 ft to be drilled with an overall displacement from start to finish of approximately 3.2 ft.

In summary, high expectations of performance, appropriate data and support, state-of-the-art technology, and an integrated operator/contractor team willing to push the limits of the technology currently available, led to the drilling performance breakthrough on this deepwater project development.

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Bob Russell, Stone House Product Center Schlumberger

Nomenclature

BHA = bottom hole assembly
DLS =dog leg severity
DAG=dual active gauge
ECD = equivalent circulation density
EMW = equivalent mud weight
GoM=Gulf of Mexico
in= inches
MD=Measured Depth
OD= Outside Diameter
PDC=Poly diamond cutter bit
PDM=Positive displacement Motor
ROP = drilling rate of penetration
RSS=Rotary Steerable System
RST=Rotary Steerable Tool
TD=total depth
TVD=true vertical depth
WOB = weight on bit

Acknowledgments

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4. Lesso, B.: 'Results of Salt Drilling, Best practices' internal Study Report, Drilling Engineering Center, Schlumberger, Houston, February 2001.

Figure 1a: Rotary Steerable Tool

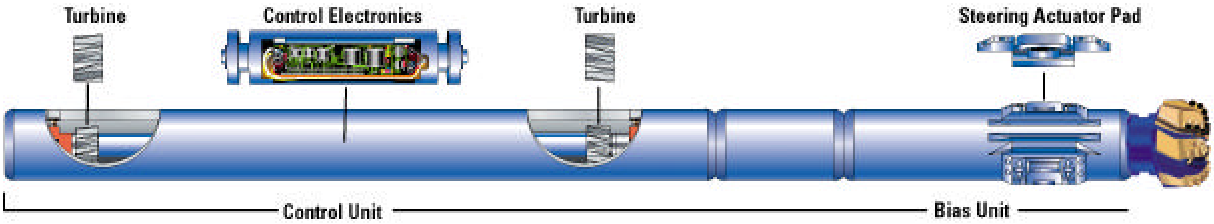


Figure 1b: Geometrical model of three points of contact analysis

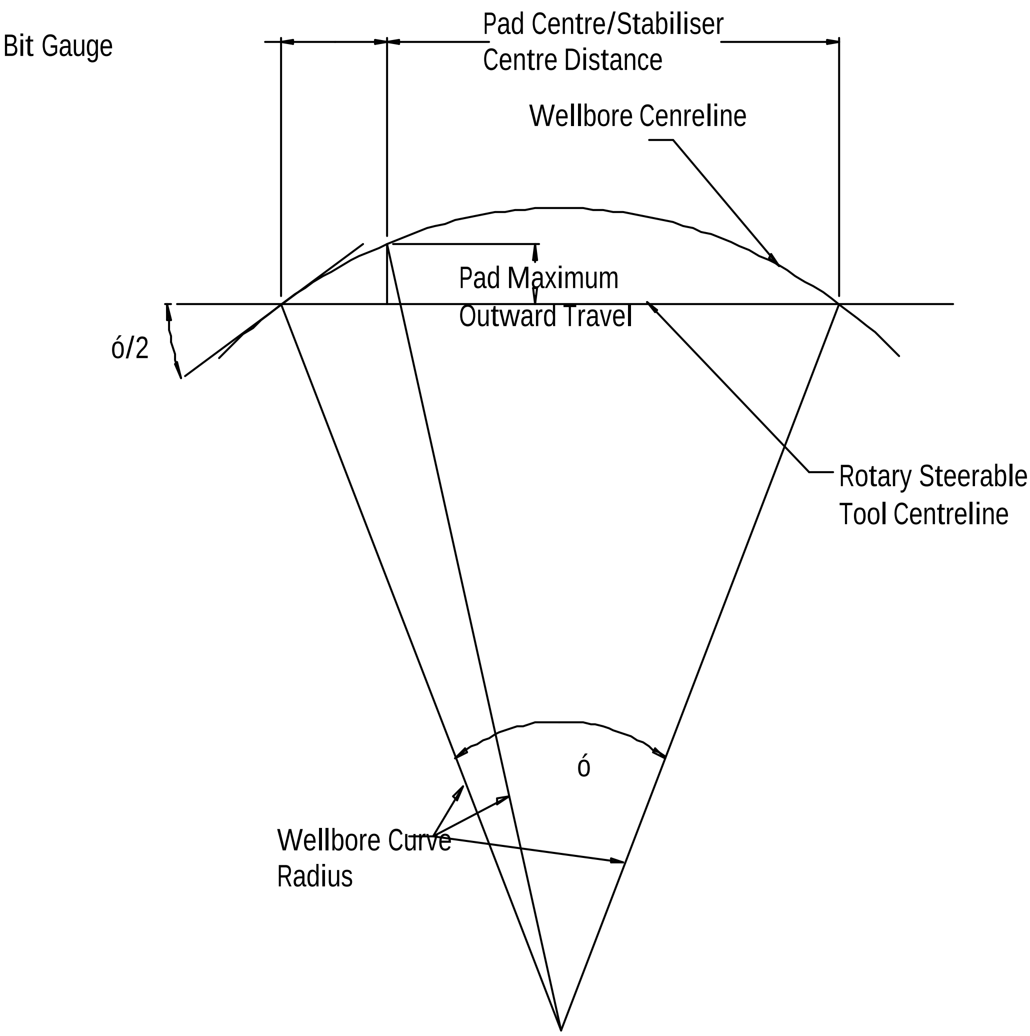


Figure 2: Rotary Steerable BHA

Figure 2a: BHA similar to drill salt section

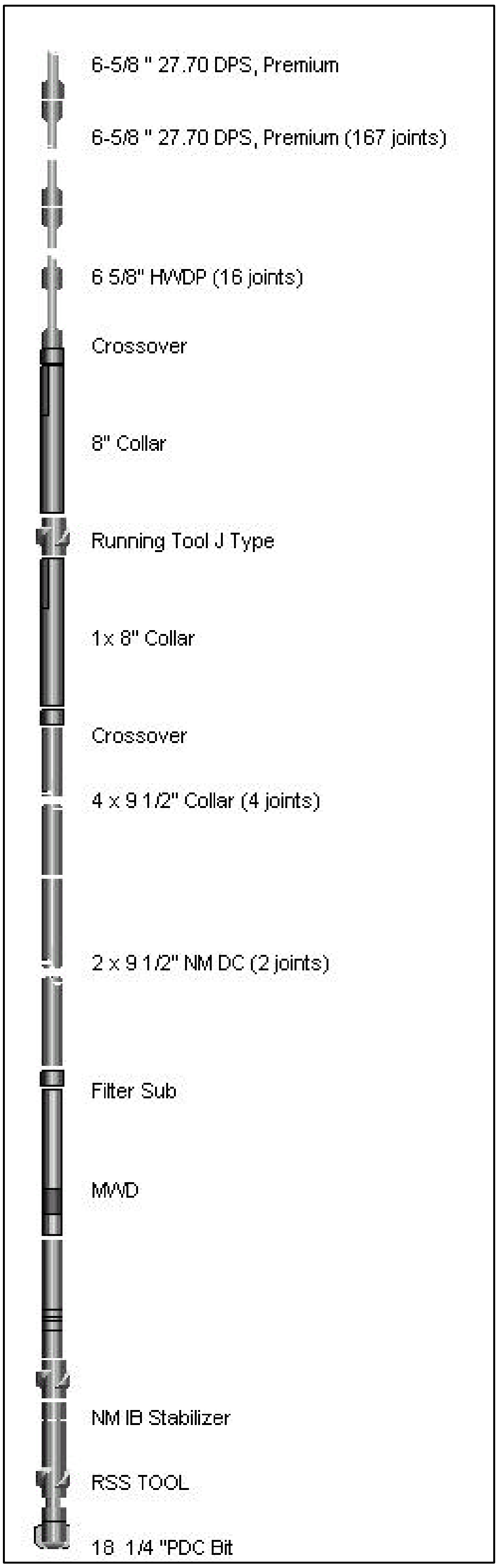


Figure 2b: BHA similar to build inclination to TD

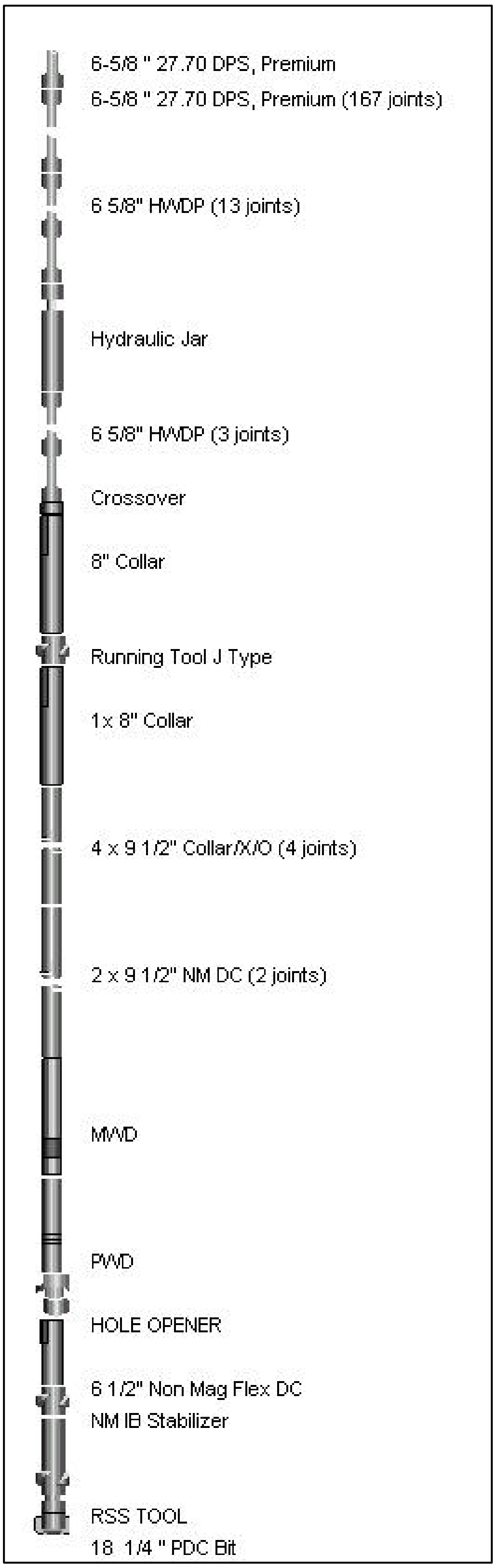


Figure 3: Geometrical modeling of RSS and bit

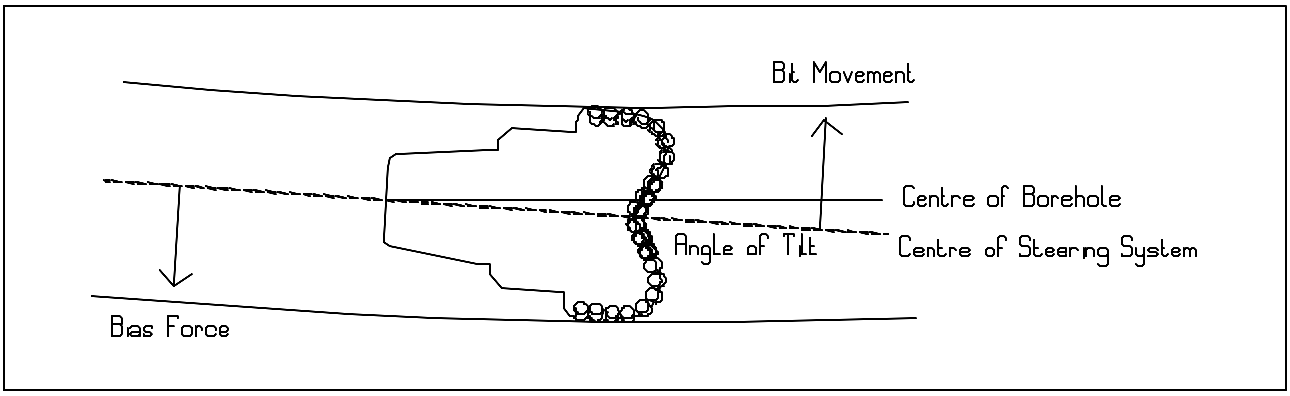
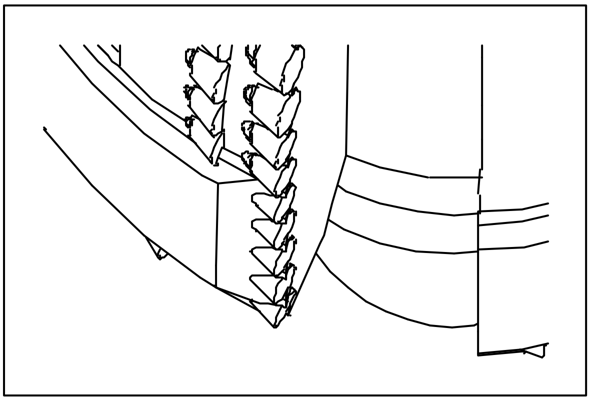


Figure 4: Full and Partial Ring designs:

Figure 5a:
Modified gauge ring geometry for RSS applications – open ring

Figure 5b:
Modified gauge ring geometry for RSS applications – back angle



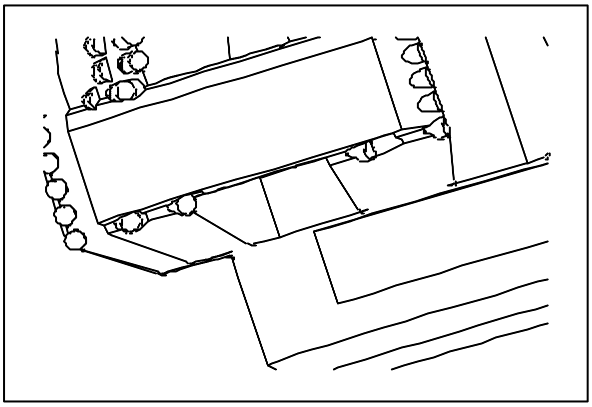


Figure 6: Vertical Section of planned well