CERTIFICATION OF APPROVAL

Drillstring Design in ERD Based on Torque and Drag Analysis using WellPlan™

by

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Approved by,

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TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AININ NURFARAHIM HAMDAN

ABSTRACT

Directional drilling has long been considered as the backbone of most offshore drilling work. With the advancement of technology and increasingly difficult to reach reservoir, Extended Reach Drilling (ERD) has taken over as the opted solution. However, excessive torque and drag can impose critical limitations in ERD. This study aims to detail issues on **DRILLSTRING DESIGN IN ERD BASED ON TORQUE AND DRAG ANALYSIS USING WELLPLAN^{TM}** focusing on associated drilling problems- buckling and pipe sticking. The Landmark software which has been used for this study is developed by Halliburton and provides WELLPLAN^{TM} software that covers torque and drag analysis. The outcome of this study is further understanding on parameters governing torque and drag analysis with regards to drillstring design. This document is a dissertation report which encompasses the background of the study, a problem statement, the objectives, scope of study, the literature review, the research methodology, results, discussion, conclusion and recommendations.

Keyword: Directional drilling; ERD; Torque and Drag; Drillstring Design; Landmark; Halliburton; analysis; optimization

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CONTENTS **PAGE NUMBER**

CHAPTER ONE : INTRODUCTION 1

1. BACKGROUND STUDY... 1
2. PROBLEM STATEMENT.. 9
3. OBJECTIVES AND SCOPE OF STUDY 10
4. RELEVANCY OF PROJECT 11
5. FEASIBILITY STUDIES 11

CHAPTER TWO : LITERATURE REVIEW AND/OR THEORY 12

CHAPTER THREE : METHODOLOGY/PROJECT WORK 16

1. RESEARCH/ PROJECT METHODOLOGY 16
2. GANTT CHART 19
3. KEY MILESTONES 19
4. TOOLS 20

CHAPTER FOUR : RESULTS AND DISCUSSION 21

CASE STUDY.. 21

16" HOLE SECTION 23

12 ¼ " HOLE SECTION 27

MACRO USING VBA 32

DISCUSSION... 34

1. PARAMETERS GOVERNING DRILL STRING DESIGN 34
2. LOADS EXPERIENCE BY THE STRING 34
3. BUCKLING.. 35
4. DIFFERENTIAL PIPE STICKING 35

CHAPTER FIVE : CONCLUSION AND RECOMMENDATION 36

CHAPTER SIX : REFERENCE...37

CHAPTER SEVEN : APPENDICES 39

TABLE OF FIGURES

Figures' Headings .... Page Number

Figure 1: Types of Pipe Buckling.. 4

Figure 2: Process Involving Drillstring Design 5

Figure 3: Differential Pipe Sticking with Embedded Pipe Length.. 6

Figure 4: Wellbore Geometry Related Pipe... 8

Figure 5: Packing Off Due to Washout... 8

Figure 6: Example of Generated Graph Using Macro... 18

Figure 7: Interface for Macro Using VBA... 18

Figure 8: Wellpath Vertical Section 21

Figure 9: 16" Hole BHA Schematics 22

Figure 10: 12 ¼ " Hole BHA Schematics 22

Figure 11: 16" Torque Point Chart 23

Figure 12: 16" Fatigue Graph... 24

Figure 13: 16" Side Force Graph.. 24

Figure 14: 12 ¼ " Hole Effective Tension Graph 27

Figure 15: 12 ¼ " Fatigue Graph.. 28

Figure 16: 12 ¼ " Torque Point Chart 28

Figure 17: Sensitivity Plot- Hook Load (Tripping In WITHOUT rotation).......................... 29

Figure 18: Sensitivity Plot- Hook Load (Tripping In WITH rotation).................................. 30

Figure 19: Calculation For Case 1.. 32

Figure 20: Calculation For Case 2.. 33

LIST OF TABLES

Table…………………………………………………………..Page Number

Table 1: 16" Torque Drag Load Summary 26

Table 2: 12 ¼ " Load Summary 31

CHAPTER ONE : INTRODUCTION

1. BACKGROUND STUDY

Extended Reach Drilling (ERD) is essentially an advanced form of directional drilling which integrates both directional and horizontal drilling techniques. ERD wells are characterized by a long lateral section after end of curve (EOC) point and high inclination angle.

Although these types of wells are challenging to drill, the benefits of an ERD well can include minimized environmental impact, reduced capital expenditure (CAPEX), optimized productivity and field recovery achieved by increasing contact with pay zone and improve recovery factor from otherwise hard to reach reserves.

ERD operations are gaining popularity in drilling operations nowadays because they allow the exploitation of reserves that were previously uneconomical to produce. By increasing the lateral departure from the production site to the reservoir and by drilling horizontally through the reservoir, projects which were previously deemed unfeasible are now seen as economically attractive investments.

Nonetheless, there are limitations when it comes to drilling an ERD well:

- Hole-cleaning issues at increased inclinations.
- Increased torque and drag due to elevated loads created by the drillstring running and rotating in highly inclined wellbores.
- An increased amount of tubulars which are required to reach the potential pay zones increase the tension, compression and axial load experienced by the tubulars.
- High tensile axial loads are experienced by the tubulars near the surface and high compressive loads on the tubulars in the bottom of the hole.

The loads experienced by the drillstring can be in the form of tension, compression, bending, torque and pressure. Subsequently, the drillstring design must take into account these load in order to ensure that targeted depth can be reached.

1.1 Torque

The frictional force between the pipe and the borehole/casing wall is the most important factor in determining the torque and drag behavior of the tubulars. The most common sources of torque are the bit torque; the torque along the wellbore; and the mechanical torque (cuttings, stabilizers, centralizers).

According to BP's Industry ERD guidelines, analysis and projections of torque should recognize the total surface torque as;

Total Surface Torque = String torque + Bit torque + Mechanical torque +Dynamic torque

By separating torque into each of the above unique elements, more accurate friction factors can be used for torque assessment. Subsequently, deviation from a predicted torque trend model provides an early-warning to inadequate hole cleaning or problem with the bit/BHA.

For this study, the torsional capacity of the string is evaluated by its tool joint capacity which is determined from its box OD, pin ID and connection type (API tool joints). Typically, these tool joints are only about 80% as strong as the drill pipe body which makes it the limiting component in a drillstring. Therefore, it limits the rotary torque that can be applied to the string. Should the torque applied exceed the makeup torque, failure will occur.

1.2 Drag

Drag is a measure of resistance to upward or downward movement of the pipe. Drag prediction for ERD wells are influenced by various factors which includes trajectory design, drillstring design, mud and formation lubricity, wellbore condition and tortuosity.

In addition to that, drag on drillstring increases during picking up, slacking off and slide drilling. Moreover, the existence of high hole inclination and curvature in ERD will bring the drag forces to a higher levels due to the pull of gravitational force, compressive forces and tensile forces.

1.3 Buckling

An issue which is unique to drag prediction is the potential buckling of the string under axial compression. Buckling is a result of drag which folds the pipe under compressional forces against the wellbore wall in a sinusoidal configuration. If loads continue to increase, the pipe will bend helically and movement is halted.

In directional and ERD wells, as the angle increases in the wellbore, so does the tendency for the pipe to lie down on the lower side of the hole. This allows the pipe to reach a state of stability and to carry higher axial compressive stresses without buckling. However, when more compressive force is applied to the tubular system, buckling can occur.

Depending on the magnitude of the compressive loads and the stiffness of the drillstring, sinusoidal or helical buckling can develop. A further increase in the compressive load will lead to lock-up, where the side forces are extremely high and no more weight can be transferred from one point to another.

The most applicable models for drillstring and liner buckling are Dawson-Paslay (1984) for inclined wellbores and Lubinski (1950) for vertical wellbores. The sinusoidal buckling load can then be calculated by using the Dawson-Paslay equation.

$$F_{sin} = \sqrt{2 \text{ x } \frac{EIW\sin\theta}{r}} \qquad (1)$$

On the other hand, the critical buckling load is the load which causes large displacements with only little increases in load. The minimal load acting on an end of a tube which creates axial buckling can be calculated by the critical buckling load formula.

$$B_{crit} = f \text{ x } [B_f^2 \text{ x } (D^2 + d^2) \text{ x } (D^2 - d^2)^3]^{1/3} \qquad (2)$$

Figure 1 below shows the buckling of the pipe if buckling load is exceeded.

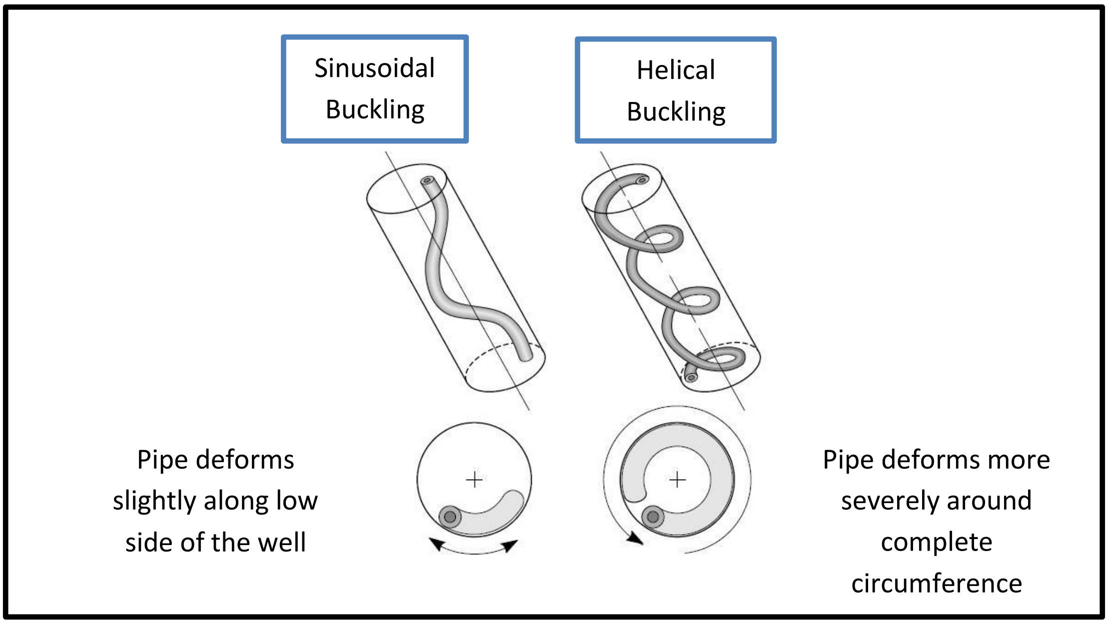


Figure 1: Types of Pipe Buckling

Buckling behavior is important when analyzing torque requirements since torque can increase significantly as a result of increasing compressive loads. Therefore, for long horizontal or high-angle sections, excessive drag can limit weight transferred to the bit, enhance drillstring buckling and reduce directional control.

1.4 Drillstring Design

Drilling extended reach wells places significant requirements on the drillstring. Lengthy drillstring can lead to high tensile loads, which in turns can lead to slip-crushing, hoisting issues and drill pipe collapse capacity concern (World Oil, 2006).

ERD drillstring loading can be characterized as high torque and low tension. For selecting the drillstring design of an ERD well, it is important to assess the load that the drillstring will experience, especially the tension and torsional load so that each component selected can safely carry this load without failure. In addition to modifying the well path, mud properties and the casing program, the redistribution of loads can also be carried out by modifying the location of individual components on the drillstring (location of stabilizers, centralizers etc)

According to BP Industry Extended Reach Well Guideline, the drillstring design of an ERD well is an iterative process involving variable with conflicting issues. Below *Figure 2* shows the process of selecting drillstring design, taking into account the non-cyclic load that the drillstring may experience.

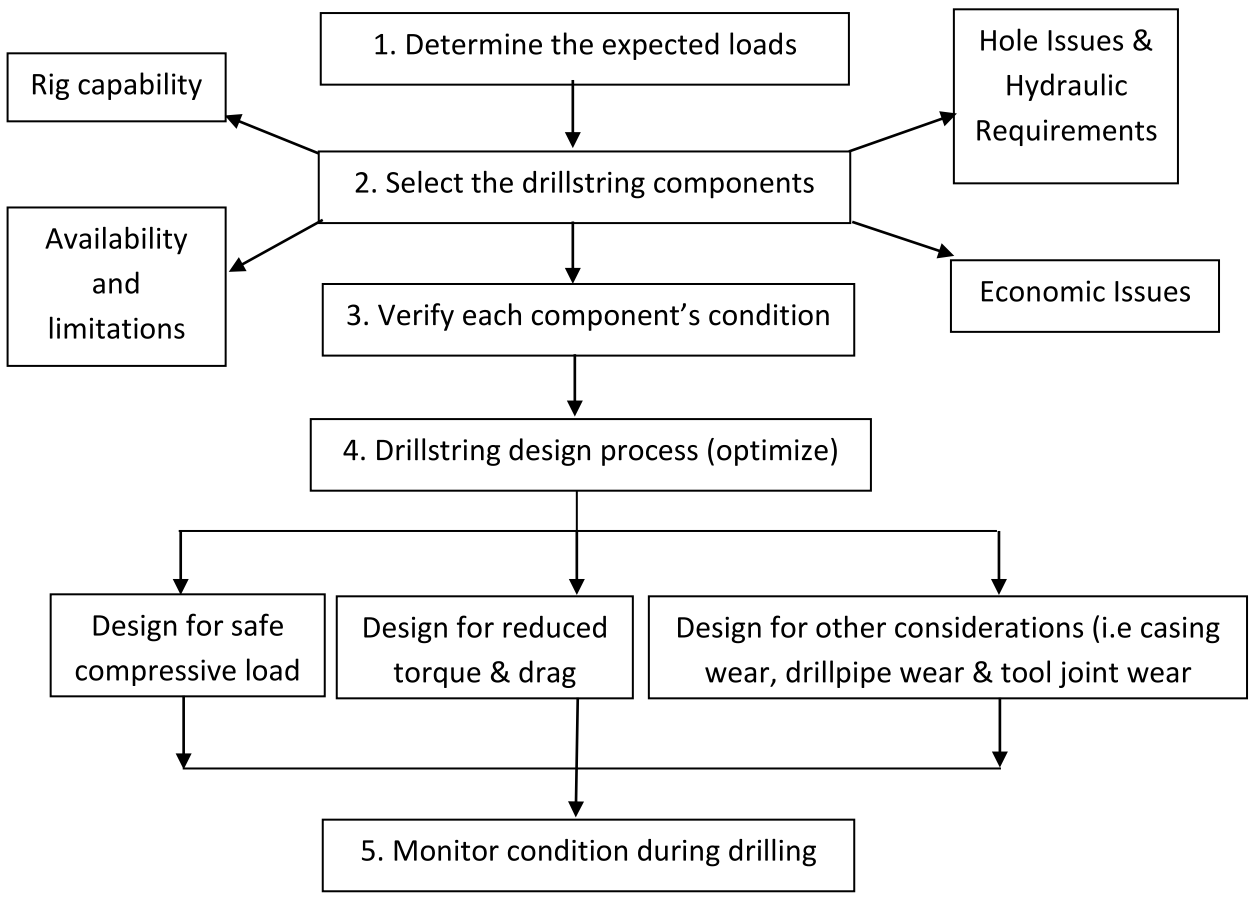


Figure 2: Process Involving Drillstring Design

According to Dr Tuna Eren, a senior drilling engineer in Eni E&P, we should always use pre-defined, tabulated constant drilling parameter values in the design calculations for consistent and comparable result. Therefore in this project, the yield stress tension, rotary torque and their combined effect will be evaluated in appropriate reference materials if necessary.

Below listed materials has been used for this study:

1) API catalogue

2) Halliburton Red book

As a rule of thumb, an overpull margin of 100,000 lbs or 50 tonnes are added to tension design consideration. For torsional load, it is a standard practice to stay below the makeup torque to give a margin below ultimate torsional strength.

1.5 Hole Issues- Pipe Sticking

Pipe sticking occurs when the pipe cannot be freed or moved when it is in the wellbore. There are two types of pipe sticking problems- differential pressure pipe sticking and mechanical pipe sticking. Below *Figure 3* shows differential pipe sticking.

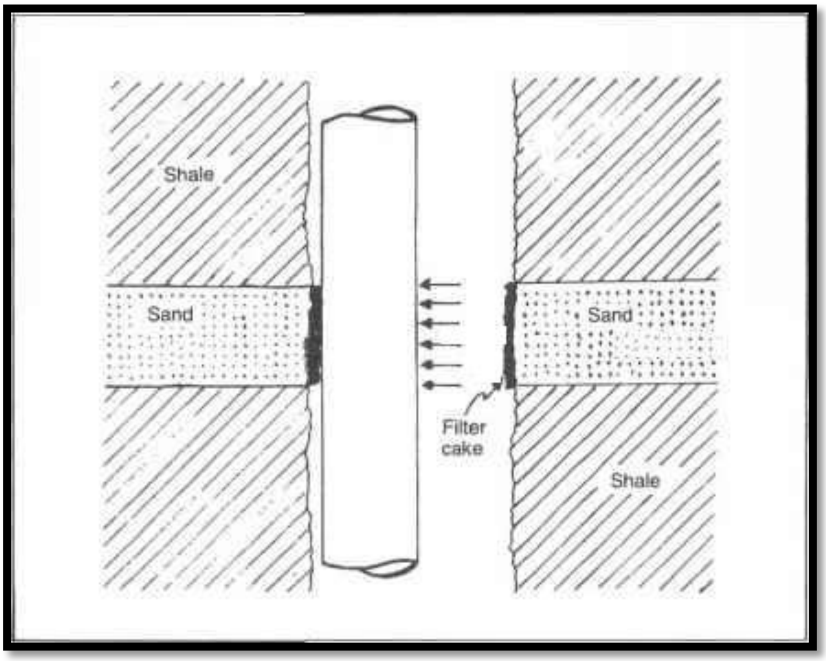


Figure 3: Differential Pipe Sticking with Embedded Pipe Length

Differential pipe sticking occurs when the drillstring is held against the wellbore by a force created by the imbalance of hydrostatic pressure in the wellbore and the pore pressure of a permeable formation. Usually, the drilling operation is done in overbalance condition; which means that the hydrostatic pressure in the wellbore (mud pressure) is always greater than the pore pressure. The resultant force of the overbalance acting on an area of the drillstring is the force that sticks the string.

The causes of differential pipe sticking are:

1) Unnecessary high differential pressure
2) Thick mud cake
3) Low lubricity mud cake
4) Excessive embedded pipe length in mud cake

On the other hand, mechanical pipe sticking is caused by:

1) high accumulative of drilled cutting in borehole
2) borehole instabilities (hole geometry related problems

Refer *Figure 4* below for example.

Mechanical sticking usually occurs when the drill string is moving and is caused by a physical obstruction or restriction. Mechanical sticking can be classified into two major subgroups:

1) Hole pack-off and bridges- stuck pipes which are related to wellbore instability or settled cuttings are in this category
2) Wellbore geometry interferences- this refers to stuck pipes which are related to the condition of wellbore geometry such as key seats or an under-gauge hole. (Shadizadeh et al, 2010)

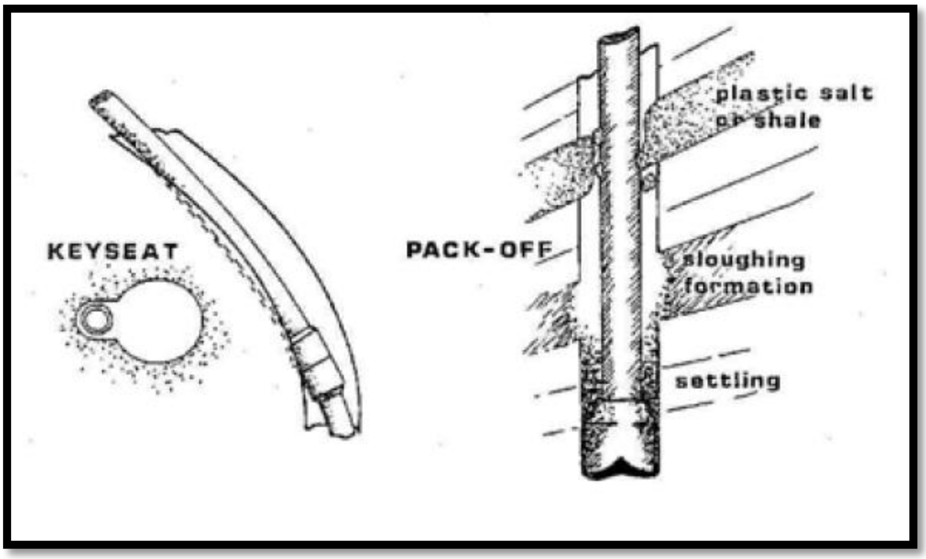


Figure 4: Wellbore Geometry Related Pipe

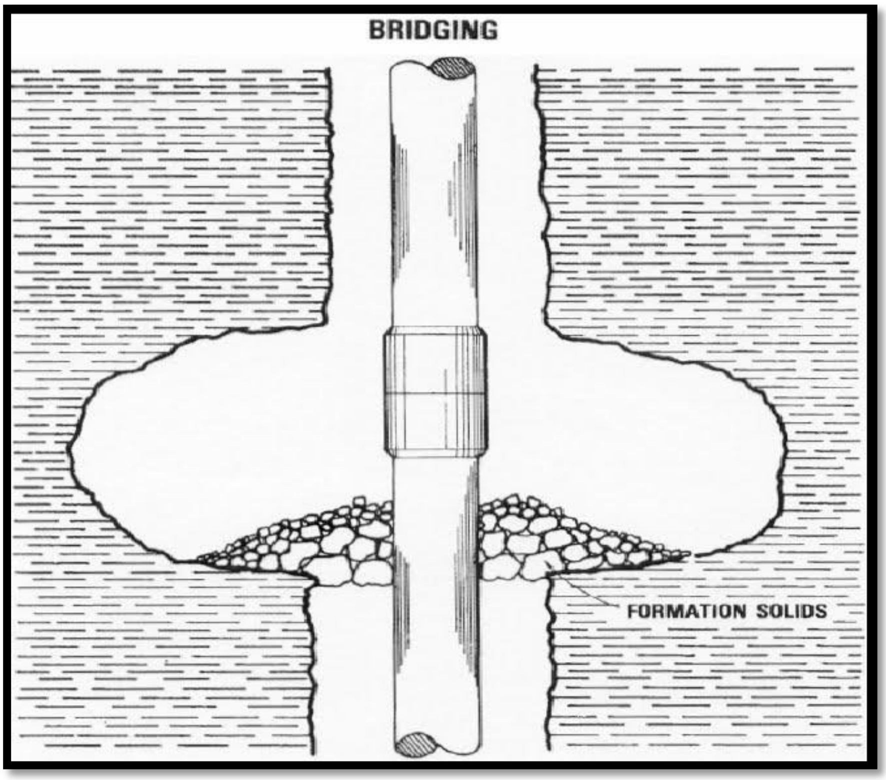


Figure 5: Packing Off Due to Washout

2. PROBLEM STATEMENT

Drill string will experience high tensile axial loads near the surface and high compressive loads at the bottom of the hole especially in the highly inclined and long tangential section of an extended reach drilling (ERD) well. In order to provide satisfactory weight on bit, the drill string is further compressed and if this compression exceeds the critical buckling load, **buckling** will occur.

Furthermore, **differential pipe sticking** in an ERD well is more prominent compared to a conventional well due to its long lateral section which increases the contact area between drill string and wellbore. If the pipe experience differential pipe sticking, the required torque to turn the drill string will increase. This problem must not be taken lightly because it may cause drilling to be halted due to excessive torque and drag, which will in turn cost a loss of time and money.

3. OBJECTIVES AND SCOPE OF STUDY

The objectives of this study are:

- To understand the parameters governing drillstring design
- To investigate the possibility of buckling and occurrence of differential pipe sticking
- To reduce torque and drag and mitigate the risk of torsional failure and buckling of the drill string without over designing the tubular for ERD well operation

Scope:

- In this project, the torque and drag load has be modeled using WELLPLAN^{TM} by Halliburton. Since the drillstring load estimation will vary depending on the operation, it was decided that modeling would be done for all six operation mode available in WELLPLAN^{TM}. The six operational modes that are available in the software are; backreaming, sliding drilling, tripping in, tripping out, and rotating on bottom and rotating off bottom.

- Conducting simulation using Landmark WELLPLAN^{TM} software on torque drag analysis with regards to drillstring design

4. RELEVANCY OF PROJECT

The torque and drag generated in ERD wells are significantly higher than conventional wells thus close attention and special drilling practices are required during operation. The analysis done in this study generates a trend curve which is used to optimize drillstring configuration for the field data. The torque and drag trend also projects incoming hole problems such as buckling and pipe sticking. This is especially useful so that early preventive actions can be taken.

5. FEASIBILITY STUDIES

This project will have a time frame of roughly 7 months for completion starting from September 2011 until May 2012. The project will be started by researching materials such as books, journals and technical papers on torque and drag considerations as well as drillstring design and management for ERD wells.

Since this project needs to be completed in a short period of time, the scope of study has been narrowed down to drillstring design and solving buckling and pipe sticking problem in ERD well. It is hoped that with a more specific topic, the project can be completed on time with sufficient data gathering and satisfactory lab work.

In order to fully understand the topic, research will be done from time. Landmark simulation lab will also be utilized in order to come out with the results.

CHAPTER TWO : LITERATURE REVIEW AND/OR THEORY

Extended-Reach Drilling (ERD) has evolved from simple directional drilling to horizontal, lateral, and multilateral step-outs. ERD employs both directional and horizontal drilling techniques and has the ability to achieve horizontal well departures and total vertical depth-to-deviation ratios beyond the conventional experience in a particular field (Gerding 1986).

ERD can be defined in terms of reach/TVD (total vertical depth) ratios. Local ERD capability depends on the extent of experience within specific fields and with specific rigs and mud systems. "ERD wells drilled in specific fields and with specific rigs, equipment, personnel, project teams, etc. do not necessarily imply what may be readily achieved in other areas" (Judzis et al. 1997).

Possible challenges to successful ERD include problematic movement of downhole drillstring and well casing, applying sufficient weight to the drill bit, buckling of well casing or drillstring, and running casing successfully to the bottom of the well. Drillstring tension may be a primary concern in vertical wells, but in ERD, drillstring torsion may be the limiting factor. Running normal-weight drill pipe to apply weight to the bit in ERD can lead to buckling of the drill pipe and rapid fatigue failure. Conventional drilling tools are prone to twist-off because of unanticipated failure under high torsional and tensile loads of an extended-reach well (JPT 1994).

Drillstring design for ERD involves: (1) determining expected loads; (2) selecting drillstring components; (3) verifying each component's condition; (4) setting operating limits for the rig team; and (5) monitoring condition during drilling. Economic and related issues in drillstring planning include cost, availability, and logistics. Rig and logistics issues include storage space, setback space, accuracy of load indicators, pump pressure and volume capacity, and top-drive output torque. Drill hole issues include hole cleaning, hole stability, hydraulics, casing wear, and directional objectives (Judzis et al. 1997).

Drillstring design is vital for operations on highly deviated, horizontal and extended reach wells. Dawson and Paslay (1984) proved that the hole supports the pipe along its lateral length and provides additional resistance to buckling. They established the boundaries between regions of stable and unstable behavior. For drill pipe that is in a compression stare, their analysis provided the maximum compressive loads that the pipe can withstand without experiencing buckling.

In shallow horizontal shale-gas wells, drillstring design becomes an even major concern because the possibility of buckling is high. In order to reach an acceptable rate of penetration, sufficient weight should be exerted on the bit without exceeding the critical buckling loads. Therefore, some inverted BHAs containing heavyweight drill pipe, or drill collars above drill pipe are proposed to help transfer the weight downhole (JPT 2011).

On the other hand, torque can be significantly reduced with the use of nonrotating drill pipe protectors (Payne et al. 1995). Advanced equipment for an ERD well may include wider diameter drill pipe, additional mud pumps, enhanced solids control, higher capacity top-drive motors, more generated power, and oil-based drilling fluids (Judzis et al. 1997).

As stated by Reinhold, a drill pipe must undergo: (1) Tension; (2) Torsion; (3) Bending and/or cyclical stress; (4) Compression; (5) Corrosion; (6) Abrasion; (7) Mechanical damage to the OD; (8) Internal pressure which may cause burst; (9) External pressure which may cause collapse and (10) Severe shock and vibration.

Based on above observation by Reinhold[8], the working relationship between various components of a drill string must be analyzed carefully. As stated in JPT 1994, conventional drill stems are about 30 ft long and are made up of a bit, stabilizer, motor, a measurement-while-drilling (logging) tool, drill collars, more stabilizers, and jars. Typically there are more than 1,600 parts to a drill string in a 24,000-foot well. A modern drill string can be made up of hundreds of components from more than a dozen vendors. These components may not always perform as anticipated and may not meet operational demands of drilling an extended-reach well (JPT 1994).

Nowadays in drillstring design of ERD well, aluminum drill pipes are emerging as a new technology to replace conventional steel drill pipes (Gelfgat et al, 2003). The drillstring assembly and its weight influence the possibility of drilling according to the designed borehole path. Therefore, the choice of drill pipe material becomes critical. Gelfgat et al (2003) considers aluminum alloys as the most prospecting material since ERD involved hard operating condition whereby large axial load existed at the bottom of the well and high torque is resulted from increased drag forces with drillstring running and rotation. They believe that since aluminum drill pipes are about three times lighter than steel pipes in air, aluminum drill pipes can improve ERD operations significantly.

High drillstring torque and excessive casing wear often pose serious problems in ERD wells. High drill string torque can threaten well completion by exceeding the capacity of Top Drive systems or drill string capacity. The time taken to solve these problems may increase well completion times and costs thus proper modeling prior to drilling is required. One approach to reducing drill string torque and preventing excessive casing wear is the use of Non-Rotating Drill Pipe Protectors (NRDPP) (N. B. Moore et al. 1996).

Jellison et al (2005) stated that the drill pipe and tool joint assembly must be capable of withstanding the anticipated service loads including: axial force (tension or compression), torsion, pressure (internal and/or external) and bending. A key consideration that drives connection design and selection is torsional strength. This is also agreed upon by McCormick and Chiu (2011) whom stated that in an ERD wells, two common problems with torque are the friction resistance to drillstring rotation and the make-up torque limitation. If the rotary torque is too high, torsional failure would result.

For this project, one of the hole problem issues that will be analyzed and modeled is pipe sticking. Differential pipe sticking usually occurs when the drillstring is stationary or moving at a slow speed, when an area of contact exist between the drillstring and the wellbore, when an overbalance is present, across a permeable formation and in a thick filter cake (Driller Stuck Pipe Handbook, 1997).

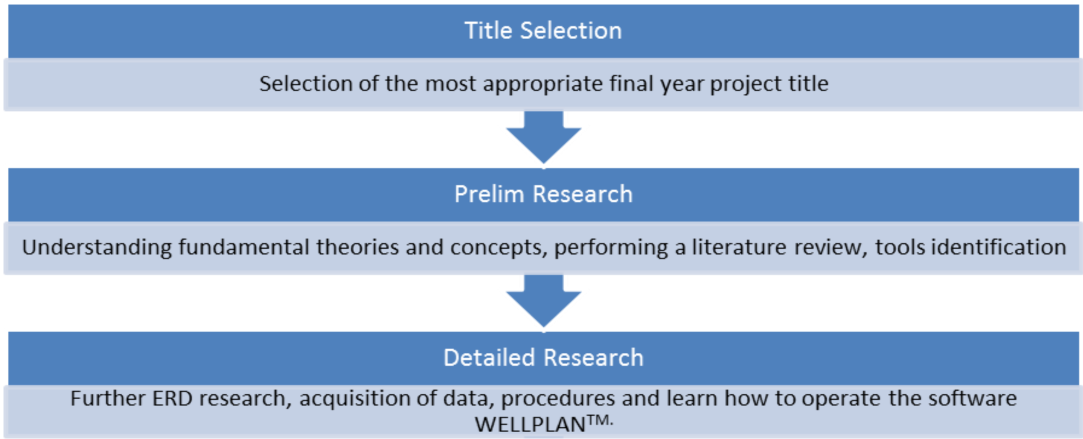
On the other hand, Shadizadeh et al. (2010) describes mechanical sticking as a physical obstruction or restriction which can be classified into two major subgroups: a) Hole pack-off and bridges; stuck pipes which are related to wellbore instability or settled cuttings are in this category and b) Wellbore geometry interferences; this refers to stuck pipes which are related to the condition of wellbore geometry such as key seats or an under-gauge hole.

CHAPTER THREE : METHODOLOGY/PROJECT WORK

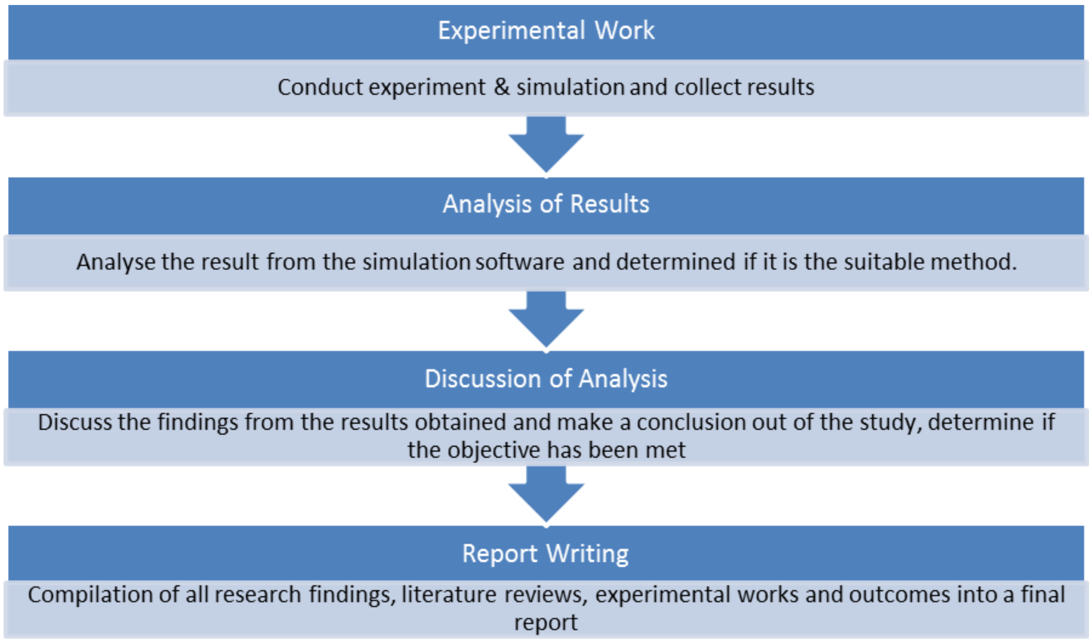
1. RESEARCH/ PROJECT METHODOLOGY

Below describes the overall methodology and general work flow that will be executed for this project.

<u>Final Year Project 1 (Last semester)</u>



<u>Final Year Project 2 (Current semester)</u>



For this project, the required data was obtained from a field offshore Terengganu, Malaysia. The work procedure done for this project is as described below.

Work Procedures (WELLPLAN^{TM})

1) Key in required input and parameters as in field data
2) Torque and drag assessment (Normal Analysis mode)
   i. Check for problems arising in the drillstring
   ii. Check for buckling/stress related failure
   iii. View result for all six operational mode
3) Amend the string configuration to mitigate or minimize torque and drag effects
4) Check charts/graph obtained

Hand calculation (Macro using VBA)

Hand calculation will be done for the maximum pull force, F_{pull}, required to free stuck pipe due to differential pressure sticking. The procedures are as follows:-

1) **Calculate the arc length, ψ**

$$\psi = 2\left\{(D_h/2 - h_{mc})^2 - \left[D_h/2 - h_{mc}(D_h - h_{mc})/(D_h - D_{op})\right]^2\right\}^{0.5}$$

Where,

D_h = hole diameter

h_{mc} = mudcake thickness

D_{op} = outer pipe diameter

2) **Calculate contact area, A_c**

$$A_c = \psi L_{ep}$$

Where,

L_{ep} = length of permeable zone

3) **Calculate required pull force, F_p**

$$F_p = \mu \Delta p A_c$$

Where,

μ = coefficient of friction

ΔP = differential pressure between mud pressure and formation fluid pressure

4) **Generate a graph by varying μ and plotting it against corresponding F_p**

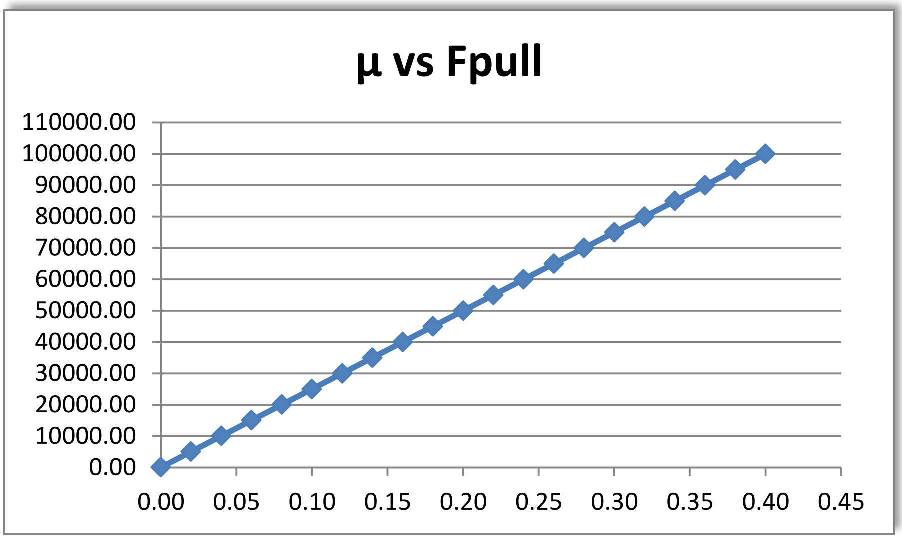


Figure 6: Example of Generated Graph Using Macro

Macro Interface

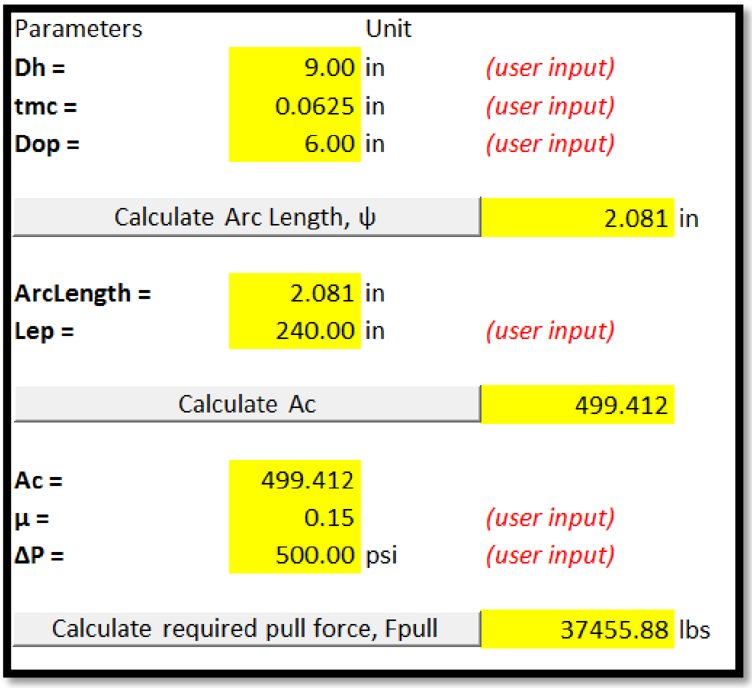


Figure 7: Interface for Macro Using VBA

2. GANTT CHART

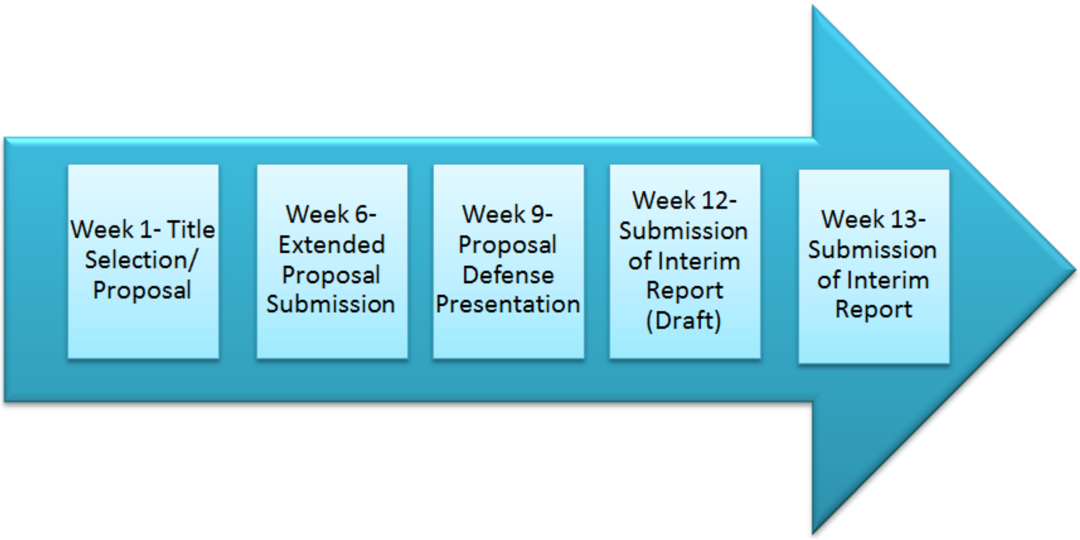
No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic Selection / Proposal							S							
2	Preliminary Research Work							e							
3	Submission of Proposal Defense Report						●	m							
4	Proposal Defense (Oral Presentation)							b							
5	Project Work Continues							r							
6	Submission of Interim Draft Report							e a					●		
7	Submission of Interim Report							k						●	

● Suggested milestone

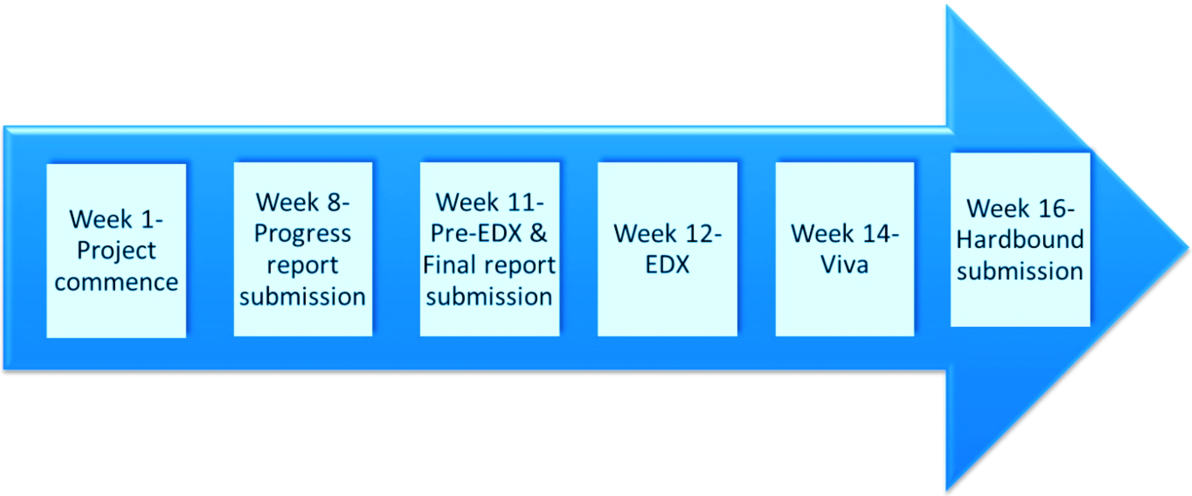
■ Process

3. KEY MILESTONES

<u>Final Year Project 1 (Last semester)</u>



Final Year Project 2 (Current semester)



4. TOOLS

- Halliburton's WELLPLAN™ software - Landmark

  This project involves simulation of real field data using WELLPLAN™ software by Halliburton to model torque and drag analysis and drillstring design related to ERD. Torque and drag computer modeling enables the study of drillstring design and expected forces/stresses on drillstring components. This is necessary to design within component and operational limitations.

- Microsoft Excel – Visual Basics for Applications (VBA)

  For this project, VBA will be used to format a program which calculates the required pull force to free stuck pipe due to differential sticking. The macro developed produces "coefficient of friction, μ vs required pull force, F_{pull}" graph.

CHAPTER FOUR : RESULTS AND DISCUSSION

CASE STUDY

The main objective of this project is to reduce torque and drag and mitigate the risk of torsional failure and buckling of the drill string without over designing the tubular. The data obtained from an offshore field Terengganu concerns an ERD well with HD to TVD ratio of 2.465.

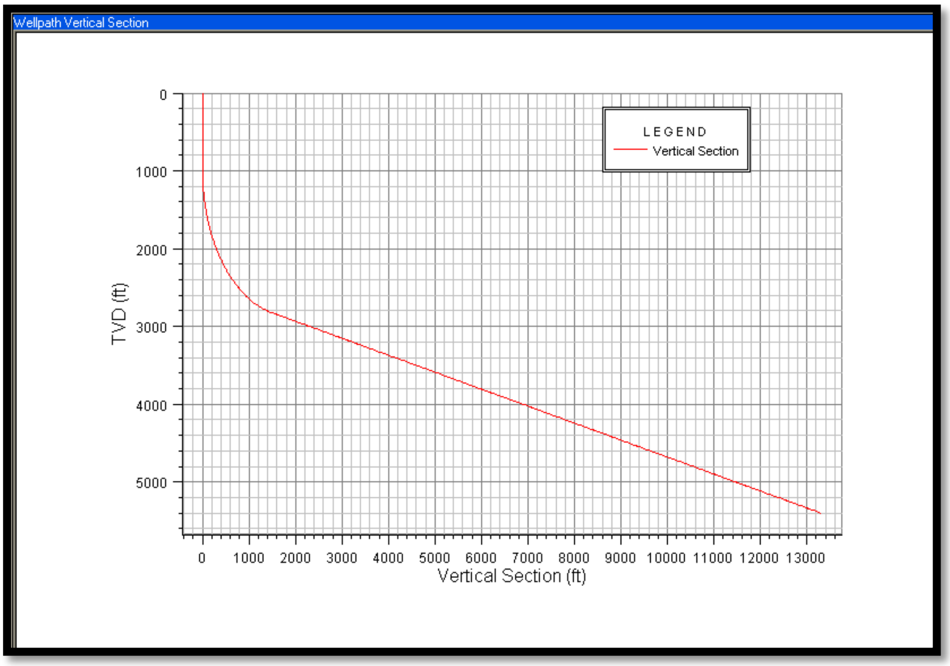


Figure 8: Wellpath Vertical Section

Wellbore information

The well (**Well X**) incorporates a build and hold trajectory, with maximum inclination of 78 degrees and maximum dogleg severity (DLS) of 3^{o}/100 ft. Kicking off at 984 ft, well X extends to a measured depth of 15653 ft with 13321 ft of tangential section. Well X was drilled with a mobile self-elevating jack up rig due to its shallow location. Above *Figure 6* shows the well trajectory plotted against depth.

Well X was drilled using five different BHA and completed with three casings plus a liner. For this project, two sections which characterize an ERD well have been chosen for analysis- the 16” build section and the 12 ¼” hold section. *Figure 7* and *Figure 8* shows the BHA schematics for 16” hole and 12 ¼” hole respectively.

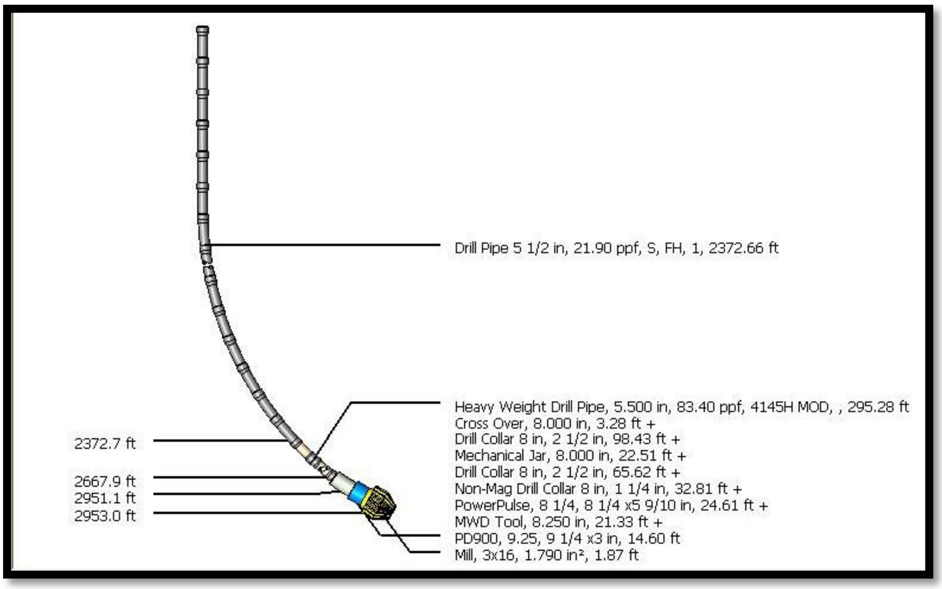


Figure 9: 16" Hole BHA Schematics

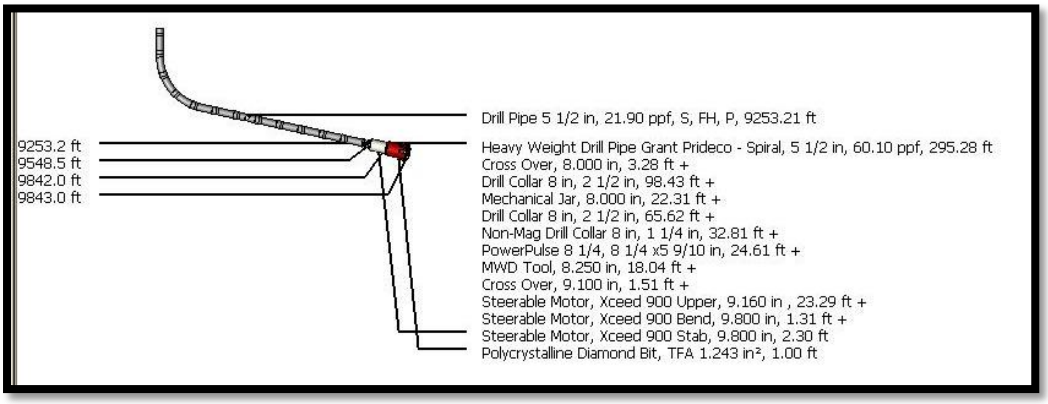


Figure 10: 12 ¼ " Hole BHA Schematics

The drilling operation for these two particular sections must be planned and executed carefully; maintaining a balance between good hole cleaning, rate of penetration (ROP) and system capability. There is a possibility of high torque and drag in these two sections thus an optimal design is necessary to provide a more efficient weight transfer and rotational ability of the string.

16” Hole Section

The 16” section is drilled from 577 ft to 2953 ft (measured depth); RSS run with 10 to 25Klbs weight on bit (WOB); build from 0^o to 57^o and rotated at 120 to 140 RPM to reduce the drag encountered. Higher RPM is desirable while drilling this section but the rotational speed is limited by the make up torque of each tubular component.

Out of the six operational modes previously mentioned, only backreaming, tripping in, rotating on bottom and rotating off bottom involves the turning of the drill string. Therefore, in below normal torque graph, it can be seen that only these four operations has an increase in torque when inclination increases.

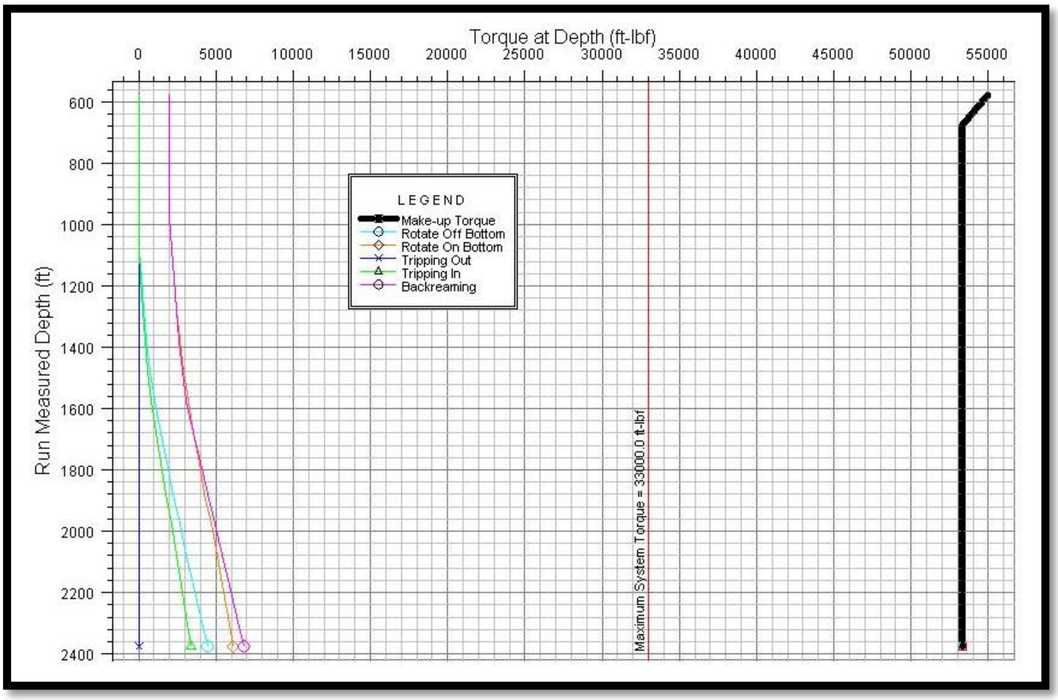


Figure 11: 16" Torque Point Chart

High levels of torque and drag can lead to situations where the casing, liner and/or completion cannot be installed at the planned depth. Problems getting casing to bottom, getting WOB or trouble sliding could also result from this. All of these can limit the ultimate depth of the well thus should be minimized as much as possible.

In addition, it can be seen from *Figure 10* below that the drill string experience an increase in fatigue ratio while drilling the inclined section because of the high contact area between tubular and wellbore.

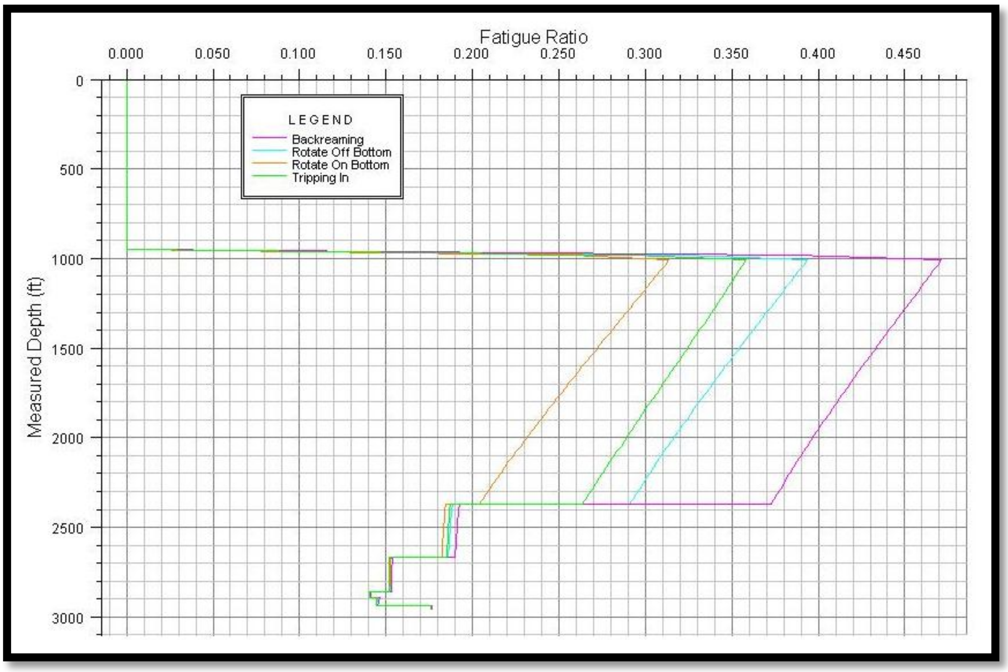


Figure 12: 16" Fatigue Graph

The side loads are the distributed normal (lateral) forces acting on the drill string. These loads, when combined with the local coefficient of friction, affect the torque required to rotate the string. The side loads are primarily affected by the wellpath and the weight of the drill string.

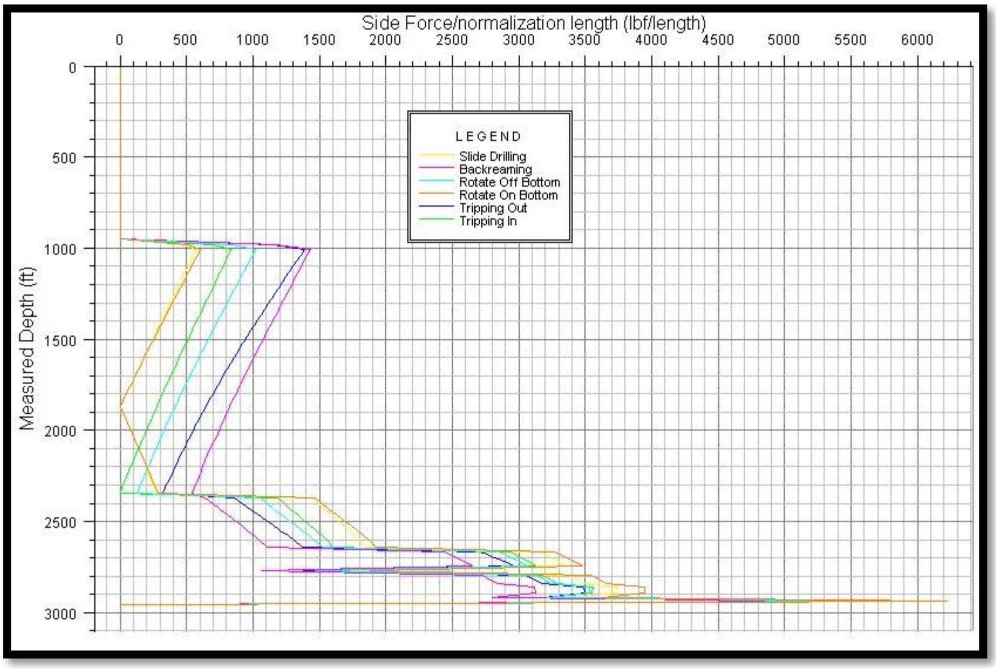


Figure 13: 16" Side Force Graph

Doglegs can also contribute to the side loads and hence, torque. To minimize these effects, RSS is used to drill this section to provide a smoother well trajectory. It is also well known that side loads can be increased by the buckling of the drill string. Therefore for well X, adequate analysis is done to ensure that the string does not experience excessive buckling.

After analysis has been done, a torque and drag load summary was generated (refer *Table 1* at next page). *Table 1* displays load summary information for the operating modes specified on the Mode Data dialog for Normal Analysis. From the load summary generated using WELLPLAN^{TM}, it is projected that we will not experience any problem with the drill string.

Below are the failure flags that can be obtained from load summary.

<u>Legend</u>

The **S** column has mode flags to indicate the type of stress failure present.

Flag

No load limit exceeded	~
Make-up torque exceeded	T
Fatigue endurance limit exceeded	F
Yield strength exceeded	Y
Yield strength and the Maximum Overpull Using % of Yield specified on the Torque Drag Setup Data Dialog are exceeded	X

The **B** column mode flags indicate the type of buckling present.

Flag

No buckling	~
Sinusoidal buckling in some part of the string	S
Helical buckling in some part of the string	H
Excessive buckling caused string lock-up	L

The table below summarizes torque and drag load summary while drilling the 16” hole section.

	Load Case	STF	B	Torque At Rotary Table (ft-lbf)	Windup With Torque (revs)	Windup Without Torque (revs)	Measured Weight (kip)	Total Stretch (ft)	Axial Stress	
									Measured Depth (ft)	**BIT** (ft)
1	BACKREAMING	~~~	~	9283.8	1.0	0.7	175.3	1.1	2667.9	285.1
2	TRIPPING OUT	~~~	~	0.0	0.0	0.0	173.2	1.0	2667.9	285.1
3	ROTATING ON BOTTOM	~~~	~	7572.2	0.9	0.6	125.3	0.4	2372.7	580.3
4	TRIPPING IN	~~~	~	0.0	0.0	0.0	132.5	0.5	2625.7	327.3
5	ROTATING OFF BOTTOM	~~~	~	6207.1	0.7	0.7	150.3	0.7	2667.9	285.1
6	SLIDING ASSEMBLY	~~~	~	0.0	0.0	0.0	122.8	0.4	2377.8	575.2

Table 1: 16" Torque Drag Load Summary

12 ¼ ” Hole Section

This 12 ¼ ” section is drilled from 2953 ft to 9843 ft with inclination building from 57^{o} to a max build angle of 78^{o} which holds tangent until section target depth. From analysis, a WOB more than 10klbs is not suitable as it leads to helical buckling. The string utilizes RSS Xceed900 to improve hole cleaning as well as hole quality (in terms of minimizing the tortuosity) and is rotated at 140 RPM.

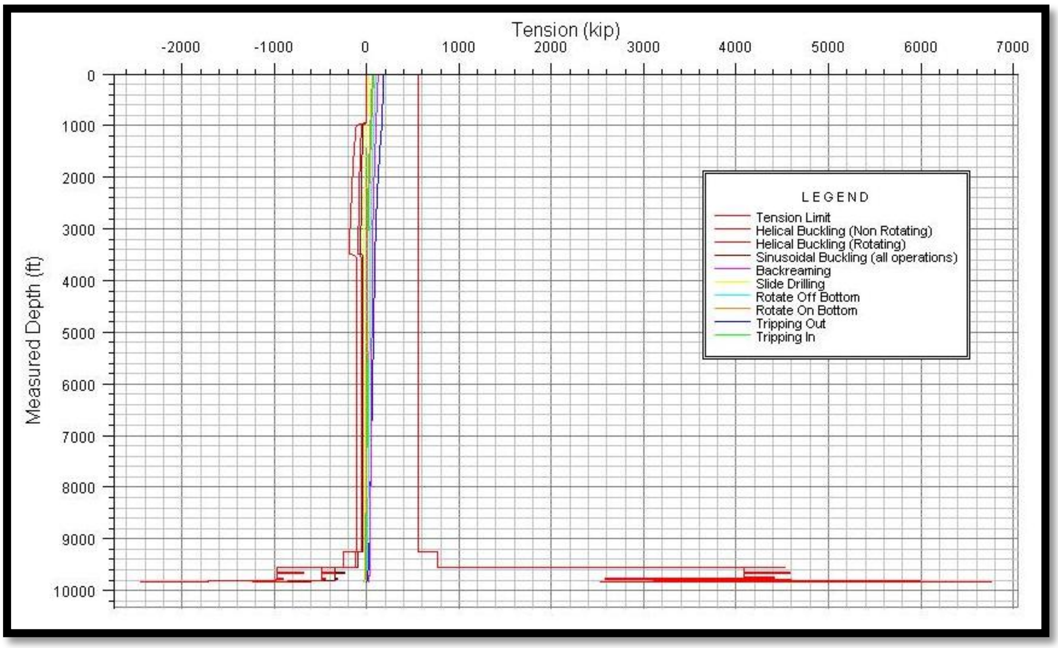


Figure 14: 12 ¼ " Hole Effective Tension Graph

Effective tension graph is used to determine when buckling may occur. Plot curves indicate the loads required to buckle (helical or sinusoidal) the drill string. When the effective tension load line for a particular operation mode crosses a buckling load line, the string will begin to buckle in the buckling mode corresponding to the buckling load line.

As shown in *Figure 12* above, slide drilling (yellow line) lightly crosses the sinusoidal buckling limit (red line). As a result, the tubular will experience sinusoidal buckling. In this case, sinusoidal buckling is acceptable because the string will return to its original state after slack off. However, while drilling this section, measures should be taken to ensure that WOB remains at 10klbs and ROP is as planned and that string has not taken weight.

The fatigue ratio is the calculated bending and buckling stress divided by the fatigue endurance limit of the pipe. Compared to the maximum fatigue ratio of 0.47 for 16" hole section, the 12 ¼ " section has relatively higher fatique ratio of 0.58 as shown in *Figure 13*. This is due to the higher bending and buckling stress experienced by the tubular when in prolonged compressive contact with the wellbore.

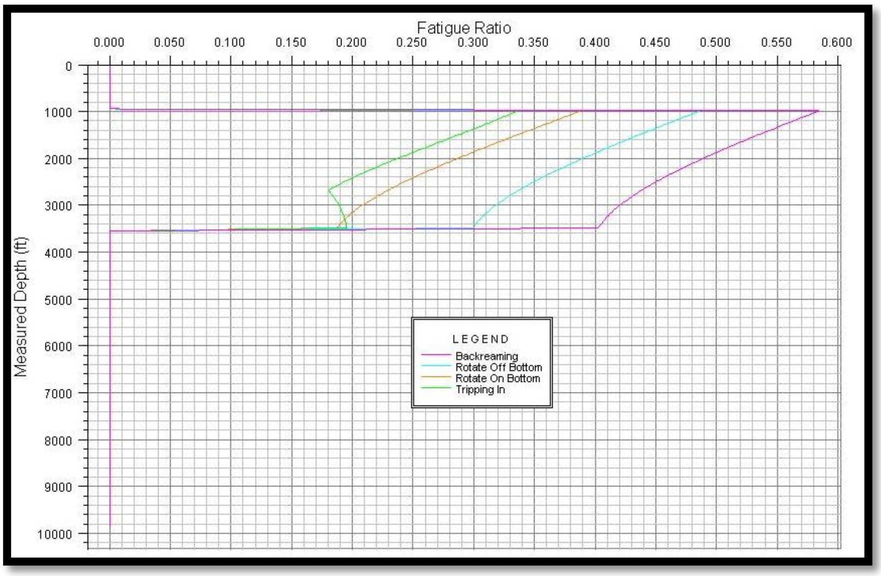


Figure 15: 12 ¼ " Fatigue Graph

Similar to the 16" hole section, torque for Well X increases as measured depth and inclination increases in the 12 ¼ " hole as well. *Figure 14* below displays the maximum torque found at the surface for each operational mode. This plot also displays the make-up torque limit for reference.

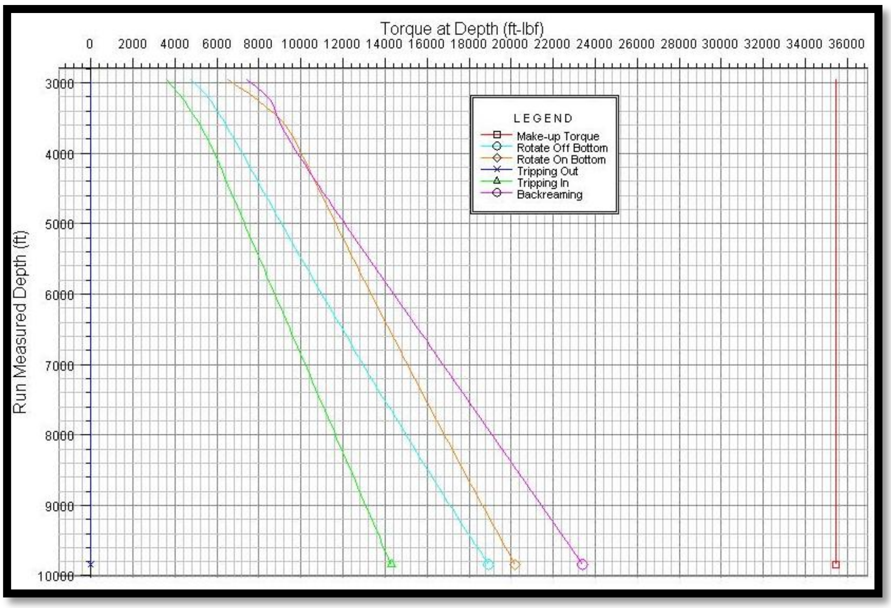


Figure 16: 12 ¼ " Torque Point Chart

Tripping in with /without rotation

Studies have shown that rotation of the drill string has a significant effect on hole cleaning during directional-well drilling. Rotation of the string also minimizes the risks of pipe buckling and helps to increase the rate of penetration.

For the 12 ¼ " hole section, it was discovered that if the string is rotated at 40 RPM while tripping in, the hookload will not exceed the maximum weight to buckle. Subsequently, if tripping was done without any rotation, buckling may occur.

This is evident in *Figure 15* and *Figure 16* below. These two plots display the hook load for tripping in calculated using different friction factors.

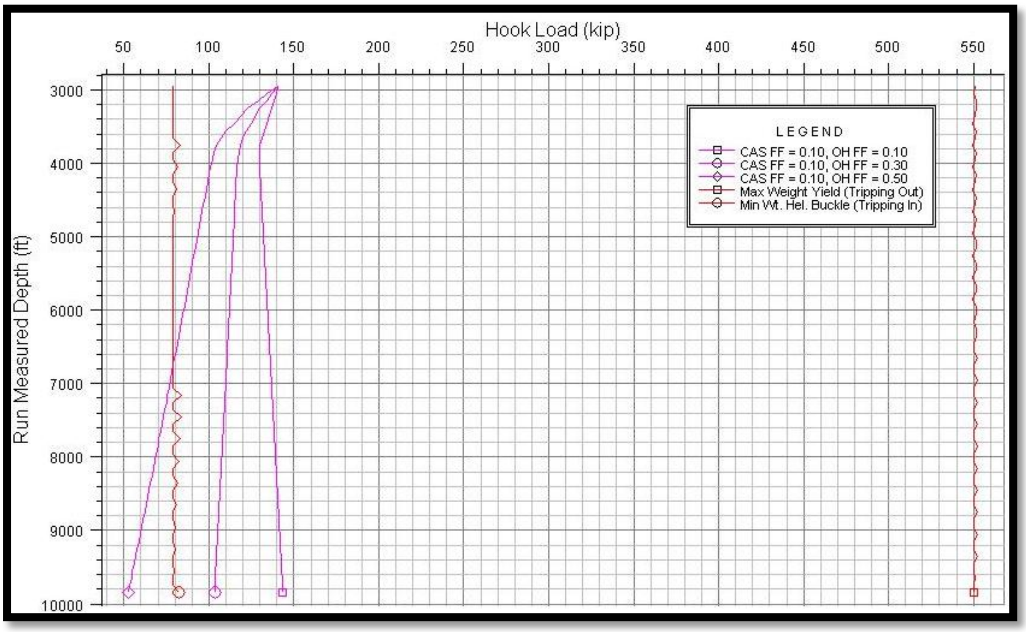


Figure 17: Sensitivity Plot- Hook Load (Tripping In WITHOUT rotation)

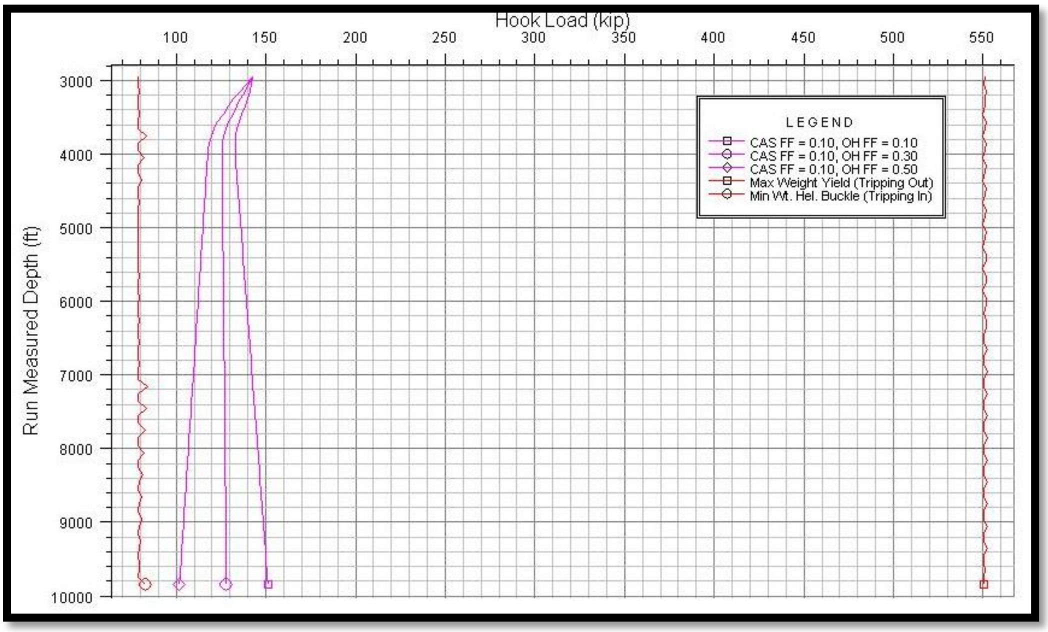


Figure 18: Sensitivity Plot- Hook Load (Tripping In WITH rotation)

The plots also show the tensile or compressive yield limits at each of the string depths analyzed. From the graph, the load that will fail the workstring can be determined, but the exact location of where the failure occurred is not shown. The most right red line (for maximum weight to yield and minimum weight to helically buckle) represent the operating envelope for the string over a range of depths.

The table below summarizes torque and drag load summary while drilling the 12 ¼ ” hole section.

	Load Case	**STF**	**B**	**Torque At Rotary Table** (ft-lbf)	**Windup With Torque** (revs)	**Windup Without Torque** (revs)	**Measured Weight** (kip)	**Total Stretch** (ft)	**Axial Stress**	
									Measured Depth (ft)	**BIT** (ft)
1	BACKREAMING	~~~	~	23412.1	7.3	6.3	189.0	5.4	9253.2	589.8
2	TRIPPING OUT	~~~	~	0.0	0.0	0.0	250.2	6.6	9253.2	589.8
3	ROTATING ON BOTTOM	~~~	~	20180.2	7.0	6.1	139.0	2.8	3711.4	6131.6
4	TRIPPING IN	~~~	~	14295.1	4.8	4.8	126.1	2.7	2670.7	7172.3
5	ROTATING OFF BOTTOM	~~~	~	18923.0	6.1	6.1	164.0	4.1	8250.3	1592.7
6	SLIDING ASSEMBLY	~~~	S	0.0	0.0	0.0	85.1	1.2	797.7	9045.3

Table 2: 12 ¼ " Load Summary

Macro Using VBA

This macro is written to compliment the drillstring analysis for this project. In the case of differential pressure stuck pipe, the increment in torque and drag will cause inability to rotate the drill string. In order to prevent or mitigate its occurrence, the lowest differential pressure is recommended during tripping operations. Ideally, the drillstring should be rotated at all times (if possible).

<u>Case study 1</u>

The drillstring is found to be differentially stuck with a differential pressure of 500 psi when tripping out of a depleted zone. The hole diameter is 9” while the drill collar outer diameter is 6”. Total length of drill collar embedded in the mud cake is 20 ft. The mud cake thickness is 2/32” and the coefficient of friction is 0.15 for oil based mud.

	A	B	C	D	E
1	PARAMETERS		UNIT		
2	Dh =	9.00	in	*(user input)*	
3	tmc =	0.0625	in	*(user input)*	
4	Dop =	6.00	in	*(user input)*	
5					
6	Calculate Arc Length, ψ			2.081	in
7					
8	ArcLength =	2.081	in		
9	Lep =	240.00	in	*(user input)*	
10					
11	Calculate Ac			499.412	
12					
13	Ac =	499.412			
14	μ =	0.15		*(user input)*	
15	ΔP =	500.00	psi	*(user input)*	
16					
17	Calculate required pull force, Fpull			37455.88	lbs
18					

Figure 19: Calculation For Case 1

Based on the calculation in above figure, the required pull force is 37455.88 lbs.

Case study 2

A pipe at 10,000 ft is found to be differentially stuck while tripping out from a long lateral section of an ERD well. The CoF is equal to 0.2 and have mud cake thickness of 1/3”. Drill collar used is 6.25” OD, with hole size of 8.5”. The mud weight is equal to 10 ppg. Formation pressure at 10.000 ft is 4950 psi and length of embedded portion is equal to 50 ft.

	A	B	C	D	E	F
1	PARAMETERS		UNIT			
2	Dh =	8.50	in	(user input)		
3	tmc =	0.3333	in	(user input)		
4	Dop =	6.25	in	(user input)		
5						
6	Calculate Arc Length, ψ			4.939	in	
7						
8	ArcLength =	4.939	in			
9	Lep =	600.00	in	(user input)		
10						
11	Calculate Ac			2963.278		
12						
13	Ac =	2963.278				
14	μ =	0.20		(user input)		
15	ΔP =	250.00	psi	(user input)		
16						
17	Calculate required pull force, Fpull			148163.89	lbs	
18						

Figure 20: Calculation For Case 2

Due to the long embedded pipe length, the force required in order to pull free the stuck pipe is more, which is 148163.89 lbs. The maximum overpull is restricted by the rig capability thus the required pull force must be predicted beforehand for various situations in order to determine a suitable rig for drilling the well. In conclusion, the calculation of F_{pull} is important in an ERD well operation.

DISCUSSION

Recap:-

The objectives of this study are:

- To understand the parameters governing drillstring design
- To investigate the possibility of buckling and occurrence of differential pipe sticking
- To reduce torque and drag and mitigate the risk of torsional failure and buckling of the drill string without over designing the tubular for ERD well operation

1. Parameters governing drill string design

Drill string design is mainly govern by the torque and drag exerted on the tubular. The long horizontal departure in an ERD well poses a high chance for the tubular to lie on the low side of the wellbore. This will increase the drag force which acts in the opposite direction of motion.

Another component that is important in drill string design is torque. As drag increases, the rotational ability of a drill string decreases. To be able to turn the string while drilling is important to maintain a good hole cleaning and to reach TD. Not only that, rotating the string helps to mitigate the risk of stuck pipe and decreases the torque for tripping operation. On the other hand, the make up torque for each component must not be less than the torque applied on the string to avoid connection failure.

One more important design factor for a drill string is its ability to maintain a good hole cleaning. At well X, hydroclean drill pipes are utilize in both 16" and 12 ¼ " hole section to assist in keeping the wellbore clean. Frequent bottoms-up and wiper trips are also recommended. Good hole cleaning can minimize torque and drag.

2. Loads experience by the string

In the analysis, several stresses are calculated and plotted against measured depth.

- Axial stress due to hydrostatic and mechanical loading
- Bending stress approximated from wellbore curvature and is due to buckling
- Hoop stress due to internal and external pressure
- Radial stress due to internal and external pressure
- Torsional stress from twist
- Transverse shear stress from contact
- Von Mises

3. Buckling

Buckling first occurs when compressive axial forces exceed a critical buckling force. Different critical buckling forces are required to initiate the sinusoidal and helical buckling phases. Buckling of the string will have an influence on reach capability, fatigue and directional control.

In SPE 36761, it was stated that in an ideal situation, without external disturbances, the pipe would stay in a sinusoidal buckling mode until the axial force reached 2.8 times the sinusoidal buckling force. At this point, the pipe would transition to the helical buckling mode.

Furthermore, buckling prevents free pipe movement which increases torque and drag. Therefore, measures must be taken to ensure that buckling does not happen. The measures include proper torque and drag modeling and keeping a watch on WOB and resultant ROP.

4. Differential Pipe Sticking

Hydraulic or differential pipe sticking could not be modeled using WELLPLAN™. Therefore, a macro that computes the required pull force, F_{pull} to free stuck pipe due to hydraulic sticking has been written to compliment this project.

The formula used for calculating F_{pull} does not take the angle of the pipe at the moment into consideration. According to J. J. Azar, although pipe angle plays a role in pipe-sticking force, it is an uncontrollable variable. Subsequently, there is no way to determine at what exact depth and angle the pipe would be stuck.

CHAPTER FIVE : CONCLUSION AND RECOMMENDATION

From the analysis done for Well X, it can be concluded that suitable WOB and rotation speed is required to ensure that well TD could be reach. Torque and drag may be an issue for the inclined and tangential section of the wellbore but there are numerous measures that have been opted and utilize by the industry.

The use of mechanical torque reduction tool such as spiral heavy weight drill pipe (HWDP), RSS and NRDPP are among the few common practices in the oil and gas business. In addition, MWD and LWD tools should be run at appropriate intervals to ensure that well X will have minimal tortuosity and deviation from plan.

For differential pipe sticking, spiral drill collars are recommended while drilling in problematic areas like depleted and subnormal zones. The shape of drill collars, availability of grooves or external upset tool joints, can minimize the sticking force. Properly managing the lubricity of the drilling fluid and quality of mudcake across permeable formations also helps to reduce the occurrence of stuck pipe.

As a conclusion, factors that should be considered when designing a drill string include:

1. Maximum expected loads
2. Accumulated fatigue
3. Equipment availability
4. Buckling
5. Hydraulics requirement

CHAPTER SIX : REFERENCE

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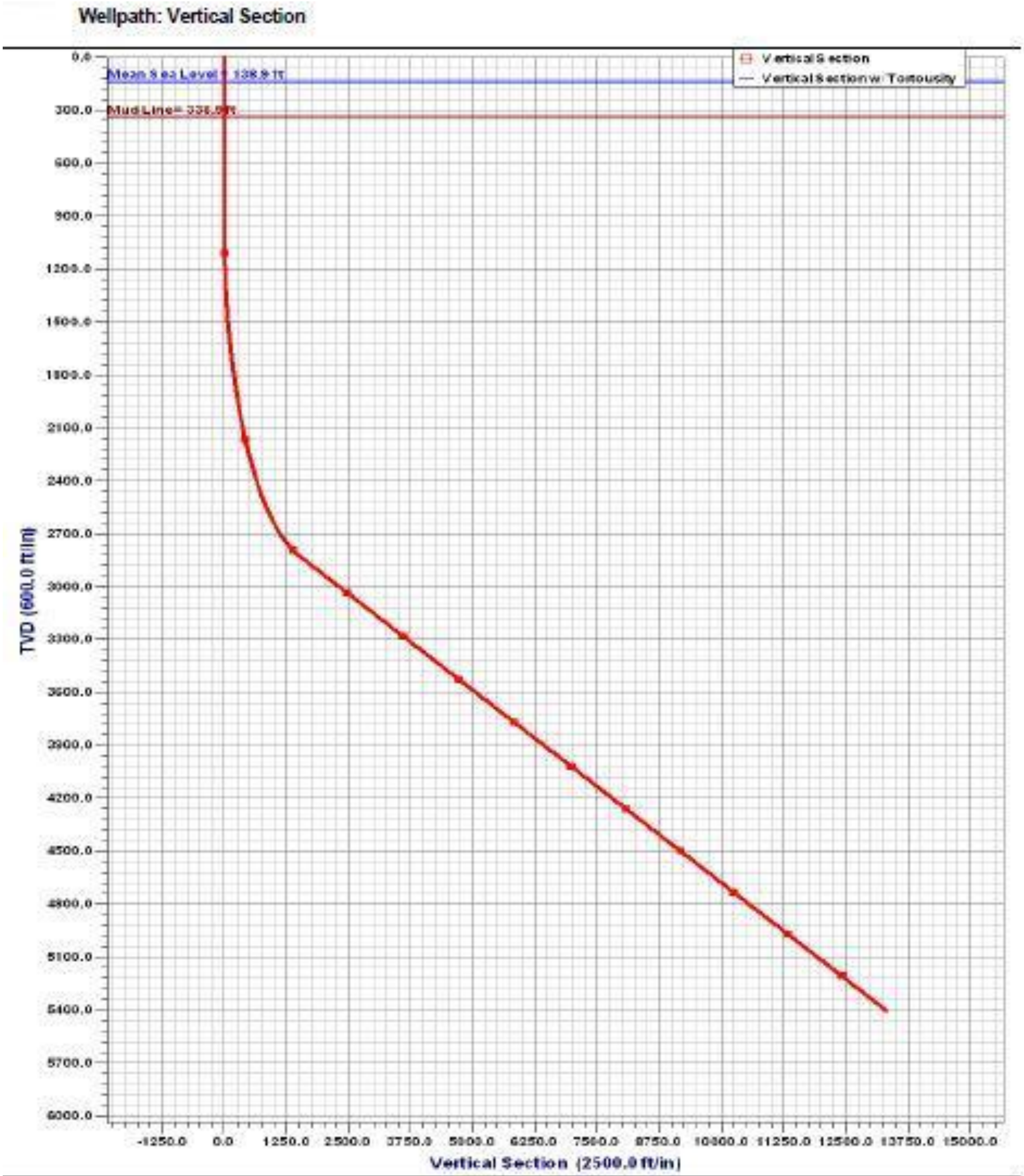
CHAPTER SEVEN : APPENDICES

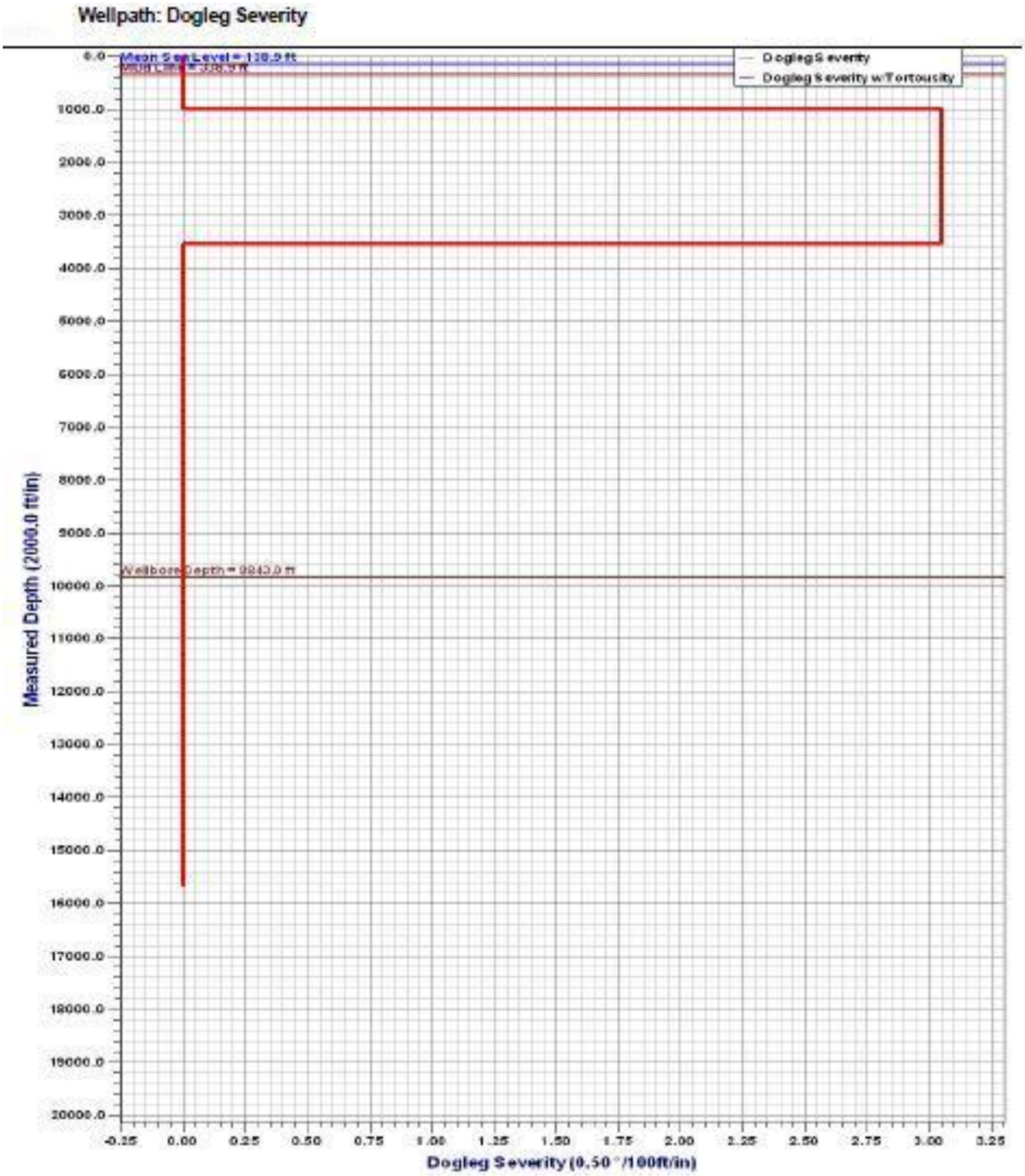
Geothermal Gradient Data

Ambient Temperature	88.00 °F	Mudline Temperature	40.00 °F
Temperature @ Depth	152.46 °F @ 5,404.8 ft	Gradient	2.22 °F/100ft

Above: *Geothermal Gradient Data*



Above: *Wellpath Vertical Section*



Above: *Wellpath DLS*

MD (ft)	INC (°)	AZ (°)	TVD (ft)	DLS (°/100ft)	AbsTort (°/100ft)	RelTort (°/100ft)	VSect (ft)	North (ft)	East (ft)	Build (°/100ft)	Walk (°/100ft)
0.0	0.00	61.02	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
98.4	0.00	61.02	98.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
196.8	0.00	61.02	196.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
295.3	0.00	61.02	295.3	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
393.7	0.00	61.02	393.7	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
492.1	0.00	61.02	492.1	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
574.1	0.00	61.02	574.1	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
590.5	0.00	61.02	590.5	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00

Above: *Wellpath Editor*

MD (ft)	INC (°)	AZ (°)	TVD (ft)	DLS (°/100ft)	AbsTort (°/100ft)	RelTort (°/100ft)	VSect (ft)	North (ft)	East (ft)	Build (°/100ft)	Walk (°/100ft)
689.0	0.00	61.02	689.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
787.4	0.00	61.02	787.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
885.8	0.00	61.02	885.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
984.2	0.00	61.02	984.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
1,082.7	3.00	61.02	1,082.6	3.05	0.28	0.00	2.6	1.2	2.3	3.05	0.00
1,181.1	6.00	61.02	1,180.7	3.05	0.51	0.00	10.3	5.0	9.0	3.05	0.00
1,279.5	9.00	61.02	1,278.3	3.05	0.70	0.00	23.1	11.2	20.2	3.05	0.00
1,377.9	12.00	61.02	1,375.1	3.05	0.87	0.00	41.1	19.9	35.9	3.05	0.00
1,476.4	15.00	61.02	1,470.8	3.05	1.02	0.00	64.1	31.0	56.0	3.05	0.00
1,574.8	18.00	61.02	1,565.1	3.05	1.14	0.00	92.0	44.6	80.5	3.05	0.00
1,673.2	21.00	61.02	1,657.9	3.05	1.26	0.00	124.9	60.5	109.2	3.05	0.00
1,771.6	24.00	61.02	1,748.8	3.05	1.35	0.00	162.5	78.7	142.2	3.05	0.00
1,870.1	27.00	61.02	1,837.6	3.05	1.44	0.00	204.9	99.3	179.2	3.05	0.00
1,968.5	30.00	61.02	1,924.1	3.05	1.52	0.00	251.8	122.0	220.3	3.05	0.00
2,066.9	33.00	61.02	2,008.0	3.05	1.60	0.00	303.3	146.9	265.3	3.05	0.00
2,165.3	36.00	61.02	2,089.1	3.05	1.66	0.00	359.0	173.9	314.1	3.05	0.00
2,263.7	39.00	61.02	2,167.2	3.05	1.72	0.00	418.9	203.0	366.5	3.05	0.00
2,362.2	42.00	61.02	2,242.0	3.05	1.78	0.00	482.8	233.9	422.4	3.05	0.00
2,460.6	45.00	61.02	2,313.4	3.05	1.83	0.00	550.6	266.8	481.6	3.05	0.00
2,559.0	48.00	61.02	2,381.2	3.05	1.88	0.00	622.0	301.3	544.1	3.05	0.00
2,657.4	51.00	61.02	2,445.1	3.05	1.92	0.00	696.8	337.6	609.5	3.05	0.00
2,755.9	54.00	61.02	2,505.0	3.05	1.96	0.00	774.9	375.4	677.8	3.05	0.00
2,854.3	57.00	61.02	2,560.7	3.05	2.00	0.00	856.0	414.7	748.8	3.05	0.00
2,952.7	60.00	61.02	2,612.2	3.05	2.03	0.00	939.9	455.4	822.2	3.05	0.00
3,051.1	63.00	61.02	2,659.1	3.05	2.06	0.00	1,026.4	497.3	897.9	3.05	0.00
3,149.6	66.00	61.02	2,701.5	3.05	2.10	0.00	1,115.2	540.3	975.6	3.05	0.00
3,248.0	69.00	61.02	2,739.1	3.05	2.12	0.00	1,206.1	584.4	1,055.1	3.05	0.00
3,346.4	72.00	61.02	2,772.0	3.05	2.15	0.00	1,298.9	629.3	1,136.3	3.05	0.00
3,444.8	75.00	61.02	2,799.9	3.05	2.18	0.00	1,393.2	675.0	1,218.8	3.05	0.00
3,533.1	77.69	61.02	2,820.8	3.05	2.20	0.00	1,479.0	716.6	1,293.8	3.05	0.00
3,543.3	77.69	61.02	2,822.9	0.00	2.19	0.00	1,488.9	721.4	1,302.5	0.00	0.00
3,641.7	77.69	61.02	2,843.9	0.00	2.13	0.00	1,585.1	768.0	1,386.6	0.00	0.00
3,740.1	77.69	61.02	2,864.9	0.00	2.08	0.00	1,681.3	814.6	1,470.7	0.00	0.00
3,838.5	77.69	61.02	2,885.9	0.00	2.02	0.00	1,777.4	861.2	1,554.9	0.00	0.00
3,937.0	77.69	61.02	2,906.9	0.00	1.97	0.00	1,873.6	907.8	1,639.0	0.00	0.00
4,035.4	77.69	61.02	2,927.9	0.00	1.93	0.00	1,969.7	954.3	1,723.1	0.00	0.00
4,133.8	77.69	61.02	2,948.9	0.00	1.88	0.00	2,065.9	1,000.9	1,807.2	0.00	0.00
4,232.2	77.69	61.02	2,969.8	0.00	1.84	0.00	2,162.1	1,047.5	1,891.3	0.00	0.00
4,330.7	77.69	61.02	2,990.8	0.00	1.79	0.00	2,258.2	1,094.1	1,975.5	0.00	0.00
4,429.1	77.69	61.02	3,011.8	0.00	1.75	0.00	2,354.4	1,140.7	2,059.6	0.00	0.00
4,527.5	77.69	61.02	3,032.8	0.00	1.72	0.00	2,450.5	1,187.3	2,143.7	0.00	0.00
4,625.9	77.69	61.02	3,053.8	0.00	1.68	0.00	2,546.7	1,233.9	2,227.8	0.00	0.00
4,724.3	77.69	61.02	3,074.8	0.00	1.64	0.00	2,642.9	1,280.5	2,311.9	0.00	0.00
4,822.8	77.69	61.02	3,095.7	0.00	1.61	0.00	2,739.0	1,327.1	2,396.1	0.00	0.00
4,921.2	77.69	61.02	3,116.7	0.00	1.58	0.00	2,835.2	1,373.7	2,480.2	0.00	0.00
5,019.6	77.69	61.02	3,137.7	0.00	1.55	0.00	2,931.3	1,420.2	2,564.3	0.00	0.00
5,118.0	77.69	61.02	3,158.7	0.00	1.52	0.00	3,027.5	1,466.8	2,648.4	0.00	0.00
5,216.5	77.69	61.02	3,179.7	0.00	1.49	0.00	3,123.7	1,513.4	2,732.5	0.00	0.00
5,314.9	77.69	61.02	3,200.7	0.00	1.46	0.00	3,219.8	1,560.0	2,816.7	0.00	0.00
5,413.3	77.69	61.02	3,221.6	0.00	1.44	0.00	3,316.0	1,606.6	2,900.8	0.00	0.00
5,511.7	77.69	61.02	3,242.6	0.00	1.41	0.00	3,412.1	1,653.2	2,984.9	0.00	0.00
5,610.2	77.69	61.02	3,263.6	0.00	1.38	0.00	3,508.3	1,699.8	3,069.0	0.00	0.00
5,708.6	77.69	61.02	3,284.6	0.00	1.36	0.00	3,604.5	1,746.4	3,153.2	0.00	0.00
5,807.0	77.69	61.02	3,305.6	0.00	1.34	0.00	3,700.6	1,793.0	3,237.3	0.00	0.00
5,905.4	77.69	61.02	3,326.6	0.00	1.32	0.00	3,796.8	1,839.6	3,321.4	0.00	0.00

Above: *Wellpath Editor (cont'd)*

MD (ft)	INC (°)	AZ (°)	TVD (ft)	DLS (°/100ft)	AbsTort (°/100ft)	RelTort (°/100ft)	VSect (ft)	North (ft)	East (ft)	Build (°/100ft)	Walk (°/100ft)
6,003.9	77.69	61.02	3,347.6	0.00	1.29	0.00	3,893.0	1,886.2	3,405.5	0.00	0.00
6,102.3	77.69	61.02	3,368.5	0.00	1.27	0.00	3,989.1	1,932.7	3,489.6	0.00	0.00
6,200.7	77.69	61.02	3,389.5	0.00	1.25	0.00	4,085.3	1,979.3	3,573.8	0.00	0.00
6,299.1	77.69	61.02	3,410.5	0.00	1.23	0.00	4,181.4	2,025.9	3,657.9	0.00	0.00
6,397.6	77.69	61.02	3,431.5	0.00	1.21	0.00	4,277.6	2,072.5	3,742.0	0.00	0.00
6,496.0	77.69	61.02	3,452.5	0.00	1.20	0.00	4,373.8	2,119.1	3,826.1	0.00	0.00
6,594.4	77.69	61.02	3,473.5	0.00	1.18	0.00	4,469.9	2,165.7	3,910.2	0.00	0.00
6,692.8	77.69	61.02	3,494.4	0.00	1.16	0.00	4,566.1	2,212.3	3,994.4	0.00	0.00
6,791.3	77.69	61.02	3,515.4	0.00	1.14	0.00	4,662.2	2,258.9	4,078.5	0.00	0.00
6,889.7	77.69	61.02	3,536.4	0.00	1.13	0.00	4,758.4	2,305.5	4,162.6	0.00	0.00
6,988.1	77.69	61.02	3,557.4	0.00	1.11	0.00	4,854.6	2,352.1	4,246.7	0.00	0.00
7,086.5	77.69	61.02	3,578.4	0.00	1.10	0.00	4,950.7	2,398.7	4,330.8	0.00	0.00
7,184.9	77.69	61.02	3,599.4	0.00	1.08	0.00	5,046.9	2,445.2	4,415.0	0.00	0.00
7,283.4	77.69	61.02	3,620.3	0.00	1.07	0.00	5,143.1	2,491.8	4,499.1	0.00	0.00
7,381.8	77.69	61.02	3,641.3	0.00	1.05	0.00	5,239.2	2,538.4	4,583.2	0.00	0.00
7,480.2	77.69	61.02	3,662.3	0.00	1.04	0.00	5,335.4	2,585.0	4,667.3	0.00	0.00
7,578.6	77.69	61.02	3,683.3	0.00	1.03	0.00	5,431.5	2,631.6	4,751.4	0.00	0.00
7,677.1	77.69	61.02	3,704.3	0.00	1.01	0.00	5,527.7	2,678.2	4,835.6	0.00	0.00
7,775.5	77.69	61.02	3,725.3	0.00	1.00	0.00	5,623.9	2,724.8	4,919.7	0.00	0.00
7,873.9	77.69	61.02	3,746.3	0.00	0.99	0.00	5,720.0	2,771.4	5,003.8	0.00	0.00
7,972.3	77.69	61.02	3,767.2	0.00	0.97	0.00	5,816.2	2,818.0	5,087.9	0.00	0.00
8,070.8	77.69	61.02	3,788.2	0.00	0.96	0.00	5,912.3	2,864.6	5,172.1	0.00	0.00
8,169.2	77.69	61.02	3,809.2	0.00	0.95	0.00	6,008.5	2,911.1	5,256.2	0.00	0.00
8,267.6	77.69	61.02	3,830.2	0.00	0.94	0.00	6,104.7	2,957.7	5,340.3	0.00	0.00
8,366.0	77.69	61.02	3,851.2	0.00	0.93	0.00	6,200.8	3,004.3	5,424.4	0.00	0.00
8,464.5	77.69	61.02	3,872.2	0.00	0.92	0.00	6,297.0	3,050.9	5,508.5	0.00	0.00
8,562.9	77.69	61.02	3,893.1	0.00	0.91	0.00	6,393.1	3,097.5	5,592.7	0.00	0.00
8,661.3	77.69	61.02	3,914.1	0.00	0.90	0.00	6,489.3	3,144.1	5,676.8	0.00	0.00
8,759.7	77.69	61.02	3,935.1	0.00	0.89	0.00	6,585.5	3,190.7	5,760.9	0.00	0.00
8,858.2	77.69	61.02	3,956.1	0.00	0.88	0.00	6,681.6	3,237.3	5,845.0	0.00	0.00
8,956.6	77.69	61.02	3,977.1	0.00	0.87	0.00	6,777.8	3,283.9	5,929.1	0.00	0.00
9,055.0	77.69	61.02	3,998.1	0.00	0.86	0.00	6,874.0	3,330.5	6,013.3	0.00	0.00
9,153.4	77.69	61.02	4,019.0	0.00	0.85	0.00	6,970.1	3,377.0	6,097.4	0.00	0.00
9,251.9	77.69	61.02	4,040.0	0.00	0.84	0.00	7,066.3	3,423.6	6,181.5	0.00	0.00
9,350.3	77.69	61.02	4,061.0	0.00	0.83	0.00	7,162.4	3,470.2	6,265.6	0.00	0.00
9,448.7	77.69	61.02	4,082.0	0.00	0.82	0.00	7,258.6	3,516.8	6,349.7	0.00	0.00
9,547.1	77.69	61.02	4,103.0	0.00	0.81	0.00	7,354.8	3,563.4	6,433.9	0.00	0.00
9,645.5	77.69	61.02	4,124.0	0.00	0.81	0.00	7,450.9	3,610.0	6,518.0	0.00	0.00
9,744.0	77.69	61.02	4,144.9	0.00	0.80	0.00	7,547.1	3,656.6	6,602.1	0.00	0.00
9,842.4	77.69	61.02	4,165.9	0.00	0.79	0.00	7,643.2	3,703.2	6,686.2	0.00	0.00
9,940.8	77.69	61.02	4,186.9	0.00	0.78	0.00	7,739.4	3,749.8	6,770.3	0.00	0.00
10,039.2	77.69	61.02	4,207.9	0.00	0.77	0.00	7,835.6	3,796.4	6,854.5	0.00	0.00
10,137.7	77.69	61.02	4,228.9	0.00	0.77	0.00	7,931.7	3,843.0	6,938.6	0.00	0.00
10,236.1	77.69	61.02	4,249.9	0.00	0.76	0.00	8,027.9	3,889.5	7,022.7	0.00	0.00
10,334.5	77.69	61.02	4,270.9	0.00	0.75	0.00	8,124.0	3,936.1	7,106.8	0.00	0.00
10,432.9	77.69	61.02	4,291.8	0.00	0.74	0.00	8,220.2	3,982.7	7,190.9	0.00	0.00
10,531.4	77.69	61.02	4,312.8	0.00	0.74	0.00	8,316.4	4,029.3	7,275.1	0.00	0.00
10,629.8	77.69	61.02	4,333.8	0.00	0.73	0.00	8,412.5	4,075.9	7,359.2	0.00	0.00
10,728.2	77.69	61.02	4,354.8	0.00	0.72	0.00	8,508.7	4,122.5	7,443.3	0.00	0.00
10,774.9	77.69	61.02	4,364.7	0.00	0.72	0.00	8,554.3	4,144.6	7,483.2	0.00	0.00
10,826.6	77.69	61.02	4,375.8	0.00	0.72	0.00	8,604.8	4,169.1	7,527.4	0.00	0.00
10,925.1	77.69	61.02	4,396.8	0.00	0.71	0.00	8,701.0	4,215.7	7,611.5	0.00	0.00
11,023.5	77.69	61.02	4,417.7	0.00	0.70	0.00	8,797.2	4,262.3	7,695.7	0.00	0.00
11,121.9	77.69	61.02	4,438.7	0.00	0.70	0.00	8,893.3	4,308.9	7,779.8	0.00	0.00
11,220.3	77.69	61.02	4,459.7	0.00	0.69	0.00	8,989.5	4,355.5	7,863.9	0.00	0.00

Above: *Wellpath Editor (cont'd)*

MD (ft)	INC (°)	AZ (°)	TVD (ft)	DLS (°/100ft)	AbsTort (°/100ft)	RelTort (°/100ft)	VSect (ft)	North (ft)	East (ft)	Build (°/100ft)	Walk (°/100ft)
11,221.2	77.69	61.02	4,459.9	0.00	0.69	0.00	8,990.3	4,355.8	7,864.6	0.00	0.00
11,318.8	77.69	61.02	4,480.7	0.00	0.69	0.00	9,085.7	4,402.0	7,948.0	0.00	0.00
11,405.9	77.69	61.02	4,499.3	0.00	0.68	0.00	9,170.8	4,443.3	8,022.5	0.00	0.00
11,417.2	77.69	61.02	4,501.7	0.00	0.68	0.00	9,181.8	4,448.6	8,032.1	0.00	0.00
11,515.6	77.69	61.02	4,522.7	0.00	0.67	0.00	9,278.0	4,495.2	8,116.3	0.00	0.00
11,590.5	77.69	61.02	4,538.6	0.00	0.67	0.00	9,351.2	4,530.7	8,180.3	0.00	0.00
11,614.0	77.69	61.02	4,543.6	0.00	0.67	0.00	9,374.1	4,541.8	8,200.4	0.00	0.00
11,712.5	77.69	61.02	4,564.6	0.00	0.66	0.00	9,470.3	4,588.4	8,284.5	0.00	0.00
11,810.9	77.69	61.02	4,585.6	0.00	0.66	0.00	9,566.5	4,635.0	8,368.6	0.00	0.00
11,909.3	77.69	61.02	4,606.6	0.00	0.65	0.00	9,662.6	4,681.6	8,452.7	0.00	0.00
12,007.7	77.69	61.02	4,627.6	0.00	0.65	0.00	9,758.8	4,728.2	8,536.9	0.00	0.00
12,106.1	77.69	61.02	4,648.6	0.00	0.64	0.00	9,854.9	4,774.8	8,621.0	0.00	0.00
12,204.6	77.69	61.02	4,669.6	0.00	0.64	0.00	9,951.1	4,821.4	8,705.1	0.00	0.00
12,303.0	77.69	61.02	4,690.5	0.00	0.63	0.00	10,047.3	4,867.9	8,789.2	0.00	0.00
12,401.4	77.69	61.02	4,711.5	0.00	0.63	0.00	10,143.4	4,914.5	8,873.4	0.00	0.00
12,499.8	77.69	61.02	4,732.5	0.00	0.62	0.00	10,239.6	4,961.1	8,957.5	0.00	0.00
12,598.3	77.69	61.02	4,753.5	0.00	0.62	0.00	10,335.7	5,007.7	9,041.6	0.00	0.00
12,696.7	77.69	61.02	4,774.5	0.00	0.61	0.00	10,431.9	5,054.3	9,125.7	0.00	0.00
12,795.1	77.69	61.02	4,795.5	0.00	0.61	0.00	10,528.1	5,100.9	9,209.8	0.00	0.00
12,893.5	77.69	61.02	4,816.4	0.00	0.60	0.00	10,624.2	5,147.5	9,294.0	0.00	0.00
12,992.0	77.69	61.02	4,837.4	0.00	0.60	0.00	10,720.4	5,194.1	9,378.1	0.00	0.00
13,090.4	77.69	61.02	4,858.4	0.00	0.59	0.00	10,816.6	5,240.7	9,462.2	0.00	0.00
13,188.8	77.69	61.02	4,879.4	0.00	0.59	0.00	10,912.7	5,287.3	9,546.3	0.00	0.00
13,287.2	77.69	61.02	4,900.4	0.00	0.58	0.00	11,008.9	5,333.8	9,630.4	0.00	0.00
13,298.8	77.69	61.02	4,902.9	0.00	0.58	0.00	11,020.2	5,339.3	9,640.4	0.00	0.00
13,385.7	77.69	61.02	4,921.4	0.00	0.58	0.00	11,105.0	5,380.4	9,714.6	0.00	0.00
13,484.1	77.69	61.02	4,942.3	0.00	0.58	0.00	11,201.2	5,427.0	9,798.7	0.00	0.00
13,582.5	77.69	61.02	4,963.3	0.00	0.57	0.00	11,297.4	5,473.6	9,882.8	0.00	0.00
13,680.9	77.69	61.02	4,984.3	0.00	0.57	0.00	11,393.5	5,520.2	9,966.9	0.00	0.00
13,779.4	77.69	61.02	5,005.3	0.00	0.56	0.00	11,489.7	5,566.8	10,051.0	0.00	0.00
13,877.8	77.69	61.02	5,026.3	0.00	0.56	0.00	11,585.8	5,613.4	10,135.2	0.00	0.00
13,976.2	77.69	61.02	5,047.3	0.00	0.56	0.00	11,682.0	5,660.0	10,219.3	0.00	0.00
14,074.6	77.69	61.02	5,068.2	0.00	0.55	0.00	11,778.2	5,706.6	10,303.4	0.00	0.00
14,145.3	77.69	61.02	5,083.3	0.00	0.55	0.00	11,847.2	5,740.0	10,363.8	0.00	0.00
14,173.1	77.69	61.02	5,089.2	0.00	0.55	0.00	11,874.3	5,753.2	10,387.5	0.00	0.00
14,271.5	77.69	61.02	5,110.2	0.00	0.54	0.00	11,970.5	5,799.8	10,471.6	0.00	0.00
14,369.9	77.69	61.02	5,131.2	0.00	0.54	0.00	12,066.6	5,846.3	10,555.8	0.00	0.00
14,468.3	77.69	61.02	5,152.2	0.00	0.54	0.00	12,162.8	5,892.9	10,639.9	0.00	0.00
14,483.9	77.69	61.02	5,155.5	0.00	0.54	0.00	12,178.0	5,900.3	10,653.2	0.00	0.00
14,566.7	77.69	61.02	5,173.2	0.00	0.53	0.00	12,259.0	5,939.5	10,724.0	0.00	0.00
14,665.2	77.69	61.02	5,194.2	0.00	0.53	0.00	12,355.1	5,986.1	10,808.1	0.00	0.00
14,763.6	77.69	61.02	5,215.1	0.00	0.53	0.00	12,451.3	6,032.7	10,892.3	0.00	0.00
14,862.0	77.69	61.02	5,236.1	0.00	0.52	0.00	12,547.4	6,079.3	10,976.4	0.00	0.00
14,868.6	77.69	61.02	5,237.5	0.00	0.52	0.00	12,553.9	6,082.4	10,982.0	0.00	0.00
14,960.4	77.69	61.02	5,257.1	0.00	0.52	0.00	12,643.6	6,125.9	11,060.5	0.00	0.00
14,961.0	77.69	61.02	5,257.2	0.00	0.52	0.00	12,644.1	6,126.1	11,061.0	0.00	0.00
15,058.9	77.69	61.02	5,278.1	0.00	0.52	0.00	12,739.8	6,172.5	11,144.6	0.00	0.00
15,157.3	77.69	61.02	5,299.1	0.00	0.51	0.00	12,835.9	6,219.1	11,228.7	0.00	0.00
15,255.7	77.69	61.02	5,320.1	0.00	0.51	0.00	12,932.1	6,265.7	11,312.9	0.00	0.00
15,345.7	77.69	61.02	5,339.2	0.00	0.51	0.00	13,020.0	6,308.3	11,389.8	0.00	0.00
15,354.1	77.69	61.02	5,341.0	0.00	0.51	0.00	13,028.3	6,312.2	11,397.0	0.00	0.00
15,452.6	77.69	61.02	5,362.0	0.00	0.50	0.00	13,124.4	6,358.8	11,481.1	0.00	0.00
15,551.0	77.69	61.02	5,383.0	0.00	0.50	0.00	13,220.6	6,405.4	11,565.2	0.00	0.00
15,649.4	77.69	61.02	5,404.0	0.00	0.50	0.00	13,316.7	6,452.0	11,649.3	0.00	0.00
15,653.5	77.69	61.02	5,404.9	0.00	0.50	0.00	13,320.8	6,454.0	11,652.9	0.00	0.00

Above: *Wellpath Editor (cont'd)*

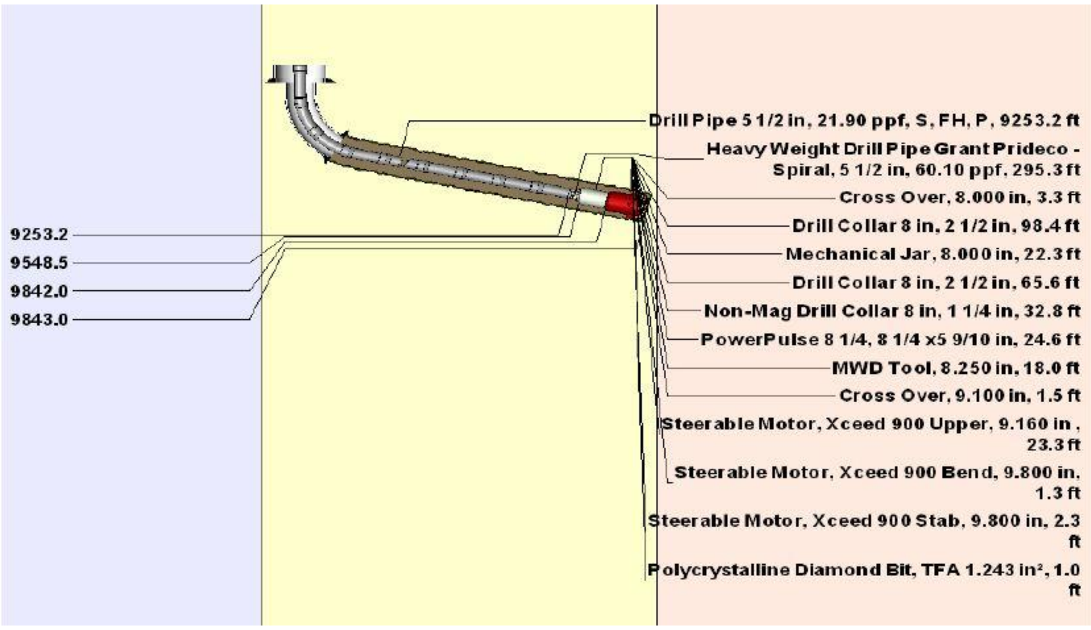
12 ¼" hole section

Section Type	Section Depth (ft)	Section Length (ft)	Shoe Depth (ft)	ID (in)	Drift (in)	Effective Hole Diameter (in)	Coefficient of Friction	Linear Capacity (bbl/ft)	Volume Excess (%)
Casing	574.0	574.00	574.0	22.000	21.813	22.000	0.25	0.4702	
Casing	2,953.0	2,379.00	2,953.0	12.415	12.259	12.415	0.25	0.1496	
Open Hole	9,843.0	6,890.00		12.250		12.250	0.30	0.1458	0.00

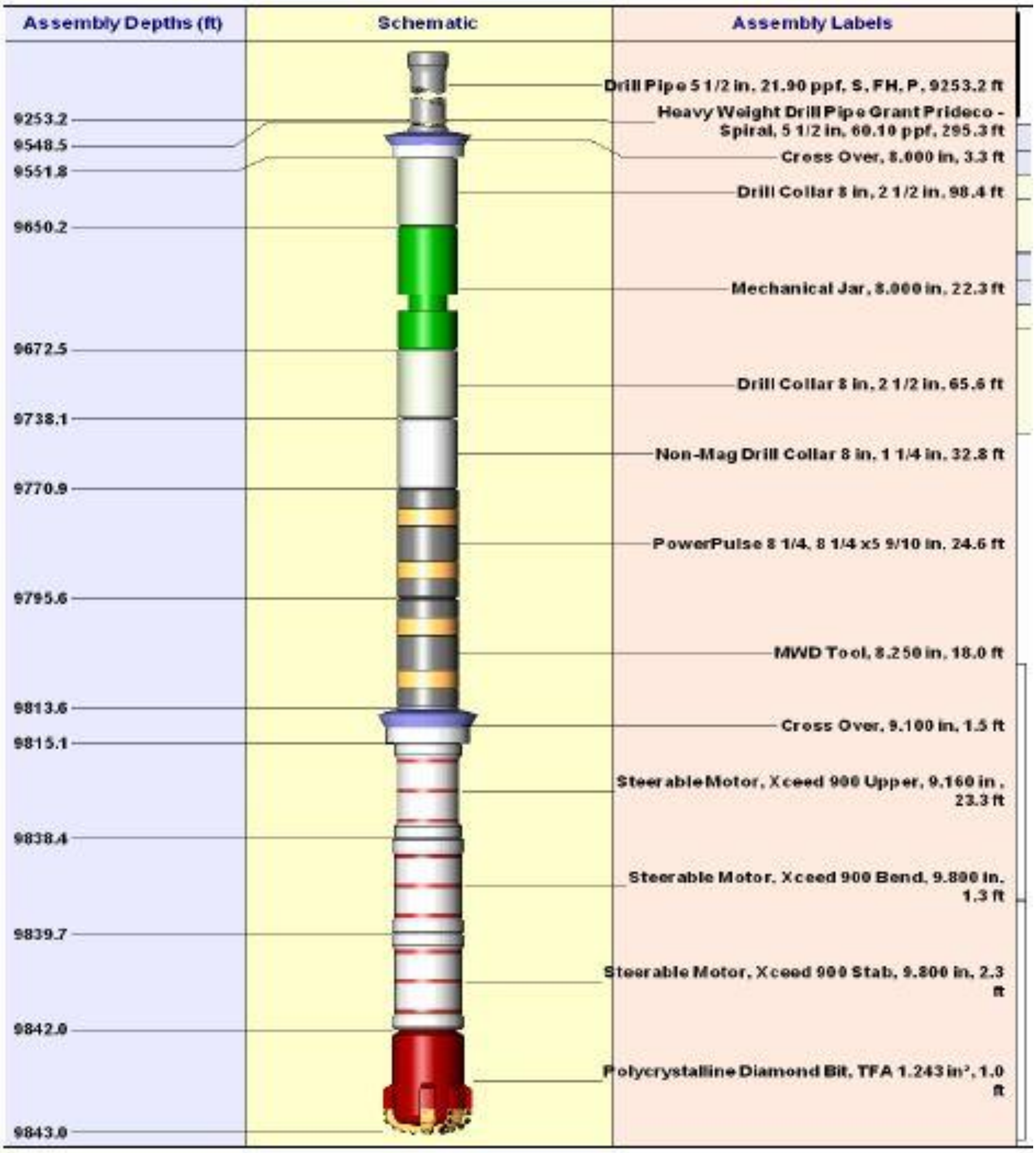
Above: *Hole section*

Type	Length	Depth	Body		Stabilizer / Tool Joint				Weight	Material	Grade	Class
			OD	ID	Avg. Joint Length	Length	OD	ID				
	(ft)	(ft)	(in)	(in)	(ft)	(ft)	(in)	(in)	(ppf)			
Drill Pipe	9,253.21	9,253.2	5.500	4.778	30.0	1.50	6.938	3.000	26.33	CS_API 5D/7	S	P
Heavy Weight Drill Pipe	295.28	9,548.5	5.500	3.250	30.0	4.00	7.250	3.313	60.10	CS_1340 MOD	1340 MOD	
Cross Over	3.28	9,551.8	8.000	2.400					154.35	CS_API 5D/7	4145H MOD	
Drill Collar	98.43	9,650.2	8.000	2.500					154.33	CS_API 5D/7	4145H MOD (2)	
Mechanical Jar	22.31	9,672.5	8.000	2.250					90.88	CS_API 5D/7	4145H MOD	
Drill Collar	65.62	9,738.1	8.000	2.500					154.33	CS_API 5D/7	4145H MOD (2)	
Non-Mag Drill Collar	32.81	9,770.9	8.000	1.250					165.01	SS_15-15LC	15-15LC MOD (2)	
MWD Tool	24.61	9,795.5	8.250	5.900					150.00	SS_15-15LC	15-15LC MOD (1)	
MWD Tool	18.04	9,813.6	8.250	3.000					147.01	SS_15-15LC	15-15LC MOD (1)	
Cross Over	1.51	9,815.1	9.100	2.400					154.35	CS_API 5D/7	4145H MOD	
Steerable Motor	23.29	9,838.4	9.160	6.630					250.00	CS_API 5D/7	4145H MOD	
Steerable Motor	1.31	9,839.7	9.800	7.970					250.00	CS_API 5D/7	4145H MOD	
Steerable Motor	2.30	9,842.0	9.800	3.000					250.00	CS_API 5D/7	4145H MOD	
Polycrystalline Diamond Bit	1.00	9,843.0	12.250						267.00			

Above: *String details*

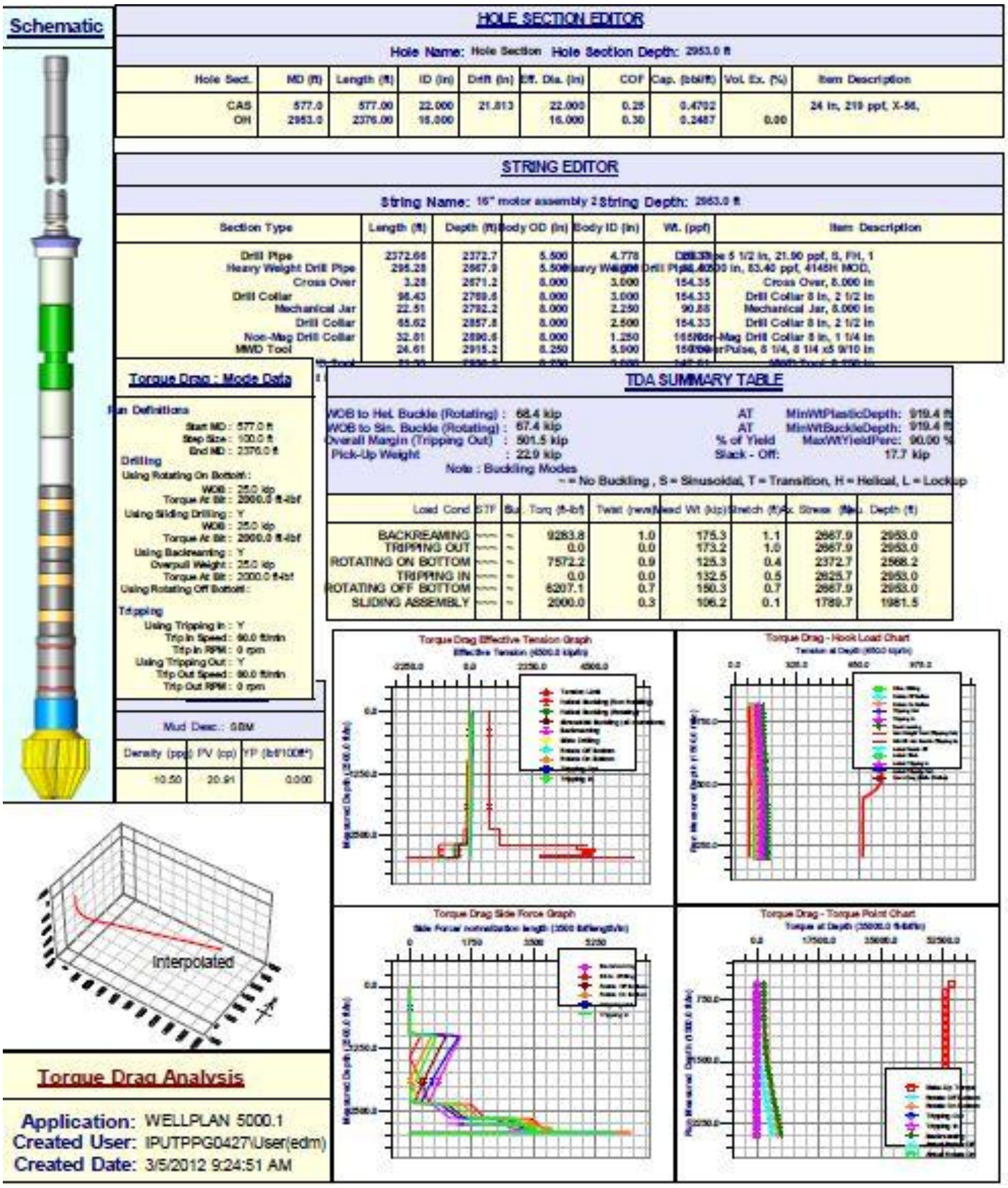


Above: 12 ¼" *BHA to scale, deviated*

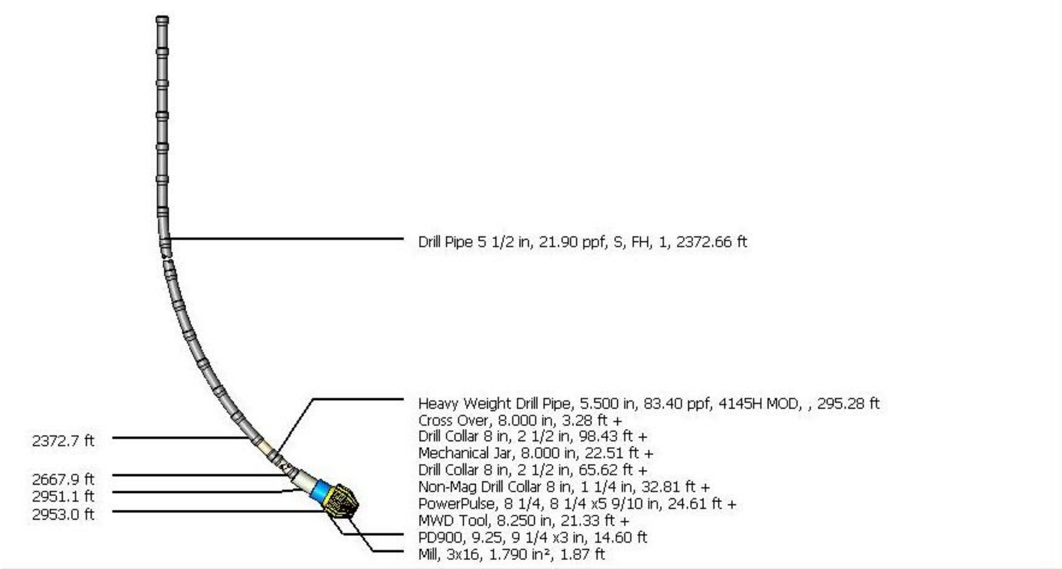


Above: *12 ¼" BHA not to scale, non-deviated*

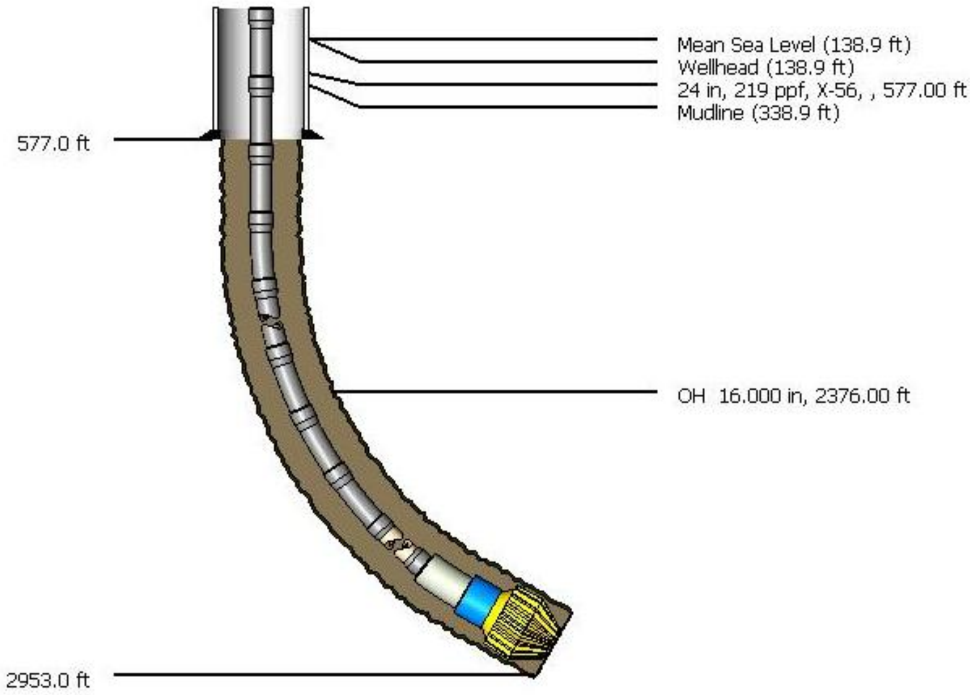
16” hole section



Above: *16” hole summary*



Above: *BHA schematic- assembly*



Above: *16'' full string*