



## Torque and Drag Modeling Predicts Tension, Compression, and Torque Limits for Horizontal Openhole Completion Systems

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### Abstract

Frictional drag that prevents installation of a completion string (CS) to total depth (TD) of a well often occurs in openhole, horizontal wellbores. Without an accurate assessment of the various stresses to which the CS can be subjected during installation, the operator can risk serious well damage or possible well abandonment. A software model that uses a wide range of well parameters to enable the operator to predict possible tension loading, compression loading, and torque limits on the CS during installation is now available. This paper discusses the software and how it is used in modeling well completion systems. Cost of drilling an offshore well can approach, and occasionally, can even exceed \$70 million. In addition, gravel packing in horizontal sections presents other special challenges, because pumping procedures may push the CS uphole.

The new system uses a wide range of well parameters and a software model to enable the operator to predict the loads and stresses that can be placed on the CS during installation. If the modeling process indicates that the CS will not stand the stresses of installation without (1) parting from tensile loading, (2) buckling from the compression load, or (3) twisting off from rotational torque, a different well plan can be devised or other remedies employed. Charts developed from actual case histories will be shown in this paper to illustrate the advantages of using torque and drag modeling as a planning procedure for all phases of well completion.

### Introduction

Since horizontal sections are now being drilled to lengths that exceed 20,000 ft, placement of the CS to planned TD may be impossible under a proposed drilling plan. During the early years of horizontal-well construction, the hanging weight of the completion string was usually adequate to push it to TD. With the extreme lengths being attempted today, there is a need to model the well plan to determine 1) whether the strength of the CS can stand the strains (tension, compression, and torque) of installation, and 2) whether there is enough weight in the upper CS to push the lower CS to TD.

If the modeling process indicates that the CS will not

stand the stresses of installation without 1) parting from tensile loading, 2) buckling from the compression load, or 3) twisting off from rotational torque, a different well plan must be devised. The operator must formulate a new configuration and can use the torque and drag model to do primary assessing of the capabilities of the configuration.

A primary key to successfully planning, drilling, and completing a well, therefore, is to first develop an organized program that foresees all possible problem areas and includes all drilling as well as completion parameters. This program should also determine appropriate bottomhole assemblies and individual tools and components.

Technological advances in drilling, particularly in the past 5 to 7 years, have resulted in the introduction of a broad scope of new drilling and measurement equipment into the offshore and onshore drilling industry. Each advancement and new tool, coupled with the breakneck pace of gathering "Know How" to apply the new concepts, have improved the drilling processes considerably.

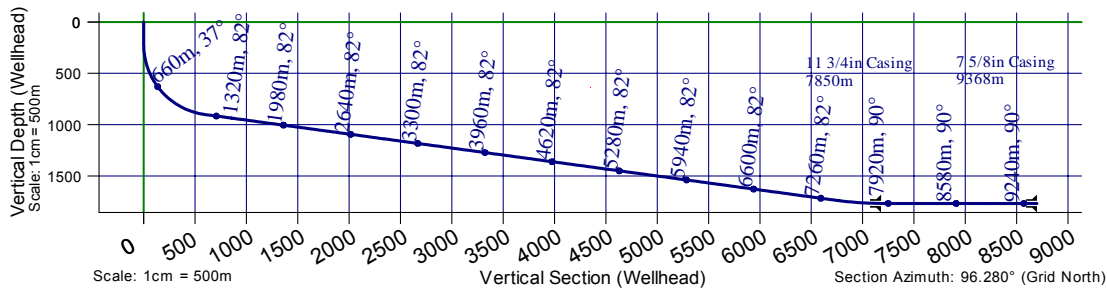
Drilling rigs are also bigger and stronger than their predecessors. High-temperature, high-pressure (HT/HP) measurement-while drilling (MWD) tools that have a greater number of better sensors than ever before are now available, and the advent of rotary steerable systems (RSS) as well as integration of the computer and generation of information technology (IT) have also been integrated into drilling processes. These IT techniques now include real-time data transmission, both from downhole to surface and from the rig site to the office; the new capabilities have improved drilling efficiency and cost to such an extent that many of the wells being drilled and completed today could not have been developed and/or financed before their development.

Rotary steerable systems have enabled wells to be drilled deeper and further horizontally and to reach reservoirs that previously were not accessible in order to improve the economics of the projects.

Although such advancements are used by the service industry, they have been more routinely used during drilling processes, and the advanced capabilities of

these methods have begun to present problems for the completion processes used by service and operating companies. Although both completion and drilling sectors of the oil industry have continued to advance into deeper environments, the completion processes have concentrated on the sand control capabilities needed in the completion rather than on the delivery of the completion components to the position needed in the ever-lengthening hole section. **Figure 1** shows an out-

reaching well plan only drillable with rotary steerable equipment. This design was slated for drilling until a completion torque and drag model was performed. The result is shown in Fig. 7; where at a bit depth of 7500m MD, the drill string is compromised due to helical buckling and does not progress even with compressional force (weight of the top drive) from the surface.



**Figure 1 — Example of an outreaching well plan.**

One of the causes of the recent problems in completion scenarios not fulfilling the depth needs has been the fact that the completion equipment is often not as rugged and strong as the drilling equipment. **Table 1** compares the strength of completion strings and drill strings.

The drill string is rotated to TD, and casing strings are floated to it. However, the completion string can neither

be rotated nor can it be floated. For a project to reach fruition, the well must be completed, and if the completion string can not be brought to TD, the drilling investment in the well is compromised — at least partially, or perhaps, entirely.

**Table 1 — Strength Comparison of completion and drill strings**

Tubular	OD	ID	lb/ft	Tension Yield, lbf	Makeup Torque, ft-lbf
250 Micron Poroflex Expandable Screens	7.37	6.37	27	151600	5700
Poroflex Expandable Blanks	7	6.39	22.6	151600	5700
Spacer Pipe	8.27	7.12	20	151600	5700
5½" S Grade DP 21.9lb/ft	5.5	4.78	26.33	620600	35000

**Torque and Drag Modeling**

Torque-and-drag modeling is a relatively old concept that has been used routinely in drilling applications. The use of this modeling tool to broaden the scope of efficiency in running completion strings is the subject of this paper. As with drilling, when this modeling technique is applied to completion scenarios, it provides a method to predict any possible completion problems beforehand, and therefore, should be a necessary step in a “Completion Prognosis” program.

By modeling the frictional forces on the completion string in advance, it is possible to predict if the string will reach bottom or if the forces resulting from friction will

exceed allowable limits. The model also would predict any possible buckling of the string along the way. When three-dimensional (Helical) buckling occurs, the string is coiled into the wellbore, and no more weight is transferred to the BHA regardless of “Slack Off”.

Torque and Drag modeling software is available from many different sources and can be leased or purchased. To be effective, however, the modeling software must contain a database of bottomhole assembly (BHA) drilling and completion components including such parameters as OD, ID, weight/foot, tensile strength and torsional strength as a minimum.

It is beyond the scope of this paper to cover the

algorithms used in calculating torque and drag or the involved formulas.

There are two algorithms that are considered — a “soft-string” and a “stiff-string.” The soft string algorithm ignores the local stiffness of the collar section (and effect of drilling stabilizers) or very crooked hole sections as this algorithm will result in a slight under-estimation of the amount of drag and torque (or over-estimation of the friction factor). Although the amount of over/under estimation is, in most cases, less than 2-3%, the stiff method appears to be more commonly used.

### Calculating Loads

The “friction factor” is the most important element needed to calculate either the “pick up” or “slack off” load or the torque needed to rotate the string. This number indicates the amount of friction as a percentage of the weight of the object. The friction factor is a function of a great number of variables including but not limited to the tortousity of the hole and the lubricity of the fluid in the annulus. Everything else being equal, oil-based mud and Synthetic Based Mud (SBM) produce a lower friction factor than that produced by brine or water-based mud (WBM). SBM may render a friction factor as low as 14% compared to a 30-45% factor for WBM. Also, long gauge bits produce much lower tortousity than bi-center bits. Tortousity is the difference between a mathematically smooth plan and a continually changing survey. In general, the friction factors also will be lower in a cased hole than they are in an open hole. Most software provides an option of adding tortousity (usually  $0.5^\circ/100'$ ) to a wellplan.

For all strings in the hole, the closest true weight of the string (load) is obtained from the rig weight indicator and only when the string is being rotated off but near the bottom of the hole. This is due to the fact that when moving (rotating), the frictional forces are at a minimum and are the result of dynamic friction as opposed to static friction. Although the friction factor is independent of the hole inclination, the frictional forces are higher in higher angle holes because of the greater portion of the weight on the low side of the hole.

Most torque-and-drag modeling software programs are capable of back calculating a friction factor, given the weight of the string. Acceptable friction factors have been calculated this way for different fluid types and drilling circumstances.

Main input to most such software is a delineation of the components of the string from the bottom to the top. For each item, the length, OD, ID, weight/foot, tensile strength and torsional strength are input manually or taken from a database. The profile of the well from top to bottom is also put into the software program. This input is in the form of a raw directional survey that consists of measured depth (MD), inclination (Inc) and azimuth (Azm). If the well has already been drilled, it is highly

recommended that the actual directional surveys of the well be used. If the well is in the plan stage, the profile listing in the said form (MD, Inc and Azm) would be the best data to use.

Due to the fact that the acting weight of the string in the hole is actually the buoyed weight, the fluid density is also an input into the software, and the submerged weight of the string is calculated and used for this purpose.

The software calculates the hanging buoyed weight (load or tension) of the string from bottom to the top. When any part of the string is under compression, the weight (load or tension) is shown as negative compression. This calculation is performed for several operational modes. These are:

- 1) *Rotating off bottom weight.* (This load is the closest true weight of the string that it is possible to obtain):
- 2) *Pick-up weight.* This load is generally the highest because the actual weight and the frictional forces (Drag) are adding together
- 3) *Slack-off weight.* This load is the actual weight minus the drag
- 4) *Rotary drilling weight with weight on bit*
- 5) *Oriented drilling (sliding) with weight on bit.*

For the purpose of modeling completion strings, the last two items (Nos. 4 and 5) are not relevant. In fact, oriented drilling weight with zero weight on bit is the same as the slack-off weight. This is the same for rotary drilling; i.e., zero weight on bit is the same as rotating off bottom.

These calculated weights are plotted as continuous curves in a plot of weight versus measured depth. Also plotted on the same chart is the tensile strength of the components as well as the buckling strength of the same. Obviously, these two curves fall on opposing sides of the plot because one is maximum tension, and the other is maximum compression. For better depiction and correlation, the vertical profile of the well is also plotted as inclination versus measured depth.

If the weight (load or tension) curve should coincide or cross the tensile strength curve at any depth, this will be the depth at which the string will part. The same is true for the other side of the chart, which would be the compressional/ buckling mode.

The software constructs a similar chart, depicting the torque for the case of rotary drilling or rotating off bottom. This plot shows the torsional load on the string at any point from top to bottom. The torsional strength of the component is also plotted. Again, if the torque exerted on the component should equate or exceed (plot lines coincide or cross) it would be at that depth where the string would twist off.

**Figures 2-7** show the plots generated from two recent cases in which the modeling was used.

**Description of a Torque and Drag Graphical Output**

The output from torque and drag modeling software usually includes two charts. One chart relates to axial loads (Tension or compression as shown in Figs. 4 and 7), and the other chart relates to rotating operations such as rotary drilling or rotating off bottom (Fig 6). The tensile strength limit of the pertinent component of the string is indicated by the shaded area on the right side of the load charts in Figs. 4 and 7. The buckling or compressional limit is represented by the left shaded area. If the curve for a lifting operation should cross the right limit, exceeding the tensile strength, the component will part at the crossing depth. If a slack-off operation crosses the left limit, buckling will occur. Fig 7 shows a helical buckling at ±1430MD. The amount of compressional force required to overcome the frictional forces below the point exceeds the buckling strength of the drill pipe component.

The torsional strength limit is shown on the right side of the torque (rotation) chart. Again, if a rotating curve crosses the torque limit, the component will twist off at the crossing depth. Fig. 5 shows that at the ±1950m measured depth, the component could twist off.

**Conclusions**

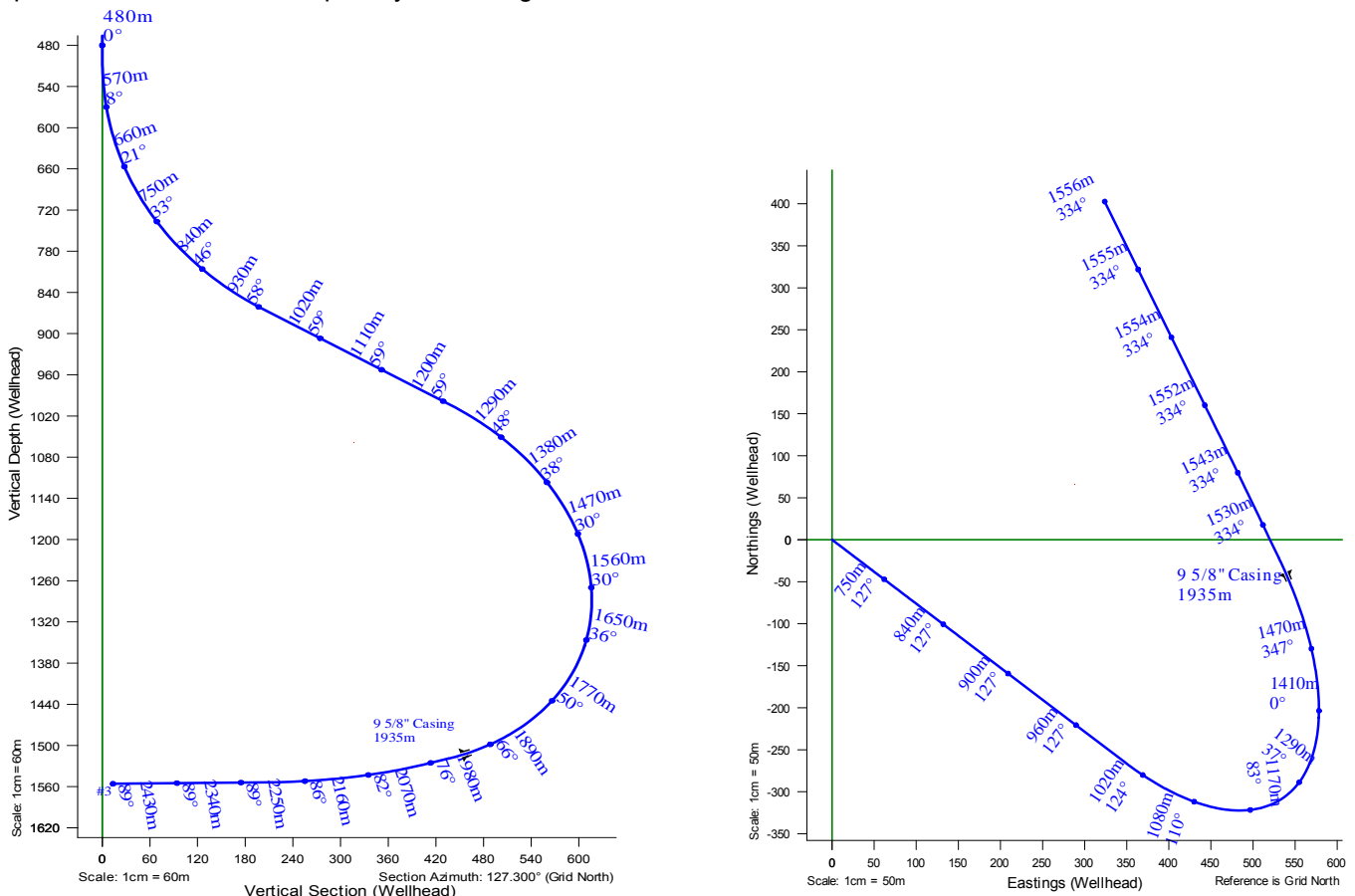
Torque and drag modeling is a well proven technique for wellbore construction that has been routinely used in the drilling segment of the industry. The advent of new techniques and the increased capability for drilling more

complicated designer directional/horizontal wells has initiated the need to apply this modeling technique to the completion strings and the techniques employed in completion scenarios.

The increased drilling capabilities and the sophistication of today’s well profiles has stretched the envelope of completion processes to the extent that an investment in a well could easily be jeopardized by unforeseen completion difficulties. The authors of this paper recommend that torque and drag modeling be used in all wells during the planning process and that it become a requirement when planning the well completion process. This will help ensure that the well will be completed as planned. Torque and drag modeling, as shown in the figures provided help to verify that the completions in these studies would be successful.

**Acknowledgments**

The authors wish to thank the management of Halliburton Energy Services, Inc. and Sperry Sun for encouragement and permission to write this paper. The authors also wish to thank the operators who allowed the new torque and drag modeling procedures to be used in their well completions, and thus, helped to prove the advantages and efficiency of the torque and drag system for well planning.



**Figure 2 — Well Plan Torque and Drag predicted to be within limits for this well @ TD**

**Drill String Details**

Comp. #	Description	Class	O.D. (in)	I.D. (in)	Weight (lbs/ft)	Length (m)	Cum. Length (m)
1	250 micron PoroFlex expandable sand screen		7.370	6.370	27.00	157.89	157.89
2	PoroFlex expandable blank		7.000	6.390	22.60	152.40	310.29
3	250 micron PoroFlex expandable sand screen		7.370	6.370	27.00	157.89	468.17
4	Spacer pipe		8.270	7.120	20.00	20.12	488.29
5	5 1/2" DP (S) FH - 21.90 lb/ft	Used - Premium	5.500	4.780	26.33	1943.55	2431.84

**Casing/Hole Details**

Comp. #	Description	O.D. (in)	I.D. (in)	Friction Factor	From		To	
					Measured Depth (m)	Vertical Depth (m)	Measured Depth (m)	Vertical Depth (m)
1	9 5/8" Casing	9.625	8.535	0.20	0.00	0.00	1935.48	1514.08
2	8 1/2in Open Hole		8.500	0.45	1935.48	1514.08	2431.84	1555.69

**Operating Parameters and Results**

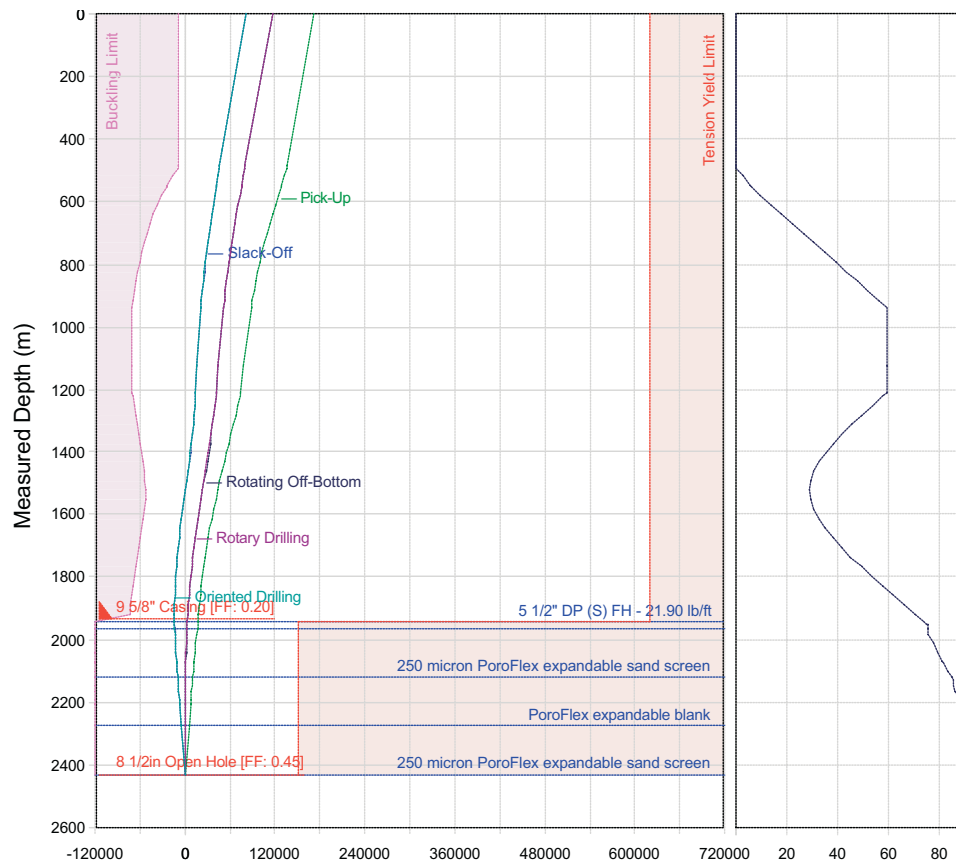
Bit Depth: 2431.84 m  
Mud Weight: 8.5 ppg  
Helical Buckling Criteria: Chen/Cheatham

Operation:	Pick-Up	Slack-Off	Rotating Off-Bottom	Rotary Drilling	Oriented Drilling
Weight On Bit (lbf):	-	-	-	100	100
Torque At Bit (ft-lbs):	-	-	-	100	-
Pipe Speed (m/h):	-	-	-	30.00	-
Rotary Speed (RPM):	-	-	-	80	-
BHA Torque (ft-lbs):	-	-	0	0	-
BHA Drag (lbf):	0	0	-	0	0
Surface Tension (lbf):	172407	82033	116831	116724	81928
Surface Torque (ft-lbs):	-	-	12174	12267	-
Safety Factors...					
Pipe Stress:	0.06	0.07	0.07	0.07	0.07
Tool Joint Makeup:	-	-	1.20	1.18	-

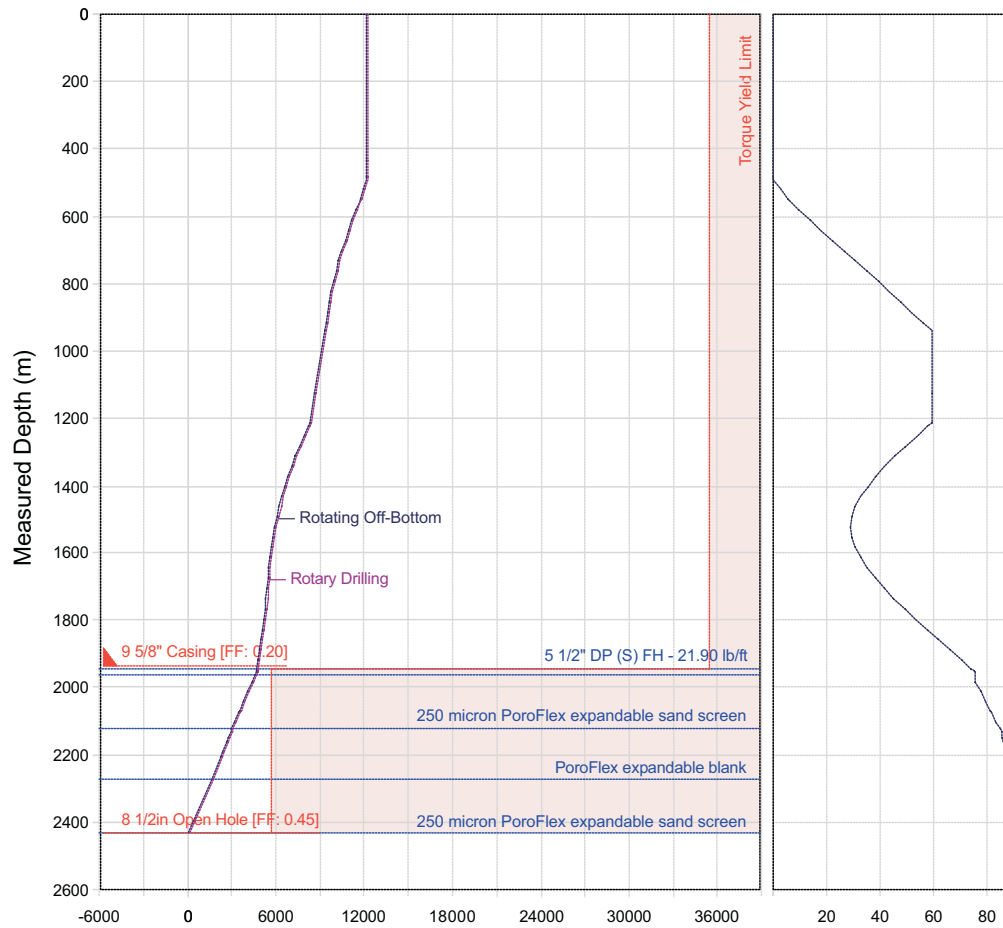
**Figure 3 — Torque and Drag Report for Structure – Survey run #3. Case @ TD**

**Drilling Parameters:**

**Bit Depth:** 2431.84 m  
**Mud Weight:** 8.5 ppg  
**Helical Buckling Criteria:** Chen/Cheatham



**Figure 4 — Drill String Tension – Operation Scenario (lbf)**

**Drilling Parameters:****Bit Depth:** 2431.84 m**Mud Weight:** 8.5 ppg**Figure 5 — Drill String Torque – Operation Scenario (ft-lbs)**

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**Operation: Operation Scenario**


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**Drill String Details**

Comp. #	Description	Class	O.D. (in)	I.D. (in)	Weight (lbs/ft)	Length (m)	Cum. Length (m)
1	Screen/Washpipe		5.700	2.259	28.30	0.00	0.00
2	Blank Pipe		4.000	3.548	9.50	0.00	0.00
3	Gravel Pack Packer		5.820	4.000	20.00	15.24	15.24
4	VGA Versa-Trieve		6.680	3.880	25.00	2.40	17.64
5	3 1/2" DP (S) NC38(IF) - 13.30 lb/ft	Used - Premium	3.500	2.764	14.69	558.00	575.64
6	5" DP (S) NC50(XH) - 19.50 lb/ft	Used - Premium	5.000	4.276	22.60	6924.36	7500.00

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**Casing/Hole Details**

Comp. #	Description	O.D. (in)	I.D. (in)	Friction Factor	From		To	
					Measured Depth (m)	Vertical Depth (m)	Measured Depth (m)	Vertical Depth (m)
1	11 3/4in Casing	11.75	11.084	0.25	0.00	0.00	7850.00	1768.18
2	9 1/2in Open Hole		9.500	0.20	7850.00	1768.18	7500.00	1748.51

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**Operating Parameters and Results**

Bit Depth:	7500.00	m					
Mud Weight:	10.0	ppg					
Helical Buckling Criteria:	Chen/Cheatham						
<b>Operation:</b>	<u>Pick-Up</u>	<u>Slack-Off</u>	<u>Rotating Off-Bottom</u>	<u>Rotary Drilling</u>	<u>Oriented Drilling</u>		
Weight On Bit (lbf):	-	-	-	25000	100		
Torque At Bit (ft-lbs):	-	-	-	100	-		
Pipe Speed (m/h):	-	-	-	20.00	-		
Rotary Speed (RPM):	-	-	-	10	-		
BHA Torque (ft-lbs):	-	-	0	0	-		
BHA Drag (lbf):	0	0	-	0	0		
Surface Tension (lbf):	260515	-283126	108190	83057	-301362		
Surface Torque (ft-lbs):	-	-	27451	26961	-		
<b>Safety Factors...</b>							
Pipe Stress:	2.15	1.98	1.96	2.05	1.86		
Tool Joint Makeup:	-	-	1.03	1.05	-		

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**Figure 6 — Torque and Drag Report for Structure Well Survey Run: Case 1A @ 7500m. String locks up on slackoff with minimum friction factor on slackoff and/or oriented drilling.**

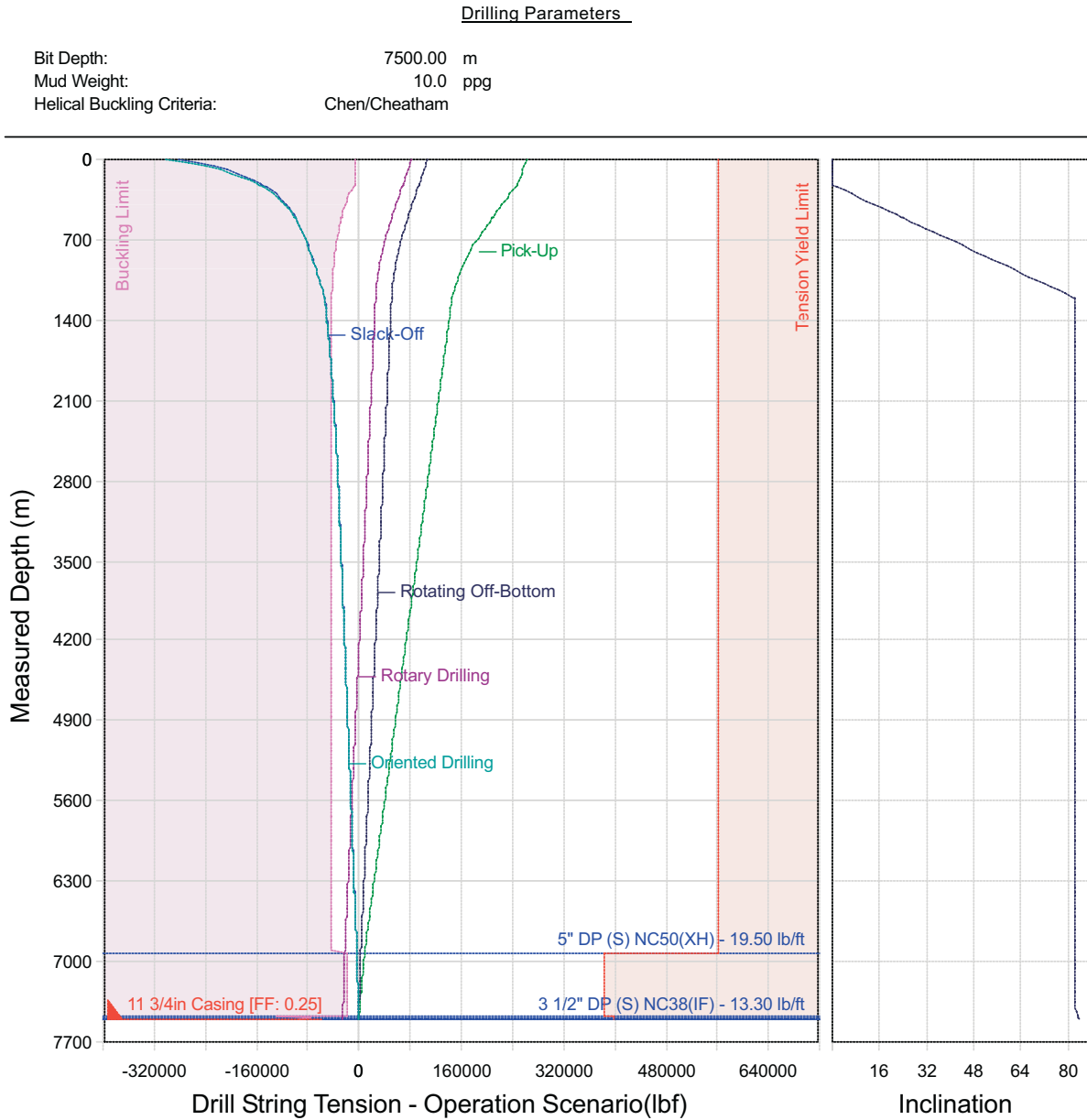


Figure 7 — Torque and Drag Report: Case 1A @ 7500 m