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Well Engineering Simulation (WellPlan^{TM}) challenges and uncertainties in Drilling Engineering.

Lecturer

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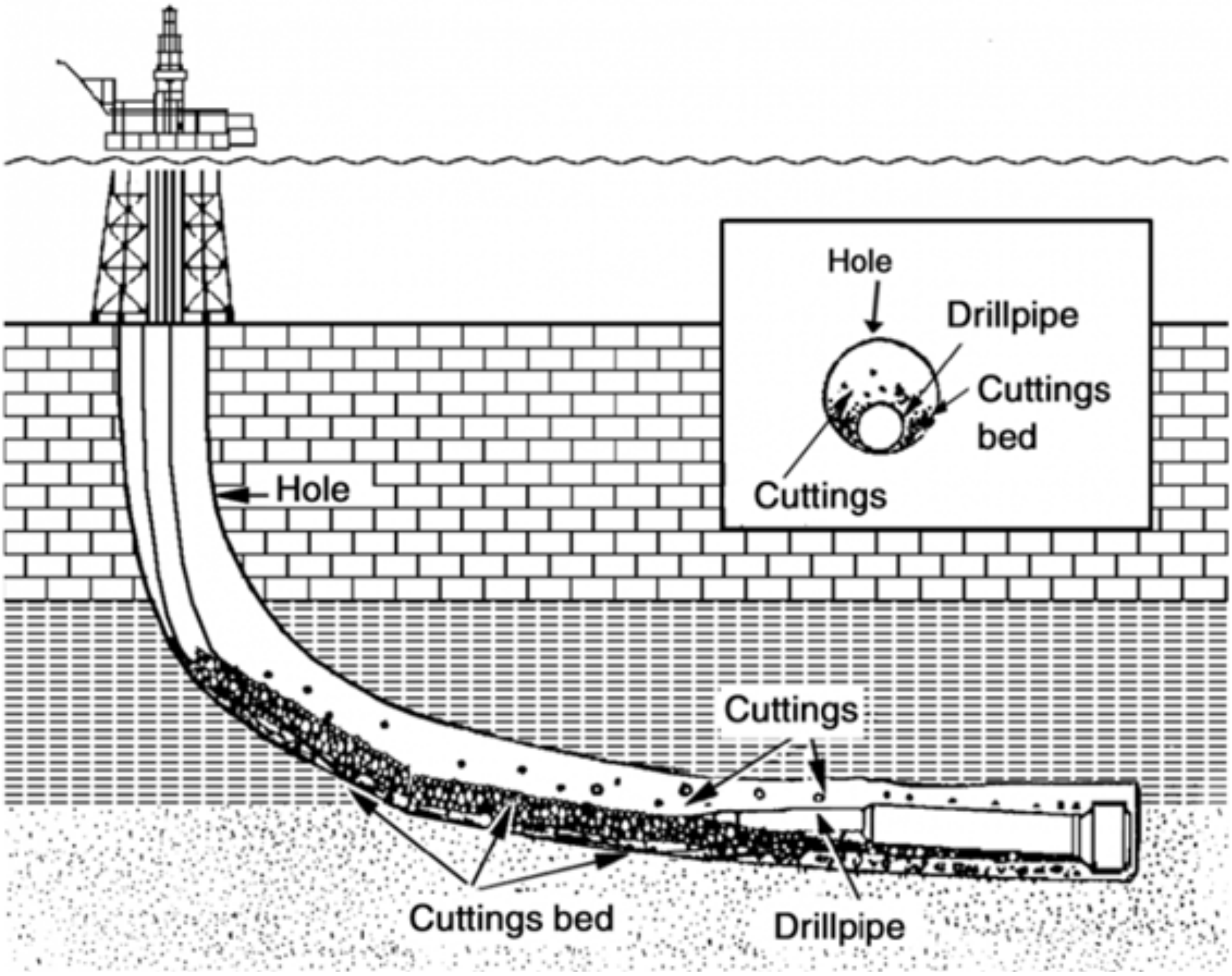
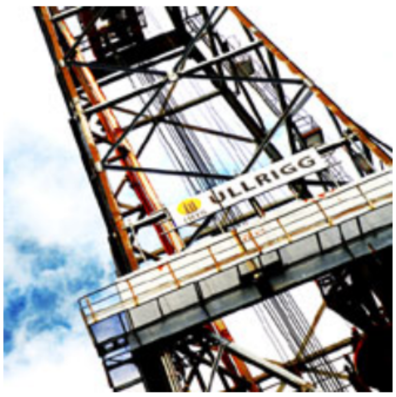


Written by Jose Vazquez Taboada



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Problem Description

The report work on this laboratory simulation, will be simulated a Drilling Operation to identify the challenges that this operation carries, and how to mitigated them.

Nowadays, the high demand by Operators to drill more wells, faster, safety and costly profitable, has become essential. Especially in directional drilling wells. Straggly against the uncertainties by Drilling and Completion originates. Trying to find the balance, from Pressure and Friction issues.

Being a well know, a common problem "the Natural Fracture", will results in lost of circulation, which will lead to reduction in mud column (h).

The challenge and the hazard, is the high probability of either going bellow the collapse gradient or the pore pressure gradient, which might result in "Kick" or "Blow out".

To carry out a good simulation, Design the right drill string (DS) and bottomhole assembly shall allow us to reduce the uncertainties and establish efficiency mud window during the Drilling Program plan and his implementation.

Abstract

This laboratory report has been to carry out for a Drilling simulation study and apply theoretical knowledge's and theories, in order to reach up a practical approach during a Drilling Operation.

The objectives could be classified in three main ones, the first simulate Torque and Drag, simulation of Hole cleaning (Operational and Parametric), and the third one to perform a sensitivity study of the challenges for Drilling and Completion operations. As goal was to demonstrate the validity and accuracy of the assumptions made, for a variety of cases and to discuss the influencing parameters.

Simulation allows, to recreate a simulative plan to reach the target (safety and costly efficiently) and predict hazards (well collapse, fracturing, gas kick, loss of circulation or pore pressure). As well as, the simulation was performed to evaluate circulating kick tolerance based on formation fracture strength at the casing shoe (4012,5 ft).

During this simulation, have provided and prove an interesting observation during pumping Flow rate (g.p.m), due to for high Flow rate regimes has good behaviour for Well cleaning (less R.P.M), but might be damage the Drilling string (buckling formation). Such as, has been well demonstrated that for high flow rates (more than 1500 g.p.m) our Von-Misses criteria pass over the Tensile Limit. Between the challenges identify, must notice that Mud Density and the Friction Factor are playing important role pressure variations, due to depending on these parameters, the Tripping out operations will safe or unsafe against the Tension Limit.

Therefore, being the key point to find out and compensate the Flow rate ($\uparrow Q_{Flow}$ = $\uparrow ROP_{Cuttings}$= $\uparrow$Pressure) versus the Stress ($\uparrow\uparrow$Von-Misses). In addition to, the pump Flow Rate is clearly function of ECD, Tensions and Depth. Wells with a narrow window (as example, in Deep waters) between "Fracture" and "Pore-Pressure gradient" are extra sensitive to ECD variations.

The main purpose of this **WellPlan™** simulation has been to study and carry out a detail survey of:

- Torque and Drag + Stresses in String
- Hydraulics (ECD + Cutting transport)
- Linear and casing drilling
- MPD (Managed Pressure Drilling)

The mere contribution of this report, has contribute to reduce the uncertainties that any Drilling operation carries. In order to address a better understanding of the challenges described, and approach them in safety way.

For instance, the main risk identify on the Max. Dogleg Severity (24,18°/100ft) at MD of 10174 ft with 36.13°(Max. Inclination), where is located max range of Friction along the well path trajectory. In order to overcome the Drill well operations at that point has demanded high rotational speed ($\uparrow\uparrow\omega$=R.P.M) with a high speed Flow rate ($\uparrow\uparrow Q_{FlowRate}$) circulation. Has been observed that for smaller cuttings are

more difficult to transport at this Directional-Well model, but with some viscosity increase and pipe rotation, fine particles seems to stay in suspension and are suitable easier to transport.

Torque and Drag Analysis software provides knowledge's of anticipated Loads for drilling and casing operations, and as a result it can be determinative to the selected rig (Specifications vs. Capabilities), if has good enough mechanical specifications to handle the well design requirements.

Moreover, to gather knowledge's from similar projects will be crucial, being a great tool to located similar wells that will be set a role in obtaining useful data for future simulations.

This model simulation has proved its ability of outcome quite realistic predicting the onset and severity of buckling example model of a Well on the North Sea.

Last but not least, **WellPlan™** has become a very useful tool for Well Engineering simulation for managing risks and making critical well control decisions.

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Foreword

The present laboratory report is part of the Advance Drilling Engineer course (PET525), during the spring semester of 2014, at the Department of Petroleum Engineering in the University of Stavanger.

First at all, I want to thank you the Professors Gerhard Nygård and Mesfin Belayneh, to allow me to be a listener student at their course and be part of it. Specially to have shared this motivated report to carry out, to run successful Drilling simulations.

Secondly, this entire report could not be a reality, without the input motivation given by my colleagues students at UiS, where always have surround me and given me a variety of input challenges tasks using WELLPLAN™ software version 5000.1.

Thirdly, I would like to express my deepest acknowledges to the entire Scientific community of Petroleum Engineers, from which ones I thank all the sharing and contribution provide to my Literature review. Especially thanks to my friend, Mihreteab S.Teklehaimanot (Petroleum Engineer).

And lastly, my thank goes to Halliburton AS, to have make available student licenses at UiS, allow us (Students) to get a better and practical understanding for Well Planing, Modeling and Well Operations simulations.

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Nomenclature

BHA	Bottom Hole Assembly
DGS	Dual Gradient Systems
DHM	Down Hole Motor
DP	Drill Pipe
DS	Drill String
DLS	Dogleg Severity
ECD	Equivalent Circulating Density
MFL	Mud Flow
HL	Hook Load
HWDP	Heavy Weight Drill Pipe
ID	Inner Diameter
MD	Measured Depth
MWD	Measurement While Drilling
OD	Outer Diameter
POOH	Pull Out the Hole
RIH	Running into the Hole
RPM	Rotations per Minute
ROP	Rate of Penetration
SG	Specific Gravity
SPP	String Pump Pressure
TD	Target Depth
TIH	Trip in Hole
TOOH	Trip Out of Hole
TVD	True Vertical Depth
WOB	Weight on Bit
WOH	Weight on Hook

1 Introduction

1.1 Background

Drilling and Completions have become more costly and risky in the last decade, and with endanger overall of the well integrity. The tendency of the current world's demand for Oil and Gas have increased sharply (high demand of drilling more Horizontal Wells), therefore the well designs have become crucial for the Oil & Gas Industry in order to design better, safety and faster.

Directional Drilling has been improved new technology and techniques, with a meaningful improvement in efficiency and reducing the forecast for drilling cost.

Since the mid-1980s, a qualitative understanding of the Hole-Cleaning problem is highly inclined wellbore (↑ϑ) had been gained on that period. Due to, more directional and horizontal wells with longer lateral reaches were being drilled, the need for more and faster, new experimental data created a demand for additional "Flow Loops" nowadays.

The continuing need to reduce drilling cost, has originated the incentive to produce new tools and develop more techniques. Being the key point, to try to minimize and avoid the not productive time (NPT) during drilling activities and downtime issues.

Computerized well planning, use of down hole motors and turbines, and more techniques to drill Horizontal wells, is well know that helps to increase the "Recovery Factor", but at the same time the challenges are higher (High Drag, Torque and ECD), collapse, fracture or pore pressure.

The higher inclination (↑ϑ) on this type of wells (Horizontal Ones!) in ultra-deep waters originates a narrow drilling window with an overburden pressure, where a very narrow merging between pore and fracture pressure profile can be very risky.

In order to have better control and carry out complex wells, through computer techniques are essential to handle a large amount of data and plan the wells efficiently, and costly profitable and reliable. The programs take much of the our labour of planning, saving a lot of time to approach better understanding for "Well Program" and "Drilling String program" through simulations.

Using WELLPAN^{TM} software is available from directional drilling Halliburton, suiting a comprehensive set of software for;

- **Well Planning.**
- **Modeling.**
- **Well Operations.**

The simulation carry out through **WellPlan^{TM}**, allows the user to have better estimations and reduce the uncertainties before to run a drilling operation in place, to recreate a simulation for an optimal well designs at any stage of the drilling process.

When we made refer to the uncertainties, may be address to Operational Problems in Directional Wells, could be classified as bellow:

- **Geological Problems**
    - Salt Dome challenges (large washouts, lost circulation, and corrosion).
- **Well Profile**
    - Well Collapse
    - Fracturing
    - Gas Kick
    - Pore Pressure
- **Reduced Axial component of gravity along the borehole** ($\vartheta > 60^{O}$)
    - Borehole instability.
- **Drilling Problems**
    - Excessive Torque & Drag.
    - Differential Sticking.
    - Exerting WOB and running in tools.
    - Controlling the well path.
    - Hole cleaning.
- **Logging problems**
    - Run logs at higher inclinations ($\vartheta >$50-60^{O}).
- **Completion problems**
    - Ensure Good displacement of the drilling mud by the cement slurry.

The aim of this report is therefore to meet the main challenges stated above, the **WellPlan™** software allows us to satisfy and provide a management control of them, through the next well engineering steps;

1. **Design better wells more Efficiently.**
   To analyze and improve well designs, prevent stuck pipe and BHA failures, reduce drilling problems and drill efficiently.
2. **Create faster and better quality engineering workflows from planning to production.**
   Rig site data collection and reporting system enables engineers to directly create a WELLPLAN case, automatically populate the case with pertinent field and rig data for faster decision makes and engineering studies.

3. **Comprehensive and Extent Well Engineering Toolkits.**

    3.1. Torque/Drag Analysis (Torque and Drag forces vs. Drill string, casing or liner)

    3.2. Hydraulics (Pressure drop calculations, bit hydraulics, and hole cleaning analysis).

    3.3. BHA Drillahead design software (Models drilling performance of addressable and rotary drilling assemblies).

3.4. Critical Speed Analysis (Model BHA behavior, to identify critical rotary speeds and high stress along the drilling string).

3.5. Optimal Cementing (Analysis tools to design and simulate cementing operations)

3.6. Surge (Transients analysis for Swab, Surge and exchange operations against Well control problems and formation damage)

3.7. Stuck Pipe (Calculates stuck point, pack-off force, and shake and tripping forces).

A representation of the challenges described above, are show bellow;

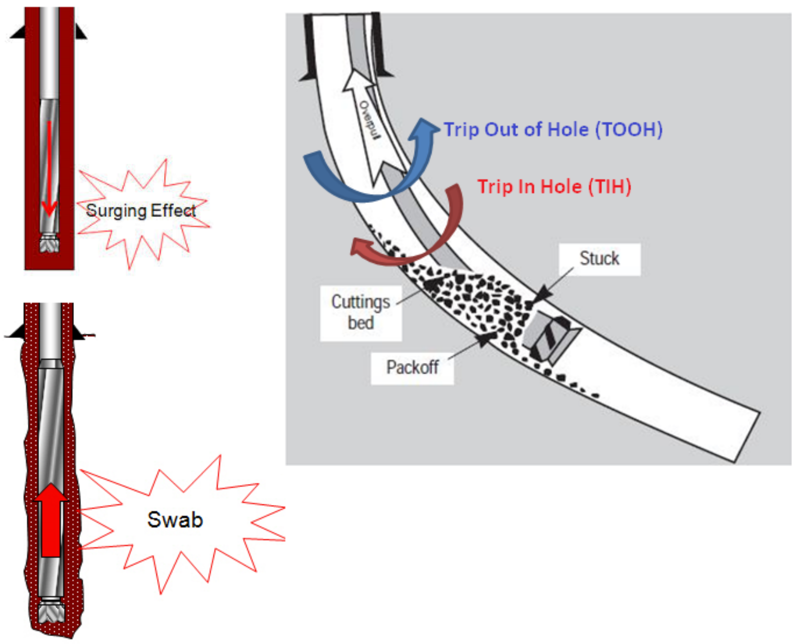

Figure 1. Overview of Challenges into a Drilling Operation.

In the next sections further, we will observe in detail the Well Engineering toolkits, and how they have contributed for a simple Well Exercise simulation using the software cited above.

1.2 Objective of the project

The purpose of this report is to carry out a compressive explanation and understanding the challenges during a Drilling Operation trough running a simulation, and how to fulfil and cover these Risks that it involve, from practical point of view (Simulation) to theoretical approach (Theories). The present well has been selected for the case study (during Laboratory Simulation) is a Horizontal well drilled in the North Sea.

From a Directional Drilling Engineering perspective to Cost Efficiency solution. The goal of the cited simulation is not only to make a "double check", also is to have a potential and realistic outcome over the specifications of the Drilling Operation in place, in order to carry out a safety implementation drilling operation(Safe came First!).

The main objectives of this task simulation, which are;

1. **Simulate Torque and Drag.**
   1.1. Define the Hole section editor.
   1.2. Define the String editor.
   1.3. Survey data.
   1.4. Fluid Editor. (Speed vs. Dial)
   1.5. Circulation System. (Specify Pressure Loss)
   1.6. Pore Pressure.
   1.7. Fracture Pressure.
   1.8. Geothermic gradient.
   1.9. Plots the Results(Stress Graph, Normal Analysis,…etc)
2. **Hole Cleaning** (Operational and Parametric)**.**
   2.1. Hole Cleaning - Parametric
      2.1.1. Set up Transport Analysis Date.
      2.1.2. Plot the Results (Total Volume, Suspended Volume,…etc)
   2.2. Hole Cleaning – Operational
      2.2.1. Set up Transport Analysis Date.
      2.2.2. Plot the Results (Operational, Minimum Flow Rate vs. ROP)

An explanation in detail on the objectives, that this simulation will be showed and described in the Section 3 (Simulation Study). Where we are going to find out the purpose of this entire simulation, and how well contribute for the Hole and String model made along this Laboratory exercise beside the Theory (on Section 2).

3. **Performance sensitive study**

3.1. Effect of Coefficient of Friction + Mud properties

Property of fluid (Drilling mud), are directly formed by the density (ρ) and viscosity (ϒ), being both key parameters in the drilling mud. The Friction coefficient (μ) vs. the bit depth (m) has a potential influence in the well pressure from top (RKB) to the target zone (TD). The friction coefficient is function of;

$$\mu = f(\omega, v)$$

From the Drilling string window, at any drilling operation and in certain areas the readings from high variation of collapse curvature, tell us the induce of high friction coefficients are creating a high probability of Buckling, due to might be lower rotation, as well as the static load curvature ($\beta*\omega*\sin\vartheta*\Delta S$) is quickly displaced to the compression limit.

Consequently, computational balance between the rotation ($\boldsymbol{\omega} = \mathbf{R.P.M}$) of the BHA and the vertical velocity (**v**) must be find out in the most reliable way (**Safety drilling + Cost-Effective**).

From the Laboratory simulation, has been carry out two different types of simulation, for the same data set (attached on Appendix):

- **Density Fluid vs. Pressure (Variation of Tª)**
- **Viscosity Fluid vs. Temperature (Variation of Pressure)**

As result the Property fluid, can be define as with the next function bellow;

$$\rho, \gamma = f(T^{a}, P)$$

The graphical results obtained varies consistently, due to the variation of parameters, are well-demonstrate on further sections (**3.1.4 Fluid Editor**).

3.2. Stress in drill string as function Flow rates, mud density

As general principle of Mechanic Solids, when we increase the Flow rate(Q) along drilling pipe, directly the Pressure rise up, with direct impact of high Stress accumulation on the material(Steel). Can be sum up of the next function;

$$\uparrow\uparrow Q \rightarrow \uparrow\uparrow Pressure \rightarrow \uparrow\uparrow \boldsymbol{\sigma} axial, \boldsymbol{\sigma} radial, \boldsymbol{\sigma} tangential$$

2 Theory

2.1 Drag and Torque modelling (Fundamentals)

Along this section, the theory for Drag and Torque will be explaining. As well as, the buckling and tensile limit will be presented. The main purpose of the theory, is to give us input of the basis of the theoretical approach for Drill string mechanics (Torque and Drag, buckling, tensile limits and stress in the Drill String). Moreover, the theory will provide the fundamentals for understating of this present simulation through **WellPlan™**, application program that simulates the cited drill string mechanics.

The Drag and Torque models are dived in two:

- For a Straight Borehole.
- For a Curved Borehole.

- **For a straight Borehole (Inclined Well Model)**

From force balance, applying the condition of equilibrium along the axial directions, the effective force along the axial direction is calculated. Representations of the Pipe segment are, showed bellow;

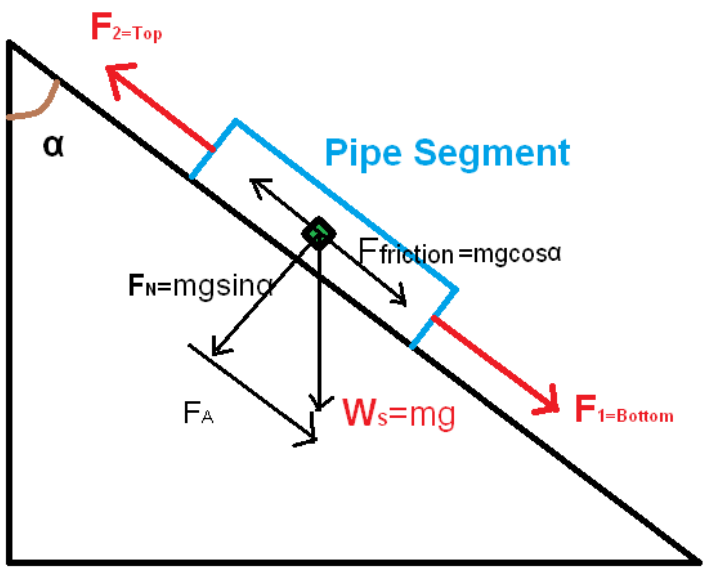

Figure 2. Drill string inclined on the well (Free body diagram of mass Element)

Applying force balance along the inclined plane one can obtain;

$$dF = w\Delta s(\cos\alpha \pm \mu \sin\alpha)$$

Where "+" is when pulling, out of the hole (*Pulling the String*), and "-" is when running into the hole (*Lowering the String*).

This is a Coulomb friction model. When the drillstring is stationary, an increase or decrease in the load will lead to upward or downward movement of the drillstring.
Integrating the Equation stated above, the top and bottom load limits, one can obtain the force in the drill string as:

$$F_{Top} = F_{Bottom} + w\Delta s(\cos\alpha \pm \mu \sin\alpha)$$

The plus sign defines pulling out of hole, and the minus sign defines running into hole. The first term inside the bracket defines the **weight of the pipe** and the second term defines the additional friction force required to move the pipe. The change in force when the motion starts either upward or downward is found by subtracting the weight from the forces defined above.

The static weight is given as:

$$w\Delta s\ cos\ \alpha$$

The rotating friction, the torque, follows the same principle. The applied torque is equal to the normal moment ($w\Delta sr$) multiplied by the friction factor μ. Giving torque as:

$$T = \mu w\Delta sr\ sin\ \alpha$$

It is important that the unit mass of the drillpipe or the weight is corrected for buoyancy. The buoyancy factor is given as:

$$\beta = 1 - \frac{\rho_{mud}}{\rho_{pipe}}$$

And the buoyed unit mass must be:

$$w = \beta w_{drill\ pipe}$$

As well was showed, on the Figure 2. The Friction Torque (M) is composed in two ($M_{2=Top}$ & $M_{1=Bottom}$). Friction Torque relation is give as:

$$M_2 = M_1 + wr\mu\ sin\ \alpha$$

- **For a Curved Borehole (Any Curved Well)**

As we can see on the next figure 3, the drill string shows a division on segments along. These segments are loaded at the top and the bottom with compressive (-) or tensile (+) loads. Furthermore, theses loads (Thermal, Hydrostatic and fluid flow Shear forces) are responsible for the variation in the length of drill pipe.

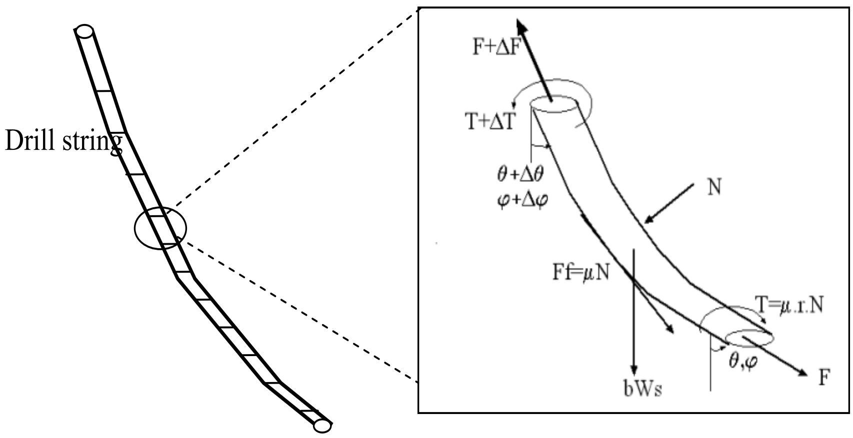

Figure 3. Segmented Drill string and loads distribution.

Borehole trajectories are seldom smooth, as desired by analytical model, with continuous changes in Inclination (θ) and Azimuth (φ) along the well path.

Balancing between the net force and the vector sum of the axial component of the weight, W and the friction force, one can obtain the first order differential force as the following (Johansick):

$$\frac{dF}{ds} = \pm\mu\left(\sqrt{\left(\beta w_s \sin\theta + F\frac{d\theta}{ds}\right)^2 + \left(F\sin\theta\frac{d\varphi}{ds}\right)^2}\right) + \beta w_s \cos\theta$$

φ = azimuth, θ = inclination

"+" is pulling out of the hole (Pulling the String) = Tension

"-" is running into the hole (Lowering the String) = Compression

The square root term in equation above is the normal force per unit length for any curved well geometry. The equation is a function of well inclination and azimuth. For each segment, it can be calculated as the following:

$$N_i = \sqrt{\left(\beta w_i \sin\left(\frac{\theta_{i+1}+\theta_i}{2}\right) + F_i\left(\frac{\theta_{i+1}-\theta_i}{S_{i+1}-S_i}\right)\right)^2 + \left(F_i \sin\left(\frac{\theta_{i+1}+\theta_i}{2}\right)\left(\frac{\alpha_{i+1}-\alpha_i}{S_{i+1}-S_i}\right)\right)^2}$$

Where:

- θ = inclination
- α = Azimuth
- w_i =weight per unit length
- β = Buoyance factor

2.1.1 Drag

The Drag load is the difference between free rotating weight and the force required to move the pipe up or down within the hole. Drag load is compered to free rotating drill string weight, which one is usually positive when pulling out of hole (POOH) and negative when running into hole (RIH).

The analytical expression of drag force can expressed as:

$$F_{i+1} = F_i + \sum_{i=1}^{n} \left[\beta w_i \cos\left(\frac{\theta_{i+1} + \theta_i}{2} \right) \pm \mu_i N_i \right] (S_{i+1} - S_i)$$

Where the plus and minus sign allows for pipe movement direction whether running in or pulling out of the hole. The plus sign is for upward motion where friction adds to the axial load and the minus sign is for downward motion where the opposite is the case. $\mathbf{F}_i$ is the bottom weight when integrating from the bottom to top type.

Pick-up drag force is usually lower than free rotating weight. While slack-off drag force is usually lower than free rotating weight. Drag force is used to overcome the axial friction in the well. A representation on these can be observed in the next figure;

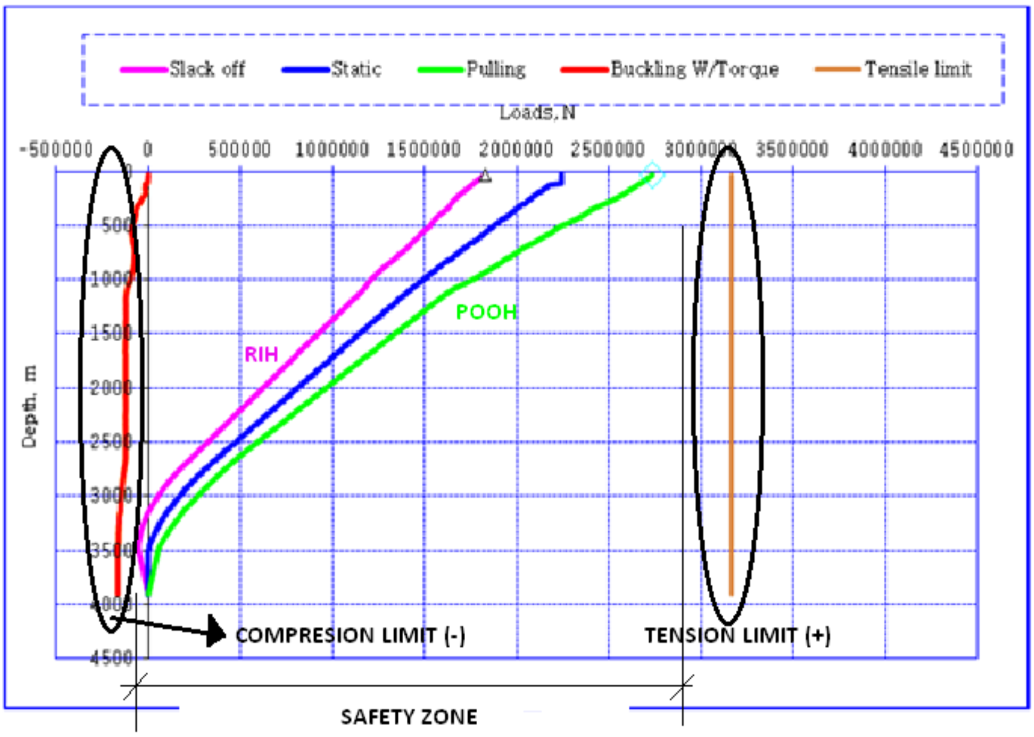

Figure 4. Well Plan window of drill mechanic program.

The practical outcome of the Well Plan window, is given by the **Wellplan™** simulator is showed on the Annexes ("Torque Drag Effective Tension Graph").

2.1.2 Torque

Moment or Torque is a force multiplied by the radius or distance in arm. Can be defined as the amount of force exerted to rotate a drill and cut a hole in a workpiece. Torque applicable in Drilling applications is the moment required to rotate a drill pipe.

The moment should be used to overcome the rotational friction in the well and on the bit. Rotational torque is lost from the rotating string so that less torque is available at the bit for destroying the formation down hole. High drag forces and high torque forces normally occur at the same time. For ideal vertical well the torque loss along the way, would be zero, except for a small loss due to viscous force resulted by the drill mud. For Horizontal and Deviated Wells the torque loss could be great, especially in extended reach well.

For this type of conditions, the loss is a major limiting factor, to how long drilling operation can be carry out.

Torque is dependent directly to the radius, which rotation occurs and the friction coefficient and the normal force is over pipe.

The **increment torque** calculation is:

$$\Delta T = \mu N_i r \Delta S$$

For both buckled and non-buckled string, the torque loss per unit length is expressed as:

$$T_{i+1} = T_i + \sum_{i=1}^{n} \mu . r_i . N_i .(S_{i+1} - S_i)$$

The contact force, N_i was given on section 2.1.

As representative figure on theses loads and forces, are show bellow:

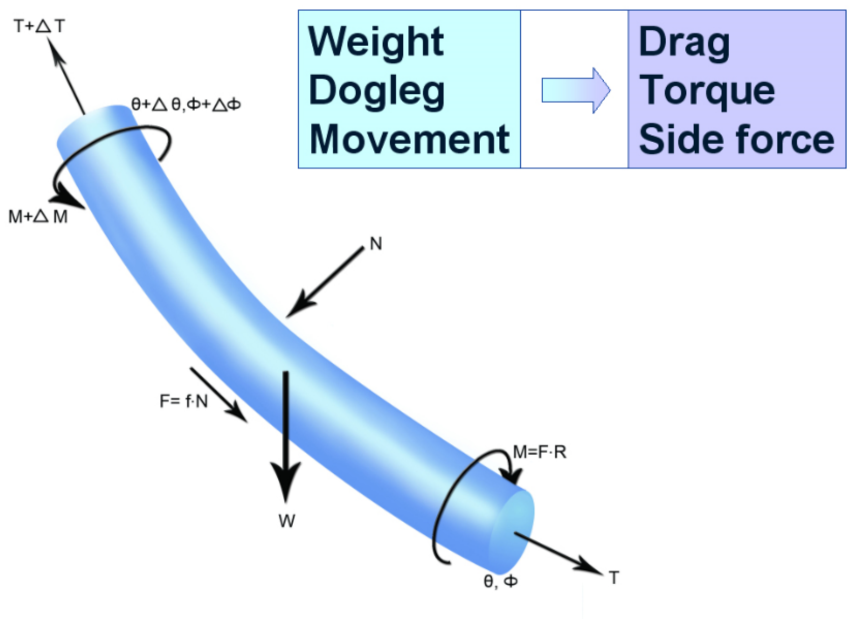

Figure 5. Torque, Drag and side forces.

The outcome obtained of a Torque obtained from WellPlan™ simulator, is attached bellow:

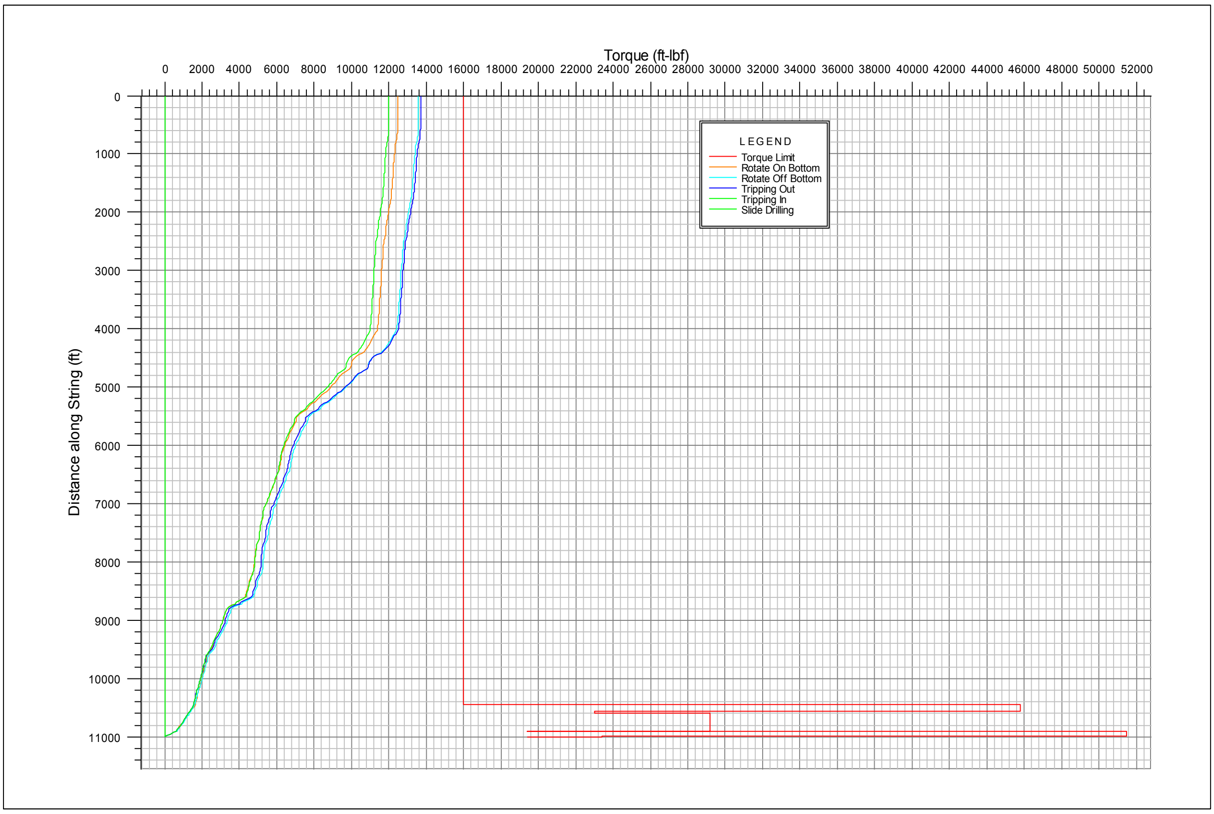

Figure 6. Torque (ft-lbf) vs. Distance along String(ft)

As we can see, the drill string is located into a safe window, due to it does not cross the Torsional limit (red line). In our model, carried out we will find out a variation of stress induced by the Torque against the Distance along String.

2.2 Helical buckling

Helical buckling is the second phase and the critical tube buckling. By increasing sufficient load, a certain load is reached that makes the tube form a helix inside the casing. This load is referred to as the "helical buckling load." Effect of buckling occurs when the compressive load in drilling pipe exceeds a critical value, beyond which one (Drill Pipe) is not longer stable and deforms into two types of shapes (Sinusoidal or Helical). The difference can be observed on the next figures:

- Sinusoidal
- Helical

Figure 7: Sinusoidal and Helical buckling

As we saw from the figure above, the Sinusoidal buckling refers to a pipe that snaps into a sinusoidal, although the Helical buckling corresponds to a pipe that snaps into a spiral shape.

Since buckling is a phenomenon that increases both the Torque and Drag.

Arriving at this point, the relationship that should be established between Drag, Torque and Buckling can be schematic in the next flow diagram:

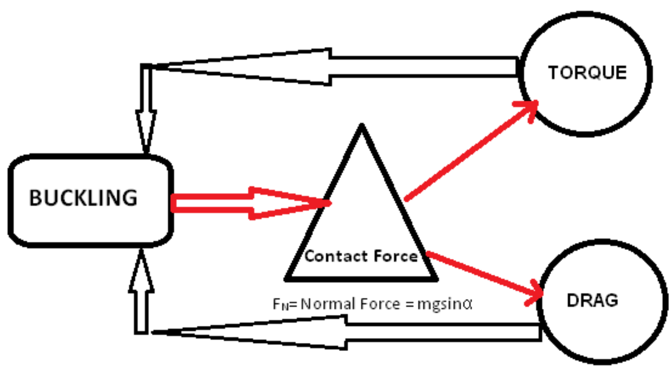

Figure 8: Relationship between Drilling String Mechanics (Drag, Torque and Buckling)

What means to us this diagram above represented, is that the variation of Normal Force along the Drilling Well path, will be directly influence on the result values for Drag, Torque and Buckling.

2.3 Stresses in drill string

Analysis of Stress along the drill string (dg) and failure is induced by the loads and forces on it. Which ones are listed bellow:

1. Hoop
2. Radial
3. Torsion
4. Shear
5. Axial
6. Buckling
7. Bending
8. Von-Mosis
9. Stress Limit.

The present simulation model, has been obtained the results all of them (See Annexes: "Torque Drag Tripping-out Stress Graph"), due to the computational understating of the results obtained are sum up on this cited graph.

The challenge on stress variation varies at thick walled cylinder, for instance in a narrow space between OD and ID, due to the pressure rise up. Then, increasing the stress (Axial, Radial and Tangential) being the most significative ones in the pipe drill. See the next representation;

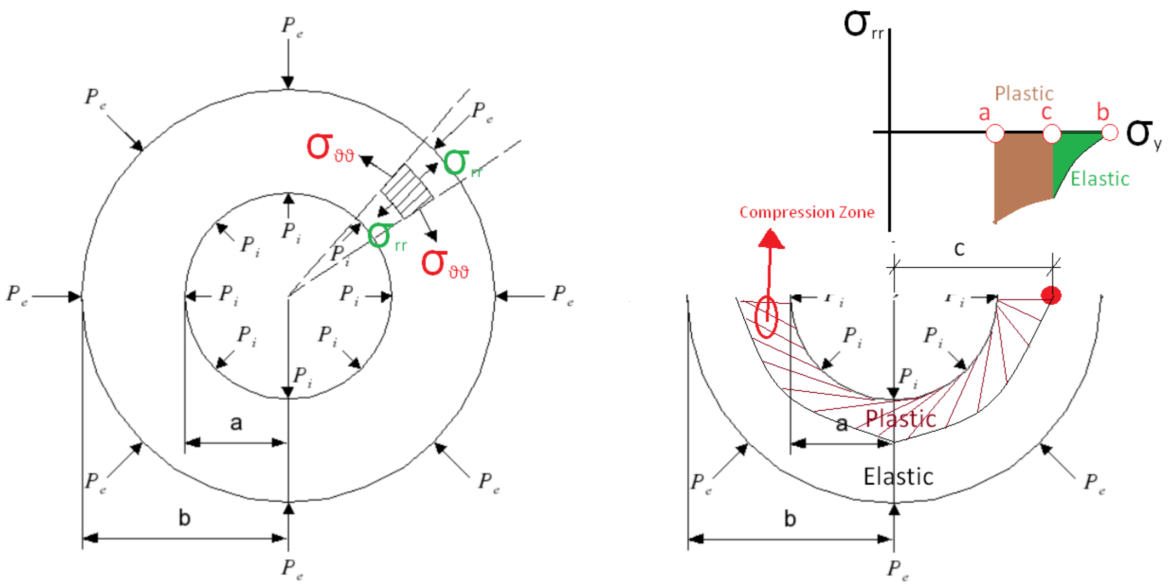

Figure 9: Thick Wall Pipe section Stress distribution

Failure along the Drilling String, induced by a combination of all stress cited may occur owing to fatigue following repeated loading cycles. Otherwise, it was explained along the course (PET525) the fracture (rupture) when exceeding the Drilling String material at the Yield Point could happen with transient Torque loading, at cutting load disturbance increases, owing to the changing rock strata encountered.

At any stress analysis results, the point is to check out the maximum principal stress (σ_{max}) is less than the Elastic limit for steel (σ_{ylimit}).
For a detail on failure criteria's (**Tresca vs. Von-Misses**), will be explained further (Section 3.2).

3 Simulation study

3.1 Simulation arrangement

As well was described on the objectives of the present report (Section 1), where have been stated the steps to carry out for a simulation through **WellPlan^{TM}**. This software is used to simulate drilling operations and predict failures. To start the simulation, as any software solution, must be set up the input information (Wellbore Data, see on Appendix).

Subdivided and formed by the next subsection;

3.1.1 Hole section Editor

The hole section editor set the hole parts (**Casing + Open Hole**), see table list bellow;

Table 1. Hole section for 6990,50 ft vertical extension.

Hole Section Editor

Hole Name: Hole Section | Import Hole Section

Hole Section Depth (MD): 11003,0 ft | ☑ Additional Columns

	Section Type	Measured Depth (ft)	Length (ft)	Tapered?	Shoe Measured Depth (ft)	ID (in)	Drift (in)	Effective Hole Diameter (in)	Friction Factor	Linear Capacity (bbl/ft)	Excess (%)	Item Description
1	Casing	4012,5	4012,50	☐	4012,5	12,615	12,459	12,615	0,30	0,1458		13 3/8 in, 54.5 ppf, J-55,
2	Open Hole	11003,0	6990,50	☐		12,615		12,615	0,30	0,1546	0,00	
3				☐								

The classification of each section type on the table sheet above, has been follow up by Catalogue format divide by Nominal Diameter, Weight and Grade by API Casing/Tubing Catalogue database.

The purpose of using this spread sheet is to define the wellbore profile and inner configuration of the well. Entering the hole section information from surface down to the bottom of the well.

3.1.2 String editor

The string editor set the Drilling string parts (**Drill pipe + BHE**), see table list bellow;

Table 2. String section for 10445,00 ft Drill pipe length.

String Editor

String Initialization — String Name: Assembly

String (MD): 11003,0 ft | Specify: Top to Bottom | Import String

Library: Export | Import

	Section Type	Length (ft)	Measured Depth (ft)	OD (in)	ID (in)	Weight (ppf)	Item Description
1	Drill Pipe	10445,00	10445,0	5,000	4,276	22,26	Drill Pipe 5 in, 19.50 ppf, E, 5 1/2 FH, P
2	Heavy Weight	120,00	10565,0	6,625	4,500	70,50	Heavy Weight Drill Pipe Grant Prideco, 6 5/8 in, 70.50 ppf
3	Jar	32,00	10597,0	6,500	2,750	91,79	Hydraulic Jar Dailey Hyd., 6 1/2 in
4	Heavy Weight	305,00	10902,0	5,000	3,000	49,70	Heavy Weight Drill Pipe Grant Prideco, 5 in, 49.70 ppf
5	Sub	5,00	10907,0	6,000	2,400	79,51	Bit Sub 6, 6 x2 1/2 in
6	MWD	85,00	10992,0	8,000	2,500	154,36	MWD Tool 8 , 8 x2 1/2 in
7	Stabilizer	5,00	10997,0	6,250	2,000	93,72	Integral Blade Stabilizer 8 1/2" FG, 6 1/4 x2 in
8	Sub	5,00	11002,0	6,000	2,400	79,51	Bit Sub 6, 6 x2 1/2 in
9	Bit	1,00	11003,0	10,625		166,00	Tri-Cone Bit, 0,589 in²
10							

As we observe from the table above. We can distinguish that each item description, belongs to the Drill pipe catalogue from API Drill Pipe database. On this example, each section type has been set mainly by Nominal diameter, Nominal Weight, Grade, Connection and Class.

3.1.3 Well path Editor

In this section, is set up the WellPath data. Formed by the values for measured depth(MD), inclination(ϑ) and azimuth (α), which ones has been entered for each WellPath (refer to Annexes "Profile Well Data") at maximum value of 3353.71 meters (11003,0 ft(MD)). The remaining information (TVD, DLS…etc) the software's calculates that by default. WellPath calculations will be base on the Minimum Curvature method. See next figure bellow:

Table 3. Wellpath Editor window

Wellpath Editor

Identification

Name: Wellpath Options...

Description:

Well Depth (MD): 11003,0 ft Generate with Actual Stations

VSection Definition

Origin N: ft

Origin E: ft

Azimuth: 0,00 °

	MD (ft)	INC (°)	AZ (°)	TVD (ft)	DLS (°/100ft)	AbsTort (°/100ft)	RelTort (°/100ft)	VSect (ft)	North (ft)	East (ft)	Build (°/100ft)	Walk (°/100ft)
1	0,0	0,00	0,00	0,0	0,00	0,00	0,00	0,0	0,0	0,0	0,00	0,00
2	100,0	0,02	298,00	100,0	0,02	0,02	0,00	0,0	0,0	0,0	0,02	0,00
3	200,0	0,03	298,00	200,0	0,01	0,01	0,00	0,0	0,0	-0,1	0,01	0,00
4	300,0	0,05	298,00	300,0	0,02	0,02	0,00	0,1	0,1	-0,1	0,02	0,00
5	400,0	0,07	298,00	400,0	0,02	0,02	0,00	0,1	0,1	-0,2	0,02	0,00
6	500,0	0,09	298,00	500,0	0,02	0,02	0,00	0,2	0,2	-0,3	0,02	0,00
7	572,0	0,10	298,00	572,0	0,01	0,02	0,00	0,2	0,2	-0,4	0,01	0,00
8	600,0	0,09	300,50	600,0	0,04	0,02	0,00	0,3	0,3	-0,5	-0,04	8,93
9	663,0	0,06	309,93	663,0	0,05	0,02	0,00	0,3	0,3	-0,5	-0,05	14,97
10	700,0	0,10	268,21	700,0	0,18	0,03	0,00	0,3	0,3	-0,6	0,11	-112,76
11	754,0	0,18	249,32	754,0	0,17	0,04	0,00	0,3	0,3	-0,7	0,15	-34,98
12	800,0	0,17	185,35	800,0	0,40	0,06	0,00	0,2	0,2	-0,8	-0,02	-139,07
13	847,0	0,31	153,14	847,0	0,40	0,08	0,00	0,0	0,0	-0,7	0,30	-68,53
14	900,0	0,25	147,17	900,0	0,13	0,08	0,00	-0,2	-0,2	-0,6	-0,11	-11,26
15	1000,0	0,16	125,51	1000,0	0,12	0,09	0,00	-0,5	-0,5	-0,4	-0,09	-21,66
16	1023,0	0,15	117,22	1023,0	0,11	0,09	0,00	-0,5	-0,5	-0,3	-0,04	-36,04
17	1100,0	0,05	195,84	1100,0	0,19	0,09	0,00	-0,6	-0,6	-0,2	-0,13	102,10
18	1114,0	0,06	222,30	1114,0	0,19	0,10	0,00	-0,6	-0,6	-0,3	0,07	189,00
19	1206,0	0,13	197,58	1206,0	0,09	0,09	0,00	-0,7	-0,7	-0,3	0,08	-26,87
20	1297,0	0,15	167,42	1297,0	0,08	0,09	0,00	-1,0	-1,0	-0,3	0,02	-33,14
21	1300,0	0,15	168,56	1300,0	0,10	0,09	0,00	-1,0	-1,0	-0,3	0,00	38,00
22	1368,0	0,23	185,68	1368,0	0,14	0,10	0,00	-1,2	-1,2	-0,3	0,12	25,18
23	1400,0	0,26	182,47	1400,0	0,10	0,10	0,00	-1,3	-1,3	-0,3	0,09	-10,03
24	1479,0	0,32	176,78	1479,0	0,08	0,10	0,00	-1,7	-1,7	-0,3	0,08	-7,20
25	1500,0	0,35	178,30	1500,0	0,15	0,10	0,00	-1,8	-1,8	-0,3	0,14	7,24
26	1600,0	0,49	183,01	1600,0	0,14	0,10	0,00	-2,6	-2,6	-0,3	0,14	4,71
27	1700,0	0,64	185,60	1700,0	0,15	0,10	0,00	-3,6	-3,6	-0,4	0,15	2,59
28	1758,0	0,72	186,62	1758,0	0,14	0,10	0,00	-4,2	-4,2	-0,5	0,14	1,76
29	1800,0	0,81	182,16	1800,0	0,26	0,11	0,00	-4,8	-4,8	-0,5	0,21	-10,62
30	1851,0	0,93	177,96	1851,0	0,27	0,11	0,00	-5,6	-5,6	-0,5	0,24	-8,24
31	1900,0	1,08	182,28	1900,0	0,34	0,12	0,00	-6,4	-6,4	-0,5	0,31	8,82
32	1944,0	1,22	185,23	1944,0	0,35	0,12	0,00	-7,3	-7,3	-0,6	0,32	6,70
33	2000,0	1,34	184,90	1999,9	0,21	0,13	0,00	-8,6	-8,6	-0,7	0,21	-0,59
34	2036,0	1,41	184,71	2035,9	0,19	0,13	0,00	-9,4	-9,4	-0,8	0,19	-0,53
35	2100,0	1,62	187,80	2099,9	0,35	0,13	0,00	-11,1	-11,1	-1,0	0,33	4,83
36	2128,0	1,71	188,92	2127,9	0,34	0,14	0,00	-11,9	-11,9	-1,1	0,32	4,00
37	2200,0	1,93	187,00	2199,9	0,32	0,14	0,00	-14,2	-14,2	-1,4	0,31	-2,67
38	2221,0	1,99	186,52	2220,8	0,30	0,14	0,00	-14,9	-14,9	-1,5	0,29	-2,29
39	2300,0	2,09	184,82	2299,8	0,15	0,14	0,00	-17,7	-17,7	-1,8	0,13	-2,15
40	2316,0	2,11	184,49	2315,8	0,15	0,14	0,00	-18,3	-18,3	-1,8	0,12	-2,06
41	2407,0	2,04	180,63	2406,7	0,17	0,14	0,00	-21,6	-21,6	-1,9	-0,08	-4,24
42	2500,0	2,56	181,46	2499,7	0,56	0,16	0,00	-25,3	-25,3	-2,0	0,56	0,89
43	2589,0	2,68	180,81	2588,6	0,14	0,16	0,00	-29,4	-29,4	-2,1	0,13	-0,73

This table sheet attached above, describe fully the wellpath data being input values (MD, Inclination and Azimuth), and the rest ones are the output results.
Must be notice that the values of the well path data, are for the planned well path not for the actual well path.

Using the WellPath editor commands, allows the user to identify the main critical issues:

- Vertical Section vs. Target Vertical Depth (TVD).
- Plan View
- Dogleg Severity(DLS) vs. Measured Depth(MD)
- Inclination vs. Measured Depth
- Azimuth vs. Measured Depth
- Absolute Tortuosity vs. Measured Depth
- Relative Tortuosity vs. Measured Depth
- Build Plane Curvature vs. Measured Depth
- Walk-Plane Curvature vs. Measured Depth.

Hence, I graphical representation must be distinguished with the most notable aspects that influence in our model simulation. Main graphical representation bellow;

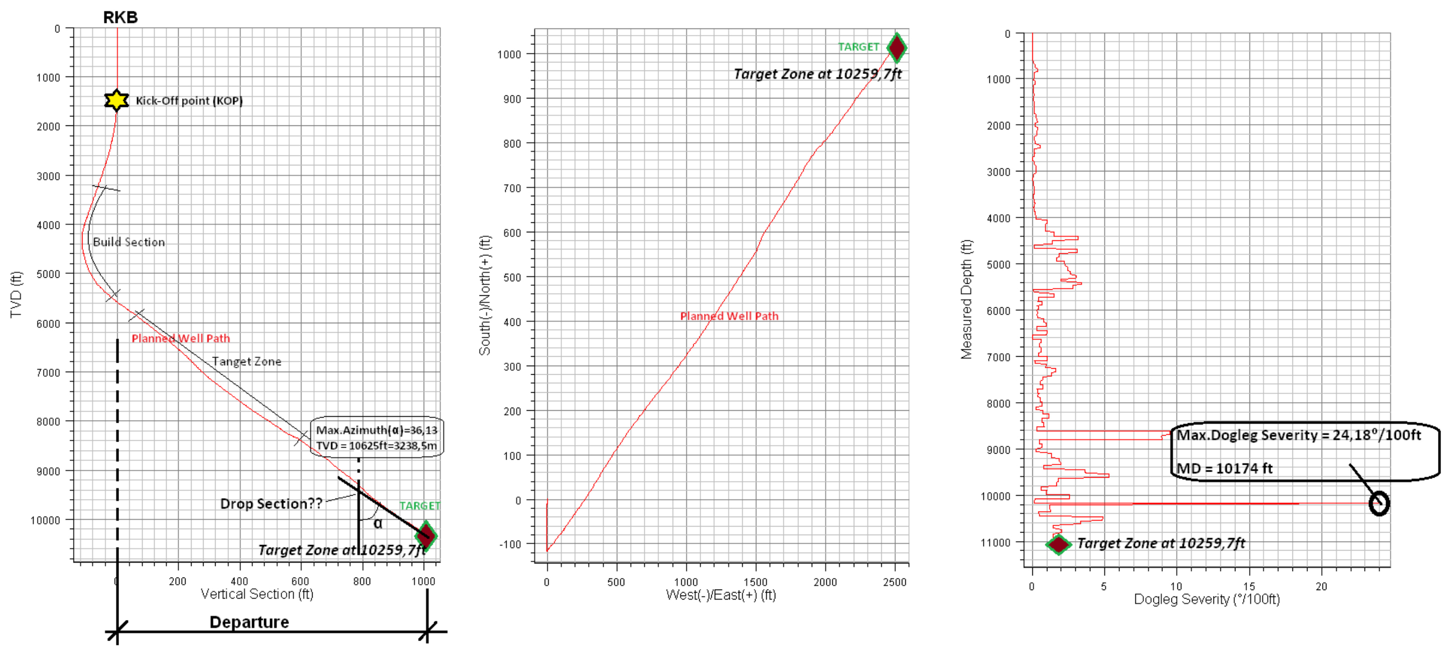

Figure 10. Vertical section vs. TVD, Plane view and Dogleg severity

One of the most notable aspect that we could observe from the first graph (TVD vs. Vertical Section), the **drop section** in our model is not visible, due to is infinite small and can be consider as continuing line of the tangent zone from 5900 ft to 8200ft approx. As well as, from MD vs. Dogleg Severity graph, can be notice two notorious pick values in two different ranges (8500 to 8900ft and 10100 to 10200ft) these ones are large, will be most significative during the analysis of the model simulation. Describing the total curvature on this directional wellbore model, where the severity of the bending moment occurs.

As second issue on this well path data talk us, is the max inclination (ϑ_{max}) being the risk area, located just before the target zone at **10259,7ft**. Here bellow;

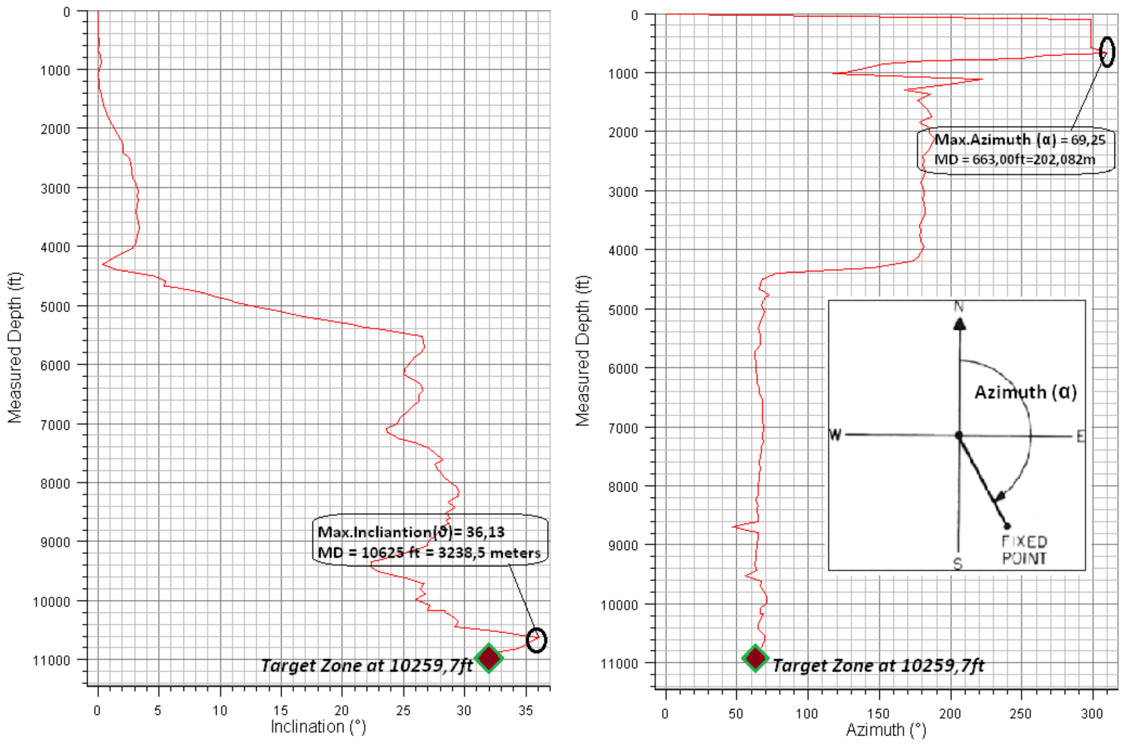

Figure 11. Measured Depths (MD) vs. Inclination and Azimuth.

Easily we can identify higher inclination (ϑ) from 5500ft to 10700ft, with a pick value of 36,16°, these range talks us the friction confidences are higher at this stage during tripping in phase. Beside that, the variation of tensions up-down will be happen, see the outcome obtained on the Torque and Drag Tripping-out Stress graph (On the Annexes attached).

In addition, further steps must be addressed in a close surveillance analyses of parameters (Mud density, RPM, ROP and Flow Rate control), in order to compensate the high friction ranges. The high-pressure levels during high friction will be a clear indicator of it too.

Then, the well path editor has contributed for a better control of the whole well path date into our simulation steps and results.

3.1.4 Fluid Editor

In order to identify the approach results obtained by the Fluid mad during the drilling operation, between the steps that involves this simulation, the next set ups from the Fluid Editor window was need it, which ones are;

- Fann Data (Speed vs. Dial)
- Mud Density: 8.50ppg
- Rheology Model: Power Law

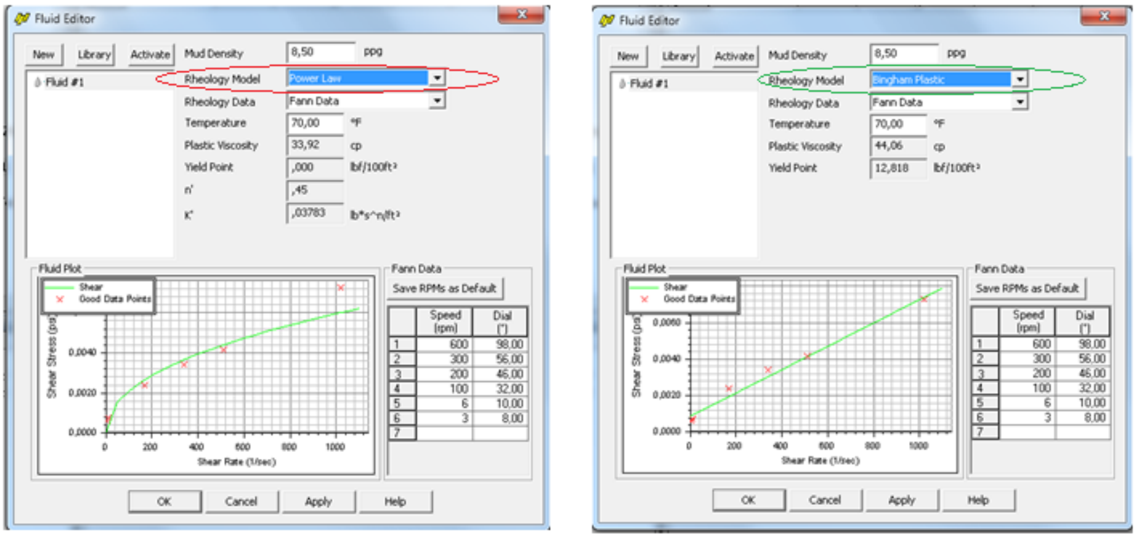

Figure 12. Fluid Plot: Shear Stress vs. Shear Rate

From theory, the relationship for Power Law model, is determined by:

Shear Stress = Consistency Factor x Shear Rate Flow Behaviour index

Describes the thickness (or pumpability) of the fluid. The Power Law Model, is the most commonly used method. This model fits the flow properties more closely, although at low shear rates, will predict slightly low shear stresses. As well as, the Power Law Model is more accurate for low shear rates, rather than Bingham model.

The equation for the Power Law model is:

Shear Stress = K x Shear rate

K: consistency index/factors (sec-1).

n: power index/flow behaviour index(0 to 1).

The Flow behaviour index (n) indicates the degree of non-Newtonian characteristics of the fluid:

High Viscous flow => The consistency Factors (K) increases.

Shear Thinning => “n” decreases.

Here bellow the classification of Flow behaviour index (n):

n = 1 (The Fluid is Newtonian)

n > 1 (The Fluid is Dilatant/Thickening)

0>n>1 (The Fluid is Pseudoplasctic= Shear-thinning)

The major difference is the viscometer readings used to determine the “K”&“n” values. Power Law uses the 300 and 600 readings. A differentiation between Pseudoplastic, Newtonian, Power Law and Dilatant into the Shear Stress Graph, can be observed bellow:

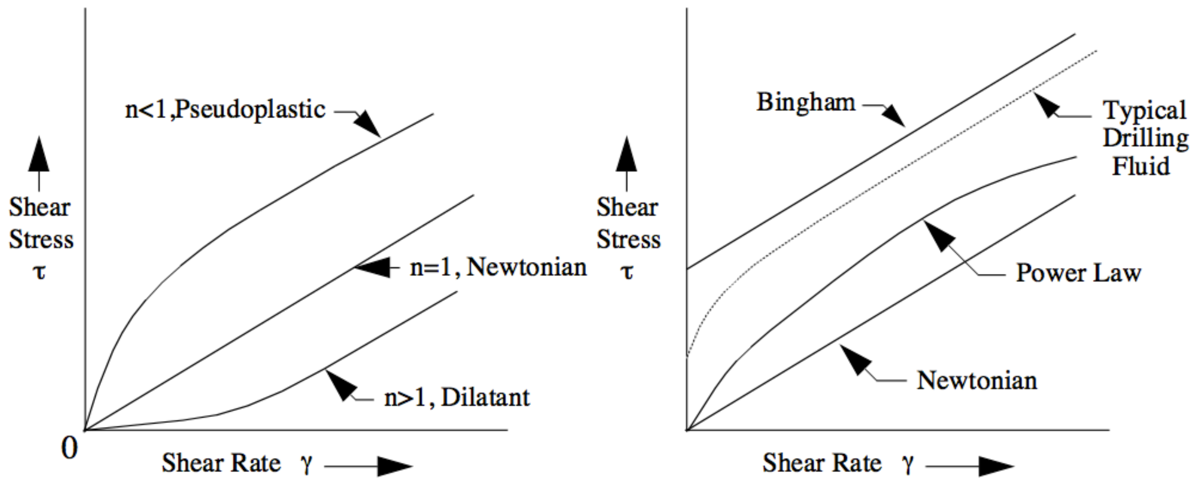

Figure 13. Shear Stress vs. Shear Rate

As we can observe on the previous graph above, the Rheology gives us a study of the Flow behaviour and Deformation. Non-Newtonian fluids may show a degree of time-dependent behaviour. For instance, if the apparent viscosity decreases with flow time (denominated “Thixotropic”), but viscosity increases with flow time, the fluid is “Rheopectic”.

Therefore, the shear stress developed in most drilling fluids is dependent upon the duration of shear. A time interval exists between an adjustment of shear rate and the stabilization of shear stress.

During the Hydraulic Calculations the parameters of the Power Law can be determined from the “FANN VG meter”. Where “K” and “n” are function of:

$$k = (1 + 0.067n) * \frac{300rpm}{511^n} \qquad n = 3.321\log\left(\frac{600rpm}{300rpm}\right)$$

The Rheology model (Power Law) is the most determinative to calculated the behaviour of the Fluid mud used in our simulation model. Using as default the “FANN Model 35” are direct reading instruments, the cuttings transport performance of the muds tested correlated best with the low-end-shear-rate viscosity, specific the six speed (6-rpm) viscometer dial readings (Becker et al[7]).

In addition, the variation of Mud Density and Friction factor influences in our model results: (See Torque Drag Effective Tension Graph, on the Appendix)

- High Mud Density and Lower Friction factor => Case 1 (Safety!! Does not pass the Tension Limit).
- Low Mud Density and Higher Friction factor => Case 2 (Unsafe!! Pass the Tension Limit)

The property fluid can be reach it on the next graphical conclusion:

Density vs. Pressure **Viscosity vs. Temperature**

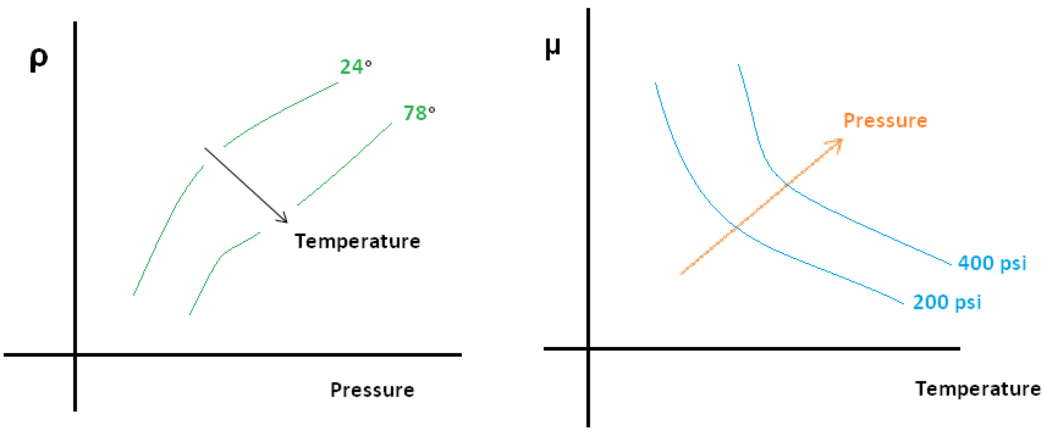

Figure14. Density vs. Pressure & Viscosity vs. Temperature

From the previous graphs with theses curves of data set, we could see that density and viscosity, are function of Temperature and Pressure.

$$\rho, \mu = f(Temperature, Pressure)$$

Furthermore, the main knowledgeable contribution that friction coefficient affects on the Torque and Drag window (**Compression vs. Tension Limit**), due to for higher friction coefficient the RIH (Running into the Hole) curve goes to the Compression limit(**-**) zone, but for lower fiction coefficients the POOH curve goes to the right side of the safety zone (on the **Tension Limit +**). Beside that, we can conclude that for higher fiction coefficients, the Drilling pipe easily is going to Buckling (into the Risky zone). Refer to the Annexes ("Torque Drag Effective Tension Graph").

The well pressure readings, along the well path(from 0 ft to 11000ft=3352.8 Km) provides a second interpretation and contribution to the Friction Coefficient (μ). From the **Dogleg** graph exist two clear severity zones (**8500 to 8900ft and 10100 to 10200ft**)on these, the friction is higher and affects our ECD line displacing to collapse and poor pressure gradient zones, or might be facing up the Fracture gradient curve. As risky result, increasing the severity of the Moment bending curvature on cited zones.

Hence, a balance between the reservoir pressure and well pressure (Flow rate) has to be found for our model, in order to reach safe drilling operation($\mathbf{P_{well}<P_{reservoir}}$). Due to being the key point, found out the optimal values of Fluid Properties. When we refer to this terminology(Optimal Fluid Properties) is to apply the right viscosity and pipe rotation, due to for smaller cuttings are more difficult to transport,

especially on this type of well(Directional-Well), where increasing the viscosity and pipe rotation, likely shall help out to transport easier fine particles.

3.1.5 Geothermal gradient

The heat of the earth is derived from main components: the heat by the formation of the Earth itself, and the heat by subsequent radioactive decline of elements in the upper parts of the surface lay on the Earth.

The energy flow generated per unit volume per second varies with depth (D), calculation of heat flow and, consequently, temperature with depth is complex.

Temperature at depth (T) is expressed as:

$$\mathbf{T = T_{surface} + D\Gamma}$$

Γ: Temperature gradient D: Depth.

The input values to set up for the Geothermal Gradient in our simulation, is divided in three ones;

- Surface Ambient ($T_{surface}$): 80ºF.
- Mudline: 40ºF.
- Temperature Gradient per Depth: 1,50ºF/100ft.

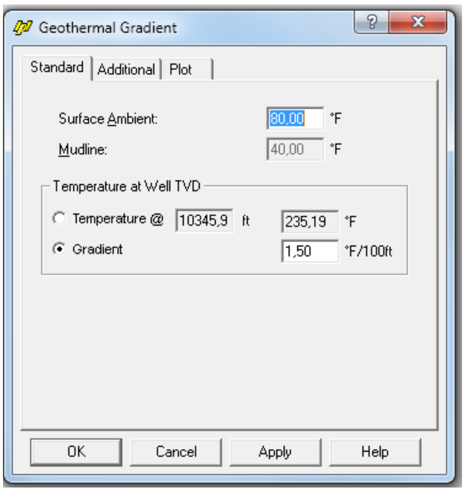

Figure 15. Geothermal Gradient window input values.

3.2 Torque, drag and buckling analysis

3.2.1 Drag and Buckling

During the Torque and Drag analysis, the Torque Drag effective Tension graph(attached on the Annexes) where the Friction Factor (see section 1.Objectives and/or 3.1.4. Fluid Editor) plays important role, due to for high levels of friction has been proven that the Drilling pipe can easily Buckling (into the Compression Limit zone). As well was stated on previous sections above, high friction levels detected must be compensate with Fluid parameters (mud density, viscosity, Rheology).

Sensitivity analysis

During the Drag and Buckling analysis, the most important parameters for this simulations (Torque & Drag), are:

- Weight of: Bit, Pipe and BHE.
- Drillpipe Friction Factor (DFF)
- Bit aggressive Factor (BAF)
- Mud Density
- Top Drive Rotational Speed

The variation of the parameters (tons, friction factor's, ppg, inches, metres…etc), influence directly in a sensitive study. For instance, can be much more sensitive the model, with a more aggressive Bit, where the drillpipe friction factor and the BHA are the sensitive ones parameters.

Nevertheless, the sensitivity study purpose will be conduct on different drilling parameters individually to see how it will effect on the different parameters at TD.

The output obtained of this Torque and Drag modelling graph ("Torque Drag Effective Tension Graph") has included the next graphical curves on Tension vs. Distance along String:

- Tension Limit
- Helical Buckling (Non Rotating)
- Helical Buckling (Rotating)
- Sinusoidal Buckling (all operations)
- Rotate Off Bottom
- Rotate On Bottom
- Tripping Out
- Tripping In

Being the most significative survey from the Torque Drag Effective graph (see Annexes), that the Tension Limit has to be over of any other Tensions (Limit, Helical Buckling, Tripping Out,…etc)

3.2.2 Torque

Torque analysis involves the rotational speed (**ω**) against the coefficient of friction (**μ**). As was explained on the Theory (on the Section 2), the torque depends of a moment times a distance. This moment, involves the coefficient of friction (**F_A= N*μ**), which one is function of rotation and velocity. Here bellow the function;

$$\mu = f(\omega, V)$$

According with this relation, when we are drilling in high revolutions (↑ RPM) the friction factor decrease. In order to find out a balance, between the life cycle(drilling BIT) and speed up and down during the drilling process, these loose of Energy (reservoir) and deterioration life cycle of drilling BIT, must be equilibrate and compensate through Hydraulics Cuttings Transport (ROP). As well as, the function of the drilling mud is to transport the cuttings (ROP) and provide a successful well/hole cleaning.

So, to accomplish this goal cited was carried out three types of graphical results in our simulation:

1. Pump Rate (100 to 900 gpm); Min.Flowrate vs. Hole Angle
2. RPM with ROP; Min.Flowrate vs. Hole Angle
3. Distance along String vs. Inclination, Min.Flowrate, Volume and Bed Height.

From each type of graph, we can be observe(see Annexes) a variety of interesting effects. For the first one, we decrease the pumping rate the curves obtained goes up the % of Total volume at the same Well Inclination (Hole Angle). That means, an incremental % of the Flow rate creates a chain of impact for ↑ EDC and ↑ Pressure into the well.

In the second one (2), can be summarize in the next graphical representation bellow:

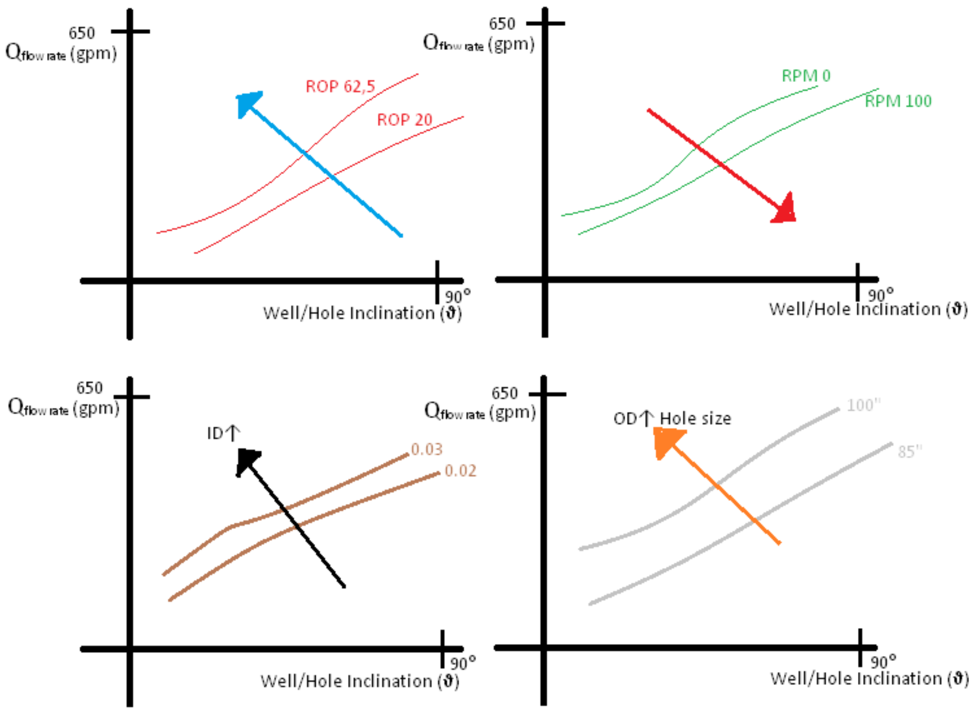

Figure 16. Flow Rate vs. Hole inclination

In regard, to the third one, is a mere graphical representation of Inclination, Min.Flowrate, Volume and Bed Height, against the distance along string (ft). What these represented graphs attached together point out, are the freeze of the parameters (rate of penetration, pump rate and minimum flow rate) during the simulation, are showed on the first graph in the annexes attached("Hydraulics Cuttings Transport Parametric, RPM vs. ROP"), on which one was set up the next freeze parameters:

-Rate of Penetration: 62.5 ft/hr

-Pump Rate: 50 gpm

-Min.Flow Rate: 794.8 gpm

The simulation has allowed us to freeze the optimal parameters in the desire way and reach up suitable Test models, in based of requirements of the reservoir.

Theses operational parameters that have influenced for a model drill simulation, are listed as:

- Well Inclination (ϑ)
- ROP
- RPM
- Q (Flowrate)
- Hole size

So the objective of this section has been to check out that the Drilling String is not damage, and the Well too (if not, we lose Energy from the Reservoir and fatigue on DS).

3.2 Stress in drill string simulation

The options proved by **WellPlan™** in order to plot the Stress Graph along the Drill string, is dived in five graphs:

- Tripping In
- Rotating On Bottom
- Tripping Out
- Rotating Off Bottom
- Slide Drilling

Along this section, the key graph that has contributed to compute the Stress Analysis of the Drill string simulation has been the "Torque Drag Tripping-in Stress Graph"(see on the Annexes). On this particular analysis, have been carried two types of analysis of Flow Rate(gpm):

- Lower Flow Rate
- Higher Flow Rate

Analysis of Stresses in tubing and failure (Hoop, Radial, Torsional, Shear…etc) and their results on each one, are showed on the graph cited, has give to us different results for the Stress (psi) vs. Distance along String (ft), moving the curves from the left side to right of the graph. Mainly depending of the type Flow rate applied it. Besides that, the critically of Failure will depend on the value of theses stress.

The Failures criteria's is classified as:

1. **Tresca:**

The Tresca failure criterion is based on the maximum and minimum principal stress. This criterion is developed based on the maximum shear stress theory. Given as:

$$\sigma_y = \sigma_{max} - \sigma_{min}$$

2. **Von-Mises:**

The Von Mises yield condition, states that yielding begins when the distortional strain-energy density at a point equals the distortional strain-energy at yield in uniaxial tension(or compression). The initial yield limit is based on the combination of the three principle stresses (axial stress, radial stress, and hoop stress) and the shear stress caused by torque. Yielding as a function of the combined three stresses is given by:

$$\sigma_{von} = \sqrt{1/2[(\sigma_r - \sigma_\theta)^2 - (\sigma_r - \sigma_a)^2 + (\sigma_\theta - \sigma_a)^2 + 3\tau^2}$$

As with the Tresca criterion, the Von-Mises criterion is fairly accurate in predicting initiation of yield for certain ductile metals. The Von-Mises is more accurate and conservative for some materials than Tresca criterion in predicting yield under pure shear. By default, we have chosen at the **WellPlan™** to apply the Von-Mises failure criteria.

Ending up that the successful part along this section, will be applied appropriate flow rate, in order to optimize and control the stress outcome in the wall thickness as consequence of the pressure. See next relationship:

$$\uparrow Flow\ Rate(Q) =\uparrow ECD =\uparrow Pressure\ into\ the\ well \equiv\uparrow\uparrow Stress$$

3.2.1 Von-mises at lower flow rate

The analysis carried out for lower levels of Flow rate (for example, **900 gpm**), can be well observed on the first graph (in the Annexes, "Torque Drag Tripping-In stress graph") that curve of the Von-Misses Stress is under the Tension limit line (red color), due to our model simulation is located into the safety window.

In addition, for depths between 8500 to 8900 ft the variation of Von-Misses stress is significantly higher, looking up to the Figure 3 (Measure Depths vs. Dogleg Severity), holds a range of pick values through that depths. A control appropriate pumping of flow rate is crucial.

3.2.2 Von-mises at higher flow rate

Flow rate, with lower flow rate regime, such as 1500 gpm has been simulated, where from the second graph ("Torque Drag Tripping-In stress graph") is well observed that the Axial, Hoop and Von-Misses pass over the Tension limit line, hence, the model at this state is not safe. Due to higher values of Flow rate(>900 gpm) our model become risky. As well as, for a Tripping operation always the flow rate increases.

At this stage, having simulate higher and lower flow rates levels tell us that the critically of failure stress on the drilling pipe, happens for a flow rate bigger than 900 gpm(Max. value!).

The simulation made it indicates that for high flow rates regimes, will remove the cuttings for any fluid, hole size, and hole angle. In contrast, flow rates high enough to transport cuttings up and out of the annulus effectively cannot be used in many wells, due to downhole dynamic pressures, limited pump capacity or high surface. In addiction, these challenges cited are true for high angles with hole sizes larger (>12$^{1/4}$).

Then, high rotary speeds are used when Flow rates does not suffice the needs.

4 Discussion and Recommendations

At any directional Drilling well, will be involved the challenges cited (well collapse, fracturing, gas kick, loss of circulation or pore pressure) only will varies the severity of the reservoir formation along the well path. But in the way we treat and manage the challenges will be crucial to optimized a safety and profitable drilling operations.

Established well control precautions and procedures, design mud program for each hole section and drilling string too, will reduce any future hazard. Being the ones the **Friction** and **Pressure**.

During the calculation loads, the "friction factor" has been the most important element needed it to calculate either "slack off" or "pickup" loads or the torque need to rotate the drilling string (DG). By modeling frictional forces on the completion string in advance, is possible to predict if the forces resulting from friction will exceed allowable limits (Tension Limit) or even if the DG will be available to reach the bottom, as well is demonstrated on the graphs obtained (Annexes).

As we demonstrated along this simulation report, the friction factor is function of a great of variables. In the way, we treat these variables and parameters shall be the key of successful applicability of drilling procedures.

The fact that when moving(R.P.M=Rotating), frictional forces are at a minimum and are the result of dynamic friction and not static friction. **WellPlan™** is capable of back-calculating a friction factor, given the weight of the string.

As the increase in bottom pressure expressed as an increased in pressure that occurs only when mud is being circulated. For instance, due to friction (μ) effect in the annulus when mud is being pumped, the bottomhole pressure will be slightly higher than when the mud is not being pumped.

Therefore, must be balance by the pressure coming up during the drilling against to the reservoir pressure itself, although different fluid types (heavier vs. Lighter mud) should apply for each drilling circumstances. Due to, the variations of decreasing and increasing the total "Torque" and shift rotating on/off bottom towards the left depending in how much we increase the mud weight. In addition, the ECD is key parameter to avowing "Kicks" and "Losses".

Successful techniques and developments using dual gradient systems (DGS) technologies raise the mud weight, could be used as an alternative to changing setting depth.

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Annexes

Drilling Pipe Representation:

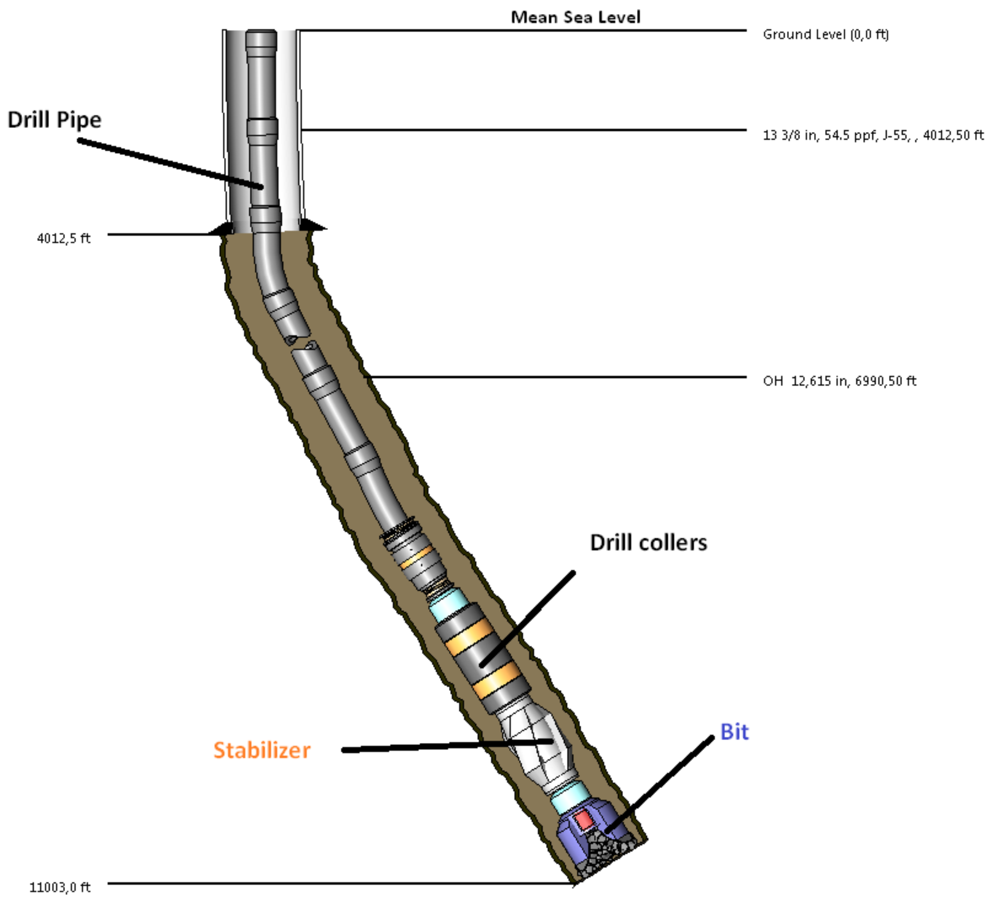


Figure 17. Drill pipe representation

Profile Well Data (Top to Bottom): // Measured Depth (MD), Inclination (ϑ), Azimuth//

MD	ϑ	Azimuth
0	0	0
100	0,02	298
200	0,03	298
300	0,05	298
400	0,07	298
500	0,09	298
572	0,1	298
600	0,09	300,5
663	0,06	309,93
700	0,1	268,21
754	0,18	249,32
800	0,17	185,35
847	0,31	153,14
900	0,25	147,17
1000	0,16	125,51
1023	0,15	117,22
1100	0,05	195,84
1114	0,06	222,3
1206	0,13	197,58
1297	0,15	167,42
1300	0,15	168,56
1368	0,23	185,68
1400	0,26	182,47
1479	0,32	176,78
1500	0,35	178,3

1600	0,49	183,01
1700	0,64	185,6
1758	0,72	186,62
1800	0,81	182,16
1851	0,93	177,96
1900	1,08	182,28
1944	1,22	185,23
2000	1,34	184,9
2036	1,41	184,71
2100	1,62	187,8
2128	1,71	188,92
2200	1,93	187
2221	1,99	186,52
2300	2,09	184,82
2316	2,11	184,49
2407	2,04	180,63
2500	2,56	181,46
2589	2,68	180,81
2600	2,7	180,96
2673	2,8	181,89
2700	2,8	181,68
2765	2,81	181,18
2800	2,84	180,3
2855	2,89	178,95
2900	3	179,58
3000	3,23	180,84
3037	3,32	181,26
3100	3,28	180,86
3127	3,26	180,69
3200	3,28	180,83
3220	3,29	180,87
3300	3,25	181,63

3314	3,24	181,77
3406	3,13	181,71
3498	3,22	179,61
3500	3,22	179,58
3591	3,28	178,28
3600	3,29	178,31
3683	3,42	178,59
3700	3,39	178,56
3769	3,28	178,41
3800	3,25	178,62
3863	3,18	179,06
3900	3,14	180,19
3943	3,09	181,55
4000	2,96	180,09
4028	2,9	179,33
4100	2,18	177,73
4120	1,98	177,08
4200	1,26	172,63
4301	0,41	144,38
4403	1,64	77,68
4486	4,25	68,48
4500	4,44	68,09
4576	5,5	66,47
4600	5,49	66,2
4671	5,47	65,41
4700	6,32	68,16
4763	8,2	72,15
4800	8,85	70,47
4850	9,73	68,56
4900	10,56	67,63
4942	11,25	66,96
5000	12,5	68,65

5043	13,44	69,7
5100	14,82	68,82
5148	15,99	68,19
5200	17,29	66,7
5226	17,94	66,03
5300	20,16	65,36
5319	20,73	65,21
5372	21,77	65,44
5400	22,71	65,84
5450	24,38	66,48
5500	25,79	66,29
5527	26,55	66,19
5600	26,61	66,19
5617	26,63	66,19
5700	26,71	63,46
5721	26,74	62,77
5800	26,42	62,88
5810	26,38	62,89
5896	25,79	63,01
5900	25,78	63,03
5988	25,47	63,45
6000	25,43	63,47
6078	25,15	63,59
6100	25,11	63,74
6165	24,98	64,19
6200	25,26	64,22
6259	25,72	64,27
6300	26,05	64,77
6348	26,43	65,34
6400	26,55	65,59
6440	26,64	65,78
6500	26,37	66,99

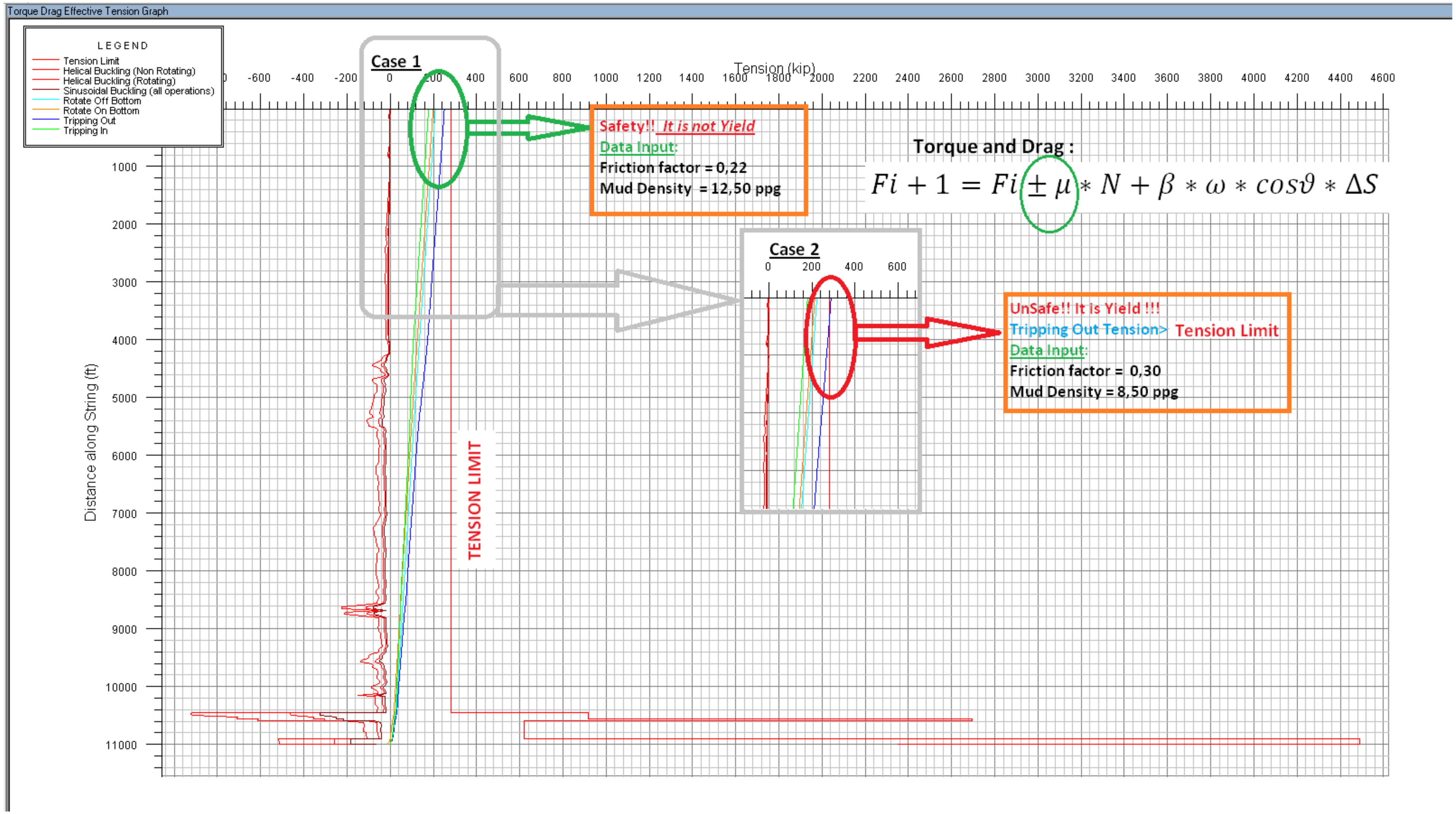
6535	26,22	67,7
6600	26,23	67,68
6628	26,23	67,67
6700	25,81	67,95
6713	25,74	68
6803	25,33	68,18
6904	24,73	68,13
6997	24,53	68,98
7000	24,5	68,96
7088	23,62	68,32
7100	23,63	68,28
7150	23,69	68,09
7200	24,16	68,21
7240	24,53	68,31
7300	25,45	67,59
7329	25,89	67,26
7400	26,82	67,03
7422	27,11	66,96
7500	27,62	66,46
7516	27,72	66,36
7600	28,11	65,88
7617	28,19	65,79
7696	27,61	66,06
7700	27,62	66,04
7796	27,9	65,66
7800	27,92	65,65
7878	28,21	65,41
7900	28,32	65,32
7979	28,71	64,98
8000	28,85	64,96
8070	29,33	64,88
8100	29,41	64,87

8153	29,54	64,86
8200	29,48	64,15
8244	29,43	63,48
8300	28,94	64,32
8333	28,66	64,83
8400	29,08	64,42
8424	29,23	64,27
8500	28,64	64,68
8515	28,52	64,76
8607	28,81	64,82
8650	28,49	56,29
8697	28,76	46,95
8700	28,7	47,5
8750	28,1	56,82
8792	28,09	64,81
8800	28,05	64,79
8895	27,59	64,58
8900	27,56	64,55
8972	27,13	64,17
9000	27,08	64,07
9064	26,96	63,84
9100	26,5	63,63
9164	25,68	63,24
9183	25,43	63,12
9200	25,11	63,1
9272	23,77	63
9300	23,22	62,77
9344	22,36	62,4
9400	22,34	63,52
9436	22,33	64,24
9500	22,94	58,35
9526	23,25	56,05

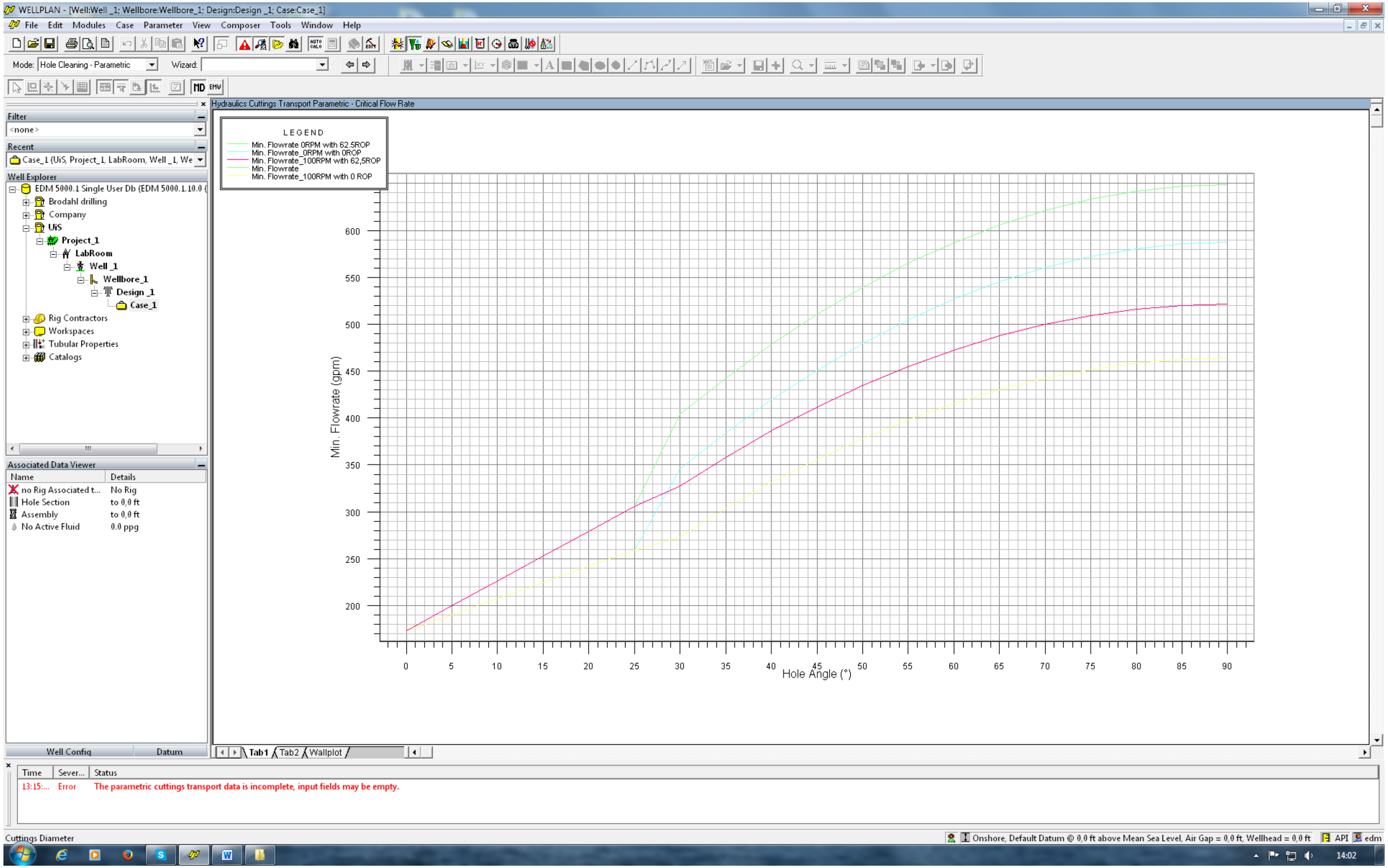
9600	24,7	65,02
9620	25,18	67,26
9700	26,57	66,45
9710	26,74	66,35
9805	26,39	69,8
9895	26,8	70,64
9900	26,75	70,65
9982	25,97	70,79
10000	26,2	69,88
10072	27,16	66,41
10100	27,11	66,43
10167	27	66,47
10174	28,36	68,64
10200	28,52	68,06
10300	29,16	65,88
10349	29,49	64,84
10400	29,33	65,19
10442	29,19	65,49
10500	31,64	68,23
10534	33,1	69,66
10600	35,3	69,36
10625	36,13	69,25
10700	35,39	67,88
10718	35,22	67,54
10805	34,45	64,7
10900	31,91	62,37
11003	31,2	63,1

Table 4. Profile Well Data

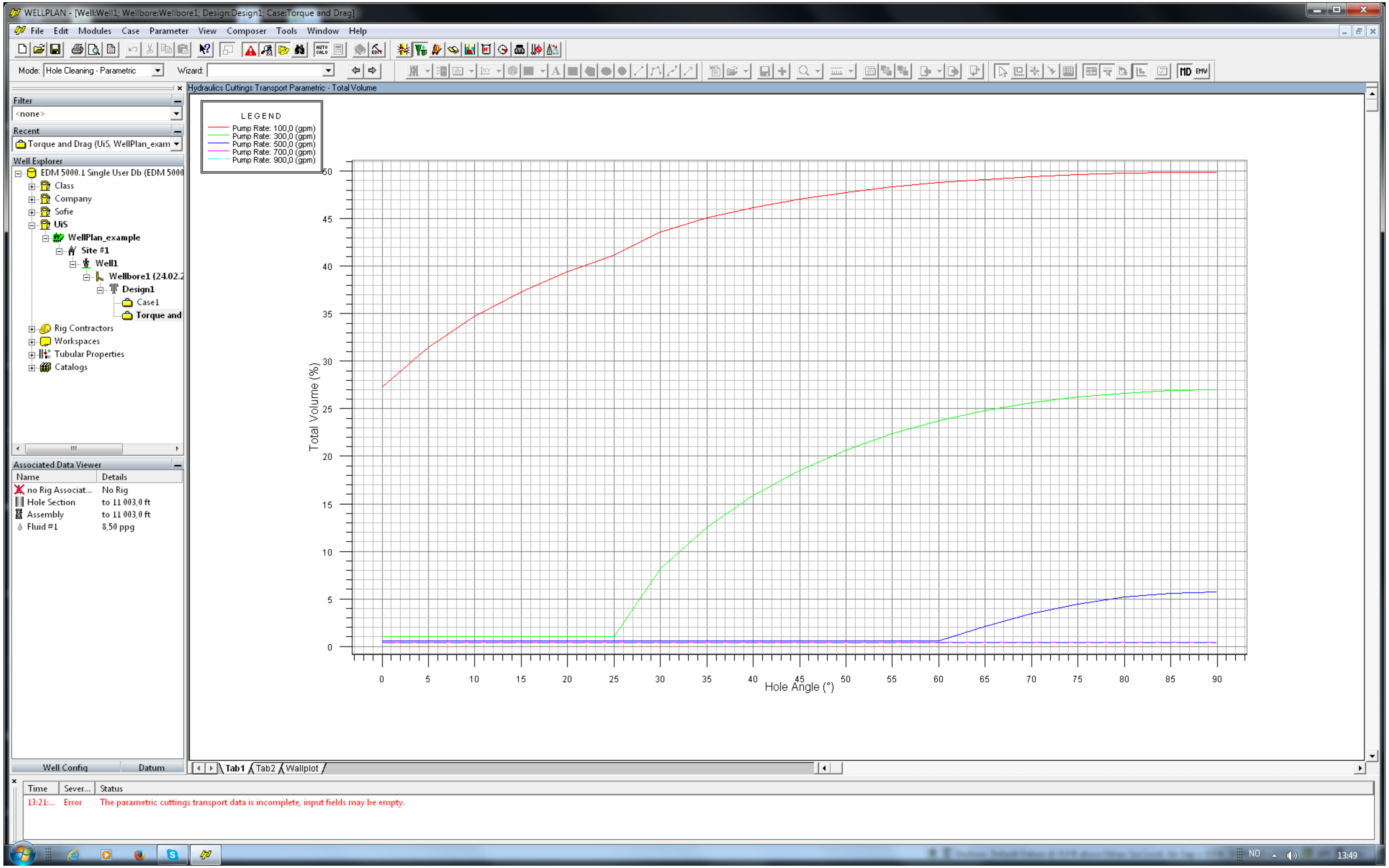
Torque Drag Effective Tension Graph: (Tension vs. Distance along String)



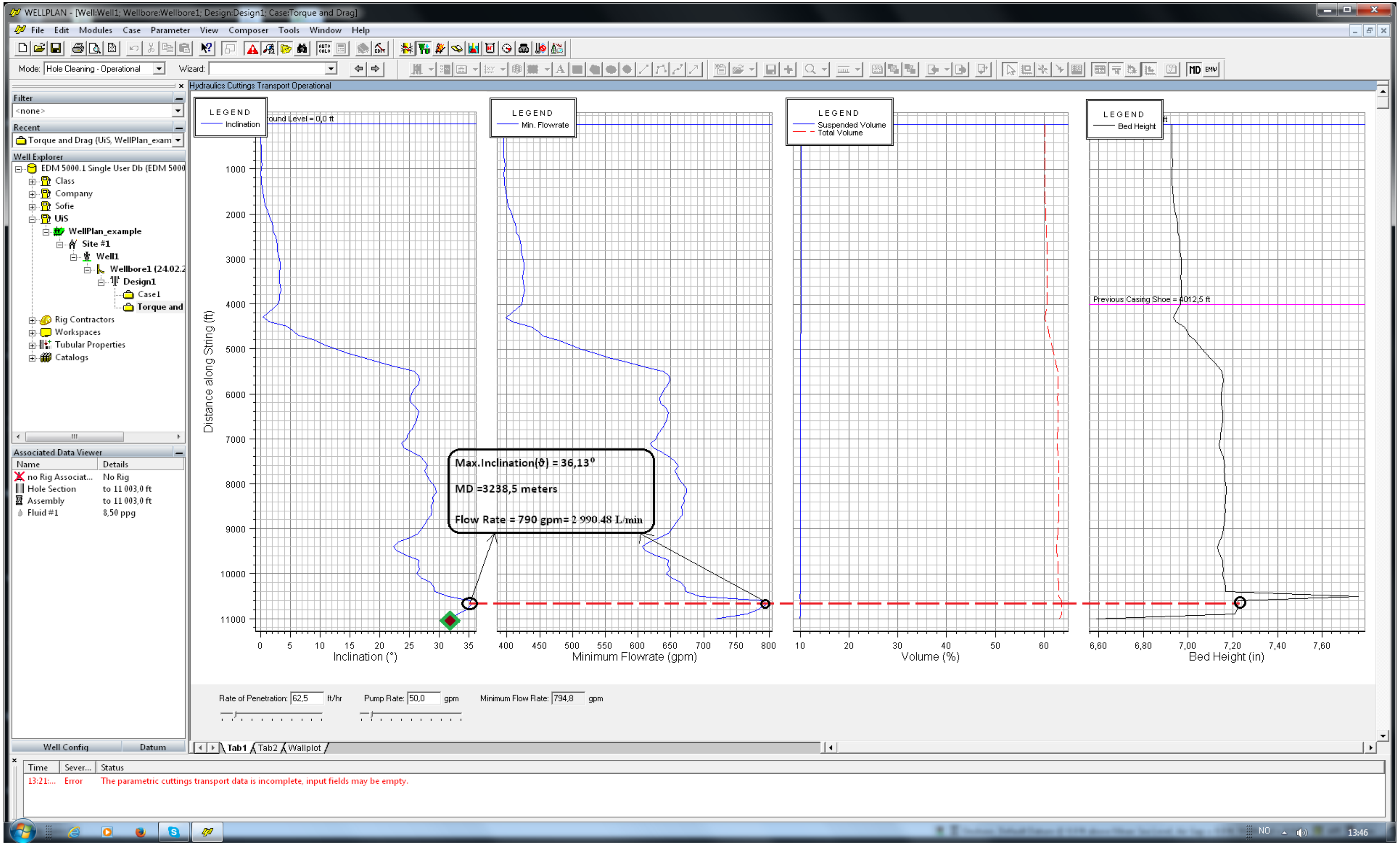
Hydraulics Cuttings Transport (RPM vs. ROP):



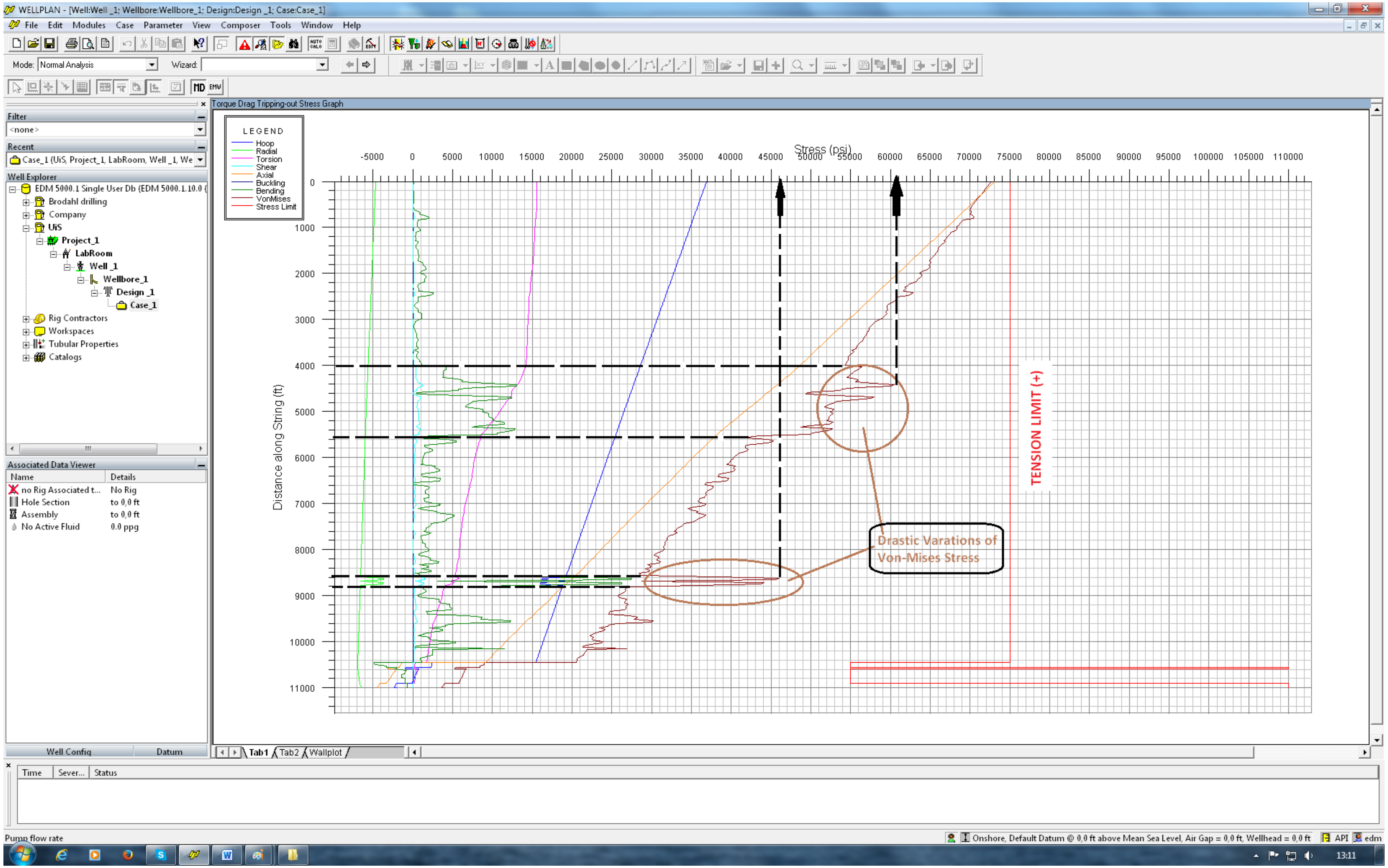
Hydraulics Cuttings Transport Parametric – Total Volume: //**Pump rate:** From 100 to 900 gpm //



Hydraulics Cuttings Operational:



Torque Drag Effective Tension: (Stress vs. Distance along String) **// Flow Rate: 900gpm // (**Ref. Section 3.2)



Torque Drag Effective Tension: (Stress vs. Distance along String) **// Flow Rate: 1500gpm //** Ref. Section 3.2