Sudan University of Science and Technology
College of Petroleum Engineering and Technology
Petroleum Engineering Department

Project title:

Analytical application on Wellplan software studying torque and drag.

(Case study horizontal well in field (B) in Sudan)

تطبيق تحليلي للعزم والسحب باستخدام برنامج Wellplan

(دراسة حاله لبئر افقيه في حقل B)

Submitted in Partial Fulfillment of the Requirements of the Degree of B.tech in Petroleum Engineering.

Prepared by:

1-Abubaker Alamen Ahmed

2-Ahmed Faisal Elsheikh

3-Emad Ibrahim Omer

4-Mustafa Ahmed Ibrahim

Supervisor:
Dr. Ahmed Abd Elaziz

Nov. 2016

الإستهلال

قال تعالى :

(يَرْفَعْ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ)

المجادله (11)

عن ابى هريره رضى الله عنه قال: قال رسول الله صلي الله عليه وسلم:

"من سلك طريقا يلتمس فيه علما سهل الله له به طريقا الى الجنه"

□اخرجه مسلم

Dedication

To our fathers and mothers who taught us great lessons about life, guiding, motivation, innovation and support us along life's level.

Without them we would not become the people who we are today.

To our brothers and sisters who stand with us, encourage us and taught us the real meaning of helping other people with all we have.

For future generations that hold future of the oil industry in Sudan. We are honor to offer you this modest work.

Thanks all for giving us a chance to prove and improve our self through all levels of university life

Acknowledgment

Undertaking a project of this size requires the support, direction and advice. We are deeply indebted to our supervisor **Dr. Ahmed Abd Elaziz** Ibrahim for his technical directions, Motivation and moral support throughout this research.

Our profound gratitude goes to Teach. Mohamed Abdelkhalig for taking time out of his busy schedule to guide us through this project. We also wish to express our sincere appreciation for Teach. Mohanad Mahjoub, for his efforts and time, that he sacrificed it for us to complete this research.

We also wish to express our appreciation and sincere thanks to Department of Petroleum Engineering and Technology for information, advices and guidance that had given to us throughout the years.

Finally, we would like to extend our gratitude to people who worked with us.

Abstract

One of the most critical limitations during horizontal drilling is torque and drag generated by the contacts between the drill string and the borehole or casing. Therefore, torque and drag analysis and calculations are very important for well design to prevent equipment and economical losses. One of the important parts of predicting torque and drag is determining the correct friction factor. Friction factor combines all unknown factors that are un measurable in the wellbore in drilling condition.

In this project, Landmark-Wellplan software is used to model torque and drag for horizontal well located in field B. The modelling process is broken down into the following: first the correct friction factor is calculated for cased and open hole sections from actual field data. Then weights, torques, and forces are calculated using the calculated friction factor. For model matching purposes, actual weights are plotted and matched along with the calculated weights.

The results show that over torque problem encountered during rotation on and off bottom at the depth of 2900 ft and helical buckling problem during all operation modes at the depth of 750-2400 ft.

Key Words: *Torque, Drag, Friction Factor*, *Landmark.*

التجريد

واحدة من العقبات الأكثر أهمية أثناء الحفر الافقي هي العزم والسحب الذي ينشأ بسبب التلامس بين عمود الحفر وجدار البئر أو أنابيب التغليف، وبالتالي تحليل وحسابات العزم والسحب مهمه جدا في تصممصم الآبار لحماية المعدات وتقليل الخسائر الاقتصادية. حديثآ تم إقتراح برامج متخصصة تستخدم لتحليل العزم والسحب وكذاك التنبوء بالمشاكل التي قد تحدث أثناء الحفر وبالتالي منعها.

في هذا البحث تم إجراء عملية تحليل العزم والسحب لبئر أفقية في حقلB بإستخدام برنامج Landmark-Wellplan تم إجراء عملية تحليل علي النحو التالي: بما أن قيم العزم والسحب تعتمد علي تحديد و حساب معامل الإحتكاك الصحيح، تم حساب هذا المعامل للجزء المبطن وغير المبطن من البئر من بيانات حقلية.ثم حسبت الأوزان، العزوم، والقوي بناءآ علي معامل الإحتكاك المحسوب. تم إدخال مجموعة من الأوزان الحقيقية أثناء حفر البئر للبرنامج وتمت مطابقتها مع الأوزان المحسوبة بإستخدام البرنامج.

أظهرت نتائج التحليل بعض المشاكل مثل العزم الزائد عند عمق 2900 قدم أثناء تدوير سكينة الحفر في قاع البئر وعلي مسافة من قاع البئر. أيضآ هنالك بعض الإلتواءات التي حدثت من عمق 750 – 2400 قدم.

كلمات مفتاحية: العزم، السحب، معامل الإحتكاك.

List of Contents

No	Contents	page
	Opening	i
	Dedication	ii
	Acknowledgement	iii
	Abstract (English)	iv
	Abstract (Arabic)	v
	List of Contents	vi
	List of figures	viii
	List of tables	x
	Nomenclature	xi
Chapter 1: Introduction		
1.1	Horizontal Drilling	1
1.2	Definition of Horizontal well	2
1.3	Types of Horizontal Wells	2
1.4	The difference between Vertical, Horizontal and Multilateral Wells	5
1.5	Statement of the Problem	6
1.6	Objective of the Study	6
Chapter 2: Literature Review and Theoretical Background		
2.1	Literature Review	7
2.1.1	Soft String Model	7
2.1.2	Stiff String Model	8
2.2	Torque and Drag Basic Theory	9
2.2.1	Torque	9
2.2.2	Drag	11
2.2.3	Friction factor	12
2.2.4	Weigh	15
2.2.5	Buoyancy	16
2.3	Torque and Drag Modelling	17
2.3.1	Torque and Drag equations	18
2.3.2	Benefits of Torque and Drag Modelling	19
Chapter 3: Methodology		
3.1	Landmark-Wellplan	22
3.2	Case Well Profile	22
3.3	Torque and Drag Modelling	22
3.3.1	General Data	23
3.3.2	Torque and Drag Module Data	31

3.3.2.1	Calibrate Coefficient of Friction	32
3.3.2.2	Normal analysi	**33**
Chapter 4: Results and Discussion		
4.1	Well Sections Description	37
4.2	Normal Analysis	38
4.2.1	Effective Tension Plot	41
4.2.2	True Tension Plot	43
4.2.3	Torque plot	45
4.3	Drag Chart Analysis	46
4.3.1	Measured Weight Chart	46
Chapter 5: Conclusion and Recommendations		
5.1	Conclusion	53
5.2	Recommendations	54
	References	55
	Appendix	56

List of Figures

No	Figures	page
Fig.1.1	Horizontal Well Types (Rabia, Well Engineering and Construction)	4
Fig. 1.2	The Difference between Vertical, Horizontal and Multilateral Drilling. (Introduction to DD :Steinar Bakke and Jun Dauday 10/20/98)	5
Fig.2.1	Short Element in a String (McCormick, Melissa and Chiu, 2011)	8
Fig. 2.2	Wellbore and Drill string Forces (Raksagati, 2008)	9
Fig. 2.3	Diagrammatic Representation of Torque Generating Forces (Agbaji, 2009)	10
Fig.2.4	Drag in Vertical and Inclined Hole (Borinb, 2012)	12
Fig.2.5	Simple Effect of Friction Force (Raksagati, 2008)	13
Fig.2.6	Illustration of Factors that Impact the Friction Factor (Raksagati, 2008)	14
Fig.2.7	Side Forces on the String in Wellbore Orientations (Bennetzen et al. 2010)	15
Fig.2.8	Drillstring Free Body Diagram(Raksagati, 2008)	18
Fig.3.1	1st Build Section General Data (Wellplan)	23
Fig.3.2	Tangent Section General Data (Wellplan)	24
Fig.3.3	2nd Build Section General Data (Wellplan)	24
Fig.3.4	1st Build Section Wellbore Editor (Wellplan)	25
Fig.3.5	Tangent Section Wellbore Editor (Wellplan)	25
Fig.3.6	2nd Build Section Wellbore Editor (Wellplan)	25
Fig.3.7	1st Build Section String Editor (Wellplan)	26
Fig.3.8	Tangent SectionString Editor (Wellplan)	26
Fig.3.9	2nd Build SectionString Editor (Wellplan)	26
Fig.3.10	1st Build Section Survey Editor (Wellplan)	27
Fig.3.11	Tangent Section Survey Editor (Wellplan)	27
Fig.3.12	2nd Build Section Survey Editor (Wellplan)	28
Fig.3.13	1st Build Section Fluid Editor (Wellplan)	29
Fig.3.14	Tangent Section Fluid Editor (Wellplan)	30
Fig.3.15	2nd Build Section Fluid Editor (Wellplan)	31
Fig.3.16	Horizontal Well T&D Setup Data (Wellplan)	32
Fig.3.17	Calibrate Coefficient of Friction (Wellplan)	33
Fig.3.18	Tangent Section Normal Analysis Mode Data (Wellplan)	34
Fig.3.19	2nd Build Section Normal Analysis Mode Data (Wellplan)	35
Fig.3.20	1st Build Section Drag Chart Run Parameters (Wellplan)	36
Fig.4.1	1st Build Section Vertical Section (Wellplan)	37
Fig.4.2	1st Build Section DLS (Wellplan)	38
Fig.4.3	1st Build Section Inclination (Wellplan)	38
Fig.4.4	Tangent Section Vertical Section (Wellplan)	39
fig.4.5	DLS Tangent Section (Wellplan)	39

Fig.4.6	Tangent Section Inclination (Wellplan)	39
Fig.4.7	2nd Build Section Vertical Section (Wellplan)	40
fig.4.8	DLS2nd Build Section (Wellplan)	40
Fig.4.9	2nd Build Section Inclination (Wellplan)	41
Fig.4.10	1st Build Section Effective Tension during Tripping in, Tripping out, Rotating on and off Bottom (Wellplan)	41
Fig.4.11	Tangent Section Effective Tension during Tripping in, Tripping out, Rotating on and off Bottom (Wellplan)	42
Fig.4.12	2nd Build Section Effective Tension during Tripping in, Tripping out, and Rotating on and off Bottom (Wellplan)	43
Fig.4.13	1st Build Section True Tension during Tripping in and Tripping out (Wellplan)	44
Fig.4.14	Tangent Section True Tension during Tripping in and Tripping out (Wellplan)	44
Fig.4.15	2ndBuild Section True Tension during Tripping in, Tripping out, rotating on and off Bottom (Wellplan)	44
Fig.4.16	1st Build Section Torque Plot (Wellplan)	45
Fig.4.17	Tangent Section Torque Plot (Wellplan)	46
Fig.4.18	2nd Build Section Torque Plot (Wellplan)	46
Fig.4.19	1st Build Section Calculated Weights during Tripping in, Tripping out, and Rotate off Bottom (Wellplan)	47
Fig.4.20	Tangent Section Measured and Calculated Weights during Tripping in, Tripping out, and Rotating on Bottom (Wellplan)	47
Fig.4.21	2nd Build Section Calculated Weights during Tripping in, Tripping out, Rotating on and off Bottom (Wellplan)	48
Fig.4.22	1st Build Section Minimum WOB Chart (Wellplan).	49
Fig.4.23	Tangent Section Minimum WOB Chart (Wellplan)	49
Fig.4.24	2nd Build Section Minimum WOB Chart (Wellplan)	49
Fig.4.25	1stBuild Section Torque Point Chart (Wellplan)	50
Fig.4.26	Tangent Section Torque Point Chart (Wellplan)	51
Fig.4.27	2nd Build Section Torque Point Chart (Wellplan)	51

List of Table

No	Table	page
Table.2.1	Ranges for Friction Factors for Different Fluid Types and Hole Conditions (Samuel, 2010)	15

Nomenclature:

MD	Measured Depth
TVD	True Vertical Depth
TD	Total Depth
T&D	Torque and Drag
BHA	Bottom Hole Assembly
DLS	Dog Leg Severity
WOB	Weight on Bit
KOP	Kick off point
RIH	Running In Hole
POOH	Pulling Out Of Hole
WBM	Water Based Mud
HWDP	Heavy Weight Drill Pipe
ROP	Rate of Penetration
RPM	Revolution per Minute
DDR	Drilling daily report
ERD	Extended Reach Drilling
RSS	Rotary Steerable System
TDA	Torque Drag analysis
ID	inside dimeter
DC	Drill collar
HWDP	Heavy weight drill pipe
API	American petroleum institute

Chapter one

Introduction

1.1 Horizontal Drilling:

Horizontal drilling is a drilling process in which the well is turned horizontally at depth. It is normally used to extract energy from a source that itself runs horizontally such as a layer of shale rock. Horizontal drilling is a common was of extracting gas from the Marcellus Shale Formation.

Since the horizontal section of a well is at great depth, it must include a vertical part as well thus, a horizontal well resembles and exaggerated letter "J." When examining the differences between vertical wells and horizontal wells, it is easy to see that a horizontal well is able to reach a much wider area of rock and the natural gas that is trapped within the rock. Thus, a drilling company using the horizontal technique can reach more energy with fewer wells.

Horizontal wells are typically kicked off from the vertical near the surface and built to an angle of inclination that allows sufficient horizontal displacement from the surface to the desired target.

1.2 Definition of Horizontal well:

Horizontal wells can be defined as extension of highly deviated wells drilled in order to increase the length of the completion zone through the reservoir, with borehole inclination approaching 90° from vertical.

In general, horizontal wells are drilled parallel to reservoir bedding plane. If the reservoir bedding plane is vertical, then a conventional vertical well, in a true sense, will be a horizontal well.

Application of horizontal well:

- Production from a single well.
- Reduction in water/gas coning.
- Intersection of vertical fractures.
- Enhanced oil recovery.
- Reducing the number of wells and platforms required to develop an offshore field.

Most of the horizontal wells have significantly accelerated production, while some of them have recovered reserves which otherwise would have been difficult to recover.

There is a misconception in some quarters within the industry that horizontal wells were introduced during the mid to late 1980's. In fact as the list below shows horizontal drilling dates back to 1950's (Rabia, Well Engineering and Construction).

1950's Russians drilled 43 horizontal wells
1978's Esso, modern horizontal, Alberta
1979's Arco drilled to overcome high gas conning
1979-1983's ELF test 3 onshore horizontals, ELF and agip drilled first offshore horizontal (Ropso Mane, Adriatic)
1986's 50 horizontals worldwide
1987-1988's Number of horizontals increased dramatically
1989's 265 horizontals drilled worldwide
1990's 1000 horizontals drilled
1991's First Australian horizontal drilled
1992's Over 2500 horizontals drilled worldwide
1993-2000' Horizontal wells became routine wells

1.3 Types of Horizontal Wells:

There are three types of horizontal wells:

- Short radius
- Medium radius
- Long radius

Short Radius:

The main feature of this type is the very high build up rate usually 60-150 degrees/100 ft with a radius range of 40-100 ft. This type requires a specialized articulated motor to affect the high build angles.

Advantages:

- Enable sharp turns into this reservoir.
- Both motor driven and drill pipe driven.
- Laterals can be completed and tied back using special liners.

Disadvantages:

- Limited extension possible record 1200 ft.
- Poor directional control.
- Special tools and equipments required.

Medium Radius:

The buildup rate for this type is usually 8-30 degrees/100 ft with a radius range of 200-700 ft. The horizontal drain is usually between 1000 -3500 ft.

The typical well profile consists of build-tangent section and build-horizontal section. Two different BHA's will therefore be required for this type of well. An angle hold assembly should be used to drill the horizontal section.

Long Radius:

This is the most common type of horizontal wells especially offshore. The buildup rate is usually from 2-6 degrees/100 ft. The most common BHA used is steerable system. Two common profiles are in use:

- A single buildup section terminating in the horizontal section.
- A build-tangent and then a higher build lateral section.

Fig.1.1 shows the horizontal well types.

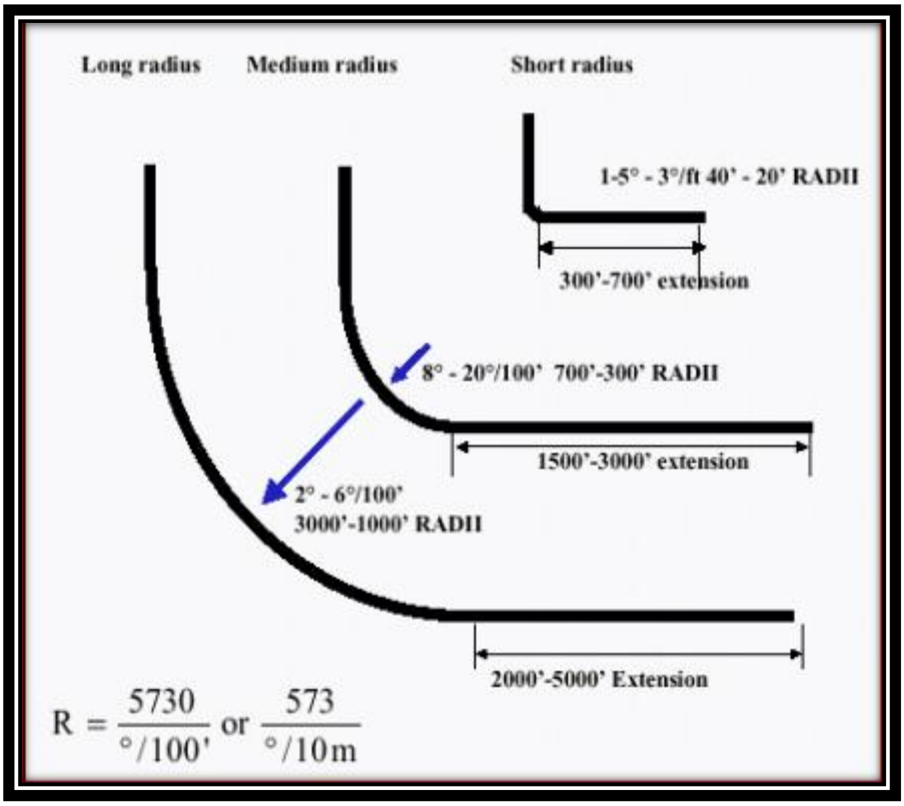


Fig.1.1: Horizontal Well Types (Rabia, Well Engineering and Construction)

1.4 The difference between Vertical, Horizontal and Multilateral Wells:

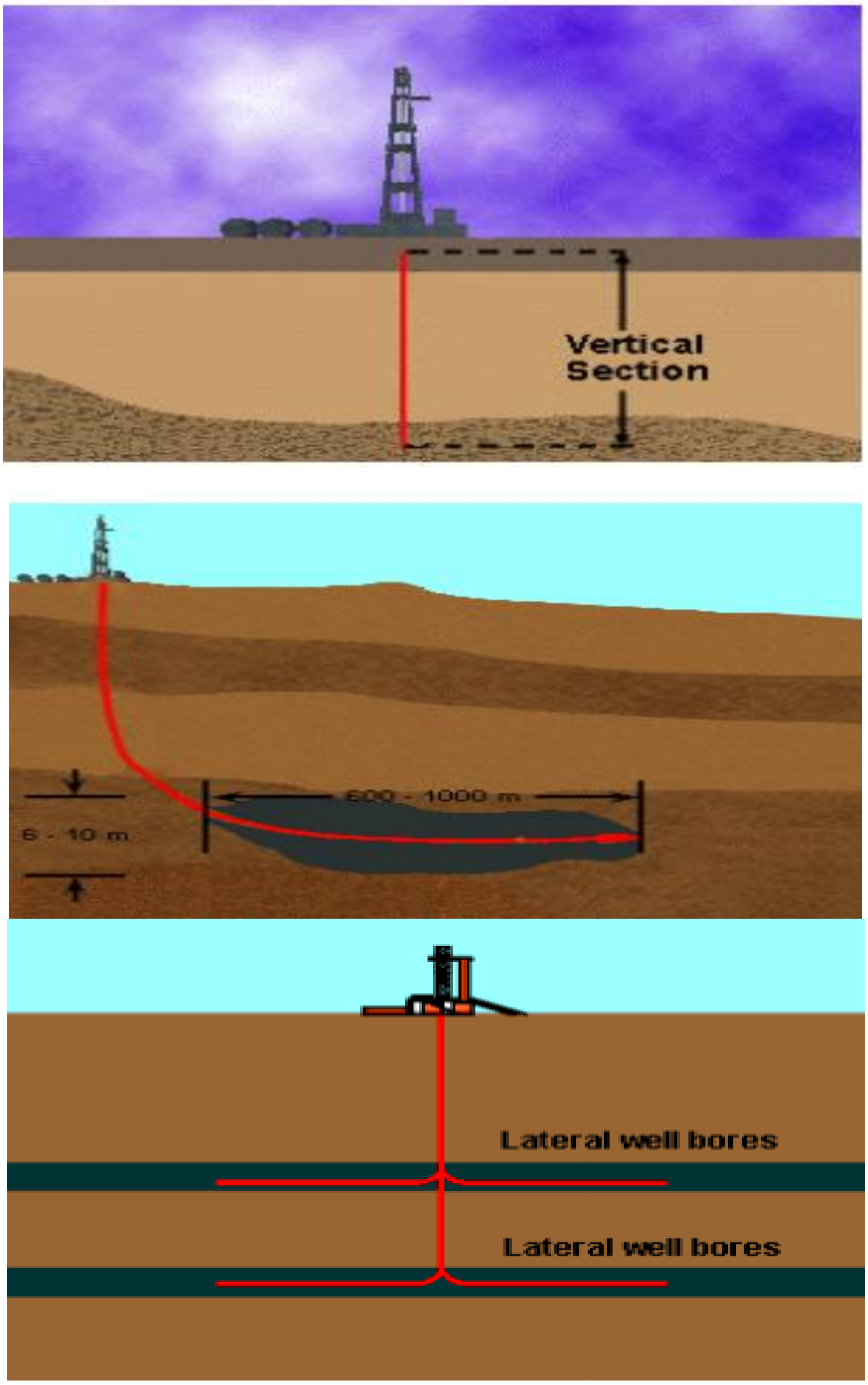


Fig. 1.2: The Difference between Vertical, Horizontal and Multilateral Drilling.
(Introduction to DD: Steinar Bakke and Jun Dauday 10/20/98).

In Fig. 1.2 above, the first picture represents a vertically drilled well, the second one represents a horizontally drilled well and the third one represents multilateral drilled well.

1.5 Statement of the Problem:

Since excessive torque and drag, T&D, can be critical limitation in horizontal drilling, T&D modelling is regarded as an invaluable process to assist in well planning to predict and prevent drilling operation.

T&D analysis is critical when well planning especially in horizontal wells. One of the important parts of predicting T&D is determining the correct friction factor. Friction factor combines all unknown factors that are un-measurable in the wellbore in drilling condition. Such as the uncertainty of the hole geometry (Dogleg Severity and Trajectory) , pipe stiffness, cutting beds, mud lubricity, pipe weight errors, Mechanical Equipment, and other interactions.

This project will analyze the drillability of horizontal well due to impact or effect of T&D.

1.6 Objective of the Study:

The general objective of this project is to facilitate understanding of T&D and determining the factors affect T&D in addition to explain the T&D analysis process and take a review on the previous work.

The specific objective of this study is to analyze the drill ability of horizontal well due to impact of T&D. The well taken as a case study is a horizontal well located in field (B).

Chapter Two

Literature Review and Theoretical Background

2.1 Literature Review:

Little horizontal drilling occurred until the early 1980's by which time improved down hole drilling motors and the invention of other necessary supporting equipment, materials, and technologies, particularly down hole telemetry equipment, had brought some kinds of applications within the imaginable realm of commercial viability. Tests indicating that commercial horizontal drilling success could be achieved in more than isolated instances were carried out between 1980 and 1983 by the French firm Elf Aquitaine in four horizontal wells drilled in three European fields. These included the Rospo Mare offshore oil field located Italy in the Mediterranean Sea where the output was very considerably enhanced.

Early horizontal production well drilling was subsequently undertaken by British Petroleum in Alaska's Prudhoe Bay Field, in a successful attempt to minimize unwanted water and gas intrusions. Horizontal drilling has since been undertaken with increasing frequency by many more operators.

In 1990, worldwide, more than 1000 horizontal wells were drilled. Market penetration of the new technology has had a noticeable impact on the drilling market and on the production of crude oil in certain regions.

As the horizontal drilling getting popular, Excessive T&D have been a critical limitation to the success of horizontal well which lead to therefore, modelling or prediction of T&D. T&D modeling has been originally started with Johancsik et al. (1984) and later put in a standard differential form by Sheppard et al. (1987). Because of the simplicity and being user friendly, it has been extensively used in the field and industry applications.

2.1.1 Soft String Model:

Most common T&D software programs available are variations of the soft string model developed by Johancsik et al. A soft string model assumes that the entire drill string lies against the wellbore, Fig.2.1, and the stiffness of the drill string is not accounted for. The drill string is modeled as a cable that is divided up into small elements, Fig.2.1 below that only carry axial loads and torque; contact forces are supported by the wellbore. The forces on the elements consist of tension, compression, and torsion that cumulatively build from the bottom of the string to the surface. In other words, T&D are calculated by assuming the segments of the T&D generated from bottom of the string to the surface.Johancsik assumed both T&D to be caused entirely by sliding friction forces that result from contact of the drill string with the wellbore.

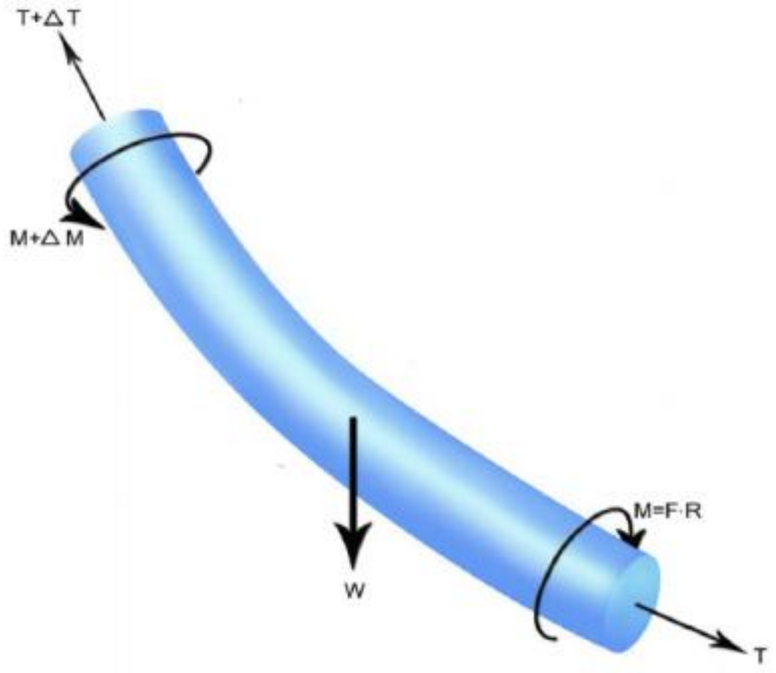


Fig.2.1: Short Element in a String (McCormick, Melissa and Chiu, 2011).

2.1.2 Stiff String Model:

Stiff string T&D models have also been developed. One major distinction between the soft string model and the stiff string model is that instead of treating the pipe as small elements of a cable, it accounts for the actual stiffness of the string.

The stiff string model takes into consideration the bending moment in the tubular and radial clearance in the wellbore. Stiff string models are most beneficial when wells that have high tortuous trajectories, high dogleg severity, or stiff tubular. The stiff string model is more complex compared to the soft string model because of the additional inputs and calculations needed to account for various bending forces.

Later Sheppard et al. (1987) put the Johancsik’s model into standard differential form and also took the mud pressure into account that acts upward when the drill string is running inside hole. Maidla and Wojtanowicz (1987) presented a method to evaluate an overall friction coefficient between the wellbore and the casing string. The computation is based on matching field data and modeling by assuming a friction coefficient.

Ho (1988) improved Johancsik soft-string model into somehow stiff-string and showed that for most parts of the drill string the stiffness effect like drill pipe, heavy-wall drill pipe is minor and for drill collars is major and has to be taken into account. Rae et al. (2005) used T&D simulator to firstly plan a drilling well and then use it to calculate the hook load and torque at the surface with the model has been used for planning and then comparing the values with field surface hook load and torque data. Kaarstad and Aadnoy (2009) also studied experimental investigation of friction factor dependence on temperature and they observed an increase in friction coefficient with temperature and a temperature dependent friction coefficient model was presented.

2.2 Torque and Drag Basic Theory:

2.2.1 Torque:

Torque is defined as the turning force that is applied to a shaft or other rotary mechanism to cause it to rotate or tend to do so, and it is measured in units of length and force. It is units depend on the unit system used, in metric system it has a unit of Newton per meter (N.m). While in imperial system, it has a unit of pound force per foot (lbf-ft) (Bakke, 2012).In drilling, torque is the force or moment used to rotate the drill string, and therefore the bit, around it is axis. The torque is generated by the top drive and is used to overcome the frictional forces opposing rotation of the drill string and bit.

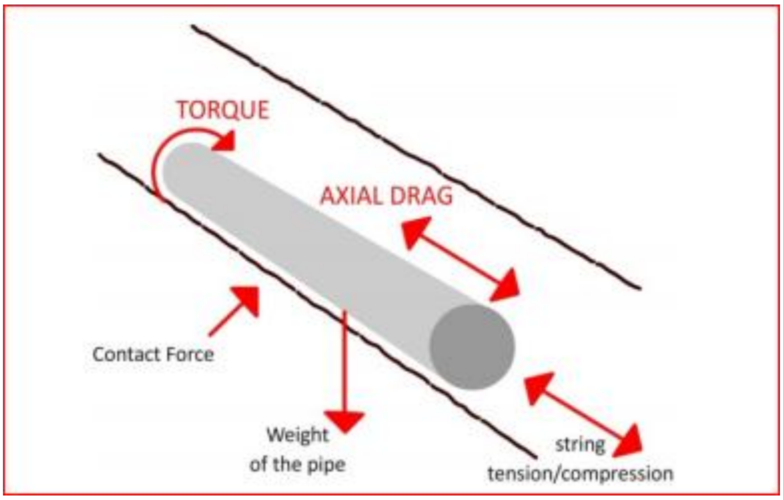


Fig. 2.2: Wellbore and Drill string Forces (Raksagati, 2008).

T&D is an important analysis in planning a well, but in a vertical well “theoretically” there is no T&D force occur because the pipe is only hanged in the well and no interactions between the wellbore and string. So what appears is only the torque on bit and compression/tension of the string.

But in a non vertical wellbore the contact between the string and wellbore occurs, because of that additional forces to the string is detected. The forces are T&D. Fig.2.2 is the picture of the forces that occurs in the wellbore.

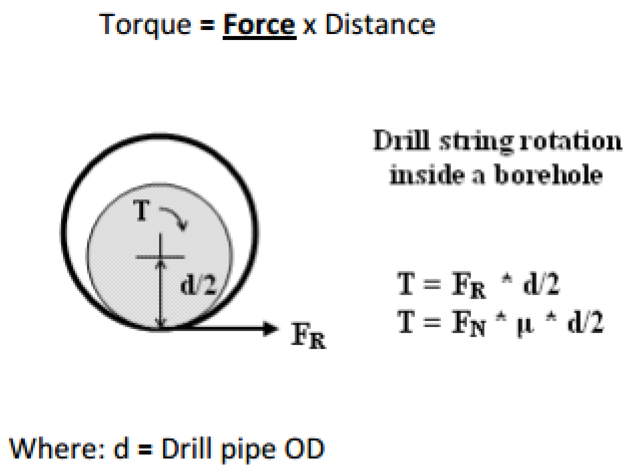


Fig. 2.3: Diagrammatic Representation of Torque Generating Forces (Agbaji, 2009).

As mentioned before torque only occurs when the drill string has a point contact with the wellbore and is being rotated. Torque analysis is important regarding the drill limitation we have such as the rig torque limit (rotating system), rig capacity and the string fatigue limits. The source of the rotational force can be caused by friction, mechanical torque and the rotation of the bit. Frictional Torque occurs when the string rotates and the force will occur in contact areas between the string and wellbore. Frictional Torque will be detected when there is no axial movement, rotating off bottom in a perfectly clean hole. The frictional Torque is affected by the following:

- Compression/tension in the drills tring: Tension can occur and force the string towards the wellbore even harder than gravity force. This will increase the contact force between the string and the wellbore.
- Dogleg severity: A diverse change of dogleg severity will result in an increase of contact area, and if
  tension occurs contact force will also increase.
- Hole and pipe size: The difference between the inner diameter of the hole and outer diameter of the string results a clearance, the smaller clearance occurs the more contact force and contact area will occur.
- String effective weight: The string effective weight will affect the normal force (force of the string to the wall) therefore will affect the contact force.
- Inclination: The effect of inclination is similar with dogleg but not also the same. The higher
  inclination occurs the contact force will increase. But at high inclination, the string tends to rest in the hole, therefore the tension will decrease and the contact forces will decrease.
- Lubricity of the mud will affect the friction caused by the string and hole contact.
  Mechanical torque occurs by the contact of the drill string with cutting beds or unstable formation.
  Bit Torque is the result of an additional torque needed when the bit is rotated to drill the formation.

2.2.2 Drag:

Drag is a resistance force to the motion of an object and it acts in the opposite direction of its axial movement. It is as a force that resists motion along a straight path. In drilling, Drag is explained as the incremental force needed to pull or lower the drill string through the borehole, or it can also be defined as the friction forces that oppose sliding the drill string into the hole. It is units depend on the unit system used, in metric system it has a unit of Newton (N). While in imperial system, it has a unit of pound force (lbf) (Bakke, 2012).

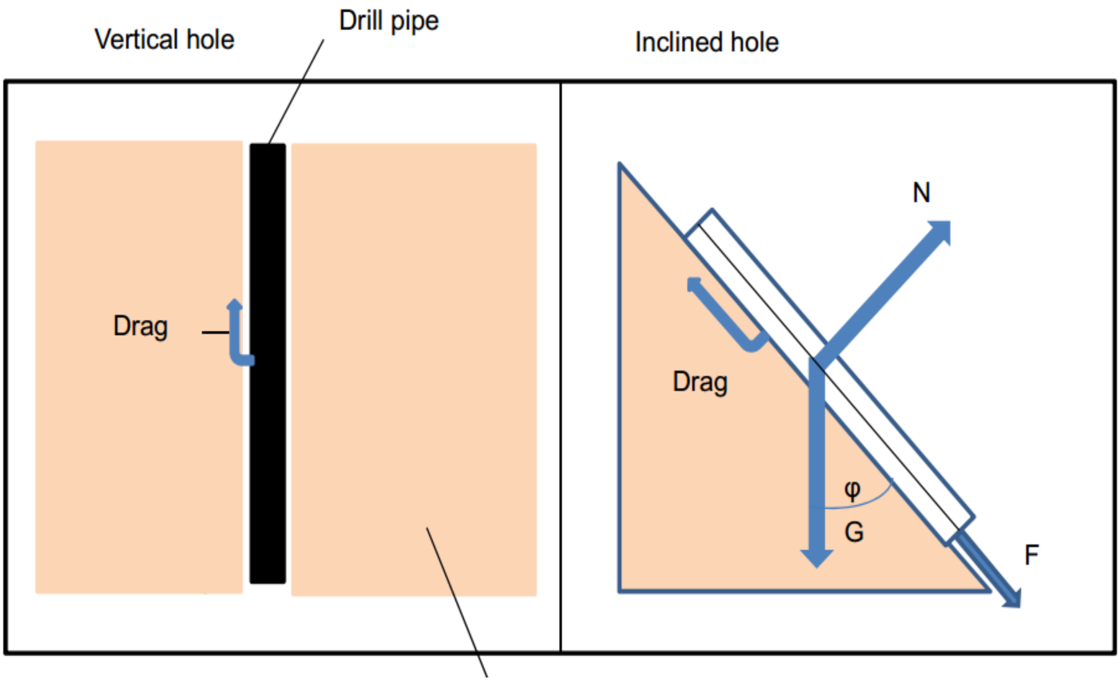


Fig.2.4: Drag in Vertical and Inclined Hole (Borinb, 2012).

In vertical well drilling ideally there will be no drag force occur. But as the inclination of the well increases contact force between the string and the hole will occur and drag will be detected. Drag appears when the string is manipulated in the axial direction and no rotation is applied. Like in ordinary physics drag force will appear like and additional force but in a direction opposite the drill string movement. The magnitude of drag is dependent with the friction factor which embraces the uncertainties in the wellbore. Drag analysis is important in well design, in order to prepare rig capacities, prime mover to manipulate the string and to calculate the weight on bit resultant with the effect of drag. Drag can reduce the drilling efficiency when transferring the weight to the bit. Sinusoidal and Helical Buckling could occur when tripping in compression axial force exceeds the critical sinusoidal or helical buckling load. This could end in pipe sticking.

2.2.3 Friction factor:

In simple physics, the coefficient of friction is a dimensionless scalar value which describes the ratio between the forces of friction between two bodies and two forces when interacting.

The resulting force acts in the opposite way as from the movement of the object. The higher the friction factor the more force resists the object to move. Here below in fig.2.5 is a simple illustration of a simple effect of friction force.

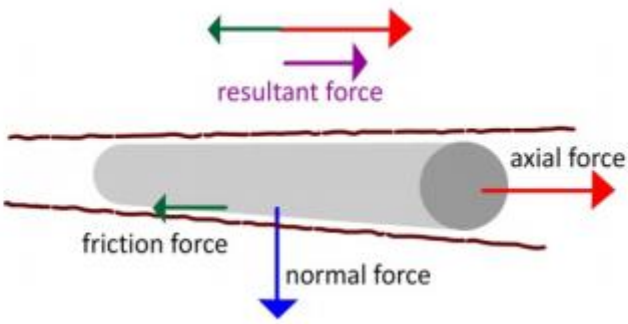


Fig.2.5: Simple Effect of Friction Force (Raksagati, 2008).

Friction factor in drilling activities is much more complicated than the ordinary friction factor shown above. The friction factor in drilling covers the uncertainties in the wellbore so it can be exerted as a single dimensionless magnitude in calculations. There are many factors that could impact the friction factor in the drilling process beside the interaction between the drill strings, such as:

- Cutting bed
- Dogleg severity and well trajectory
- Mechanical equipments (BHA, stabilizer, OD tool joint, etc)
- Mud lubricity
- Pipe stiffness effects
- Viscous drag

Here below in fig.2.6 is the illustration of the factors that impact the magnitude of friction factor.

Friction factor could also be different even in the same wellbore with the same conditions. Different types of manipulation of the string exerts different friction factor, example when Pull out of the hole, POOH, run in the hole, RIH, and rotation occurs at the drill string. This must be a concern in T&D analysis.

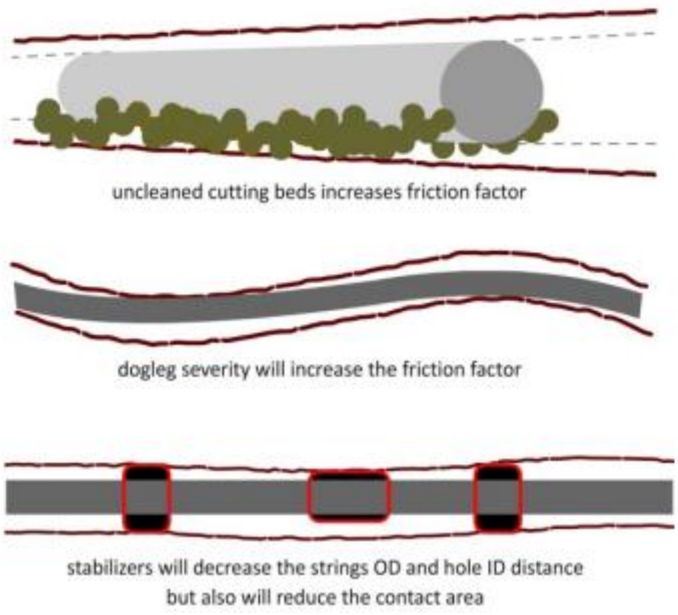


Fig.2.6: Illustration of Factors that Impact the Friction Factor (Raksagati, 2008).

The friction factor plays a more significant role in horizontal well compared to a vertical well. Fig.2.5 illustrates this, where the drill string is forced against the side of the horizontal well, and in that way the friction becomes an important source of wear and energy losses in the tubular system. The drill strings is in general placed centrally in the borehole in a vertical hole, leading to negligible contact between the drill string and the borehole wall, and consequently zero T&D.

The middle sketch in Fig.2.7 shows that during a build section the drill string is pressed against the top side of the borehole wall and is in tension or compression, leading to varying degree of T&D forces. The right picture in Fig.2.7 presents a tangential section of the hole where the entire drill string is in contact with the low side of the borehole wall, and can be in some tension or compression (Aadnoy et al. 2010; Xie et al. 2012; Bennetzen et al. 2010).

Friction factor differ as the mud used to drill the hole differ, table.2.1, and it's generally can be calculated using the following equation:

$$\mu = \frac{F_F}{F_N} \longrightarrow (1)$$

Where:

F_F = Net friction force acting on the element, lbf [N]

F_N = Net normal force acting on the element, lbf [N]

μ = sliding friction coefficient between drillstring and wellbore

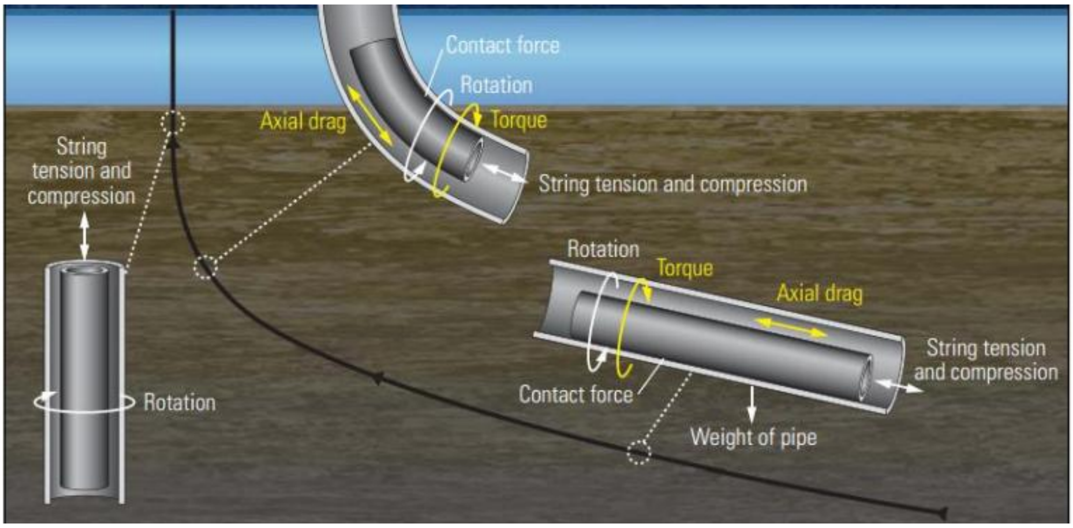


Fig.2.7: Side Forces on the String in Wellbore Orientations (Bennetzen et al. 2010).

Table.2.1: Ranges for Friction Factors for Different Fluid Types and hole Conditions (Samuel, 2010).

Fluid Type	Friction Factor	
	Cased hole	Open hole
Oil-based	0.16-0.20	0.17-0.25
Water-based	0.25-0.35	0.25-0.40
Brine	0.30-0.4	0.3-0.4
Polymer-based	0.15-0.22	0.2-0.3
Synthetic-based	0.12-0.18	0.15-0.25
Foam	0.30-0.4	0.35-0.55
Air	0.35-0.55	0.40-0.60

2.2.4 Weight:

The weight of the drill pipe is extremely important for T&D. The weight depends on the material density of the pipe and pipe wall thickness. To calculate mass of a pipe the equation below is used:

$$M = \rho_{pipe} * V \longrightarrow \quad (2)$$

Where:

$M =$ Mass of pipe

$\rho =$ Density of pipe

$V = \text{Volume of pipe material}$

Nominal weight in lb/ft is often used in tables and is calculated from this equation:

$$m = \rho\pi(r_o - r_i) \longrightarrow (3)$$

Weight including tool joints is calculated from the following equation:

$$M = \rho_{pipe}\pi(r_o^2 - r_i^2)(l_{pipe} - l_{tj}) + M_M + M_F \longrightarrow (4)$$

Where:

$r_o = \text{Pipe outer radius}$

$r_i = \text{Pipe inner radius}$

$l_{pipe} = \text{length of pipe}$

$l_{tj} = \text{length of tool joint}$

$M_M = \text{Mass of male tool joint}$

$M_F = \text{Mass of female tool joint}$

After the pipe weight is calculated. Then, it is used to calculate the borehole normal force on the pipe from the equation below:

$$F_N = M\, g \sin\alpha \longrightarrow (5)$$

Where:

$g = \text{gravity constant}$

$\alpha = \text{borehole inclination}$

The normal force is then used to calculate friction force by multiplying it with the friction factor from the equation below:

$$F_F = F_N * \mu \longrightarrow (6)$$

The friction force is the major constituent of T&D. Any reduction of friction force will therefore give a direct reduction in T&D forces. Materials like aluminum and titanium have lower density than steel, and the normal force will be smaller for these materials than the alternative steel equivalent (Borinb, 2012)

2.2.5 Buoyancy:

For drill pipes, the buoyancy equals the weight of the mud that the drill pipe displaces. The submerged weight of a wellbore tubular can be obtained by multiplying the weight in air with a buoyancy factor:

$$\beta = \frac{\text{Suspended weight in mud}}{\text{Weight in air}} \longrightarrow (7)$$

Where:

β = buoyancy factor

And it is given by the following equation:

$$\beta = 1 - \frac{\rho_{fluid}}{\rho_{pipe}} \longrightarrow (8)$$

ρ_{fluid} = density of fluid the pipe is submerged in

The above equation is only valid if the mud inside and outside the drill pipe has the same density. This is not always the case, and for operations that involve different density fluid inside and outside the wellbore tubular, such as cementing operations and displacement of mud, the following formula must be used:

$$\beta = 1 - \frac{\rho_{mo} r^2 - \rho_{mi} r^2}{\rho_{pipe}(r_o^2 - r_i^2)} \longrightarrow (9)$$

Where:

ρ_{mo} = density of mud outside the pipe

ρ_{mi} = density of mud inside the pipe

Using a mud with high density will give more buoyancy than using a less dense mud, and therefore influence T&D simulations. The opposite is true for the drill string, using a less dense material will reduce T&D (Borinb, 2012).

2.3 Torque and Drag Modelling:

The T&D model is based on a simple mathematical model. This model assumes that the load on the drill string is only dependent to the effects of gravity and frictional drag mentioned before as friction factor. The force that indicates the magnitude of interaction between the string and the hole is the normal force. Normal force in this model is contributed by (Raksagati, 2008):

- effects of gravity
- effects of compression and tension in the wellbore curvatures

2.3.1 Torque and Drag equations:

To estimate and calculate the T&D, nowadays engineers use computer models, in this project computing T&D is used with the Landmark-Wellplan 2000 PC based software.

But before proceeding with the modeling understanding the basic physics equations is needed to know the basics.
The T&D model is based on a simple mathematical model, first developed by the Exxon Production Research (Johancsik et al., 1984). This assumes that the load on the drill string is only dependent to the effects of gravity and frictional drag mentioned before as friction factor.

The force that indicates the magnitude of interaction between the string and the hole is the normal force. As mentioned, normal force in this model is contributed by effects of gravity and effects of compression and tension in the wellbore curvatures. Here in fig.2.8 is a simple free body diagram of the string with the wellbore.

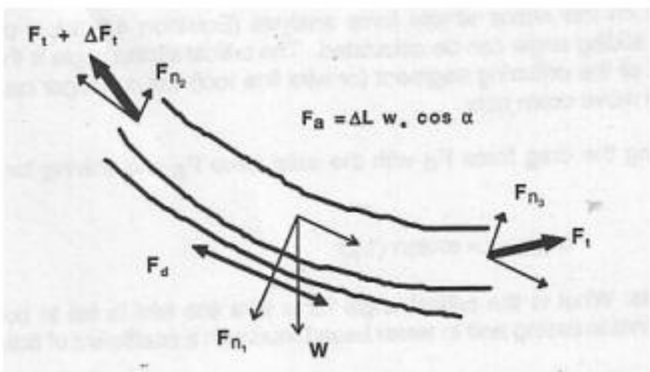


Fig.2.8: Drill string Free Body Diagram (Raksagati, 2008).

Researchers derivate it into equations that could calculate T&D, These equations are listed below as following:

$$F_N = [(F_t \Delta\theta \sin\alpha)^2 + (F_t \Delta\alpha + W_e \sin\alpha)^2]^{0.5} \longrightarrow (10)$$

$$\Delta F_t = W_e \cos\alpha \pm \mu F_N \longrightarrow (11)$$

In the above equation the plus sign is used in case of tension, while the minus sign is used in case of compression.

$$\Delta T = \mu F_N r \longrightarrow (12)$$

$$F_t = F_t + \Delta F_t \longrightarrow (13)$$

$$T = T + \Delta T \longrightarrow (14)$$

Where:

F_N = Net normal force acting on the element, lbf [N]

F_t = Axial tension force acting at the lower end of the element, lbf [N]

ΔF_t = Increase in tension over the length of element, lbf [N]

T = Torsion at the lower end of the element, ft − lbf [Nm]

ΔT = Increase in tension over the length of the element, ft − lbf [Nm]

μ = sliding friction coefficient between drillstring and wellbore

r = characteristic radius of drillstring element, ft [m]

α = Average wellbore inclination, degrees [rad]

W_e = buoyed weight of drillstring elemen, lbf [N]

θ = Azimuth angle at lower end of drillstring element, degrees [rad]

$\Delta\theta$ = increase in azimuth angle over length of element, degrees[rad]

$\propto$= inclination angle at lower end of drillstring element, degrees [rad]

$\Delta\alpha$ = increase in inclination angle over length of element, degrees [rad]

The calculation is not too complicated but to simulate the real condition the calculation is divided in segments regarding the different condition in the drill string and wellbore. Starting from the bottom of the string until the top (rig), and accumulate that to obtain the total load and torsion. This process nowadays is easier when computer software simulation take place.

2.3.2 Benefits of Torque and Drag Modelling:

T&D analysis have an essential part in drilling design. T&D analysis although often uses data from other field and with many uncertainties is nearly always conducted, this is because there are benefits that can be obtained from this analysis, such as:

- To determine the drilliability of the well and improve the design
- To prepare rotating system rig capacity, the obtained surface torque data generated in the model could be a useful reference in determining it

- To prevent buckling limitation when drilling in well, if the axial force/tension/compression shown in the model exceeds the critical buckling force then the drill plan must be readjusted, and when its valid model can be a reference when drilling operation
- To prepare the rig capacity when maximum hook load from model is known and plus a certain of safety factor and margin over pull
- To know the magnitude of torque on bit
- To prepare the block weight and string configuration needed
- To be an additional data in casing and completion design.

Chapter Three

Methodology

As mentioned earlier, T&D modelling in this project is performed on a horizontal well located in field (B) using Landmark-Wellplan software. The modelling process is performed to each of the horizontal well sections individually but before proceeding with the inputs and the modelling process, a review on the Landmark-Wellplan software is required to know the software basics.

3.1 Landmark-Wellplan:

Wellplan is a component of Landmark software developed by Halliburton. Wellplan software is able to solve number of technical challenges such as Extended Reach Drilling, ERD, slim hole drilling, deep water drilling, and environmentally sensitive drilling areas. Wellplan software can be used at the rig site and in the office to provide integration between engineering functions. It is used during the design and operational phases for drilling and well completion. This software allows the user to identify potential problems during the drilling and completion process in terms of wellbore design. Integrated technologies enable the user to study and evaluate BHA, T&D, stuck pipe, cementing, hydraulics and well kick scenarios.

For this particular project, the main focus will be on the T&D module. Wellplan T&D Analysis software provides knowledge of anticipated loads for drilling and casing operations. It can be applied to diagnose the measured weights and torques that can be expected during:

- Tripping in
- Tripping out
- Rotating on bottom
- Rotating off bottom
- Sliding drilling
- Back reaming

In this project T&D modelling will be performed only on the following conditions:

- Tripping in
- Tripping out
- Rotating on bottom
- Rotating off bottom

Based on the simulation results, engineers are able to determine if the selected rig has good enough mechanical specifications to handle the well design requirements, also if the well can be drilled, or to evaluate what is occurring while drilling a well.

Landmark-Wellplan T&D analysis module uses the soft string model as it is commonly known. The work string is treated as an extendible cable with zero bending stiffness. For contact force analysis the string may be imagined as lying against the side of the wellbore although for calculation simplicity the centre line of the work string is assumed to follow the centre line of the wellbore. Friction is assumed to act in one direction, this being defined by the type of analysis; RIH, POOH, and rotating. Wellplan T&D model does not include wellbore cleaning aspects and assumes that all the cuttings are removed (Landmark Wellplan user manual, 2000).

3.2 Case Well Profile:

The well chosen as a case study for this project is a horizontal well located in field (B) The tested well is drilled using double curve profile which means the well profile consists of:

- First build section
- Tangent section
- Second build section

The well is drilled from surface vertically to 2361 ft MD where the inclination began to increase, first build section, till 3488 ft MD where the first build section end. From this point, 3488 ft MD, the tangent section, where the angle is held constant, began and continues till 3610 ft MD. The second build section starts at 3610 ft MD and continue to total depth, 6043 ft MD.

3.3 Torque and Drag Modelling:

To perform T&D modelling process using Landmark-Wellplan software properly, well data need to be entered to Landmark-Wellplan software. The next paragraph represents and explains the data need to be entered into Landmark-Wellplan software. It should be noted that there is general data need to be entered into the Landmark-Wellplan and can be used by all other modules on the software as general and data need to be entered into T&D module and can be used by each of the analysis modes inside the T&D module such as:

- Normal analysis
- Drag charts
- Calibrate coefficient of friction
- Top down analysis

As mentioned, the tested well profile is divided into three sections each of which will be analyzed individually, these are: first build section, tangent section, and second build section.

3.3.1 General Data:

General:

In this section inputting the general data from the well such as Origin N, E, Azimuth, well depth MD and reference point is inputted.

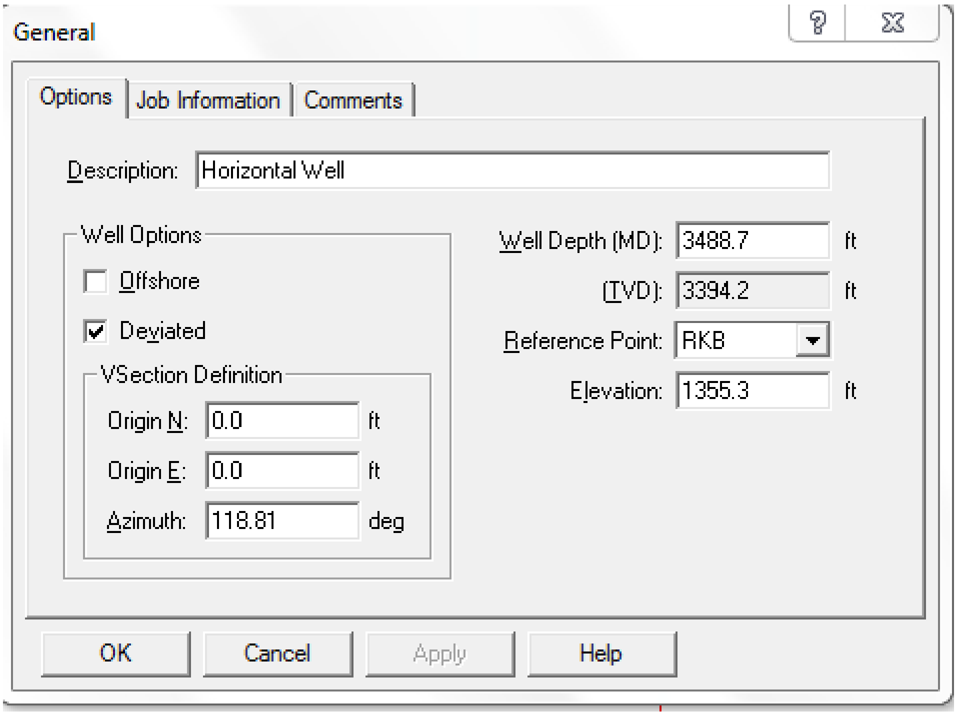


Fig.3.1: 1^{st} Build Section General Data (Wellplan).

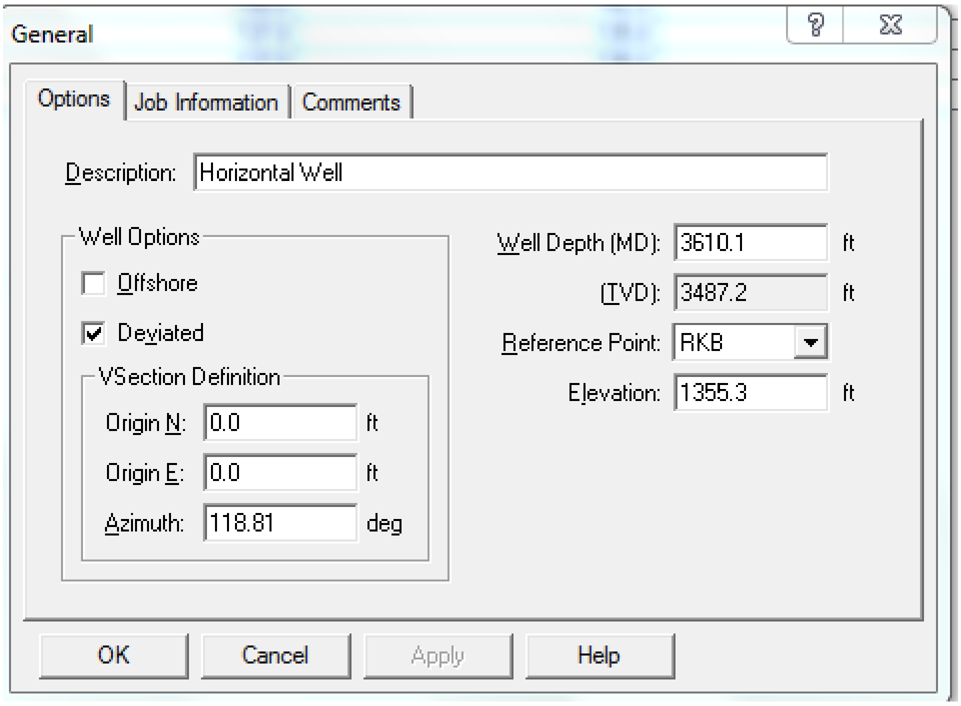


Fig.3.2: Tangent Section General Data (Wellplan).

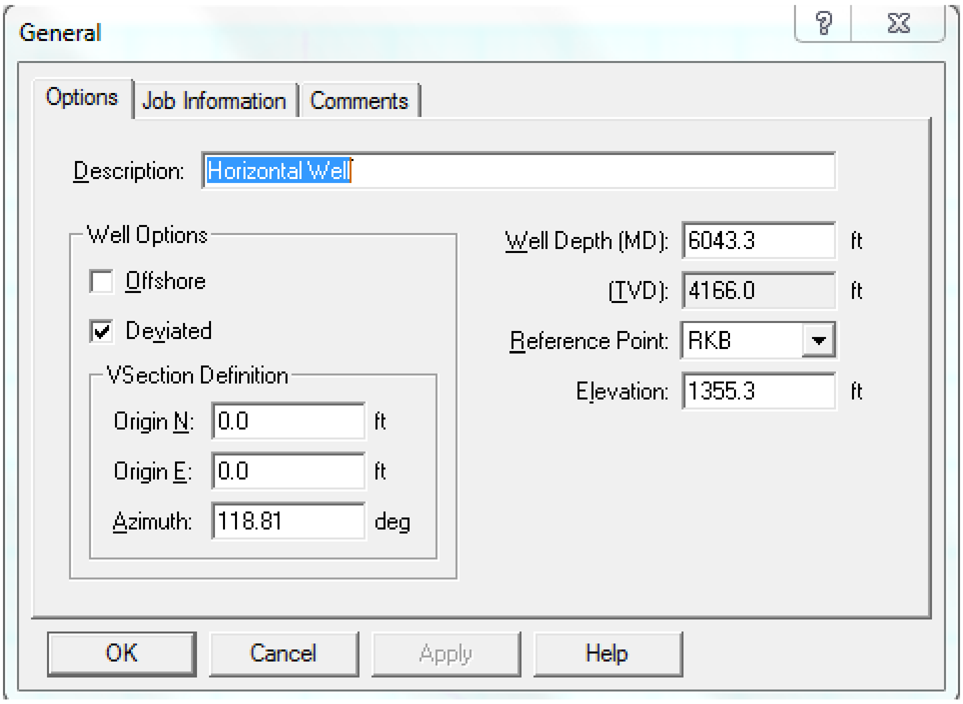
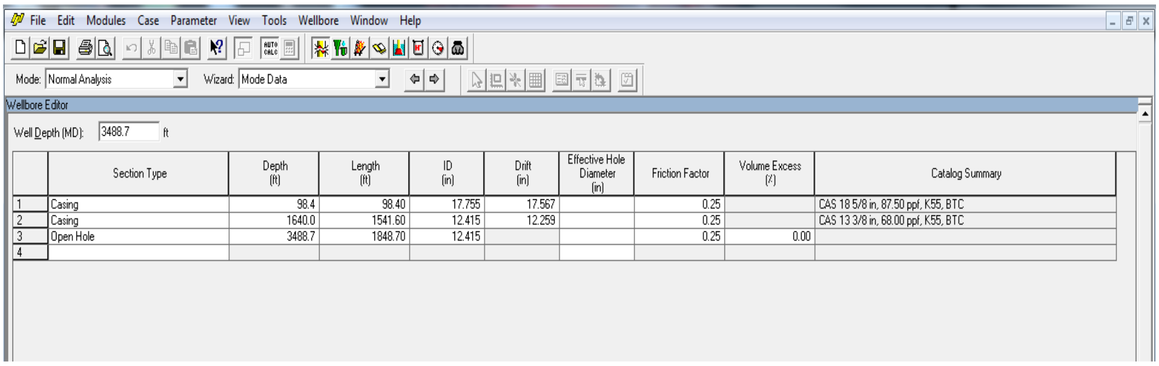


Fig.3.3: 2nd Build Section General Data (Wellplan).

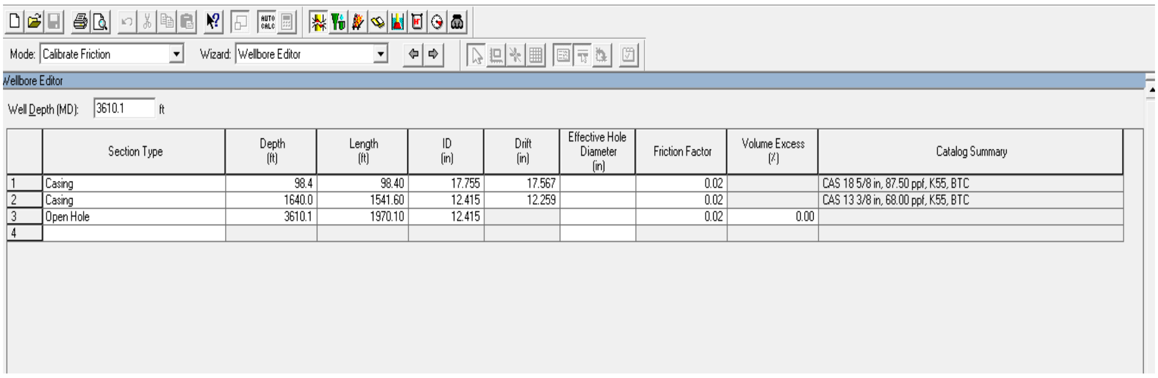
Wellbore editor:

Wellbore editor enables the user to input the wellbore information for casing and open hole such as Length, internal diameter (ID), and friction factor. The friction factor is assumed or could be matched later with the actual data. It should be noted that in this project the friction factor is matched with the available actual T&D data.



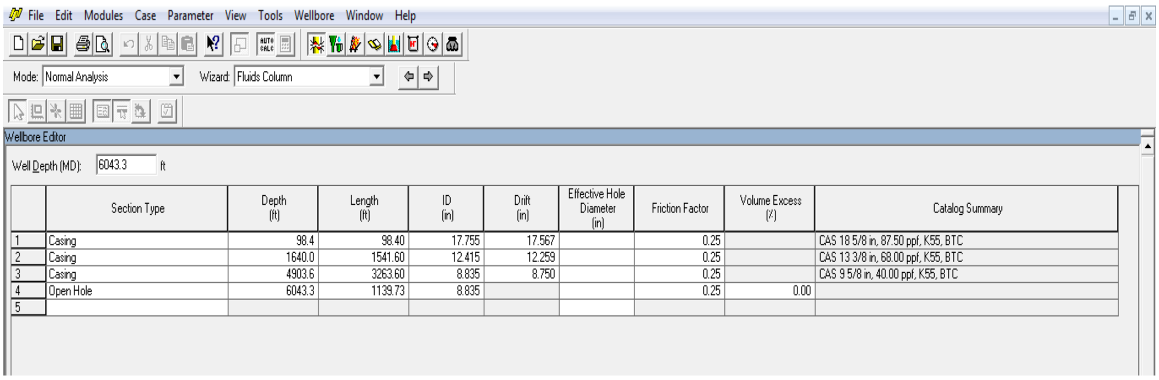
	Section Type	Depth (ft)	Length (ft)	ID (in)	Drift (in)	Effective Hole Diameter (in)	Friction Factor	Volume Excess (%)	Catalog Summary
1	Casing	98.4	98.40	17.755	17.567		0.25		CAS 18 5/8 in, 87.50 ppf, K55, BTC
2	Casing	1640.0	1541.60	12.415	12.259		0.25		CAS 13 3/8 in, 68.00 ppf, K55, BTC
3	Open Hole	3488.7	1848.70	12.415			0.25	0.00	
4									

Fig.3.4: 1st Build Section Wellbore Editor (Wellplan).



	Section Type	Depth (ft)	Length (ft)	ID (in)	Drift (in)	Effective Hole Diameter (in)	Friction Factor	Volume Excess (%)	Catalog Summary
1	Casing	98.4	98.40	17.755	17.567		0.02		CAS 18 5/8 in, 87.50 ppf, K55, BTC
2	Casing	1640.0	1541.60	12.415	12.259		0.02		CAS 13 3/8 in, 68.00 ppf, K55, BTC
3	Open Hole	3610.1	1970.10	12.415			0.02	0.00	
4									

Fig.3.5: Tangent Section Wellbore Editor (Wellplan).

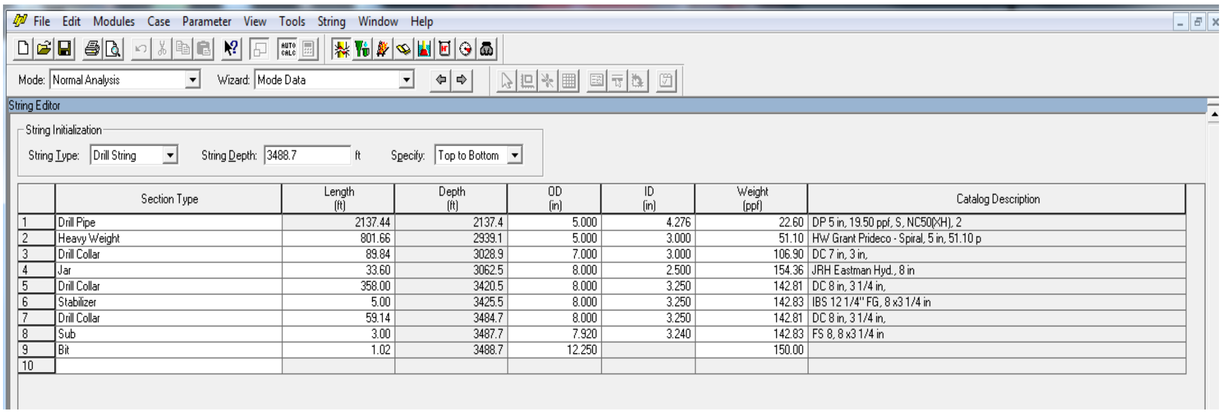


	Section Type	Depth (ft)	Length (ft)	ID (in)	Drift (in)	Effective Hole Diameter (in)	Friction Factor	Volume Excess (%)	Catalog Summary
1	Casing	98.4	98.40	17.755	17.567		0.25		CAS 18 5/8 in, 87.50 ppf, K55, BTC
2	Casing	1640.0	1541.60	12.415	12.259		0.25		CAS 13 3/8 in, 68.00 ppf, K55, BTC
3	Casing	4903.6	3263.60	8.835	8.750		0.25		CAS 9 5/8 in, 40.00 ppf, K55, BTC
4	Open Hole	6043.3	1139.73	8.835			0.25	0.00	
5									

Fig.3.6: 2nd Build Section Wellbore Editor (Wellplan).

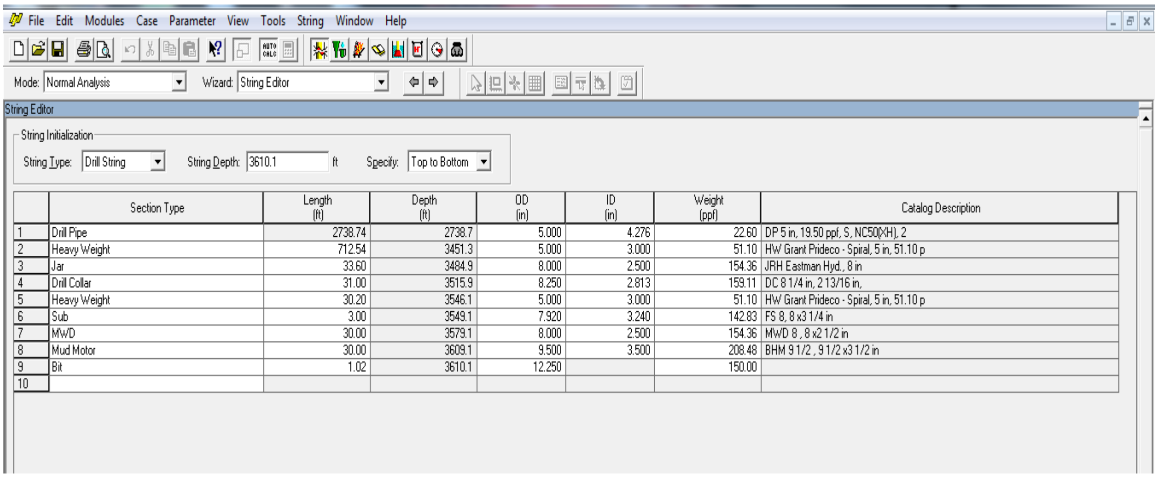
String editor:

String and BHA data can be inputted in the string editor. It includes the outer diameter, yield strength, torsional strength, weight, etc.



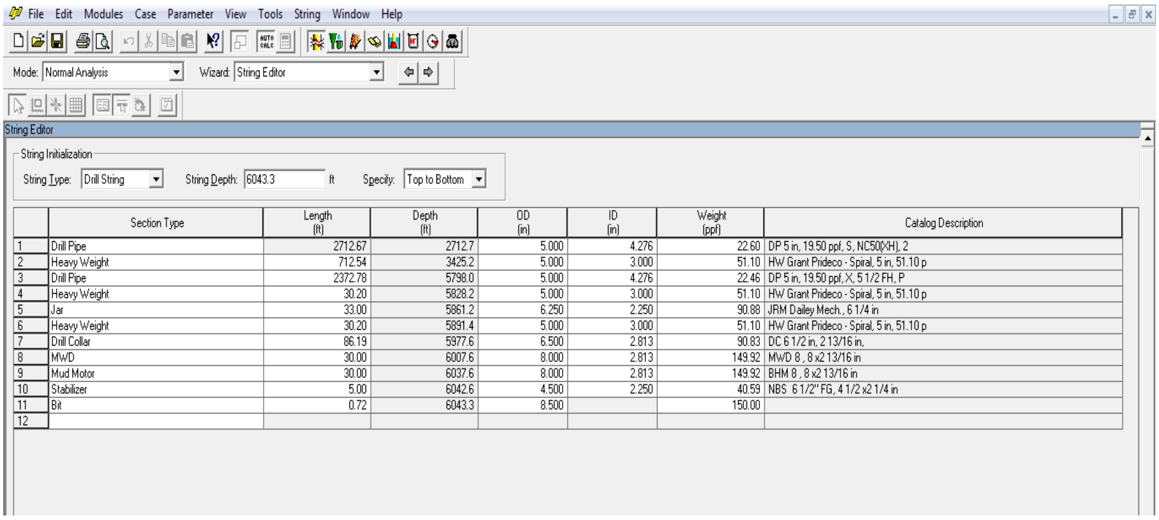
	Section Type	Length (ft)	Depth (ft)	OD (in)	ID (in)	Weight (ppf)	Catalog Description
1	Drill Pipe	2137.44	2137.4	5.000	4.276	22.60	DP 5 in, 19.50 ppf, S, NC50(XH), 2
2	Heavy Weight	801.66	2939.1	5.000	3.000	51.10	HW Grant Prideco - Spiral, 5 in, 51.10 p
3	Drill Collar	89.84	3028.9	7.000	3.000	106.90	DC 7 in, 3 in,
4	Jar	33.60	3062.5	8.000	2.500	154.36	JRH Eastman Hyd., 8 in
5	Drill Collar	358.00	3420.5	8.000	3.250	142.81	DC 8 in, 3 1/4 in,
6	Stabilizer	5.00	3425.5	8.000	3.250	142.83	IBS 12 1/4" FG, 8 x3 1/4 in
7	Drill Collar	59.14	3484.7	8.000	3.250	142.81	DC 8 in, 3 1/4 in,
8	Sub	3.00	3487.7	7.920	3.240	142.83	FS 8, 8 x3 1/4 in
9	Bit	1.02	3488.7	12.250		150.00	
10							

Fig.3.7: 1st Build Section String Editor (Wellplan).



	Section Type	Length (ft)	Depth (ft)	OD (in)	ID (in)	Weight (ppf)	Catalog Description
1	Drill Pipe	2738.74	2738.7	5.000	4.276	22.60	DP 5 in, 19.50 ppf, S, NC50(XH), 2
2	Heavy Weight	712.54	3451.3	5.000	3.000	51.10	HW Grant Prideco - Spiral, 5 in, 51.10 p
3	Jar	33.60	3484.9	8.000	2.500	154.36	JRH Eastman Hyd., 8 in
4	Drill Collar	31.00	3515.9	8.250	2.813	159.11	DC 8 1/4 in, 2 13/16 in,
5	Heavy Weight	30.20	3546.1	5.000	3.000	51.10	HW Grant Prideco - Spiral, 5 in, 51.10 p
6	Sub	3.00	3549.1	7.920	3.240	142.83	FS 8, 8 x3 1/4 in
7	MWD	30.00	3579.1	8.000	2.500	154.36	MWD 8 , 8 x2 1/2 in
8	Mud Motor	30.00	3609.1	9.500	3.500	208.48	BHM 9 1/2 , 9 1/2 x3 1/2 in
9	Bit	1.02	3610.1	12.250		150.00	
10							

Fig.3.8: Tangent Section String Editor (Wellplan).

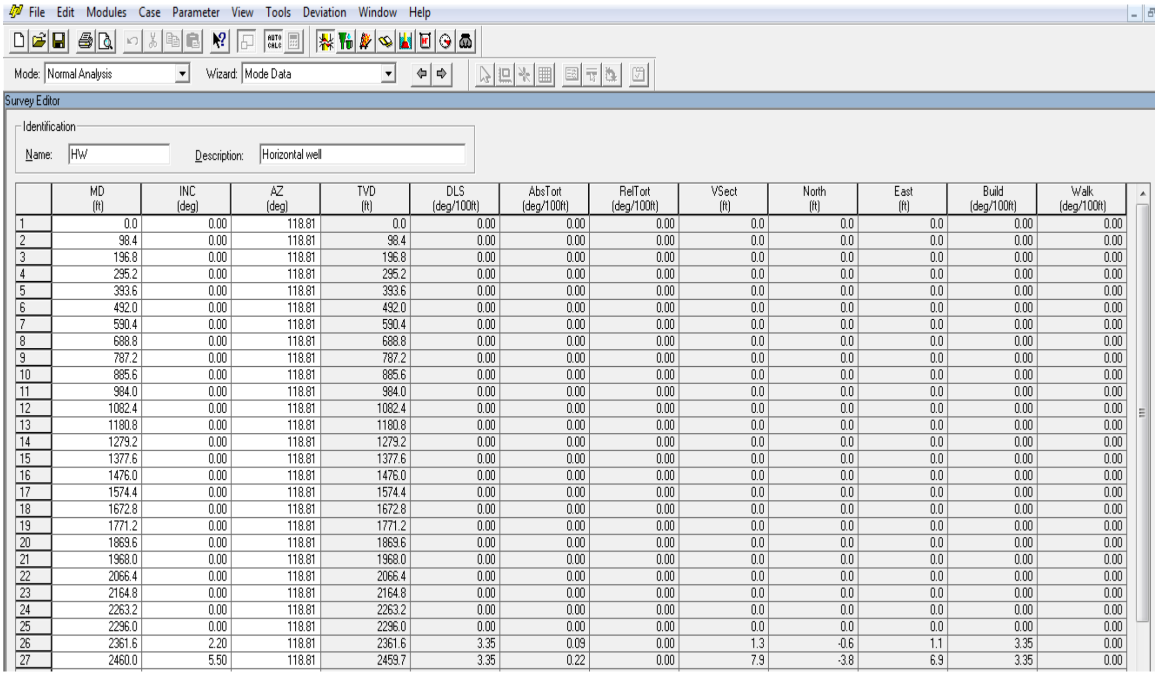


	Section Type	Length (ft)	Depth (ft)	OD (in)	ID (in)	Weight (ppf)	Catalog Description
1	Drill Pipe	2712.67	2712.7	5.000	4.276	22.60	DP 5 in, 19.50 ppf, S, NC50(XH), 2
2	Heavy Weight	712.54	3425.2	5.000	3.000	51.10	HW Grant Prideco - Spiral, 5 in, 51.10 p
3	Drill Pipe	2372.78	5798.0	5.000	4.276	22.46	DP 5 in, 19.50 ppf, X, 5 1/2 FH, P
4	Heavy Weight	30.20	5828.2	5.000	3.000	51.10	HW Grant Prideco - Spiral, 5 in, 51.10 p
5	Jar	33.00	5861.2	6.250	2.250	90.88	JRM Dailey Mech., 6 1/4 in
6	Heavy Weight	30.20	5891.4	5.000	3.000	51.10	HW Grant Prideco - Spiral, 5 in, 51.10 p
7	Drill Collar	86.19	5977.6	6.500	2.813	90.83	DC 6 1/2 in, 2 13/16 in,
8	MWD	30.00	6007.6	8.000	2.813	149.92	MWD 8 , 8 x2 13/16 in
9	Mud Motor	30.00	6037.6	8.000	2.813	149.92	BHM 8 , 8 x2 13/16 in
10	Stabilizer	5.00	6042.6	4.500	2.250	40.59	NBS 6 1/2" FG, 4 1/2 x2 1/4 in
11	Bit	0.72	6043.3	8.500		150.00	
12							

Fig.3.9: 2nd Build SectionString Editor (Wellplan).

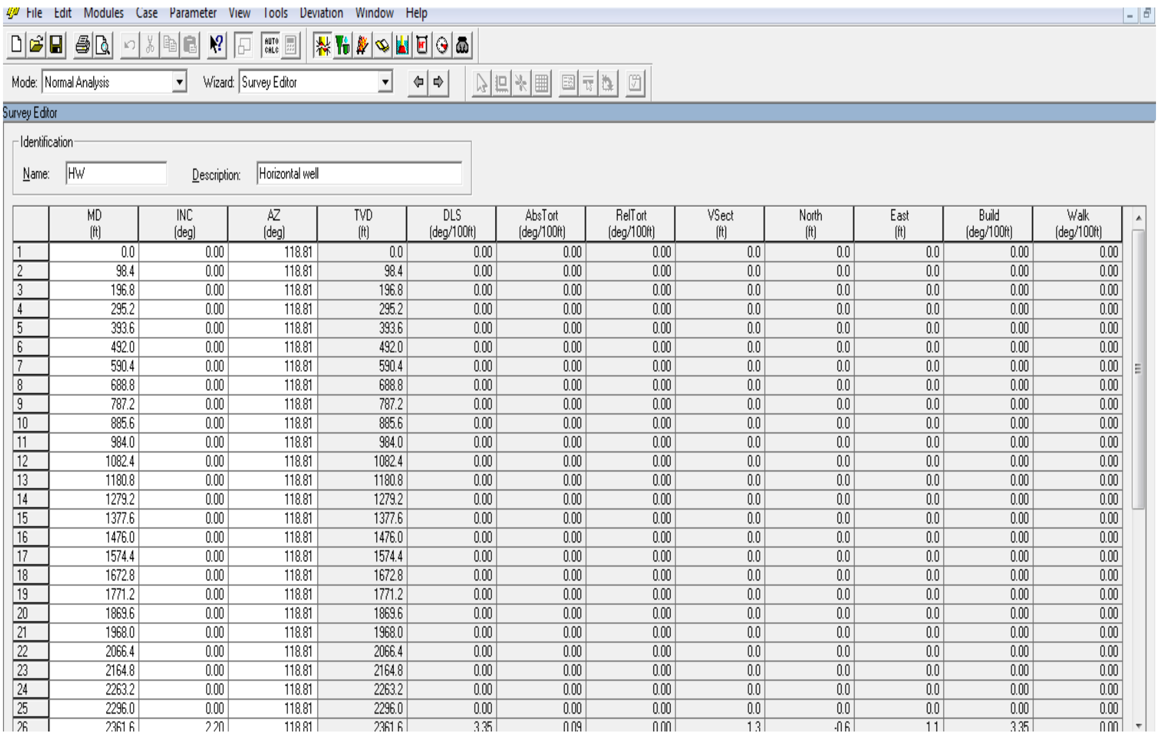
Survey Editor:

In Survey editor, MD, Inclination and Azimuth are inserted from the survey file in well Daily Drilling Report (DDR). The TVD, dogleg, Vertical section is calculated automatically as the MD, Inclination and Azimuth data inserted.



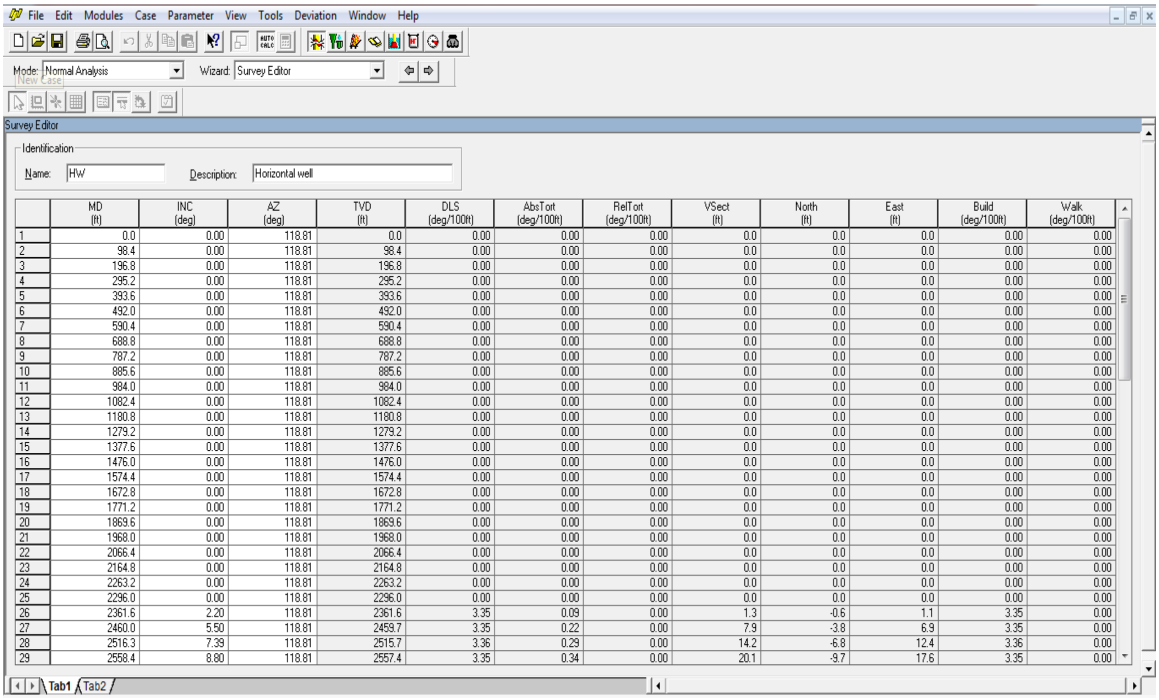
	MD (ft)	INC (deg)	AZ (deg)	TVD (ft)	DLS (deg/100ft)	AbsTort (deg/100ft)	RelTort (deg/100ft)	VSect (ft)	North (ft)	East (ft)	Build (deg/100ft)	Walk (deg/100ft)
1	0.0	0.00	118.81	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
2	98.4	0.00	118.81	98.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
3	196.8	0.00	118.81	196.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
4	295.2	0.00	118.81	295.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
5	393.6	0.00	118.81	393.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
6	492.0	0.00	118.81	492.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
7	590.4	0.00	118.81	590.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
8	688.8	0.00	118.81	688.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
9	787.2	0.00	118.81	787.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
10	885.6	0.00	118.81	885.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
11	984.0	0.00	118.81	984.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
12	1082.4	0.00	118.81	1082.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
13	1180.8	0.00	118.81	1180.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
14	1279.2	0.00	118.81	1279.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
15	1377.6	0.00	118.81	1377.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
16	1476.0	0.00	118.81	1476.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
17	1574.4	0.00	118.81	1574.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
18	1672.8	0.00	118.81	1672.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
19	1771.2	0.00	118.81	1771.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
20	1869.6	0.00	118.81	1869.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
21	1968.0	0.00	118.81	1968.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
22	2066.4	0.00	118.81	2066.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
23	2164.8	0.00	118.81	2164.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
24	2263.2	0.00	118.81	2263.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
25	2296.0	0.00	118.81	2296.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
26	2361.6	2.20	118.81	2361.6	3.35	0.09	0.00	1.3	-0.6	1.1	3.35	0.00
27	2460.0	5.50	118.81	2459.7	3.35	0.22	0.00	7.9	-3.8	6.9	3.35	0.00

Fig.3.10: 1st Build Section Survey Editor (Wellplan).



	MD (ft)	INC (deg)	AZ (deg)	TVD (ft)	DLS (deg/100ft)	AbsTort (deg/100ft)	RelTort (deg/100ft)	VSect (ft)	North (ft)	East (ft)	Build (deg/100ft)	Walk (deg/100ft)
1	0.0	0.00	118.81	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
2	98.4	0.00	118.81	98.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
3	196.8	0.00	118.81	196.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
4	295.2	0.00	118.81	295.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
5	393.6	0.00	118.81	393.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
6	492.0	0.00	118.81	492.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
7	590.4	0.00	118.81	590.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
8	688.8	0.00	118.81	688.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
9	787.2	0.00	118.81	787.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
10	885.6	0.00	118.81	885.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
11	984.0	0.00	118.81	984.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
12	1082.4	0.00	118.81	1082.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
13	1180.8	0.00	118.81	1180.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
14	1279.2	0.00	118.81	1279.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
15	1377.6	0.00	118.81	1377.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
16	1476.0	0.00	118.81	1476.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
17	1574.4	0.00	118.81	1574.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
18	1672.8	0.00	118.81	1672.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
19	1771.2	0.00	118.81	1771.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
20	1869.6	0.00	118.81	1869.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
21	1968.0	0.00	118.81	1968.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
22	2066.4	0.00	118.81	2066.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
23	2164.8	0.00	118.81	2164.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
24	2263.2	0.00	118.81	2263.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
25	2296.0	0.00	118.81	2296.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
26	2361.6	2.20	118.81	2361.6	3.35	0.09	0.00	1.3	-0.6	1.1	3.35	0.00

Fig.3.11: Tangent Section Survey Editor (Wellplan).



	MD (ft)	INC (deg)	AZ (deg)	TVD (ft)	DLS (deg/100ft)	AbsTort (deg/100ft)	RelTort (deg/100ft)	VSect (ft)	North (ft)	East (ft)	Build (deg/100ft)	Walk (deg/100ft)
1	0.0	0.00	118.81	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
2	98.4	0.00	118.81	98.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
3	196.8	0.00	118.81	196.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
4	295.2	0.00	118.81	295.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
5	393.6	0.00	118.81	393.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
6	492.0	0.00	118.81	492.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
7	590.4	0.00	118.81	590.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
8	688.8	0.00	118.81	688.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
9	787.2	0.00	118.81	787.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
10	885.6	0.00	118.81	885.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
11	984.0	0.00	118.81	984.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
12	1082.4	0.00	118.81	1082.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
13	1180.8	0.00	118.81	1180.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
14	1279.2	0.00	118.81	1279.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
15	1377.6	0.00	118.81	1377.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
16	1476.0	0.00	118.81	1476.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
17	1574.4	0.00	118.81	1574.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
18	1672.8	0.00	118.81	1672.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
19	1771.2	0.00	118.81	1771.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
20	1869.6	0.00	118.81	1869.6	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
21	1968.0	0.00	118.81	1968.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
22	2066.4	0.00	118.81	2066.4	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
23	2164.8	0.00	118.81	2164.8	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
24	2263.2	0.00	118.81	2263.2	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
25	2296.0	0.00	118.81	2296.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
26	2361.6	2.20	118.81	2361.6	3.35	0.09	0.00	1.3	-0.6	1.1	3.35	0.00
27	2460.0	5.50	118.81	2459.7	3.35	0.22	0.00	7.9	-3.8	6.9	3.35	0.00
28	2516.3	7.39	118.81	2515.7	3.36	0.29	0.00	14.2	-6.8	12.4	3.36	0.00
29	2558.4	8.80	118.81	2557.4	3.35	0.34	0.00	20.1	-9.7	17.6	3.35	0.00

Fig.3.12: 2nd Build Section Survey Editor (Wellplan).

Fluid editor:

Fluid editor options enable the user to input the fluid used in the drilling such as: rheology properties, mud base and other mud properties.

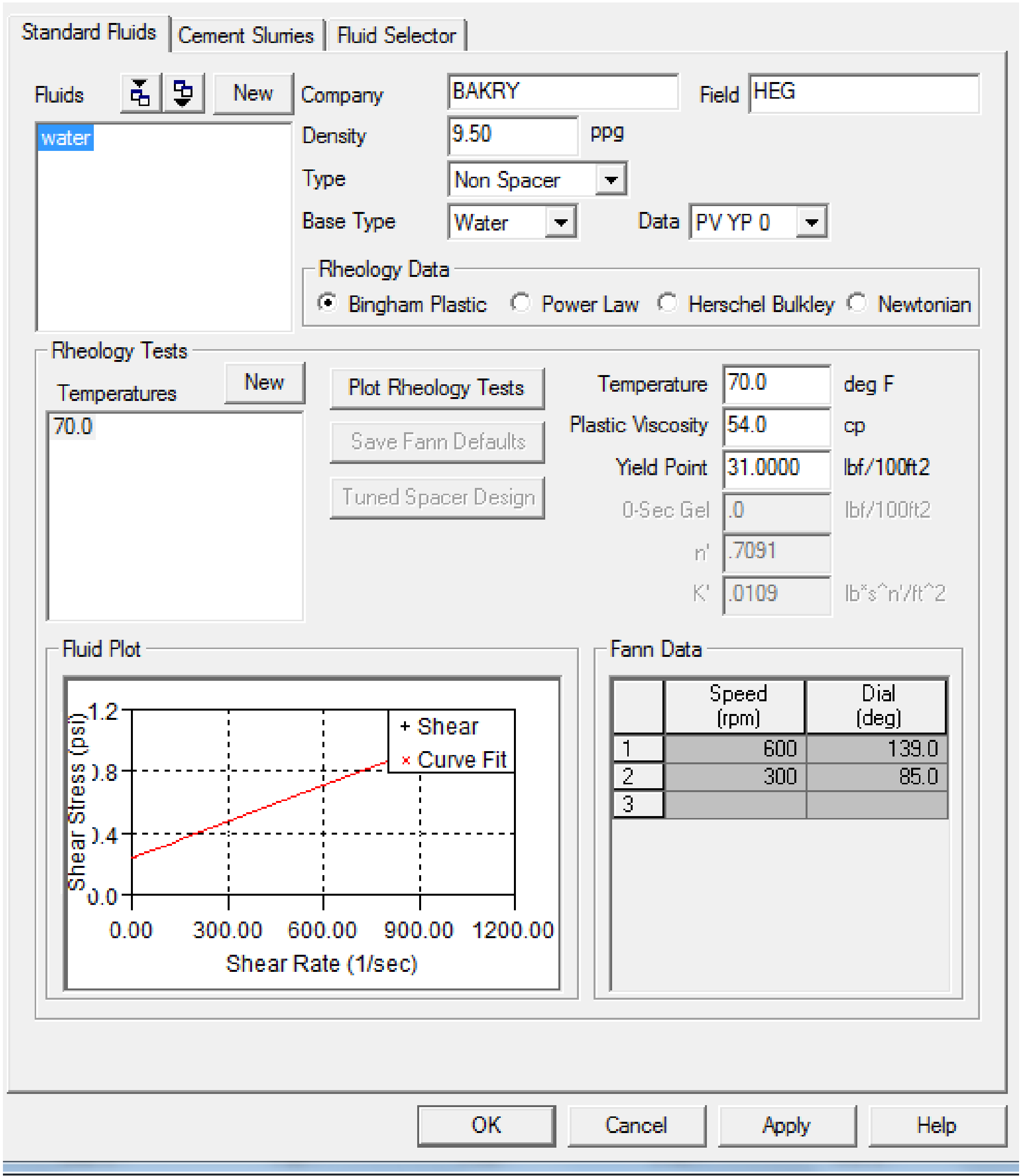


Fig.3.13: 1st Build Section Fluid Editor (Wellplan).

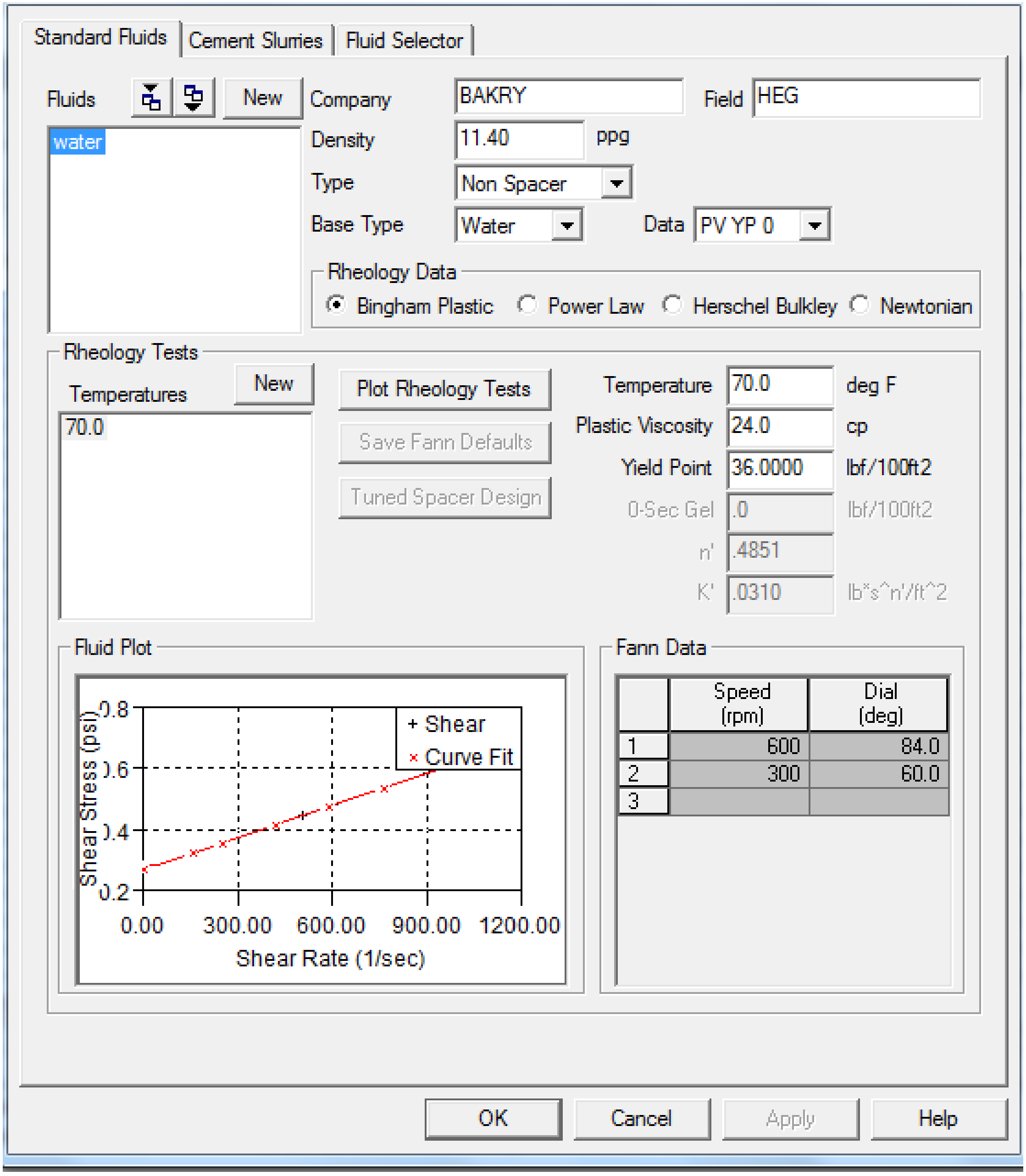


Fig.3.14: Tangent Section Fluid Editor (Wellplan).

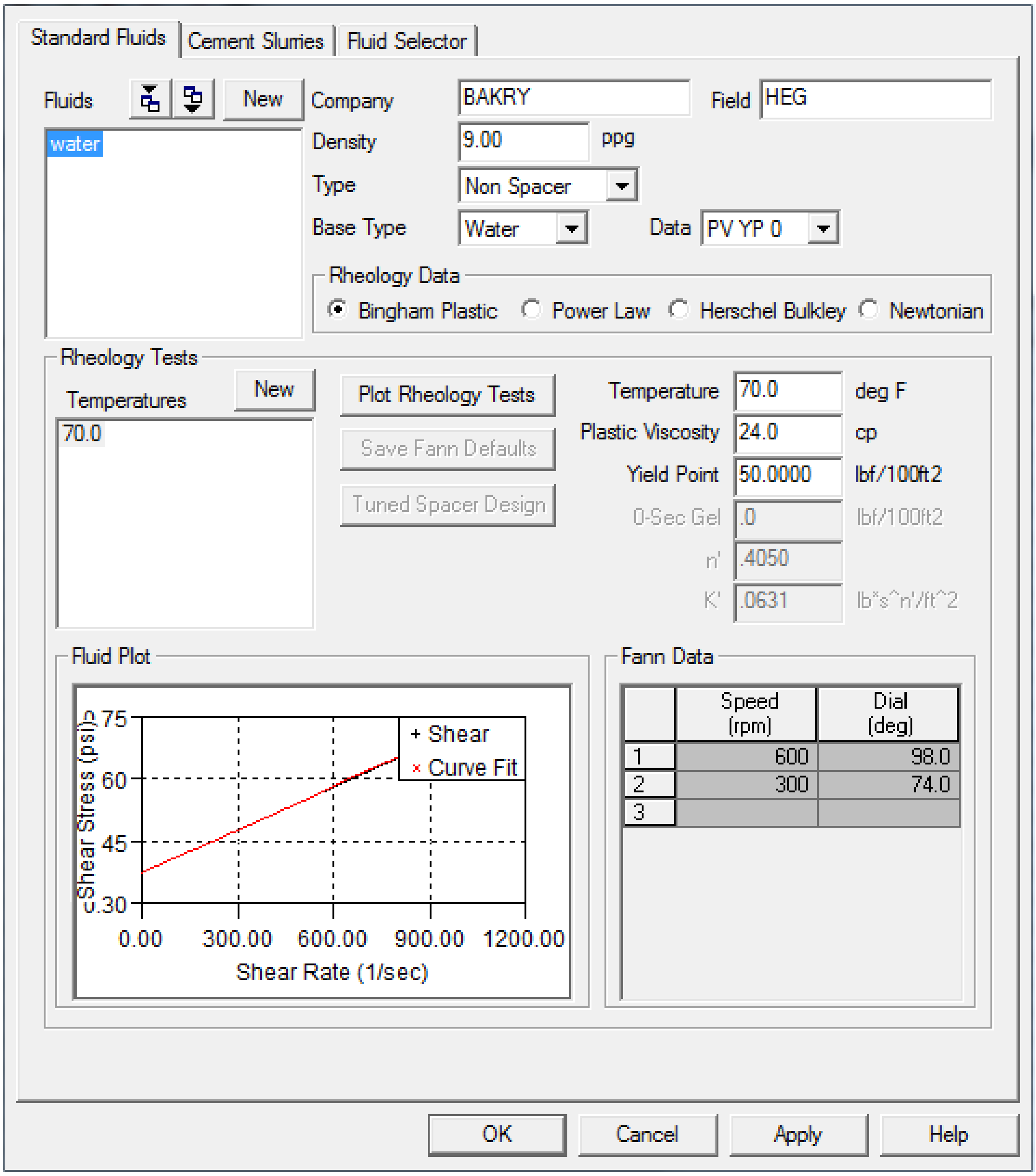


Fig.3.15: 2nd Build Section Fluid Editor (Wellplan).

3.3.2 Torque and Drag Module Data:

Landmark-Wellplan T&D Analysis module can be used to predict the measured weights and torques to be expected while tripping in, tripping out, rotating on bottom, rotating off bottom, slide drilling, and back reaming. This information can be used to determine if the well can be drilled, or to evaluate hole conditions while drilling a well.

To determine the analysis specifications for T&D analysis, T&D setup dialog is used to specify the use of either the soft or stiff string model in the analysis.

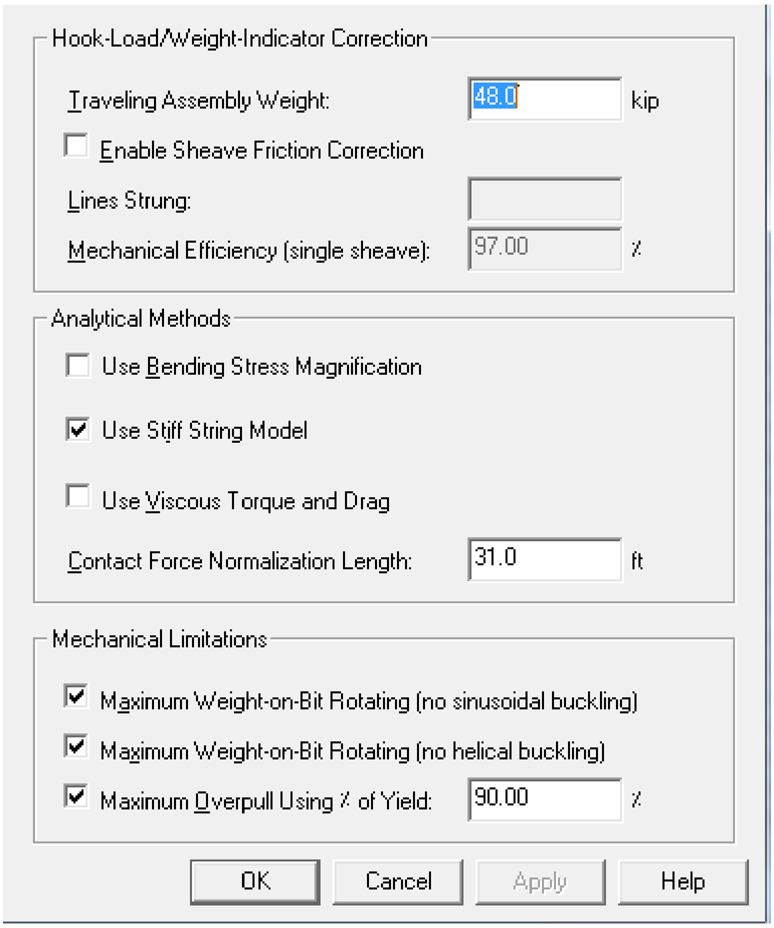


Fig.3.16: Horizontal Well T&D Setup Data (Wellplan).

T&D module has four available analysis modes; only three of them will be used in this project, as following:

3.3.2.1 Calibrate Coefficient of Friction:

Calibrate coefficient of friction provides a mean to calculate the coefficient of friction along the wellbore from actual data collected while drilling. This provides a means of calibrating the model against actual field result. Coefficient of friction in the casing section must be calculated first, then the open hole. This is required because data recorded in the open hole section includes the combined effects of friction between the string and the casing as well as the friction between the string and the open hole. Therefore, the coefficient of friction for the cased hole must be determined before that of the open hole.

Actual Loads dialog is used to record actual load data, if available, encountered at certain depths. This information can be used to calculate coefficients of friction using the Calibrate Friction analysis or it can be displayed in the Drag Chart analysis graphs to compare actual values with calculated values.

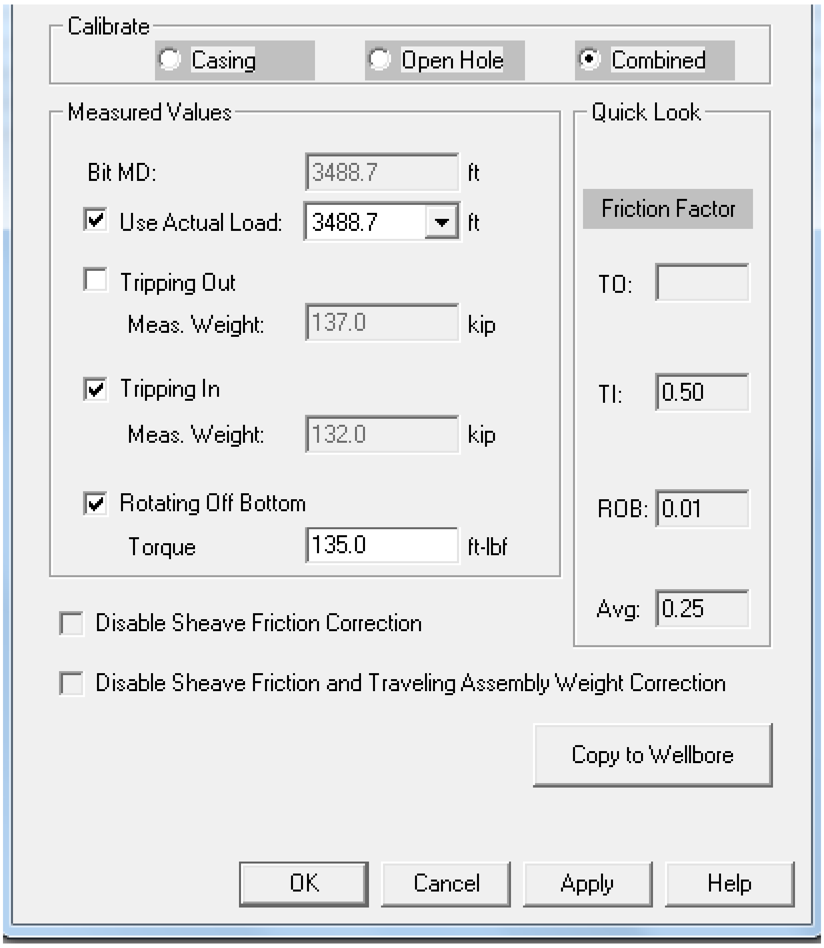


Fig.3.17 Calibrate Coefficient of Friction (Wellplan)

3.3.2.2Normal analysis:

Normal analysis calculates the torque, drag, normal force, axial force, buckling force, neutral point, stress and other parameters for a work string in a three dimensional wellbore. With a normal analysis, all calculations are performed with the bit at one position in the wellbore with one set of operational parameters.

Normal analysis mode calculates the forces acting along the string and at the surface for several operating conditions including: tripping in, tripping out, rotating on bottom, rotating off bottom, and back reaming.

Based on the API material specifications of pipe class, material, and grade, the following special load cases are also calculated: Maximum weight on bit to avoid sinusoidal buckling, maximum weight on bit to avoid helical buckling, and Maximum over pull to not exceed yield while tripping out of hole.

Results for a Normal Analysis are presented in tables, plots, and reports. In this project, only plots will be used to display the results. There are several plots containing analysis results for a normal analysis. These include:

Effective Tension Plot:

The Effective Tension plot displays the tension in all sections of the work string for the operating modes specified on the normal analysis mode data dialog calculated using the buoyancy method. The graph includes data for measured depths from the surface to the string depth specified on the String Editor. The effective tension can be used to determine when buckling may occur. On the plot there are curves indicating the loads required to buckle the work 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.

The plot also indicates the tension limit for the work string component at the corresponding measured depth. If the effective tension curve for a particular operating mode exceeds the tension limit curve, the work string is in danger of parting at that point.

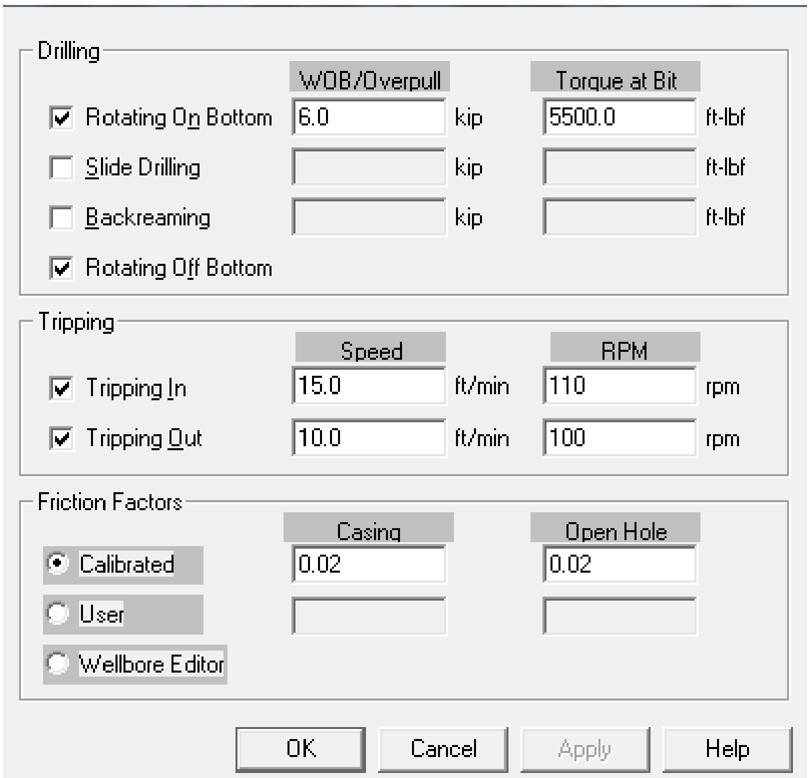


Fig.3.18: Tangent Section Normal Analysis Mode Data (Wellplan).

True Tension Plot:

The True Tension plot displays the tension in all sections of the work string for the operating modes specified on the normal analysis mode data dialog as calculated using the pressure area method. The graph includes data for measured depths from the surface to the string depth specified on the String Editor.

There are other plots in normal analysis mode include:

- Torque plot
- Side force plot
- Fatigue graph
- **Drag charts:**

Drag chart analysis is used to predict the measured weights and torques that will be experienced while operating the work string at a range of depths in the wellbore. The calculations performed

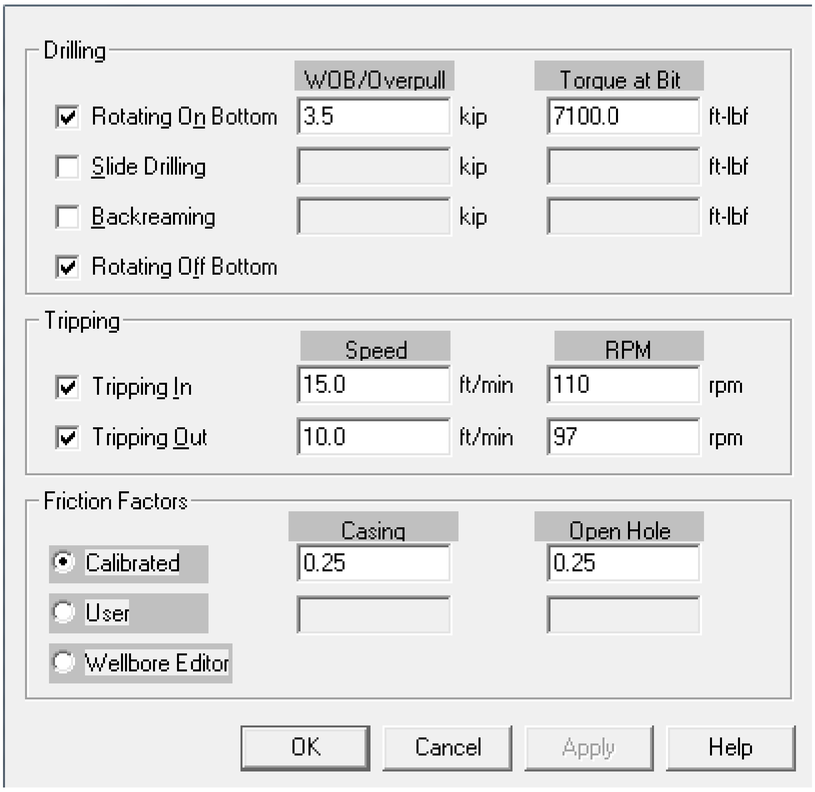


Fig.3.19: 2nd Build Section Normal Analysis Mode Data (Wellplan).

For this analysis are similar to those used in the Normal Analysis except the calculations are performed over a range of depths.

The drag charts results are displayed in form of plots such as:

Measured Weight Chart:

The Measured Weight chart shows measured weights for all operating modes selected on the Run Parameters dialog. This analysis covers only the measured depth interval specified on the run parameters dialog.

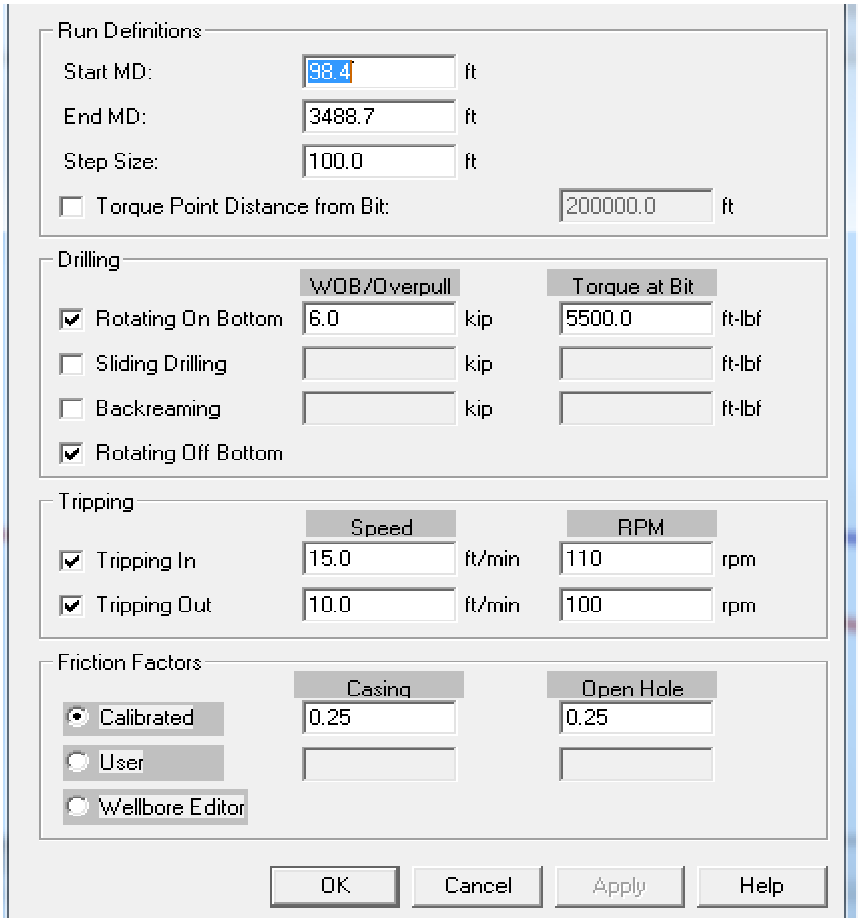


Fig.3.20: 1st Build Section Drag Chart Run Parameters (Wellplan).

Torque Point Chart:

The Torque Point chart displays the maximum torque found at the surface, or at a user specified point in the work string for all rotary operating modes selected on the Run Parameters dialog. The Torque Point chart covers only the measured depth interval specified on the Run Parameters dialog.

Minimum Weight on Bit Chart:

This chart displays minimum weight on bit to start helical or sinusoidal buckling (Landmark Wellplan user manual, 2000).

Chapter Four

Results and Discussion

4.1 Well Sections Description:

The figures below show the vertical section, DLS, and inclination for the first build section, tangent section, and second build section.

For the First Build Section:

- Fig.4.1 shows vertical section with depth which remains constant till the point where the well is kicked off and increases as the well drilled away from the kick off point.
- Fig.4.2 shows the DLS with depth, the value of DLS remains constant till the KOP where it starts to increase gradually and reached the maximum value of 3.70 degree/100 ft, which is within the acceptable range, at the depth of 2900 ft.
- Fig.4.1 shows the inclination which is 40 degree at the end of the first build section.

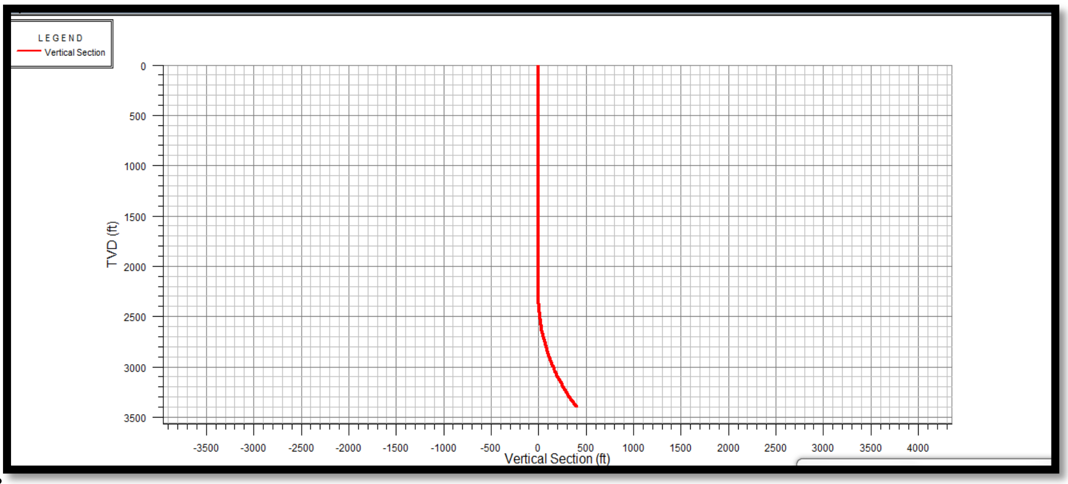


Fig.4.1: 1st Build Section Vertical Section (Wellplan).

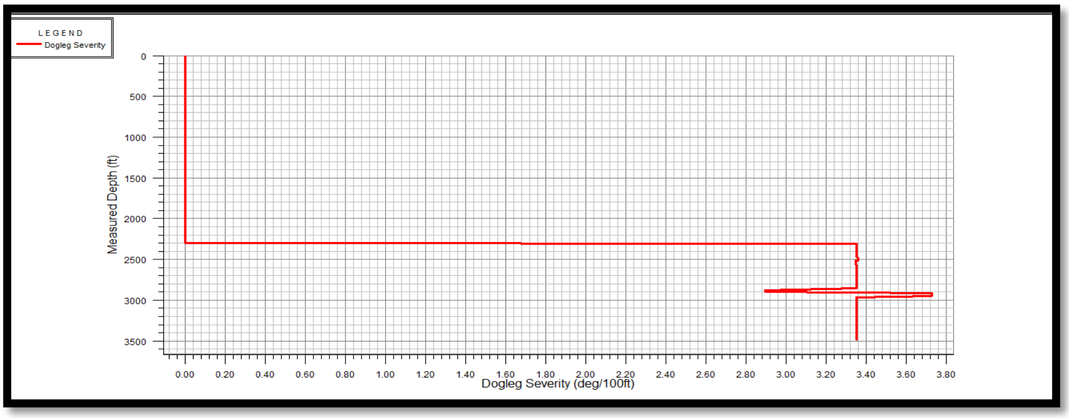


Fig.4.2: 1st Build Section DLS (Wellplan).

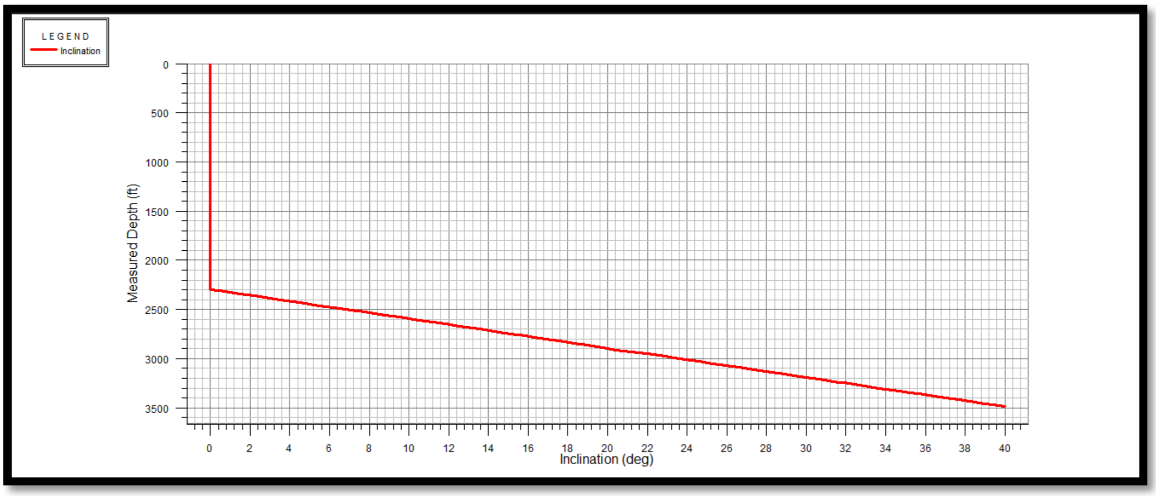


Fig.4.3: 1st Build Section Inclination (Wellplan).

For the Tangent Section:

- Fig.4.4 shows vertical section with depth which increases as the well drilled away from the kick off point.
- Fig.4.5 shows the DLS with depth, the value of DLS is zero at the depth of 3610 ft due to the fact that the section is tangent.
- Fig.4.6 shows the inclination which is held constant at 40 degree along the tangent section.

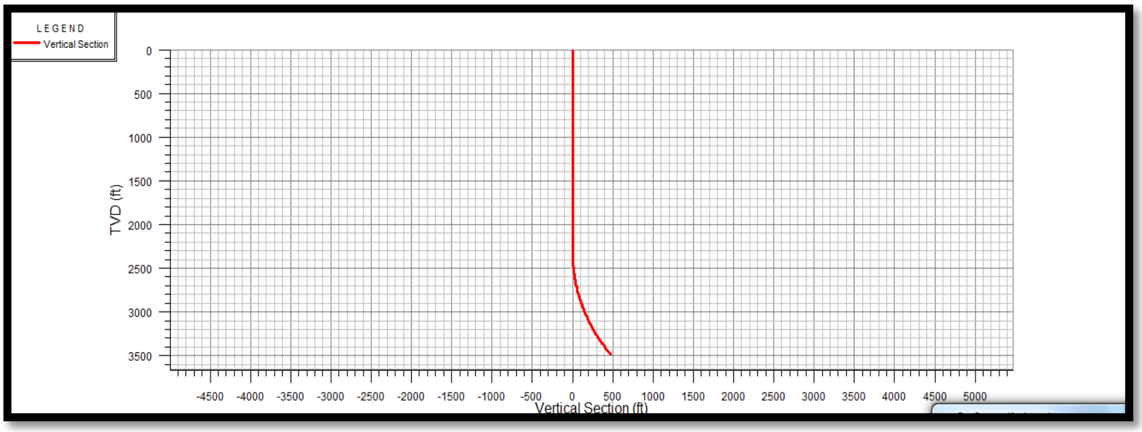


Fig.4.4: Tangent SectionVertical Section (Wellplan).

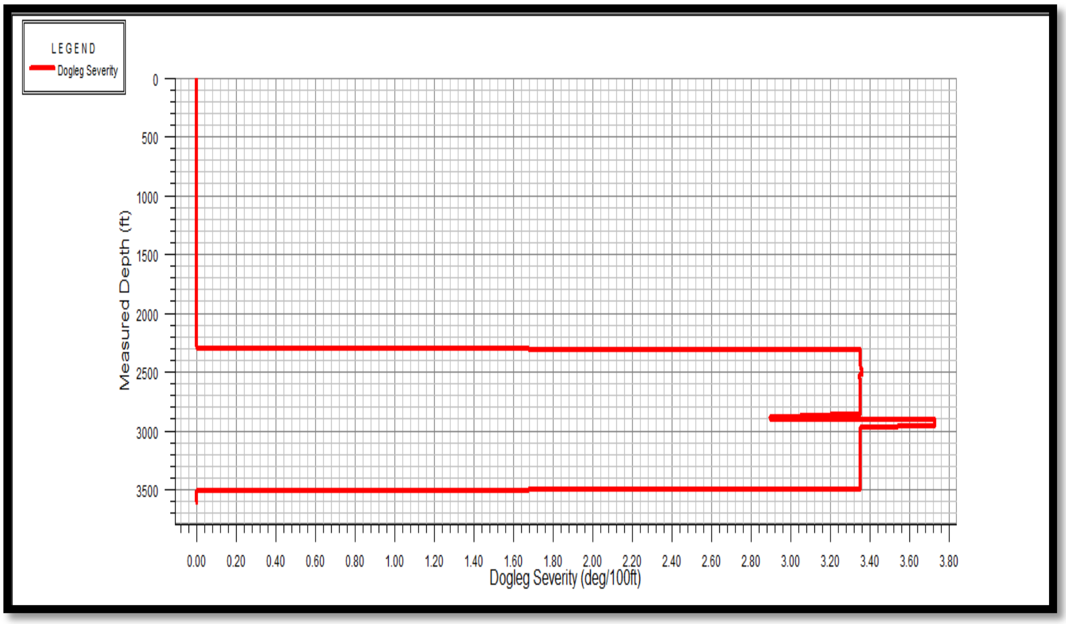


fig.4.5: DLS Tangent Section (Wellplan).

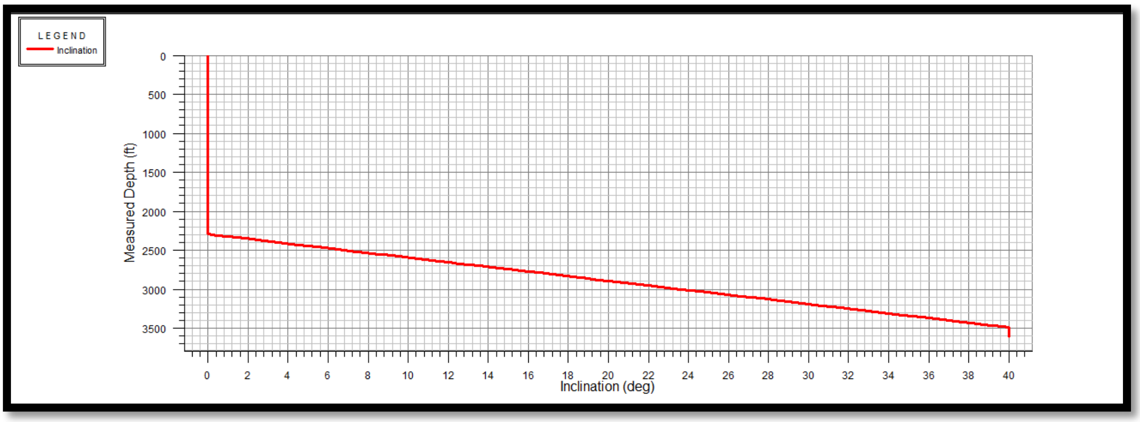


Fig.4.6: Tangent Section Inclination (Wellplan).

For the Second Build Section:

- Fig.4.7 shows vertical section with depth which increases as the well drilled away from the kick off point.
- Fig.4.8 shows the DLS with depth, the value of DLS increases gradually and reached the value of 3.5 at the depth of 4100 ft. Then decreases gradually till reached the value of 0.4 at the depth of 5100 ft.
- Fig.4.9 shows the inclination which is 90 degree at the end of the second build section. i.e. total depth.

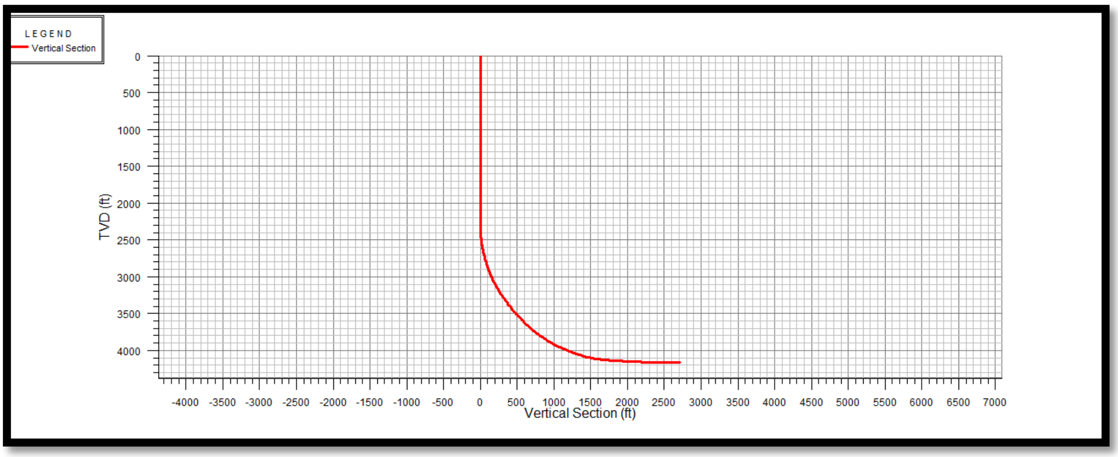


Fig.4.7: 2nd Build Section Vertical Section (Wellplan).

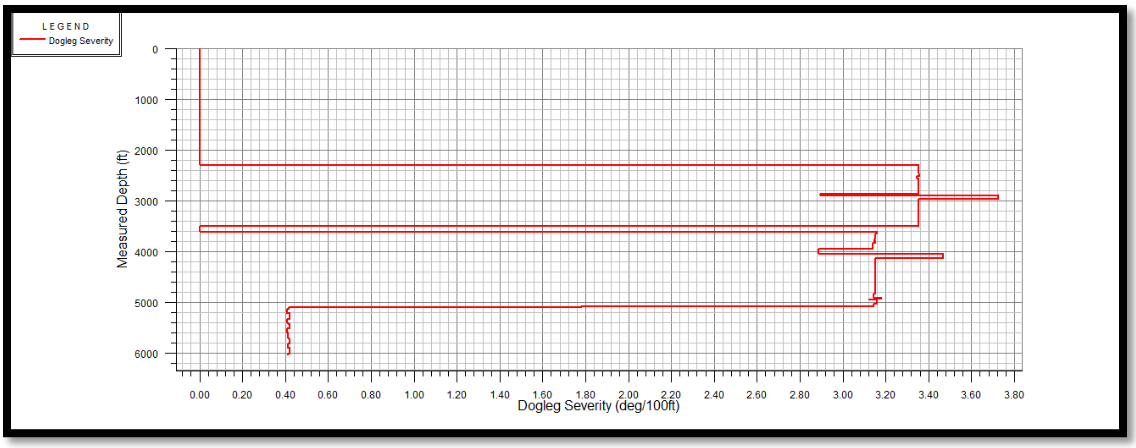


fig.4.8: DLS 2nd Build Section (Wellplan).

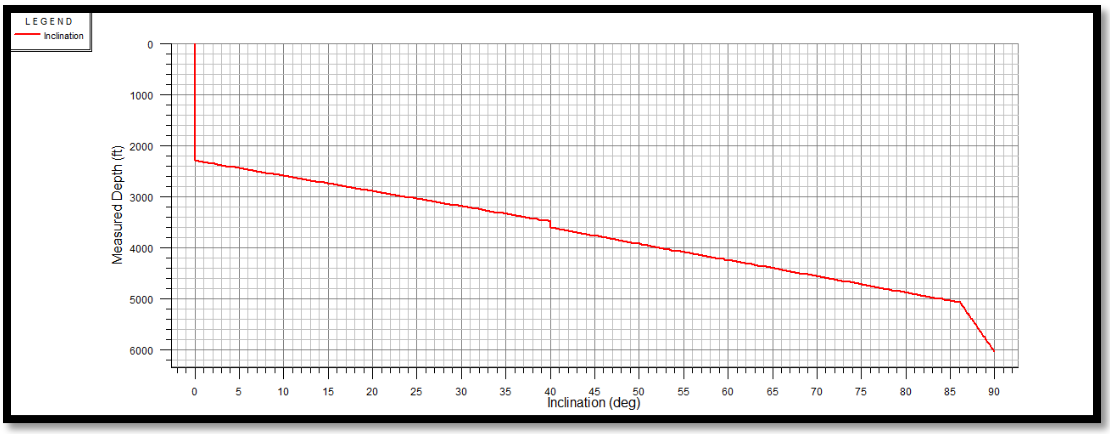


Fig.4.9: 2nd Build Section Inclination (Wellplan).

4.2 Normal Analysis:

4.2.1 Effective Tension Plot:

Figures below show the effective tension plot for the first build section, tangent section, and second build section.

- Fig.4.10 shows the effective tension for 1st build section. According to API class of materials and grade, the tension limit, the range of sinusoidal and helical buckling is calculated.

It can be noticed that the effective tension in the string during tripping in, tripping out, rotating on and off bottom is identical. At the surface the tension value is 120 kip and the amount of tension decreases as the depth increases. The value at the depth of 3500 is -10 kip which indicates that the string at this point is at compression.

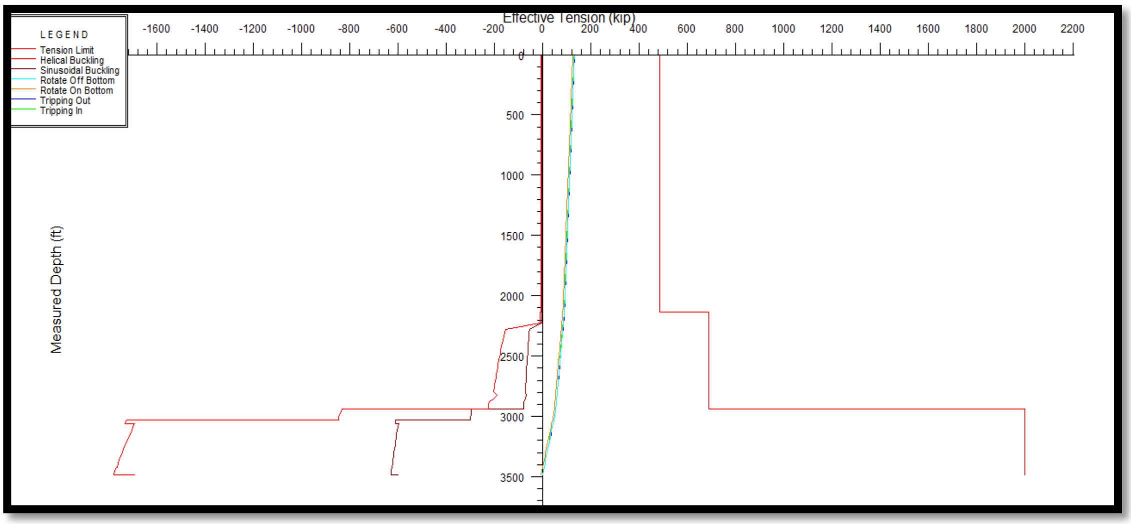


Fig.4.10: 1st Build Section Effective Tension during Tripping in, Tripping out, Rotating on and off Bottom (Wellplan).

- Fig.4.11 shows the effective tension for tangent section. According to API class of materials and grade, the tension limit, the range of sinusoidal and helical buckling is calculated.

  It can be noticed that the effective tension in the string during tripping in, tripping out, rotating on and off bottom is identical. At the surface the tension value is 100 kip and the amount of tension decreases as the depth increases. The value at the depth of 3610 is 0 kip which indicates that the string at this point is not under tension or compression, i.e. neutral point.

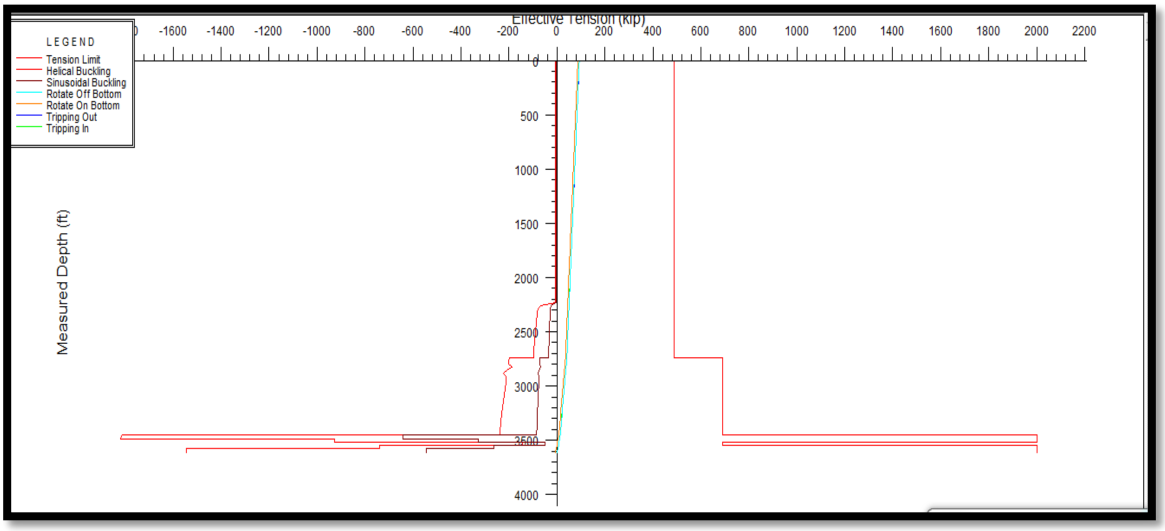


Fig.4.11: Tangent Section Effective Tension during Tripping in, Tripping out, Rotating on and off Bottom (Wellplan).

- Fig.4.12 shows the effective tension for 2nd build section. According to API class of materials and grade, the tension limit, the range of sinusoidal and helical buckling is calculated.

  It can be noticed that the effective tension in the string during tripping in, tripping out, rotating on and off bottom is identical. At the surface the tension value is 110 kip and the amount of tension decreases as the depth increases. The value at the depth of 3610 is 0 kip which indicates that the string at this point is not under tension or compression, i.e. neutral point. From this point, the drill string is compressible by an amount of -10 kip.

  It can be noticed that for all three plots of the effective tension, no tension or buckling limit is reached which indicates that no critical problems encountered.

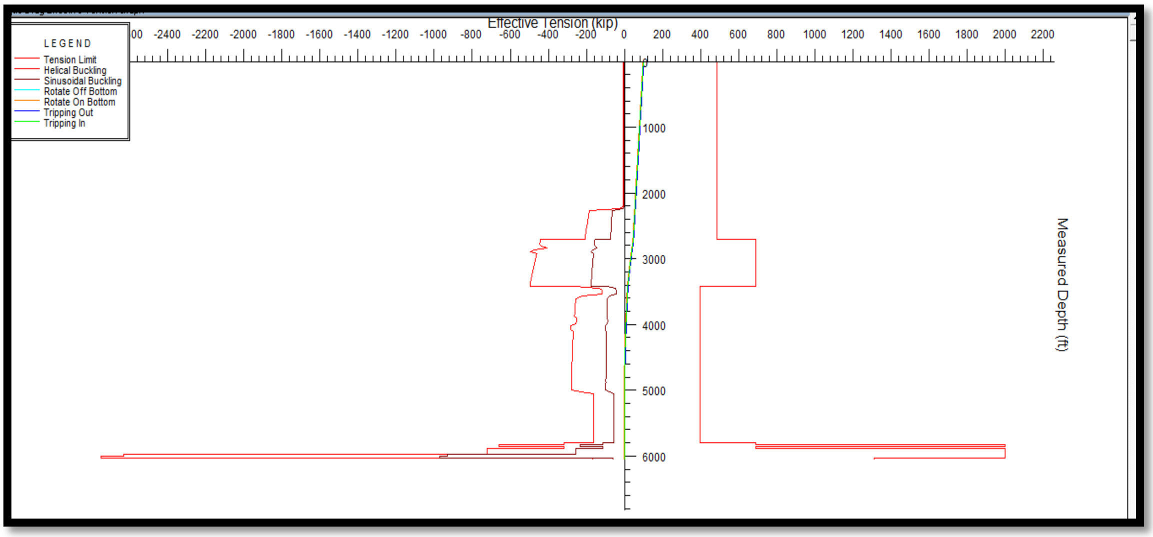


Fig.4.12: 2nd Build Section Effective Tension during Tripping in, Tripping out, and Rotating on and off Bottom (Wellplan).

4.2.2 True Tension Plot:

Figures below show the true tension plot for the first build section, tangent section, and second build section.

- Fig.4.13 shows the true tension plot for the first build section during tripping in, tripping out, rotate on and off bottom. It can be noticed that the true tension during tripping in, out, and rotate on bottom is found to be 164, 166, and 158 kip respectively. The true tension value decreases to the value of -50, -50, and -55 kip respectively.
- Fig.4.14shows the true tension plot for the tangent section during tripping in, tripping out, rotate on and off bottom. It can be noticed that the true tension during tripping in, out, and rotate on bottom is found to be 126, 126, and 120 kip respectively. The true tension value for the three operating conditions decreases to the value of -110 kip.
- Fig.4.15 shows the true tension plot for the second build section during tripping in, tripping out, rotate on and off bottom. It can be noticed that the true tension during tripping in, out and rotate on bottom is found to be 164, 168, and 158 kip respectively. The true tension value for tripping in, out, rotating on bottom is found -70, -70, and -74 kip respectively.

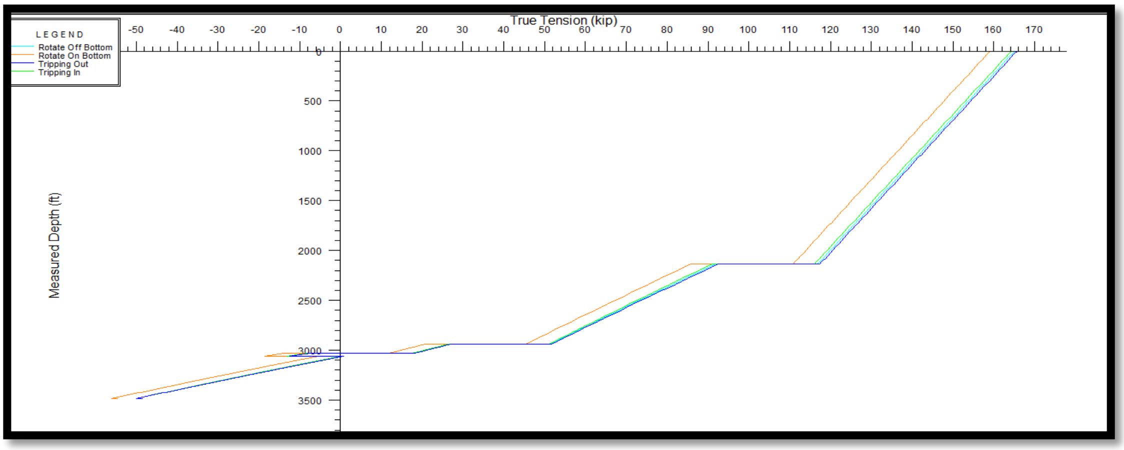


Fig.4.13: 1st Build Section True Tension during Tripping in and Tripping out (Wellplan).

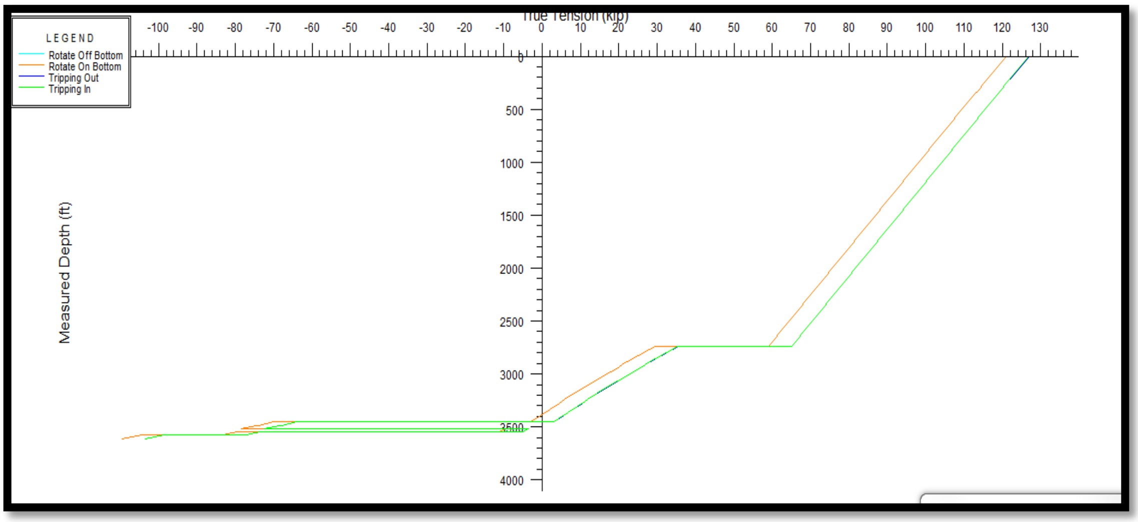


Fig.4.14: Tangent Section True Tension during Tripping in and Tripping out (Wellplan).

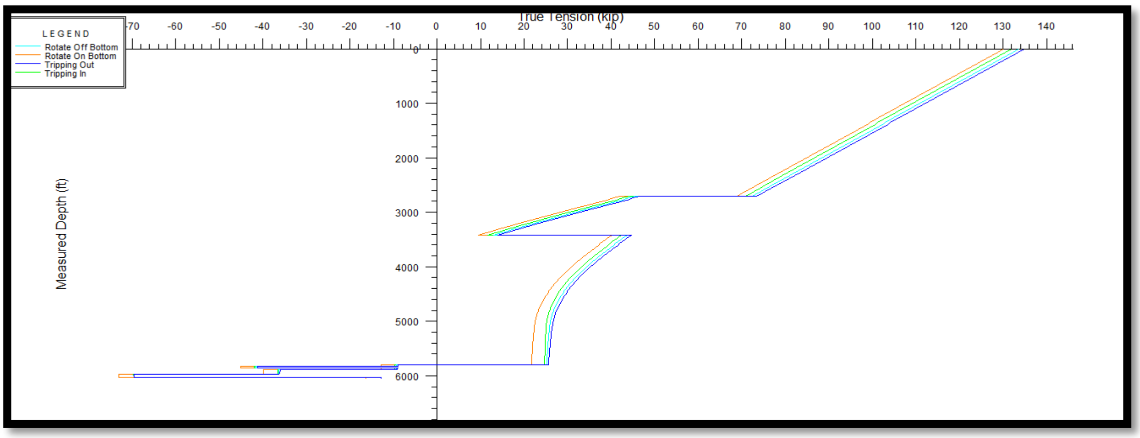


Fig.4.15: 2nd Build Section True Tension during Tripping in, Tripping out, rotating on and off Bottom (Wellplan).

4.2.3 Torque plot:

Figures below show the torque plot for the first build section, tangent section, and second build section.

- Fig.4.16 shows torque displayed in all sections of the string in the first build section for the tripping in, tripping out, rotate on bottom, and rotate off bottom operations. It is obvious that the torque at surface during the rotating on bottom operation is greater than that of the rotating off bottom operation. It should be noted that the torque values during the tripping in and tripping out operations are equal to zero due to the fact that there is no rotation in the string. Torque values at the depth of 2900 ft during different rotating on and off bottom operation modes exceed the makeup torque limit at this depth which indicates that the tool joints for the string are liable to over torque or break.
- Fig.417 and fig.4.18 displays torque for tangent and second build sections respectively. Torque value is constant for tangent section. The second build section torque decreases as the depth increase until it reach the minimum value at the final depth which is known as torque at bit. Since all the displayed torque values during different operation modes do not exceed the makeup torque limit, the tool joints for the string are not liable to over torque or break.

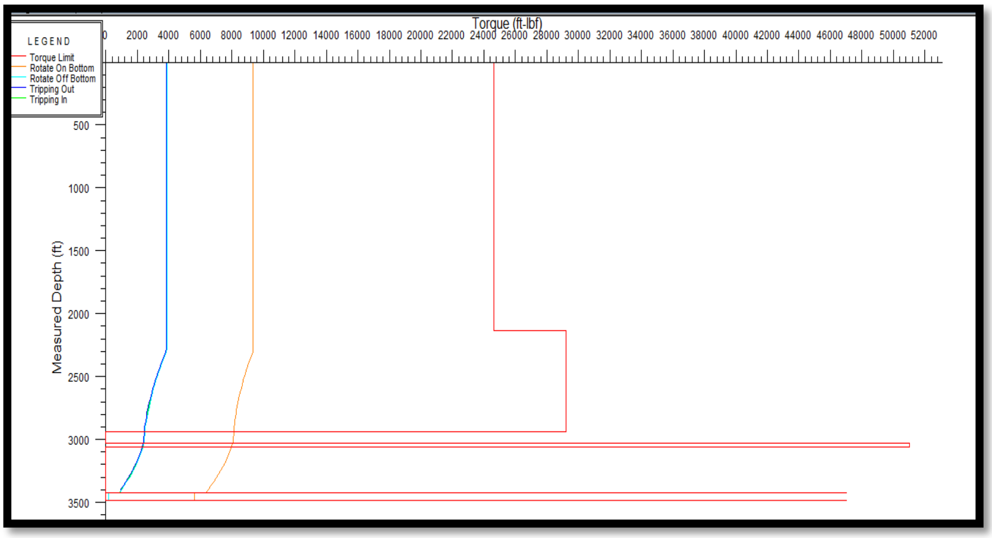


Fig.4.16: 1st Build Section Torque Plot (Wellplan).

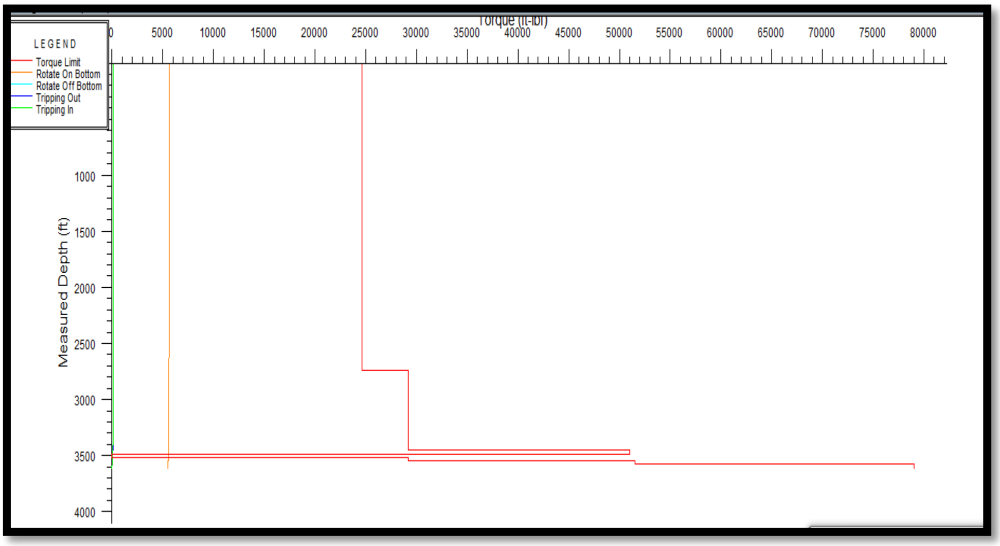


Fig.4.17: Tangent Section Torque Plot (Wellplan).

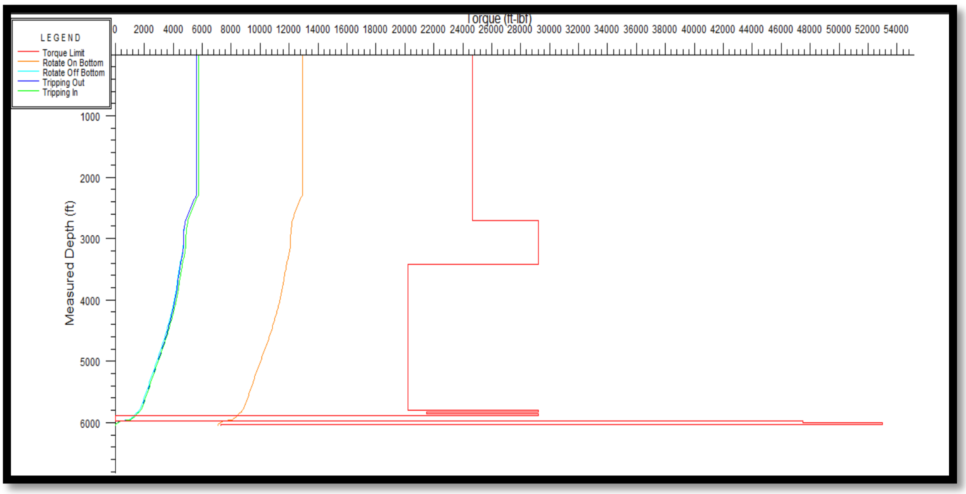


Fig.4.18: 2nd Build Section Torque Plot (Wellplan).

4.3 Drag Chart Analysis:

4.3.1 Measured Weight Chart:

The figures below shows the weights encountered during drilling of the horizontal well during the tripping in, tripping out, and rotating off bottom operation modes.

- With reference to fig.4.19 for the 1st build section, it is clear that the weights during the tripping out operations are larger than those during the tripping in and rotating off bottom operations due to the fact that the string is lifted upward, i.e. against gravity.

- Fig.4.20 shows the weights calculated using Landmark-Wellplan software along with the actual weights encountered during drilling of the horizontal well during many operation modes for the tangent section. It is clear that at the depth of 700 ft to 2600 ft the string start to buckle according to helical buckling mode during rotating on and off bottom operations. So care should be taken during drilling at this depth. Buckling problem can be minimized or even prevented by use of stiff tubulars in the well such as heavy weight drill pipe.

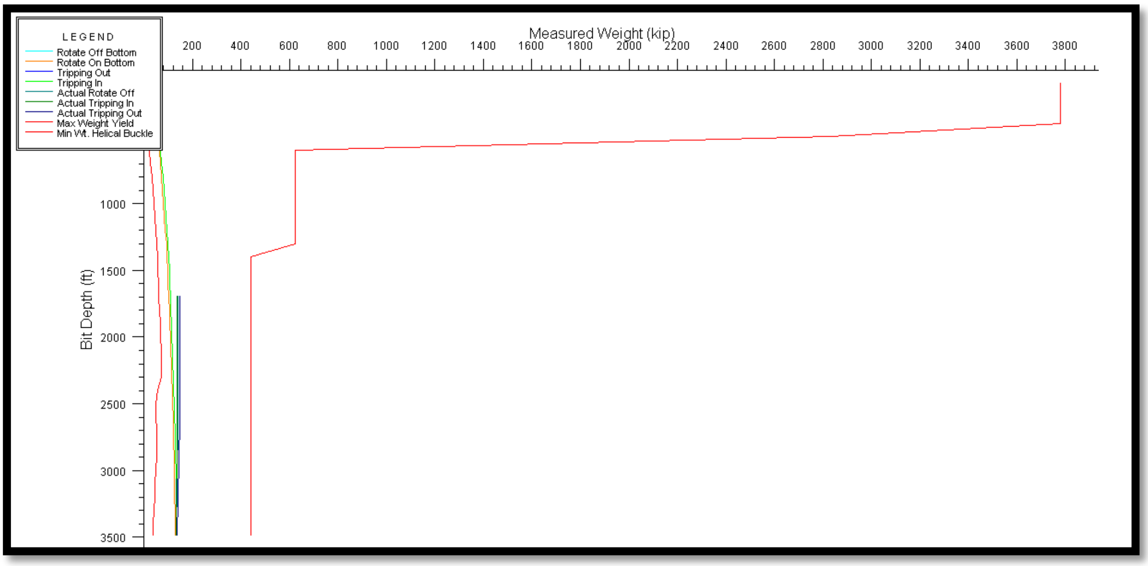


Fig.4.19: 1st Build Section Calculated Weights during Tripping in, Tripping out, and Rotate off Bottom (Wellplan).

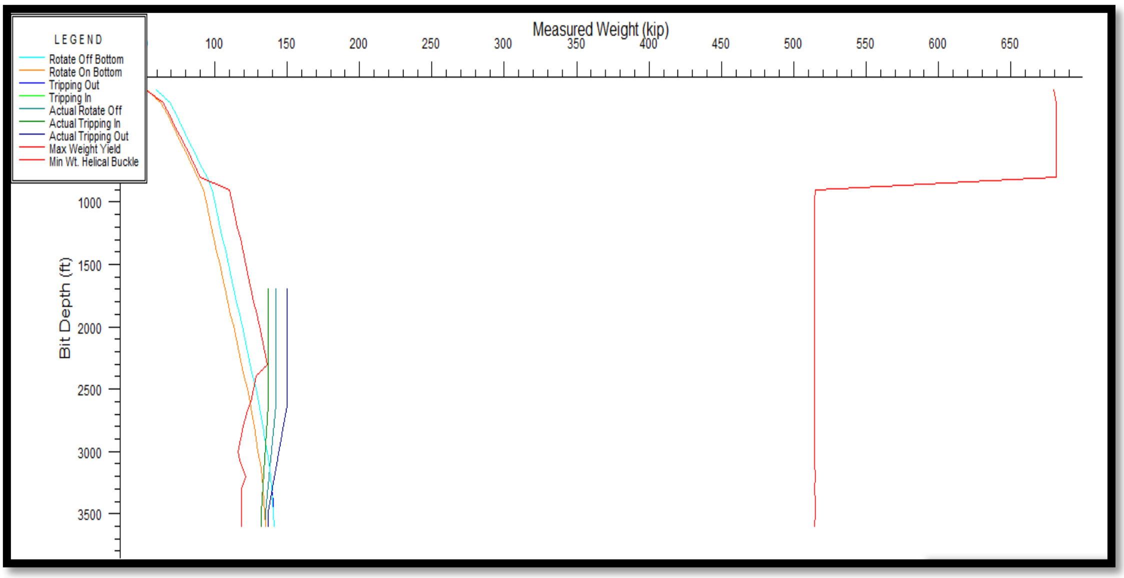


Fig.4.20: Tangent Section Measured and Calculated Weights during Tripping in, Tripping out, and Rotating on Bottom (Wellplan).

- Fig.4.21 shows the weights calculated using Landmark-Wellplan software during various operation modes for the second build section. It can be noticed that during all the listed operation modes, the string start to buckle according to helical buckling mode from the depth of 300 ft to 2600 ft. A solution to buckling problem is to use more stiff tubulars, i.e. heavy weight drill pipe, instead of the drill pipe.

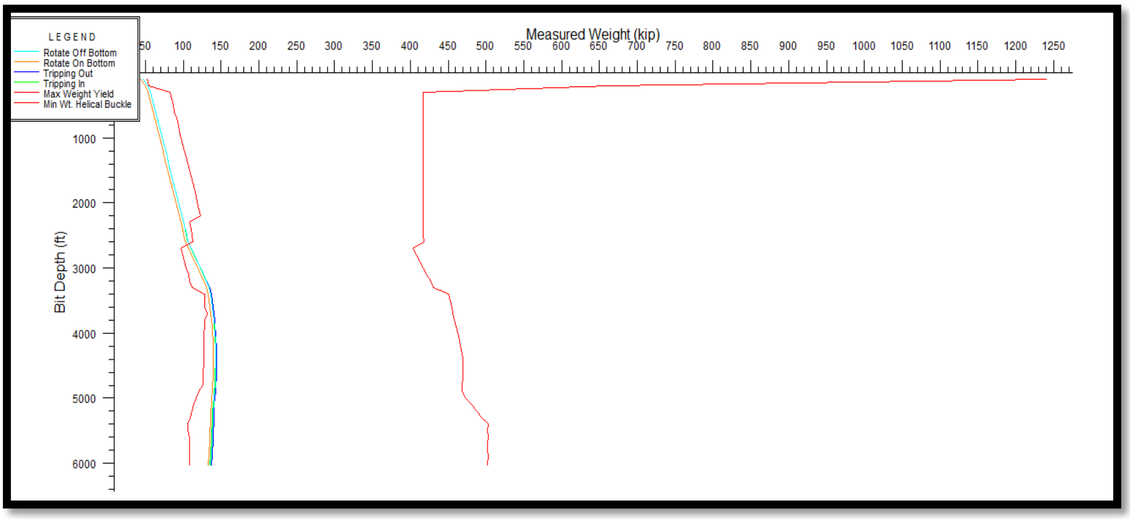


Fig.4.21: 2nd Build Section Calculated Weights during Tripping in, Tripping out, Rotating on and off Bottom (Wellplan).

Minimum Weight on Bit Chart:

- Fig.4.22, Fig.4.23, and Fig.4.24 shows Minimum WOB to initiate helical or sinusoidal buckling during the drilling of the horizontal well. Some care should be taken into account to ensure that the WOB is kept less than the values displayed in these figures at the corresponding bit depths. Once the WOB exceeds the minimum WOB at the corresponding bit depths, the string will start to buckle according to the corresponding buckling mode.

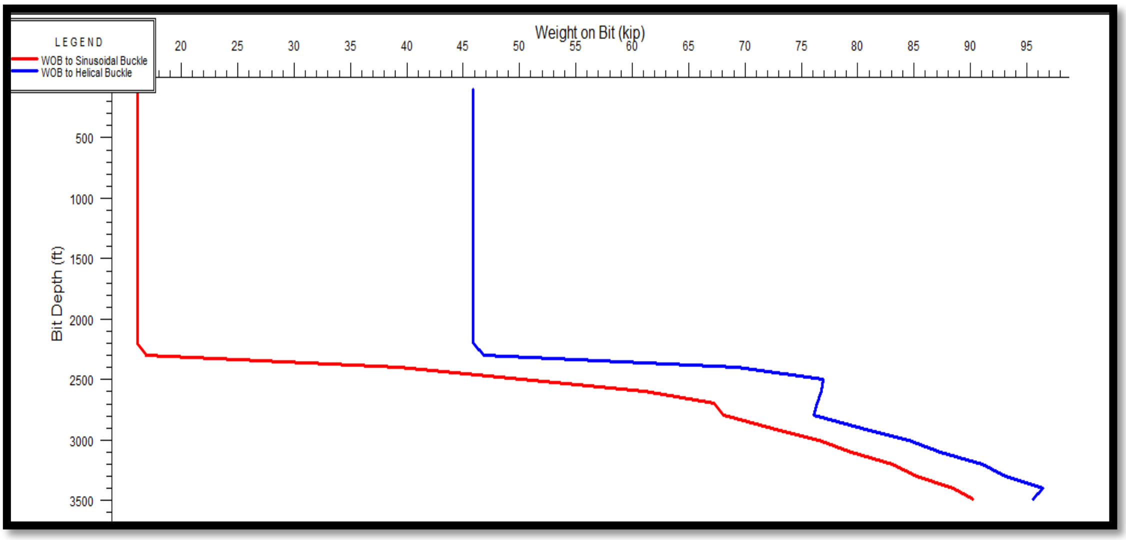


Fig.4.22: 1st Build Section Minimum WOB Chart (Wellplan).

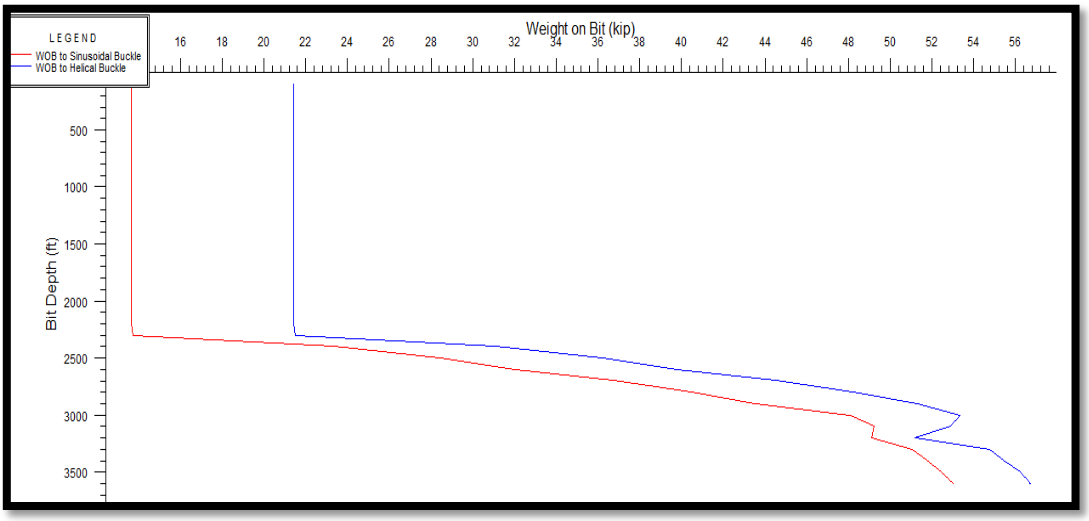


Fig.4.23: Tangent Section Minimum WOB Chart (Wellplan).

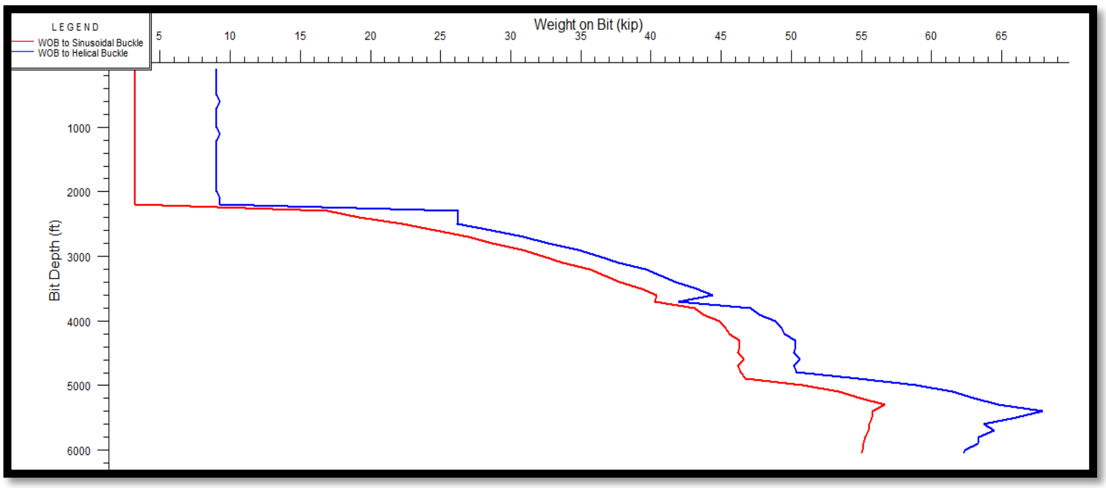


Fig.4.24: 2nd Build Section Minimum WOB Chart (Wellplan).

Torque Point Chart:

- Fig.4.25shows the torque point chart for the first build section during rotating on and off bottom operation modes. It is obvious that the torque at depth increases as the bit depth increases. Torque during rotating off bottom equals zero until the point where the well is kicked off where it start to increase as the depth increase.
- Fig.4.26 shows the torque point chart for the tangent section during rotating on and off bottom operation modes along with the actual torque encountered during rotating on bottom. It is clear that the torque value is constant from surface until the depth of 2600 ft where it is start to increase by small magnitude.
- Fig.4.27 shows torque point chart for the second build section during rotating on and off bottom operations. It is obvious that the torque at depth increases as the bit depth increases. Torque during rotating off bottom equals zero until the point where the well is kicked off where it start to increase as the depth increase.

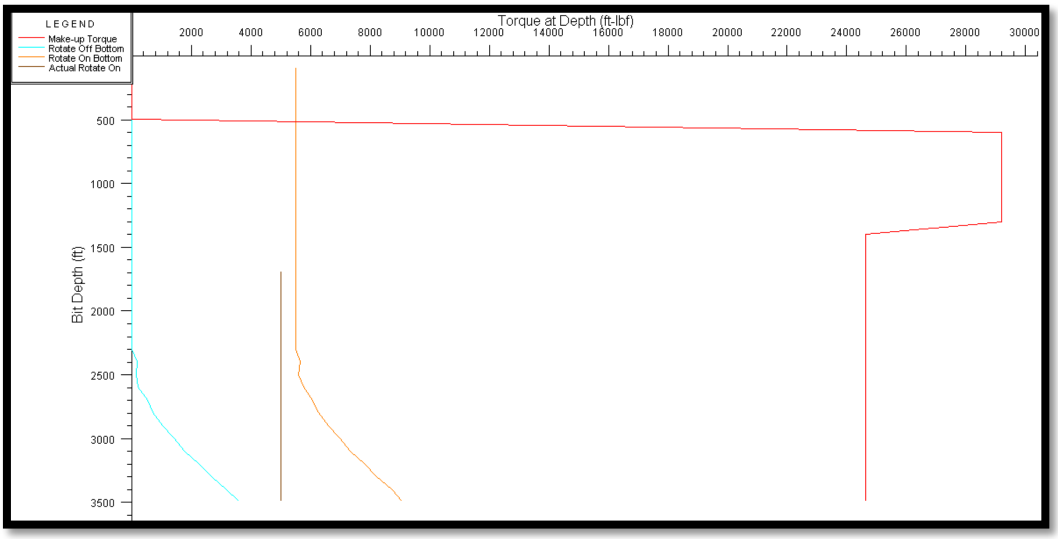


Fig.4.25: 1st Build Section Torque Point Chart (Wellplan).

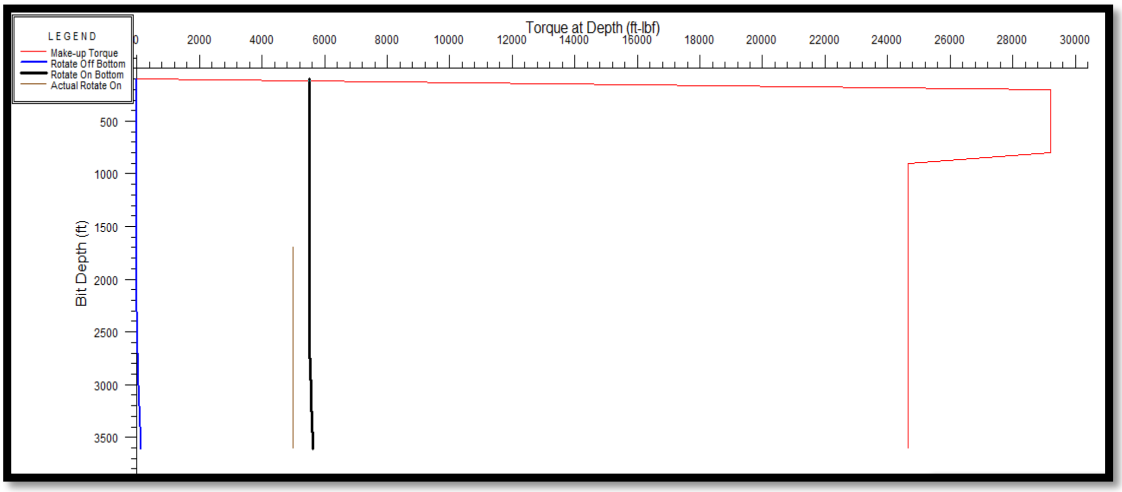


Fig.4.26: Tangent Section Torque Point Chart (Wellplan).

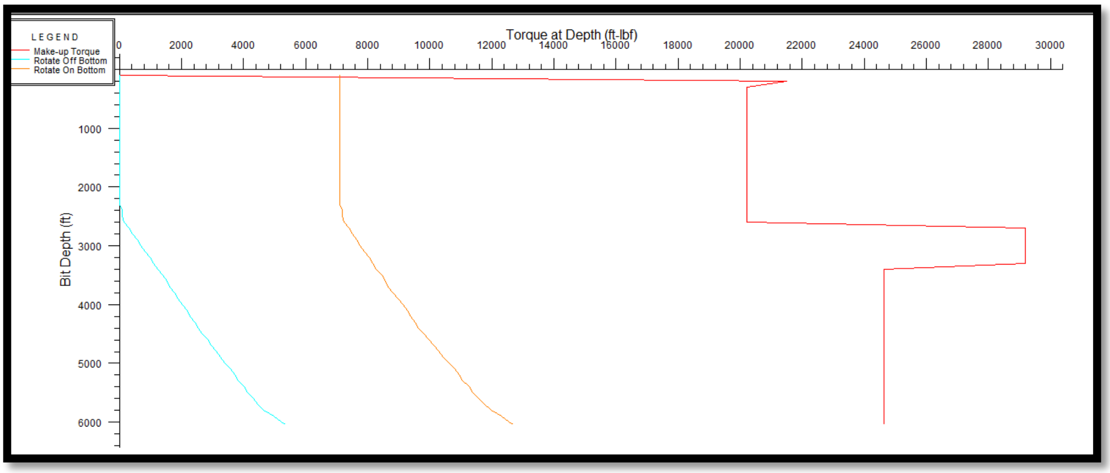


Fig.4.27: 2nd Build Section Torque Point Chart (Wellplan).

Discussion of result

- Fig.4.16 shows the torque plot for the first build section. It can be noticed that torque during rotating on bottom and off bottom operations at the depth of 2900 ft exceeded the makeup torque limit which indicates that the string tool joint is liable to break or over torque. Torque should be reduced at this point, i.e. 2900 ft below the displayed value to avoid tool joint breakage.

- Fig.4.17 shows the weights calculated using Landmark-Software for the tangent section during tripping in, tripping out, rotating on, and rotating off bottom operations. It is obvious that during the various operation modes there is a problem of string helical buckling from the depth of 750 ft to 2400 ft. Also there is a problem of helical buckling during various operation modes from the depth of 300 ft to 2600 ft, fig.4.18, for the second build section. The buckling problem at the mentioned depths can be solved by one of the following: using more stiff pipes in the well, i.e. heavy weight drill pipe, could solve the problem, use of more length of drill collars could also solve the problem because it lift the neutral point, i.e. the under compression part of the string, upward to the drill collars instead of the less stiff pipes, reduction of the weight on bit could also solve the problem because it allow the neutral point to move downward and thereby allow the less stiff pipes to be in tension mode instead of compression mode.
- Fig.4.22, Fig.4.23, and Fig.4.24 shows Minimum WOB to initiate helical or sinusoidal buckling during the drilling of the horizontal well. Some care should be taken into account to ensure that the WOB is kept less than the values displayed in these figures at the corresponding bit depths.

Chapter Five

Conclusion and Recommendations

5.1 Conclusion:

- Torque and drag are key factors in the planning and drilling of horizontal wells.
- String torque/drag should be analyzed based on examination of distinct friction factors for the cased hole and open hole. Torque/ drag friction factors can vary significantly from their default values and should be derived from field data for each hole section.
- Both cased hole and open hole friction factors can vary substantially between wells and even in single hole sections of a given well as a result of wellbore condition with regard to cutting beds, etc. Collection and analysis of field data is critical to being able to quantify these variations.
- Drag prediction is dependent on accurate diagnosis of frictional drag in the well and the extent of buckling in the string. Moderate sinusoidal buckling can be tolerated and does not lead to severe increases in drag. Extensive helical buckling of the string should be avoided and can lead to severe drag and lock up.
- The maximum weight encountered during drilling of the horizontal well is 150 kip during rotating on bottom at the depth of 6040 ft. The maximum weight that can be provided by the drilling rig used to drill the horizontal well is 690 kip which indicates that the maximum load to be encountered during drilling of the horizontal well is within the acceptable range that can be handled by the drilling rig.
- The maximum torque encountered during drilling of the horizontal well is 12400 ft-Ibf during tripping out at the depth of 6040 ft. The maximum torque that can be provided by the drilling rig used to drill the horizontal well is 37000 ft-Ibf which indicates that the maximum torque to be encountered during drilling of the horizontal well is within the acceptable range that can be handled by the drilling rig.

5.2 Recommendations:

- The wellplan software for all drilling operation it is highly recommended to be the evaluation method in universities, research center and companies.
- Recommended to use wellplan software to group of well in Sudan oil field to get better analysis for T&D
- At the depth of 700ft to 2600ft to avoid buckling problem recommended using stiff tubulars in the well such as heavy weight drill pipe.

References

1. J.c. Rastogi R.D, BadgyanA. K, MehraChiman Lal (1994): Drilling operations manual.

2. Johancsik, C.A., Friesen, D.B. and Dawson. R., "Torque and Drag in Directional Wells–Prediction and Measurement", IADC/SPE 11380, *IADC/SPE Drilling Conference*. New Orleans, February 1983.

3. Halliburton, 2001. Wellplan (2000). [Computer Program] Landmark Graphics Corporation.

4. Halliburton, 1996. Compass (1996). [Computer Program] Landmark Graphics Corporation.

5. Aarrestad, T.V., "Effect of Steerable BHA on Drag and Torque in Wells", SPE 20929,*Europec 90*. The Hague, Netherlands, 22-24 October 1990.

6. Aadnoy, B.S., Djurhuus J.,-Theory and application of a new generalized model for Torque and Drag‖, SPE/IADC 114684, presented at the SPE/IADC Asia Pacific Drilling Tech. Conf. and Exhibition, Jakarta, Indonesia, August 2008.

7. Rabia, (2002) Well Engineering and Construction entrac consulting.

9. T.a.Inglis: "Directional Drilling", Petroleum Engineering and Development Studies, November 1987.

10. Steinar Bakke and Jun Dauday 98 (Introduction to DD).

11. Aarrestad T. V, and Blikra H., "Torque and Drag – Two Factors in Extended Reach Drilling", SPE 27491, IADC/SPE Drilling Conference. Dallas, February 15-18 1994.

12. Sheppard, M.C. Wick, C., Burgess, T. ―Designing well Paths to Reduce Drag and Torque‖, SPE Drilling Engineering, December 1987.

13. Aguilera, Roberto (1991) horizontal oil drilling.

Appendix: Wellplan T&D Equations

1-Torque is calculated using the following equation:

$$\tau = F_N r \mu \frac{|A|}{|V|}$$

Where:

τ = Torque

F_N= Side or normal force

μ = Coefficient of friction

r = Radius of component (for collars the OD of the collar is used for drill pipe, heavy weight and casing, the OD of the tool joint is used for stabilizers the OD of the blade is used)

$$|A| = \text{Angular speed} = \text{diameter} * \pi * \frac{\text{RPM}}{60}$$

$$|V| = \text{Resultant speed} = \sqrt{(T^2)} + \sqrt{(A^2)}$$

2- Drag is calculated using the following equation:

$$F_D = F_N \mu \frac{|T|}{|V|}$$

Where:

F_D= Drag force

3- Axial force:

The T&D analysis uses two calculations for axial force. In checking for the onset of buckling, the buoyancy method is used. This is because the Critical Buckling Force calculations are based on the same assumptions regarding hydrostatic pressure. For stress calculations, the pressure area method is used.

Buoyancy method (used to determine buckling)

$$F_{axial} = \Sigma\left[LW_{air}\cos(inc) + F_{drag} + \Delta F_{area}\right] - F_{bottom} - W_{WOB} + F_{BS}$$

Pressure area method (used to calculate stress)

$$F_{axial} = \Sigma\left[LW_{air}\cos(inc) + F_{drag} + \Delta F_{area}\right] - F_{bottom} - W_{WOB}$$

Where:

L= Length of drill string hanging below point, ft

W_{air} = Weight per foot of the drill string in air, lb/ft

inc = Inclination, degrees

F_{bottom} = Bottom pressure force, a compression force due to fluid pressure applied over the cross sectional area of the bottom component

F_{area} = Change in force due to a change in area at junction between two components of different cross sectional areas, such as the junction between drill pipe and heavy weight or heavy weight and drill collars. If the area of the bottom component is larger the force is a tension, if the top component is larger the force is compression.

W_{WOB} = Weight on bit, lb (0 for tripping in & out)

F_{drag} = Drag force, lb

F_{BS} = Buckling Stability Force = (Press External * Area External) – (Press Internal * Area Internal)

Pipe:

Area External = $\pi/4$*(0.95*BOD*BOD + 0.05*JOD*JOD)

Area Internal = $\pi/4$*(0.95*BID*BID + 0.05*JID*JID)

Collar:

Area External = $\pi/4$*(BOD*BOD)

Area Internal = $\pi/4$*(BID*BID)

Press External = Annulus Surface Press + Σ (Annulus Press Grad * TVD)

Press Internal = String Surface Press + Σ (StringPressGrad * TVD)

4. Additional side force due to buckling calculations:

Once buckling has occurred, there is an additional side force due to increased contact between the wellbore and the drill string. For the soft string model, the following calculations are used to compute the additional side force. These calculations are not included in a stiff string analysis because the Stiff String model considers the additional force due to buckling in the derivation of the side force.

Sinusoidal buckling mode:

No additional side force due to buckling is added.

Helical Buckling mode:

$$F_{add} = \frac{rF_{axial}^2}{4EI}$$

Where:

F_{add} = Additional side force

F_{axial} = Axial compression force calculated using the buoyancy method

I = Young’s modulus of elasticity

r = Radial clearance between wellbore and work string

E = Moment of Inertia.