University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Petroleum Engineering/ Drilling and Well Technology	Spring semester, 2013. Open access
Writer: *Wasal Ahmed Abbasi*	……………………………………………….. (Writer)
Faculty supervisor: *Mesfin A. Belayneh,* External supervisor(s):	
Title of thesis: **Analysis of the Factors that affect the target depth in deviated wells**	
Credits (ECTS):	
Key words: Directional Drilling Survey calculations Methods Errors in Azimuth and Inclination Pressure and Temperature Effect	Pages: 83 + Enclosure: 02 CDs Stavanger, 15/06/2013 Date/year

Acknowledgement

First of all special thanks to my father, who motivated his children towards quality of education, and to my family whose prayers and moral support made me to achieve this goal. I would also like to thank my friends, mates and my teachers who have always been very supportive during my studies. Last but not least, a very special thanks to my supervisor ***Mesfin A. Belayneh*** who has helped me in improving my abilities and confidence during my studies and has been a great motivation to accomplish my degree.

Abstract

This thesis presents the analysis of the factors that affect the target depth. Depth measurement is one the most important parameter and most difficult to identify. For the target depth measurement key factors that affecting the drill string that is pressure temperature, axial load, drag and the errors in the surveys is described in the study. For the study a realistic well geometry and drilling string parameters were considered. WELLLPLAN ™ software and Microsoft Excel are used for the calculation and graph.

In the analysis phase most of the factors that affect the target depth in deviated well are discussed and the emphasis is on the key factors that are the major contributors in wellbore position uncertainty. This study presents two major areas:

- The first one is sensitivity study in order to investigate the effect of survey uncertainty on various parameters such as dogleg severity, vertical section, tortuosity and torque. This was done by introducing +/- 10% error in inclination and azimuth. The result is compared with the reference survey well data.

- The second part is to calculate the elongations due to mechanical loading, thermal and hydraulic effects.

The analysis was under various drilling operations like "tripping in", "rotate on bottom", "tripping out", "rotate off bottom" and "slide drilling".

The details of the analysis result shown in Chapter §3. Here some of the result is presented as the following:

a) +/-10% error affects on the graphs like dogleg severity, vertical section and tortuosity and deviate the wellpath from the reference well data. It also shows the torque will increase and decrease due to effect of the errors.
b) Elongation due to pressure effect on the reference geometry is about 10 ft. for tripling in and 12 ft. for tripping out operation.
c) Elongation due to temperature on the reference geometry is 8.23 ft.
d) Loading effect on the reference geometry is from 5 ft. for sliding drilling and to 8.4 ft. for tripping out.
e) Total elongation due to key factors on the reference geometry is 23ft. for sliding drilling, 25.5 ft. for tripping in and rotate on bottom and to 28.6 ft. for tripping out.

Contents

List of Figures

List of Tables

CHAPTER 1: INTRODUCTION

At present, energy demand is increasing and population growth is also increasing. Due to this reason energy consumption jumps every year. As the energy demand increases, there is a need to exploit the reservoir more efficiently. To increase the productivity and the exposure to reservoir, more wells need to drill with the help of different techniques and technologies. Currently, one of the major applications of directional drilling is to exploit the wells economically by drilling many wells from main wellbore and exploits the reservoir efficiently with more exposure to the pay zone. Figure 1 is a typical drilling environment and one can observe more challenges in directional wells than vertical wells.

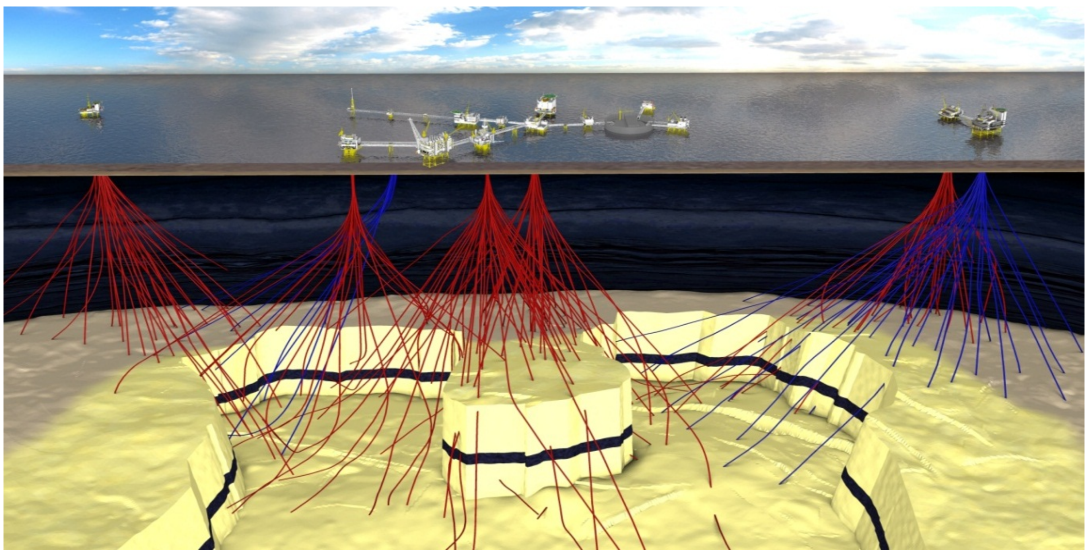

Figure 1 Ekofisk Fields Platform Ad Wells [20]

Directional drilling technology gained more importance and development by the mid of 19th century and became essential element in oil industry. More advanced tools and technologies have been implemented to gain the maximum benefits. The directional driller has the responsibility to supervise the operations at well site and for pointing the well along the proposed well path. It is very important to direct the well according to the well plan in order to successfully intersect the target depth. Here, the main focused on the problem while drilling a directional well is to direct the well along the well path to intersect the correct target depth and avoid collision with other wells. In reaching and intersecting the exact target depth, it is necessary to follow the planned path of the well. It is difficult to keep the well exactly as proposed plan well path, as there are always uncertainties in well placement. To overcome these uncertainties many survey tools and techniques have been introduced but the errors in these tools affect the trajectory as well as on the different loading.

In this study the sensitivity analysis of the factors that affect the target depth have done by assuming +/-10% error in directional survey (i.e. inclination and azimuth). Analysis describes how error in survey will impact on loadings for example torque and drag etc. Analysis also shows that which element is critical for loadings and how it will impact on loading while others don't have major affect on loadings. Drilling operations like tripping in rotate on bottom; rotate off bottom, tripping out and slide drilling have analyzed and which operation has more affected by errors.

1.1 Problem formulation

Drilling is making a hole in order to reach a reservoir and produce hydrocarbon. Target depth is one of the major elements to identify. However, due to several factors, there could be a possibility for the drilling operation could not reach the target. If this is the case, then all the drilling companies will loose a large amount of money. If the reservoir is not produce efficiently and hitting the geological target is not correct for example sometime errors in survey data result in

- Coring points at the top of the reservoir section had missed
- Bit had drilled too far and passed the pay zone and drilled water zone.

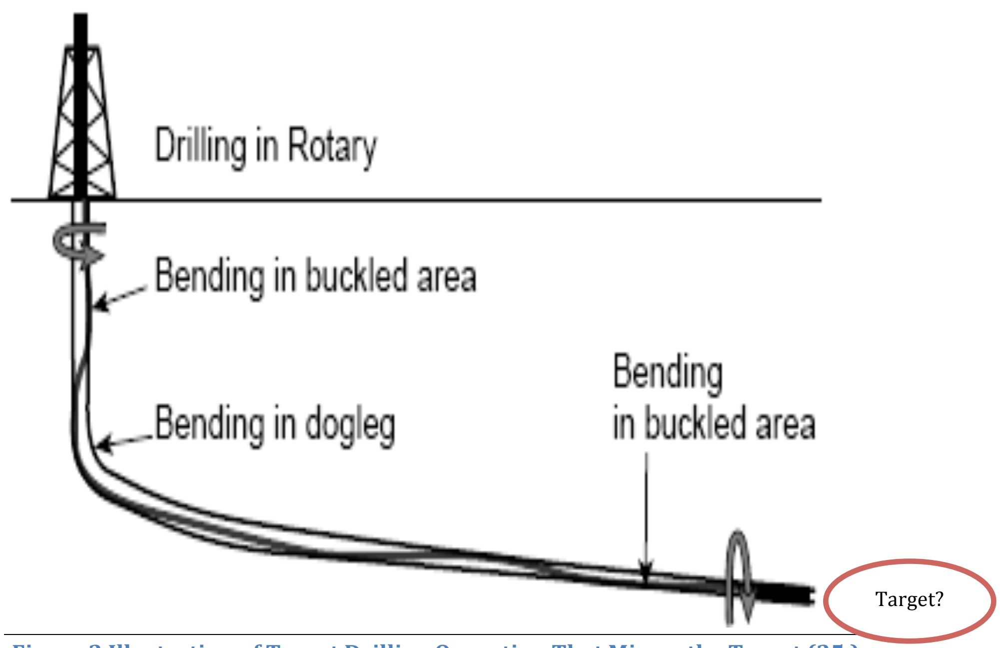

Figure 2 Illustration of Target Drilling Operation That Misses the Target (25)

As shown in the (Figure 2), the drill string is buckled. The drilling string is not reaching the reservoir. Therefore, during design it is important to consider all aspects that affect the target uncertainty.

Figure 3 shows a spider plot of a surface section planned versus the actual drilled using Wireline Gyro-Single-Shot survey instrument.

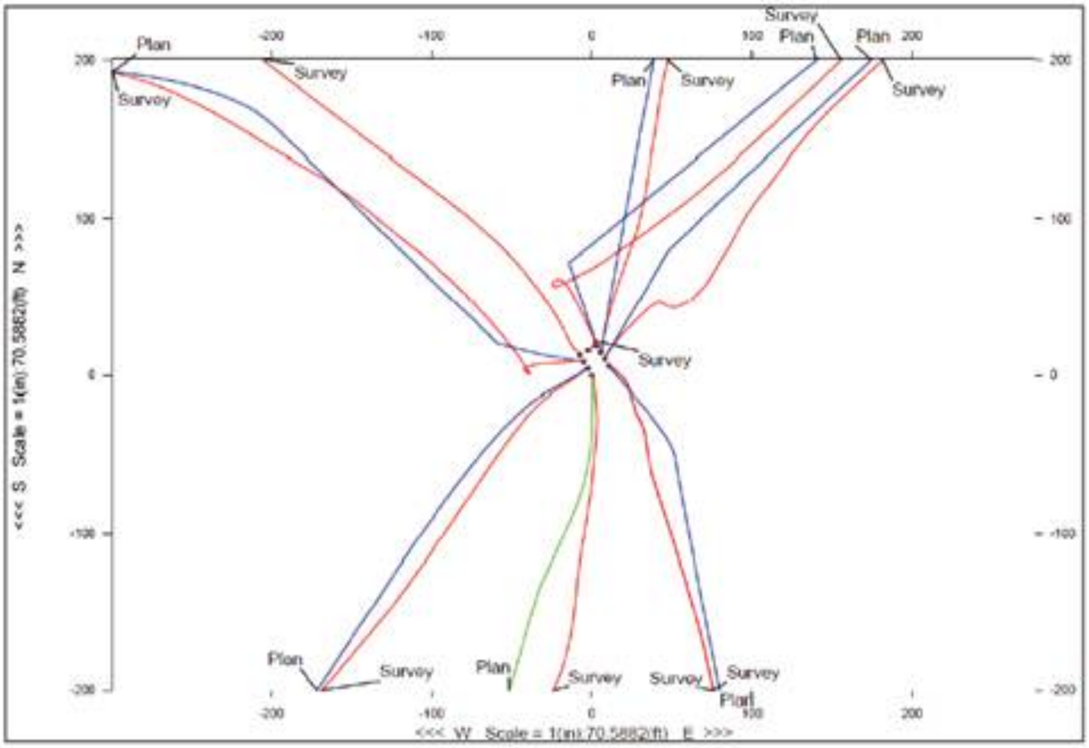

Figure 3 Wellbore Geometry- Planned vs. Actual Drilled using Gyro Single-Shot [12]

This shows that the comparisons of the planned and the real trajectory can cause several uncertainties on the design parameters including torque and drag and this as result do have effect on the position of the drill string. In addition, the loading also causes additional elongation or contraction. This thesis work deal the sensitivity analysis of factors that affect survey uncertainty this study will analyses the problem using Wellplan simulator by taking a real drilling well and drilling operational condition.

1.2 Objective of the thesis

The objectives of the thesis are as follows:

- To review directional drilling applications, types of profiles, survey calculation methods, directional surveying tools and sources of errors.
- To review and perform depth measurement errors like drill pipe stretch due to its own weight, elongation due to pressure, temperature.
- To study how directional survey errors effect on torque and drag.
- Sensitivity analysis of the effect of the errors in directional surveys.

1.3 Scope of the thesis

All companies are struggling to overcome the challenge to direct the well as the planned trajectory to intersect the correct target depth by minimizing the errors in surveying tools and loading effect on the drilling string. To drill well as planned trajectory is almost not possible there are always errors, which causes uncertainties in wellbore positioning.

The scope of the thesis is limited in analysis of the problem with wellplan and hand calculations of the result of the Well plan.

CHAPTER 2: LITERATURE REVIEW

Literature review explain the application of directional drilling, survey calculation method to calculate the wellpath course at different two-survey station. Major instrument and tools have discussed which are using to survey the borehole. The errors cause by the tools and other factors also described. The models to calculate elongation due to pressure, temperature axial and drag elements are presented.

2.1. Directional Drilling

The American petroleum institute defines directional drilling as

> "The art and science involving the intentional deflection of a wellbore in a specific direction in order to read a predetermined objective below the surface of the earth" [1]

Directional drilling conventionally defined as a procedure for drilling a non-vertical hole through the earth [2]

2.1.1. Applications of Directional Drilling

There are number of application of directional drilling which have been develop with time and can be grouped as:

1. Sidetracking
2. Horizontal drilling
3. Drilling to avoid geological problems
4. Offshore development drilling
5. Controlling vertical holes
6. Drilling beneath inaccessible locations
7. Drilling relief wells to control blowing wells crooked
8. Non-petroleum uses

1) Sidetracking
During the drilling if any obstacle halt the operation for example failure of drilling string or falling of any object in the wellbore, which cannot be fish, and no further progress can be made. To overcome this problem we drill around the obstruction and later it was realized that sidetracking is much cheaper than abandon the hole and start again [3].

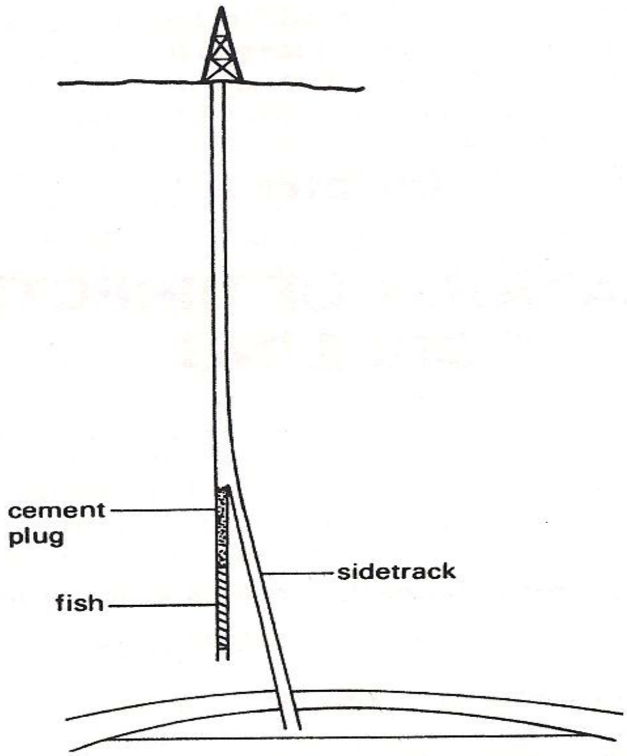

Figure 4 Side Tracking [3]

2) Horizontal drilling

Wells that are drilled more than 60° are horizontal wells and more complex and difficult to drill. However there are certain benefits in horizontal wells. These includes:

- Increasing the drainage area of the platform.
- Prevention of gas coning or water coning problems.
- Increased penetration of the production formations.
- Increasing the efficiency of enhanced oil recovery (EOR) techniques.
- Improving productivity in fractured reservoirs by intersecting a number of vertical fractures [3]

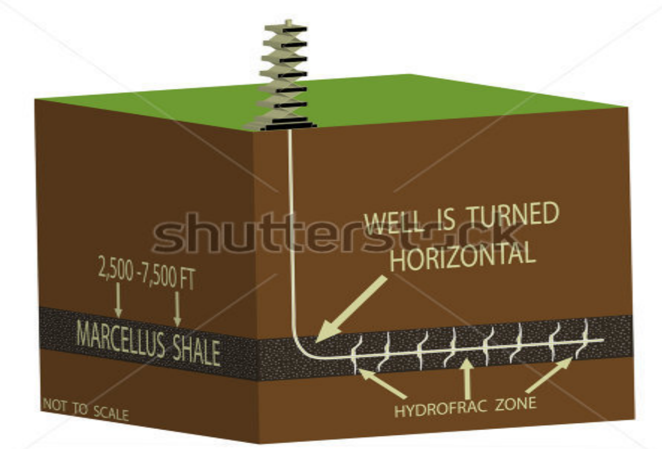

Figure 5 Horizontal Drilling [17]

Carefully studied the risk and the potential benefits before drilling the well is vital. The increased productivity should justify the additional cost spent before drilling the horizontal well.

3) Drilling to avoid geological problems

Geological problems like Fault and salt domes difficult of drill vertically because of various difficulties for example salt dome can be directly above the reservoir, so that a vertical well would have to penetrate the salt formation before reaching the target. Drilling through salt section leads certain drilling problems such as lost circulation, large washout, corrosion and changing the chemistry of mud. To avoid these problems it is wiser to drill around the salt dome as shown in figure [3]

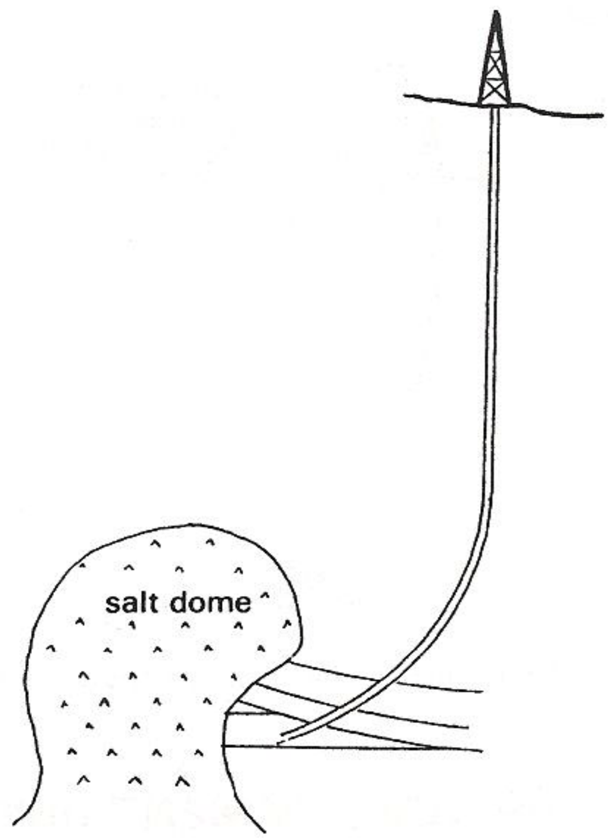

Figure 6 To avoid geological problems [3]

Another geological problem that has been seen from experience that to drill a vertical well through a steeply dipping fault plane there is a risk of deflecting a bit passing through the fault or slippage along that plane. To overcome this problem a directional well is a wise choice [3].

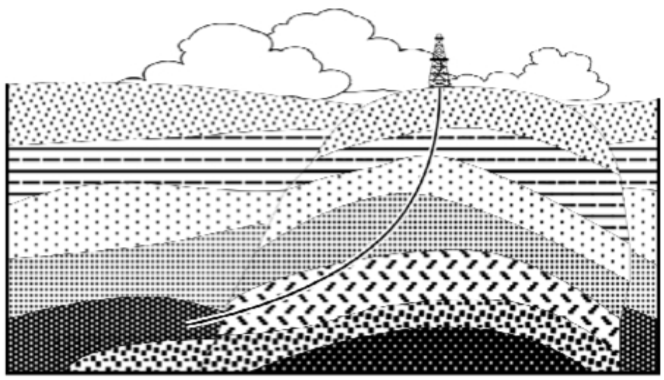

Figure 7 to avoid geological promblems [0]

4) Offshore development drilling

One the key application of directional drilling is the offshore development drilling. Drilling of multiple wells from a single offshore location is the most common and economical in Gulf of Mexico, North Sea and other areas of the world where the hydrocarbon deposits are located beyond the read of land-based rigs [2].

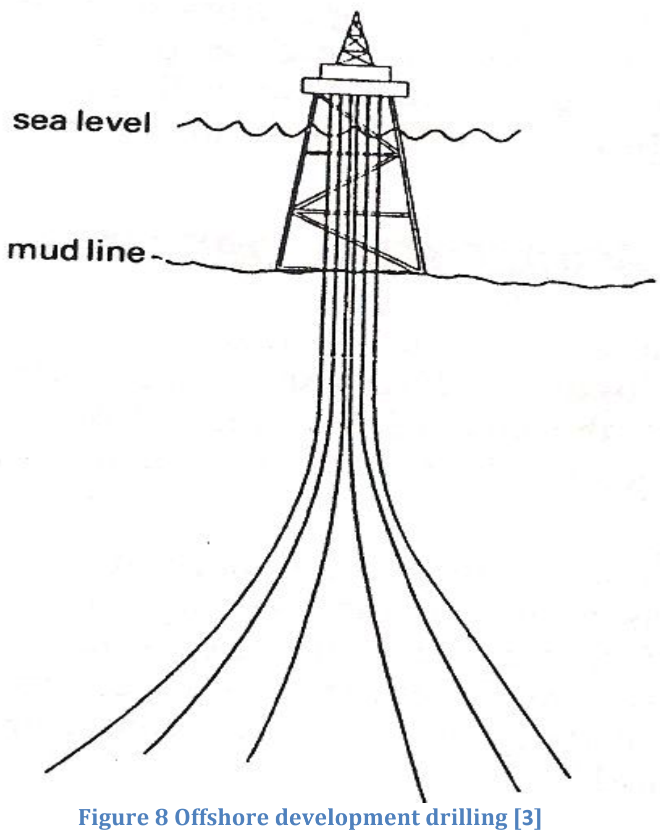

Figure 8 Offshore development drilling [3]

5) Controlling vertical holes

Directional drilling techniques have used to control or prevent the deviation from planned course while drilling a vertical well to keep the wells straight and vertical.

Some formations can deflect the bit from its planned wellpath, which can be corrected by varying the drilling parameters or changing the bottom hole assembly (BHA) [2].

6) Drilling beneath inaccessible locations

Some reservoirs situated near the land, beneath natural or man made obstruction and sensitive areas where environment is the risk. To drill these areas maybe permission will not be granted. In such cases, it is possible to exploit the reservoir by directional drilling from the surface location outside the restricted area [2].

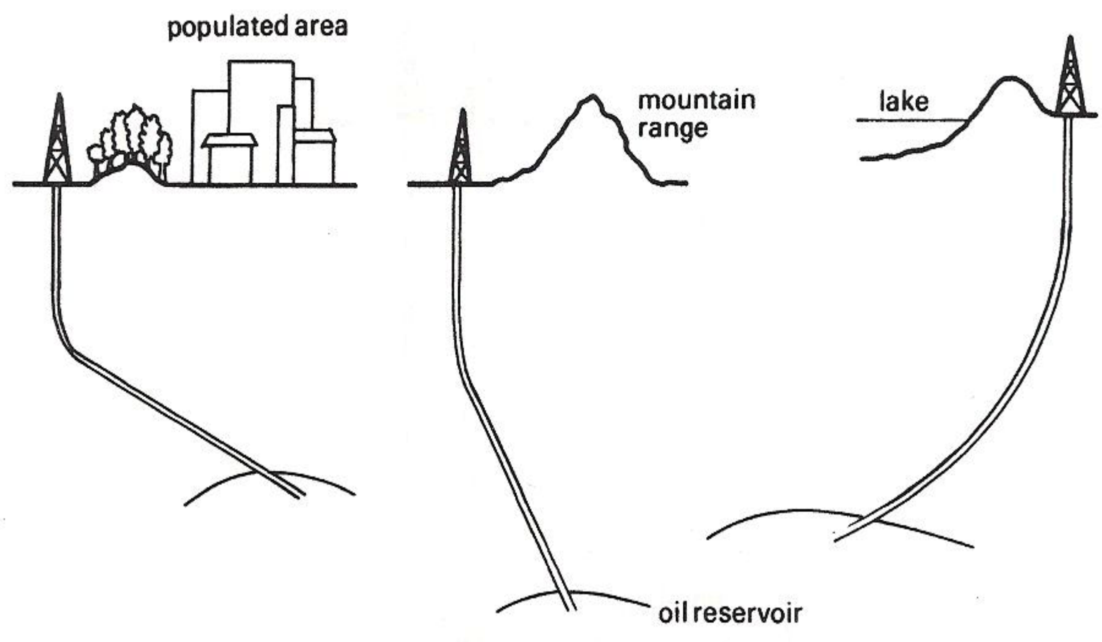

Figure 9 Drilling inaccessible locations [3]

7) Drilling relief wells to control blowing wells crooked

If blowout damage or destroy the platform in such a way that capping operations are impossible, relief wells are drilled to control the blowout. Often relief wells are drilled from the surface locations to ensure that blowout is killed [3].

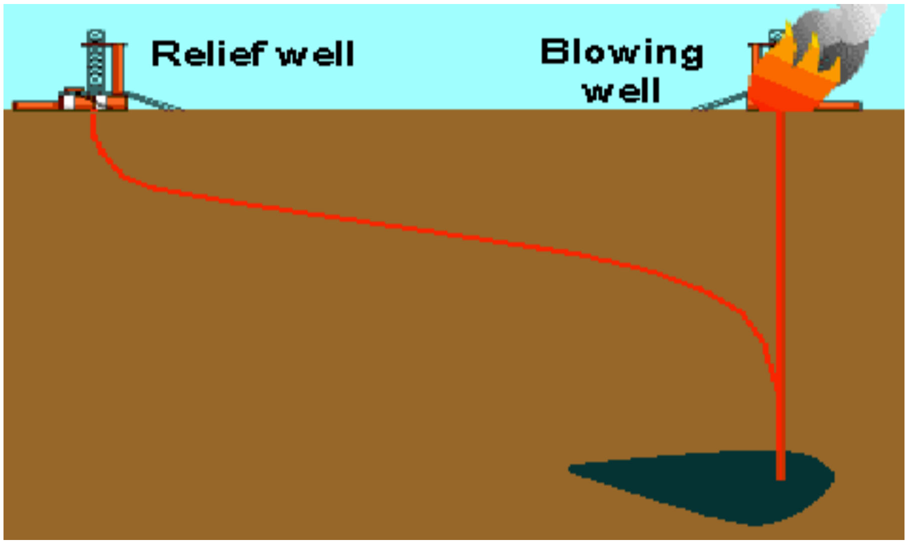

Figure 10 Drilling relief wells [24]

2.1.2. Profile types

The wellpath may have a different type of profile. The main types are discussed below

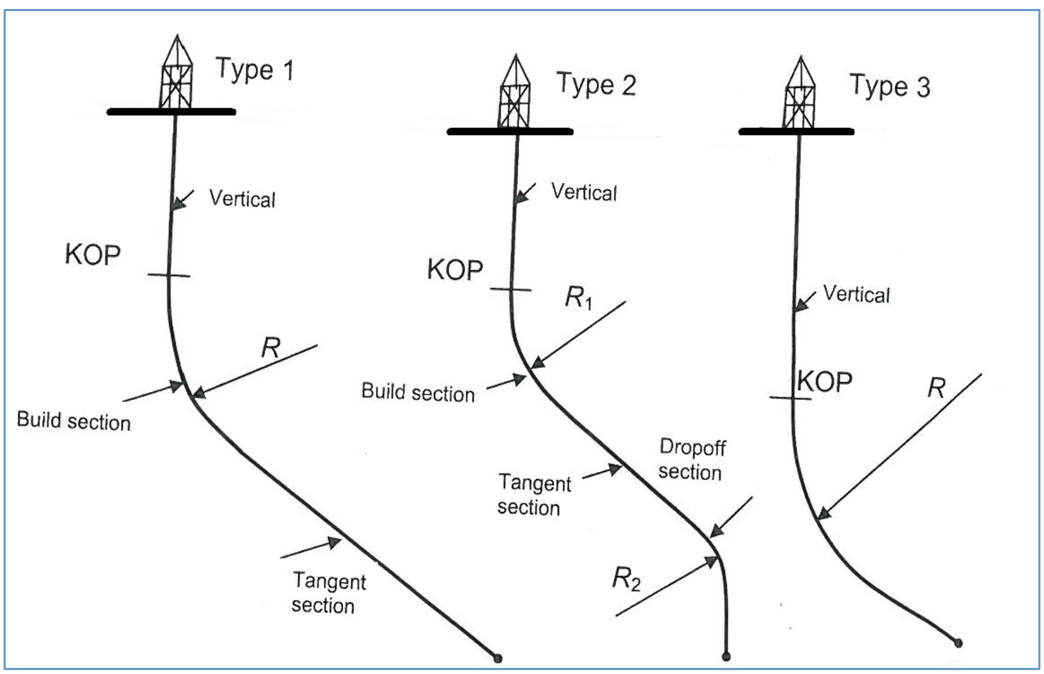

Figure 11 types of wellbore profiles [18]

1) Type I (Build and Hold)

Most common and the simplest profile for directional well also called L profile wells as it's L-shaped as shown in Figure 11. The Type I is drilled vertical from the surface down to the kick off point (KOP), From the KOP the well is deviated steadily and smoothly to a required inclination (Build). Then the establish inclination and direction are maintained (Hold) while drilling to target depth. Generally this method is employed when a large horizontal displacement is required or when drilling shallow target depths [3].

2) Type II (Build, Hold and Drop)

In this profile there is vertical section, kick-off point, build-up section, tangent section same as profile type I in addition drop-off section and hold section to target depth. This type also called S profile wells, as it is S- shaped. After reaching tangent section as in profile type I, profile enters a drop-off section where the inclination is reduced steadily and smoothly as shown in Figure 11. At the end of drop-off section the well is near vertical and finally the angle and direction is maintained till we reach the target depth. This profile type is more challenging than type I because of problems due to drop-off section just above the target and the extra torque and drag due to additional bending. Usually this method is used when the target is deep and horizontal displacement is small, hit multiple targets and to avoid the faulted region [3].

3) Type III (Deep kick-off and Build)

In this profile there is vertical section, deep kick off and a build up to target and also known as deep kick off wells or J profile well as it shaped looks like J. this profile is same like profile type I except the kick off point is at deeper depth. The deflection starts after the kick off point and the inclination start built through the target interval (Build). The use of this well profile is common in drilling salt domes or sidetracking [3]

4) Horizontal Wells

This profile consist of anyone of the above profile in addition a horizontal section within the reservoir also called horizontal directional well or horizontal wells. As illustrated in Figure 12, the horizontal well profile there are more than one build-up sections used to achieve the 90° inclinations. The horizontal well is a well in which the inclination reached to 90° through the reservoir section and have important applications in improving the production from the certain reservoir that would not be economical otherwise. Horizontal drilling is used to produce thin reservoir zones having water or gas coning problems and to maximize the production [3]

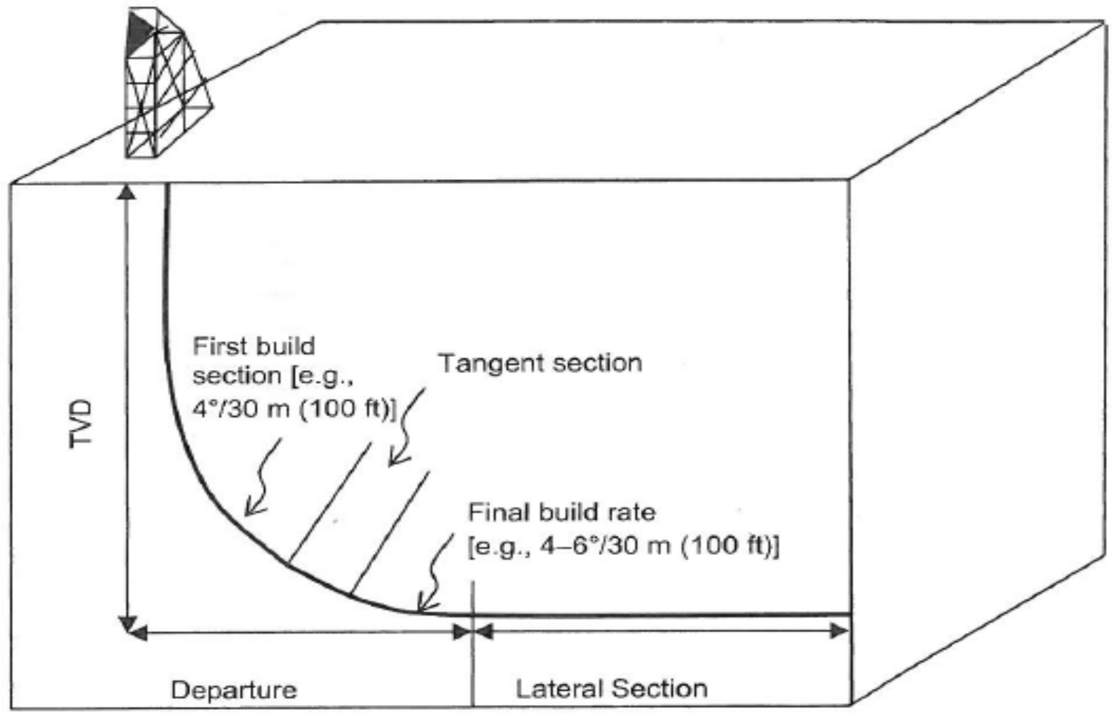

Figure 12 Horizontal well profile [18]

5) Designer Wells

Figure 13 is another well geometry, which are called designers wells. These wells were drilled in geological complex Gullfaks field in the Norwegian sector of the North Sea. The field has complex reservoir, which many normal and reverse faults. Typically, the designer types wellpath involve a strong change in hole azimuth combined with relatively some change in well inclination. This wells are classified as ''designer well'' (Eck-Olsen,et al 1995)

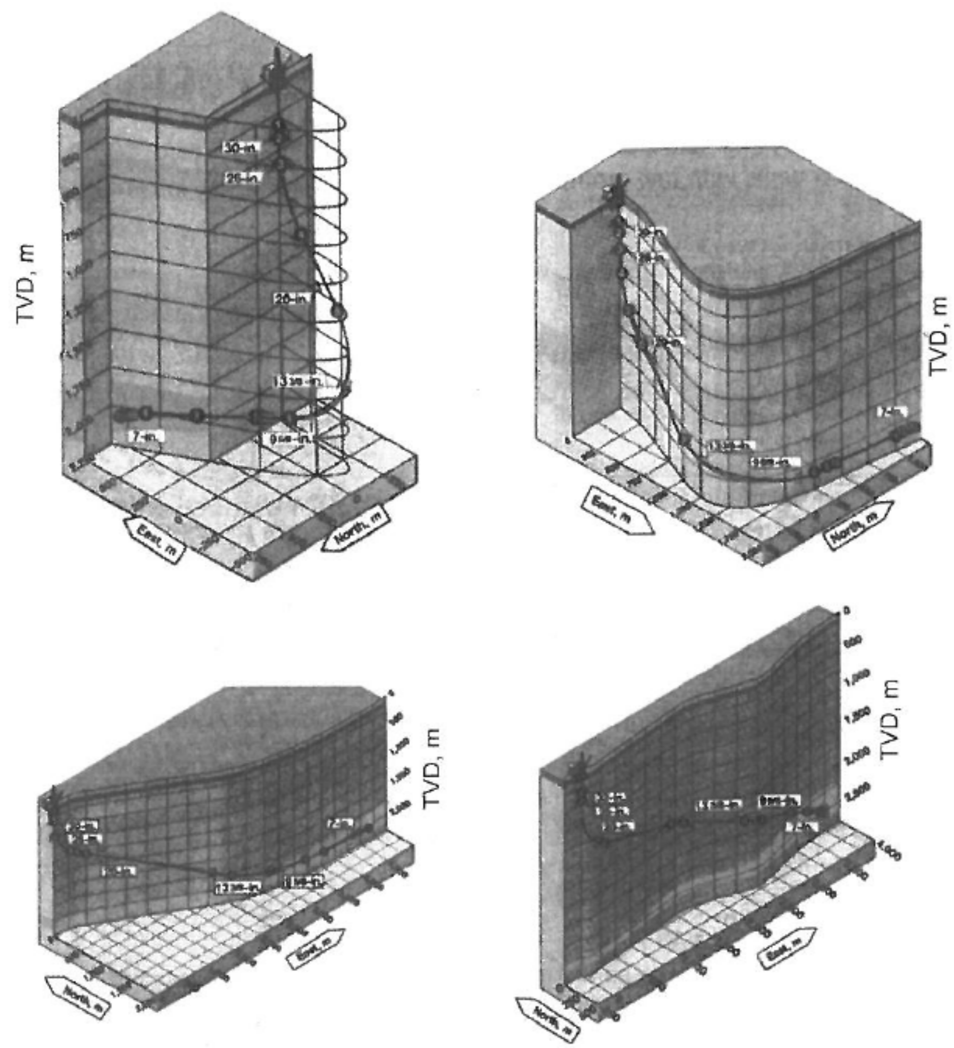

Figure 13 Example of designer wells in Gullfaks field (Eck-Olsen, 1995)

2.2. Survey Calculations

In directional drilling to determine the actual position of the wellbore as compared to surface location directional survey is needed. For this purpose the incremental distances ΔV, ΔE, ΔN between the successive survey stations must be computed[3]. By using mathematical calculations the coordinates of the lower station can be computed if the coordinated of the upper station is known [3]
How good assumed trajectory used in model estimates to the actual trajectory in the borehole gives the accurate final coordinates.

2.2.1. Calculation techniques

There are several techniques to calculate the survey data, some of them are accurate while other maybe create some error for a given situation. In this section inclination and azimuth will be represented by α and β respectively with the subscript 1 denoting the upper station and 2 denoting the lower station[3]. The course length represented by L between the two stations and in each method course length L has to be resolved in both the vertical and horizontal planes. Incremental distances between stations are ΔV, ΔN and ΔE along axes (i.e. vertical, northing and easting [3]

Some of the method used in the industry to calculate survey calculation:

- Tangential Method
- Balanced Tangential Method
- Average Angle Method
- Radius of curvature method
- Minimum curvature method

2.2.2. Tangential Method

In this method wellpath take as straight line that is tangent to lower survey station. The actual wellbore is curved line as shown in figure below. The tangent drawn at the lower survey station is assumed wellbore course and α_2 is the required inclination, which is same as inclination at lower station [3]

$$\Delta V = L\cos\alpha_2 \tag{2.1}$$

$$\Delta N = L\sin\alpha_2\cos\beta_2 \tag{2.2}$$

$$\Delta E = L\sin\alpha_2\sin\beta_2 \tag{2.3}$$

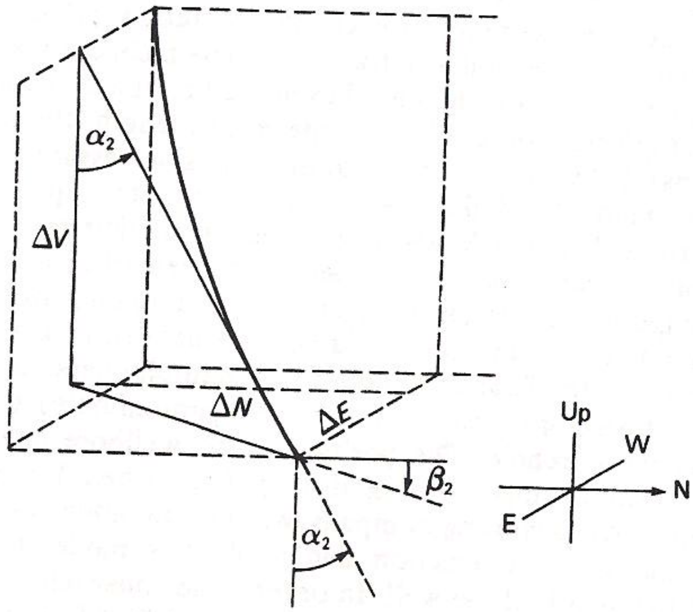

Figure 14 Tangential model [3]

It is obvious from the figure that this method gives large errors in Wellbore position (measured depth and departure).

2.2.3. Balanced Tangential Method

This method assumes the actual wellpath can be approximated by two straight-line segment of equal length. The upper segment is defined by α_1 and β_1, while the lower segment defined by α_2 and β_2 [3]

$$\Delta V = \frac{1}{2} L(\cos\alpha_1 + \cos\alpha_2) \quad (2.4)$$

$$\Delta N = \frac{1}{2} L(\sin\alpha_1 \cos\beta_1 + \sin\alpha_2 \cos\beta_2) \quad (2.5)$$

$$\Delta E = \frac{1}{2} L(\sin\alpha_1 \sin\beta 1 + \sin\alpha_2 \sin\beta 2) \quad (2.6)$$

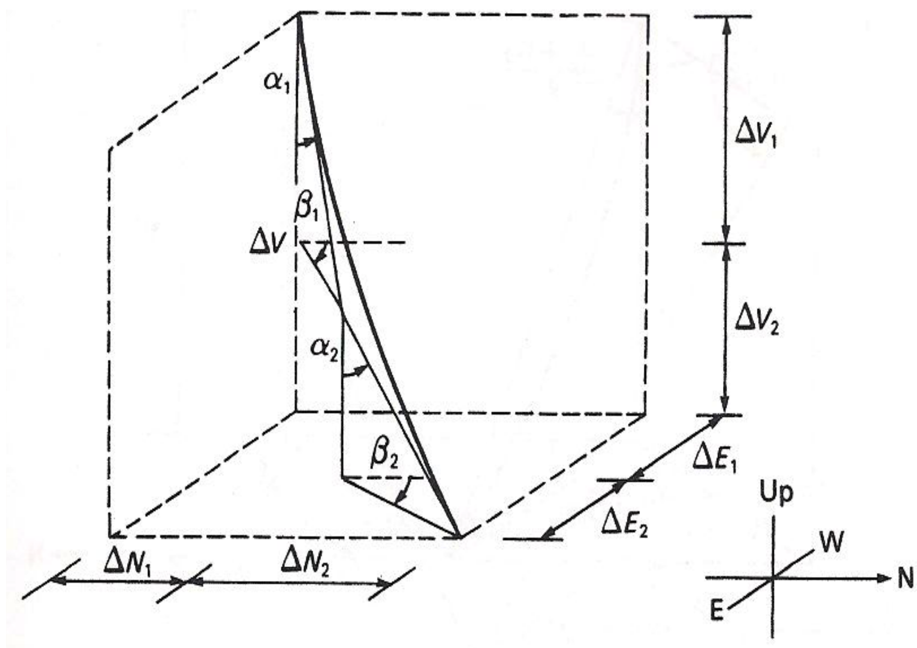

Figure 15 Balanced tangential model [3]

This method is more accurate than tangential method but still having some error, which can be improved by applying ratio factor.

2.2.4. Average Angle Method

In this method, the inclination and azimuth at lower and upper survey stations are mathematically averaged, and then the wellbore course is assumed to be tangential to the average inclination and azimuth [3]

$$\Delta V = L\cos\left(\frac{\alpha_1+\alpha_2}{2}\right) \quad (2.7)$$

$$\Delta N = L\sin\left(\frac{\alpha_1+\alpha_2}{2}\right)\sin\left(\frac{\beta_1+\beta_2}{2}\right) \quad (2.8)$$

$$\Delta E = L\sin\left(\frac{\alpha_1+\alpha_2}{2}\right)\sin\left(\frac{\beta_1+\beta_2}{2}\right) \quad (2.9)$$

This method is gives fairly accurate result and easy to calculate with the aid of hand-held calculator. This method can be use in the field if a programmable calculator or computer is not available. This method is not reliable for vertical wells.[3]

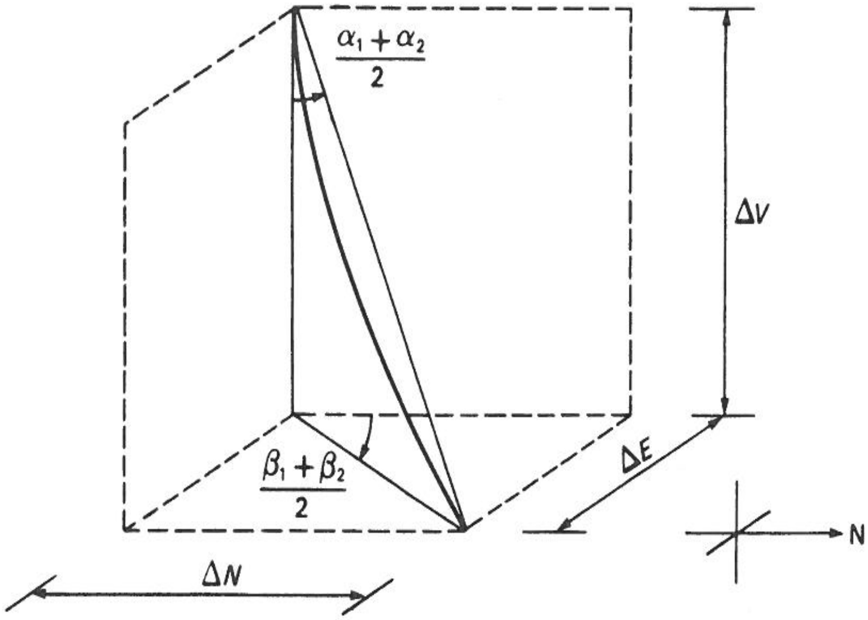

Figure 16 Average angle model [3]

2.2.5. Radius Of Curvature Method

Then method is assumes that the wellpath is not a straight line but a circular arc when viewed in both the vertical and horizontal planes. The arc is tangential to inclination and azimuth at each survey station. The wellpath can therefore be described as an arc in vertical plane, which is wrapped around a right vertical cylinder [3]

In the vertical plane:

$$\mathrm{AOB} = \alpha_2 - \alpha_1$$

Therefore,

$$\frac{\alpha_2 - \alpha_1}{360} = \frac{\mathrm{L}}{2\pi\mathrm{R}}$$

The radius is in the vertical plane. R can be found from:

$$\mathrm{R} = \frac{\mathrm{L}}{\alpha_2 - \alpha_1}\left(\frac{180}{\pi}\right)$$

$$\Delta\mathrm{V} = \mathrm{R}_v\,(\sin\alpha_2 - \sin\alpha_1) \qquad (2.10)$$

Substituting for R_v , the vertical increment becomes

$$\Delta V = \frac{L}{\alpha_2 - \alpha_1}\left(\frac{180}{\pi}\right)(\sin\alpha_2 - \sin\alpha_1) \qquad (2.11)$$

The horizontal increment (ΔH) can be found from

$$\Delta H = R_v\,(\cos\alpha_2 - \cos\alpha_1) \qquad (2.12)$$

In the horizontal plane:

$$EOB = \beta_2 - \beta_1,$$

Therefore

$$\frac{\beta_2 - \beta_1}{360} = \frac{H}{2\pi R_h}$$

The radius is in the horizontal plane. R_h Can be found from

$$R_h = \frac{\Delta H}{\beta_2 - \beta_1}\left(\frac{180}{\pi}\right)$$

$$\Delta N = R_h \sin\beta_2 - R_h \sin\beta_1 \qquad (2.13)$$

$$\Delta V = R_h(\sin\beta_2 - \sin\beta_1) \qquad (2.14)$$

Substituting for R_h ,

$$\Delta N = \frac{\Delta H}{\beta_2 - \beta_1}\left(\frac{180}{\pi}\right)(\sin\beta_2 - \sin\beta_1) \qquad (2.15)$$

Substituting for ΔH,

$$\Delta N = \frac{R_v(\cos\alpha_1 - \cos\alpha_2)}{\beta_2 - \beta_1}\left(\frac{180}{\pi}\right)(\sin\beta_2 - \sin\beta_1) \qquad (2.16)$$

Substituting for R_v ,

$$\Delta N = \frac{L}{\alpha_2 - \alpha_1}\left(\frac{180}{\pi}\right)^2 \frac{(\cos\alpha_1 - \cos\alpha_2)(\sin\beta_2 - \sin\beta_1)}{\beta_2 - \beta_1} \qquad (2.17)$$

Similarly for ΔE,

$$\Delta E = \frac{L}{\alpha_2 - \alpha_1}\left(\frac{180}{\pi}\right)^2 \frac{(\cos\alpha_1 - \cos\alpha_2)(\cos\beta_1 - \cos\beta_2)}{\beta_2 - \beta_1} \qquad (2.18)$$

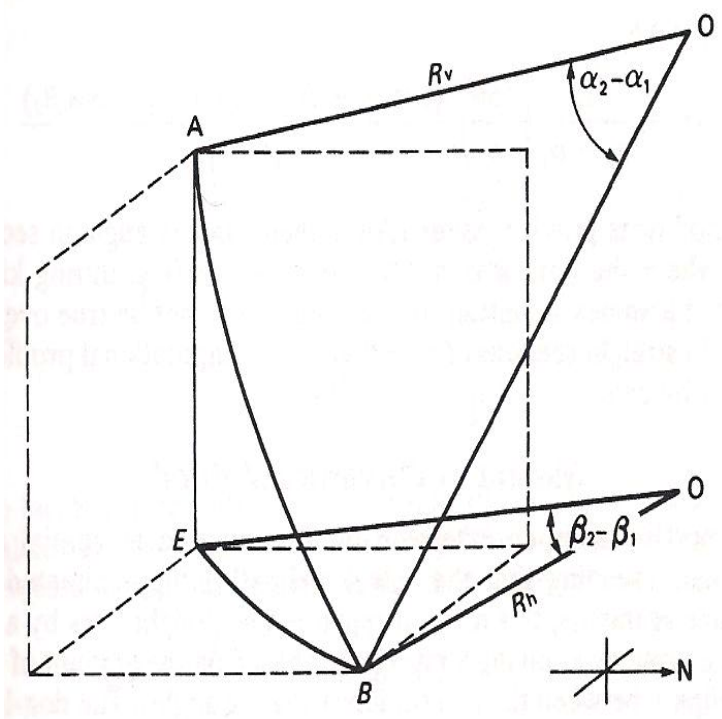

Figure 17 Radius of curvature model [3]

2.2.6. Minimum Curvature Method

Rather than assuming that two straight-line segments approximate the actual wellpath, this method replaces the straight lines by a circular arc. This is done by applying a ratio factor based on the amount of bending in the wellpath between two stations (dog-leg angle).

The dogleg angle can be calculated from

$$\phi = cos^{-1} [\cos\alpha_1 \cos\alpha_2 + \sin\alpha_1 \sin\alpha_2 \, cos(\beta_2 - \beta_1)] \qquad (2.19)$$

The ratio factor can be calculated from

$$\mathrm{F} = \frac{\mathrm{AB} + \mathrm{BC}}{\mathrm{arc\ AC}}$$

And

$$\mathrm{AB} = \mathrm{BC} = \mathrm{R}\tan(\phi|2)$$

And

$$\frac{\mathrm{AC}}{2\pi\mathrm{R}} = \frac{\phi}{360}$$

$$\mathrm{AC} = \frac{\pi\mathrm{R}\phi}{180}$$

Therefore,

$$F = \frac{2}{\phi}\left(\frac{180}{\pi}\right)\tan\left(\frac{\phi}{2}\right)$$

$$\Delta V = F\frac{L}{2}\ (\cos\alpha_1 + \cos\alpha_2) \qquad (2.20)$$

$$\Delta N = F\frac{L}{2}\ (\sin\alpha_1\cos\beta_1 + \sin\alpha_2\cos\beta_2) \qquad (2.21)$$

$$\Delta E = F\frac{L}{2}\ (\sin\alpha_1\cos\beta_1 + \sin\alpha_2\sin\beta_2) \qquad (2.22)$$

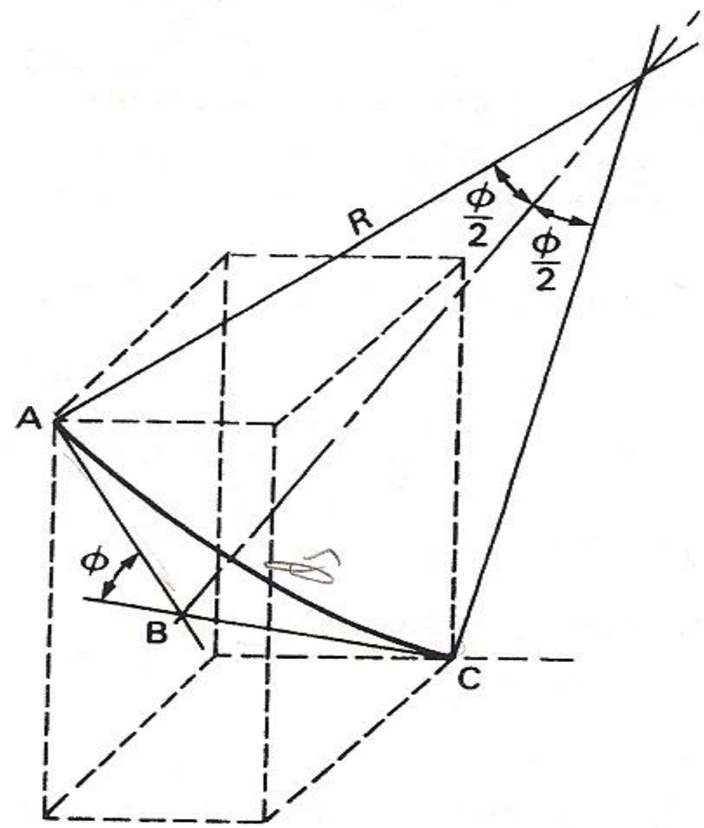

Figure 18 Minimum curvature model [3]

2.2.7. Dogleg Angle and Dogleg Severity:

As shown above in minimum curvature method the dogleg angle can be calculated from

$$\phi = \cos^{-1}\left[\cos\alpha_1\cos\alpha_2 + \sin\alpha_1\sin\alpha_2\cos(\beta_2 - \beta_1)\right] \qquad (2.23)$$

The dogleg severity is the measure of amount of the inclination or azimuth that causes a sharp bend in the wellpath and usually expressed in terms of degree per 100-ft and can be calculated from the formula

$$\mathrm{DLS} = 100\,\frac{\phi}{\mathrm{L}} \qquad (2.24)$$

Where ϕ = dogleg angle (degrees)
L = difference in survey depth (ft.)
DLS = dogleg severity (degrees/100ft.)

2.2.8. Vertical section

Vertical section is the side view of the wellpath, which tells the location of KOP (kick off point), build and drop section and plotted against TVD (true vertical depth). The purpose of the vertical section is to determine the length of the horizontal section and shows if the wellbore is above or below the proposed plan. Vertical section can be calculated from formula [3]

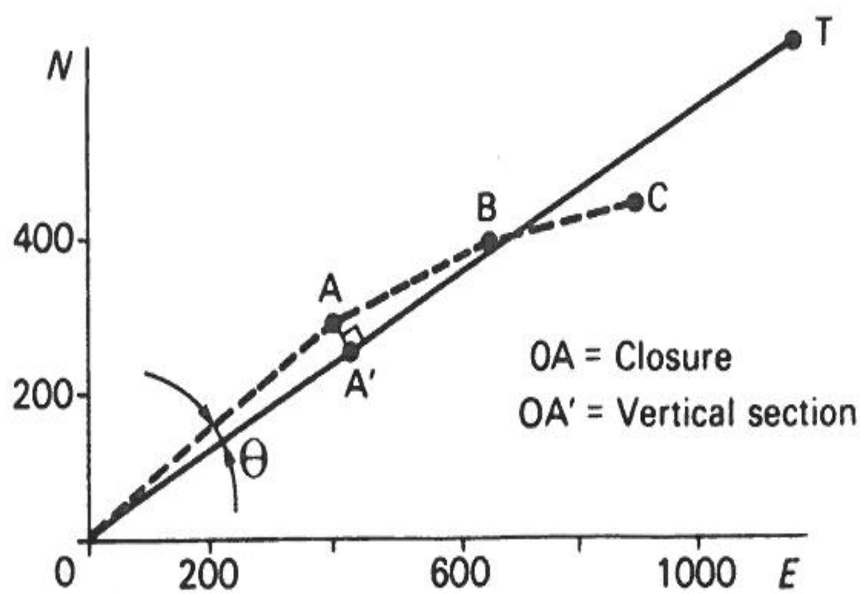

Figure 19 Vertical Section [3]

$$\mathrm{OA} = \sqrt{(\mathrm{north})^2 + (\mathrm{Easting})^2}$$

Where OA = closure of point A

$$\text{angle AON} = \tan^{-1}\left(\frac{\text{Easting}}{\text{Northing}}\right)$$

$$\text{angle TON} = \tan^{-1}\left(\frac{\text{Easting}}{\text{Northing}}\right)$$

Where TON = Target bearing

Let ϕ = TON –AON

$$\textbf{Vertical section: } OA' = OA\cos\varphi \tag{2.25}$$

The profile can be plotted on vertical plane after knowing the TVD (true vertical depth) and vertical section at each point.

2.2.9. Tortuosity

In general tortuosity is defined as the ratio of the summation of the total curvature, including build and walk, to the length of the survey stations[16].wellbore tortuosity provides the designer to see how the wellpath is undulating.

Tortuosity is given as:

$$T = \frac{\sum_{i=1}^{m} \alpha_{n-1} + \Delta D \times \delta_i}{D_i - D_{i-1}} \tag{2.26}$$

Models used various techniques i.e. “rippling” or “roughness” to stimulate the changes in the actual wellpath surveys to planned wellpath. Numerous methods are used depending on the dithering of the smooth wellpath data. These methods give an indirect formulation to measure the degree to which the wellbore is going to undulate from the planned path and is usually expressed in degree/100 ft., which is like the expression of dogleg severity [16].

Absolute and Relative Tortuosity

Absolute and relative tortuosities are used to illustrate the complexity of the wellpath. The calculation of the absolute tortuosity is based on from station to station of the normalized total curvature to a standard wellbore course length. Relative tortuosity describes the tortuosity of the wellpath relative to the absolute tortuosity.

The absolute tortuosity of the initial wellpath at survey point n is given by the following equation [16].

$$\Gamma_{(abs)_n} = \left(\frac{\sum_{i=1}^{i=n} \alpha_{adj}}{D_n + \Delta D_n}\right) \frac{deg}{100} \text{ft.} \tag{2.27}$$

Where,

$\alpha_{adj} = \alpha_i + \Delta D_i \times \delta_i$ Is the dogleg adjusted summed total inclination angle[16].

To quantify how the well trajectory is deviating after applying the artificial tortuosity, a relative tortuosity is used, which is the tortuosity of the wellbore relative to the absolute tortuosity and is given by:

$$\Gamma_{(rel)_n} = \Gamma^{tor}_{(abs)_n} - \Gamma^{notor}_{(abs)_n} \frac{deg}{100} ft. \quad (2.28)$$

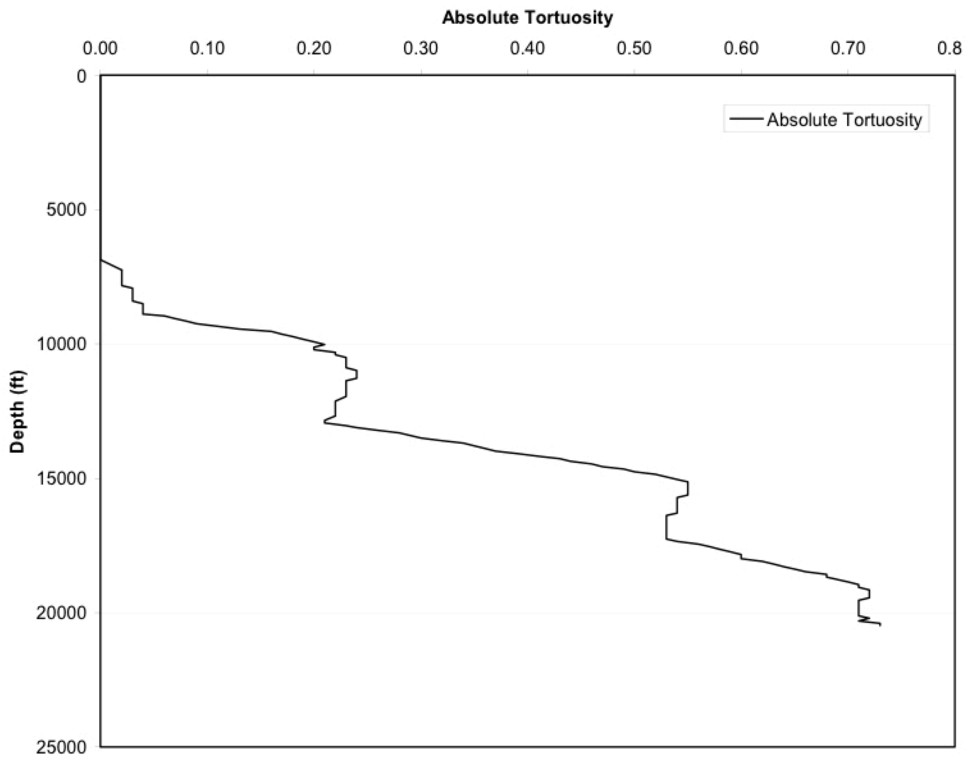

Figure 20 Wellpath Absolute Tortuosity

2.2.10. Comparisons of survey calculation methods

In the literature four-survey calculation methods have discussed to calculate the actual position of the well bore at different survey stations. Several kind of geometrical models have been used to generate a number of mathematical equations. In the models, different approaches have been used by assuming that the well path is the straight line connecting the two survey stations or it might be a curved arc. The accuracy of the final coordinates is depending on the how good well trajectory is assumed and used in the models. Using one method to calculate the well bore positioning and apply that model to all surveys in order to be consistent.

The tangential method is not recommended at all in deviated well because the well path assumed in this method is a straight line throughout the course length [(21)]. The method is shows errors because in deviated well the inclination and azimuth change significantly [(3)]. In balanced tangential method there are less errors than tangential method but still its not using in the industry because it can be improved more by applying ratio factor. The average angle method is simple and sometime is used in well site to compute the results with the aid of hand calculator but this method is not valid for vertical wells. The curvature method is more accurate than all the method mention before. In this method rather than assuming the well path as the straight line, circular arc is assumed which it more accurate [3].

The Wellplan software employs to compute the well´s trajectory, which use the minimum curvature method to calculate the points between two survey stations. Today the minimum curvature method is the industry standard for calculations. The model represents the trajectory of the well by a series of circular and straight lines. This model used complex mathematical equation for the calculation and it was difficult to calculate them with the help of hand calculator. Today the extensive uses of computer make it easy for the calculation and the model emerged as the accepted standard of the industry. The distance between two-survey stations is normally 30 to 500ft. over 100ft course length the total angle change at the time of build rates would rarely be exceed 5 degree (22).

The Table 1 shows the results from the different models presented above. In the table it is noticed that minimum curvature method and radius of curvature methods gives the same close results of ΔV, ΔN, ΔE. The tangential method has give variation in results and it is clear that it underestimates ΔV and overestimates ΔN and ΔE.

Table 1 Summary of results using each of the models [3]

	M.D.	*INC*	*AZI*	*ΔV*	*ΔN*	*ΔE*
Tangential	2000	2.0	045			
	2090	4.5	050	89.72	4.54	5.41
	2180	7.5	053	89.23	7.07	9.38
	2270	10.5	048	88.49	10.98	12.19
	2360	14.0	055	87.33	12.49	17.84
Balanced tangential	2000	2.0	045			
	2090	4.5	050	89.83	3.38	3.82
	2180	7.5	053	89.48	5.80	7.40
	2270	10.5	048	88.86	9.02	10.79
	2360	14.0	055	87.91	11.73	15.01
Average angle	2000	2.0	045			
	2090	4.5	050	89.86	3.45	3.76
	2180	7.5	053	89.51	5.86	7.36
	2270	10.5	048	88.89	8.96	10.86
	2360	14.0	055	87.95	11.89	14.94
Radius of curvature	2000	2.0	045			
	2090	4.5	050	89.85	3.45	3.76
	2180	7.5	053	89.50	5.86	7.36
	2270	10.5	048	88.88	8.95	10.86
	2360	14.0	055	87.94	11.88	14.93
Minimum curvature	2000	2.0	045			
	2090	4.5	050	89.84	3.38	3.82
	2180	7.5	053	89.50	5.80	7.40
	2270	10.5	048	88.88	9.02	10.79
	2360	14.0	055	87.94	11.73	15.02

2.3. Factors that affect target uncertainty

One of the most vital formation evaluation measurements is Depth and at the same time its one of the most difficult to determine accurately. Different approaches and work have been conducted to explain this problem for both wire-line and drill pipe-based systems [9]

In this section, emphasis on the factors that are the key reason for depth error, which is one of the challenging problems in the industry. The factors are divided in two parts mechanical error and survey error. In the first part number of mechanical error, which affects the target, depth while drilling that is [9]

- Axial load and torque effect
- Temperature effect (Tension)
- Pressure effect (Compression)
- Buckling effect
- Drag effect

Other effects, which are not consider in this study but still is important in considerations are listed as below:

- Heave compensator on floating rigs
- Weight and tension of wires in hoist
- Friction in hoisting system
- Effect of downhole equipment's like jars and shock subs.

To measure the depth while drilling there are various measurements but the two-reference depths used in downhole environment is Loggers depth also know as wire line logger depth and driller depths. Generally drillers depth are not most accurate because of the factors mention above but is always recorded, and represents the primary depth system, unless it is outdated by a more accurate measurement that is open hole or cased hole wire line log.

2.3.1. Axial load, torque and drag effect in wellbores

Before drilling, designing of drill string mechanics and well mechanics are primary steps. The drill string mechanics program is to compute a load in drill string in tripping, and drilling condition. In addition to compute the buckling and tensile load limits. The main objective is to describe the allowable loads on drill string, which is bounded by the buckling and the tensile limits.

The torque and drag can be modeled by two equations. First for straight wellbore and second for the curved wellbore. Assuming soft string model does the analysis. The equation below gives the hook loads for hoisting and lowering operations and also torque for the drilling string in a well.

A 3D modeling is shown in the Figure 21, which is complex well shape as its direction changes in a 3-dimensional space. The model was derived by Aadnøy in (2010).

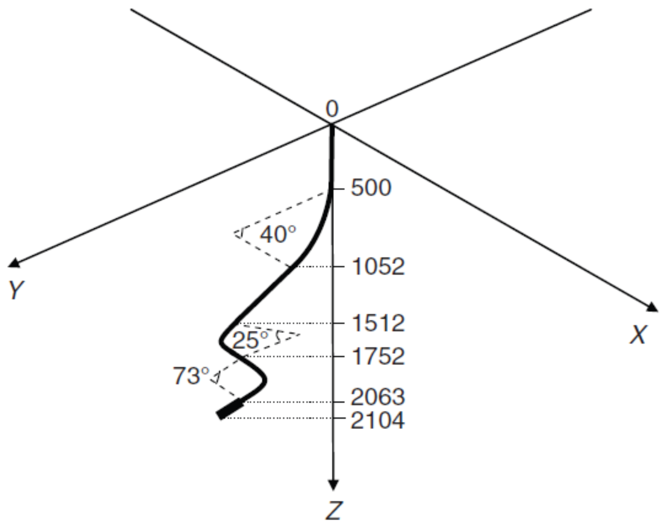

Figure 21 A 3D well shape

Drag for straight inclined wellbore sections without pipe rotation

Pipe tension is not taking part to the normal pipe force in the straight wellbore. Straight sections are weight dominated as only normal weight component gives friction[7]. The top force F_2 is given by

$$F_2 = F_1 + \beta \Delta L w \{\cos\alpha \pm \mu \sin\alpha\} \qquad (2.29)$$

Where "+" means hoisting and "-" refer to lowering of the pipe

Torque for straight inclined wellbore sections without axial pipe rotation

The torque in straight inclined wellbore section is given by normal weight multiplied by the coefficient of friction and the pipe tool joint radius [7].

$$T = \mu r \beta \Delta L w \sin\alpha \qquad (2.30)$$

Drag for curved wellbore sections without pipe rotation

In curved borehole, the normal contact force between string and borehole is strongly dependent on the axial weigh of pipe. Due to axial weight this is tension-dominated process. For example in the short bends the tension will increase than the weight of the pope inside the bend. Moreover, dogleg angle is related to both inclination and azimuth of the wellbore. So the pipe will contact either the high side or the low side of the wellbore, its contact surface is given by the dogleg plane [7].

For buildup, [7] dropoff, sidebends or combination of these the axial force becomes

$$F_2 = F_1 e^{\pm\mu|\theta_2-\theta_1|} + \beta\Delta L w \left\{\frac{\sin\alpha_2-\sin\alpha_1}{\alpha_2-\alpha_1}\right\} \quad (2.31)$$

Where "+" means hoisting and "–" means lowering of the pipe.

Where, θ is the dogleg angle, which is a function of inclination and azimuth (3). This can be given as:

$$\theta = \cos^{-1}\left[\cos\alpha_1 \cos\alpha_2 + \sin\alpha_1 \sin\alpha_2 \cos(\phi_2 - \phi_1)\right] \quad (2.23)$$

Bu using the circle segment $\Delta L = R$, the equation can also be written as[7]:

$$F_2 = F_1 e^{\pm\mu|\theta_2-\theta_1|} + \beta w R \sin\alpha_1 \quad (2.32)$$

Torque for curved wellbore sections without axial rotation
For bend section the torque will be expressed as:

$$T = \mu r N = \mu r F_1 |\theta_2 - \theta_1| \quad (2.33)$$

The forces and torques are summed from bottom to top of the well and divide the wellbore shape into straight and curved elements.

Combined axial motion and Rotation
Earlier the torque and drag is given by the equations for individual scenarios for example rotation or axial motion. Here the solution is presented if combined motion take place. Combined motion shows a well know effect for example while rotating the linear the axial drag reduces. During the combine motion, the resultant velocity V is given by the axial velocity V_h and tangential velocity V_r. The angle between the axial and tangential velocity is given by [7]

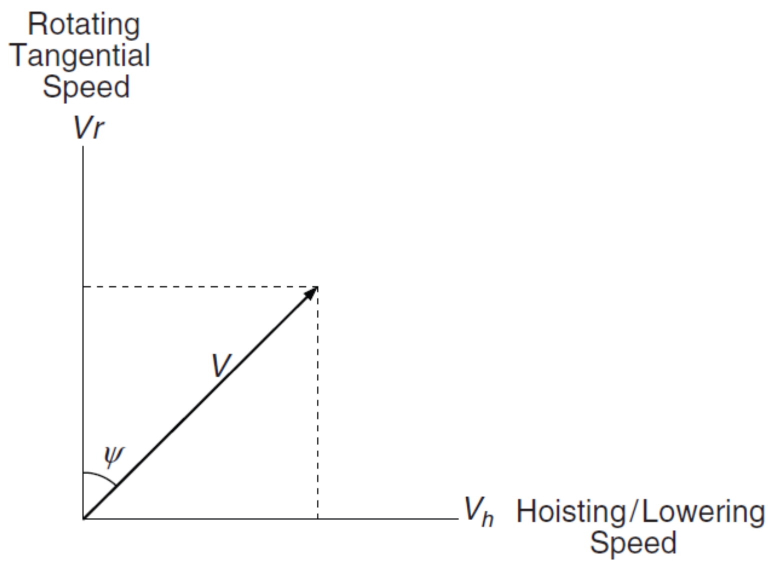

Figure 22 Resultant velocity of axial and tangential velocity [7]

$$\psi = \tan^{-1}\frac{V_h}{V_r} = \tan^{-1}\frac{60V_h(m/s)}{2\pi N_r(rpm)r(m)} \tag{2.34}$$

For combined motion torque and drag will be expressed as

Torque for straight pipe section

$$T = \mu r\beta w\Delta L \sin\alpha \cos\psi \tag{2.35}$$

Drag for straight section

$$F_2 = F_1 + \beta\Delta Lw\cos\alpha \pm \mu\beta w\Delta L\sin\alpha\sin\psi \tag{2.36}$$

Torque for Curved pipe section

$$T = \mu rN = \mu rF_1|\theta_2 - \theta_1|\cos\psi \tag{2.37}$$

Drag for Curved Pipe section

$$F_2 = F_1 + F_1\left(e^{\pm\mu|\theta_2-\theta_1|} - 1\right)\sin\psi + \beta\Delta Lw\left\{\frac{\sin\alpha_2 - \sin\alpha_1}{\alpha_2 - \alpha_1}\right\} \tag{2.38}$$

Where,
α = Wellbore inclination
β = Buoyancy factor
ϕ = Wellbore azimuth

θ = Absolute change in direction
μ =Coefficeient of friction
ψ =Angle between axial and tangential pipe velocities
w= unit pipe weight
F= Force in string
N_r = Rotary pipe speed
V = velocity

2.3.2. Temperature effects

Temperature is one of the key factors that affect the actual well trajectory as planned. The drill string will be gradually heated, as it is immersed into the well. As the depth increases the temperature will rise and will lead to increase in pipe length. A simple model will be defined to explain the effects of thermal expansion. Due to the thermal expansion the length change is given by [13]:

$$\Delta L = \alpha L \Delta T \tag{2.39}$$

Where ΔT = Temperature increase from top of the string
α = Thermal coefficient.

Erik Kårstad and Bernt S. Aadøy presented a model to analyze temperature profile during drilling. The result was compared with field data, which shows that model is valid for short time frame and therefore applicable for drilling phase [14]. In this model temperature of inside drilling string and annulus temperature were calculated by the formula [14].

For drilling string

$$T_d(z,t) = \alpha e^{\lambda_1 z} + \beta e^{\lambda_2 z} + g_G z - B g_G + T_{sf} \tag{2.40}$$

For Annulus

$$T_a(z,t) = (1+\lambda_1 B)\alpha e^{\lambda_1 z} + (1+\lambda_2 B)\beta e^{\lambda_2 z} + g_G z - B g_G + T_{sf} \tag{2.41}$$

λ_1, λ_2, α, β, A and B can be calculated from:

$$\lambda_1 = \frac{1}{2A}\left(1 - \sqrt{1 + \frac{4A}{B}}\right)$$

$$\lambda_2 = \frac{1}{2A}\left(1 + \sqrt{1 + \frac{4A}{B}}\right)$$

$$\alpha = -\frac{\left(T_{in} + B_{gG} - T_{sf}\right)\lambda_2 e^{\lambda_2 D} + gG}{\lambda_1 e^{\lambda_1 D} - \lambda_2 e^{\lambda_2 D}}$$

$$\beta = -\frac{\left(T_{in} + B_{gG} - T_{sf}\right)\lambda_1 e^{\lambda_1 D} + gG}{\lambda_1 e^{\lambda_1 D} - \lambda_2 e^{\lambda_2 D}}$$

$$A = \frac{w C_{fl}}{2\pi r_c U_a}\left(1 + \frac{r_c U_a f(t_D)}{K_f}\right)$$

$$B = \frac{w C_{fl}}{2\pi r_c U_a}$$

By assuming steady state condition the temperature in drill string can be calculated as [4]:

$$T = \frac{(T_d - T_a)}{\ln(d/a)}\ln(a/r) + T_a \qquad (2.42)$$

Changed in temperature ΔT can be calculated by:

$$\Delta T = T - T_{sf} \qquad (2.43)$$

Where T_d = Temperature in drill string
α = Coefficient of thermal expansion
z = vertical depth
g_G = Geothermal gradient
T_{sf} = Temperature at surface

Various temperature profiles are shown in fig.

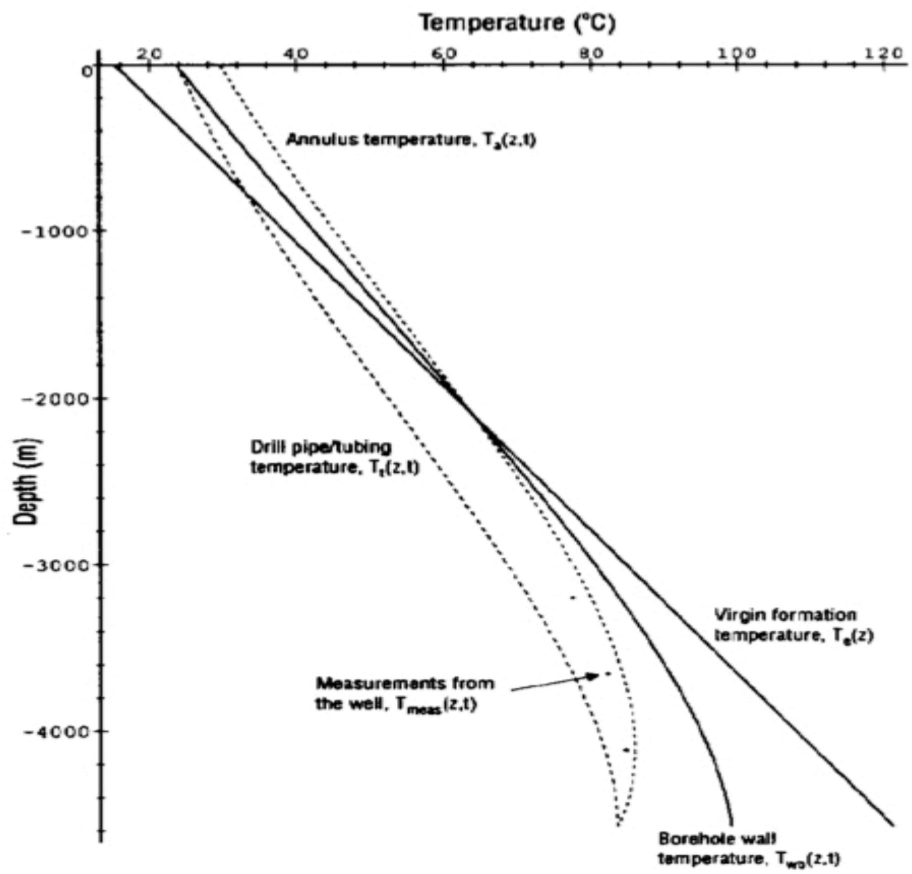

Figure 23 Temperature Profile [14]

2.3.3. Pressure effects

As the fluid moves through tubular it will experience the flow pressure effects. These effects on tubular can be categorized as

- Swelling or ballooning effect
- Elongation due to hydraulic effect

Both effect mentions below in details contribute to affect the target depth.

1. Ballooning or Swelling Effect

The changing of the diameter of the tubular due the pressure acting on the tubular wall is called ballooning. Inside pressure tends to increase the diameter of tubular result in shortening of tubular, on the other hand pressure outside the tubing reduces the diameter of tubular result in increasing the pipe length called reverse ballooning. Indications of ballooning is loss of mud while circulating, gaining mud back with off pumps, reading the pressure if the well is shut in [7]. To reduce the

uncertainties in the HPHT wells the study ballooning have taken place in 1993 by the Norwegian operator.
The change in length due to ballooning effect is given by the equation

$$\Delta L = -\frac{\nu L_t^2}{E}\left(\frac{\Delta\rho_i - R^2\,\Delta\rho_o - (1+2\nu|2\nu)\,\delta}{R^2-1}\right) - \frac{2\nu L_t}{E}\left(\frac{\Delta p_{ts} - R^2\,\Delta p_{ans}}{R^2-1}\right) \qquad (2.44)$$

2. Elongation due to hydraulic pressures

When the drilling string is exposed to an internal pressure it will be elongated. Due to the pressure effect the incremental length change is given by [13].

$$\Delta L_p = L\,\frac{(1-2\nu)\,(p_i A_i - p_0 A_0)}{(A\,E)} \qquad (2.45)$$

Using the expressions for the radial, axial and tangential components of stress (δ_{ap}, δ_{rp}, δ_{tp}) due to hydraulic pressure p_i and p_o [13].

$$\Delta L_p = L\,\frac{\delta_{ap} - \nu(\delta_{rp} + \delta_{tp})}{(E)} \qquad (2.46)$$

2.3.4. Buckling effect

One of the most critical factors in depth measurement error is the buckling of the drill string and prediction of buckling is important in depth measurement and planning of drilling string in wellbores. Buckling is defined as " structural elements are said to be unstable when an infinitesimal load increases or the disturbance induces the structure to change from one equilibrium situation to another of different character" [4].
Since most of the wells are directional wells, a more general solution would take into account pipe weight ad inclination. Pasley and Bogy derived this solution in 1964, which is further developed, by Pasley and Dawson in 1984. The equation is [9]

$$P_{cr} = 2\sqrt{\frac{EIw\sin\theta}{r}} \qquad (2.47)$$

I = Moment of inertia
w= unit buoyed pipe weight,
θ= inclination of the pipe
r= radial clearance of between pipe and hole.

Fundamental differences between Euler model and Dawson-Pasley-Bogy model is in the first case the pipe is totally unsupported whereas in the later case the pipe is supported sideways alone the whole length [9].

1. Buckling in curved boreholes and torsion

For general use we use Dawson-Pasley-Bogy model but for other conditions that have practical application Kyllingstad summarize the buckling equation in 1995.

$$P_{cr} = \sqrt{\frac{KEIf_0}{r}} \qquad (2.48)$$

Where the factor K is:

For sinusoidal buckling K = 4 – 12.25
For Helical buckling K = 8 – 7.5

The wellbore curvature is taken into account by the normal force f_0. The outcomes of simultaneously applying axial load and torque is analyzed by He, Hasley and Kyllingstad in 1995 and found that under given conditions the critical buckling force is lower. The defined the relationship between torque less solution and when applying torque is given by (9)

$$P_{cr}^{\cdot} = P_{cr}\,(1 - 0.42\tau) \qquad (2.49)$$

The tubular can also buckle only by torque and no axial load, as follows [9]

$$T_{cr} = 2.09\sqrt[4]{\frac{(EI)^3 f_0}{r}} \qquad (2.50)$$

Typical Oil well geometry comprises of both inclination and azimuth gradients. The contact force, given in Eq. 1, is a simple expression and doesn't take the mentioned gradients. Kyllingstad (1995) has generalized the contact force of a string for any inclination and azimuth as [9]:

$$f_o = \sqrt{[(bW_s sin\theta - F\theta)]^2 + [Fsin\theta\varphi]^2} \qquad (2.51)$$

Where θ (dθ/ds) is Inclination gradient and φ' (dφ/ds) is Azimuth gradient.
When there is no inclination and azimuth gradient (dθ/ds =0and dφ/ds =0)

In the table all the models of the buckling is summarized.

Table 2 Buckling in the vertical sections [4]

Section	Buckling	
	Sinusoidal	Helical
Vertical	Lubiniski: $F_{sin} = 1.94(EIw^2)^{1/3}$ $I = \frac{\pi}{64}(OD^4 - ID^4)$ • E Youngus modulus • W Weight per unit length	
	Wu at et $F_{sin} = 2.55(EIw^2)^{1/3}$	Wu at et $F_{sin} = 2.55(EIw^2)^{1/3}$

Table 3 Buckling in the curved sections [4]

Section	Buckling	
	Sinusoidal	Helical
Curved	Mitchel: $F_{sin} = \frac{2EIk}{r}\left[1 + \sqrt{\frac{w\sin\alpha r}{EIk^2}}\right]$ • $k = {}^{1}/_{R}$ (build or drop) • $r = \frac{1}{2}(ID_{well/casing} - OD_{tubing})$ • r = Radial clearance	Mitchel: $F_{hel} = 2.83F_{sin}$

Table 4 Buckling in the Inclined sections [4]

Inclined	Dowsons Pasley: $F_{sin} = 2\left(\frac{EIw\sin\alpha}{r}\right)^{0.5}$ • r = Radial clearance • α= incllination	Chen: $F_{hel} = 2\sqrt{2}(EI)^{0.5}(w\sin\alpha)^{0.5}({}^{1}/_{r})^{0.5}$ $\sqrt{2} \times F_{Dowson\ Paslay\ sinusoidal}$
		Wu et al: $F_{hel} = 2(2\sqrt{2} - 1)(EI)^{0.5}(w)^{0.5}({}^{\sin\alpha}/_{r})^{0.5}$ $2(2\sqrt{2} - 1) \times F_{Dowson\ Paslay\ sinusoidal}$
		Kyllingstad: $F_{hel} = 2.90(EI)^{0.5}(w)^{0.5}({}^{\sin\alpha}/_{r})^{0.5}$ $1.45 \times F_{Dowson\ Paslay\ sinusoidal}$

		Miska et al: $$F_{hel} = 4\sqrt{2}(EI)^{0.5}(w)^{0.5}\left(\sin\alpha/_{r}\right)^{0.5}$$ $$2\sqrt{2} \times F_{Dowson\ Paslay\ sinusoidal}$$
		Aasen and Aadnøy: $$F_{hel} = 3.75(EI)^{0.5}(w)^{0.5}\left(\sin\alpha/_{r}\right)^{0.5}$$ $$1.875 \times F_{Dowson\ Paslay\ sinusoidal}$$

Length change due to helical buckling
Due to the helical buckling factor the incremental length change over section ΔS is given as (13):

$$\Delta L_b = \Delta S\left[1 - \sqrt{1 + (kr)^2}\right] \quad (2.52)$$

Where,

$k = \frac{2\pi}{p}$ And it is assumed that $(kr)^2 << 1$.

Where, p is the pitch length.

2.4. Survey tools

During the drilling it is important to determine the position of the wellbore beneath the surface in both straight and deviated well. To measure the wellpath i.e. hole inclination and directions at different depths we have to use various survey tolls. The directional drilling company always aims to plan the ideal wellpath from surface to target and supervise the drilling according to panned wellpath. The position of the well determined from survey data compares with planned position by the directional driller. The directional driller directs the well to stay on the plan and penetrates the target depth.
Earlier survey tolls were fairly simple and inaccurate. As the directional drilling activities start increasing more reliable surveying toll needed to overcome the challenges. Modern tools and techniques are developing to provide the high degree of accuracy.
The purposes of drilling surveys are as follows[3]:

- Orient the drilling string in order to point the bit in right direction in order to not to intersect the existing well nearby.

- Compare the actual drilled well and planned well to ensure that the target is reached.
- To reached the exact bottom hole position for the relief well drilling in the event of blowout.
- For accurate geological mapping and reservoir data.
- To determine the sections of the wellpath with high curvature and evaluate the dogleg severity.

Oil wells were surveyed in 1920s when it was determined that many verticals wells in fact deviated by up to 30° from true vertical. These large deviations encountered on some of the early oilfields. More struggle have been made in order to choose suitable bottom hole assemblies and changing drilling factors to reduce the deviation.

Earlier the mechanisms of the surveying toll was simple to record the required angles and directions. Although different new surveying tools have been introduced with the time and some of the older survey tools have now been abandoned. Some old tools like single shoot is still used to check the results of advanced tools. There are different survey tools described briefly:

1. Acid Bottle

One of the earliest and simplest types of surveying tool is the "acid bottle" practiced in oil industry. Before this technique was used in mining industry. This type based on measurement with an acid bottle inside the drill rod. The principle of the technique is that the liquids always stay horizontal in the container nevertheless how the container is placed. This tool consists of glass cylinder container and hydrofluoric acid. Acid will react with glass after leaving the tool in inclined position for a certain period of time and leave a sign on the wall of the cylinder. Distance between the original position of acid and sign after reaction can be use to calculate the inclination angle of borehole. Time period and concentration of acid determines the quality of sign left after reaction.

Additional sections that is magnetic compass needle and gelatin is required to measure the hole direction. The direction of directional well is referred by magnetic north because magnetic compass aligned itself with magnetic north[3]. The key demerit of this technique is that acid didn't leave the clear sign to show the interface. In reading the mark some allowance had also to be made for capillary effects. [3]

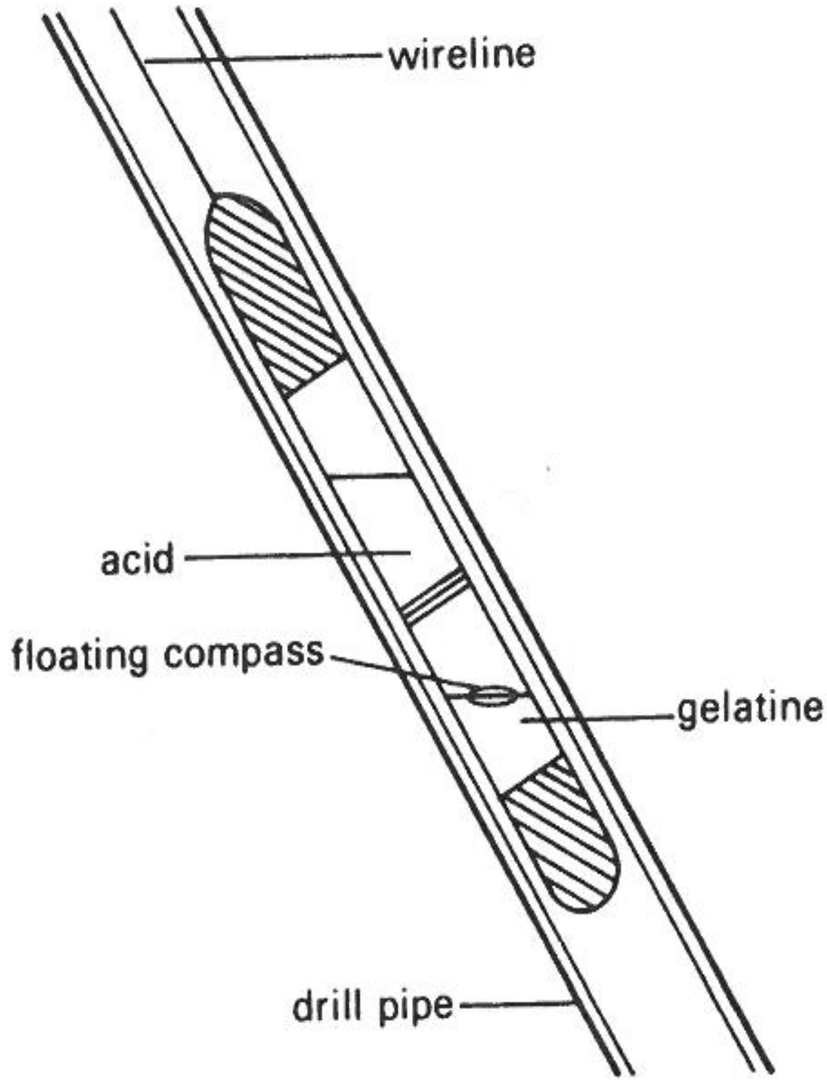

Figure 24 Acid Bottle [3]

2. Photomechanical Devices

Due to inaccuracy and problems in acid bottle technique new attempts have been made to design a better tools for surveying. The principal requirements are a). To find precise and failsafe method of measuring direction and inclination of the hole. b). To develop a system that can records all these angles so that it can interpreted easily when the tool brought to the surface.

Most of the tools used plumb bob and compass to measure the inclination and direction of the well. A camera was included additionally into the instrument that photographed the angles when the instrument is in stationary position at the bottom of drill string and records these angles down hole. After taking the pictures the tool is recovered to surface and developed a disc from which results are read off directly from pictures. This kind of tools is called as " single shoot". The tool is run on assembly as shown in Figure 25.

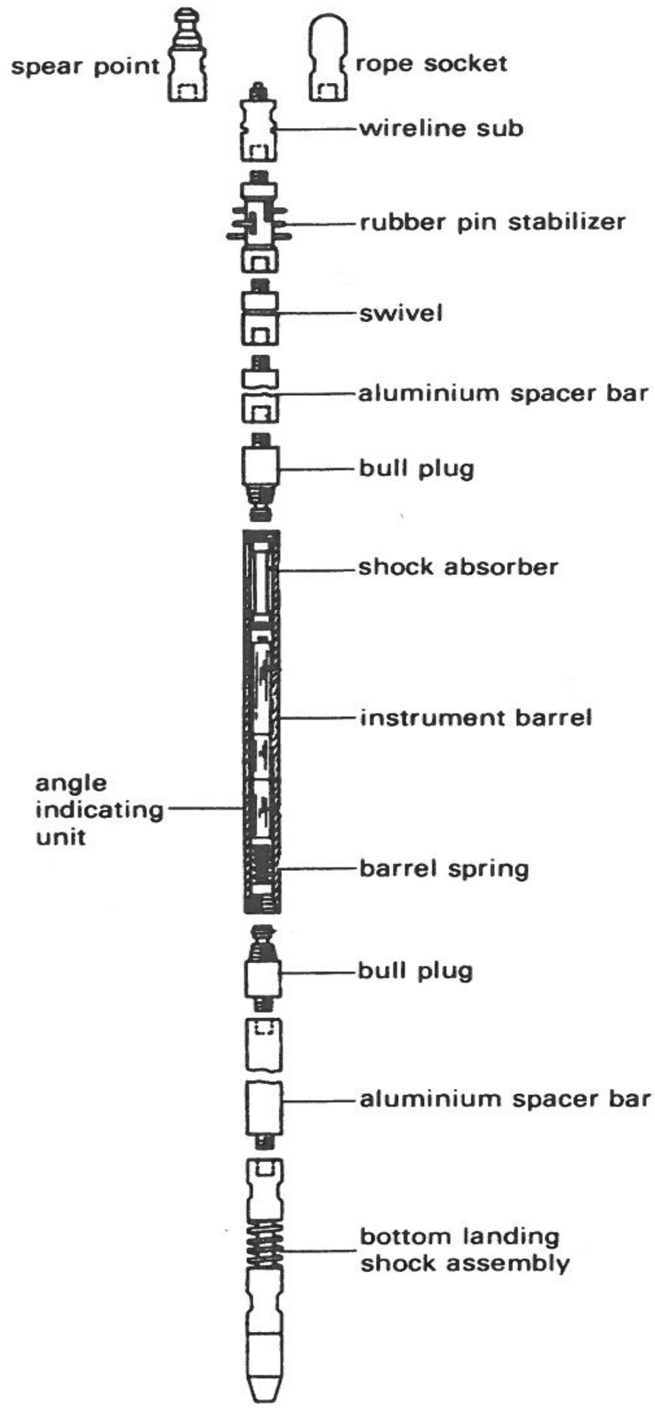

Figure 25 Surveying assembly run on wireline [3]

3. Non-Magnetic Collars

Non-magnetic drill collars are necessary to provide housing to the MWD tools in order to get the highly accurate directional survey. Usually magnetic compass respond to the Earths magnetic field in magnetic single shot and alter the compass reading. It is important that any local magnetic filed in the drill string should not allowed to alter the compass reading. To avoid the magnetic compass from the possible distortion the tool must be installed in non-magnetic environment that is non-magnetic drill collars. The material used in non-magnetic drill collar usually mentioned, as “monels” are alloys containing copper, nickel, chromium and other metals. The number of non-magnetic collars required depends on the several factors including the direction and inclination of the hole and the geographical location of the well as measured by its latitude[3]. The compass responds to the horizontal component of the Earths magnetic field, this component is small in the high northern latitudes[3]. Occasionally compass might not differentiate between this small component and other various causes of magnetism nearby, in order to minimize the effect of other various sources more monel collars needed to run[3].

4. Magnetic Single Shot

A magnetic single shot is a survey instrument, which is used to records the magnetic direction, inclination and toolface orientation simultaneously of an uncased wellbore on a singe film disc. Non-magnetic collars are needed to place the tool in it so that it is separated from the possibly magnetized, steel components of the drilling assembly. Earlier, while the well was drilled, magnetic single shoot were taken at regular intervals to monitor the well course but today MWD tools have replaced this function mostly.

The components angle-measuring units are shown in Figure 26

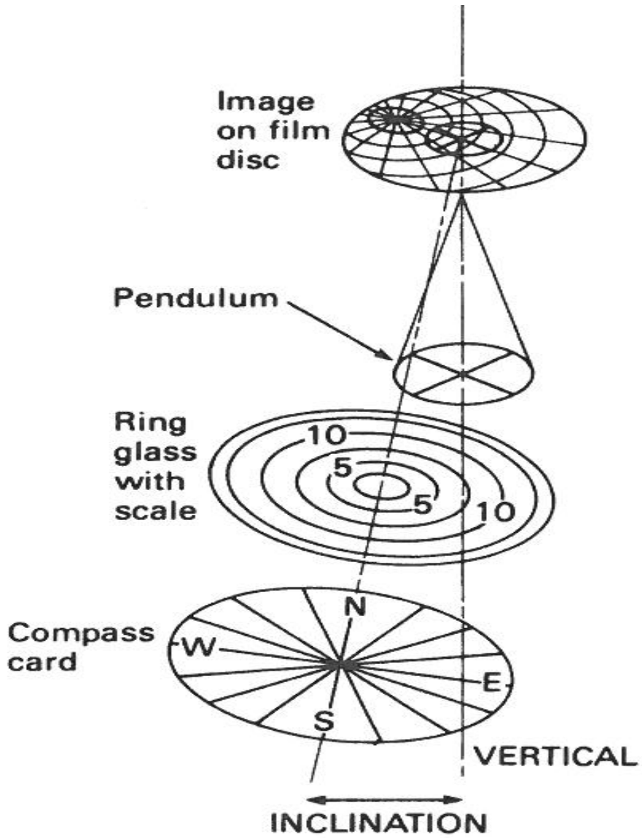

Figure 26 Diagrammatic view of single shot instrument [3]

Some developed pictures of single shot is shown in Figure 27

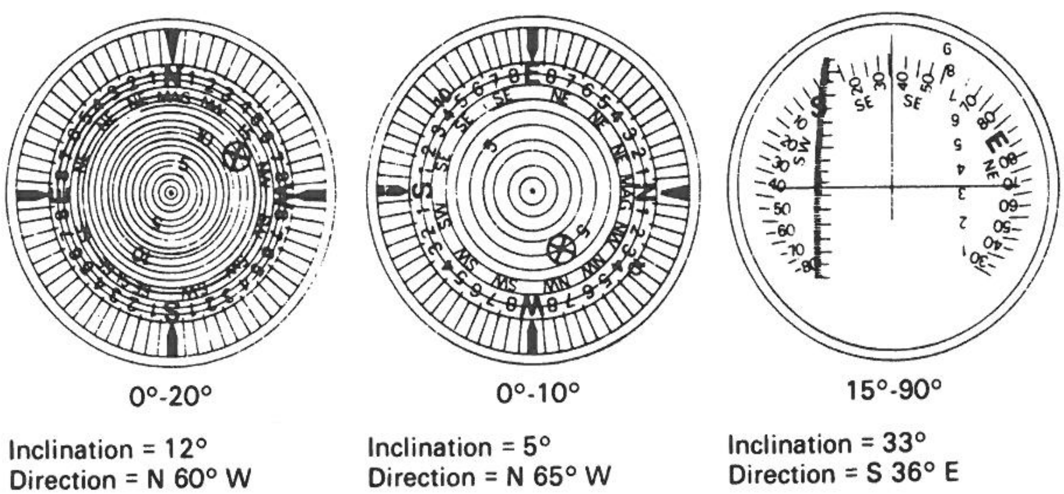

Figure 27 Single shot pictures [3]

5. Magnetic Multishot

A magnetic multi shot is the survey tool that is used to record the magnetic direction and inclination of an uncased hole at multiple stations on a filmstrip in memory module. This tool works on the similar principle as the magnetic single shot the only difference is that this tool is capable of taking a series of pictures at multiple stations. Generally multishots are run when BHA is being pull put of hole and casing point is reached. To prevent the magnetic compass from any possible magnetized steel, the downhole tool is positioned in a non-magnetic drill collar.

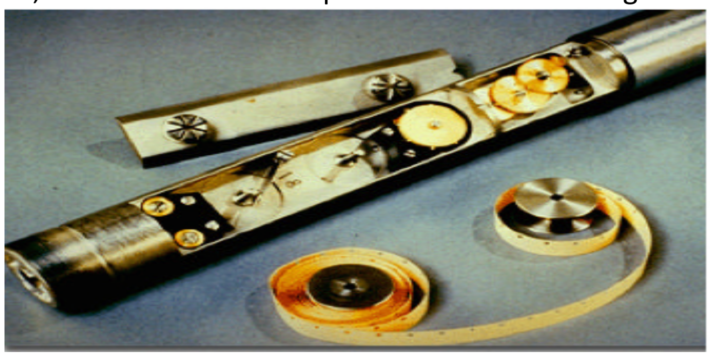

Figure 28 Magnetic Multishot [10]

6. Gyro single shot

As explained in by T.A Inglis in Directional Drilling volume 2 that while surveying the cased hoe with magnetic compass the presence of steel casing will give inaccurate results. Similarly, error will be obtained if surveying the open hole when there are cased wellbores nearby. At this situation the magnetic single shot is not reliable. Due to these errors it is necessary to replace magnetic compass by a gyroscopic compass that will not disturbed by the existence of magnetic fields.

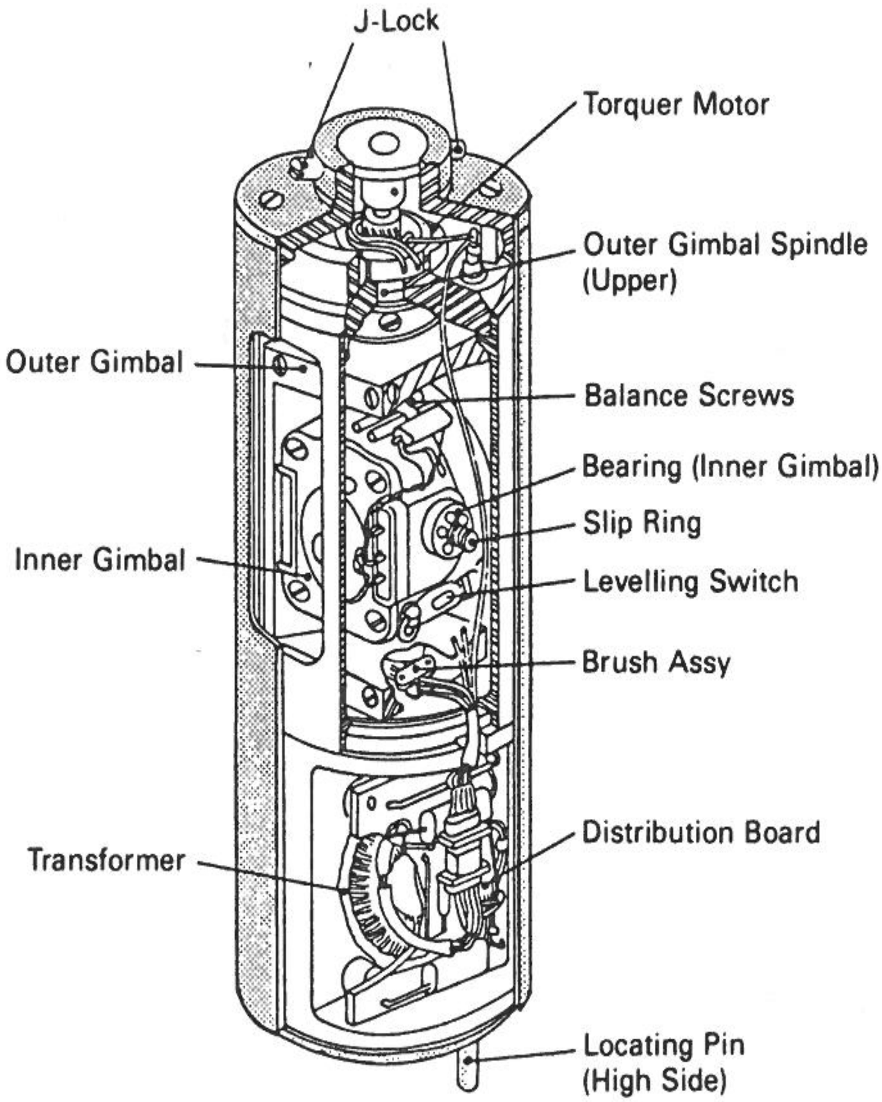

Figure 29 Diagrammatic view of Gyroscope [3]

7. Gyro Multishot

The main purpose of gyro multishot is to provide definitive trajectory of the cased borehole after the string of casing has been run in the hole. To reduce the error introduced by gyro drift, which becomes major over long times the gyro multishot is run on a wireline and surveys are taken while running into the hole. While running in and pulling out of hole, the surveys results are corrected for gyro drift. The tool is stopped for few minutes to record the surveys.

8. Wire line Steering Tool

While drilling with a down hole motor a wire line steering tool is used to give continuous surface readout of the survey data. A wireline steering tool is a magnetic survey tool consists of solid-state electronic probe plus spacer bars and muleshoe, which is located in within a NMDC (non magnetic drill collar). The data is transmitted from the probe to the surface through the conducting wire line. The surface computer calculates the survey data after decoding the signals. Wet connect technology is reviving concentration in the steering tool.

9. MWD (Measurement While Drilling) tool

Most of the MWD tools are magnetic type tools used to measure the survey data and the other hole parameters while drilling. They measure the survey data as the same way as wire line steering tools and are the part of bottom hole assembly. The data is transmitted to the surface through the drilling fluid as the pressure pulses.

2.5. Survey tool effects

The magnetic and gyro tools always show some error how to reduce these errors and take into account to correct the directional survey data. All the effects of the tools is mention below:

2.5.1. Magnetic tool effect

A magnetic single shot or multi shot is a survey instrument, which is used to records the magnetic direction, inclination and tool face orientation simultaneously of an uncased wellbore on a single film disc. While taking the survey from magnetic tools there are several source of errors that can lead to inaccuracy in wellbore positioning, errors must be corrected in order to get accurate survey results. Some of the errors mention below:

Errors like magnetic declination that is angular difference between magnetic north and true north must be corrected. Azimuth data always transmitted with reference to Magnetic north, which is not constant, Azimuth must be referenced to True North, so that position of a borehole will remain constant in time.

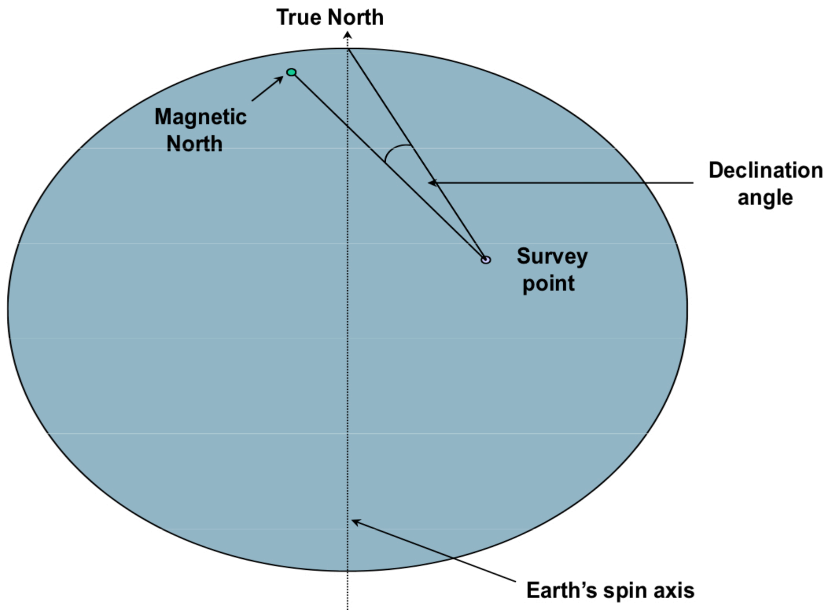

Figure 30 Magnetic Declination [19]

When changing North reference from Magnetic north to true north or vice versa magnetic declination can be used.
West Declination = subtract "correction"
East Declination = add "correction"

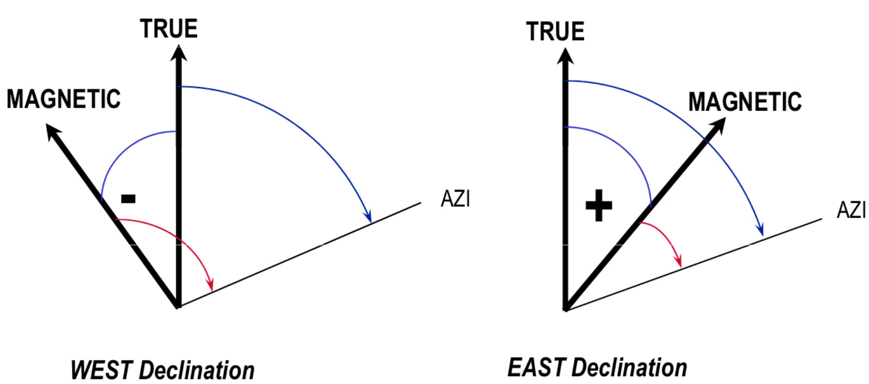

Figure 31 East West Declination[19]

Another error in magnetic survey tolls, which is very common and of noticeable priority is that the magnetic sensor should be out of range of neighboring casing or other source of magnetic interference. When drilling beneath the casing shoe we can use both gyro and magnetic instrument to check the magnetic interference and compared their results.

2.5.2. Gyro tool effect

Gyro tool is used where magnetic tool is not reliable owing to the close proximity of adjacent wells. Prior to running gyro tool the gyro must be aligned with an identified reference direction, which is generally true north. Accurate sighting of a benchmark using a telescope does this. In gyro tool no need to apply correction for magnetic declination as the survey result from the picture referred to the True North.

One key disadvantage of gyro surveys is to make allowance for gyro drift. While the tool is run in the hole, there will be slight drift in orientation of gyro from its original heading due the influence of uneven forces acting on it. The alignment of the gyro should be checked after the tool is retrieved from the hole and a correction then applied to the survey result. Gyro should be run on wire line due to chances of damage's sensitive mechanism.

2.6. Source of Errors

There are numerous causes of errors, which may result in determining the inaccurate position of the wellbore. To determine the borehole position correctly ones need to use the sophisticated instrument. It is important to determine the error in a way that it is possible to specify the borehole position within certain tolerance limit. The experience to predict the accuracy at which depth, inclination and azimuth can be measured at the survey station by defining the uncertainty around the survey station. The area of uncertainty forms an ellipsoid within which the real wellbore position lies. How much uncertainty is tolerable is depend on the particular application. To successfully reach the target in conventional directional well it maybe tolerable to have a lateral error of 10 ft. per 1000 ft. drilled. In multiwall platform it is vital to limit the error to 2 ft. per 1000 ft. when kicking off to prevent the risk of collision with adjacent wells. Below different source of errors are described [3]

Errors related to the instrument itself

The operating mechanism of both magnetic and gyroscopic devices that is used to measures the required angles has inherent inaccuracies. Magnetic field cause error due to any magnetic field present. In some cases 10° error in the compass reading has been notice due to local magnetic field of the steel drill string. A conventional gyroscope relies on accurate alignment on surface with the reference direction. The succeeding surveys will be affected by the errors in setting up the benchmark on the rig to define the reference direction, or in aligning the spin axis of the gyro to that direction [3]

Errors related to the survey depth

To measure the accurate survey depth is important for the accurate measure the borehole position. Errors can be found in an incorrect tally of the drill pipe lengths, or inaccurate wire line measurements. Errors can also be possible for the baffle plate to have been installed at the wring position within the BHA result in inconsistency between the actual survey depth and the assumed survey depth [3]

Errors in reading or reporting survey results
Pictures taken from single shot and multi shot instruments can be tough to read and mistakes can be made easily particularly at low inclinations. Sometimes correction applied for magnetic declination is not correct or forgotten completely.

Error in borehole Position
Errors in magnetic compass, which includes effects such as instrument error, value of magnetic declination describe in detail in section 2.5.1 and magnetization of the drill string.
Gyroscopic compass error, which contains initial orientation error and gyro drift.
Errors mention above result in inaccurate borehole position.

Misalignment of the survey tool
Another source of error is misalignment of the tool with the axis of the bore caused by poor centralization of the tool inside the drill collar, or the bending of the drill collars themselves within the borehole.

Errors related to borehole environment
Borehole environment refers to pressure and temperature and if the downhole pressure and temperature exceed the requirements of the survey tool being used, then the tool will not be able to provide the consistent results. The specifications may also impose limits on inclination e.g. gyro is not allow to run in the wells whose inclination exceeds 70°. At high angles of latitudes the magnetic compass will be affected by Earths magnetic field [3].

2.7. Geological factors

One of the key factor to drill the well according to plan to reach the target depth in deviated well is the type of formation. It can affect the profile of the drilling well in many ways as mentioned in (Inglis, 1987) especially in deviated well.

- The selection of the kick off point is depending on the hardness of the formation. Better practice to select the successful kick-off is a soft-medium formation. As the kick-off in soft formations may result in large washouts and kick-off in hard formation may result in poor response of the deflecting tool.
- Certain formations show the trend to deflect the bit either to the right or to the left. When positioning the deflecting tool, the directional driller job is to compensate for this effect by allowing some "lead angle". If the bit is

suppose to walk to the right by a certain number of degrees, the lead angle will point the bit an equal number of degrees to the left as shown in fig given below.

-

According to the (R. Boualleg, 2006) it is well recognized today that the one of the key factor in deviation of wellbore trajectory is the type of formation. Since long time, the consequence of the formation anisotropy on the directional behavior of the drilling system has been observed on laboratory tests as well as on fields. In various drilling application the geological formation anisotropy effect is often encountered. Commonly this effect is generates many difficulties in during drilling operations.

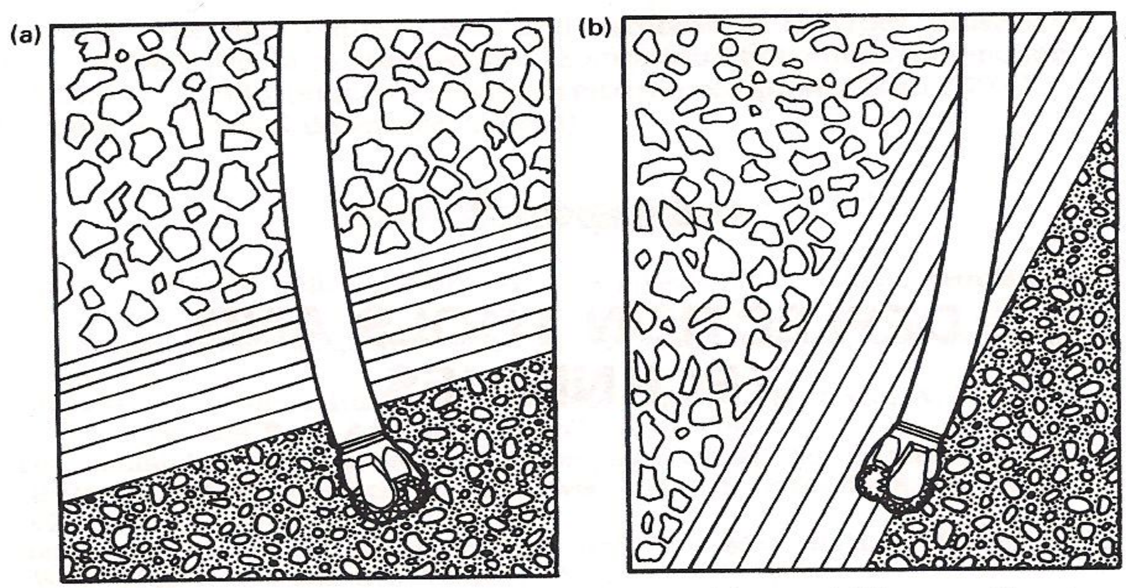

Figure 32 Deviation due to geological factors [3]

CHAPTER 3: TARGET UNCERTAINTY ANALYSIS

The concept of target depth analysis is that comparing reference well planned geometry with real operation phase condition by taking +/- 10% error in both inclination and azimuth. For the analysis, various scenario and real cases are considered.
In the study, analysis of the survey data (Measured depth, Inclination and Azimuth) is presented. By assuming +/- 10% error in inclination, azimuth and the combination of both factors to observe their impact on loading and wellpath course in different scenarios of the real operation phase condition. To see the impact on loadings and different wellpath course, simulation have been run in **WELLLPLAN ™** simulator **(Halliburton)** and obtained the results, which is presented below.

3.1. Simulation arrangement and input data

The input data for the simulation is given below.

3.1.1. Survey and Well data

Reference Survey Data (Inclination, Azimuth and Measured Depth):
Here is the reference data, which includes measure depth (MD), Azimuth (AZI) and inclination (INC) to analyze various factors.

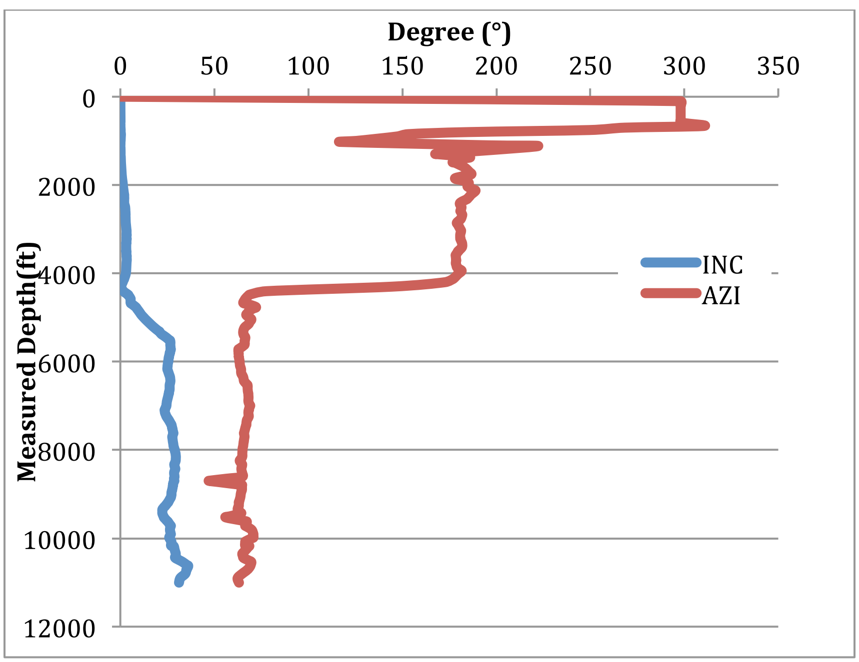

Figure 33 Reference Survey Data

Hole section

Table 5 Hole section data for wellplan

	Section type	Measured Depth (ft.)	Length (ft.)	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	4012.5	4012.5	12.250	12.459	12.615	0.25	0.1458		13 3/8in, 54.5ppf, J-55
2	Open Hole	11003.0	6990.50		12.250		12.250	0.30	0.1458	0.00	

Drill String data (Drill pipe + BHA)

Table 6 Drill string data for wellplan

Type	Length (ft)	Depth (ft)	Body OD (in)	Stabilizer/tool joint ID (in)	Avg.joint Length (ft)	Length (ft)	OD (in)	ID (in)	Weight (ppf)	Material	Grade	Class
Drill pipe	10445	10445.00	5.0	4.276	30.00	1.42	6.406	3.75	22.26	CS_API 5D/7	E	P
Heavy weight Drill pipe	120.0	10565.0	6.625	4.5	30.00	4.00	8.25	4.5	70.50	CS_1340 MOD	1340 MOD	
Hydraulic Jar	32.00	10597	6.5	2.75					91.79	CS_API 5D/7	4145H MOD	
Heavy weight Drill pipe	305.0	10902	5.0	3.0	30.00	4.00	6.50	3.063	49.7	CS_1340 MOD	1340 MOD	
Bit sub	5.00	10907	6.0	2.4					79.51	CS_API 5D/7	4145H MOD	
MWD tool	85.00	10992	8.0	2.5					154.36	SS_15-15LC	15-15LC MOD	
Integral blade stabilizer	5.00	10997	6.25	2.0		1.00	8.453		93.72	CS_API 5D/7	4145H MOD	
Bit sub	5.00	11002	6.0	2.4					79.51	CS_API 5D/7	4145H MOD	
Tri-cone bit	1.00	11003	10.625						166.0			

Rheology data

Table 7 Rheology data for wellplan

Temperature	Base Density	Ref. Fluid Properties	PV (Mulnf) (cp)	YP (Tau0) (lb./100ft2)	n'	K' (lb.*s^n/ft2)	Fann Data Speed (rpm)	Dial
70,00	8,50	Yes	49,42	0,000	0,81	0,00388	600	98,00
							300	56,00

Operational Parameters

Drilling:

Table 8 Operational Parameters for driling

	WOB/ Over pull,kip	Torque at bit,ft/lbf
Rotating on bottom	10,0	0,0

Tripping:

Table 9 Operational Parameters for tripping

	Speed,ft/min	RPM, rpm
Tripping In	60,0	100
Tripping out	60,0	100

Well schematics

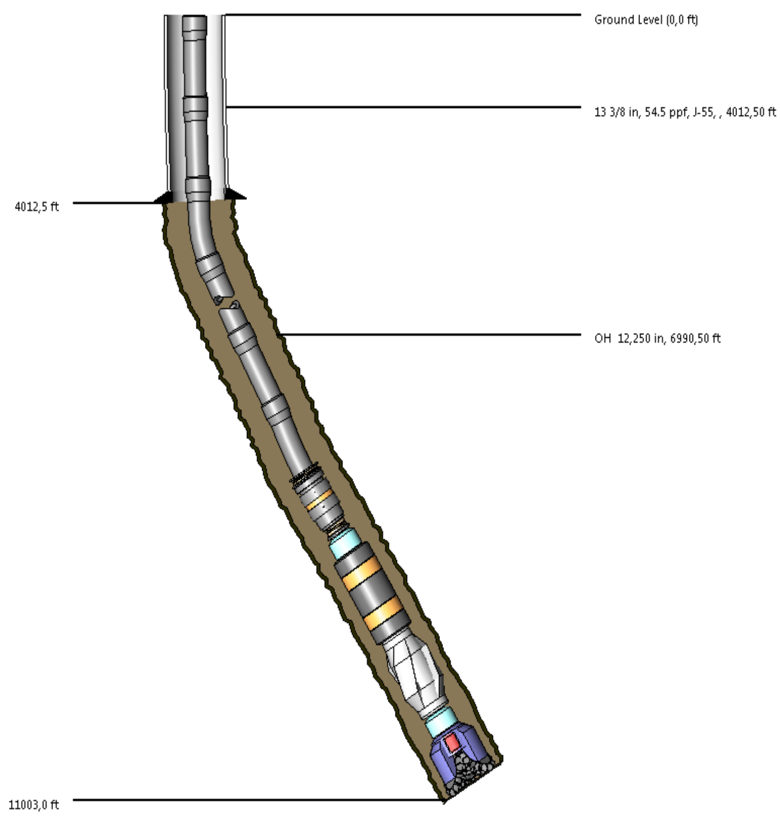

Figure 34 Well schematics from Wellplan

3.1.2. Operations' Condition

The operations analyzed in this study are tripping in, tripping out, rotate off bottom, rotate on bottom and slide drilling.

3.1.3. Simulation Scenarios

We consider various scenarios by assuming +/- 10% error in inclination and azimuth and the combination of both.

3.2 Simulation Results

The wellplan software is used to analyze the well data mentioned above; the following results are taken from this simulator and plotted in Microsoft Excel.

3.2.1 Effect of +/-10% error of azimuth and inclination

Due to errors in survey data the real trajectory of the well is not the same as the planned well. The +/-10% error in inclination and azimuth are shown in Figure 35 and Figure 36, respectively.

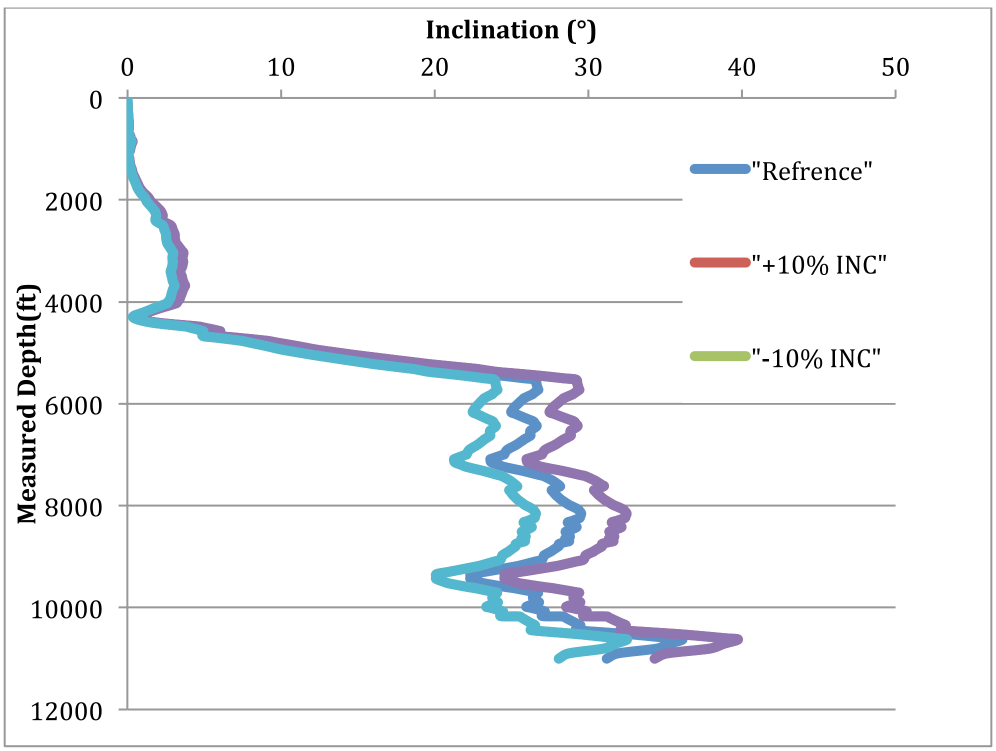

Figure 35 Reference Inclination VS ± 10% Inclination error

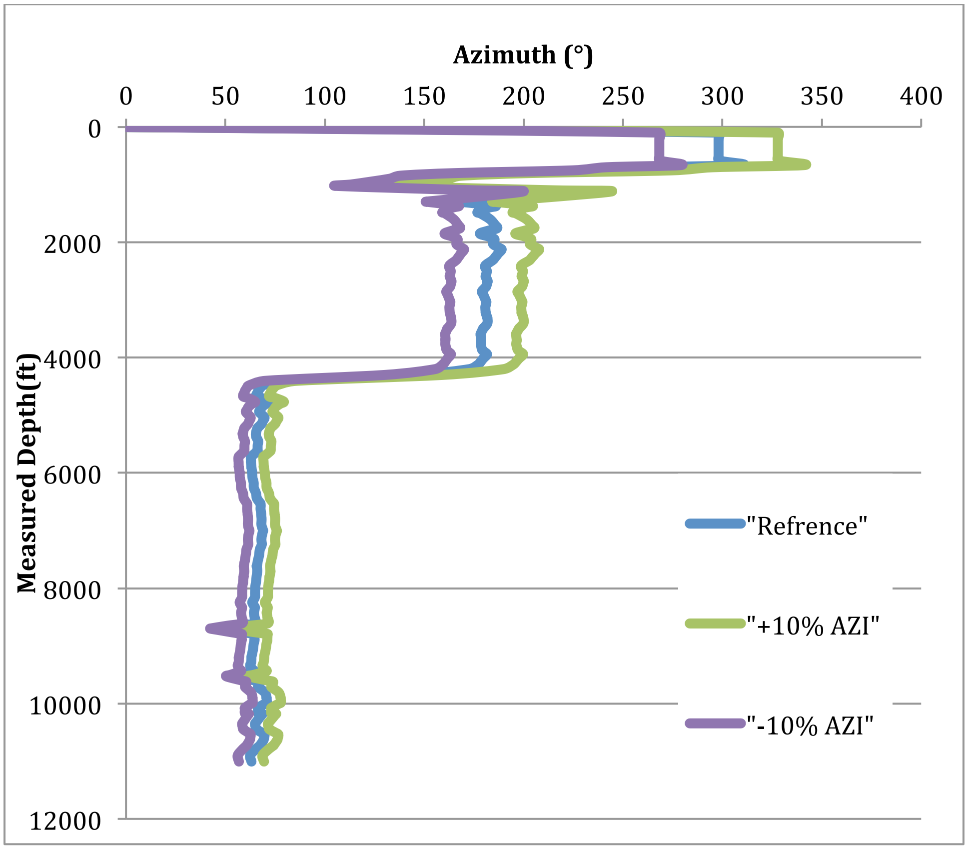

Figure 36 Reference Azimuth VS ± 10% Azimuth error

Vertical Section

Figure 37 describe the vertical section versus true vertical depth of the reference well and the effect of the errors in inclination and azimuth. Vertical section is one of the important elements to determine how the wellbore trajectory is deviated above or below the planned trajectory as shown in Figure 37. Further, it is also noticeable from the figure that the inclination and the azimuth both take part in deviating the wellbore trajectory. Vertical section also shows the location of kick-off-point, build and drop section. As illustrated in the Figure 37, the top section has not much deviation because the well is vertical but the bottom section shows noticeable difference which means wellbore is deviating from the planned well.

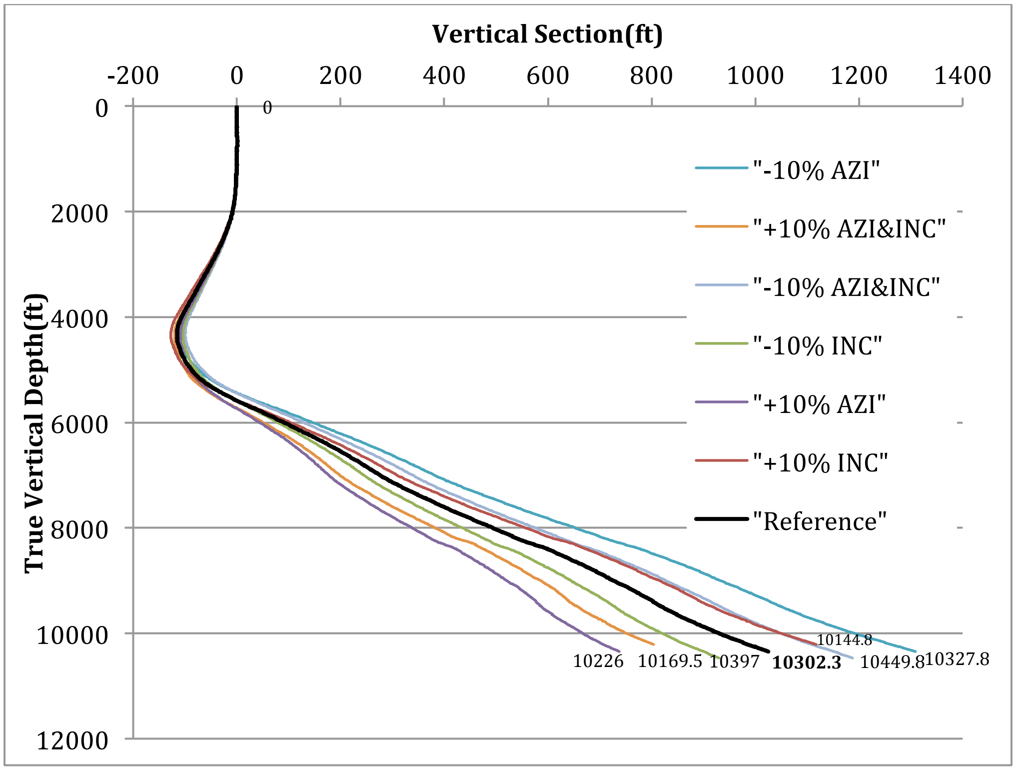

Figure 37 Vertical Section of Reference And With 10% Errors

Dogleg Severity

Dogleg severity of the reference data is shown in Figure 38. The dogleg severity increases as the dogleg angle increases. Dogleg is the function of inclination and azimuth, which refers to the change in inclination and azimuth because it bends the wellpath. The excessive dogleg severity can be detected by high torque and drag on the drilling string. It is illustrated in the figure that the dogleg severity is higher where the inclination and azimuth are higher in the wellpath**.** The combined effect of +10% error in inclination and azimuth gives maximum dogleg severity. The dogleg severity for the +/- 10 errors in inclination and azimuth is presented in the appendix.

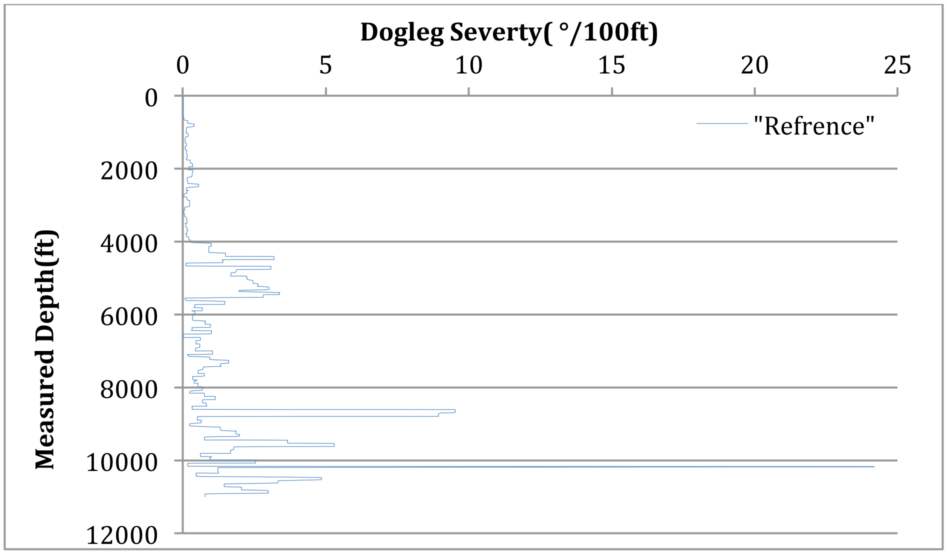

Figure 38 Doglegs Severity VS MD

Tortuosity

In Figure 39, it can be seen that the errors in inclination and azimuth affects the reference well. As the tortuosity is the function of both inclination and azimuth and the effect of both gives more severe tortuosity. The "**+**" 10% error has more effect than the "**–**" 10% error. At Bottom more tortuosity has been noticed because of high inclination that shows the difficulty of drilling a smooth well. Tortuosity has major effect on torque and drag. The more the tortuosity the higher the problem related to rotation of the string or while running casing.

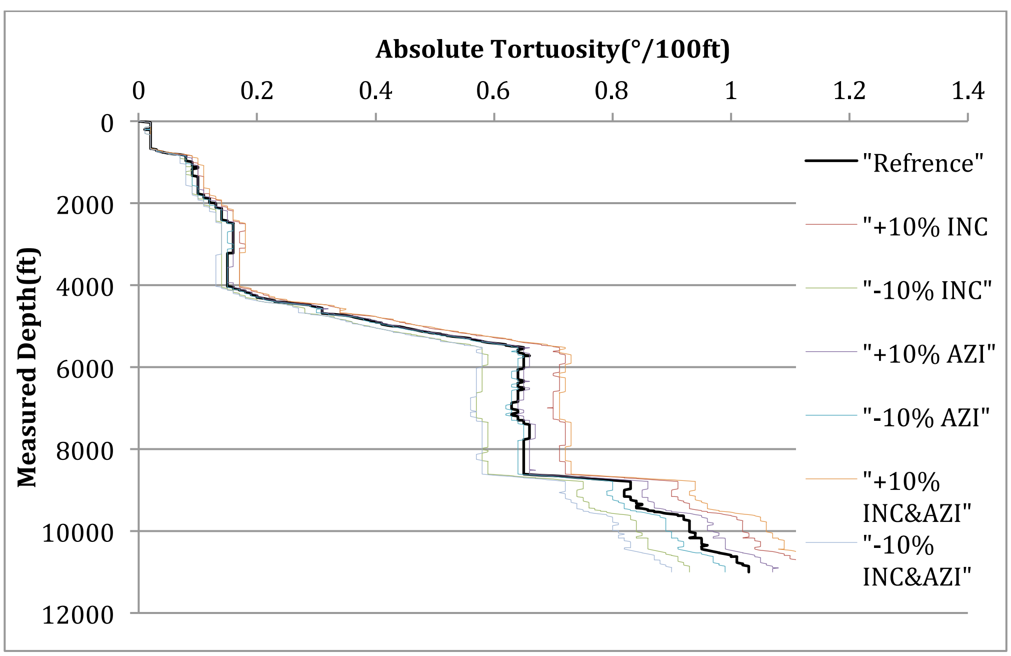

Figure 39 Tortuosity (°/100ft) of Reference Data with 10%error

Torque Effect on Operation with ±10% Errors

The analysis considers different operations during drilling and the comparison of torque of the *Reference* data and the +/- errors in inclination and azimuth. By assuming +/- 10% error in inclination and azimuth, the torque didn't exceed the torque limit during various drill operations. By the combination of both inclination and azimuth, it experiences maximum torque, while by increasing the error up to 20% in inclination and azimuth, the torque on the drill string exceeds the torque limits which is available in appendix (Figure 57). The slide drilling operation gives zero torque because slide drilling is the non-rotating operation.

Tripping In

The errors indicate the effect on torque while tripping in operation. The torque limit of drilling string exceeds if the error in survey is not minimized. Errors in azimuth have less effect than inclination, however the combination of both will increase the torque. The torque is depending on dogleg angle, which is the function of inclination and azimuth. The Figure 40 also illustrates that if the errors in the survey are increased, it also results in the increase of torque and may exceed the torque limit.

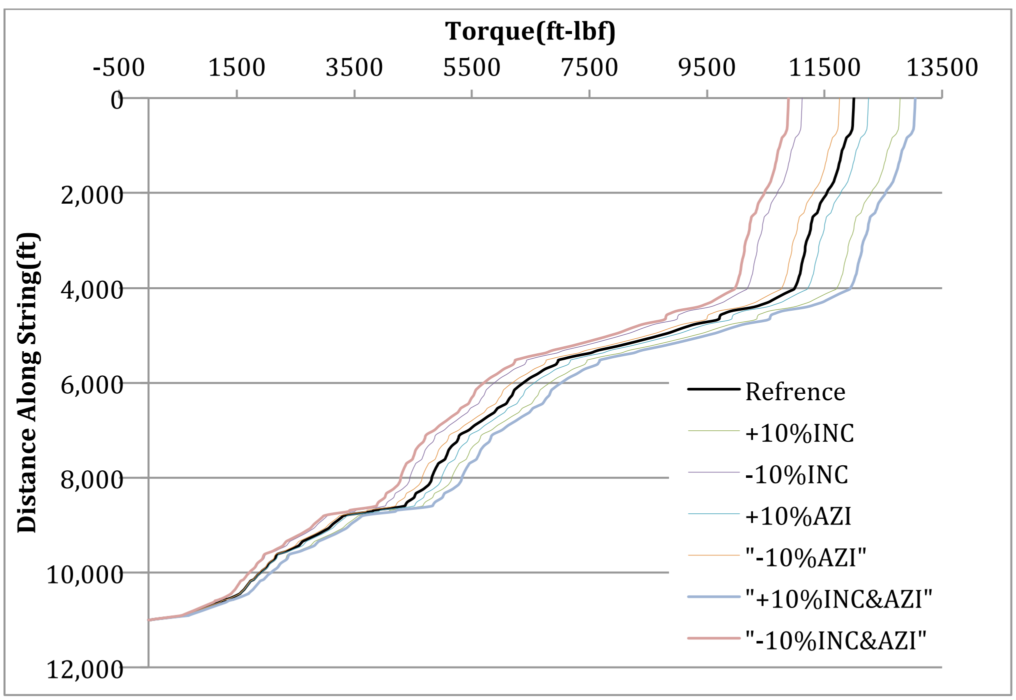

Figure 40 Torque Graph While Tripping In

Rotate On Bottom

Here another operation is described. In this figure it is clear that while rotating on bottom the torque increases, as more force is required to rotate the drill string. If the inclination and azimuth increase with +10% error is considered it increases torque, however decreased with -10% error case.

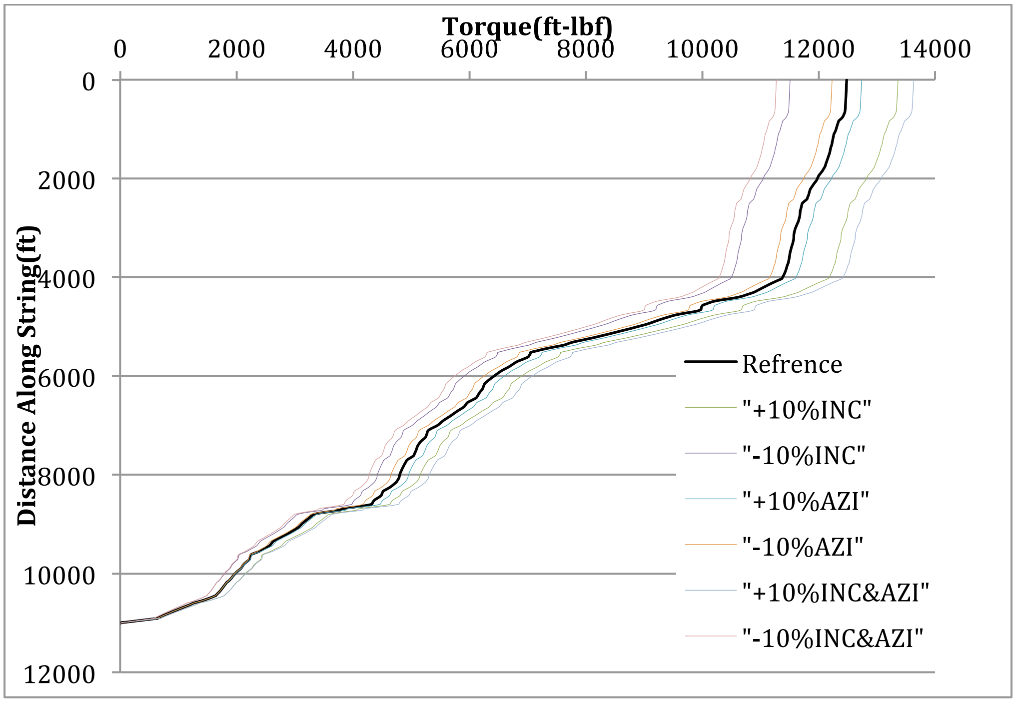

Figure 41 Torque Graph While Rotate On Bottom

Tripping Out

In this operation drill string experiences max torque because more force is required to perform this operation. The force is directly proportional to the torque. Chances of exceeding the torque limit are more than other operations as described above. Increase in inclination and azimuth enhances the torque on drill string.

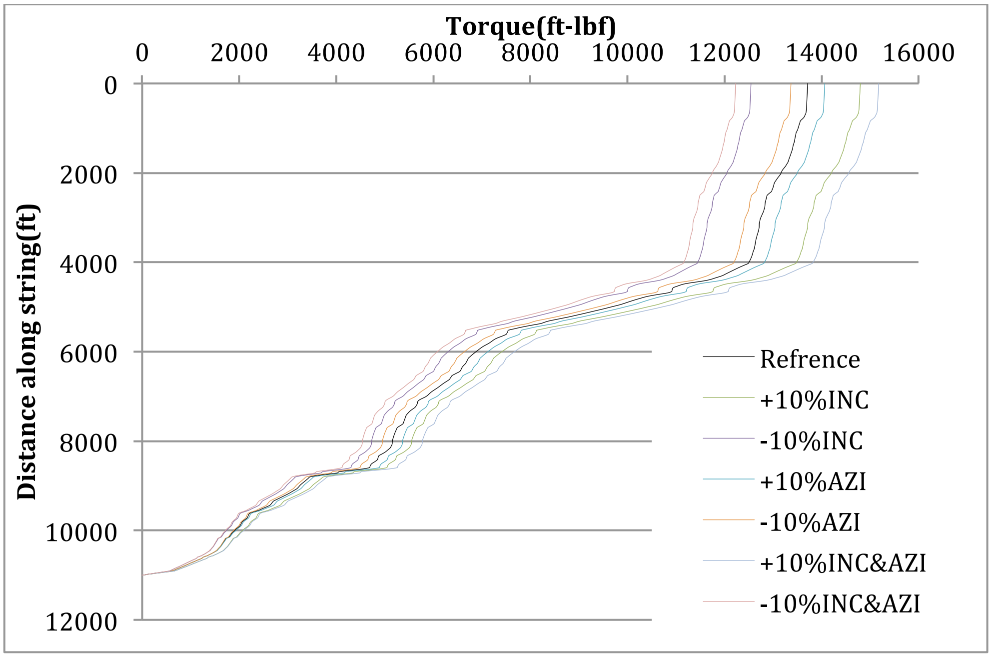

Figure 42 Torque Graph while Tripping Out

Rotate Off Bottom

In this operation, torque is also higher than rotate on bottom and tripping-in but it is lower than tripping-out operation. The reason of increase in torque for this operation is the rotation of the drill string without contacting the bottom. Inclination and azimuth make the same effect as described above for other operation.

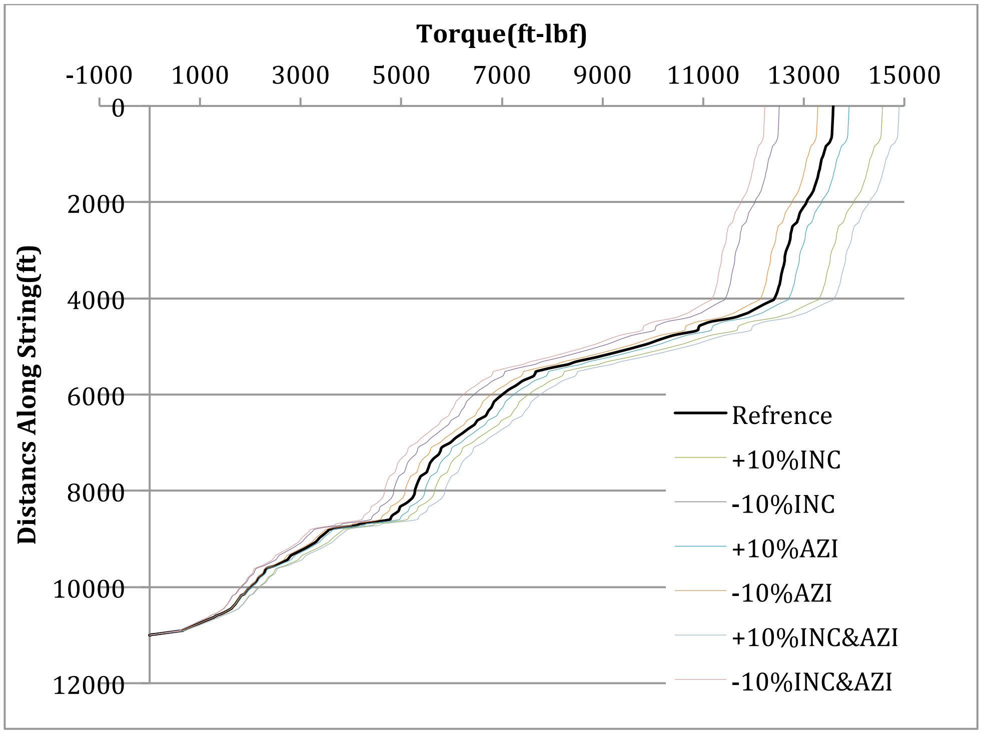

Figure 43 Torque Graph While Rotate Off Bottom

Table 10 Torque while different operation with errors

Torque							
	Reference	**`+10% INC**	**`-10% INC**	**`+10% AZI**	**`-10% AZI**	**`+10% INC&AZI**	**`-10% INC&AZI**
Tripping In	11998.3	12785.1	11118.8	12247.2	11753.9	13042.7	10886.3
Rotate on bottom	12482.4	13364.8	11509.5	12739	12231.8	13633.3	11273.8
Tripping out	13712	14797.9	12544.7	14065.1	13368.5	15176.3	12228.7
Rotate off bottom	13585.4	14564.4	12512.2	13899.9	13278.1	14895.6	12224.6

3.2.2 Elongation due to temperature Effects

The input parameter to calculate all the temperature profiles in the wellbore is mentioned in the Table 11.

Table 11 Well and mud data

Drill stem OD, in	0.155575
Drill-bit size, in,	0.064008
Formation thermal conductivity, W/(m°C),	3
Mud thermal conductivity, W/(m°C)	2
Circulation rate (m3/s)	0.009166667
Mud density, Kg/m3	1200
Mass flow ratew	11
Formation specific heat, J/(kg°C)	500
Inlet temperature, °C	10
Surface temperature, °C	3
Geothermal gradient, °C/m	0.03
Well depth, m	3427

In the graph curve represent different temperature profiles. The blue curve represents the formation temperature profile, which is linear and increases as the depth increases.

The green curve represents the drill string temperature profile, which is heated at the bottom and transfer the heat to the top of the drill string. The temperature curve of the drills string is calculated from the equation (2.40)**.** As its shown in the graph the drillstring at bottom experience high temperature because the of the high formation temperature. The drillstring at the top is getting hotter after sometime due to heat transfer. The red graph shows the annulus temperature profile and is calculated from the equation (2.41). The profile describes the temperature behavior in the annulus. At the bottom annulus temperature decrease due to heat transfer to drill string.

Due to heating of the drillstring, elongation will be experience in the drill string and this elongation will be more in the drill pipe instead of BHA (bottom hole assembly).

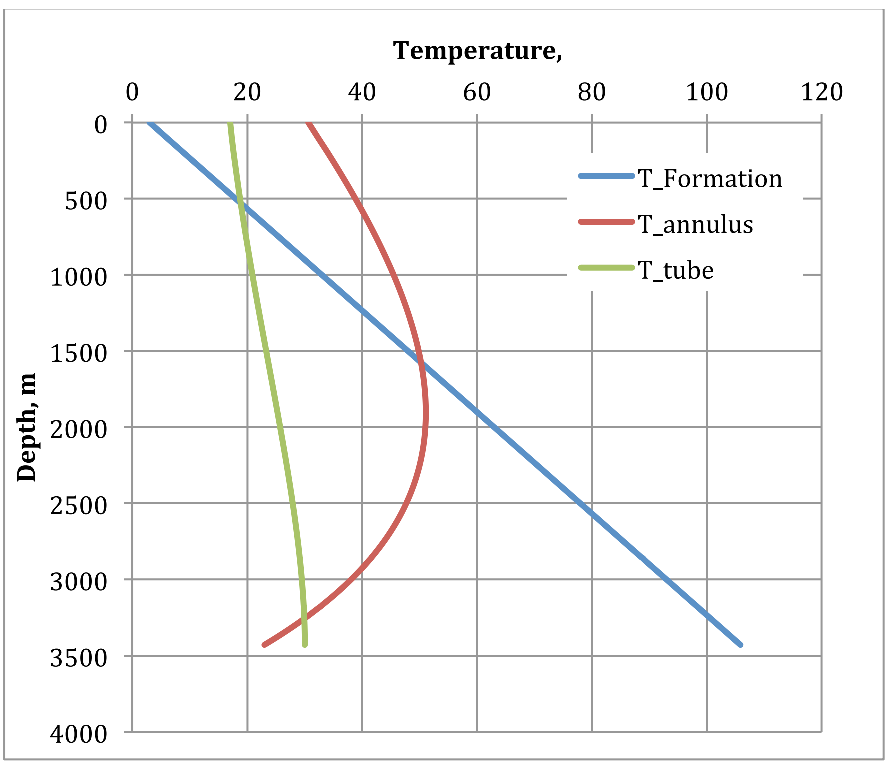

Figure 44 Temperature profiles

By assuming steady state condition, the temperature is calculated from the equation (2.42). In the Figure 45, the purple line shows the change in temperature ΔT at the different depth and is calculated by taking the difference of temperature in annulus and temperature in drilling string at different depths. By calculating ΔT, elongation due to temperature is calculated by the equation (2.43).

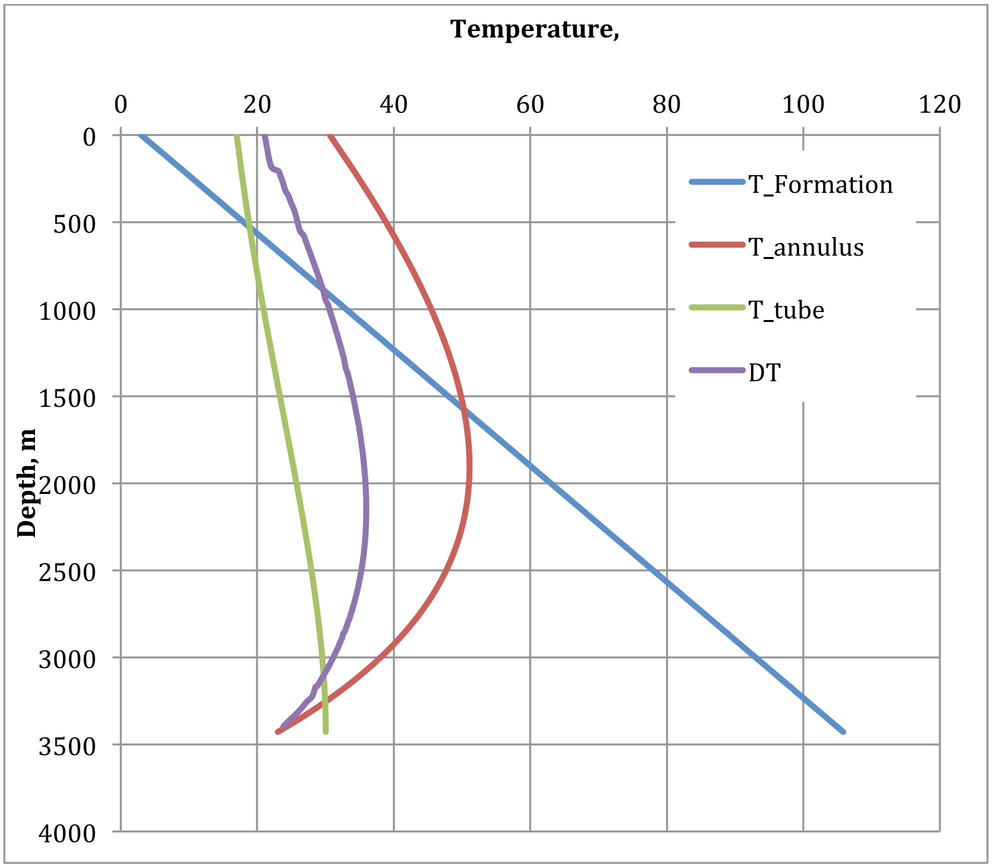

Figure 45 Difference of temperature

Elongation Due to Temperature:
Elongation is calculated due to temperature effect at different depths and by adding the total elongation of the drill string that is 8.25 ft. (2.51 m), which is presented in Figure 46.

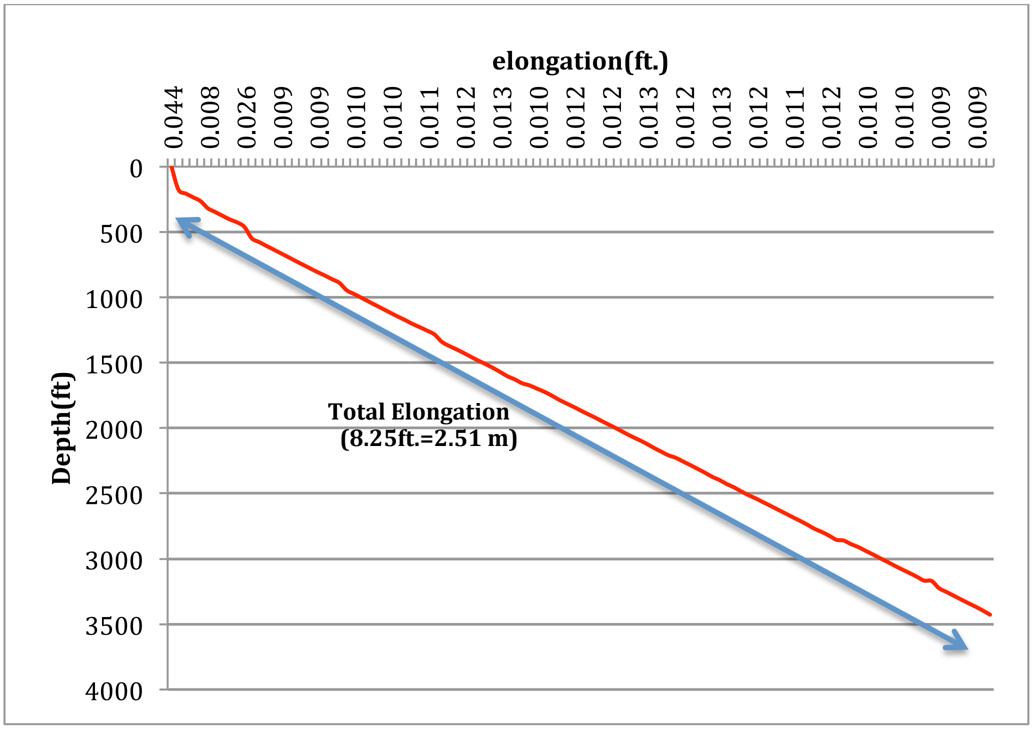

Figure 46 Elongation at different depth due to temperature

3.2.3 Elongation Due to Drag

In the analysis elongation due to drag effect is calculated and the effect of the error in inclination and azimuth on the elongation of the pipe is plotted. Various drilling operations in the Figure 47show variation of the elongation in the drill string length. In figure the impact of the inclination and azimuth on the elongation of the drill string can also be seen.

In the Figure 47 elongations is higher, if the inclination is less which means in vertical well drillstring elongation is more than the curved section and the azimuth have no effect on elongation of drillstring. More elongation is experienced in the vertical section than the curved section due to the increase of the contact forces in the curved borehole. For +10% inclination error, it gives more deviated result in terms of decrease in elongation and -10% inclination error gives decreased deviation result but more elongation.

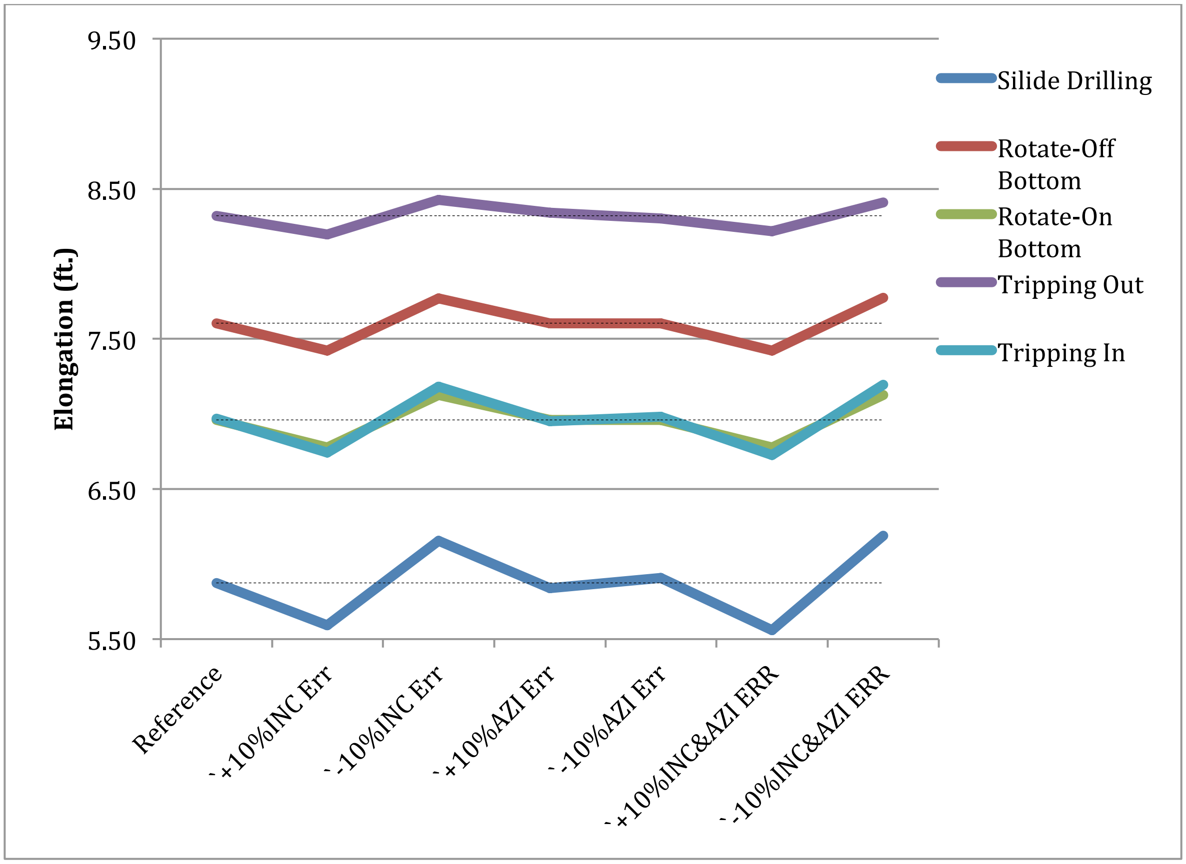

Figure 47 Elongation due to drag with different errors

The elongation is measure while tripping in operation, which is 6.96 ft. of the reference well. The variation is seen in the elongation and it can be observed in the Figure 47 that elongation increases and decreases with the ±10% error in inclination, respectively. The elongation remains constant while taking the error in Azimuth. Elongations of the drill string while tripping in and rotate on bottom shows the same behavior.

The max elongation is observed for tripping out, i.e., 8.3 ft. and the minimum elongation is while slide drilling i.e., 5.8 ft., whereas the error behavior is same as others. The reason for less elongation while slide drilling is contact forces acting on the string and string experienced less tension than other operations. Rotate off bottom have less elongation than tripping out because in tripping out operation more force is required to pull the pipe.

Table 12 Elongation due to drag

Elongation Due To Drag							
Drilling Operations	**± 10% Error In Inclination And Azimuth**						
	Reference	**+10%INC Error**	**-10%INC Error**	**+10%AZI Error**	**-10%AZI Error**	**+10%INC&AZI Error**	**-10%INC&AZI Error**
Slide Drilling	**5.87**	5.59	6.15	5.84	5.91	5.56	6.19
Rotate-Off Bottom	**7.61**	7.42	7.77	7.60	7.61	7.42	7.77
Rotate-On Bottom	**6.96**	6.78	7.13	6.96	6.96	6.78	7.13
Tripping Out	**8.32**	8.19	8.43	8.34	8.30	8.22	8.41
Tripping In	**6.97**	6.74	7.18	6.95	6.98	6.73	7.20

3.2.4 Elongation Due to Pressure Effect

In the Analysis, the elongation is calculated using the equation **(2.46)** mentioned in the literature in which radial, tangential and axial forces are used. The simulator calculates these forces. By putting these forces in the equation following results are computed using the Microsoft Excel. The elongation due to pressure is higher than the elongation due to temperature and drag. Pressure effect mud system and the circulation rate are the key factors, which affect the elongation depending upon condition of the well.

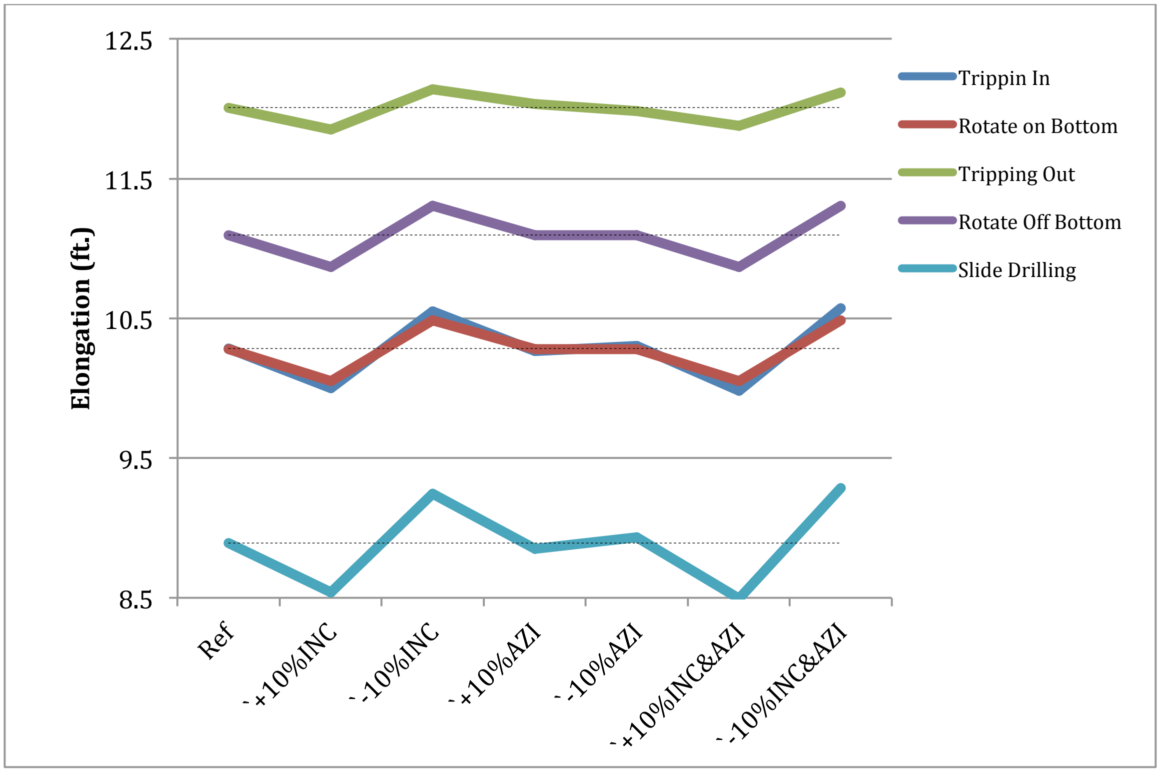

Figure 48 Elongation due to Pressure with different error

The elongation in the tripping-in operation is 10.3 ft. of the reference well and the inclination and azimuth have the same behavior as the elongation due to drag. The elongation due to rotate-on bottom is almost the same as the elongation due to tripping-in but less than tripping-out and rotate-off bottom.

Table 13 Elongation due to pressure

Elongation Due to Pressure							
Drilling Operations	± 10 % Error In Inclination And Azimuth						
	Reference	+ 10% INC Error	-10% INC Error	+10% AZI Error	-10% AZI	+10%INC&AZI	-10%INC&AZI
Tripping In	10.28	10.00	10.55	10.26	10.30	9.98	10.57
Rotate on Bottom	10.28	10.05	10.49	10.28	10.28	10.05	10.49
Tripping Out	12.01	11.85	12.14	12.03	11.98	11.88	12.12
Rotate Off Bottom	11.10	10.87	11.30	11.10	11.10	10.87	11.30
Slide Drilling	8.89	8.54	9.24	8.85	8.93	8.49	9.29

3.2.5 Total Elongation Due to Different operations

Key factors are analyzed which take part in drill pipe elongation and the result in depth uncertainty. By assuming factors that is temperature, pressure, axial and drag. Total elongation of the drill pipe is calculated in the range of 22 to 29 ft. during various drilling condition.

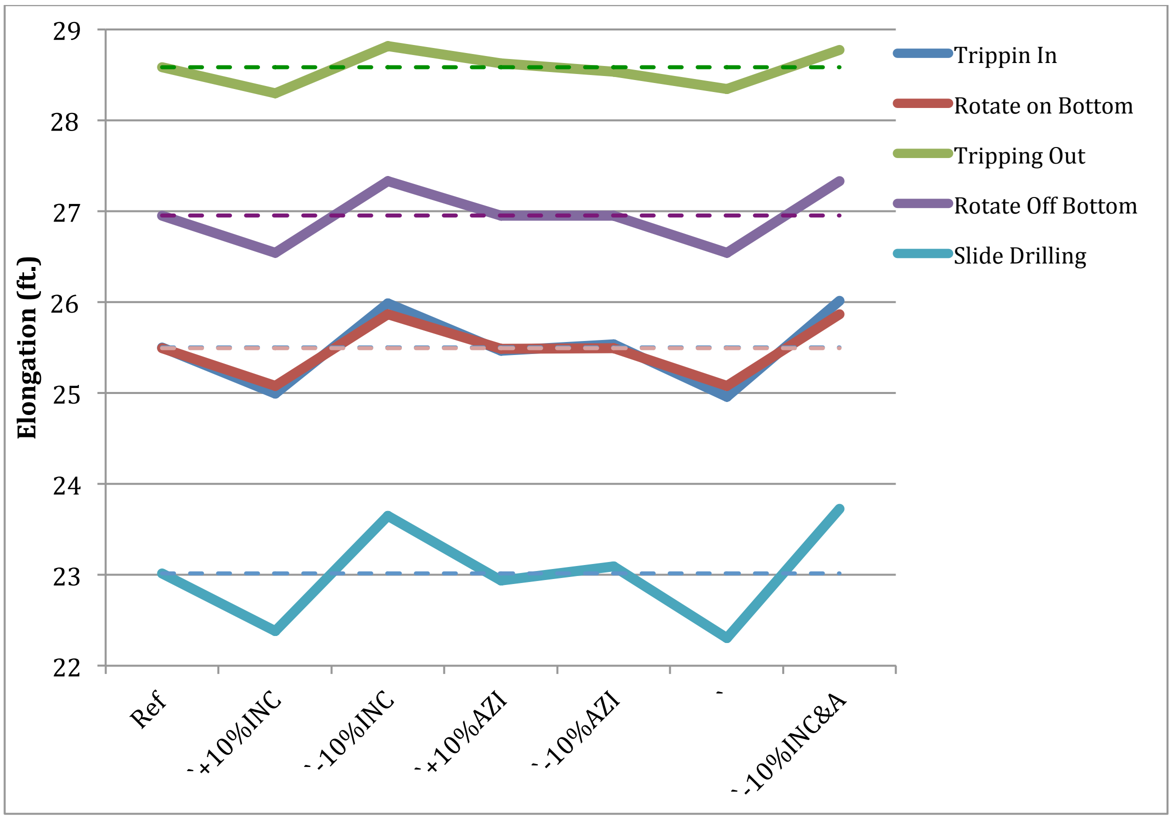

Figure 49 Total elongation due to various factors

In tripping out operation drill string experiences maximum elongation than other operation. This is due to high forces acting on string while tripping out and drill string has more tension than other operations. While tripping in and rotate on bottom the elongation is almost similar and higher than slide drilling. Slide drilling has reduced elongation because in slide drilling there are more contact forces acting on string and pipe is not rotating.

Table 14 Total elongation due to pressure temperature and drag

Total Elongation (ΔL (weight)+ΔL (Tem)+ΔL (Pressure))							
Drilling Operations	**± 10% Error In Inclination And Azimuth**						
	Ref	**+10%INC**	**-10%INC**	**+10%AZI**	**-10%AZI**	**+10%INC& AZI**	**-10%INC& AZI**
Tripping In	25.50	24.99	25.98	25.47	25.54	24.96	26.02
Rotate on Bottom	25.49	25.08	25.86	25.49	25.49	25.08	25.86
Tripping Out	28.58	28.30	28.82	28.63	28.53	28.34	28.78
Rotate Off Bottom	26.95	26.54	27.33	26.95	26.95	26.54	27.33
Slide Drilling	23.02	22.38	23.65	22.94	23.09	22.30	23.72

CHAPTER 4: SUMMARY AND CONCLUSION

In the analysis phase most of the factors that affect the target depth in deviated well are discussed and the main emphasis of this thesis is on the key factors that are the major contributors in wellbore position uncertainty. This study presents two major areas:

- Sensitivity study in order to investigate the effect of survey uncertainty on various parameters such as dogleg severity, vertical section, and tortuosity, is considered first. By introducing the +/-10% error in inclination and azimuth for the reference well data.

- In the second part, the elongation is calculated which is due to mechanical, thermal and hydraulic effects.

The analysis and the results are based on the well geometry and operation parameters shown in Chapter 3.

Considering +/-10% error in the inclination and azimuth, the dogleg severity, tortuosity increases and decreases, respectively. +10% error in both inclination and azimuth gives higher dogleg severity and tortuosity, which results in the increase in torque and drag. Vertical-section result shows that after having error in survey data real trajectory will deviate from the planned well and results incorrect target depth.

Pressure and temperature are the key factors, which must be taken into account because it enhances the elongation. The study shows that the total elongation due to pressure, temperature, axial and drag is 22ft for sliding drilling and 29 ft. for tripping out. The pressure factor gives maximum elongation of 12 ft. than other factors. Elongation due to temperature on the reference geometry is 8.23 ft.

The errors in inclination and azimuth also affect the elongation in drill string. The study shows that the inclination is dominant factor than azimuth. Due to the increase and decrease of inclination, the elongation deviates from the reference well data by +/- 0.4 ft., respectively. The increase in inclination results a decrease in elongation of drill strings and vice versa. On the other hand, the analysis result shows that azimuth does not show a significant effect on the elongation in drill string.

Future work

There are many other factors that are not included in the thesis, which are, buckling effect, heave compensator on floating rigs, weight and tension of wires in hoist, friction in hoisting system, effect of downhole equipment's like jars and shock subs. These factors are also important in reducing the error in target depth measurements, which can be possible extension to this study.

NOMENCLATURE

AZI	Azimuth
BHA	Bottom Hole Assembly
CH	Cased hole
DS	Drilling string
DD	Drillers depth
DL	dogleg Angle
DLS	Dogleg Severity
EOR	Enhanced Oil Recovery
GD	Geothermal gradient
INC	Inclination
KOP	Kick Off Point
LWD	Logging while drilling
LD	Loggers depth
MWD	Measurement while drilling
MD	Measured Depth
NPT	Non-productive time
OH	Open hole
ROP	Rate of penetration
Ref	Reference
TD	Target depth
TVD	True Vertical Depth

REFERENCES

1. E. Hall, *Directional Drilling*, 2011, (A. Time, & M. Tengs-Larsen Interviewers)
2. J.A. JIM, *Introduction to directional and horizontal drilling*, PennWell Books, 1993
3. T.A. Inglis, *Directional Drilling*, Vol. 2, Kluwer Academic Publishers, 1987
4. B. Mesfin, *A review of buckling in oil wells,* 2006
5. *Buckling*, Accessed on May 2013, URL: http://mysite.du.edu/~jcalvert/tech/machines/buckling.htm
6. B.G. Matson, M.A. Whitfield, G.R. Dysart*, Computer calculations of Pressure and Temperature effects on length of tubular goods during deep well stimulation*, in Journal of Petroleum Technology, Vol. 19, no. 4, pp. 551-558
7. S.A. Bernt, *Modern well design,* A.A. Balkema*,* 1996
8. M.A. Mian. *Petroleum engineering handbook for the practicing engineer*, Vol. 2, PennWell Publishing Company, 1992
9. Bernt S. Aadnoy, Mechanics of drilling, Shaker, 2006.
10. *Wellbore positioning*, Baker Hughes, 2013
11. *Introduction to Ekofisk*, ConocoPhillips Norway
12. B.A. Alidi, H.F. Al-Sarrani, Saudi Aramco, J. Stewart, A. Sarkar, G. Smith, *Use of Gyro-MWD Technology Offshore, A Step Change in Drilling Performance in Saudi Aramco*, Saudi Aramco Journal Of Technology, 2010
13. Yunfeng Yi, et al, *An advanced coiled tubing simulator for calculations of mechanical and flow effects; Model advancements, and full-scale verification experiments*, in SPE/ICoTA Coiled Tubing Conference and Exhibition, 2004
14. Erik Kårstad and Bernt S. Adnøy, *Analysis of temperature measurements during drilling*, SPE Annual Technical Conference and Exhibition, 1997
15. J. Eck-Olsen, K.E. Drevdal, J. Samuell and J. Reynolds, *Designer Drilling Increases Recovery*, World Oil Vol. 216, No. 4, pp. 55-60, 1995
16. R. Samuel, Halliburton, L. Xiushan*, Sinopec Wellbore tortuosity, torsion, drilling indices, and energy: what do they have to do with wellpath design*, SPE Annual Technical Conference and Exhibition, 2009
17. *Cross Section of a Horizontal Drill in Marcellus Shale*, Accessed on April 2013, URL: http://www.shutterstock.com/pic-44445184/stock-photo-cross-section-of-a-horizontal-drill-in-marcellus-shale.html

18. F.M. Rovert, Z.M. Stefan, *Fundamentals of Drilling Engineering*, SPE Textbook Series, No. 12, 2011
19. *MWD (Measurement While Drilling) Directional services*, Baker Hughes, 2013
20. M.O. Ajetunmobi, *Depth Issues in the Oil Patch (A Study of Wellbore Position Uncertainty on the Ekofisk Field)*, Universtiy of stavanger, Norway, 2012
21. Xiushan Liu, Rushan Liu, New techniques improve well planning and survey calculation for rotary-steerable drilling; IADC/SPE Asia Pacific drilling technology conference and exhibition, 2004.
22. S.J.Sawaryn, J.L.Thorogood, A compendium of directional calculations based on minimum curvature method; SPE annual technical conference and exhibition, 2003
23. William C. Lyons Gary J. Plisga, “Petroleum and natural gas engineering”, 2005.
24. Drilling through relief wells, Accessed on May 2013, URL: http://dc122.4shared.com/doc/tE3Fm0s7/preview.html

25 O. Vaisberg1, O. Vincké1, G. Perrin1, J.P. Sarda1 and J.B. Faÿ // Fatigue of Drillstring: State of the Art//*Oil & Gas Science and Technology – Rev. IFP*, Vol. 57 (2002), No. 1, pp. 7-37

APPENDIX

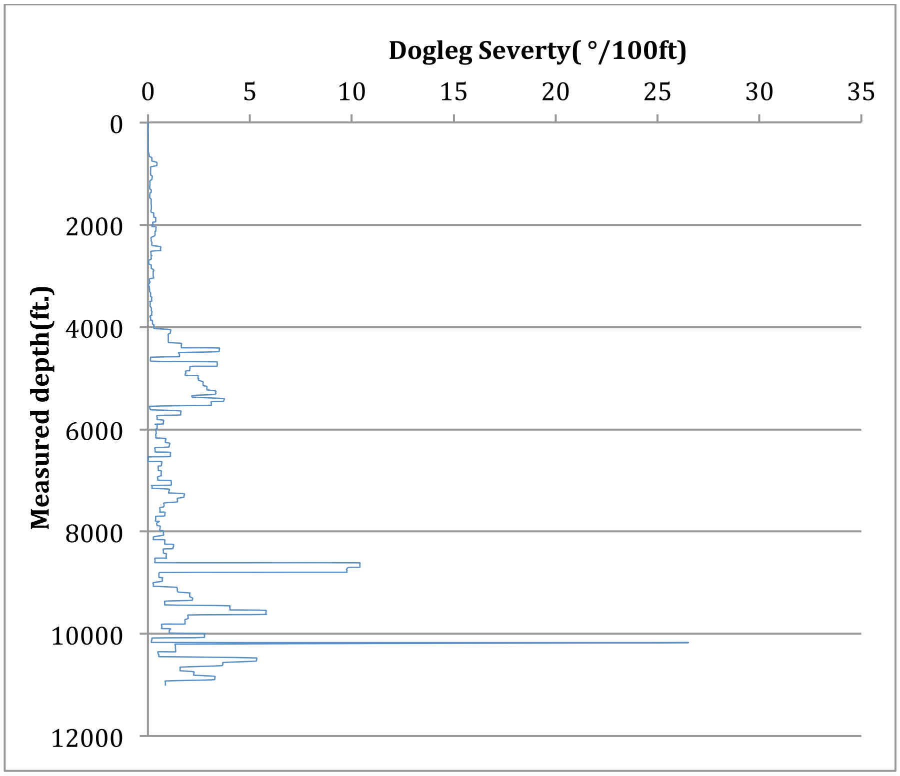

Figure 50 dogleg severity with +10% INC

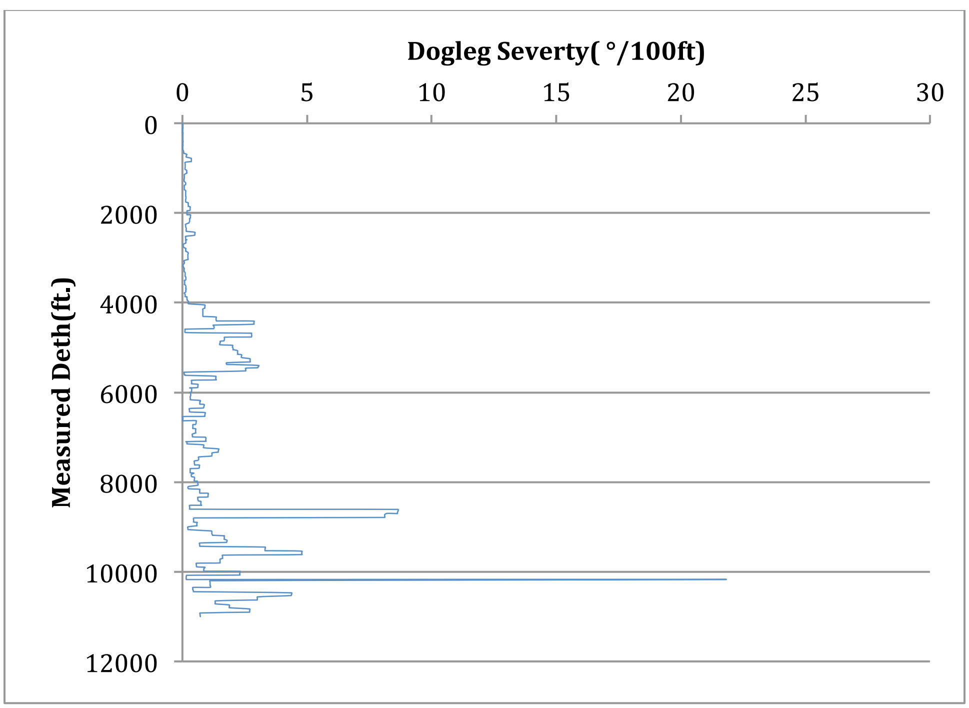

Figure 51 Dogleg severity with -10% INC

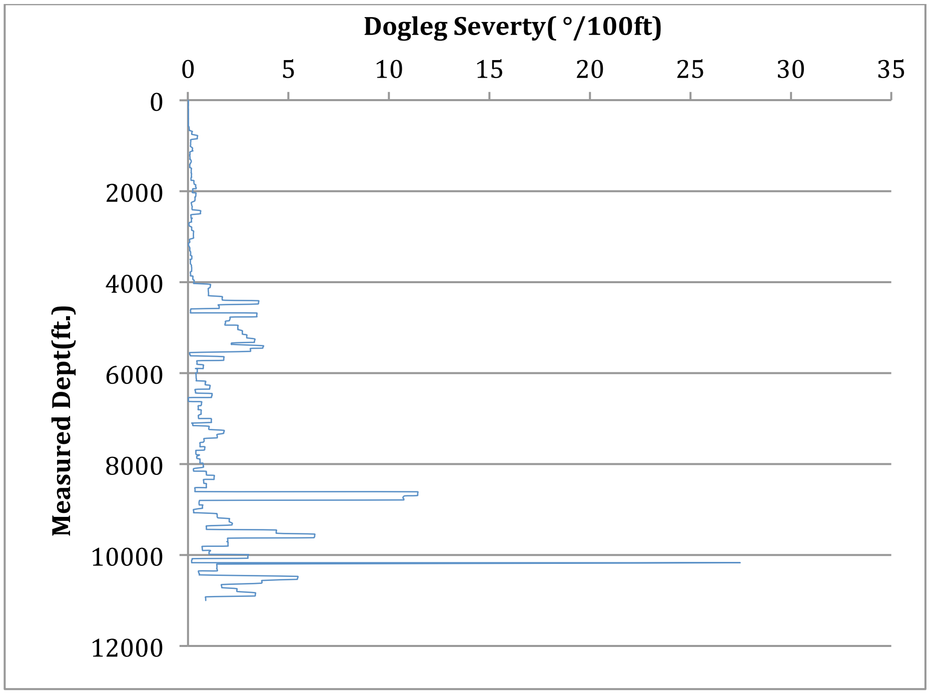

Figure 52 Dogleg severity with +10% INC&AZI

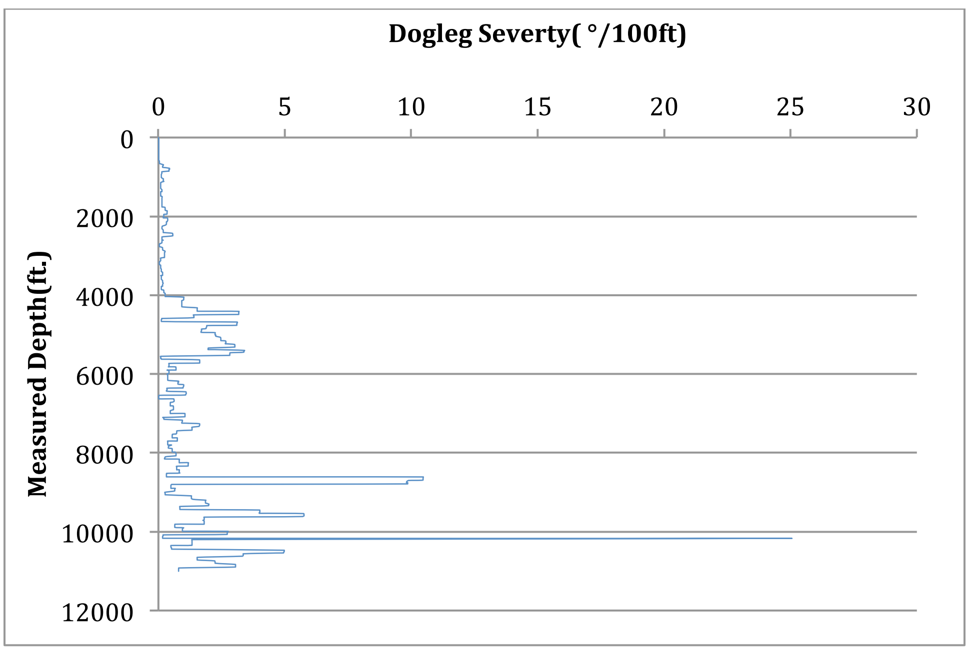

Figure 53 Dogleg severity with +10% AZI

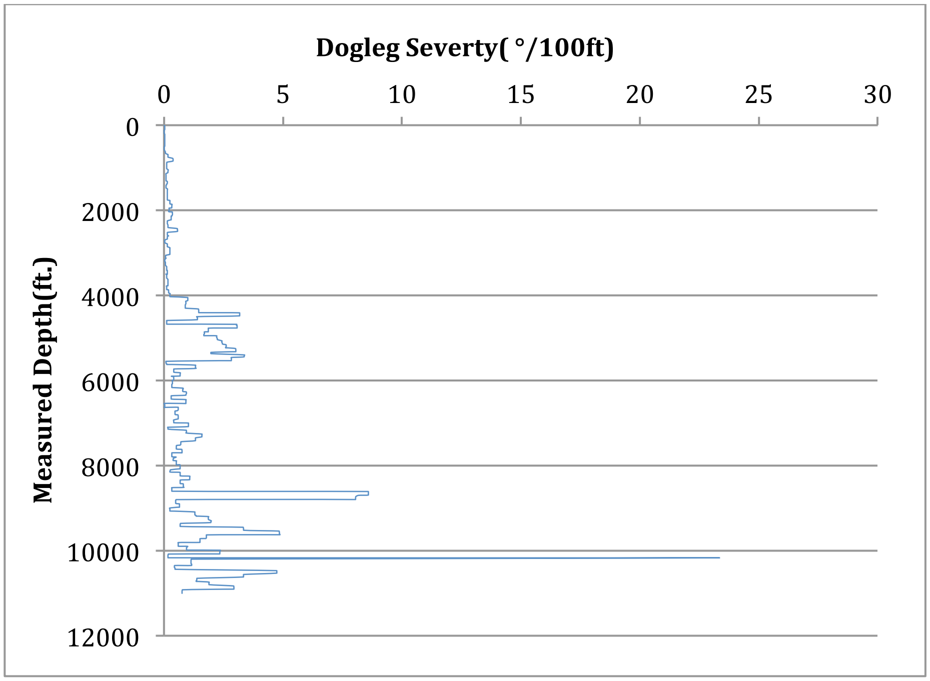

Figure 54 Dogleg severity with -10% AZI

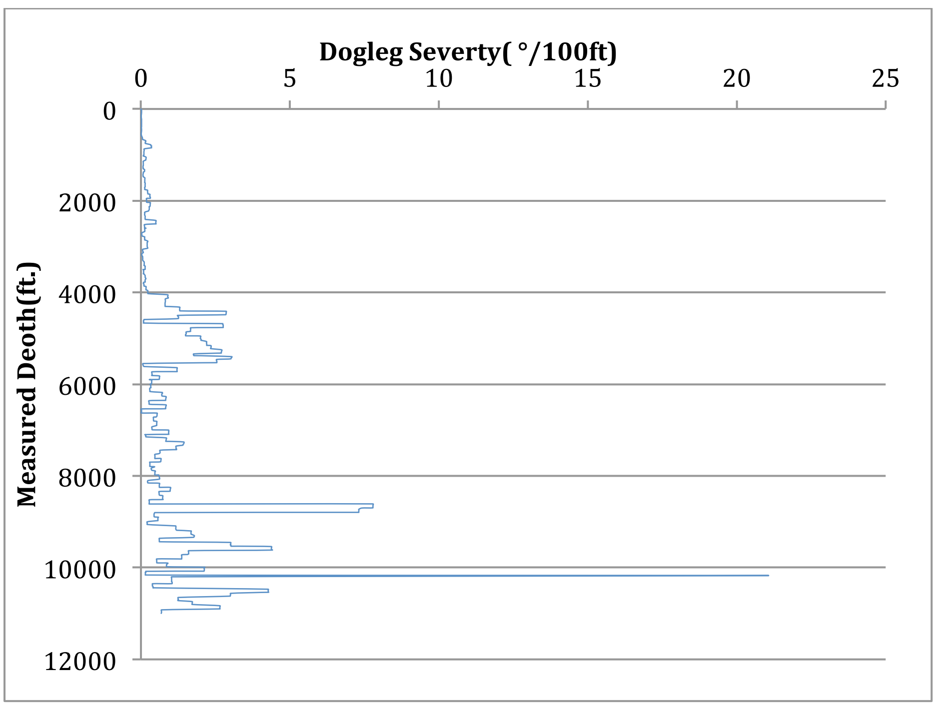

Figure 55 Dogleg severity with -10% INC&AZI

Figure 56 Torque graph of reference well

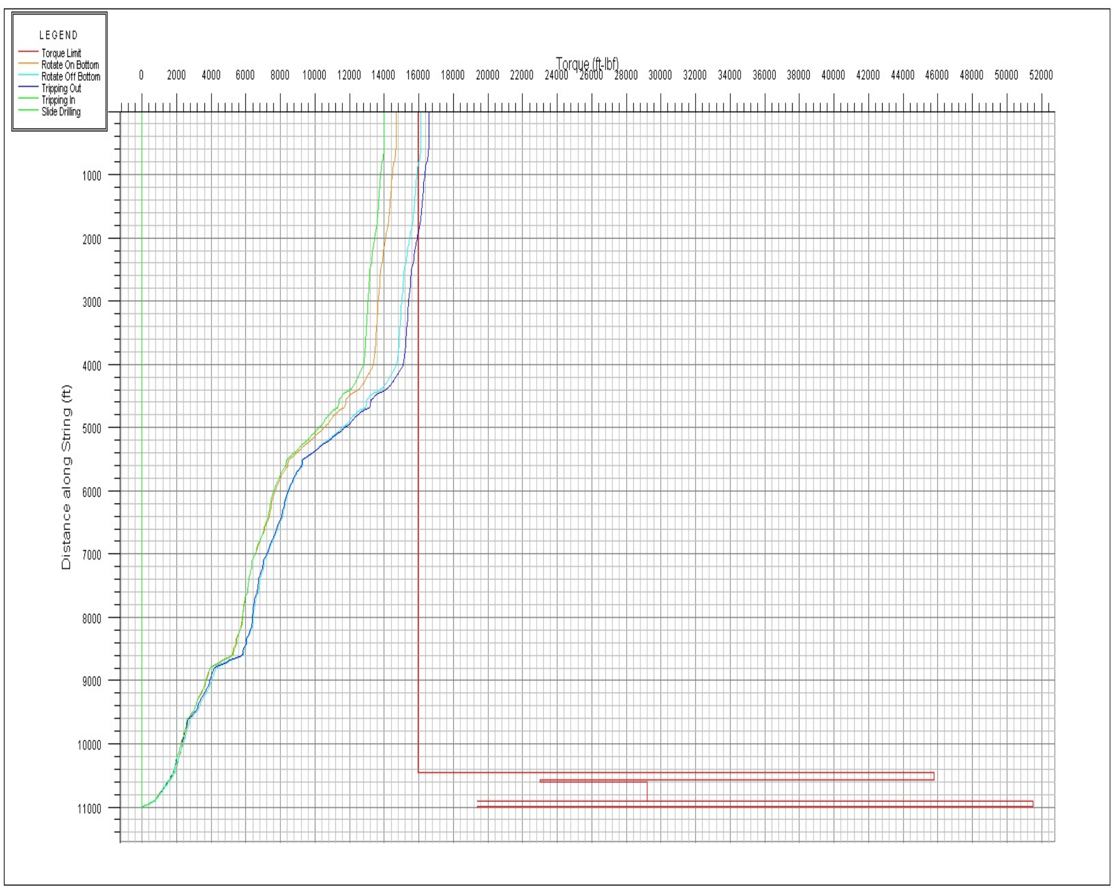

Figure 57 Torque graph with +20& eroor in inclination and azimuth