Global Scientific JOURNALS

GSJ: Volume 12, Issue 10, October 2024, Online: ISSN 2320-9186
www.globalscientificjournal.com

SELECTION OF SURVEYING METHOD FOR DIRECTIONAL WELLS TRAJECTORY DESIGN USING MATLAB

Prepared by:

OMAR SALIH KHALAF Al-FAHDAWI

eng.omarsalih333@gmail.com

September 2024

CONTENTS

ABSTRACT

Technology regards to Oil and Gas industries has developed very fast on par with the
research and development activity. In 1930, the first controlled directional well was drilled in Huntington Beach, **California**, USA. The well was drilled from an onshore location into offshore oil sands. And for nowadays especially on the offshore field, many companies prefer to use the directional drilling technology in order to save time & cost without having to build another drilling platform which is very expensive. In 1934, directional drilling was used to kill a wild well near Conroe, Texas, USA. As a result, directional drilling became established as one way to overcome wild well.

The main objectives in a successful directional drilling operation are to construct safe and economically efficient wells, but the success also depends on **hitting** the **target**. Therefore, to drill a directional well it is drilled with **intentional** control to hit a predetermined **target** and for hit a target it's important to have the professional driller with a very accurate tool in determining a very good precise value of inclination angle and azimuth direction of the wellbore during drilling operation. By obtaining the cost of inclination and azimuth, the driller will then use that particular data to calculate the wellbore trajectory and determine the exact position and location of the wellbore.

Based on the available methods of survey calculation, I will use the most simple and common methods in analyzing the well trajectory of Well XXX-1. I will also calculate the absolute error for each of the method in order to determine which method is the most suitable to be apply for Well XXX-1. And the results indicate the minimum of **curvature** method have the smallest error follow by the average tangential method accordingly

CHAPTER 1

1.1 INTRODUCTION

Enhanced access to underground energy resources (such as oil and gas) requires drilling complex curved boreholes. Drill rigs, as schematically depicted in Figure 1, are employed to generate boreholes targeting resource locations in the Earth's crust. As part of these so-called directional drilling rigs. And as the technology become more advance from day to day, now a lot of wells has been drilled much further away beyond the original starting point. There many advantages of having a directional well which one of it is to get a longer producing interval length by drilling through the target at an angle. So, it is important to drill the well path in the right direction to hit your target or several targets' thousands of meters downhole.

Directional drilling is a process of directing a well trajectory to some preplanned target intentionally [1,2]. This is done under the consideration of effective economical application of both time and cost, as well as a means of managing subsurface challenges.

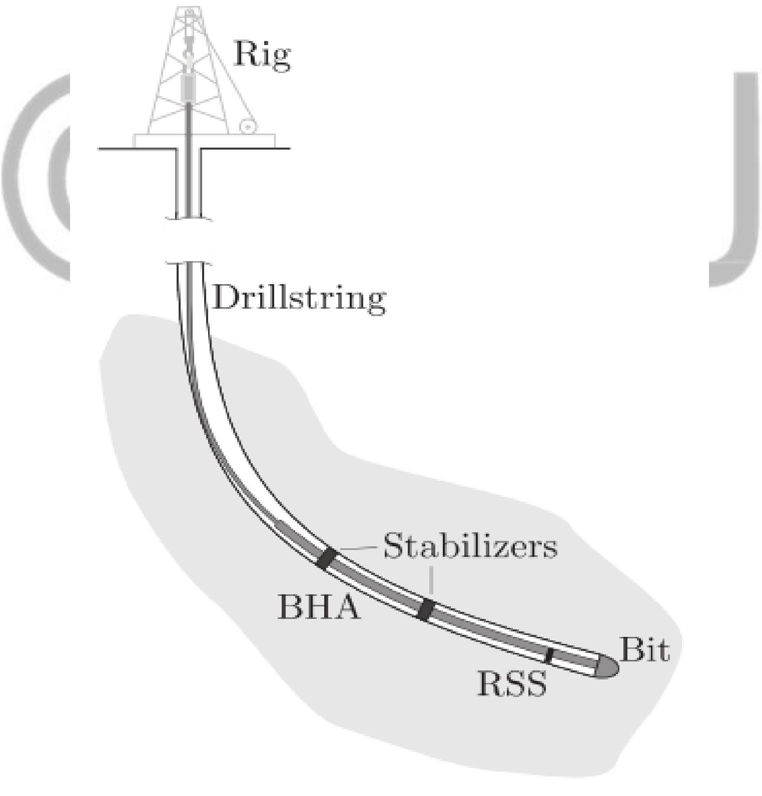


Fig. 1. Schematic overview of a directional drilling system

One main **aim** in directional well trajectory plan is the development of a mathematical model that will best represent a given well path. There are three (3) basic directional well trajectory designs; **Build-and-Hold trajectory**, **Build-Hold-and-Drop trajectory** and **Continuous build trajectory**, whose mathematical models are presented across some drilling technology texts [1-5]. These models were modelled using straight lines in the horizontal departure with azimuth direction.

Currently there are a lot of Petroleum Company providing tools to deflect the path of the wellbore in the direction of as per plan and measure the azimuth and inclination angle precisely. The directional survey data gain from the tools can be analyze and used to calculate the northing and easting at the depth of each survey station. In this project, I will make a study between several methods of wellbore trajectory calculation based on proposed survey field data of well XXX.

1.2. PROBLEM STATEMENT

As the directional well become more important these days due to the ability of reaching several target sands in single well and due to the limitation of space and cost to build another drilling platform. Therefore, it is important to plan, calculate, and determine the position and the path of the wellbore trajectory precisely to avoid any negative implication.

There are five different methods of the survey calculation of wellbore trajectory that can be used in determining the position and location of the wellbore. Survey measurement tools provide parameters at various survey stations but cannot provide real trajectory of the well [2].

In this project, I make some study between several methods namely tangential method, average tangential method, balance tangential method, radius of curvature method and minimum curvature by using proposed survey field data of Well XXX-1.

1.3 PROJECT OBJECTIVES

The main objective of this project has been to identify the different calculation models used in these programs and to program suitable functions similar to those found in existing **planning** software, in an attempt to **create** a new and more ***user-friendly well planning software.***

The objectives of this project are:

1) To test and apply different methods of survey calculation in determining the wellbore trajectory based on the proposed survey of Well XXX-1.
2) To calculate and analyze the error between different methods used.

1.4 SCOPE OF STUDY

There are many methods of survey calculation in order to determine the wellbore trajectory. And for this project, I will using proposed survey data of Well XXX-1. And I will mainly focus on five most simple and common methods used in calculating the survey of the wellbore trajectory namely as the following:

1. Tangential Method
2. Average Tangential Method
3. Balanced Tangential Method
4. Radius of Curvature Method
5. Minimum Curvature Method

And I will also study on the method to define the error between those methods.

CHAPTER 2
LITERATURE REVIEW

2.1 Directional Drilling

Directional drilling is defined as the science and art of deviating a wellbore along a planned course from a starting surface location to a target subsurface location below the earth", whose location is a given lateral distance and direction from the vertical [4]. Directional drilling can also be described as the practice of controlling the direction and deviation of a wellbore to a predetermined underground target or location [3].

At one time, it was assumed all oil wells were essentially vertical or the bottom of the hole was directly under the drilling rig. Unfortunately, this is not true. The petroleum industry did not become fully aware of deviated well problems until the development of the Seminole, Oklahoma field. The wells in this field were drilled very close together. As a result of the deviation tendencies, wells were drilled into other life wells or producing well. Also, wells were encountering the producing formation at different measured depths. The true vertical depths were similar, but measured depths varied significantly [5].

In 1930s, there is one directional well was drilled in Huntington Beach, California, USA, from an onshore location but to hit the target at the offshore oil sands [6]. Oil was produced from under the ocean by placing the rig on the shore and the well was drilled in a directional way moving towards the offshore oil deposits. And after a catastrophic fire incident at Conroe field in 1933 which threatened the entire field production, an entrepreneur George Everett Failing and his crew drilled multiple directional relief wells near the surface location of the blowout in order to extinguish the fire after so many attempts and methods used to stop the fire failed [7]. Ever since the incident, directional drilling has been widely recognized and as of today there are a lot of improvement and R&D to invent new technology and technique in making the directional drilling more safe, accurate and economical.

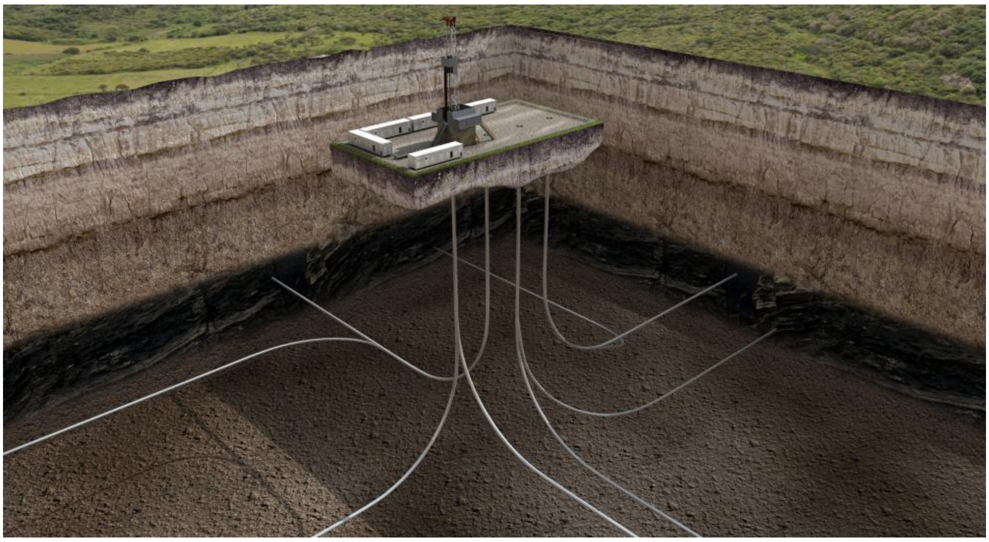


Figure 2.1: Multilateral Wells: Example of a Directional Drilling Application (Butler, 2018).

2.2 Applications of Directional Drilling

There are several types of applications for directional drilling such as [4]:

a) Drilling Sidetracking well
b) Drilling to avoid geological problems
c) Controlling vertical well trajectories
d) Drilling beneath inaccessible locations
e) Drilling Relief wells
f) Drilling Salt Dome
g) Fault Drilling
h) Drilling multiple land wells for environmental reasons
i) Drilling multiple wells from offshore structures
j) Offshore development drilling
k) Drilling horizontal wells
l) Non-petroleum uses

2.2.1 Directional Well Profiles:

In general, the Directional Well profiles can be divided into trajectories confined to one plane (2D trajectories) and more complex trajectories that are not restricted to one plane (3D trajectories). There are three basic 2D trajectories: Type I, II, and III. Additional 2D types are the Horizontal and Vertical Wells. The 3D well trajectories examples consist of Cluster Drilling and Designer Wells (Mitchell & Miska, 2016).

2.2.2 2D Well Trajectories

- **Type I - Slant-Type:** The well is confined in the vertical 2D plane, and it consists of a vertical section that ends at the Kick-of-Point (KOP). The well starts to build up angle from the KOP until a certain depth where the desired inclination is reached. A tangent section is initiated, and it goes until the target is hit.

- **Type II - S-Type:** A S-type well starts with a vertical section until the KOP, followed by a build-up section. A tangent section comes after the desired inclination was reached in the build-up section and ends at a certain depth with a drop section. Sometimes, the inclination is reduced in the drop section to almost vertical until it hits the target.
- **Type III - J-Type:** The J-Type profile is normally used in Appraisal well to assess the extent of a newly discovered reservoir (Krishnan & Kulkarni, 2016). The well is kept vertical until the KOP. A build-up section starts, and the angle is kept increasing until the target is hit.

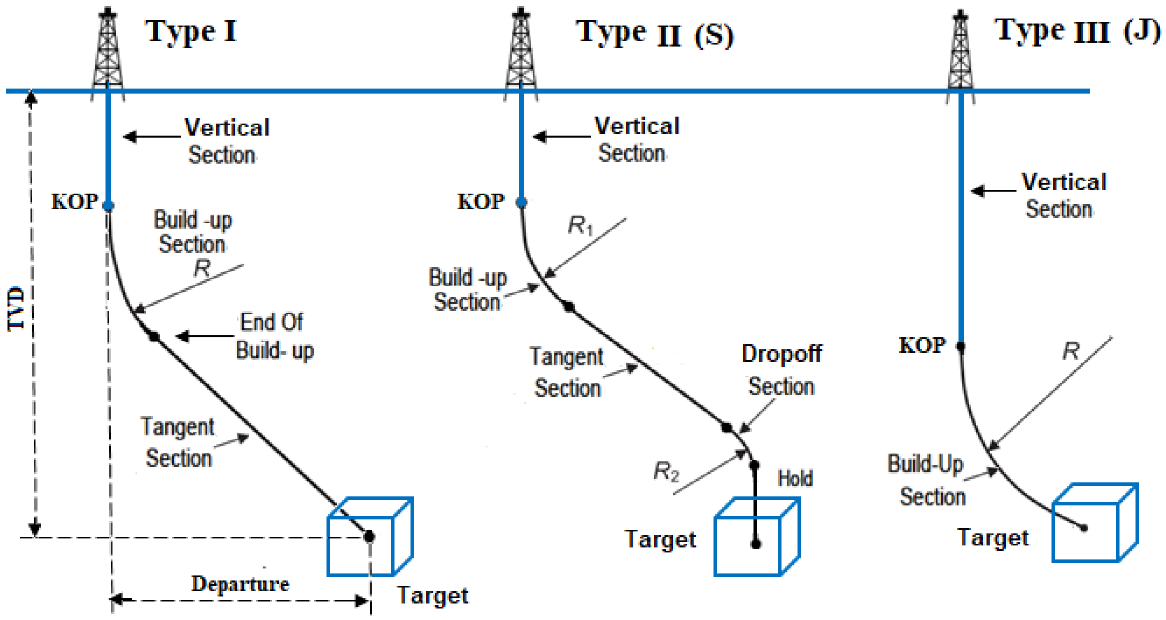


Figure 2.2: Example of Type I, II and II 2D Well Profile (Mitchell & Miska, 2016).

Additional Types: Vertical and Horizontal Wells: The Vertical well is the simplest and economic well to be drilled and historically is the most common onshore well. Now a day is normally used to investigate geological marks or hazards. The Horizontal wells are wells with high inclination angles between 80°to 100°, with an ideal one being 90°of inclination. The Horizontal wells are drilled in the reservoir to potentially increase the wellbore contact and enhance the oil recovery. The well initiates with a vertical section, followed by a build-up segment, and ends with a horizontal section after the desired angles were achieved in the build-up section. Before it reaches horizontal, the well can have different profiles than just a build-up section, for example, a tangent section.

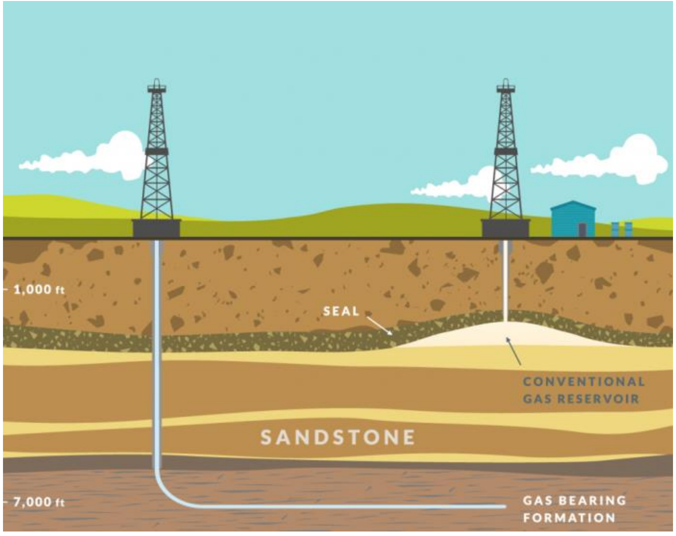


Figure 2.3: Examples of Vertical and Horizontal Wells (Cumming, 2017)

2.2.3. Horizontal Drilling

Normally the deviation of a directional well is around 60º of inclination and the inclination beyond 60º will lead to many drilling issues and will further increase the total cost of the drilling operation [4]. Even though the risk is high but horizontal drilling has several advantages which it cannot be achieve by normal deviated wells. Some of the advantages are:

a) Increase the drainage area
b) Prevent gas coning or water coning issues
c) Increase the length of penetration of the production zone
d) Increase the EOR technique
e) Improve productivity in fractured reservoirs by intersecting a number of vertical fractures.

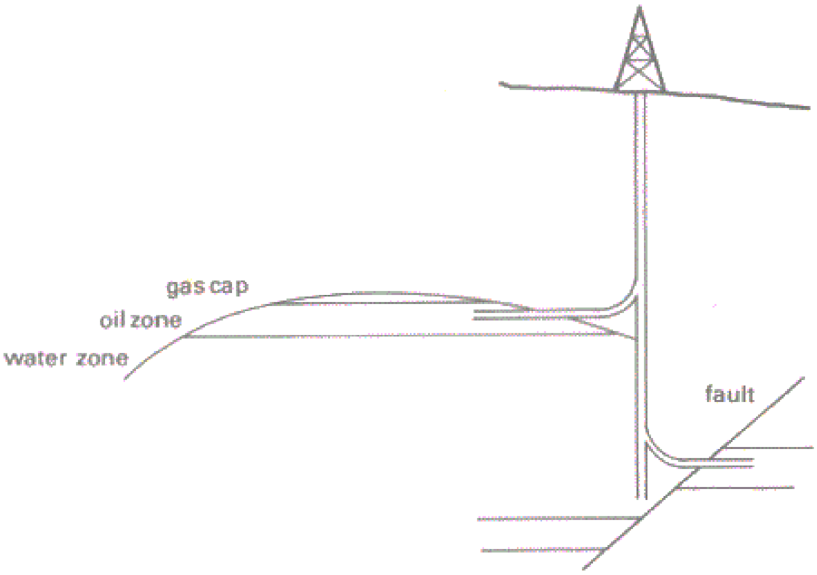


Figure 2.4: Horizontal drilling application [4]

Even though the cost of horizontal drilling will rise up exponentially, but the production rate can also be increase and improve greatly. The potential benefit from the horizontal well and the risk involved will need a very extensive analyze before the project can be decided to proceed or not. Figure 2.4 shows the illustration of the horizontal well.

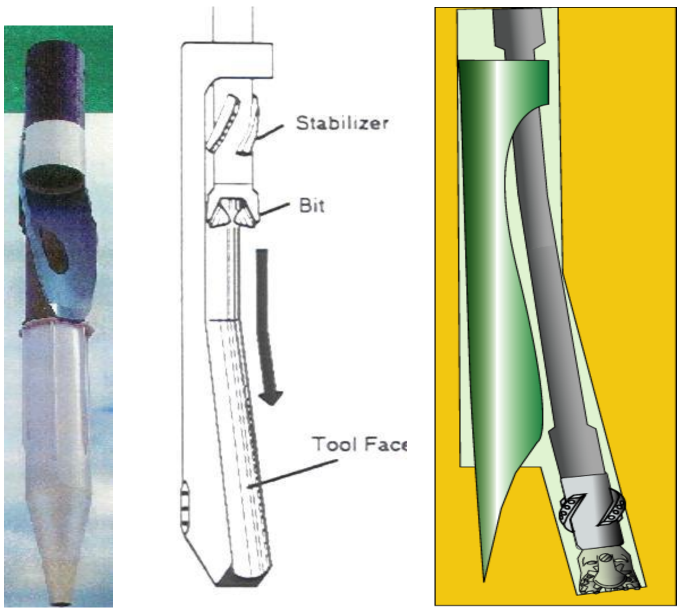
2.2.4 Deflecting Tools

Even though the rotary assemblies can be designed is such a way that it can alter the path of the wellbore, there are certain conditions where it is necessary to used special tools. These are several types of deflection tools [4]:

2.2.4.1 Whipstocks

Whipstocks were used in directional wells to start kick off as illustrated in Fig. 2.5. The direction in which the tapered edge was facing is known as the "tool-face". A standard whipstock is seldom used nowadays, but it has not disappeared completely. Whipstocks are used in coiled tubing drilling for re-entry work. There are three types of whipstocks used in conventional directional drilling:

1) Standard removable Whipstock, which can be used to initiate deflection in open hole, or straighten the vertical wells that have become crooked.
2) Circulating Whipstock
3) Permanent Casing Whipstock, which normally used in cased hole for sidetracking around a fish.



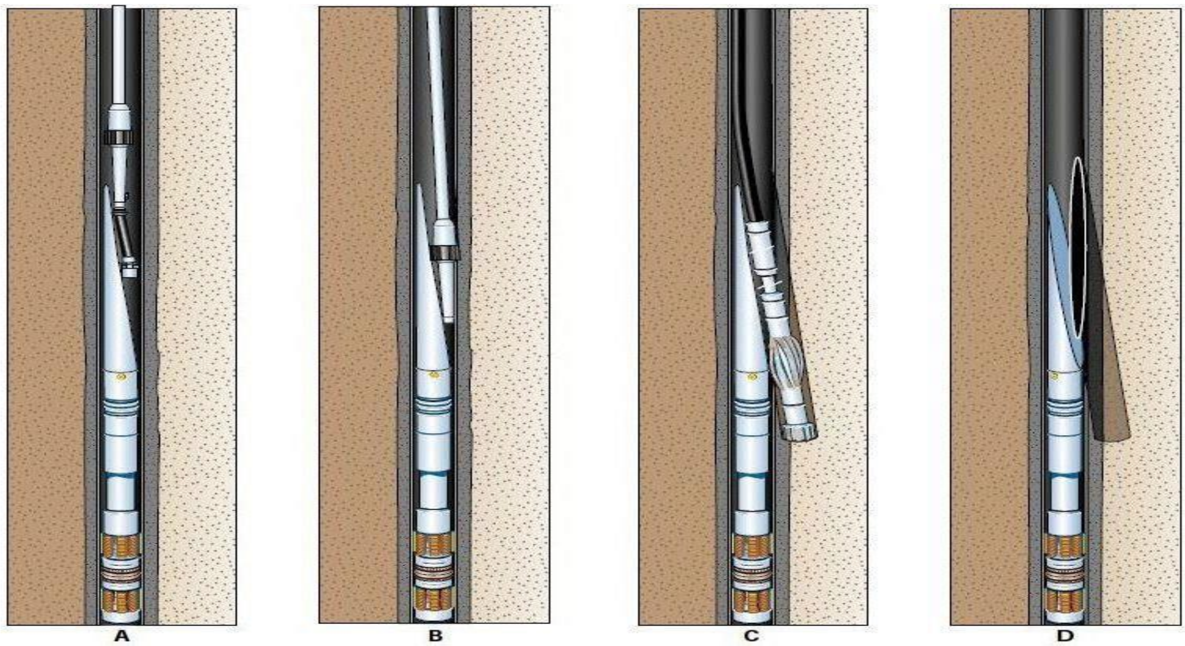


Figure 2.5: Application of Whipstock

2.2.4.2 Jet Bit

Jetting bit (or badgering) is a technique used to deviate wellbores in soft formations [2]. See **Fig**. 2.6. The technique was developed in the mid of 1950s and superseded the use of whipstocks as the primary deflection technique. Although jetting has subsequently been supplanted by downhole motor deflection assemblies it is still used frequently and offers several advantages which makes it the preferred method in some situations. A special jet bit may be used, but it is also common practice to use a standard soft formation tri-cone bit, with one very large nozzle and two smaller ones. See **Fig**.11.

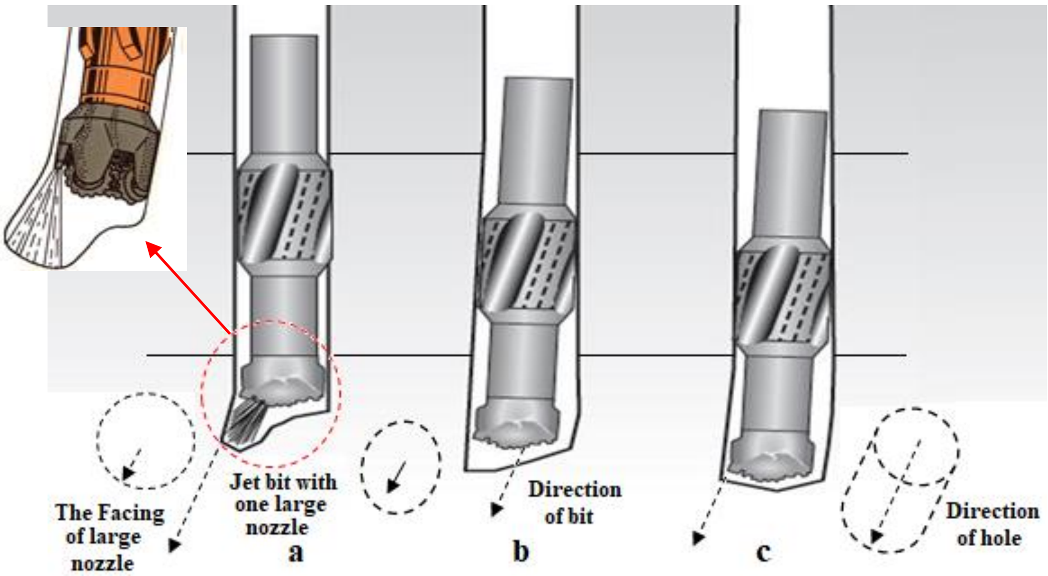


Fig. 2.6. Jetting bit technique: a) Wash away a pocket by jetting; b) Start to drill, bit follows pocket direction; c) Well deviated in pocket direction

2.2.4.3 Downhole Motor and Bent Sub

Another deflection tool is a positive displacement motor which drive the bit without rotating the drill string. The deflection is provided by a special bent sub placed above the motor to create slightly bent in an angle as shown in **Fig**. 2.7. Mud is pumped through the drill string to operate the motor and drive the bit without rotating the drill-string. An MWD tool or steering tool should be run to monitor the tool-face heading continuously.

Figure 2.7: Positive Displacement Motor with Bent Sub and Bent Housing [4]

The advantages of using a Bent sub or bent housing with a mud motor are that:

(a) Full-gauge hole can be drilled without the need for a pilot hole.

(b) The continuous side force produced at the bit by the bent sub gives a smooth curvature with less risk of severe dog-legs.

(c) Depending on the orienting of the bent sub, this technique can be used to build or drop inclination, and to steer the bit to the left or right.

When a very rapid change of angle is required, a bent sub can be used together with a bent housing. One important disadvantage is that the rubber components of the motor can be damaged by high temperatures.

2.2.4.4 Rotary Steerable System RSS

The RSS is an evolution and development of technology that overcomes the weaknesses in steerable motors and in conventional rotary assemblies. By using **RSSs**, it can allow continuous rotation of the drillstring while steering the bit to the targeted direction.

Therefore, **RSS** will give a better penetration rate, in general, than the conventional steerable motor assemblies. Another advantage of **RSS** is having a better hole cleaning, lower torque and drag, and better hole quality. The only drawback of **RSS** is the cost of running it which is considerably expensive.

There are two types of steering concepts for **RSS**, one is point-the-bit and another one is push-the-bit. The point-the-bit system applies the same principle employed in the bent-housing motor systems. Point-the-bit systems claim to allow the use of a long-gauge bit to reduce hole spiraling and drill a straighter wellbore. On the other hand, push-the-bit system uses the principle of applying side force to the bit, pushing it against the borehole wall to achieve the desired trajectory.

Rotary drilling is described as a system in which the **BHA** is connected to a rotatable drill string driven from the drilling platform at the surface. The RSS is an evolution in DD technology that overcomes the disadvantages in steerable motors and in conventional rotary assemblies. To begin a change in the well trajectory the actuator introduces a deflection from the centerline of the hole, this mode is known as the steering mode Figure 2.8 [61].

RSSs permit the drill string to continuously rotate while the drill bit steer its direction. Consequently, they generally provide better **ROP** than the conventional steerable motor assemblies.

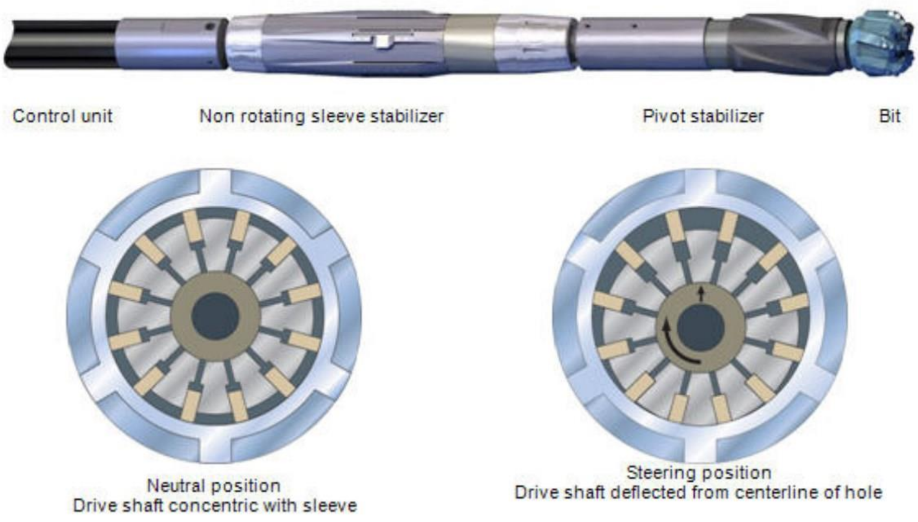


Figure 2.8: Modes of Rotary Steerable System

The RSS consists of three points of contact **Figure** 2.9. First of all is the drill bit, which is the contact part with the formulation, then the steering actuator located at L_1 from the bit. This actuator eccentrically deflects the centerline of the drill string away from the centerline of the hole by a controllable amount **ecc** in a given plane. The third point is the stabilizer which is located at a distance L_2 from the actuator. The stabilizer, actuator, and control unit are placed in a non-rotating sleeve [62].

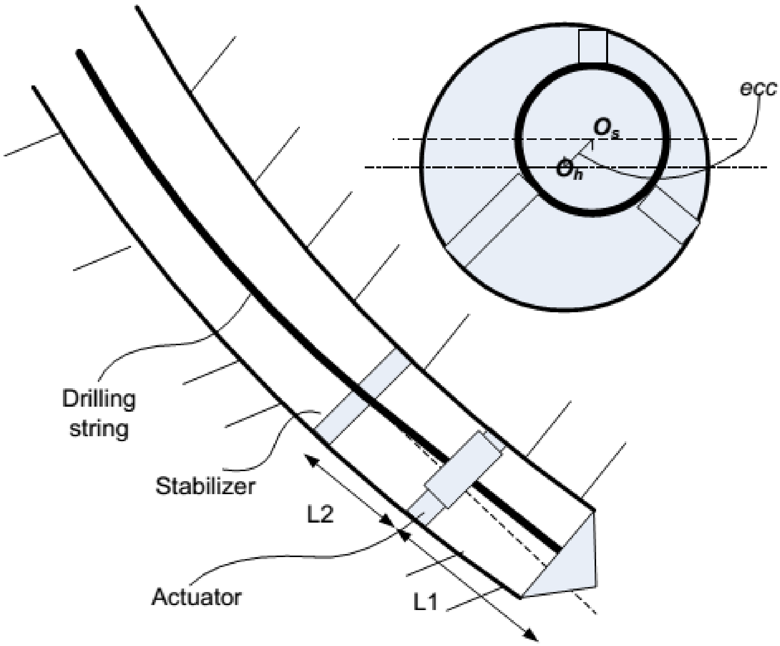


Figure 2.9: Rotary Steerable System structure

2.3 Methods of Wellbore Trajectory Calculation

Although the wellbore course is determined by measurements of inclination and azimuth at different survey stations, the real shape of the wellbore between stations are not known [9]. Hence, it is industry practices to make assumptions utilizing several calculation methods. Table 1 shows the various methods that can be used in survey calculation to determine the wellbore trajectory [2].

Table 1: Different Types of Survey Calculation Methods

Methods	Contributor	Description/Assumption
Numerical Integral	Xiushan Liu	Inclination and azimuth are cubic multi-nominals, the coordinates are determined through numerical
Curve Structure	Xiushan Liu	The coordinates are functions of borehole curvature and torsion at two survey station
Natural Curve	Xiushan Liu	A 3D curve that rates the inclination change and

		azimuth change remains individually constant
Constant tool-face	F.J. Schuh, Guo Boyun	A 3D curves that borehole curvature and tool-face remain individually constant.
Rectified Average Angel	Jiying Zheng	An approximate calculation from the radius of curvature.
Chord Step	Fuqi Liu	An arc in an inclined plane, but the measured course length is assumed as its chord.
Minimum Curvature	H.L Taylor, W.A. Zaremba	An arc in an inclined plane, the borehole curvature remains constant and borehole torsion remain zero
Radius of Curvature	G.J. Wilson, Jiying Zheng	A cylinder-helix curve, the curvature in a vertical expanded plot and in a horizontal projected plot remain individually constant
Average Angle	J. E. Edison	A linear section
Balanced Tangential	J. E. Walstrom	A polygonal line
Tangential	Unknown	The simple's calculation. The wellbore is a straight

Following are the most simple and common **survey calculation** methods used for determine the well trajectory [10]:

2.3.1 Tangential Method

This method assumes that the wellbore is straight line defined by the inclination and azimuth of the next survey station. Tangential method is not a good method to determine the wellbore trajectory because it assumes all changes in direction occurs only at the survey stations.

2.3.2 Average Tangential Method

The average angle method uses the average value between the two survey point of inclination and azimuth and assumes the wellbore to be tangent to the average angle.

2.3.3 Balance Tangential Method

In this method, the length between two survey stations is divided into two halves and assumes the first half is tangent to the wellbore at the first survey station, and the second half is tangent to the wellbore at the next survey station.

2.3.4 Radius of Curvature Method

This method assumes that the wellbore has the shape of a smooth arc and it is tangent to the inclination and azimuth at each survey station. This method is better than the Tangential and Balanced tangential methods, it assumes, as the other two that changes in the wellbore correspond with depth of survey stations.

2.3.5 Minimum Curvature Method

Minimum Curvature method assumes that the two survey stations lie on a smooth circular arc by using the angles measured. The arc is smoothed out by multiplying with a ratio factor (RF). This method is basically the Balanced Tangential method timed with the dogleg ratio factor.

2.4 Survey Tools

These are the different types of survey tools [10]:

2.4.1 Measurement While Drilling (MWD) Tools

MWD is the process by which certain information is measured near the bit and transmitted to surface without interrupting normal drilling operations. The type of information may be:

(a) Directional data (inclination, azimuth, toolface);

(b) Formation characteristics (gamma-ray, resistivity logs);

(c) Drilling parameters (downhole WOB, torque, and rpm).

MWD tools are a very good and fast way to measure several different parameters and steer a well in the targeted direction simultaneously. Multi station processing technique can be used in order to improvise the accuracy of wellbore directional survey [11]. There are two main components in the MWD tools which are accelerometers and magnetometers. Accelerometers measure local acceleration while for the magnetometers; it will measure strength of earth's magnetic field.

2.4.2 Gyro Measurement While Drilling

Gyro measurement while drilling was introduced as another option to Gyro single shot tool for certain applications. While the Gyro single shot is run on wireline, the Gyro MWD is real-time tool run alone or with regular MWD tool on drill pipe. Normally, Gyro MWD is commonly used in the top sections near the surface to get a more accurate measurement of the magnetic interference. This is to ensure no colliding will occur with an existing wellbore when drilling from a platform which the slots is very close to each other.

CHAPTER 3

METHODOLOGY

All the way through this project, there are some methodologies that will be applied in
order to achieve the objective and meet the purpose of this project. The methodologies
that involved in this project are (**Figure** 3.1):

3.1.1 Project Process Flow:

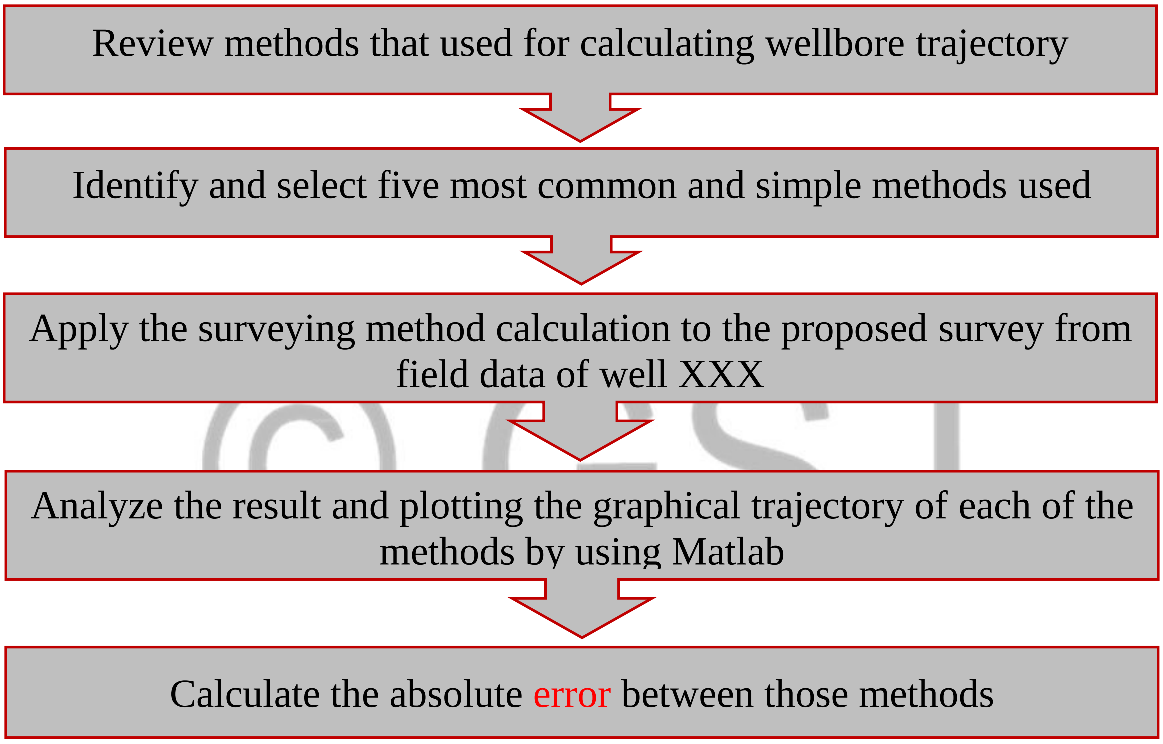


Figure 3.1: Process Flow for Research Methodology

3.1.2 Survey Calculation Methods

There are several different methods used in survey calculation in determining the wellbore trajectory. As for this project, I will apply five most simple and common methods used to test on the proposed survey field data of Well XXX-1.

3.1.2.1 Tangential Method

This method assumes that the wellbore is straight line from two survey stations (**Figure** 3.2) [12]. Tangential method is not practical to be used in calculating the wellbore position because it assumes all changes in direction occurs only at the survey stations [10].

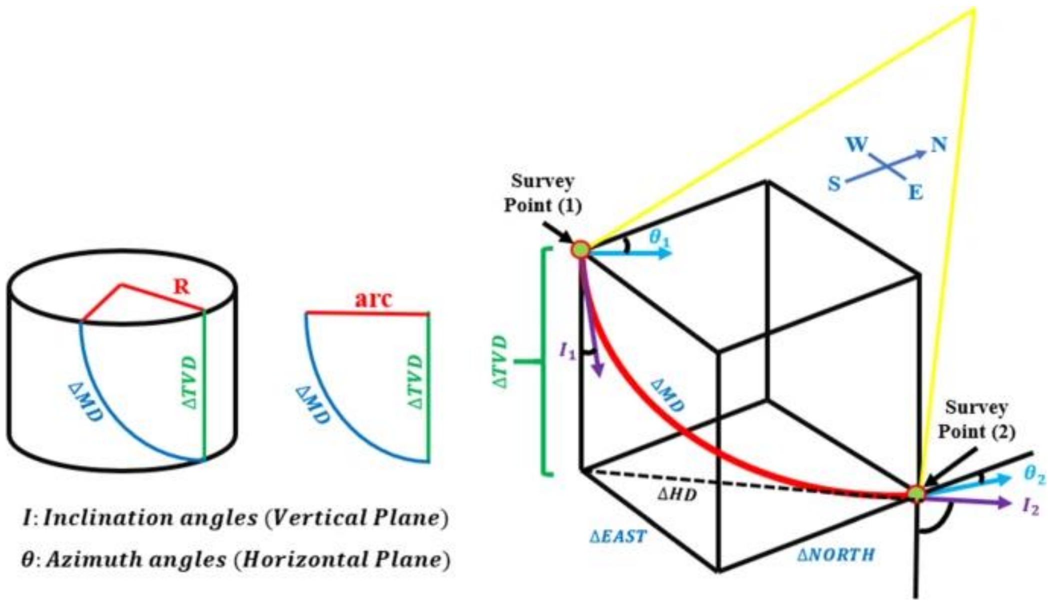


Figure 3.2: Illustration of Tangential method [13]

Formula for Tangential Method:

North = MD x Sin (I_i) x Cos (Θ_i) (1.1)

East = MD x Sin (I_i) x Sin (Θ_i) (1.2)

TVD = MD x Cos (I_i) (1.3)

3.1.2.2 Average Tangential Method

The average tangential method takes the average between two survey stations and assumes that the wellbore has a tangential path as shown in the **Figure** 3.3 [2].

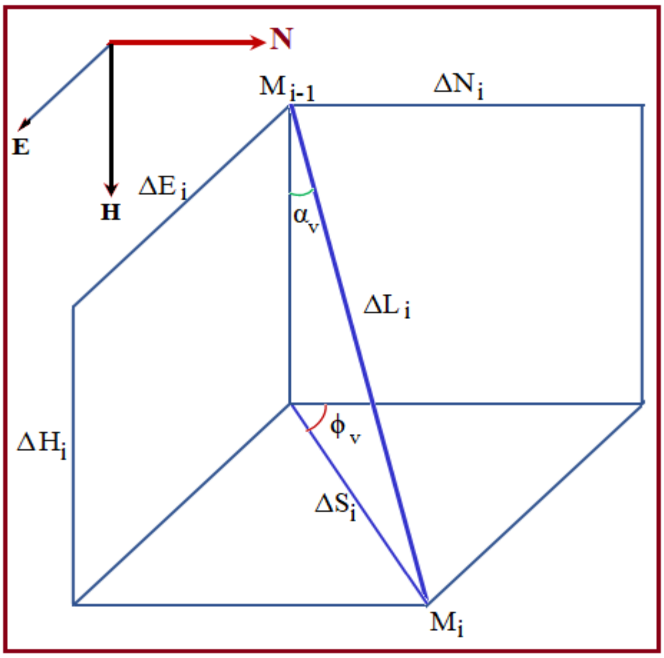


Figure 3.3: Illustration of Average Tangential method [2]

<u>Formula for Average Tangential Method:</u>

$$\text{North} = \text{MD x Sin}\left(\frac{I_{i-1}+I_i}{2}\right) \text{x Cos}\left(\frac{A_{i-1}+A_i}{2}\right) \quad (2.1)$$

$$\text{South} = \text{MD x Sin}\left(\frac{I_{i-1}+I_i}{2}\right) \text{x Sin}\left(\frac{A_{i-1}+A_i}{2}\right) \quad (2.2)$$

$$\text{TVD} = \text{MD x Cos}\left(\frac{I_{i-1}+I_i}{2}\right) \quad (2.3)$$

3.1.2.3 Balanced Tangential Method

In the balanced tangential method, the course length between the two survey stations is divided into halves (Figure 3.4). It assumes that the first half is tangent to the first survey station and the second half is tangent to the second survey station.

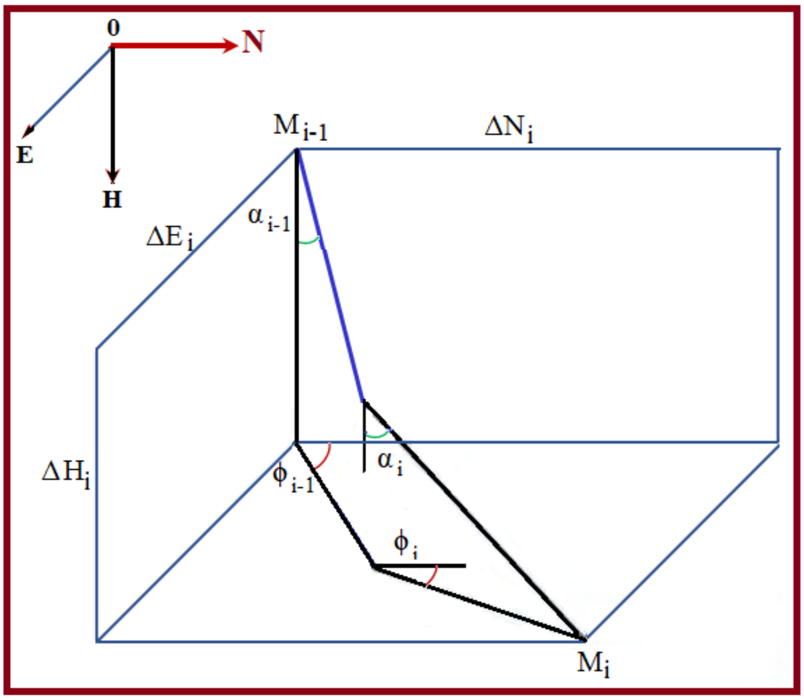


Figure 3.4: Illustration of Balanced Tangential method [2]

<u>Formula for Balanced Tangential Method</u>

$$\text{North} = \frac{\text{MD}}{2} \text{ x [Sin}(I_{i-1}) \text{ x Cos}(A_{i-1}) + \text{Sin}(I_i) \text{ x Cos}(A_i)] \quad (3.1)$$

$$\text{South} = \frac{\text{MD}}{2} \text{ x [Sin}(I_{i-1}) \text{ x Sin}(A_{i-1}) + \text{Sin}(I_i) \text{ x Sin}(A_i)] \quad (3.2)$$

$$\text{TVD} = \frac{\text{MD}}{2} \text{ x [Cos}(A_{i-1}) + \text{Cos}(A_i)] \quad (3.3)$$

3.1.2.4 Radius of Curvature Method

The radius of curvature method is currently considered to be one of the most accurate methods available. The method assumes the wellbore course is a smooth curve between the upper and lower survey stations. And the curvature of the **arc** is determined by the survey inclinations and azimuths at the upper and lower survey stations. And the length of the arc between I_1 and I_2 is the measured depth between survey stations.

The radius of curvature method assumes that the wellbore has a shape of smooth curve described by a circular arc (Figure 3.5) [14]. This method is less accurate when a severe dogleg is present in the interval of calculation [2].

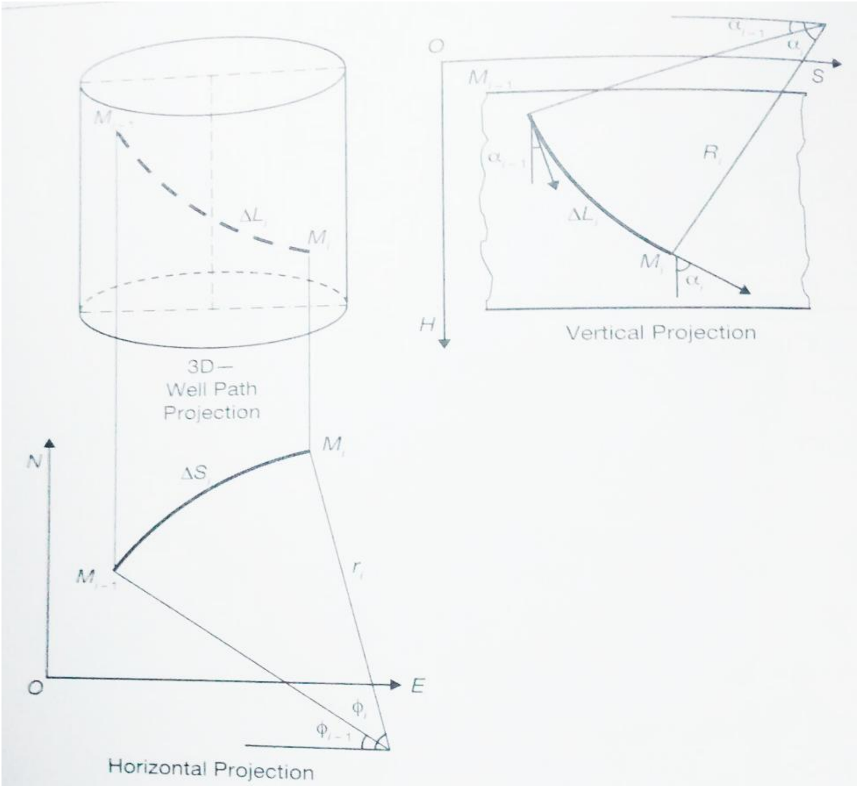


Figure 3.5: Illustration of Radius of Curvature method

Formula for Radius of Curvature Method:

$$\text{North} = \frac{(180)^2(\text{MD})(\text{Cos } I_1 - \text{Cos } I_2)(\text{Sin } A_2 - \text{Sin } A_1)}{\pi^2 (I_2 - I_1)(A_2 - A_1)} \quad (4.1)$$

$$\text{East} = \frac{(180)^2(\text{MD})(\text{Cos } I_1 - \text{Cos } I_2)(\text{Cos } A_1 - \text{Cos } A_2)}{\pi^2 (I_2 - I_1)(A_2 - A_1)} \quad (4.2)$$

$$\text{TVD} = \frac{(180)(\text{MD})(\text{Sin } I_2 - \text{Sin } I_1)}{\pi(I_2 - I_1)} \quad (4.3)$$

$$\text{DEP} = \frac{(180)(\text{MD})(\text{sin } I_1 - \text{cos } I_2)}{\pi(I_2 - I_1)} \quad (4.4)$$

$$r = \frac{(180)}{\pi(DLS)} \quad (4.5)$$

$$MD = \frac{(I_2 - I_1)}{B_1} \quad (4.6)$$

3.1.2.5 Minimum of Curvature Method

The minimum curvature method uses the angles measured at two consecutive survey stations to describe a smooth **circular arc** representing the wellbore path as shown in the **Figure** 3.6 [15]. It uses the dogleg ratio factor (FC) in order to get smooth wellbore section. This method replaces the straight lines assumed in the balanced tangential method by a circular arc.

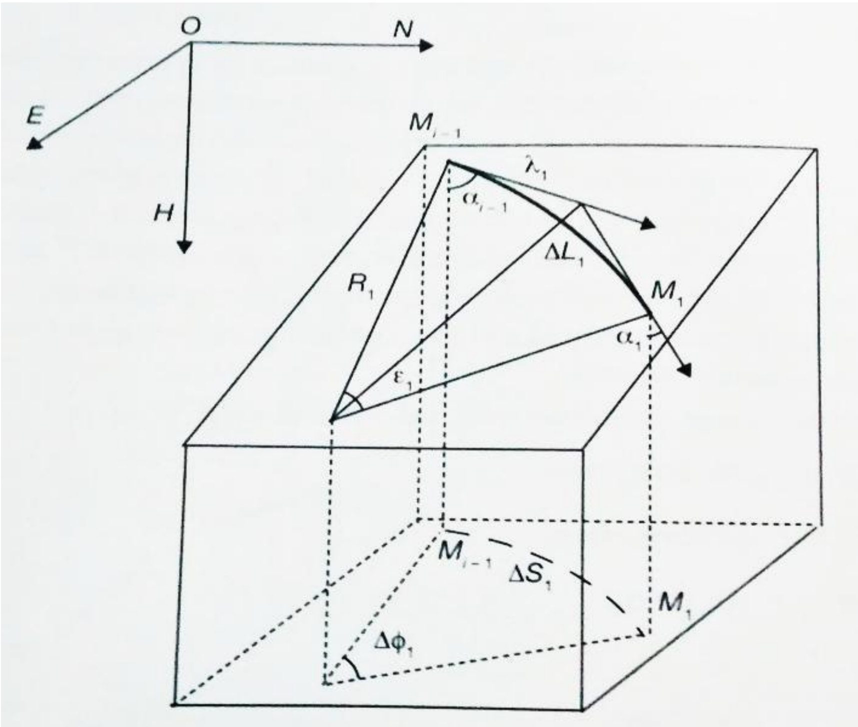


Figure 3.6: Illustration of Minimum Curvature method

Formula for Minimum Curvature Method:

$$\Delta North = FC \times \left(\frac{\Delta MD}{2}\right) \times \left[\left(Sin\,(I_2) \times Cos\,(A_2)\right) + \left(Sin\,(I_1) \times Cos\,(A_1)\right)\right] \quad (5.1)$$

$$\Delta East = FC \times \left(\frac{\Delta MD}{2}\right) \times [(Sin\,(I_2) \times Sin\,(A_2)) + (Sin\,(I_1) \times Sin\,(A_1))] \quad (5.2)$$

$$\Delta TVD = FC \times \left(\frac{\Delta MD}{2}\right) \times [Cos\,(I_1) + Cos\,(I_2)] \quad (5.3)$$

$$D_1 = Cos(I_2 - I_1) - \left[Sin\,(I_2) \times Sin\,(I_1) \times \left(1 - Cos(A_2 - A_1)\right)\right] \quad (5.4)$$

$$D_2 = Tan^{-1} \sqrt{\left(\frac{1}{D_1^2}\right) - 1} \quad (5.5)$$

$$FC = \frac{2}{D_2} x\, Tan\left(\frac{D_2}{2}\right) \quad (5.6)$$

3.1.3 Absolute Error calculation analysis

Absolute error is the square roots of the squared sums of the single coordinate errors between the calculated result and the exact target with north course coordinated, east course coordinate and course vertical depth [2].

$$Error = \sqrt{(N_{ci} - N_{ti})^2 + (E_{ci} - E_{ti})^2 + (TVD_{ci} - TVD_{ti})^2} \quad (6.1)$$

3.2 INPUT WELL DATA:

3.2.1 Lithology (Formations):

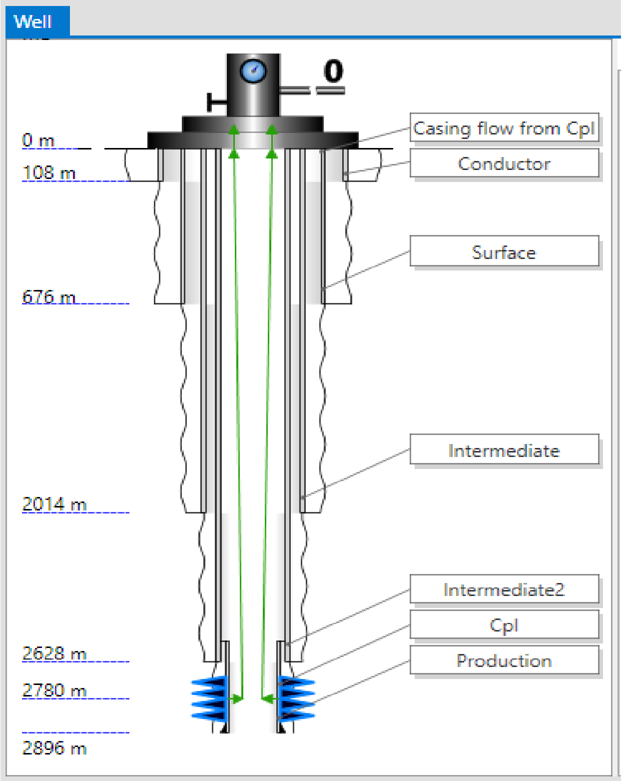
Lithology

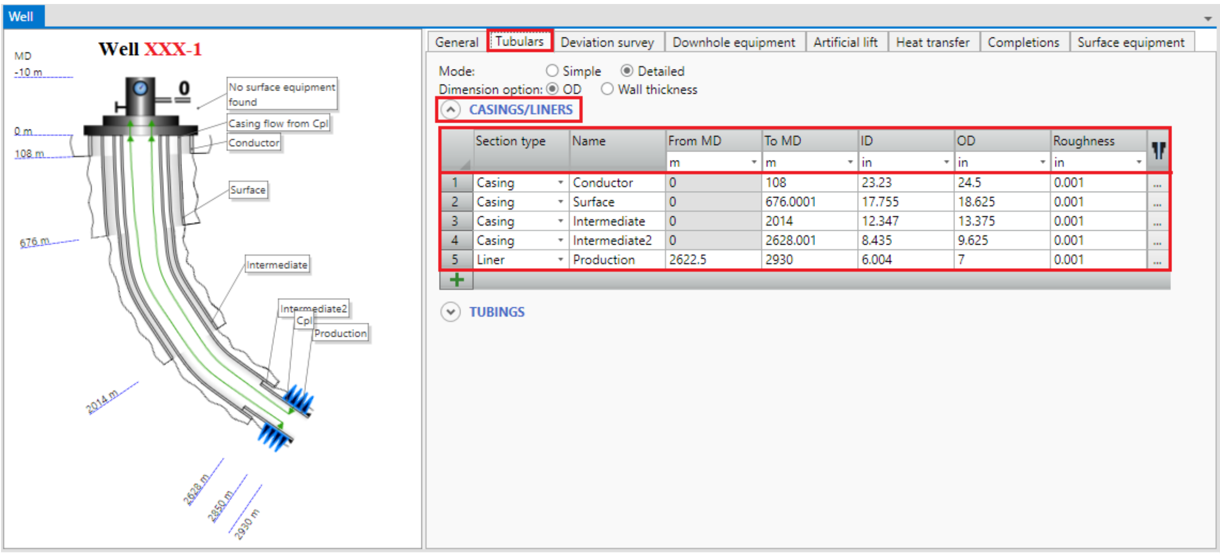
	Layer Name	Layer Type	Layer Top TVD (ft)	Competent Layer	Overbalance Margin (ppg)	Diff. Sticking Limit (psig)	Stability Min. MW (ppg)
1	L. Fars Marl	Sand	1173	Yes	0.50	1500	8.50
2	Ghar	Shale, Sandy	1698	Yes	0.50	1500	8.60
3	Dammam	Limestone, Argillaceo	2207	Yes	0.50	1500	8.60
4	RUS	Dolomite	2866	Yes	0.50	1400	8.60
5	Umm Er-Radhu	Dolomite	3158	Yes	0.50	1400	8.60
6	Tayarat Bitumin	Shale, Siliceous	4887	Yes	0.50	1500	9.00
7	Shiranish	Limestone, Argillaceo	5747	Yes	0.50	1500	8.70
8	Hartha	Limestone, Argillaceo	6158	Yes	0.50	1500	9.10
9	Sadi	Shale, Sandy	6768	Yes	0.50	1500	10.40
10	Tanuma	Limestone, Argillaceo	8169	Yes	0.50	1500	12.00
11	Khasib	Limestone, Argillaceo	8340	Yes	0.50	1500	12.25
12	Mishrif	Limestone, Argillaceo	8693	Yes	0.50	1500	12.50

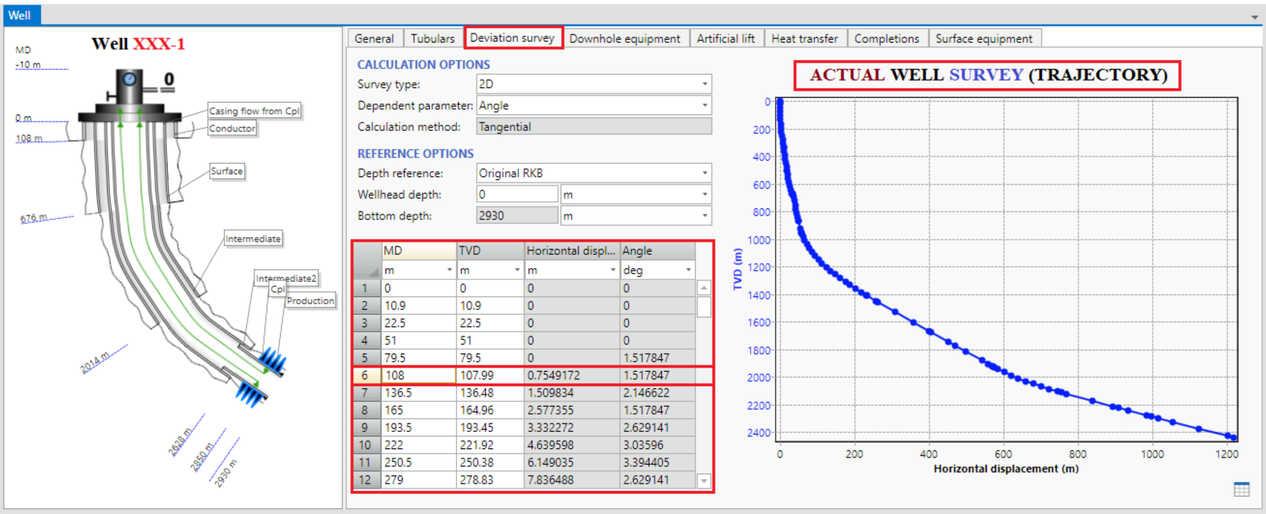
1. Hole and Casing Size:

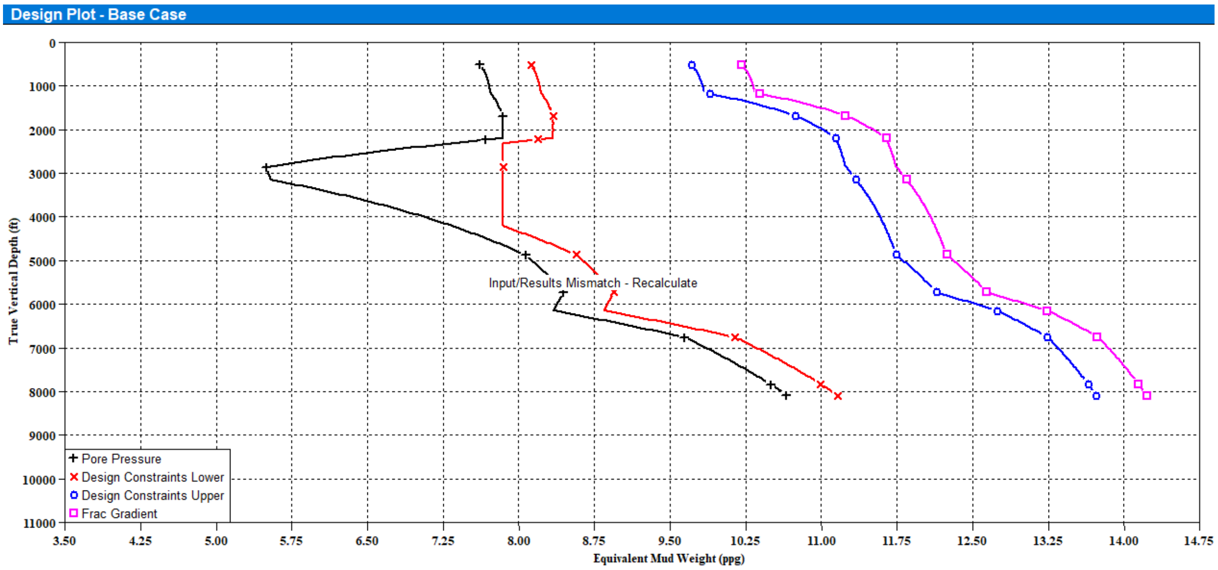
Casing Type	Hole Size (bit), (in)	Casing (OD) Diameter, (in)	MD From (m)	MD To (m)
Conductor	24.500	18.625	0.000	10.900
Surface Casing	23.000	18.625	0.000	676.000
Intermediate Casing 1	17.500	13.375	0.000	2041.000
Intermediate Casing 2	12.250	9.625	0.000	2628.000
Production Liner	8.500	7.000	2628.000	2896.000

2. The Well Schematic & Survey using PIPESIM software:


Well
0
0 m
108 m
676 m
2014 m
2628 m
2780 m
2896 m
Casing flow from Cpl
Conductor
Surface
Intermediate
Intermediate2
Cpl
Production


Well
Well XXX-1
MD
-10 m
0 m
108 m
676 m
2014 m
2628 m
2850 m
2930 m
No surface equipment found
Casing flow from Cpl
Conductor
Surface
Intermediate
Intermediate2
Cpl
Production
General
Tubulars
Deviation survey
Downhole equipment
Artificial lift
Heat transfer
Completions
Surface equipment
Mode: Simple Detailed
Dimension option: OD Wall thickness
CASINGS/LINERS
Section type | Name | From MD | To MD | ID | OD | Roughness
m | m | in | in | in
1 Casing | Conductor | 0 | 108 | 23.23 | 24.5 | 0.001
2 Casing | Surface | 0 | 676.0001 | 17.755 | 18.625 | 0.001
3 Casing | Intermediate | 0 | 2014 | 12.347 | 13.375 | 0.001
4 Casing | Intermediate2 | 0 | 2628.001 | 8.435 | 9.625 | 0.001
5 Liner | Production | 2622.5 | 2930 | 6.004 | 7 | 0.001
TUBINGS





PLANNING OF THE DIRECTIONAL WELL XXX-1

Well Type I (Build-Hold):

Well Data:

Target Depth (TVD)	2,440.31 m (8,006.3 ft) TVD
Kick-off-Point (KOP)	696 m (2,283.5 ft) TVD
Horizontal Departure (HD)	1,200 m (3,937 ft)
Direction of Departure	N30°E
Rate of Build	1.5°/30m (1.5°/100 feet)
Total Depth of Well (TVD)	2,467 m (8,093.832 ft) TVD

And we should determine the followings:

1. True vertical depth (TVD) for each section
2. Measured depth (MD) for each section
3. Horizontal departure (HD) for each section
4. North coordinate at target and TD
5. East coordinates at target and TD

6. Closure distance at target and TD
7. Closure direction at target and TD
8. Construct a vertical plan view section and horizontal plan view.

1. SECTION 1 - Vertical Section to KOP

From the information given, the kickoff point (KOP) is 696 m (2283.5 ft). Since this is a **vertical** hole, there is no horizontal departure, and the MD is the same as the TVD.

The following shows the data for this section of the hole. In reality, the hole will not be perfectly vertical but for planning purposes, it is sufficient to assume that it is vertical.

SECTION	MD, m	TVD, m	Horizontal Departure, m
Vertical to KOP	696 m (2283.5 ft)	696 m (2283.5 ft)	0

2. SECTION 2 – Buildup Rate

To **determine** the angle necessary to achieve the desired horizontal departure of 1,200m (3,937 ft), the 1.5°/30 m (1.35°/100 feet) buildup graph is used. And to use this graph, one must determine the TVD remaining in which to accomplish the horizontal departure.

The TVD remaining in this example is the total TVD to the target minus the TVD to the kickoff point.

or:

The TVD remaining = Well target depth - VD to KOP

The TVD remaining = 8,006.3 - 2,283.5 = 5,722.8 ft

In 6,316.8 ft of TVD, the hole must have a horizontal departure of 3,937 ft.

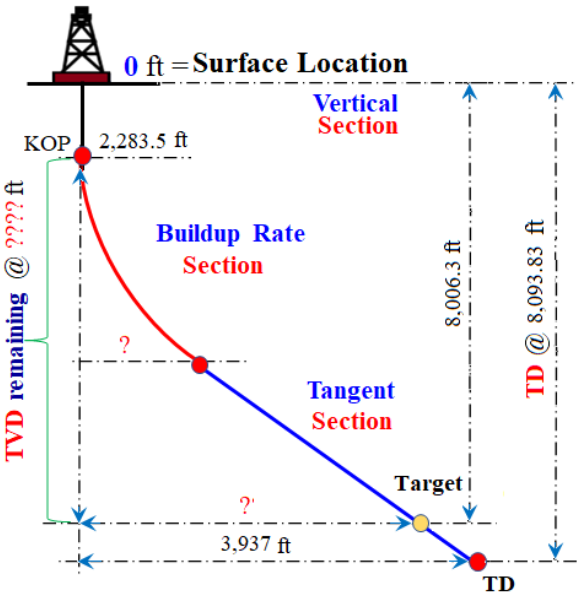


Figure 3.13: Well Planning

Using the 1.5°/30m (1.5°100 feet) buildup graph (chart below), enter the graph at 3,937 ft on the horizontal departure scale (bottom). And draw a line up until it meets the TVD depth (vertical scale) of 5,722.8 ft. Then read the angle of inclination running through this point.

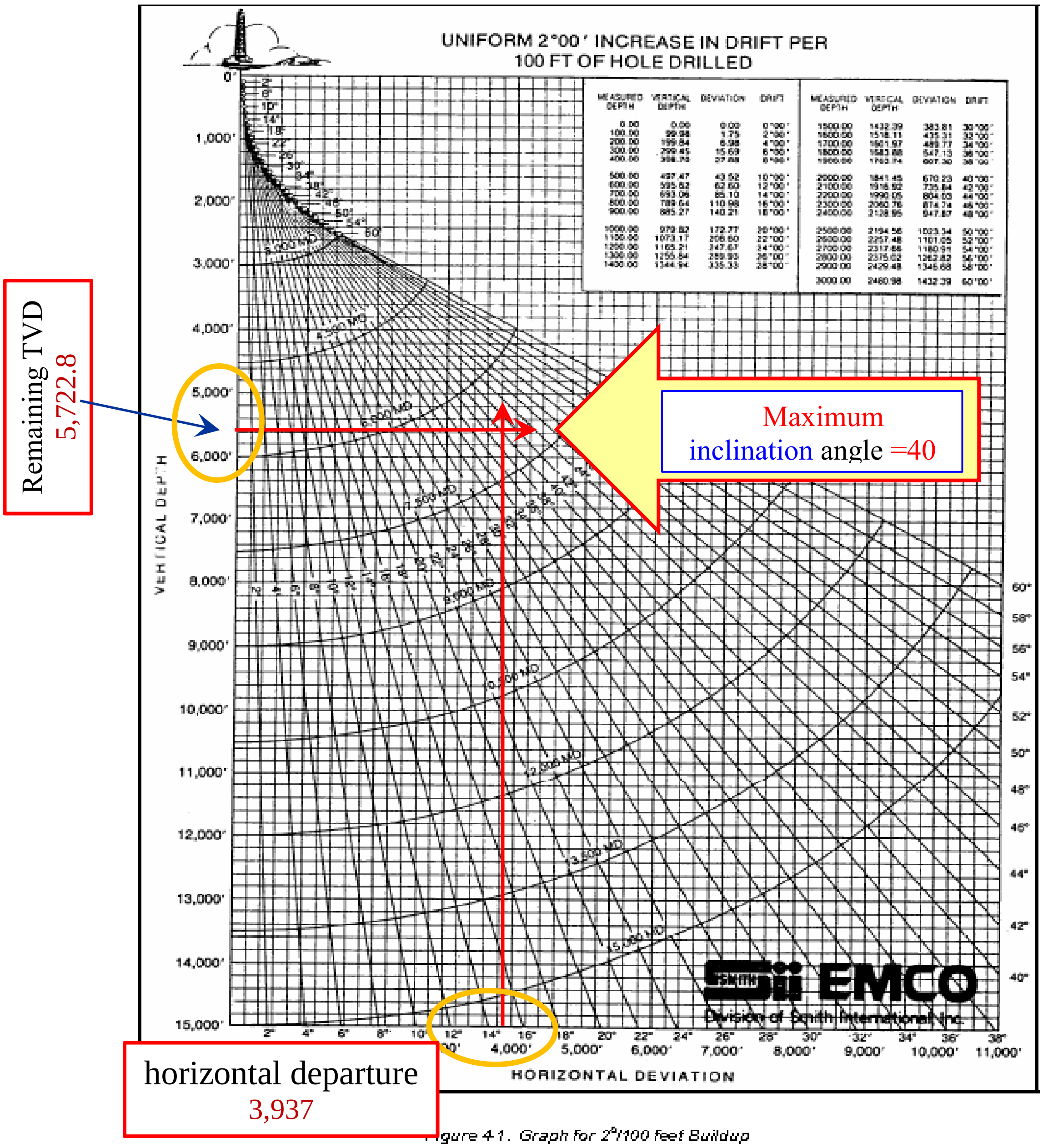


Figure 3.14: Build UP Chart

That inclination is 40°. Therefore, if the inclination is increased at 1.5°/100 feet to 40° and then maintained; the horizontal departure will be 3,937 ft after drilling 5,722.8 ft of true vertical depth (TVD).
When the hole is kicked off at 2,283.5 ft VD, the inclination should be built to 40° at a rate of 1.5°/100 feet. The 40° inclination is maintained until a target depth of 8,006.3 ft is reached which will hit the target. And drilling is continued at 40° to a total depth of 8,093.83 ft TVD.

Now determine the MD, TVD, and DEP for the **buildup** section of the hole. And this information can be obtained from the 1.5°/100 feet **buildup** **table**. At an inclination of 40°, the following is the corresponding MD, TVD, and DEP.

Table (3.1): Buildup Table

MEASURED DEPTH	VERTICAL DEPTH	DEVIATION	DRIFT	MEASURED DEPTH	VERTICAL DEPTH	DEVIATION	DRIFT
0.00	0.00	0.00	0°00'	1500.00	1432.39	383.81	30°00'
100.00	99.98	1.75	2°00'	1600.00	1518.11	435.31	32°00'
200.00	199.84	6.98	4°00'	1700.00	1601.97	489.77	34°00'
300.00	299.45	15.69	6°00'	1800.00	1683.88	547.13	36°00'
400.00	398.70	27.88	8°00'	1900.00	1763.74	607.30	38°00'
500.00	497.47	43.52	10°00'	2000.00	1841.45	670.23	40°00'
600.00	595.62	62.60	12°00'	2100.00	[illegible]	[illegible]	42°00'
700.00	693.06	85.10	14°00'	2200.00	1990.05	804.03	44°00'
800.00	789.64	110.98	16°00'	2300.00	2060.76	874.74	46°00'
900.00	885.27	140.21	18°00'	2400.00	2128.95	947.87	48°00'
1000.00	979.82	172.77	20°00'	2500.00	2194.56	1023.34	50°00'
1100.00	1073.17	208.60	22°00'	2600.00	2257.48	1101.05	52°00'
1200.00	1165.21	247.67	24°00'	2700.00	2317.66	1180.91	54°00'
1300.00	1255.84	289.93	26°00'	2800.00	2375.02	1262.82	56°00'
1400.00	1344.94	335.33	28°00'	2900.00	2429.48	1346.68	58°00'
				3000.00	2480.98	1432.39	60°00'

Buildup Rate Section Results:

Section	MD, ft	TVD, ft	DEP, ft
Buildup Rate	2000	1841.45	670.23

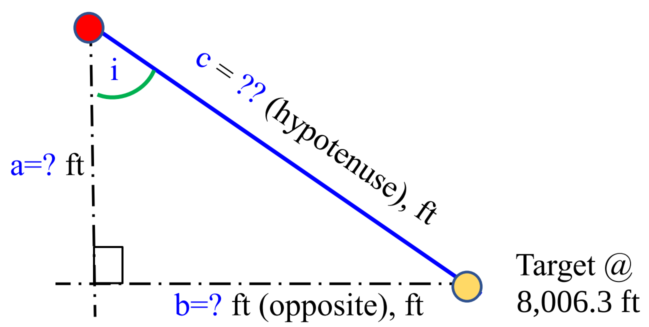
- It takes 2,000 ft of measured hole to increase the inclination from 0° to 40°. The true vertical depth for the 2000 ft of drilling is 1,841.45 ft and the horizontal departure is 670.23 feet.
- **With the above table results were calculated** using the ***Radius of Curvature method.***

3. SECTION 3: HOLD ANGLE SECTION TO TARGET

The **MD** of the hold section of the hole can be calculated using the **geometry** of a **right** triangle with the **hypotenuse** being the measured depth (MD).

The remaining horizontal departure (HD) and **true vertical depth** can be calculated by subtracting the **TVD** and **DEP** to the end of the build section from the **total**.

TVD Remaining (AC) = **8,006.3 – 2,283.5 – 1,841.45** = 3,881.35 ft
DEP Remaining (CB) = **3,973 - 670.23** = 3,302.77 ft



The previous figure is a right triangle which represents the hold section of the hole with Angle "(i)" being the inclination (40°).

Side "a" is the **TVD** (3,881.35 feet).

Side "b" (opposite) is the horizontal departure (HD) (3,302.77 feet).

Side "c" (hypotenuse) is the **MD** which must be calculated. From the trigonometric functions of a right triangle.

$$\text{Sin (i)} = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\text{Side "2"}}{\text{Side "3"}} = \frac{3302.77}{\text{MD}}$$

$$\textbf{MD} = \frac{3302.77}{\text{Sin } 40} = \frac{3302.77}{0.643} = 5136.50 \text{ ft}$$

Or

$$\textbf{Sin (40)} \text{x MD} = 0.643 \text{ x } 5136.50 = 3302.77 \text{ ft}$$

Then the section 3: hold angle to target (From EOB to target)

Section 3	MD, ft	TVD, ft	DEP, ft
Hold to Target	5136.5	3881.35	3302.77

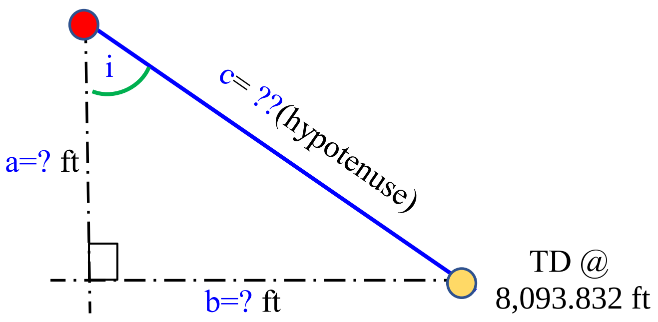
4. SECTION 4: HOLD TO TD

The horizontal departure and measured depth of the well must be calculated from 8,006.3 feet TVD to 8,093.832 feet TVD which is the remaining section of the well to be drilled.

It can also be calculated using the trigonometric functions of a right triangle.

The inclination is 40° and the TVD remaining is as follows:

TVD Remaining = 8,093.832- 8006.3 = **87.532 ft**



In the triangle shown in the above figure, the Angle "i" is equal to the inclination (40°).

Side "a" is equal to TVD (87.53 feet).

Side "b" (DEP) must be determined. The horizontal departure can be determined from the tangent of Angle "i."

And Side "c" (MD)

$$\tan 40 = \frac{a}{87.53} \qquad a = 0.01 \text{ ft}$$

Or

DEP = 0.01 ft

Also

$$\cos 40 = \frac{87.53}{c} \qquad c = 114.26 \text{ ft}$$

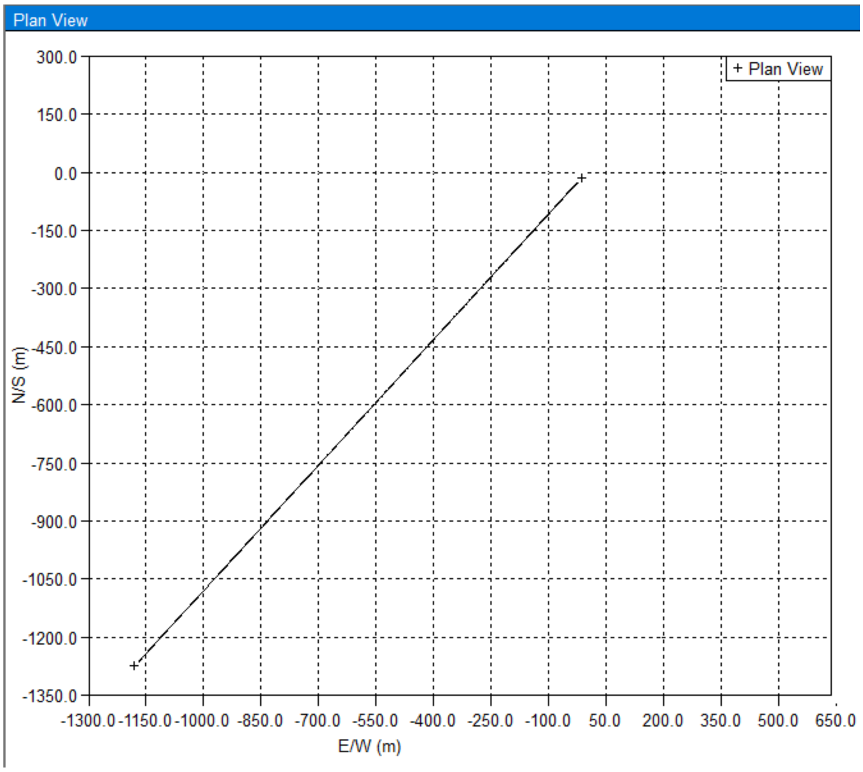
Or

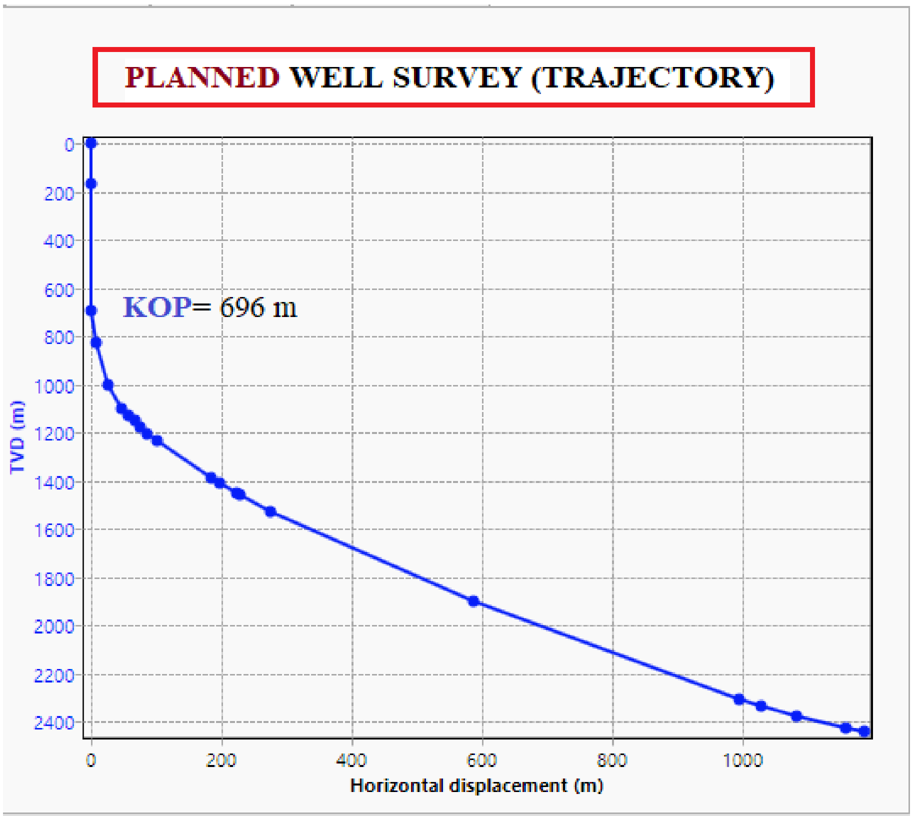
MD = 114.26ft

Finally:

Section 3	MD, ft	TVD, ft	DEP, ft
Vertical to KOP	2283.5	2283.5	0
Buildup Rate	2000	1841.45	670.23
Hold to Target	5136.5	3881.35	3302.77
Hold to TD	114.26	87.53	0.01
Total	9534.26	8093.83	3973.01

Therefore, the TVD is 8,093.83 feet and the DEP is 3,006.81 feet. From the previous tables the vertical section is labeled as shown in the following figure.


Plan View
+ Plan View
300.0
150.0
0.0
-150.0
-300.0
-450.0
-600.0
-750.0
-900.0
-1050.0
-1200.0
-1350.0
N/S (m)
-1300.0 -1150.0 -1000.0 -850.0 -700.0 -550.0 -400.0 -250.0 -100.0 50.0 200.0 350.0 500.0 650.0
E/W (m)


PLANNED WELL SURVEY (TRAJECTORY)
KOP= 696 m
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
TVD (m)
0 200 400 600 800 1000
Horizontal displacement (m)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Well Data:

Data was obtained from an operator company based in Iraq. The proposed survey field data is for well XXX-1. Well XXX-1 is located in Iraq. There is a reservoir location for Well XXX-1 which is called target, as shown in Table 4.2. This well has a simple profile which includes build and hold angle to target. Although it has a simple well profile but it is a highly deviated well in which the highest deviation angle is 79° of inclinations and it also have a quite long well path which around 3400 m of measure depth. Table 4.1 shows the proposed survey field data of well XXX-1.

Table 4.1: Proposed Survey field data from Well XXX-1

MD, (m)	Incl, (°)	Azim Grid, (°)						
0.00	0.00	0.00	756.10	4.07	344.77	*1758.00*	*33.57*	*223.18*
10.90	*0.10*	*73.53*	784.53	3.97	341.85	1764.88	33.55	223.15
22.50	0.20	73.53	813.09	4.06	335.25	1851.01	33.27	226.17
51.00	0.30	89.33	842.69	3.71	305.33	*1885.00*	*33.35*	*223.95*
79.50	1.70	349.83	*868.00*	*4.90*	*274.84*	1937.23	33.55	220.56
108.00	1.20	344.53	871.37	5.13	272.03	2012.95	34.28	217.56
136.50	1.60	340.03	928.56	6.50	258.71	2041.00	34.42	218.00
165.00	2.00	343.53	954.00	6.88	248.20	2058.93	34.51	218.28
193.50	2.00	351.03	957.49	6.95	246.86	2068.00	35.07	219.01
222.00	3.00	6.33	*960.00*	*7.03*	*245.55*	*2070.00*	*35.19*	*219.17*
250.50	3.20	359.93	986.29	8.02	233.56	2088.19	36.32	220.58
279.00	3.10	1.73	1015.17	9.90	226.68	2116.59	38.21	222.54
307.50	2.70	1.63	1044.09	12.58	218.19	2145.74	40.15	223.29
336.00	2.90	10.03	1073.02	14.43	211.81	2174.01	42.24	224.08
340.00	*2.91*	*9.64*	1101.94	16.07	205.72	2203.24	44.94	224.85
364.50	3.00	7.33	1130.53	16.96	200.83	2231.66	46.96	225.11
393.00	2.80	10.33	1159.41	18.85	197.53	2260.22	48.86	225.50
421.50	2.90	11.83	1187.97	21.06	195.86	2289.41	50.73	225.32
450.00	2.90	15.23	1216.81	22.43	194.06	2318.03	52.70	225.05
478.50	3.00	17.33	1245.93	25.13	194.52	2331.00	53.20	224.56
505.00	*2.91*	*14.64*	1274.47	26.17	198.68	2346.71	53.80	223.98
507.00	2.90	14.43	1303.72	27.45	203.01	2434.01	54.20	222.54
535.50	2.90	14.03	1334.97	28.53	207.03	*2501.00*	*54.25*	*222.67*
564.00	4.20	6.53	1358.90	29.20	210.71	2519.71	54.27	222.71
592.50	5.10	10.33	1390.70	29.76	213.14	*2551.00*	*54.25*	*222.88*
621.00	5.90	6.83	1422.30	30.93	219.33	2611.36	54.22	223.21
649.50	6.60	0.63	1447.18	31.89	222.73	2628.00	54.48	223.22
672.00	*6.95*	*357.79*	1449.00	31.90	222.71	*2650.00*	*54.81*	*223.23*
675.00	7.00	357.43	*1497.00*	*32.17*	*222.09*	2697.12	55.54	223.26
676.00	6.97	357.42	1505.68	32.22	221.98	2783.95	55.52	222.65
698.60	6.35	357.04	1592.05	33.24	225.07	**2877.17**	**55.53**	**222.65**
727.15	4.87	346.87	1680.41	33.79	223.46	**2896.00**	**55.52**	**222.65**

Table 4.2: Target Location of Well XXX-1

Location	NORTH (m)	EAST (m)	TVD (m)
Surface	0	0	0

Target	1629.94	-55.10	2440.31

4.2 Surveying Calculation Result

In this project, there are five different surveying calculation methods used in determining the trajectory of the well. And I used the MATLAB software to calculate the functions for these methods. The first method used is tangential method.

4.2.1 Tangential Method

Figure 18 shows the wellbore trajectory of Well XXX-1 based on tangential method. The final location of the wellbore is at 1638.90m north, -67.18m east, and 2408.87m TVD (**Table** 6). Based on this method, the trajectory of the well seems to be deviated quite far from the target as shown in **Figure** 18.

Table 6: Tangential Method for Well XXX-1

MD (m)	Incl (°)	Azim (°)	Tangential Method								
			North	East	TVD						
			(m)								
0.00	0.00	0.00	0.00	0.00	0.00	**1159.41**	18.85	197.53	-3.06	1.25	1159.41
10.90	*0.10*	*73.53*	-0.31	-1.01	10.85	1187.97	21.06	195.86	448.57	843.04	-706.65
22.50	0.20	73.53	-1.31	-4.27	22.05	1216.81	22.43	194.06	-388.20	338.18	-1102.52
51.00	0.30	89.33	3.07	14.75	48.72	1245.93	25.13	194.52	-1.53	0.40	1245.93
79.50	1.70	349.83	-34.83	-70.73	-10.24	1274.47	26.17	198.68	-797.34	-750.02	652.68
108.00	1.20	344.53	50.50	-87.07	39.13	1303.72	27.45	203.01	-347.32	887.51	-889.60
136.50	1.60	340.03	100.94	91.80	-3.99	1334.97	28.53	207.03	-320.86	104.04	-1291.65
165.00	2.00	343.53	-68.54	-133.47	-68.66	1358.90	29.20	210.71	1059.57	238.15	-816.82
193.50	2.00	351.03	118.95	-129.65	-80.52	1390.70	29.76	213.14	-1223.72	650.05	-118.25
222.00	3.00	6.33	31.29	1.47	-219.78	1422.30	30.93	219.33	-555.08	364.85	1257.66
250.50	3.20	359.93	3.16	-14.28	-250.07	1447.18	31.89	222.73	-626.48	209.75	1287.58
279.00	3.10	1.73	-1.84	11.45	-278.76	1449.00	31.90	222.71	-634.48	229.18	1282.38
307.50	2.70	1.63	-7.78	131.19	-278.00	*1497.00*	*32.17*	*222.09*	-586.01	841.80	1090.40
336.00	2.90	10.03	-66.11	-45.74	-326.24	1505.68	32.22	221.98	-517.70	952.81	1044.61
340.00	*2.91*	*9.64*	-75.06	-16.41	-331.20	1592.05	33.24	225.07	665.01	-1390.41	-398.93
364.50	3.00	7.33	25.74	44.54	-360.85	1680.41	33.79	223.46	-1071.52	-461.80	-1209.28
393.00	2.80	10.33	-81.30	-103.55	-370.29	*1758.00*	*33.57*	*223.18*	-1456.84	-179.09	-967.53
421.50	2.90	11.83	74.72	-67.73	-409.26	1764.88	33.55	223.15	-1485.22	-144.40	-942.38
450.00	2.90	15.23	-95.60	49.52	-436.93	1851.01	33.27	226.17	1776.70	-43.84	-517.36
478.50	3.00	17.33	3.46	-67.44	-473.71	*1885.00*	*33.35*	*223.95*	-1101.10	-1375.38	-670.18
505.00	*2.91*	*14.64*	-56.62	102.96	-491.14	1937.23	33.55	220.56	1305.41	989.32	-1034.40
507.00	2.90	14.43	-35.01	116.14	-492.28	2012.95	34.28	217.56	-388.12	-391.79	-1935.93
535.50	2.90	14.03	13.70	127.38	-519.95	2041.00	34.42	218.00	-93.55	-264.10	-2021.68
564.00	4.20	6.53	-476.67	-120.10	-276.51	2058.93	34.51	218.28	-5.93	-97.62	-2056.61
592.50	5.10	10.33	338.73	431.46	223.95	2068.00	35.07	219.01	-629.01	786.96	-1806.01
621.00	5.90	6.83	-198.32	-120.73	575.96	*2070.00*	*35.19*	*219.17*	-905.52	822.11	-1670.05
649.50	6.60	0.63	163.50	119.21	617.18	2088.19	36.32	220.58	-1608.68	-1270.60	397.83
672.00	*6.95*	*357.79*	390.75	-144.51	527.27	2116.59	38.21	222.54	-901.65	508.00	1846.32
675.00	7.00	357.43	335.86	-289.59	508.88	2145.74	40.15	223.29	-1328.82	-320.85	-1653.93
676.00	6.97	357.42	321.30	-285.48	521.77	2174.01	42.24	224.08	1108.45	1833.03	-371.02
698.60	6.35	357.04	19.75	-38.52	697.26	2203.24	44.94	224.85	404.01	-1756.09	1267.74
727.15	4.87	346.87	-194.44	-691.14	115.16	2231.66	46.96	225.11	170.11	-321.93	-2201.76
756.10	4.07	344.77	-420.64	435.63	-452.74	2260.22	48.86	225.50	-1712.77	1427.12	371.95
784.53	3.97	341.85	482.81	-317.12	-530.86	2289.41	50.73	225.32	657.69	-787.00	2046.82
813.09	4.06	335.25	402.22	-504.17	-495.12	2318.03	52.70	225.05	622.43	-1371.16	-1762.32
842.69	3.71	305.33	374.72	254.53	-710.58	2331.00	53.20	224.56	-30.01	-486.84	-2279.40
868.00	*4.90*	*274.84*	44.28	852.34	158.07	2346.71	53.80	223.98	539.39	718.63	-2167.87
871.37	5.13	272.03	224.64	-765.00	351.56	2434.01	54.20	222.54	1510.73	-851.16	-1708.10
928.56	6.50	258.71	91.21	180.41	906.29	*2501.00*	*54.25*	*222.67*	1741.15	-695.78	-1655.08
954.00	6.88	248.20	-537.27	-7.17	788.29	2519.71	54.27	222.71	1802.78	-643.96	-1638.36
957.49	6.95	246.86	-141.68	575.13	752.29	*2551.00*	*54.25*	*222.88*	1880.81	-327.59	-1691.99
960.00	*7.03*	*245.55*	569.51	312.95	706.62	2611.36	54.22	223.21	1873.33	296.40	-1794.99
986.29	8.02	233.56	453.17	860.64	-163.42	2628.00	54.48	223.22	2272.11	382.43	-1263.97
1015.17	9.90	226.68	-407.35	-215.49	-904.54	*2650.00*	*54.81*	*223.23*	-783.90	-875.03	2367.36
1044.09	12.58	218.19	-1.91	-12.24	1044.02	2697.12	55.54	223.26	1009.03	1223.52	2173.58
1073.02	14.43	211.81	-256.65	-995.24	-308.22	2783.95	55.52	222.65	1567.80	-53.05	2291.91
1101.94	16.07	205.72	20.81	392.82	-1029.34	**2877.17**	**55.53**	**222.65**	1655.75	-56.02	2384.33
1130.53	16.96	200.83	-1046.56	243.55	-351.41	**2896.00**	**55.52**	**222.65**	**1638.90**	**-67.18**	**2408.87**

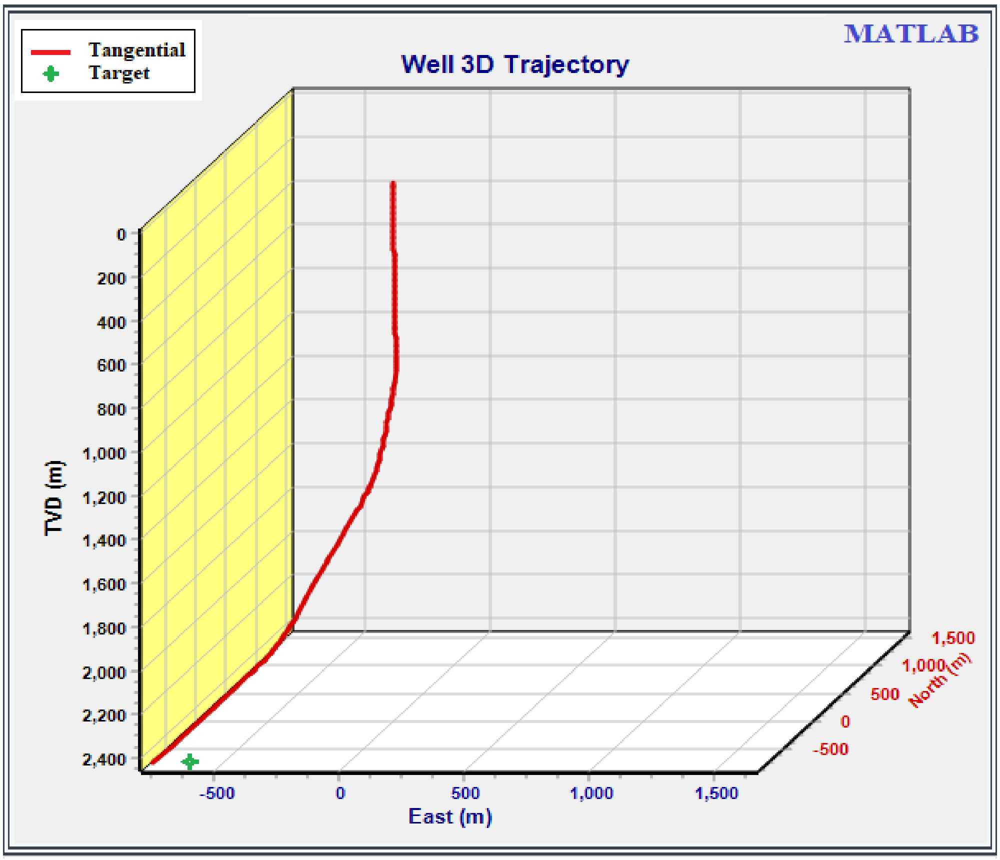


Figure 18: Graphical Trajectory for Well XXX-1 - Tangential Method

All of the three targets are far from the trajectory which means that this method is not suitable to be used in getting the smooth and good trajectory.

4.2.2 Average Tangential Method

Figure 19 shows the wellbore trajectory of Well XXX-1 based on average tangential method. The final location of the wellbore is at 1630.90 m north, -55.18 m east, and 2427.71 m TVD (**Table** 7). This method seems to have a better trajectory and closer to the target compared to the tangential method.

Table 7: Average Tangential Method for Well XXX-1

MD (m)	Incl (°)	Azim (°)	Average Tangential Method								
			North	East	TVD						
			(m)								
0.00	0.00	0.00	0.00	0.00	0.00	**1159.41**	18.85	197.53	972.87	-9.87	-630.60
10.90	*0.10*	*73.53*	6.49	-5.05	7.16	1187.97	21.06	195.86	711.96	511.21	801.90
22.50	0.20	73.53	11.44	-8.90	17.21	1216.81	22.43	194.06	553.24	1002.75	411.16
51.00	0.30	89.33	-13.31	-23.10	43.48	1245.93	25.13	194.52	196.85	-1031.07	671.18
79.50	1.70	349.83	-49.35	62.31	1.65	1274.47	26.17	198.68	-87.80	660.03	1086.70
108.00	1.20	344.53	65.07	42.06	75.24	1303.72	27.45	203.01	-269.90	751.22	-1030.78
136.50	1.60	340.03	133.74	14.36	23.20	1334.97	28.53	207.03	109.21	-1083.46	-772.23
165.00	2.00	343.53	90.15	-119.93	-68.66	1358.90	29.20	210.71	-779.24	-986.87	515.25
193.50	2.00	351.03	-109.51	-137.72	-80.52	1390.70	29.76	213.14	75.13	460.71	1310.02
222.00	3.00	6.33	46.57	-62.41	-207.89	1422.30	30.93	219.33	417.00	1341.23	223.92
250.50	3.20	359.93	-17.11	152.31	-198.14	1447.18	31.89	222.73	410.75	35.49	-1387.21
279.00	3.10	1.73	3.29	-135.77	-243.71	1449.00	31.90	222.71	391.00	19.91	-1395.11
307.50	2.70	1.63	3.53	27.90	-306.21	*1497.00*	*32.17*	*222.09*	-126.80	151.28	-1483.93
336.00	2.90	10.03	-6.40	-69.22	-328.73	1505.68	32.22	221.98	-156.30	265.56	-1473.81
340.00	*2.91*	*9.64*	-48.33	-60.11	-331.13	1592.05	33.24	225.07	1410.87	689.52	261.99
364.50	3.00	7.33	107.63	69.02	-341.34	1680.41	33.79	223.46	-350.05	-852.51	1405.16
393.00	2.80	10.33	8.03	-21.49	-392.33	*1758.00*	*33.57*	*223.18*	-1012.44	-951.30	1077.29
421.50	2.90	11.83	44.37	75.08	-412.38	1764.88	33.55	223.15	-1075.47	-936.01	1040.22
450.00	2.90	15.23	92.11	-13.56	-440.26	1851.01	33.27	226.17	-921.04	1558.39	386.43
478.50	3.00	17.33	-166.26	23.05	-448.09	*1885.00*	*33.35*	*223.95*	600.54	-1678.73	611.93
505.00	*2.91*	*14.64*	56.25	-93.94	-492.99	1937.23	33.55	220.56	1564.40	-42.61	1141.80
507.00	2.90	14.43	23.37	-102.26	-496.03	2012.95	34.28	217.56	57.04	-304.50	1988.97
535.50	2.90	14.03	-40.62	-103.08	-523.91	2041.00	34.42	218.00	544.08	-482.30	1907.11
564.00	4.20	6.53	379.35	-276.46	312.67	2058.93	34.51	218.28	940.53	-296.76	1807.36
592.50	5.10	10.33	-74.43	199.04	553.08	2068.00	35.07	219.01	1405.12	1437.71	485.03
621.00	5.90	6.83	-610.99	111.04	2.47	*2070.00*	*35.19*	*219.17*	1053.84	1778.43	107.27
649.50	6.60	0.63	324.92	-17.89	-562.10	2088.19	36.32	220.58	152.15	0.42	-2082.64
672.00	*6.95*	*357.79*	0.08	-2.04	-672.00	2116.59	38.21	222.54	-480.44	96.80	2059.07
675.00	7.00	357.43	-24.17	-44.60	-673.09	2145.74	40.15	223.29	578.48	769.51	-1917.66
676.00	6.97	357.42	-11.26	-19.72	-675.62	2174.01	42.24	224.08	508.38	-847.37	1936.45
698.60	6.35	357.04	483.97	261.83	-430.42	2203.24	44.94	224.85	924.35	115.76	-1996.61
727.15	4.87	346.87	-10.21	-14.12	726.94	2231.66	46.96	225.11	-620.24	-350.68	2114.86
756.10	4.07	344.77	-413.46	-562.85	289.72	2260.22	48.86	225.50	34.23	67.19	-2258.96
784.53	3.97	341.85	727.56	-225.80	187.52	2289.41	50.73	225.32	461.56	504.27	2184.96
813.09	4.06	335.25	-540.54	529.75	297.15	2318.03	52.70	225.05	-993.72	-449.24	-2045.47
842.69	3.71	305.33	87.35	828.80	-124.84	2331.00	53.20	224.56	559.61	-177.38	-2255.87
868.00	*4.90*	*274.84*	-49.92	15.03	866.43	2346.71	53.80	223.98	818.79	-1989.76	-936.74
871.37	5.13	272.03	73.42	-338.12	799.73	2434.01	54.20	222.54	-2343.40	472.16	458.22
928.56	6.50	258.71	-458.09	-351.16	-727.37	*2501.00*	*54.25*	*222.67*	-2409.43	-1.31	670.55
954.00	6.88	248.20	81.13	54.41	-948.99	2519.71	54.27	222.71	-2407.51	-135.39	731.10
957.49	6.95	246.86	-0.07	0.45	-957.49	*2551.00*	*54.25*	*222.88*	-2340.80	-755.32	676.58
960.00	*7.03*	*245.55*	107.14	-26.94	-953.62	2611.36	54.22	223.21	-1764.41	-1839.31	568.31
986.29	8.02	233.56	796.92	580.08	34.60	2628.00	54.48	223.22	-1474.65	-1583.33	1491.60
1015.17	9.90	226.68	936.60	-259.33	293.41	*2650.00*	*54.81*	*223.23*	-783.90	-875.03	2375.36
1044.09	12.58	218.19	-782.99	375.54	579.68	2697.12	55.54	223.26	1009.03	1223.52	2181.58
1073.02	14.43	211.81	-867.80	585.03	-236.71	2783.95	55.52	222.65	1567.80	-53.05	2299.91
1101.94	16.07	205.72	-948.54	287.19	-481.74	**2877.17**	**55.53**	**222.65**	1655.75	-56.02	2352.33
1130.53	16.96	200.83	-162.29	699.93	872.84	**2896.00**	**55.52**	**222.65**	**1630.90**	**-55.18**	**2427.71**

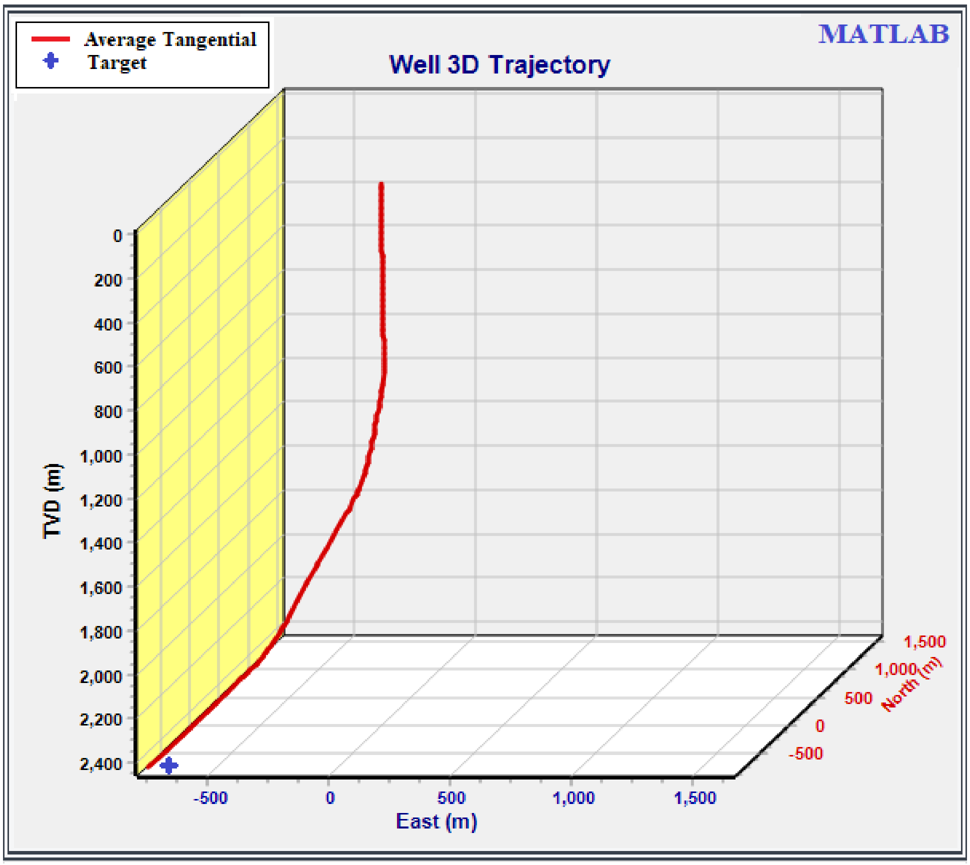


Figure 19: Graphical Trajectory for Well XXX-1 - Average Tangential Method

According to **Figure** 19, one of the targets lies on the trajectory while the other two is close to it. This shows that average tangential method will produce a better trajectory compare to the tangential method.

4.2.3 Balanced Tangential Method

Figure 20 shows the wellbore trajectory of Well XXX-1 based on balanced tangential method. The final location of the wellbore is at 1632.70 m north, -55.32 m east, and 2428.27 m TVD (Table 8). This method is definitely better than tangential but not as good as average angel method in term of having a trajectory which closes to the target.

Table 8: Balance Tangential Method for Well XXX-1

MD (m)	Incl (°)	Azim (°)	Balance Tangential Method								
			North	East	TVD						
			(m)								
0.00	0.00	0.00	0.00	0.00	0.00	**1159.41**	18.85	197.53	87.32	-7.77	-642.55
10.90	*0.10*	*73.53*	5.65	0.03	-6.84	1187.97	21.06	195.86	777.72	8.28	871.01
22.50	0.20	73.53	10.92	0.11	-14.13	1216.81	22.43	194.06	-241.30	-2.81	370.33
51.00	0.30	89.33	-10.25	0.13	29.02	1245.93	25.13	194.52	-163.82	10.06	796.47
79.50	1.70	349.83	-9.69	-0.03	-57.06	1274.47	26.17	198.68	-419.16	-7.59	-1082.33
108.00	1.20	344.53	-28.34	-0.46	2.43	1303.72	27.45	203.01	196.99	20.12	144.89
136.50	1.60	340.03	71.19	0.43	116.41	1334.97	28.53	207.03	-45.35	-8.24	804.76
165.00	2.00	343.53	-35.57	0.64	-119.80	1358.90	29.20	210.71	494.00	3.32	-1146.46
193.50	2.00	351.03	-68.94	0.74	40.76	1390.70	29.76	213.14	-638.61	13.88	671.38
222.00	3.00	6.33	63.64	1.02	175.16	1422.30	30.93	219.33	-269.97	19.38	586.67
250.50	3.20	359.93	44.98	1.13	61.25	1447.18	31.89	222.73	-224.17	-5.45	-863.57
279.00	3.10	1.73	67.90	0.54	81.84	1449.00	31.90	222.71	-237.81	-5.15	-842.47
307.50	2.70	1.63	114.12	1.00	115.14	*1497.00*	*32.17*	*222.09*	-362.39	5.44	-141.78
336.00	2.90	10.03	-68.15	0.97	-293.24	1505.68	32.22	221.98	-329.41	7.45	3.02
340.00	*2.91*	*9.64*	-77.82	0.92	-286.36	1592.05	33.24	225.07	25.22	-24.89	-75.23
364.50	3.00	7.33	244.49	0.35	273.24	1680.41	33.79	223.46	-1219.04	4.62	-1468.32
393.00	2.80	10.33	-95.06	0.61	-316.96	*1758.00*	*33.57*	*223.18*	-1241.87	10.09	-1434.06
421.50	2.90	11.83	-137.74	1.02	121.41	1764.88	33.55	223.15	-1237.73	10.56	-1424.70
450.00	2.90	15.23	-111.63	2.08	-220.64	1851.01	33.27	226.17	1250.77	-11.11	1405.91
478.50	3.00	17.33	-189.04	1.27	-182.18	*1885.00*	*33.35*	*223.95*	-1304.36	-10.77	-1526.42
505.00	*2.91*	*14.64*	7.09	0.52	-1.23	1937.23	33.55	220.56	1476.75	3.33	1681.36
507.00	2.90	14.43	85.79	1.02	91.52	2012.95	34.28	217.56	-1136.41	0.08	-1692.71
535.50	2.90	14.03	255.10	0.74	268.12	2041.00	34.42	218.00	-948.59	-5.79	-1334.30
564.00	4.20	6.53	54.80	2.59	479.18	2058.93	34.51	218.28	-781.15	-8.12	-960.85
592.50	5.10	10.33	385.22	2.41	-477.86	2068.00	35.07	219.01	-470.55	-1.16	314.74
621.00	5.90	6.83	-136.35	1.68	544.38	*2070.00*	*35.19*	*219.17*	-514.40	0.75	594.91
649.50	6.60	0.63	-36.54	2.59	565.18	2088.19	36.32	220.58	-1486.25	-6.97	1806.60
672.00	*6.95*	*357.79*	-132.80	5.23	387.33	2116.59	38.21	222.54	-422.14	-4.38	-983.08
675.00	7.00	357.43	-153.68	-2.12	208.25	2145.74	40.15	223.29	-1434.22	10.77	-1818.28
676.00	6.97	357.42	-151.80	5.60	200.28	2174.01	42.24	224.08	976.67	18.03	-1649.09
698.60	6.35	357.04	-0.30	2.91	-16.14	2203.24	44.94	224.85	234.56	-17.23	-522.95
727.15	4.87	346.87	-137.05	2.22	446.17	2231.66	46.96	225.11	-418.65	-22.17	-27.17
756.10	4.07	344.77	-195.09	2.11	175.64	2260.22	48.86	225.50	-762.63	31.70	728.59
784.53	3.97	341.85	-179.30	1.97	-323.81	2289.41	50.73	225.32	503.62	3.63	391.52
813.09	4.06	335.25	-187.26	2.26	-123.11	2318.03	52.70	225.05	-312.17	-37.51	-150.14
842.69	3.71	305.33	33.42	2.14	-736.08	2331.00	53.20	224.56	-967.40	-17.69	-1089.33
868.00	*4.90*	*274.84*	280.46	1.22	-399.39	2346.71	53.80	223.98	-397.88	9.36	-1874.59
871.37	5.13	272.03	-355.80	3.21	162.68	2434.01	54.20	222.54	740.93	-3.91	-1130.50
928.56	6.50	258.71	-138.02	-0.10	671.32	*2501.00*	*54.25*	*222.67*	834.61	-3.50	-1398.16
954.00	6.88	248.20	109.22	4.40	-740.01	2519.71	54.27	222.71	862.53	-3.32	-1470.85
957.49	6.95	246.86	-218.83	2.90	214.77	*2551.00*	*54.25*	*222.88*	864.33	0.36	-1751.35
960.00	*7.03*	*245.55*	95.60	2.77	842.48	2611.36	54.22	223.21	775.14	6.84	-2158.13
986.29	8.02	233.56	533.59	0.51	721.08	2628.00	54.48	223.22	1197.02	2.57	-2179.41
1015.17	9.90	226.68	432.87	4.33	890.82	*2650.00*	*54.81*	*223.23*	1644.61	-3.11	-2207.28
1044.09	12.58	218.19	478.44	4.19	-558.21	2697.12	55.54	223.26	1973.66	-13.09	-2266.02
1073.02	14.43	211.81	-257.14	2.63	-643.51	2783.95	55.52	222.65	1305.25	-33.88	-1512.79
1101.94	16.07	205.72	-254.85	-2.81	-507.88	**2877.17**	**55.53**	**222.65**	1657.88	-70.24	2399.13
1130.53	16.96	200.83	-172.57	-5.28	740.21	**2896.00**	**55.52**	**222.65**	**1632.70**	**-55.32**	**2428.27**

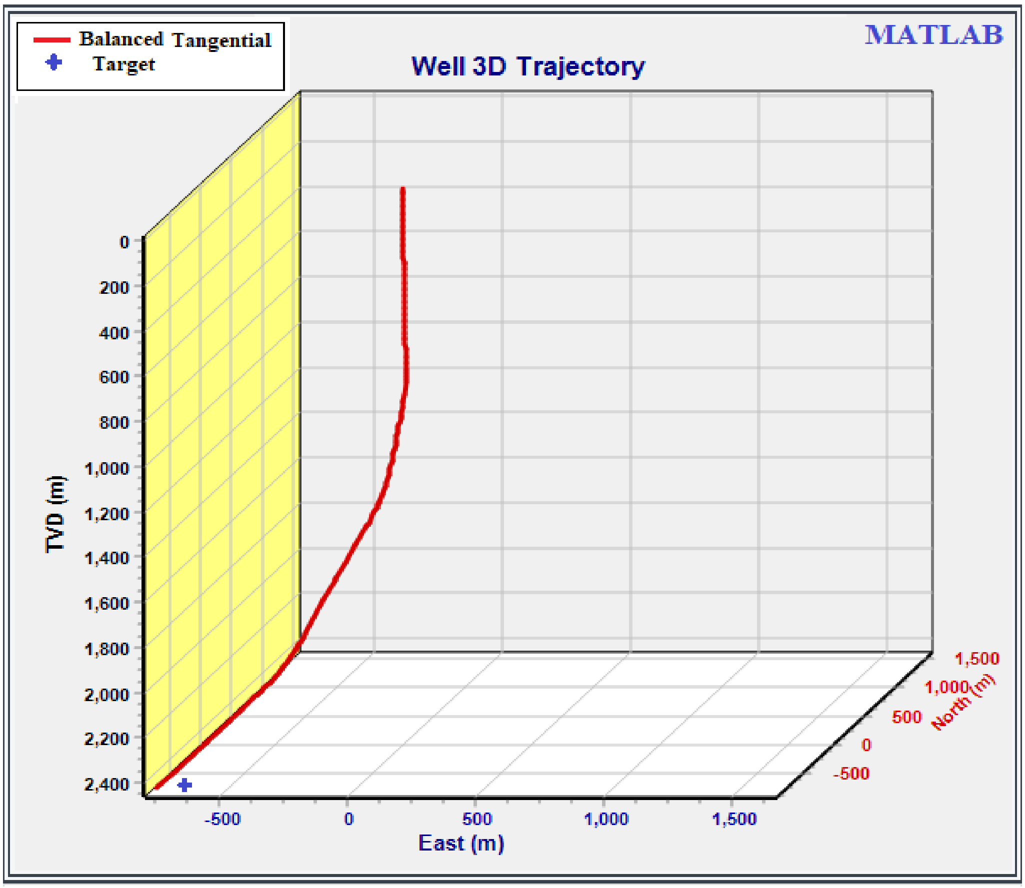


Figure 20: Graphical Trajectory for Well XXX-1 - Balanced Tangential Method

By referring to **Figure** 20, even the first target is not exactly lies on the trajectory produce by the balanced tangential method.

4.2.4 Radius of Curvature Method

Figure 21 shows the wellbore trajectory of Well XXX-1 based on **radius** of curvature method. The final location of the wellbore is at 1631.20m north, -55.11m east, and 2430.40m TVD (**Table** 9). This method seems to produce a trajectory that closes to the target.

Table 9: Radius of Curvature Method for Well XXX-1

MD (m)	Incl (°)	Azim (°)	Radius of Curvature Method								
			North	East	TVD						
			(m)								
0.00	0.00	0.00	0.00	0.00	0.00	**1159.41**	18.85	197.53	973.57	-9.52	-630.02
10.90	*0.10*	*73.53*	6.62	-5.37	6.44	1187.97	21.06	195.86	712.09	510.89	801.90
22.50	0.20	73.53	11.57	-9.22	16.49	1216.81	22.43	194.06	553.37	1002.43	411.16
51.00	0.30	89.33	-13.18	-23.42	42.76	1245.93	25.13	194.52	196.98	-1031.39	671.18
79.50	1.70	349.83	-49.22	61.99	0.93	1274.47	26.17	198.68	-87.67	659.71	1086.70
108.00	1.20	344.53	65.20	41.74	74.52	1303.72	27.45	203.01	-269.77	750.90	-1030.78
136.50	1.60	340.03	133.87	14.04	22.48	1334.97	28.53	207.03	109.34	-1083.78	-772.23
165.00	2.00	343.53	90.28	-120.25	-69.38	1358.90	29.20	210.71	-779.11	-987.19	515.25
193.50	2.00	351.03	-109.38	-138.04	-81.24	1390.70	29.76	213.14	75.26	460.39	1310.02
222.00	3.00	6.33	46.70	-62.73	-208.61	1422.30	30.93	219.33	417.13	1340.91	223.92
250.50	3.20	359.93	-16.98	151.99	-198.86	1447.18	31.89	222.73	410.88	35.17	-1387.21
279.00	3.10	1.73	3.42	-136.09	-244.43	1449.00	31.90	222.71	391.13	19.59	-1395.11
307.50	2.70	1.63	3.66	27.58	-306.93	*1497.00*	*32.17*	*222.09*	-126.67	150.96	-1483.93
336.00	2.90	10.03	-6.27	-69.54	-329.45	1505.68	32.22	221.98	-156.17	265.24	-1473.81
340.00	*2.91*	*9.64*	-48.20	-60.43	-331.85	1592.05	33.24	225.07	1411.00	689.20	261.99
364.50	3.00	7.33	107.76	68.70	-342.06	1680.41	33.79	223.46	-349.92	-852.83	1405.16
393.00	2.80	10.33	8.16	-21.81	-393.05	*1758.00*	*33.57*	*223.18*	-1012.31	-951.62	1077.29
421.50	2.90	11.83	44.50	74.76	-413.10	1764.88	33.55	223.15	-1075.34	-936.33	1040.22
450.00	2.90	15.23	92.24	-13.88	-440.98	1851.01	33.27	226.17	-920.91	1558.07	386.43
478.50	3.00	17.33	-166.13	22.73	-448.81	*1885.00*	*33.35*	*223.95*	600.67	-1679.05	611.93
505.00	*2.91*	*14.64*	56.38	-94.26	-493.71	1937.23	33.55	220.56	1564.53	-42.93	1141.80
507.00	2.90	14.43	23.50	-102.58	-496.75	2012.95	34.28	217.56	57.17	-304.82	1988.97
535.50	2.90	14.03	-40.49	-103.40	-524.63	2041.00	34.42	218.00	544.21	-482.62	1907.11
564.00	4.20	6.53	379.48	-276.78	311.95	2058.93	34.51	218.28	940.66	-297.08	1807.36
592.50	5.10	10.33	-74.30	198.72	552.36	2068.00	35.07	219.01	1405.25	1437.39	485.03
621.00	5.90	6.83	-610.86	110.72	1.75	*2070.00*	*35.19*	*219.17*	1053.97	1778.11	107.27
649.50	6.60	0.63	325.05	-18.21	-562.82	2088.19	36.32	220.58	152.28	0.10	-2082.64
672.00	*6.95*	*357.79*	0.21	-2.36	-672.72	2116.59	38.21	222.54	-480.31	96.48	2059.07
675.00	7.00	357.43	-24.04	-44.92	-673.81	2145.74	40.15	223.29	578.61	769.19	-1917.66
676.00	6.97	357.42	-11.13	-20.04	-676.34	2174.01	42.24	224.08	508.51	-847.69	1936.45
698.60	6.35	357.04	484.10	261.51	-431.14	2203.24	44.94	224.85	924.48	115.44	-1996.61
727.15	4.87	346.87	-10.08	-14.44	726.22	2231.66	46.96	225.11	-620.11	-351.00	2114.86
756.10	4.07	344.77	-413.33	-563.17	289.00	2260.22	48.86	225.50	34.36	66.87	-2258.96
784.53	3.97	341.85	727.69	-226.12	186.80	2289.41	50.73	225.32	461.69	503.95	2184.96
813.09	4.06	335.25	-540.41	529.43	296.43	2318.03	52.70	225.05	-993.59	-449.56	-2045.47
842.69	3.71	305.33	87.48	828.48	-125.56	2331.00	53.20	224.56	559.74	-177.70	-2255.87
868.00	*4.90*	*274.84*	-49.79	14.71	865.71	2346.71	53.80	223.98	818.92	-1990.08	-936.74
871.37	5.13	272.03	73.55	-338.44	799.01	2434.01	54.20	222.54	-2343.27	471.84	458.22
928.56	6.50	258.71	-457.96	-351.48	-728.09	*2501.00*	*54.25*	*222.67*	-2409.30	-1.63	670.55
954.00	6.88	248.20	81.26	54.09	-949.71	2519.71	54.27	222.71	-2407.38	-135.71	731.10
957.49	6.95	246.86	0.06	0.13	-958.21	*2551.00*	*54.25*	*222.88*	-2340.67	-755.64	676.58
960.00	*7.03*	*245.55*	107.27	-27.26	-954.34	2611.36	54.22	223.21	-1764.28	-1839.63	568.31
986.29	8.02	233.56	797.05	579.76	33.88	2628.00	54.48	223.22	-1474.52	-1583.65	1491.60
1015.17	9.90	226.68	936.73	-259.65	292.69	*2650.00*	*54.81*	*223.23*	-783.77	-875.35	2375.36
1044.09	12.58	218.19	-782.86	375.22	578.96	2697.12	55.54	223.26	1009.29	1223.20	2181.58
1073.02	14.43	211.81	-867.67	584.71	-236.71	2783.95	55.52	222.65	1568.43	-53.17	2299.91
1101.94	16.07	205.72	-948.67	286.87	-481.04	**2877.17**	**55.53**	**222.65**	1656.38	-56.24	2352.26
1130.53	16.96	200.83	-162.42	699.61	872.12	**2896.00**	55.52	**222.65**	**1631.20**	**-55.11**	**2430.40**

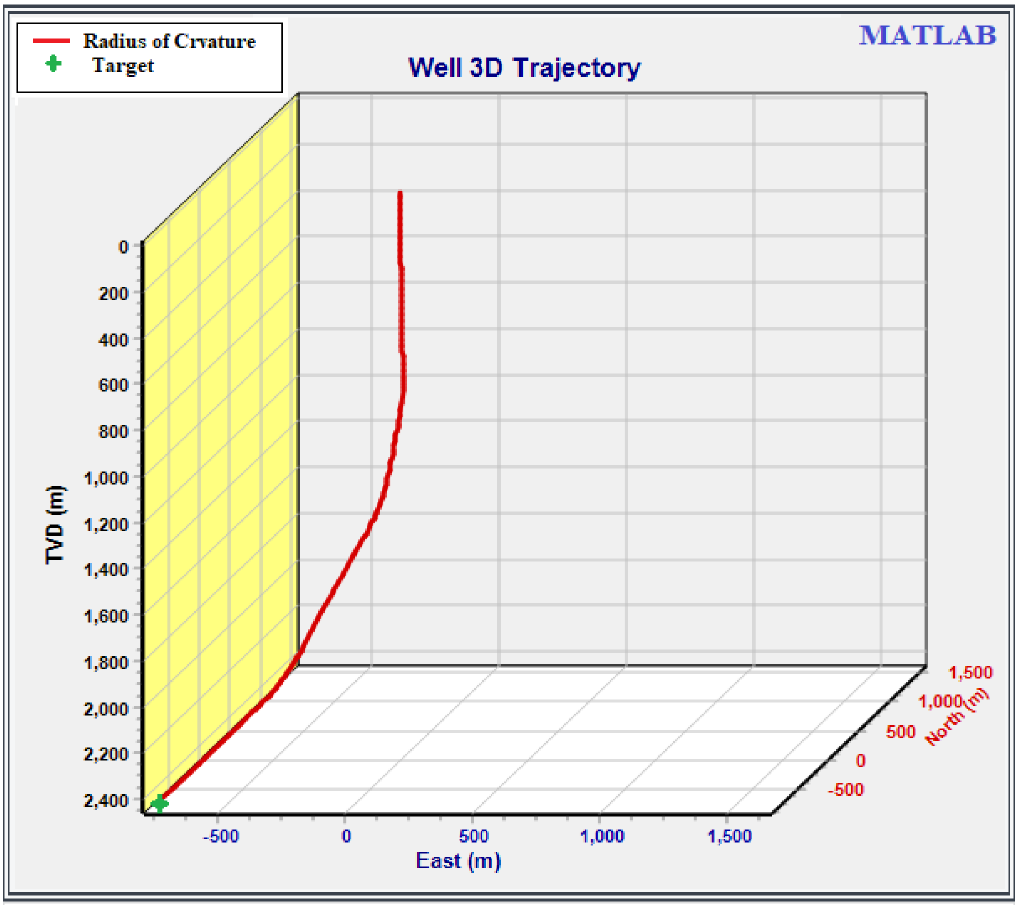


Figure 21: Graphical Trajectory for Well XXX-1 - Radius of Curvature Method

According to **Figure 21**, the target lies on the trajectory which is almost the same trajectory as the **average** tangential method.

4.2.5 Minimum Curvature Method

Figure 22 shows the wellbore trajectory of Well XXX-1 based on minimum of curvature method. The final location of the wellbore is at 1632.70m north, -55.32m east, and 2428.27m TVD (**Table** 10). Minimum curvature method produces a trajectory which exactly the same with the balance tangential method based on the data of Well XXX-1.

Table 10: Minimum of Curvature Method for Well XXX-1

MD (m)	Incl (°)	Azim (°)	Minimum Curvature Method North	East	TVD						
			(m)								
0.00	0.00	0.00	0.00	0.00	0.00	**1159.41**	18.85	197.53	87.32	-7.77	-642.55
10.90	*0.10*	*73.53*	5.65	0.03	-6.84	1187.97	21.06	195.86	777.72	8.28	871.01
22.50	0.20	73.53	10.92	0.11	-14.13	1216.81	22.43	194.06	-241.30	-2.81	370.33
51.00	0.30	89.33	-10.25	0.13	29.02	1245.93	25.13	194.52	-163.82	10.06	796.47
79.50	1.70	349.83	-9.69	-0.03	-57.06	1274.47	26.17	198.68	-419.16	-7.59	-1082.33
108.00	1.20	344.53	-28.34	-0.46	2.43	1303.72	27.45	203.01	196.99	20.12	144.89
136.50	1.60	340.03	71.19	0.43	116.41	1334.97	28.53	207.03	-45.35	-8.24	804.76
165.00	2.00	343.53	-35.57	0.64	-119.80	1358.90	29.20	210.71	494.00	3.32	-1146.46
193.50	2.00	351.03	-68.94	0.74	40.76	1390.70	29.76	213.14	-638.61	13.88	671.38
222.00	3.00	6.33	63.64	1.02	175.16	1422.30	30.93	219.33	-269.97	19.38	586.67
250.50	3.20	359.93	44.98	1.13	61.25	1447.18	31.89	222.73	-224.17	-5.45	-863.57
279.00	3.10	1.73	67.90	0.54	81.84	1449.00	31.90	222.71	-237.81	-5.15	-842.47
307.50	2.70	1.63	114.12	1.00	115.14	*1497.00*	*32.17*	*222.09*	-362.39	5.44	-141.78
336.00	2.90	10.03	-68.15	0.97	-293.24	1505.68	32.22	221.98	-329.41	7.45	3.02
340.00	*2.91*	*9.64*	-77.82	0.92	-286.36	1592.05	33.24	225.07	25.22	-24.89	-75.23
364.50	3.00	7.33	244.49	0.35	273.24	1680.41	33.79	223.46	-1219.04	4.62	-1468.32
393.00	2.80	10.33	-95.06	0.61	-316.96	*1758.00*	*33.57*	*223.18*	-1241.87	10.09	-1434.06
421.50	2.90	11.83	-137.74	1.02	121.41	1764.88	33.55	223.15	-1237.73	10.56	-1424.70
450.00	2.90	15.23	-111.63	2.08	-220.64	1851.01	33.27	226.17	1250.77	-11.11	1405.91
478.50	3.00	17.33	-189.04	1.27	-182.18	*1885.00*	*33.35*	*223.95*	-1304.36	-10.77	-1526.42
505.00	*2.91*	*14.64*	7.09	0.52	-1.23	1937.23	33.55	220.56	1476.75	3.33	1681.36
507.00	2.90	14.43	85.79	1.02	91.52	2012.95	34.28	217.56	-1136.41	0.08	-1692.71
535.50	2.90	14.03	255.10	0.74	268.12	2041.00	34.42	218.00	-948.59	-5.79	-1334.30
564.00	4.20	6.53	54.80	2.59	479.18	2058.93	34.51	218.28	-781.15	-8.12	-960.85
592.50	5.10	10.33	385.22	2.41	-477.86	2068.00	35.07	219.01	-470.55	-1.16	314.74
621.00	5.90	6.83	-136.35	1.68	544.38	*2070.00*	*35.19*	*219.17*	-514.40	0.75	594.91
649.50	6.60	0.63	-36.54	2.59	565.18	2088.19	36.32	220.58	-1486.25	-6.97	1806.60
672.00	*6.95*	*357.79*	-132.80	5.23	387.33	2116.59	38.21	222.54	-422.14	-4.38	-983.08
675.00	7.00	357.43	-153.68	-2.12	208.25	2145.74	40.15	223.29	-1434.22	10.77	-1818.28
676.00	6.97	357.42	-151.80	5.60	200.28	2174.01	42.24	224.08	976.67	18.03	-1649.09
698.60	6.35	357.04	-0.30	2.91	-16.14	2203.24	44.94	224.85	234.56	-17.23	-522.95
727.15	4.87	346.87	-137.05	2.22	446.17	2231.66	46.96	225.11	-418.65	-22.17	-27.17
756.10	4.07	344.77	-195.09	2.11	175.64	2260.22	48.86	225.50	-762.63	31.70	728.59
784.53	3.97	341.85	-179.30	1.97	-323.81	2289.41	50.73	225.32	503.62	3.63	391.52
813.09	4.06	335.25	-187.26	2.26	-123.11	2318.03	52.70	225.05	-312.17	-37.51	-150.14
842.69	3.71	305.33	33.42	2.14	-736.08	2331.00	53.20	224.56	-967.40	-17.69	-1089.33
868.00	*4.90*	*274.84*	280.46	1.22	-399.39	2346.71	53.80	223.98	-397.88	9.36	-1874.59
871.37	5.13	272.03	-355.80	3.21	162.68	2434.01	54.20	222.54	740.93	-3.91	-1130.50
928.56	6.50	258.71	-138.02	-0.10	671.32	*2501.00*	*54.25*	*222.67*	834.61	-3.50	-1398.16
954.00	6.88	248.20	109.22	4.40	-740.01	2519.71	54.27	222.71	862.53	-3.32	-1470.85
957.49	6.95	246.86	-218.83	2.90	214.77	*2551.00*	*54.25*	*222.88*	864.33	0.36	-1751.35
960.00	*7.03*	*245.55*	95.60	2.77	842.48	2611.36	54.22	223.21	775.14	6.84	-2158.13
986.29	8.02	233.56	533.59	0.51	721.08	2628.00	54.48	223.22	1197.02	2.57	-2179.41
1015.17	9.90	226.68	432.87	4.33	890.82	*2650.00*	*54.81*	*223.23*	1644.61	-3.11	-2207.28
1044.09	12.58	218.19	478.44	4.19	-558.21	2697.12	55.54	223.26	1973.66	-13.09	-2266.02
1073.02	14.43	211.81	-257.14	2.63	-643.51	2783.95	55.52	222.65	1305.25	-33.88	-1512.79
1101.94	16.07	205.72	-254.85	-2.81	-507.88	**2877.17**	**55.53**	**222.65**	1657.88	-70.24	2399.13
1130.53	16.96	200.83	-172.57	-5.28	740.21	**2896.00**	**55.52**	**222.65**	**1632.70**	**-55.32**	**2428.27**

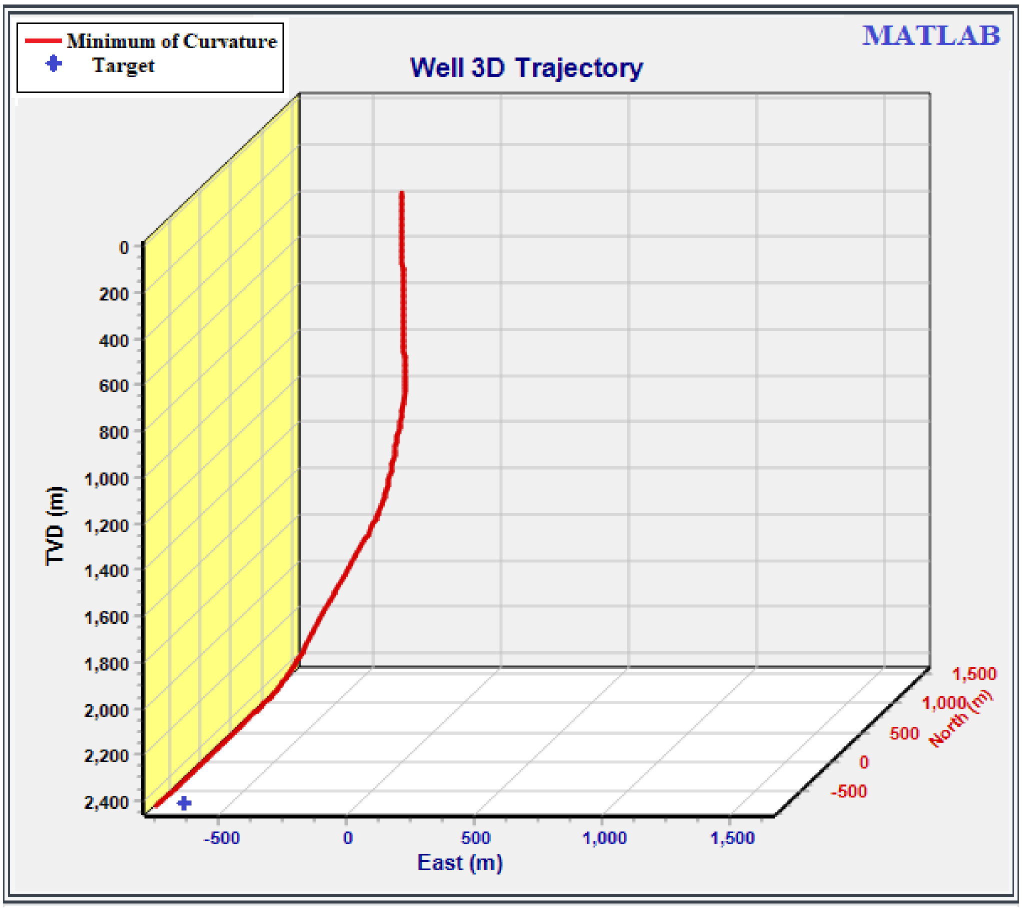


Figure 22: Graphical Trajectory for Well XXX-1 - Minimum of Curvature Method

By referring to **Figure** 22, the trajectory produces by applying the minimum curvature method will put the first target on it while the other two is close to the path.

4.3 MODEL COMPARISON

Based on the **Figure** 23 and **Table** 11, the well trajectory from the **radius of curvature** method and the **average tangential** method is the closest to the target. On the other hand, the **tangential** method is the least accurate method to apply for well XXX-1.

Table 11: Wellbore trajectory for Well XXX-1 using five different methods

MD (m)	Incl (°)	Azim (°)	Tangential Method North	East	TVD	Average Tangential North	East	TVD	Balance Tangential North	East	TVD	Radius of Curvature North	East	TVD	Minimum Curvature North	East	TVD
			(m)			(m)			(m)			(m)			(m)		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.90	0.10	73.53	-0.31	-1.01	10.85	6.49	-5.05	7.16	5.65	0.03	-6.84	6.62	-5.37	6.44	5.65	0.03	-6.84
108.00	1.20	344.53	50.50	-87.07	39.13	65.07	42.06	75.24	-28.34	-0.46	2.43	65.20	41.74	74.52	-28.34	-0.46	2.43
222.00	3.00	6.33	31.29	1.47	-219.78	46.57	-62.41	-207.89	63.64	1.02	175.16	46.70	-62.73	-208.61	63.64	1.02	175.16
250.50	3.20	359.93	3.16	-14.28	-250.07	-17.11	152.31	-198.14	44.98	1.13	61.25	-16.98	151.99	-198.86	44.98	1.13	61.25
307.50	2.70	1.63	-7.78	131.19	-278.00	3.53	27.90	-306.21	114.12	1.00	115.14	3.66	27.58	-306.93	114.12	1.00	115.14
421.50	2.90	11.83	74.72	-67.73	-409.26	44.37	75.08	-412.38	-137.74	1.02	121.41	44.50	74.76	-413.10	-137.74	1.02	121.41
450.00	2.90	15.23	-95.60	49.52	-436.93	92.11	-13.56	-440.26	-111.63	2.08	-220.64	92.24	-13.88	-440.98	-111.63	2.08	-220.64
505.00	2.91	14.64	-56.62	102.96	-491.14	56.25	-93.94	-492.99	7.09	0.52	-1.23	56.38	-94.26	-493.71	7.09	0.52	-1.23
564.00	4.20	6.53	-476.67	-120.10	-276.51	379.35	-276.46	312.67	54.80	2.59	479.18	379.48	-276.78	311.95	54.80	2.59	479.18
621.00	5.90	6.83	-198.32	-120.73	575.96	-610.99	111.04	2.47	-136.35	1.68	544.38	-610.86	110.72	1.75	-136.35	1.68	544.38
698.60	6.35	357.04	19.75	-38.52	697.26	483.97	261.83	-430.42	-0.30	2.91	-16.14	484.10	261.51	-431.14	-0.30	2.91	-16.14
727.15	4.87	346.87	-194.44	-691.14	115.16	-10.21	-14.12	726.94	-137.05	2.22	446.17	-10.08	-14.44	726.22	-137.05	2.22	446.17
813.09	4.06	335.25	402.22	-504.17	-495.12	-540.54	529.75	297.15	-187.26	2.26	-123.11	-540.41	529.43	296.43	-187.26	2.26	-123.11
928.56	6.50	258.71	**91.21**	**180.41**	**906.29**	**-458.09**	**-351.16**	**-727.37**	-138.02	-0.10	671.32	**-457.96**	**-351.48**	**-728.09**	-138.02	-0.10	671.32
1015.17	9.90	226.68	-407.35	-215.49	-904.54	936.604	-259.33	293.411	432.87	4.33	890.82	936.734	-259.65	292.691	432.87	4.33	890.82
1187.97	21.06	195.86	448.566	843.036	-706.65	711.964	511.205	801.903	777.72	8.28	871.01	712.094	510.885	801.903	777.72	8.28	871.01
1216.81	22.43	194.06	-388.2	338.182	-1102.5	553.242	1002.75	411.158	-241.30	-2.81	370.33	553.372	1002.43	411.158	-241.30	-2.81	370.33
1390.70	29.76	213.14	-1223.7	650.05	-118.25	75.1306	460.705	1310.02	-638.61	13.88	671.38	75.2606	460.385	1310.02	-638.61	13.88	671.38
1422.30	30.93	219.33	-555.08	364.852	1257.66	416.998	1341.23	223.921	-269.97	19.38	586.67	417.128	1340.91	223.921	-269.97	19.38	586.67
1505.68	32.22	221.98	-517.7	952.811	1044.61	-156.3	265.56	-1473.8	-329.41	7.45	3.02	-156.17	265.24	-1473.8	-329.41	7.45	3.02
1680.41	33.79	223.46	-1071.5	-461.8	-1209.3	-350.05	-852.51	1405.16	-1219.04	4.62	-1468.32	-349.92	-852.83	1405.16	-1219.04	4.62	-1468.32
1758.00	33.57	223.18	-1456.8	-179.09	-967.53	-1012.4	-951.3	1077.29	-1241.87	10.09	-1434.06	-1012.3	-951.62	1077.29	-1241.87	10.09	-1434.06
1851.01	33.27	226.17	1776.7	-43.842	-517.36	-921.04	1558.39	386.43	1250.77	-11.11	1405.91	-920.91	1558.07	386.43	1250.77	-11.11	1405.91
1937.23	33.55	220.56	1305.41	989.325	-1034.4	1564.4	-42.607	1141.8	1476.75	3.33	1681.36	1564.53	-42.927	1141.8	1476.75	3.33	1681.36
2012.95	34.28	217.56	-388.12	-391.79	-1935.9	57.0354	-304.5	1988.97	-1136.41	0.08	-1692.71	57.1654	-304.82	1988.97	-1136.41	0.08	-1692.71
2088.19	36.32	220.58	-1608.7	-1270.6	397.827	152.146	0.42165	-2082.6	-1486.25	-6.97	1806.60	152.276	0.10165	-2082.6	-1486.25	-6.97	1806.60
2116.59	38.21	222.54	-901.65	507.998	1846.32	-480.44	96.7997	2059.07	-422.14	-4.38	-983.08	-480.31	96.4797	2059.07	-422.14	-4.38	-983.08
2145.74	40.15	223.29	-1328.8	-320.85	-1653.9	578.478	769.513	-1917.7	-1434.22	10.77	-1818.28	578.608	769.193	-1917.7	-1434.22	10.77	-1818.28
2174.01	42.24	224.08	1108.45	1833.03	-371.02	508.378	-847.37	1936.45	976.67	18.03	-1649.09	508.508	-847.69	1936.45	976.67	18.03	-1649.09
2203.24	44.94	224.85	404.007	-1756.1	1267.74	924.352	115.761	-1996.6	234.56	-17.23	-522.95	924.482	115.441	-1996.6	234.56	-17.23	-522.95
2318.03	52.70	225.05	622.425	-1371.2	-1762.3	-993.72	-449.24	-2045.5	-312.17	-37.51	-150.14	-993.59	-449.56	-2045.5	-312.17	-37.51	-150.14
2434.01	54.20	222.54	1510.73	-851.16	-1708.1	-2343.4	472.155	458.22	740.93	-3.91	-1130.50	-2343.3	471.835	458.22	740.93	-3.91	-1130.50
2611.36	54.22	223.21	1873.33	296.403	-1795	-1764.4	-1839.3	568.315	775.14	6.84	-2158.13	-1764.3	-1839.6	568.315	775.14	6.84	-2158.13
2628.00	54.48	223.22	2272.11	382.428	-1264	-1474.6	-1583.3	1491.6	1197.02	2.57	-2179.41	-1474.5	-1583.6	1491.6	1197.02	2.57	-2179.41
2650.00	54.81	223.23	-783.9	-875.03	2367.36	-783.9	-875.03	2375.36	1644.61	-3.11	-2207.28	-783.77	-875.35	2375.36	1644.61	-3.11	-2207.28
2697.12	55.54	223.26	1009.03	1223.52	2173.58	1009.03	1223.52	2181.58	1973.66	-13.09	-2266.02	1009.29	1223.2	2181.58	1973.66	-13.09	-2266.02
2783.95	55.52	222.65	1567.8	-53.045	2291.91	1567.8	-53.045	2299.91	1305.25	-33.88	-1512.79	1568.43	-53.165	2299.91	1305.25	-33.88	-1512.79
2877.17	**55.53**	**222.65**	1655.75	-56.021	2384.33	1655.75	-56.021	2352.33	1657.88	-70.24	2399.13	1656.38	-56.241	2352.26	1657.88	-70.24	2399.13
2896.00	**55.52**	**222.65**	**1638.9**	**-67.18**	**2408.87**	**1630.9**	**-55.18**	**2427.71**	**1632.70**	**-55.32**	**2428.27**	**1631.2**	**-55.11**	**2430.4**	**1632.70**	**-55.32**	**2428.27**

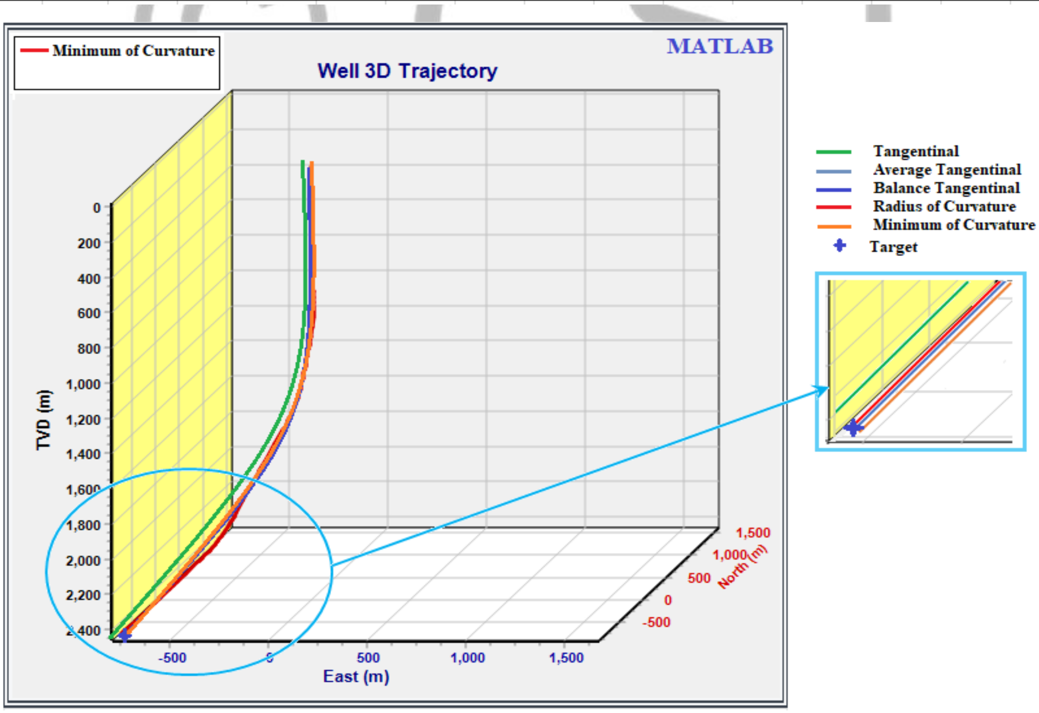


Figure 23: Graphical wellbore trajectory for Well XXX-1 using five different methods

According to Figure 23, the radius of curvature and the average tangential method are both the closes to the target compared to other three methods. The most deviated well path is the trajectory produce by applying the tangential method which is absolutely not practicable to be used and applied on the field.

4.4 VALIDATION / MODEL SELECTION

After apply different methods of survey calculation and plot the wellbore trajectory for each of the methods, it has to be justified the error between those methods in order to select the most suitable method in determining the smooth and good wellbore trajectory.

4.4.1 The error calculation:

1. For the tangential method with target (T):

$$\text{Error} = \sqrt{(\text{N}_{\text{ci}} - \text{N}_{\text{ti}})^2 + (\text{E}_{\text{ci}} - \text{E}_{\text{ti}})^2 + (\text{TVD}_{\text{ci}} - \text{TVD}_{\text{ti}})^2} \quad (6.1)$$

$$\text{Error} = \sqrt{(1638.9 - 1629.94)^2 + ((-62.18) - (-55.10))^2 + (2408.87 - 2440.31)^2}$$
$$= 33.44\text{m}$$

2. For the average tangential method with target (T):

$$\text{Error} = \sqrt{(1630.9 - 1629.94)^2 + ((-55.18) - (-55.10))^2 + (2429.71 - 2440.31)^2}$$
$$= 10.64\text{m}$$

3. For the balanced tangential method with target (T):

$$\text{Error} = \sqrt{(1632.7 - 1629.94)^2 + ((-55.32) - (-55.10))^2 + (2428.27 - 2440.31)^2}$$
$$= 12.35\text{m}$$

4. For the Radiuses of curvature method with target (T):

$$\text{Error} = \sqrt{(1631.2 - 1629.94)^2 + ((-55.11) - (-55.10))^2 + (2430.4 - 2440.31)^2}$$
$$= 47.85\text{m}$$

5. For the Minimum of curvature method with target (T):

$$\text{Error} = \sqrt{(1632.7 - 1629.94)^2 + ((-55.32) - (-55.10))^2 + (2428.27 - 2440.31)^2}$$
$$= 12.35\text{m}$$

By applying the error calculation based on equation 6.1, these are all the error analysis for each method based on the proposed survey field data of Well XXX-1 as shown in Table 12.

Table 12: Error analysis for all methods

METHOD	NORTH (m)	EAST (m)	TVD (m)	ERROR (m)
Tangential	1638.9	-67.18	2408.87	33.44
Average of Tangential	1630.9	-55.18	2429.71	10.64
Balanced of Tangential	1632.7	-55.32	2428.27	12.35
Radius of Curvature	1631.2	-55.11	2430.40	9.99
Minimum of Curvature	1632.7	-55.32	2392.27	12.35

Based on the **Table** 12, the radius of curvature has the smallest error (9.99m) between all of the methods. While the average tangential method producing a trajectory which has the error (10.64m) and it is the second method close to the targets. On the other hand, the tangential method has the highest error (33.44m), which is not suitable to be used in calculating the wellbore trajectory.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Although there are many methods that can be used in calculating the survey to get the wellbore trajectory, but not all methods are applicable to all types of well. Different well will have a different characteristic and profile, in which this will lead to different trajectory of the wellbore.

In **most** cases, the minimum of curvature knows to be the most suitable method to be for survey calculation and getting the trajectory profile. But through this project, it shows that the radius of curvature is the most suitable method to be used and applied based on the proposed survey data of Well XXX-1. And at the end from the MATLAB analysis results the **radius of curvature** method **shows** the smallest error between all other methods which is 9.99 m based on the absolute error calculation.

5.2 Recommendation for Future Work

For future recommendation, I suggest to applied different methods apart from tangential:

- The different methods are average tangential, balanced tangential, radius of curvature and minimum curvature and study the different between those methods.
- Another recommendation is to include more wells and advisable to include all wells in one whole big field and study the different between those methods.

REFERENCES

[1] Motor, M. Brushless DC motors for downhole and directional drilling. Available from: http://www.maxonmotorusa.com/maxon/view/application/DRILLING-AB

[2] Liu, G.R.S.a.X., Advanced Drilling Engineering: Principles and Designs. 2009.

[3] PetroWiki. Directional drilling. Available from: http://petrowiki.org/Directional_drilling

[4] Ingilis, T.A., Directional Drilling. 1987.

[5] Carden, R.S., Horizontal and Directional Drilling. 2007.

[6] Schlumberger, K.M.-. The Art of Controlling Wellbore Trajectory.

[7] Driller, D. Blow Out in Conroe. Available from: http://directional-driller.com/page46/Blow%20out%20in%20Conroe/Blow%20out%20in%20Conroe.html

[8] Society, A.O.G.H. Technology and the "Conroe Crater". Available from: http://aoghs.org/technology/directional-drilling/

[9] Williamson, H.S., Accuracy Prediction for Directional MWD, Society of Petroleum Engineers.

[10] Ibrahim, H., Survey Interpolation, 2012.

[11] Nyrnes, E. and T. Torkildsen, Analyses of the Accuracy and Reliability of Magnetic Directional Surveys, Society of Petroleum Engineers.

[12] Wilson, G.J., An Improved Method for Computing Directional Surveys.

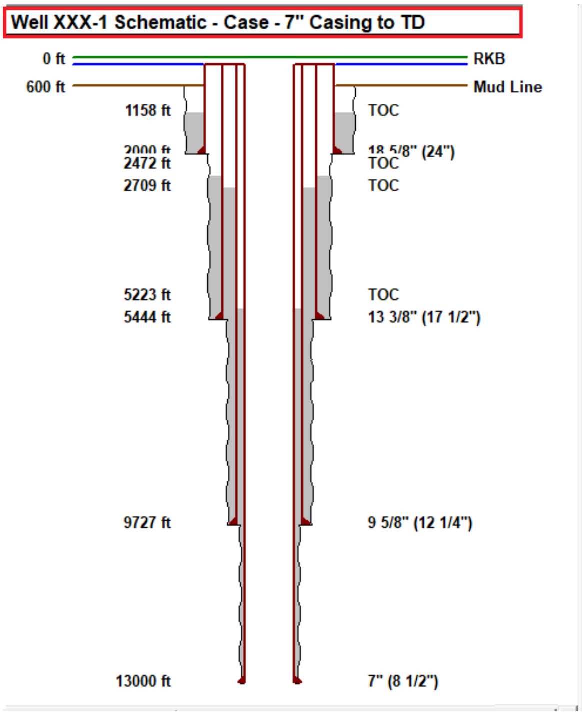
[13] Tangential Method Calculation. 2010; Available from: http://www.drilling formulas.com/tangential-method-calculation/

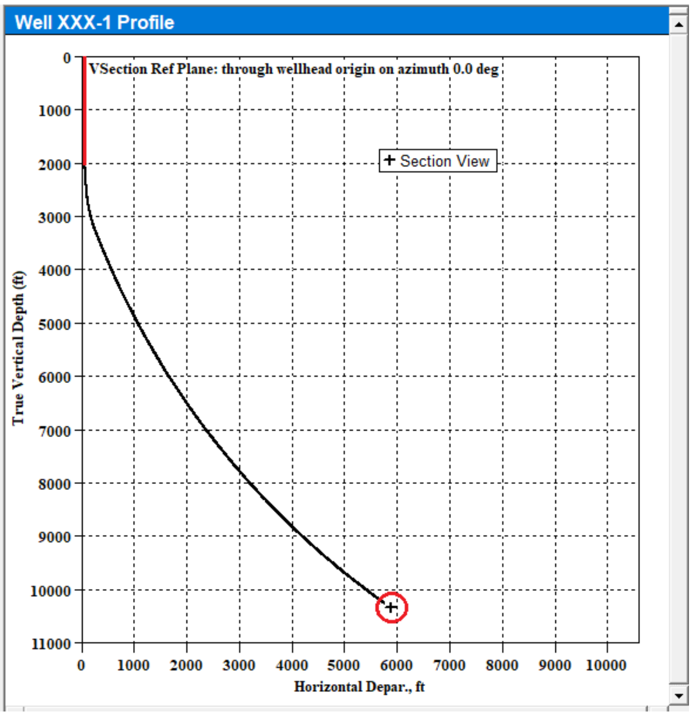
[14] Walstrom, J.E., R.P. Harvey, and H.D. Eddy, A Comparison of Various Directional Survey Models and an Approach to Model Error Analysis.

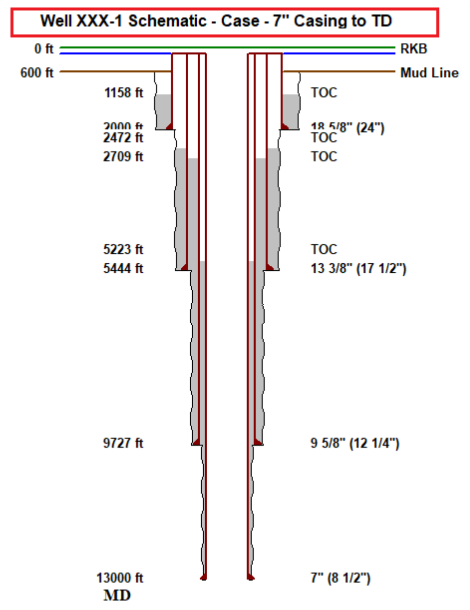
[15] Callas, N.P., Computing Directional Surveys with a Helical Method (includes associated papers 6409 and 6410).

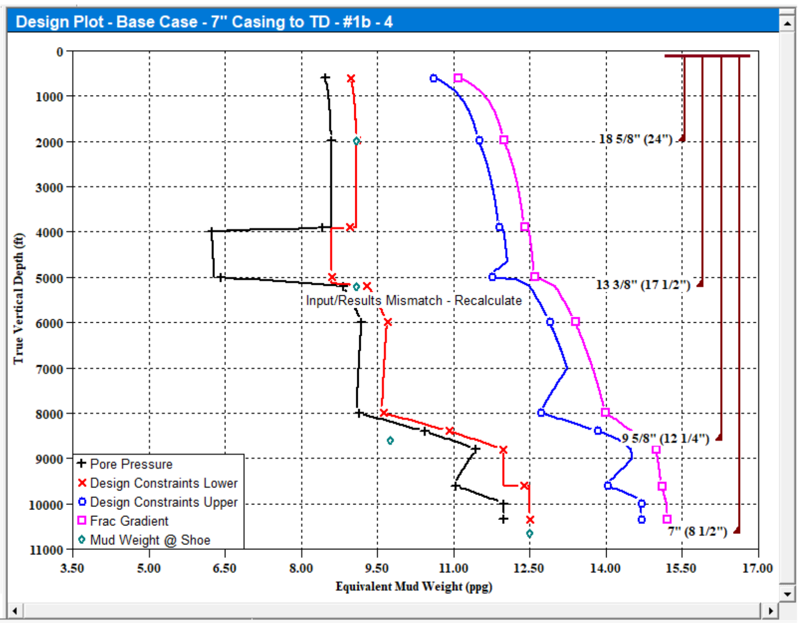
Lithology

	Layer Name	Layer Type	Layer Top TVD (ft)	Competent Layer	Overbalance Margin (ppg)	Diff. Sticking Limit (psig)	Stability Min. MW (ppg)	Formatio Pressures - EMW (ppg)	
								Pore	Fracture
1	L. Fars Marl	Sand	1173	Yes	0.50	1500	8.50	8.48	11.10
2	Ghar	Shale, Sandy	1698	Yes	0.50	1500	8.60	8.60	12.00
3	Dammam	Limestone, Ar	2207	Yes	0.50	1500	8.60	8.60	12.40
4	RUS	Dolomite	2866	Yes	0.50	1400	8.60	6.00	12.50
5	Umm Er-Radhu	Dolomite	3158	Yes	0.50	1400	8.60	6.00	12.60
6	Tayarat Bitumin	Shale, Siliceo	4887	Yes	0.50	1500	9.00	8.83	13.00
7	Shiranish	Limestone, Ar	5747	Yes	0.50	1500	8.70	9.20	13.40
8	Hartha	Limestone, Ar	6158	Yes	0.50	1500	9.10	9.10	14.00
9	Sadi	Shale, Sandy	6768	Yes	0.50	1500	10.40	10.40	14.50
10	Tanuma	Limestone, Ar	8169	Yes	0.50	1500	12.00	11.46	15.00
11	Khasib	Limestone, Ar	8340	Yes	0.50	1500	12.25	11.34	15.10
12	Mishrif	Limestone, Ar	8693	Yes	0.50	1500	12.50	11.00	15.20





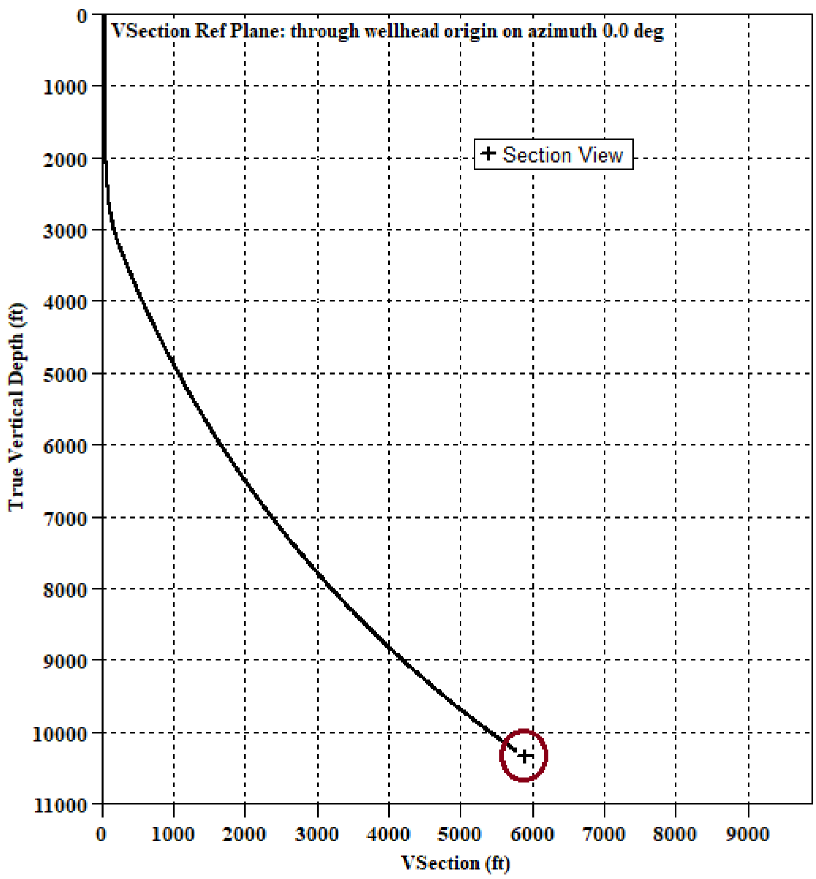


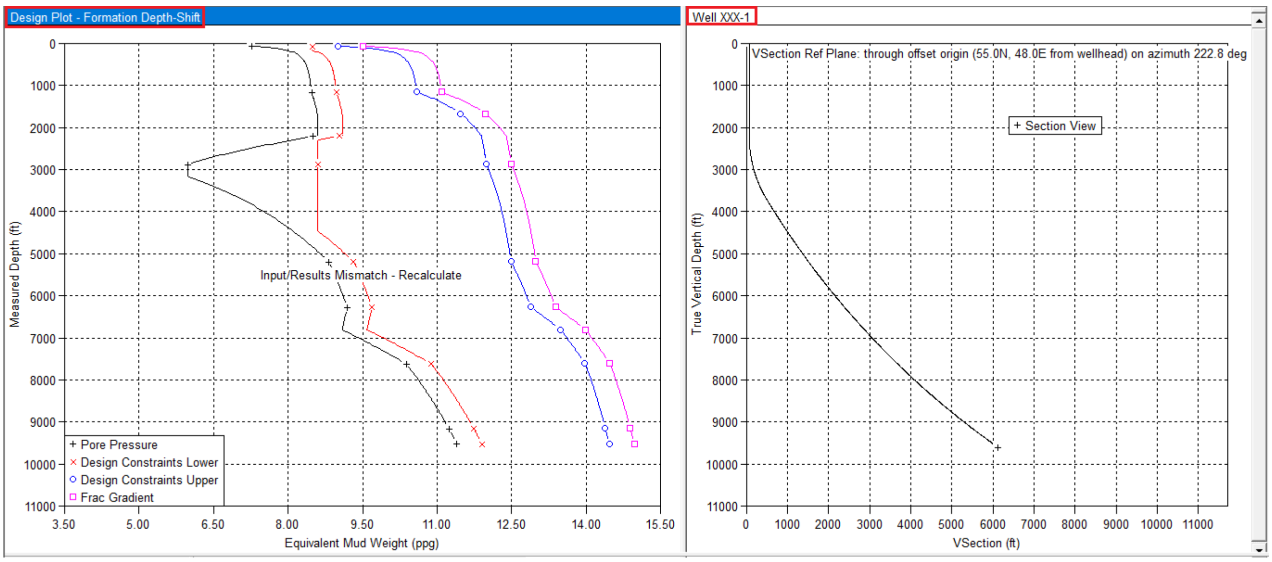


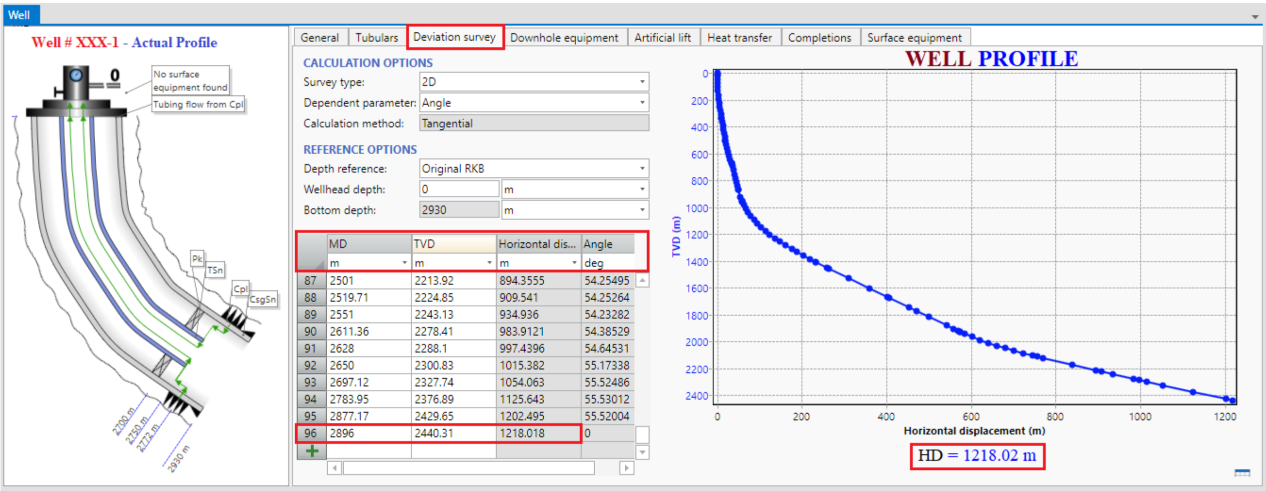
Survey

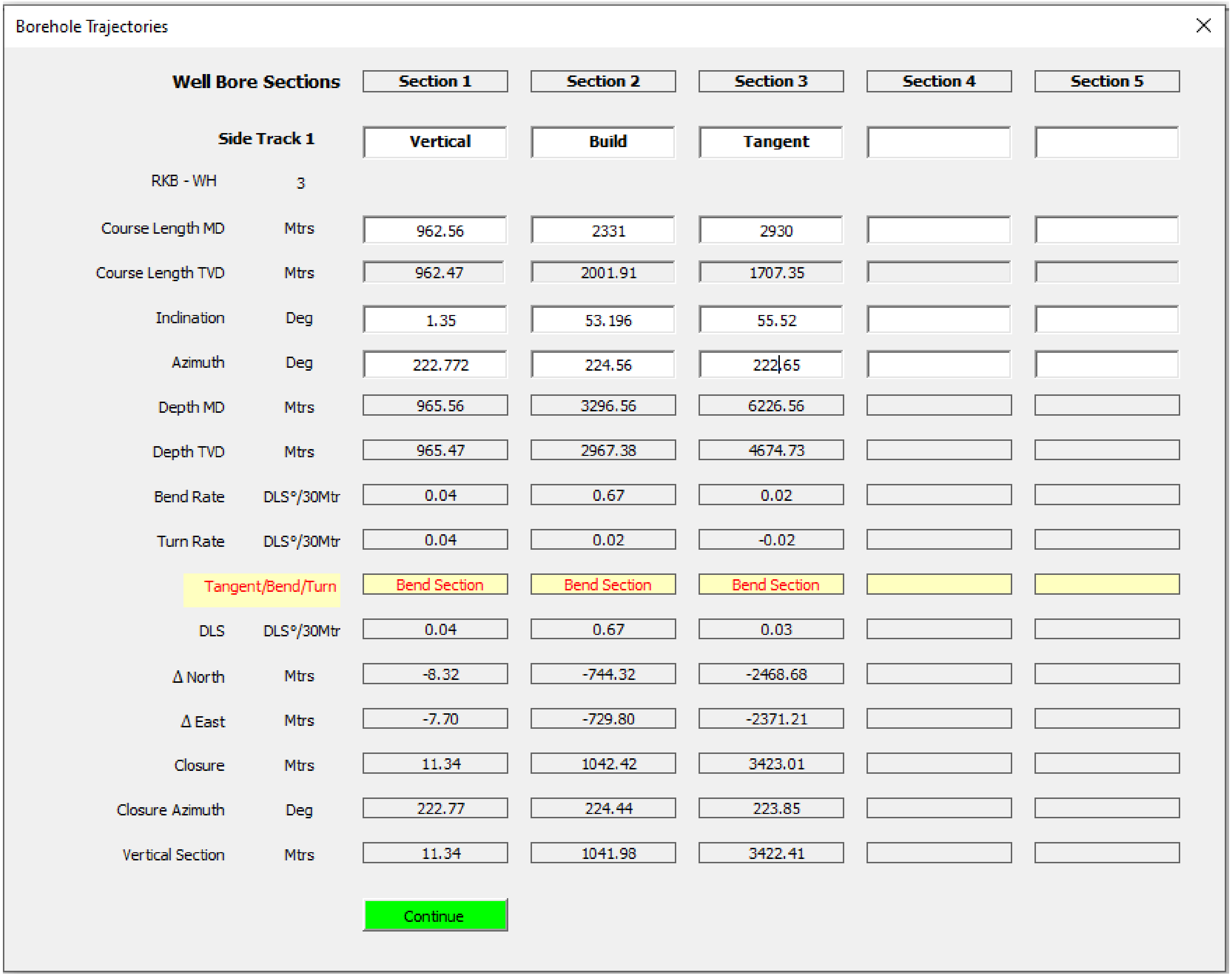
	Data-Entry Mode	MD (ft)	INC (deg)	AZ (deg)	TVD (ft)	DLS (deg/100ft)	Max DLS (deg/100ft)	Vsection (ft)	Departure (ft)
1	MD-INC-AZ	0	0.00	0.00	0			0	0
2	MD-INC-AZ	2500	4.35	0.00	2498	0.17	0.17	95	95
3	INC-AZ-DLS	3363	21.60	0.00	3335	2.00	2.00	288	288
4	INC-AZ-TVD	12478	55.52	0.00	10359	0.37	0.37	5887	5887

Section View





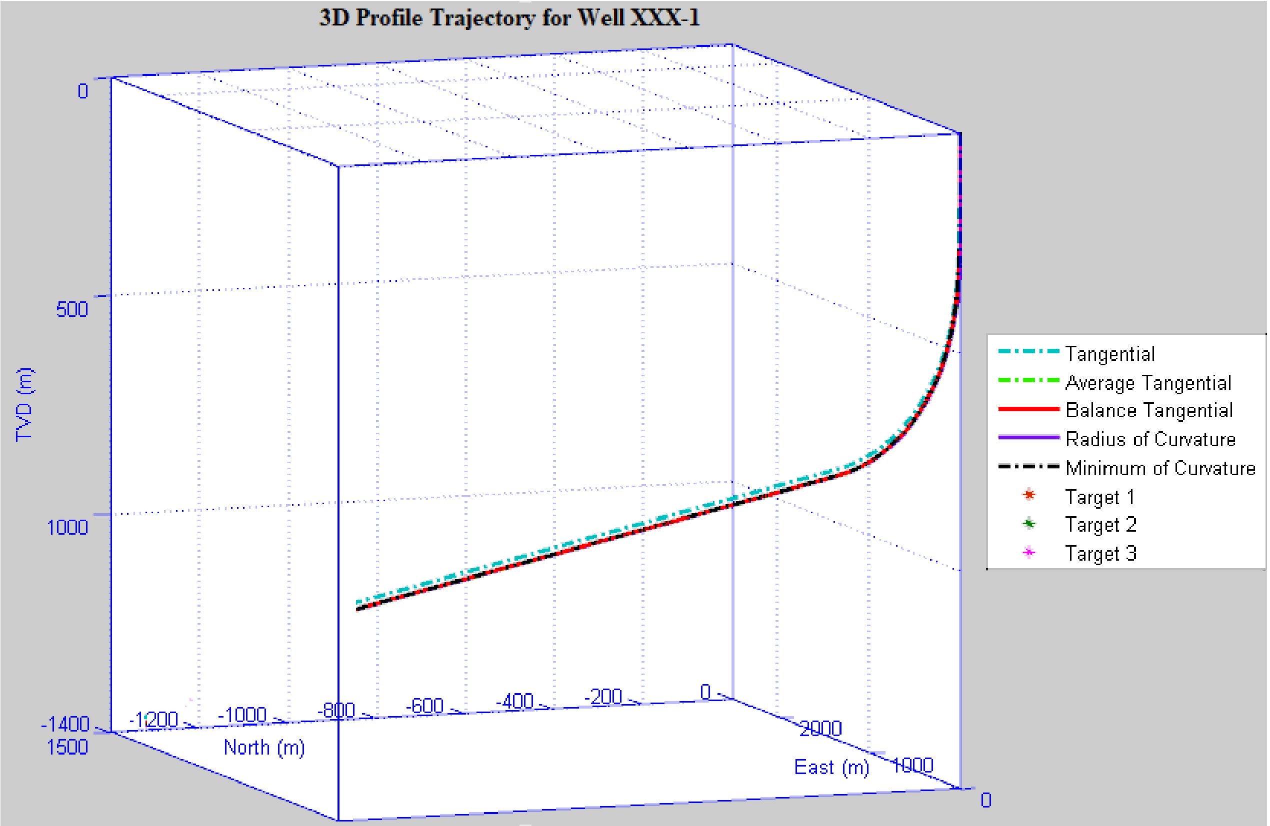




Borehole Trajectories

Well Bore Sections		Section 1	Section 2	Section 3	Section 4	Section 5
Side Track 1		Vertical	Build	Tangent		
RKB - WH	3					
Course Length MD	Mtrs	962.56	2331	2930		
Course Length TVD	Mtrs	962.47	2001.91	1707.35		
Inclination	Deg	1.35	53.196	55.52		
Azimuth	Deg	222.772	224.56	222.65		
Depth MD	Mtrs	965.56	3296.56	6226.56		
Depth TVD	Mtrs	965.47	2967.38	4674.73		
Bend Rate	DLS°/30Mtr	0.04	0.67	0.02		
Turn Rate	DLS°/30Mtr	0.04	0.02	-0.02		
Tangent/Bend/Turn		Bend Section	Bend Section	Bend Section		
DLS	DLS°/30Mtr	0.04	0.67	0.03		
Δ North	Mtrs	-8.32	-744.32	-2468.68		
Δ East	Mtrs	-7.70	-729.80	-2371.21		
Closure	Mtrs	11.34	1042.42	3423.01		
Closure Azimuth	Deg	222.77	224.44	223.85		
Vertical Section	Mtrs	11.34	1041.98	3422.41		

Continue


3D Profile Trajectory for Well XXX-1
TVD (m)
0
500
1000
-1400
1500
North (m)
-1200
-1000
-800
-600
-400
-200
0
East (m)
2000
1000
0
Tangential
Average Tangential
Balance Tangential
Radius of Curvature
Minimum of Curvature
Target 1
Target 2
Target 3