Selection of Surveying Method for Trajectory Design at Well X

by

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13662

Dissertation submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Petroleum Engineering Programme

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(PETROLEUM)

Approved by,

____

(Dr. Syahrir Ridha)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MUHAMMAD AMIRUL BIN ROSLI

ABSTRACT

Technology regards to Oil and Gas industries has developed very fast on par with the research and development activity. Back to 1930s, directional drilling is not a very common method for drilling, but not for nowadays especially on the offshore field, many operators prefer to use the directional drilling technology in order to save cost without having to build another drilling platform which is very expensive. Therefore, it is important to have a very accurate tool in determining a very good precise value of inclination and azimuth of the wellbore during drilling operation. By obtaining the precise 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, the author will use the most simple and common methods in analyzing the well trajectory of Well X. The Author 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 X. The results indicate the minimum of curvature method have the smallest error follow by the average tangential method accordingly

ACKNOWLEDGEMENT

First and foremost, I would like to thank the Almighty God for His blessings, and giving me health, strength and knowledge to complete this project.

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LIST OF ABBREVIATIONS AND NOMENCLATURES

MD = Measure Depth (m)

TVD = True Vertical Depth (m)

A_i = Azimuth (º)

I_i = Inclination (º)

r_i = Radius of curvature on the horizontal projection (º)

R_i = Radius of curvature on the vertical plane (º)

N_{c_i} = Calculated north (m)

N_{t_i} = Targeted north (m)

E_{c_i} = Calculated east (m)

E_{t_i} = Targeted east (m)

TVD_{c_i} = Calculated true vertical depth (m)

TVD_{t_i} = Targeted true vertical depth (m)

CHAPTER 1

INTRODUCTION

1.1. Background of Study

When talking about drilling a well to extract the hydrocarbon underneath the ground, people outside the oil and gas industry will think that the well is only a straight vertical well but the real well is not as simple as what they thought. Some of the wells are design not to be in a vertical way but to moving toward a different direction. These kind of well were also known as directional wells as illustrated in Figure 1. There are several reasons to design a well to be in such a way that it is directional, some of the reason are:

1) Side track
2) Offshore wells
3) Multiple sands target
4) Inaccessible location
5) Fault drilling
6) Salt dome
7) Relief well
8) Horizontal drilling
9) Multilateral From a platform

Figure 1: Illustration of Directional Drilling [1]

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 or steer the well path in the right direction to hit several targets thousands of meters downhole.

Currently there are a lot of Oil and Gas Company providing tools to deflect and steer the path of the wellbore in the direction of as per plan and measure the azimuth and inclination 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, the author will make a study between several methods of wellbore trajectory calculation based on proposed survey field data of well X.

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 a number of 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, the author 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 X.

1.3 Objectives

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 X.
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. As for this project, the author will mainly focus on five most simple and common methods used in calculating the survey of the wellbore trajectory namely tangential method, average tangential method, balance tangential method, radius of curvature method and minimum curvature method. The author will also study on the method to define the error between those methods.

CHAPTER 2

LITERATURE REVIEW

2.1 Directional Drilling

2.1.1 Definition and History of Directional Drilling

Directional drilling is defined as the practice of controlling the direction and deviation of a wellbore to a predetermined underground target or location [3]. Directional drilling can also be describe as “the art and science involved in the deflection of a wellbore in a specific direction in order to reach a pre-determine objective below the surface of the earth” [4]. 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].

Back to 1920s, when the basic wellbore surveying methods were introduced, the drillers notice that the well which supposed to be drill in a vertical ways is not really drilled in vertical direction and was actually drilled in deflected and unwanted direction. To solve the undesirable deviation issues, the drillers invented new techniques to ensure the well path is drill as vertical as possible [6]. Later, the same idea and techniques were used in propagating the well path to hit several targeted producing sands.

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 ways moving towards the offshore oil deposits.

Directional drilling is not a common practice neither famous back to 1930s. Only 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]. Figure 2 shows the location where entire drilling rigs on Conroe field sank out of sight. 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: Entire drilling rigs on Conroe field sank out of sight [8]

2.1.2 Applications of Directional Drilling

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

a) Sidetracking
b) Drilling to avoid geological problems
c) Controlling vertical holes
d) Drilling beneath inaccessible locations
e) Offshore development drilling
f) Horizontal drilling
g) Non-petroleum uses

2.1.2.1 Sidetracking

Once in a while, the driller might encounter some obstruction and might lead to drill string stuck at the downhole. This can be happen due to the drill string failure or an intentional back-off while some part of the drill string is left inside the hole. There will be no further action can be done if the fish cannot be pulled out of hole.

If in this case, in order to proceed with the drilling operation, a cement plug is needed to be set on top of the fish in which it can form a good foundation to kicked off and drill around the obstruction as illustrate in Figure 3. Once the obstruction manages to be bypass by the sidetrack, the hole can be continued to drill to the target. Side Tracking can also be used to re-drill or re-completion in case of the original well does not have the expected producing capacity.

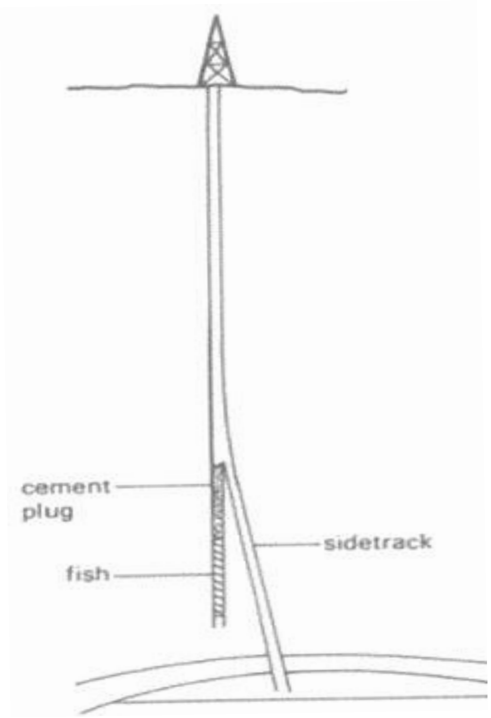


Figure 3: Illustration of Sidetracking [4]

2.1.2.2 Drilling to avoid geological problems

Sometimes, the hydrocarbon reservoirs are located close to the salt dome structures. Part of the salt dome may be directly above of the targeted reservoir. If the drillers drill straight to the bottom in a vertical ways, it will hit and penetrate the salt dome first before hit the targeted reservoir. Drilling through a salt dome will increase the risks of corrosion and lost circulation. Hence, in order to avoid from hitting the salt dome zone, the well should be drill in a directional path as illustrate in Figure 4. Same goes to the situation where drilling through a fault which is very risky and can lead to blowout due to the massive different between the formations. This can also be avoided by applying directional drilling to avoid the obstacles.

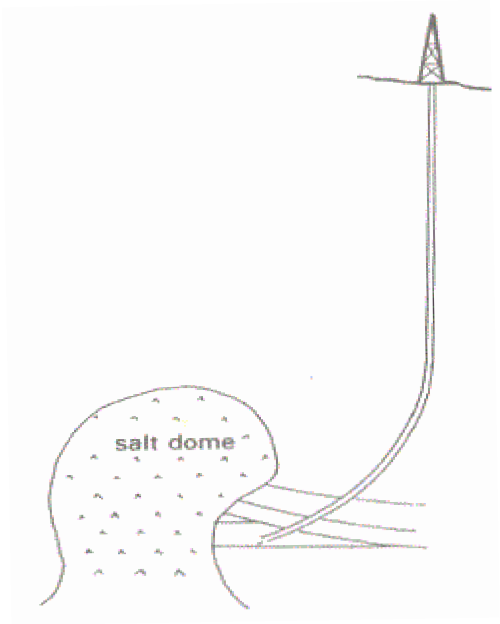


Figure 4: Directional drilling to avoid salt dome [4]

2.1.2.3 Controlling Straight Wells

Directional drilling can also be applied to keep vertical well to stay as vertical as possible. Any small deviation from the plan pathway can be adjusted by altering certain drilling parameters or changing the setup of the bottom hole assembly. To some extent of extreme cases, the driller will need to use the downhole motor or bent sub to make sure the pathway is not deviated from vertical path. The same technique can also be applied in the tangential section of the well.

2.1.2.4 Inaccessible locations

In certain cases or situations, there are some restrictions and obstruction which does not allow the well to be drill vertically such as the target reservoir is underneath a populated area, mountain range, lake and so forth. There are some areas that cannot be drill vertically as it need to consider some sensitive area and may create a high potential risk to the population and environment. Referring to those cases, it is possible to reach the target reservoir by drilling a directional wells from a surface location outside of the restricted area as illustrated in Figure 5.

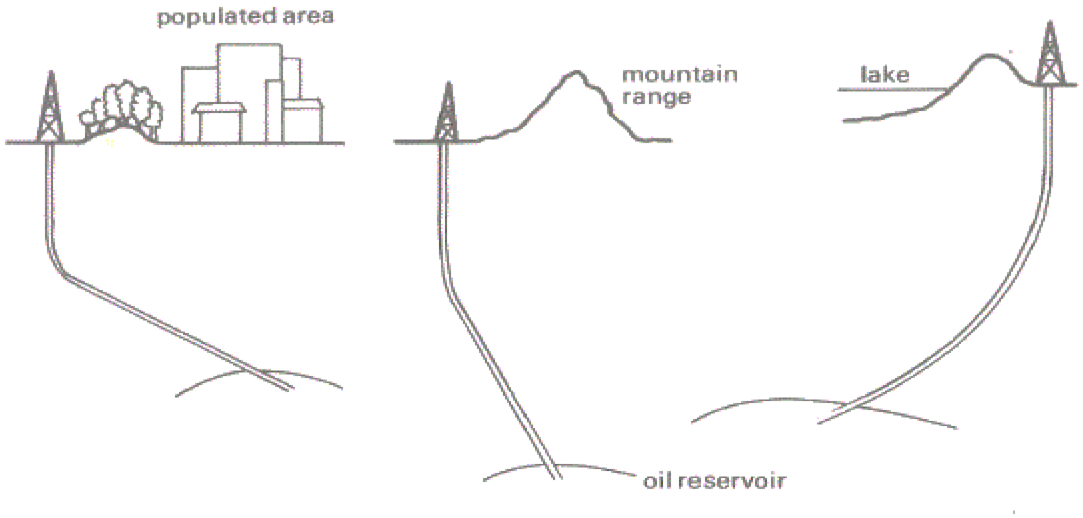


Figure 5: Example of inaccessible location [4]

2.1.2.5 Offshore Development Drilling

One of the major applications of directional drilling is toward the development of offshore reservoirs. Many of the offshore reservoirs situated far from the shore and it is not economical to drill from the shore. If a vertical drilling technique is to be applied, there will be too much platform to be installed and this is also very uneconomical and impracticable. Therefore, a directional drilling is applied and this can be done by drill through several different location and target from single point based on the location of where the platform been installed as shown in Figure 6. These wells can be drill directionally using several types of drilling rigs such as semi-submersible rig, jack-up rig, or drill-ship depending on the water depth and situation.

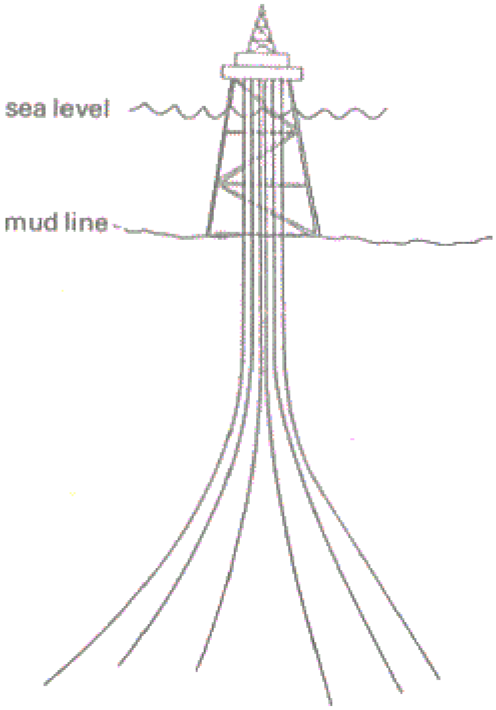


Figure 6: Offshore Development Drilling from a fixed platform [4]

The challenges when drilling a deviated well from a floater compared to a fixed platform is that the effect of the vessel's movements. Nowadays, exploration of the hydrocarbon already extent to the deep water drilling and this will affect the cost of the drilling operation significantly, because it will require to use and rent a floating drilling and production units rather than to use the fixed one as shown in Figure 7. Furthermore, drilling at the offshore wells will need more attention and safety precaution especially during the bad weather.

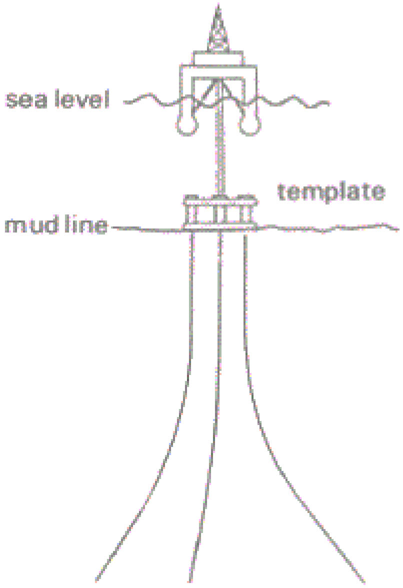


Figure 7: Floating rig and platform [4]

2.1.2.6 Horizontal Drilling

Normally the deviation of a directional well is around 60° of inclination and the inclination beyond 60° 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

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 8 shows the illustration of the horizontal well.

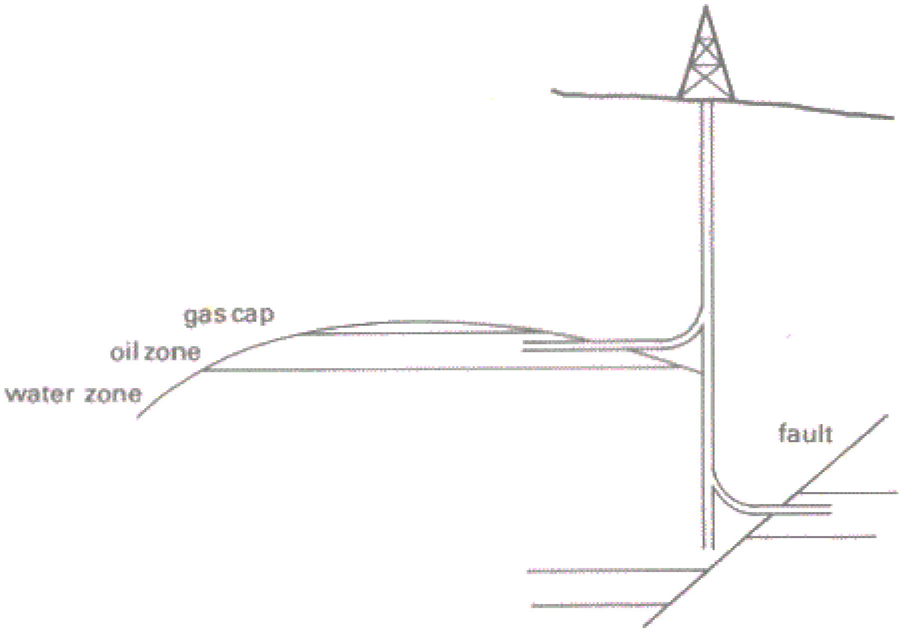


Figure 8: Horizontal drilling application [4]

2.1.2.7 Non-petroleum Application

a) Mining industry

Directional wells are also used in mining industry to bring out all the methane gas that is contained in coal bed before the mining activity start. In the deep coal bed that cannot reach by conventional mining techniques, a directional wells should be drilled for in situ gasification projects.

b) Construction industry

Directional drilling can also be used in the installation of pipelines beneath river beds. A small-diameter hole is drilled beneath the river until it reaches on the other side. The small diameter hole act as a guide for the larger-diameter pipe that forms the conduit. The pilot hole is drilled using a downhole motor and bent sub.

c) Geothermal energy

The granite source rock is generally impermeable except for vertical fractures. In order to extract the heat from this rock, it is necessary to drill injection and production wells. The wells are directionally drilled to take advantage of the orientation of the fractures. Due to the very high temperatures and hardness of the rock, it can induce some major drilling problems such as severe abrasion of downhole components and many more

2.1.3 Defecting 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]:

2.1.3.3 Whipstocks

Whipstocks were used in directional wells to start kick off as illustrated in Figure 9. The direction in which the tapered edge was facing is known as the "toolface". There are two different types of whipstock available. The first one is a “removable whipstock" can be used to initiate deflection in open hole, or straighten the vertical wells that have become crooked. The second type of whipstock is a "permanent whipstock" which normally used in cased hole for sidetracking around a fish.

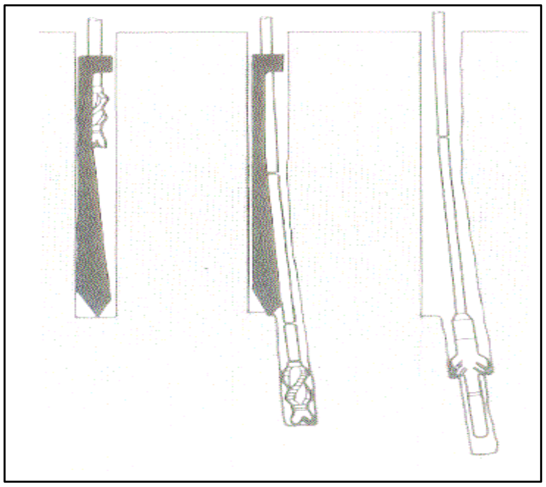


Figure 9: Application of Whipstock

2.1.3.4 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 Figure 10. Mud is pumped through the drill string to operate the motor and drive the bit without rotating the drillstring. An MWD tool or steering tool should be run to monitor the toolface heading continuously.

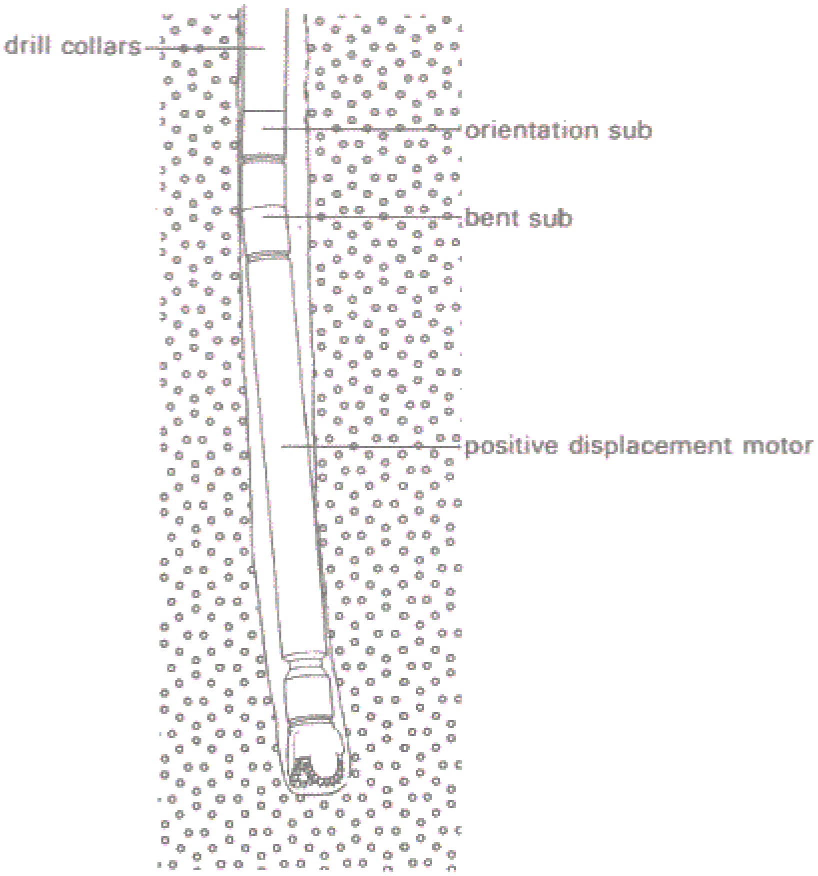


Figure 10: Positive Displacement Motor and Bent Sub [4]

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.

2.1.3.5 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 advantages 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.

2.2 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 multinominals, the coordinates are determined through numerical integral
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 remain individually constant
Constant toolface	F.J. Schuh, Guo Boyun	A 3D curve that borehole curvature and toolface 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 simples calculation. The wellbore is a straight line between two survey stations

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

2.2.1 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..

2.2.2 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.

2.2.3 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.

2.2.4 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.

2.2.5 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.

2.3 Survey Tolls

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

2.3.1 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.

2.3.2 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

3.1 Research 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 11):

3.1.1 Project Process Flow

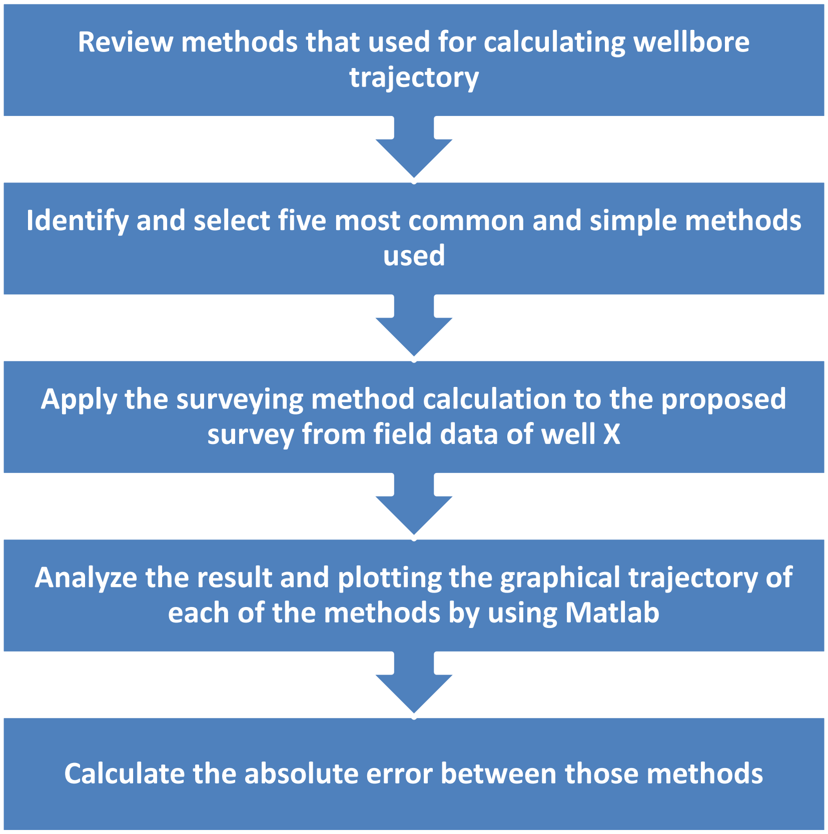


Figure 11: Process Flow for Research Methodology

3.1.2 Survey Calculation Methods

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

3.1.2.1 Tangential Method

This method assumes that the wellbore is straight line from two survey stations (Figure 12) [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].

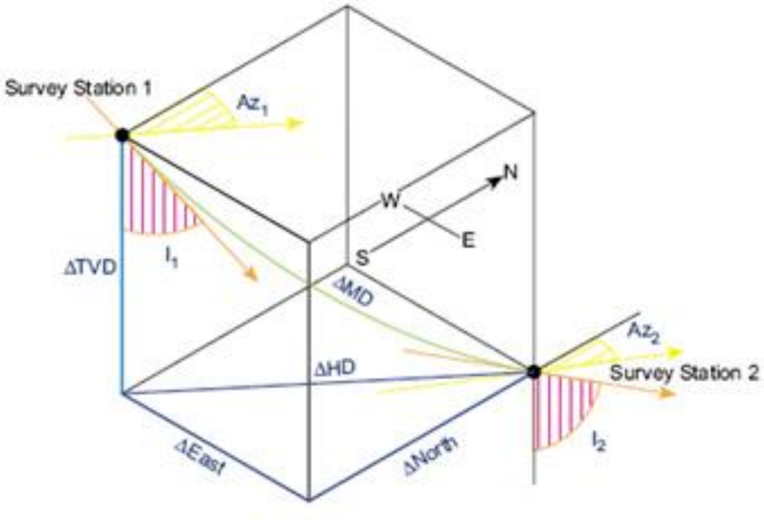


Figure 12: Illustration of Tangential method[13]

Formula for Tangential Method

$$North = MD \times \sin(I_i) \times \cos(A_i) \quad (1.1)$$

$$South = MD \times \sin(I_i) \times \sin(A_i) \quad (1.2)$$

$$TVD = MD \times \cos(I_i) \quad (1.3)$$

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 13 [2].

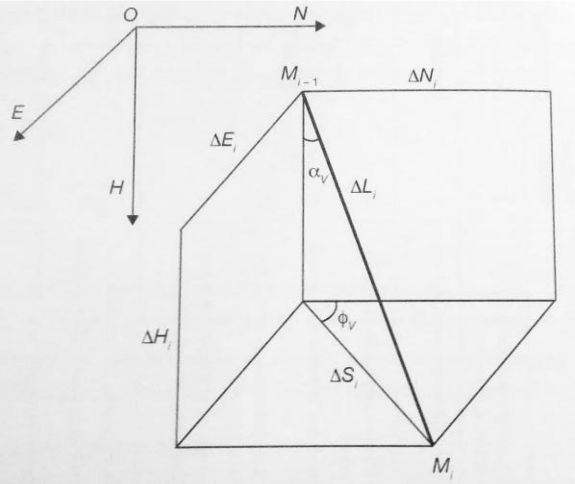


Figure 13: Illustration of Average Tangential method [2]

Formula for Average Tangential Method

$$North = MD \times \sin\left(\frac{I_{i-1}+I_i}{2}\right) \times \cos\left(\frac{A_{i-1}+A_i}{2}\right) \tag{2.1}$$

$$South = MD \times \sin\left(\frac{I_{i-1}+I_i}{2}\right) \times \sin\left(\frac{A_{i-1}+A_i}{2}\right) \tag{2.2}$$

$$TVD = MD \times \cos\left(\frac{I_{i-1}+I_i}{2}\right) \tag{2.3}$$

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 14). It assumes that the first half is tangent to the first survey station and the second half is tangent to the second survey station.

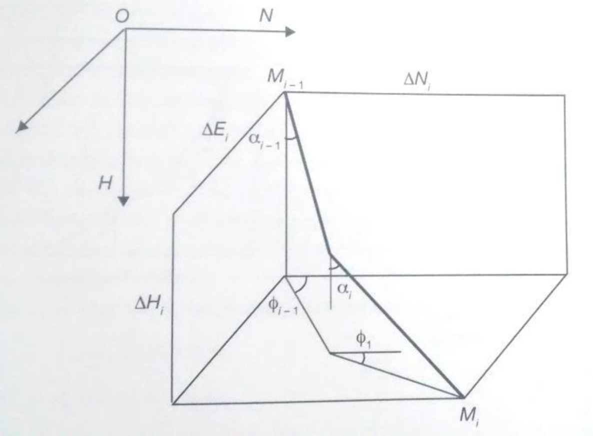


Figure 14: Illustration of Balanced Tangential method [2]

Formula for Balanced Tangential Method

$$North = \frac{MD}{2} \times [\sin(I_{i-1}).\cos(A_{i-1}) + \sin(I_i).\cos(A_i)] \qquad (3.1)$$

$$South = \frac{MD}{2} \times [\sin(I_{i-1}).\sin(A_{i-1}) + \sin(I_i).\sin(A_i)] \qquad (3.2)$$

$$TVD = \frac{MD}{2} \times [\cos(A_{i-1}) + cos(A_i)] \qquad (3.3)$$

3.1.2.4 Radius of Curvature Method

The radius of curvature method assumes that the wellbore has a shape of smooth curve described by a circular arc (Figure 15) [14]. This method is less accurate when a severe dogleg is present in the interval of calculation [2].

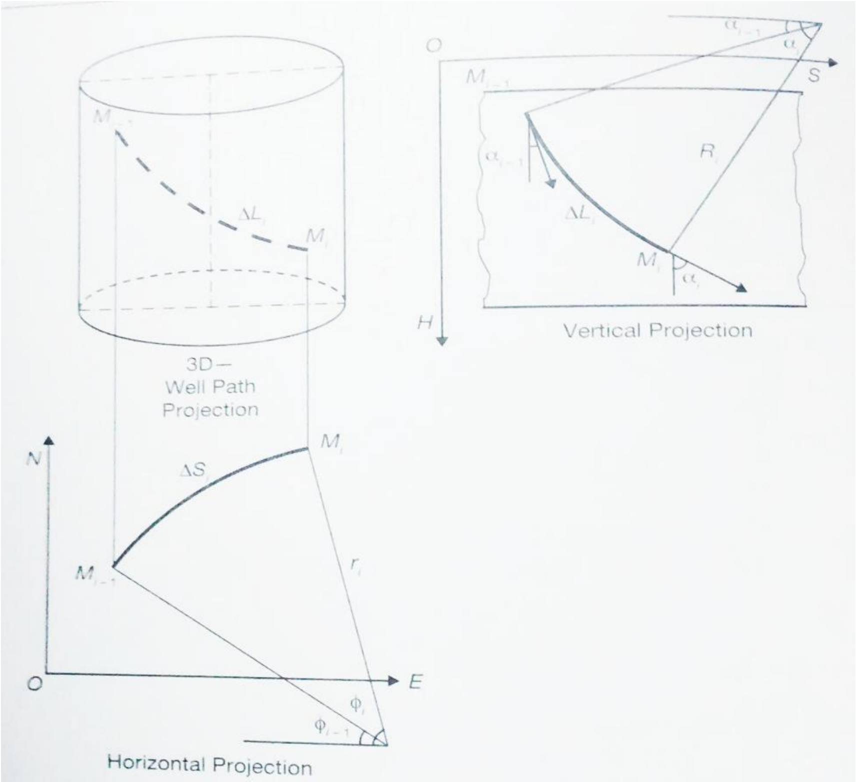


Figure 15: Illustration of Radius of Curvature method

Formula for Radius of Curvature Method

$$North = r_i \times [\sin(A_i) - \sin(A_{i-1})] \tag{4.1}$$

$$South = r_i \times [\cos(A_{i-1}) - \cos(A_i)] \tag{4.2}$$

$$TVD = R_i \times [\sin(I_i) - \sin(I_{i-1})] \tag{4.3}$$

Where,

$$R_i = \frac{180}{\pi} \cdot \frac{MD}{I_i - I_{i-1}} \qquad r_i = \frac{180}{\pi} \cdot \frac{R_i}{A_i - A_{i-1}} \tag{4.4}$$

When ΔI_i or ΔA_i is equal to zero, it is not possible to calculate R_i or r_i. The following are the general formulas that are applicable for all the cases:

$$\Delta H_i = MD \cos I_i \qquad if\ \Delta I_i = 0 \tag{4.5}$$

$$= R_i[\sin(I_i) - \sin(I_{i-1})] \qquad if\ \Delta I_i \neq 0 \tag{4.6}$$

$$\Delta S_i = MD \sin I_i \qquad if\ \Delta I_i = 0 \tag{4.7}$$

$$= R_i[\cos(I_{i-1}) - \cos(I_i)] \qquad if\ \Delta I_i \neq 0 \tag{4.8}$$

$$\Delta N_i = \Delta S_i \cos A_i \qquad if\ \Delta A_i = 0 \tag{4.9}$$

$$= r_i[\sin(A_i) - \sin(A_{i-1})] \qquad if\ \Delta A_i \neq 0 \tag{4.10}$$

$$\Delta E_i = \Delta S_i \sin A_i \qquad if\ \Delta A_i = 0 \tag{4.11}$$

$$= r_i[\cos(A_{i-1}) - \cos(A_i)] \qquad if\ \Delta A_i \neq 0 \tag{4.12}$$

Where,

$$R_i = \frac{180}{\pi} . \frac{MD}{I_i - I_{i-1}} \qquad r_i = \frac{180}{\pi} . \frac{\Delta S_i}{A_i - A_{i-1}} \tag{4.13}$$

3.1.2.5 Minimum 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 16 [15]. It uses the dogleg ratio factor in order to get smooth wellbore section.

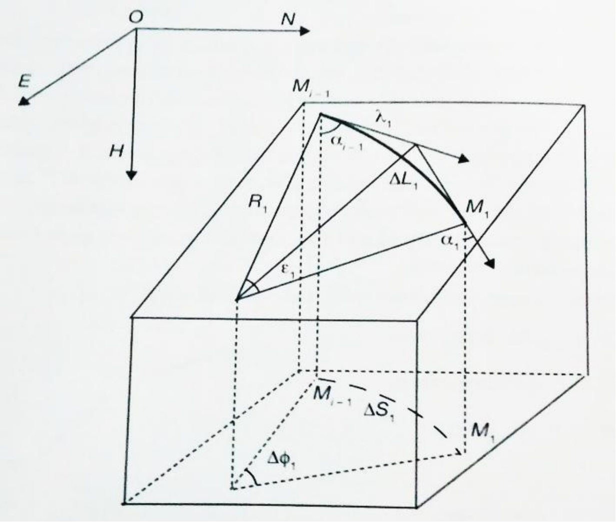


Figure 16: Illustration of Minimum Curvature method

Formula for Minimum Curvature Method

$$North = \lambda_i \times [\sin(I_{i-1}).\cos(A_{i-1}) + \sin(I_i).\cos(A_i)] \tag{5.1}$$

$$South = \lambda_i \times [\sin(I_{i-1}).\sin(A_{i-1}) + \sin(I_i).\sin(A_i)] \tag{5.2}$$

$$TVD = \lambda_i \times [\cos(I_{i-1}) + \cos(I_i)] \tag{5.3}$$

$$\lambda_i = \frac{180}{\pi} . \frac{MD}{\varepsilon_i} . \tan\frac{\varepsilon_i}{2} \tag{5.4}$$

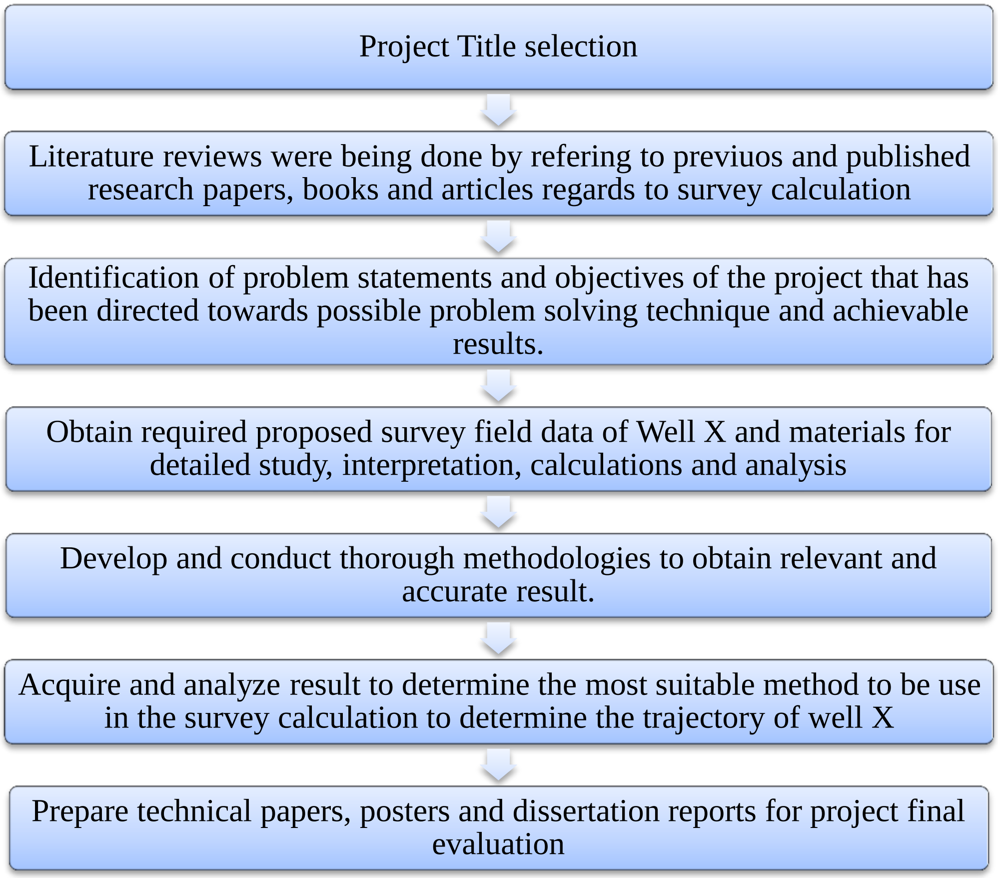
$$\cos\varepsilon_i = [\cos(I_{i-1}).\cos(I_{i-1}) + \sin(I_{i-1}).\sin(I_i).\cos(\Delta A_i)] \tag{5.5}$$

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].

$$Error = \sqrt{(N_{c_i} - N_{t_i})^2 + (E_{c_i} - E_{t_i})^2 + (TVD_{c_i} - TVD_{t_i})^2} \qquad (6.1)$$

3.2 Project Activity



Project Title selection

Literature reviews were being done by refering to previuos and published research papers, books and articles regards to survey calculation

Identification of problem statements and objectives of the project that has been directed towards possible problem solving technique and achievable results.

Obtain required proposed survey field data of Well X and materials for detailed study, interpretation, calculations and analysis

Develop and conduct thorough methodologies to obtain relevant and accurate result.

Acquire and analyze result to determine the most suitable method to be use in the survey calculation to determine the trajectory of well X

Prepare technical papers, posters and dissertation reports for project final evaluation

Figure 17: Project Activity Flow Chart

3.3 Project Key Milestone

Table 2 is the estimated project key milestones that should be completed by the end of this project:

Table 2: Project Key Milestone

Week No.	Key Milestone
6	Submission of extended proposal
18	Prepared excel work sheet for all the methods
20	Draw all the trajectory for each methods by using Matlab
23	Applied error calculation analysis for all methods
29	Submission of hard bound of Project Dissertation

3.4 Gantt Chart

Table 3: Gantt chart

FYP I													
No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12
1	Selection Project Topic	■	■										
2	Make some reading based on books, research papers and journals and prepare for extended proposal		■	■	■	■							
3	Data Gathering regards to all methods						■	■	■	■			
4	Analyze and study each methods especially on the formulas and prepare for interim report										■	■	■

FYP II													
	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12
5	Prepare the excel worksheet to calculate and analyze all of the methods	■	■	■	■								
6	Learn to use Matlab and draw the trajectory for each of the methods					■	■	■					
7	Apply error calculation analysis for each methods and prepare for Dissertation Report								■	■	■		
8	Prepare, finalize and submit Dissertation report											■	■

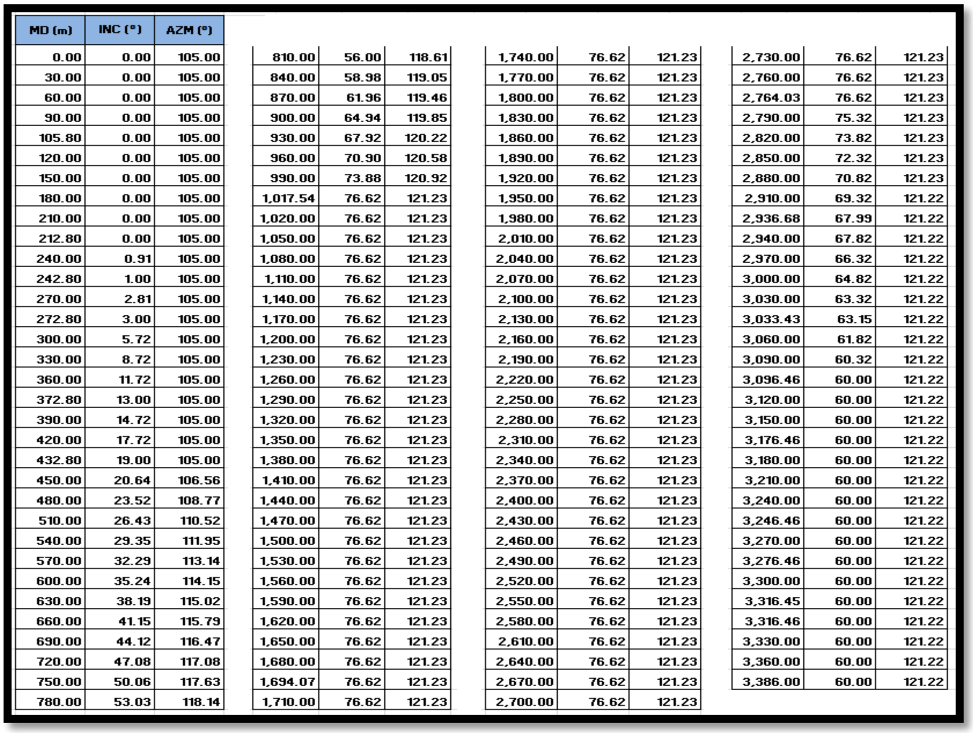
CHAPTER 4

RESULTS AND DISCUSSION

4.1 Data

Data was obtained from an operator company based in Kuala Lumpur, Malaysia. The proposed survey field data is for well X. Well X is located in Terengganu offshore Peninsular Malaysia. There are 3 targets location for Well X which are Target 1, Target 2 and Target 3 as shown in Table 5. This well has a simple profile which includes build, hold and drop. 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 shows the proposed survey field data of well X.

Table 4: Proposed Survey field data from Well X



MD (m)	INC (°)	AZM (°)
0.00	0.00	105.00
30.00	0.00	105.00
60.00	0.00	105.00
90.00	0.00	105.00
105.80	0.00	105.00
120.00	0.00	105.00
150.00	0.00	105.00
180.00	0.00	105.00
210.00	0.00	105.00
212.80	0.00	105.00
240.00	0.91	105.00
242.80	1.00	105.00
270.00	2.81	105.00
272.80	3.00	105.00
300.00	5.72	105.00
330.00	8.72	105.00
360.00	11.72	105.00
372.80	13.00	105.00
390.00	14.72	105.00
420.00	17.72	105.00
432.80	19.00	105.00
450.00	20.64	106.56
480.00	23.52	108.77
510.00	26.43	110.52
540.00	29.35	111.95
570.00	32.29	113.14
600.00	35.24	114.15
630.00	38.19	115.02
660.00	41.15	115.79
690.00	44.12	116.47
720.00	47.08	117.08
750.00	50.06	117.63
780.00	53.03	118.14
810.00	56.00	118.61
840.00	58.98	119.05
870.00	61.96	119.46
900.00	64.94	119.85
930.00	67.92	120.22
960.00	70.90	120.58
990.00	73.88	120.92
1,017.54	76.62	121.23
1,020.00	76.62	121.23
1,050.00	76.62	121.23
1,080.00	76.62	121.23
1,110.00	76.62	121.23
1,140.00	76.62	121.23
1,170.00	76.62	121.23
1,200.00	76.62	121.23
1,230.00	76.62	121.23
1,260.00	76.62	121.23
1,290.00	76.62	121.23
1,320.00	76.62	121.23
1,350.00	76.62	121.23
1,380.00	76.62	121.23
1,410.00	76.62	121.23
1,440.00	76.62	121.23
1,470.00	76.62	121.23
1,500.00	76.62	121.23
1,530.00	76.62	121.23
1,560.00	76.62	121.23
1,590.00	76.62	121.23
1,620.00	76.62	121.23
1,650.00	76.62	121.23
1,680.00	76.62	121.23
1,694.07	76.62	121.23
1,710.00	76.62	121.23
1,740.00	76.62	121.23
1,770.00	76.62	121.23
1,800.00	76.62	121.23
1,830.00	76.62	121.23
1,860.00	76.62	121.23
1,890.00	76.62	121.23
1,920.00	76.62	121.23
1,950.00	76.62	121.23
1,980.00	76.62	121.23
2,010.00	76.62	121.23
2,040.00	76.62	121.23
2,070.00	76.62	121.23
2,100.00	76.62	121.23
2,130.00	76.62	121.23
2,160.00	76.62	121.23
2,190.00	76.62	121.23
2,220.00	76.62	121.23
2,250.00	76.62	121.23
2,280.00	76.62	121.23
2,310.00	76.62	121.23
2,340.00	76.62	121.23
2,370.00	76.62	121.23
2,400.00	76.62	121.23
2,430.00	76.62	121.23
2,460.00	76.62	121.23
2,490.00	76.62	121.23
2,520.00	76.62	121.23
2,550.00	76.62	121.23
2,580.00	76.62	121.23
2,610.00	76.62	121.23
2,640.00	76.62	121.23
2,670.00	76.62	121.23
2,700.00	76.62	121.23
2,730.00	76.62	121.23
2,760.00	76.62	121.23
2,764.03	76.62	121.23
2,790.00	75.32	121.23
2,820.00	73.82	121.23
2,850.00	72.32	121.23
2,880.00	70.82	121.23
2,910.00	69.32	121.22
2,936.68	67.99	121.22
2,940.00	67.82	121.22
2,970.00	66.32	121.22
3,000.00	64.82	121.22
3,030.00	63.32	121.22
3,033.43	63.15	121.22
3,060.00	61.82	121.22
3,090.00	60.32	121.22
3,096.46	60.00	121.22
3,120.00	60.00	121.22
3,150.00	60.00	121.22
3,176.46	60.00	121.22
3,180.00	60.00	121.22
3,210.00	60.00	121.22
3,240.00	60.00	121.22
3,246.46	60.00	121.22
3,270.00	60.00	121.22
3,276.46	60.00	121.22
3,300.00	60.00	121.22
3,316.45	60.00	121.22
3,316.46	60.00	121.22
3,330.00	60.00	121.22
3,360.00	60.00	121.22
3,386.00	60.00	121.22

Table 5: Target Location of Well X

TARGET LOCATION	NORTH (m)	EAST (m)	TVD (m)
Platform	0.00	0.00	0.00
Target 1	-1236.99	2113.65	1333.30
Target 2	-1266.99	2168.65	1330.00
Target 3	-1291.99	2212.65	1365.00

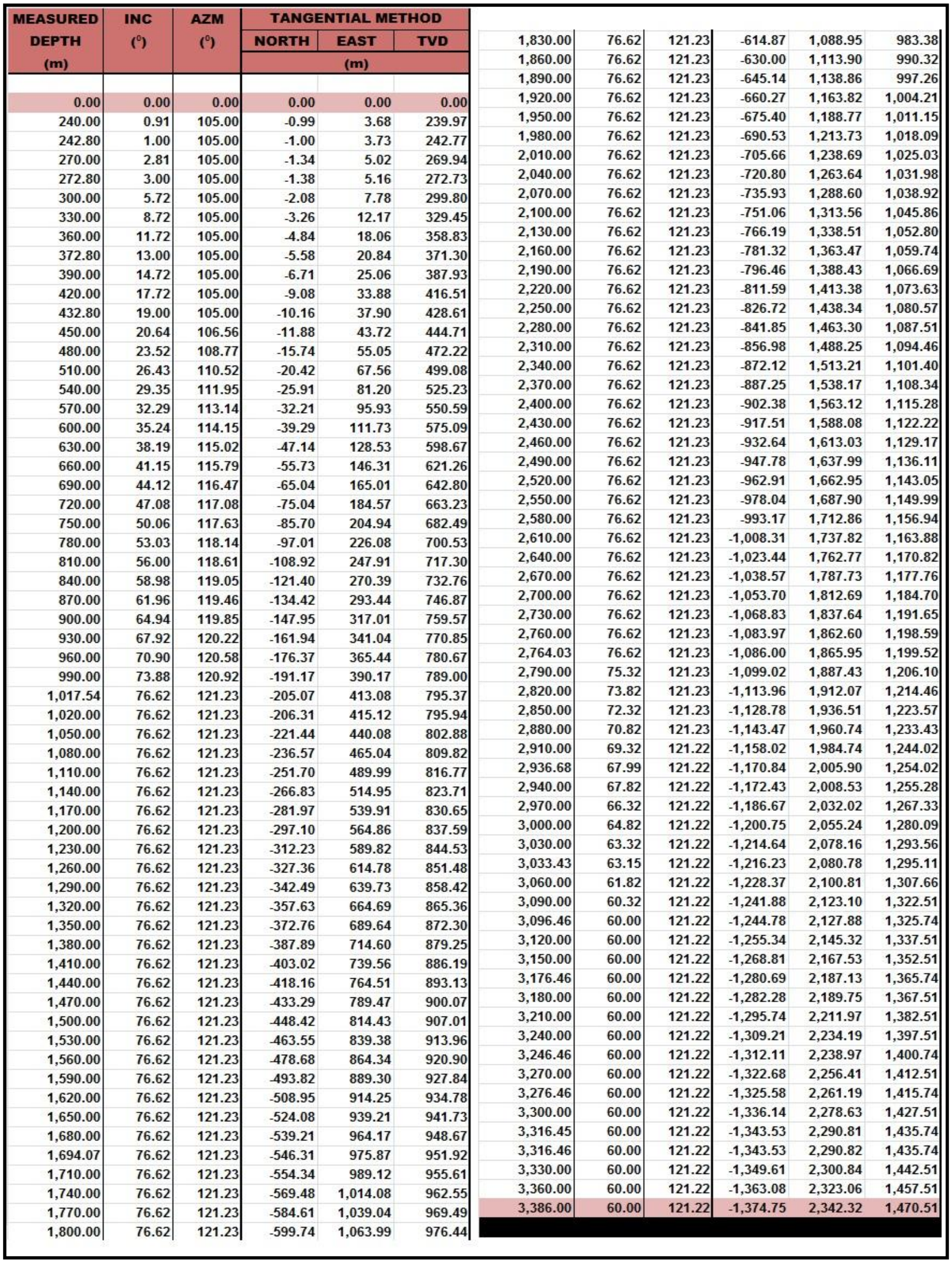
4.2 Surveying Calculation Result

In this project, there are five different surveying calculation methods used in determining the trajectory of the well. The first method used is tangential method.

a) Tangential Method

Figure 18 shows the wellbore trajectory of Well X based on tangential method. The final location of the wellbore is at -1374.75 m north, 2342.32 m east, and 1470.51 m TVD (Table 6). Based on this method, the trajectory of the well seems to be deviated quite far from all three targets as shown in Figure 18.

Table 6: Tangential Method for Well X



MEASURED DEPTH (m)	INC (°)	AZM (°)	TANGENTIAL METHOD		
			NORTH	EAST	TVD
			(m)		
0.00	0.00	0.00	0.00	0.00	0.00
240.00	0.91	105.00	-0.99	3.68	239.97
242.80	1.00	105.00	-1.00	3.73	242.77
270.00	2.81	105.00	-1.34	5.02	269.94
272.80	3.00	105.00	-1.38	5.16	272.73
300.00	5.72	105.00	-2.08	7.78	299.80
330.00	8.72	105.00	-3.26	12.17	329.45
360.00	11.72	105.00	-4.84	18.06	358.83
372.80	13.00	105.00	-5.58	20.84	371.30
390.00	14.72	105.00	-6.71	25.06	387.93
420.00	17.72	105.00	-9.08	33.88	416.51
432.80	19.00	105.00	-10.16	37.90	428.61
450.00	20.64	106.56	-11.88	43.72	444.71
480.00	23.52	108.77	-15.74	55.05	472.22
510.00	26.43	110.52	-20.42	67.56	499.08
540.00	29.35	111.95	-25.91	81.20	525.23
570.00	32.29	113.14	-32.21	95.93	550.59
600.00	35.24	114.15	-39.29	111.73	575.09
630.00	38.19	115.02	-47.14	128.53	598.67
660.00	41.15	115.79	-55.73	146.31	621.26
690.00	44.12	116.47	-65.04	165.01	642.80
720.00	47.08	117.08	-75.04	184.57	663.23
750.00	50.06	117.63	-85.70	204.94	682.49
780.00	53.03	118.14	-97.01	226.08	700.53
810.00	56.00	118.61	-108.92	247.91	717.30
840.00	58.98	119.05	-121.40	270.39	732.76
870.00	61.96	119.46	-134.42	293.44	746.87
900.00	64.94	119.85	-147.95	317.01	759.57
930.00	67.92	120.22	-161.94	341.04	770.85
960.00	70.90	120.58	-176.37	365.44	780.67
990.00	73.88	120.92	-191.17	390.17	789.00
1,017.54	76.62	121.23	-205.07	413.08	795.37
1,020.00	76.62	121.23	-206.31	415.12	795.94
1,050.00	76.62	121.23	-221.44	440.08	802.88
1,080.00	76.62	121.23	-236.57	465.04	809.82
1,110.00	76.62	121.23	-251.70	489.99	816.77
1,140.00	76.62	121.23	-266.83	514.95	823.71
1,170.00	76.62	121.23	-281.97	539.91	830.65
1,200.00	76.62	121.23	-297.10	564.86	837.59
1,230.00	76.62	121.23	-312.23	589.82	844.53
1,260.00	76.62	121.23	-327.36	614.78	851.48
1,290.00	76.62	121.23	-342.49	639.73	858.42
1,320.00	76.62	121.23	-357.63	664.69	865.36
1,350.00	76.62	121.23	-372.76	689.64	872.30
1,380.00	76.62	121.23	-387.89	714.60	879.25
1,410.00	76.62	121.23	-403.02	739.56	886.19
1,440.00	76.62	121.23	-418.16	764.51	893.13
1,470.00	76.62	121.23	-433.29	789.47	900.07
1,500.00	76.62	121.23	-448.42	814.43	907.01
1,530.00	76.62	121.23	-463.55	839.38	913.96
1,560.00	76.62	121.23	-478.68	864.34	920.90
1,590.00	76.62	121.23	-493.82	889.30	927.84
1,620.00	76.62	121.23	-508.95	914.25	934.78
1,650.00	76.62	121.23	-524.08	939.21	941.73
1,680.00	76.62	121.23	-539.21	964.17	948.67
1,694.07	76.62	121.23	-546.31	975.87	951.92
1,710.00	76.62	121.23	-554.34	989.12	955.61
1,740.00	76.62	121.23	-569.48	1,014.08	962.55
1,770.00	76.62	121.23	-584.61	1,039.04	969.49
1,800.00	76.62	121.23	-599.74	1,063.99	976.44
1,830.00	76.62	121.23	-614.87	1,088.95	983.38
1,860.00	76.62	121.23	-630.00	1,113.90	990.32
1,890.00	76.62	121.23	-645.14	1,138.86	997.26
1,920.00	76.62	121.23	-660.27	1,163.82	1,004.21
1,950.00	76.62	121.23	-675.40	1,188.77	1,011.15
1,980.00	76.62	121.23	-690.53	1,213.73	1,018.09
2,010.00	76.62	121.23	-705.66	1,238.69	1,025.03
2,040.00	76.62	121.23	-720.80	1,263.64	1,031.98
2,070.00	76.62	121.23	-735.93	1,288.60	1,038.92
2,100.00	76.62	121.23	-751.06	1,313.56	1,045.86
2,130.00	76.62	121.23	-766.19	1,338.51	1,052.80
2,160.00	76.62	121.23	-781.32	1,363.47	1,059.74
2,190.00	76.62	121.23	-796.46	1,388.43	1,066.69
2,220.00	76.62	121.23	-811.59	1,413.38	1,073.63
2,250.00	76.62	121.23	-826.72	1,438.34	1,080.57
2,280.00	76.62	121.23	-841.85	1,463.30	1,087.51
2,310.00	76.62	121.23	-856.98	1,488.25	1,094.46
2,340.00	76.62	121.23	-872.12	1,513.21	1,101.40
2,370.00	76.62	121.23	-887.25	1,538.17	1,108.34
2,400.00	76.62	121.23	-902.38	1,563.12	1,115.28
2,430.00	76.62	121.23	-917.51	1,588.08	1,122.22
2,460.00	76.62	121.23	-932.64	1,613.03	1,129.17
2,490.00	76.62	121.23	-947.78	1,637.99	1,136.11
2,520.00	76.62	121.23	-962.91	1,662.95	1,143.05
2,550.00	76.62	121.23	-978.04	1,687.90	1,149.99
2,580.00	76.62	121.23	-993.17	1,712.86	1,156.94
2,610.00	76.62	121.23	-1,008.31	1,737.82	1,163.88
2,640.00	76.62	121.23	-1,023.44	1,762.77	1,170.82
2,670.00	76.62	121.23	-1,038.57	1,787.73	1,177.76
2,700.00	76.62	121.23	-1,053.70	1,812.69	1,184.70
2,730.00	76.62	121.23	-1,068.83	1,837.64	1,191.65
2,760.00	76.62	121.23	-1,083.97	1,862.60	1,198.59
2,764.03	76.62	121.23	-1,086.00	1,865.95	1,199.52
2,790.00	75.32	121.23	-1,099.02	1,887.43	1,206.10
2,820.00	73.82	121.23	-1,113.96	1,912.07	1,214.46
2,850.00	72.32	121.23	-1,128.78	1,936.51	1,223.57
2,880.00	70.82	121.23	-1,143.47	1,960.74	1,233.43
2,910.00	69.32	121.22	-1,158.02	1,984.74	1,244.02
2,936.68	67.99	121.22	-1,170.84	2,005.90	1,254.02
2,940.00	67.82	121.22	-1,172.43	2,008.53	1,255.28
2,970.00	66.32	121.22	-1,186.67	2,032.02	1,267.33
3,000.00	64.82	121.22	-1,200.75	2,055.24	1,280.09
3,030.00	63.32	121.22	-1,214.64	2,078.16	1,293.56
3,033.43	63.15	121.22	-1,216.23	2,080.78	1,295.11
3,060.00	61.82	121.22	-1,228.37	2,100.81	1,307.66
3,090.00	60.32	121.22	-1,241.88	2,123.10	1,322.51
3,096.46	60.00	121.22	-1,244.78	2,127.88	1,325.74
3,120.00	60.00	121.22	-1,255.34	2,145.32	1,337.51
3,150.00	60.00	121.22	-1,268.81	2,167.53	1,352.51
3,176.46	60.00	121.22	-1,280.69	2,187.13	1,365.74
3,180.00	60.00	121.22	-1,282.28	2,189.75	1,367.51
3,210.00	60.00	121.22	-1,295.74	2,211.97	1,382.51
3,240.00	60.00	121.22	-1,309.21	2,234.19	1,397.51
3,246.46	60.00	121.22	-1,312.11	2,238.97	1,400.74
3,270.00	60.00	121.22	-1,322.68	2,256.41	1,412.51
3,276.46	60.00	121.22	-1,325.58	2,261.19	1,415.74
3,300.00	60.00	121.22	-1,336.14	2,278.63	1,427.51
3,316.45	60.00	121.22	-1,343.53	2,290.81	1,435.74
3,316.46	60.00	121.22	-1,343.53	2,290.82	1,435.74
3,330.00	60.00	121.22	-1,349.61	2,300.84	1,442.51
3,360.00	60.00	121.22	-1,363.08	2,323.06	1,457.51
3,386.00	60.00	121.22	-1,374.75	2,342.32	1,470.51

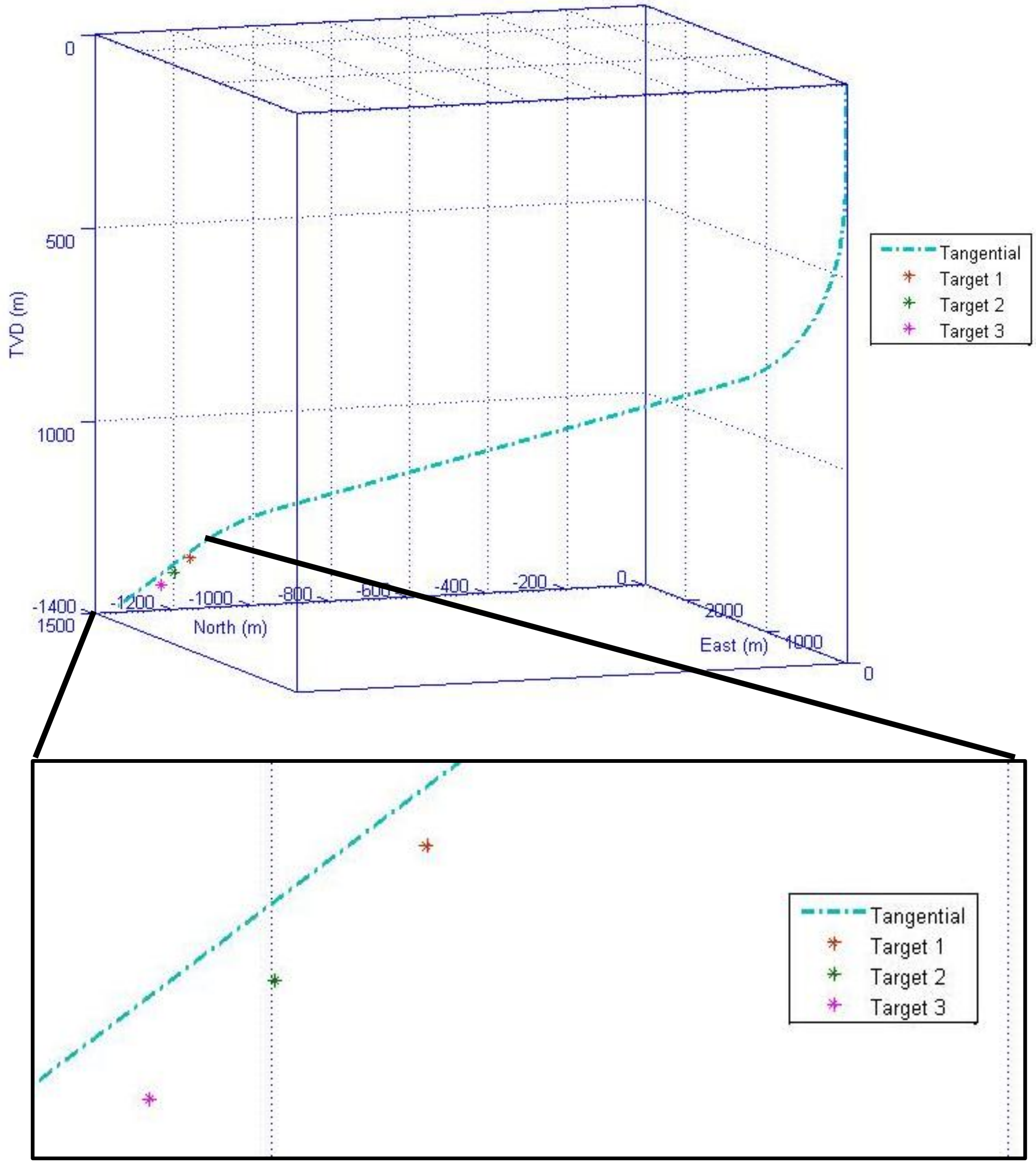


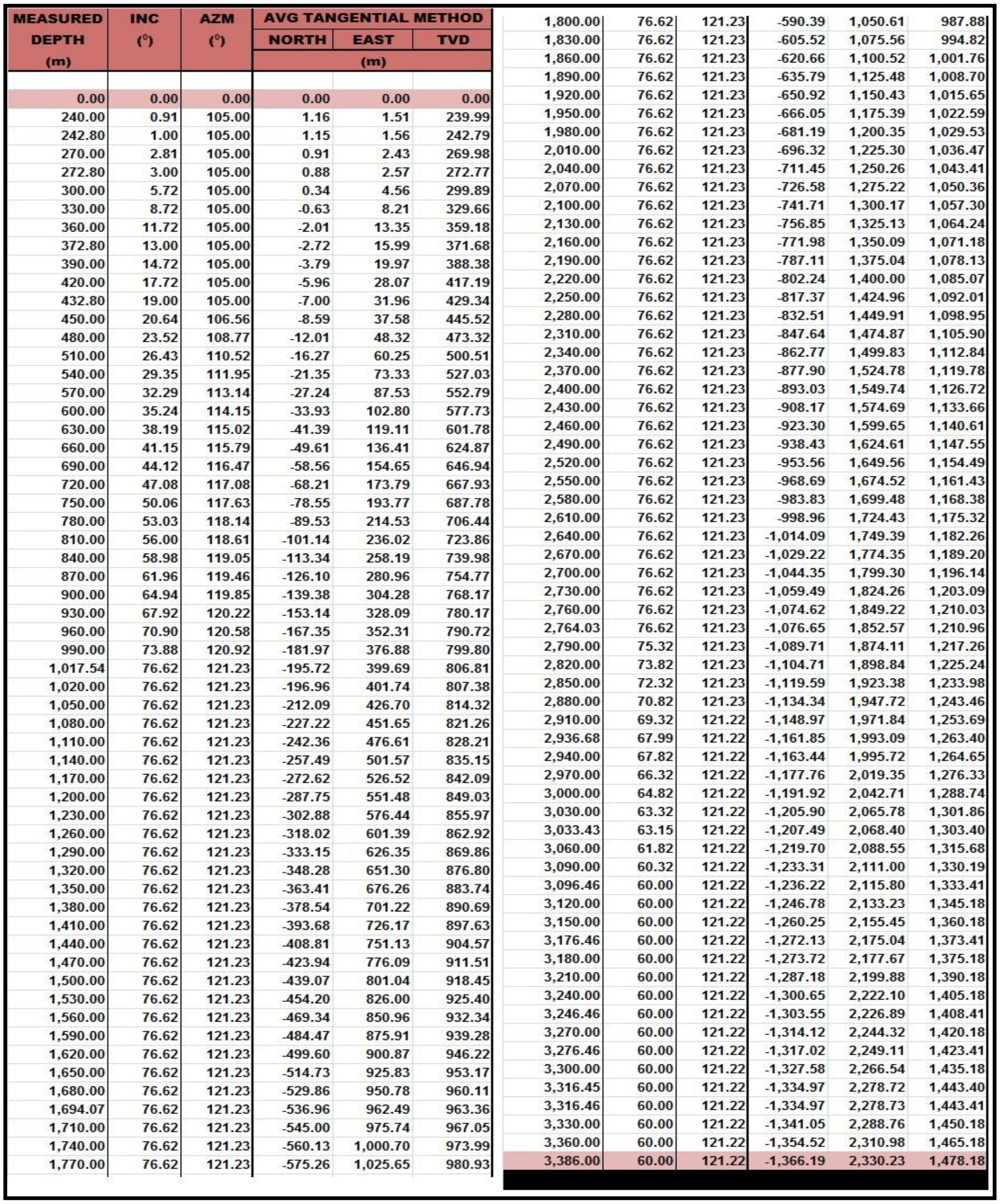
Figure 18: Graphical Trajectory for Well X - Tangential Method

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.

b) Average Tangential Method

Figure 19 shows the wellbore trajectory of Well X based on average tangential method. The final location of the wellbore is at -1366.19 m north, 2330.23 m east, and 1478.18 m TVD (Table 7). This method seems to have a better trajectory and closer to the targets compared to the tangential method.

Table 7: Average Tangential Method for Well X



MEASURED DEPTH (m)	INC (°)	AZM (°)	AVG TANGENTIAL METHOD		
			NORTH	EAST	TVD
			(m)		
0.00	0.00	0.00	0.00	0.00	0.00
240.00	0.91	105.00	1.16	1.51	239.99
242.80	1.00	105.00	1.15	1.56	242.79
270.00	2.81	105.00	0.91	2.43	269.98
272.80	3.00	105.00	0.88	2.57	272.77
300.00	5.72	105.00	0.34	4.56	299.89
330.00	8.72	105.00	-0.63	8.21	329.66
360.00	11.72	105.00	-2.01	13.35	359.18
372.80	13.00	105.00	-2.72	15.99	371.68
390.00	14.72	105.00	-3.79	19.97	388.38
420.00	17.72	105.00	-5.96	28.07	417.19
432.80	19.00	105.00	-7.00	31.96	429.34
450.00	20.64	106.56	-8.59	37.58	445.52
480.00	23.52	108.77	-12.01	48.32	473.32
510.00	26.43	110.52	-16.27	60.25	500.51
540.00	29.35	111.95	-21.35	73.33	527.03
570.00	32.29	113.14	-27.24	87.53	552.79
600.00	35.24	114.15	-33.93	102.80	577.73
630.00	38.19	115.02	-41.39	119.11	601.78
660.00	41.15	115.79	-49.61	136.41	624.87
690.00	44.12	116.47	-58.56	154.65	646.94
720.00	47.08	117.08	-68.21	173.79	667.93
750.00	50.06	117.63	-78.55	193.77	687.78
780.00	53.03	118.14	-89.53	214.53	706.44
810.00	56.00	118.61	-101.14	236.02	723.86
840.00	58.98	119.05	-113.34	258.19	739.98
870.00	61.96	119.46	-126.10	280.96	754.77
900.00	64.94	119.85	-139.38	304.28	768.17
930.00	67.92	120.22	-153.14	328.09	780.17
960.00	70.90	120.58	-167.35	352.31	790.72
990.00	73.88	120.92	-181.97	376.88	799.80
1,017.54	76.62	121.23	-195.72	399.69	806.81
1,020.00	76.62	121.23	-196.96	401.74	807.38
1,050.00	76.62	121.23	-212.09	426.70	814.32
1,080.00	76.62	121.23	-227.22	451.65	821.26
1,110.00	76.62	121.23	-242.36	476.61	828.21
1,140.00	76.62	121.23	-257.49	501.57	835.15
1,170.00	76.62	121.23	-272.62	526.52	842.09
1,200.00	76.62	121.23	-287.75	551.48	849.03
1,230.00	76.62	121.23	-302.88	576.44	855.97
1,260.00	76.62	121.23	-318.02	601.39	862.92
1,290.00	76.62	121.23	-333.15	626.35	869.86
1,320.00	76.62	121.23	-348.28	651.30	876.80
1,350.00	76.62	121.23	-363.41	676.26	883.74
1,380.00	76.62	121.23	-378.54	701.22	890.69
1,410.00	76.62	121.23	-393.68	726.17	897.63
1,440.00	76.62	121.23	-408.81	751.13	904.57
1,470.00	76.62	121.23	-423.94	776.09	911.51
1,500.00	76.62	121.23	-439.07	801.04	918.45
1,530.00	76.62	121.23	-454.20	826.00	925.40
1,560.00	76.62	121.23	-469.34	850.96	932.34
1,590.00	76.62	121.23	-484.47	875.91	939.28
1,620.00	76.62	121.23	-499.60	900.87	946.22
1,650.00	76.62	121.23	-514.73	925.83	953.17
1,680.00	76.62	121.23	-529.86	950.78	960.11
1,694.07	76.62	121.23	-536.96	962.49	963.36
1,710.00	76.62	121.23	-545.00	975.74	967.05
1,740.00	76.62	121.23	-560.13	1,000.70	973.99
1,770.00	76.62	121.23	-575.26	1,025.65	980.93
1,800.00	76.62	121.23	-590.39	1,050.61	987.88
1,830.00	76.62	121.23	-605.52	1,075.56	994.82
1,860.00	76.62	121.23	-620.66	1,100.52	1,001.76
1,890.00	76.62	121.23	-635.79	1,125.48	1,008.70
1,920.00	76.62	121.23	-650.92	1,150.43	1,015.65
1,950.00	76.62	121.23	-666.05	1,175.39	1,022.59
1,980.00	76.62	121.23	-681.19	1,200.35	1,029.53
2,010.00	76.62	121.23	-696.32	1,225.30	1,036.47
2,040.00	76.62	121.23	-711.45	1,250.26	1,043.41
2,070.00	76.62	121.23	-726.58	1,275.22	1,050.36
2,100.00	76.62	121.23	-741.71	1,300.17	1,057.30
2,130.00	76.62	121.23	-756.85	1,325.13	1,064.24
2,160.00	76.62	121.23	-771.98	1,350.09	1,071.18
2,190.00	76.62	121.23	-787.11	1,375.04	1,078.13
2,220.00	76.62	121.23	-802.24	1,400.00	1,085.07
2,250.00	76.62	121.23	-817.37	1,424.96	1,092.01
2,280.00	76.62	121.23	-832.51	1,449.91	1,098.95
2,310.00	76.62	121.23	-847.64	1,474.87	1,105.90
2,340.00	76.62	121.23	-862.77	1,499.83	1,112.84
2,370.00	76.62	121.23	-877.90	1,524.78	1,119.78
2,400.00	76.62	121.23	-893.03	1,549.74	1,126.72
2,430.00	76.62	121.23	-908.17	1,574.69	1,133.66
2,460.00	76.62	121.23	-923.30	1,599.65	1,140.61
2,490.00	76.62	121.23	-938.43	1,624.61	1,147.55
2,520.00	76.62	121.23	-953.56	1,649.56	1,154.49
2,550.00	76.62	121.23	-968.69	1,674.52	1,161.43
2,580.00	76.62	121.23	-983.83	1,699.48	1,168.38
2,610.00	76.62	121.23	-998.96	1,724.43	1,175.32
2,640.00	76.62	121.23	-1,014.09	1,749.39	1,182.26
2,670.00	76.62	121.23	-1,029.22	1,774.35	1,189.20
2,700.00	76.62	121.23	-1,044.35	1,799.30	1,196.14
2,730.00	76.62	121.23	-1,059.49	1,824.26	1,203.09
2,760.00	76.62	121.23	-1,074.62	1,849.22	1,210.03
2,764.03	76.62	121.23	-1,076.65	1,852.57	1,210.96
2,790.00	75.32	121.23	-1,089.71	1,874.11	1,217.26
2,820.00	73.82	121.23	-1,104.71	1,898.84	1,225.24
2,850.00	72.32	121.23	-1,119.59	1,923.38	1,233.98
2,880.00	70.82	121.23	-1,134.34	1,947.72	1,243.46
2,910.00	69.32	121.22	-1,148.97	1,971.84	1,253.69
2,936.68	67.99	121.22	-1,161.85	1,993.09	1,263.40
2,940.00	67.82	121.22	-1,163.44	1,995.72	1,264.65
2,970.00	66.32	121.22	-1,177.76	2,019.35	1,276.33
3,000.00	64.82	121.22	-1,191.92	2,042.71	1,288.74
3,030.00	63.32	121.22	-1,205.90	2,065.78	1,301.86
3,033.43	63.15	121.22	-1,207.49	2,068.40	1,303.40
3,060.00	61.82	121.22	-1,219.70	2,088.55	1,315.68
3,090.00	60.32	121.22	-1,233.31	2,111.00	1,330.19
3,096.46	60.00	121.22	-1,236.22	2,115.80	1,333.41
3,120.00	60.00	121.22	-1,246.78	2,133.23	1,345.18
3,150.00	60.00	121.22	-1,260.25	2,155.45	1,360.18
3,176.46	60.00	121.22	-1,272.13	2,175.04	1,373.41
3,180.00	60.00	121.22	-1,273.72	2,177.67	1,375.18
3,210.00	60.00	121.22	-1,287.18	2,199.88	1,390.18
3,240.00	60.00	121.22	-1,300.65	2,222.10	1,405.18
3,246.46	60.00	121.22	-1,303.55	2,226.89	1,408.41
3,270.00	60.00	121.22	-1,314.12	2,244.32	1,420.18
3,276.46	60.00	121.22	-1,317.02	2,249.11	1,423.41
3,300.00	60.00	121.22	-1,327.58	2,266.54	1,435.18
3,316.45	60.00	121.22	-1,334.97	2,278.72	1,443.40
3,316.46	60.00	121.22	-1,334.97	2,278.73	1,443.41
3,330.00	60.00	121.22	-1,341.05	2,288.76	1,450.18
3,360.00	60.00	121.22	-1,354.52	2,310.98	1,465.18
3,386.00	60.00	121.22	-1,366.19	2,330.23	1,478.18

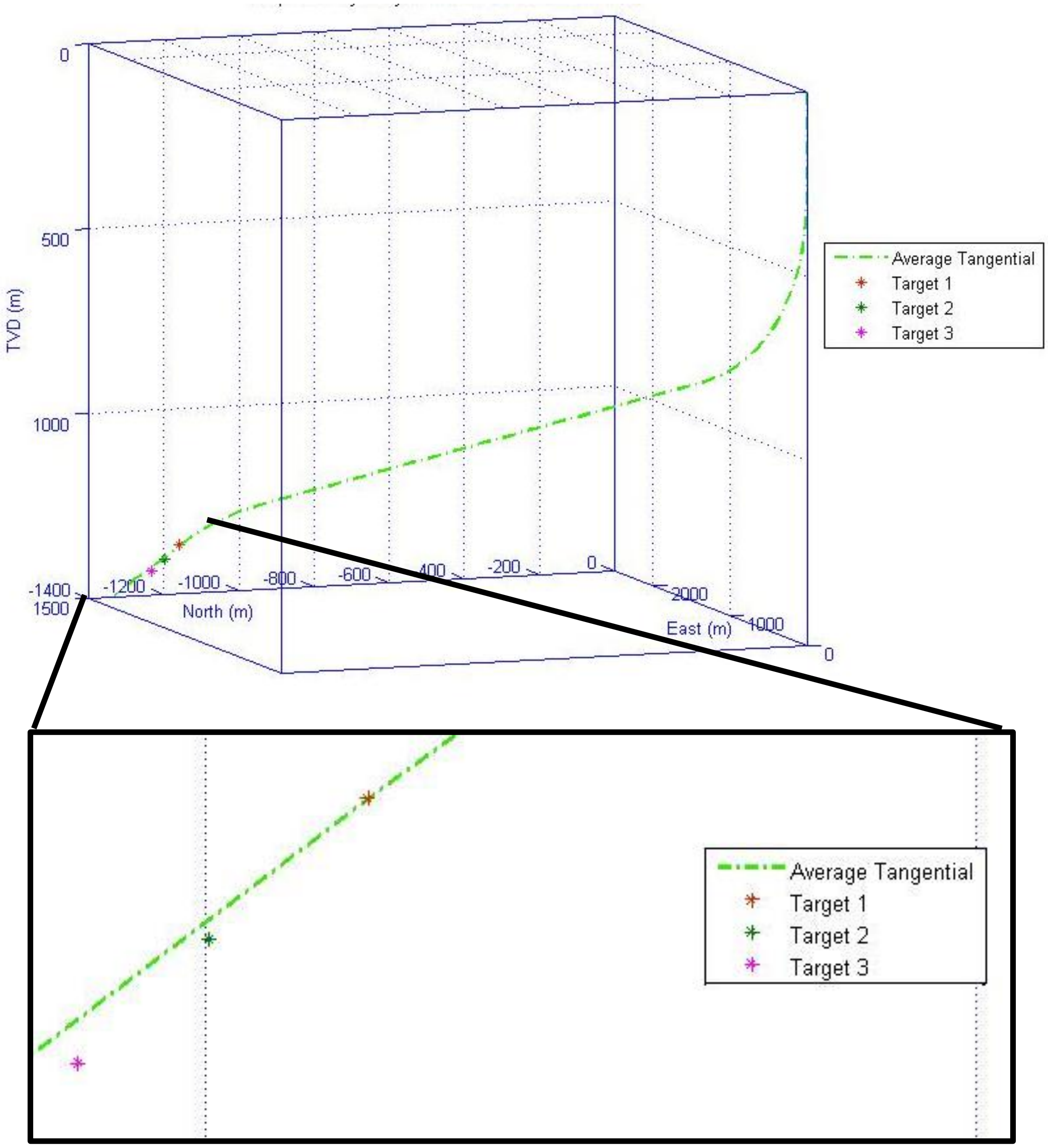


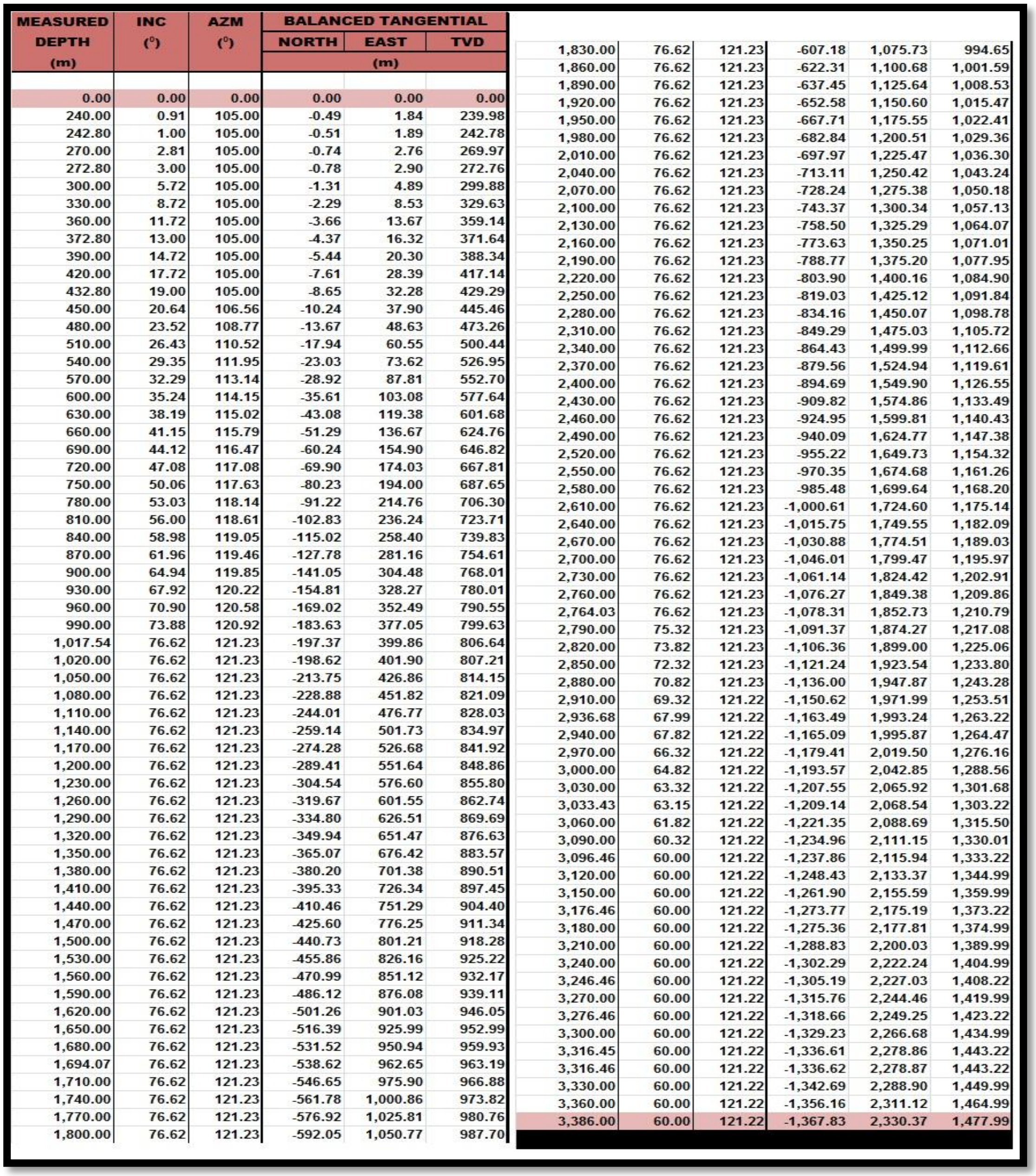
Figure 19: Graphical Trajectory for Well X - Average Tangential Method

According to Figure 19, one of the target 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.

c) Balanced Tangential Method

Figure 20 shows the wellbore trajectory of Well X based on balanced tangential method. The final location of the wellbore is at -1367.83 m north, 2330.37 m east, and 1477.99 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 targets.

Table 8: Balance Tangential Method for Well X



MEASURED DEPTH (m)	INC (°)	AZM (°)	BALANCED TANGENTIAL		
			NORTH	EAST	TVD
			(m)		
0.00	0.00	0.00	0.00	0.00	0.00
240.00	0.91	105.00	-0.49	1.84	239.98
242.80	1.00	105.00	-0.51	1.89	242.78
270.00	2.81	105.00	-0.74	2.76	269.97
272.80	3.00	105.00	-0.78	2.90	272.76
300.00	5.72	105.00	-1.31	4.89	299.88
330.00	8.72	105.00	-2.29	8.53	329.63
360.00	11.72	105.00	-3.66	13.67	359.14
372.80	13.00	105.00	-4.37	16.32	371.64
390.00	14.72	105.00	-5.44	20.30	388.34
420.00	17.72	105.00	-7.61	28.39	417.14
432.80	19.00	105.00	-8.65	32.28	429.29
450.00	20.64	106.56	-10.24	37.90	445.46
480.00	23.52	108.77	-13.67	48.63	473.26
510.00	26.43	110.52	-17.94	60.55	500.44
540.00	29.35	111.95	-23.03	73.62	526.95
570.00	32.29	113.14	-28.92	87.81	552.70
600.00	35.24	114.15	-35.61	103.08	577.64
630.00	38.19	115.02	-43.08	119.38	601.68
660.00	41.15	115.79	-51.29	136.67	624.76
690.00	44.12	116.47	-60.24	154.90	646.82
720.00	47.08	117.08	-69.90	174.03	667.81
750.00	50.06	117.63	-80.23	194.00	687.65
780.00	53.03	118.14	-91.22	214.76	706.30
810.00	56.00	118.61	-102.83	236.24	723.71
840.00	58.98	119.05	-115.02	258.40	739.83
870.00	61.96	119.46	-127.78	281.16	754.61
900.00	64.94	119.85	-141.05	304.48	768.01
930.00	67.92	120.22	-154.81	328.27	780.01
960.00	70.90	120.58	-169.02	352.49	790.55
990.00	73.88	120.92	-183.63	377.05	799.63
1,017.54	76.62	121.23	-197.37	399.86	806.64
1,020.00	76.62	121.23	-198.62	401.90	807.21
1,050.00	76.62	121.23	-213.75	426.86	814.15
1,080.00	76.62	121.23	-228.88	451.82	821.09
1,110.00	76.62	121.23	-244.01	476.77	828.03
1,140.00	76.62	121.23	-259.14	501.73	834.97
1,170.00	76.62	121.23	-274.28	526.68	841.92
1,200.00	76.62	121.23	-289.41	551.64	848.86
1,230.00	76.62	121.23	-304.54	576.60	855.80
1,260.00	76.62	121.23	-319.67	601.55	862.74
1,290.00	76.62	121.23	-334.80	626.51	869.69
1,320.00	76.62	121.23	-349.94	651.47	876.63
1,350.00	76.62	121.23	-365.07	676.42	883.57
1,380.00	76.62	121.23	-380.20	701.38	890.51
1,410.00	76.62	121.23	-395.33	726.34	897.45
1,440.00	76.62	121.23	-410.46	751.29	904.40
1,470.00	76.62	121.23	-425.60	776.25	911.34
1,500.00	76.62	121.23	-440.73	801.21	918.28
1,530.00	76.62	121.23	-455.86	826.16	925.22
1,560.00	76.62	121.23	-470.99	851.12	932.17
1,590.00	76.62	121.23	-486.12	876.08	939.11
1,620.00	76.62	121.23	-501.26	901.03	946.05
1,650.00	76.62	121.23	-516.39	925.99	952.99
1,680.00	76.62	121.23	-531.52	950.94	959.93
1,694.07	76.62	121.23	-538.62	962.65	963.19
1,710.00	76.62	121.23	-546.65	975.90	966.88
1,740.00	76.62	121.23	-561.78	1,000.86	973.82
1,770.00	76.62	121.23	-576.92	1,025.81	980.76
1,800.00	76.62	121.23	-592.05	1,050.77	987.70
1,830.00	76.62	121.23	-607.18	1,075.73	994.65
1,860.00	76.62	121.23	-622.31	1,100.68	1,001.59
1,890.00	76.62	121.23	-637.45	1,125.64	1,008.53
1,920.00	76.62	121.23	-652.58	1,150.60	1,015.47
1,950.00	76.62	121.23	-667.71	1,175.55	1,022.41
1,980.00	76.62	121.23	-682.84	1,200.51	1,029.36
2,010.00	76.62	121.23	-697.97	1,225.47	1,036.30
2,040.00	76.62	121.23	-713.11	1,250.42	1,043.24
2,070.00	76.62	121.23	-728.24	1,275.38	1,050.18
2,100.00	76.62	121.23	-743.37	1,300.34	1,057.13
2,130.00	76.62	121.23	-758.50	1,325.29	1,064.07
2,160.00	76.62	121.23	-773.63	1,350.25	1,071.01
2,190.00	76.62	121.23	-788.77	1,375.20	1,077.95
2,220.00	76.62	121.23	-803.90	1,400.16	1,084.90
2,250.00	76.62	121.23	-819.03	1,425.12	1,091.84
2,280.00	76.62	121.23	-834.16	1,450.07	1,098.78
2,310.00	76.62	121.23	-849.29	1,475.03	1,105.72
2,340.00	76.62	121.23	-864.43	1,499.99	1,112.66
2,370.00	76.62	121.23	-879.56	1,524.94	1,119.61
2,400.00	76.62	121.23	-894.69	1,549.90	1,126.55
2,430.00	76.62	121.23	-909.82	1,574.86	1,133.49
2,460.00	76.62	121.23	-924.95	1,599.81	1,140.43
2,490.00	76.62	121.23	-940.09	1,624.77	1,147.38
2,520.00	76.62	121.23	-955.22	1,649.73	1,154.32
2,550.00	76.62	121.23	-970.35	1,674.68	1,161.26
2,580.00	76.62	121.23	-985.48	1,699.64	1,168.20
2,610.00	76.62	121.23	-1,000.61	1,724.60	1,175.14
2,640.00	76.62	121.23	-1,015.75	1,749.55	1,182.09
2,670.00	76.62	121.23	-1,030.88	1,774.51	1,189.03
2,700.00	76.62	121.23	-1,046.01	1,799.47	1,195.97
2,730.00	76.62	121.23	-1,061.14	1,824.42	1,202.91
2,760.00	76.62	121.23	-1,076.27	1,849.38	1,209.86
2,764.03	76.62	121.23	-1,078.31	1,852.73	1,210.79
2,790.00	75.32	121.23	-1,091.37	1,874.27	1,217.08
2,820.00	73.82	121.23	-1,106.36	1,899.00	1,225.06
2,850.00	72.32	121.23	-1,121.24	1,923.54	1,233.80
2,880.00	70.82	121.23	-1,136.00	1,947.87	1,243.28
2,910.00	69.32	121.22	-1,150.62	1,971.99	1,253.51
2,936.68	67.99	121.22	-1,163.49	1,993.24	1,263.22
2,940.00	67.82	121.22	-1,165.09	1,995.87	1,264.47
2,970.00	66.32	121.22	-1,179.41	2,019.50	1,276.16
3,000.00	64.82	121.22	-1,193.57	2,042.85	1,288.56
3,030.00	63.32	121.22	-1,207.55	2,065.92	1,301.68
3,033.43	63.15	121.22	-1,209.14	2,068.54	1,303.22
3,060.00	61.82	121.22	-1,221.35	2,088.69	1,315.50
3,090.00	60.32	121.22	-1,234.96	2,111.15	1,330.01
3,096.46	60.00	121.22	-1,237.86	2,115.94	1,333.22
3,120.00	60.00	121.22	-1,248.43	2,133.37	1,344.99
3,150.00	60.00	121.22	-1,261.90	2,155.59	1,359.99
3,176.46	60.00	121.22	-1,273.77	2,175.19	1,373.22
3,180.00	60.00	121.22	-1,275.36	2,177.81	1,374.99
3,210.00	60.00	121.22	-1,288.83	2,200.03	1,389.99
3,240.00	60.00	121.22	-1,302.29	2,222.24	1,404.99
3,246.46	60.00	121.22	-1,305.19	2,227.03	1,408.22
3,270.00	60.00	121.22	-1,315.76	2,244.46	1,419.99
3,276.46	60.00	121.22	-1,318.66	2,249.25	1,423.22
3,300.00	60.00	121.22	-1,329.23	2,266.68	1,434.99
3,316.45	60.00	121.22	-1,336.61	2,278.86	1,443.22
3,316.46	60.00	121.22	-1,336.62	2,278.87	1,443.22
3,330.00	60.00	121.22	-1,342.69	2,288.90	1,449.99
3,360.00	60.00	121.22	-1,356.16	2,311.12	1,464.99
3,386.00	60.00	121.22	-1,367.83	2,330.37	1,477.99

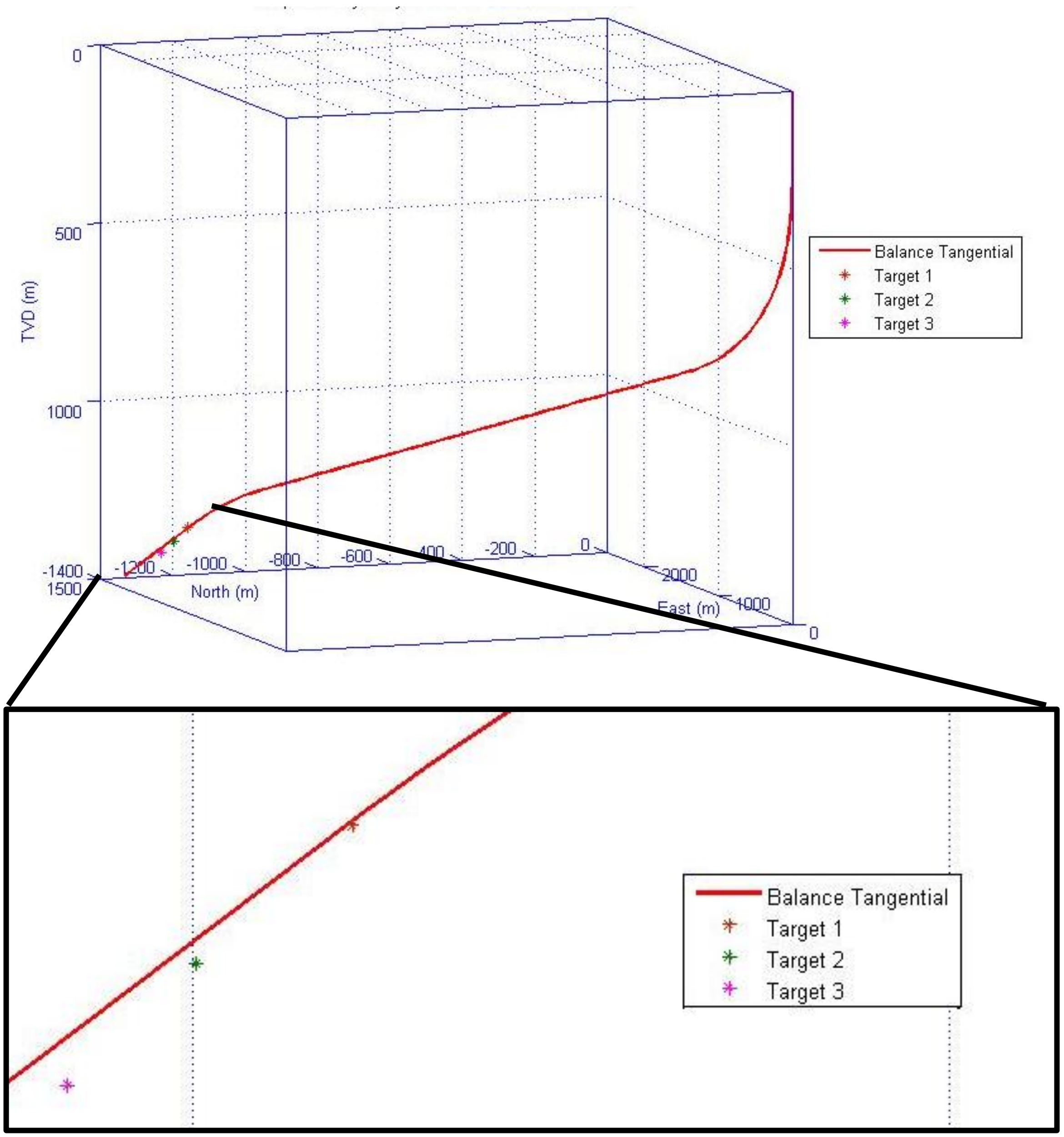


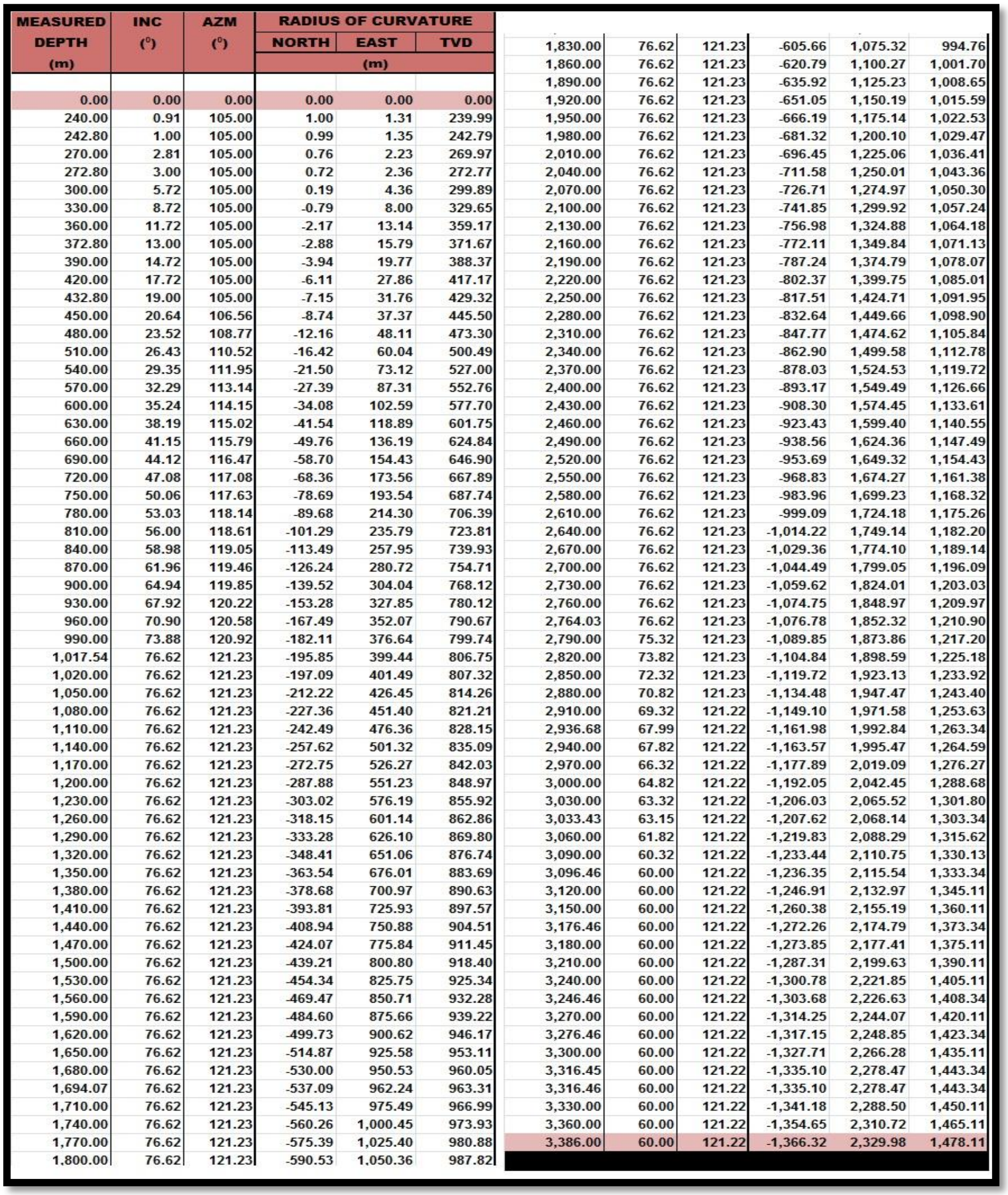
Figure 20: Graphical Trajectory for Well X - Balanced Tangential Method

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

d) Radius of Curvature Method

Figure 21 shows the wellbore trajectory of Well X based on radius of curvature method. The final location of the wellbore is at -1366.32 m north, 2329.98 m east, and 1478.11 m TVD (Table 9). This method seems to produce a trajectory that closes to the targets.

Table 9: Radius of Curvature Method for Well X



MEASURED DEPTH (m)	INC (°)	AZM (°)	RADIUS OF CURVATURE		
			NORTH	EAST	TVD
			(m)		
0.00	0.00	0.00	0.00	0.00	0.00
240.00	0.91	105.00	1.00	1.31	239.99
242.80	1.00	105.00	0.99	1.35	242.79
270.00	2.81	105.00	0.76	2.23	269.97
272.80	3.00	105.00	0.72	2.36	272.77
300.00	5.72	105.00	0.19	4.36	299.89
330.00	8.72	105.00	-0.79	8.00	329.65
360.00	11.72	105.00	-2.17	13.14	359.17
372.80	13.00	105.00	-2.88	15.79	371.67
390.00	14.72	105.00	-3.94	19.77	388.37
420.00	17.72	105.00	-6.11	27.86	417.17
432.80	19.00	105.00	-7.15	31.76	429.32
450.00	20.64	106.56	-8.74	37.37	445.50
480.00	23.52	108.77	-12.16	48.11	473.30
510.00	26.43	110.52	-16.42	60.04	500.49
540.00	29.35	111.95	-21.50	73.12	527.00
570.00	32.29	113.14	-27.39	87.31	552.76
600.00	35.24	114.15	-34.08	102.59	577.70
630.00	38.19	115.02	-41.54	118.89	601.75
660.00	41.15	115.79	-49.76	136.19	624.84
690.00	44.12	116.47	-58.70	154.43	646.90
720.00	47.08	117.08	-68.36	173.56	667.89
750.00	50.06	117.63	-78.69	193.54	687.74
780.00	53.03	118.14	-89.68	214.30	706.39
810.00	56.00	118.61	-101.29	235.79	723.81
840.00	58.98	119.05	-113.49	257.95	739.93
870.00	61.96	119.46	-126.24	280.72	754.71
900.00	64.94	119.85	-139.52	304.04	768.12
930.00	67.92	120.22	-153.28	327.85	780.12
960.00	70.90	120.58	-167.49	352.07	790.67
990.00	73.88	120.92	-182.11	376.64	799.74
1,017.54	76.62	121.23	-195.85	399.44	806.75
1,020.00	76.62	121.23	-197.09	401.49	807.32
1,050.00	76.62	121.23	-212.22	426.45	814.26
1,080.00	76.62	121.23	-227.36	451.40	821.21
1,110.00	76.62	121.23	-242.49	476.36	828.15
1,140.00	76.62	121.23	-257.62	501.32	835.09
1,170.00	76.62	121.23	-272.75	526.27	842.03
1,200.00	76.62	121.23	-287.88	551.23	848.97
1,230.00	76.62	121.23	-303.02	576.19	855.92
1,260.00	76.62	121.23	-318.15	601.14	862.86
1,290.00	76.62	121.23	-333.28	626.10	869.80
1,320.00	76.62	121.23	-348.41	651.06	876.74
1,350.00	76.62	121.23	-363.54	676.01	883.69
1,380.00	76.62	121.23	-378.68	700.97	890.63
1,410.00	76.62	121.23	-393.81	725.93	897.57
1,440.00	76.62	121.23	-408.94	750.88	904.51
1,470.00	76.62	121.23	-424.07	775.84	911.45
1,500.00	76.62	121.23	-439.21	800.80	918.40
1,530.00	76.62	121.23	-454.34	825.75	925.34
1,560.00	76.62	121.23	-469.47	850.71	932.28
1,590.00	76.62	121.23	-484.60	875.66	939.22
1,620.00	76.62	121.23	-499.73	900.62	946.17
1,650.00	76.62	121.23	-514.87	925.58	953.11
1,680.00	76.62	121.23	-530.00	950.53	960.05
1,694.07	76.62	121.23	-537.09	962.24	963.31
1,710.00	76.62	121.23	-545.13	975.49	966.99
1,740.00	76.62	121.23	-560.26	1,000.45	973.93
1,770.00	76.62	121.23	-575.39	1,025.40	980.88
1,800.00	76.62	121.23	-590.53	1,050.36	987.82
1,830.00	76.62	121.23	-605.66	1,075.32	994.76
1,860.00	76.62	121.23	-620.79	1,100.27	1,001.70
1,890.00	76.62	121.23	-635.92	1,125.23	1,008.65
1,920.00	76.62	121.23	-651.05	1,150.19	1,015.59
1,950.00	76.62	121.23	-666.19	1,175.14	1,022.53
1,980.00	76.62	121.23	-681.32	1,200.10	1,029.47
2,010.00	76.62	121.23	-696.45	1,225.06	1,036.41
2,040.00	76.62	121.23	-711.58	1,250.01	1,043.36
2,070.00	76.62	121.23	-726.71	1,274.97	1,050.30
2,100.00	76.62	121.23	-741.85	1,299.92	1,057.24
2,130.00	76.62	121.23	-756.98	1,324.88	1,064.18
2,160.00	76.62	121.23	-772.11	1,349.84	1,071.13
2,190.00	76.62	121.23	-787.24	1,374.79	1,078.07
2,220.00	76.62	121.23	-802.37	1,399.75	1,085.01
2,250.00	76.62	121.23	-817.51	1,424.71	1,091.95
2,280.00	76.62	121.23	-832.64	1,449.66	1,098.90
2,310.00	76.62	121.23	-847.77	1,474.62	1,105.84
2,340.00	76.62	121.23	-862.90	1,499.58	1,112.78
2,370.00	76.62	121.23	-878.03	1,524.53	1,119.72
2,400.00	76.62	121.23	-893.17	1,549.49	1,126.66
2,430.00	76.62	121.23	-908.30	1,574.45	1,133.61
2,460.00	76.62	121.23	-923.43	1,599.40	1,140.55
2,490.00	76.62	121.23	-938.56	1,624.36	1,147.49
2,520.00	76.62	121.23	-953.69	1,649.32	1,154.43
2,550.00	76.62	121.23	-968.83	1,674.27	1,161.38
2,580.00	76.62	121.23	-983.96	1,699.23	1,168.32
2,610.00	76.62	121.23	-999.09	1,724.18	1,175.26
2,640.00	76.62	121.23	-1,014.22	1,749.14	1,182.20
2,670.00	76.62	121.23	-1,029.36	1,774.10	1,189.14
2,700.00	76.62	121.23	-1,044.49	1,799.05	1,196.09
2,730.00	76.62	121.23	-1,059.62	1,824.01	1,203.03
2,760.00	76.62	121.23	-1,074.75	1,848.97	1,209.97
2,764.03	76.62	121.23	-1,076.78	1,852.32	1,210.90
2,790.00	75.32	121.23	-1,089.85	1,873.86	1,217.20
2,820.00	73.82	121.23	-1,104.84	1,898.59	1,225.18
2,850.00	72.32	121.23	-1,119.72	1,923.13	1,233.92
2,880.00	70.82	121.23	-1,134.48	1,947.47	1,243.40
2,910.00	69.32	121.22	-1,149.10	1,971.58	1,253.63
2,936.68	67.99	121.22	-1,161.98	1,992.84	1,263.34
2,940.00	67.82	121.22	-1,163.57	1,995.47	1,264.59
2,970.00	66.32	121.22	-1,177.89	2,019.09	1,276.27
3,000.00	64.82	121.22	-1,192.05	2,042.45	1,288.68
3,030.00	63.32	121.22	-1,206.03	2,065.52	1,301.80
3,033.43	63.15	121.22	-1,207.62	2,068.14	1,303.34
3,060.00	61.82	121.22	-1,219.83	2,088.29	1,315.62
3,090.00	60.32	121.22	-1,233.44	2,110.75	1,330.13
3,096.46	60.00	121.22	-1,236.35	2,115.54	1,333.34
3,120.00	60.00	121.22	-1,246.91	2,132.97	1,345.11
3,150.00	60.00	121.22	-1,260.38	2,155.19	1,360.11
3,176.46	60.00	121.22	-1,272.26	2,174.79	1,373.34
3,180.00	60.00	121.22	-1,273.85	2,177.41	1,375.11
3,210.00	60.00	121.22	-1,287.31	2,199.63	1,390.11
3,240.00	60.00	121.22	-1,300.78	2,221.85	1,405.11
3,246.46	60.00	121.22	-1,303.68	2,226.63	1,408.34
3,270.00	60.00	121.22	-1,314.25	2,244.07	1,420.11
3,276.46	60.00	121.22	-1,317.15	2,248.85	1,423.34
3,300.00	60.00	121.22	-1,327.71	2,266.28	1,435.11
3,316.45	60.00	121.22	-1,335.10	2,278.47	1,443.34
3,316.46	60.00	121.22	-1,335.10	2,278.47	1,443.34
3,330.00	60.00	121.22	-1,341.18	2,288.50	1,450.11
3,360.00	60.00	121.22	-1,354.65	2,310.72	1,465.11
3,386.00	60.00	121.22	-1,366.32	2,329.98	1,478.11

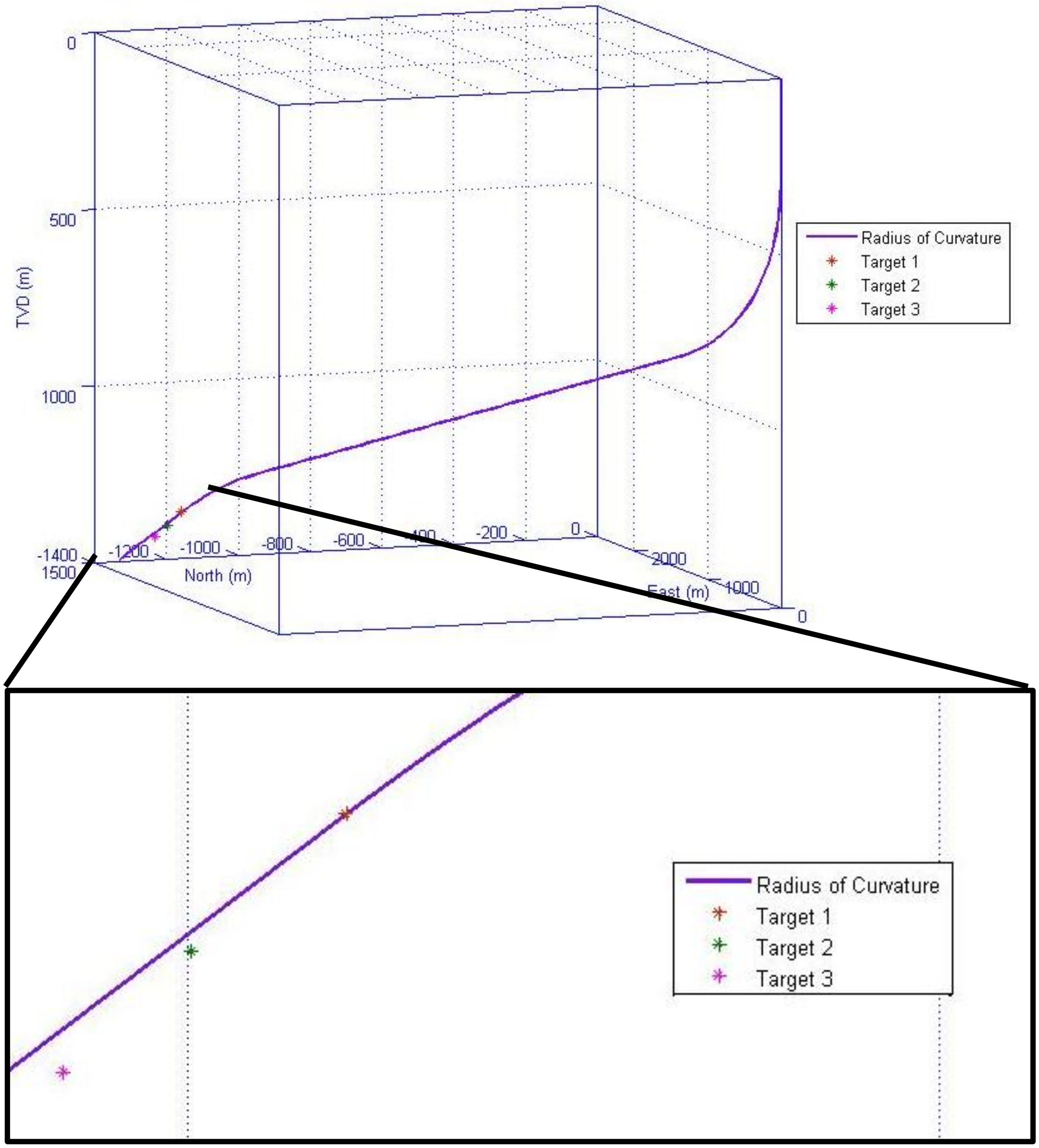


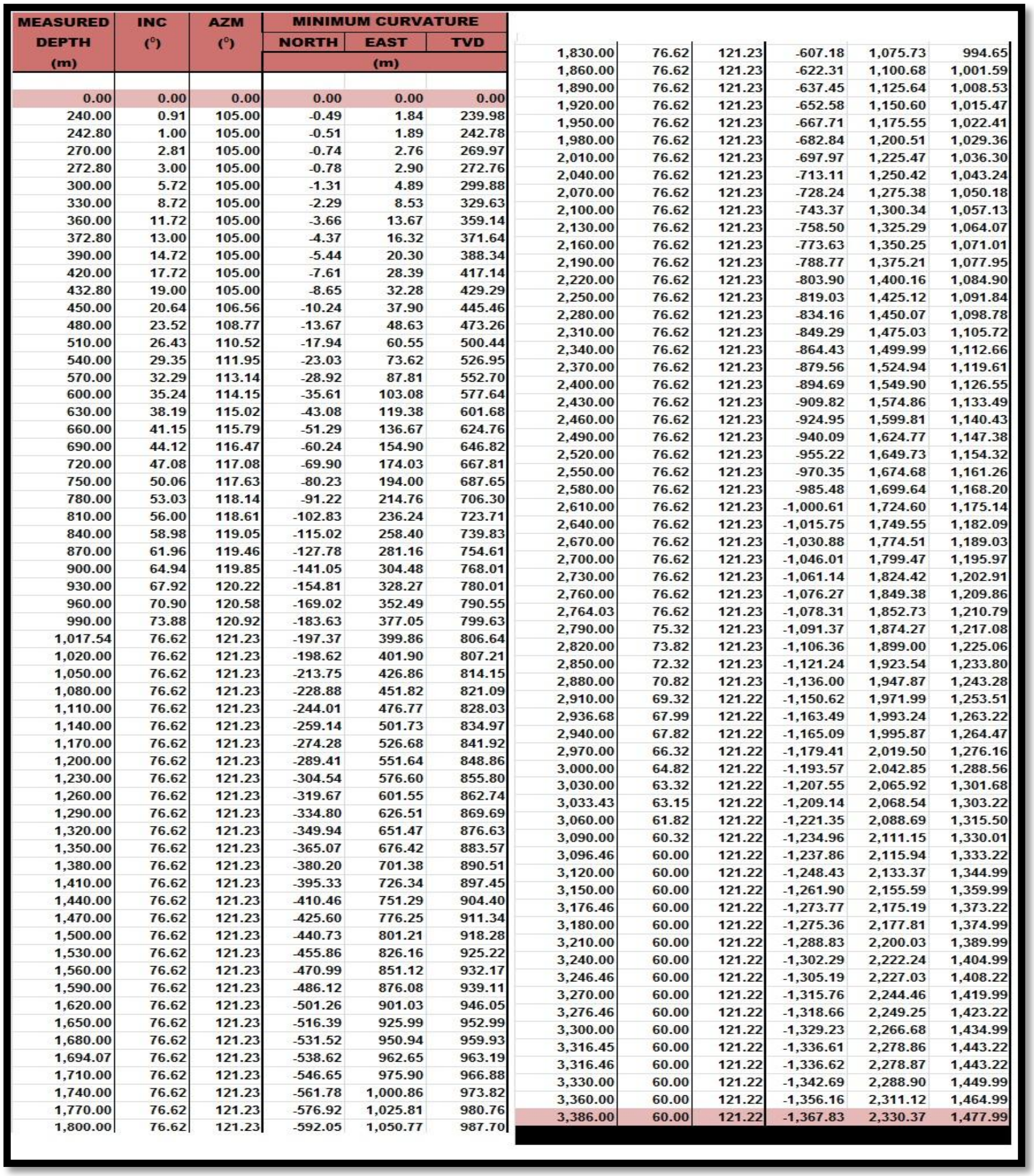
Figure 21: Graphical Trajectory for Well X - Radius of Curvature Method

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

e) Minimum Curvature Method

Figure 22 shows the wellbore trajectory of Well X based on minimum of curvature method. The final location of the wellbore is at -1367.83 m north, 2330.37 m east, and 1477.99 m TVD (Table 10). Minimum curvature method produces a trajectory which exactly the same with the balance tangential method based on the data of Well X.

Table 10: Minimum of Curvature Method for Well X



MEASURED DEPTH (m)	INC (°)	AZM (°)	MINIMUM CURVATURE		
			NORTH	EAST	TVD
			(m)		
0.00	0.00	0.00	0.00	0.00	0.00
240.00	0.91	105.00	-0.49	1.84	239.98
242.80	1.00	105.00	-0.51	1.89	242.78
270.00	2.81	105.00	-0.74	2.76	269.97
272.80	3.00	105.00	-0.78	2.90	272.76
300.00	5.72	105.00	-1.31	4.89	299.88
330.00	8.72	105.00	-2.29	8.53	329.63
360.00	11.72	105.00	-3.66	13.67	359.14
372.80	13.00	105.00	-4.37	16.32	371.64
390.00	14.72	105.00	-5.44	20.30	388.34
420.00	17.72	105.00	-7.61	28.39	417.14
432.80	19.00	105.00	-8.65	32.28	429.29
450.00	20.64	106.56	-10.24	37.90	445.46
480.00	23.52	108.77	-13.67	48.63	473.26
510.00	26.43	110.52	-17.94	60.55	500.44
540.00	29.35	111.95	-23.03	73.62	526.95
570.00	32.29	113.14	-28.92	87.81	552.70
600.00	35.24	114.15	-35.61	103.08	577.64
630.00	38.19	115.02	-43.08	119.38	601.68
660.00	41.15	115.79	-51.29	136.67	624.76
690.00	44.12	116.47	-60.24	154.90	646.82
720.00	47.08	117.08	-69.90	174.03	667.81
750.00	50.06	117.63	-80.23	194.00	687.65
780.00	53.03	118.14	-91.22	214.76	706.30
810.00	56.00	118.61	-102.83	236.24	723.71
840.00	58.98	119.05	-115.02	258.40	739.83
870.00	61.96	119.46	-127.78	281.16	754.61
900.00	64.94	119.85	-141.05	304.48	768.01
930.00	67.92	120.22	-154.81	328.27	780.01
960.00	70.90	120.58	-169.02	352.49	790.55
990.00	73.88	120.92	-183.63	377.05	799.63
1,017.54	76.62	121.23	-197.37	399.86	806.64
1,020.00	76.62	121.23	-198.62	401.90	807.21
1,050.00	76.62	121.23	-213.75	426.86	814.15
1,080.00	76.62	121.23	-228.88	451.82	821.09
1,110.00	76.62	121.23	-244.01	476.77	828.03
1,140.00	76.62	121.23	-259.14	501.73	834.97
1,170.00	76.62	121.23	-274.28	526.68	841.92
1,200.00	76.62	121.23	-289.41	551.64	848.86
1,230.00	76.62	121.23	-304.54	576.60	855.80
1,260.00	76.62	121.23	-319.67	601.55	862.74
1,290.00	76.62	121.23	-334.80	626.51	869.69
1,320.00	76.62	121.23	-349.94	651.47	876.63
1,350.00	76.62	121.23	-365.07	676.42	883.57
1,380.00	76.62	121.23	-380.20	701.38	890.51
1,410.00	76.62	121.23	-395.33	726.34	897.45
1,440.00	76.62	121.23	-410.46	751.29	904.40
1,470.00	76.62	121.23	-425.60	776.25	911.34
1,500.00	76.62	121.23	-440.73	801.21	918.28
1,530.00	76.62	121.23	-455.86	826.16	925.22
1,560.00	76.62	121.23	-470.99	851.12	932.17
1,590.00	76.62	121.23	-486.12	876.08	939.11
1,620.00	76.62	121.23	-501.26	901.03	946.05
1,650.00	76.62	121.23	-516.39	925.99	952.99
1,680.00	76.62	121.23	-531.52	950.94	959.93
1,694.07	76.62	121.23	-538.62	962.65	963.19
1,710.00	76.62	121.23	-546.65	975.90	966.88
1,740.00	76.62	121.23	-561.78	1,000.86	973.82
1,770.00	76.62	121.23	-576.92	1,025.81	980.76
1,800.00	76.62	121.23	-592.05	1,050.77	987.70
1,830.00	76.62	121.23	-607.18	1,075.73	994.65
1,860.00	76.62	121.23	-622.31	1,100.68	1,001.59
1,890.00	76.62	121.23	-637.45	1,125.64	1,008.53
1,920.00	76.62	121.23	-652.58	1,150.60	1,015.47
1,950.00	76.62	121.23	-667.71	1,175.55	1,022.41
1,980.00	76.62	121.23	-682.84	1,200.51	1,029.36
2,010.00	76.62	121.23	-697.97	1,225.47	1,036.30
2,040.00	76.62	121.23	-713.11	1,250.42	1,043.24
2,070.00	76.62	121.23	-728.24	1,275.38	1,050.18
2,100.00	76.62	121.23	-743.37	1,300.34	1,057.13
2,130.00	76.62	121.23	-758.50	1,325.29	1,064.07
2,160.00	76.62	121.23	-773.63	1,350.25	1,071.01
2,190.00	76.62	121.23	-788.77	1,375.21	1,077.95
2,220.00	76.62	121.23	-803.90	1,400.16	1,084.90
2,250.00	76.62	121.23	-819.03	1,425.12	1,091.84
2,280.00	76.62	121.23	-834.16	1,450.07	1,098.78
2,310.00	76.62	121.23	-849.29	1,475.03	1,105.72
2,340.00	76.62	121.23	-864.43	1,499.99	1,112.66
2,370.00	76.62	121.23	-879.56	1,524.94	1,119.61
2,400.00	76.62	121.23	-894.69	1,549.90	1,126.55
2,430.00	76.62	121.23	-909.82	1,574.86	1,133.49
2,460.00	76.62	121.23	-924.95	1,599.81	1,140.43
2,490.00	76.62	121.23	-940.09	1,624.77	1,147.38
2,520.00	76.62	121.23	-955.22	1,649.73	1,154.32
2,550.00	76.62	121.23	-970.35	1,674.68	1,161.26
2,580.00	76.62	121.23	-985.48	1,699.64	1,168.20
2,610.00	76.62	121.23	-1,000.61	1,724.60	1,175.14
2,640.00	76.62	121.23	-1,015.75	1,749.55	1,182.09
2,670.00	76.62	121.23	-1,030.88	1,774.51	1,189.03
2,700.00	76.62	121.23	-1,046.01	1,799.47	1,195.97
2,730.00	76.62	121.23	-1,061.14	1,824.42	1,202.91
2,760.00	76.62	121.23	-1,076.27	1,849.38	1,209.86
2,764.03	76.62	121.23	-1,078.31	1,852.73	1,210.79
2,790.00	75.32	121.23	-1,091.37	1,874.27	1,217.08
2,820.00	73.82	121.23	-1,106.36	1,899.00	1,225.06
2,850.00	72.32	121.23	-1,121.24	1,923.54	1,233.80
2,880.00	70.82	121.23	-1,136.00	1,947.87	1,243.28
2,910.00	69.32	121.22	-1,150.62	1,971.99	1,253.51
2,936.68	67.99	121.22	-1,163.49	1,993.24	1,263.22
2,940.00	67.82	121.22	-1,165.09	1,995.87	1,264.47
2,970.00	66.32	121.22	-1,179.41	2,019.50	1,276.16
3,000.00	64.82	121.22	-1,193.57	2,042.85	1,288.56
3,030.00	63.32	121.22	-1,207.55	2,065.92	1,301.68
3,033.43	63.15	121.22	-1,209.14	2,068.54	1,303.22
3,060.00	61.82	121.22	-1,221.35	2,088.69	1,315.50
3,090.00	60.32	121.22	-1,234.96	2,111.15	1,330.01
3,096.46	60.00	121.22	-1,237.86	2,115.94	1,333.22
3,120.00	60.00	121.22	-1,248.43	2,133.37	1,344.99
3,150.00	60.00	121.22	-1,261.90	2,155.59	1,359.99
3,176.46	60.00	121.22	-1,273.77	2,175.19	1,373.22
3,180.00	60.00	121.22	-1,275.36	2,177.81	1,374.99
3,210.00	60.00	121.22	-1,288.83	2,200.03	1,389.99
3,240.00	60.00	121.22	-1,302.29	2,222.24	1,404.99
3,246.46	60.00	121.22	-1,305.19	2,227.03	1,408.22
3,270.00	60.00	121.22	-1,315.76	2,244.46	1,419.99
3,276.46	60.00	121.22	-1,318.66	2,249.25	1,423.22
3,300.00	60.00	121.22	-1,329.23	2,266.68	1,434.99
3,316.45	60.00	121.22	-1,336.61	2,278.86	1,443.22
3,316.46	60.00	121.22	-1,336.62	2,278.87	1,443.22
3,330.00	60.00	121.22	-1,342.69	2,288.90	1,449.99
3,360.00	60.00	121.22	-1,356.16	2,311.12	1,464.99
3,386.00	60.00	121.22	-1,367.83	2,330.37	1,477.99

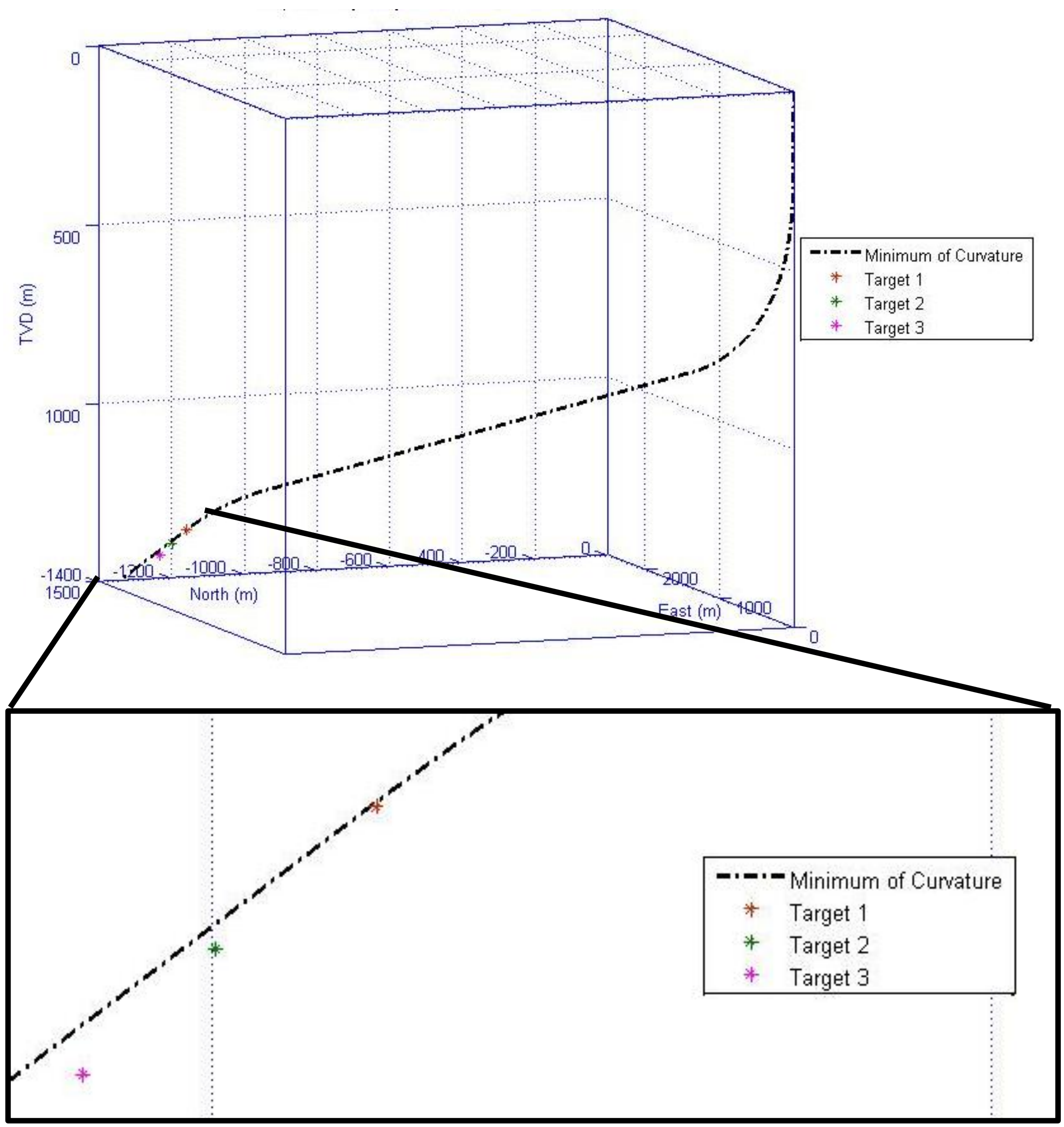


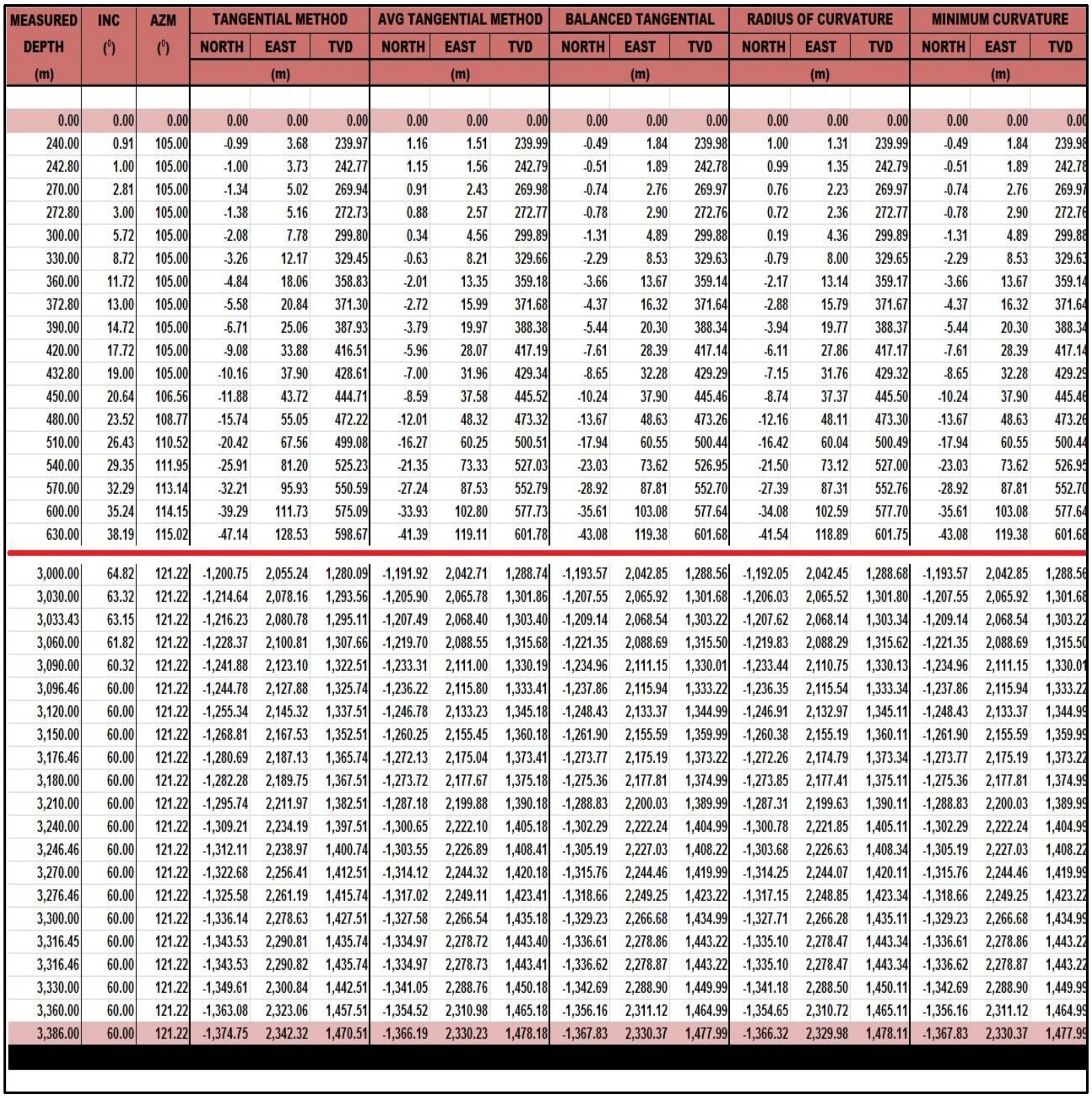
Figure 22: Graphical Trajectory for Well X - Minimum of Curvature Method

By referring to Figure 22, the trajectory produce 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 23and Table 11, the well trajectory from the radius of curvature method and the average tangential method is the closest to all three targets. On the other hand, the tangential method is the least accurate method to apply for well X.

Table 11: Wellbore trajectory for Well X using five different methods



MEASURED	INC	AZM	TANGENTIAL METHOD			AVG TANGENTIAL METHOD			BALANCED TANGENTIAL			RADIUS OF CURVATURE			MINIMUM CURVATURE		
DEPTH	(^{0})	(^{0})	NORTH	EAST	TVD	NORTH	EAST	TVD	NORTH	EAST	TVD	NORTH	EAST	TVD	NORTH	EAST	TVD
(m)			(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
240.00	0.91	105.00	-0.99	3.68	239.97	1.16	1.51	239.99	-0.49	1.84	239.98	1.00	1.31	239.99	-0.49	1.84	239.98
242.80	1.00	105.00	-1.00	3.73	242.77	1.15	1.56	242.79	-0.51	1.89	242.78	0.99	1.35	242.79	-0.51	1.89	242.78
270.00	2.81	105.00	-1.34	5.02	269.94	0.91	2.43	269.98	-0.74	2.76	269.97	0.76	2.23	269.97	-0.74	2.76	269.97
272.80	3.00	105.00	-1.38	5.16	272.73	0.88	2.57	272.77	-0.78	2.90	272.76	0.72	2.36	272.77	-0.78	2.90	272.76
300.00	5.72	105.00	-2.08	7.78	299.80	0.34	4.56	299.89	-1.31	4.89	299.88	0.19	4.36	299.89	-1.31	4.89	299.88
330.00	8.72	105.00	-3.26	12.17	329.45	-0.63	8.21	329.66	-2.29	8.53	329.63	-0.79	8.00	329.65	-2.29	8.53	329.63
360.00	11.72	105.00	-4.84	18.06	358.83	-2.01	13.35	359.18	-3.66	13.67	359.14	-2.17	13.14	359.17	-3.66	13.67	359.14
372.80	13.00	105.00	-5.58	20.84	371.30	-2.72	15.99	371.68	-4.37	16.32	371.64	-2.88	15.79	371.67	-4.37	16.32	371.64
390.00	14.72	105.00	-6.71	25.06	387.93	-3.79	19.97	388.38	-5.44	20.30	388.34	-3.94	19.77	388.37	-5.44	20.30	388.34
420.00	17.72	105.00	-9.08	33.88	416.51	-5.96	28.07	417.19	-7.61	28.39	417.14	-6.11	27.86	417.17	-7.61	28.39	417.14
432.80	19.00	105.00	-10.16	37.90	428.61	-7.00	31.96	429.34	-8.65	32.28	429.29	-7.15	31.76	429.32	-8.65	32.28	429.29
450.00	20.64	106.56	-11.88	43.72	444.71	-8.59	37.58	445.52	-10.24	37.90	445.46	-8.74	37.37	445.50	-10.24	37.90	445.46
480.00	23.52	108.77	-15.74	55.05	472.22	-12.01	48.32	473.32	-13.67	48.63	473.26	-12.16	48.11	473.30	-13.67	48.63	473.26
510.00	26.43	110.52	-20.42	67.56	499.08	-16.27	60.25	500.51	-17.94	60.55	500.44	-16.42	60.04	500.49	-17.94	60.55	500.44
540.00	29.35	111.95	-25.91	81.20	525.23	-21.35	73.33	527.03	-23.03	73.62	526.95	-21.50	73.12	527.00	-23.03	73.62	526.95
570.00	32.29	113.14	-32.21	95.93	550.59	-27.24	87.53	552.79	-28.92	87.81	552.70	-27.39	87.31	552.76	-28.92	87.81	552.70
600.00	35.24	114.15	-39.29	111.73	575.09	-33.93	102.80	577.73	-35.61	103.08	577.64	-34.08	102.59	577.70	-35.61	103.08	577.64
630.00	38.19	115.02	-47.14	128.53	598.67	-41.39	119.11	601.78	-43.08	119.38	601.68	-41.54	118.89	601.75	-43.08	119.38	601.68
3,000.00	64.82	121.22	-1,200.75	2,055.24	1,280.09	-1,191.92	2,042.71	1,288.74	-1,193.57	2,042.85	1,288.56	-1,192.05	2,042.45	1,288.68	-1,193.57	2,042.85	1,288.56
3,030.00	63.32	121.22	-1,214.64	2,078.16	1,293.56	-1,205.90	2,065.78	1,301.86	-1,207.55	2,065.92	1,301.68	-1,206.03	2,065.52	1,301.80	-1,207.55	2,065.92	1,301.68
3,033.43	63.15	121.22	-1,216.23	2,080.78	1,295.11	-1,207.49	2,068.40	1,303.40	-1,209.14	2,068.54	1,303.22	-1,207.62	2,068.14	1,303.34	-1,209.14	2,068.54	1,303.22
3,060.00	61.82	121.22	-1,228.37	2,100.81	1,307.66	-1,219.70	2,088.55	1,315.68	-1,221.35	2,088.69	1,315.50	-1,219.83	2,088.29	1,315.62	-1,221.35	2,088.69	1,315.50
3,090.00	60.32	121.22	-1,241.88	2,123.10	1,322.51	-1,233.31	2,111.00	1,330.19	-1,234.96	2,111.15	1,330.01	-1,233.44	2,110.75	1,330.13	-1,234.96	2,111.15	1,330.01
3,096.46	60.00	121.22	-1,244.78	2,127.88	1,325.74	-1,236.22	2,115.80	1,333.41	-1,237.86	2,115.94	1,333.22	-1,236.35	2,115.54	1,333.34	-1,237.86	2,115.94	1,333.22
3,120.00	60.00	121.22	-1,255.34	2,145.32	1,337.51	-1,246.78	2,133.23	1,345.18	-1,248.43	2,133.37	1,344.99	-1,246.91	2,132.97	1,345.11	-1,248.43	2,133.37	1,344.99
3,150.00	60.00	121.22	-1,268.81	2,167.53	1,352.51	-1,260.25	2,155.45	1,360.18	-1,261.90	2,155.59	1,359.99	-1,260.38	2,155.19	1,360.11	-1,261.90	2,155.59	1,359.99
3,176.46	60.00	121.22	-1,280.69	2,187.13	1,365.74	-1,272.13	2,175.04	1,373.41	-1,273.77	2,175.19	1,373.22	-1,272.26	2,174.79	1,373.34	-1,273.77	2,175.19	1,373.22
3,180.00	60.00	121.22	-1,282.28	2,189.75	1,367.51	-1,273.72	2,177.67	1,375.18	-1,275.36	2,177.81	1,374.99	-1,273.85	2,177.41	1,375.11	-1,275.36	2,177.81	1,374.99
3,210.00	60.00	121.22	-1,295.74	2,211.97	1,382.51	-1,287.18	2,199.88	1,390.18	-1,288.83	2,200.03	1,389.99	-1,287.31	2,199.63	1,390.11	-1,288.83	2,200.03	1,389.99
3,240.00	60.00	121.22	-1,309.21	2,234.19	1,397.51	-1,300.65	2,222.10	1,405.18	-1,302.29	2,222.24	1,404.99	-1,300.78	2,221.85	1,405.11	-1,302.29	2,222.24	1,404.99
3,246.46	60.00	121.22	-1,312.11	2,238.97	1,400.74	-1,303.55	2,226.89	1,408.41	-1,305.19	2,227.03	1,408.22	-1,303.68	2,226.63	1,408.34	-1,305.19	2,227.03	1,408.22
3,270.00	60.00	121.22	-1,322.68	2,256.41	1,412.51	-1,314.12	2,244.32	1,420.18	-1,315.76	2,244.46	1,419.99	-1,314.25	2,244.07	1,420.11	-1,315.76	2,244.46	1,419.99
3,276.46	60.00	121.22	-1,325.58	2,261.19	1,415.74	-1,317.02	2,249.11	1,423.41	-1,318.66	2,249.25	1,423.22	-1,317.15	2,248.85	1,423.34	-1,318.66	2,249.25	1,423.22
3,300.00	60.00	121.22	-1,336.14	2,278.63	1,427.51	-1,327.58	2,266.54	1,435.18	-1,329.23	2,266.68	1,434.99	-1,327.71	2,266.28	1,435.11	-1,329.23	2,266.68	1,434.99
3,316.45	60.00	121.22	-1,343.53	2,290.81	1,435.74	-1,334.97	2,278.72	1,443.40	-1,336.61	2,278.86	1,443.22	-1,335.10	2,278.47	1,443.34	-1,336.61	2,278.86	1,443.22
3,316.46	60.00	121.22	-1,343.53	2,290.82	1,435.74	-1,334.97	2,278.73	1,443.41	-1,336.62	2,278.87	1,443.22	-1,335.10	2,278.47	1,443.34	-1,336.62	2,278.87	1,443.22
3,330.00	60.00	121.22	-1,349.61	2,300.84	1,442.51	-1,341.05	2,288.76	1,450.18	-1,342.69	2,288.90	1,449.99	-1,341.18	2,288.50	1,450.11	-1,342.69	2,288.90	1,449.99
3,360.00	60.00	121.22	-1,363.08	2,323.06	1,457.51	-1,354.52	2,310.98	1,465.18	-1,356.16	2,311.12	1,464.99	-1,354.65	2,310.72	1,465.11	-1,356.16	2,311.12	1,464.99
3,386.00	60.00	121.22	-1,374.75	2,342.32	1,470.51	-1,366.19	2,330.23	1,478.18	-1,367.83	2,330.37	1,477.99	-1,366.32	2,329.98	1,478.11	-1,367.83	2,330.37	1,477.99

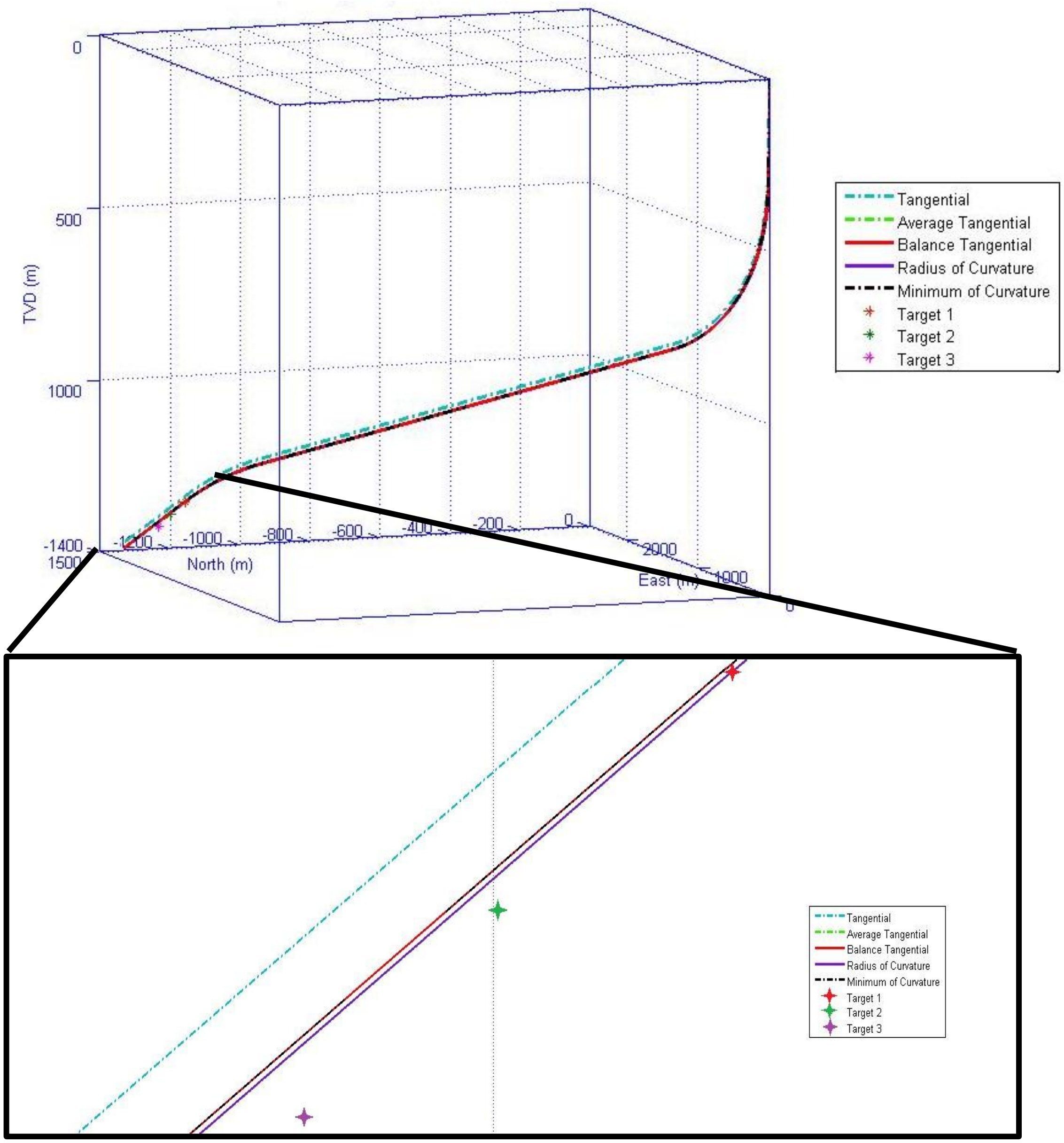


Figure 23: Graphical wellbore trajectory for Well X using five different methods

According to Figure 23, the radius of curvature and the average tangential method are both the closes to the targets 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 justify the error between those methods in order to select the most suitable method in determining the smooth and good wellbore trajectory. 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 X as shown in Table 12.

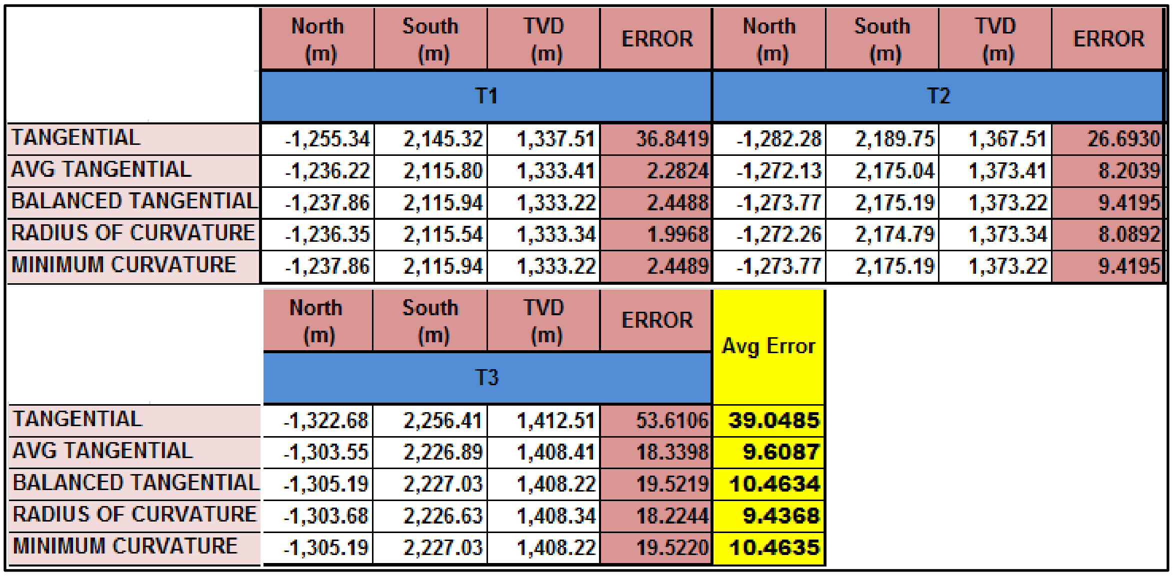
Example based on tangential method for target 1 (T1):

$$Error$$

$$= \sqrt{((-1255.34) - (-1236.99))^2 + (2145.32 - 2113.65)^2 + (1337.51 - 1,333.30)^2}$$

= 36.8419m

Table 12: Error analysis for all methods



	North (m)	South (m)	TVD (m)	ERROR	North (m)	South (m)	TVD (m)	ERROR
	T1				T2			
TANGENTIAL	-1,255.34	2,145.32	1,337.51	36.8419	-1,282.28	2,189.75	1,367.51	26.6930
AVG TANGENTIAL	-1,236.22	2,115.80	1,333.41	2.2824	-1,272.13	2,175.04	1,373.41	8.2039
BALANCED TANGENTIAL	-1,237.86	2,115.94	1,333.22	2.4488	-1,273.77	2,175.19	1,373.22	9.4195
RADIUS OF CURVATURE	-1,236.35	2,115.54	1,333.34	1.9968	-1,272.26	2,174.79	1,373.34	8.0892
MINIMUM CURVATURE	-1,237.86	2,115.94	1,333.22	2.4489	-1,273.77	2,175.19	1,373.22	9.4195

	North (m)	South (m)	TVD (m)	ERROR	Avg Error
	T3				
TANGENTIAL	-1,322.68	2,256.41	1,412.51	53.6106	**39.0485**
AVG TANGENTIAL	-1,303.55	2,226.89	1,408.41	18.3398	**9.6087**
BALANCED TANGENTIAL	-1,305.19	2,227.03	1,408.22	19.5219	**10.4634**
RADIUS OF CURVATURE	-1,303.68	2,226.63	1,408.34	18.2244	**9.4368**
MINIMUM CURVATURE	-1,305.19	2,227.03	1,408.22	19.5220	**10.4635**

Based on the Table 12, the radius of curvature has the smallest error between all of the methods. While the average tangential method producing a trajectory which has the second close to the targets. On the other hand, the tangential method has the highest error 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 X. Radius of curvature method shows the smallest error between all other methods which is 9.4368 m based on the absolute error calculation.

5.2 Recommendation for Future Work

For future recommendation, the author suggest to applied different methods apart from tangential, 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.

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APPENDICES

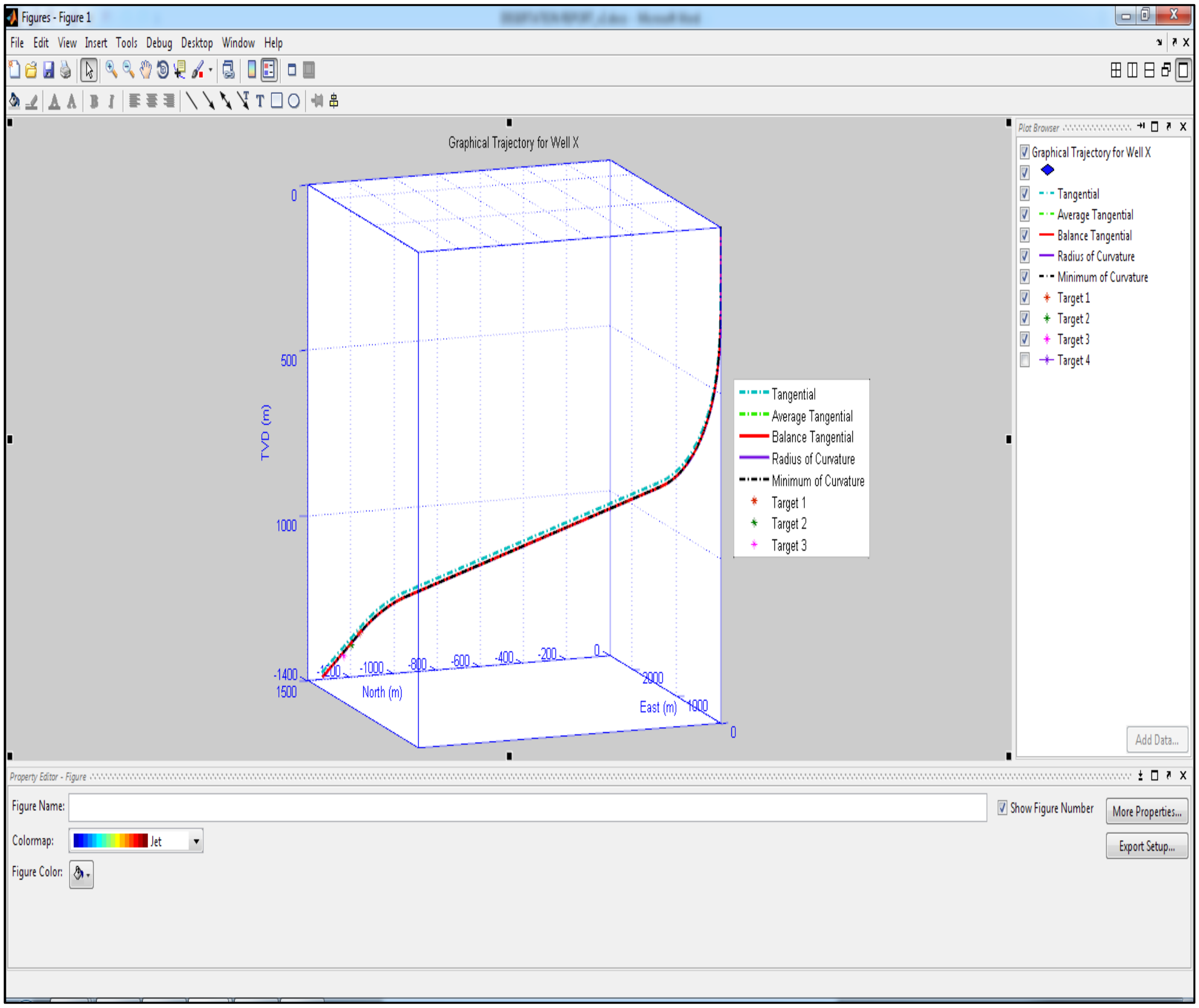

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Figure 24: Drawing well trajectory using Matlab