Journal of the Nigerian Association of Mathematical Physics
Volume33,(January, 2016), pp 337 – 346

A Design Model for Directional Wells Trajectories

[1]Egwuenu Iremise and [2]K. O. Bello

Department of Petroleum Engineering, University of Benin, Nigeria.

Abstract

There are several models for designing the trajectories of directional wells. Most of these models are designed for only one type of trajectory. Due to the complexity of the trajectories of modern directional wells, there is the problem of flexibility with these models. Therefore, a more robust model is required. This model can be used to design five different types of directional well trajectories.
In light of the above, a sketch model for five different types of directional well trajectory was created. Every trajectory was sectioned and the mathematical relationships for each section were derived. A computer program that has been coded in order to simplify the model and generate coordinates of the path of the well trajectory that can be plotted on any spread sheet, was developed.
Some examples were made to test the model. The plots of five different types of trajectories clearly showed the paths the wells will take in the rock formation in the given vertical and horizontal coordinates. The model has been found to be more robust and flexible when compared with similar models in the literatures.

Key word: Trajectory, Wellbore, Directional Well, Design Model, Sketch Model.

1.0 Introduction

In some cases, the exploration and production of petroleum require the use of directional wells. Unlike vertical wells, directional wells gradually bend away from the vertical (normal), at an angle, towards the intended target (at a horizontal distance from the vertical) along predetermined paths [1], as shown in Figure 1. The path the well takes through the rock formation is called its trajectory [1]. Directional wells have various applications or purposes in the petroleum arena [2, 3]. Due to some factors, directional wells have different types of trajectories [4], such as the S-Type, Sidetrack (build and hold), Double-Build, Dogleg, etc. Regardless of the type of trajectory selected, every trajectory of a directional well must be precisely planned and designed. Thus, a design model is required to effectively design the trajectory of a directional well.

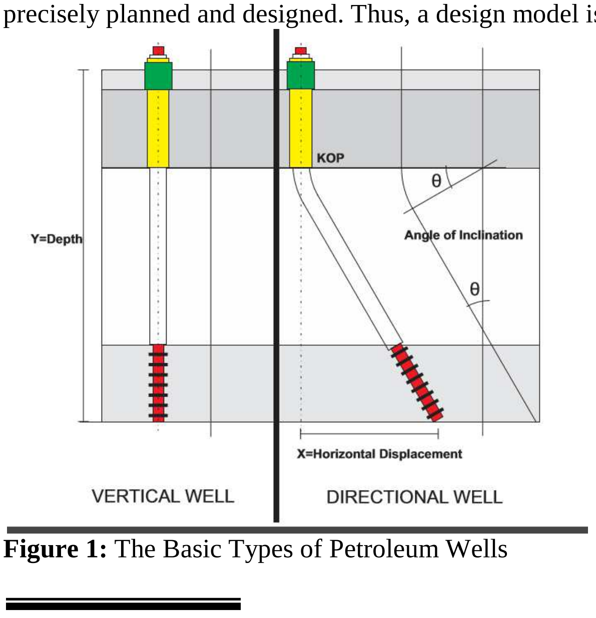


Figure 1: The Basic Types of Petroleum Wells

Corresponding author: Egwuenu Iremise, E-mail:eiremise4u@gmail.com, Tel.: +2348062356959

A design model for directional well trajectory is a platform that provides the geometry, mathematical relationships and procedures for effective design of the trajectory of the directional well [5]. Initially, directional wells trajectories were manually designed on paper. These days, computer programs are employed. Most design models are for a particular type of directional well trajectory. However, the design model presented in this paper has been created for five different directional well trajectories, namely: the Sidetrack, the S-type, the Double-build, the Big-build and the Dogleg trajectory. Figure 2 shows the general architecture of these trajectories. Note, these trajectories exist in a plane, that is in 2-dimension.

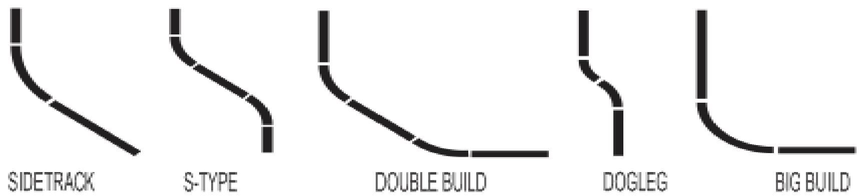


Figure 2: The Five Types Directional Well Trajectory

2.0 Parts of a Directional Well

Most directional wells are designed on the same principle that is they begin as vertical wellbores (the hole of wells). Then, they kick off at predetermined points (Kick off Point) as they bend toward their intended targets [6]. The basic parts of directional well trajectories in 2-dimension are illustrated in Figure 3.

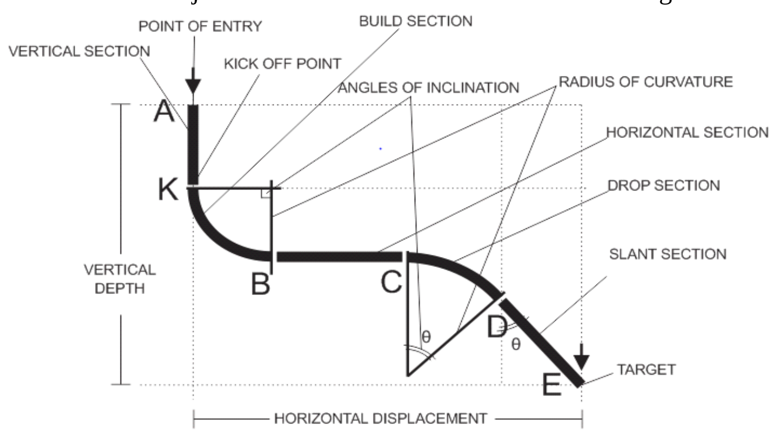


Figure 3: Parts of the Trajectory of Directional Wells

3.0 The Model

In developing this model, a step by step approach was adopted.

A. Creation of the sketch model
B. Segmentation of the trajectories
C. Generation of the mathematical relationships for every segment
D. Coding and development of the computer program
E. Procedures for applying the model

4.0 The Sketch Model

The sketch model presents the layout of the various directional well trajectories as shown below in Figure 4. Represented in depth versus horizontal displacement, this sketch model was created with the assumption that the trajectories lied in a plane, that is in 2-Dimention. For every trajectory, its path starts from point A (the point of entry) to their respective point M (the target in the reservoir). A combination of the basic section (vertical, build, slant, drop and Horizontal section) was used to generate the path of every trajectory.

The principle adopted in the design of the sketch model is the principle of tangency [5, 7]. Here, the lines intersect tangentially. The sketch model was built from the tangent between the initial build and the next curve. The angle of inclination of the tangent to the vertical (normal) becomes the angle of inclination of the initial build.

The sketch model was designed:

1. To guide the designer's choice of directional well trajectory to adopt.

2. To determine specifications of the initial values required by the selected trajectory.
3. To assist the designer to have a good mental picture of the selected trajectory
4. To serve as the foundation for the design of the directional well trajectories.

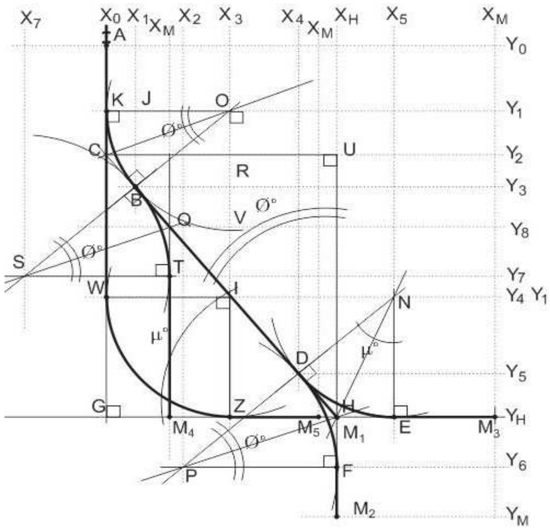


Figure 4: The Sketch Model

5.0 Segmentation of the Trajectories

From the sketch model in Figure 4, five types of trajectories for directional wells were presented, namely: the sidetrack, the s-type, the double build, the dogleg and the big build trajectory. Every one of these trajectories was broken down into basic geometrical segments– vertical, build, slant, drop and horizontal section. Figure 5 shows the various trajectories in their respective segments.

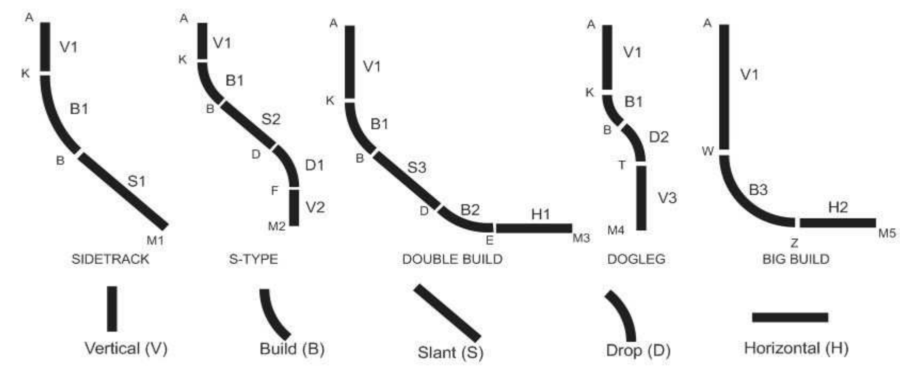


Figure 5: The Segments of the Trajectories

6.0 The Mathematical Relationships

The dimensions or parameters on the sketch model can be grouped under two categories, namely:

Initial Parameters:

These are independent values. They are values that are known or specified at the start of the design of the directional well trajectory. They include

$X_0 =$ Horizontal displacement of the point of entry
$Y_0 =$ Depth of the point of entry
$Y_2 =$ Depth of the point of intersection of the tangent and the vertical (normal)
$X_M =$ Maximum horizontal displacement of the tangent
$Y_M =$ Maximum depth of the tangent
$X_H =$ Horizontal displacement of the point where the tangent intersects with the maximum depth
$Y_H =$ Depth of the point where the tangent intersects with the maximum horizontal displacement
$q_1 =$ Rate of inclination angle buildup for first build

$q_2 =$ Rate of inclination angle buildup for second build or drop

Derived Parameters:

As the name imply, they are derived from or dependent on the initial values. All the other values fall into this category.

For every segment of the trajectories, a required mathematical relationship that can properly delineate the segment was generated using principles of geometry, equation of a straight line and equation of a circle [8, 9].

Table 1: A Table of Mathematical Relationships for Every Segment of the Trajectories

SECTIONS OF THE TRAJECTORIES		EQUATION OF LENGTH OF SECTION	EQUATION OF LINE	RELIEVANT PARAMETERS/ COORDINATES OF THE SECTION
VERTICAL SECTION	V1	$L_{V1} = Y_1 - Y_0$	$X = a$	(X_0,Y_0) to (X_0,Y_1) $\theta = \tan^{-1}\left(\frac{X_H - X_0}{Y_H - Y_2}\right)$ $R_1 = \frac{180°}{q\pi}$ $Y_1 = Y_2 - R\tan\frac{\theta}{2} = KOP$
	V2	$L_{V2} = Y_M - Y_6$	$X = a$	(X_M,Y_6) to (X_M,Y_M) $Y_6 = Y_M - R_2\tan\frac{\theta}{2}$
	V3	$L_{V3} = Y_M - Y_7$	$X = a$	(X_M,Y_7) to (X_M,Y_M) $Y_7 = Y_H + R_2\tan\left(\frac{\theta}{2}\right)$
BUILD SECTION	B1	$L_{B1} = \frac{\theta°}{q_1}$	$Y = Y_1 + \sqrt{R_1^{\,2} - (X - R_1)^2}$	(X_0,Y_1) to (X_1,Y_3) $\theta = \tan^{-1}\left(\frac{X_H - X_0}{Y_H - Y_2}\right)$ $R_1 = \frac{180°}{q_1\pi}$ $X_1 = R_1(1-\cos\theta)$ $Y_3 = Y_1 + R_1(\sin\theta)$
	B2	$L_{B2} = \frac{\mu°}{q_2}$	$(X - X_5)^2 + (Y - Y_4)^2 = R^2$ $Y = Y_4 + \sqrt{R_2^2 - (X - X_5)^2}$	(X_4,Y_5) to (X_5,Y_H) $\mu° = 90° - \theta°$ $\theta° = \tan^{-1}\left(\frac{X_H - X_0}{Y_H - Y_2}\right)$ $R_2 = \frac{180°}{q_2\pi}$ $X_5 = X_H + R_2\tan\left(\frac{\mu°}{2}\right)$ $Y_4 = Y_H - R_2$ $Y_5 = Y_3 + L_{S3}(\cos\theta)$ $X_4 = X_1 + L_{S3}(\sin\theta)$

	B3	$L_{B3}=\frac{\theta}{q_1}$	$(X-R)^2+(Y-Y_1)^2=R^2$ $Y=Y_1+\sqrt{R^2-(X-R)^2}$	(X_0,Y_1) to (X_3,Y_H) $\theta=90°$ $R=\frac{180°}{q\pi}$ $X_3=X_0+R$
SLANT SECTION	S1	$L_{S1}=\sqrt{(X_H-X_0)^2+(Y_H-Y_2)^2}-R_1\tan\left(\frac{\theta}{2}\right)$	$Y=\left(\frac{Y_H-Y_3}{X_H-X_1}\right)X+Y_2$	(X_1,Y_3) to (X_H,Y_H) $R_1=\frac{180°}{q\pi}$ $X_1=R_1(1-\cos\theta)$ $Y_3=Y_1+R_1(\sin\theta)$
	S2	$L_{S2}=\sqrt{(X_H-X_0)^2+(Y_H-Y_2)^2}-R_1\tan\left(\frac{\theta}{2}\right)-R_2\tan\left(\frac{\theta}{2}\right)$	$Y=\left(\frac{Y_H-Y_3}{X_H-X_1}\right)X+Y_2$	(X_1,Y_3) to (X_4,Y_5) $R_1=\frac{180°}{q_1\pi}$ $R_2=\frac{180°}{q_2\pi}$ $X_1=R_1(1-\cos\theta)$ $Y_3=Y_1+R_1(\sin\theta)$ $Y_5=Y_3+L_{S2}(\cos\theta)$ $X_4=X_1+L_{S2}(\sin\theta)$
	S3	$L_{S3}=\sqrt{(X_H-X_0)^2+(Y_H-Y_2)^2}-R_1\tan\left(\frac{\theta}{2}\right)-R_2\tan\left(\frac{\mu}{2}\right)$	$Y=\left(\frac{Y_H-Y_3}{X_H-X_1}\right)X+Y_2$	(X_1,Y_3) to (X_4,Y_5) $R_1=\frac{180°}{q_1\pi}$ $R_2=\frac{180°}{q_2\pi}$ $X_1=R_1(1-\cos\theta)$ $Y_3=Y_1+R_1(\sin\theta)$ $Y_5=Y_3+L_{S3}(\cos\theta)$ $X_4=X_1+L_{S3}(\sin\theta)$
DROP SECTION	D1	$L_{D1}=\frac{\theta}{q_2}$	$Y=Y_6-\sqrt{R_2{}^2-(X-X_2)^2}$	(X_4,Y_5) to (X_H,Y_6) $X_2=X_H-R_2$ $Y_6=Y_H+R_2\tan\left(\frac{\theta}{2}\right)$ $Y_5=Y_3+L_{S2}(\cos\theta)$ $X_4=X_1+L_{S2}(\sin\theta)$

	D2	$L_{D2} = \frac{\theta}{q_2}$	$(X - X_7)^2 + (Y - Y_7)^2 = R^2$ $Y = Y_7 - \sqrt{R_2^2 - (X - X_7)^2}$	(X_1, Y_3) to (X_M, Y_7) $q_2 = \frac{180}{\pi R_2}$ $R_2 = \frac{X_M}{(1 - \cos\theta)} - R_1$ $\theta = \tan^{-1}\left(\frac{X_H - X_0}{Y_H - Y_2}\right)$ $X_1 = R(1 - \cos\theta)$ $Y_3 = Y_1 + R(\sin\theta)$ $X_7 = X_M - R_2$ $Y_7 = Y_H + R_2 \tan\left(\frac{\theta}{2}\right)$
HORIZONTAL SECTION	H1	$L_{H1} = X_M - X_5$	$Y = b$	(X_5, Y_H) to (X_M, Y_H) $X_5 = X_H + R_2 \tan\left(\frac{\mu^\circ}{2}\right)$
	H2	$L_{H2} = X_M - X_3$	$Y = b$	(X_3, Y_M) and (X_M, Y_M) $X_3 = X_0 + R$

7.0 The Computer Program

The Visual Basic 2015 (Visual Studio 2015) [10] was used to develop the computer program that will generate the working values (Derived Parameters). The program was developed for every one of the five trajectories. The interface of the program displayed:

Input Text Boxes: Initial parameters are entered here correctly, before the enter button is clicked.

Output Text Boxes: the final working values are displayed here once the enter button is clicked

Enter Button: This button has been coded to execute all the required mathematical relationships to yield the expected working values.

Exit Button: This button ends the program.

8.0 Application of the Directional well Trajectory Model

The procedure for applying this model has been arranged in two stages, based on every aspect of the model.

STAGE ONE: THE SKETCH MODEL

1. Identify the point of entry and the target in the reservoir from the available logs and the location of the drilling platform.
2. Specify both horizontal displacement and vertical depth of the point of entry (X_0 and Y_0) and the target (X_M and Y_M) from the drilling platform.
3. Select the best type of directional well trajectory based on the following
   i) The recommended architecture of the wellbore. Whether it is vertical, horizontal or slant.
   ii) The ratio of the horizontal displacement to depth of the target from the point of entry.
   iii) Drilling and completion cost of well of the selected directional well trajectory.
   iv) Available personnel and technology for the selected trajectory
4. Specify Y_2 that is the depth the tangent to the build intersects with the vertical or normal as shown in the sketch model.

5. Based on the intended angle of inclination, specify X_H for Double Build directional well trajectory, where the tangent intersects with the maximum depth or Y_H for S-Type and Dogleg directional well trajectory, where the tangent to the build intersect with the maximum horizontal displacement, as shown in the sketch model.
6. Then, choose a suitable rate of first build (q_1) and the second rate of build or drop (q_2) respectively.
7. For the trajectories, some of these values X_0, Y_0, Y_2, X_H, Y_H, X_M, Y_M, q_1 and q_2 are the initial values needed in their respective next stage.

STAGE TWO: COMPUTATION AND PLOT

Computation of the other dimensions or working values has been simplified by the use of a visual basic computer program developed for the model. The procedures for applying this program and using the generated coordinates (depth to horizontal displacement values) to plot the trajectory of the directional wells is as follows:

1. Open the folder of the computer program, then open the selected type of trajectory folder and run program.
2. Enter the required initial values in their respective text boxes.
3. Then, click on the 'ENTER' button to generate the other working values.
4. Carefully copy the values of depth to horizontal displacement on a spread sheet, preferably Microsoft excel.
5. Then, make a plot of these values with the depth on the vertical (y-axis) in a reverse other.
6. Finally, adjust the plot to scale to properly show the trajectory of the directional well.

9.0 Results

In this section, we shall put the design model to a test. Two examples, for S-Type Trajectory and Double Build Trajectory, have been selected.

The S-Type Trajectory

EXAMPLE

GIVEN DATA

Y_0=500ft	X_0=0ft	Y_2=4,000ft	X_H=X_M=4,000ft
Y_H=12,000ft	q_1=1^0/100ft	Y_M=15,000ft	q_2=2^0/100ft

SOLUTION:

The S-Type program was run and initial values entered as shown in Figure 6. Then, the 'ENTER' button was clicked and the other working values were generated by the program as shown in Figure 6.

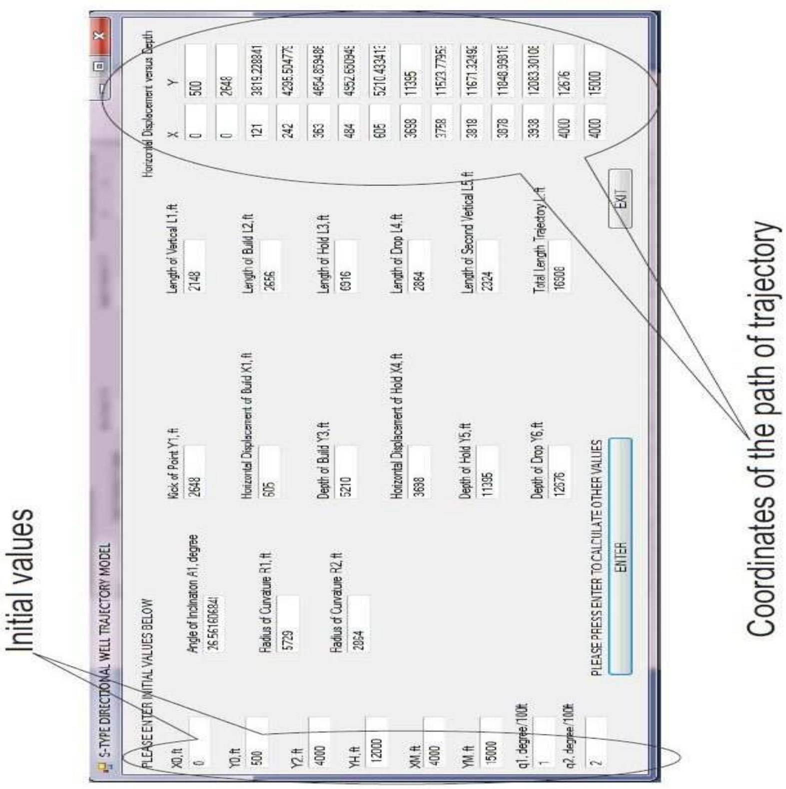


Figure 6: THE VISUAL BASIC INTERFACE FOR S-TYPE TRAJECTORY

The x and y values were carefully copied into a Microsoft excel spread sheet and the trajectory of the S-Type directional well was plotted as shown in Figure 7

HORIZONTAL DISPLACEMENT X, ft	DEPTH Y, ft
0	500
0	2648
121	3819.229
242	4295.505
363	4654.859
484	4952.651
605	5210.433
3698	11395
3758	11523.78
3818	11671.33
3878	11849
3938	12083.3
4000	12676
4000	15000

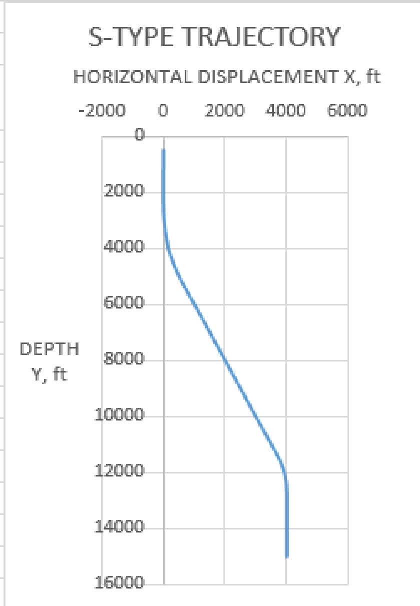


Figure 7: The Table and Graphical Presentation of The S-Type Trajectory

The Double Build Trajectory

EXAMPLE:

GIVEN DATA

Y_0=300ft X_0=0ft Y_2=5,000ft X_H=4000ft

X_M=12,000ft $Y_H=Y_M$ $q_1=2^0/100$ft Y_M=15,000ft $q_2=1^0/100$ft

The Double Build program was run and initial values entered as shown in Figure 8. Then, the 'ENTER' button was clicked and the other working values were generated by the program as shown in Figure 8

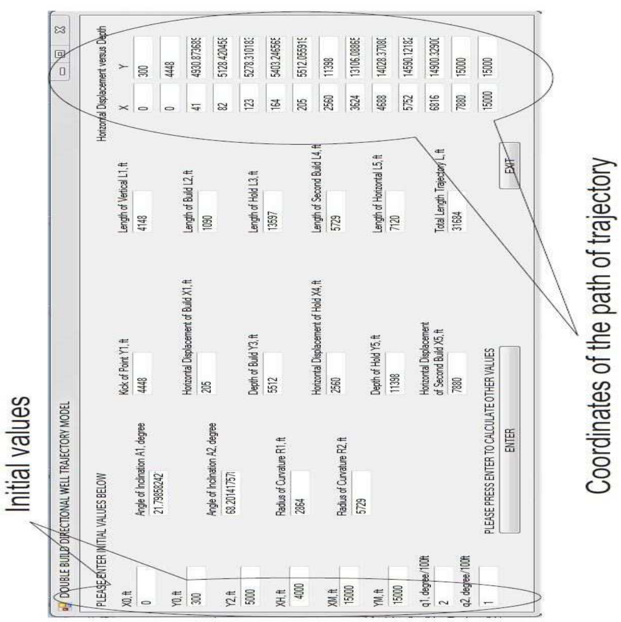
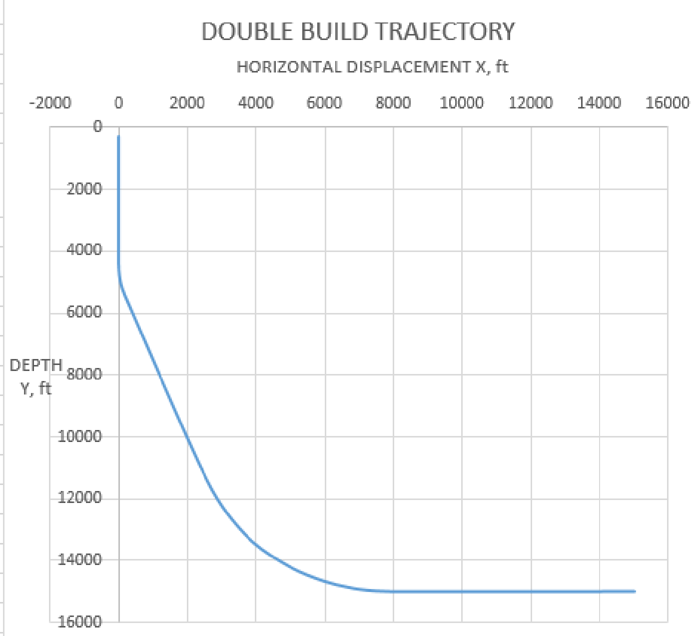


Figure 8: The Visual Basic Interface for the Double Build Trajectory

The x and y values were carefully copied into a Microsoft excel spread sheet and the trajectory of the double build directional well was plotted as shown in Figure 9

HORIZONTAL DISPLACEMENT X, ft	DEPTH Y, ft
0	300
0	4448
41	4930.874
82	5128.42
123	5278.31
164	5403.247
205	5512.056
2560	11398
3624	13106.09
4688	14028.37
5752	14590.12
6816	14900.33
7880	15000
15000	15000



Sheet1

Figure 9: The Table and Graphical Presentation of the Double Build Trajectory

10.0 Conclusion

In light of the above, the following inference can be drawn.

1. The directional well trajectories were successfully designed by use of the new model.
2. The plots clearly revealed the path of the trajectories in depth to horizontal displacement.
3. Computations were simplified when compared to the cumbersome calculations associated with existing models.
4. The cost of the designs was relatively cheap.

In addition, the concept of the model can be applied to some other type of trajectories of directional wells. This makes the model much more robust and flexible than most design models.

11.0 References

[1] Adam T. Bourgoyne Jr., Keith K. Millheim, Martin E. Chenevert, F. S. Young Jr. (1991) Directional Drilling and Deviation Control, Applied Drilling Engineering, Society of Petroleum Engineers, Richardson TX, pp. 351-453Dr.

[2] Baker Hughes Inteq (1995) Directional Drilling, Drilling Engineering Workbook, pp. 5.2-5.98

[3] NEAL J. ADAMS (1985) Directional Planning, Drilling Engineering, pp. 331-356, PennWell Publishing Company, Oklahoma, USA

[4] Bill Mitchel (1995) Directional Drilling, Advanced Oil Well Drilling Engineering Handbook, 10th Edition, Mitchell Engineering, pp. 296-359

[5] Andreas Holm Stromhaug (2014) Directional Drilling- Advanced Trajectory Modeling, NTNU, http://www.diva-portal.org/smash/get/diva2:746157/FULLTEXT01.pdf, Date Accessed: August 2015.

[6] Kate Mantle (2014) Art of Controlling Wellbore Trajectory, Defining Directional Drilling, Oilfield Review, Winter2013/2014, pp. 54-55

[7] Farah Omar Farah (2013) Directional Well Design, Trajectory and Survey Calculation, With a Case Study in Fiale, Asal Rift, Djibouli, United Nations University Geothermal Training Programme, Reykjavik, Iceland, pp. 625-657

[8] Stroud K A, Dexter J Booth (2001) Engineering Mathematics, 5th Edition, Industrial Press, Inc. New York

[9] Roger A. Johnson (1960) Advanced Euclidean Geometry, Dover Publications, Inc., New York, pp. 110-125

[10] VISUAL BASIC 2015 TUTOR, http://www.vbtutor.net/index.php/visual-basic-2013-tutorial/, Date Accessed: August 2015.