3. COMPARATIVE STUDY OF DIRECTIONAL SURVEY COMPUTATION MODELS IN DIRECTIONAL DRILLING TECHNOLOGY FOR NIGER DELTA FORMATION USING FORTRAN†

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Abstract

A main setback of directional and horizontal well drilling is the complex computations that is involved to be done while drawing up plan for a welltobedrilled. The calculations involved are tedious and take a lot of time especially when it is done manually. One of the reason of carrying out this study was to use computer program .A FORTRAN program was used for the Minimum Curvature method (and for other four methods which are the Tangential, Angle Averaging, Balanced Tangential and Radius of Curvature) for planning and designing well path. The differences in results obtained using the four methods are very small hence any of the techniques can be used for calculating the well trajectory but the degree of error in Tangential method is higher and is highly deviated from the plan hence it is not proper to use it in directional survey calculation. From the T-Test carried out and graphs plotted, the best and most accurate method for directional survey computation can be said to be the Minimum Curvature Method because it is highly superimposed on the plan.

†***African Journal of Physics Vol.10, pp. 37-51, (2017)***
ISSN: PRINT: 1948-0229 CD ROM:1948-0245 ONLINE: 1948-0237

1. INTRODUCTION

Directionally drilled wells represent an effectivemethod to reach special targets that are difficult to reach using vertically drilled wells (Farah, 2013). The techniques used to obtain the values needed to compute and draw the 3D well path is known to be directional survey (Sperry-Sun, 2001). When drilling a directional well, the trajectory of the well must be checked from time to time to be certain that it conforms to the planned trajectory. This is achieved by surveying the location of the well at consistent intervals. Surveys are carried out at close intervals (30 ft or every connection) in the critical sections of the well. Normally the surveying programme will be stated in the drilling programme. If the well was not drilled according to its planned course, a directional orientation tool must be run to correct it. In general, the earlier such problems are recognized the easier they are to be corrected. Surveying therefore plays a very important role in directional drilling (Robert, 2006).

There are three parameters that are recorded at multiple locations along the well path and they are; MD, inclination, and hole direction. MD is the real depth of the hole drilled to any location along the wellbore. Inclination is the angle in degrees, by which the wellbore or survey instrument axis changes from an actual vertical line (Inglis, 1987)

This work is to develop a program that will be able to compare directional survey models and select the most accurate one for computation in directional drilling.

This study will help the drilling engineers with the best model for calculating well path position and direction.Hence,there will be reduction of risks and uncertainty or prevent deviation from targetand minimize drilling cost (Robello et al, 2007).

Surveys are taken to permit calculation of well coordinates at different measured depths, thereby accurately specifying the path of the well and the current location.

Accurate Knowledge of a borehole is necessaryforthefollowingreasons:

To hit geological target areas.

To avoid interception with other wells, especially during platform drilling.

To specified the aim of a relief well in the course of a blowout.

To give a better definition of geological and reservoir data to allow for optimization of production.

To accomplish the requirements of local legislation.

There are some surveying terms and their meaning;

Measured Depth (MD); is the length measured along the real course of the bore hole from the reference point to the survey point.

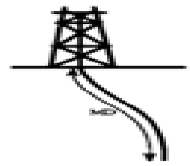

Fig. 1: True Vertical Depth

The vertical depth ((TVD) is the vertical length from the depth reference level to a corresponding point on the borehole course. This is shown in Fig.1

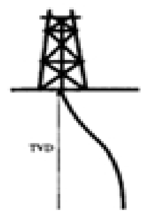

Fig 2: Inclination (drift)

Inclination is the angle between the local vertical and the tangent to the well bore axis at a particular point. By oilfield convention, 0° is vertical and 90° is horizontal. This is shown in Fig. 2.

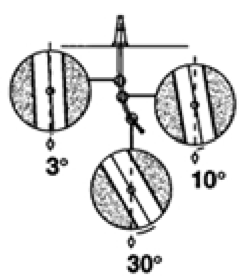

Fig3: Azimuth (hole direction)

The azimuth of a borehole at a point is the direction of the borehole on the horizontal plane, measured as a clockwise angle (0°-360°) from the North as shown in Fig3.

2. Methods for Calculating Wellbore Trajectories

There are over eighteen ways available for computing or finding the path of a wellbore (Bourgoyne et al, 1991). The major difference in all the methods is that one uses straights lines and the other assumes the wellbore to be a curve.Below are five of the methods arranged in ascending order of preference and also intricacy of the techniques?

1. Tangential techniques
2. Balanced tangential techniques
3. Angle Averaging techniques
4. Radius of techniques
5. Minimum radius of curvature techniques

The Tangential techniques are also referring to as backward station or terminal angle method. It is the easiest techniqueused for years (Bourgoyne, 1991).

The balanced tangential techniques use trigonometric functions which are used for computation.

The averaging method uses the angles average over a course length increment in its calculations (Bourgoyne , 1991). This depends on the assumptionthat wellbore is parallel to the average of both the drift and course angles between two stations.

The radius of curvature techniques assumes that wellbore is a smooth arc between surveys (Tarek, 2000).

Minimum curvature techniques have been accepted in industry as standard for the calculation of 3D directional surveys. The well's trajectory is represented by a different circular arcs and straight lines (Sawaryn, 2005). This method involves very complex computation but with the advent of computers and programmable hand calculators, it has become the most acceptable method for the industry. Table 1 shows the parameters that determine accuracy of the five methods.

Table 1 Comparison of accuracy of the five methods (Bourgoyne et al, 1991**)**

Method	TVD	Diff. From Actual (ft)	North Displacement	Diff. From Actual (ft)
Tangential	1628.61	-25.38	998.02	43.09
Balanced Tangential	1653.61	-0.38	954.72	-0.21
Angle –Averaging	1654.18	0.19	955.04	0.11
Radius of Curvature	1653.99	0	954.93	0
Minimum Curvature	1653.99	0	954.93	0

The data type required to carry out this study are;

1. A well plan data for an X-well shown in Table 2.

Table 2 Well plan data for an X-well

PLAN		
Measured Depth (MD) (meters)	**Inclination (I) (meters)**	**Azimuth (A) (meters)**
0	0	0
30.00	0.00	0.00
150.00	0.00	0.00
270.00	0.00	0.00
390.00	0.00	0.00
540.00	11.48	350.00
690.00	17.67	12.80
791.20	21.50	35.00
934.74	29.38	63.84
1050.00	32.98	75.52
1170.00	40.85	85.41
1260.00	42.00	86.53

2. Measurement While Drilling (MWD) survey data for the X-well as shown in Table 3 which includes Measured Depth (MD), Inclination Angle (I) and Azimuth (A).

Table 3 Real time survey data for well X

ACTUAL		
Measured Depth (MD) (meters)	***Inclination (I) (meters)***	***Azimuth (A) (meters)***
0	*0*	*0*
30.00	*0.97*	*121.00*
150.00	*1.32*	*134.27*
270.00	*0.26*	*145.00*
388.00	*0.00*	*198.70*
532.00	*9.06*	*336.51*
675.30	*24.90*	*0.50*
791.30	*27.18*	*26.69*
934.74	*29.38*	*63.84*
1049.30	*29.03*	*89.89*
1164.55	*39.59*	*87.69*
1252.50	*42.20*	*87.80*

The well plan and MWD survey data used in this work were gotten from an X-well recently drilled in Port-Harcourt, Rivers State Nigeria.

3. Procedure

STEP 1: Design of program using the FORTRAN programming language for all the formulas needed for calculations under the scope of this work.
STEP 2: Testing of program using data gotten from the work done by Richard Amorin in 2009.
STEP 3: Computation of the 3D-coordinates and other calculation necessary using the tested program, with the data gotten form the X-well.
STEP 4: Comparing and analyzing of results.
Figure 5 istheflowchartoftheprogram

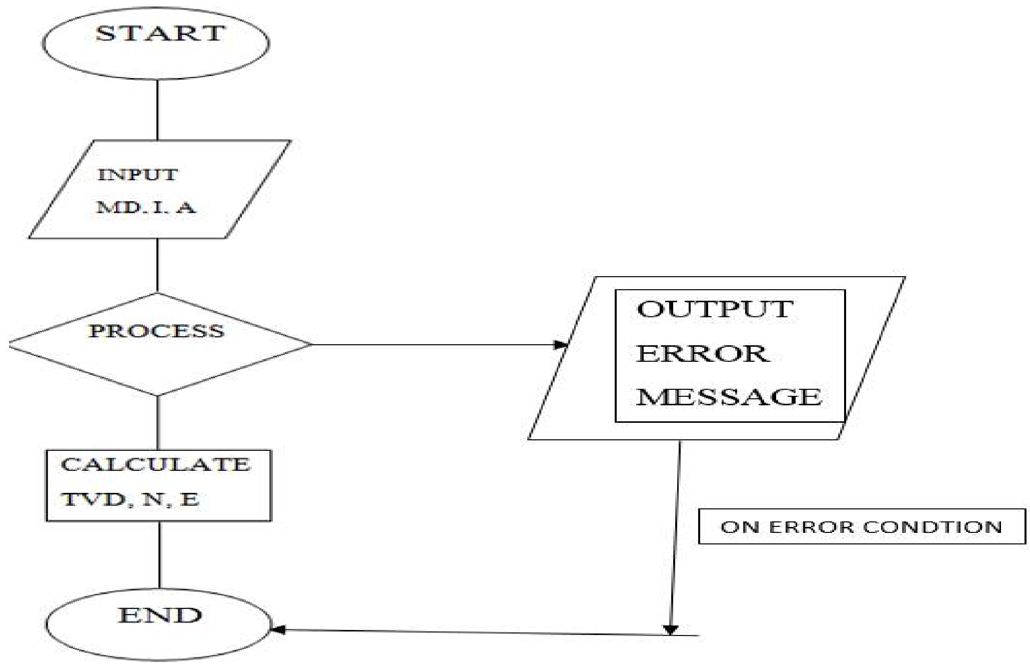

Fig 5: Flow Chart Program Algorithm

A sample of the algorithm used in this work is shown below, others can are shown in appendix A.

```
program Tangential
double precision::pi,E1, MD1,MD2,R1,V1,b1,b2, TVD1
real:: I1,I2, A1,A2
print*, 'Enter the values of b2 and b1'
read*,b2,b1
```

```
pi= 4.0*atan(1.0)
MD1 = b2-b1
print*,'The Result of MD1 is:',MD1
print*, 'Enter the values of I2 and A2'
read*,I1,A1
E1 = MD1*sin(I1*pi/180)*sin(A1*pi/180)
print*,'The Change in Easting is',E1
R1 = MD1*sin(I1*pi/180)*cos(A1*pi/180)
print*,'The Change for Northing is:',R1
V1= MD1*cos(I1*pi/180)
print*, 'The Change in TVD is:',V1
TVD1 = b2+V1
print*,'the Result of tvd is:',TVD1
Vs1=R1*cos(Vsd*pi/180)+E1*sin(Vsd*pi/180)
print*,'The vertical section is '
print"(f10.2)",Vs1
CDis1=SQRT((R1)**2+(E1)**2)
print*,'The closure distance is:',CDis1
CDir1= atan((E1/R1)*pi/180)
print*,'The closure direction is:'
print"(f10.2)",CDir1
end Tangential
```

Data Input Interface

The data needed to be entered for the computation of the 3D-coordinates are Measured Depth (MD), Inclination angle (I) and measured bearing “Azimuth” (A).

Where MD is in ft, inclination and azimuth are in degrees.

Validation Of The Fortran Program

Two literature data were used in validating the FORTRAN program. (1) Data used by Adams, (1985) and (2) data from Bourgoyne, (1991).

4. Results

The results of Tangential method is shown inTable 4. From the result, one can see that as True Vertical Depth (TVD) increases, the vertical section also increases.From result also there was negative value for vertical section (-3.16).This is an indication of deviation. In order to get the positive vertical section or zeroVertical section, a well path must have difference of angle between vertical section direction and average Azimuth, within arrange of +90 to -90 degree.The values of TVD and Verticalsection were used to plot figure 6.

Table 4: Tangential Method Result

TANGENTIAL METHOD			
True Vertical Depth (TVD) (meters)	Northing (N) (meters)	Easting (E) (meters)	Vertical Section (Vs) (meters)
0	0	0	0
30	-0.26	0.43	0.38
149.97	-2.19	2.41	2.01
269.98	-2.63	2.73	2.25
387.97	-2.64	2.73	2.25
530.17	18.16	-6.31	-3.16
660.15	78.49	-5.78	7.53
763.34	125.83	18.02	38.96
888.33	156.86	81.18	106.45
988.50	156.97	136.78	161.27
1077.31	159.93	210.16	234.10
1141.76	162.17	268.56	292.04

The results of Balanced Tangential method is shown in Table 5. Here,we can see that the results are similar to that of Tangentialmethod.To also get the positive vertical section or zero vertical section, a well path must have different of angle between vertical section direction and average Azimuth, within arangeof +90 to -90 degree.The values of TVD and Vertical section were used to plot figure 7.

Table 5: Balanced Tangential Method Result

BALANCED TANGENTIAL METHOD			
True Vertical Depth (TVD) (meters)	Northing (N) (meters)	Easting (E) (meters)	Vertical Section (Vs) (meters)
0	0	0	0
30	0.22	-0.13	-0.09
149.98	-1.62	2.08	1.78
269.96	-2.8	3.22	2.70
387.96	-3.03	3.38	2.82
531.06	7.37	-1.14	0.12
666.81	47.89	-5.38	2.77
771.01	95.98	6.74	22.82
897.31	140.76	53.03	75.99
997.30	153.20	106.05	130.35
1092.10	154.74	170.71	194.34
1157.09	156.95	226.96	250.16

The results of Angle Averaging method is shown in Table 6. Here,we can see that the results are similar to that of Tangential method. To also get the positive vertical section or zero vertical section, a well path must have different of angle between vertical section direction and average Azimuth,within arangeof +90 to -90 degree.The values of TVD and Vertical section were used to plot figure 8.

Table 6: Angle Averaging Method Result

AVERAGE ANGLE METHOD			
True Vertical Depth (TVD) (meters)	Northing (N) (meters)	Easting (E) (meters)	Vertical Section (Vs) (meters)
0	0	0	0
30	0.13	0.22	0.24
149.98	-1.34	2.12	1.86
269.97	-2.60	3.19	2.71
387.96	-2.86	3.23	2.70
531.51	-3.34	-8.13	-8.58
668.57	-44.35	0.21	-7.27
772.79	5.15	12.18	12.87
899.11	52.98	60.45	68.51
999.11	65.68	114.89	124.31

1094.31	67.05	179.84	188.57
1160.07	69.29	236.75	245.04

The results of Radius of Curvature method is shown in Table 7. Here,we can see that the results are similar to that of Tangential method. To also get the positive vertical section or zero vertical section, a well path must have different of angle between vertical section direction and average Azimuth, within arangeof +90 to -90 degree.The values of TVD and Vertical section were used to plot figure 9.

Table 7: Radius of Curvature Method Results

RADIUS OF CURVATURE METHOD			
True Vertical Depth (TVD) (meters)	Northing (N) (meters)	Easting (E) (meters)	Vertical Section (Vs) (meters)
0	0	0	0
30	0.10	0.18	0.19
149.98	-1.35	2.08	1.82
269.96	-2.62	3.15	2.66
387.96	-2.87	3.18	2.65
531.36	-3.24	-5.62	-6.09
667.98	-6.13	-5.03	-5.99
772.20	42.93	6.83	13.97
898.51	89.92	54.26	68.63
998.51	102.52	108.23	123.96
1093.57	103.89	173.08	188.11
1159.33	106.13	229.99	244.58

The results of Minimum Curvature method is shown in Table 8. Here,we can see that the results are similar to that of Tangential method except that there was no negative value for vertical section. Therefore there will be no need for conversion as it was done for others..The values of TVD and Vertical section were used to plot Figure 10. Minimum Curvature Method is more accurate because it is highly superimposed on the plan when compared with others.

Table 8: Minimum Curvature Method Result

MINIMUM CURVATURE METHOD			
True Vertical Depth (TVD) (meters)	Northing (N) (meters)	Easting (E) (meters)	Vertical Section (Vs) (meters)
0	0	0	0
30	0.22	-0.13	0.19
149.98	-1.62	2.08	1.78
269.96	-2.81	3.22	2.70
387.96	-3.03	3.38	2.82
531.07	7.37	-1.14	0.11
666.82	47.89	-5.38	2.78
771.02	95.98	6.74	22.90
897.32	140.76	53.04	76.49
f997.32	153.20	106.05	131.07
1092.11	154.74	170.71	195.25
1157.10	156.95	226.96	252.33

Comparison

The results gotten for TVD and Vertical section was used for the vertical section plot. The graphs below shows the vertical section plot, they are a plots of Actual vs Plan.

Fig. 6.shows a graph of TVD on the vertical axis andvertical section on the horizontal axis. It is a graph of actual survey thatform the tangential method versus planned survey. The red line represent the well path from the plan while the blue line represent the actual survey calculated using the Tangential method.

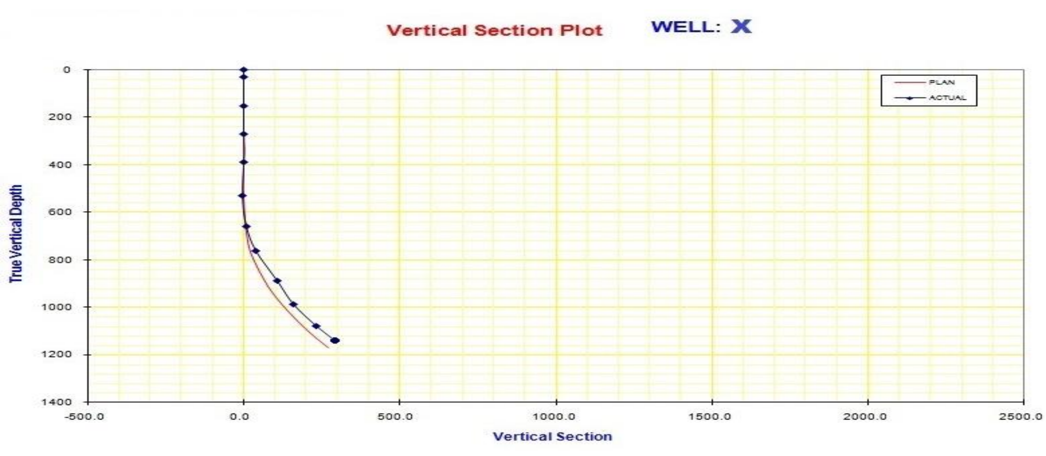

Fig.6 Tangential Method

Fig.7 shows a graph of TVD on the vertical axis and vertical section on the horizontal axis which is the vertical section plot. It is a graph of actual survey thatform the balanced tangential method versus planned survey. The red line represents the well path from the plan while the blue line represent the actual survey calculated using the balanced tangential method.

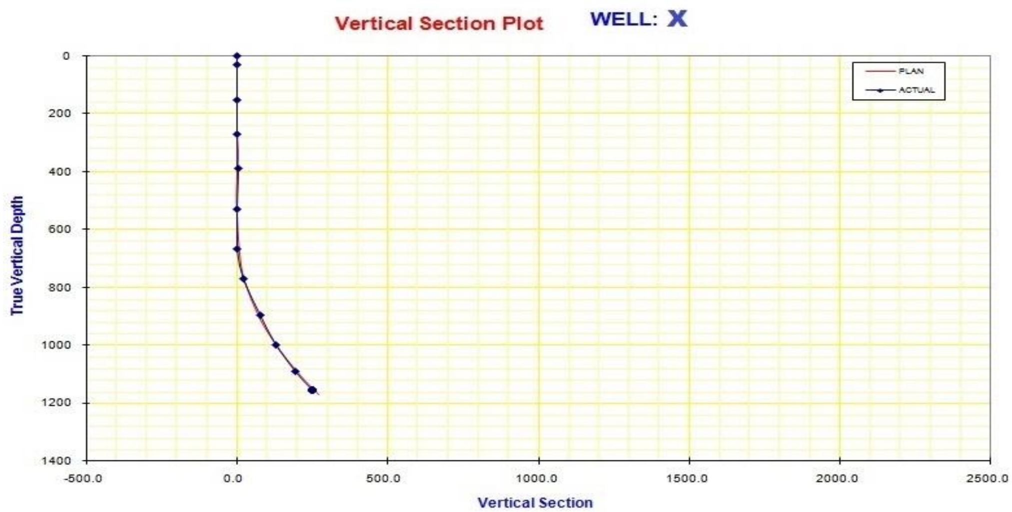

Fig. 7: Balanced Tangential Method

Fig.8 shows a graph of TVD on the vertical axis and vertical section on the horizontal axis which is the vertical section plot. It is a graph of actual survey form the Angle Averaging method versus planned survey. The red line represent the well path from the plan while the blue line represent the actual survey calculated using the Angle Averaging method.

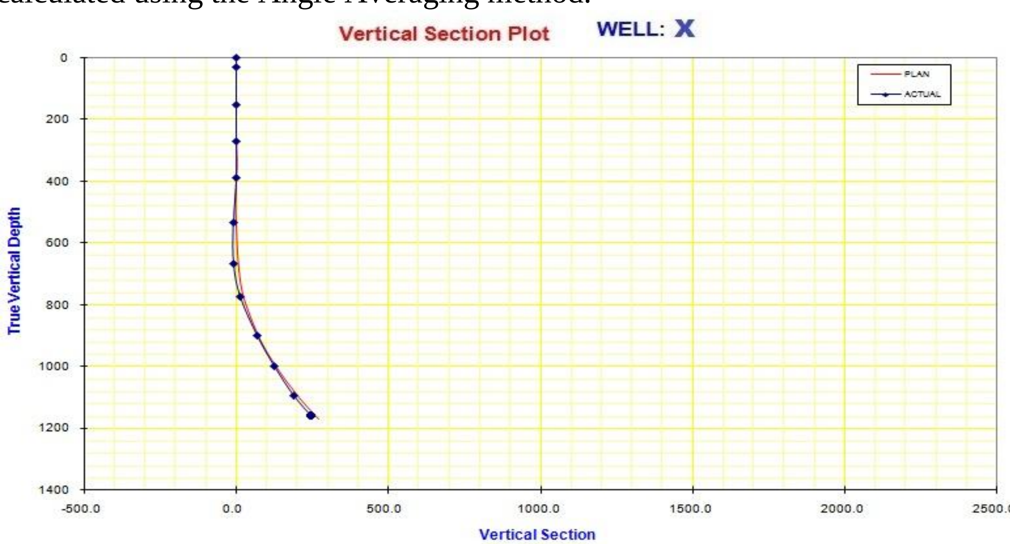

Fig.8: Angle Averaging Method

Fig.9 shows a graph of TVD on the vertical axis and vertical section on the horizontal axis which is the vertical section plot. It is a graph of actual survey form the Radius of Curvature method versus planned survey. The red line represents the well path from the plan while the blue line represent the actual survey calculated using the Radius of Curvature method.

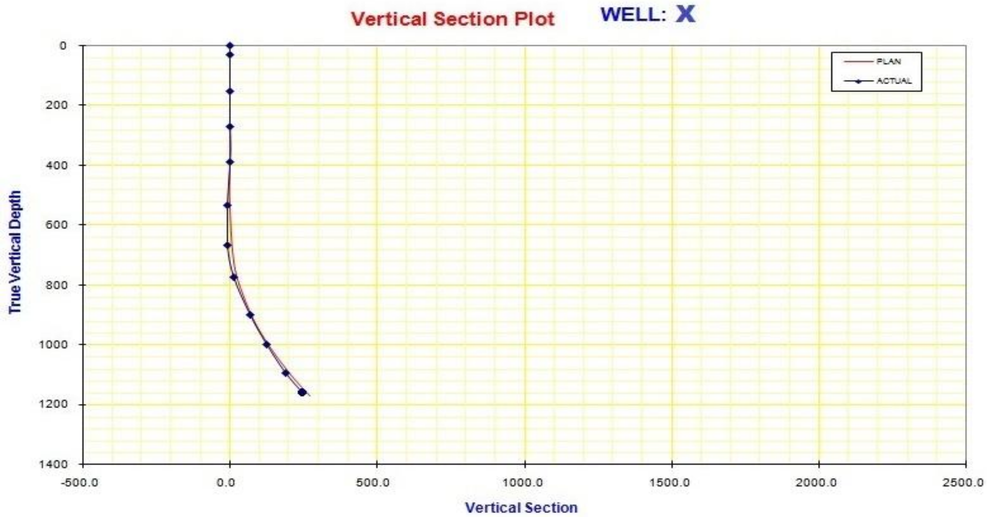

Fig. 9: Radius of Curvature Method

Fig.10 shows a graph of TVD on the vertical axis and vertical section on the horizontal axis which is the vertical section plot. It is a graph of actual survey form the Minimum Curvature method versus planned survey. The red line represents the well path from the plan while the blue line represent the actual survey calculated using the Minimum Curvature method.

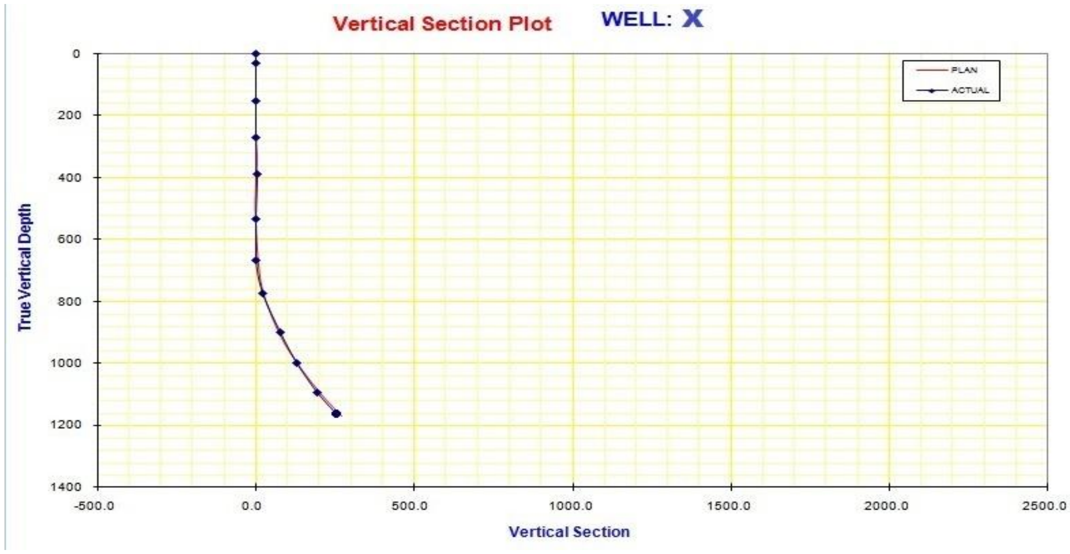

Fig. 10: Minimum Curvature Method Vs Plan

Observation and Analysis

The following observations and analysis can be drawn from the graphs above

The tangential method shows considerable error, the deviation from plan is highly noticeable hence the least accurate followed by the angle averaging method. The radius of curvature method shows negligible deviation from the plan. The balanced tangential and minimum curvature methods are highly superimposed on the plan.

Comparison Using T-Test Statistical Method

Using the T-Test statistical method to compare the values gotten for the vertical section from plan with that of the actual survey for the Angle Averaging, Balanced Tangential, Radius of Curvature and the Minimum Curvature methods, the result gotten is tabulated below;

Table 9. Table showing the result of the T-Test

Table 9 Result of the T-TestMETHOD	T-RATIO
Balanced Tangential Method vs plan	0.11
Angle Averaging Method vs plan	0.23
Radius of Curvature Method vs plan	0.22
Minimum Curvature Method vs plan	0.10

“Null hypothesis”: H_o= mean of X – mean of Y = 0

Significant level (α)= 0.05

The degree of freedom (df) = 12+12-2 = 22
From the t-ratio tabled value as shown in appendix C, ($\alpha = 0.05$) for 22df is 2.074. Therefore, since the obtained t-ratios from table 4.6 are all far lesser than that of the tabled value (2.074) then the "null hypothesis" H_o is accepted.
Also from table 4.6, it can be seen that the minimum curvature method vs plan has the lowest t-ratio of 0.10, and the lower the t-ratio, the more accurate the null hypothesis.

Conclusion

From the T-Test carried out and graphs plotted, the best and most accurate method for directional survey computation can be said to be the Minimum Curvature Method because it is highly superimposed on the plan.

References

Adams J. N. and Charrier T., (1985), Drilling Engineering, "A Complete Well Planning Approach", PennWell Publishing Company, Tulsa, Oklahoma

Bourgoyne A.T., Millheim, K.K., Chenevert, M.E., and Young, F.S. Jr., (1991) Applied drilling engineering. SPE Textbook Series, 2, 502 pp

Farah F. O. (2013) Directional well design, trajectory and survey calculations, with a case study in Fiale, Asal Rift, Djibouti.

Inglis T. A.,, (1987), Directional Drilling, Vol. 2, Aiden Press, Oxford, Great Britain

Richard A.,(2009), "Application of Minimum Curvature Method To Well path Calculations".

Robello Samuel and Xiushan Liu, (2007), "Advanced Drilling Engineering-Principles and design", Gulf Publishing Company

Robert, F.M. and Larry W.L., (2006), Petroleum Engineering Handbook Volume II.

Sawaryn S.J., SPE, and Thorogood J.L, "A Compendium of Directional Calculations Based on the Minimum Curvature Method", SPE 84246-PA, 2005, 1st "Presented at the 2003 SPE Annual Technical Conference and Exhibition", Denver. Colorado.

Sperry-Sun (2001) Directional surveying fundamentals.Sperry-Sun Training Department, a Halliburton Company, Houston, TX, United States, 108 pp.

Tarek Ahmed, (2006), Reservoir Engineering Handbook, Fourth Edition, Gulf Publishing Company, Houston, Texas.