Available online at www.ejournals.uofk.edu

UofKEJ Vol. 7 Issue 1 pp. 52-57 (February 2017)

UNIVERSITY OF KHARTOUM ENGINEERING JOURNAL (UOFKEJ)

Directional Drilling Design Using Computer Model

Mugahid A. Musa, Mosab M. Ahmed, Mohammed A. Yusuf, Hassan B. Nimir

Department of Petroleum and Natural Gas, Faculty of engineering, University of Khartoum
Khartoum, Sudan (E-mail: mosabpetro@gmail.com)

Abstract: The number of directionally drilled wells in Sudan is progressively increasing. Directional drilling calculations when done manually or through Microsoft Excel are tedious, susceptible to mistakes and take long time. The software prescribed in this paper is designed to treat these problems. This paper describes Software called CDD which stands for Computerized Directional Drilling. It is employing the minimum curvature method using visual basic (VB.NET) as a programming language to achieve calculations and minimize the uncertainty and risks related to achieve a predetermined target. The Software is capable of calculating the survey data of the well trajectory for all types of directional drilling wells. In addition, the CDD computes the actual coordinates along the planned trajectory at regular or irregular intervals and designs plots to show the well trajectory in 2D charts in top and side views. It also gives 3D graph for more visual representation of the well trajectory. The CDD enables the user to compare different well trajectories and show them in the same chart. The input data could be saved in the database section and the output results could be exported into various formats. Based on applying the CDD on the Case Studies, this Software gives accurate results and can be used in planning of CDD with error of less than 1%.

Keywords: *Drilling Engineering; Directional Drilling; Software; Well Design; Horizontal Wells; Well Trajectory.*

1. INTRODUCTION

Directional Drilling (DD) is the Science and Art of deviating a wellbore along a planned course to a subsurface target whose location is a given lateral distance and direction from the vertical [1].

DD has become a commonly very important technology in petroleum industry. Some of the major applications of DD are: Inaccessible surface location, salt-dome exploration, multiple target zones and side-tracking [2].

The first step in planning any directional well is to design the wellbore path, or trajectory to intersect a given target. The initial design should propose the various types of paths that can be drilled economically [3].

A major drawback of directional and horizontal well drilling is the numerous complex computations required to be done ahead of time before drilling resumes and also during drilling operations. These computations become very tedious and more complex when done manually [4]. The Software programs available in the market used for these computations are usually very expensive to acquire and are subjected to American Sanctions (e.g. COMPASS™ and Hawk Eye™). Development of a Computer Software which employs the Minimum Curvature Method for well path planning would help to minimize the stress and time in executing these complex computations. More importantly, such Computer Software is flexible and can easily be modified and updated at any time to meet the needs of Petroleum industry.

In this paper the Minimum Curvature Method is used to construct well path using computer software to determine its optimum parameters. This would help reduce risks and uncertainty and prevent deviation from target depth. Consequently, it minimizes Non-Productive Time (NPT) and reduces drilling cost. This would therefore enhance planning process and maximize return on investment.

This work aims to use Minimum Curvature Method to design Computer Software that is capable of calculating the survey data of the well trajectory for all DD well types. In addition, it aims to construct plots to show the well trajectory in 2D charts in top view and side view as well as 3D view. Furthermore, to enable the user to compare different well trajectories and show them in the same charts. Finally, to handle a large amount of data using the means of export and import in various formats as well as saving the input data in the database.

2. MATERIAL AND METHODS

2.1. Types of Directional wells

In the following part different types of directional wells as well as known methods will be reviewed:

2.1.1. Build and Hold

This pattern employs a shallow initial deflection and a straight-angle approach to the target. The wellbore penetrates the target at an angle equal to the maximum build-up angle. It requires the lowest inclination angle to hit the target as shown on Fig. 1-A.The Build and Hold model is mostly used for Moderate depth wells with no intermediate casing and deeper wells without large lateral displacement [6].

2.1.2. Build, Hold and Drop (S-shape)

They are made up of a vertical section, a kick- off point, a build-up section, a tangent section, a drop-off section and a hold section up to target [5]. Fig. 1-B depicts the S- shape which requires high inclination angle to hit the target .For the S- shape, the wellbore trajectory penetrates the target vertically.

2.1.3. Build, Hold, partial drop and Hold (modified S-shape)

This pattern is illustrated in Fig.1-C.After a relatively shallow deflection, this pattern holds angle until the well has reached most of its required horizontal displacement. At this point, the angle is reduced to some degree to reach the target. The wellbore penetrates the target at an inclination angle less than the maximum inclination angle in the holds section.

2.1.4. Continuous Build

Continuous build pattern is shown in Fig. 1-D. This trajectory has a relatively deep initial deflection. It requires the highest inclination angle of all the trajectory types to hit the target. In this case, the inclinations keep increasing right up to or through the target. The continuous build pattern is well-suited for Salt-Dome drilling, Fault drilling and for Side-tracking [6].

2.1.5. Horizontal Drilling

Is one in which the inclination reaches 90° through the reservoir section. It has an important application in improving production from certain reservoirs that would otherwise be uneconomical. There are mainly two types of horizontal drilling, either horizontal single curve where deflection to 90° is achieved in one curve as shown in Fig. 1-E, or horizontal double curve where the well course is achieved throw two curves as in Fig. 1-F.

2.1.6. Complex Wells (Designer Wells)

There are some directional well designs that do not fit any of the above types, which are wells that with several targets and the targets are widely spaced as in Fig. 1-G. They require significant changes in azimuth along with changes in inclination. A highly engineered well plan is required in order to perform such design [7].

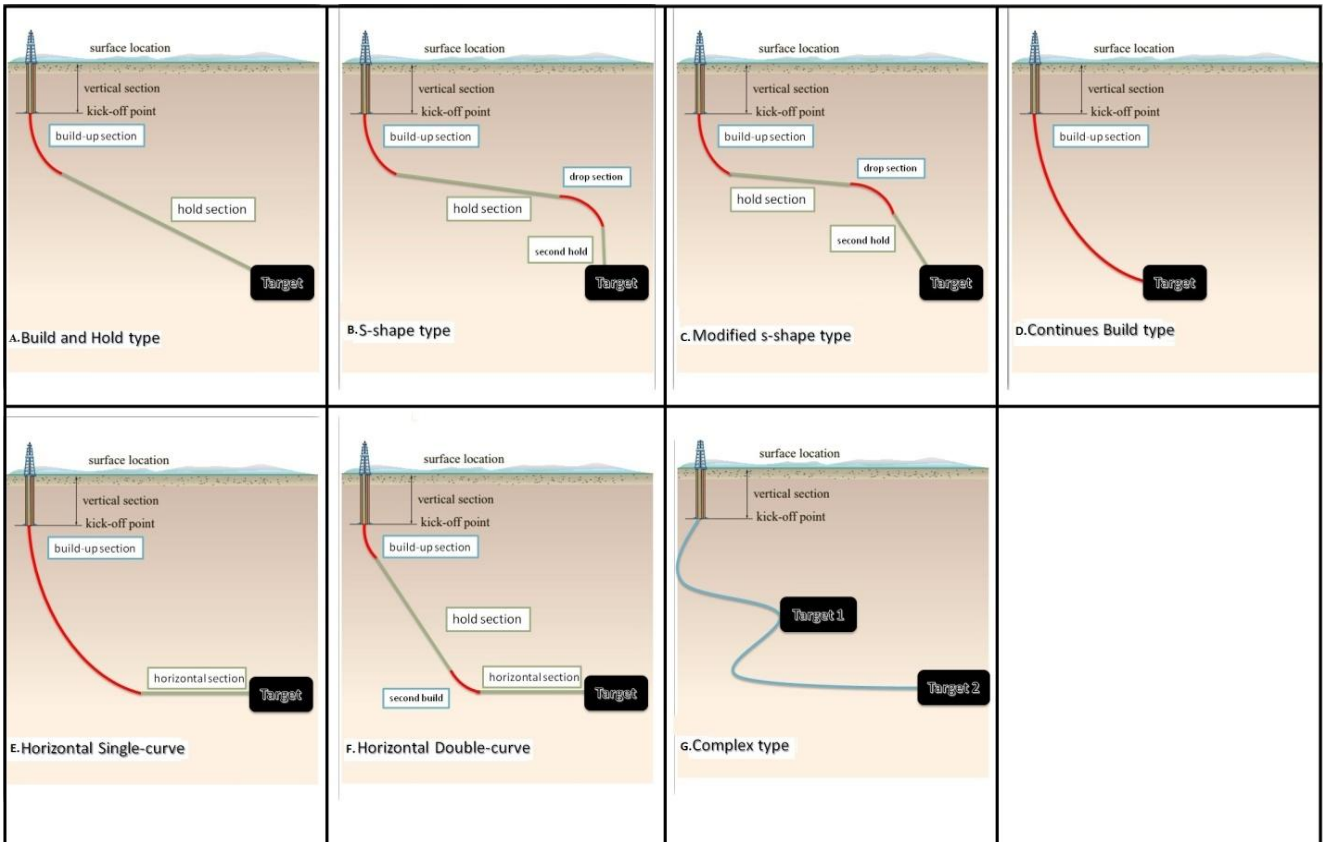

Fig. 1. Directional Drilling well types

2.2 Minimum curvature method

Minimum curvature method is illustrated in **Fig. 2**. It is one of the methods used for calculating wellbore trajectory using the principle of minimizing the total curvature within the constraints of the wellbore in order to produce a smooth circular arc. The surveys at the two stations define vectors which are tangent to the wellbore at the survey points. A Ratio Factor (RF) is used to smooth the vectors on to the wellbore curve [6]. This method involves very complex calculations but with the advent of computers, it has become the most common and acceptable method for the industry [7].
The ratio factor (RF)is calculated using Eq. (1).

$$\boldsymbol{RF = \frac{2\times180}{DL\times\pi}\times tan\frac{DL}{2}} \quad (1)$$

where, RF = Ration Factor, DL = dogleg angle in degree; and

$$\boldsymbol{cosDL = cos(I_2 - I_1) - sinI_1 \times sin\,I_2 \times (1 - cos(A_2 - A_1))} \quad (2)$$

$$\boldsymbol{\Delta TVD = \frac{\Delta MD}{2}(cosI_1 + cosI_2) \times RF} \quad (3)$$

$$\boldsymbol{\Delta N = \frac{\Delta MD}{2} \times (sinI_1 cosA_1 + sinI_2 cosA_2) \times RF} \quad (4)$$

$$\boldsymbol{\Delta E = \frac{\Delta MD}{2}(sinI_1 sinA_1 + sinI_2 sinA_2) \times RF} \quad (5)$$

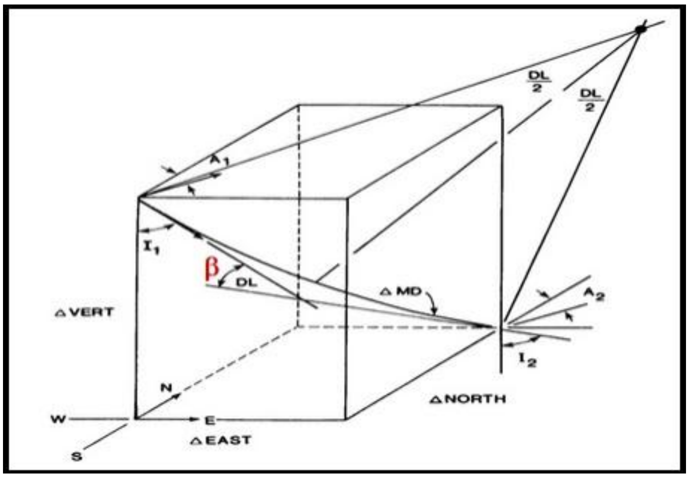

Fig. 2. Minimum curvature method [8]

where, ΔTVD=Change in True Vertical Depth, ΔMD=Change in Measured Depth, ΔN=Change in Northing ΔE=Change in Easting.

2.3. Methodology

The first step is to construct a flow diagram for the software shown in **Fig. 3**.

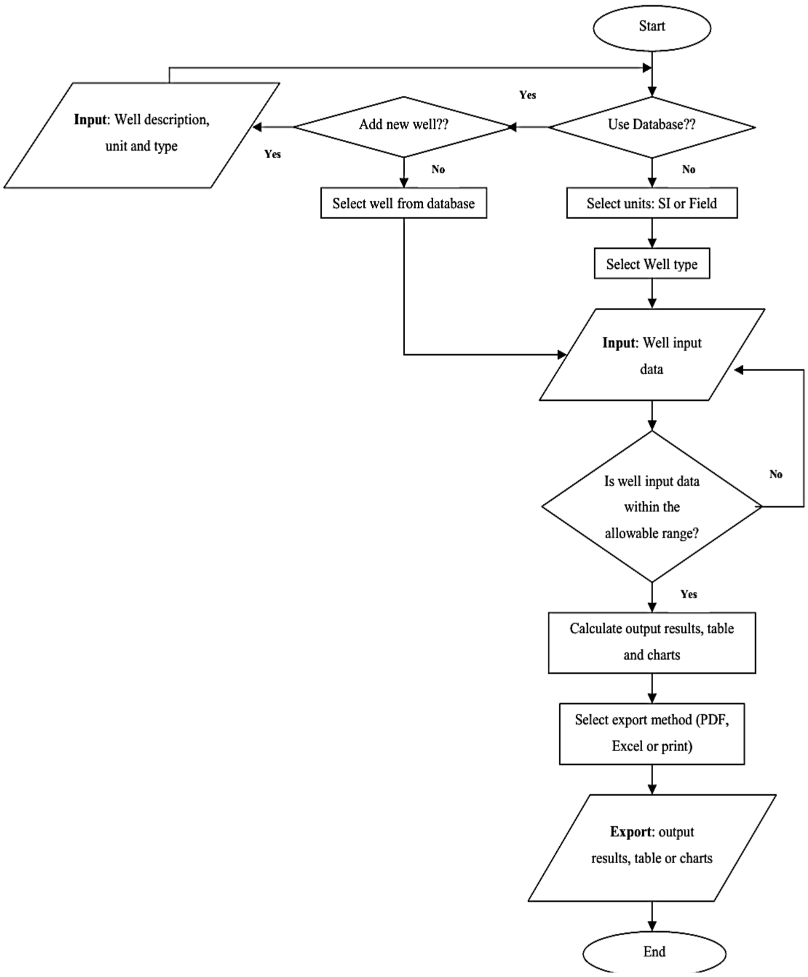

Fig.3. The Software flow diagram

The second step includes choosing suitable equations that would result in accurate calculations of the well trajectory. The most common types of survey calculations used in the industry are: Tangential, Balanced Tangential, Average Angle, Radius of Curvature and Minimum Curvature methods. Each method assumes that the survey trajectory has a specific shape which results in certain error and hence some methods are more accurate than others.

In this work, the minimum curvature method was used in the calculations since it has demonstrated conservative results while determining the position of the wellbore. The accuracy of the common methods of survey calculations are shown in **Table 1** [9].

As seen from the table, the tangential method has the highest error for TVD and displacement, while the other methods has small differences , therefore, any of them can be used for the calculations of the trajectory. However, the minimum curvature method presents the most accurate results and hence it's the most preferred method in the oil industry. Accordingly, it was utilized in this work also.

The third step starts from choosing the programming language. The choice was for visual basic (VB.NET) because it is powerful, flexible and relatively easy to learn [10]. The 2013 version of visual studio was used as software environment. Then, the user interface (UI) was designed followed by coding and equations entry. The coding enables data import and export and plots of well trajectory presentation. In addition to that a 3-D library was used to plot the trajectory. Finally, three case studies with different types of well trajectory were reviewed to determine the accuracy of the CDD.**3**

Table 1. Comparison between common trajectory methods of calculation

Methods	Results			% Difference From Actual		
	TVD Feet	NORTH Feet	EAST Feet	TVD %	NORTH %	EAST %
Tangential	4364.4	1565.23	648.4	0.144	-0.507	-0.197
Balanced Tangential	4370.46	1542.98	639.77	-0.005	0.002	0.001
Average Angle	4370.8	1543.28	639.32	-0.002	-0.005	0.011
Radius of Curvature	4370.69	1543.22	639.3	0	-0.004	0.011
Minimum Curvature	4370.7	1543.05	639.8	0	0	0

3. RESULTS AND DICUSSION

3.1. The CDD Program

The CDD has four windows with different features, but the most important window is the well mode window, which consists of many sections. Those sections are numbered in **Fig. 4**. In the figure the numbers are divided in to data input Sections 1-3, the output Sections 4-6and the export Section7 as illustrated in **Table 2.**

The chart section has three more tabs, the 3D view (Fig.5-A), the side view (Fig.5-B) and the top view (Fig.5-C), beside the "side and top view" tab shown in Fig.4.

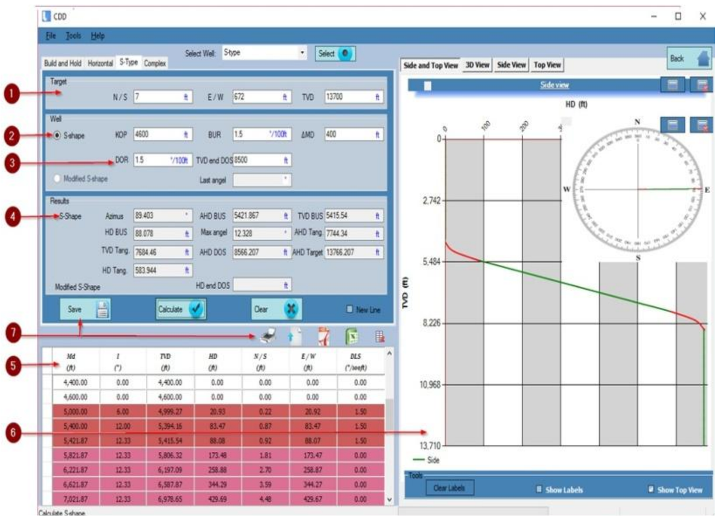

Fig. 4.CDD Well Mode main sections

Table 2. Well Mode window main sections

Sections	Sub-Sections	Data
The data input ection	1- Target coordinates	TVD, North or South, East or West
	2- Well type	BAH , continues build, … etc
	3-Well input data	KOP, Delta MD, BUR…etc
The output section	4- The output results	Azimuth, max angle, TVD BUS …etc
	5-The output table	MD , Inclination , HD …etc
	6- Charts	top view , side view , 3D view
The export section		Excel, PDF or Print out

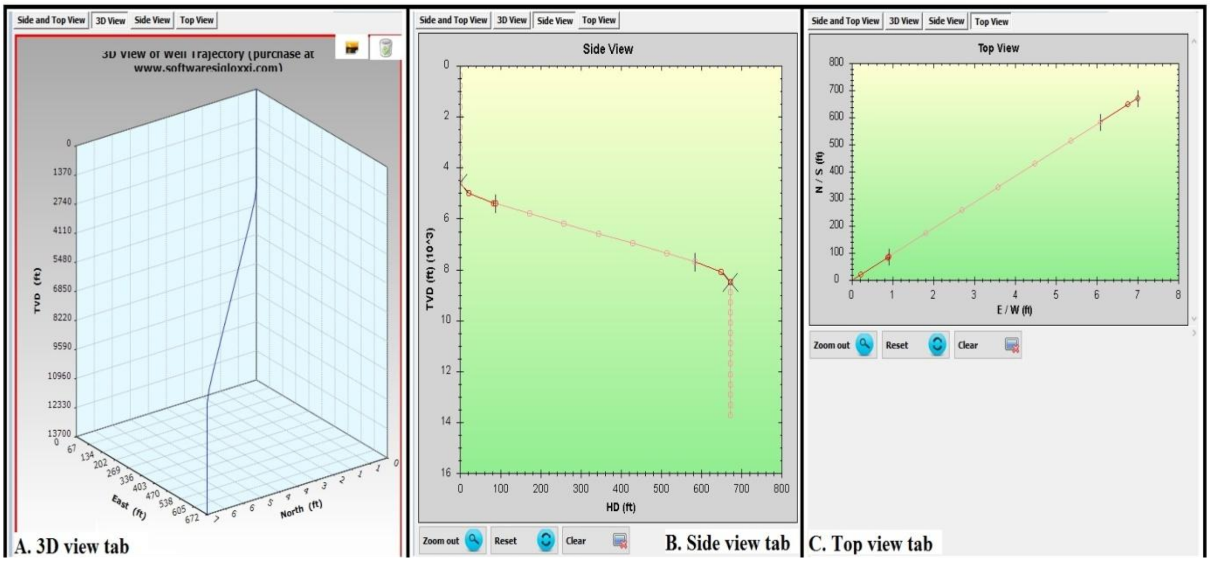

Fig. 5. The chart section tabs

3.2. Case Study

This case study is from Sudanese well in which directional drilling was used due to small reservoir thickness. This case study was used to validate the accuracy of the CDD. The comparison was done between the CDD and Software called Stoner Engineering Software V5.11 (SES) which is American leading software in directional drilling design and is being used by famous petroleum companies [11].

Table 3 illustrates the input data and the output results obtained from CDD and SES.

Table 3. Comparison of the results between CDD and SES

Input Data			SES Results								CDD Results							
Depth (m)	Inclination (deg)	Azimuth (deg)	MD (m)	I (°)	Azimus (m)	TVD (m)	N/S (m)	E/W (m)	VS (m)	DLS (°/m)	MD (m)	I (°)	Azimus (m)	TVD (m)	N/S (m)	E/W (m)	VS (m)	DLS (°/m)
0	0	0	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
405.66	0.17	93.19	405.66	0.17	93.19	405.66	-0.03	0.60	-0.50	0.01	405.66	0.17	93.19	405.66	-0.03	0.60	-0.5	0.01
518.78	0.38	114.33	518.78	0.38	114.33	518.78	-0.20	1.11	-0.86	0.06	518.78	0.38	114.33	518.78	-0.20	1.11	-0.86	0.06
669.72	0.58	118.48	669.72	0.58	118.48	669.71	-0.77	2.24	-1.55	0.04	669.72	0.58	118.48	669.71	-0.77	2.24	-1.55	0.04
819.55	0.53	62.66	819.55	0.53	62.66	819.54	-0.81	3.52	-2.64	0.10	819.55	0.53	62.66	819.54	-0.81	3.52	-2.64	0.1
893.83	1.56	196.42	893.83	1.56	196.42	893.81	-1.62	3.54	-2.25	0.79	893.83	1.56	196.42	893.80	-1.62	3.54	-2.25	0.79
924.13	4.37	212.8	924.13	4.37	212.80	924.07	-2.99	2.80	-0.93	2.88	924.13	4.37	212.80	924.05	-2.99	2.80	-0.93	2.88
961	8.74	223.63	961.00	8.74	223.63	960.69	-6.20	0.10	3.01	3.68	961.00	8.74	223.63	960.65	-6.20	0.10	3.01	3.68
1000.06	13.1	225.78	1000.06	13.10	225.78	999.03	-11.44	-5.12	10.15	3.36	1000.06	13.10	225.78	998.98	-11.43	-5.12	10.15	3.36
1030.67	14.99	228.24	1030.67	14.99	228.24	1028.72	-16.49	-10.56	17.39	1.94	1030.67	14.99	228.24	1028.67	-16.49	-10.56	17.39	1.94
1059.71	16.95	232.79	1059.71	16.95	232.79	1056.64	-21.56	-16.73	25.27	2.40	1059.71	16.95	232.79	1056.58	-21.55	-16.73	25.26	2.4
1090	18.42	237.52	1090.00	18.42	237.52	1085.50	-26.80	-24.29	34.43	2.03	1090.00	18.42	237.52	1085.44	-26.79	-24.28	34.42	2.03
1117.54	19.52	239.18	1117.54	19.52	239.18	1111.55	-31.49	-31.91	43.38	1.33	1117.54	19.52	239.18	1111.48	-31.48	-31.90	43.37	1.33
1156	23.3	243.63	1156.00	23.30	243.63	1147.35	-38.16	-44.25	57.40	3.21	1156.00	23.30	243.63	1147.27	-38.15	-44.24	57.39	3.21
1193.59	25.98	245.63	1193.59	25.98	245.63	1181.51	-44.86	-58.41	73.02	2.24	1193.59	25.98	245.63	1181.43	-44.85	-58.40	73	2.24
1232.94	26.09	245.26	1232.94	26.09	245.26	1216.87	-52.04	-74.12	90.21	0.15	1232.94	26.09	245.26	1216.78	-52.03	-74.11	90.19	0.15
1271.65	26.6	243.63	1271.65	26.60	243.63	1251.56	-59.45	-89.62	107.34	0.69	1271.65	26.60	243.63	1251.47	-59.44	-89.60	107.32	0.69
1315.14	25.47	240.1	1315.14	25.47	240.10	1290.64	-68.44	-106.45	126.41	1.32	1315.14	25.47	240.10	1290.55	-68.43	-106.43	126.39	1.32
1356.18	24.88	239.47	1356.18	24.88	239.47	1327.78	-77.22	-121.53	143.86	0.47	1356.18	24.88	239.47	1327.69	-77.21	-121.52	143.84	0.47
1394.06	25.92	239.74	1394.06	25.92	239.74	1362.00	-85.44	-135.55	160.11	0.83	1394.06	25.92	239.74	1361.91	-85.43	-135.53	160.09	0.83
1422.04	26.52	239.87	1422.04	26.52	239.87	1387.10	-91.66	-146.23	172.47	0.65	1422.04	26.52	239.87	1387.01	-91.65	-146.22	172.45	0.65
1446	27.2	240	1446.00	27.20	240.00	1408.47	-97.09	-155.60	183.30	0.85	1446.00	27.20	240.00	1408.38	-97.07	-155.59	183.28	0.85

From the studied case, Table 4 shows maximum error of 0.087% between the compared results obtained from SES and CDD. Using excel sheet the results from **Table 3** are plotted in Fig. 6tocompare Vertical Section (VS) and True Vertical Depth (TVD) inside view. **Fig. 7** compares between East/West and North/South in top view of the well trajectory. **Fig. 6 and 7** show the overlay between the results from CDD and SES.

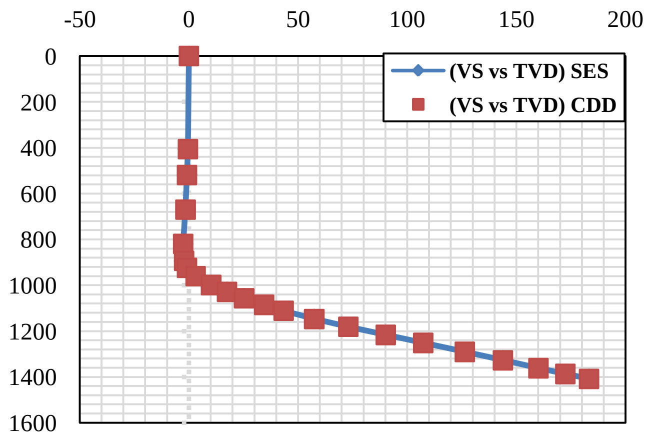

Fig . 6. Excel comparison between CDD and SES in side view

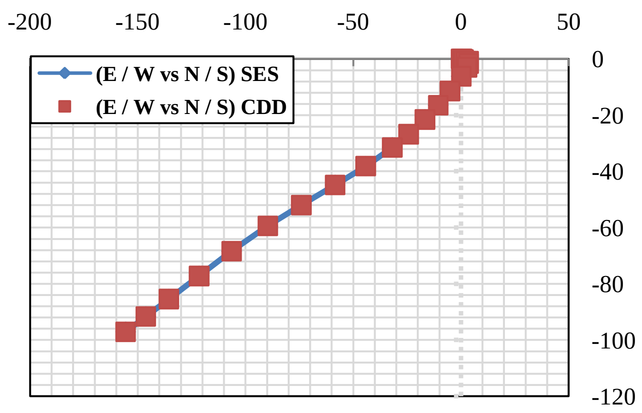

Fig. 7. Excel comparison between CDD and SES in top view

5. CONCLUSIONS

The following conclusions are drawn:

- The major advantages of this Software are that it doesn't need high computer requirements to install and doesn't require large computer space or speed to run.
- The CDD is simple, friendly, and easy to learn. It can provide graphical view in side view, top view and 3D view.
- It gives accurate results with an error of less than 1% and can be used in planning for drilling operations.
- The case study shows that the Software can produce matching results as the ones obtained from the SES, thus it can be used for designing directional drilling in real field with minimum cost when compared to the commercial available software.
- This work may be improved with more data from Sudanese oil fields.

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