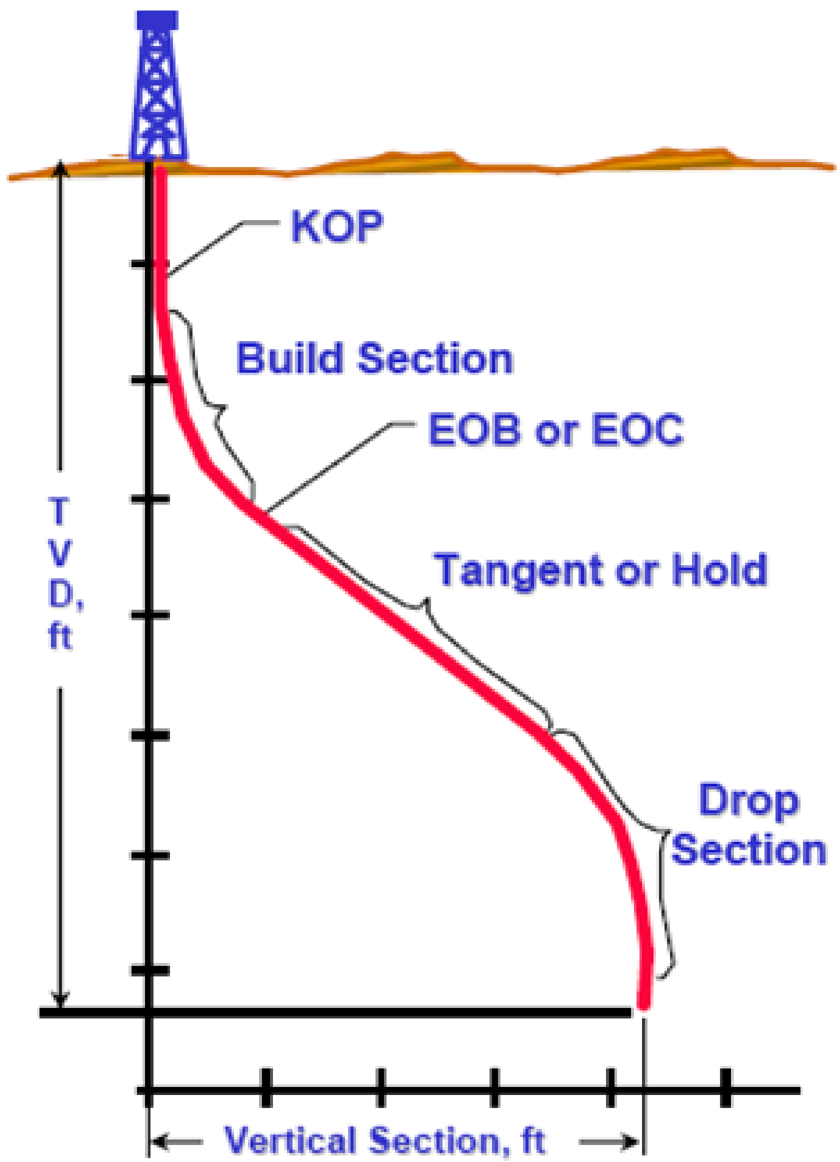
Note planning for directional drilling calculation

Fundamental of planning directional wellbore

Planning

Planning well is a task that involves many disciplines, people generally assume that planned directional wells require only a few geometry calculations as an additional additive of common tasks, but almost every aspect in the planning of wells affected when a directional wells planned



Ilustration 1.0

Well Profiles and Terminology

To facilitate understanding of the profile type Directional wells hold and Drop Build better known as the "S" well images can facilitate the illustration 1.0

- Kick of Point (KOP) is the beginning of Section Build up, Build up the Section often designed on Build-up Rate (BUR) to obtain a constant angle drill holes are expected or the end of the Build the target location (EOB).
- BUR usually specified in degrees per hundred feet ("/ 100 ft) which facilitates the calculation of the change in angle in the Measure Depth (MD) which is being drilled, the hole or the inclination angles are always specified in degrees from vertical well bore, the direction or Azimuth from wells in mentioned with regard to a field usually true north, the location of a point in the well is generally shown in a Cartesian degrees with the rig as a location determinant.
- True Vertical Depth is usually shown as a vertical distance below the rig.
- End of Build (EOB) is defined by coordinates and TVD, EOB specification also contains the angle and direction of the well at that point, the proper angle and direction is crucial in enables a target was obtained, also needed to penetrate pay zone at the optimum angle to the needs production.
- Departure or Vertical Section is the distance between two points in the survey that projected into the horizontal plane; Departure is the distance between two points of the projected survey locations in the horizontal plane.
- Tangent Section shown after the Build section, the usefulness of the tangent is to keep the angle and direction until the target is reached,

the Section Drop images are shown as the end of the tangent, the usefulness of Section Drop usual to place the wells drilled in the reservoir with a maximum orientation with regard to permeability formations or in-situ formation pressure; as an alternative, horizontal expansion can be performed in cases where there is a lot pay zone vertical fracture or who have the potential of gas or water coning, factor in the design of the well is the key to the design completion and reservoir drainage as well as further production, in horizontal wells.

TVD placement will minimize the production of gas or water coning, in formation with a vertical fracture where the fracture would probably help the flow of hydrocarbons, the direction of the trajectory of wells in the reservoir can be selected for cutting multiple fractures, alternatively, can also be placed on the direction of the well trajectory to avoid the areas of fault which is expected to allow migration of water, optimal placement of wells drilled in the reservoir will result in maximum production and is a good first step in the planning of wells

Planning Directional wells with a single equation

Interpolation calculation shows the planning of directional wells is very difficult because it requires a lot of similarities as well as the use of the Build-up chart, to facilitate planning Directional wells can be used to calculate the equation Wiggins hold Inclination
Figure 1.0 can explain the type of directional wells in the geometry and various parameters can be determined using the similarity of the geometry parameters are:

$r_1 = \frac{180}{\pi B_r}$ --(1.1)

$r_2 = \frac{180}{\pi B_r}$..(1.2)

$R = r_1 + r_2$ .... (1.3)

$TVD = TVD_4 - TVD_1$ .... (1.4)

$X = DEP_4 - R$ .... (1.5)

$L = [TVD^2 + X^2 - R^2]^{\frac{1}{2}}$ .... (1.6)

$I = sin^{-1}\left[\frac{(TVD)R + XL}{R^2 + L^2}\right]$ .... (1.7)

From this equation divide into

Type Build and hold trajectory

This type is the most common type of directional wells where there is only one corner of the establishment (r_1), and then the angle is maintained in order to achieve a predetermined target position along the Departure (DEP_3)

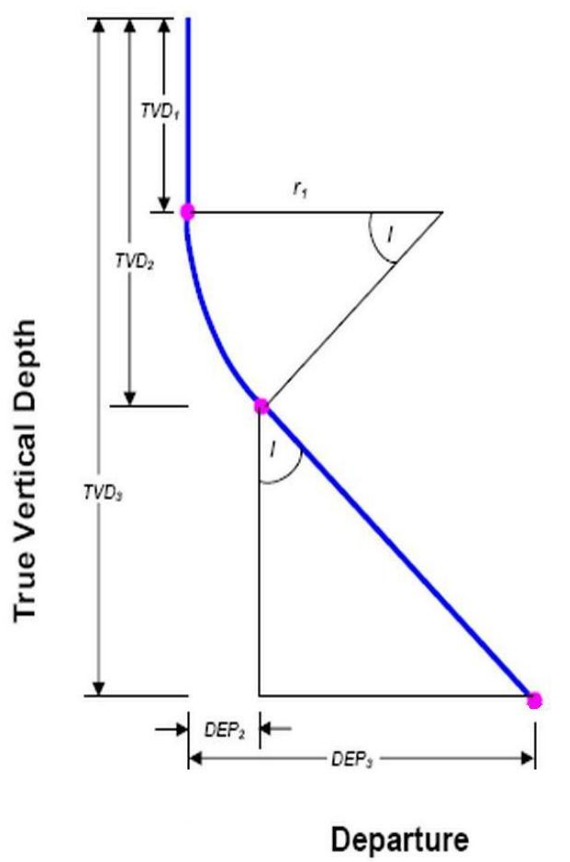


Illustration 2 build and hold type

The calculations are done on this type are:

- Calculation of the initial trajectory angle formation (r_1)
  This calculation involves determining the Kick of Point (KOP) with Build-up rate that has been planned.
- Build up the length of the trajectory calculation section build up the length of the trajectory calculation section is intended that the well has direction remains on target so that the final angle (r_{target}) can be formed.
- Hold the length trajectory calculation the calculation of path length of time the hold is so that drilling can be calculated carefully so that the cost involved can be minimized.
- Calculation of Departure (DEP3) the calculation is intended to find out how far a target of drilling the initial position.

Build hold and drop trajectory

Directional wells of this type is quite difficult because not only maintain the angle formed along the hold, but also change the back angle Hold the corner Drop then maintain it until it reaches the target position along the Departure (DEP_4), usually used when doing this type of salt dome drilling area or avoid fish (side tracking)

The calculations are done on this type are:

- Build angle calculation (r_1)
  This calculation involves determining the kick of point (KOP) with Build-up rate that has been planned
- Build up the length of the trajectory calculation section

Build up the length of the trajectory calculation section is intended that the well has direction remains on target so that the final angle (r_{target}) can be formed

- Hold the length trajectory calculation

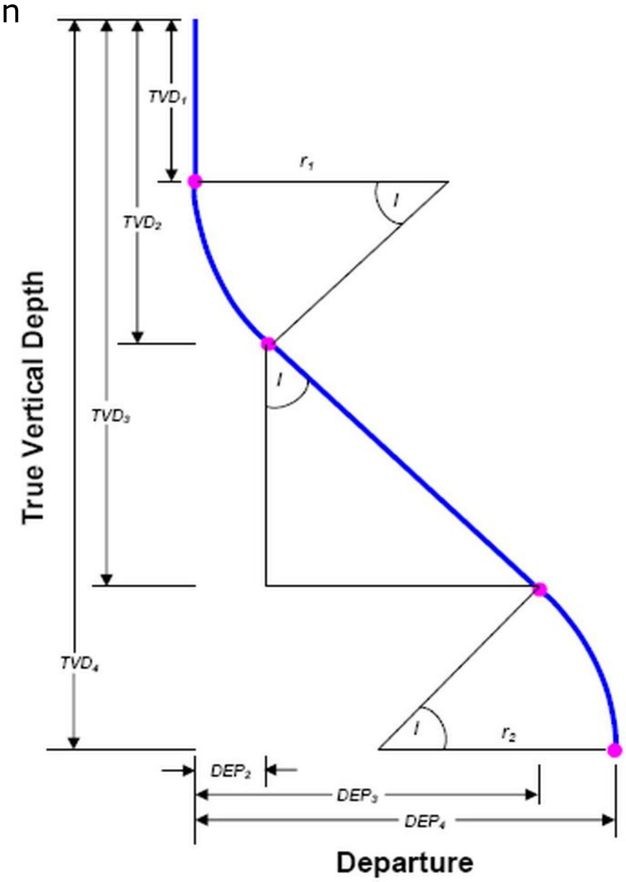
  The calculation of path length of time the hold is so that drilling can be calculated carefully so that the cost involved can be minimized

- Drop angle calculation (r_2)

  Angle calculation is done because the wells are expected to avoid the problems that exist in the process of drilling as well as avoiding the geological problem

- Calculation of Departure (DEP_4)

  The calculation is intended to find out how far a target of drilling the initial position



Illustrations 3 build hold and drop

After a well is completed planned the next step is the implementation of surveys on drilling trajectory that has been formed, the process is intended to minimize the possibility of a missed target of the initial plan due to problems arising in the process of drilling as the presence of faults in the area that causes the well trajectory changed slope and position of Northing, Easting and Azimuth

Survey

Survey on directional drilling is to compare the planned trajectory to the path is formed; therefore there are some parameters in the survey which is used as reference include:

- The depth of vertical wells (TVD)
- The slope of the trajectory (Inclines)
- Coordinates north (North)
- Coordinates east (East)
- Direction of the trajectory formed (Azimuth)

This parameter is the same as the parameters used in planning the trajectory of a well, because the final results were read in the trajectory mapping the depth of the wells are vertical wells range of Vertical Section View and Section in the north and east on the Plan View These five parameters are calculated in two different survey locations are generally within thirty or a hundred yards, the calculation of the above parameters are useful to know how big the changes that occur during a series of formations through which drilling equipment has its own character, so the trajectory deflected from its original plan and allow problems such as increase the burden Drag, Key Settings, dogleg, Pipe Sticking and not achieving the planned target point

After the survey data obtained at two stations, then the mapping obtained while the well in Section View and Plan View, from the point of this last survey was made re-planning when the trajectory deviates from the wells which formed the initial planning so that problems that might occur in drilling can be avoided in directional drilling survey there are several methods used are: tangential, Average Angle, Balance tangential, Mercury, Radius of curvature, Minimum of curvature

although the current calculation of the survey will be done using a computer program but the basic calculation is the initial method that has a high accuracy among other methods are Minimum of curvature.

Minimum curvature

Minimum of curvature method is almost the same as the radius of curvature method by assuming the well bore that is formed is an arc between the two survey points. This method uses the same equation with only tangential Balance equation multiplied by a factor described ratio of the arc formed by the wells drilled by this method therefore provides an accurate method of determining the position of boreholes, illustration 4 shows the basic calculations used in the calculation of minimum curvature

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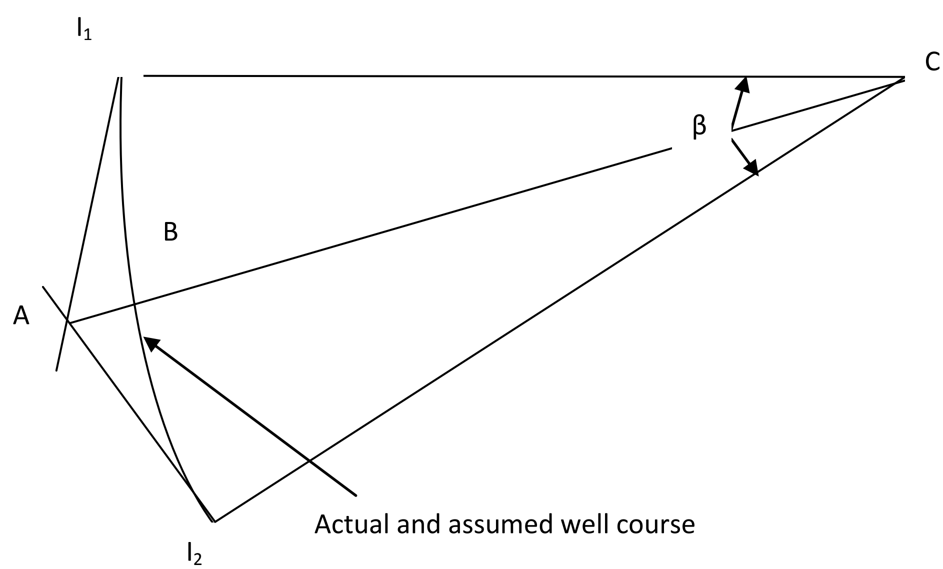

Illustration 4 measurement with minimum curvature

Calculation Minimum of curvature that modification from the trajectory Balance tangential considers boreholes is along the line $I_1A + A_I2$ calculation of the ratio of factors changed the trajectory $I_1B + B_I2$ which is an arc from the point, is mathematically similar to the radius of curvature in the slope changes only at this method converted into radians angle. As long as there is no change in Azimuth borehole, the equation Radius of curvature and minimum curvature will give the same results, but if there are changes Azimuth then there will be changes in the calculation. Minimum curvature calculations assume that the arc is the shortest path to drill wells to meet on the second point of the survey on a small slope with Azimuth changes are large, the shortest distance possible will result in decreased slope of the wells and deflection, this is a problem because the method does not take into account the minimum of curvature changes tilt and Azimuth separately as is done Radius of curvature calculation method The equation used in this method are:

TVD Change

$$\Delta TVD = \frac{\Delta MD}{2}(\cos I_1 + \cos I_2)(FC) \quad \text{..........(2.1)}$$

North change

$$\Delta North = \frac{\Delta MD}{2}(\sin I_2 \cos A_2) + (\sin I_1 \cos A_1)(FC) \quad \text{..........(2.2)}$$

East change

$$\Delta East = \frac{\Delta MD}{2}(\sin I_2 \sin A_2) + (\sin I_1 \cos A_1)(FC) \quad \text{..........(2.3)}$$

$$D_1 = cos\,(I_2 - I_1) - \{\sin I_2 \sin I_1 [1 - cos(A_2 - A_1)]\} \quad \text{..........(2.4)}$$

$$D_2 = tan^{-1}\sqrt{\left(\frac{1}{{D_1}^2}\right)} - 1 \quad \text{..........(2.5)}$$

$$FC = \frac{2}{D_2} tan\left(\frac{D_2}{2}\right) \quad \text{..........(2.6)}$$

Mapping

Once the survey data obtained through the calculation, the Closure and Direction calculation apply to know how much trajectory direction and the direction that has been formed for later depicted in the map the direction of North-East or the Plan View, but it needs to be done calculations Vertical Section to map the direction of True Vertical depth of Vertical Section formed because of the formation or Section View, calculations are also incorporated into the survey is a dogleg

Closure and Direction

the closure is defined as a "straight line, in the horizontal plane containing the location of a recent survey data drawn from the location of the upper surface until the final location survey" Closure line as shown in illustration 5. It can be said, Closure is the shortest distance between the location of the surface and the horizontal projection of the last point of the survey Closure is always a straight line because a straight line is the shortest distance between two points can also be said closure is the polar coordinates at the point of the survey that was opposed by the North and East into longitude coordinates. When the set closure, the direction must be provided for without direction, the basic point in the field of horizontal wells can be anywhere in a circle with a distance equal to the distance Closure circle, the distance and direction from the bottom of the well closure is determine position against the surface location, distance and direction calculated Closure by the following equation assuming zero feet coordinates of wells drilled from the North and zero feet from the East, if the coordinates of boreholes is not zero then the interpolation can be performed to determine the closure

$$Closure\ Direction = tan^{-1}\left(\frac{East}{North}\right) \quad \ldots\ldots(2.7)$$

$$Closure\ Distance = \sqrt{(North)^2 + (East)^2} \quad \ldots\ldots(2.8)$$

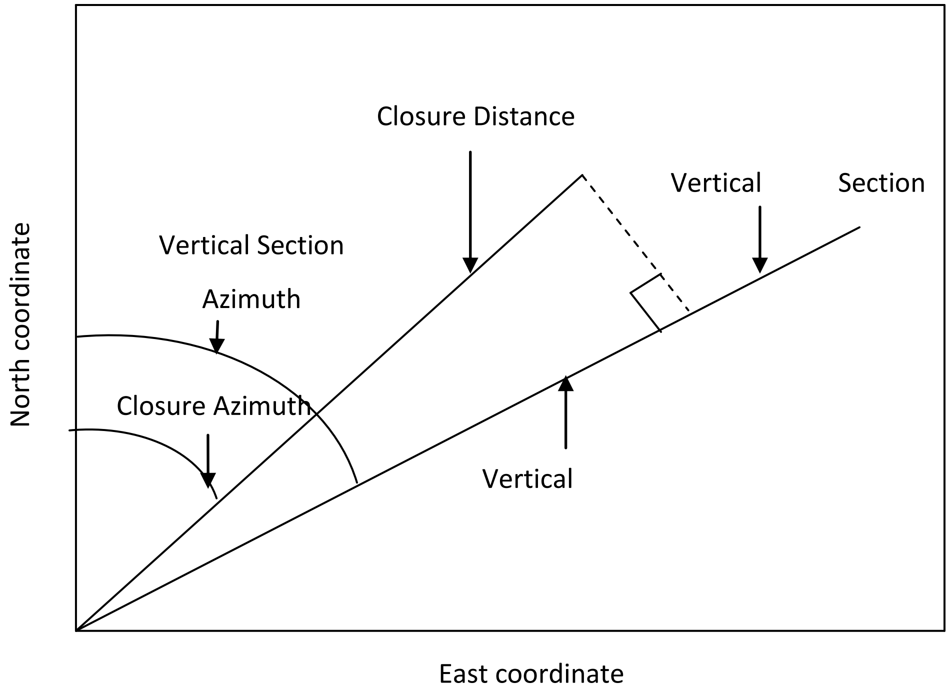

Illustration 5 difference between closure distance and vertical section on horizontal view

Vertical Section

Vertical Section is the horizontal distance of wells drilled in a particular field and is drawn tilted towards True Vertical Depth. When line drawn vertical wells drill ed on Section portrayed True Vertical Depth, distance closure can not be described accurately due to field closure (Closure Direction), vertical image of the wells drilled there in the field. Illustration 5 graphically shows the difference between closure distance and Vertical Section, a distance of Closure and Vertical Section will be the same if the direction of closure is equal to the field of Vertical Section. Vertical Section Azimuth Azimuth is usually chosen as the location of the surface to the target position. If there are many targets and changes in the Azimuth are required to achieve each target, Vertical Section Azimuth usually chosen as the surface location to the point of each target, calculated from the Vertical Section Closure Distance and Direction. The equation for calculating the Vertical Section is as follows:

$VS = \cos(Az_{VS} - Az_{cl})\,(Closure\ distance)$……………………………………………………………………(2.9)

Problem with Vertical Section negative value

Vertical section is the horizontal distance of wellbore that moves in the direction of the target per each station or in total. For instance, in the figure below, vertical section is the distance from survey to survey point and it's measured in the same direction of the vertical section direction.

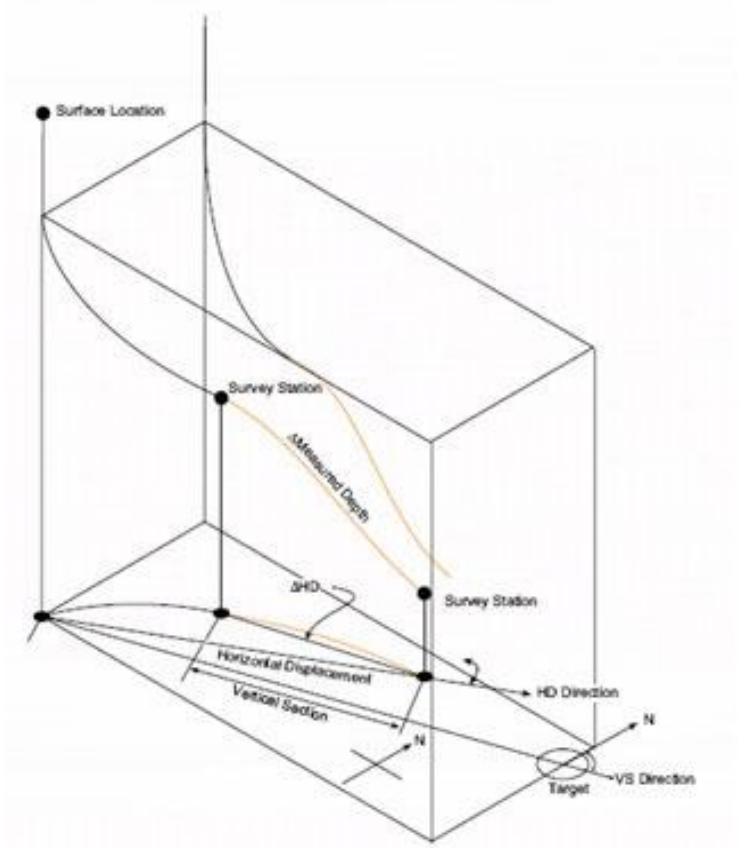

Illustration 6 changes value of vertical section

The two factors that affect vertical section are as follows:

1. The Incremental horizontal displacement (∆ HD)
2. Vertical section direction (VSD) is the azimuth that is used to reference to the vertical section. Normally, VSD is the azimuth of the last target.

The simple mathematics as Average Angle Method calculation demonstrates the relationship of the VS as below:

$$\boldsymbol{VS = cos\,(VSD - Az\,avg)\;X\;\Delta HD}$$

VS : Vertical Section

VSD : Vertical Section Direction

Azimuth avg : Average Azimuth between 2 points (Az1 + Az2) ÷2

∆HD : Delta Horizontal Displacement

In order to get the Positive Vertical Section or Zero Vertical Section, a well path must have difference of angle between VSD and Azimuth avg, (VSD – Azimuth avg), within a range of +90 to -90 degree. On the other hands, the negative Vertical Section can occur because the difference of angle between VSD and Azimuth avg, (VSD – Azimuth avg), is out of range of +90 to -90 degree AZI.

Dogleg severity

Dogleg severity is the calculation of the amount of change in angle (Inclination), and direction (Azimuth) of drill holes, typically shown in degrees per 100 feet of path length Dogleg severity will increase if the angle and direction changes occur in the short track and changing rapidly, the magnitude of the dogleg severity can be calculated using the following equation:

$$DLS = \left(\frac{100}{\Delta MD}\right) cos^{-1}\{(sin\, I_1 sin\, I_2)\lfloor(sin\, A_1 sin\, A_2) + (cos\, A_1 cos\, A_2)\rfloor + (cos\, I_1 cos\, I_2)\} \text{.....(2.21)}$$

Dogleg severity is not really a problem in directional drilling, but will be considered on cutting transport and well clean up. Problems associated with the dogleg is the greater torque and drag the dogleg will lead to greater torque and drag, Drill String will experience a small torque of the dogleg as drilling, because the collar in tension except in horizontal wells and wells with high slope but when doing tripping and reaming, the torque will be even greater because the collar becomes tense and add to the overall stress of the drill string In horizontal wells or wells with a high slope, the torque may be small when the spins on the bottom of the well, attention should be focused on an important change in the slope or direction of the well, because the Bottom Hole Assembly may be toward the bottom of the well but will not be reappointed by dogleg and cause problems in drilling, therefore, the survey calculated the value of dogleg severity become so important to determine whether the Bottom Hole Assembly has been setting still able to be appointed after a change of direction and slope are important

Case Study planning and survey directional well

A directional trajectory will be applied in oil well to provide better reservoir drainage on a fault with data acquire as seen below, please calculate the well planning;

Departure (DEP)	: 800 m
Target Depth (TD)	: 3531 m
Build up Rate (Br)	: 3/30 m
Inclination 1 (I_1)	: 0^0
Inclination 2 (I_2)	: 20.17^0

- Depth increment trajectory *(ΔMD)*
- TVD increment trajectory *(ΔTVD)*
- Displacement from the initial drill point *(ΔDEP)*
- Displacement *(DEP_{hold})*
- Displacement of true vertical depth *(TVD_{hold})*
- Kick of point *(KOP)*

Answer

- ***Depth increment trajectory (ΔMD)***

$$\Delta MD = \frac{I_2 - I_1}{Br}$$

$$\Delta MD = \frac{20.17 - 0}{3/30}$$

$$\Delta MD = 201.70\, m$$

- ***TVD increment trajectory (ΔTVD)***

$$\Delta TVD = \frac{(180)(\Delta MD)(Sin\, I_2 - Sin\, I_1)}{\pi(I_2 - I_1)}$$

$$\Delta TVD = \frac{(180)(201.70)(Sin\, 20.17 - Sin\, 0)}{\pi(20.17 - 0)}$$

$$\Delta TVD = 197.56\, m$$

- ***Displacement from the initial drill point (ΔDEP)***

$$\Delta DEP = \frac{(180)(\Delta MD)(Cos\ I_1 - Cos\ I_2)}{\pi(I_2 - I_1)}$$

$$\Delta DEP = \frac{(180)(201.70)(Cos\ 0 - Cos 20.17)}{\pi(20.17 - 0)}$$

$$\Delta DEP = 35.14\ m$$

- ***Displacement (DEP_{hold})***

$$DEP_{Hold} = DEP - \Delta DEP$$

$$DEP_{Hold} = 800 - 35.14$$

$$DEP_{Hold} = 764.86\ m$$

- ***Displacement of true vertical depth (TVD_{hold})***

$$TVD_{Hold} = \frac{DEP_{Hold}}{Tan\ I}$$

$$TVD_{Hold} = \frac{764.86}{Tan\ 20.17}$$

$$TVD_{Hold} = 2082.20\ m$$

- ***Kick of point (KOP)***

$$KOP = TD - TVD_{Hold}$$

$$KOP = 3531 - 2082.20$$

$$KOP = 1251.24\ m$$

With additional data below, also calculate; Closure direction, closure distance, and vertical section.

MD	: 1300 mMD
Inclination	: 5^0
Azimuth	: 9^0
TVD	: 1299.94 mTVD
N	: 2.15 m
E	: 0.34 m

- ***Closure direction***

$$Closure\ Direction = tan^{-1}\left(\frac{East}{North}\right)$$
$$Closure\ Direction = tan^{-1}\left(\frac{0.34}{2.15}\right)$$
$$Closure\ Direction = 8.986\ m$$

- ***Closure distance***

$$Closure\ Distance = \sqrt{(North)^2 + (East)^2}$$
$$Closure\ Distance = \sqrt{(2.15)^2 + (0.34)^2}$$
$$Closure\ Distance = 2.1768\ m$$

- ***Vertical section***

$$VS = \cos(Az_{VS} - Az_{cl})\ (Closure\ distance)$$
$$VS = \cos(9 - 8.986)\ (2.1768)$$
$$VS = 2.1768\ \mathrm{m}$$

With the data below please do survey calculation

Measure Depth	Inclination	Azimuth
2012.72	*19.84*	*11.32*
2041.60	*19.92*	*8.38*

With FC: 1.0002985

- ***Calculation TVD on depth 2012.72 mMD***

$$\Delta TVD = \frac{\Delta MD}{2}(\cos I_1 + \cos I_2)(FC)$$
$$\Delta TVD = \frac{30}{2}(\cos 19.84 + \cos 19.84)(1.0002985)$$
$$\Delta TVD = 28.22$$

- ***Calculation of north direction on 2012.72 mMD***

$$North = \frac{\Delta MD}{2}(\sin I_2\ \cos A_2) + (\sin I_1\ \cos A_1)(FC) + \Delta N$$
$$North = \frac{30}{2}(\sin 19.84\ \cos 11.32) + (\sin 19.84\ \cos 10.71)(1.0002985) + \Delta N$$
$$North = 234.57\ m$$

- ***Calculation of East direction on 2012.72 mMD***

$$East = \frac{\Delta MD}{2}(\sin I_2 \ \sin A_2) + (\sin I_1 \ \cos A_1)(FC) + \Delta E$$

- ***Calculation of Closure Direction on 2012.72 mMD***

$$Closure\ Direction = tan^{-1}\left(\frac{East}{North}\right)$$

$$Closure\ Direction = tan^{-1}\left(\frac{44.67}{234.57}\right)$$

$$Closure\ Direction = 10.87\ m$$

- ***Calculation of Closure distance on 2012.72 mMD***

$$Closure\ Distance = \sqrt{(North)^2 + (East)^2}$$

$$Closure\ Distance = \sqrt{(234.57)^2 + (44.67)^2}$$

$$Closure\ Distance = 238.78\ m$$

- ***Calculation of Vertical Section on 2012.72 mMD***

$$VS = \cos(Az_{VS} - Az_{cl})\ (Closure\ distance)$$

$$VS = \cos(11.32 — 10.87)\ (238.78)$$

$$VS = 238.77\ \text{m}$$

- ***Calculation of Dogleg severity on 2012.72 mMD***

$$DLS = \left(\frac{100}{\Delta MD}\right) cos^{-1}\{(sin\ I_1 sin\ I_2)[(sin\ A_1 sin\ A_2) + (cos\ A_1 cos\ A_2)] + (cos\ I_1 cos\ I_2)\}$$

$$DLS = \left(\frac{100}{30}\right) cos^{-1}\{(sin\ 19.84\ sin\ 19.84)[(sin\ 10.71\ sin\ 11.32) + (cos\ 10.71 \cos 11.32)] +$$

$$(cos\ 19.84\ cos\ 19.84)\}$$

$$DLS = 0.21$$

- ***Calculation of TVD on depth 2041.60 mMD***

$$\Delta TVD = \frac{\Delta MD}{2}(\cos I_1 + \ \cos I_2)(FC)$$

$$\Delta TVD = \frac{30}{2}(\cos 19.84 + \cos 19.84)(1.0002985)$$

$$\Delta TVD = \ 28.22$$

- ## *Calculation of North direction on 2041.60 mMD*

$$North = \frac{\Delta MD}{2}(\sin I_2\ \cos A_2) + (\sin I_1\ \cos A_1)(FC) + \Delta N$$

$$North = \frac{30}{2}(\sin 19.92\ \cos 8.38) + (\sin 19.84\ \cos 11.32)(1.0002985) + \Delta N$$

$$North = 244.24\ m$$

- ## *Calculation of East direction on 2041.60 mMD*

$$East = \frac{\Delta MD}{2}(\sin I_2\ \sin A_2) + (\sin I_1\ \cos A_1)(FC) + \Delta E$$

$$East = \frac{30}{2}(\sin 19.92 \sin 8.38) + (\sin 19.84 \cos 11.32)(1.0002985) + \Delta E$$

$$East = 46.35\ m$$

- ## *Calculation of Closure Direction on 2041.60 mMD*

$$Closure\ Direction = tan^{-1}\left(\frac{East}{North}\right)$$

$$Closure\ Direction = tan^{-1}\left(\frac{46.35}{244.24}\right)$$

$$Closure\ Direction = 10.74\ m$$

- ## *Calculation of Closure distance on 2041.60 mMD*

$$Closure\ Distance = \sqrt{(North)^2 + (East)^2}$$

$$Closure\ Distance = \sqrt{(244.24)^2 + (46.35)^2}$$

$$Closure\ Distance = 248.59\ m$$

- ## *Calculation of Vertical Section on 2041.60 mMD*

$$VS = \cos(Az_{VS} - Az_{cl})\ (Closure\ distance)$$

$$VS = \cos(8.38 — 10.74)\ (248.59)$$

$$VS = 248.38\ \mathrm{m}$$

- ***Calculation of Dogleg severity on 2041.60 mMD***

$DLS = \left(\frac{100}{\Delta MD}\right) cos^{-1}\{(sin\ I_1 sin\ I_2)[(sin\ A_1 sin\ A_2) + (cos\ A_1 cos\ A_2)] + (cos\ I_1 cos\ I_2)\}$

$DLS = \left(\frac{100}{30}\right) cos^{-1}\{(sin\ 19.84\ sin\ 19.92)[(sin\ 11.32\ sin\ 8.38) + (cos\ 11.32\ \cos 8.38)] + (cos\ 19.92\ cos\ 19.84)\}$

$DLS = 1.04$

Sidetracking calculation

Customers want a re-planning due to problems in the well drilling process, with the data below please planning the side track kick of point for the well

Data:

Course length : 30 mMD

Target Depth : 3725 mTVD

Inclination at station 1 : 21.6^0

Inclination at station 2 : 22.3^0

Desired inclination : 21^0

Answer:

- **Calculation of TVD Hold Sidetracking**

$$TVD_{Hold} = \frac{180(I_3)(sinI_2 - \sin I_1)}{\pi(I_2 - I_1)} \Big/ \operatorname{Tan} I_3$$

$$TVD_{Hold} = \frac{180(21)(sin\ 22.3 - \sin 21.6)}{\pi(22.3 - 21.6)} \Big/ \operatorname{Tan} 21$$

$$TVD_{Hold} = 35.519\ m$$

- **Calculation of ΔTVD**

$$\Delta TVD = \frac{180(I_3)(sinI_2 - \sin I_1)}{\pi(I_2 - I_1)}$$

$$\Delta TVD = \frac{180(21)(sin22.3 - \sin 21.6)}{\pi(22.3 - 21.6)}$$

$$\Delta TVD = 13.634\ m$$

- **Calculation of KOP Sidetracking**

$KOP\ ST = TD - TVD_{Hold} - \Delta TVD$

$KOP\ ST = 3725 - 35.519 - 13.634$

$KOP\ ST = 3675.847\ m$

I Hope will never experiences to calculate directional drilling planning and survey with manual calculation, three well it's enough for me !

Mufti Ghazali