SURVEY CALCULATIONS

Survey calculations are used to predict the position of the wellbore relative to the surface location

Survey Calculations

- Terminology used in this section
  - MD = Measured depth – Length of the wellbore measured by the drill string
  - TVD = True vertical depth – Vertical component of the measured depth
  - North = North component of the horizontal departure

2

Survey Calculations

- East = East component of the horizontal displacement
- Δ = Delta meaning the difference in
- Subscript 1 = The upper survey of two survey points
- Subscript 2 = The lower survey of the lower survey point
- I = Inclination from vertical

3

Survey Calculations

- A = Azimuth of the survey (0 to 360 degrees)
- r = Radius of curvature
- VS = Vertical section
- DLS = Dogleg severity
- DEP = The departure in the horizontal plane

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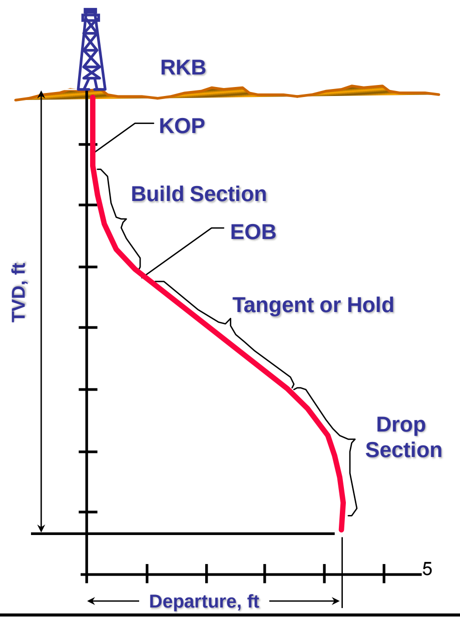
Survey Calculations

- Common terminology for a directional profile

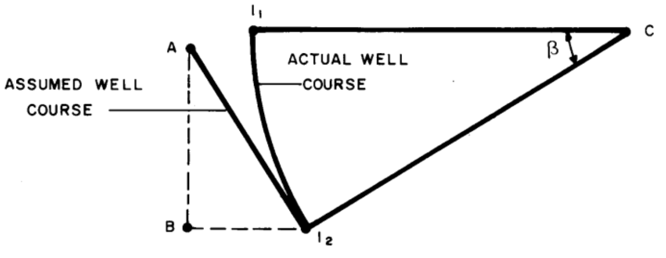


Survey Calculations

- Most common survey methods
  - Tangential
  - Balanced Tangential
  - Average Angle
  - Radius of Curvature
  - Minimum Curvature

Survey Calculations

- **Tangential method** uses only the lower survey point and is the least accurate survey method



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Survey Calculations

- The tangential method assumes the wellbore course is a straight line tangent to the lower inclination or azimuth
- Tangential method equations

$$\Delta TVD = \Delta MD \times Cos\, I_2$$

$$\Delta North = \Delta MD \times Sin\; I_2 \times Cos\; A_2$$

$$\Delta East = \Delta MD \times Sin\; I_2 \times Sin\; A_2$$

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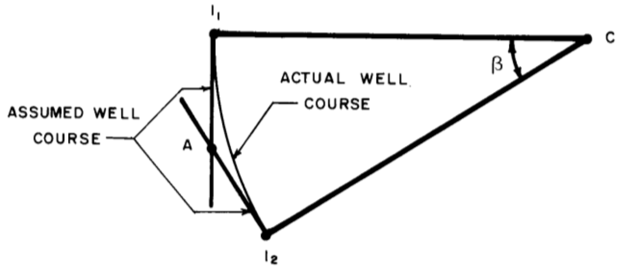
Survey Calculations

- **The balanced tangential survey method** assumes the wellbore course is two straight lines with half the wellbore course tangent to the upper survey point and the other half to the lower survey point



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Survey Calculations

- The balance tangential is an accurate survey method but seldom used
- Balanced tangential equations

$$\Delta TVD = \frac{\Delta MD}{2}\left(Cos\, I_1 + Cos\, I_2\right)$$

$$\Delta North = \frac{\Delta MD}{2}\left[\left(Sin\ I_1 \times Cos\ A_1\right) + \left(Sin\ I_2 \times Cos\ A_2\right)\right]$$

$$\Delta East = \frac{\Delta MD}{2}\left[\left(Sin\ I_1 \times Sin\ A_1\right) + \left(Sin\ I_2 \times Sin\ A_2\right)\right]$$

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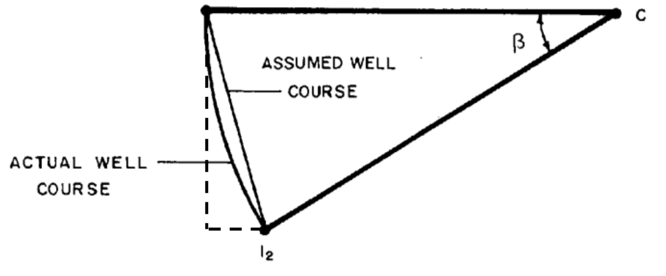
Survey Calculations

- The average angle method assumes the wellbore course is a straight line tangent to the average angle



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Survey Calculations

- The average angle method is accurate as long as the surveys are not too far apart and there is no large change in azimuth at low angles
- **Average angle equations**

$$\Delta TVD = \Delta MD \times Cos\left(\frac{I_1 + I_2}{2}\right)$$

$$\Delta North = \Delta MD \times Sin\left(\frac{I_1 + I_2}{2}\right) \times Cos\left(\frac{A_1 + A_2}{2}\right)$$

$$\Delta East = \Delta MD \times Sin\left(\frac{I_1 + I_2}{2}\right) \times Sin\left(\frac{A_1 + A_2}{2}\right)$$

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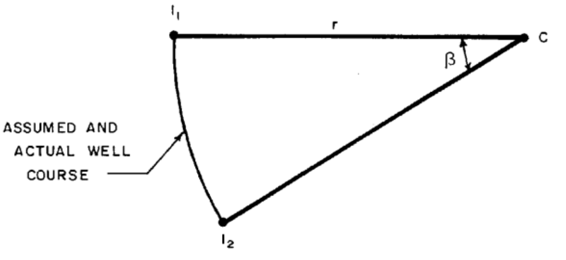
Survey Calculations

- Radius of curvature method assumes that the wellbore course is an arc of a circle
- Used for planning but not for final survey



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Survey Calculations

- Radius of curvature has problems when inclinations and azimuths are equal because the radius of curvature in infinite
- Radius of curvature also has problems when the well walks past north

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Survey Calculations

- Radius of curvature equations

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

$$\Delta North = \frac{(180)^2(\Delta MD)(Cos\,I_1 - Cos\,I_2)(Sin\,A_2 - Sin\,A_1)}{\pi^2(I_2 - I_1)(A_2 - A_1)}$$

$$\Delta East = \frac{180^2(\Delta MD)(Cos\,I_1 - Cos\,I_2)(Cos\,A_1 - Cos\,A_2)}{\pi^2(I_2 - I_1)(A_2 - A_1)}$$

$$\Delta DEP = \frac{180(\Delta MD)(CosI_1 - CosI_2)}{\pi(I_2 - I_1)}$$

$$\Delta MD = \frac{I_2 - I_1}{B_r} \qquad r = \frac{180}{(\pi)(DLS)}$$

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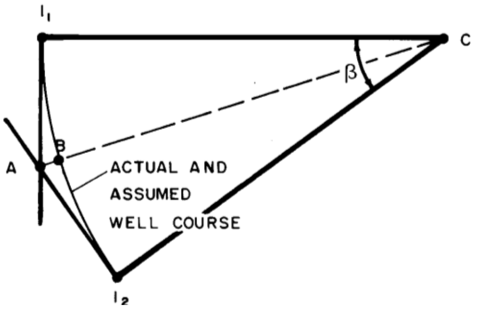
Survey Calculations

- Minimum Curvature method is the balanced tangential method but the straight lines are smoothed into an arc by a correction factor



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Survey Calculations

- **Minimum curvature** is suitable for a computer or programmable calculator
- The inclinations and azimuths must be changed to **radians** before entering them in the equations
- It is considered the most **accurate survey method**

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Survey Methods

- Minimum curvature equations

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

$$\Delta North = \left(\frac{\Delta MD}{2}\right)\left[\left(Sin\ I_2 \times Cos\ A_2\right) + \left(Sin\ I_1 \times Cos\ A_1\right)\right]\left(FC\right)$$

$$\Delta East = \left(\frac{\Delta MD}{2}\right)\left[\left(Sin\ I_2 \times Sin\ A_2\right) + \left(Sin\ I_1 \times Sin\ A_1\right)\right]\left(FC\right)$$

$$D1 = Cos\left(I_2 - I_1\right) - \left\{Sin\, I_2 \times Sin\, I_1 \times \left[1 - Cos\left(A_2 - A_1\right)\right]\right\}$$

$$D2 = Tan^{-1}\sqrt{\left(\frac{1}{D1^2}\right) - 1}$$

$$FC = \frac{2}{D2} \times Tan\left(\frac{D2}{2}\right)$$

- Note: inclination and azimuth must be entered in radians

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Survey Calculations

- ***Example 2***

Tangential Method

- At 0 and 1,000 feet the inclination is 0°, therefore, the wellbore position is 0 North and 0 East.
- A survey at 1,100 feet shows the inclination to be 3° in the N21.7E direction (Azimuth = 21.7). Calculate the position of the wellbore at 1,100 feet.

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Survey Calculations

$$\Delta MD = MD_2 - MD_1$$

$$\Delta MD = 1100 - 1000$$

$$\Delta MD = 100'$$

- Using the tangential method, calculate ΔTVD

$$\Delta TVD = (\Delta MD)(Cos\, I_2)$$

$$\Delta TVD = (100)(Cos\, 3°)$$

$$\Delta TVD = 99.86'$$

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Survey Calculations

- Calculate the true vertical depth

$$TVD_2 = \Delta TVD + TVD_1$$
$$TVD_2 = 99.86 + 1000$$
$$TVD_2 = 1099.86'$$

- Calculate ΔNorth

$$\Delta North = (\Delta MD)(Sin\ I_2)(Cos\ A_2)$$
$$\Delta North = (100)(Sin\ 3°)(Cos\ 21.7°)$$
$$\Delta North = 4.86'$$

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Survey Calculations

- Calculate the North coordinate

$$North_2 = \Delta North + North_1$$
$$North_2 = 4.86' + 0'$$
$$North_2 = 4.86'$$

- Calculate the ΔEast

$$\Delta East = (\Delta MD)(Sin\, I_2)(Sin\, A_2)$$
$$\Delta East = (100)(Sin 3°)(Sin 21.7)$$
$$\Delta East = 1.94'$$

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Survey Calculations

- Calculate the East coordinate

$$East_2 = \Delta East + East_1$$

$$East_2 = 1.94' + 0'$$

$$East_2 = 1.94'$$

- The process is repeated until all the surveys are calculated

Survey Calculations

MEASURED DEPTH (feet)	DRIFT ANGLE (degrees)	DRIFT AZIMUTH (degrees)	COURSE LENGTH (feet)	TRUE VERTICAL DEPTH (feet)	RECTANGULAR COORDINATES NORTH	RECTANGULAR COORDINATES EAST	VERTICAL SECTION 10 DEGREES (feet)	DOGLEG SEVERITY (deg/100')
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1000.00	0.00	0.00	1000.00	1000.00	0.00	0.00	0.00	0.00
1100.00	3.00	21.70	100.00	1099.95	2.43	0.97	2.56	3.05
1200.00	6.00	26.50	100.00	1199.63	9.54	4.27	10.14	3.02
1300.00	9.00	23.30	100.00	1298.77	21.40	9.70	22.76	3.03
1400.00	12.00	2030	100.00	1397.08	38.34	16.40	40.61	3.05
1500.00	15.00	23.30	100.00	1494.31	59.98	25.12	63.44	3.08
1600.00	18.00	23.90	100.00	1590.18	86.00	36.51	91.03	3.00
1700.00	21.00	24.40	100.00	1684.44	116.45	50.17	123.40	3.00
1800.00	24.00	23.40	100.00	1776.81	151.44	65.65	160.54	3.02
1900.00	27.00	23.70	100.00	1867.06	190.90	82.86	202.39	3.00
2000.00	30.00	23.30	100.00	1954.93	234.66	101.88	248.78	3.01
2100.00	30.20	22.80	100.00	2041.45	280.81	121.51	297.64	0.32
2200.00	30.40	22.50	100.00	2127.79	327.37	140.94	346.87	0.25
2300.00	30.30	22.10	100.00	2214.08	374.12	160.11	396.23	0.23
2400.00	30.60	22.40	100.00	2300.29	421.02	179.30	445.76	0.34
2500.00	31.00	22.50	100.00	2386.19	468.34	198.86	495.76	0.40
2600.00	31.20	21.60	100.00	2471.81	516.22	218.25	546.27	0.51
2700.00	30.70	20.80	100.00	2557.58	564.16	236.85	596.72	0.65
2800.00	31.40	20.90	100.00	2643.25	612.36	255.20	647.38	0.70
2900.00	30.60	22.00	100.00	2728.96	660.30	274.03	697.86	0.98
3000.00	30.50	22.50	100.00	2815.08	707.35	293.28	747.53	0.27
3100.00	30.40	23.90	100.00	2901.29	753.92	313.24	796.86	0.72
3200.00	30.00	24.50	100.00	2987.72	799.80	333.86	845.63	0.50
3300.00	30.20	24.90	100.00	3074.23	845.37	354.82	894.14	0.28
3400.00	31.00	25.70	100.00	3160.31	891.39	376.57	943.23	0.90
3500.00	31.10	25.50	100.00	3245.98	937.90	398.86	992.91	0.14
3600.00	32.00	24.40	100.00	3331.20	985.34	420.92	1043.47	1.07
3700.00	30.80	24.00	100.00	3416.55	1032.86	442.28	1093.97	1.22
3800.00	30.60	22.30	100.00	3502.54	1079.80	462.36	1143.68	0.89
3900.00	31.20	21.70	100.00	3588.34	1127.42	481.59	1193.91	0.67
4000.00	30.80	20.80	100.00	3674.06	1175.42	500.26	1244.43	0.61
4100.00	30.00	20.80	100.00	3760.31	1222.72	518.23	1294.13	0.80
4200.00	29.70	19.80	100.00	3847.04	1269.40	535.50	1343.10	0.58
4300.00	29.80	20.80	100.00	3933.87	1315.94	552.71	1391.92	0.51
4400.00	29.50	21.10	100.00	4020.77	1362.14	570.40	1440.49	0.33
4500.00	29.20	20.80	100.00	4107.94	1407.91	587.93	1488.61	0.33
4600.00	29.00	20.60	100.00	4195.31	1453.40	605.12	1536.40	0.22
4700.00	28.70	21.40	100.00	4282.90	1498.45	322.41	1583.77	0.49
4800.00	28.50	21.20	100.00	4370.70	1543.05	639.80	1630.71	0.22

Survey Calculations

Table 9 *Comparison of survey calculation methods.*

METHOD	TVD	NORTH	EAST
Tangential	4364.40	1565.23	648.40
Balanced Tangential	4370.46	1542.98	639.77
Average Angle	4370.80	1543.28	639.32
Radius of Curvature	4370.69	1543.22	639.30
Minimum of Curvature	4370.70	1543.05	639.80

Table 10 *Relative difference between survey calculation methods.*

METHOD	DIFFERENCE IN TVD	DIFFERENCE IN NORTH	DIFFERENCE IN EAST
Tangential	-6.30	22.18	+8.60
Balanced Tangential	-0.24	-0.07	-0.03
Average Angle	+0.10	+0.23	-0.48
Radius of Curvature	-0.01	+0.17	-0.50
Minimum Curvature	+0.00	+0.00	+0.00

Survey Methods

- **Class Problem**
  - $MD_1 = 100'$ $MD_2 = 200'$
  - $I_1 = 1^o$ $I_2 = 1^o$
  - $A_1 = 0^o$ $A_2 = 180^o$
  - Calculate the change in TVD, North and East coordinate using the average angle method and the radius of curvature method

Survey Calculations

AVERAGE ANGLE METHOD

$$\Delta TVD = \Delta MD \times Cos\left(\frac{I_1 + I_2}{2}\right)$$

$$\Delta TVD = (200 - 100) \times Cos\left(\frac{1+1}{2}\right) = 99.98$$

$$\Delta N = \Delta MD \times Sin\left(\frac{I_1 + I_2}{2}\right) \times Cos\left(\frac{A_1 + A_2}{2}\right)$$

$$\Delta N = (200 - 100) \times Sin\left(\frac{1+1}{2}\right) \times Cos\left(\frac{0+180}{2}\right) = 0.00$$

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Survey Calculations

$$\Delta E = \Delta MD \times Sin\left(\frac{I_1 + I_2}{2}\right) \times Sin\left(\frac{A_1 + A_2}{2}\right)$$

$$\Delta E = (200 - 100) \times Sin\left(\frac{1+1}{2}\right) \times Sin\left(\frac{0+180}{2}\right) = 1.75$$

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Survey Calculations

- **RADIUS OF CURVATURE METHOD**

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

$$\Delta TVD = \frac{(180)(200-100)(Sin(1.001)-Sin(1))}{\pi(1.001-1)} = 99.98$$

$$\Delta N = \frac{(180)^2(\Delta MD)(Cos\,I_1 - Cos\,I_2)(Sin\,A_2 - Sin\,A_1)}{\pi^2(I_2 - I_1)(A_2 - A_1)}$$

$$\Delta N = \frac{(180)^2(200-100)(Cos(1)-Cos(1.001))(Sin(180)-Sin(0))}{\pi^2(1.001-1)(180-0)} = 0.00$$

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Survey Calculations

- **RADIUS OF CURVATURE METHOD**

$$\Delta E = \frac{180^2(\Delta MD)(Cos\,I_1 - Cos\,I_2)(Cos\,A_1 - Cos\,A_2)}{\pi^2(I_2 - I_1)(A_2 - A_1)}$$

$$\Delta E = \frac{180^2(200-100)(Cos(1)-Cos(1.001))(Cos(0)-Cos(180))}{\pi^2(1.001-1)(180-0)} 1.11$$

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Survey Methods

- MINIMUM CURVATURE METHOD

$$D1 = Cos(I_2 - I_1) - \{Sin I_2 \times Sin I_1 \times [1 - Cos(A_2 - A_1)]\}$$

$$D1 = Cos(0.0175 - 0.0175) - \{Sin(0.0175) \times Sin(0.0175) \times [1 - Cos(3.1416 - 0.000)]\}$$
$$D1 = 0.999391$$

$$D2 = Tan^{-1}\sqrt{\left(\frac{1}{D1^2}\right) - 1}$$

$$D2 = Tan^{-1}\sqrt{\left(\frac{1}{(0.999391)^2}\right) - 1} = 0.034907$$

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Survey Methods

- MINIMUM CURVATURE METHOD

$$FC = \frac{2}{D2} \times Tan\left(\frac{D2}{2}\right)$$

$$FC = \frac{2}{0.034907} \times Tan\left(\frac{0.034907}{2}\right) = 1.000102$$

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

$$\Delta TVD = \left(\frac{200 - 100}{2}\right)(Cos(0.0175) + Cos(0.0175))(1.000102)$$
$$\Delta TVD = 100.00$$

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Survey Methods

- MINIMUM CURVATURE METHOD

$$\Delta N = \left(\frac{\Delta MD}{2}\right)\left[\left(Sin I_2 \times Cos A_2\right) + \left(Sin I_1 \times Cos A_1\right)\right]\left(FC\right)$$

$$\Delta N = \left(\frac{200-100}{2}\right)\left[\left(Sin(0.0175)\times Cos(3.1416)\right) + \left(Sin(0.0175)\times Cos(0.000)\right)\right](1.000127)$$

$$\Delta N = 0.00$$

$$\Delta E = \left(\frac{\Delta MD}{2}\right)\left[\left(Sin I_2 \times Sin A_2\right) + \left(Sin I_1 \times Sin A_1\right)\right]\left(FC\right)$$

$$\Delta E = \left(\frac{200-100}{2}\right)\left[\left(Sin(0.0175)\times Sin(3.1416)\right) + \left(Sin(0.0175)\times Sin(0.000)\right)\right](1.000127)$$

$$\Delta E = 0.00$$

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Survey Methods

- **RESULTS**

Method	ΔTVD	ΔN	ΔE
Average Angle	99.98	0.00	1.75
Radius of Curv.	99.98	0.00	1.11
Minimum Curv.	100.00	0.00	0.00

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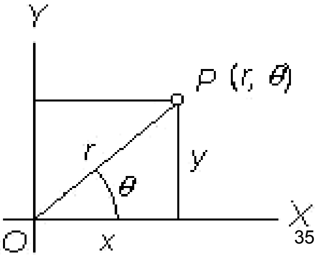
Survey Calculations

- Closure distance and direction is the North and East coordinate expressed as polar coordinates rather than rectangular coordinates
- Closure distance is $a^2 + b^2 = c^2$



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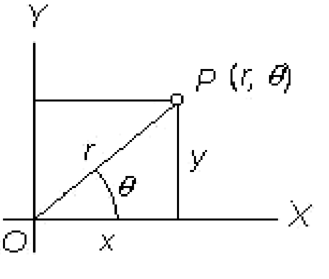
Survey Calculations

- Closure distance and direction equations

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

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



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Survey Calculations

- Dogleg severity is a measure of the amount of change in the inclination and/or azimuth of a borehole, usually expressed in degrees per 100 feet or degrees per 30 meters course length

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Survey Calculations

- To make it a little easier to understand, the dogleg severity is approximately equal to the vectorial sum of the change in inclination and the change in azimuth
- The equation does not work well at low inclinations

$$DLS = \frac{100}{\Delta MD}\sqrt{(I_2 - I_1)^2 + \left[\sin\left(\frac{I_2 + I_1}{2}\right)(A_2 - A_1)\right]^2}$$

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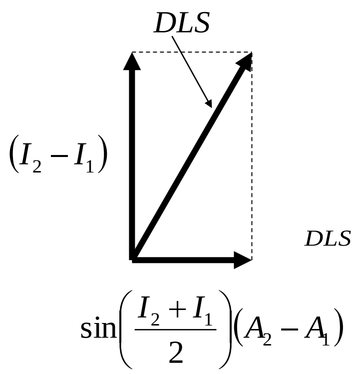
Survey Calculations



$$a^2 + b^2 = c^2$$

$$DLS = \frac{100}{\Delta MD}\sqrt{(I_2 - I_1)^2 + \left[\sin\left(\frac{I_2 + I_1}{2}\right)(A_2 - A_1)\right]^2}$$

The dogleg severity can be estimated by the above means

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Survey Calculations

- Problems caused by doglegs
  - Torque and drag
  - Keyseats and casing wear
  - Fatigue

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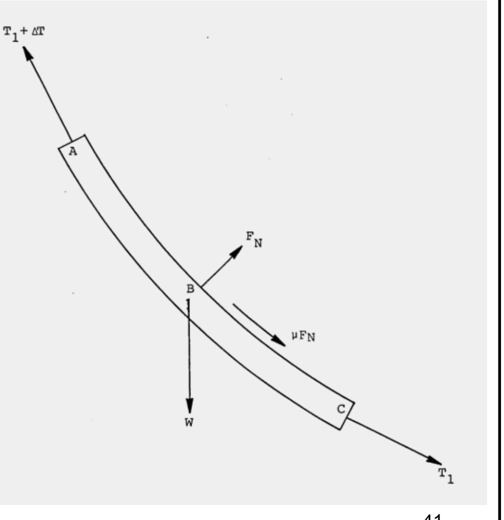
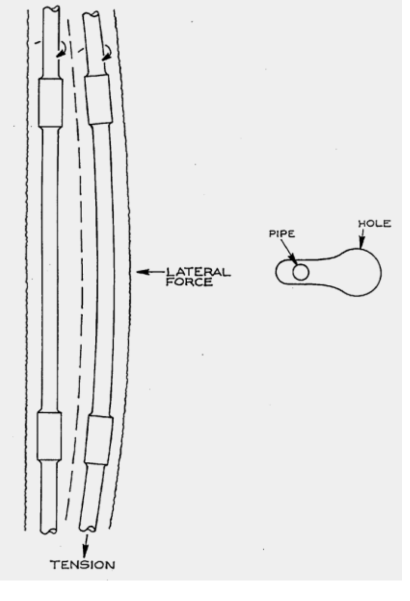
Survey Calculations

- Torque and drag are caused by the friction between the drill string and the wall of the hole
- Higher tension and doglegs result in higher torque and drag



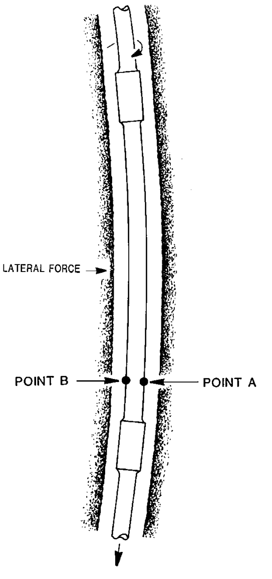
Survey Calculations



- Keyseats and casing wear are caused by the drill string being rotated in a dogleg with higher tension

Survey Calculations

- Fatigue is caused by rotating the drill string in a bend
- The cyclic stresses cause fatigue



Survey Uncertainty

- Directional surveys are not absolute and the accuracy of the surveys must be considered
- Wolff and DeWardt is one systematic survey error model used to predict the ellipse of uncertainty (actually an ellipsoid since it is in three dimensions)

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Survey Uncertainty

- Generally, the inclination of a survey is relatively accurate because it is only affected by depth measurement and the accuracy of the tool
- The direction of the well is more inaccurate due to accuracy of the tools, magnetic interference, magnetic storms, etc.

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Survey Uncertainty

- As the inclination of the well increases, the error in the vertical and horizontal plane increases
- Most survey errors are systematic rather than random which means they accumulate rather than cancel each other out

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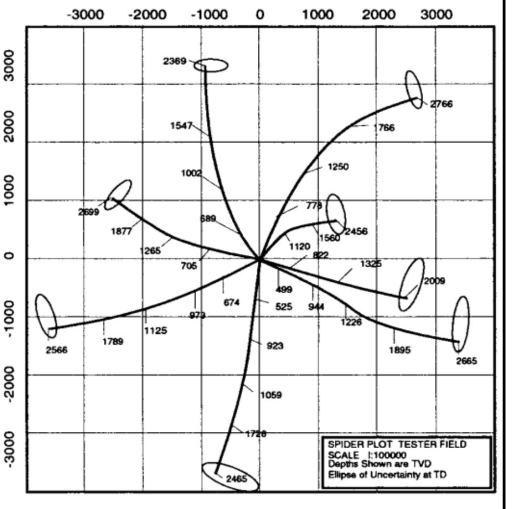
Survey Uncertainty

- Ellipse of Uncertainty at TD showing possible location of wellbore
- Spider maps are used to plot exiting wells and future wells



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Survey Uncertainty

- The size of the ellipse of uncertainty increases with depth