"SURVEY CALCULATIONS USING MINIMUM CURVATURE METHOD".

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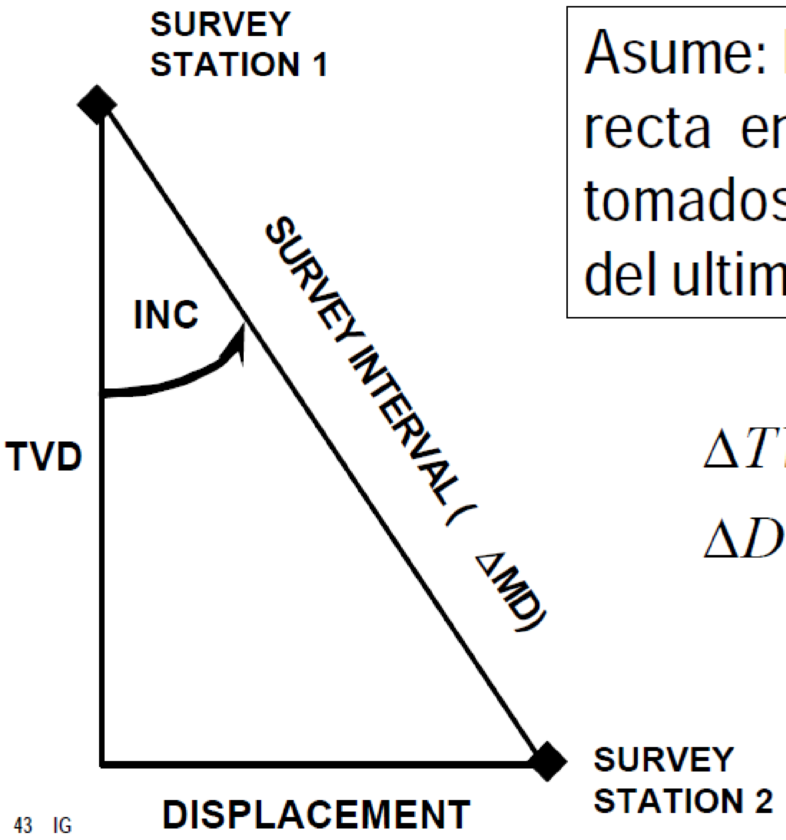
Six methods are applied to make survey computations for wellbore trajectories. In all of them, we obtain parameters as True Vertical Depth, Northing, Easting, Displacement, Vertical Section (Vs) and Dog leg severity. These methods are : Tangential, Balanced Tangential, Mercury, Average angle, Curvature Radius and Minimum Curvature.

Metodo 1: Tangencial



Asume: La trayectoria es una linea recta entre los dos ultimos surveys tomados. Toma la inclinacion y Azm del ultimo survey

$$\Delta TVD = \Delta MD \times \cos(inc)$$

$$\Delta Displaceme\,nt = \Delta MD \times \sin(inc)$$

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12/7/2005

Schlumberger

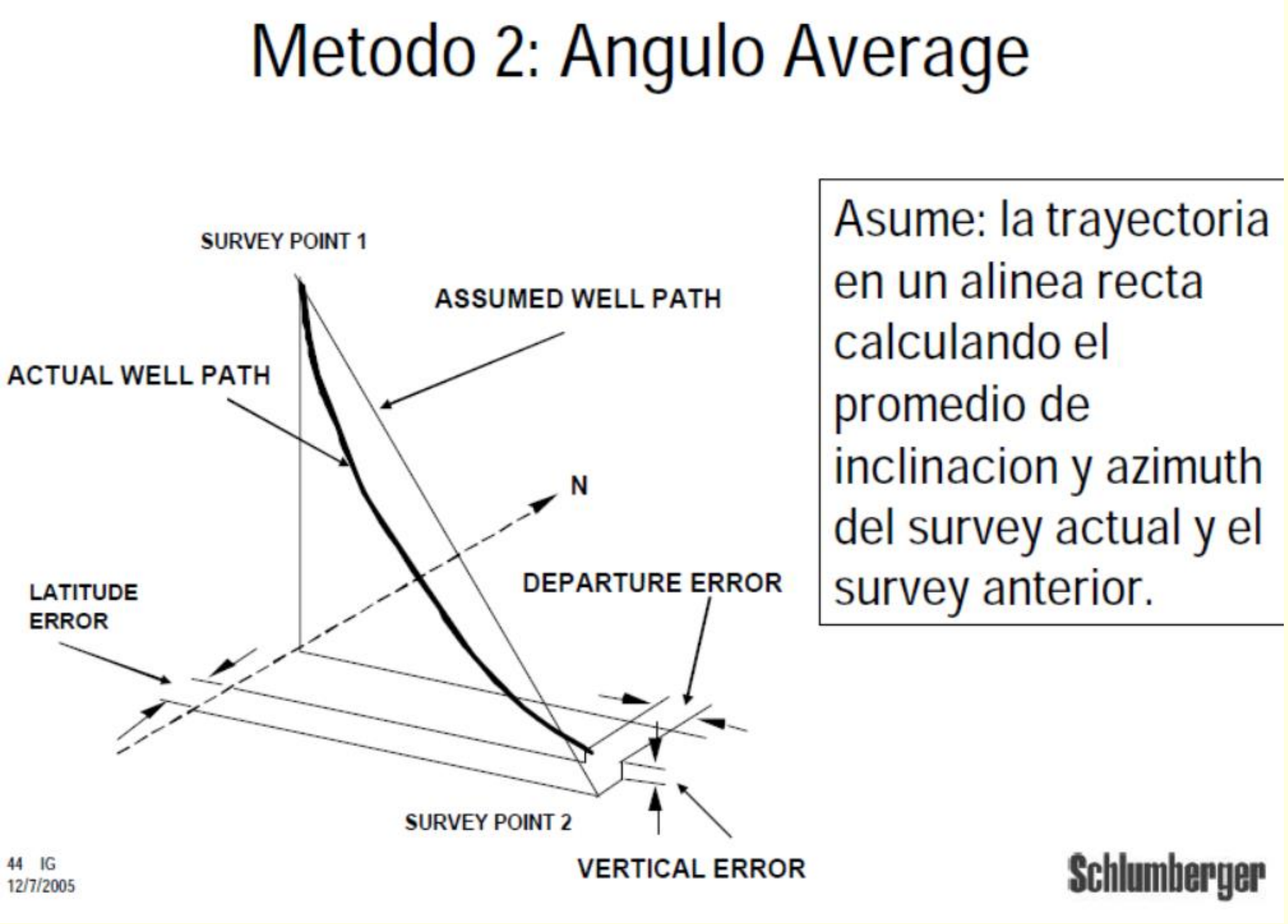
Metodo Tangencial

$$North_2 = \left[(MD_2 - MD_1) \cdot (\sin I_2) \cdot (\cos A_2) \right] + North_1$$

$$East_2 = \left[(MD_2 - MD_1) \cdot (\sin I_2) \cdot (\sin A_2) \right] + East_1$$

$$TVD_2 = \left[(MD_2 - MD_1) \cdot (\cos I_2) \right] + TVD_1$$

Six methods are applied to make survey computations for wellbore trajectories. In all of them, we obtain parameters as True Vertical Depth, Northing, Easting, Displacement, Vertical Section (Vs) and Dog leg severity. These methods are : Tangential, Balanced Tangential, Mercury, **Average angle**, Curvature Radius and Minimum Curvature.



Metodo del Angulo promedio

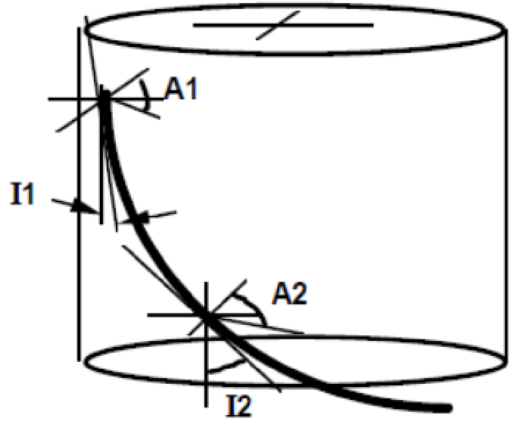
$$North_2 = \left[\left(MD_2 - MD_1 \right) \cdot \sin\left(\frac{I_1 + I_2}{2} \right) \cdot \cos\left(\frac{A_1 + A_2}{2} \right) \right] + North_1$$

$$East_2 = \left[\left(MD_2 - MD_1 \right) \cdot \sin\left(\frac{I_1 + I_2}{2} \right) \cdot \sin\left(\frac{A_1 + A_2}{2} \right) \right] + East_1$$

$$TVD_2 = \left[\left(MD_2 - MD_1 \right) \cdot \cos\left(\frac{I_1 + I_2}{2} \right) \right] + TVD_1$$

Six methods are applied to make survey computations for wellbore trajectories. In all of them, we obtain parameters as True Vertical Depth, Northing, Easting, Displacement, Vertical Section (Vs) and Dog leg severity. These methods are : Tangential, Balanced Tangential, Mercury, Average angle, **Curvature Radius** and Minimum Curvature.

Metodo 3: Radio de Curvatura



Asume: La trayectoria es una curva suave que puede ser fajustada a la superficie de un cilindro con un radio especifico

- Mejora la exactitud

Metodo del Radio de Curvatura

$$North_2 = \left[\frac{(MD_2 - MD_1)\cdot(\cos I_1 - \cos I_2)\cdot(\sin A_2 - \sin A_1)}{(I_2 - I_1)\cdot(A_2 - A_1)} \right] + North_1$$

$$East_2 = \left[\frac{(MD_2 - MD_1)\cdot(\cos I_1 - \cos I_2)\cdot(\cos A_1 - \cos A_2)}{(I_2 - I_1)\cdot(A_2 - A_1)} \right] + East_1$$

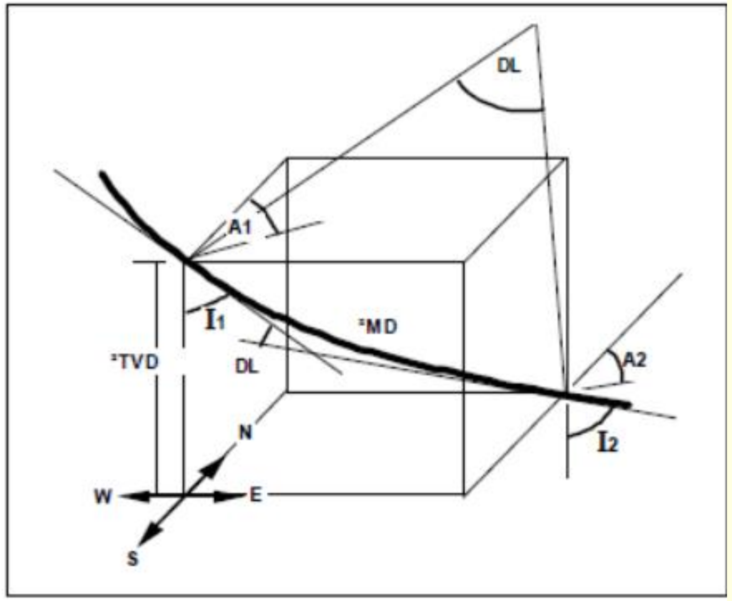
$$TVD_2 = \frac{\left[(MD_2 - MD_1)\cdot(\sin I_2 - \sin I_1)\right]}{(I_2 - I_1)} + TVD_1$$

Six methods are applied to make survey computations for wellbore trajectories. In all of them, we obtain parameters as True Vertical Depth, Northing, Easting, Displacement, Vertical Section (Vs) and Dog leg severity. These methods are : Tangential, Balanced Tangential, Mercury, Average angle, Curvature Radius and **Minimum Curvature**.

Metodo 4: Minimo Curvatura

Asume: La trayectoria es una curva suave que puede ser ajustada a la superficie de una esfera con un radio especifico.

- Mejora la exactitud de calculos
- Muy similar a Radio curvatura
- Preferido por la industria



Metodo de Minima Curvatura

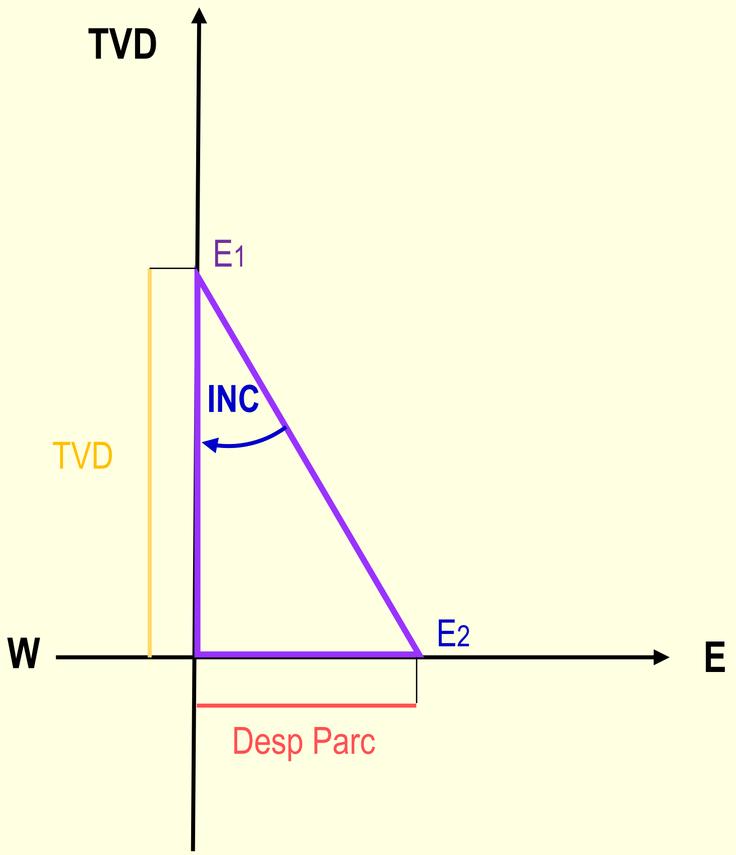
$$North_2 = \left[\left(\frac{MD_2 - MD_1}{2}\right)\cdot\left(\left(\sin I_1 \cos A_1\right) + \left(\sin I_2 \cos A_2\right)\right)\cdot RF\right] + North_1$$

$$East_2 = \left[\left(\frac{MD_2 - MD_1}{2}\right)\cdot\left(\left(\sin I_1 \sin A_1\right) + \left(\sin I_2 \sin A_2\right)\right)\cdot RF\right] + East_1$$

$$TVD_2 = \left[\left(\frac{MD_2 - MD_1}{2}\right)\cdot\left(\cos I_1 + \cos I_2\right)\cdot RF\right]$$

$$RF = \frac{180}{\pi}\cdot\frac{2}{DLS}\tan\left(\frac{DLS}{2}\right);\ if\ \ DLS = 0,\ RF = 1$$

In Wellbore-47 at 4305 md, compute TVD, Displacement, Northing, Easting, DLS, Closure Azimuth(Caz) & Vertical Section(@ 60.91 degrees). Apply Minimum Curvature Method.



MD	Incl (º)	Azi (º)
4275	38.85	35.56
4305	**43.08**	**37.16**

$$Desp\_Parc = (MD_2 - MD_1) * \sin(inc)$$

$$Desp\_Tot = (MD_2 - MD_1) * \sin(inc) + \mathrm{Desp\_Parc}(E_1)$$

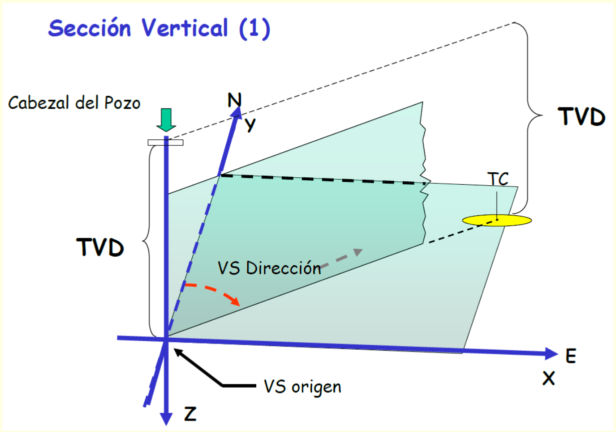
$$Desp\_Parc = (MD_2 - MD_1) * \sin(inc) = (4305 - 4275) * \sin(43.08)$$

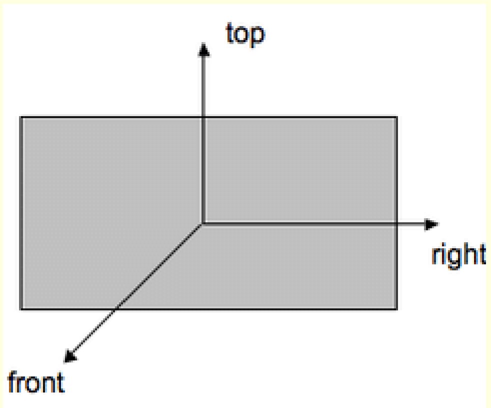
$$Desp\_Parc = 20.49\ m$$

$$TVD_2 = \left[\left(\frac{MD_2 - MD_1}{2}\right) \cdot \left(\cos I_1 + \cos I_2\right) \cdot RF\right] + TVD_1$$

Angulo Promedio

$$TVD_2 = \left[\left(MD_2 - MD_1\right) \cdot \left(\cos I_2\right)\right] + TVD_1$$





In Wellbore-47 at 4305 md, compute TVD, Displacement, Northing, Easting, DLS, Closure Azimuth(Caz) & Vertical Section(@ 60.91 degrees). Apply Minimum Curvature Method.

The ratio of dividing the straight line section (Eq. 6 and 7) with the curved section (Eq. 4 and 5) respectively, defines the ratio factor, RF:

$$RF = A_1B / A_1Q = BA_2 / QA_2 = \tan(\beta/2)/\beta/2 \quad (8)$$

$$RF = A_1B / A_1Q = BA_2 / QA_2 = \tan(\beta/2)/\beta/2 \quad (9)$$

$$RF = 2 / \beta_i \tan(\beta_i / 2) \quad (10)$$

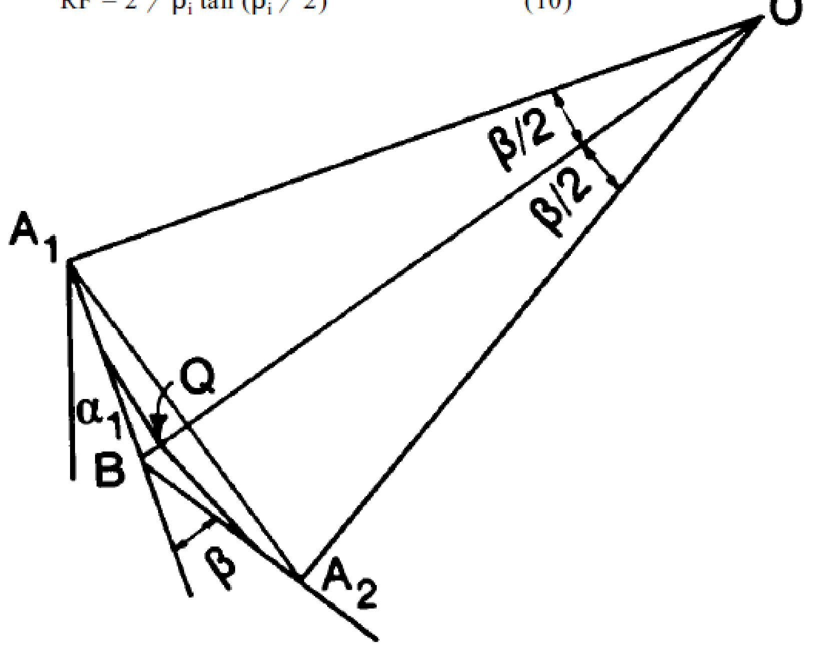


Fig. 8.21—Representation of minimum curvature ratio factor, *F*.

$$DLS = a\cos\left[\cos(I_2 - I_1) - \left(\sin I_1 \cdot \sin I_2 \cdot \left(1 - \cos(A_2 - A_1)\right)\right)\right]$$

$$DLS = a\cos\left[\cos(43.08 - 38.85) - \left(\sin(38.85) \cdot \sin(43.08) \cdot \left(1 - \cos(37.16 - 35.56)\right)\right)\right]$$

$$DLS = 4.36 \ \ (^{o}/30\,m)$$

$$RF = \frac{180}{\pi} \cdot \frac{2}{DLS} \tan\left(\frac{DLS}{2}\right); \ if \ \ DLS = 0, \ RF = 1$$

$$RF = \frac{180}{\pi} \cdot \frac{2}{4.36} \tan\left(\frac{4.36}{2}\right) = 1.00048$$

$$TVD_2 = \left[\left(\frac{4305 - 4275}{2}\right) \cdot \left(\cos(38.85) + \cos(43.08)\right) \cdot 1.00048\right] + 4194.37$$

$$TVD_2 = 4217.11\ m$$

In Wellbore-47 at 4305 md, compute TVD, Displacement, Northing, Easting, DLS, Closure Azimuth(Caz) & Vertical Section(@ 60.91 degrees). Apply Minimum Curvature Method.

MD	Incl (°)	Azi (°)
4275	38.85	35.56
4305	**43.08**	**37.16**

$$North_2 = \left[\left(\frac{MD_2 - MD_1}{2}\right)\cdot\left(\left(\sin I_1 \cos A_1\right) + \left(\sin I_2 \cos A_2\right)\right)\cdot RF\right] + North$$

$$North_2 = \left[\left(\frac{4305 - 4275}{2}\right)\cdot\left(\left(\sin(38.85)\cos(35.56)\right) + \left(\sin(43.08)\cos(37.16)\right)\right)\cdot 1.00048\right] + (-400.27)$$

$$North_2 = \left[(15)\cdot\left(\left(\sin(38.85)\cos(35.56)\right) + \left(\sin(43.08)\cos(37.16)\right)\right)\cdot 1.00048\right] + (-400.27)$$

$$North_2 = \left[(15)\cdot(0.5099 + 0.5443)\cdot 1.00048\right] + (-400.27)$$

$$North_2 = 15.82 - 416.1 = -400.27$$

In Wellbore-47 at 4305 md, compute TVD, Displacement, Northing, Easting, DLS, Closure Azimuth(Caz) & Vertical Section(@ 60.91 degrees). Apply Minimum Curvature Method.

MD	Incl (º)	Azi (º)
4275	38.85	35.56
4305	**43.08**	**37.16**

$$East_2 = \left[\left(\frac{MD_2 - MD_1}{2}\right)\cdot\left(\left(\sin I_1 \sin A_1\right)+\left(\sin I_2 \sin A_2\right)\right)\cdot RF\right] + East_1$$

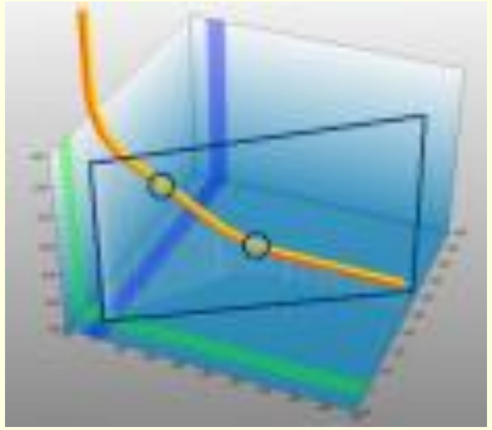
$$East_2 = \left[\left(\frac{4305-4275}{2}\right)\cdot\left(\left(\sin(38.85)\sin(35.56)\right)+\left(\sin(43.08)\sin(37.16)\right)\right)\cdot 1.00048\right]+17.38$$

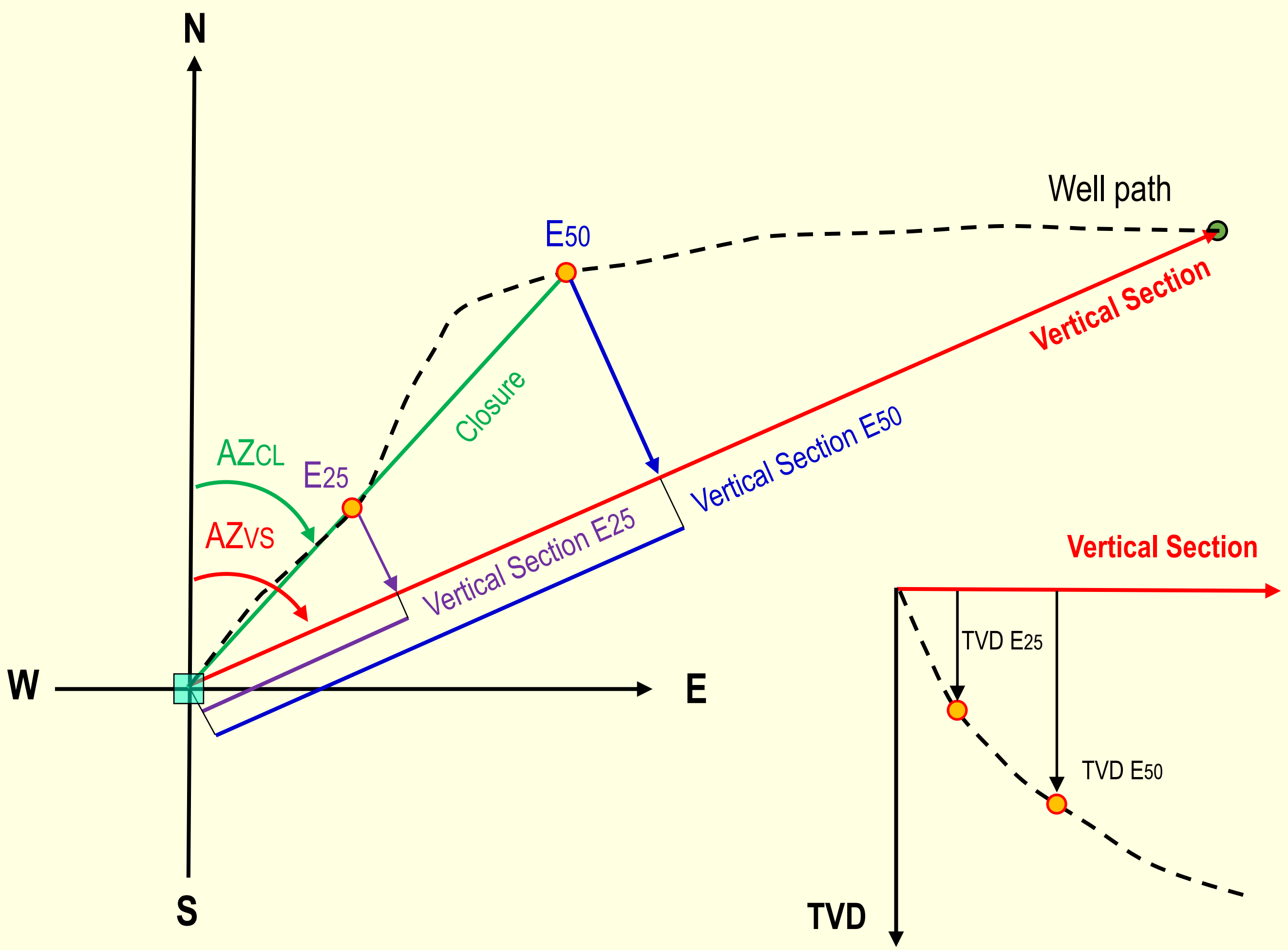
$$East_2 = \left[(15)\cdot(0.3648+0.4125)\cdot 1.00048\right]+17.38$$

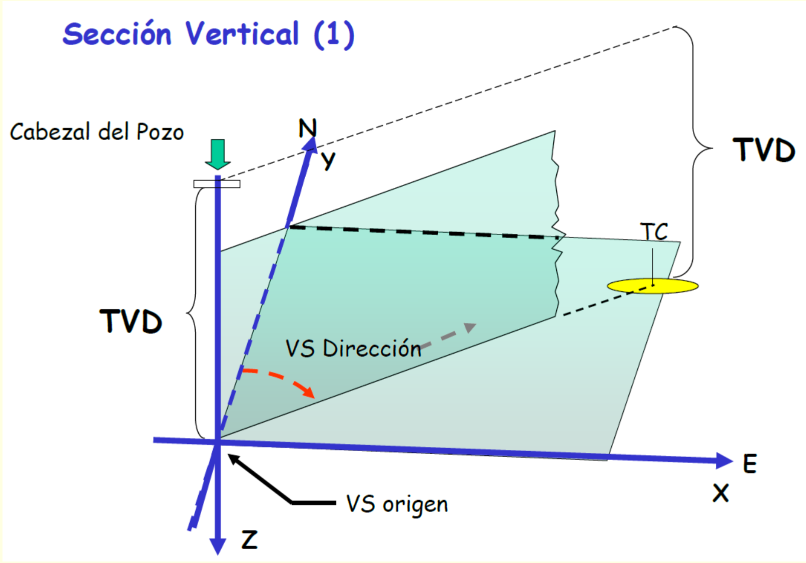
$$East_2 = 29.09$$

El Azimuth de la Sección Vertical se refiere al ángulo medido desde el Norte y hacia el plano de sección vertical, se define de manera arbitraria. La longitud de la Sección Vertical es la proyección del desplazamiento horizontal en la Estación del Survey de interés(E_{50} o E_{25}) sobre el plano de Sección Vertical.

Para describir la posición de un punto en la trayectoria, es posible hacerlo imaginándolo como coordenadas polares, con su distancia al origen (Cierre o Closure), su dirección (Closure Azimuth) y su profundidad TVD.







Para determinar la sección vertical a una profundidad dada, se obtiene con la siguiente ecuación:

$$V_s(m) = \cos(\mathrm{AZ}_{VS} - AZ_{CL}) \cdot \mathrm{CD}$$

Donde:
CD - Closure Distance (Longitud del Cierre).
AZVS - Azimuth del plano de Sección Vertical (dato arbitrario).
AZCL - Azimuth de Cierre (Dirección del Cierre).

Para el caso del primer cuadrante, la distancia de cierre podemos calcularla mediante (como si fuesen coordenadas polares):

$$CD = \sqrt{(E/\mathrm{W})^2 + (N/S)^2}$$

El Azimuth de Cierre se calcula mediante:

$$AZ_{CL} = \arctan\left(\frac{E/W}{N/S}\right)$$

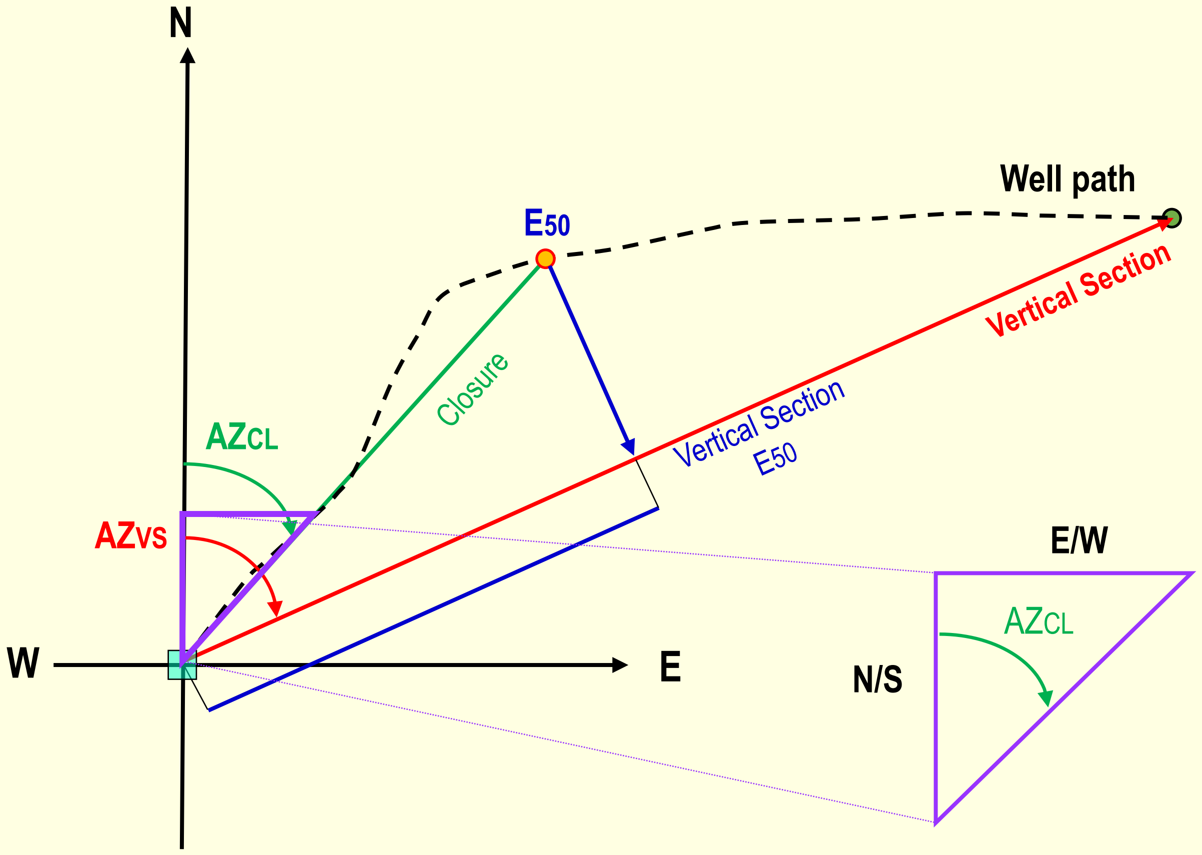
En función del cuandrante donde estemos ubicados, tenemos:

$$0^\circ - 90^\circ,\ AZ_{CL} = \arctan\left(\frac{E/W}{N/S}\right)$$

$$90^\circ - 180^\circ,\ AZ_{CL} = 180^\circ - \arctan\left(\frac{E/W}{N/S}\right)$$

$$180^\circ - 270^\circ,\ AZ_{CL} = 180^\circ + \arctan\left(\frac{E/W}{N/S}\right)$$

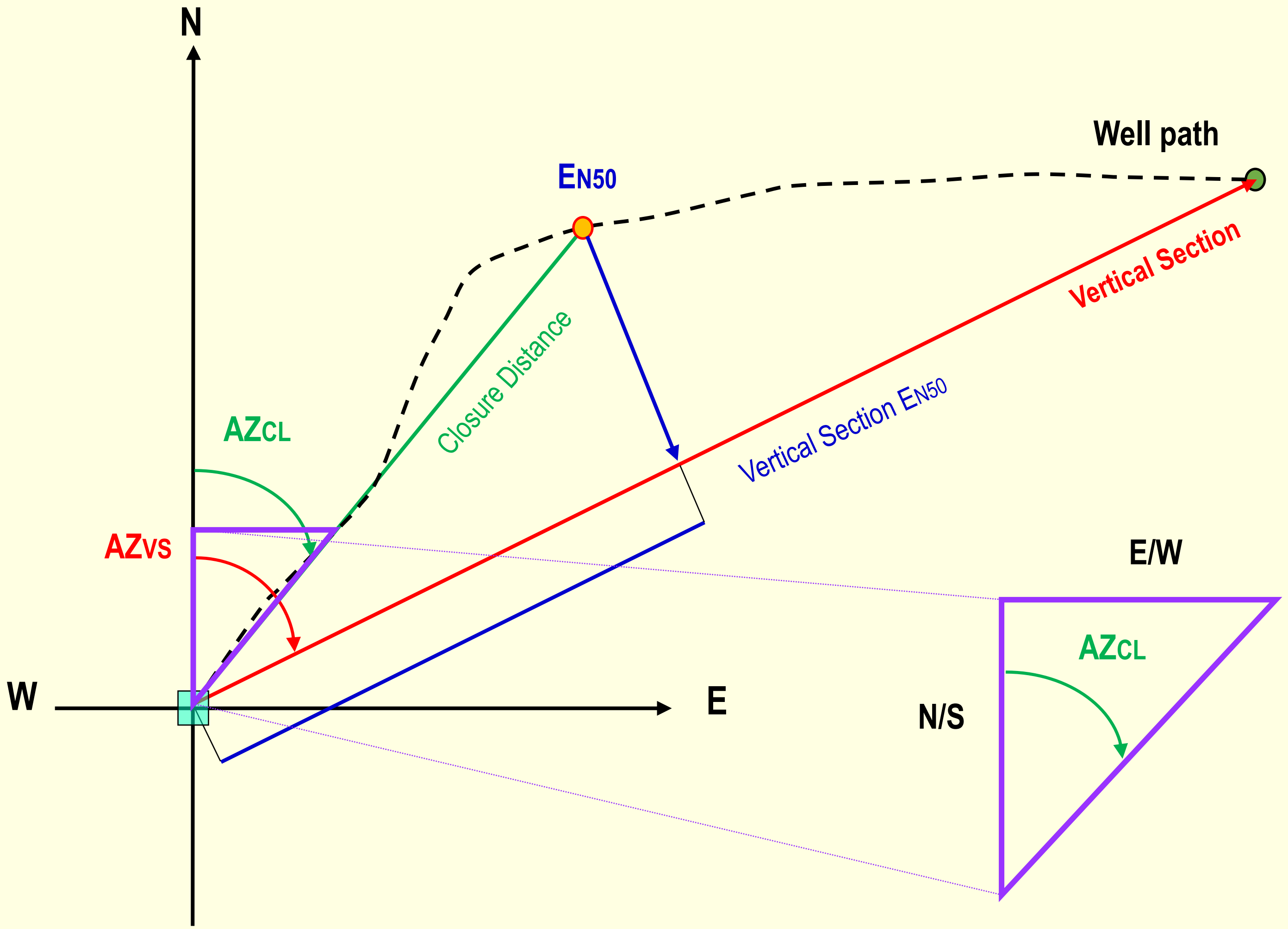
$$270^\circ - 360^\circ,\ AZ_{CL} = 360^\circ - \arctan\left(\frac{E/W}{N/S}\right)$$



Primer Cuadrante:

Para el pozo Balam-47, en la estación 4938 md, se tienen los datos siguientes:
N/S = 58.43 m, E/W = 376.09 m, AZ_{VS} = 60.91°.

Calcule el Cierre (Closure Distance), Azimuth de Cierre (AZ_{CL}) y la Sección Vertical (V_S).



Calculamos el Cierre:

$$CD = \sqrt{(376.09)^2 + (58.43)^2}$$

$$CD = 380.60\ (m)$$

Calculando el Azimuth de Cierre:

$$0^\circ - 90^\circ,\ AZ_{CL} = \arctan\left(\frac{E/W}{N/S}\right)$$

$$AZ_{CL} = \arctan\left(\frac{376.09}{58.43}\right)$$

$$AZ_{CL} = 81.17^o$$

Por último, obtenemos la Sección Vertical:

$$V_s(m) = \cos(AZ_{VS} - AZ_{CL}) \cdot CD$$

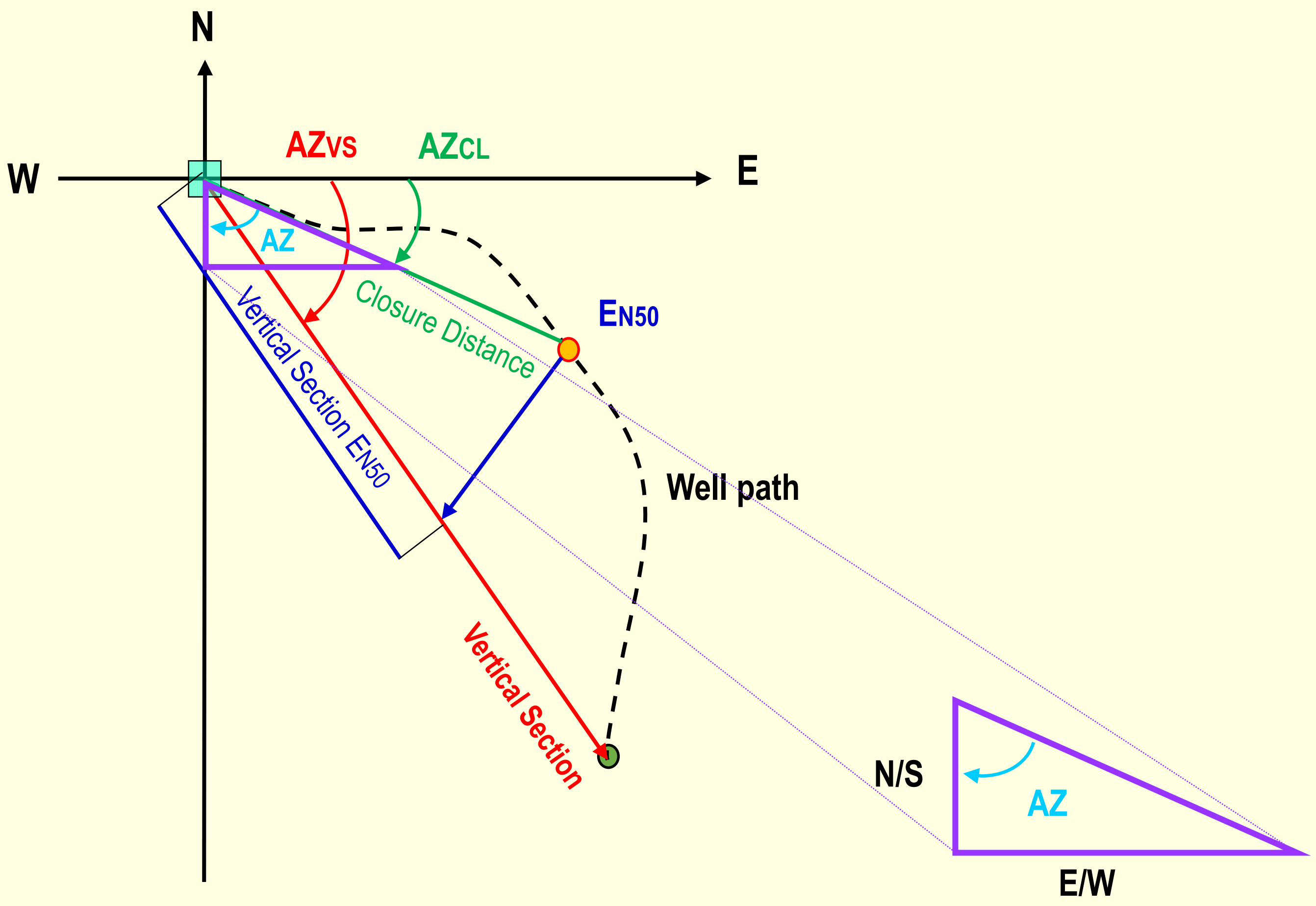
$$V_s(m) = \cos(60.91 - 81.14) \cdot 380.60$$

$$V_s(m) = 357.12\,(m)$$

Second Quadrant:

For Wellbore-47, at a depth 4305 md, input data are the following:
N/S = -400.64 m, E/W = 29.71 m, AZ_{VS} = 60.91°.

Compute Closure Distance, Closure Azimuth (AZ_{CL}) and Vertical Section (V_S).



Computing the closure distance:

$$CD = \sqrt{(29.71)^2 + (-400.64)^2}$$
$$CD = 401.74\ (m)$$

Computing the closure azimuth:

$$90^\circ - 180^\circ,\ AZ_{CL} = 180^\circ - \arctan\left(\frac{E/W}{N/S}\right)$$
$$AZ_{CL} = 180^\circ - \arctan\left(\frac{(29.71)}{(400.64)}\right)$$
$$AZ_{CL} = 175.76^\circ$$

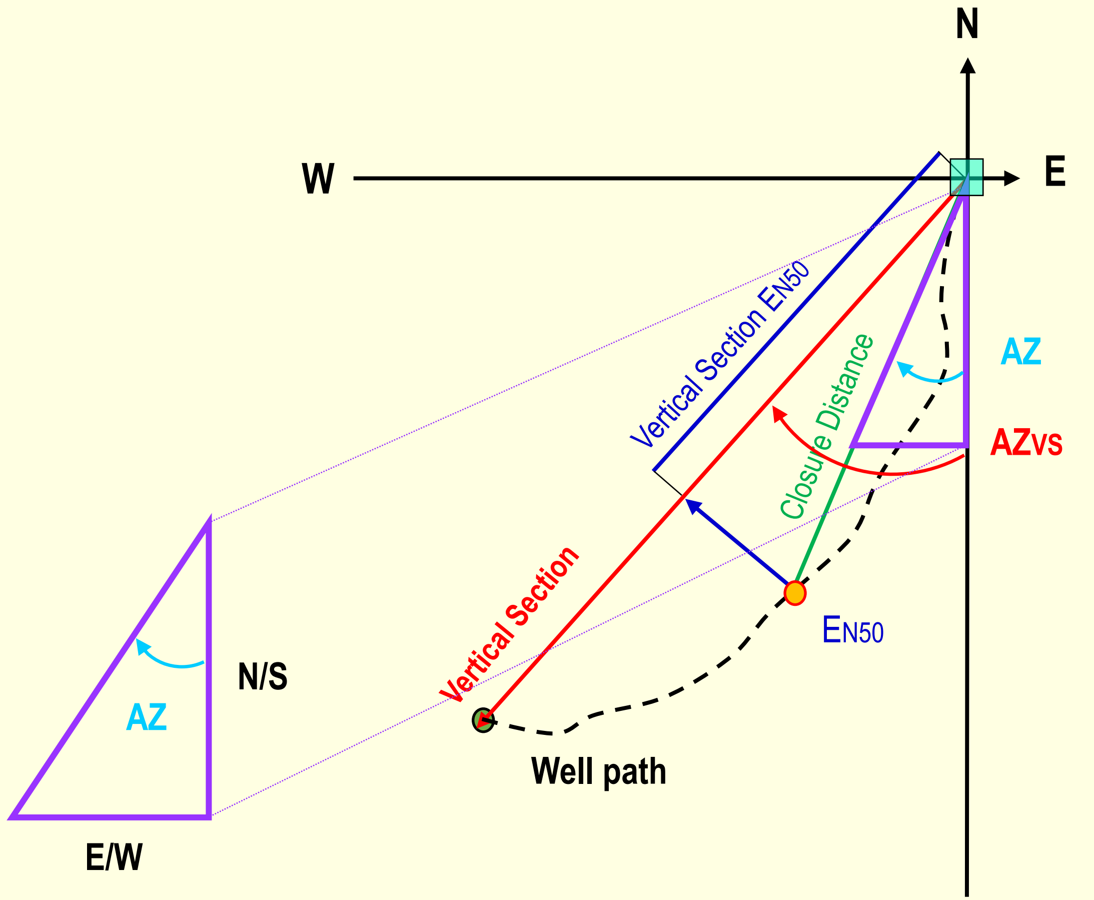
Finally, computing the Vertical section:

$$V_s(m) = \cos(60.91 - 175.76) \cdot 401.74$$
$$V_s(m) = -168.83\ (m)$$

Tercer Cuadrante:

Para el pozo Balam-47, en la estación 2720 md, se tienen los datos siguientes:
N/S = -363.25 m, E/W = -96.07 m, AZ_{VS} = 60.91º.

Calcule el Cierre (Closure Distance), Azimuth de Cierre (AZ_{CL}) y la Sección Vertical (V_S).



Calculamos el Cierre:

$$CD = \sqrt{(-96.07)^2 + (-363.25)^2}$$

$$CD = 375.74\ (m)$$

Calculamos el Azimuth de Cierre:

$$180^\circ - 270^\circ,\ AZ_{CL} = 180^\circ + \arctan\left(\frac{E/W}{N/S}\right)$$

$$AZ_{CL} = 180^\circ + \arctan\left(\frac{96.07}{363.25}\right)$$

$$AZ_{CL} = 194.81^\circ$$

Por último, obtenemos la Sección Vertical:

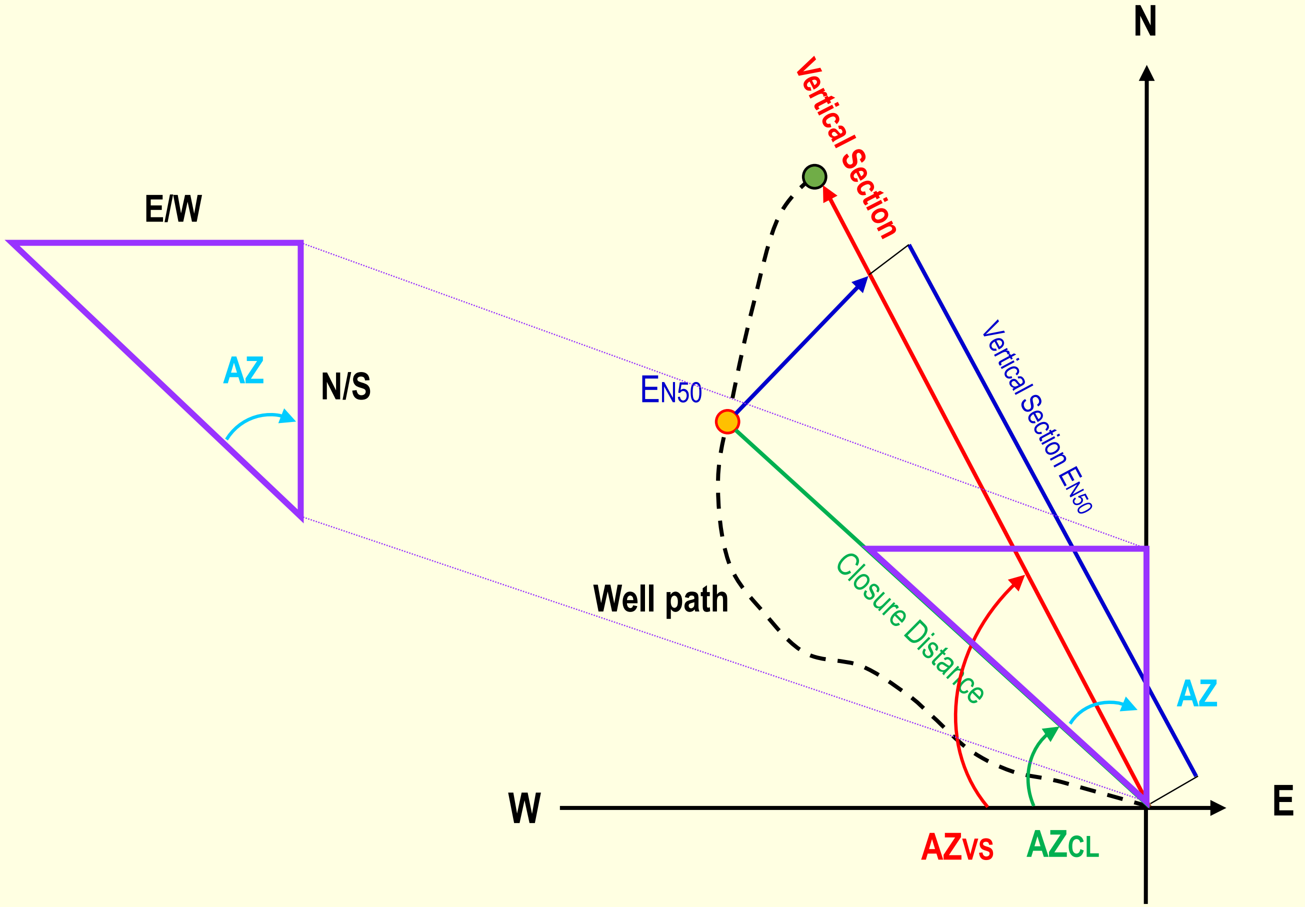
$$V_s(m) = \cos(60.91 - 194.81) \cdot 375.74$$

$$V_s(m) = -260.55\ (m)$$

Cuarto Cuadrante:

El pozo Balam-47 no tiene estaciones en el cuarto cuadrante, sin embargo a manera de ejemplo vamos a considerar que en la estación 4878 md, se tienen los datos siguientes:
N/S = 10.75 m, E/W = -339.71 m, AZ_{VS} = 60.91º.

Calcule el Cierre (Closure Distance), Azimuth de Cierre (AZ_{CL}) y la Sección Vertical (V_S).



Calculamos el Cierre:

$$CD = \sqrt{(-339.71)^2 + (10.75)^2}$$

$$CD = 339.88\ (m)$$

Calculamos el Azimuth de Cierre:

$$270^\circ - 360^\circ,\ AZ_{CL} = 360^\circ - \arctan\left(\frac{E/W}{N/S}\right)$$

$$AZ_{CL} = 360^\circ - \arctan\left(\frac{339.71}{10.75}\right)$$

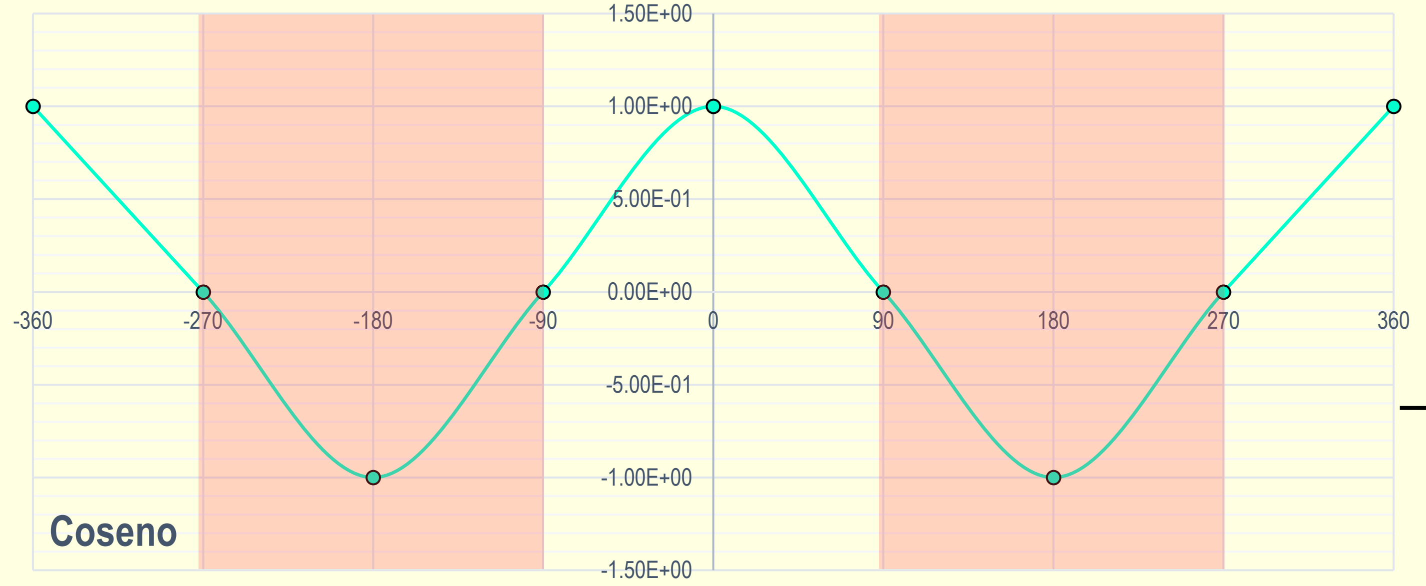
$$AZ_{CL} = 271.81^\circ$$

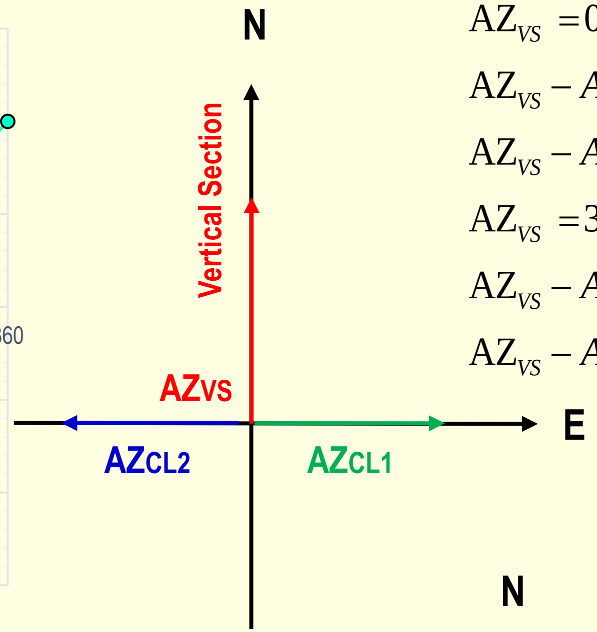
Por último, obtenemos la Sección Vertical:

$$V_s(m) = \cos(60.91 - 271.81) \cdot 339.88$$

$$V_s(m) = -291.63\ (m)$$

La función coseno adquiere valores negativos en la rangos de -270º a -90º y de 90º a 270º. La función Atan se mantiene positiva en valores positivos, por lo que el argumento de la misma al calcular el Azimuth debe manejarse como valor absoluto valores positivos.
Para nuestro ejemplo, de una sección vertical de 60.91º, se tendrán valores negativos en el rango de





$$AZ_{VS} = 0^{o}$$
$$AZ_{VS} - AZ_{CL1} = 0 - 90^{o} = -90$$
$$AZ_{VS} - AZ_{CL2} = 0 - 270^{o} = -270$$
$$AZ_{VS} = 360^{o}$$
$$AZ_{VS} - AZ_{CL1} = 360 - 90^{o} = 270$$
$$AZ_{VS} - AZ_{CL2} = 360 - 270^{o} = 90$$

Para nuestro ejemplo, de una sección vertical de 60.91º, se tendrán valores negativos cuando la diferencia entre el AZ_{VS} y el AZ_{CL} sea 90 – 270º, lo cual ocurre cuando el AZ_{CL} está entre 150.91 y 330.91º.

$$AZ_{VS} - AZ_{CL1} = 90^{o}$$
$$AZ_{CL1} = 90^{o} + AZ_{VS} = 150.91^{o}$$
$$AZ_{VS} - AZ_{CL2} = 270$$
$$AZ_{VS} - AZ_{CL1} = 270^{o}$$
$$AZ_{CL1} = 270^{o} + AZ_{VS} = 330.91^{o}$$