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New Method of High Quality and High Speed Drilling Based on Stratigraphic Naturally Whipstocking Law

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Abstract
High steep dip formation is one of the important keys effecting well deviation and azimuth during drilling. According to space gridding data of formation,calculation method of angle and tendency and analysis model of offset of deviation and azimuth are derived considering formation anisotropy. Combined with the field experiment, calculation orbit is similar to true track, also increasing drilling speed. The result shows that using formation natural deflecting law to optimize well position and design well trajectory, to increase drill pressure in order to increase ROP while not effect reaching the target naturally are feasible. This indicates analysis method is correct and reasonable. It has important theoretical value and practical worth in engineering.

Key words: Formation anisotropy; Whipstocking law; Weight on bit; New drilling method

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INTRODUCTION

Demonstrated by drilling practice that stratigraphic naturally whipstocking characteristic is one of the main factors influencing well deviation and azimuthal change. Due to the obvious difference of geologic structure and formation lithology in different area[1], formation deflecting force is also changed. Although geologic factors are out of man force control, but the relationship between borehole deviation & azimuth change and attitude of stratum can be used to optimize well position and well track. By using this method, exploratory target can be realized and WOB (weight on bit) can be released. The final goal for drilling engineering, that is raising ROP(rate of penetration), can also be obtained. For that, researching on stratigraphic naturally whipstocking law is very useful for optimizing wellbore trajectory, raising ROP and wellbore quality. It has important theoretical and practical value.

1. CALCULATION OF INCLINATION ANGLE AND DIP DIRECTION IN HIGH STEEP DIP FORMATION

In order to calculating inclination angle and dip direction of arbitrary point in formation, space grid data of various stratigraphic horizon can be obtained from geologists, and then calculate followed by certain steps. The projection of various stratigraphic horizon grid on horizontal plane is by serial-arrangement and regular spread square grid. The grid point on horizontal plane and corresponding grid point of various stratigraphic horizon are at the same pedal line in spite of the different vertical depth. Fig. 1 shows horizontal projection schematic drawing of stratigraphic space grid. The horizontal projection of arbitrary point A(N,E,D) is located at square(a,b,c,d).

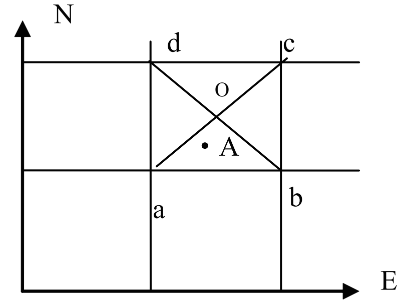

Figure 1
Horizontal Projection Schematic Drawing of Stratigraphic Space Grid

1.1 Locating Four Apexes Coordinates of the Square Point A Located on Horizontal Projection Plane

On the horizontal projection plane,because grid space is a fixed value - *grid_space*, so the coordinates (N, E) of various point on projection plane are integral multiple of the fixed value *grid_space.* Showed as figure 1, the coordinates (N,E) of point a are as follows:

$$N_a = \text{int}\left(\frac{N}{grid\_space}\right) \times grid\_space \tag{1}$$

$$E_a = \text{int}\left(\frac{E}{grid\_space}\right) \times grid\_space \tag{2}$$

So the coordinates(N,E) of point b, point c and point d showed as follows:

$$N_b = N_a \tag{3}$$

$$E_b = E_a + grid\_space \tag{4}$$

$$N_c = N_a + grid\_space \tag{5}$$

$$E_c = E_a + grid\_space \tag{6}$$

$$N_d = N_a + grid\_space \tag{7}$$

$$E_b = E_a \tag{8}$$

1.2 Locating Point A in the Square on Horizontal Projection Plane

On horizontal projection plane(Fig.1),the two diagonal lines of arbitrary square(e.g. square abcd) can divide it into four triangle pieces, that is: ⊿oab, ⊿obc, ⊿ocd& ⊿oda. The diagnosis that locates point A in which triangle piece can be made by following equations (9)~(12).

The condition that point A locates in ⊿oab is:

$$\begin{cases} N - N_a < E - E_a \\ N - N_b < E_b - E \end{cases} \tag{9}$$

The condition that point A locates in ⊿obc is:

$$\begin{cases} N - N_a < E - E_a \\ N - N_b > E_b - E \end{cases} \tag{10}$$

The condition that point A locates in ⊿ocd is:

$$\begin{cases} N - N_a > E - E_a \\ N - N_b > E_b - E \end{cases} \tag{11}$$

The condition that point A locates in ⊿oda is:

$$\begin{cases} N - N_a > E - E_a \\ N - N_b < E_b - E \end{cases} \tag{12}$$

1.3 Arbitrary Surface's Normal Component in the Prism Obtained by Vertically Extended Triangle Piece of Point A's Projection Located

Suppose that the four square space apexes(a,b,c,d) of point A's projection located correspond to four space apexes (i,j,k,l), so the normal component can be calculated by following equations (13)~(16).

When point A locates in ⊿oab:

$$\vec{n} = \big[(H_a - H_d, N_a - N_d, E_a - E_d) \times (H_b - H_a, N_b - N_a, E_b - E_a) + (H_b - H_a, N_b - N_a, E_b - E_a) \times (H_c - H_b, N_c - N_b, E_c - E_b)\big]/2 \tag{13}$$

When point A locates in ⊿obc:

$$\vec{n} = \big[(H_b - H_a, N_b - N_a, E_b - E_a) \times (H_c - H_b, N_c - N_b, E_c - E_b) + (H_c - H_b, N_c - N_b, E_c - E_b) \times (H_d - H_c, N_d - N_c, E_d - E_c)\big]/2 \tag{14}$$

When point A locates in ⊿ocd:

$$\vec{n} = \big[(H_c - H_b, N_c - N_b, E_c - E_b) \times (H_d - H_c, N_d - N_c, E_d - E_c) + (H_d - H_c, N_d - N_c, E_d - E_c) \times (H_a - H_d, N_a - N_d, E_a - E_d)\big]/2 \tag{15}$$

When point A locates in ⊿oda:

$$\vec{n} = \big[(H_d - H_c, N_d - N_c, E_d - E_c) \times (H_a - H_d, N_a - N_d, E_a - E_d) + (H_a - H_d, N_a - N_d, E_a - E_d) \times (H_b - H_a, N_b - N_a, E_b - E_a)\big]/2 \tag{16}$$

1.4 Calculation of Normal Component of Point

Using the range formula of point to plane, calculate the range from point A to corresponding triangle piece on various plane and find out the nearest two up and down triangle piece from point A. Then point A's normal component $\vec{n}_A(\vec{n}_A = H_A\vec{e}_H + N_A\vec{e}_N + E\vec{e}_E)$ is:

$$\vec{n}_A = \frac{d_{\min1}}{d_{\min1} + d_{\min2}}\vec{n}_2 + \frac{d_{\min2}}{d_{\min1} + d_{\min2}}\vec{n}_1 \qquad (17)$$

where

d_{min1}—range from point A to the nearest up triangle piece,m;d_{min2}—range from point A to the nearest down triangle piece,m;

$\vec{n}_1$—normal component of the nearest up triangle piece; $\vec{n}_2$—normal component of the nearest down triangle piece.

1.5 Formation Inclination Angle Calculation of Point A Formation Inclination Angle

$$a_d = \arccos\frac{|H_A|}{|\vec{n}_A|}$$

formation azimuth

$$\varphi_d = \begin{cases} \arctan\frac{E_A}{N_A} & (N_A 0) \\ \arctan\frac{E_A}{N_A} + \pi & (N_A 0) \\ \frac{\pi}{2} & (N_A = 0, E_A \geq 0) \\ \frac{3\pi}{2} & (N_A = 0, E_A 0) \end{cases}$$

2. OFFSET DISTANCE CALCULATION OF WELL POSITION

During drilling design, if surface condition permitted, stratigraphic naturally whipstocking law can be used to reach geologic target by removing well ground position. It can also release WOB and enhance the ROP. Because the parameters of well deviation, azimuth and depth are already known and it was well known that the main reason leading to the offset of deviation and azimuth is formation anisotropy, so we should calculate based on the formation anisotropy[2], and then by using inverse method, calculate from bottom hole to wellhead. By this, we can obtain the off-set value from new well position to the in-situ one.

Based on the relationship between drilling bit acting force and ROP[3,4,5], the equation of formation anisotropy exponent h, formation deflecting coefficient K_α and azimuth drifting coefficient K_φ can be obtained.

$$h = \frac{F_x\tan\Delta\alpha - F_z}{(\tan\Delta\alpha\sin(\beta-\alpha) - \cos(\beta-\alpha))(F_x\sin(\beta-\alpha) + F_z\cos(\beta-\alpha))} \qquad (18)$$

$$K_\alpha = \frac{h(\cos\alpha\cos\beta + \sin\alpha\sin\beta\cos(\varphi-\gamma))(\cos\alpha\sin\beta\cos(\varphi-\gamma) - \sin\alpha\sin\beta)}{hc + (1-h)} \qquad (19)$$

$$K_\varphi = \frac{h(\cos\alpha\cos\beta + \sin\alpha\sin\beta\cos(\varphi-\gamma))\sin\beta\sin(\varphi-\gamma)}{hc + (1-h)} \qquad (20)$$

$$c = g_2^2 + g_3^2 + g_1(g_2\tan\Delta\varphi + g_3\tan\Delta\alpha)$$

$$g_1 = \cos\alpha\cos\beta + \sin\alpha\sin\beta\cos(\varphi-\gamma)$$

$$g_2 = \sin\beta\sin(\varphi-\gamma)$$

$$g_3 = \cos\alpha\sin\beta\cos(\varphi-\gamma) + \sin\alpha\cos\beta$$

Inclination offset value $\Delta\alpha = \Delta L \cdot K_\alpha$

Azimuth offset value $\Delta\varphi = \Delta L \cdot K_\varphi$

then

$$\alpha_{i+1} = \alpha_0 + \Delta\alpha$$

$$\varphi_{i+1} = \varphi_0 + \Delta\varphi$$

where

F_x, F_z—bit acting force component on x and y axis in borehole axial line coordinate system, N;α—hole deviation angle, *rad;*

β—formation dip direction, *rad*;φ—azimuth angle, *rad*;γ—formation dip direction azimuth angle, *rad*; ΔL —length between two trajectory nodes, *m; α_0*—bottom hole deviation angle, *rad; φ_0*—bottom hole azimuth angle, *rad*; *i*-node number.

3. CASE STUDY

The depth of well Y225 is 3150m. Based on the analysis of off-set well data, lower formation has certain natural deflecting ability. Calculating by the new method mentioned above, lower formation inclination is 15° and dip direction 185°. The predictive result is consistent with the actual result properly. It verifies the calculation method. Based on the design parameters of well targets and combining with formation anisotropy research, wellhead position is optimized. Demonstrated by calculation, wellhead position should be removed 98m at the direction of 180°, illustrated in figure 2 and figure 3. The true measured track is illustrated in figure 4.

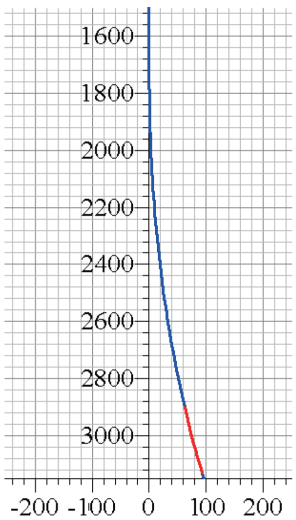

Figure 2
Vertical Projection Drawing (m)

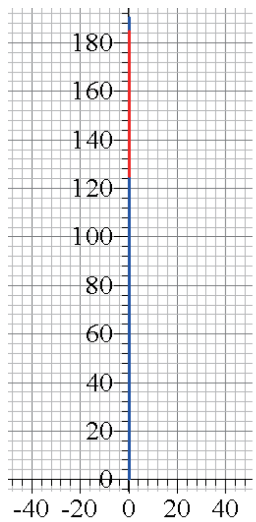

Figure 3
Horizontal Projection Drawing (m)

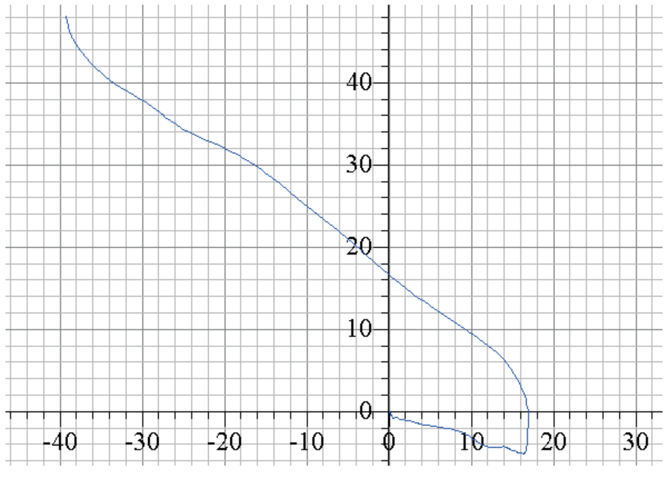

Figure 4
Actual Trajectory Horizontal Projection of Well Y225(m)

As illustrated in figure 4, calculation orbit is similar to true track in lower formation and it verifies the validity of the new drilling method. After releasing the WOB about one multiple amount, the ROP of rock roller bits enhanced by the percentage of 15%. The practice in well Y225 shows that the new drilling method of using formation natural deflecting law to optimize well position and design well trajectory, to increase drill pressure in order to increase ROP while not effect reaching the target naturally is feasible. This indicates the analysis method is correct and reasonable. It has important deployment worth.

CONCLUSION

(1) Based on the space grid data of various formation horizon, the calculation method of formation inclination angle and dip direction is built. It can help engineers confirming formation naturally whipstocking law with geologic data.

(2) Considering the characteristic of formation anisotropy, the calculation module of deviation and azimuth offset distance is deducted.

(3) The practical result shows that the new drilling method of using formation natural deflecting law to optimize well position and design well trajectory, to increase drill pressure in order to increase ROP while not effect reaching the target naturally is feasible and rational.

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