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A New Type of Composite String Shale Gas Horizontal Well Free Point Depth Calculation Model

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Abstract

During the workover process of shale gas horizontal wells, blockage accidents can easily occur due to factors such as formation structure problems or improper operation. After the jam, the jam needs to be released quickly to avoid more complicated underground accidents. The depth of the free point is an important basis for judging downhole conditions. In this paper, after fully considering the influence of friction load, buoyancy, drill pipe joint and thickened part, establish a new analytical model and method suitable for calculating the position of the composite pipe string in horizontal wells, and the correction coefficient of the free point formula is determined; taking a horizontal well with a long radius of curvature as a calculation example, the free point position of the composite string of a horizontal well is 3989.3 m.

Keywords

Composite String; Friction Torque; Free Point; Shale Gas Horizontal Well.

1. Introduction

During the workover process of shale gas horizontal wells, blockage accidents can easily occur due to factors such as formation structure problems or improper operation [1, 2]. The jam accident not only prolongs the workover cycle, but may also cause secondary failures and cause serious economic losses. After the jam, the jam needs to be released quickly to avoid more complicated underground accidents. The depth of the free point is an important basis for judging downhole conditions.

Many scholars have done a lot of research on the calculation of free point position. Cheng et al. [3] proposed the use of segmented analysis to determine the depth of the pipe string stuck in a vertical well, and proposed a soft rod iteration method further, based on the analysis of the force and deformation of the pipe string. Wang et al. [4] introduced the working principle and operation steps of the three free point measurement methods in detail, compared and analyzed the three measurement methods. It is recommended that when determining the position of the free point, the card measuring instrument and the formula calculation method of free point can be combined to determine the position of the free point more efficiently and accurately, so that effective measures can be taken in time to solve the card and reduce economic losses. Zhou et al. [5] established a prediction model of free points under a single pipe string and a combined pipe string based on the torsional deformation of the pipe string. The experimental method is used to conduct torsion experiments on the two pipe strings. The study found that the torsion method can be used to predict the free point of the drill string in the vertical well. The drill pipe joint and the thickened part of the drill string have a greater influence on the free point calculation, and the calculation formula with the correction coefficient has a higher prediction accuracy.

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In summary, many scholars have used numerical methods and finite element methods to conduct detailed studies on the location of the free points. The models have been simplified to a certain extent, and the effects of friction load, buoyancy, drill pipe joints and thickened parts have not been fully considered. In this paper, a new analytical model and method for calculating the position of the composite pipe string stuck in horizontal wells is established under the conditions of fully considering the friction load, buoyancy, drill pipe joints and thickened parts; taking the long curvature radius horizontal well as a calculation example, the composite string model is used to calculate the drag and torque of the drill string, and the horizontal well composite string free point position calculation model is used to obtain the free point position. The research work of this paper provides a new method for accurately finding the position of the free point in engineering practice, which has an important practical role in engineering.

2. New Type of Free Point Calculation Model

2.1 Model Building

Horizontal wells have large frictional resistance, and the drill string is composed of a variety of different materials and different sizes of drilling tools, and the structure is complex. At the same time, when the downhole string is jammed, the condition of free string is not met. Therefore, the axial load calculated by the friction torque model should be corrected. To accurately calculate the position of the free point in a horizontal well, it is necessary to comprehensively consider the effects of friction, composite string, buoyancy, drill pipe joints and thickened parts. Based on the related theories of material mechanics and pipe string mechanics, this paper establishes a new analytical model for calculating the position of the composite pipe string stuck in horizontal wells, taking into account the influence of friction load, buoyancy, drill pipe joints and thickened parts.

This paper calculates the new model based on the friction torque, and uses the lifting method to calculate the position of the horizontal well free point. The calculation process is shown in Fig. 1. The calculation steps are mainly divided into the following steps:

(1) Weighing, lift the bit away from the bottom of the well, and the drill string is in a free state. The weight on bit and torque at the bit are used as the boundary conditions of the mechanical model, and the friction torque calculation model is used to obtain the initial load Fa of the hook from the bottom of the well to the wellhead.

(2) Determine the initial load of the hook from the first step of calculation to ensure that the initial tension does not exceed the elastic limit of the drill string. Then pull three times continuously on the basis of the initial load of the hook, and each pull is pulled with a certain increment of pull based on the last pull. By comparing the relationship between the axial force of the first pull and Fa, judge whether the axial force of the first pull is transmitted to the free point, "No", then the first pull is invalid. "Yes" is for the next pull.

(3) The average axial force of the three pulls in the second step of the calculation is used as the mechanical boundary condition of the friction torque calculation model, and the friction torque calculation model is used to obtain each unit body from the well head to the bottom. Axial load at the upper and lower ends. Then calculate the elongation of each unit body according to the calculation model of the position of the free point of the composite pipe, superimpose the elongation of each unit body, and accumulate the length of each unit body at the same time.

(4) The drill string elongation calculated in the third step minus the pipe elongation under the initial hook load Fa, the difference between the two is $\Delta\lambda t$.

(5) According to the comparison between the measured elongation increment $\overline{\Delta L}$ and the theoretically calculated elongation increment $\Delta\lambda$, the calculation error is within the accuracy range, and the calculation steps (3) and (4) are repeated until the result meets the calculation accuracy.

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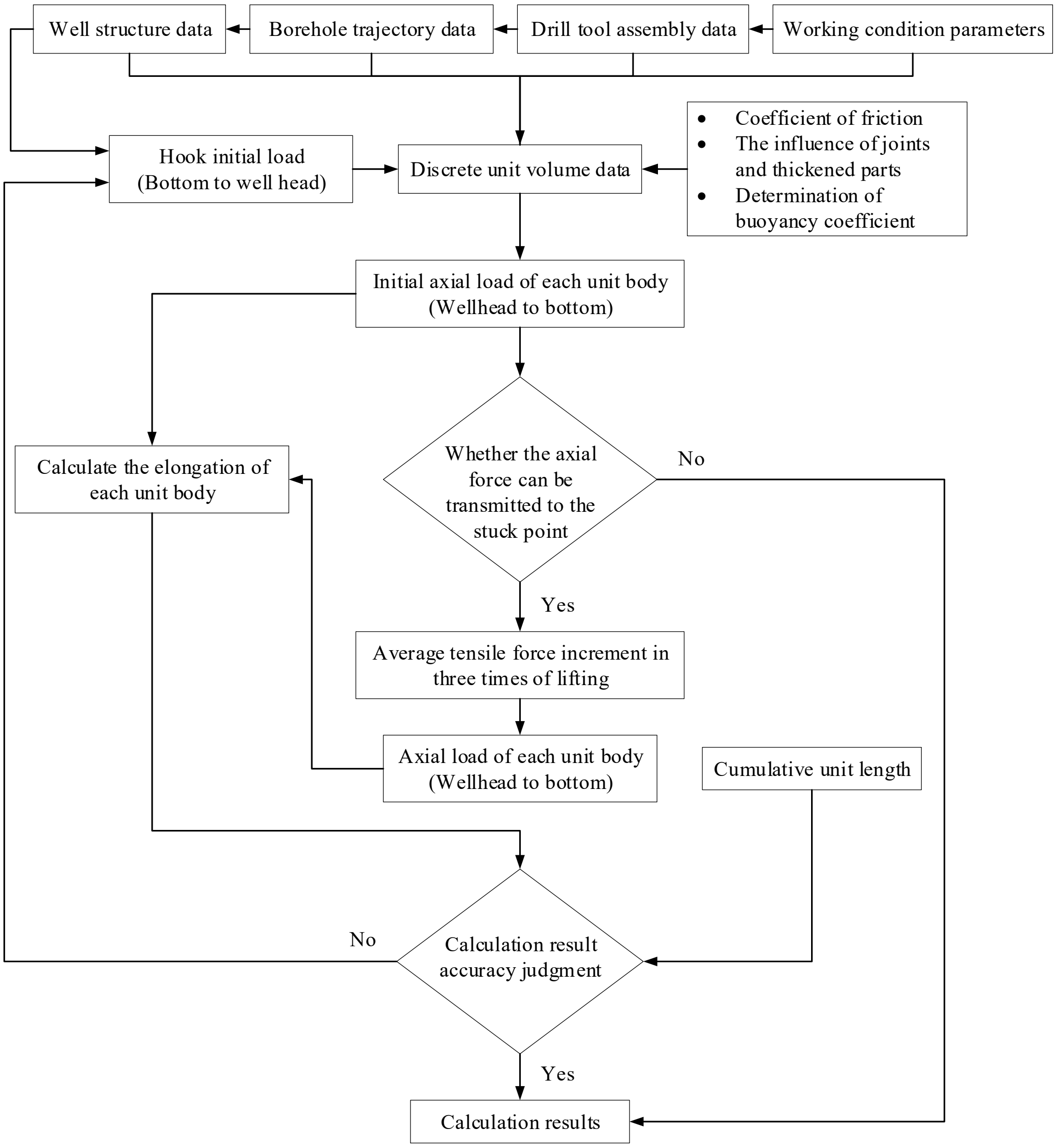

Fig. 1 Flow chart for calculating the free point position of a horizontal well

2.2 Determination of the Correction Coefficient of the Free Point Formula

For composite pipe strings, when the impact of drill string joints is not considered, the relative error is -3.8%. When considering the influence of the drill pipe joint, the relative error is -1.02%. In the drilling operation of extended reach and horizontal wells, the structure of the drilling tool is relatively complicated. As the depth of the well increases, the joints and thickened parts of the drill pipe have an increasing influence in the calculation of the position of the free point. Therefore, it is necessary to consider the influence of the thickened part of the drill pipe joint on the accurate calculation of the position of the free point.

Suppose the cross-sectional areas of the drill pipe body, joints, and thickened parts are Ax, Ay, and Az, the lengths are lx, ly, and lz, and the section moments of inertia are Ix, Iy, and Iz, respectively. The extension Δλ of the drill rod under the action of the tensile force F and the torsion angle $\Delta\varphi$ under the action of the torque T can be expressed as:

$$\Delta\lambda = \frac{Fl_x}{EA_x} + \frac{Fl_y}{EA_y} + \frac{Fl_z}{EA_z} \tag{1}$$

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$$\Delta\varphi=\frac{Tl_x}{GI_x}+\frac{Tl_y}{GI_y}+\frac{Tl_z}{GI_z} \tag{2}$$

The entire drill pipe is regarded as the body, and the calculated elongation $\Delta\lambda'$ and torsion angle $\Delta\varphi'$ are respectively:

$$\Delta\lambda'=\frac{Fl_x}{EA_x}+\frac{Fl_y}{EA_y}+\frac{Fl_z}{EA_z}=\frac{F\left(l_x+l_y+l_z\right)}{EA_x} \tag{3}$$

$$\Delta\varphi'=\frac{T(l_x+l_y+l_z)}{GI_x} \tag{4}$$

Then the correction coefficients of the lifting method and the torsion method are:

$$K_\lambda=\frac{\Delta\lambda'}{\Delta\lambda}=\frac{l_x+l_y+l_z}{A_x}\Bigg/\frac{l_x}{A_x}+\frac{l_y}{A_y}+\frac{l_z}{A_z} \tag{5}$$

$$K_\varphi=\frac{\Delta\varphi'}{\Delta\varphi}=\frac{l_x+l_y+l_z}{I_x}\Bigg/\frac{l_x}{I_x}+\frac{l_y}{I_y}+\frac{l_z}{I_z} \tag{6}$$

(1) Determine the cross-sectional area and length of the drill pipe joint

The drill pipe joint is shown in Fig. 2. The inner and outer diameters of the joint are dy and Dy respectively, the threaded length of the joint is ls, the length of the female joint is lb, and the length of the male joint is lp.

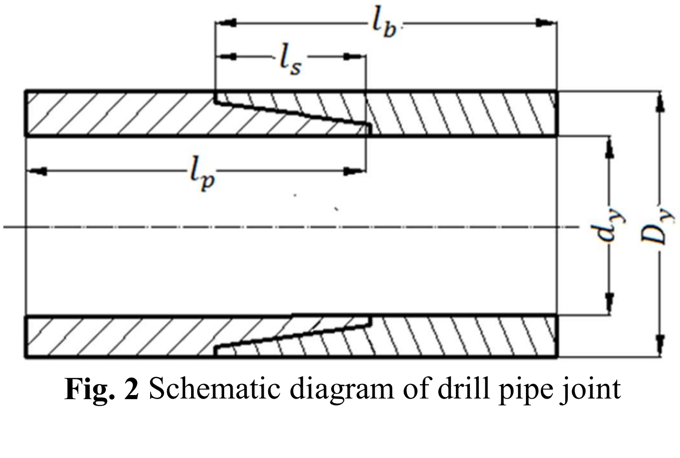

Fig. 2 Schematic diagram of drill pipe joint

The total length ly after the male and female connectors are connected is:

$$l_y=l_b+l_p-l_s \tag{7}$$

The cross-sectional area Ay is:

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$$A_y = \frac{\pi}{4}(D_y^{\ 2} - d_y^{\ 2}) \tag{8}$$

The section moment of inertia Iy is:

$$I_y = \frac{\pi}{32}(D_y^{\ 4} - d_y^{\ 4}) \tag{9}$$

(2) Determine the cross-sectional area and length of the thickened part of the drill pipe

The thickened part of the drill pipe is divided into three forms: inner thickening, outer thickening, and inner and outer thickening, as shown in Fig. 3. The inner and outer diameters of the thickened part are respectively Dz and dz, the length of the pure thickened part is lh, and the length of the tapered part is lc.

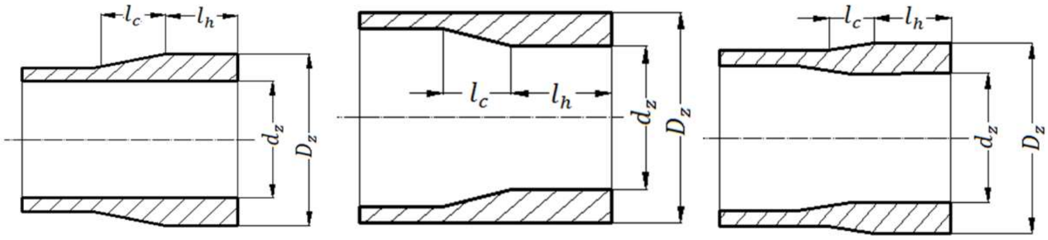

Fig. 3 Schematic diagram of the thickened part of the drill pipe

If the form of the thickened part of the drill pipe is internal and external thickening, the length of the taper part shall be the average of the length of the internal and external taper parts, and the total length lz of the thickened part of the drill pipe shall be:

$$l_z = 2(\frac{1}{2}l_c + l_h) = l_c + 2l_h \tag{10}$$

If calculated according to the cross-sectional area of the pure thickened part, the cross-sectional area Az is:

$$A_z = \frac{\pi}{4}(D_z^{\ 2} - d_z^{\ 2}) \tag{11}$$

The polar moment of inertia Iz of the thickened part is:

$$I_z = \frac{\pi}{32}(D_z^{\ 4} - d_z^{\ 4}) \tag{12}$$

The drill string tensile test method is used to calculate the position of the free point of a horizontal well, and a numerical calculation method is introduced to solve the position of the free point of the

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horizontal well, and the corresponding calculation model is established. It is mainly divided into the following five calculation steps:

1) Assuming the initial value of the free point position (starting from the position of the drill bit by default), and dividing the micro-element segment from the initial free point position to the wellhead, using the friction torque calculation model mentioned above, it can be calculated from the free point position to The frictional resistance on the wellhead.

2) From the calculation result of the first step, the minimum pull force required by the wellhead when the drill string is lifted can be obtained, which can be used to determine whether the initial pull force of the drill string can be transferred to the position of the free point, and obtain the calculation method according to the axial force transmission of the drill string. The minimum pulling force transferred to the free point when the drill string is lifted.

3) According to the judgment result of the second step, "No" means the calculation ends, and the test is performed again and the parameters are entered; "Yes" means the increment of the upward pulling force is entered.

4) The effective pulling force acting on the pipe string above the free point can be obtained from the incremental pull force and the differential force of the frictional resistance. According to the effective pulling force and the method of calculating the position of the free point of the composite pipe string, the cumulative elongation L of the drill string above the free point to the wellhead can be obtained.

5) According to the comparison between the input actual measured drill string elongation L1 and the calculated drill string cumulative elongation, the calculation error is within the accuracy range, and the initial input free point position can be regarded as the actual free point position; otherwise, the initial input free point position is not To meet the calculation accuracy requirements, re-enter the initial free point position and repeat the calculation process from the first to fourth steps until the result meets the calculation accuracy.

3. Examples of Calculation of Free Point Positions in Horizontal Wells

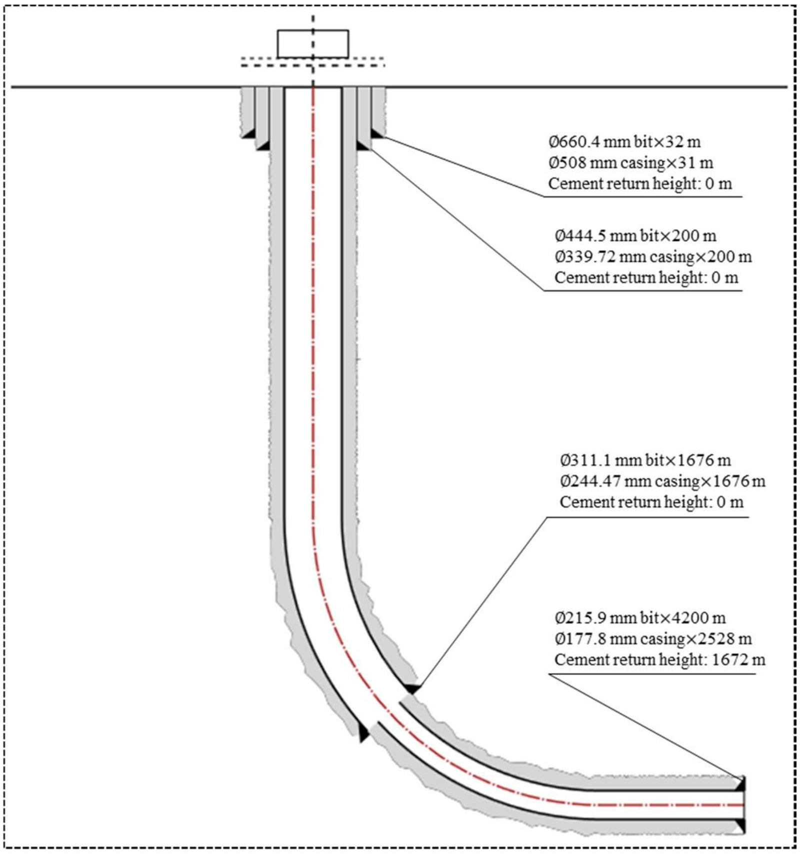

Fig. 4 Structure of well XH

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Well XH is a horizontal well with a long radius of curvature located in western Sichuan, with a design depth of 4200 m. In the first opening, a Ø660.4 mm drill bit was used to drill to a depth of 32 m, and a Ø508 mm pipe was inserted to seal the loose ground and protect the surface water; the second opening uses a Ø444.5 mm drill bit to drill to a depth of 200 m, and a Ø339.7 mm surface casing is inserted to seal the loose ground and protect the surface water; the three-opening uses a Ø311.15 mm drill bit to drill to a depth of 1676 m, and a Ø244.5 mm technical casing is inserted to seal the deflection section; the quarto-open uses a Ø215.9 mm drill bit to drill to the completion depth, and a Ø177.8 mm production casing is inserted, as shown in Fig. 4. The borehole trajectory data is shown in Table 1.

Table 1. design data of XH well profile

Well section	Well deep (m)	Well angle (°)	azimuth (°)	Vertical depth (m)	North coordinates (m)	East coordinates (m)	Dogleg degree (°/30m)	Deviation change rate (°/30m)	Azimuth change rate (°/30 m)
wellhead	0	0	0	0	0	0	0	0	0
lean point	1116	0	0	1116	0	0	0	0	0
Inclined segment	1379	42	36.85	1356.0	73.74	55.27	4.79	4.79	0
Target A	2000	85.5	40.23	1624.2	496.94	396.41	2.11	2.1	0.16
Target B	3800	87.6	54	1733.0	1716.4	1709.8	0.23	0.03	0.23
Target C	4200	88.23	56.3	1747.6	1945.7	2037.2	0.16	0.05	0.15

When the XH well was drilled to a depth of 4000 m, due to the slow drilling speed, the PDC bit was used for tripping and changing the roller bit. At this time, the drilling tool assembly is: 215.9 mm PDC drill bit + rotary steering drilling tool + back pressure valve + 127.0 mm non-magnetic pressure bearing weighted drill pipe×1 + MWD suspension short connection + 127.0 mm weighted drill pipe×6 + 127.0 mm slope Drill pipe×56 columns + 127.0 mm weighted drill pipe×24 pieces + drilling jar + 127.0 mm weighted drill pipe×26 pieces + 127.0 mm slope drill pipe to the wellhead. Drilling down to the depth of 3780.5 m, there is a resistance phenomenon, and then a kelly is connected to the hole to reaming off. The reaming parameters: displacement 21 L/s, drilling pressure 10 ~ 20 KN, torque 16 KN·m. After the hole is reaming off to the depth of 3789.8 m, the drill string is lifted up and connected to a single one. The drill string was lowered after the completion of the single root operation, and there was a resistance phenomenon during the lowering process, and the lifting and lowering pressure did not open. After that, a single kelly rod was thrown, the pump was turned on and the circulating pump pressure was normal, and the up and down movable drilling tools were ineffective and stuck. At this time, the performance parameters of the drilling fluid are shown in Table 2.

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Table 2. Drilling fluid parameters

Inlet drilling fluid density (g/cm3)	Density of drilling fluid at outlet (g/cm3)	Funnel viscosity (s)	Molding viscosity (MPa·s)	Dynamic shear force (Pa)	First cut (Pa)	Final cut (Pa)
1.8	1.8	63	35	17.5	9	18.5

Taking the drilling fluid data shown in Table 2, the casing friction coefficient is 0.25, the open-hole friction coefficient is 0.3, the axial movement speed of the bored pipe string is 0.25 m/min, the rotation speed of the turntable is 24 rpm, when the hook load is 1200 KN, the torque of the drill disk is 35 KN·m. The composite string model is used to calculate the drag torque of the drill string, and the bit weight in the bottom hole is 209.9 KN, and the bottom torque is 4.9 KN·m. The distribution of weight-on-bit and torque with well depth is shown in Fig. 5.

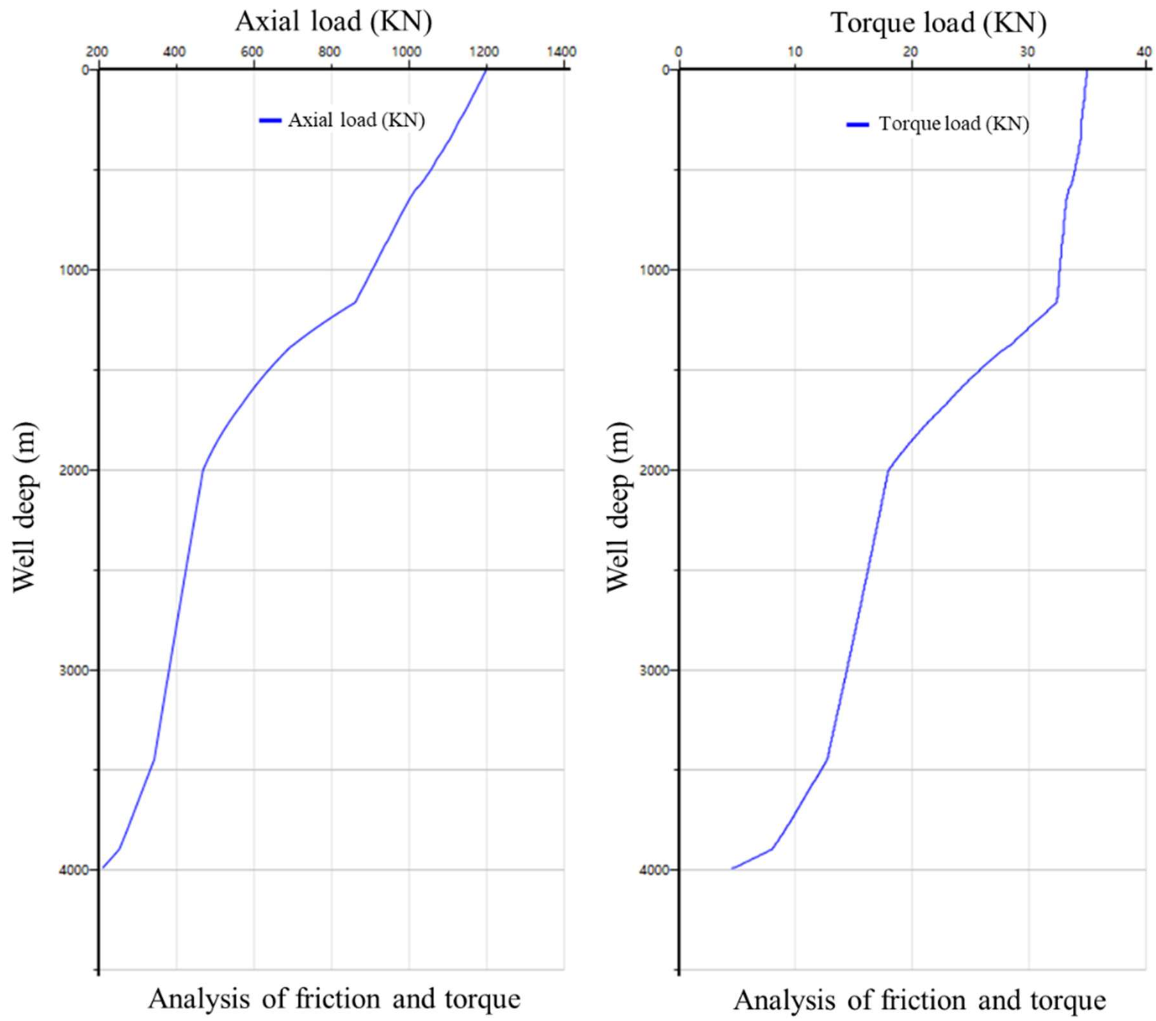

Fig. 5 The bit weight and torque distribution diagram with the well depth

When the drill string is completely stuck, the free point position is calculated using the horizontal well composite pipe string free point position calculation model through three pulls. When using the pulling method to determine the position of the free point, the wellhead measurement parameters are shown in Table 3. Using Hooke's Law of Tension and Compression, the free point position is 3989.3 m.

Table 3. Wellhead measurement parameters of the lifting method

Bit position (m)	Initial tension (KN)	Final tension (KN)	Measured elongation increment (cm)	Tension increment (KN)
4000	800	900	396.3	100
4000	900	950	97.2	50
4000	950	1000	96.8	50

4. Conclusion

Aiming at the problem that the free point of shale gas horizontal well is difficult to accurately determine after the jam occurs during the workover process. In this paper, a new analytical model for the calculation of the free point of the pipe string is established and verified by an example. The research came to the following conclusions:

(1) Based on the calculation model of composite pipe string free point, and fully consider the influence of friction load, buoyancy, drill pipe joint and thickened part, a new analytical model and method for calculating the position of composite pipe string free point in horizontal wells is established. Considering the influence of the thickened part of the drill pipe joint on the accurate calculation of the position of the free point, the correction coefficient of the free point formula is determined.

(2) Taking a horizontal well with a long radius of curvature as a calculation example, the composite string model is used to calculate the drag torque of the drill string, and the bottom hole bit weight is 209.9 KN and the bottom torque is 4.9 KN·m. The free point position of the composite string of horizontal wells is calculated using the calculation model, and the free point position is calculated to be 3989.3 m.

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