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# Analysis of Wellhead Collision in Offshore Extended Reach Well Drilling

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## Abstract

In order to solve the problem of wellhead equipment damage caused by vibration, impact and eccentric wear of wellhead drill string in the process of offshore extended reach well drilling, the finite element method is used to simulate and calculate the load state and deformation of cantilever beam of drilling platform under different working conditions, and the deformation is converted into wellhead offset according to the geometric relationship of position, so as to analyze the influence of wellhead deviation on eccentric wear of drill string; Based on the mechanical analysis of the drill string, the lateral force and casing wear of the wellhead are quantitatively analyzed. Taking an extended reach well in Chenghai as an example, the problem of wellhead drill string collision is analyzed. The theoretical analysis method of wellhead collision is helpful to guide the drilling operation of offshore extended reach wells.

**Key words:** Wellhead impact; Lateral force; Casing wear; Cantilever beam; Offshore drilling platform

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Offshore extended reach wells need shallow orientation to meet the demand of displacement extension, which results in large friction torque during drilling construction, weak stability of wellhead drill string, serious lateral and torsional vibration of drill string under tension, and impact and eccentric wear of wellhead equipment or casing[1].To study the vibration and eccentric wear of wellhead drill string, the premise is to ensure the crown block, rotary table and wellhead are in the middle level. The influencing factors of wellhead in the middle level are complex[2-3]. With the change of drilling conditions and operating environment, the cantilever beam of offshore drilling platform will be affected by wind load, yard load, hook load and other variables after stretching out, and will be deformed to varying degrees[4-5]. It is necessary to first eliminate the influence of cantilever deformation on the central level of the wellhead. Then the problems of equipment installation, formation stability around drilling platform legs and top drive centrality are analyzed.If the wellhead deviation factor is excluded, it is necessary to calculate the lateral positive pressure on the wellhead caused by the bending of the drill string and the wear of the wellhead casing during drilling, so as to determine the root cause of the wellhead collision problem in extended reach wells.

## 1. THEORETICAL MODEL OF WELLHEAD COLLISION

### 1.1 Calculation Model of Lateral Normal Pressure

The main reasons for serious wear of casing and protective sleeve near the wellhead are as follows: the derrick is out of alignment, which makes the drill string lean to one side of the wellhead; the wellhead is offset, which makes the drill string bear a large lateral force. Both of these reasons can be described by the simplified mechanical model of flexible cables shown in Figure 1.

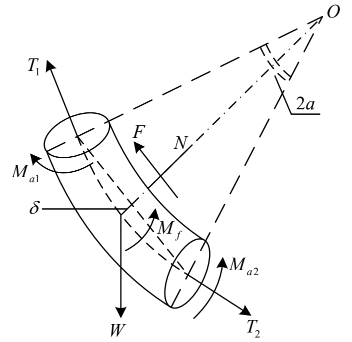



**Figure 1**
**Schematic diagram of drill string stress**

Due to the deviation of the derrick or the misalignment of the wellhead, the drill string with a length of ΔL bends near the wellhead and forms a circular curve. In the state of drilling, this section of drill string is subjected to the axial tension sum (unit: N) and torque sum (unit: N • m) of the upper and lower drill strings, the dead weight W of the drill string, the positive pressure N of the wellhead casing or protective sleeve (unit: n), frictional resistance moment (unit: n • m), and friction force F (unit is N, and frictional resistance coefficient is).The derrick misalignment or wellhead eccentricity is equivalent to the effective eccentricity δ (i.e., the eccentricity that can cause eccentric wear, which is related to the casing inner diameter, drill string outer diameter, actual eccentricity, etc., and shall be less than the actual eccentricity, in m), and the bending curvature of the drill string caused thereby is K (rad/m), so the following simple approximate calculation formula is obtained:

$T_2 T_2 M_{a1} M_{a2} M_f f$

$$(T_1 - T_2)(1 - k\delta) + fN - w = 0 \quad (1)$$

$$(2)\quad N = (T_1 + T_2)\sqrt{K\delta(2 - K\delta)}$$

For a drill string under tension at both ends, the relationship between the bending curvature of the drill string due to eccentricity and the eccentricity can be expressed by Equation (3):

$$\delta = \frac{1}{K}\left[1 - \cos\left(\frac{K\Delta L}{2}\right)\right] \quad (3)$$

From the formulas (1) and (2), when the sum δ is given, the calculation formula of the sum of two unknown quantities N is as follows:

$$N = \frac{(W - 2T_1 + 2K\delta T_1)\sqrt{2K\delta - K^2\delta^2}}{K\delta - 1 + f\sqrt{2K\delta - K^2\delta^2}} \quad (4)$$

$$T_2 = \frac{W - T_1 + K\delta T_1 + fT_1\sqrt{2K\delta - K^2\delta^2}}{K\delta - 1 + f\sqrt{2K\delta - K^2\delta^2}} \quad (5)$$

When considering the wear between the drill string and the wear sleeve, the positive pressure (N) and the number of rotations are the key factors. The greater the positive pressure, the greater the degree of wear will be. For the wear sleeve and drill string near the wellhead, the positive pressure is mainly caused by the derrick being out of alignment and the wellhead being eccentric, which can be quantitatively expressed by the eccentricity (δ) in Formula 3.

### 1.2 Quantitative Calculation Model of Wellhead Wear

The field and laboratory wear experiments show that the casing wear is mainly caused by the rotation of the drill pipe in contact, and the casing wear is relatively small during tripping. The greater the contact pressure and sliding distance between the joint and the casing, the greater the wear of the casing. At the same time, the greater the hardness of the casing material, the more difficult it is to wear, while the sand content of drilling fluid has little effect on the wearAdopt White

$$W = fFL_h \quad (6)$$

The energy consumed by casing wear is

$$U = VH \quad (7)$$

The wear efficiency E is

$$(8)\quad E = U/W = \frac{VH}{fFL_h}$$

So that that wear area of the sleeve can be obtain

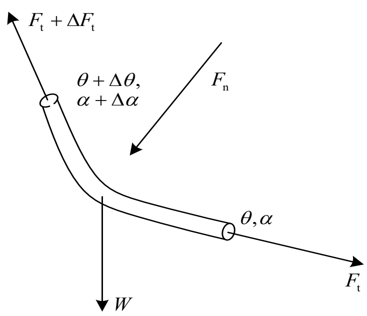
$$A = \frac{dV}{dL} = \frac{EfL_h}{H}\frac{dF}{dL} = \frac{E}{H}fF_nL_h \quad (9)$$

The wear area of the casing during rotary drilling of the drill pipe is

$$A = \frac{E}{H}fF_n\pi rN_R \quad (10)$$

The relationship between wear efficiency and steel grade and drilling fluid system can be obtained through a large number of test data. See the first volume of Drilling Manual (Party A) for details.

Assuming that the drill string is a flexible cable, which can transmit tension and compression, and is mainly affected by the weight, tension and lateral pressure of the drill string, a small segment of drill string element is taken, and the lateral force between the casing and the drill string can be calculated according to Johancsick's string force element model, which divides the string into several segments. The sum of the tension and deadweight contributed from each section on the bottom hole is the sum of the load on the string.




**Fig**ure **2**
**Stress diagram of drill string unit**

According to fig. 2 there are

$$F_n = \sqrt{(F_t\Delta\alpha sin\bar{\theta})^2 + (F_t\Delta\theta + Wsin\bar{\theta})^2} \quad (11)$$

Increment of axial force of infinitesimal element is

$$\Delta F_t = Wcos\bar{\theta} \pm \mu F_n \quad (12)$$

Where, "+" refers to lifting the drill string, and "-" refers to lowering the drill string.

According to the basic theory of string wear, if the wear is caused by the rotary drilling of the drill string, there should be crescent-shaped wear marks on the interface in a certain direction, or plastic deformation developed from this type of wear marks. The small crescent (red part in the figure) formed by the intersection of the two circles shown in Figure 3 is the casing wear interface, the small circle straight well is the outer diameter of the drill pipe coupling, the intersecting circle straight well is the inner diameter of the casing, and the outermost big circle diameter is the outer diameter of casing.

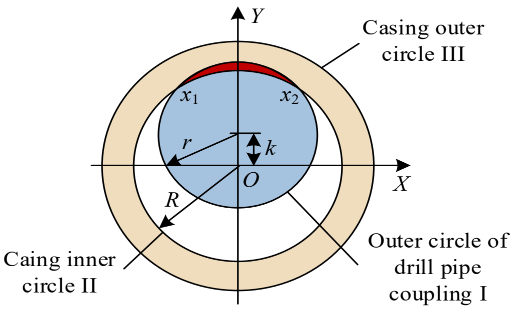



**Figure 3**
**Worn section of casing**

Equation of circle I: $x^2+(y-k)^2=r^2$

Circle II equation: $x^2+y^2=R^2$

According to the geometric relationship in Figure 3, the casing wears area A is

$$A=\int_{X_1}^{X_2}\left(\sqrt{(r^2-x^2}+k-\sqrt{R^2-x^2}\right)dx \qquad (13)$$

After the simultaneous equations are established,

$$\frac{E}{H}fF_n\pi rN_R=\int_{X_1}^{X_2}\left(\sqrt{(r^2-x^2}+k-\sqrt{R^2-x^2}\right)dx \qquad (14)$$

Obtain the lateral force and put it into the above formula to obtain the drill pipe axis offset, and finally obtain the casing wear thickness according to the relationship between the wear thickness H and. The relationship between H and can be obtained from the geometric relationship in Fig. 2-2-36$kkc$

$$h=k-(R-r) \qquad (15)$$

Where, the initial wear is?; if the casing is worn through, there is?; the limit wear area of the casing can be obtained from the above boundary conditions.

$$h=0k=R-rh=th=R+t-rA_{max}$$

On the basis of calculating the contact force, the wear area A can be obtained through Formula 13. At that time, the casing is worn through, and at that time, the casing is partially worn. The wear amount H and the residual thickness can be obtained from the wear area, and finally the residual strength of the casing can be obtained.
$A>A_{max}A<A_{max}$

Symbol description: friction factor, dimensionless; contact force between casing and drill pipe per unit length, N/m; H is Brinell hardness, N/m; L is drilling distance, m; friction distance, m; is the number of turns of the drill string, R is the outer radius of the drill pipe coupling, m. R is the inner radius of the casing, m. T is the wall thickness of the casing, m and V is the wear volume, m;W is the floating weight of drill string element, N/m; is the azimuth angle, °; is the well deviation angle, °; K is the axis offset of drill pipe coupling,

m.$fF_nL_hL_h=\pi rN_RN_RN_R=60R_pL/R_0\alpha\theta$

## 2. CASE ANALYSIS OF WELLHEAD COLLISION IN CHENGHAI EXTENDED REACH WELL

In the process of drilling extended reach wells on a drilling platform in Chenghai block, the wellhead drill string collides and wears the wear sleeve of casing head eccentrically, which makes the wear sleeve deformed and difficult to take out.

### 2.1 Calculation of Bearing Deformation of Cantilever Beam

The drilling platform used for drilling is a three-leg cantilever offshore jack-up drilling platform. As the core module of the platform, the drilling module is mainly composed of cantilever beam, drill floor and derrick. The cantilever beam is a single-web beam structure with a length of 41 m and a height of 6.2 m.70mm, the transverse rail is located above the cantilever beam and at the bottom, welded with the cantilever beam (the upper panel of the cantilever beam is butted with the lower panel of the transverse rail), and consists of two parallel single-web beams. The track is 23 m long and 2.8 m high, and the distance between the two tracks is 10.668 m (i.e. the distance between the four legs of the derrick).The web is 30 mm thick, the upper and lower panels are 650 mm wide, the upper panel is 50 mm thick, and the lower panel is 45 mm thick; it is mainly used to bear drilling operation load, equipment load, etc. A transverse moving support is arranged above the transverse base, and the moving support can move left and right on the transverse rail. The cantilever drill pipe storage yard is located on the cantilever beam and consists of 11 beams (I26 × 1000/2 × 26 × 300) with a length of 18 m.And three 18m long beams (T20 × 740/26 × 300) with a Φ159 × 8 stop bar at the side of the beam. During drilling operation, the cantilever beam extends out of the platform body, and during towing or shifting, the cantilever beam is retracted into the main deck.

After the cantilever beam extends out, a suspended structural model is formed. The hook at the wellhead produces a vertical hook load on the cantilever beam and the derrick, drilling equipment and drill pipe yard above it. Under the action of the dead weight of the cantilever beam and the hook load, the cantilever structure will produce a certain downward arc bending displacement.

The mechanical model of the cantilever beam and the transverse rail is established by using the ANSYS program, and the finite element model is established and loaded according to the longitudinal moving distance, the transverse moving distance and the hook load of the cantilever beam, so that the displacement and inclination angle of the wellhead of the cantilever caused by the force of the cantilevers can be accurately calculated.

**Table 1**
**Checklist of relevant parameters of cantilever beam**

| Working Condition | Distance from derrick center to platform tail (m) | Longitudinal displacement of cantilever beam (m) | Lateral movement of wellhead center (m) | Hook load (t) | Li Gen (t) |
|---|---|---|---|---|---|
| 86 HP (Example 1) | 9.5 | 15.36 | 2.3 | 81.6 | |
| 86 HP (example 2) | 9.5 | 15.36 | 2.3 | 22 | 81 |

The weight of the drill floor on the cantilever beam is 850t, and the maximum load of the storage yard is 400t. For the whole calculation model, the force exerted by the weight of the drill floor and the storage yard on the model is quantitative. See Table 1 for two examples of different cantilever beam longitudinal and lateral displacement distances and hook load design. The yard load is applied to the upper end of the cantilever I-beam in the form of line load in the model. Since the cantilever beam is composed of two I-beams, the I-beam on one side of the yard load is loaded with 200t.

The cantilever beam, transverse rail, drill floor, drill floor enclosure wall and stand are also subjected to wind load, which also exerts pressure on the transverse rail through the four legs of the derrick according to the principle of moment. The wind load is applied in three directions of 0 °, 90 ° and 45 °. In order to simplify the model, the wind load is simplified as a couple acting on the derrick legs.

After the model is established by Ansys program, it is constrained and loaded. The load mainly includes the load of drill floor and equipment, hook load, stand load, wind load couple and uniform load of storage yard.

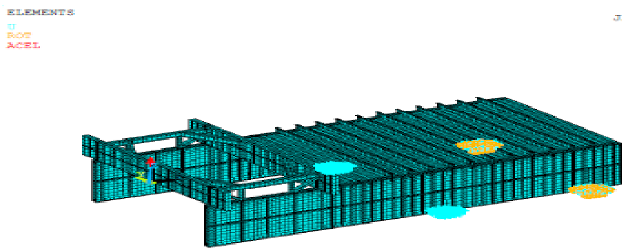



**Figure 4**
**Finite Element Model of Cantilever Beam and Transverse Track**

**Table 2**
**Calculation Results of Maximum Displacement of Cantilever Beam and Transverse Track**

| Calculation example | Cantilever beam Maximum displacement (mm) | Transverse track maximum displacement (mm) | Wellhead displacement (m) |
|---|---|---|---|
| Well 89HP (example 1) | 11.78 | 11.77 | 4.3 |
| 86 HP well (example 2) | 5.52 | 5.7 | 4.3 |

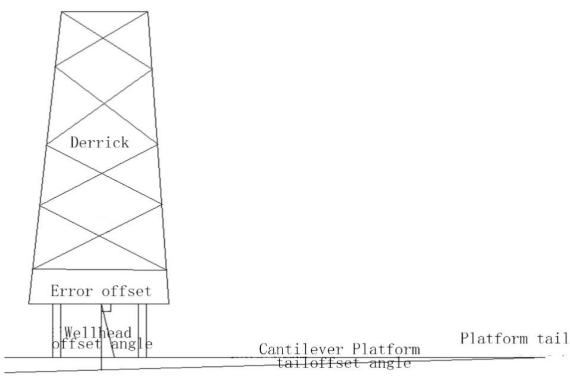



**Figure 5**
**Schematic Diagram of Wellhead Error Offset**

Through the offset angle of the cantilever beam, the offset displacement of the wellhead is calculated according to the position relationship shown in Figure 5.

(1) Wellhead displacement of example 1

The dip angle of the cantilever is arctg (4.3/9560) = 0.025 °, and the displacement at the wellhead is 0.9580-9580 × cos 0.025 ° = 0.00091mm

(2) Wellhead displacement of example 2

The dip angle of the cantilever is arctg (4.3/9560) = 0.025 °, and the displacement at the wellhead is 0.9580-9580 × cos 0.025 ° = 0.00091mm

From the analysis of error displacement results, the wellhead lateral displacement caused by the displacement of the cantilever beam is almost zero, so the displacement of the cantilever beam due to the load is not the main reason for the damage of wellhead tools.

## 2.2 Calculation of Lateral Force and Wear of Drill String

The casing sequence of “339. 7 mm-244. 5 mm-177. 8 mm-101. 6 mm” was used for the fourth spudding, the designed depth was 4 640 m, the first spudding depth was 143 m, the kick-off rate was 2. 68 °/30 m, and the completion deviation was 66 ° during the first spudding. After reaching the well depth of about 2,310 m, the second built-up section begins, with an average build-up rate of 2.39 °/30 m. After the trajectory is landed and confirmed to enter the reservoir, the technical casing is run to the window entry point for sealing. The initial azimuth is 281 °, the azimuth of the entry point of the horizontal section is adjusted to 344 °, and the azimuth is changed by 63 °. The closure distance to the first target point is 3120m.

The friction coefficient of the casing section is 0.25, and that of the open hole section is 0.3. The lateral force variation at the wellhead wear sleeve obtained through calculation is shown in Figure 6.

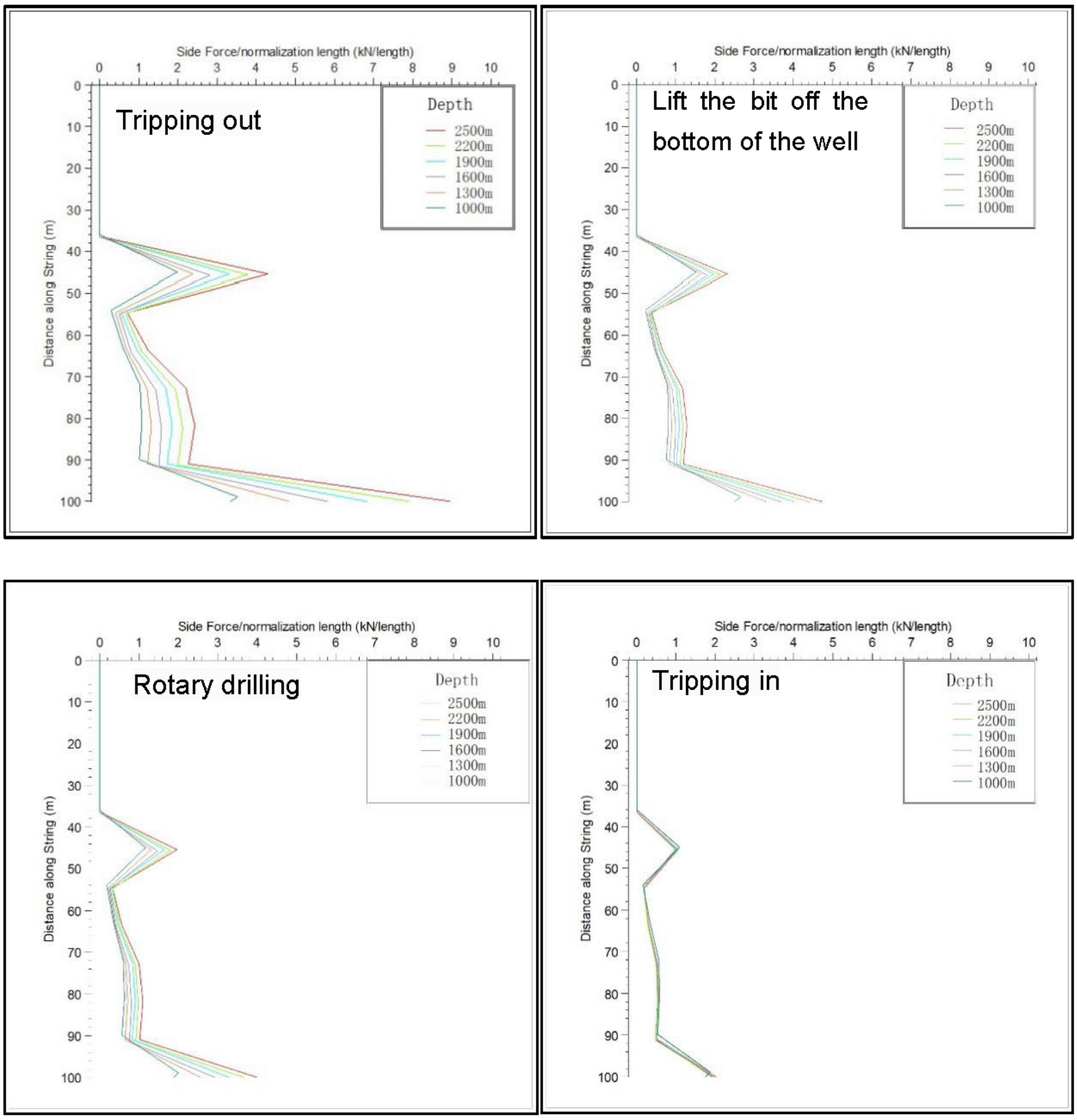



**Figure 6**
**Wellhead lateral force under different working conditions**

The lateral force is greatly affected by the well deviation, and the lateral force increases with the increase of the well deviation, and the magnitude of the lateral force is different under different working conditions. The lateral force on the wellhead is in the following order: upward drilling, idling drilling, downward drilling, rotating drilling, sliding drilling; under all working conditions, the lateral force on the drill string increases with the increase of drilling depth and deviation angle. Under the trip-out condition, the maximum lateral force on the wellhead is 4.2k N.

The casing wear is calculated according to the above trajectory parameters, and the maximum wear value of the wellhead casing wall thickness of the well is 9.4%, as shown in Figure 7.

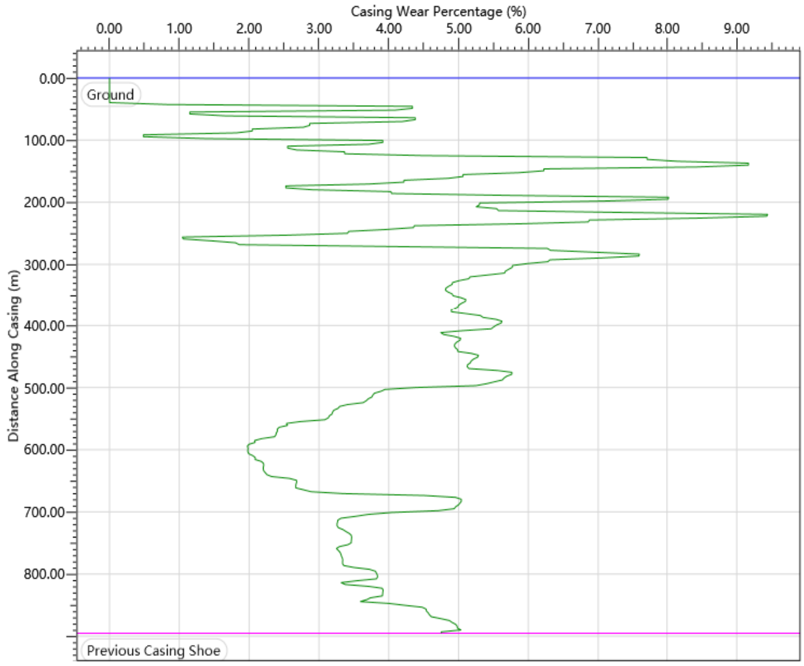



**Figure 7**
**Simulation of Surface Casing Wear**

### 2.3 Analysis of Wellhead Collision Factors

Carry out structural modeling calculation on that cantilever beam and the transverse rail, load by using the weight of the cantilever beam and the equipment above the cantilever beam as well as the hook load when an accident occurs, calculating the maximum vertical displacement of the deform cantilever beam, and further analyzing the horizontal deviation value at the wellhead caused by the vertical displacement. Through calculation, it is considered that the main reason for the wear of the wear sleeve in the well is not the small bearing deformation after the cantilever beam is extended. Through the calculation of lateral force and wear, it can be seen that the location of eccentric wear of drill string is relatively lower, and the probability of occurrence at the wellhead is relatively small. Therefore, other factors need to be analyzed.

The structural deformation caused by the material size error, construction and installation error and the temperature change during the operation of the cantilever beam makes the shape accuracy of the cantilever beam have a certain error compared with the design. Wind, wave and current may cause slight subsidence of platform legs, resulting in non-horizontal cantilever beam.

The geological conditions of the seabed are very complex and diverse. Before the platform goes to the well site, it is necessary to conduct marine geological survey and obtain geological data through drilling and sampling. Since it is not possible to drill holes at all pile leg insertion locations, the actual geological conditions of the seabed at the pile insertion location may be different from the geological data. In the process of operation, because the cantilever beam extends out, it will produce a certain vertical additional ground pressure on the legs close to each other, which may lead to foundation liquefaction and slow subsidence of the legs.

The cantilever beam moving system is driven by hydraulic cylinders. The cantilever beam has two sets of identical moving mechanisms distributed on both sides of the cantilever beam. The tail of the cylinder is connected with the hull structure through the base. The piston rod end is connected with a cantilever beam driving bolt mechanism, which drives the cantilever beam through a pin on the bolt mechanism. Each time the hydraulic cylinder reciprocates, it pushes the cantilever beam to move one pin hole spacing on the truss plate.However, in the process of actual movement, due to the fact that the speed is too fast or too slow, or the two sides are not synchronized, the pin hole is not in place uniformly, which will produce certain error deformation and affect the centrality of the drill pipe. In addition, improper installation of the top drive will cause the guide rail to tilt and drive the drill string to tilt, which may cause the drill string to hit the wellhead equipment frequently.

## 3. CONCLUSION AND UNDERSTANDING

(1) That main factor of wellhead collision in offshore extend reach wells is that the drill str is not centered, and the main causes of wellhead misalignment are cantilever deformation, seabed geology, wind, wave and current disturbance, etc. Large friction torque and shallow kick-

off point in extended reach wells will also cause wellhead drill string vibration and lateral contact with the wellhead to form lateral positive pressure, resulting in wellhead eccentric wear.

(2) At present, there are many complex factors causing wellhead collision, so it is necessary to eliminate each factor one by one in the construction, and analyze the causes of wellhead collision one by one in combination with the quantitative calculation method mentioned in this paper.

## REFERENCES

[1] Yang, C. X., Sun, M. X., & Tang, H. L. (2016). Research on casing wear prediction and anti-wear technology in extended reach wells. *Petroleum machinery, 0* (1), 5-9.

[2] Xu, F., Lü, S. L., Kang, Y. J., Yang, C. X., Li, H. Z., & Qin, H. D. (2011) Cause analysis and preventive measures of wellhead casing wear and failure. *Petroleum Drilling and Production Technology, 33* (2), 140-142.

[3] Xu, Z. X., Wang, Y. B., & Hu, Y. B. (2007). Influence of wellhead eccentricity on casing eccentric wear in Tarim Oilfield. *Natural Gas Industry, 27* (3), 75-76154.

[4] Ji, C. J., & Lin, H. X. (2014). Analysis and Countermeasures of wellhead eccentric wear of coalbed methane wells based on well deviation factors. *Coal Technology, 0* (11), 289-291.

[5] Li, D. H., & Nan, Y. M. (2015). Treatment and experience of wellhead casing wear of well TK1210 in Tahe Oilfield. Western Exploration Engineering, *27*(1), 78-80.