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ANALYSIS OF THE STABILITY AND INFLUENCING FACTORS OF UNDERWATER WELLHEAD DURING DEEP WATER DRILLING

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Abstract: In the stage of deepwater drilling, there is a risk of instability of the underwater wellhead under the vertical loads generated by BOP and casing operations and the environmental lateral loads such as wind, wave and current on the riser. The stress on the underwater wellhead before and after the installation of the deepwater drilling riser and BOP was analyzed, and a deepwater wellhead stability analysis model was established; combined with a deepwater well drilling example, the mechanical calculation of the underwater wellhead during the deepwater drilling stage was carried out, and the stability of the underwater wellhead was analyzed. A sensitivity analysis of the influencing factors was carried out. The example analysis shows that in the stage of deepwater drilling, the vertical bearing capacity of the underwater wellhead has little influence on it, but the lateral load has a greater influence on it; the top tension is positively correlated with the offset and dip angle of the underwater wellhead, and the bending moment is affected by the top tension. The effect is not obvious; the mud outlet height of the conduit has a great influence on the stability of the underwater wellhead; the change of the drilling fluid density has little effect on the bending moment of the underwater wellhead.
Keywords: Deepwater drilling; Subsea wellhead; Stability; Influencing factors

1 FORCE ANALYSIS OF UNDERWATER WELLHEAD IN DEEPWATER DRILLING

The deepwater drilling subsea wellhead system consists of the riser system, BOP group system and subsea high and low pressure wellheads, which consist of expansion joints, risers, bottom flexible joints, LMRP, BOP, and subsea wellheads from top to bottom[1]. Scholars at home and abroad have carried out some research on the stability of underwater wellheads in deepwater drilling. King, Da Costa and others found that in deepwater drilling operations, there is a risk of instability in the temporary wellhead guide plate (TGB) and the conduit, but did not propose a specific solution[2-3]; In the three-dimensional plane, the in-plane dynamic analysis of the riser was carried out[4]; Thorogood et al. believed that the fatigue failure of the conduit and wellhead should be focused on, and the riser system, BOP group system and underwater high and low pressure wellhead should be considered as a system , but did not give a specific analysis model[5]; Gong Dawei and others analyzed the force of the BOP group and the underwater wellhead, but lacked a complete theoretical analysis[6]; Yang Jin et al. In actual situation, the lateral bearing capacity of deepwater drilling riser and subsea wellhead was calculated based on finite element software, and the sensitivity analysis of relevant influencing factors was carried out, but the different working conditions before and after BOP running in deepwater drilling were not considered [7].

Therefore, according to the two different stages before and after the deepwater drilling riser and BOP running, the stress on the underwater wellhead is analyzed respectively, and on this basis, the riser and wellhead stability analysis models in different stages of deepwater drilling are established, which can be used for deepwater drilling. Provide reference for solving practical drilling engineering problems.

1.1 Wellhead Stress Analysis before Riser and BOP Installation

Before the riser and BOP are installed, there is no lateral load on the wellhead, and all loads are vertical, and the force is the largest when the surface conduit is not cemented, as shown in Figure 1.

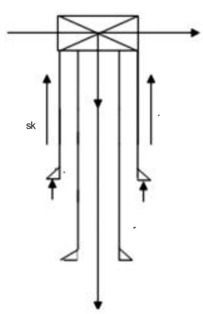

Fig. 1 Schematic diagram of wellhead force before installation of riser and BOP
Note: Qsk is pipe wall friction force, kN; Qpk is pile end supporting force, kN

The maximum vertical load N on the underwater wellhead at this stage is:

$$N = GC + GS \quad (1)$$

Where: GC is the buoyant weight of the conduit, in kN; GS is the buoyant weight of the surface casing, in kN.

1.2 Wellhead Force Analysis after Riser and BOP Installed

1.2.1 Riser force analysis

During the drilling operation stage, the riser system is affected by the dead weight of the riser, the buoyant weight of the buoyancy block, the top tension load, the platform drift load, the wind wave current load, etc.

1.2.2 Mechanical analysis of underwater wellhead

After the riser and BOP are installed, the underwater wellhead of the well is subjected to ocean current force, wellhead BOP load, riser load, etc.

1.2.3 Establishment method of underwater wellhead mechanical analysis model

When establishing the mechanical analysis model of the underwater wellhead, the underwater wellhead system is divided into two parts: the riser and the underwater wellhead. First, the finite element analysis software is used to calculate the riser system, and the connection between the riser and the underwater wellhead is calculated. The space is subjected to force, and the reaction force of this force and the ocean current force on the underwater wellhead are analyzed as the boundary conditions of the force on the underwater wellhead.

2. UNDERWATER WELLHEAD STABILITY ANALYSIS MODEL FOR DEEP WATER DRILLING

2.1 Vertical bearing capacity of underwater wellhead

The calculation of the vertical stability of the underwater wellhead adopts the empirical formula of the axial ultimate bearing capacity of a single pile[8], during the subsequent drilling process, the soil layer at the bottom of the conduit is destroyed, so the resistance at the bottom end is negligible. The simplified formula for the vertical ultimate bearing capacity Qd of the conduit is:

$$Qd = Qf = f\,As = f\,\pi D2L2 \quad (2)$$

Where: Qd is the vertical ultimate bearing capacity of the conduit, × 10 kN; D2 is the outer diameter of the conduit, m; L2 is the depth from the bottom of the conduit to the mud surface, m.

For structures in seawater, there is an interaction between the ocean current and the structure, but because the ocean current moves relatively slowly and steadily, when considering its effect, it is mainly to consider its static force and the vortex caused by the eddy around the current. Exciting vibration. In order to simplify the ocean current force model on the riser, only the influence of static force is considered here, then the sum of the ocean current force is:

$$Fd = B \overset{h}{0} fD\, dz \quad (3)$$

In the formula: Fd is the sum of the forces acting on the whole member, in kN; fD is the drag force per unit height, in kN; h is the length of the structure in the z direction of the longitudinal axis, in m.

In the static force analysis method, considering that the transverse static force on the riser is the wave flow force, tension component force and gravity component force, the static deflection differential equation of the riser is obtained according to the deflection theory of the beam:

$$EI \frac{d^4y}{dx^4} = p \frac{d^2y}{dx^2} + W \frac{dy}{dx} + fc \quad (4)$$

In the formula: EI is the bending stiffness, kN m2; p is the tensile force on the riser, kN; W is the self-weight per unit length of the riser, kN/m; fc is the sea current force per unit length of the riser, kN/m.

The deflection can be obtained by solving the solution, then the rotation angle, bending moment and shear force are respectively:

$$\theta = \frac{dy}{dx} \quad (5)$$

$$M = -EI \frac{d^2y}{dx^2} \quad (6)$$

$$Q = -EI \frac{d^3y}{dx^3} \quad (7)$$

In the formula: y is the deflection, m; θ is the rotation angle, (o) ; M is the bending moment, kN·m; Q is the shear force, kN.

In the dynamic mechanical analysis of the riser, it is assumed that $\sum R$(f) is the sum of the reaction forces on the riser per unit length, assuming that ∑F(f) is the sum of the forces on the riser per unit length, and the following balance equation is obtained according to Newton's third law:

$$\sum F(f) = \sum R(f) \tag{8}$$

The reaction force R(f) on the riser includes the reaction force Rf(f) caused by bending stiffness, the reaction force Rt(f) caused by the tension rope, the reaction force RG(f) caused by its own weight and the reaction force caused by inertial force Rm(f), the reaction force (f) on the riser is:$\sum R$

$\sum R$(f) = Rf (f) +Rt(f) +RG (f) +Rm(f) (15) where: ∑F(f) is the sum of forces on the riser per unit length, kN; ∑R (f) is the sum of the reaction force per unit length of the riser, in kN; Rf(f) is the reaction force caused by the bending stiffness, in kN; Rt(f) is the reaction force caused by the tension rope, in kN; RG(f) is the reaction force caused by self-weight, kN; Rm(f) is the reaction force caused by inertial force, kN; according to the calculation model, the subsea wellhead analysis model before and after BOP running is established by using ANSYS programming language (APDL).

3. CALCULATION OF DEEPWATER OIL AND GAS WELL DRILLING AND ANALYSIS OF INFLUENCING FACTORS

3.1 Calculation of Deepwater Wellhead Stability

Taking a deepwater oil and gas well (well A) in PetroChina's overseas offshore project as a calculation case, the deepwater drilling riser and underwater wellhead stability analysis is carried out.

The casing structure dimensions shown in Table 1 were used in Deepwater Oil and Gas Well A, in which the depth of the conduit injection was 89.5 m, and the depth of the surface conduit was 139 m. The pipe connected to the low-pressure wellhead is a pipe with a wall thickness of 1.5 in (1in = 25.4 mm), a pipe diameter of 36 in, and a length of 40 ft (1 ft = 0.304 8 m). A casing with a diameter of 20 in and a length of 40 ft is shown in Table 1 for the structural size parameters of the casing.

Table 1 Structural dimensions and material parameters of casing

Casing type	Borehole size/in	Casing size/in	steel grade	wall thickness /in	Mass/(lbs·ft- 1)
catheter	injection	36	X56	1.5 1	553 374
Surface casing	17- 1/2	13- 3/8	N80	0.625	68

Note: 1 lbs = 0.453 592 37 kg.

the soil survey data in Well A is 58.85 m. Based on the existing soil data, it is necessary to fit the upper and lower limits of the undrained shear strength of the shallow soil. strength.

Undrained shear strength/kPa The vertical stability of the underwater wellhead is provided by the vertical bearing capacity after the surface conduit is placed, and the friction between the surface conduit and the surrounding shallow seabed soil is closely related to the static time after the conduit is sprayed into place. The relationship between pipe and soil lateral friction recovery coefficient is adopted to calculate the real-time change of bearing capacity under different static times after the pipe is sprayed in place.

The surface casing cementing cement slurry has a density of 1 890-1 900 kg/m3, 1 890 kg/m3 is taken as 1 890 kg/m3; the drilling fluid density is 1 100 kg/m3; the wellhead is 4.5 m above the seabed mud surface. The drilling platform offset is set to 0%, 1%, 3%, 5%, 7% and 9%, and the bearing capacity of the riser under the working condition of the riser connection drilling operation is checked and analyzed. The specific results are shown in Table 2.

Table 2 Check results of riser bending moment and equivalent stress

Drilling platform offset/%	Riser maximum bending moment /(MN·m)	Riser maximum equivalent Stress/MPa	High pressure wellhead maximum bending moment /(MN·m)	Low pressure wellhead maximum bending moment /(MN·m)
0	0.022	122.03	0.42	0.21
1	0.023	120.26	0.89	0.45
3	0.024	120.60	1.77	0.89
5	0.033	124.16	2.57	1.3
7	0.045	127.76	3.31	1.67
9	0.06	131.40	3.89	2.02

The bearing capacity is calculated according to the soil parameters of Well A. The calculation results of the theoretical axial limit recovery bearing capacity of the conduit in Well A for 0.01, 5, and 10 days are shown in Table 3. The calculated real-time bearing capacity is shown in Figure 6 and Figure 7, about After 10 days, the upper limit of bearing capacity recovery was reached.

Table 3 Calculation results of the axial recovery bearing capacity of the conduit in Well A

Standing time/d	Lower limit of recovery bearing capacity/kN	Upper limit of recovery bearing capacity/kN
0.01	310.73	408.35
5	2 310.75	3 036.68
10	2 509.73	3 298.10
recovery limit	2 538.72	3 336.27

3.2 Analysis of Sensitivity Factors

Factors such as different sea state recurrence periods, mud discharge heights from conduits, drilling fluid density, and top tension all have varying degrees of impact on wellhead stability. To study the influence of the above factors on the wellhead stability, in order to improve the stability of the wellhead system.

3.2.1 Effects of different sea state return periods on wellhead stability

With the increase of sea current velocity, the bending moments of high and low pressure wellheads and conduits increase significantly, and the bending moment and equivalent stress of the upper part of conduits also increase significantly with the increase of sea state return period. Therefore, before a strong typhoon comes, the drilling platform must recover the riser and evacuate. If the riser cannot be fully recovered, the platform should recover as many risers as possible, and then perform the riser suspension evacuation.

3.2.2 Influence of mud outlet height of conduit on wellhead stability

The wellhead offset and inclination angle both increase with the increase of the mud outlet height of the conduit, and the high and low pressure wellhead bending moments decrease with the increase of the mud outlet height of the conduit; the bending moment and equivalent stress of the upper part of the conduit are relatively significantly affected by the mud outlet height of the conduit , both increase with the increase of the mud outlet height of the conduit.

3.2.3 The impact of top tension on wellhead stability

As shown in Figure 14 and Figure 15, the wellhead offset and inclination angle both increase with the increase of the top tension, and the high and low pressure wellhead bending moments are not significantly affected by the top tension; the conduit bending moment and equivalent stress both increase with the top tension increases, but the bending moment does not change significantly.

3.2.4 Influence of drilling fluid density on wellhead stability

The change of drilling fluid density has almost no effect on the bending moment of high and low pressure wellheads; the bending moment and equivalent stress of the conduit increase with the increase of drilling fluid density, but the bending moment is less affected.

4 CONCLUSION

(1) According to the different operating conditions before and after BOP running in deepwater drilling, the stress on the underwater wellhead under different working conditions was analyzed, and a mechanical calculation model for deepwater drilling riser and wellhead stability was established. Based on the finite element software, the deepwater riser and underwater wellhead stability analysis models are established.

(2) Taking a deepwater well in an overseas offshore project of PetroChina as an example, the mechanical analysis of the underwater wellhead stability during the deepwater drilling stage and the sensitivity analysis of the factors affecting the stability of the drilling wellhead were carried out. The calculation example analysis shows that the axial bearing capacity of the underwater wellhead and surface conduit increases with the static time, and the bearing capacity increases after about 10 days, and the ultimate recovery bearing capacity is reached after about 10 days; The vertical bearing capacity has a great influence on it, but the vertical bearing capacity has no obvious influence on it; the mud output height of the wellhead has a great influence on the stability of the underwater wellhead; the variation of the drilling fluid density has little effect on the bending moment of the underwater wellhead.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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