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Analysis Method of Underwater Wellhead Stability of Unstable Seabed Oil and Gas Wells

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Abstract

Drilling safety and efficiency are greatly affected by shallow seabed environments in deep water, including shallow geological hazards, seabed geomorphology, and seabed dip Angle. The underwater wellhead is built on the seabed, and the stability of the seabed determines the stability of the underwater wellhead. Based on multi-body dynamics, the coupling model of the drilling platform-riser-surface conduit system is established, and the key factors affecting the stability of the wellhead are analyzed. The results show that the maximum lateral displacement and the maximum stress of the surface conduit increase linearly with the increase of the slope Angle of the surface conduit and with the increase of the mud discharge height of the surface conduit. Therefore, in the field operation, the stability of the wellhead can be improved by reducing the mud height and increasing the surface conduit size in the unstable seabed environment.

Keywords

Well construction, Jet method, Drilling method, Underwater piling, Quantitative optimization

The South China Sea is a large area with complex and variable geological genesis and environmental conditions, and there is a certain area of unstable seabed; especially the large area in the northern part of the South China Sea belongs to the transition from continental belt to deep sea, with high seabed inclination and high instability. The use of the existing technology and control means for good construction under the unstable seabed environment is prone to the risks of conduit sinking, difficulty in putting the conductor into place, and the wellhead destabilizing, which poses great challenges to the operation time and safety of good construction. The surface conductor, while supporting the upper subsea wellhead and blowout preventer and other components, must be able to resist the complex loads generated by deepwater drilling operations in the ocean to ensure the stability of the subsea wellhead. One of the biggest differences between deep water and shallow water (land) is the establishment of the subsea wellhead. The stability of the subsea wellhead is the guarantee for subsequent drilling operations.

1. Theoretical analysis method

The dynamical relaxation method for the calculation of the static equilibrium position of a multibody system refers to the following: by artificially increasing the damping of the system in the dynamical calculation of the multi-body system, the system can be stabilized to the static equilibrium position relatively quickly after a period of calculation; the methods of artificially increasing the damping include: choosing the integration method of numerical damping with large numerical damping (e.g., the 1st-order backward differencing method), increasing the damping of the flexible material, and the linearization of the integral of the time of each step The iterative expression $\boldsymbol{M}\ddot{\boldsymbol{x}} + \boldsymbol{C}\dot{\boldsymbol{x}} + \boldsymbol{K}\boldsymbol{x} = \boldsymbol{f}$ is rewritten as $\boldsymbol{M}\ddot{\boldsymbol{x}} + (\boldsymbol{C} + \alpha\boldsymbol{M})\dot{\boldsymbol{x}} + \boldsymbol{K}\boldsymbol{x} = \boldsymbol{f}$, where α is a suitable mass damping factor [1].

In the system, the riser, conductor, expansion joints, and short joints all use beam units as flexible units, and the output forces in the beam units are given in the form of three directional forces and three directional torques, which need to be converted into the form of stresses in order to determine the limiting conditions of the structure based on a yield criterion (e.g., the MISES Stress Criterion), and to determine the amount of platform drift and the velocity of the currents for the limiting conditions.

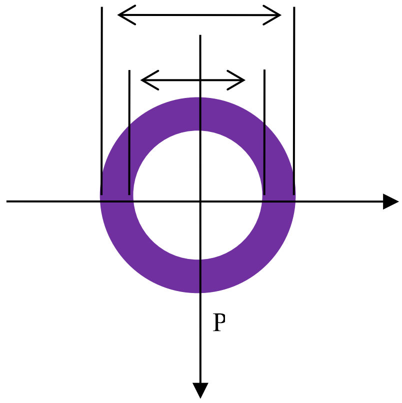

Figure 1. Toroidal circular beam section and coordinate system.

The stresses in the circular beam are calculated according to the *New Mechanics of Materials by Shaoshi Zhang* [2, 3]. The tensile force along the x-direction of the beam axis contributes only to the normal stress, let $A = \pi(D^2 - d^2)/2$ be the area of the beam cross-section, and the normal stress produced by the tensile force is

$$\sigma_{F_x} = \frac{F_x}{A}$$

The normal stress generated by the bending momentM_y along the y-axis is

$$\sigma_{M_y} = \frac{M_y R}{I_z}$$

Where, $I_z = \frac{\pi D^4}{64}(1 - \alpha^4)$, $W_z = \frac{\pi D^3}{32}(1 - \alpha^4)$, $\alpha = \frac{d}{D}$,d is the inner diameter of the beam, D is the outer diameter of the beam, and $R = (\frac{D}{2} + \frac{d}{2})/2$ is the average radius of the beam shell.

The normal stress generated by the bending moment M_z along the z-axis is

$$\sigma_{M_z} = \frac{M_z R}{I_z}$$

The tangential stress generated by the torque M_x along the x-axis is

$$\tau_{M_x} = \frac{M_x}{2\pi R^2 \delta}$$

For an annular section beam with wall thickness δ much smaller than the mean radius R, since δ is very small, it can be assumed that the shear stresses are uniformly distributed along the wall thickness δ and tangent to the circumference, yielding [4]

$$\tau_{F_y} = \frac{F_y}{\pi R \delta}$$

$$\tau_{F_z} = \frac{F_z}{\pi R \delta}$$

The values obtained from the above calculations are the absolute values of the normal and shear stresses which are vector components, and the vectors can be linearly superimposed. After obtaining the total value of normal and shear stresses at points P_1 P_2 or P_3 or P_4, the MIESE stresses at these four points can be calculated respectively, and the maximum MIESE stress value is taken as its MISES stress.

For the beam cell, the formula for the MIESE stress is simplified as

$$\sigma_{MISES} = \sqrt{\sigma^2 + 3\tau^2}$$

where σ is the total value of normal stress and τ is the total value of shear stress.

2. Analytical Modeling of Underwater Wellhead Stability

2.1 Overall model

The scope of multibody dynamics modeling includes all the constituent parts, the boundary conditions of the parts, their interconnections, and the environmental loads.

All components can be simulated using beam units and rigid bodies: long and thin components such as riser (including joints, smooth risers, buoyancy risers), expansion joints, conductor, and casing are modeled with geometrically accurate beam units for mass and flexibility; Rigid-body modeling quality information is used for components such as drilling platforms, flexible joints, bottom end assemblies, blowout preventers, and wellheads that are small in length or have negligible deformation. All components are connected from top to bottom by fixed joints, except for four joints: the platform and the upper flexible joint, the riser, and the lower flexible joint use spherical hinge + torsional spring to simulate the rotational freedom and torque characteristics of the flexible joint [5]. A cylindrical pair is used to simulate the degree of freedom between the inner cylinder and the outer cylinder of the expansion joint. The tensioner ring and the platform use force to simulate the connecting action of the tensioner [6].

The boundaries of the system consist of the conductor and casing at the bottom and the drilling platform at the top. The bottom ends of the conductor and casing are hinged with the soil; the boundaries of the drilling platform vary according to the operating conditions: static analysis gives the lateral displacement of the platform according to the specified drift amount, the platform is fixed in the mode analysis, and the rebound analysis gives the platform 6 degrees of freedom (3 degrees of translation freedom and 3 degrees of rotation freedom) according to the wave amplitude and period, and the platform frequency response curve.

The environmental loads include gravity, hydrostatic pressure (mud inside the pipe, seawater outside the pipe), dynamic water pressure (seawater Morison force), dynamic water friction (mud underflow), and soil pressure. The assumptions, simplifications, and software applicability conditions for the components, environmental loads, and forces during the modeling process are described separately in the detailed modeling sections for each element [7, 8].

2.2 Conductor and casing modeling

The structure of the conductor and casing is shown in 4 when viewed from the top down. The outer layer of the conductor is soil, between the conductor and the casing is a sealing cement layer, and inside the casing is the wellbore for passing the drill pipe. The conductor and casing generally use steel as a material.

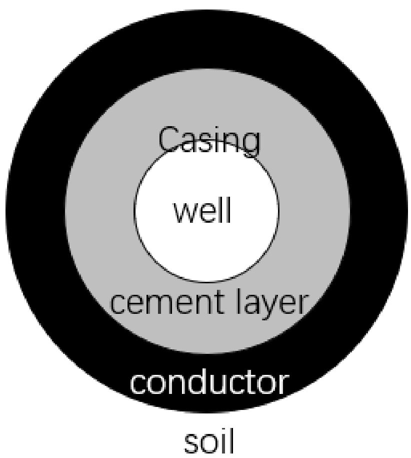

Figure 2. Overhead view of conductor-casing-soil.

In the multi-body dynamic modeling, the conductor, cement layer, and casing are regarded as an elastic whole and are simulated using a single beam: the total axial tensile and compressive stiffness (each stiffness superimposed), the total bending stiffness in each direction (each stiffness superimposed), and the total linear density (each linear density superimposed) are determined [9].

The force between the soil and the conductor is defined using a P-Y curve, as shown in Figure 5, the schematic diagram on the left and the demonstration of the P-Y curve definition on the right (only 2 heights of the P-Y values are given), which actually establishes a series of nonlinear springs at specified heights between the flexible beam representing the conductor-cement-casing and the ground. The concept of the P-Y curve method was first proposed by Mcclelland and Focht. They proposed this method of solving for nonlinear lateral resistance of piles by recognizing the correlation between the measured reaction force versus displacement curve of a test pile and the stress-strain curve of a simultaneous consolidated undrained triaxial test of the soil. The P-Y curves of the soils were provided by Engineering personnel.

3. Analysis of factors affecting wellhead stability

An analytical model of the stability of the drilling platform - riser - underwater wellhead is established through multi-body dynamics, and the results of the maximum stress, maximum bending moment, and maximum displacement of the surface conduit in the unstable seabed environment with different wellhead inclination and different mud-out height are obtained, and then the impacts of different influencing factors on the stability of the wellhead are analyzed.

In the process of deepwater jetting installation of surface conductor, the platform and pipe column are deflected by wind, waves, and currents, and at the same time, due to the inhomogeneity of the strata, the jetting process is prone to the phenomenon of surface conduit tilting. The effects of different surface conduit tilting amounts (0, 0.5, 1.0, 1.5, 2.0, 2.5) on the deformation and mechanical characteristics of the surface conduit were analyzed using the finite element method. The maximum lateral displacement of the surface conduit, the maximum stress of the surface conduit, and the maximum bending moment of the surface conduit, under different tilt angles are shown in Fig. 3 and Fig. 4, respectively.

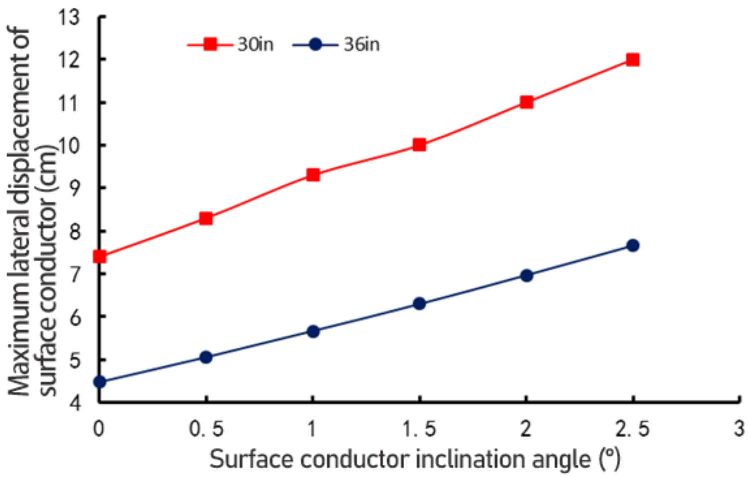

Figure 3. Effect of surface conductor tilt angle on maximum lateral displacement.

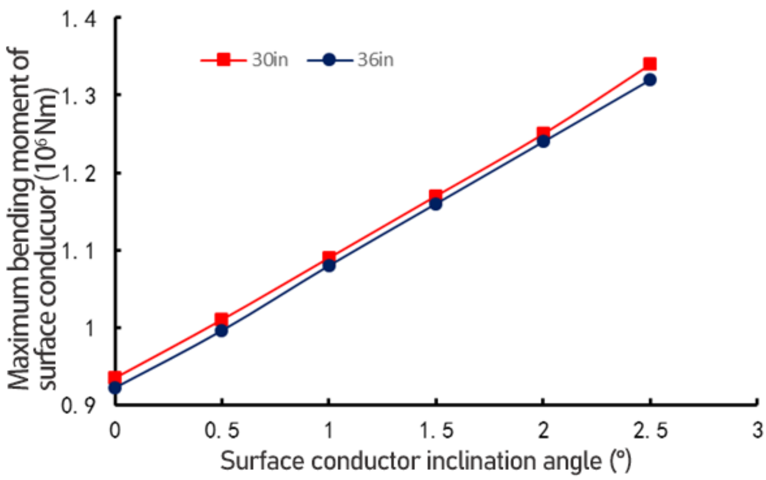

Figure 4. Effect of surface conductor tilt angle on maximum bending moment.

From the analysis results, it can be seen that the maximum lateral displacement, bending moment and maximum stress values of the surface conductor increase approximately linearly with the increase of the surface conductor tilt angle, i.e., the tilt of the surface conductor is unfavorable to its mechanical stability. Increasing the size of the surface conductor can effectively reduce its stress and deformation, and then improve the stability of the underwater wellhead.

4. Conclusions and recommendations

1) Various components of the drilling platform, riser, and underwater wellhead interact with each other, and the force relationship is complicated, using the multi-body dynamics analysis method can accurately calculate the motion state and force of each module.

2) The maximum lateral displacement, bending moment and the maximum stress value of the surface conductor increase approximately linearly with the increase of the surface conductor tilt angle, i.e., the tilt of the surface conductor is not conducive to its mechanical stability. Increasing the surface conductor size can effectively reduce its stress and deformation and improve the wellhead stability.

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References

[1] Liu Shujie, Xie Renjun, Tong Gang, et al. Progress and prospect of deepwater drilling and completion technology of China National Offshore Oil Corp [J]. Journal of Petroleum, 2019, 40(S2): 168-173.

[2] Zhou Bo, Yang Jin, Zhou Jianliang, et al. Design method of conductor displacement under jetting for deepwater drilling [J]. Oil Drilling Technology, 2016, 44(3): 21-26.

[3] Yang Jin, Huang Xin, Yang Yuxiang, et al. Mechanical properties of a new type of expanded conductor for deepwater oil and gas wells[J]. Journal of Petroleum, 2019, 40(S2):116-122.

[4] Xu Yunjin, Yang Jin, Zhou Bo, et al. Determination of ultimate downward depth of surface conductor installed by jetting method in deepwater drilling [J]. Oil Drilling Process, 2016, 38(05): 553-557.

[5] Mackenzie B, Francis M, Garrett I, et al. Conductor jetting experiences in deepwater offshore Ghana—an investigation into geotechnical and operational influences on success, and establishment of future best practice [C]. One Petro, 2012.

[6] Xu Hui. Construction of a hazard evaluation system for air extraction zones based on hierarchical analysis [J]. Energy and Environmental Protection, 2020, 42(12): 12-19.

[7] Ma Xiaoxiang. Research on collaborative filtering algorithm based on improved weight calculation [D]. Jilin University, 2017.

[8] Wang Yanbin. Research on the mechanical behavior of deepwater conductor and riser installation process [D]. China University of Petroleum (Beijing), 2016.

[9] Wang Huanhuan, Yang Jin, Liu Zhengli, et al. Analysis of factors affecting cementation strength in deepwater shallow cemented wells [J]. Oil Drilling Technology, 2011.