Journal of Contemporary Educational Research, 2022, Volume 6, Issue 5
http://ojs.bbwpublisher.com/index.php/JCER
ISSN Online: 2208-8474
ISSN Print: 2208-8466

Design and Control Scheme of the Mooring System

Jing Cong*

Basic Department of Liaoning Institute of Science and Technology, Benxi 117000, Liaoning Province, China

***Corresponding author:** Jing Cong, congjing_2003@163.com

Abstract: In this paper, by analyzing the design and control scheme of the mooring system based on theoretical mechanics, force analysis is conducted on the buoy, steel pipe, steel drum, and anchor chain, and a reasonable mathematical model is constructed to solve the problems of the inclination angle of the steel drum and each section of the steel pipe, the shape of the anchor chain, the draft of the buoy, and the swimming area under different wind speeds, thus providing a reliable basis for the design of the system.

Keywords: Mooring system; Static balance; Force analysis; Catenary

Online publication: May 30, 2022

1. Introduction

The transmission node of the offshore observation network is composed of a buoy system, a mooring system, and an underwater acoustic communication system. In designing the mooring system, the focus is on determining the type, length, and mass of the anchor chain as well as making the draft and swimming area of the buoy and the inclination angle of the steel drum as small as possible.

The buoy system of the transmission node studied in this paper can be simplified as a cylinder with a bottom diameter and a height of 2 meters, respectively, and a 1,000-kilogram buoy. The mass of the anchor is 600 kilograms. There are four sections of steel pipes, and each section is 1 meter in length and 50 millimeters in diameter; the mass of each section is 10 kilograms. The angle from the tangential direction of the link between the end of the anchor chain and the anchor to the seabed should not exceed 16 degrees. The underwater acoustic communication system is installed in a sealed cylindrical steel drum with a length of 1 meter and an outer diameter of 30 centimeters. The total mass of the equipment and the steel drum is 100 kilograms. The steel drum is connected to the fourth section of the steel pipe, and the bottom is connected to the electric welding anchor chain. When the steel drum is vertical, the underwater acoustic communication equipment will work best. When the inclination angle of the steel drum exceeds 5 degrees, the working effect of the equipment will be substandard. To control the inclination angle of the steel drum, the mass of the heavy ball selected in this study is 1,200 kilograms, and the transmission node adopts the 22.05-meter-long electric welding anchor chain. The per unit length of the mass is 7 kilograms per meter. When the sea surface wind speed is 12 m/s and 24 m/s, the inclination angle of the steel drum and each section of the steel pipe, the shape of the anchor chain, the draft of the buoy, as well as the swimming area are investigated. Except for the draft of the buoy, the same parameters are investigated and calculated when the sea surface wind speed is 36 m/s. In addition, the mass of the heavy ball is adjusted so that the inclination angle of the steel drum does not exceed 5 degrees, and the angle between the anchor chain and the seabed does not exceed 16 degrees.

2. Principles and methods of the design and control scheme of the mooring system

In order to solve the problem of the mooring system design, this study adopts the static and dynamic analyses of a single-point mooring system. With the help of micro-element method, the inclination angle of the steel drum and each section of steel pipe, the shape of the anchor chain, the draft of the buoy, and the swimming area are calculated when the buoy and the anchor are relatively stationary in the offshore mooring system. By establishing a static equilibrium equation, the magnitude and direction of the force on each node of the mooring system in the near-shallow sea area can be clearly reflected. Moreover, when constructing the dynamic balance equation, a mathematical model is established between the wind speed and the inclination angle of the steel drum and each section of the steel pipe, the shape of the anchor chain, the draft of the buoy, as well as the swimming area. Then, MATLAB is used to fit the shape of the anchor chain, and the floating area can be calculated by the projection of the anchor chain, steel pipe, and steel drum in the horizontal direction [1-4].

3. Design of the mooring system and the establishment of a control scheme

3.1. Force analysis of each component and the establishment of a static equilibrium equation

(1) Buoy

It is assumed that the draft of the buoy is h_1, the height of the buoy is *h*, and the wind speed is *v*. The buoy is analyzed with force, as shown in **Figure 1**. The gravity is m_1 g, the horizontal wind force to the right is *F*, and the vertical upward buoyancy is B_1. The downward pulling force is T_1, its angle with the vertical direction is θ_1, and the diameter of the buoy is d_1.

$$T_1 \sin\theta_1 = F_{wind} \qquad T_1 \cos\theta_1 + m_1 g = B_1 \qquad B_1 = \rho h_1 \bullet (\frac{\pi d_1^2}{4}) g \qquad F_{wind} = 0.625 d_1 (h - h_1) v^2 \tag{1}$$

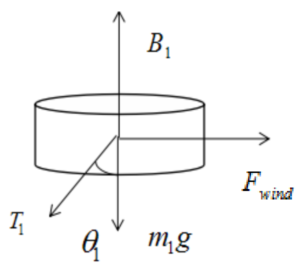

Figure 1. Force diagram of the buoy

(2) Steel pile

Each steel pile is also analyzed with force. The gravity on the steel pile is m_2 g, the vertical upward buoyancy is B_2, and the diagonal upward pulling force is T_i. The diagonal downward pulling force of the *i*-th steel pipe is T_{i+1}, the angle between the *i*-th diagonal pulling force and the vertical direction is θ_{i+1}, and the diameter of the steel pipe is d_2. Taking the first steel pipe as an example (**Figure 2**), a force analysis is carried out.

$$T_i \sin\theta_i = T_{i+1} \sin\theta_{i+1} \tag{2}$$

$$T_i \cos\theta_i + B_2 = T_{i+1} \cos\theta_{i+1} + m_2 g \quad (i = 1,2,3,4) \tag{3}$$

$$B_2 = \rho h_2 (\frac{\pi d_2^2}{4}) g \quad (4)$$

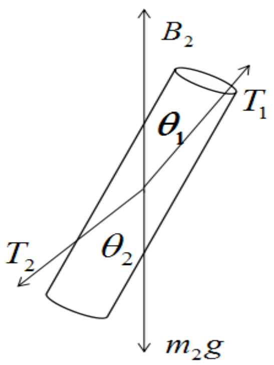

Figure 2. Force diagram of steel pipe

(3) Steel drums and heavy objects

The steel drums and heavy objects are regarded as a whole for analysis. The gravity in the vertical direction is $(m_3 + m_4)g$, the downward pulling force is T_6, and its angle with the vertical direction is θ_6. The equation can be obtained by establishing a balance, where B_3 is the buoyancy of the steel drum, and B_4 is the buoyancy of the heavy ball:

$$T_5 \sin\theta_5 = T_6 \sin\theta_6 \; T_5 \cos\theta_5 + B_3 + B_4 = T_6 \cos\theta_6 + (m_3 + m_4)g \quad (5)$$

(4) Anchor chain

The anchor chain is analyzed with force. The electric welding anchor chain is 22.05 meters, and the mass of the anchor chain per unit length is 7 kg/m. Assuming that the anchor chain is made of steel, the total mass can be 154.35 kg, and the buoyancy of the anchor chain is calculated as follows:

$$B_5 = \rho \cdot \frac{m_5}{\rho_{steel}} g \quad (6)$$

$$T_6 \cos\theta_7 = T_7 \cos\theta_8 \quad T_6 \sin\theta_7 + B_5 = T_7 \sin\theta_8 + \rho_{steel} g s \quad (7)$$

(5) Anchor

The pulling force of the anchor chain to the anchor is T_7, the friction force of the anchor subjected to the seabed is f, and the buoyancy force of the anchor subjected to the seabed is B_6. The angle between the pulling force of the anchor and the anchor chain is θ_8, and the supporting force is N.

$$m_{\text{Anchor}} g = N + B_6 + T_7 \cos\theta_8 \qquad F_{wind} = T_7 \sin\theta_8 \qquad f = T_7 \sin\theta_8 \quad (8)$$

3.2. Building mathematical models

In building mathematical models [5], taking the seabed surface as the x-axis, the seawater depth is y. Among them, the draft of the buoy is h_1. The setting is as follows: the coordinate of point A is (x_1, y_1), the coordinate of point B is (x_2, y_2), the coordinate of point C is (x_3, y_3), the coordinate of point D is (x_4, y_4), the coordinate of point E is (x_5, y_5), and the coordinate of point F is (x_6, y_6), as shown in **Figure 3**.

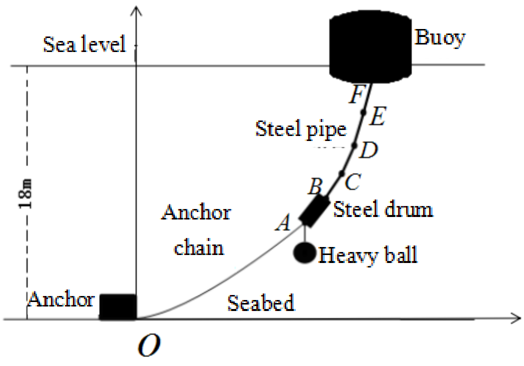

Figure 3. Schematic diagram of the transmission node

In determining the equation of the anchor chain OA, the solution can be obtained by using the catenary equation:

$$y = a\left[\sec\gamma(ch\frac{x}{a}-1)+tg\gamma\cdot sh\frac{x}{a}\right] = \frac{R}{w}\left[\frac{1}{\cos\gamma}\left(\frac{e^{\frac{x'w}{\gamma}}+e^{-\frac{x'w}{\gamma}}}{2}-1\right)+tg\gamma\cdot\frac{e^{\frac{x'w}{\gamma}}+e^{-\frac{x'w}{\gamma}}}{2}\right] \tag{9}$$

Among them, y refers to the depth of the water, R is the external force acting on the buoy, and x is the horizontal distance from the anchor point to the chain point; γ is the anchor angle, and w is the chain weight per meter. In the formula, the anchoring angle is set as $\gamma = T$. The integral over arc OA is as follows:

$$\int_0^x \sqrt{1+y'^2}\,dx = 22.05 \tag{10}$$

If $a = \frac{r}{\omega}$,

$$y' = \frac{R}{\omega}\left[\frac{1}{2\cos T}\left(\frac{\omega}{R}e^{\frac{\omega x}{R}} - \frac{\omega}{R}e^{-\frac{\omega x}{R}}\right)+\frac{tgT}{2}\left(\frac{\omega}{R}e^{\frac{\omega x}{R}}+\frac{\omega}{R}e^{-\frac{\omega x}{R}}\right)\right]$$

$$= \frac{1}{2\cos T}[1+\sin T]e^{\frac{\omega x}{R}} + \frac{1}{2\cos T}[\sin T - 1]e^{-\frac{\omega x}{R}} \tag{11}$$

If $e^{\frac{wx}{R}} = S$,

$$\therefore (1+\sin T)\frac{R}{\omega}\bullet S^2 - (1-\sin T)\frac{R}{\omega} = 22.05\bullet 2\cos\bullet S + \frac{R}{\omega}tgT\bullet 2\cos T\bullet S \tag{12}$$

$$x = a\ln\frac{(44.1\cos T + 2a\sin T)\pm\sqrt{44.1^2\cos^2 T + 176.4\sin T\cos T + 4a^2}}{2a(1+\sin T)} \tag{13}$$

From the equation, the following can be obtained:

$$y = a\left[\sec r\left(ch\frac{x}{a} - 1\right) + tgrsh\frac{x}{a}\right] \tag{14}$$

The tangent direction of the catenary at point *A* (the direction of the force between the anchor chain and the barrel at point *A*) is as follows:

$$y'\Big|_{x=x_1(r)} = \sec rsh\frac{x}{a} + tgrch\frac{x}{a} \tag{15}$$

3.3. Combined with theoretical mechanics

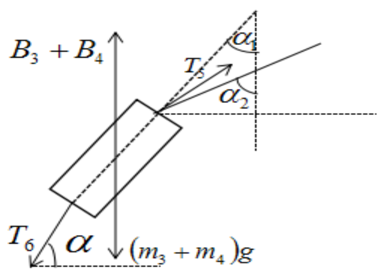

Figure 4. Overall force analysis of steel drum and heavy ball

As shown in **Figure 4**, since the force is not on the same direction with the force of the steel drum, it is assumed that the direction of the force is on the angle bisector of the centerline of the steel drum and the steel pipe, and the equation of the inclination angle between the steel drum and the heavy object can be obtained as follows:

$$F_{wind} = T_6\cos\alpha = T_5\cos\left(\frac{\pi}{2} - \frac{\alpha_1 + \alpha_2}{2}\right) \tag{16}$$

$$T_6\sin\alpha_1 + (m_3 + m_4)g = B_3 + B_4 + T_5\sin\left(\frac{\pi}{2} - \frac{\alpha_1 + \alpha_2}{2}\right) \tag{17}$$

The inclination angle equation of the fourth steel pipe is as follows:

$$F_{wind} = T_4\cos\left(\frac{\pi}{2} - \frac{\alpha_3 + \alpha_2}{2}\right) \quad m_2g + T_5\sin\left(\frac{\pi}{2} - \frac{\alpha_1 + \alpha_2}{2}\right) = B_2 + T_4\sin\left(\frac{\pi}{2} - \frac{\alpha_2 + \alpha_3}{2}\right) \tag{18}$$

Similarly, the inclination angle equations of the third steel pipe, second steel pipe, and the first steel pipe can be obtained as follows:

$$F_{wind} = 0.625d_1(h - h_1)v^2 \qquad m_1g + T_1\sin\left(\frac{\pi}{2} - \frac{\alpha_5}{2}\right) = B_1 \qquad \tan T = \frac{B_{total} - G_{total}}{F_{wind}} \tag{19}$$

The buoy equation:

$$B_{tatol} = B_1 + 4B_2 + B_3 + B_4 + B_5 \qquad G_{tatol} = m_1 g + 4m_2 g + m_3 g + m_4 g + m_5 g \tag{20}$$

According to the force analysis diagram, the relationship between the angle θ from the force direction to the vertical direction and the inclination angle is as follows:

$$\frac{\alpha_1 + \alpha_2}{2} = \theta_5,\ \frac{\alpha_2 + \alpha_3}{2} = \theta_4,\ \frac{\alpha_3 + \alpha_4}{2} = \theta_3,\ \frac{\alpha_4 + \alpha_5}{2} = \theta_2,\ \frac{\alpha_5}{2} = \theta_1,\ \alpha = \theta_6 \tag{21}$$

4. Conclusion

According to the coordinate (x_6, y_6) and the sea depth, the following can be ascertained:

$$h_1 + y_6 = H \ \ x_6{}^2 + H^2 = R^2 \tag{22}$$

By combining with the previous equation, when H = 18 and v_1 = 12, h_1 = 0.71 m, and the swimming radius is in the circle with R = 26.5 m. The inclination of the four steel pipes and the steel drums are as follows: α_5 = 2.43°, α_4 = 3.27°, α_3 = 5.63°, α_2 = 7.21°, α_1 = 3.07°. When H = 18 and v_1 = 24, h_1 = 0.79 m, and the swimming radius is in the circle with R = 32.8 m. The inclination of the four steel pipes and the steel drums are as follows: α_5 = 3.01°, α_4 = 3.97°, α_3 = 5.78°, α_2 = 7.63°, α_1 = 2.56°. When H = 18 and v_1 = 36, h_1 = 1.1 m, and the inclination of the four steel pipes and the steel drums are as follows: α_5 = 3.03°, α_4 = 4.09°, α_3 = 6.38°, α_2 = 8.08°, α_1 = 2.32°. The swimming radius is in the circle with R = 32.8 m. The inclination angle of the steel drum should not exceed 5 degrees, and the angle between the anchor chain and the seabed should not exceed 16 degrees. Adjusting the mass of the heavy ball, 983 kg ≤ m_4 ≤ 1,425 kg can be obtained.

Funding

The Undergraduate Teaching Reform Research Project of Liaoning Institute of Science and Technology in 2021 "Research and Practice on the Construction of 'Dual Teachers and Dual Energy' Teachers in Applied Undergraduate Universities" (Grant Number: 2021053)

Disclosure statement

The author declares no conflict of interest.

References

[1] Zhang L, Li H, Ma Y, et al., 2016, Research on a Combined Mooring System and Its Influence on Mooring Characteristics. Ship Mechanics, 20(3): 306-314.

[2] Yuan Y, Wang X, Zhang C, et al., 2015, Dynamic Response Analysis of Semi-Submersible Platform Mooring System Failure Mode. China Offshore Platform, 30(2): 36-41.

[3] Yang X, 2015, Fast Calculation Method and Application of Mooring System. Port Technology, 2015(5): 17-23.

[4] Yuan P, Zhao Y, Guo J, et al., 2016, Design and Hydrodynamic Performance Analysis of Multi-Floating Mooring System. Ship Science and Technology, 38(2): 80-84.

[5] Chen J, Wang Z, Fu J, et al., 2015, Mooring System and Motion Response Characteristics of Single Pontoon of Floating Trestle in Shallow Water. Ship Science and Technology, 37(5): 42-46.