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Coupling and Analysis of 981 Deep Water Semi-submersible Drilling Platform and the Mooring System

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Abstract. With the increasing water depth, semi-submersible platform mooring system weight has increased rapidly. Because the coupling of the platform and mooring system will directly affect the safety of platform location, the mooring system must use the design of multi-component mooring line. The paper introduces coupled time domain analysis theory of platform and mooring system, and then uses AQWA software to build the three-dimensional hydrodynamic model of the 981 Semi-submersible Platform. MATLAB is used for the multi-component mooring system design calculations. The load is applied to the model of the marine environment in the South China. It studies its changes with top angle of tension mooring system and platform offset, and finally checks the platform safety. Ultimately it determines a reasonable horizontal inclination at the top of mooring lines. Check and assess mooring positioning system of the 981 platform once in a century environmental loads. This paper has a positive meaning to optimization of 981 semi-submersible drilling platform mooring system at the deep water state, pre-anchor operation and positioning system security evaluation.

Introduction

With the development of the offshore oil industry, the scope of its operations and research gradually goes to the deep sea. As the South China Sea is rich in oil and gas resources, in order to enhance the development level of deep-sea oil and gas resources, China has developed the 981 Semi-submersible Rig for use in deep sea [1]. Due to the increase of water depth, the weight of catenary type mooring system which consists of the traditional type catenary mooring has increased rapidly. The multi-component catenary mooring lines uses a type of synthetic material. The 981 Deep-water Semi-submersible Platform and mooring lines are a system of mutual coupling. Nonlinear coupling of the system increases the difficulty of solving the coupling problem. Theoretically, time domain simulations can deal with any movement of waves and objects. Due to finite element software AQWA modules have a strong problem solving ability which are suitable for large-scale projects, the AQWA modules are suitable for calculating the three-dimensional fluid dynamics and finite element analysis. We can use AQWA-DRIFT module to analyze the semi-submersible drilling platform and mooring system with coupled time domain simulation.

Deep-water multi-component mooring system design used to base on experience. The reference [2] conducted a multi-component derivation of deep water mooring system catenary equation, but the multivariate equations derived did not give numerical methods for solving equations and numerical examples. In this paper, the MATLAB mathematical software is used to calculate design mooring system based on the derived catenary equation in the reference [2]. Through it we can design geometric and determine its segment length equilibrium mooring system in the steady state. Usually, people select horizontal inclination at the top of mooring lines in pretension anchor field operation based on experience. This paper research on horizontal inclination influence on mooring system response and platform offset at 1500m water depth. Then we get its recommended best value through comparative analysis. The mooring positioning system of 981 platform is checked and assessed under the conditions of extreme environmental loads.

The Analysis of Time Domain Theory for the Mooring System and Platform

Cummins put forward making use of calculated generalized wave force, additional mass and damping by frequency domain method in 1962. Fourier transformation is used to obtain generalized wave force, additional mass and delaying function. Finally, its motion time history was gotten by solving the equations of floating body in the time domain [3]. Hydrodynamic parameters is calculated by the frequency domain analysis of semi-submersible drilling platform, such as: first order wave force of semi-submersible platform, second order wave drift force, added mass factor, added damping factor and RAO response function. Combined with the South China Sea marine environment, AQWA-DRIFT module was used to couple and simulate about the semi-submersible drilling platform and mooring system in time domain analysis. Although the time-domain analysis and calculation time is longer, but it has obvious advantages by comparison to frequency calculation in the case of sufficient computing resources. Time domain method can reflect changes in tension mooring system and can be analyzed mooring system coupled with the movement of the deep water platform.

Coupling Time Domain Analysis Theory.onsidering mooring system coupled with semi-submersible platform, time domain equations of semi-submersible drilling platform's motion as follows [4]:

$$[M + m]\{\ddot{x}(t)\} + \int_{-\infty}^{t} [L(t - t)]\{\dot{x}(t)\}dt + [C]\{x(t)\} = \{F_{iW}(t) + F_{im}(t)\} \quad (1)$$

Where there $[M]$ is general mass matrix of platform, $[m]$ is additional mass matrix of platform, $[L(t-t)]$ is delaying functional matrix of platform, $[C]$ is hydrostatic recovery coefficient matrix of platform, $\{F_{iW}(t)\}$ is generalized force matrix of fluid acting on the platform, $\{F_{im}(t)\}$ is generalized force matrix of mooring system acting on the platform.

Environmental Loads Calculation. Wind loads have a significant impact on semi-submersible platform motion response. It has main effect on building structure above water semi-submersible platform. Wind load value is determined by wind speed, the projection area, shape and height of the compressed member. Calculation of wind load is to the reference [5].

Currents force is a kind of flow resistance that effects on marine petroleum structures. According to the resistance mathematical expression, currents force can be calculated as followed [6];

$$F_{cs} = \frac{1}{2} r (C_{d1} A_c + C_{d2} A_f) v^2 \quad (2)$$

Where there r is density of seawater, A_c is projected area of the cylindrical member under the sea, when A_f is projected area of the planar member under the sea, v is velocity of seawater, when C_d is structural member resistance factor, C_{d1}=0.5 in cylindrical member, and C_{d2}=1.5 in planar member.

In the calculation of wave force, First-order wave amplitude is proportional to the amplitude of the incident wave under the action of single frequency. Maruo proved that the second order wave drift force in horizontal is proportional to echo amplitude-squared away from object in terms of the two-dimensional floating body [7]. The first-order wave force and the second-order wave force is calculated according to the reference [8].

Calculation and Analysis

The Configuration of Semi-submersible Platform's Mooring and Mooring System Design. 981 Semi-submersible Platform have 12 anchor chains. Configuration and load schematic diagram are shown in figure 1 [6].

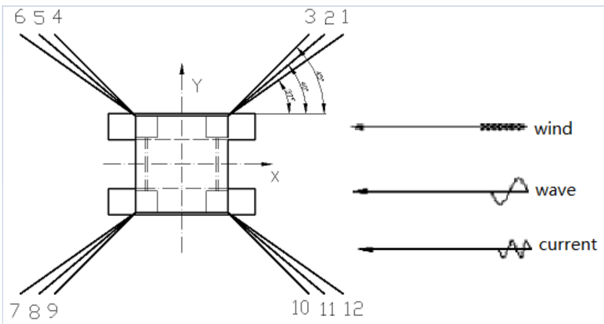

Fig .1 981 semi-submersible configuration of mooring system

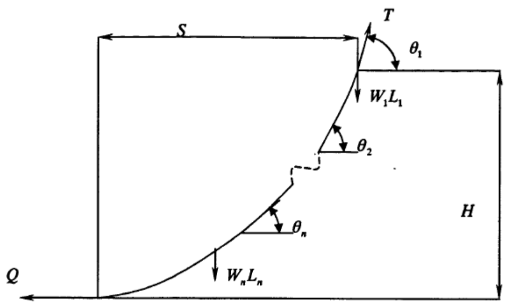

Fig .2 Static force diagram of multi-component mooring system

The reference [2] deduced catenary equations of multi-component mooring lines. Static analysis is expected to determine the geometry and the length of three components each chain in its equilibrium state. Combined with the environmental load, water depth, the top horizontal inclination and weight per unit length of mooring system, the length of each segment mooring system is determined according to the catenary equation. There are 18 variables, including horizontal inclination at the top of mooring lines q_i, mooring line length l_i, the horizontal length S_i, the vertical length h_i, weight per unit length W_i, the total vertical height H, pretension of mooring line T and horizontal force Q ($i = 1,2,3$). There are 7 known parameters, including horizontal inclination (distal end of the seabed) q_1, l_1, W_1, W_2, W_3, H and T. Equations have identified the only real solution since it has 11 equations. MATLAB can be used to solve the equations. The calculation results are shown in Table 1.

Tab. 1 Use MATLAB to solve a single multi-component mooring line catenary equation

Known parameters	value	Calculated parameters	value	Calculated parameters	value
q_1(°)	40	q_2(°)	33.868	h_1 (m)	120.3
l_1 (m)	200	q_3(°)	31.495	h_2 (m)	1174
T (KN)	2000	l_2 (m)	2174	h_3 (m)	205.7
h (m)	1500	l_3 (m)	729.42	Q (KN)	1532.089
W_1($N \cdot m^{-1}$)	1286.94	S_1 (m)	159.62		
W_2($N \cdot m^{-1}$)	41.16	S_2 (m)	1829		
W_3($N \cdot m^{-1}$)	1286.94	S_3 (m)	690.1		

Chain length design results of 981 Semisubmersible Platform are basically identical with the reference [9]. The reference [9] configuration anchor line is 2137m and anchor chain is 782.38m at 1371m water depth. These are basically identical with calculation results that l_2=2174m and l_3=729.42m at 1500m water depth.

The Overall Parameters of 981 Semi-submersible Platform and Finite Element Model. Hydrodynamic model was established consider from body size [6], the coupling with semi-submersible platform and the mooring system.

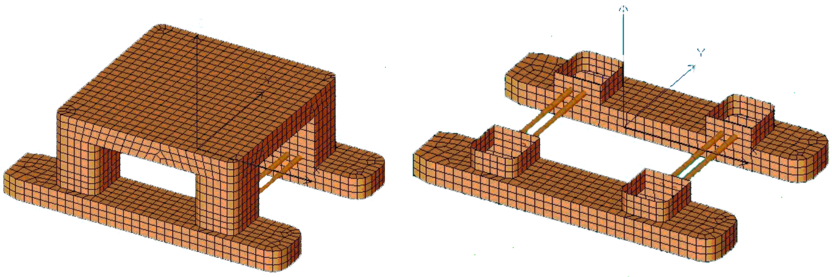

Fig .3 three-dimensional hydrodynamic model of 981 Semi-submersible Platform

Mooring System Safety Assessment and Semi-submersible Platform Offset Assessment under the Normal Operating Conditions. Normal operating conditions is considered in South China Sea at 1500m water depth [6]. The conditions are as follows: wave JONSWAP spectrum, significant wave height is 6m, the peak period is 11.2s, API wind spectrum, mean wind velocity in 1 minute is 23.15m/s and surface velocity is 0.93m/s. Time domain analysis time is set to 10800s. The step size is set to 0.5s. Its different horizontal inclination at the top of mooring lines corresponds to different design results of mooring lines. Mooring line tension stress variation with different inclination at the top of mooring lines in AQWA software calculations is shown in figure 4.

According to the results of figure 4, research horizontal inclination changes with safety factor of mooring line. The mooring line safety coefficient are all greater than the minimum coefficient of

1.67 according to "API RP 2 SK" standard [10]. With the increase horizontal inclination at the top of mooring lines, the maximum tension of mooring lines reduced and the safety coefficient increased.

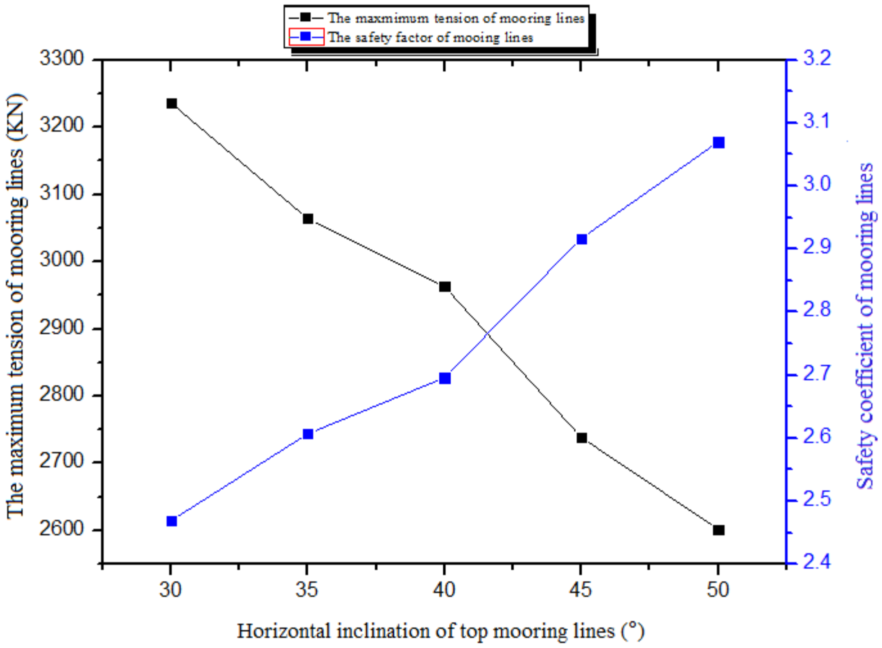

Fig.4 The maximum mooring line tension and safety factor changes with top angle of tension mooring system

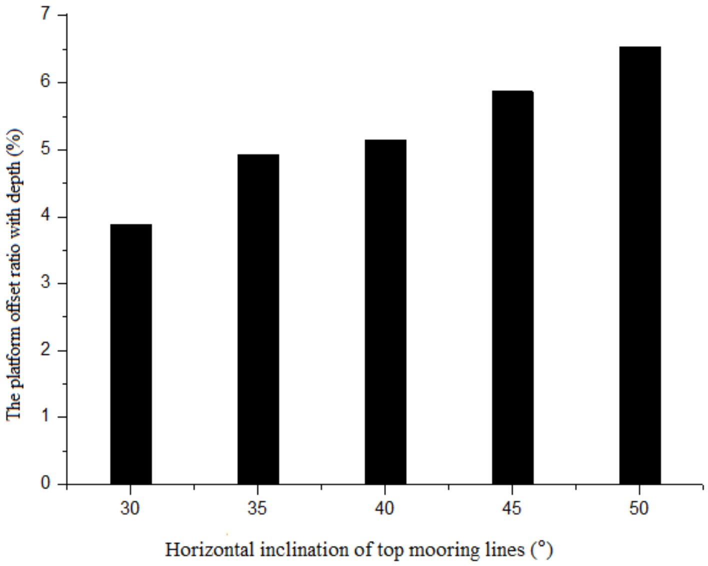

Fig.5 Semi-submersible platform offset changes with top angle of tension mooring system.

With the increase horizontal inclination at the top of mooring lines, the maximum offset value of drilling rig increases gradually. But the offset are still within the scope of limit operational areas. The ratio of Semi-submersible platform offset to water depth gradually increased with horizontal inclination at the top of mooring system. When the horizontal inclination is 40°, the ratio has been close to the limits of 5% in normal drilling conditions. By comprehensive consideration, it is recommended that the horizontal inclination at the top of mooring lines take 40°.

Mooring System Safety Assessment and 981 Semi-submersible Platform Offset Assessment under the Extreme Conditions. We should ensure that every anchor have enough strength to resist the external environment load under the once-in-century environmental loads. The tension of the mooring line and the offset of platform is evaluated according to the “API RP 2SK” specification. When the horizontal inclination at the top of mooring lines is 40°, we get the maximum tension of mooring lines as shown in Table 3 and platform offset as shown in Table 4 by the once-in-century environment loads [11] at 1500m water depth.

Tab.2 The maximum tension of mooring line

Mooring line number	Maximum tension(N)	Safety factor
6	4616763	1.73

Tab.3 Semi-submersible platform offset

	The maximum offset(m)	The offset ratio with water depth (%)	The ratio of normal operation (%)	The ratio of restrictions operation (%)
value	125.36	8.38%	≤5	5%~10

From the analysis results, we can see the maximum tension value of the mooring line of the platform is 4616763N and the safety factor is 1.73, which is greater than 1.67 of the “API RP 2 SK” standard and less than the breaking load of the mooring line. Platform maximum offset value is 125.36m in horizontal, which is beyond the normal operation area but within the range of the restrictions operation. Under the action of the mooring system, the platform can survive in once-in-century extreme weather.

Conclusion

In the statics analysis of mooring line, it is mainly used to expect the geometry, stress distribution and determine each section’s length. The mooring line can be designed smoothly by MATLAB software.

By using the AQWA, we can accurately calculate wave load of semi-submersible platform. We can get the horizontal inclination of mooring lines influence to the mooring system tension and offset of deep-water drilling rig. At last, we get the result that the 981 Semi-submersible Platform mooring system’s horizontal inclination at the top should be 40° at 1500m water depth.

Under the extreme load of a once-in-century, the mooring line safety of coefficient drilling rig is 1.73 which is bigger than the API standard (1.67). Although the platform’s maximum offset in horizontal has exceeded the scope of normal operation, it is within the scope of the restrictions operation. Under the action of the mooring system, the platform can survive in hundred-year extreme weather at 1500m water depth.

To get the optimum proposal of semi-submersible platform, it must be carried on research in many ways, such as overall quality distribution in rig, structure strength and fatigue strength, etc.

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