Study on motion performance and mooring system of deep-water semi-submersible drilling unit

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Abstract: This paper analyzes the motion performance and mooring system of deep-water semi-submersible drilling unit in district of the South China Sea utilizing the MOSES procedure system. After the 3-D panel model of the unit is built, the 3-D diffraction-radiation theory is used to obtain the hydrodynamic loads on the wet surfaces and the Response Amplitude Operators (RAO) of the unit. According to the environment data, the short-term motion response for motion performance of the unit is predicted by spectral method. And then a time-domain calculation is done to analyze the motion of the unit with mooring system. The research results are referential meaning to the model test of unit.

Key words: deep-water semi-submersible drilling unit, motion response, RAO, mooring system

The sixth generation semi-submersible drilling unit is well designed for a large variable deck load and large storage volumes, a wide range water depth of work and deep water capability, an adequate structural strength and fatigue life, which could resist wave and wind forces, and be suitable for harsh environment operation. Therefore, this unit has become the indispensable equipment to the development of deep water oil and gas fields. There are abound oil and gas resources in deepwater district of the South China Sea. In order to meet the needs of oil and gas exploration and development strategy, master the advanced technologies and possess the equipment with independent intellectual property right, the key technology researches on the deep-water semi-submersible drilling unit are carried out. In the design process, the motion performance and mooring system of deep-water semi-submersible drilling unit is the critical technical parameters relating to the unit operating performance as well as the normal operation of main equipments. This paper takes the MOSES procedure system as the main tool to analyze the motion performance and mooring system capability of the unit in ultra-deepwater district of the South China Sea. The research results are referential meaning to the model test of this unit.

1 Theoretical basis for motion performance analysis

1.1 Calculation principle

The semi-submersible unit consists of a box-type deck, four columns, twin pontoons and frame bracing. For small scale structures compared to the wavelength of wave such as the bracing, the wave drag and inertia force is the main force of the wave loads which can be calculated by the way of utilizing Morison equation; For large scale structures compared to the wavelength of wave such as the columns and pontoons, the wave diffraction and radiation force is considered as the main wave loads on the structures. The 3-D diffraction-radiation theory can be used to get the hydrodynamic loads on the structures of the unit. When the semi-submersible unit motions in regular wave for six degrees of freedom, the control equation of motion is given by [1, 2]:

$$m_k \ddot{x}_k + \sum_{l=1}^{6} \left(M_{lk} \ddot{x}_l + N_{lk} \dot{x}_l + C_{lk} x_l \right) = F_k \qquad (k = 1,2,...,6) \tag{1}$$

in which the quantity m_k is the structural mass matrix, the M is the added mass and the N is the damping matrix including cross terms. The matrix C includes hydrostatic as well as the external stiffness terms. The F term is the external force experienced by the structure from the waves.

1.2 Analysis model

To analyze the overall performance of the deep-water semi-submersible drilling unit, three types of analysis model need to be established. The 3-D panel model of the unit is built to calculate the hydrodynamic loads adopting the diffraction-radiation theory; the Morison model is used to get the wave drag and inertia force; and the mass model is set up to describe the characteristics of the mass distribution such as the gravity center of unit and the radius of inertia. Fig.1 shows the 3-D panel model of the unit built by MOSES procedure system. There are about 1650 panels in the model which includes the bracing system. To consider the wave response, the upper hull and structures are not included here.

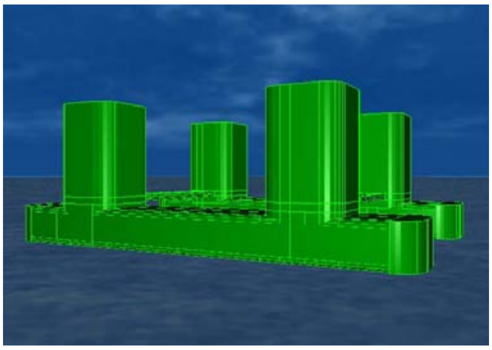


Fig.1. 3-D panel model of the unit

After the 3-D panel model has been finished, the Response Amplitude Operators (RAO) can be calculated which is global response of the unit when it is under a regular wave with unit amplitude. The coordinate system for MOSES is shown in Fig.2. Wave comes from the stern is 0 deg of wave direction, wave comes from starboard is 90 deg of wave direction, and wave comes from bow is 180 deg of wave direction. In each motion response, the period is set up from 3 seconds to 35 seconds, the wave angles are from 90 deg to 180 deg and the increment is 15 deg.

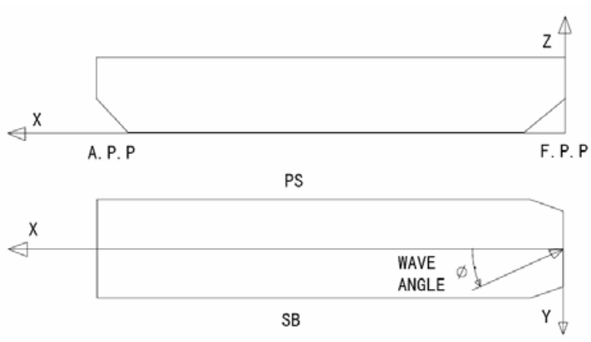


Fig.2. Coordinate system in MOSES

1.3 Short-term statistical prediction

Based on the rigid body assumption, as the RAO motion of the center of gravity is given out, the motion of any point on the unit can be obtained, and then the air-gap results can be gotten. According to the environment data, the short-term statistical analysis results can be released by spectral method. The JONSWAP spectrum is suitable for the environment data of South China Sea, which is used to do short-term statistical analysis. The short-term motion response of the unit can be considered as a random process, and thus the expression of response spectrum can be given by:

$$S_R(\omega) = \left|H(\omega)\right|^2 S_w(\omega) \tag{2}$$

in which the $H(\omega)$ is the RAO of unit and the $S_w(\omega)$ is the wave spectrum in a short-term period.

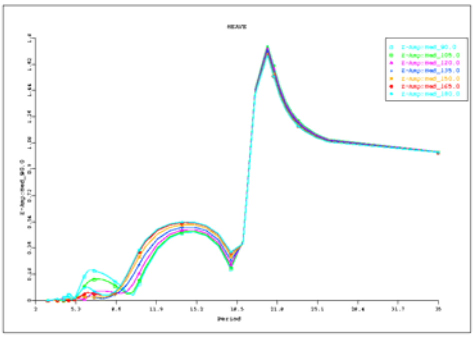
Statistical data show that the amplitude of short-term motion response of the unit accords to the Rayleigh distribution [2,3]. The variance σ^2 is the only parameter for the Rayleigh distribution and can be calculated by:

$$\sigma^2 = m_0 = \int_0^\infty S_Y(\omega)d\omega = \int_0^\infty \left|H_Y(\omega)\right|^2 S_w(\omega)d\omega \tag{3}$$

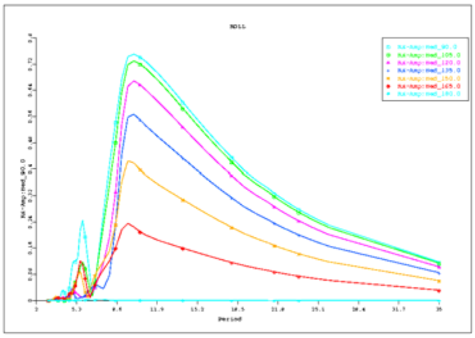
Therefore, the short-term statistical prediction results can be obtained including significant values and maximum values.

2 Analysis results

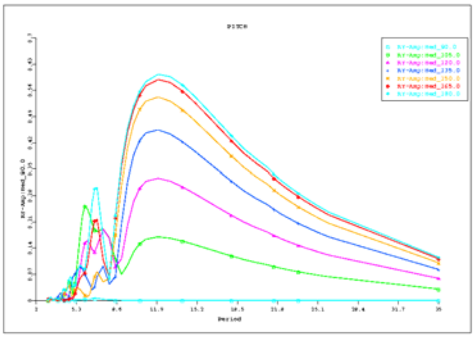
The detailed motion RAO in drilling condition are shown in Fig.3 in which the horizontal ordinate is the wave period and the vertical ordinate is the amplitude of motion response. The natural period of unit motion response in regular wave under drilling condition can be gotten from the results of motion RAO. For instance, the heave period is 21.8 seconds and meets the Rules of classification society which require that the heave period of semi-submersible unit should be greater than 20 seconds in general.



(a) Heave RAO



(b) Roll RAO



(c) Pitch RAO

Fig.3. RAO of the unit in drilling condition

The short-term motion response and air gap predictions are carried out combined with the environment data for South China Sea summarized as the Table 1 showing, and the calculation is carried out for 7 wave directions relative to the unit length. The purpose of air gap prediction is to ensure that the wave elevation will not impact the bottom of the deck in drilling case and survival case, and the minimum air gap height should be greater than 1.5m. The maximum motion response and the minimum air gap height are shown as the Table 2. According to the Rules requirements, the amplitude of the Roll and Pitch should be less than 5 deg in drilling case. From Table 2 it can be seen, the motion performance of the unit can meet the Rules requirements.

Table 1. Environment data

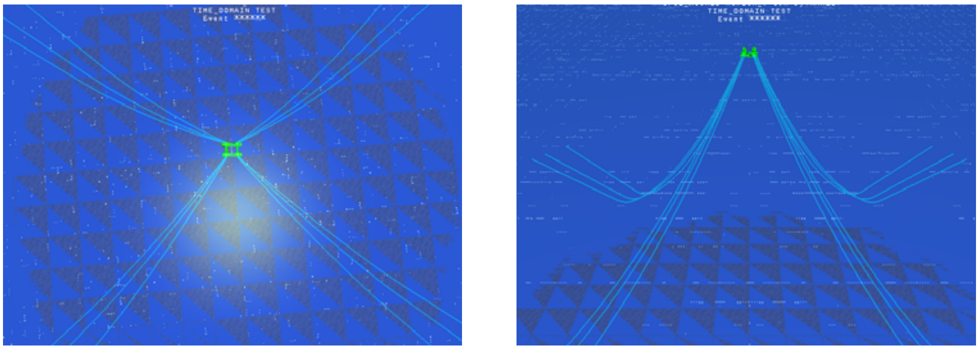
Load case	Significant wave height (m)	peak period (s)
Drilling	5.8	11.0
Survival	13.3	16.2

Table 2. The maximum motion response and the minimum air gap height

Load case	Heave (m)	Roll (deg)	Pitch (deg)	Air gap (m)
Drilling	1.87	3.36	2.59	6.05
Survival	8.17	7.63	6.92	3.06

3 Analysis results of mooring system

The water depth of the deep-water semi-submersible drilling unit is about 3000m. For drilling case below the water depth of 1500m, the chain-wire-chain mooring system is the most normal means of position because the mooring system is more economical and expedient in employment compared to the DP system. A fit mooring system for the unit is arranged and the plan of the mooring lines is shown in Fig.5. Four mooring points are arranged in four columns separately, and three mooring lines will connect the column to the seabed at each point. Each mooring line is made up of a top chain, a middle wire and a bottom chain.



(a) Top view (b) Starboard view

Fig.4. Plan mooring lines

A time-domain calculation has been done to analyze the mooring system capability. The Table 3 shows the mooring system capability in drilling condition and in maximum design condition when the pre-tension is 200 tons. According to the Rules requirements, below the water depth of 1500m, the mooring system should have the capability to control the maximum displacement less than 5% water depth of work in drilling condition and less than 10% water depth of work in maximum design condition. From Table 3 it can be seen, at heading of 90 deg, the maximum displacement of the unit with mooring system exceeds the design requirements in drilling condition; and the same results occur at heading of 90 deg and 135deg in maximum design condition. Taking into account the fact that the excess values are limited and the safety factors for the maximum tension of mooring system are greater than the allowable value, the pre-tension can be increased so that the mooring system capability meets the design requirements.

Table 3. Mooring system capability in drilling and maximum design condition

Condition	Drilling condition			Max design condition		
Heading (deg)	90	135	180	90	135	180
Max displacement (m)	77.7	68.7	63.3	193.4	168.1	146.1
Ratio of max displacement to max water depth (%)	5.18	4.58	4.22	12.89	11.21	9.74

Max tension (tons)	243	257	237	384.8	451.9	350
Ratio of max tension to breaking load (%)	30.38	32.13	29.63	48.10	56.49	43.75
Calculation safety factor	3.3	3.1	3.4	2.08	1.77	2.29
Allowable safety factor	2.0	2.0	2.0	1.67	1.67	1.67

4 Conclusion

The researches on the motion performance of the deep-water semi-submersible drilling unit can provide a basis to optimize the unit design. Both motions of the unit and the mooring system have dynamic effect on each other and the coupling effect can not be simulated by the model test of the unit. In order to predict the motion response of the unit, the calculation results need to be combined the results of the model test. In this paper, motion performance of unit has been analyzed and the mooring system capability has been calculated. The results are significant to the model test.

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References

1. Subrata K. Chakrabarti, "Handbook of Offshore Engineering", Elsevier Ocean Engineering Series, 1st edition, 2005.
2. Nie Wu, Liu Yuqiu, "Dynamic Analysis of Offshore Structures", Harbin Engineering University Press, 2002.
3. Journee, J. M. J., Massie, W. W., "Offshore Hydromechanics", 1st edition, Delft University of Technology, 2001.