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Research on the Comfort of Swing Motion on Semi-submersible Accommodation Platform

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ABSTRACT: *For the self-developed semi-submersible accommodation platform， based on the three-dimensional potential flow theory of the ocean engineering and the Morison equation, using the marine engineering hydrodynamic analysis software AQWA, a numerical analysis model for the platform was established, and six degree of freedom motion of the platform in the marine environment were predicted. The acceleration values in three directions at key positions were studied. The effects of the platform's motion and acceleration amplitude on human comfort were evaluated, and the comfort of the platform was evaluated.*

KEYWORDS*: Semi-submersibleaccommodation platform, swing motion, comfort.*

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I. INTRODUCTION

Semi-submersible accommodation platform is an auxiliary platform for the production platform, also known as "offshore Hotel", which can provide life and engineering support for the production platform, improve the production efficiency of the production platform, and provide a comfortable living environment for the platform staff[1]. According to the people-oriented principle, the living environment of workers on semi-submersible accommodation platform is paid more and more attention, and the living comfort of accommodation platform has become a hot issue.

When the semi-submersible accommodation platform is working on the sea, it will inevitably produce swaying motion due to the interference of the external environment force of the wind, wave and current[2]. The violent swaying motion will seriously affect the comfort of the platform. At present, most of the research on the comfort of semi-submersible accommodation platform is about the comfort related to vibration and noise. For example, WANG[3]has predicted the overall vibration characteristics of the semi-submersible crane living platform, YANG[4]has carried out the research on the optimal layout of the semi-submersible crane living platform based on noise analysis, etc., and there is still a lack of research on the impact of swing motion on the comfort. In this paper, the swaying motion of a North Sea type accommodation platform is studied under the working conditions of the designated sea area, and the influence of the swaying motion on the comfort of the platform is analyzed.

II. FREQUENCY DOMAIN EQUATION OF FLOATING BODY MOTION

The main floating body and column of the semi-submersible accommodation platform belong to large-scale structure. The hydrodynamic performance of the semi-submersible accommodation platform should be calculated and analyzed based on the three-dimensional potential flow theory[5]-[7]. The wave load acting on the platform should be solved and its motion response should be predicted. At the same time, the viscous effect of small-scale components such as horizontal cross brace and the damping correction of the vertical motion of the platform should be considered. In this paper, Morison is used the drag force acting on the horizontal brace is calculated by the equation[8]. For the simple harmonic motion of rigid body system, based on the frequency domain motion theory of floating body, the mass force, damping force, restoring force and external excitation force acting on the hydrodynamic surface element and Morison element can be expressed by the following equations:

$$\left[-\omega^2\left(M+A(\omega)\right)+i\omega\left(B(\omega)_p+B_v\right)+C+C_e\right]X(\omega,\beta)=F(\omega,\beta) \qquad (1)$$

Where, M is the inertial force coefficient matrix; $A(\omega)$ is the additional mass coefficient matrix; $B(\omega)_p$ is the potential flow damping coefficient matrix; B_v is the linearized viscous flow damping coefficient matrix; C is the hydrostatic recovery force coefficient matrix; C_e is the external recovery force coefficient matrix; $F(\omega,\beta)$ is the excitation force matrix; $X(\omega,\beta)$ represents the displacement matrix of the floating body movement.

The drag force acting on the horizontal brace is calculated by Morison equation. The wave force on the unit length cross brace is:

$$dF = \frac{1}{2}\rho C_D D dz(u - \dot{\eta}_1)\left|u - \dot{\eta}_1\right| + \rho C_M \frac{\pi D^2}{4} dz a_1 - \rho(C_M - 1)\frac{\pi D^2}{4} dz \ddot{\eta}_1 \quad (2)$$

Where CM is the drag force coefficient and CD is the inertia force coefficient. According to DNV's environmental conditions and environmental load rule, in general, for cylinders, CM = 1.0, CD = 2.0.

When the dominant frequency of the wave is close to the natural frequency of the platform, the viscous force is the dominant component. In this paper, the method of defining the critical damping percentage is used to estimate the magnitude of the viscous force on the platform. The range of damping ratio is usually between 3% and 7%. In this paper, 3% damping ratio is adopted.

Based on the above frequency domain theory and Morison equation viscosity theory, the motion response and acceleration Rao of semi-submersible accommodation platform can be predicted.

III. RESEARCH ON MOTION RESPONSE OF SEMI-SUBMERSIBLE ACCOMMODATION PLATFORM

In order to analyze the impact of swaying motion on the comfort of semi-submersible living platform, it is necessary to analyze the motion response of semi-submersible accommodation platform in waves.

3.1 Platform scale parameters and modeling

The research object of this paper is a self-developed Beihai semi-submersible accommodation platform. The main shape parameters of the platform are shown in Tab.1, and the quality parameters are shown in Tab.2.

Tab.1 Main scale parameters of semi-submersible accommodation platform (unit: m)

component	dimension	value
Main body	length	104.45
	breadth	74.10
	height	38.50
Buoy	length×breadth×height	104.45×15.60×9.10
Column	length×breadth×height	13.975×15.60×29.40
cross-brace	diameter	2.80

Tab.2 Quality parameters of semi-submersible accommodation platform

Item	Symbol	Unit	Operation condition	Max.Operation condition
Draft	T	m	17.5	20.0
Displacement	D	t	35329.3	37224.3
Center of gravity	XG	m	0	0
	YG	m	0	0
	ZG	m	20.6	19.78
Moment of inertia	IXX	Kg.m2	2.908E10	3.015E10
	IYY	Kg.m2	3.023E10	3.135E10
	IZZ	Kg.m2	4.515E10	4.757E10

The three-dimensional potential flow analysis software Aqwa is used in the hydrodynamic analysis. Shell elements of pontoons and columns under the platform are built with shell 63 element in the pre-processing of ANSYS for the calculation of hydrodynamic diffraction and radiation.

Morison model of horizontal cross brace is built with pipe59 element for the compensation of drag force based on Morison formula.

The surface element of the platform hydrodynamic model under the operation condition is shown in Fig. 1.

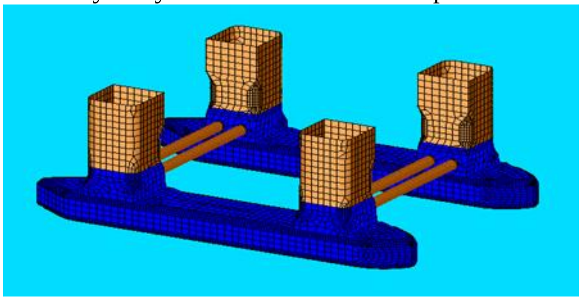


Fig.1. Surface element model of semi-submersible platform

The design water depth of the semi-submersible accommodation platform is 2500m, adopting 12 point mooring. The platform is arranged with gymnasium, cinema, restaurant and other living areas. In addition, it also includes the HELIDECK, heliport and other key areas. The location coordinates of each living area and key area are shown in Table 3. The coordinate system is defined as the origin in the center of the base plane platform, with the x-axis direction pointing to the bow as positive, Y-axis direction pointing to the bow as positive in the axial direction, the port side is positive, and in the z-axis direction, it is positive.

Tab.3Parameters of key position of platform

Serial number	Key position	Coordinate
P1	Reading room	(31.413, -26.35,33.55)
P 2	Gym	(6.312, -15.588,33.55)
P 3	Cinema	(32.337,0,35.2)
P 4	Entertainment Room	(27.777,15.438,36.85)
P 5	Dining room	(7.088,4.056,40.25)
P 6	Kitchen	(20.95,13.237,40.25)
P 7	Driver's cab	(37.989,0,56.95)
P 8	Office	(31.359,25.753,40.25)
P 9	Meeting room	(7.685,25.436,40.25)
P 10	HELIDECK	(-2.395, -30.812,58.485)
P 11	Helicopter waiting room	(26.803,0,53.55)

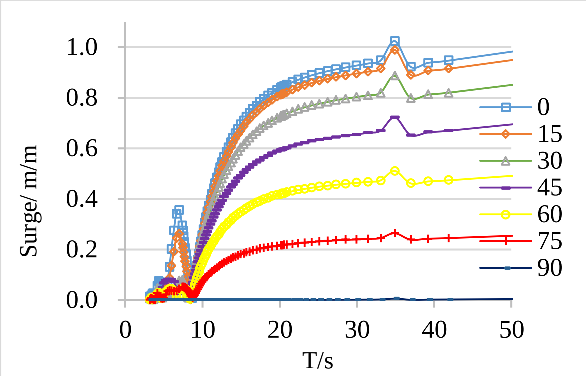
3.2 Platform motion response

Using AWQA-LINE module, the hydrodynamic parameters and motion responses of the platform under different wave directions are calculated. The frequency range of incident wave is 0.10 rad / s 2.00 rad / s, and 100 wave frequencies are set. As the platform is symmetrical with respect to plane and plane, the incident direction is set as 0 ° ~ 90 °, one wave direction angle is taken every 15 °, and a total of 7 wave directions are set. It can be seen from table 4 that the natural periods of heave, roll and pitch of the platform are far away from the concentration range of ocean wave periods, which can avoid large resonance with the waves, so the platform meets the safety requirements of the platform in terms of motion performance. The specific calculation results are as follows:

The inherent period of platform motion under operation and max. operation conditions is shown in Table 4.Under the operation condition, the six degree of freedom motion response Rao of the platform is shown in Figure 2 to figure 7;Under the max. operation condition, the six degree of freedom motion response Rao of the platform is shown in Fig. 8. to Fig. 13.

Tab.4 Inherent period of motion of semi-submersible accommodation platform (unit: s)

Working condition	Heave	Roll	Pitch
Operation	20.3	38.8	35.3
Max.Operation	20.4	36.5	33.6



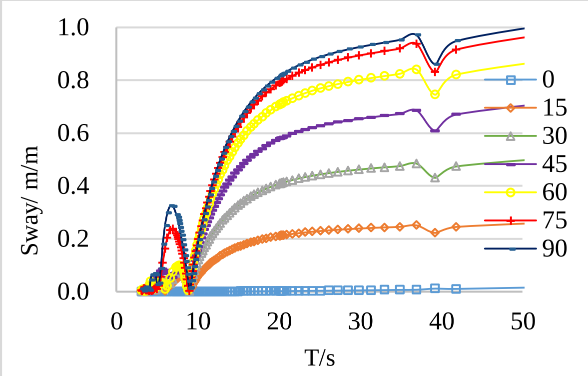
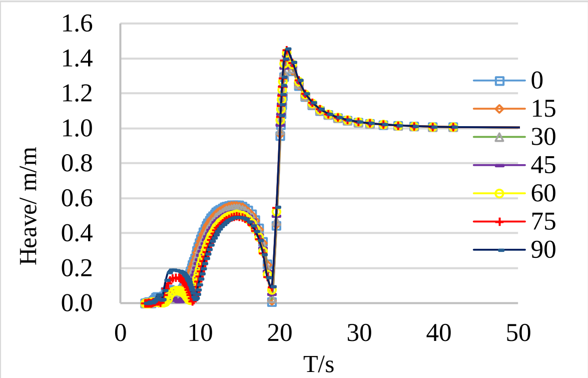


Fig.2.SurgeRAO(Operation condition)Fig.3.Sway RAO(Operation condition)



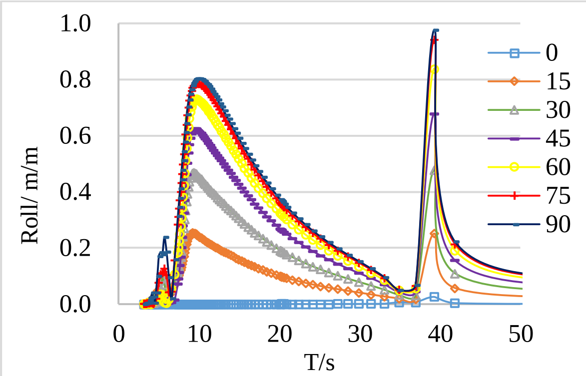
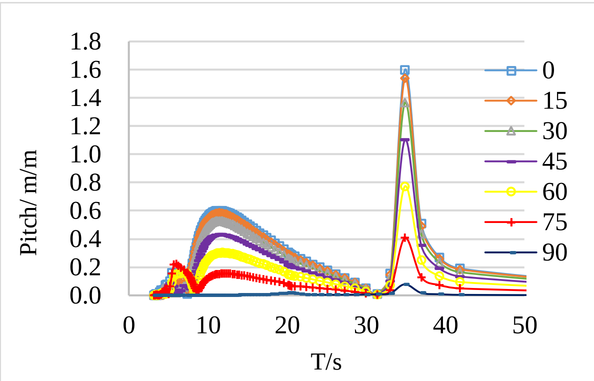


Fig.4.Heave RAO(Operation condition)

Fig.5.Roll RAO(Operation condition)



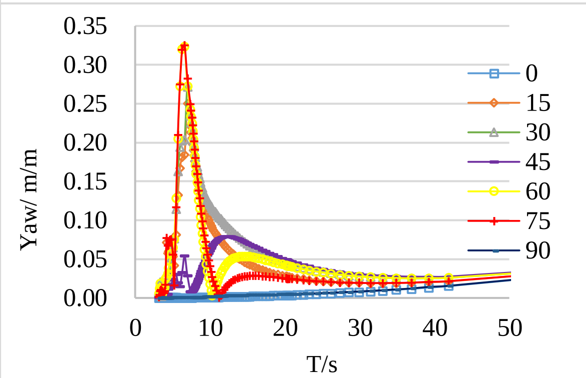
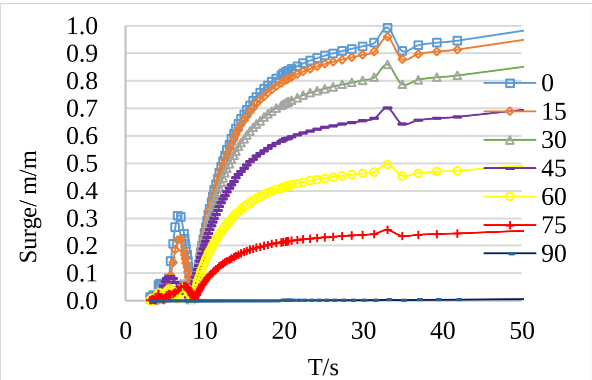


Fig.6.Pitch RAO(Operation condition)

Fig.7.Yaw RAO(Operation condition)



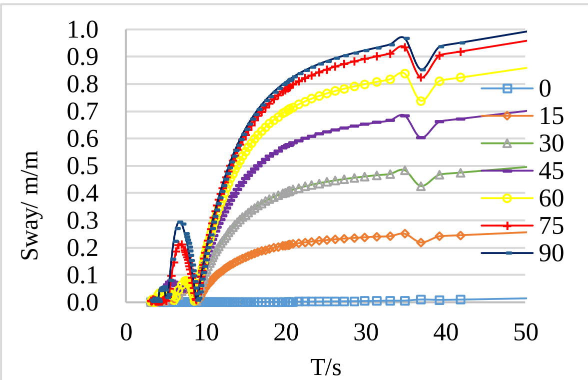
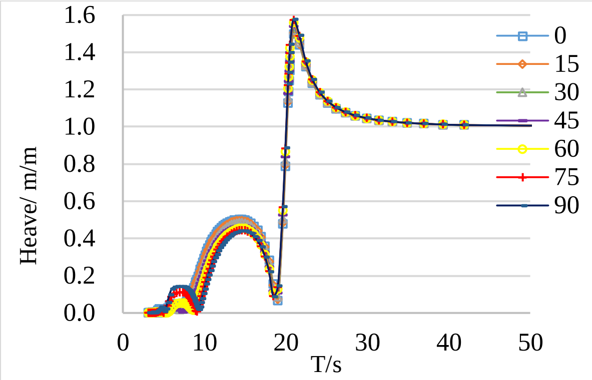


Fig.8.Surge RAO(Max Operation condition) Fig.9.Sway RAO(Max Operation condition)



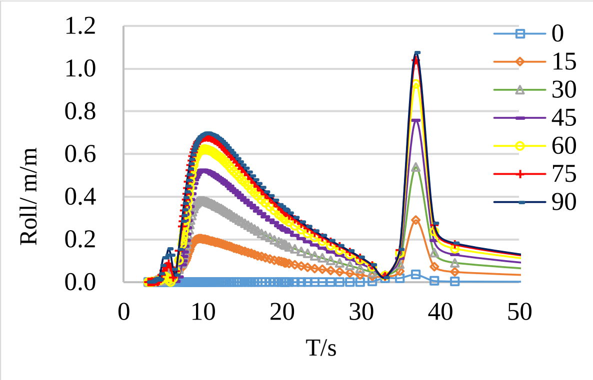
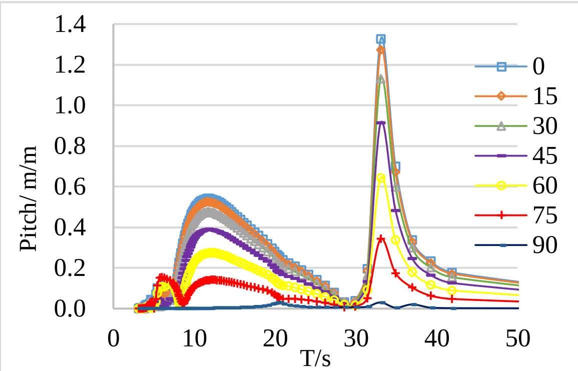


Fig.10.Heave RAO(Max Operation condition) **Fig.11.Roll RAO(Max Operation condition)**



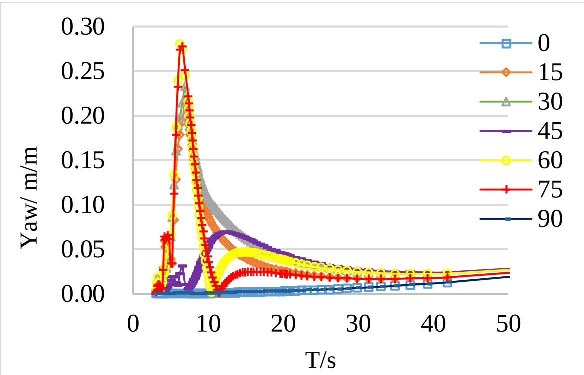


Fig.12.Pitch RAO(Max Operation condition) **Fig.13.Yaw RAO(Max Operation condition)**

3.3Short term prediction of platform movement

On the premise of the theory of slight wave and the assumption of small amplitude sway motion, the acceleration of any key position on the platform can be obtained by the transformation of the acceleration at the center of gravity and the relative coordinate relationship between them.

$$\vec{a}=\begin{Bmatrix}\ddot{\eta}_1\\ \ddot{\eta}_2\\ \ddot{\eta}_3\end{Bmatrix}+\vec{\alpha}\times\vec{r}_b=\begin{Bmatrix}\ddot{\eta}_1\\ \ddot{\eta}_2\\ \ddot{\eta}_3\end{Bmatrix}+\begin{Bmatrix}\ddot{\eta}_4\\ \ddot{\eta}_5\\ \ddot{\eta}_6\end{Bmatrix}\times\begin{Bmatrix}x_b\\ y_b\\ z_b\end{Bmatrix} \quad (3)$$

Where, $\ddot{\eta}_1$、$\ddot{\eta}_2$、$\ddot{\eta}_3$ are the lateral, longitudinal and vertical accelerations at the center of gravity, $\ddot{\eta}_4$、$\ddot{\eta}_5$、$\ddot{\eta}_6$ are the platform roll, pitch and yaw accelerations respectively.

Based on the sea state environment and the platform motion Rao, the aqwa-drift module is used to calculate the time history curve of the platform motion response value in the sea wave and the acceleration of each key position changing with time. The specific calculation results include: under the operation condition, when the wave direction angle is 0 °, 45 °, 90 °, when the platform moves in the sixth level sea state, the roll, pitch angle, and the center of gravity and the key position are horizontal Time history curve of longitudinal and vertical acceleration; under max. operation condition, when the wave angle is 0 °, 45 ° and 90 °, when the platform moves in the seven level sea state, the time history curve of roll, pitch angle, and transverse, longitudinal and vertical acceleration of center of gravity and key position. See Table 3 for specific parameters of key positions.

Through the statistical analysis of the calculated roll and pitch angles, the center of gravity and the lateral, longitudinal and vertical acceleration of each key position, the maximum roll and pitch amplitude and the maximum acceleration amplitude of the platform within three hours under different working conditions can be obtained. The specific calculation results are as follows:

(1) Under the operation condition, when the wave direction angle is 0 °, 45 ° and 90 °, the maximum amplitude of rolling and pitching of the platform in the sixth level sea condition, and under the max. operation condition, when the wave direction angle is 0 °, 45 ° and 90 °, the maximum amplitude of rolling and pitching of the platform in the seventh level sea condition, as shown in Tab.5.

Tab. 5 Maximum amplitude of platform roll (pitch) under different working conditions (degree)

Working condition	Sea state level	Wave direction angle	Roll angle	Pitch angle
Operation	six	0°	0.024	0.775
		45°	0.546	0.583
		90°	1.018	0.582
Max.Operation	seven	0°	0.079	1.240
		45°	0.963	0.983
		90°	2.534	0.472

(2) Under the operation condition, when the wave direction angle is 0 °, 45 ° and 90 °, when the platform moves in the sixth level sea state, the maximum lateral, longitudinal and vertical acceleration values of the center of gravity and key positions are as shown in Tab.6.

Tab. 6 Maximum platform acceleration (m.s-2) under operation condition and sea state 6 condition

angle / position	0°			45°			90°		
	longitudinal	lateral	vertical	longitudinal	lateral	vertical	longitudinal	lateral	vertical
COG	0.123	0.000	0.125	0.085	0.043	0.125	0.002	0.089	0.125
P 1	0.126	0.000	0.103	0.091	0.053	0.108	0.011	0.099	0.108
P 2	0.126	0.000	0.122	0.090	0.047	0.115	0.009	0.098	0.115
P 3	0.127	0.000	0.102	0.089	0.054	0.108	0.010	0.100	0.107
P 4	0.128	0.000	0.109	0.089	0.053	0.105	0.011	0.101	0.104
P 5	0.130	0.000	0.122	0.090	0.049	0.122	0.013	0.103	0.122
P 6	0.130	0.000	0.114	0.090	0.052	0.108	0.013	0.103	0.108
P 7	0.139	0.000	0.100	0.095	0.063	0.104	0.022	0.116	0.104
P 8	0.130	0.000	0.108	0.0091	0.055	0.104	0.013	0.103	0.102
P 9	0.130	0.000	0.115	0.091	0.049	0.121	0.014	0.103	0.121
P 10	0.139	0.000	0.127	0.098	0.058	0.119	0.023	0.117	0.119
P 11	0.137	0.000	0.105	0.094	0.058	0.110	0.020	0.113	0.111

(3) Under max. operation condition, when the wave direction angle is 0 °, 45 ° and 90 °, when the platform moves in class 7 sea state, the maximum horizontal, longitudinal and vertical acceleration values of the center of gravity and key positions are as shown in Tab.7.

Tab. 7 Maximum platform acceleration (m.s-2) under max. operation condition and sea state 7 condition

angle / position	0°			45°			90°		
	longitudinal	lateral	vertical	longitudinal	lateral	vertical	longitudinal	lateral	vertical
COG	0.176	0.000	0.121	0.110	0.054	0.121	0.004	0.149	0.121
P 1	0.173	0.000	0.105	0.124	0.096	0.106	0.018	0.179	0.105
P 2	0.172	0.000	0.113	0.116	0.070	0.113	0.011	0.177	0.112
P 3	0.172	0.000	0.105	0.110	0.099	0.105	0.011	0.184	0.105
P 4	0.172	0.000	0.104	0.114	0.095	0.104	0.012	0.188	0.103
P 5	0.170	0.001	0.118	0.109	0.075	0.118	0.014	0.192	0.118
P 6	0.171	0.001	0.107	0.114	0.090	0.107	0.014	0.194	0.107
P 7	0.172	0.001	0.103	0.113	0.119	0.103	0.022	0.223	0.103
P 8	0.170	0.001	0.103	0.121	0.102	0.102	0.018	0.196	0.102
P 9	0.170	0.001	0.118	0.122	0.077	0.118	0.017	0.194	0.118
P 10	0.172	0.001	0.117	0.130	0.080	0.117	0.022	0.226	0.115
P 11	0.170	0.001	0.108	0.112	0.105	0.108	0.020	0.221	0.108

IV. COMFORT EVALUATION OF SEMI-SUBMERSIBLE ACCOMMODATION PLATFORM

The working ability and comfort of the residents on the offshore platform are mainly affected by two kinds of motion characteristics, namely acceleration and swing motion amplitude. The acceleration of the platform will cause people to get seasick. Generally, the rate of seasickness increases with the acceleration. The acceptability standard of hull motion has been discussed in nordforsk (1987), and Tab.8 lists acceleration and rolling standards related to passenger comfort for some special types of operation.

Tab.8 Acceleration and rolling Criterion

Vertical acceleration（m*s-2）	Lateral acceleration（m*s-2）	Rolling angle（°）	Remarks
1.96	0.98	6	Light labor
1.47	0.686	4	Heavy labor
0.98	0.49	3	Mental labour
0.49	0.392	2.5	Transport tourists
0.196	0.294	2	Tour boats

For the operation condition, when the wave direction angle of the semi-submersible accommodation platform is 0 °, 45 ° and 90 °, the roll amplitude and pitch amplitude of the platform meet the requirements of the cruise ship, and the lateral, longitudinal and vertical acceleration of the center of gravity and each key position also meet the requirements of the cruise ship. The comfort of the platform is good in this sea condition.

For the Max.Operation condition, when the wave angle of the semi-submersibleaccommodation platform is 0 °, 45 ° and 90 ° under the seven level sea condition, the lateral, longitudinal and vertical acceleration of the center of gravity and each key position meet the requirements of the cruise ship; when the wave angle is 0 ° and 45 °, the roll amplitude and pitch amplitude of the platform meet the requirements of the cruise ship; when the wave angle is 90 °, the maximum roll amplitude of the platform meets the requirements of the cruise ship The rolling amplitude is slightly larger than the standard required by the cruise ship, and the comfort of the people on the platform may be slightly affected.

V. CONCLUSION

In this paper, the comfort measurement standard of the semi-submersible accommodation platform is established, and the comfort of the platform in different wave environment is analyzed,after calculation and analysis, the following conclusions are drawn:

1) The motion response amplitude of the semi-submersible accommodation platform conforms to the general marine engineering specifications, the motion period is far away from the wave period, and the hydrodynamic performance is good;

2) The motion and acceleration of the semi-submersible accommodation platform meet the criteria of human motion comfort and the comfort is good.

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