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Research on Hydrodynamic Performance of Floating Platform near a Reef Island

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Abstract

In this paper, three-dimensional models of the seabed topography and floating platform are constructed by Solidworks, a three-dimensional modeling software, based on terrain data of some reefs and island. The seabed topography and floating platform are meshed in ANSYS, a finite element simulation software. Three-dimensional hydrodynamic model of the floating platform near reefs and islands is constructed. Hydrodynamic performance of floating platform is calculated by AQWA, a hydrodynamic potential flow simulation software. In order to investigate the influence of reefs and islands on motion response of the platform and mooring tensions, the motion response prediction of the platform(with and without reefs and islands) with mooring system in regular and irregular waves is carried out, with the measured data of waves near reefs and islands as input parameters. The transfer functions of floating platform (without reefs and islands), the mooring tensions and motion response of the platform are given. The influence of incident waves' angle and period on hydrodynamic performance of floating platform, distribution of mooring tensions and motion response of the platform are analyzed. The influence of reefs and islands on motion response of the platform and mooring tensions is quantitatively analyzed. Model tests of the floating platform near reefs and islands are carried out in a wave tank with real three-dimensional topography of the seabed to achieve experimental data. The comparison between calculated value and experimental data of motion response of the floating platform shows that the two agree well. The research achievements of this paper are meaningful to the design of offshore floating structures near reefs and islands.

Key words: reefs and islands; platform; hydrodynamic performance

1 Introduction

Nowadays, exploiting and utilizing the ocean have been a very significant direction to the development of global economy and scientific technology, because of the abundant resources of oil and gas, as well as the fishery inside of it. There are usually hundreds to thousands of reefs around the island, which are not only full of fishery and sightseeing resources, but also have the function to protect the island from the waves. A floating platform can work as a basis near an island since it have a few good characteristics. On one hand, this kind of floating platform would not have much side influence on the ecosystem of the island. On the other hand, it is flexible and also can be used as a foundation to developing the island and the surrounding sea.

Regarding to the hydrodynamic of floating platform, there have been a lot of research work domestic and overseas. Hang Zhu[1] gave a simulation and its motion response analysis of HYSY-981 semi-submersible platform under the combined conditions of waves and winds in the time domain. Wei Zhang[2] studied the hydrodynamic performances of a semi-submersible platform in deep water (1500 m) in the frequency domain, moreover compared the result with that of model experiment. Xiaoye Long[3] investigated the coupled dynamic problems of the Truss Spar Platform in coupling of time and frequency domains. Based on the theory of the hydrodynamic potential flow, Bo Wu[4] studied the hydrodynamic performances of a floating platform near reefs and islands, whose result agrees well with experimental analysis. Mansour[5] calculated a new type semi-submersible platform numerically and did a comparison with the conventional one. Clauss[6] studied a semi-submersible platform of GVA4000 numerically and the result had a good agreement with experiment data. Lowa[7] did a time and frequency coupled analysis of a floating platform, and he concentrated on studying the motion response actuated by the first and second order wave forces.

Although lots of research results are well known in the literature, most of these focus on platforms in deep water and these in shallow water or near reefs and islands have not drew much attention so far. In this paper, the AQWA software is used to numerically calculate the hydrodynamic response of platforms with and without reefs and islands, respectively, in which the influences of reefs and islands to the hydrodynamic performances of the platforms are taken as wet surface of solid. The comparison between calculated value and experimental data of motion response of the floating platform shows that the two agree well. The research achievements of this paper are meaningful to the design of offshore floating structures near reefs and islands.

2 Basic Theory

Based on the linear theory, numerical analysis was conducted in the frequency time domain. Considering the effect of topography of reefs and islands acting on the motion responses of the platform, the overall velocity potential can be expressed as follows [8]:

$$\phi(x,y,z,t)=\phi_I(x,y,z,t)+\phi_D(x,y,z,t)+\phi_R(x,y,z,t) \tag{1}$$

where, $\phi_I(x,y,z,t)$, $\phi_D(x,y,z,t)$ and $\phi_R(x,y,z,t)$ denote the incidence potential, diffraction potential and radiation potential, respectively. In this analysis, $\phi_I(x,y,z,t)$ is taken under shallow water condition without reefs and islands. $\phi_D(x,y,z,t)$ is treated on the shallow water condition with reefs and islands with fixed platform. And $\phi_R(x,y,z,t)$ is on the condition of reefs and islands with flexible platform.

2.1 Incidence

The incidence potential of waves in a set water deep can be shown in the following form:

$$\phi_I=-i\frac{Ag}{\omega}\frac{\cosh\left[k(z+d)\right]}{\cosh(kd)}e^{ik(x\cos\theta+y\cos\theta)} \tag{2}$$

where, d is the water depth, k is the wave number and θ is incident angle. Using AQWA software to analyze regular waves with amplitude of 1 meter in the frequency domain. Then based on the linearized Bernorlli's Equation, the pressure distribution of the surface of platform can be derived. Integrating this pressure, the Froude-Krylov Force can be obtained as follows:

$$P_I=-\rho\frac{\partial\phi_I}{\partial t} \tag{3}$$

$$F_{F-K}=\iint_{Splatform} p_I \cdot n_j ds \tag{4}$$

2.2 Diffraction

Regarding to the numerical calculation of the diffraction problem under the condition with reefs and islands, the control equation of the diffraction potential and its boundary conditions are expressed as follows:

$\Delta\phi_D=0$ in the computational domain

$\frac{\partial\phi_D}{\partial z}-\frac{\omega^2}{g}\phi_D=0$ on the freedom where z=0

$V_n=0$ the body surface

$$\lim_{R\to\infty}\sqrt{R}\left(\frac{\phi_D}{R}-ik\phi_D\right)=0 \qquad R=x^2+y^2\to\infty \tag{5}$$

where, body surface condition as shown in (6), incidence potential ϕ_I is known, diffraction ϕ_D as shown in (7) :

$$V_n=\nabla(\phi_D+\phi_I)\cdot\vec{n}=\frac{\partial\phi_D}{\partial n}+\frac{\partial\phi_I}{\partial n}=0 \tag{6}$$

$$\phi_D=\iint_{S平台}\sigma\cdot Gds+\iint_{S平台}\sigma\cdot Gds \tag{7}$$

where, *G is Green function*

$$G(x,y,z,\xi,\eta,\zeta)=\frac{1}{r}+\frac{1}{r^2}+P.V.\int_0^\infty\frac{2(k+\upsilon)e^{-kH}\cosh k(z+H)\cosh k(\zeta+H)}{k\sinh(kH)-\upsilon\cosh(kH)}J_0(kR)dk+$$

$$i\frac{2\pi(k+\upsilon)e^{-kH}\sinh(KH)\cosh K(z+H)\cosh K(\zeta+H)}{\upsilon H+\sinh^2(KH)} \tag{8}$$

Platform by diffraction wave force can be represented as:

$$F_D=\iint_{Splatform} P_D \cdot n_j ds=\iint_{Splatform}\left(-\rho\frac{\partial\phi_D}{\partial t}\right)\cdot n_j ds \tag{9}$$

2.3 Radiation

Regarding to the numerical calculation of the radiation problem under the condition with reefs and islands, the control equation of the radiation potential and its boundary conditions are expressed as follows:

$\Delta\phi_R=0$ inside the watershed

$\frac{\partial\phi_R}{\partial z}-\frac{\omega^2}{g}\phi_R=0$ on the free surface of z=0

$$V_n=\nabla\phi_R\cdot\vec{n}=\frac{\partial\phi_R}{\partial n}=\begin{cases}V_{paltform} & \text{on the surface of paltform}\\ 0 & \text{on the surface of topography}\end{cases}$$

$$\lim_{R\to\infty}\sqrt{R}\left(\frac{\phi_R}{R}-ik\phi_R\right)=0 \qquad R=x^2+y^2\to\infty \tag{10}$$

where, the boundary condition is that the normal velocity in the seabed equals null and the horizontal velocity has the same value of that of the platform. Therefore, the diffraction potential and the diffraction wave force can be expressed in the following forms:

$$\phi_R=\iint_{Splatform}\sigma\cdot Gds+\iint_{Splatform}\sigma\cdot Gds \tag{11}$$

$$F_R=\iint_{Splatform}P_R\cdot n_j ds=\iint_{Splatform}\left(-\rho\frac{\partial\phi_R}{\partial t}\right)\cdot n_j ds \tag{12}$$

3 Calculation Model

3.1 Principles of the platform

The platform analyzed in this paper is square type with both ends contracted. When conducting the experiment, the living, craning and mooring systems on the platform are simulated by coupled analysis the effects of winds and waves. The platform and its principles are shown in Fig1 and Table1 as follows, where the right-hand coordinate is applied.

Table1 Main Principles of the Platform

Size Parameters		Size Parameters	
Length (m)	100	Draft (m)	2.7
Width (m)	25	Displacement (t)	6494.8
Height (m)	6	Gravity Center (m)	(0,0,4.30)

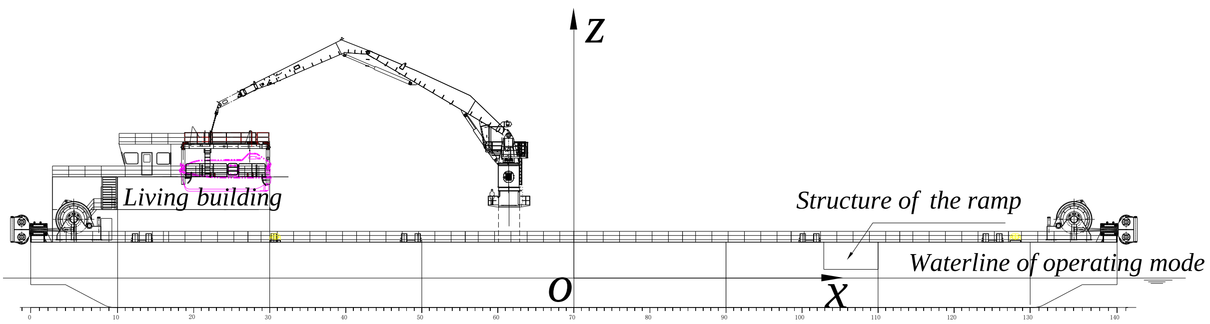

Fig.1 the Schematic of the Platform

3.2 Simulating the topography of reefs and islands

Based on terrain data of some reefs and island as well as considering the calculation efficiency and the restriction of the number of mesh units, our calculation is only applied to a finite area of $200m\times150m$, which is located in the position of the mooring system and it fully submerged in the water. The water depth at the center of the platform is 16m and surrounded water is about 30m deep and has a minor changes along with the topography.

In the area near reefs and islands, as the water depth decreases, the wave velocity will decrease and its direction becomes normal to the shoreline. Meanwhile, the sinusoidal waves also transit into trochodal wave, whose peak to valley values lose the symmetry. This kind of situations has much influence on the forces acting on the platform and its motion responses, thus it is considered necessary to take this kind of influence into consideration when analyzing the motion responses of a platform. Fig2 gives the three-dimensional topography of reefs and islands and Fig3 is the coordinate system of the platform used in this paper.

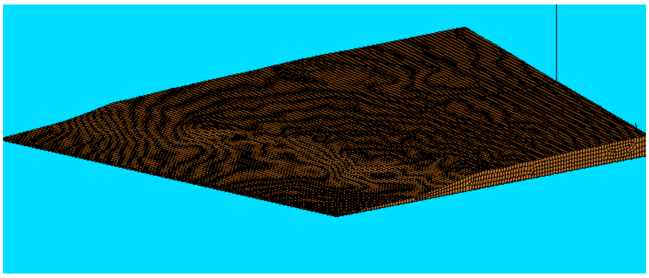

Fig.2 Three-dimensional Topography of Reefs and Islands

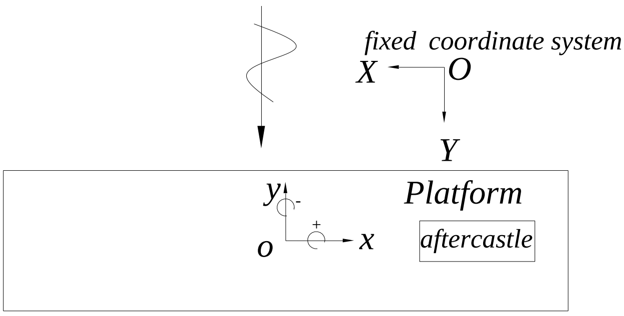

Fig.3 Coordinate System of the Platform

3.3 Mooring System

The mooring system is designed with the priority to satisfying the requirements of living and operating safely, meanwhile making sure its convenience, reliability and economy mostly used during the actual operation. A hybrid (buoy) mooring system is adopted to the platform, i.e. when operated at low sea status, the platform is moored parallel to the shoreline only through the mooring system in fore and aft, which is convenient for ships berthing and operating. In order to reduce the environmental disturbances and have a better survivability, it would become a single point mooring system located at the fore. Fig4 shows the design plan of the mooring system and the distribution of the measuring points of mooring tensions during the experiments. The prestressing force of the mooring system for the platform is 100 tons, and for the ship is 10 tons.

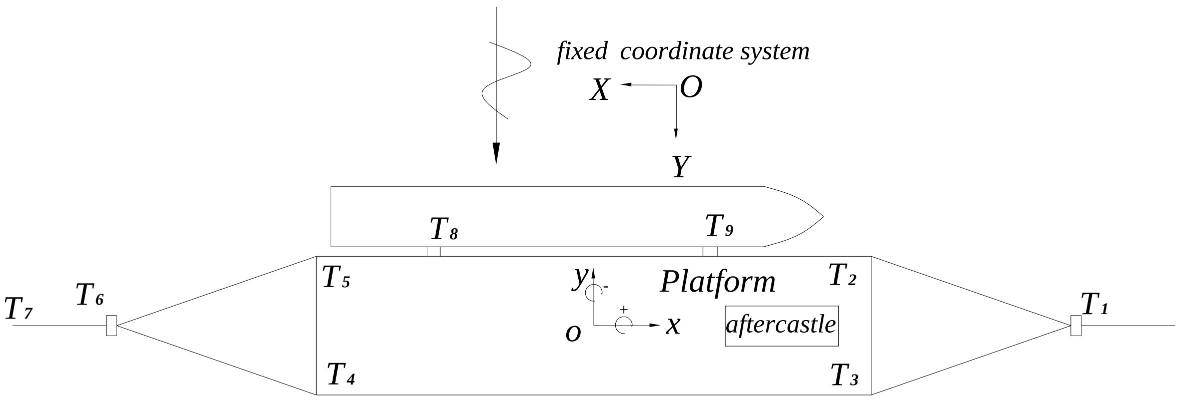

Fig.4 Distribution of Measuring Points of Mooring Tensions

A numerical calculation of regular waves with amplitude of 1m, incident angle of 135 degree is given in the frequency domain. The calculation of a platform located in the water depth of 30m without reefs and island is compared with one located in the water depth of 16m with reefs and islands, whose incident waves are taken as in water depth of 30m. These conditions are shown in detail in Table2.

Table2 Conditions of Numerical Calculation

	Platform	Platform

	(without Reefs and Islands)	(with Reefs and Islands)
Wave Height	1m	1m
Wave Direction	135°	135°
Calculated Water Depth	30m	30m(at the Platform is 16m)

Using the model experiments to simulate the motion responses and mooring tensions of the platform on the conditions of with and without ships, respectively. The experimental conditions are shown in Table3.

Table 3 Environmental Conditions of Model Experiments

Sea Codition	Significant Wave Height （m）	Period （s）	Wave Direction （°）	Average Wind Speed （m/s）	Wind Direction （°）
A1	0.6	4.0	90	15	90
A2	0.6	6.0			

4 Analysis of the Hydrodynamic Performance

4.1 Influence of Topography of Reefs and Islands to Motions Response

Fig5 ~ Fig10 show the comparison of motion responses of the platform between the results with and without reefs and islands. The fitted curves with dot denote the varying regulation of the RAOs (Response Amplitude Operator) of the platform without reefs or islands. On the other hand, the fitted curves with triangle present calculated RAOs with reefs and islands. Horizontal coordinate axis is the incident wave period. Meanwhile, the RAOs of surge, sway, heave, roll, pitch and yaw are presented by the displacements and turn angles under the condition of wave height of 1m, respectively. In order to express the RAOs in six degrees of freedom, the incident wave angle is taken as 135 degree in this paper, under which the platform have all results with greater magnitudes.

When the period of incident wave is smaller than 12s, the RAOs of the platform have similar varying regulations and the results calculated under the condition with reefs and islands are smaller than those without reefs or islands, except for yaw RAO.

When the period of incident wave is greater than 12s, RAOs of the other 5 DOFs of the platform near reefs are larger than the ones without reefs. The reasons are as follows:

Incident wavelength is longer than effective terrain length, which enhance the diffraction effect of the platform, but weaken the attenuation. Due to squeezing effect of the reef topography, the platform moves violently. The incident wave is a sine wave, which develops into a flat valley wave when propagates to the platform position. And the uplift capacity to the platform is weakened. Therefore, the heave movement of the platform is weaker than that near the terrain.

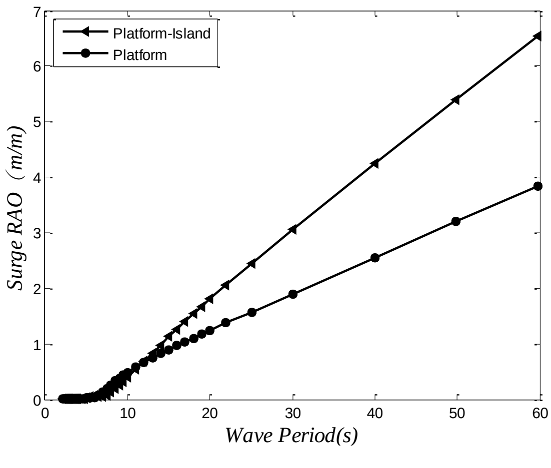

Fig.5 platform surge motion response RAO

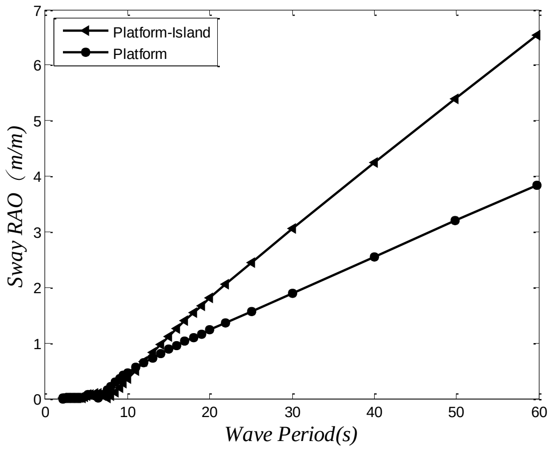

Fig.6 platform sway motion response RAO

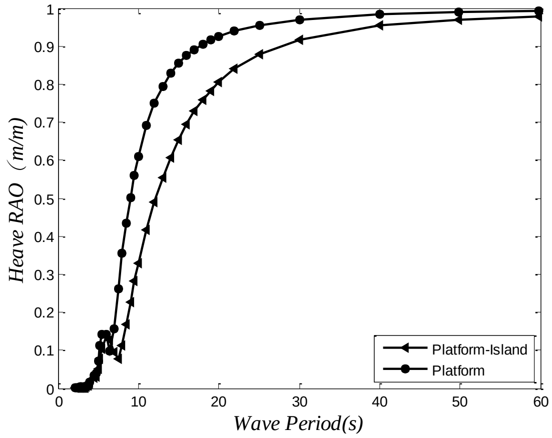

Fig.7 platform heave motion response RAO

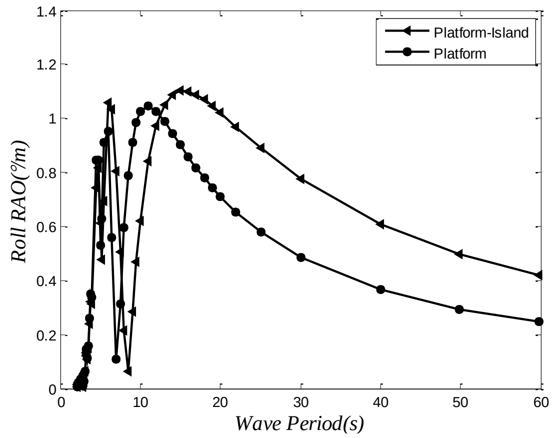

Fig.8 platform roll motion response RAO

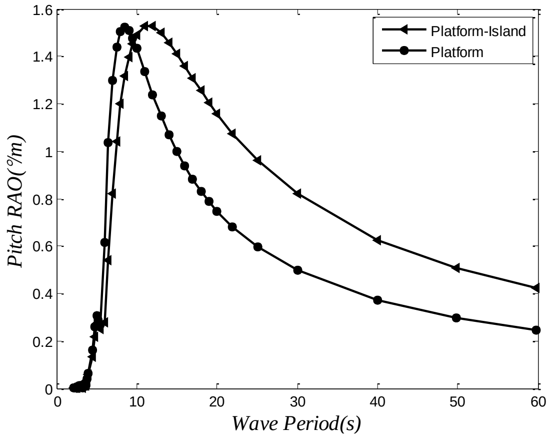

Fig.9 platform pitch motion response RAO

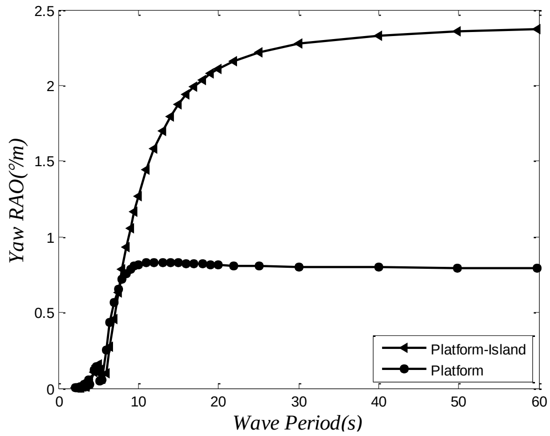

Fig.10 platform yaw motion response RAO

4.2 Comparative analysis of the response of platform and test results

Heavy-load platform model test was developed in the comprehensive pool of wind and waves flow in Nanjing Hydraulic Research Institute. Three-dimensional seabed terrain was constructed in accordance with the reefs measured topographic data of the bottom of the pool and model scale factor (1:40). Figure 11 is a schematic diagram of reef 3D terrain construction and figure 12 shows the model test graph of platform with terrain conditions. Experimental tests were carried out to test the dynamic response of the platform under the action of regular waves, and the RAO values of the three degrees of freedom (including heave, roll and pitch) of the platform in the deep water area and those with terrains were obtained. To carry out the numerical simulation with the help of commercial software AQWA software, the island terrain and platform placement must be consistent with the experiments. Figure 13~18 are motion response RAO contrast diagrams of platform under the conditions of deep water and with reef terrain, which was obtained separately from numerical calculation and model test.

Fig.11 Construction of terrain near reefs

Fig.12 Model of platform

The wave period range of platform model test is from 5.0 to 12.0 (ΔT=1s). Four soft springs are used to eliminate the horizontal movement of the platform, so the model test only gives the three vertical degrees of freedom RAO. As we can see from the figure 13~ Figure 18, the numerical results are in good agreement with the model test results. The test values are generally greater than the calculated values, especially those with reef topography, and the possible reasons is that only the linear wave theory was adopted in numerical calculation, which means that the nonlinear characteristics was ignored. When there is the existence of reef terrain, the nonlinear characteristics will be more obvious and numerical calculation error will increase when there are reefs terrain. Overall, based on the application AQWA software, numerical calculation results of platform motion response under the condition of reef topography are in good agreement with the model test values.

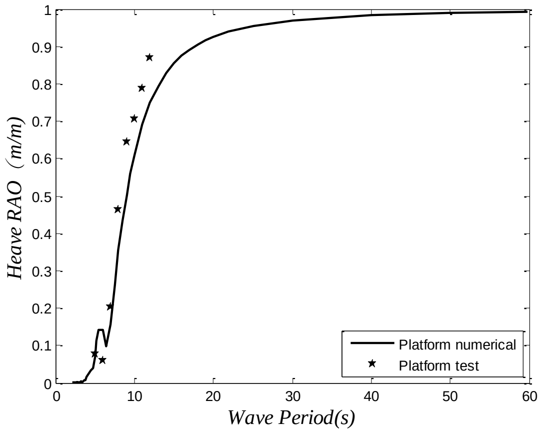

Fig.13 comparison chart of platform's heave RAO and test results（deep water）

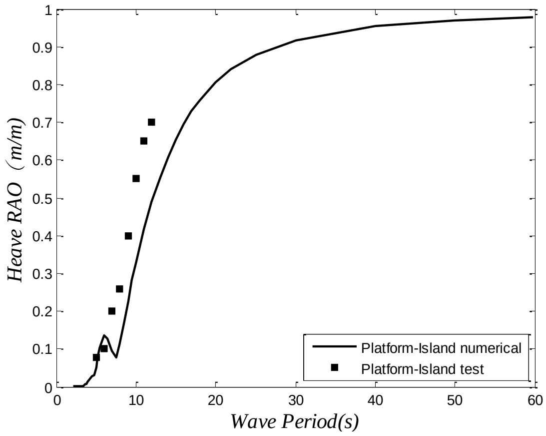

Fig.14 comparison chart of platform's heave RAO and test results（terrain）

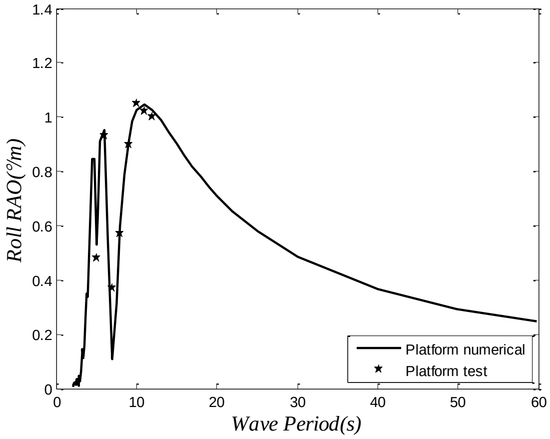

Fig.15 comparison chart of platform's sway RAO and test results（deep water）

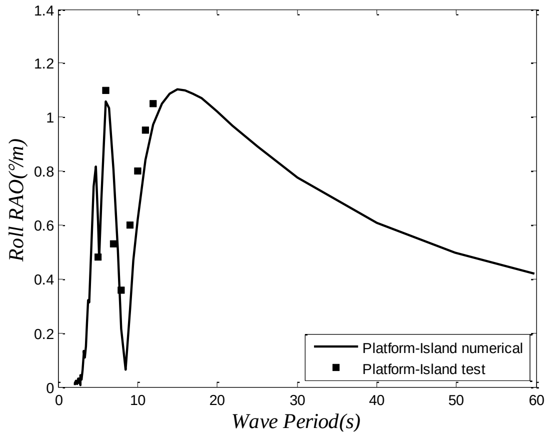

Fig.16 comparison chart of platform's sway RAO and test results（terrain）

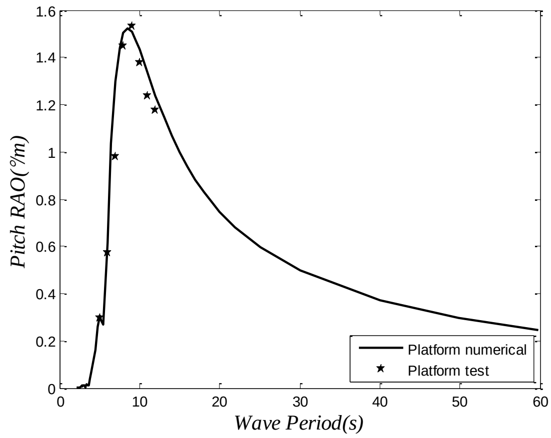

Fig.17 comparison chart of platform's pitch RAO and test results（deep water）

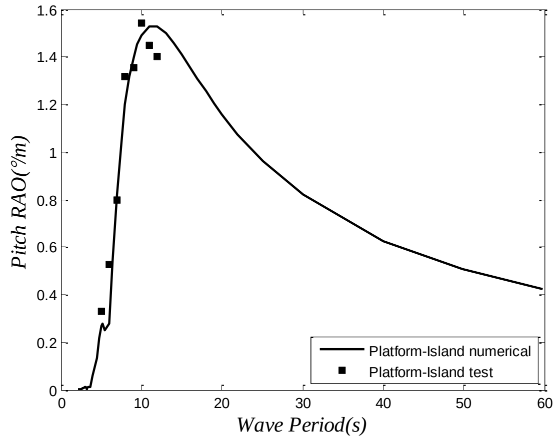

Fig.18 comparison chart of platform's pitch RAO and test results（terrain）

4.3 Forecast analysis of platform near reef terrain

The motion response of platform near reef terrain in irregular wave is obtained from three hours short-term forecast statistic value. The JONSWAP spectrum was adopted as the incident wave and the spectral peak growth factor is 3. Comparison of platforms' movement response of the maximum numerical calculation and model test was presented in table 4, and comparison of maximum tension of mooring line of numerical calculation and model test was presented in table 5. platform near reef terrain with on the ship in mooring mode belongs to the complicated multi-body interaction (Figure 19 shows the calculation model), and external input load include wave and wind loads. From tables 4 and 5 we can see that numerical calculation results are slightly higher than those of the model test, and the error of freedom degrees of those with large amount of motion is less than 20%; which means AQWA software can be a means to deal with such complicated multi-body coupling problem.

In order to make it easy for subsequent scholars to research this kind of problem, platform motion response and mooring line tension test statistics results under A1 and A2 sea conditions are given separately in table 6 and table 7.

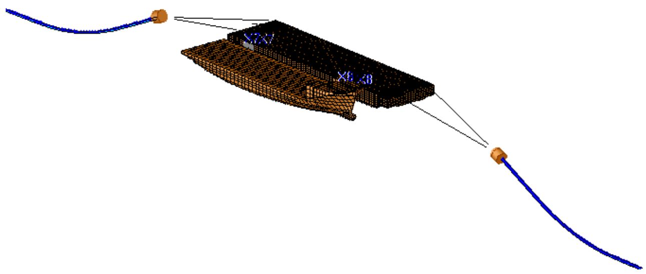

Fig.19 the calculation model diagram

Table4 Comparison table of maximum numerical calculation and model test for six degree of freedom motion of platform

Sea condition	Surge(m)	Sway(m)	Heave(m)	Roll(°)	Pitch(°)	Yaw(°)
A1-numerical	0.1	7.5	0.3	2.2	0	0.3
A1-test	0.20	6.68	0.24	1.98	0.33	0.59
A2-numerical	0.1	8.2	0.42	1.6	0.15	0.4
A2-test	0.22	7.56	0.39	1.92	0.28	0.66

Table5 Comparison table of numerical calculation and model test for tension of mooring line

Sea condition	Platform positioning mooring line maximum tension(t)	Water drum largest chain tension（t）	Platform and largest ship tail connection cable tension(t)	Platform and largest ship stem department connection cable tension(t）
A1-numerical	118	225	15	23
A1-test	112	218	15	22.3
A2-numerical	121	230	31	49
A2-test	114	222	36.2	52.3

Table6 Test values of six degrees of freedom of platform under A1 condition

Statistic of conditions A1 Units(m)									
	hogged			sagging			double amplitude		
DOF	mean	significant	max	mean	significant	max	mean	significant	max
surge	0.124	0.156	0.196	0.028	-0.004	-0.056	0.096	0.152	0.232
sway	-5.672	-5.472	-5.076	-6.128	-6.312	-6.68	0.456	0.8	1.28
heave	0.184	0.212	0.24	0.124	0.104	0.052	0.06	0.1	0.176
pitch	0.02	0.06	0.33	-0.08	-0.12	-0.33	0.1	0.16	0.42
roll	-1.15	-1.02	-0.68	-1.52	-1.64	-1.98	0.37	0.56	1.21
yaw	0.14	0.26	0.59	-0.1	-0.22	-0.53	0.23	0.4	0.88
Statistic of conditions A2 Units(m)									
	hogged			sagging			double amplitude		
DOF	mean	significant	max	mean	significant	max	mean	significant	max
surge	0.088	0.128	0.216	-0.036	-0.076	-0.124	0.124	0.196	0.284
sway	-6.092	-5.68	-4.132	-6.528	-6.924	-7.564	0.436	1.36	3.356
heave	0.26	0.312	0.388	0.068	0.012	-0.1	0.192	0.292	0.452
pitch	0.07	0.12	0.28	-0.09	-0.13	-0.26	0.15	0.24	0.45
roll	-0.39	-0.14	0.44	-1.12	-1.34	-1.92	0.72	1.16	2.14
yaw	0.27	0.43	0.66	-0.15	-0.26	-0.46	0.42	0.65	0.87

Note: moving along the coordinate system is hogged, negative motion along the coordinate system is sagging, double amplitude of movement

Table7 Tension test of mooring line under A1 condition

Statistic of conditions A1 Units(kg)				Statistic of conditions A2 Units(kg)			
sensor number	mean	significant	max	sensor number	mean	significant	max
T1	2.15E+05	2.16E+05	2.18E+05	T1	2.17E+05	2.18E+05	2.22E+05
T2	9.64E+04	9.71E+04	9.83E+04	T2	9.78E+04	9.87E+04	9.92E+04
T3	1.10E+05	1.11E+05	1.12E+05	T3	1.11E+05	1.12E+05	1.14E+05
T4	1.08E+05	1.08E+05	1.09E+05	T4	1.09E+05	1.10E+05	1.12E+05

T5	9.58E+04	9.64E+04	9.69E+04	T5	9.73E+04	9.83E+04	9.91E+04
T6	2.12E+05	2.13E+05	2.14E+05	T6	2.14E+05	2.15E+05	2.17E+05
T7	1.63E+05	1.64E+05	1.65E+05	T7	1.66E+05	1.67E+05	1.69E+05
T8	8.09E+03	1.08E+04	1.50E+04	T8	2.40E+04	2.97E+04	3.62E+04
T9	6.98E+03	1.21E+04	2.23E+04	T9	3.24E+04	4.04E+04	5.23E+04

Note：Yellow shading is the selected test values to compare with the calculation results

5 Conclusions

According to the measured terrain data, three-dimensional model of reef terrain has been established. Based on AQWA software, we carried out the numerical calculation and analysis of the hydrodynamic performance for platform under the island terrain, focusing on the influence of reef topography on the platform motion response. The platform motion response and the mooring line tension on a typical sea condition that ship is docked was also provided in this paper. By comparison and analysis the model test results, the following conclusions are drawn:

(1) With the application of AQWA software, using multi body coupling mode can ensure the numerical simulation of platform in reefs and islands. As a result, calculation results and the experimental results are in good agreement.

(2) By comparing the motion response of the floating platform with and without reefs and islands, we can find that the motion response of the floating platform with reefs and islands are generally less than that without reefs and islands when the incident wave excitation period is less than 12s.

(3) Numerical calculation results are generally lower than that of the model test results. Because of the limitations of linear wave theory, it is difficult to consider the nonlinear problem, especially in the treatment of the motion response of platform near reefs and islands.

(4) In typical sea state, the motion response and mooring line tension of platform (ship docked) in mooring mode are generally too large, so the numerical solution algorithm of multi body coupling in complex environment needs to be further improved.

The numerical calculation method was adopted in this paper, by comparing and analyzing the corresponding model test results that with and without reefs and islands terrain, an effective analysis method for the motion performance of platform near reefs and islands and the design scheme of mooring system has been provided.

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