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Roll Motion Analysis of Deepwater Pipelay Crane Vessel

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Abstract: For a large floating vessel in waves, radiation damping is not an accurate prediction of the degree of roll unlike other degrees of freedom motion. Therefore, to get the knowledge of roll motion performance of deepwater pipelay crane vessels and to keep the vessel working safety, the paper presents the relationship between a series of dimensionless roll damping coefficients and the roll response amplitude operator (RAO). By using two kinds of empirical data, the roll damping is estimated in the calculation flow. After getting the roll damping coefficient from the model test, a prediction of roll motion in regular waves is evaluated. According to the wave condition in the working region, short term statistics of roll motion are presented under different wave parameters. Moreover, the relationship between the maximal roll response level to peak spectral wave period and the roll damping coefficient is investigated. Results may provide some reference to design and improve this kind of vessel.

Keywords: deepwater pipelay crane vessel; roll damping; RAO; short term statistics; roll motion; regular waves

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1 Introduction

The deepwater pipelay crane vessel is an important vessel in the fabrication of marine engineering and laying pipe. It's a symbol to measure the ability to exploit the marine resources of a country. "Haiyangshiyou 201" is the first Chinese deepwater pipelay crane vessel. It is designed to accomplish both pipelaying in water as deep as 3000m deep water and cranes up to 4000t with the dynamic position system. There have been several scholars analyzing the motion and working performance of this vessel currently (Li, 2010). Also, some researchers focus on the refine method of the roll motion coefficient, like the concept of roll energy decay function which was put forward based on the Froude's energy method (Ma, 2013). By use of CFD method, roll and pitch damping derivatives are calculated from an unsteady RANS solver (Zhao, 2013). For the motion of ship of conventional shapes like FPSO considering bilge keel in extreme sea state, researchers also show interest(De Oliveira, A.C, 2012). All these works contribute to the study of the roll motion of the ship. However, few detailed studies have been done on the roll damping of the deepwater pipelay crane vessel. In this paper, we give special focus on investigating the roll motion performance. This idea is the result of two reasons. One reason is that the roll motion makes a significant contribution to the vessel's working performance. The other factor is that the roll potential damping calculated from the potential theory is not enough to describe the roll damping. The roll damping coefficient should be added to the viscid part.

Therefore, this paper analyzes the relationship between the roll damping coefficient and the roll RAO based on the potential theory and empirical data. Moreover, it is quite difficult to estimate the constitution of the roll damping of structures with bilge-keels. Until now, some researchers, like Ikeda, Kato and Tanaka, have made large contributions to this study. So we also investigated the roll motion of pipelay crane vessels using the empirical expressions of their research.

2 Methodologies

2.1 Linear responses in regular waves

The linear response in regular waves is a basic problem to solve for the responses of floating bodies in waves. A brief description is given in this section. The fluid is assumed as inviscid and irrotational fluid. Under these assumptions, the total velocity potential $\Phi(x, y, z, t)$ can be written:

$$\Phi(x, y, z, t) = \mathrm{Re}[\varphi(x, y, z)e^{-i\omega t}] \tag{1}$$

The space potential $\varphi(x, y, z)$ is split into three parts,

$$\varphi(x, y, z) = \varphi_0 + \varphi_j + \varphi_7 \ (j = 1, 2, \cdots, 6) \tag{2}$$

in which:

φ_0 is the incident undisturbed wave potential

$\varphi_j \ (j = 1, 2, \cdots, 6)$ is the radiation potentials

φ_7 is the diffraction potential

$\varphi_j \ (j = 1, 2, \cdots, 7)$ satisfies the Laplace equation:

$$\Delta\varphi=0 \tag{3}$$

Also radiation and diffraction potentials satisfies the free surface condition, body surface condition, sea bed condition and far field condition. Taking these into account, the radiation and diffraction potentials can be calculated. Thus, the wave forces and moments, hydrodynamic forces and moments can be gotten. Considering the restoring matrix and inertial matrix, the linear motion equations in regular waves can be solved.

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2.2 Linear roll equations

When the floating body only rolls in still water with the small angle, the damping moment is considered to be proportional to the angle velocity of the roll with the opposite direction. Thus in the linear damping condition the free roll motion equation after experiencing the external force is:

$$(J_{\varphi\varphi}+\Delta J_{\varphi\varphi})\ddot{\varphi}+2N_{\varphi\varphi}\dot{\varphi}+C_{\varphi\varphi}\varphi=0 \tag{4}$$

or can be written:

$$\ddot{\varphi}+2v_{\varphi\varphi}\dot{\varphi}+n_{\varphi}^{2}\varphi=0 \tag{5}$$

in which $J_{\varphi\varphi}$ and $\Delta J_{\varphi\varphi}$ is the moment of inertia and added moment of inertia, $2v_{\varphi\varphi}$ is the roll damping coefficient, the other items in (4) and (5) are familiar to us.

$$2v_{\varphi\varphi}=\frac{2N_{\varphi\varphi}}{J_{\varphi\varphi}+\Delta J_{\varphi\varphi}} \tag{6}$$

Dimensionless roll damping coefficient (DRDC as follows) is defined as equation (7), in which n_φ is the inherent frequency of the roll. DRDC includes the part of radiation damping and the damping caused by viscid. Radiation damping is related to the incident wave frequency. It can be calculated by the potential theory. The viscid damping part is often evaluated by model tests or empirical data.

$$u_{\varphi\varphi}=v_{\varphi\varphi}/n_{\varphi} \tag{7}$$

2.3 Constitution of roll damping

While using the Sesam software, the Wadam module calculates the roll damping which is made of contributions from four kinds of hydrodynamic effects, potential damping, damping of skin-friction of the hull, damping from eddy-making of the bilge-keel and damping from the bilge-keel. All the damping is linearised to solve the harmonic equations of motion. The roll damping from eddy-making due to the naked hull is computed based on empirical data given by Tanaka (1960), while the damping of skin-friction and eddy-making from bilge keels is computed according to Kato (1966).

3 Numerical Simulation

Taking the deepwater pipelay crane vessel as an example, this paper calculates the response amplitude operator of 4000ton pre-crane conditions in regular waves. The principal dimensions and main parameters are shown in Table 1 below.

Table 1 Dimensions and main parameters of deepwater pipelay crane vessel in 4000t pre-crane condition

Name	Units	Value
L_{pp}	m	185
B	m	39.2
D	m	14
Tm	m	9.173
△	t	57428.8
BM	m	5.984

The wet surface of this vessel is modeled as seen in Fig. 1 which has been created into the panel model. The Wadam module is based on the WAMIT program in Sesam software and is used in the hydrodynamic calculation.

3.1 The relationship between DRDC and roll RAO

According to the empirical data of the dimensionless roll damping coefficient (DRDC), Firsov advises that the coefficient of the bilge keel vessel is $2\mu_{\varphi\varphi}$= 0.11～0.14. Now considering the vessel motion in the beam sea, this causes the maximal roll response. Based on the principal dimensions and principal parameters in the 4000t pre-crane condition, Table.2 shows the peak amplitude of the roll RAO in different DRDC. Peak amplitude always happens in the same frequency w = 0.386rad/s because damping torque has negligible influence on the roll motion frequency.

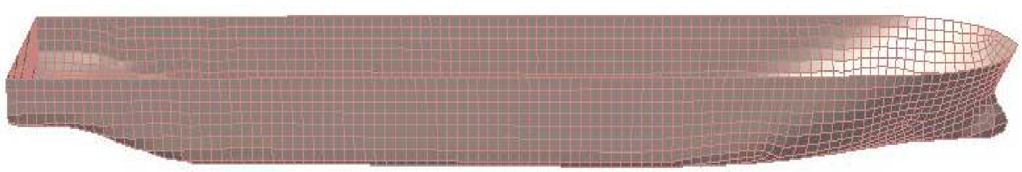


Fig. 1 The panel model of the wet surface of the vessel

Table 2 The relationship between dimensionless roll damping coefficient and roll RAO in beam sea

u	θ/(°)
0.055	4.996
0.060	4.524
0.065	4.231
0.070	3.956

The roll motion of the vessel in working conditions should be controlled gently. Full-scale data of DRDC is increased because of current speed and appendages such as shaft bossing. Thus it's necessary to calculate the peak amplitude of the roll RAO in larger DRDC. Fig.2 illustrates the relationship between the peak amplitude of the roll RAO and DRDC. The curve approaches to the function of second order $y = 0.0365x^2 - 1.0427x + 9.4665$. The horizontal ordinate is one hundred times DRDC in Fig.2.

Fig.2 shows that the peak amplitude of the roll RAO decreases as the DRDC increases. Also we can get the trend of the two parameters. In the DRDC range of 0.055～0.090, DRDC has a great influence on the peak amplitude of the roll RAO, roll angle decreases 0.55 as DRDC increases 0.01; When DRDC is in the range of 0.09～0.14, the curve changes gently and the roll angle decreases 0.21°as the roll damping coefficient increases 0.01.

The roll damping model test demonstrates that the dimensionless roll damping coefficient $u_{\varphi\varphi}$ is 0.065. The results are in the range of Firsov's model test values.

In the study above, we computed the roll damping from experimental data directly. The idea is to examine the relationship between the roll motion and the roll damping. Moreover, it is of utmost importance that a good estimate of the nonlinear components of the roll damping is made for such structures. This detailed calculation of roll damping will help the designer to refine the motion performance of such vessels more efficiently. Moreover, it's essential to establish the strip model for the calculation of roll damping, in which we can get the bilge radius at each strip. The bilge radius is used in the expression of the naked hull's friction damping and eddy making damping. It should be noticed here that these empirical coefficients of damping are derived from model tests of a limited number of ships/barges neglecting the scale effect. For conventional vessel shapes, they are considered to be adequate. Fig.3 shows the sketch map of the panel model with the bilge-keel highlighted in black.

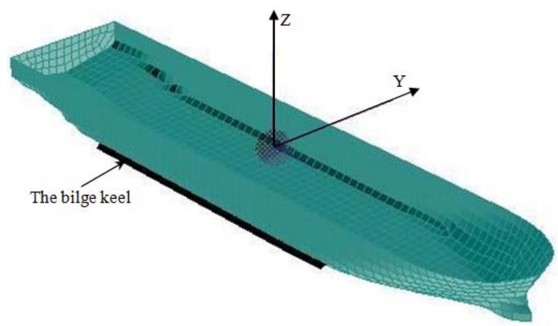


Fig. 3 The panel model of the vessel with the bilge keel

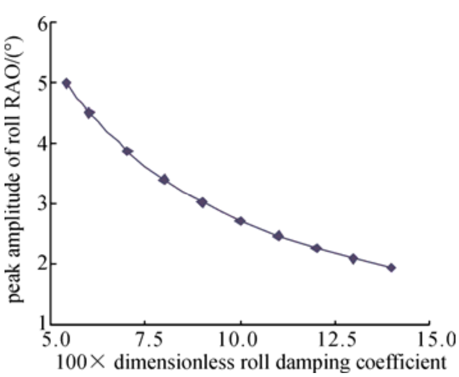


Fig. 2 The relationship between the roll damping coefficient and the peak amplitude of roll RAO

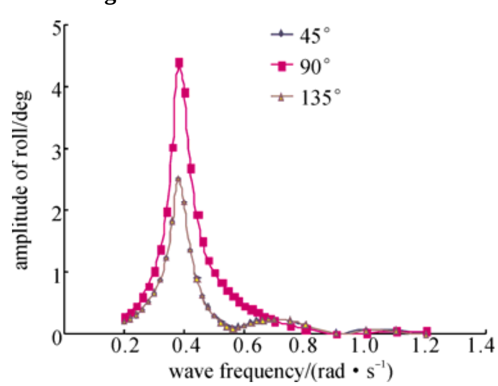


Fig. 4 RAO of roll motion which is given by calculating each component of roll damping

Fig.4 illustrates the RAO of roll motion in the presence of regular waves with different incident angles. It can be found that the results of calculating each component of roll damping are acceptable. The amplitude of roll motion falls within the range gotten above.

3.2 Short term statistics of roll motion

Although we can get the dimensionless roll damping coefficient from the model test, it's reasonable to believe that the real DRDC is in the neighborhood of the test value. This is caused by the scale effect, etc. Also we want to get the relationhip between the DRDC and maximal roll response level. Thus it's necessary to discuss the short term statistics of the rolling motion in a series of possible DRDC.

Table 3 Working condition of deepwater pipelay crane vessel

Wave condition	Wave spectrum	*Hs*/m	*Tp*/s
Wind waves	Jonswap	2.5	6-8
Swell	Jonswap	2	10-12

Table 3 shows the wave conditions which include the wind waves and swell. According to the principal dimensions and main parameters in the 4000t pre-crane condition, short term statistics of roll motion in beam sea is calculated. To demonstrate the effects of DRDC, wave height and peak spectral wave period (T_p) on maximal roll response level, two examples are shown (Fig.5 and Fig.6).

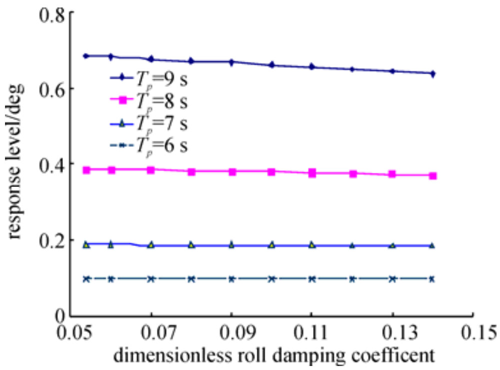
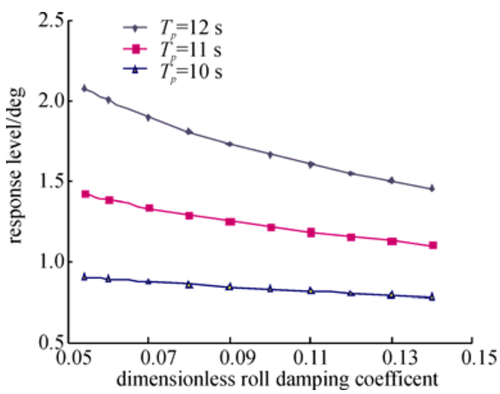


Fig. 5 Short term statistics of roll in the wind waves condition



(A) In wind waves conditions calculations are done by choosing peak spectral wave periods 9s, 8s, 7s and 6s;
(B) In swell conditions calculations are done by choosing peak spectral wave periods 12s, 11s and 10s;
(C) The difference between the two wave conditions is the wave height in Table 3.

Fig. 6 Short term statistics of roll in swell conditions

The two figures show that at constant wave height, the maximal roll response level decreases rapidly with the Tp decreasing. Compared with DRDC, the maximal roll response level is much more influenced by *Tp*. Fig.4 demonstrates that the maximal roll response level also reduces with DRDC increasing and has a large impact when *Tp* is 12s. At the Tp levels of 12s, 11s and 10s, response level decreases by 0.0837°, 0.0421°and 0.0150°when the DRDC increases by 0.01. Fig.3 shows a special phenomenon. In the wind waves condition, response level doesn't change much as DRDC increases to the *Tp* levels of 9s, 8s, 7s and 6s.

4 Conclusion

In this paper, the research on the roll motion of the first Chinese pipelay crane vessel is conducted based on the 3D potential theory and empirical expressions. The relationship between the peak amplitude of the roll RAO and the dimensionless roll damping coefficient is analysed. Then short term statistics of rolling motion were calculated by use of the roll damping coefficient which is gotten from the model tests under different wave conditions. It finds that the maximal roll response amplitude decreases as the roll damping coefficient increases, and the maximal roll response amplitude varies monotonically from low to high as the increasing of the peak spectral wave period.

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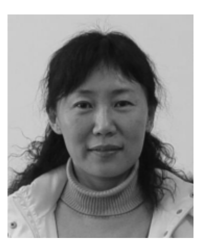
Author biography



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