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Studies on parametric roll motion of ship under wave group by numerical simulation

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ABSTRACT

In this paper, the 1DOF differential equations of the parametric roll motion is established and the random wave is simulated by the wave envelope spectrum. The group height and the group length of the wave are controlled by two parameters *GFH* and *GLF*. Then the parametric roll motion of the ship is simulated and the influence of wave group height factor and wave group length factor on the roll motion of ship is studied. The research concludes that the group length factor has more obvious effects on the parametric roll.

1. Introduction

More recently, there has been an increasing interest in parametric roll motion which is a common cause of ship capsizing and is one of the failure mode in the second generation of integrity stability (Bassler et al., 2011). Today's ship stability and safety are facing enormous challenges, and this has put forward higher requirements for the ship design and technical specifications, thus how to improve ship stability and safety has become an important issue (Bačkalov et al., 2016).

The multi-scale method is often used to study the dynamic stability of parametric roll motion in regular wave, and it is found that the penetration phenomenon between heave (pitch) and roll in the longitudinal wave (Nayfeh and Sanchez, 1990; Sayed and Hamed, 2011; Nayfeh et al., 1973). The 3 DOF coupling model considering heave and pitch is more comprehensive than single DOF model (Breu and Fossen, 2010), but it is difficult to adopt analytical method to study the dynamic stability, the numerical calculation method is more efficient (Neves and Rodríguez, 2006, 2007,2009). Monte Carlo method and path integral method are two common approaches to study parametric roll in random waves (Kim and Kim, 2011; Lee and Kim, 2016). As a common analytical method, path integral method is very convenient and effective to calculate capsizing probability of ship in random wave (Cottone et al., 2009; Kougioumtzoglou and Spanos, 2014; Chai et al., 2015). Monte Carlo time domain simulation is widely used in nonlinear multi-DOFs coupling parametric roll in stochastic waves (Ribeiro E Silva, 2005; Ribeiro E Silva and Guedes Soares, 2013). However, the traditional Monte Carlo method and the path integral method do not focus on the wave group height and the group length. In view of the above research, most researchers have little focus on influence of wave group on parametric roll.

Parametric roll is the result of successive wave effect (Belenky et al., 2011), so in the model test, it is easy to simulate the parametric roll phenomenon under the regular wave, but it is difficult to observe in the irregular wave. The tests show that in long peak irregular waves the initial transient and the effective time of the waves are the key factors that can trigger the parameter roll[19, 20], which depends on the frequency composition of the random wave. For more than one frequency of excitation at the same time, embodies the "group" concept (Nayfeh, 1985). Combining the Karhunen-Loève theory and the Markov process, the spectral compatibility method is used to construct the wave group system. The shape of the realistic wave is determined by the wave height and period of the central wave (Anastopoulos and Spyrou, 2016). Therefore, the wave composition of stochastic waves is very important for parametric roll motion.

The group height factor *GFH* has more obvious effects on the mooring ship than the group length factor *GLF* (Ma et al., 2011). In this paper, the group height and the group length of the wave are controlled by two parameters *GFH* and *GLF* and the random wave group is simulated by the wave envelope spectrum (Liu et al., 2013)。And then the influence of group height factor and group length factor on the parametric roll motion of ship is discussed.

2. Wave group simulation

Random wave elevations can be superimposed by multiple cosine waves of different cycles,

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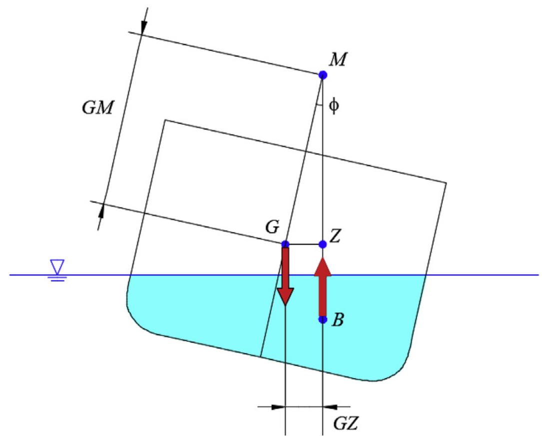

Fig. 1. Static stability of a ship in water.

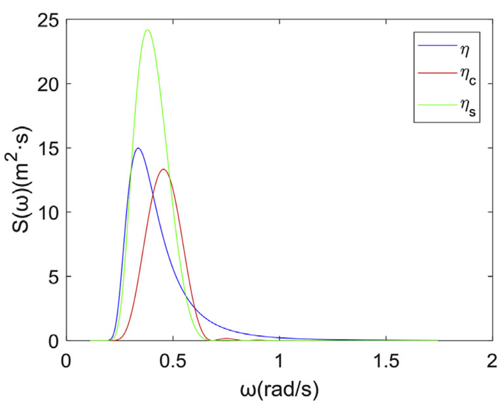

Fig. 2. Wave spectrum.

$$\eta(t)=\sum_{n=1}^{N}a_n\cos(\omega_n t+\varepsilon_n) \tag{1}$$

where $a_n=\sqrt{2S(\omega_n)\Delta\omega_n}$, $S(\omega)$ is wave spectrum, $\Delta\omega_n$ is interval frequency, ω_n is wave frequency, ε_n is random phase angles, uniformly distributed in $[0,2\pi]$

The waves with different groupiness have large differences in their envelope spectrums, although the wave spectrum is the same. Therefore, it is not enough to simulate the wave only with wave spectrum, and another spectrum or parameter is needed to simulate the phase spectrum. The wave envelope contains important information of the wave group. The traditional method for the simulation of the envelope amplitude function is introduced by Rice (1944). In this paper, to specify the wave groups, the group height factor and length factor are defined in terms of parameters of both wave and envelope spectral parameters, the advantage of the approach is that, for a given sea state, the intensity of wave grouping phenomena is controlled by the parameters *GFH* and *GFL* of the empirical spectrum (Xu et al., 1993).

Funke and Mansard (1980) used the instantaneous wave energy process line SIWEH to simulate the phase spectrum, but that just includes the group's height features *GFH*. In this paper, the wave envelope is used to describe the wave group, the wave spectrum is used as the target spectrum to simulate the phase spectrum, and the empirical wave envelope spectrum formula proposed by Liu et al. (2010), $S_A(f)$ can be expressed as:

$$S_A(f)=[0.042+0.019(f/f_{PA})]\pi m_{0\eta}(GFH)^2/f_{PA},\quad 0\le f\le f_{PA} \tag{2}$$

$$S_A(f)=0.085\pi e^{-\frac{1}{3.1}(f/f_{PA})}m_{0\eta}(GFH)^2/f_{PA},\quad f>f_{PA} \tag{3}$$

If $GFH\le 0.7$, $f_P/f_{PA}=5\sim 15$, else if $GFH>0.7$, $f_P/f_{PA}=10\sim 28$ .where $m_{0\eta}$ is the zeroth moment of the wave spectrum, f_P and f_{PA} are the peak values of the wave spectrum and wave envelope spectrum respectively. $GFH=\sqrt{2}\sigma_A/\overline{A}$, $GLF=f_P/f_{PA}$, these two factors are used to describe wave group height and length. The wave tends to be regular when *GFH* is equal to zero. σ_A and $\overline{A}$ are the variance and mean value of the wave envelope.

The method of simulating the irregular wave group is as follows:

(1) Given the wave parameters and the wave groupiness parameters, calculate the JONSWAP spectrum $S_\eta(f)$ and envelope spectrum $S_A(f)$ according to Eqs. (2) and (3), then simulate the wave elevation $\eta'(t)$ and $\eta_A(t)$ according to Eq. (1).
(2) The envelope line $A_1(t)=\eta_A(t)+\overline{A_1}$, where $\overline{A_1}=\left(\frac{\pi}{2}m_{0\eta}\right)^{1/2}$, $m_{0\eta}$ is the zeroth moment of the spectrum $S_\eta(f)$;
(3) The phase angle $\varphi(t)=\arctan[\widetilde{\eta'}(t)/\eta'(t)]$, $\varphi(t)$ is the phase function of the envelope of $\eta'(t)$, $\widetilde{\eta'}(t)$ is the Hilbert transform of $\eta'(t)$;
(4) The new wave surface can be simulated, $\eta_1(t)=A_1(t)\cos[\varphi(t)]$.

JONSWAP spectrum was developed for the limited fetch North Sea and is used extensively (Goda, 1999):

$$S(f)=\beta_J H_{1/3}^2 T_p^{-4} f^{-5}\exp[-1.25(T_p f)^{-4}]\gamma^{\exp[-(T_p f-1)^2/2\sigma^2]} \tag{4}$$

where

$$\beta_J\simeq\frac{0.06238}{0.230+0.0336\gamma-0.185(1.9+\gamma)^{-1}}[1.094-0.01915\ln\gamma] \tag{5}$$

$$T_{1/3}\simeq[1-0.132(\gamma+0.2)^{-0.559}]T_p \tag{6}$$

$$\sigma=\begin{cases}0.07: f\le f_p\\ 0.09: f>f_p\end{cases} \tag{7}$$

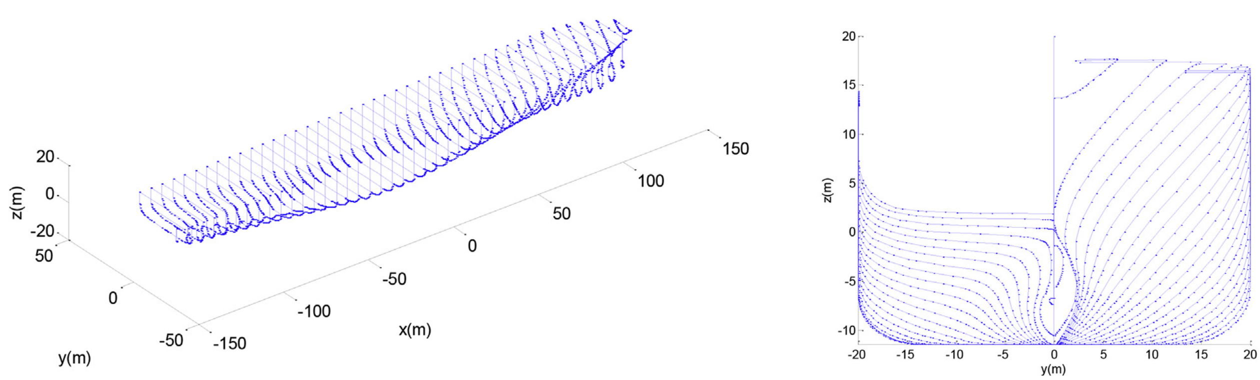

Fig. 3. Hull lines of C11 container ship.