Available online at www.sciencedirect.com

ScienceDirect

Journal of Ocean Engineering and Science 1 (2016) 149–156

www.elsevier.com/locate/joes

Reliability evaluation of the roll motion under the wind and irregular beam waves

Wei Chai*

Department of Marine Technology, Norwegian University of Science and Technology, Trondheim, Norway

Received 14 August 2015; received in revised form 18 November 2015; accepted 17 December 2015
Available online 16 March 2016

Abstract

This paper intends to study the stochastic response and reliability of the roll motion under the action of wind and wave excitation. The roll motion in random beam seas is described by a four-dimensional (4D) Markov dynamic system whose probabilistic properties are governed by the Fokker–Planck (FP) equation. The 4D path integration (PI) method, an efficient numerical technique based on the Markov property of the 4D system, is applied in order to solve the high dimensional FP equation and then the stochastic statistics of the roll motion are derived. Based on the obtained response statistics, the reliability evaluation of the ship stability is performed and the effect of wind action is studied. The accuracy of the 4D PI method and the reliability evaluation is assessed by the versatile Monte Carlo simulation (MCS) method.
© 2016 Shanghai Jiaotong University. Published by Elsevier B.V.
This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Keywords: Path integration method; Stochastic roll response; Reliability evaluation; Wind action; Monte Carlo simulation.

1. Introduction

The roll motion in random seas is the most critical mode leading to ship stability failure. Generally, there are two types of intact stability failures, i.e., total intact stability failure and partial stability failure [1]. Ship capsizing is classified as the former category, while the latter is associated with the occurrence of large or extreme roll angles, which would impair the normal operations or even lead to damage of the ship. Therefore, prediction of the extreme roll responses and the associated risk assessment of ship stability are crucial for reliability based design and operation in practice.

However, the current criteria of the International Maritime Organization (IMO) for evaluation of the intact stability of a vessel under the action of random wave and wind excitation are simply based on the weather criterion. This criterion is hydrostatic and the stochastic properties of the external excitation have not been taken into consideration. In this study, the dynamic stability is evaluated by means of a probabilistic approach and the associated stochastic roll response as well as the reliability evaluation may provide insight with respect to the effect of random external excitation on the nonlinear roll dynamics.

The mean upcrossing rate is a key parameter for a detailed assessment of the response statistics of marine structures subjected to random excitation loads [2]. Moreover, the reliability analysis methodology based on the mean upcrossing rate is robust and widely used in the reliability engineering. However, determining the stochastic response (such as the mean upcrossing rate) of the nonlinear roll motion excited by random external excitation is a challenge and limited progress has been made in the past decades. Monte Carlo simulation (MCS) is the simplest methodology to determine the mean upcrossing rate of the roll motion, but the associated computation burden may be prohibitive for estimation of the high-level responses with low probability levels.

In addition to the versatile and straightforward MCS method, the methodology based on the Markov diffusion theory is attractive since the probabilistic properties are governed by the Fokker–Planck (FP) equation [3]. It is well known that the Markov model is only valid for the dynamic systems driven by Gaussian white noise or filtered white noise. Therefore, the shaping filter technique is introduced in order

* Corresponding author.
E-mail address: chai.wei@ntnu.no.

http://dx.doi.org/10.1016/j.joes.2016.03.003
2468-0133/© 2016 Shanghai Jiaotong University. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

to approximate the random external excitation term as a filtered white noise process. For the extended Markov system, established by combining the roll motion equation and the filter model, the efficient path integration (PI) method is applied in order to obtain the response statistics by solving the corresponding FP equation. The main advantage of the PI method and the Markov dynamic system is that a host of accurate and useful response statistics can be obtained within one calculation [4,5]. Moreover, the great performance and high efficiency of the PI technique in calculating the mean upcrossing rate of high-level roll responses will be demonstrated.

In this paper, we aim to quantify the wind action on the stochastic roll response as well as on the intact ship stability. The MCS method serves as an efficient tool to evaluate the accuracy of the proposed numerical methods. The results and conclusions obtained in this work hopefully can provide useful references for ship stability research and practical operations.

2. Mathematical model of roll motion

For the case of dead ship condition, i.e. a ship with zero speed (or low speed) under unidirectional beam seas and beam wind action, the roll motion can be represented by the following single-degree-of-freedom (SDOF) equation [6]:

$$(I_{44}+A_{44})\ddot{\theta}(t)+B_{44}\dot{\theta}(t)+B_{44q}\dot{\theta}(t)|\dot{\theta}(t)| + \Delta GZ(\theta(t)) = M_{wave}(t)+M_{wind}(t) \tag{1}$$

where $\theta(t)$ and $\dot{\theta}(t)$ are the roll angle and the roll velocity, respectively. I_{44} represents the moment of inertia in roll and A_{44} is the added mass moment term. B_{44} and B_{44q} are linear and quadratic damping coefficients, respectively. The stiffness term $\Delta GZ(\theta(t))$ relates to the restoring moment of the roll motion, $M_{wave}(t)$ represents the random wave excitation moment and $M_{wind}(t)$ denotes the excitation moment caused by wind.

The restoring moment is expressed in terms of the displacement Δ and the restoring arm GZ, which can be obtained from standard hydrostatic software. The restoring moment term is usually given by a nonlinear odd function of the roll angle, i.e.

$$GZ(\theta)=C_1\theta-C_3\theta^3 \tag{2}$$

in which, C_1 and C_3 are the linear and the nonlinear roll restoring coefficients of the restoring arm, respectively. Note that the roll motion has a softening characteristic since the nonlinear stiffness term is negative. For the softening cases, ship capsizing would happen when the roll angle exceeds the angle of vanishing stability beyond which the restoring moment becomes negative.

The random wave excitation moment $M_{wave}(t)$ can be described by the wave excitation moment spectrum, $S_{Mwave}(\omega)$. The latter is related to the wave energy spectrum, $S_{\xi\xi}(\omega)$, by the following relationship:

$$S_{M_{wave}}(\omega)=|F_{roll}(\omega)|^2 S_{\xi\xi}(\omega) \tag{3}$$

where $|F_{roll}(\omega)|$ represents the roll moment amplitude per unit wave height at frequency ω. Moreover, the wave elevation and the wave excitation moment are assumed to be stationary Gaussian processes.

For the wind induced excitation moment, $M_{wind}(t)$, it can be calculated by the following formula:

$$M_{wind}(t)=\frac{1}{2}\rho_{air}C_wA_wl_W(U_m+U(t))^2 \tag{4}$$

where ρ_{air} is the mass density of air and C_w denotes a wind pressure coefficient. U_m is the mean wind speed and $U(t)$ is the fluctuating wind speed. A_w represents the lateral windage and l_w is the wind moment arm.

Generally, $(U(t)/\ U_m) << 1$ and the wind excitation moment (4) can be expressed as [7]:

$$\begin{aligned} M_{wind}(t) &= \bar{M}_{wind}+M_f(t) \\ &= \frac{1}{2}\rho_{air}C_wA_wl_WU_m^2+\rho_{air}C_wA_wl_WU_mU(t) \end{aligned} \tag{5}$$

where $\bar{M}_{wind}$ and $M_f(t)$ denote the mean wind moment and fluctuating wind moment, respectively. The mean wind action results in a heeling angle θ_s and their relationship can be expressed as:

$$\bar{M}_{wind}=\Delta GZ(\theta_s) \tag{6}$$

As for the fluctuating wind moment, its spectral density is related to the wind spectrum $S_U(\omega)$, by the following relationship [2]:

$$S_{M_f}(\omega)=(\rho_{air}C_wA_wl_WU_m)^2\cdot\chi(\omega)\cdot S_U(\omega) \tag{7}$$

where $\chi(\omega)$ is the aerodynamic admittance function, which can be determined as:

$$\chi(\omega)=\frac{1}{1+\left(\frac{\omega\sqrt{A_w}}{\pi U_m}\right)^{4/3}} \tag{8}$$

The wind spectrum, which governs the fluctuating wind speed, is given by the Davenport spectrum:

$$S_U(\omega)=4K\frac{U_m^2}{\omega}\frac{X_D^2}{(1+X_D^2)^{4/3}} \tag{9}$$

where $K=0.003$ and the dimensionless variable X_D is given by the following equation [8]:

$$X_D=600\frac{\omega}{\pi U_m} \tag{10}$$

Dividing Eq. (1) by $(I_{44}+A_{44})$, the final format of the differential equation is given as:

$$\begin{aligned} &\ddot{\theta}(t)+b_{44}\dot{\theta}(t)+b_{44q}\dot{\theta}(t)|\dot{\theta}(t)|+c_1\theta(t)-c_3\theta^3(t) \\ &= (m_{wave}(t)+m_f(t))+\bar{m}_{wind}=m(t)+\bar{m}_{wind} \end{aligned} \tag{11}$$

where b_{44}, b_{44q}, c_1, c_3 are relative ship parameters. $m_{wave}(t)$, $m_f(t)$ and $\bar{m}_{wind}$ are relative moments. The total relative random external excitation is denoted as $m(t)$, which is assumed to be the sum of the relative wave excitation $m_{wave}(t)$ and the relative fluctuating wind moment $m_f(t)$. Correspondingly, the spectrum of $m(t)$ can be given as the sum of the spectrum of

Download English Version:

https://daneshyari.com/en/article/827658

Download Persian Version:

https://daneshyari.com/article/827658

Daneshyari.com