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An analytical and experimental study on dynamic stability of a vessel

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Many researchers have studied the roll stability of ships since it is the most critical case of capsizing for conventional vessels. In this study external exerted forces from waves or winds on a vessel are modeled as a step exciting moment. Calculation of dynamic angle of stability Φ_{dy}, which is the first overshoot angle of vessel response to exciting moment, is the main objective of this paper. For this purpose two methods are used. The first one, so-called traditional method, determines Φ_{dy} by equalizing the external heeling moment energy and righting moment energy; while the other solves the rolling equation assuming step exciting moment and linear damping.

Additionally, a model experiment is carried out with a step exciting moment then model rolling responses are registered. The results of both theoretical methods are compared with experimental results. The comparison shows that for large rolling amplitude such as 35 degrees, inclusion of linear damping does not have any considerable effect dynamic angle of stability. It means that the traditional method is reliable.

Keywords: *Forced rolling, dynamic angle of stability, exciting moment, damping*

Notations

A_{XX}: [Kgm^2] – Roll added moment of inertia
B_{44}: [Kgm^{2}Sec^{-1}] – Linear damping coefficient
D: [m] – Dynamic lever of stability
g: [mSec^{-2}] – Gravitational acceleration
$f(t)$: [Nm] – Exciting moment
$\overline{GM}$: [m] – Metacentric height
$\overline{GZ}$: [m] – Righting arm
I_{XX}: [Kgm^2] – Ship longitudinal mass moment of inertia
M_0: [Nm] – Step exciting moment
M_{44v}: [Nm] – Nonlinear damping moment
t: [Sec] – Time
W: [Nm] – Potential energy of vessel
W': [Nm] – External work of exciting moment
ω_d: [Sec^{-1}] – Roll damped frequency
ω_n: [Sec^{-1}] – Roll natural frequency
ς: – Linear damping ratio
ε – Relative error
Φ: [Rad] – Roll angle

$\dot{\Phi}$: [RadSec^{-1}] – Roll velocity
$\ddot{\Phi}$: [RadSec^{-2}] – Roll acceleration
Φ_{dy} : [Rad] – Dynamic angle of stability
Φ_{st} : [Rad] – Static angle of stability
Δ : [Kg] – Ship displacement
Hint: Parameters whose units are not mentioned are dimensionless.

1. Introduction

Large rolling and losing transverse stability is a known reason of ship capsizing. Severe casualties have been still reported due to severe rolling. Hence, studying of the phenomenon of ship rolling has become an interesting subject for researchers.

One of these cases may be considered as excitation of a vessel by external forces of sea waves or winds. Such an exciting force is modeled as step moment in this study. Questioned force leads to an overshoot heeling angle, which is called dynamic angle of stability, as the most important and hazardous part of transient response of a ship. To evaluate Φ_{dy} two methods have been introduced in this study.

Although most of these studies focus on frequency-domain, time-domain solutions of both linear and non-linear rolling equation have its own enthusiasts. Odabasi and Vince (1982) studied the effects of initial angle variations and roll damping on the roll response of a ship under the sudden action of a wind [1]. Various models of roll motion including nonlinear damping terms have been studied by Bass and Haddara (1988). These models have been curve fitted on experimental results and their validity was compared with each other [2]. In 1998 Taylan determined steady response of a vessel to sinusoidal wave for four types of ships assuming nonlinear damping and restoring. He also studied the effect of different forms of nonlinear damping and restoring moment in resonant condition [3].

2. Formulation and mathematical model

In this section two methods for assessing of dynamic angle of stability are presented. The first one is the traditional method which is also used in some rule books. The main feature of traditional method is disregarding of damping during of rolling that leads to over estimation of Φ_{dy}. On the contrary, the second method solves the rolling equation where the damping is included by assumption of a linear damping.

2.1. Energy method

Righting moment opposes the roll motion of a vessel. This leads to absorbing and storing of potential energy whose amount is a function of heeling angle. When the ship is inclined from zero up to a given heeling angle "Φ", the amount of potential energy can be calculated as follows: