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On unstable ship motions resulting from strong non-linear coupling

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Abstract

In this paper, the modelling of strong parametric resonance in head seas is investigated. Non-linear equations of ship motions in waves describing the couplings between heave, roll and pitch are contemplated. A third-order mathematical model is introduced, aimed at describing strong parametric excitation associated with cyclic changes of the ship restoring characteristics. A derivative model is employed to describe the coupled restoring actions up to third order. Non-linear coupling coefficients are analytically derived in terms of hull form characteristics.

The main theoretical aspects of the new model are discussed. Numerical simulations obtained from the derived third-order non-linear mathematical model are compared to experimental results, corresponding to excessive motions of the model of a transom stern fishing vessel in head seas. It is shown that this enhanced model gives very realistic results and a much better comparison with the experiments than a second-order model.

Keywords: Ship stability; Parametric resonance; Non-linear equations; Ship motions; Roll motion; Hill equation

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Nomenclature

∇	incremental volume for displaced hull
ρ	density of water
ϕ	roll angular displacement
θ	pitch angular displacement
∇_0	volume at average hull position
∇_1	volume at instantaneous hull position
A_0	waterplane area at average hull position
A_w	wave amplitude
F_n	Froude number
g	acceleration of gravity
h_i	height of elemental prisms
I_{xx0}	transversal second moment of waterplane area
I_{yy0}	longitudinal second moment of waterplane area
J_{xx}	transversal mass moment of inertia
J_{yy}	longitudinal mass moment of inertia
k	wave number
m	ship mass
U	ship speed of advance
x_{f0}	longitudinal co-ordinate of centroid of waterplane
z	heave displacement of the ship
λ	wavelength
ζ	wave elevation
χ	wave incidence
ω_e	encounter frequency
ω_w	wave frequency
$\hat{I}, \hat{J}, \hat{K}$	unit vectors along axes of inertial frame
$\hat{i}, \hat{j}, \hat{k}$	unit vectors along axes fixed in the ship
$\bar{x}$	longitudinal position of a transversal station
$\bar{y}$	half-beam of a transversal station
$\bar{z}_G$	vertical position of the ship's centre of gravity
$\bar{z}_{B0}$	vertical position of hull volume centroid

1. Introduction

Any comprehensive investigation on the safety of intact vessels in waves must take into consideration the possible occurrence of parametric resonance. In fact, parametric rolling of ships has continuously received wide attention of researchers and designers, since it is a relevant instabilizing mechanism, see Kerwin (1955), Paulling and Rosenberg (1959), Blocki (1980), De Kat and Paulling (1989), Munif and Umeda (2000). Much of such attention has been devoted to the particular configuration of longitudinal regular waves, either with or without speed, bow or