ABSTRACT

The present study considers the nonlinear roll motion of containerships. The nonlinear wave excitation and restoring are applied for the ship motion, based on the assumption of weakly nonlinear ship motion. For the radiation component, an impulse response function (IRF) approach is applied. The nonlinear roll motions for a large containership and S175 hull are predicted in regular and irregular waves, and the results are compared with the results of a state-of-art program for nonlinear ship motion, called WISH. The effects of a few physical parameters on parametric roll motion are observed. The developed program is extended to creating polar diagram to predict nonlinear roll motion in various ocean conditions.

KEY WORDS: Parametric roll; Nonlinear ship motion; Impulse response function; Time-domain analysis.

INTRODUCTION

Roll motion of ships has been of great interest because it is the most important factor that affects stability and comfort of sailing. Since ships grow faster and larger in a recent decade, particularly in containerships, LNG carriers, and cruise ships, the nonlinearity of roll motion becomes a crucial element of large-ship design.

Since the excitation of roll motion is transverse moment, large roll motion of symmetric ships has not been considered in head or following waves. However, many researches have proved the possibility of occurrence of very large roll angle in head or following waves when the wave encounter frequency is twice of roll natural frequency. This roll motion so called parametric roll is of great concern, nowadays. Strictly speaking, ‘parametric’ indicates the self-excitation or parametric excitation which can be used in Mathieu equation.

Pauling and Rosenberg (1959) solved coupled heave-pitch-roll motion and showed the possibility of great roll angle in head or following waves. The researches at that point were based on the assumption that metacentric height, $GM$, varies in harmonic manner. However, $GM$ variation is not harmonic in actual situation. So Dunwoody (1989) associated $GM$ variation with spectrum. Large roll motion including parametric roll has significant nonlinearity. To consider nonlinearity, Oh et al. (1994) solved nonlinear roll motion coupled with heave and pitch, and compared their result with experiment.

The accident of Post-Panamax containership (1998) sailing from Taiwan to Seattle in almost head sea condition brought many concerns in parametric roll. France et al. (2003) studied the possibility of parametric roll of accident ship model. They used BEM (boundary element method) and compared result with experiment. Shin et al. (2004) introduced the theoretical and numerical criteria of parametric roll occurrence.

Panel method is widely used in ship motion analysis, including nonlinear ship motion analyses in time domain. Many past studies were based on the panel method. However, this method requires significant amount of calculation time, still hard to be applicable for long simulation to predict parametric roll phenomena. In this study, instead of using time-consuming methods, impulse-response-function (IRF) approach is chosen. This approach just solves the equation of ship motion using pre-computed hydrodynamic coefficients, therefore computation time is much shorter than any other heavy numerical methods.

Cummins (1962) introduced an IRF approach in ship motion analysis, and many applications and variations can be found afterwards. Ballard et al. (2003) shows that the IRF can be extended to parametric roll analysis. Also we can find that Dimitris and Apostolos (2007) applied the IRF method in parametric roll analysis of fishing vessel.

In this paper, nonlinear roll motion of containerships is studied using IRF for 6-DOF motions. The developed program based on the IRF approach is validated through comparisons not only between linear and nonlinear motion analysis but also with other computational results. To observe the occurrence of parametric roll, various conditions for wave frequency, amplitude and viscous damping coefficient are tested in regular waves. Finally, ship motion in irregular waves is simulated to create polar diagrams which can be used for operation purpose as well as for ship design.

EQUATION OF MOTION

The equation of ship motion is represented as Eq. 1.

$$M \ddot{\xi} = F_{F.K.} + F_{\text{Diff}} + F_{\text{Rest}} + F_{\text{Rad}}$$

$M$ is mass of ship and $\ddot{\xi}$ is motion. $F_{F.K.}$ and $F_{\text{Diff}}$ denote Froude-Krylov and diffraction force. $F_{\text{Rest}}$ represents restoring force, and $F_{\text{Rad}}$ is radiation force.