Numerical Prediction of Hull Girder Vibration due to Ship Springing

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ABSTRACT

Since modern ships become large and their longitudinal strength may be concerned, severe vibration of ship caused by the resonance with natural frequencies, so-called springing has to be considered and its effect on the hull strength should be applied to the design of such a large ship. In this study, the hull girder vibration due to ship springing is estimated by solving the hydro-elastic problem using the strip-theory-based numerical tool. The ship is assumed to be an elastic beam (Timoshenko beam) and its hydrodynamic force is calculated by the quadratic-strip theory. To solve the equation of elastic body motion, the hydrodynamic coefficients are calculated using the Lewis form method for fast calculation and simplicity of the program. Using the developed program, various types of ships are examined and their vertical bending moments are compared to evaluate the springing responses.

KEY WORDS: Springing; quadratic strip theory; Timoshenko beam; container ship; hydrodynamic coefficient; Lewis form.

INTRODUCTION

Due to the recent development of the Arctic Ocean routes, the precise analysis of the structural safety of a ship is becoming important under harsh environment. In addition, as the volume of world trade increases, the demand of very large container ships (VLCS) up to 18,000 TEU Class increases rapidly. Because of new trend of ships such as larger and faster ship hulls, the natural frequencies of hull girder and the incident waves are getting closer. Then, the resonance of ship vibration, so called springing may occur. If such a large container ship has great openings, bending or torsional vibration of ship also occurs in relatively low frequencies compared to the transverse bending vibration. Thus, the chance of severe vibration can be greater. In general, the springing phenomenon can be found in the tail of the response spectrum (high frequency region) that makes the fatigue strength of the hull decrease and reduce the life of the hull resultantly.

In this study, hull girder vibration due to ship springing for various container ships is predicted by solving the hydro-elastic problem using the strip-theory-based numerical tool. The ship is assumed to be Timoshenko beam. The quadratic strip theory used in the present study was proposed in Jensen and Pedersen (1979) and Jensen and Pedersen (1981), which was known to be efficient for wave load calculation. Using this theory, Jensen and Dogliani (1996) conducted the proper short-term analysis and investigated the response of ship in stationary and non-stationary seas. They also performed the fatigue analysis with the nonlinear springing loads.

MATHEMATICAL FORMULATION

Equation of ship motions

The lower modes of ship motion are accurately calculated using a single beam modeling of hull girder. In this study, a free-free Timoshenko beam model is used to consider ship flexibility and the hull deflection for each section of ship. The vertical loads and responses are calculated using a quadratic strip theory.

Using the viscoelastic stress-strain relationship the constitutive vibration equations for the Timoshenko beam become

\[ M = EI \left( 1 + \eta_M \frac{\partial}{\partial t} \right) \frac{\partial \phi}{\partial x} \]  

(1)

and

\[ V = \mu GA \left( 1 + \eta_s \frac{\partial}{\partial t} \right) \left( \frac{\partial w}{\partial x} - \phi \right) \]  

(2)

where M and V denote bending moment and shear force, respectively and \( w(x, t) \) the total deflection, \( \phi(x, t) \) the angular displacement (the slope), \( E \) the Young’s modulus of elasticity, \( G \) the shear modulus, \( I \) the cross-sectional inertia and \( A \) the sectional area. \( \mu \) is the constant (correction factor) depending on the non-uniform distribution of shear stresses over the sectional area. The damping coefficients (\( \eta_u \) and \( \eta_s \)) for viscoelastic material properties are...