Numerical and Experimental Investigations of Whipping and Springing of Ship Structures

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We present a computational method to assess whipping and springing effects on accelerations and sectional loads of ship structures, and to compare numerical results with model tests. The nonlinear rigid-body equations of motion and the linear equation of motion of the nodal degrees of freedom (vibratory modes) are implicitly coupled in the time domain with a Reynolds-averaged Navier-Stokes equations (RANSE) solver. Three finite element (FE) structure dynamics methods are described. Comparative measurements of motions, accelerations and sectional loads were obtained on the segmented model of a postpanamax containership.

INTRODUCTION

It has increasingly become common sense that structural elasticity of ships is an important contribution to the life-cycle load spectra of wave-induced hull girder stresses. Long-term full-scale measurement campaigns (e.g. Kahl and Menzel, 2008; Storhaug et al., 2003; Storhaug, 2007; Vidic-Perunovic, 2005) underline this point of view, although they do not indicate a general level of load amplification. This is most likely due to varying magnitudes of vibration excitation for different ship types and sizes, areas of operation, loading conditions, ship speeds, etc.; see Storhaug (2007) for an assessment of the impacts of different operational conditions. Nevertheless, classification society rules still operate with constant overall safety factors to account for the dynamic amplification of structural stresses. Therefore, an effort has to be made to establish improved prediction tools that include effects of ship structural elasticity in the design and assessment process of ship structures.

Not only is the amplification of sagging and hogging extreme values due to severe slamming impacts and consecutive vibration of concern, but the increase in load cycles at a broad range of load levels affects the whole stress spectrum and thus contributes to fatigue damage. Fig. 1 shows measured stress ranges presented by Kahl and Menzel (2008), revealing a contribution of hull girder vibration to the life-cycle extreme stresses of 20% to 25%. The evaluated contribution of vibration to the total fatigue damage is of the same order of magnitude.

Most computer codes used for the numerical investigation of dynamic ship structural responses to wave-induced loads are based on potential theory flows. Instead, we use a RANS-based approach, implicitly accounting for relevant flow features that have to be explicitly modelled in potential theory codes. Oberhagemann et al. (2010) discuss the advantages and disadvantages of this approach. Here we restrict ourselves to demonstrating the capabilities of the developed method.

We present systematic investigations in regular waves of various lengths. Fourier analysis of computed and measured time series data yielded pseudo-transfer functions of vibratory hull girder responses. Further on, comparisons with measured data in irregular waves are shown. The investigations were part of the joint industry project WILS-II organised by Korea’s Maritime and Ocean Engineering Research Institute (MOERI), which performed extensive model tests with a segmented model, Hong (2009) and Hong (2010).

In the literature, there is often a clear distinction between hull girder vibration in response to impulsive loading, referred to as whipping, and resonant vibration excitation, referred to as springing. On the other hand, many authors, e.g. Storhaug et al. (2003), discuss the difficulties in categorising the type of vibration from measured data. Therefore, a reliable numerical method would preferably have a common formulation for all kinds of excitation. The presented method does not treat springing and whipping excitation separately; instead, the first-principle approach to the fluid dynamics problem provides a consistent formulation.

An important observation from measurement is that the lowest eigenmodes of the hull girder contribute most to the overall vibration stresses, namely the fundamental 2-node vertical bending vibration. Although the natural frequency for 1-node torsion is typically lower for container ships with large deck openings, related vibrations are less pronounced.

Fig. 1 Comparison of total (unfiltered) and wave encounter frequency (low-pass filtered) stress spectra, measured aboard Panamax container vessel (source: Kahl and Menzel, 2008)