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Nonlinear effects from wave-induced maximum vertical bending moment on a flexible ultra-large containership model in severe head and oblique seas☆

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ABSTRACT

Vertical bending moment (VBM) is of crucial importance in ensuring the survival of vessels in rough seas. With regard to conventional vessels, wave-induced maximum VBM is normally considered to be experienced in head seas. It is conservative to determine the extreme VBM based on either numerical simulations or model tests in long-crested head seas. Extensive model tests have been conducted in head seas with focus on the nonlinear vertical responses in severe seas, and the measured results were compared with numerical calculations for validation. Unexpected phenomena, however, were observed during the model tests of an ultra-large containership. The maximum sagging and hogging VBMs were encountered in oblique seas. Furthermore, the significant wave height used in oblique seas was even smaller than that used in head seas. The nonlinear vertical load effects in oblique seas require further investigations for this particular vessel. Limited experimental results in oblique seas have been reported, in which the lateral responses were always more concerned than the vertical responses. Up to now, rare systematic comparisons of the nonlinear vertical responses between head and oblique seas have been published, especially when the hydroelastic effects are also accounted for. A 13000-TEU ultra-large containership model, which was designed by Hyundai Heavy Industries (HHI), has been tested in the towing tank and the ocean

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basin at the Marintek center in Trondheim. The experimental results in regular waves are first compared between head and oblique seas. The statistical characteristics of the VBM amidships under nineteen irregular wave conditions are then investigated. Next, the extreme hogging and sagging VBMs are compared under different wave conditions with focus on the extreme hogging VBMs. At the end of the paper, the uncertainties in the experiments are discussed.

1. Introduction

The determination of the maximum vertical bending moment (VBM) is of crucial importance for conventional ship design. The total hull girder VBM mainly consists of still-water (static) VBM and wave-induced (dynamic) VBM. The still-water VBM can be obtained according to the mass distributions under different load conditions. The accurate estimation of wave-induced extreme VBM is quite complicated. Current numerical tools cannot reflect the nonlinear load effects in severe seas, especially when springing and whipping are considered. In this study, wave-induced nonlinear effects on flexible vessels are roughly divided into two parts. One is the nonlinear wave-frequency response, which is the main focus of this paper. The other is the high-frequency vibrations due to springing and whipping.

For conventional vessels, it is widely recognized that maximum VBMs are experienced in long-crested head seas. Realistic vessels generally advance in short-crested, slightly oblique seas. The results in long-crested head seas from either the numerical simulations or model tests, therefore, can be used to determine the extreme hogging and sagging VBMs encountered during their design lives. And this determination can guarantee sufficient design margin. Baarholm and Moan [1] estimated the nonlinear, long-term extreme VBMs by including a limited number of head sea states. Extensive model tests have been conducted in head seas. Fonseca and Soares [2,3] studied the wave-induced nonlinear vertical responses of an S175 containership model in both regular and irregular waves, and only the rigid-body responses were considered. Drummen et al. [4] experimentally and numerically investigated the nonlinear vertical load effects of a large containership model in severe head seas, in which the hydroelastic effects were significant. The influence of whipping on long-term VBM in head seas for the S175 containership was discussed by Baarholm and Jensen [5].

Full-scale measurements, however, showed that ships actually advanced under different heading angles in realistic seas [6]. When rough seas were encountered, the heading angle did not always keep 0 deg (0 deg denotes head waves) and it varied from 0 deg to approximately 60 deg [7]. Several unexpected phenomena were observed during the full-scale measurements, which could hardly be explained by the common recognition about the asymmetry between hogging and sagging VBMs. The recognition is that the tails of the sagging and hogging peak distributions were, respectively, much heavier and lighter than the Rayleigh tail [8,9]. Mathisen et al. [7] compared the test results in six irregular wave conditions under different heading angles for a 4400-TEU containership. It was found that the wave-frequency hogging and sagging stresses followed each other closely. The tails of the probability distributions of the hogging peaks were unexpectedly heavier than the Rayleigh distributions. Extreme hogging stresses above the design rule stress were experienced under four conditions although the measured significant wave heights were below 7.0 m. Furthermore, the asymmetry between the extreme sagging and hogging VBMs was different under different heading angles. Mao et al. [10] investigated the short-term cumulative probability distributions of the hogging and sagging VBMs for two containerships based on the full-scale measurements. For the 2800-TEU vessel, the high-frequency responses could lead to a 40% and 10% increase of extreme sagging and hogging VBMs. With regard to the 4400-TEU containerships, the high-frequency responses contributed to 43% to the extreme responses. The wave-frequency VBM responses could be well approximated by Gaussian assumption. Heggelund et al. [11] presented the extreme hogging and sagging VBMs of an 8600-TEU containership from each of the half hour records during nine months. The maximum hogging VBM was above the rule design value, which was also approximately 15% larger than the maximum sagging