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Comparison of Springing and Whipping Responses of Model Tests with Predicted Nonlinear Hydroelastic Analyses

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The aim of this study was to investigate the hydroelastic responses on a large container ship and to provide reliable experimental data of the global loads acting on the ship. In this study, Fluid Structure Interaction (FSI) models are used to investigate nonlinear wave actions and wave-induced global loads acting on a 10,000 TEU-class container ship. The results from the computational analyses have been correlated with those from model tests. Comparisons of numerical results with experimental results are summarised and discussed.

INTRODUCTION

The demand for larger container ships has increased dramatically in the last few years as world trade continues to grow and the marine industry requires more energy-efficient ships. Currently the largest of these ships have capacities of 14,000 TEU, and designs for 18,000 TEU or more are currently being prepared. Due to the large deck openings of these ships, springing and whipping phenomena can be critical for their design and operation.

Ship springing is the continual hull girder vibration as a consequence of the waves exciting resonant hull girder frequencies. The flexing of the hull girder due to springing may continue for a significant period once initiated. Springing is an issue for ships with low natural vibration frequencies of bending or torsion modes, typically when the lowest natural frequency is less than 3 rad/s ($\approx$ 0.5 Hz), and the ship operation speed is above 20 knots. This is the case for large container ships due to their high speed and open cross-sections. The magnitude of the springing moments (stresses) is usually low, hence springing is not normally a strength issue. However, the number of cycles is very large (4 to 8 times the number of wave cycles), and this makes springing important with regard to the fatigue life of a structure.

Ship whipping is the rapid flexing of the hull girder as a consequence of a wave impact on the hull. This usually results in hig- frequency cyclic oscillations of the hull girder which may result in increased vertical wave-induced bending moments and shear forces compared to linear theory. High whipping responses are usually driven by bow flare impacts due to large bow flare angle and high speed or by bottom slamming. Occasionally, stern counter slamming can lead to high whipping responses. The oscillations of the whipping responses usually decay rapidly after several wave periods due to damping effects. Whipping is primarily a strength issue. It is not a fatigue issue as the whipping-induced vertical bending moment oscillations usually damp out quickly, hence the total number of whipping cycles in the ship's life is small.

Ships with hull girder natural frequencies close to the frequencies of the wave energy region are thus potentially prone to springing. In addition, springing may be excited after a wave impact as there is little damping resistance of the hull girder natural vibrations. Full-scale measurements of the amidships vertical wave-induced bending moment of an 8,100 TEU container ship are shown in Figs. 1 and 2. A typical hull girder response due to a bow slamming impact measured by a long base strain gauge is given in Fig. 1. The hull girder natural frequency response has been extracted from the total response in Fig. 1 and is shown in Fig. 2. A whipping event is shown by the sudden amplitude increase at 418 s caused by the slamming impact; the initial high response decreases quite quickly due to hydrodynamic and structural damping effects. This time trace also shows a continuous springing hull girder vibration (Bakkers, 2009).

Recently, the important contribution due to the global wave-induced hull vibration on container ships has been investigated through several full-scale measurements and model tests. Lloyd's Register has participated in the WILS II JIP (Wave Induced Loads on Ships Joint Industry Project) during the last 2 years. The aim of this project is to enhance our understanding with respect to the combined effects of fully nonlinear wave actions and wave-induced loads on the global dynamic response of container ships. The main objectives of this JIP are to provide reliable model test data of a large container ship, and to compare these with predicted springing and whipping responses from current hydroelastic analysis tools.

This paper presents the predictions of springing and whipping responses for a 10,000 TEU WILS II container ship in frequency and time domain using 2D linear and 3D nonlinear hydroelastic numerical methodologies. For idealising the ship and handling the flexible modes of the structure, a boundary element method and a finite element method are employed for coupling fluid and structure domain problems. The hydrodynamic module takes into account nonlinear effects of Froude-Krylov and restoring force. This fluid structure interaction model is also coupled with slamming loads to predict wave loads due to whipping effects. Vibration modes and natural frequencies of the ship hull girder are calculated by idealising the ship structure as a Timoshenko beam.

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