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Design of a ship model for hydro-elastic experiments in waves

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ABSTRACT: *Large size ships have a very flexible construction resulting in low resonance frequencies of the structural eigen-modes. This feature increases the dynamic response of the structure on short period waves (springing) and on impulsive wave loads (whipping). This dynamic response in its turn increases both the fatigue damage and the ultimate load on the structure; these aspects illustrate the importance of including the dynamic response into the design loads for these ship types. Experiments have been carried out using a segmented scaled model of a container ship in a Seakeeping Basin. This paper describes the development of the model for these experiments; the choice was made to divide the hull into six rigid segments connected with a flexible beam. In order to model the typical feature of the open structure of the containership that the shear center is well below the keel line of the vessel, the beam was built into the model as low as possible. The model was instrumented with accelerometers and rotation rate gyroscopes on each segment, relative wave height meters and pressure gauges in the bow area. The beam was instrumented with strain gauges to measure the internal loads at the position of each of the cuts. Experiments have been carried out in regular waves at different amplitudes for the same wave period and in long crested irregular waves for a matrix of wave heights and periods. The results of the experiments are compared to results of calculations with a linear model based on potential flow theory that includes the effects of the flexural modes. Some of the tests were repeated with additional links between the segments to increase the model rigidity by several orders of magnitude, in order to compare the loads between a rigid and a flexible model.*

KEY WORDS: Model experiment; Segmented model; Hydro-elasticity; Internal loads.

INTRODUCTION

The growth in size of especially container ships is a reason of concern. Structurally these ships are very demanding, the structure is essentially U-shaped especially causing flexibility in the torsional direction. Next to this it is a real challenge to have enough steel at deck level so that the neutral axis is sufficiently high. A consequence of the U-shaped structure is that the sheer center of the structure is well below the keel, typically a distance of the order of the depth of the vessel. This low sheer center means that there is a strong coupling between lateral and torsional bending.

Another aspect of large container vessels is the low resonance frequencies of the global modes. The resonance frequency for the two-node vertical bending, the two-node horizontal bending and the one-node torsion mode all are in the order of 2 *sec.* for a 9,000 *TEU* vessel. This characteristic makes the vessel sensitive to impulsive wave loads, whipping, and even springing. The EU FP7 TULCS project was started to address these issues. The project involved the development of new calculation tools,

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coupling tools from the hydrodynamic loads to the structural response, full scale measurements and several types of model experiments for the validation of the tools. This paper focuses on the so-called 'sophisticated model tests' that aimed at model testing a flexural model of a large size container ship in waves.

REVIEW OF THE LITERATURE

Many experiments on all sorts of ships have been performed, also experiments to measure the internal loads. One of the very first experiments was carried out by Lewis (1954), who already studied slamming and whipping events. He concluded that the elastic response of the ships is quite different to that of a model, thus initiating in fact a whole new research area. It lasted until well in the 1980s before experiments were reported in which the elastic behavior of the ship was modeled. There appeared two different methods to model the flexibility of the ship; the first is to really build a model from some elastic material, the second is to build the model subdivided in a number of rigid segments that are connected by a flexible beam.

The first option is the least popular. Watanabe et al. (1989) used a model made of PU foam and resin to study wave loads on a model of the S-175 container ship and on a variant of this design having more bow flare. The publication gives no details on the benefits or problems of this approach. Results are presented on the differences between the peaks in hogging and sagging in a regular head wave. Hay et al. (1994) used a PVC model of a frigate for their experiments. The main structural members of the ship were present in the model. Due to the required instrumentation and equipment of the model, only sectional loads could be measured amidships. Normal strain gauges were used to measure stresses at 7 longitudinal positions. Iijima et al. (2009) balances pro's and con's of a fully elastic model and a segmented one. He concludes that a fully elastic model, made from some plastic, suffers from too much internal damping for a proper evaluation of the vibration modes. Instead he opts for a segmented model with a flexural beam consisting of a rectangular aluminum extrusion with five, relatively small, cut-outs in the upper face. Sawada et al. (1987) built models of various ships using a construction in composites and a segmented model connected by a flexible beam. Both methods seem to work satisfactory. Details are unknown, the article is in Japanese, only the summary is in English.

The second option is to build a segmented model and connect these either by a fully elastic beam or by a 'segmented' beam having rigid parts over the length of the segments and hinges at the interface between the segments. An advantage of this latter system is, that the connections can be made adjustable so that different resonance frequencies can be simulated. McTaggart et al. (1997) built a model of a frigate consisting of 6 fiberglass segments held together by a flexible beam. The beam was constructed of Lexan, a polycarbonate plastic with carbon/epoxy stiffeners in the corners. The carbon/epoxy stiffeners are the real backbone, they are the only elements that run over the full length of the beam. By changing the height and the width of the beam, the variation of the stiffness over the length could be modeled. McTaggart achieved to properly model the first 3 modes for vertical bending (resonance frequencies); there was no full scale data to compare horizontal bending. Kapsenberg and Brizzolara (1999) built a model of a fast ferry consisting of two segments. The segments were connected with a spring with adjustable stiffness. The construction allowed a reduction of the resonance frequency by a factor two. Reducing the stiffness showed a very strong increase of higher harmonics in the VBM amidships. Malenica et al. (2003) used a 10 segment model to measure the motions and deformations of a very flexible barge. The segments were connected by two flexible plates. The resonance frequencies of the deformation modes were higher than the wave frequency, so in fact the model deformed in a quasi-static way. Dessi et al. (2003), Dessi and Mariani (2006) and Ciappi et al. (2003) carried out model tests on a (very) fast ferry. The model consisted of 6 segments, connected with an elastic beam. The beam consisted of 20 elements of aluminum extrusions with varying dimensions to properly model the vertical mode shapes. The focus was on vertical loads in head seas, the achieved a good correlation with the theoretical mode shapes up to the 3-node VB. Storhaug and Moan (2006) did springing and whipping experiments on a 4-segment model of a bulk carrier. They used a beam consisting of rigid parts with adjustable flexible connections at the interface of the segments. Drummen (2008) carried out model tests on 4-segment model of a container ship. The system of the backbone was similar to the one used by Storhaug and Moan, not surprising since both experiments were carried out at Marintek, Norway. An identical system in the same facility was used by Wu et al. (2010) to measure the loads on a model of a 13,000 *TEU* container ship. Iijima et al. (2009) carried out springing experiments on a 17 segment model of a bulk carrier. They used a continuous aluminum beam with cut-outs to reduce the torsion stiffness, the beam was more or less the same length as the model and placed on top of the hull segments. The experiments were also conducted in the Marintek facilities. Miyake et al. (2009; 2010) carried out experiments on a very large container ship. They used a model consisting of 6 segments that were connected by a prismatic beam, the beam was located close to the design water line of the model. Tests were only conducted in