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USCGC BERTHOLF (WMSL 750).

Live testing of fatigue prediction

MARIN's objective is to further improve the understanding of wave loading leading to fatigue damage of hulls.

One of the services of MARIN (Maritime Research Institute Netherlands) is carrying out measurement campaigns on board ships at sea and analyzing the collected data. At the moment MARIN is carrying out a project for the United States Coast Guard. The main goal is to increase the confidence in fatigue lifetime prediction.

Predicting the fatigue lifetime of a ship hull structure involves the prediction of hull loading in a seaway, and the comparison of this with the structural capacity. Particularly the former is an effort requiring information from a multitude of disciplines.

Based on Floating Production Storage and Offloading (FPSOs), Kaminski (2007) discussed the many steps involved in fatigue design. A graphical summary is shown in figure 1 (Kaminski, 2007). Each of these steps is associated with its own uncertainty. These uncertainties are typically dealt with by introducing a so called Design Fatigue Factor on Lifetime. A better solution would, however, be to introduce partial safety factors. These account for the individual uncertainties associated with the processes and data is shown in figure 1.

»The forecasted fatigue damage will be compared with the one determined for the design of the vessel«

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In July 2007, the Valid Joint Industry Project was started. The project was initiated by the United States Coast Guard (USCG), and is also known as the Fatigue Lifetime Assessment Project (FLAP). MARIN is the contractor. In order to ensure the best possible results, MARIN was keen to involve other stakeholders. American Bureau of Shipping, Bassin D'essais des Carenes, Bureau Veritas, Defence R&D Canada, the Dutch Navy, Lloyd's Register, Northrop Grumman Ship Systems, Office of Naval Research and Schelde Naval Shipbuilding are currently participating. The goals of the project are to

- forecast structural maintenance needs of USCG Cutters,
- further improve the understanding of wave loading leading to fatigue damage,
- increase the confidence level in predicting wave loading leading to fatigue damage.

In order to achieve these objectives the scope of work includes a trials and monitoring campaign, a model test program and an evaluation part including the numerical work.

The investigations will be performed for the USCG Cutter BERTHOLF. The first goal, forecasting the structural maintenance needs, will be achieved based on the results from the four year monitoring campaign. During this campaign the vessel will continuously be monitored during normal operation.

The fatigue lifetime consumption will be determined using conventional Rainflow counting of the measured stress signals, and using Fatigue Damage Sensors (FDSs), developed by Kawasaki (Yamamoto et al, 2007). As shown in figure 2, the latter sensor consists of sensing foil and base foil. In the centre part of the foil a groove is formed to amplify strain. In the centre of this groove an initial notch is again present. When the FDS is attached firmly to a component of the hull structure the accumulated fatigue damage of the structure can be related to the fatigue damage measured by the sensor.

The possible occurrence of fatigue cracks in the steel will be monitored using the advanced Acoustic Emission Method developed by Lloyd's Register. Acoustic emissions are the elastic stress waves which result from the sudden release of strain energy due to micro-fracture events. By recording these emissions the instrumentation can detect stable crack growth. Rogers (2001) gave a thorough account of the method. He also discussed a number of case studies in which the method was applied.

It is expected that the forecasted fatigue damage will differ from the one determined for the design of the vessel. A general fatigue design calculation as illustrated in figure 1 can be condensed as follows: a certain combination of environmental and operational conditions is input to a suitable method based on particular tools. Two methods with corresponding tools will be investigated. One is a Preliminary Fatigue Design Method (PFDM), based on the research of amongst others Sikora et al (1983). The second is a method based on the tools developed within Cooperative Research Ships (CRS). In CRS MARIN brings together a group of companies with a common interest in non-competitive research.

Both environmental and operational conditions are associated with significant uncertainties which can explain differences between the design and the actual fatigue lifetime of the vessel. For the full scale tests the ship is therefore instrumented with equipment measuring the relevant operational and environmental parameters. The effect of the uncertainty associated with these parameters will be quantified by determining influencing factors. These are found by comparing the fatigue damage, obtained by using the design operational and environmental conditions, with that found by employing the measured conditions.

Of particular importance are the wave measurements. During the trials MARIN will therefore collect wave data in three different ways. The relative wave will be measured by a level gauge at the bow. Wave directional information will be provided by a WaMoS wave radar (e.g. Borge et al, 2000) at the mast. In addition a wave rider buoy (see figure 3) will be deployed for obtaining the wave direction and the directional spectrum. The wave rider buoy is superior to other wave measurement devices. The wave data obtained from the wave rider buoy during trials will be used to calibrate the wave radar system and the level gauge.

During the monitoring campaign the waves will only be measured using the level gauge and the wave radar. Due to inherent limitations the wave buoy cannot be used during the monitoring campaign.

Furthermore, during both the trials and the monitoring campaign a data fusion approach will be used to update the measured waves. As discussed by Stredulinsky and Thornhill (2009) in data fusion the measured wave is combined with the calculated response amplitude operators (RAOs) of the rigid body (RB) motions to obtain the "calculated" rigid body motions. By comparing this with the measured rigid body motions the obtained wave data can be updated, see figure 4.

Hydrodynamic calculations are another area of great uncertainty which can explain differences between design and forecasted fatigue damage. In order to quantify the uncertainties in these calculations model tests will be performed, see figure 5. These will consist of two phases. In the first phase interesting conditions from the trials will be created in the model test basin so that the responses measured during the model tests can be compared with those measured during the trials.

These results will provide information about the degree of correlation between the trials and the model tests. The main goal of the second phase is to obtain systematic experimental data under controlled conditions. Combined with the results

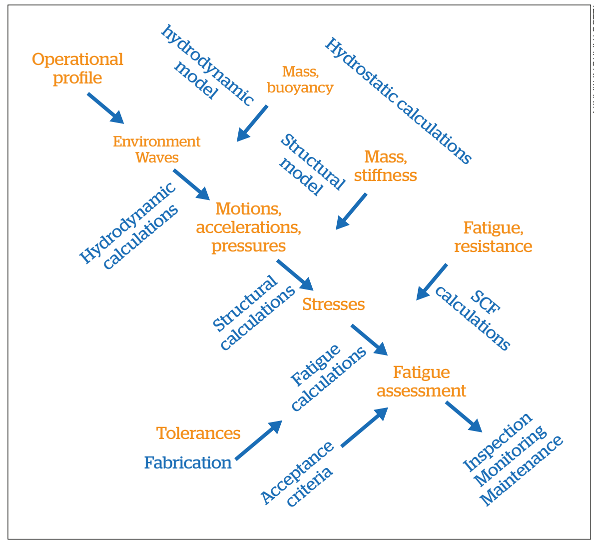

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Figure 1. Elements of fatigue design

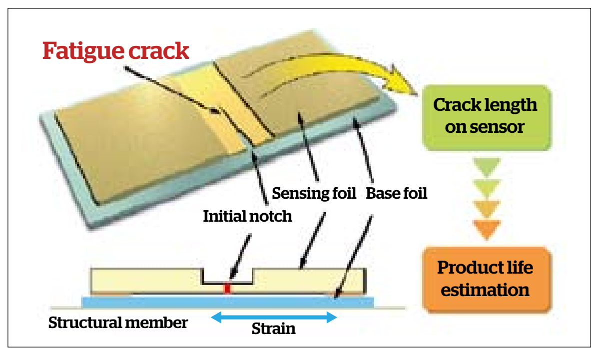

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Figure 2. Illustration of the Fatigue Damage Sensor (Courtesy Kawasaki)

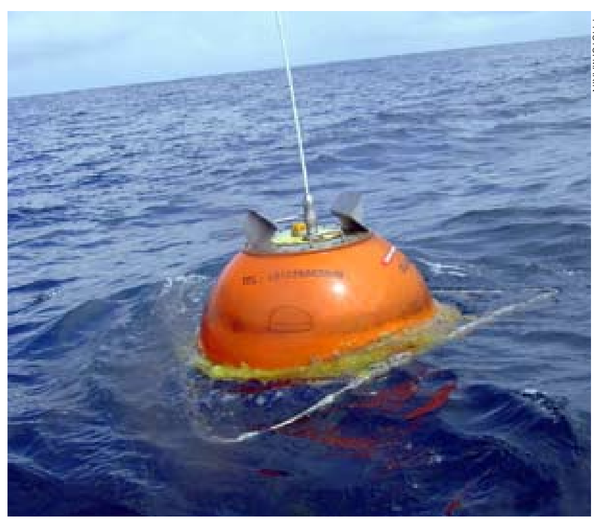

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Figure 3. Wave buoy

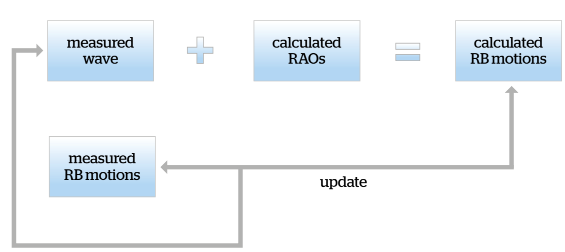

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Figure 4. Data fusion approach


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Figure 5. Model tested in severe wave conditions.

from the trials this will give insight into the accuracy of the hydrodynamic design tools. The accuracy will partly be determined by comparing RAOs of the hydrodynamic responses. As an example figure 6 compares the midships vertical bending moment RAOs obtained from calculations and experiments. The example is taken from Drummen (2008) and shows that the numerical and experimental results agree very well. The tools that will be considered are the one described by Sikora et al (1983) in case of the PFDM, and a within CRS developed 3D potential theory code. Figure 7 shows the hydrodynamic model of the cutter for the latter method. Also here, the effect of the uncertainty will be quantified by determining influencing factors.

Obtaining accurate RAOs based on full scale measurements is, however, a challenging task. During the trials optimal wave conditions will therefore be sought. Desirable conditions are waves coming from a single direction. In general the wave system is a superposition of different swells and wind seas coming from a number of directions. None of the wave measuring instruments discussed above distinguishes these components. During the trials the measurements of the wave radar and of the buoy will therefore be post processed using the XWaves software, e.g. Tracy et al (2007). The first step performed by this software is to isolate spectral regions associated with individual energy peaks. Figure 8 shows an example of a partitioned wave spectrum.

Subsequently the characteristics of the area are identified. The different wave systems can then be sorted into wind sea and swell. To be classified as wind sea a spectral peak must be forced by a component of the existing wind. All remaining peaks are labelled as swell.

A comparison based on RAOs, as described above, will provide information about the accuracy of the linear and partly about the weakly nonlinear part of the response. The latter being the nonlinear contribution to the hydrostatic restoring and Froude-Krylov forces. Recent research has, however, shown that whipping can have a significant contribution to the fatigue damage, (e.g. Drummen, 2008 or Aal-

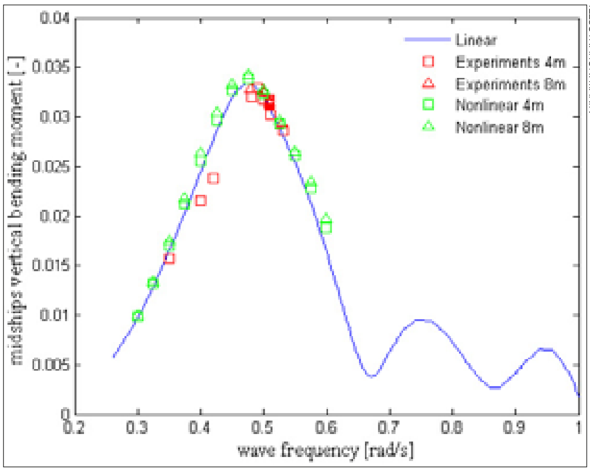

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Figure 6. RAOs obtained from calculations and experiments.

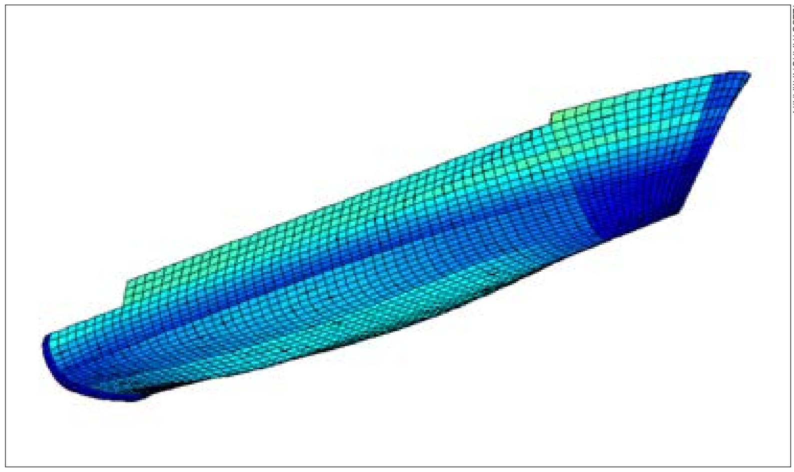

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Figure 7. Hydrodynamic model USCGC BERTHOLF.

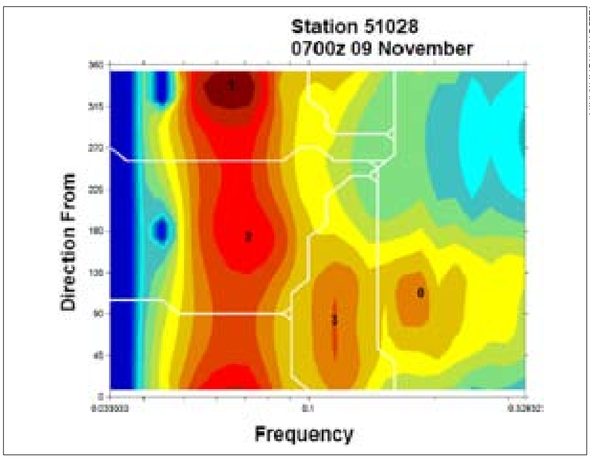

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Figure 8. Partitioned wave spectrum.

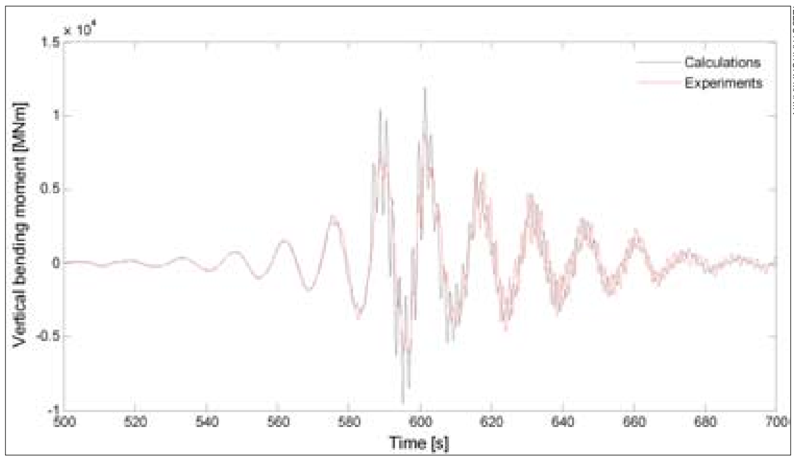

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Figure 9. Comparison between the midships vertical bending moments due to whipping, as obtained from calculations and experiments.

berts and Nieuwenhuijs, 2006). Whipping is the transient elastic vibration of the ship hull girder caused for example by slamming. The validation of this strongly nonlinear component will be done based on a comparison of time series and statistics, see figure 9.

In order to reduce the uncertainties between the comparison, a deterministic reproduction of the test results will be done for the CRS tool.

The fact that whipping is an important aspect means that the test model needs to be flexible. This flexibility will be introduced by building the model in six segments and mounting these on a flexible backbone. A six segmented model will well represent the lowest flexural modes of the cutter. The correct shapes and natural frequencies of the two- and three-node vertical and horizontal flexural vibration modes will be created by locally weakening the backbone with transverse and vertical cuts.

The above described investigations will provide a more rational basis for the design of USCG Cutters. The measured environmental and operational conditions can be used directly for future designs. Other aspects such as the uncertainty of the hydrodynamic calculations can be used as partial safety factors. The uncertainties and influencing factors also provide direction as to where research should be focused in order to decrease the total uncertainty in the prediction of fatigue loading in the most efficient manner.

Finally, the investigations will result in recommendations for increasing the confidence of the actual software and procedures used in CRS calculation suite. *

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