Whipping Investigations Based on Large-Scale Measurements and Experimental Fatigue Testing

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ABSTRACT

Wave loads and slamming loads acting on the ship’s hull lead to superposition of low-frequency wave-induced stresses and high-frequency stresses from whipping as well as springing effects. The question to which amount the latter contributes to the total fatigue damage of structural details is still under discussion. Furthermore the question to which amount high-frequency effects are covered by the Rule-based design loads is not finally solved. Also, fatigue damage assessment typically relies on rainflow counting and Palmgren-Miner Rule for linear damage accumulation but it is not yet proven whether this approach works well for superimposed high- and low-frequency stresses. Loads recorded in full-scale measurements onboard of a containership are the basis of this investigation. Fatigue assessment of measured stress shows a significant damage increase due to high-frequency contribution. However, it has to be emphasized that this is not reflected by observed damages of the fleet in service. To get more insight into the fatigue damaging mechanism of combined low- and high-frequency loads, fatigue tests have been performed in cooperation between DNV GL and TUHH. Transverse stiffeners on a continuous plate have been selected for tests as a representative structural detail. The Palmgren-Miner rule will be verified by test series with measured unfiltered as well as with low-pass filtered loads sequences.

KEY WORDS: Hull girder; longitudinal strength; wave load; whipping; fatigue damage; fatigue test

INTRODUCTION

Ship hulls at sea are not only subjected to bending stresses due to waves, but also to stresses caused by wave impacts (slamming) and subsequent vibrations (whipping). Such impacts can occur at the bottom of the forebody which emerges in rough seas and subsequently hits the water surface with a certain relative velocity. The frequency of whipping vibrations is typically much higher than that of wave-induced bending, being determined by the lowest natural frequencies of the hull girder.

As bottom slamming occurs mainly at smaller draft, usually in ballast condition, where wave-induced bending stresses are smaller than at full draft, additional whipping stresses were not taken into account during design in the past according to the longitudinal strength assessment procedure which was internationally unified by IACS (1978).

The situation has changed during the past years. Modern container ships are characterized by pronounced bow and stern flare, which cause more frequent slamming impacts on them particularly at design draft. First indications that the associated whipping stresses can be relatively high and may have to be considered during design were found during long-term measurements in the early 1990s on four container ships sailing in the North Atlantic (Hansen, 1993). These measurements showed significant differences between three container ships having moderate bow flare and a fourth one with pronounced bow flare and in addition a smaller length of 167 m showing larger pitch motions in North Atlantic waves. The observed bending moments were 30% higher than those expected from the design values and the number of load cycles was doubled. The conclusion was that the recently revised longitudinal strength requirements (IACS, 1989) agree better with the observations than the previous ones. Furthermore, an increased wave bending moment was introduced in the rules of Germanischer Lloyd (GL, 1991) for ships with relatively pronounced bow flare and high speed.

After fatigue damages were found on a large ore carrier being related to higher frequency stress cycles, their effect on longitudinal strength was further examined (Storhaug et al., 2006). A share of 41 – 73% of the total fatigue damage was related to wave-induced vibrations. Similar results were found during further on-board measurements on a container (Kahl et al., 2013, Storhaug and Moe, 2007) and on an LNG carrier (Heggelund et al., 2010). Also tests with flexible models were performed (Storhaug et al., 2010a and 2010b). A typical history of the bending moment is shown in Fig. 1. All measurements showed that the contribution of the wave-induced vibration to the total fatigue damage was relatively large and exceeded in some cases 50%.

Usually the rainflow counting method of stress cycles (Matsuishi and Endo, 1968), considering the memory effect during elastic-plastic material behavior in notches, as well as the Palmgren-Miner rule are applied to predict the fatigue damage under variable amplitude loading, yielding the so-called life curve compared to the S-N curve. In the Palmgren-Miner rule, the damage due to small stress cycles below the knee point of the S-N curve (fatigue limit) is usually considered by assuming a modified slope exponent of the S-N curve beyond the fatigue limit (Haibach’s correction). In addition, a reduced damage sum of $D = 0.5$ has been proposed in the recommendations of the International Institute of Welding (Hobbacher 2009).