Marine Structures 61 (2018) 142–154

Contents lists available at ScienceDirect

Marine Structures

journal homepage: www.elsevier.com/locate/marstruc

Statistics of extreme hydroelastic response for large ships

Oleg Gaidai[a,*], Gaute Storhaug[b], Arvid Naess[c]

[a] Jiangsu University of Science and Technology, Zhenjiang, China
[b] DNV-GL, Oslo, Norway
[c] Norwegian University of Science and Technology, Trondheim, Norway

ARTICLE INFO

Keywords:
Whipping
Ship structural loads
Container ship
Extreme value statistics
Exceedance rate
Return period
Data clustering

ABSTRACT

For the safety of crew, ship and cargo, it is essential to assess all aspects of the wave loading to ensure that ships are designed to endure extreme events. This paper describes a practical method for prediction of extreme stresses using as an example measured strain in the deck amidships of a container vessel operating in the North Atlantic. The focus is placed on the whipping structural response, which refers to transient vibratory response of the hull girder due to wave impacts occurring mainly in the bow area.

Due to non-stationarity and complicated nonlinearities of the wave induced loads, as well as the human factor in operation of ships, reliable numerical prediction of extreme response, including whipping, is challenging even though significant advances have been made in developing hydro-elastic computational tools in recent decades. Moreover, laboratory tests and numerical simulation tools may not fully reproduce the critical conditions that take place in reality, and these conditions may not even be well understood. Therefore, measurements on real ships provide an opportunity for unique insights into the structural responses when the vessel is at sea.

In addition, a discussion of the ACER (Average Conditional Exceedance Rate) method is provided. It is shown that this method is suitable for practical prediction of extreme values of structural stresses. Unlike methods based on asymptotic extreme value theory, the ACER method explores pre-asymptotic statistics. The latter is of great practical importance for engineering and design. This method opens up for the possibility to predict simply and efficiently both short-term and long-term extreme response statistics, which may also be useful for the captain on board.

The last, but not least is data clustering issue. Whipping process possesses clustering due to its resonance nature; therefore conventional and widely used Poisson assumption is no more valid. ACER method effectively accounts for data clustering, leading to more accurate extreme response estimate, than Poisson assumption methods.

1. Introduction

This paper studies measured hydroelastic response of large container vessel. Hydroelastic loads are represented here with whipping and springing [1].

The Post-Panamax container ship MSC Napoli broke in January 2007. Another Post-Panamax container ship, MOL Comfort broke in June 2013. Although these two ships may not have been designed and approved according to current safety practise resulting in substandard collapse strength compared to other similar ships, both ships broke because of hull girder overloading. MSC Napoli was broken in way of the engine room bulkhead and MSC Napoli was broken amidships in way of a pillar bulkhead. These severe

* Corresponding author.
E-mail address: oleg.gaidai@yahoo.com (O. Gaidai).

https://doi.org/10.1016/j.marstruc.2018.05.004
Received 4 February 2017; Received in revised form 8 April 2018; Accepted 23 May 2018
0951-8339/

accidents affected the industry, in particular the container ship industry. The latter two cases have been intensively followed up by thorough investigations [2,3]. Investigation reports focus on the estimate of the three main load components that may contribute to break such ships in two:

- Still water vertical bending moment due to the ballast and cargo loading
- Wave induced vertical bending moment due to the sea state and relative vessel heading
- Wave induced vibration, i.e. whipping due to bow flare slamming, contributing to increase the vertical bending moment

The investigation reports [2,3] analyzed the collapse strength that has been determined by nonlinear FEM (finite element analysis). The collapse strength must exceed potential loading, but in the two accidents it was clearly not the case. There are many possible elements that could have made the collapse strength dangerously weak. For MSC Napoli, the transverse stiffening without redundancy was a critical element, while for MOL Comfort double bottom bending and reduced buckling strength due to bi-axial buckling was critical.

It can be concluded, that uncertainties are of big importance both on the capacity and the loading side. Especially on the loading side there are big uncertainties, exemplified by the deterministic versus the probabilistic assessment on MSC Napoli, where one appendix of the report [3] suggests that whipping was a key contribution, while another appendix suggests that it is likely contribution, but not necessary an only collapse cause. On MOL Comfort there were significant uncertainties to both the still water bending moment, and to the wave bending moment and whipping. The latter was exemplified also by the assumptions on significant wave height, which was increased from 5.5 m reference to an interim report [2] to 7.5 m.

The International Association of Classification Societies (IACS) has issued recently (as a consequence of these two accidents) new unified requirements for longitudinal strength standard for container ships, URS11A [4] as well as new unified requirements for functional requirements on load cases for strength assessment of container ships by finite element analysis, URS34 [4]. These requirements address the hull girder loading and collapse strength, and URS11A now is including functional requirements to whipping to be addressed on Post Panamax container ships. The latter requirements should be implemented by all class societies, and in some cases the scantlings (steel weight) may increase, but some class societies consider already whipping in the approval. Other class societies have also updated guidelines for whipping, but the different class societies do not have similar or harmonised procedures or tools, therefore the results can differ.

From the above it can be concluded that uncertainties are present and important. One of the major uncertainties is related to the hull girder loads. The latter is the focus of this paper, i.e. the wave loading and the whipping, while the still water loading has not been considered. Rather than using numerical calculations, real stress measurements of a 2800TEU container ship operating in North Atlantic have been considered. Each voyage (crossing) represents a new random process, taking place in different seasons in the years 2007–2010. Assembling all different voyages into one single time process introduces additional non-stationarity. Different authors have being studying statistics of whipping of the same 2800TEU container ship, see for example [5].

Although ship stress statistics in irregular waves can be accurately determined in a well-designed model test, obtaining reliable estimates for the extreme response is challenging. Due to nonlinearity of the response in steep sea states, data from many realizations of a given sea state are often required to obtain robust estimates. In model tests, this is a time consuming and costly process. In many cases only one or a few 3-h realizations are therefore simulated in the model basin or towing tank (head sea only), and the assumptions regarding sea states, loading condition, heading, speed, wave energy spreading and model representation introduce significant uncertainties.

Thus, the real operational data are of great importance, if available. In case the measured dataset is representative, but contains only limited amounts of crossings, the natural question can be asked is how to extrapolate the statistics towards extreme response levels, which have not been crossed by the measured time series. Therefore, there is a substantial need for new statistical approaches to be able to utilize limited non-stationary data sets, and give reasonable prediction of the probability of extreme events. There is also a significant need to investigate the statistical robustness of these estimates in more detail, and, if possible, develop and establish new methods to improve the estimates obtained from a limited data set. The approach adopted in this paper was previously benchmarked in various applications; see [6–8]. A further development of this method was published in [9–12].

An important study was done, based on full-scale measurements obtained from a one year monitoring campaign onboard the Victoriaborg, a general cargo/container vessel [13]. report extreme distribution tail of whipping stress and its low and high pass components which are of similar qualitative tail shape as presented in this study, compare Figs. 5–7 and cumulative distribution of vertical hull girder bending moments plot in [13].

The authors have previously applied the ACER method to ship whipping data [14,15] [16]; and [17], but the current study analyses significantly larger datasets, enabling deeper insights into the extreme value statistics and the importance of whipping versus design rules. The presented approach assesses the extreme response by employing the ACER function combined with an efficient optimization procedure that allows prediction at extreme response levels. The latter is a novel state of art approach and is benchmarked against what is considered to be a robust state-of-the-art method. The main objective of this paper is to come up with improved methods for assessment of extreme response, with special emphasis on whipping.

A typical loaded container TUE ship is presented in Fig. 1. The stress is measured amidships in the longitudinal direction on a flat bar below upper deck. At this location the stress is dominated by vertical bending and whipping. The measurements cover an effective period of two years. Further explanation of the hull monitoring system can be found in [18].