Marine Structures 41 (2015) 244–266

Contents lists available at ScienceDirect

Marine Structures

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

A regression and beam theory based approach for fatigue assessment of containership structures including bending and torsion contributions

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A R T I C L E   I N F O

Article history:
Received 18 November 2013
Received in revised form 26 January 2015
Accepted 29 January 2015
Available online 3 March 2015

Keywords:
Beam theory
Containership
Fatigue damage
Finite element analysis
Full-scale measurement
Horizontal bending
Hydrodynamic analysis
Torsion

A B S T R A C T

Container shipping has been expanding dramatically during the last decade. Due to their special structural characteristics, such as the wide breadth and large hatch openings, horizontal bending and torsion play an important role to the fatigue safety of containerships. In this study the fatigue contributions from vertical bending, horizontal bending and torsion are investigated using full-scale measurements of strain records on two containerships. Further, these contributions are compared to results from direct calculations where a nonlinear 3D panel method is used to compute wave loads in time domain. It is concluded that both bending and torsion have significant impacts on the fatigue assessment of containerships. The stresses caused by these loads could be correctly computed by full-ship finite element analysis. However, this requires large computational effort, since for fatigue assessment purposes the FE analysis needs to be carried out for all encountered sea states and operational conditions with sufficient time steps for each condition. In this paper, a new procedure is proposed to run the structure finite element analysis under only one sea condition for only a few time steps. Then, these results are used to obtain a relationship between wave loads and structural stresses through a linear regression analysis. This relation can be further used to compute stresses for arbitrary sea states and operational conditions using the computed wave loads (bending

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http://dx.doi.org/10.1016/j.marstruc.2015.01.001

and torsion moments) as input. Based on this proposed method for structure stress analysis, an efficient procedure is formulated and found to be in very good agreement with the full-ship finite element analysis. In addition it is several orders of magnitude more time efficient for fatigue assessment of containership structures.

1. Introduction

Driven by economies of scale and technical development, the size of ships, in particular containerships, has rapidly increased during the last decade [1]. The ship structures are therefore subjected to larger wave loads causing larger stress variations. Further, the wide use of high-tensile steel in modern containerships and higher service speeds also challenge the fatigue safety of these ship structures [2,3]. In particular, Müller [4] reported that a growing number of fatigue cracks are observed in side-shell structures of approximately 10 year old Panamax containerships. In addition to the improvement of manufacture techniques in fatigue critical regions, current fatigue design methods may also need to be updated to provide correct fatigue life predictions for these large ships. It was reported by Fricke et al. [5] that the large scatter in predicted fatigue life is found from the use of different but widely accepted class guidelines. Conventional ship fatigue design is based on the linear Palmgren-Miner law [6,7] combined with a specific S–N curve for each structural detail. It estimates the fatigue damage accumulated due to stress cycles with ranges S_i as:

$$D = \sum_{i=1}^{N} \frac{S_i^m}{\alpha} \tag{1}$$

where α and m are the intercept and slope of a linear S–N curve, respectively. In order to estimate the fatigue life of a ship structural detail the long-term stress range distribution is needed. It is often provided by empirical formulae from classification societies. However, for a novel design of a large containership empirical stress range distributions are rarely available for all details. In these cases the stresses can be computed by direct calculation procedures as e.g. in Fig. 1. These methods are introduced to better capture factors for each individual ship and detail, such as ship structural geometry, loading conditions, encountered wave environments, operational modes etc.

A containership is characterized by a pronounced bow flare, an overhanging stern and large hatch openings. Large modern containerships are also becoming wider and less slender. The wave induced torsion and horizontal bending are believed to have significant impact on the global structure stress [8,9]. Further, the non-linear effects becoming essential for the wave load analysis. Therefore, to capture the nonlinear characteristics (such as hull geometry and wetted surface), a 3D panel method is often used to the wave loads calculations for fatigue assessment [10–12]. Recently, computational fluid

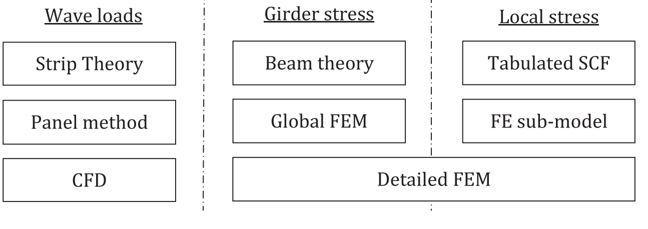

Fig. 1. Overview of some direct calculation methods for wave loads and structural stress analysis.