ARTICLE IN PRESS

Ocean Engineering xx (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Ocean Engineering

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

Still water vertical loads during transient flooding of a tanker in full load condition with a probabilistic damage distribution

J.M. Rodrigues, C. Guedes Soares*

Centre for Marine Technology and Ocean Engineering (CENTEC), Instituto Superior Técnico, Universidade de Lisboa, Portugal

ARTICLE INFO

Keywords:
Transient flooding
Damaged ship
Still water loads

ABSTRACT

The study of the transient still water vertical loads progression, throughout the flooding process, is presented for a damaged shuttle tanker in full load condition. The vessel is damaged by box-shaped volumes following the probabilistic distribution models of their extent and position suggested by the Marine Environment Protection Committee of the International Maritime Organization (IMO). A subset of this model is considered, by taking into account only the collision cases where the centre of the damage is about the waterline. Discretization of the problem is implemented with 90 damage configurations and the flooding progression is simulated by a quasi-static version of a generalized adaptive mesh pressure integration technique code for progressive flooding of floating objects. The vertical loads are determined at each time step, which provides initial, minimum, maximum and final values of bending moment and shear force, evaluated along the length of the ship, for the total simulation time. The probability and magnitude of higher intermediate loads and the main effects of the damage parameters and the factor interactions between these are determined and analysed, with and without introducing the IMO probabilistic distribution.

1. Introduction

As an evolution of increasingly more advanced computational capabilities, the common practice for designing ships is being extended from the usual approach of designing the intact structures so that several accidental limit states are considered during the design process. The goal is to make the structures more robust to resist some of the most frequent damages ships can be subjected to.

One important damage scenario being studied is that of collision situations resulting in damage in way of the waterline and the variation of the loads, on the ship's structure, relative to the intact case. Such scenario has already been investigated by Rodrigues et al. (2015a, 2015b), regarding the still water loads. However, while those studies consider the final situation attained by the ship, the present paper deals with the transient phases in which the loads are varying. In addition, the expected loads aggravation for different types of damage, and their cross-effects, is predicted, which was not done in previous studies.

Predicting global vertical loads on damaged vessels is particularly important for the reliability assessment of the hull girder where its diminished moment-carrying capacity is also calculated and the combination of both factors is assessed – Campanile et al. (2015), Gaspar et al. (2016), Prestileo et al. (2013) and Saydam and Frangopol (2013) are some of the many examples of studies of this kind. These types of investigations constitute the typical application of the current study.

An approach to the determination of damage induced still water loads may be that of a stochastic nature, as in (Guedes Soares and Moan, 1988) and (Teixeira and Guedes Soares, 2010). In such an approach a factor is typically estimated, which aggravates the intact minimum design loads distribution due to the added still water loads arising from the flooding of otherwise intact internal spaces. In determining this factor, Luís et al. (2009) arrived at values varying between 1.1 and 1.5, by considering an oil tanker symmetrically damaged at the bottom in way of the midship section. Corroborating the study of Luís et al. (2009), an increase up to nearly 50% on the vertical bending moment amidships was attained by Hussein and Guedes Soares (2009), regarding a tanker with a small set of asymmetrically distributed damages to ballast tanks due to grounding.

On the other hand, under a deterministic approach, Rodrigues et al. (2015a) identified cases where the maximum vertical bending moment would reach between 2.0 and 2.5 times those of the intact case. In their study, a collision damaged shuttle tanker, considering a parametric variation of box-shaped damage configurations in still water, was analysed. Such approach can be speculated to be reasonably realistic even considering (moderate) sea states, depending on the level of the compartmentation and the damage configuration (Khaddaj-Mallat

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* Corresponding author.
E-mail address: c.guedes.soares@centec.tecnico.ulisboa.pt (C. Guedes Soares).

http://dx.doi.org/10.1016/j.oceaneng.2016.10.044
Received 26 February 2016; Received in revised form 22 October 2016; Accepted 24 October 2016

Please cite this article as: Rodrigues, J.M., Ocean Engineering (2016), http://dx.doi.org/10.1016/j.oceaneng.2016.10.044

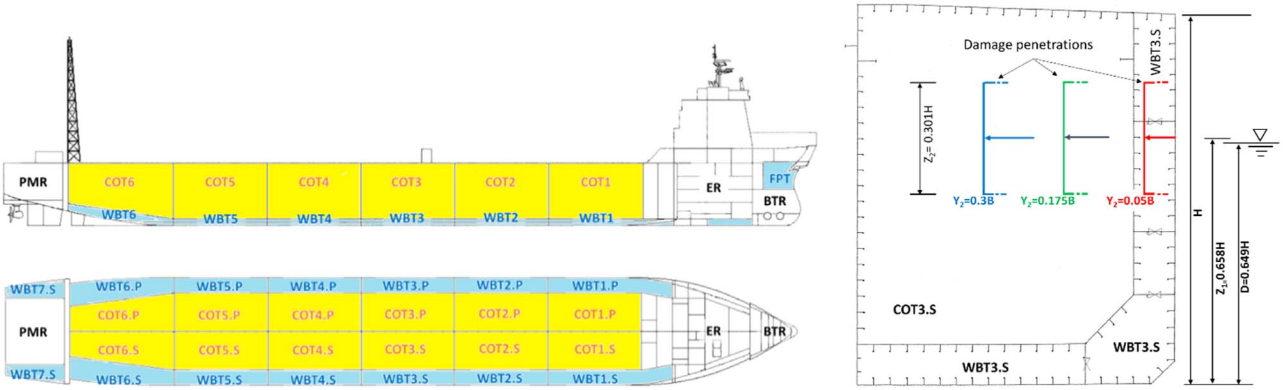

Fig. 1. General arrangement and midship section.

et al., 2011, Papanikolaou et al., 2004). The configurations in Rodrigues et al. (2015a) were introduced as a discretized subset of the probabilistic distributions presented in IMO (2003); a full probabilistic study considering such distribution, and also including the shear force assessment, was latter published by Rodrigues et al. (2015b). The number of cases where these high ratios took place was very limited though, and an aggravation of the global loads was seen to be within those suggested by Guedes Soares and Moan (1988) in most cases – only the final condition loads were assessed.

A generalized adaptive mesh pressure integration technique (GAMPIT) (Rodrigues and Guedes Soares, 2014), was used by Rodrigues et al. (2015b), where a progressive flooding model carried out the simulations. The model has been validated in Rodrigues and Guedes Soares (2015); examples of its application are those by Varela et al. (2014, 2015). Several other progressive flooding models are described in the literature, though most are not focused on loads assessment. A recently developed scheme is that by Manderbacka et al. (2015), where the inflow momentum is taken into account regarding the transient flooding phase and its effects on roll motion; it was later applied to the flooding of a passenger ship in Manderbacka and Ruponen (2016).

Introducing a tool for progressive loads assessment in damaged vessels allows for retrieving the information on all stages of the flooding process. However, it also allows for the consideration of the individual flow on each damage-induced opening. Accounting for these may lead to different final conditions from those if a simple imposition of breached compartments flood water level to be the same as that of the exterior is applied. Santos and Guedes Soares (2008) had already resorted to a pressure integration technique to carry out the calculations of the global loads on a progressively flooding ship. Their work was based on the pioneering studies of Witz and Patel (1985), van Santen (1986) and Schalck and Baatrup (1990), in what relates to the pressure integration formulations. Yet, unlike GAMPIT, no true adaptive meshing method was applied, the pressure integration formulation was not as robust, and penetration of cargo oil tanks, and consequent leaking and mixing on other compartments, had not been considered. Both GAMPIT and the method by Santos and Guedes Soares (2008) have been validated with experimental results published by van Wallree and Papanikolaou (2007), which summarized some of the tests carried out by Ruponen (2006).

Only the final global loads are usually assessed, but the intermediate loads can be higher than at the initial and final stages, as has been made patent in Santos and Guedes Soares (2008) results, regarding several damage configurations applied to a passenger vessel. In the present study, the full history of the vertical loads – bending moment and shear force – during progressive flooding is investigated for a set of damage configurations at the waterline, which follow a probabilistic model from IMO (2003). The obtained loads are compared with minimum design envelopes for vertical bending moment and shear force as per IACS (2012). Also, the intermediate increase of loads is assessed and probabilistically analysed. Furthermore, an investigation into the main effects and interactions of the damage characteristics' factors (Montgomery, 2001) is carried out. This, to the best of the authors' knowledge, is yet to be found in the literature concerning global loads. The realization of this type of investigation follows the path to the intermediate flooding stages analysis as outlined by Khaddaj-Mallat et al. (2011) regarding the therein defined *Category A entailed factors*, i.e. the damage opening characteristics (shape, height, longitudinal extent, vertical location, penetration) and the time of damage creation. An upgrade of the progressive flooding code in Rodrigues et al. (2015b) has been implemented to allow the back-logging of intermediate loads, and a much smaller time step has been considered in the simulations to provide a realistic assessment of these.

Finally, one should mention the thorough review on loads for use in the design of ships and offshore structures, which has been recently published by Hirdaris et al. (2014), where the assessment of damage induced loads is also included.

A brief description and modelling of the ship under investigation and of the damaged cases is carried out in Section 2, together with the expressions for determining the global loads and their minimum design envelopes. In Section 3, a short listing of the numerical method's main assumptions and the formulation of the forces calculation expressions are done. The results are analysed in Section 4 and the main findings and general conclusions of the study are presented in Section 5.

2. Case study

2.1. Intact ship mass distribution

The case study is that of a shuttle tanker, with the superstructure located above the engine room, contiguous to the bow loading system. Two electrically powered z-pods are fit at the stern for propulsion and steering, in addition to two bow thrusters. A schematic version of the general arrangement and the ship's midship section is shown in Fig. 1. The engine room subdivision is presented in Fig. 2, as it is modelled for input to the simulations carried out in the present work. The ship's principal characteristics are listed in Table 1 and the intact load distribution is shown in Fig. 3. The lightweight amounts to nearly 15,000 t, whereas the full load condition, which was applied in this study, equals to about 63,000 t of deadweight. A hydrostatics and stability code was used to estimate the full load condition. The lightweight was obtained from applying the statistical results presented by Cudina (2008), for the steel, equipment and machinery mass values. Weights of particular equipment items, such as the z-pods and stern flare stack, were estimated from available data for similar equipment presented by manufacturers. The superstructure, forecastle and cargo handling and deck stores were introduced following the estimation procedures proposed by Martinez (2009) and were added to the steel