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Ultimate strength analysis of a bulk carrier hull girder under alternate hold loading condition – A case study Part 1: Nonlinear finite element modelling and ultimate hull girder capacity

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ABSTRACT

This is the first of two companion papers dealing with nonlinear finite element modelling and analysis of the ultimate strength of a bulk carrier hull girder under alternate hold loading (AHL) condition. The purpose is to contribute to establishing rational ultimate longitudinal strength criteria for the hull girder under combined loading. The focus is on the hogging condition. An important issue is the significant double bottom bending in empty holds in AHL due to combined global hull girder bending moment and local loads. The local loads may substantially reduce the strength of the hull girder. Different AHL conditions, i.e. fully loaded cargo and (partially) heavy cargo are considered. A critical review of external and internal design pressures for different AHL conditions is accomplished using both CSR-BC rules and DNV rules. A methodology for nonlinear finite element modelling of hold tanks of a bulk carrier under AHL is presented by use of ABAQUS. A mesh convergence study is carried out in order to find the appropriate mesh for the model. The implication of using different design pressures on the hull girder strength is assessed. The FE results can be used as a basis for establishing simplified methods applicable to practical design of ship hulls under combined loadings. This issue is discussed in the companion paper.

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1. Introduction

In the design of bulk carriers the alternate hold loading (AHL) condition is usually assumed to be the dimensioning loading condition for the double bottom structure when the global hull girder is in hogging, see Fig. 1. In the AHL condition the middle cargo hold is empty and alternate holds are loaded with maximum cargo deadweight at maximum draught. Lateral loading on the bottom, inner bottom and lower sides of holds acts together with (typically) an overall hogging bending moment as shown in Fig. 1. As a result, the global strength of the hull girder is reduced due to significant double bottom bending at the middle of the empty hold.

The ultimate hull girder capacity of any ship type can be estimated by a hierarchy of methods, such as: (a) Full nonlinear FE analysis (first attempted by Chen et al. [1], Kutt et al. [2] and Valsgård et al. [3]); (b) Simplified FE methods such as ISUM (initially proposed by Ueda and Rashed [4]); (c) "Smith-type" simplified methods (proposed by Smith [5]) based on Navier's hypothesis and average stress–average strain relationship for individual panels; and (d) Simple "closed-form" formulations based on further simplifications as compared to "Smith-type" methods, e.g. without considering the progressive development of the collapse and load redistribution (initially suggested by Caldwell [6]). Significant efforts have been devoted to methods (b), (c) and (d) that include works done by Ueda et al. [7] for ISUM, Yao [8,9] for "Smith-type" method and Mansour et al. [10] for Simple "closed-form" formulations. However, fewer studies are reported using method (a), because it requires huge computational resources. An issue is that the present conventional "Smith-type" simplified methods cannot account for the effect of double bottom bending in bulk carriers and therefore seem to be on the non-conservative side as reported, e.g. in Moan et al. [11]. On the other hand, a simplified linear approach could be quite conservative because it neglects the effect of stress redistribution, or reserve capacity beyond the collapse of typical bottom panels [11].

Most of the nonlinear FE analyses published so far seem to be dealing with ships under pure bending, e.g. [1–3,12]. This type of loading allows for modelling and analysis of a single cargo tank or even only a few frame spacing's of a tank. Proper treatment of the double bottom bending in the AHL conditions requires that a larger part of the ship including both loaded and empty hold tanks be included in the FE model.

It seems that, so far, only the study by Østvold et al. [13] has been carried out to investigate the effect of double bottom bending on the hull girder strength. The vessel was a Panamax bulk carrier with an optimized bottom design for combined loading according to DNV rules. Therefore, further work using different (local and global) load combinations by nonlinear finite element analysis is necessary. In particular, such an analysis is required when the new rule for bulk carriers, e.g. CSR-BC [14] is applied. It is also important to appropriately deal with different AHL conditions.

The overall objectives of this paper and the companion paper [15] are as follows:

(a) To describe a methodology for the finite element modelling of $(1/2+1+1/2)$ hold tanks of a bulk carrier under AHL condition;
(b) To calculate loads for a bulk carrier under AHL condition according to different rules, e.g. CSR-BC [14] and DNV [16] and to assess the ultimate strength of the hull girder under such loadings;
(c) To study the influence of using different (local and global) load combinations on the ultimate hull girder strength;

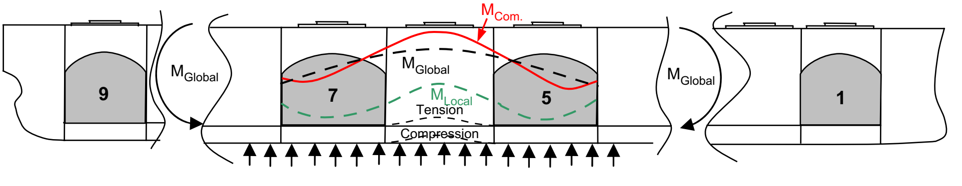

Fig. 1. Global and local load distribution of a bulk carrier in alternate hold loading condition.