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An algorithm for shear stress evaluation in ship hull girders

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ABSTRACT

The Common Structural Rules for Oil Tankers (OT) and Bulk carriers (BC) of IACS mandate the computation of shear flow in hull girders. Such computation involves determinate as well as indeterminate shear flow evaluation due to the multi-celled nature of the OT and BC transverse sections. This necessitates formulation of an algorithm for automatic detection of closed cells within a ship section as well as for automatic determination of positions of virtual slits for computation of indeterminate shear flows. It is also common practice to neglect the effect of longitudinal stiffeners when evaluating the shear flow in cross sections or to consider such effect using a gross approach. In the current work, the computation of shear flow in practical ship transverse sections has been performed. For this purpose an algorithm and subsequent program was developed to automate shear flow calculations which is applicable to any ship type. The results of the program were validated against benchmark examples as well as finite element results. Case studies were performed on VLCC and BC midship sections. The results also prove that consideration of longitudinal stiffeners does not significantly affect the magnitude of the shear stresses developed in the ship plating.

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1. Introduction

Ship structures are assessed for their integrity against classification society rules. It is an established practice to evaluate the hull girder longitudinal strength against applied still water and wave bending moments. The present rule practices for evaluating adequacy of scantlings against shear stresses are approximate in nature as they mainly consider the vertical longitudinal plate elements (bulkheads and side shell) which contribute to resisting the applied vertical shear forces. However, the recently released Common Structural Rules (CSR) for Oil Tankers (OT) and Bulk Carriers (BC) (IACS, 2014) mandate the actual computation of shear flow and shear stresses in hull girder cross sections subjected to applied still water and wave induced shear forces.

Ship hull girder cross sections are essentially multi-celled cross sections. Evaluation of shear flow in open cross sections (i.e., cross section with no cells or loops) is a relatively straight forward task as such a section is determinate with respect to shear flow calculations. Evaluation of shear flow distribution in multi-celled cross sections, however, involves computation of determinate as well as indeterminate components of shear flow which arise due to multiple flow paths for shear in such sections. Complexity of manual calculations further increases if longitudinal stiffeners are also considered essentially making the hull girder a composite combination of open and multi-celled closed cross sections, i.e., an open-closed section. For aiding the automation of such analyzes as required in CSR, an algorithm is required which is the subject of this research.

The present work explores the calculation of shear stresses in ship hull girder sections using first principles of the Euler-Bernoulli beam theory in combination with the theory of thin-walled structures. The effects of longitudinal stiffeners without any approximations have also been considered which adds further generality to the present work. The developed algorithm enables the present work to be applied not only to any ship section, but also to any general homogeneous linear isotropic prismatic arbitrarily shaped thin-walled beam cross section.

2. Literature survey

2.1. Theory

Hull girder bending moments have been extensively researched in literature. However the consideration of hull girder shear forces (still water and wave) has not been so elaborate. The theory behind shear flow and shear stress calculations for thin-walled open or single-celled closed cross sections is well established (Neiman, 1948; Pilkey, 2008, 2007; Shama, 2010; Slivker, 2007;

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Srinath, 2003, Vlasov, 1961). Ship hull girders being multi-celled open-closed cross sections, however, present difficulties for evaluation of shear flow and shear stresses as the automation algorithm for such sections is not adequately clarified from the aforementioned references.

Conventional practices for calculating shear stresses have sought to consider the cross section areas of the longitudinal vertical members, such as longitudinal bulkheads, side shell, girders, and projected areas of inclined members on a vertical plane, for e.g., hopper tank, to get the average shear force generated in the vertical members. Thus conventional practices are based on engineering approximations. However, the maximum stresses are higher than the average shear stresses, and it is not straightforward to calculate these peak stresses from their average and hence, the use of this approach is not advisable. Hence, attempts were made to develop empirical formulae and parametric relations between ship scantlings and shear flow.

Shama (1969) used five independent parameters of main plating scantlings, breadth-to-depth ratio and distance of transverse bulkheads from the centerline of the section to study their effect on shear stress distribution in ship hull girders. In this parametric study, the effect of stiffeners and girders was assumed to be taken into account by smearing their total area over the main plating of the section. Shama (1971) concluded from a parametric study on oil tankers using effective thickness approach that the transverse position of longitudinal bulkheads and the relative effective thicknesses of the side shell and the longitudinal bulkheads influence the maximum shear stress values significantly. Shama (1975) then performed a parametric study of shear stresses in bulk carriers considering variables such as the scantlings of the hopper plate, top wing tank, internal partitions of the top wing tanks, width of hatch openings, and depth of the double bottom structure. Further study (Shama, 1976) concluded that double bottom plates do not contribute to resistance to vertical shear forces and the side shell between the hopper and top wing tanks carries about 35% of the total shear force making it a critical portion insofar as shear stresses are concerned. Effects of longitudinal stiffeners were neglected. Shama (2010) again proposed thickness smearing for bulk carriers and oil tankers.

In aerospace applications, particularly in aircraft wings, the general practice is to lump the stiffeners as point masses or areas called 'booms' assuming the size of the stiffeners to be small compared to the dimensions of the cross section (Megson, 2012). References of this methodology being applied to ship structures, however, were not available within the references studied in the present work. Stiffener lumping is a better approach as compared to thickness smearing since moments of inertia, position of center of gravity, etc. are better approximated by lumping rather than by smearing which only approximates the area correctly and not other section properties. However, if an automatic shear flow calculation algorithm and a convenient 2-D modeling methodology are available, then stiffener lumping as well as the as-is consideration of stiffeners require roughly the same amount of effort from the user since in the former case, stiffener properties (positions, areas, and moments of inertia) have to be manually fed to the program, whereas in the latter case, stiffeners have to be directly modeled. Also, stiffener lumping is more suited for manual shear flow calculations since automating these calculations requires exactly the same algorithm as that required for evaluation without lumping.

Thus has been the gradual shift from average shear stress determination to equivalent thickness by stiffener smearing pertaining to ships. To the best of the authors' knowledge, stiffeners have not been considered in ships either by lumping or as-is within the literature surveyed.

2.2. Implementation of automatic calculation of shear stresses in multi-celled sections

A number of computer program implementations to automate shear flow evaluation have been proposed. Shama (1971) wrote a program to perform shear flow analysis specifically for tankers and used it for optimization of shear carrying members. Marshall (1974) developed a FORTRAN program based on Batho-Bredt equations for the calculation of shear flow in multi-celled thin-walled beams. Its application to a ship hull girder was demonstrated. However, the program had limitations as it assumed a symmetric structure, and the positions of virtual slits and closed cells had to be manually fed as user inputs to the computer program. Alfano et al. (1996) used the Depth First Search algorithm developed by Tarjan (1972) and an Open Section Cut algorithm they proposed to automate shear flow calculations with bare minimum inputs of section geometry, and demonstrated the application to a ship hull girder. However, the formulation of the program was unclear due to the academic nature of its description in terms of tensors, vectors and integrals (Edlund, 1997). Accordingly, Edlund (1997) expanded the work of Alfano et al. (1996) and gave formulae for the integrals and matrices appearing in the computer program. Utility of the procedure was demonstrated by computation of shear stresses for a passenger ship section, however, without including longitudinal stiffeners. Prokić (2000) also developed a program on the lines of Alfano et al. (1996). The coordinate system had to be rotated to the principal coordinate system of the beam which decreased the efficiency of the program by increasing the number of calculations.

Thus computer programs have been proposed for shear flow evaluation. However, all the programs except for the one written by Edlund (1997) have limitations.

2.3. Classification society approaches

Rules of various classification societies (BV, 2013; DNV, 2014; GL, 2013; IRS, 2014; LR, 2013; NK, 2013) and CSR (IACS, 2014) prescribe simplistic evaluation of the net shear force carried by the vertical hull girder members for an applied vertical shear force for various candidate ship configurations. The effect of stiffeners appears to be neglected/implicitly considered in all these configurations, and the empirical formulae given are only valid for a vertically applied shear force. These simplistic evaluations may need to be augmented for consideration of horizontal shear forces as well. However it is acknowledged that some of the rules also recommend the use of explicit shear flow calculations (ABS, 2014; CSR IACS, 2014, etc.).

2.4. Summary from literature survey

From the literature survey, the following salient findings were noted:

1. Analysis of shear stresses in ship hull girders can be performed by considering them as thin-walled multi-celled open-closed cross sections.
2. While theoretical background for shear analysis of open-closed thin walled cross sections is available, illustrative examples providing insight into step by step calculation of shear flow in complex multi-celled open-closed sections is scarce. Also relevant literature with application to ship structures is also rare.
3. Computer implementation of automatic shear analysis of thin-walled cross sections has been performed previously. However the practical applications attempted were relatively simple when compared to ship hull girders. Hull girders have been analyzed with such programs (Alfano et al., 1996; Edlund, 1997), but stiffeners were not considered.

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