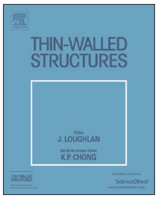
Thin-Walled Structures 94 (2015) 545–561

Contents lists available at ScienceDirect

Thin-Walled Structures

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



Ship structural integrity using new stiffened plates

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A R T I C L E I N F O

Article history:
Received 3 April 2015
Received in revised form
26 May 2015
Accepted 30 May 2015
Available online 15 June 2015

Keywords:
Stiffened panels
IACS
Axial load
Ultimate strength
Y-stiffeners

A B S T R A C T

The objective of the present paper is to use novel longitudinal Y (Hat+Conventional) stiffener profiles instead of the conventional stiffener profiles. That helps obtaining more safety margin (the ultimate strength minus the applied compression stress) to weight ratio. Using the hat section (closed section) gives more torsional rigidity and more effective plate allowing an increase of the stiffener spacing, hence a reduction in the number of stiffeners. During the replacement process the following constraints are taken into account: the weight of the stiffened bottom and deck panels, and the unstiffened plate width using the Y-stiffener profiles are less than those of panels with the original conventional stiffeners, whereas the section modulus of the Y-stiffener with the attached effective plate is larger than that of the original conventional stiffener. The safety margin of bottom and deck panels with Y-stiffeners is to be more than that of panels with the original conventional stiffeners. The ultimate strength of stiffened panels with either longitudinal conventional or Y-stiffener profiles were calculated according to the International Association of Classification Societies-Common Structural Rules for double hull oil tanker based on the following failure modes: unstiffened plate buckling, stiffener beam-column buckling, and stiffener torsional/flexural buckling (tripping). The attached effective plate for the Y-stiffener was calculated according to Eurocode. The Y-stiffener is a built-up section and the simplest production method is to weld the lower end of the web of a conventional stiffener to the top of the hat part. The conventional stiffener as a part of the Y-stiffener is fabricated according to the ratios stated in the International Association of Classification Societies-Common Structural Rules, while the hat part of the Y-stiffener is made by a hot-rolling process with inclination angle of the two webs of the hat taken as 30°, 45°, 60°, and 90°.

1. Introduction

The main type of framing system found in ships nowadays is a longitudinal one, with stiffening in two orthogonal directions. Bottom and deck structure panels are reinforced mainly in the longitudinal direction with widely spaced heavier transverses. In typical tanker structures, bottom and deck plate panels are reinforced by longitudinals in the longitudinal direction and transversely supported by widely spaced transverse structures (such as transverse bulkheads, deck beams and bottom floors). The bottom and deck longitudinals are T-sections, angles, bulbs or flat bars, while the deck transverses are typically T-sections. These transverse members usually have significantly greater stiffness in the plane of the lateral load, while the longitudinals have greater stiffness in the aspects of bending and axial loading. The boundary conditions for the ends and along the sides of the bottom and deck panels may be considered as simply supported. Ship panels, in general, are divided into three distinct categories: (1) unstiffened panels bounded by longitudinal stiffeners and transverse frames called subpanels, (2) longitudinally stiffened panels between adjacent transverse frames as one bay of a grillage and usually called stiffened panels, and (3) gross panels with longitudinal stiffeners and transverse frames called grillages.

A stiffened panel is an assembly of plating and stiffeners. It is normally designed so that the buckling of a local plate panel between stiffeners initially takes place and is then followed by overall collapse due to excessive yielding and/or stiffener failure. The primary failure modes of a stiffened panel can be categorized into the following six types [1].

- Mode I: Overall collapse after overall buckling of the plating and stiffeners as a unit.
- Mode II: Biaxial compressive-type collapse in plating between support members, i.e., without failure of support members (plate-induced failure by yielding at the corners of plating between stiffeners).

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http://dx.doi.org/10.1016/j.tws.2015.05.018
0263-8231/

- Mode III: Beam-column-type collapse of plate–stiffener combination, i.e., stiffener with associated plating (stiffener/plate-induced failure by yielding of stiffeners with attached plating at mid-span).
- Mode IV: Buckling of stiffener web (stiffener-induced failure by local buckling of stiffener web).
- Mode V: Flexural–torsional buckling or tripping of stiffener (stiffener-induced failure by lateral–torsional buckling or tripping of stiffeners).
- Mode VI: Gross yielding.

Some of these failure modes may in some cases interact and occur simultaneously. However, for design purposes, they are typically treated separately, i.e., the buckling collapse strength of a stiffened panel is usually assumed to be equal to the minimum strength value, obtained with each buckling collapse failure mode separately [2].

The present study aims at improving the geometrical and ultimate strength characteristics of bottom and deck panels of a very large crude carrier (VLCC) under axial compressive loads based on replacing the conventional stiffener profiles with novel Y-stiffener profiles.

Bottom and deck panels experience large in-plane compression or tension primarily in the ship's longitudinal direction caused by the hull girder bending moment. While outer bottom panels are subjected to additional bending moment due to lateral pressures from the seawater and ballast water, inner bottom panels are subjected to additional bending moment from the cargo lateral pressure. On the other hand, for tankers, lateral pressure applied on the deck structure is negligible.

The bottom and deck panels considered in the present study are situated amidships and there are two loading conditions:

- Loaded condition (sagging vertical bending moment).
- Ballast condition (hogging vertical bending moment).

The vertical sagging bending moment causes deck panels to be in compression and bottom panels in tension, while vertical hogging bending moment puts the deck panels in tension and bottom panels in compression. Since the ultimate strength capacity in tension is higher than that in compression, the ultimate strength failure occurs when applied compressive stress exceeds the ultimate strength of the bottom and deck panels. So during the loaded condition, deck panels are studied, while during the ballast condition, outer and inner bottom panels are studied.

In this study, three different dimensions of Y-stiffener profiles are used in the midship section, one of them is used in the outer bottom, another one is used in the inner bottom and the last one is used in the deck.

In addition, bottom and deck section moduli of the overall midship section with the Y-stiffeners do not differ much from those with the original conventional stiffeners but still satisfy the International Association of Classification Societies-Common Structural Rules (IACS-CSR) requirements for both hull girder section modulus and moment of inertia. Furthermore, the safety margin of bottom and deck panels with Y-stiffeners is to be more than that of panels with the original conventional stiffeners.

The authors used an analytical software program called EES (Engineering Equation Solver) [3] to get the analytical models of the stiffened panels' ultimate strength and geometrical characteristics with either conventional or novel Y-stiffener profiles based on the various stiffened panels' failure modes stated in IACS-CSR [4] (unstiffened plate buckling, stiffener beam-column buckling and stiffener torsional/flexural buckling) and also in Eurocode [5] to calculate the attached effective plate of the Y-stiffener profiles.

2. Literature survey

The Y-stiffener concept was introduced by Ludolphy [6] who introduced the Y-stiffener and proved that it has a significantly higher resistance against collisions and grounding than the traditional stiffeners. The energy absorption by the Y-stiffener has been studied by Naar et al. [7]. Tests of Y-stiffeners were carried out by Badran et al. [8] who studied the stability of Y-stiffeners analytically and thus obtained approximate expressions for calculation of the elastic buckling coefficients of the T part of the Y stiffener. Also, the critical buckling load of Y-stiffeners was calculated for two studied groups with different boundary conditions and compared with T-stiffeners as has been presented by Badran et al. [9]. Multi-objective optimization with real-coded genetic algorithms for designing optimum Y-stiffeners under the action of uniaxial compressive loads has been presented by Badran et al. [10]. Badran et al. studied the effect of three levels of initial imperfection on the ultimate strength of Y and T-stiffeners subjected to lateral loads [11]. *El-Hanafi et al. clarified how the dimensions of the Y-stiffener are obtained from original T-stiffener in the midship section and how the Y-stiffener with attached plate is designed against the buckling strength according to new IACS Common Structural Rules [12].* Brubak et al. computed semi-analytical elastic methods for stiffened plate analysis in addition to eigenvalue analysis, such methods may also offer a viable approach for the prediction of ultimate strength limits (USLs) of the plates when combined with appropriate strength criteria [13]. Cai Xu and Soares tested five specimens under axial compression until collapse to investigate the ultimate strength of wide stiffened panels with four stiffeners. To avoid the side bays collapse and reduce the influence of the clamped boundary condition on the collapse behavior, the tests were made on panels with two half bays plus one full bay in the longitudinal direction with simply supported condition at the end edge of loading [14]. Choung et al. evaluated the distributions of three slenderness ratios of the plates, the stiffeners, and the stiffened panels, and presented a comparison of the load-shortening behaviors of the stiffened panels. The slenderness ratios, which represent the geometry and material properties of the stiffened panels, were obtained from bottom and deck plating of the midship area of 163 vessels, including 59 tankers, 46 bulkers, 28 product carriers, 15 container carriers, and 12 miscellaneous ships [15]. Gordo and Soares presented the results of eight tests on stiffened panels under axial compression until collapse and beyond. The tests considered panels with different combinations of mechanical material properties and geometric configurations for the stiffeners including the use of 'U'-shaped stiffeners [16]. Hamedani and Ranji presented the buckling analysis of stiffened plates, using both conventional and super finite element methods (FEM). Effects of various combinations of biaxial loads along with different boundary conditions on buckling characteristics of stiffened panels were also investigated [17].

Liu and Glass investigated the effects of wall thickness and geometric shape of thin-walled structures on their performance during structural analysis [18]. Liu and Wang investigated the strengthening effects of regular stiffened plates which are subjected to uniaxial stress and then arbitrarily stiffened plates that are subjected to biaxial stress. The optimal height, number, and arrangement of the stiffener that provide the best strengthening effect were revealed and it was also found that the strengthening effects of an arbitrarily oriented stiffener (or oblique stiffener) can be decoupled to two perpendicular regular stiffeners which are located in appropriate positions [19]. Paulo et al. presented a set of finite element analyses using ABAQUS to reproduce the mechanical behavior of integrally stiffened panels when subject to longitudinal compression. Most fabrication processes, such as welding, introduce distortions and affect the material properties. The sensitivity to these defects was assessed in [20].