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Simplified analytical method for the evaluation of longitudinal strength of large sailing yachts

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ABSTRACT

Yacht manufactory industries have been faced with two different trends over the last few years: on the one hand, the current economic crisis, which has halted the production of super and mega yachts, and on the other, the increase in the dimensions of both sailing and motor yachts. In the case of sailing yachts, this trend has brought about a consequent increase in rigging proportions. Higher masts and wider sail plans have led to an enormous increase in rigging and sheet loadings. Meanwhile, speed has become an increasingly important focal point in the design process, in order to respond to market requirements; this scenario requires an acceptable compromise between structural requirements due to high rigging loads and structural weight reduction to improve the craft speed and to reduce costs and production times.

For these reasons, the global strength of the hull has become a crucial aspect in the design process. Traditionally, only still water and wave bending moment in hogging and sagging conditions have been considered as global loads. For sailing yachts, however, the dock tuning bending load, which has a similar order of magnitude to the global bending moment, must be implemented in primary strength response.

In this paper, the authors present a Simplified Analytical Method (S.A.M.) to estimate the longitudinal strength of a large sloop sailing yacht; this approach has been developed studying a 47-meter yacht by FE technique coupled with classic beam theory and has been verified through the analysis of other two sailing vessels of similar length. A user-friendly routine for this aim, called “StrengthCalc”, has also been created.

1. Introduction

For a long time the structure scantling of conventional pleasure craft was carried out on the base of static local loads and wave impact loads for very fast vessels. With the continuous dimension increasing of last twenty years, at present approaching the unbelievable length of 200 m, major attention has been devoted also to hull girder strength and for larger motoryachts, say above 45–50 m in length, Classification Societies require a verification of longitudinal strength by applying the usual methodology based on still water and wave bending moment distribution.

The same trend appeared also in the sailing yacht market where many shipyards built vessels with lengths over 50 m. Just to give some examples of the most recent production we can quote “Maltese Falcon” (88 m), a three mast clipper built by Perini Navi shipyard and “A” (144 m) another three mast clipper built by Blohm+Voss shipyard. In the category of single mast yachts (sloop) we can quote “Perseus 3” (60 m) built by Perini Navi shipyard, “Ahimsa” (66 m) built by Vitters shipyard and the most famous “Mirabella V” (78,4 m) built by Vosper Thornycroft shipyard.

The structural design of vessels of these dimensions and economical value, should then be carried out with great care, following the usual procedure based on local scantling and hull girder strength verification normally adopted for motor yachts and merchant ships. The importance of primary strength for sailing yachts has been highlighted by several authors in literature (Boote et al., 1985; Lewis, 1988; Larsson and Eliasson, 1994) and by most Classification Societies (American Bureau of Ships, 2001; Germanischer, 2003; Lloyd's Register of Shipping, 2011; Registro Italiano Navale, 2011; Det Norske Veritas, 2011). A comprehensive review of structural problems regarding sailing yachts is available in the ISSC 2009 Report of the V.8 Committee “Sailing Yacht Design” (ISSC, 2009).

The need for a significant reduction in costs and production time, in order to cope with the current financial crisis, has led to the use of different materials for hull construction, with lower mechanical properties, such as light aluminium alloy and composites. The longitudinal strength of large vessels has thus become one of the most important aspects in the structural design of sailing yachts.

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Nomenclature

S.A.M	Simplified Analytical Method
q_x	Out-of-plane external loads
E	Young's elasticity modulus (N mm^{-2})
ν	Poisson's modulus
Js	momentum of inertia of a cross-section of the steel hull (mm^4)
Ja	momentum of inertia of a cross-section of the aluminium superstructure (mm^4)
w_x	Out-of-plane displacement (mm)
x	Longitudinal position along the beam
M_x	Global bending moment (N mm)
φ_x	Rigid rotation of a cross section
t	Shell thickness
b	Shell breadth

In a sailing yacht, the mast is maintained in position by shrouds and spreaders, which basically fix particular mast sections to the hull. Nevertheless, if shrouds were simply placed, the mast would break as soon as the sail were reefed up. The ability of the mast to withstand sail loads is given by the pre-tension applied to shrouds and compressing the mast tube. This tension force is called "dock tuning load", since it is applied when the yacht is docked in a rest condition.

In large yachts, the tuning force is applied under the mast step by using an hydraulic system which basically forces the mast tube upwards. The compression of the mast tube is matched by the tensile stress of the backstay and forestay, which are fixed somewhere to the stern and bow of the hull.

When hull length and sail areas become relevant, i.e. above 30 m in hull length, the magnitude of the dock tuning load also starts to be relevant. Considering that the force applied has a value of between 50% and 80% of the yacht displacement, the resulting bending moment reaches values comparable to wave bending moment in sagging or hogging conditions, and influences the structural elements all along the hull; hence, it is a truly global load and cannot be neglected. Considering the superposition principle, the real loading condition becomes the one shown in Fig. 1.

The aim of this work is to study a Simplified Analytical Method (S.A.M.) for taking into account the dock tuning load in the global strength procedure, in order to introduce this component into forthcoming rules of Classification Societies for rig scantling.

This method has been strengthened using a parametric algorithm, based on classic beam theory and on the hull girder theory, appropriately modified to be implemented into a numerical procedure. It has been further tested by making a comparison with the results of the global Finite Element analyses, which have been performed for three different vessels. The S.A.M. is based on a case study consisting of a 47-meter sloop vessel, with a steel hull and a light aluminium alloy superstructure, which will be named "Yacht A".

2. Classical approach to longitudinal strength

The most common approach to longitudinal strength is based on the well known hull girder theory, developed for large merchant ships in order to perform stress and strain calculations along hull cross-sections. Among the wide variety of articles available in literature on this argument the paper by Yao (2003), even if related to merchant ships, represent a good synthesis of the method with some interesting historical reviews. A comprehensive example of hull girder strength evaluation to a motor yacht has been presented by Roy et al. (2008). A specific application of the same method to a very large sailing yacht has been presented by Shimell et al. (2012).

This theory requires some basic simplifications in order for it to be easily applicable, both in the structural schematisation and in the loading scenario:

•all loads must be considered static;

•loads must only be dependent on longitudinal location along the hull (x axis), meaning that they are applied on the hull's neutral axis regardless of the actual vertical application point and direction;

•deflections have to be very small compared to the length of the vessel, in order to ensure linear and completely elastic structural behaviour;

•the cross-section must be constant along the length;

•cross-sections remain planar and do not deform even if loadings are applied. This means that each cross-section remains perpendicular to the neutral axis and is characterised only by a vertical displacement and a rigid rotation around the transversal y axis;

•internal stresses are due only to the bending moment, without considering vertical shear force, while the torsional moment can be considered separately;

•longitudinal compression is disregarded, but may be considered separately;

•the constitutive equation must be valid, which means that stress and strain are directly proportional.

The above hypotheses relative to cross sections are obviously not realistic for ship and yacht structures (Fig. 2a, b, c and d). This means that hull has to be longitudinally subdivided into several blocks along which cross-sectional area and second order momentums can be considered constant, thus creating a stepped curve instead of a continuous one representing real distribution of cross-sectional properties along the length (Fig. 3).

Further investigations need to be made regarding boundary conditions; in a certain sense, the hull girder model has no boundary condition, since it is self-equilibrated by external loads and buoyancy.

This assumption – which is very close to reality – simplifies the calculations, since it excludes the presence of concentrated forces and momentums generated by boundary conditions.

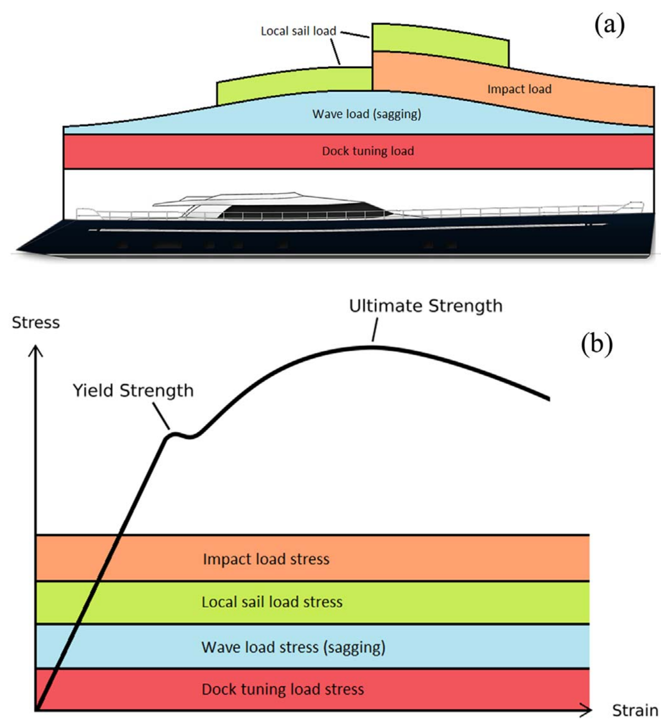

Fig. 1. (a) Schematisation of global loads and (b) Global stress condition compared with stress-strain diagram.