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ORIGINAL PAPER

An automated computational tool for offshore supply vessels' structural preliminary design

Richard D. Schachter[1] · Ricardo S. Gomes Jr.[1]

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Abstract
This work presents the application of the rules of the Classification Society American Bureau of Shipping (ABS) for steel vessels in a development of an Excel computational tool that allows to speed up the preliminary structural design calculation process, from several days to minutes, with no precision loss, based on the main particulars and a few structural characteristics, automating everything that does not depend on decision-making. This tool is intended to be a first of a few to perform the required calculations for the preliminary structural design, in this case, applied to Offshore Support Vessels. Once the frame type, the selection of the commercial steel type, and manufacturer are prescribed by the user, all the rules are automatically calculated, all the thicknesses are computed and presented, and rounded up to the commercial values and which reinforcements need to be dimensioned are defined. The user then should dimension these structural elements by selecting the profile type, thickness and height of the web, and thickness and length of the flange, such as stiffeners and/or girders of the bottom, double bottom, sides, double sides, decks, and bulkheads; solid and open floor, side stringers, frames, bottom and deck girders, deck transverses, bulkhead girders, and webs. Besides verifying if the structural strength values are in accordance with the classification society rules in each and every step of the dimensioning process, the program also shows a sketch of the Midship Section that is redrawn at each decision change of the user. The program also verifies the global structural resistance; calculates the steel area, the hull girder section modulus, and moment of inertia; compares these values with the minimum rules requirements; and analyzes if the ship fulfills the longitudinal resistance. Soon after, based on the midship section, the sectional area and the transverse bulkheads positions, the program estimates the steel weight, and center of gravity of the ship. Finally, the user can generate a detailed Report that contains all the information produced by the program, as well as the calculation memory. An application example is presented.

Keywords Structural preliminary design · Offshore supply vessels · Computational tool

1 Introduction

This work aims to present the development of a tool capable of determining the structural topology as well as the preliminary structural design of any Offshore Supply Vessel, according to the ABS rules for this type of vessel. The program uses commercial steel plates thicknesses to approximate the calculated thicknesses to ensure realistic structural weight results.

✉ Richard D. Schachter
richard@oceanica.ufrj.br

1 Departamento de Engenharia Naval e Oceânica, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil

The motivation to develop this type of program that integrates the different design factors comes from the need for a tool that helps the designer to contextualize them in an efficient way for a vessel in the preliminary design phase.

It was necessary to develop the structural module in order to speed up the process of elaborating the structural topology from some information about the vessel and some decisions regarding the structural topology. From this and the steel type and manufacturer, the program performs the rule calculations and subsequently the structural elements dimensioning. After designing the structure, the user can visualize not only the design of the midship section, but also the results of the structural weight calculation. Finally, the user can generate a detailed report containing all the information generated by the program as well as the calculation memory, and use it as preliminary structural design, or even correction of academic works.

2 State of art

The state of art of ship design methodology has evolved enormously from the classical, but fundamental, Design Spiral [1–3], but with its cyclic characteristics still being followed until today. Nowadays, several design approaches have been developed and proposed in computer-aided design, such as the application of optimization, expert systems (rule-based). There are specific approaches, such as Concurrent Engineering [4], Solution-Focused Design [5], but they all are for the overall design, being the structural design usually one of their modules.

As in other areas, but particularly in Structural Design, several tools have been developed to assist the designer, and some pay special attention to the preliminary design [6].

Thanks to the computer assistance, the development of optimization algorithms has become easier. In this analysis, structural optimization consists of defining optimum scantling of the shell plating and framing, while the general dimensions and hull form are considered fixed. In other words, for a defined hull dimension, the program calculates the closest commercial thickness for the shell plating comparing to that required by rule, and for the reinforcement sizing, it will be signaled whenever the calculated values differ too much from the values required, which would indicate a structural oversizing resulting in an unnecessary steel weight.

The structural design is an iterative process involving the definition of the most important loads that act on the structure, development of the structural configuration and estimation of weight and center of gravity, creation of a model of the proposed structure, analysis of the model, and comparison of its performance against the specified design criterion and modification of the structural configuration for proper performance, avoiding unnecessary costs [7].

The steel structure of the ship's hull is one of the most expensive project concepts. A possible design process is shown in Fig. 1 [8], where the main frame is usually based on a similar vessel already built. The classic designs are performed as defined by the Classification Societies in order to guarantee the safety [9], and FEM calculations are done in addition. This project focuses only on the main frame, the scantling calculation, and the weight estimation.

Usually, the preliminary structural design takes several days, but the development of computational tools, especially this one, has been able to reduce this time to minutes.

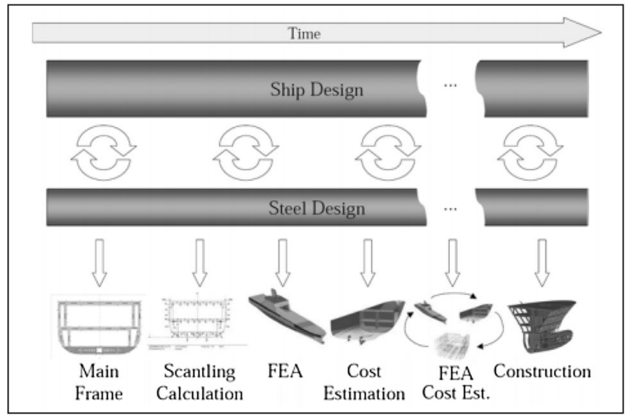


Fig. 1 Ship and steel design process. *Source* Krüger [8]

2.1 Software comparison

Typically, some software packages essentially perform a rule-based check of the modeled midship scantlings—such as MARS 2000 (from BV), Nauticus Hull (from DNV), High Speed Structure [10], while other just check the properties of the main frame designed—such as Maxsurf Structure (from Maxsurf), Section Modulus Editor (from HECSALV).

The Nauticus Hull is a DNV GL's software which allows to evaluate the vessel structural strength offering all necessary tools for hull design and verification according to DNV GL rules for ships and FPSOs and IACS Common Structural Rules for bulk carriers and oil tankers [11]. Although it has a powerful modeling capability making, it is limited to bulk carriers and tankers.

The Mars 2000 is one of the supporting tools of the Joint Bulker Project, and was developed by Bureau Veritas. Its latest release can check the scantlings of cross-section and transverse bulkheads for tankers according to the new IACS-CSR 2012 requirements [12]. Similar to Nauticus Hull, Mars 2000 is limited to bulk carriers and tankers.

The Maxsurf Structure module provides initial definition of structural parts including hull plates, stringers, transverse frames, decks, and longitudinal structure for all types of Maxsurf designs. So, one of the greatest disadvantages comparing the tool developed in this study is the necessity to import the hull from another Maxsurf module [13].

Nauticus Hull, Mars 2000, and Maxsurf Structure do not provide detailed calculations report and a structure's weight and CG estimation, nor a midship section automatic drawing.

Section Modulus Editor is a detailed structural section definition tool Program in HECSALV™ to build structural cross sections from a library of standard structural shapes and compute section modulus as well as other structural properties. As it can be seen, this tool allows the definition of a main frame, but it does not check the rules [14].

High Speed Structure is an integrated software that allows for compartmentation, makes the necessary structural design calculations by applying the rules to High Speed Craft of the Classification Society ABS for monohull vessels built in steel or aluminum [10]. It tries to improve the integration between structural detailing and the Rule calculation, and, comparing to the previous software, it is the only one that provides the weight of steel/aluminum and its center of gravity. The hull needs to be imported from an existing system program called Planing Hull Form (PHF) [15]. This software is integrated with a System for high speed craft, but again, it is necessary to import the hull form from another program.

The design computational tools developed to perform calculations on each subject reflect the overall design approach of the developer. The program presented in this work follows the philosophy adopted by the authors, the Solution-Focused Design approach [5] and one of its main programs of its design system [16], where, in order to fulfill special issues of software integration (multidisciplinary screens and files, coding structure allowing to interleave from one design program to other, etc.), is required to have modules programmed to minimize the inputs and screens, and automate all processes that do not require human reasoning. In the case of the automated tool proposed on this study, its development was based on high speed structure that is part of the solution-focused design system (SFDS). It is expected that this tool be able to perform a rule-based calculation and an estimation of the weight of steel and its center of gravity. Differently from the software presented above, this tool will not focus on vessels such as oil tankers and bulk carriers, which already have excellent references, but in OSVs.

The philosophy explained above was applied to the development of this program and consists of its contribution. From experience in structural design, all the design following a classification society was, step by step, scrutinized, and all required inputs and decisions were separated from the calculations and drawing that could be done automatically, resulting in a structural design process that usually takes days to make, to be done in minutes, with no precision loss, and providing an automatic drawing of the main section, a fully detailed calculus memory using commercial thicknesses, and a structural weight and CG calculation. As can be seen, most programs in the literature require that the user define the main frame in advance or that the hull be imported from another program in order to perform the calculations (including SFDS), but for this program, the user will only need to provide the main dimensions and the program will automatically generate the midship section, based on the sectional area curve or an estimation of it. The user will only have to define the spacing and size structural elements and the tool will automatically position all the relevant structural elements, which will allow a considerable reduction of the design time, as well as a structural optimization.

3 Rules implemented in the structural model

Firstly, there is no intention of reaching the final structure that will be classified and approved by the classification society, but rather, from some information regarding the vessel and the structural topology, find a valid initial approximation of longitudinal resistance, defining a preliminary structure that can be considered as an initial estimate for the structural design of an OSV and obtain the weight and center of gravity of the structure. For this reason, the use of the rule is made partially, not taking into account all parts and chapters. For the development of this tool, the ABS Rules for Building and Classing—Offshore Support Vessels 2016 were implemented.

As such, the following was used:

Part 3, Chapter 2,

- *Section 1* Longitudinal strength
- *Section 2* Shell plating
- *Section 3* Decks
- *Section 4* Bottom structures
- *Section 5* Frames
- *Section 6* Web frames and side stringers
- *Section 7* Beams and longitudinals
- *Section 8* Pillars, deck girders, and transverses
- *Section 9* Watertight bulkheads and doors
- *Section 11* Superstructure, deckhouses, and helicopter decks.

The use of these chapters and sessions allows the calculation of the hull girder bending moments, the shell plating thickness, and the calculation of the required section modulus of the various structural elements, such as stiffeners and girders. Since the program will make partial use of the rules, local analyses for resistance and fatigue analysis will not be considered. In addition, the program will be developed to work only with transverse or longitudinal reinforcement, without considering mixed reinforcement. Also, the variation of the spacings between rigid elements will not be taken into account, that is, once the spacings of the elements have been defined, they will not be altered. Finally, although the tool is able to calculate the thickness of the tunnel of the bow thrusters, the superstructure, and the forecastle, these elements will not be detailed nor considered for the calculation of the steel weight, since the main objective of the program will be the overall longitudinal strength of the vessel.

3.1 Programmed rules

The rules of Part 3, Chapter 2, as mentioned, have been implemented, of which the following stand out:

3.1.1 Hull girder longitudinal resistance

i. Hull girder section modulus;
ii. Bending moment and shear force;
iii. Moment of inertia.

3.1.2 Shell plating

Minimum thickness:

- Bottom plating;
- Double bottom plating;
- Side plating;
- Decks plating;
- Bulkhead plating;
- Forecastle plating;
- Bow thrusters tunnel plating;
- Superstructure plating.

3.1.3 Stiffeners and girders resistance

The program allows the user to size the following structural elements since the rule provides a minimum section modulus for them:

- Bottom
- Inner-bottom stiffeners;
- Side stiffeners;
- Main deck stiffeners;
- Lower decks stiffeners;
- Bulkhead stiffeners;
- Center and side girders or keelson;
- Open or solid floors;
- Side Stringers;
- Web frames;
- Deck girders;
- Deck transverses;
- Bulkhead girders and web.

3.2 Manufacturers

As not all thickness values are manufactured, 6 steel plate manufacturers were cataloged. Thus, the values found in the calculations for plate thicknesses through the ABS rules were adjusted to the next higher value in order to satisfy the rule and to define for the plates actual thickness values. The registered manufacturers were:

i. Aços Sul Norte;
ii. Açobril;
iii. Gerdau;
iv. Lineaço;
v. Paulisteel;
vi. SC Aços.

4 Program description

The main purpose of this development is to allow the times spent in the structural topology calculations as well as the preliminary structural design of an Offshore Supply Vessel to go from several days to minutes with great precision. In addition, such tool is expected to be able to compare the section modulus of the vessel with the rule section modulus, as well as generate the midship section drawing, calculate the estimated steel weight of the shell, and in the end, generate a report completely detailed. The main tasks are:

- Determination of the bending moment and shear forces;
- Structural dimensioning by ABS rules;
- Detailing of the main structural elements;
- Calculation of the section modulus and moment of inertia;
- Midship section drawing;
- Calculation of the steel weight of the structure and center of gravity.

4.1 Main particulars of the vessel

As a basis for calculations of structural strength, the user should provide some information regarding the vessel, such as scantling length, breadth, depth, draft, molded displacement at the summer load line, midship section coefficient, deadweight, deadrise angle, and deck load.

In addition, it is at this moment that some decisions must be made, regarding the structural topology of the vessel, such as frame type, number of transverse bulkheads, lower decks, number and position of longitudinal bulkheads and if there is double bottom, double side, and bow thrusters. It is from this information that the program will perform the tasks already described.

4.2 Calculation of the ABS rules and plate sizing

From the particulars defined by the user and some structural topology decision-making, the bending moment and shear force curves are generated automatically and both the moment of inertia and the section modulus required by the ABS are calculated.

Then, by means of the rules already described in Sect. 3, the rule thicknesses of the hull plates are calculated and approximated for commercial steel elements, depending on the selection of material and the manufacturer.

4.3 Detailing of structural elements

The stiffeners and girders are automatically defined by the program based on the structural topology defined. In order to perform the section modulus calculation of each of the structural elements, the user must detail the elements that contribute to the longitudinal and transverse strength of the vessel by providing:

- Section profile—”I” or “L”;
- Web dimensions;
- Flange dimensions.

With this information, the program calculates the section modulus of each of the structural elements $\left(\mathrm{SM}_e\right)$,

$$\mathrm{SM}_e = \frac{I_e}{z_n}, \tag{1}$$

where I_e is the total inertia of the element and y_n is the greater distance between the centroid of the element to its ends of the section. Finally, the section modulus of the element is compared with the required by ABS.

4.4 Section modulus

Once all the structural elements as well as the plates are completely dimensioned and meeting the requirements imposed by the ABS, the program calculates the hull girder section modulus (SM). In this calculation, only the longitudinal elements are considered, since the transversal elements do not contribute to the longitudinal resistance of the vessel.

$$\mathrm{SM} = \frac{\sum_i I_i}{\overline{Z}}, \tag{2}$$

where $\sum_i I_i$ is the sum of the moment of inertia with respect to the neutral line of the plates and all the longitudinal elements and $\overline{Z}$ is the greater distance between the neutral axis and the depth or the base line.

Once again, all data are automated by the program based on the vessel’s main characteristics and the structural topology defined. Then, a table containing the neutral axis height, steel area, moment of inertia, and the hull girder section modulus is displayed.

The neutral axis $\left(N_a\right)$ and the steel area $\left(A_s\right)$ are calculated considering the sum of the area $\left(\sum_i A_i\right)$ and the moments of area $\left(\sum_i A_i z_i\right)$ of all longitudinal elements i on the midship section.

$$A_s = \sum_i A_i \tag{3}$$

$$N_a = \frac{\sum_i A_i z_i}{\sum_i A_i} \tag{4}$$

Finally, in addition to the program comparing the section modulus and the moment of inertia calculated with the values required by the ABS, it also shows the percentage difference between the calculated section modulus and the required one. That is, in addition to showing if the vessel has the required minimum section modulus, according to the classification society rules, it also shows if the calculations are overestimated.

4.5 Midship section drawing

Based on the main dimensions and the structural topology, the program automatically scales the midship section of the vessel.

In this sketch, the spacings between stiffeners and girders are considered, as well as the frame type and the detailing of the elements, done previously.

4.6 Steel weight

Finally, this tool produces an estimate calculation of the steel weight and center of gravity of the vessel.

There are several ways of calculating the structural weight of a vessel. Some are more conventional and converge to fairly accurate results, such as when a modeling software is used. It is also possible to estimate the weight of the structure by means of empirical formulations based on the main characteristics of the vessel, but these provide more satisfactory results for ships that present a very significant parallel body when compared to the total length of the vessel.

However, the method used by the program is simplified and consists of using the midship section as the basis of calculation. In other words, since this station is, by definition, the section that best represents the structure of the ship, it is sufficient to estimate the steel weight and center of gravity for this section and then use such results to extrapolate the other sections of the ship and add them at the end.

To do this, the user must provide not only the sectional area curve of the vessel containing up to 20 stations (or an estimation of the section distribution along the stations), but also the position of the transverse bulkheads. In the case of transverse bulkheads, there is a limit of 15 bulkheads and collision bulkheads must be included.

$$W = V\rho_{\text{steel}}, \tag{5}$$

where, W is the steel weight, V is the steel volume, and ρ_{steel} is the steel density. Once all the structural elements of the midship section have been defined, the program calculates the steel volume of the midship section and then extrapolates the results to the other sections, based on the sectional area curve. Note now that for the calculation of the steel weight of the block, the transverse elements also need to be taken into account. In other words, since the area and the thickness of each structural element have already been calculated based on the previous structural design, it is only necessary to define the length of the block to be extrapolated. And Eq. (5) becomes

$$W = A_s l \rho_{\text{steel}} + \sum_i A_i t_i \rho_{\text{steel}}, \tag{6}$$

where $\sum_i A_i t_i \rho_{\text{steel}}$ accounts for the weight of every transverse element inside of the block. The length of each block (l) is automatically and strategically set to match the distance between the stations given by the user on the sectional area curve. In this way, it is possible to obtain the steel volume of the midship block and thus estimate the volume of steel used in each of the remaining blocks along the entire length of the ship.

$$W_h = W \frac{\sum_i A_{i_c}}{A_{M_c}}, \tag{7}$$

where W_h is the steel weight of the hull; W is the weight of the main block defined previously; A_{M_c} is the midship area obtained from the sectional area curve; and A_{i_c} is the area of each station also obtained from there.

The volume of steel of the bulkheads (W_b) is done analogously. The bulkhead steel volume at the midship section is calculated and then its value is extrapolated to the other bulkheads. In order to doing so, the program assumes that there is a bulkhead in the midship section and calculates the volume of that supposed bulkhead. From there and from the user-defined bulkhead position, the program extrapolates the volume value of this reference bulkhead to each of the actual bulkheads. To extrapolate this volume, the program interpolates the value of the area of each bulkhead from the sectional area curve and then multiplied by the respective thickness to obtain the volume of the bulkhead plate and finally adds the structural elements.

$$W_b = V_r \frac{\sum_i A_b}{A_r} \rho_{\text{steel}}, \tag{8}$$

where $\sum_i A_b$ is the sum of the area of all bulkheads and A_r and V_r are the area and the volume of the hypothetical bulkhead.

The steel weight of each block and bulkheads is added and then a margin of 2% is added for welding, thus obtaining an estimate of the steel weight of the hull.

$$W_{\text{steel}} = 1.02\left(W_h + W_b\right) \tag{9}$$

Knowing that the lightship weight involves many other parameters such as the weight of the superstructure, outfit, and equipment, this tool calculates only the steel weight of the hull.

In order to calculate the center of gravity, the program multiplies the steel weight of each block by the longitudinal position and the vertical position of each station, calculating the mass moment (mt). This moment is divided by the total weight of steel to obtain the GC estimate. Note that the program assumes hull symmetry in relation to the center line, because of this the hull TCG is assumed to be zero.

$$\text{LCG} = \frac{\sum_i W_i x_i}{W_{\text{steel}}} \tag{10}$$

$$\text{TCG} = 0 \tag{11}$$

$$\text{VCG} = \frac{\sum_i W_i z_i}{W_{\text{steel}}}, \tag{12}$$

where W_i is the weight of each block defined by the program; W_{steel} is the steel weight as defined previously; x_i is the longitudinal position of each station; and z_i is the vertical position of each station.

4.7 Case studies

In order to validate the proposed method, four OSVs were used as case studies. Two with longitudinal framing (PLSV and AHTS) and two with transverse framing (PSV and ORSV). All vessels presented in Table 1 are academic reports, and each one of them was modeled on Rhinoceros in order to obtain their steel weight and their center of gravity with precision. Note that although the models were created taking into account the superstructure as shown from Figs. 2, 3, and 4, the superstructure weight value was discounted because the program only calculates the value of the steel weight of the hull.

During the academic projects, the preliminary structural design was carried out and all the structural elements were dimensioned. Then, to obtain the values of the steel weights of these vessels, the values established by the designers were

Table 1 Comparison between methods

		Weight (t)	LCG (m)	VCG (m)
PSV [17]	Rhinoceros	837.4	44.2	4.32
	Tool	826.25	47.03	4.47
	Difference	1.35%	6.02%	3.36%
ORSV [18]	Rhinoceros	338.8	34.26	3.4
	Tool	345.42	33.14	3.25
	Difference	1.92%	3.38%	4.62%
PLSV [19]	Rhinoceros	1729.13	59.06	4.86
	Tool	1656.69	56.04	4.61
	Difference	4.37%	5.39%	5.42%
AHTS [20]	Rhinoceros	1294	39.2	5.91
	Tool	1232.35	37.3	5.58
	Difference	5.00%	5.09%	5.91%

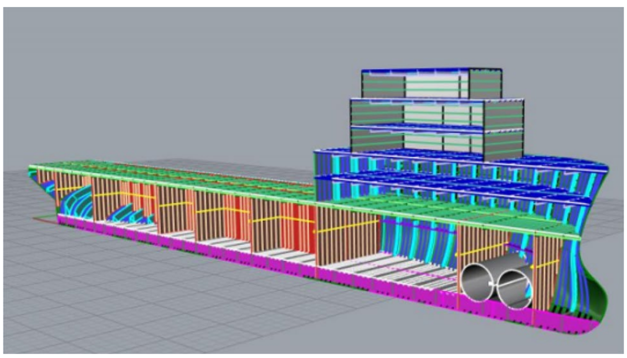


Fig. 2 PSV rhinoceros model. *Source* [17]

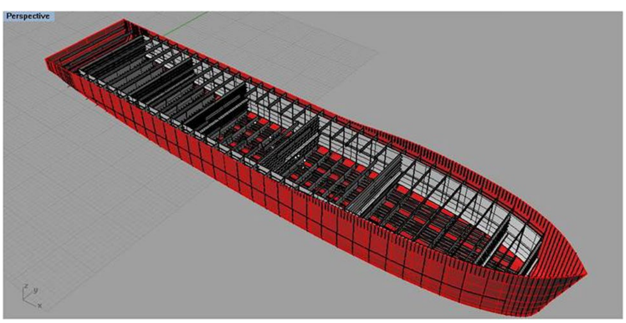


Fig. 3 PLSV rhinoceros model. *Source* [19]

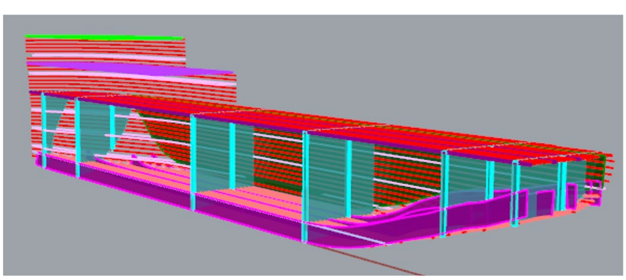


Fig. 4 AHTS Rhinoceros model. *Source* [20]

respected. To obtain weight by Rhinoceros, the area and area centroids of each set of elements were calculated and then multiplied by the dimensioned thicknesses. These values result in weight when multiplied by the density of the steel $\left(\rho_{\text{steel}} = 7.86\ \text{t/m}^3\right)$.

$$\text{Weight}_{\text{steel}} = At\rho_{\text{steel}}, \tag{13}$$

where A is the area of the set of elements and t is the thickness. For the CG, the sum of the moments of mass are calculated and then divided by the total weight.

$$X_G = \frac{\sum_i \text{Weight}_i X_{g_i}}{\text{Total weight}} \tag{14}$$

$$Z_G = \frac{\sum_i \text{Weight}_i Z_{g_i}}{\text{Total weight}} \tag{15}$$

Note that the values of the steel weight and the position of the center of gravity calculated by the tool did not differ much from the values obtained by the modeling in Rhinoceros, which indicates that the applied method is in fact a good approximation.

5 Use of the program

A description of the use of the program showing ergonomics of use is shown below.

5.1 Ergonomics of tabs

Firstly, it is important to note that the program can be executed in both Portuguese and English, but the tabs and messages to the user are only in the English language.

The program has a total of 7 tabs for the preliminary structural design of the vessel. Each of the tabs is intended for one of the stages of the structural design process. In developing the program, the goal was to use as few tabs as possible, as well as ensuring that all essential information can be easily viewed without having to have the user search the information in the worksheet.

When opening the program, it is possible to observe the arrangement of the 7 tabs in which the entire preliminary structural design is developed as shown in Fig. 5.

(1) *General particulars* It is in this tab that the user must enter all the main characteristics that are required for the calculations. It is also in this tab that the user must make the decisions regarding the structural topology. It

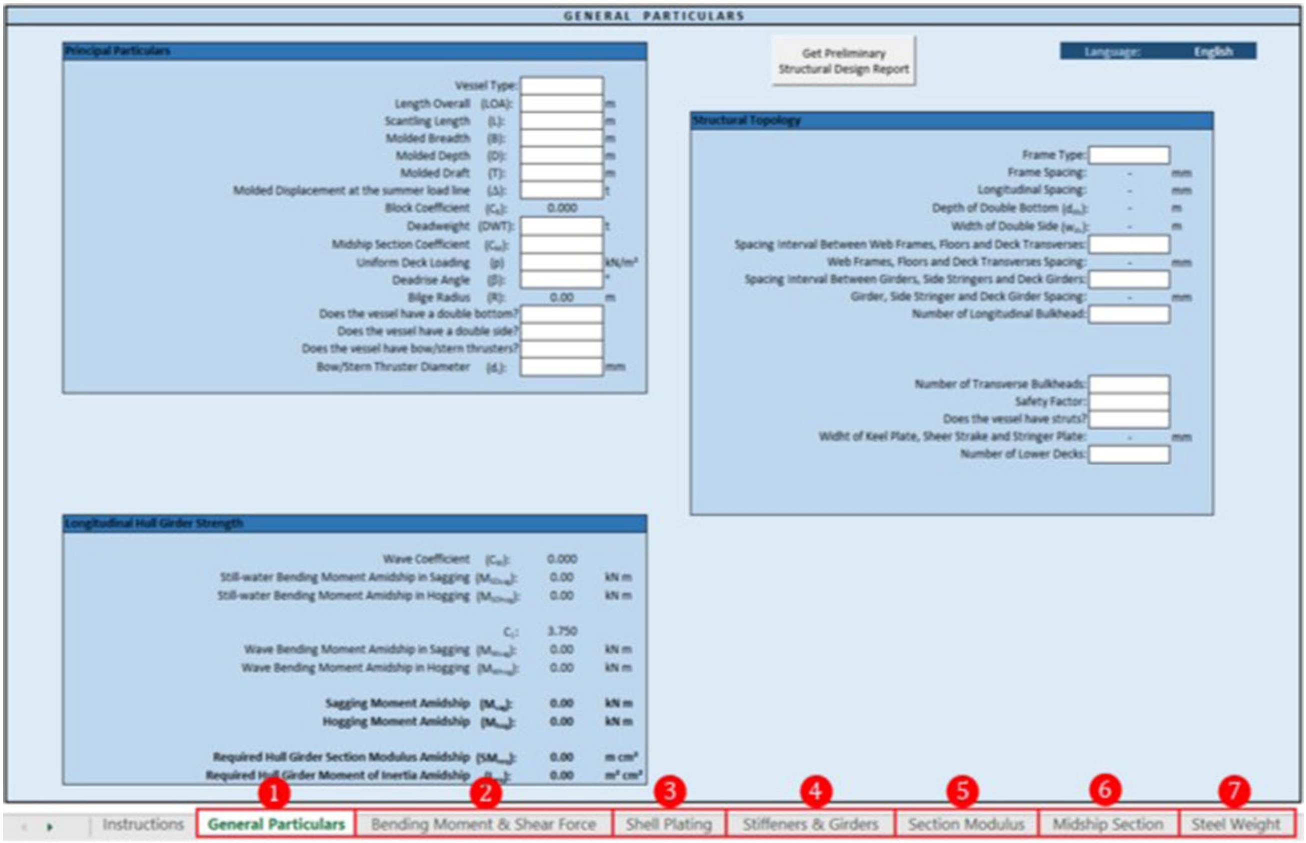


Fig. 5 Ergonomics of tabs

is worth mentioning that all *white cells* need to be *filled by the user*.

(2) *Bending moment and shear force* It shows the bending moment curves in calm water, in conditions of hogging and sagging and shear forces due to waves.

(3) *Shell plating* The user chooses not only the steel type, but also the manufacturer of commercial plates. The program displays the required thicknesses of plating by the rule and then rounds them up to commercial steel elements.

(4) *Stiffeners and girders* In this tab, the user must dimension each of the stiffeners and girders providing the type of profile, thickness and height of the web, and thickness and length of the flange. A comparison is also shown between the section modulus of the dimensioned element and the value required by the rule. Also, if the section modulus of the element is more than 15% larger than the modulus required by the rule, the program signals that there may be an unnecessary oversizing of the element.

(5) *Section modulus* It displays the calculation of the neutral axis height, steel area, hull girder section modulus, and moment of inertia. In addition, it is also displayed if the last two parameters are greater than that required by the ABS and, in the case of the section modulus, the percentage difference between the calculated and the required.

(6) *Midship section* It displays the sketch of the midship section, where on the right side the cargo hold view is displayed while on the left side the transverse bulkhead view is displayed.

(7) *Steel weight* The user must enter the sectional area curve and the position of the transverse bulkheads and then the steel weight and the CG are calculated.

5.2 Program processing

Before beginning the processing, the user must select in which language the program should be executed, choosing between Portuguese and English in the cell of the upper right corner of the General Particulars tab, as shown in Fig. 5. The program should be processed as follows:

5.2.1 Insert general particulars

It is not necessary for the user to provide neither the block coefficient nor the bilge radius, as this information is automatically calculated from the given data. While the block coefficient (C_B) is obtained from the definition itself

$$C_B = \frac{\Delta}{1.025LBd}, \tag{16}$$

where L is the scantling length; B is the breadth; d is the draft; and Δ is the molded displacement at the summer load line.

The bilge radius (R) is obtained from formulations obtained from Practical Ship Design [21]. The first one is expressed in terms of the rise of floor, and the second one is applied for vessels with no rise of floor.

$$R = \sqrt{\frac{Bd\left(1 - C_m\right) - F\left({}^{B}/_{2} - {}^{K}/_{2}\right)}{2\left[\left(1 - {}^{\pi}/_{4}\right) - {}^{F}/_{(B-K)}\right]}} \tag{17}$$

$$R = \sqrt{\frac{Bd\left(1 - C_m\right)}{2\left(1 - {}^{\pi}/_{4}\right)}}, \tag{18}$$

where B is the breadth; d is the draft; C_m is the midship area coefficient; F is the rise of floor; and K is the width of keel.

In addition, some information obtained later will be associated to some design decisions that the user needs to take at this moment, such as presence of double bottom (y/n), double side (y/n), and bow thrusters (y/n).

5.2.2 Insert structural topology

Also, on the 'General Particulars' tab the user needs to provide information on the structural topology of the vessel, as shown in Fig. 5. Among them, it is necessary to state whether the frame type is transverse or longitudinal, if the spacing between longitudinal and transverse girders is 3, 4, or 5 times the spacing of stiffeners, the number of longitudinal and transverse bulkheads (must include collision bulkheads), if the ship has struts and the number of lower decks. It should be noted that both the position of the lower decks and the longitudinal bulkheads will only be visible to the user if he indicates the amount of them, in addition the height of the lower decks must coincide with the height of a side stringer and the position of the longitudinal bulkheads should coincide with the position of a girder, otherwise the program will request that the value to be revised. It is not necessary for the user to provide the frame and longitudinal spacing, since both are automatically calculated by the ABS formulation and according to recommendations given in Fig. 6 in [22].

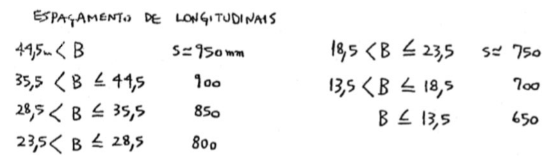


Fig. 6 Recommendation for longitudinal spacing [22]

Table 2 Wave coefficient

Wave coefficient	
L	C_W
L ≤ 100 m	$0.0792L$
100 < L < 300 m	$10.75 - \left[(300 - L)/100\right]^{3/2}$
300 < L < 350 m	10.75
L ≥ 350 m	$10.75 - \left[(L - 350)/150\right]^{3/2}$

In addition, the height of the double bottom, the width of the double side, and the width of the keel plate are also calculated by the program and follow recommendations of the ABS [23] and Marpol [24], whichever is greater.

Finally, it is not necessary to provide the positions of the transverse bulkheads, as these will be requested only in the 'Steel Weight' tab.

5.2.3 Check bending moment and shear force curves

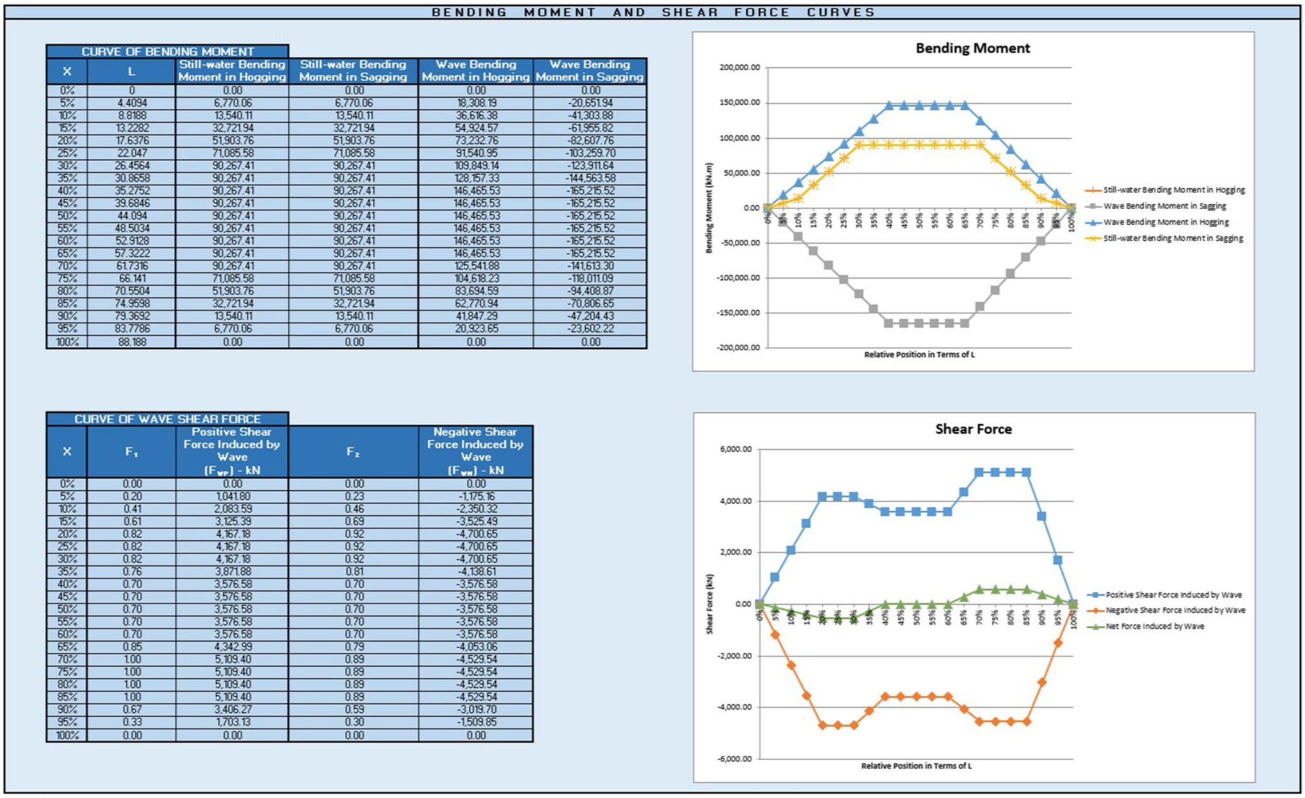
Once the general particulars and structural topology inputs have been provided, the program calculates the required hull girder section modulus and moment of inertia by the ABS in the 'Longitudinal Hull Girder Strength' table of the 'General Particulars' tab. For such calculations ABS formulations were used for Offshore Support Vessels. An exception is made by using the formulation of Det Norske Veritas, DNV [25], for the calculation of the bending moment in calm waters (kNm), since ABS does not provide an empirical approximation for this.

$$M_{SO_S} = -0.065C_W L^2 B\left(C_B + 0.7\right) \text{ Sagging} \tag{19}$$

$$M_{SO_H} = C_W L^2 B\left(0.1225 - 0.015C_B\right) \text{ Hogging}, \tag{20}$$

where L is the scantling length; B is the breadth; C_B is the block coefficient; and C_W is the wave coefficient given by Table 2.

Soon after, bending moment curves and shear forces are generated and, if the user wishes, they can be viewed on the 'Bending Moment & Shear Force' tab, as shown in Fig. 7.



CURVE OF BENDING MOMENT

X	L	Still-water Bending Moment in Hogging	Still-water Bending Moment in Sagging	Wave Bending Moment in Hogging	Wave Bending Moment in Sagging
0%	0	0.00	0.00	0.00	0.00
5%	4.4094	6,770.06	6,770.06	18,308.19	-20,651.94
10%	8.8188	13,540.11	13,540.11	36,616.38	-41,303.88
15%	13.2282	32,721.94	32,721.94	54,924.57	-61,955.82
20%	17.6376	51,903.76	51,903.76	73,232.76	-82,607.76
25%	22.047	71,085.58	71,085.58	91,540.95	-103,259.70
30%	26.4564	90,267.41	90,267.41	109,849.14	-123,911.64
35%	30.8658	90,267.41	90,267.41	128,157.33	-144,563.58
40%	35.2752	90,267.41	90,267.41	146,465.53	-165,215.52
45%	39.6846	90,267.41	90,267.41	146,465.53	-165,215.52
50%	44.094	90,267.41	90,267.41	146,465.53	-165,215.52
55%	48.5034	90,267.41	90,267.41	146,465.53	-165,215.52
60%	52.9128	90,267.41	90,267.41	146,465.53	-165,215.52
65%	57.3222	90,267.41	90,267.41	146,465.53	-165,215.52
70%	61.7316	90,267.41	90,267.41	125,541.88	-141,613.30
75%	66.141	71,085.58	71,085.58	104,618.23	-118,011.09
80%	70.5504	51,903.76	51,903.76	83,694.59	-94,408.87
85%	74.9598	32,721.94	32,721.94	62,770.94	-70,806.65
90%	79.3692	13,540.11	13,540.11	41,847.29	-47,204.43
95%	83.7786	6,770.06	6,770.06	20,923.65	-23,602.22
100%	88.188	0.00	0.00	0.00	0.00

CURVE OF WAVE SHEAR FORCE

X	F_1	Positive Shear Force Induced by Wave (F_{WP}) - kN	F_2	Negative Shear Force Induced by Wave (F_{WN}) - kN
0%	0.00	0.00	0.00	0.00
5%	0.20	1,041.80	0.23	-1,175.16
10%	0.41	2,083.59	0.46	-2,350.32
15%	0.61	3,125.39	0.69	-3,525.49
20%	0.82	4,167.18	0.92	-4,700.65
25%	0.82	4,167.18	0.92	-4,700.65
30%	0.82	4,167.18	0.92	-4,700.65
35%	0.76	3,871.88	0.81	-4,138.61
40%	0.70	3,576.58	0.70	-3,576.58
45%	0.70	3,576.58	0.70	-3,576.58
50%	0.70	3,576.58	0.70	-3,576.58
55%	0.70	3,576.58	0.70	-3,576.58
60%	0.70	3,576.58	0.70	-3,576.58
65%	0.85	4,342.99	0.79	-4,053.06
70%	1.00	5,109.40	0.89	-4,529.54
75%	1.00	5,109.40	0.89	-4,529.54
80%	1.00	5,109.40	0.89	-4,529.54
85%	1.00	5,109.40	0.89	-4,529.54
90%	0.67	3,406.27	0.59	-3,019.70
95%	0.33	1,703.13	0.30	-1,509.85
100%	0.00	0.00	0.00	0.00

Fig. 7 Bending moment and shear force curves

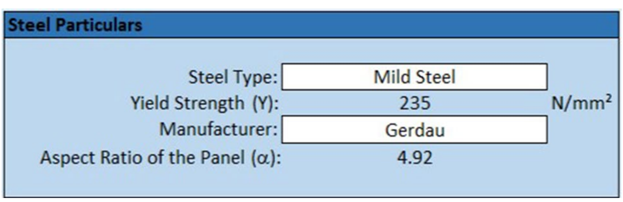


Fig. 8 Steel particulars

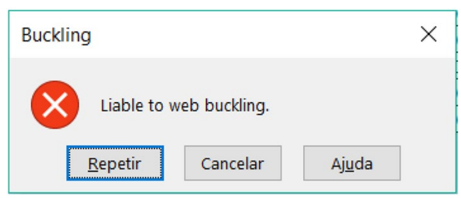


Fig. 9 Error message for web buckling

5.2.4 Insert steel particulars

In the third tab, 'Shell Plating,' is when the structural dimensioning begins. First, it is necessary for the user to select the type of steel to be used and the steel manufacturer in the 'Steel Particulars' table, shown in Fig. 8. The user can choose between 4 types of steel: mild steel, high tensile steel 32, high tensile steel 36, and quenched-tempered naval steel. For the selection of the manufacturer of thick plates, the user can select any of the manufacturers mentioned in Sect. 3.2. In general, in Brazil thick plates have maximum dimensions of 12 m × 2.44 m, so it was decided to keep constant the aspect ratio of the plates. After selecting the steel and the manufacturer, the program automatically calculates the thicknesses of the hull plating required by the ABS and rounds them up to the commercial thicknesses, as shown in Fig. 9.

5.2.5 Structural elements sizing

In the fourth tab, 'Stiffeners & Girders,' the user should detail all the secondary structural elements that make up the reinforced panels of the vessel. To do this, the user will need to select the profile of each element as well as the thickness and height of the web and the thickness and length of the flange. In the case of thicknesses, the program allows to select a commercial thickness according to the manufacturer selected in the tab 'Shell Plating,' but the program does not allow the selected thickness to be greater than the thickness

Fig. 10 Approximation of rule thickness by commercial thickness

Required Shell Plating Thicknesses

		ABS Required Thicknesses		Gerdau Commercial	
Bottom Shell Plating Amidship	(t_{bottom}):	11.46	mm	12.50	mm
Flat Keel Plate Amidship	(t_{keel}):	11.46	mm	12.50	mm
Bilge Plating Amidship	(t_{bilge}):	11.46	mm	12.50	mm
Inner-Bottom Plating Amidship	($t_{inner-bottom}$):	8.43	mm	9.50	mm
Side Shell Plating Amidship	($t_{side\ shell}$):	9.95	mm	12.50	mm
Sheer Strake and Deck Stringer Plating Amidship	($t_{strake-stringer}$):	10.18	mm	12.50	mm
Inner-Side Plating	($t_{inner-side}$):	7.10	mm	8.00	mm
Deck Plating Amidship	(t_{deck}):	10.18	mm	12.50	mm
Forecastle Side Plating	($t_{side-castle}$):	9.87	mm	12.50	mm
Forecastle Deck Plating	($t_{deck-castle}$):	7.20	mm	8.00	mm
Watertight Bulkhead Plating	($t_{wt-bulkhead}$):	7.75	mm	8.00	mm
Collision Bulkhead Plating	($t_{col-bulkhead}$):	8.63	mm	9.50	mm
Second Deck Plating Amidship	($t_{second-deck}$):	-	mm	-	mm
Third Deck Plating Amidship	($t_{third-deck}$):	-	mm	-	mm
Bow and Stern Thruster Tunnels	($t_{thruster-tunnel}$):	29.70	mm	31.50	mm
Superstructure Front Bulkhead Plating	($t_{sup-frontal}$):	7.50	mm	8.00	mm
Superstructure Side and End Bulkheads Plating	($t_{sup-side}$):	6.50	mm	8.00	mm
Superstructure Deck Plating	($t_{sup-deck}$):	4.65	mm	6.30	mm
Center Girder Plating Amidship	($t_{center-girder}$):	10.44	mm	12.50	mm
Side Girders Plating Amidship	($t_{side-girder}$):	7.87	mm	8.00	mm
Solid Floor Plating Amidship	($t_{solid-floor}$):	7.87	mm	8.00	mm

of the panel. For the height of the web and length of the flange, it is up to the user to enter the corresponding values, however, because they are manufactured profiles, the stiffeners are subject to buckling and therefore, if the stiffener is subject to buckling of web or flange, the program signals as shown in Fig. 10.

$$t_w \geq {}^{d_w}\!/_{60}, \tag{21}$$

$$t_f \geq {}^{b_f}\!/_{30}, \tag{22}$$

where t_w and t_f are the thicknesses of the web and the flange, respectively; d_w is the depth of the web; and b_f is the width of the flange.

From the dimensioning of the structural elements, the program calculates the section modulus of the profile set + collaborative plate and then compares with the section modulus required by the ABS. While ABS has empirical formulations for calculating the required section modulus of each element, the calculation of the section modulus of dimensioned elements is automatically done as follows:

I. The neutral axis of the profile is calculated by dividing the moment of total area $\left(\sum_i A_i z_i\right)$ by the total area $\left(\sum_i A_i\right)$, based on the dimensioning of the structural elements and the plates:

$$\bar{z}_{\text{section}} = \frac{\sum_i A_i z_i}{\sum_i A_i} \tag{23}$$

II. The moment of inertia of each element i (plate, web, and flange) in relation to the respective centroid is calculated as follows:

$$I_0 = \sum_i \frac{b_i h_i^3}{12} \tag{24}$$

III. The Steiner's Theorem is applied and the moment of inertia is calculated in relation to the centroid of the profile + collaborative plate assembly $\left(\bar{z}_{section}\right)$:

$$I = I_0 + \sum_i A_i \left(z_i - \bar{z}_{section}\right)^2 \tag{25}$$

IV. The moment of total inertia $\left(I_e\right)$ is divided by the greater distance between the centroid of the element to its ends of the section:

$$SM_e = \frac{I_e}{z_n} \tag{26}$$

Finally, the program compares the section modulus of the calculated element with the section modulus required by the rule. The program then returns one of the three options, as shown in Fig. 11 for the evaluation of the section modulus: No (if the element section modulus is less than required); Greater than 15% (if the element section modulus is greater than 15% of the required value, which could indicate oversizing of the element) or Yes (if the element section module is greater than required, but not more than 15% of the required value).

Selected Stiffeners and Girders

STIFFENERS		Plate		Web		Flange		Section Modulus
	Profile	t_p (mm)	b_p (mm)	t_w (mm)	h_w (mm)	t_f (mm)	b_f (mm)	GREATER than required?
Bottom Transverse Frames	L	12.50	630.00	8.00	120.00	8.00	120.00	Greater than 15%
Inner-Bottom Transverse Frames	L	9.50	630.00	6.30	105.00	6.30	105.00	No
Side Transverse Frames	L	12.50	630.00	9.50	115.00	9.50	115.00	Yes
Inner-Side Transverse Frames	L	8.00	630.00	6.30	105.00	6.30	105.00	No
Deck Beams	L	12.50	630.00	6.30	100.00	6.30	100.00	Yes
Watertight Bulkheads Stiffeners	L	8.00	700.00	8.00	105.00	8.00	105.00	Greater than 15%
Collision Bulkheads Stiffeners	L	9.50	700.00	8.00	100.00	8.00	100.00	Yes

GIRDES		Plate		Web		Flange		Section Modulus
	Profile	t_p (mm)	b_p (mm)	t_w (mm)	h_w (mm)	t_f (mm)	b_f (mm)	GREATER than required?
Side Stringers	I	12.50	2100	8.00	1000.00	-	-	Yes
Web Frames	I	12.50	2520	9.50	1000.00	-	-	Yes
Deck Girder	L	12.50	2100	6.30	300.00	6.30	300.00	No
Deck Transverses	L	12.50	2520	8.00	410.00	8.00	410.00	No
Watertight Bulkhead Girders	L	8.00	2100	8.00	290.00	8.00	290.00	Yes
Watertight Bulkhead Web	L	8.00	2100	6.30	310.00	6.30	310.00	Yes
Collision Bulkhead Girders	L	9.50	2100	9.50	325.00	9.50	325.00	Greater than 15%
Collision Bulkhead Web	L	9.50	2100	9.50	305.00	9.50	305.00	Greater than 15%

Fig. 11 Evaluation of the defined structural elements

Final Result of the Analysis of the Longitudinal Hull Girder Strength

Neutral Axis Height	(Z):	3.89	m
Steel Area	(A):	1.09	m²
Is the steel area enough to resist the shear force required by ABS?		TRUE	
Hull Girder Moment of Inertia Amidship	(I):	109,095.68	m² cm²
Is the hull girder Moment of Inertia GREATER than the one required by ABS?		TRUE	
Hull Girder Section Modulus Amidship	(SM):	27,225.78	m cm²
Is the hull girder Section Modulus GREATER than the one required by ABS?		TRUE	
Percentage difference between the calculated Section Modulus and the one required by ABS:		81.27%	

Fig. 12 Result of the longitudinal resistance analysis

5.2.6 Check section modulus

After the structural sizing, it is possible to check the hull girder section modulus. In 'Section Modulus' tab, the program calculates the height of the neutral axis, the steel area, the moment of inertia, and the hull girder section modulus. In the section of modulus calculation, only the longitudinal elements are considered, since the transverse elements do not contribute to the longitudinal resistance of the vessel. Considering a safety factor defined, the program calculates an allowable shear stress by dividing the yield strength by the safety coefficient and then compares if the dimensioned steel area is sufficient to withstand the shear forces calculated by the formulation of ABS. In addition, the program compares the moment of inertia and the hull girder section modulus with the values required by the ABS calculated on the 'General Particulars' tab, as shown in Fig. 12. The program also shows the percentage difference between the calculated section modulus and that required by the ABS, which is a way of indicating a possible over-dimensioning and consequently an unnecessary use of steel and consequently unnecessary steel weight.

5.2.7 Check the sketch of the midship section

At any point of the design, the user can access the Midship Section and check the sketch in scale of the midship section of the vessel. This sketch is based on the main characteristics, the structural topology and the structural design, in

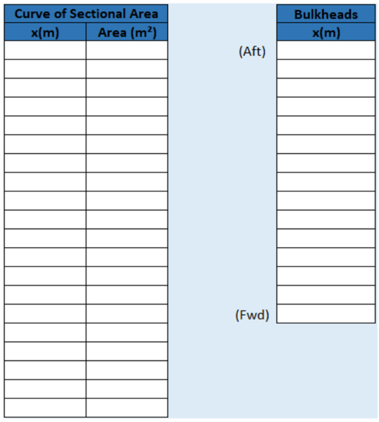


Fig. 13 Data for the calculation of steel weight

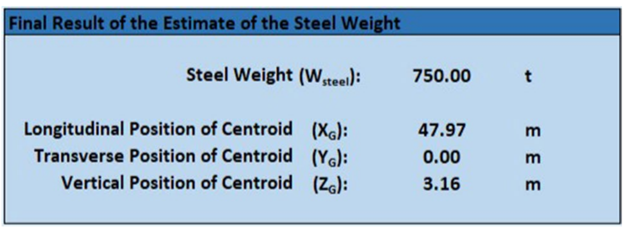


Fig. 14 Steel weight estimate and CG

which on the right the view of the cargo hold is observed and on the left the view of the bulkhead, see the example of Fig. 22.

5.2.8 Insert sectional area curve and bulkhead position

The next step is to enter the sectional area curve and the position of the transverse bulkheads. In the 'Steel Weight' tab, the user must first provide the longitudinal position of the station and the area of each of them and then the longitudinal position of each of the transverse bulkheads. The program allows up to 20 stations and 15 transverse bulkheads to be inserted, as shown in Fig. 13. In the case of transverse bulkheads, the user must first insert the position of the aft collision bulkhead and then insert the position of the following bulkheads and finally the position of the forward collision bulkhead.

5.2.9 Check the steel weight

Once the sectional area curve has been entered as well as the position of the transverse bulkheads, still on the 'Steel Weight' tab, the program calculates an estimate of the steel weight and the center of gravity of the steel (Fig. 14). The

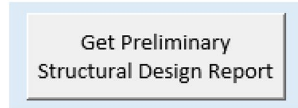


Fig. 15 Report generator

method for obtaining such values has already been explained in Sect. 4.6, but consists of using the midship section as the basis of calculation by estimating the steel weight and center of gravity for this section and then using such results to extrapolate the other sections of the ship and adding them at the end.

5.2.10 Print report

Finally, returning to the 'General Particulars' tab, the user can generate a detailed report containing all the information generated by the program as well as the calculation memory by clicking the button 'Get Preliminary Structural Design Report,' as shown in Fig. 15.

5.3 Main limitation of the program

Nowadays, some supply vessels have a moon pool. The moon pool consists of an opening in the hull, going from the main deck to the bottom of the vessel that serves as a platform for launching equipment and also remote operated vehicles (ROVs), as well as being a gate for saturated dives. Because it is a structural discontinuity of the hull, moon pool can bring structural problems and therefore requires special attention. The fact that the program does not consider that there might be a moon pool is its main limitation since the section module calculated for the midship section will not be representative.

6 Application example

In order to illustrate the use of the program, an example putting into practice the procedure described in Sect. 5.2 will be described in this section. Note that all results were obtained from the generated report [26].

6.1 General particulars

6.1.1 Definition of principle particulars

For example, a 5400 DWT Platform Supply Vessel was used [17]. Such vessel has the following characteristics:

Scantling length (L) = 88.19 m
Breadth (B) = 17.6 m
Depth (D) = 7.9 m

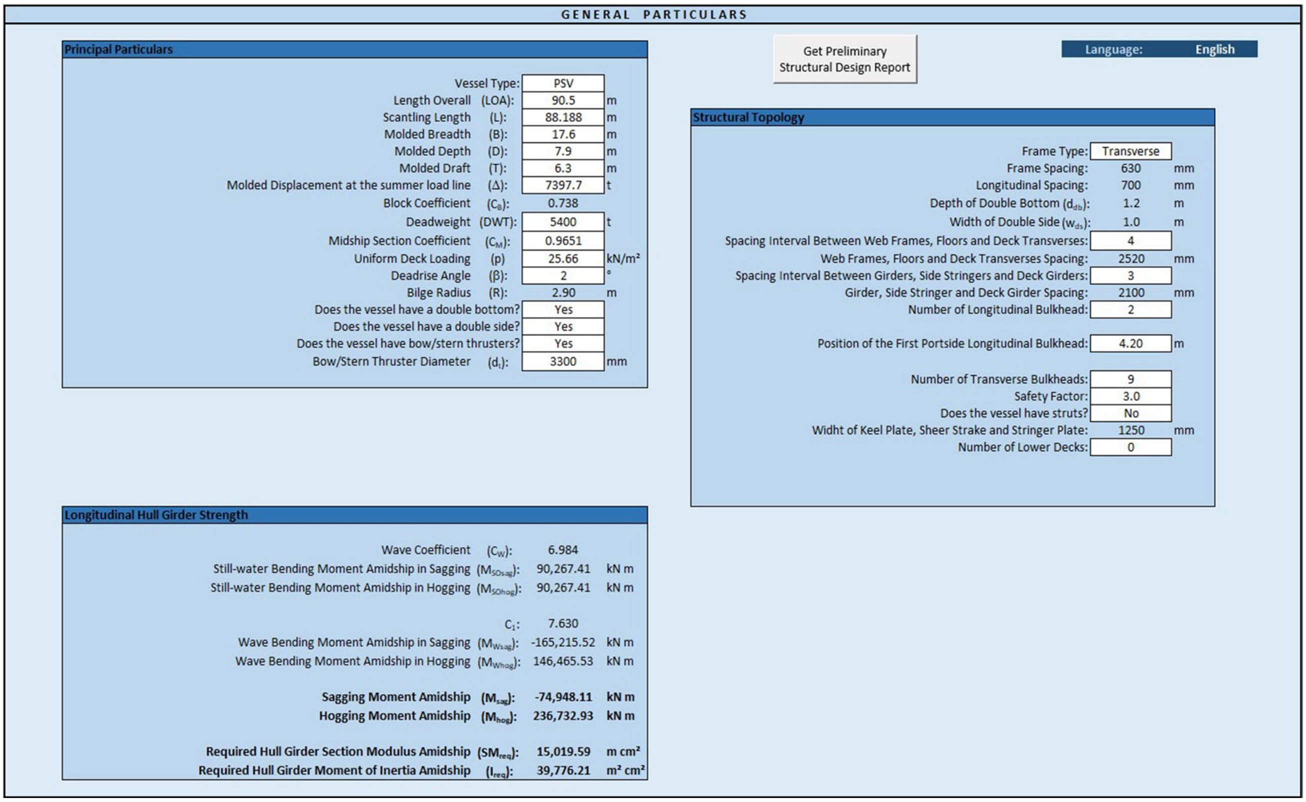


Fig. 16 Input data example

Draft $(T) = 6.3$ m
Displacement $(\Delta) = 7397.7$ t
Midship coefficient $(C_m) = 0.965$
Deck load $(p) = 25.6$ kN/m^2
Deadrise Angle $(\beta) = 2°$

6.1.2 Definition of structural topology

First, a PSV needs to load diesel to supply the platforms, so it has been decided that this vessel will have both double bottom and double side. In addition, this type of vessel requires a type DP-2 dynamic positioning system to perform offshore operations, so bow thrusters of 3 m in diameter were used and there would be no need for struts.

The type of structural reinforcement used is generally a function of the length of the vessel. The transverse type is recommended for vessels with a length of less than 120 m due to the absence or small extension of a parallel body, where longitudinal reinforcement is commonly used for practicality and ease of construction with elements that contribute to the longitudinal rigidity of the vessel. Therefore, it was decided to adopt a transverse frame system.

In addition, it was decided that at every 4 spacings of transverse stiffeners they would have a girder and that at every 3 spacings of longitudinal stiffeners there would be a giant element. In addition, it was determined that there would be two longitudinal bulkheads located on the second side girder of each side and there would be no intermediate decks. Finally, a total of 9 transverse bulkheads were estimated.

After defining the principal particulars and the structural topology, all data were entered in the first tab of the program as shown in Fig. 16.

From the definition of the main characteristics and the structural topology, the program calculates the following parameters:

Block coefficient $(C_b) = 0.738$
Bilge radius $(R) = 2.90$ m
Frame spacing = 630 mm
Longitudinal spacing = 700 mm
Depth of double bottom $(d_{db}) = 1.2$ m
Width of double side $(w_{ds}) = 1.0$ m
Width of keel plate $(w_k) = 1.25$ m
Spacing between transverse girders = 2520 mm
Spacing between longitudinal girders = 2100 mm
Required section modulus $(SM_{req}) = 15{,}019.59$ m cm^2
Required moment of inertia $(I_{req}) = 39{,}776.21$ m^2 cm^2

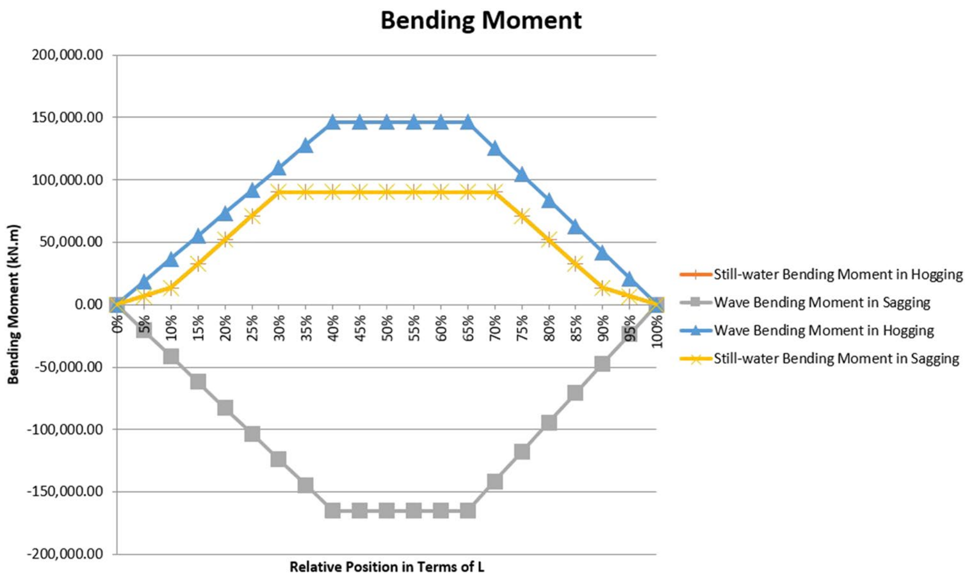


Fig. 17 Bending moment curve example

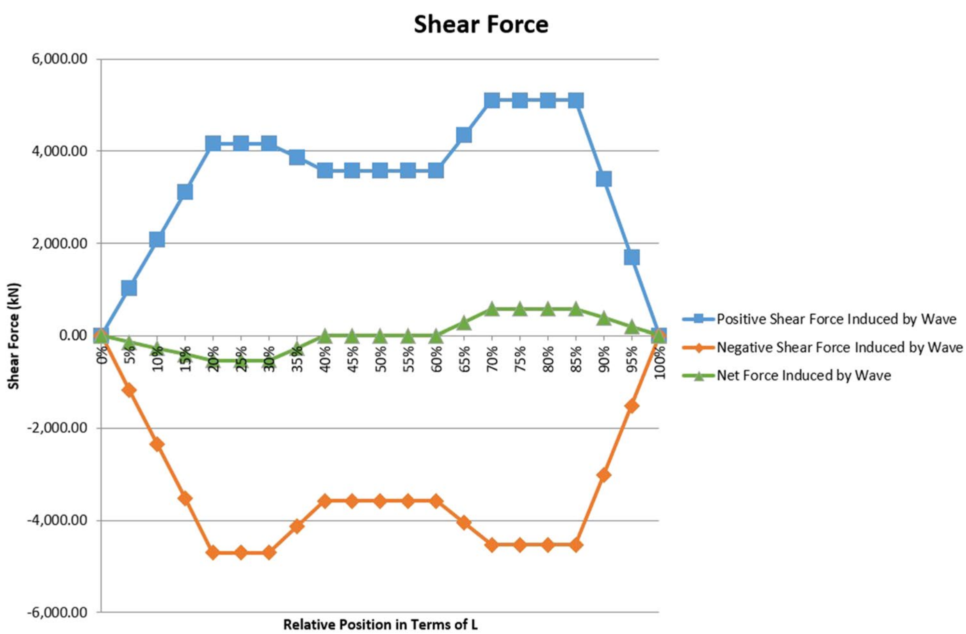


Fig. 18 Shear force curve example

6.2 Generation of bending moment and shear force curves

In the 'Bending Moment & Shear Force' tab, the bending moment curves and shear forces are generated, as shown in Figs. 17 and 18, respectively.

Note For space-saving reasons and to improve viewing, the curves shown on the screens are cropped to show the details mentioned.

6.3 Calculating plate thicknesses

For this step, the mild steel and Paulisteel were chosen as the steel type and manufacturer, as shown in Fig. 8. The calculation of the thicknesses according to the ABS was done automatically and approximated to the commercial thickness of Paulisteel. The program then generates a table containing such information as shown in Fig. 19.

6.4 Structural elements sizing

Afterwards, the elements were dimensioned to reinforce the structure of the vessel. As the frame type is transverse,

Fig. 19 Plate thicknesses example

Required Shell Plating Thicknesses

		ABS Required Thicknesses		Paulisteel Commercial	
Bottom Shell Plating Amidship	(t_{bottom}):	11.46	mm	11.91	mm
Flat Keel Plate Amidship	(t_{keel}):	11.46	mm	11.91	mm
Bilge Plating Amidship	(t_{bilge}):	11.46	mm	11.91	mm
Inner-Bottom Plating Amidship	$(t_{inner\text{-}bottom})$:	8.43	mm	8.73	mm
Side Shell Plating Amidship	$(t_{side\ shell})$:	9.95	mm	10.32	mm
Sheer Strake and Deck Stringer Plating Amidship	$(t_{strake\text{-}stringer})$:	10.18	mm	10.32	mm
Inner-Side Plating	$(t_{inner\text{-}side})$:	7.10	mm	7.14	mm
Deck Plating Amidship	(t_{deck}):	10.18	mm	10.32	mm
Forecastle Side Plating	$(t_{side\text{-}castle})$:	9.87	mm	10.32	mm
Forecastle Deck Plating	$(t_{deck\text{-}castle})$:	7.20	mm	7.94	mm
Watertight Bulkhead Plating	$(t_{wt\text{-}bulkhead})$:	7.75	mm	7.94	mm
Collision Bulkhead Plating	$(t_{col\text{-}bulkhead})$:	8.63	mm	8.73	mm
Second Deck Plating Amidship	$(t_{second\text{-}deck})$:	-	mm	-	mm
Third Deck Plating Amidship	$(t_{third\text{-}deck})$:	-	mm	-	mm
Bow and Stern Thruster Tunnels	$(t_{thruster\text{-}tunnel})$:	29.70	mm	30.16	mm
Superstructure Front Bulkhead Plating	$(t_{sup\text{-}frontal})$:	7.50	mm	7.94	mm
Superstructure Side and End Bulkheads Plating	$(t_{sup\text{-}side})$:	6.50	mm	7.14	mm
Superstructure Deck Plating	$(t_{sup\text{-}deck})$:	4.65	mm	5.56	mm
Center Girder Plating Amidship	$(t_{center\text{-}girder})$:	10.44	mm	11.11	mm
Side Girders Plating Amidship	$(t_{side\text{-}girder})$:	7.87	mm	7.94	mm
Solid Floor Plating Amidship	$(t_{solid\text{-}floor})$:	7.87	mm	7.94	mm

there will only be transverse stiffeners except for the bulkhead stiffeners, while the girders will be in the longitudinal and transverse directions. The stiffeners sized were:

- *Bottom transverse frames* multiple reinforcers spaced 630 mm apart;
- *Inner-bottom transverse frames* multiple reinforcers spaced 630 mm apart;
- *Side transverse frames* multiple reinforcers spaced 630 mm apart;
- *Inner-side transverse frames* multiple reinforcers spaced 630 mm apart;
- *Deck beams* multiple reinforcers spaced 630 mm apart;
- *Watertight bulkheads stiffeners* multiple reinforcers spaced 700 mm apart;
- *Collision bulkheads stiffeners* multiple reinforcers spaced 700 mm apart.

On the other hand, the girders sized were:

- *Side girder or keelson* multiple reinforcers spaced 2100 mm apart;
- *Open or closed floors* multiple reinforcers spaced 2520 mm apart;
- *Side stringers* multiple reinforcers spaced 2100 mm apart;
- *Web frames* multiple reinforcers spaced 2520 mm apart;
- *Deck girders* multiple reinforcers spaced 2100 mm apart;
- *Deck transverses* multiple reinforcers spaced 2520 mm apart;
- *Watertight bulkhead girders* multiple reinforcers spaced 2100 mm apart;
- *Watertight bulkhead webs* multiple reinforcers spaced 2100 mm apart;
- *Collision bulkhead girders* multiple reinforcers spaced 2100 mm apart;
- *Collision bulkhead webs* multiple reinforcers spaced 2100 mm apart.

Figure 20 shows the sizing of each of the forementioned elements except for the side girders and closed floors. Note that all elements have the section modulus larger than required, but not more than 15% of the required value.

Note If the vessel has a double bottom, the ABS provides an empirical formula for calculating the thickness of the side girders and floors, so they were dimensioned on the 'Shell Plating' tab as shown in Fig. 19.

6.5 Section modulus calculation

After the topology was elaborated, the hull girder resistance was verified. The results (Fig. 21) were as follows:

- Neutral Axis Height: 3.78 m;
- Steel Area: 1.00 m^2
- Hull girder moment of inertia: 98,839.61 $m^2\ cm^2$
- Hull girder section modulus: 24,012.82 m cm^2
- Percentage difference between calculated section modulus and that required by ABS: 59.88%

Selected Stiffeners and Girders

STIFFENERS		Plate		Web		Flange		Section Modulus
	Profile	t_p (mm)	b_p (mm)	t_w (mm)	h_w (mm)	t_f (mm)	b_f (mm)	GREATER than required?
Bottom Transverse Frames	L	11.91	630.00	8.00	120.00	8.00	120.00	Yes
Inner-Bottom Transverse Frames	L	8.73	630.00	8.00	105.00	8.00	105.00	Yes
Side Transverse Frames	L	10.32	630.00	9.50	115.00	9.50	115.00	Yes
Inner-Side Transverse Frames	L	7.14	630.00	8.00	105.00	8.00	105.00	Yes
Deck Beams	L	10.32	630.00	6.30	100.00	6.30	100.00	Yes
Watertight Bulkheads Stiffeners	L	7.94	700.00	6.30	105.00	6.30	105.00	Yes
Collision Bulkheads Stiffeners	L	8.73	700.00	8.00	100.00	8.00	100.00	Yes

GIRDES		Plate		Web		Flange		Section Modulus
	Profile	t_p (mm)	b_p (mm)	t_w (mm)	h_w (mm)	t_f (mm)	b_f (mm)	GREATER than required?
Side Stringers	I	10.32	2100	8.00	1000.00	-	-	Yes
Web Frames	I	10.32	2520	9.50	1000.00	-	-	Yes
Deck Girder	L	10.32	2100	8.00	300.00	8.00	300.00	Yes
Deck Transverses	L	10.32	2520	12.50	410.00	12.50	410.00	Yes
Watertight Bulkhead Girders	L	7.94	2100	8.00	290.00	8.00	290.00	Yes
Watertight Bulkhead Web	L	7.94	2100	6.30	310.00	6.30	310.00	Yes
Collision Bulkhead Girders	L	8.73	2100	8.00	325.00	8.00	325.00	Yes
Collision Bulkhead Web	L	8.73	2100	8.00	305.00	8.00	305.00	Yes

Fig. 20 Example of dimensioning of the structural elements

Fig. 21 Result of the longitudinal strength of the example

Final Result of the Analysis of the Longitudinal Hull Girder Strength

Neutral Axis Height	(Z):	3.78	m
Steel Area	(A):	1.00	m^2
Is the steel area enough to resist the shear force required by ABS?		TRUE	
Hull Girder Moment of Inertia Amidship	(I):	98,839.61	$m^2\ cm^2$
Is the hull girder Moment of Inertia GREATER than the one required by ABS?		TRUE	
Hull Girder Section Modulus Amidship	(SM):	24,012.82	$m\ cm^2$
Is the hull girder Section Modulus GREATER than the one required by ABS?		TRUE	
Percentage difference between the calculated Section Modulus and the one required by ABS:		59.88%	

That is, the elaborate topology meets the basic requirements of longitudinal resistance.

6.6 Midship section sketch

Based on the main vessel dimensions and structural topology defined, in other words, considering the dimensions given in 6.1 and the spacings between stiffeners and girders, as well as the frame type and the detailing of the elements shown in Fig. 20, the program elaborates the sketch of the midship section of the vessel. Figure 22 shows the midship section of the example ship. Note that on the right it is possible to observe the view of the cargo hold while on the left it is possible to observe the view of the bulkhead.

6.7 Steel weight

Finally, the steel weight of the vessel was determined. For this, the sectional area curve was obtained by the FreeShip software (Fig. 23) and the position of the bulkheads was estimated in the following positions:

- Aft collision bulkhead: 2.40 m
- 1st bulkhead: 7.20 m
- 2nd bulkhead: 16.80 m
- 3rd bulkhead: 31.20 m
- 4th bulkhead: 38.40 m
- 5th bulkhead: 48.00 m
- 6th bulkhead: 57.60 m

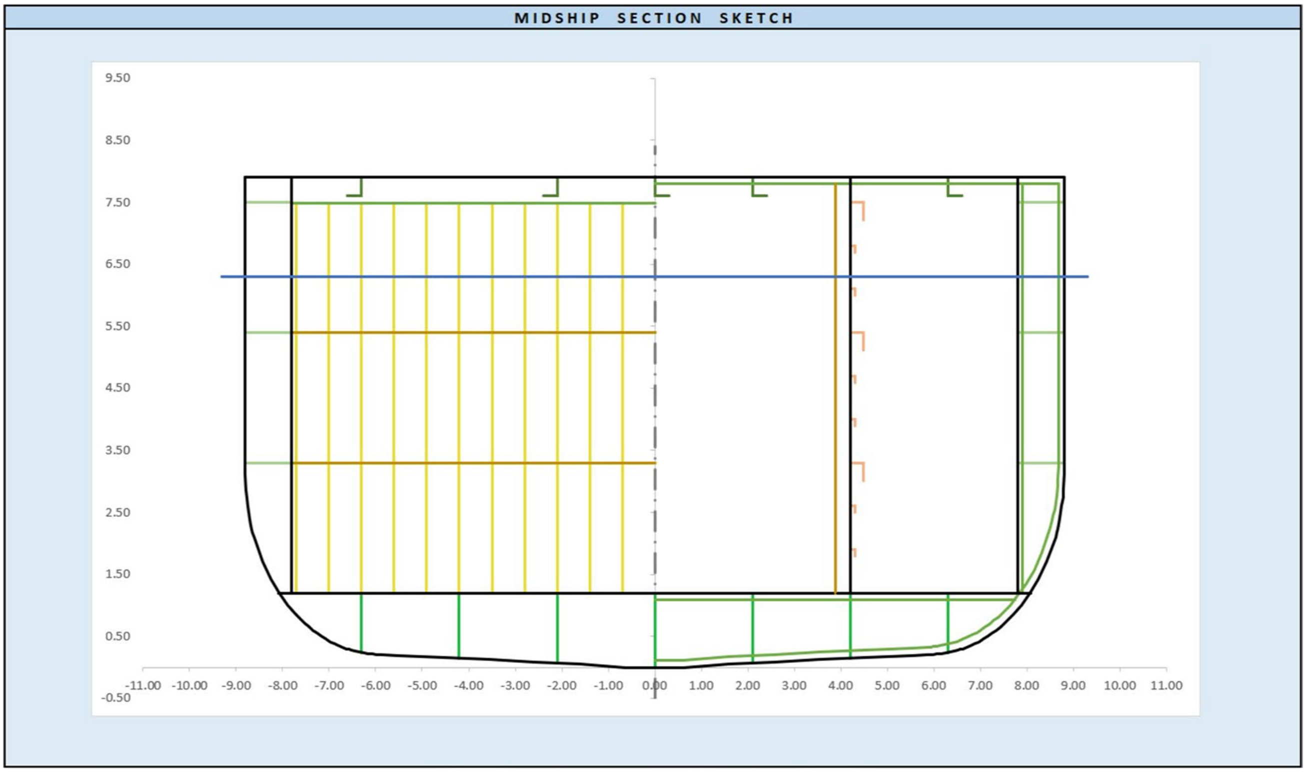


Fig. 22 Sketch of the midship section of example

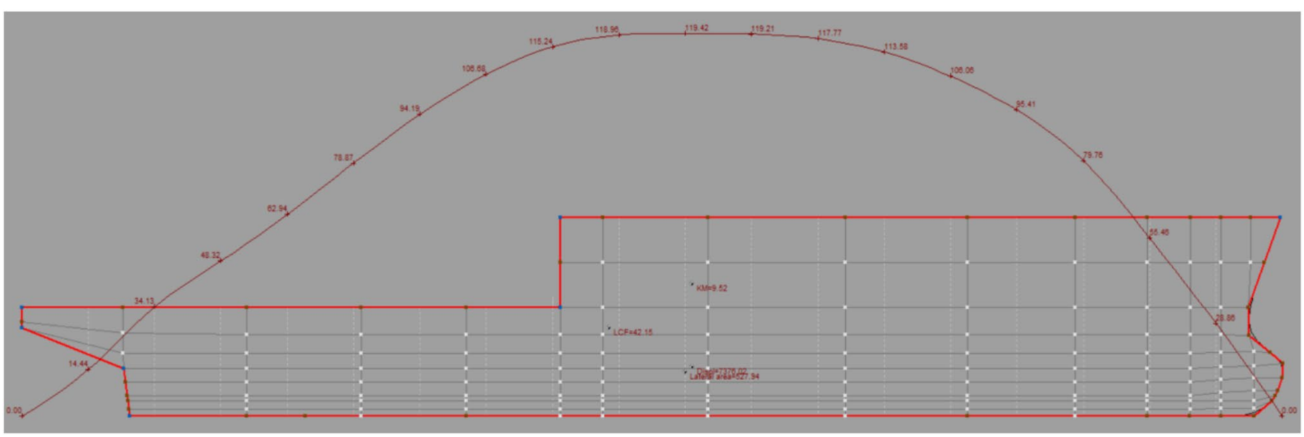


Fig. 23 Example of the sectional area curve made in the FreeShip software (2006)

Final Result of the Estimate of the Steel Weight			
Steel Weight	(W_{steel}):	820.72	t
Longitudinal Position of Centroid	(X_G):	47.03	m
Transverse Position of Centroid	(Y_G):	0.00	m
Vertical Position of Centroid	(Z_G):	4.07	m

Fig. 24 Estimated steel weight and CG example

- 7th bulkhead: 74.40 m
- Forward collision bulkhead: 81.60 m

The steel weight estimation of the vessel was then verified, as shown in Fig. 24, and the result for steel weight and center of gravity is as follows:

- Steel weight: 820.72 t
- Center of gravity: X: 47.03 m; Y: 0.00 m; Z: 4.07 m

7 Conclusions

It is believed that this program may be useful for designers because of its ease of handling, application and presentation of useful results for the preliminary structural design of a vessel, as a starting point for more detailed future structural designs or as tool for the correction of academic work.

The programming development philosophy allows the times spent in these calculations to go from several days to minutes with the same precision. In addition, the program developed proved to be efficient because it accurately details all structural elements, according to the definitions made by the user.

The program also evaluates in a very practical way the overall structural strength of the vessel by calculating its section modulus and moment of inertia and comparing with the values required by the rule, in addition to estimating the structural steel weight and center of gravity of the vessel with adequate precision.

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