An algorithm for preliminary estimating hull structure mass and mass centre height of inland navigation ships

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ABSTRACT

The paper presents an algorithm for preliminary calculation of mass and mass centre height of hull structure of inland navigation ships. It was elaborated basing on requirements of the Rules for the Classification and Construction of Inland Navigation Ships of Polish Register of Shipping, with application of a simplified method of estimating mass of hull plating stiffeners. The algorithm deals with the dimensioning of scantlings of structural members of classical ships intended for shipping dry cargo, and dry and liquid bulk cargoes; however it does not cover ships of entirely different structural arrangement such as roll-on-roll-off ships fitted with heavy decks, as the dimensioning of their scantlings is based on different models.

Key words : preliminary ship design, ship structure, preliminary ship mass estimation

INTRODUCTION

In the ship design theory an important role is played by the methods intended for preliminary, approximate estimation of mass and mass centre coordinates of a designed ship.

Knowledge of the parameters is necessary already in early designing phases to balance ship floatability and stability before exact structural strength calculations are performed. In the subject-matter literature many similar methods dealing with sea-going ships are known e.g. [1, 2, 3, 4]. However only few methods concerning inland navigation ships have been published so far, e.g. [5, 6, 7].

Such methods are elaborated on the basis of statistical investigations of mass of built ships or the rules of classification institutions, which provide analytical and tabulated relationships or diagrams. Applicability range of a particular method is usually limited to ships of a given functional type and hull structural arrangement; moreover it concerns a given structural material and ship size range.

For elaboration of the algorithm in question the rules for dimensioning hull structural elements, contained in the Rules of Polish Register of Shipping [9], were applied, as well as a method of accounting for mass of hull plating stiffeners [5] was used. The simplyfing assumptions applied in the considered mathematical model have been deemed allowable for approximate estimating the total mass of ship hull structure.

The elaborated calculation algorithm has been made easy for computer programming as it is intended for preparation of a computer software to perform series of simulation calculations of ship hull structure mass to provide a basis for elaboration of a parametric method to predict mass characteristics of inland navigation ships.

An origin of the presented research are problems met during the design work on realization of the Eureka - INCOWATRANS (Inland and Costal Water Transport System) project E!3065. One of the goals of the project is to develop a modern fleet for ecological inland waterways navigation.

Formulation of the problem and its assumptions

The algorithm concerns inland navigation ships intended for shipping both solid and liquid cargoes, whose construction corresponds with the midship section shown in Fig.1.

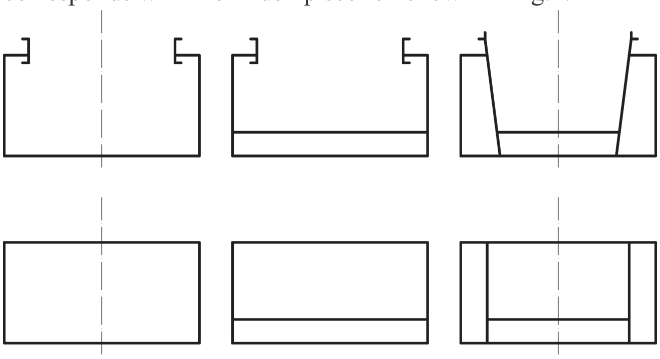

Fig. 1. *Schematic diagrams of standard midship sections of inland navigation ships*

The presented standard midship sections are special cases of the generalized midship section shown in Fig.2. By respective establishing the following dimensions : double bottom depth, double side breadth, hatch opening breadth and hatch coaming height as well as number of longitudinal bulkheads – – an appropriate standard midship section can be generated from the generalized one defined in the algorithm.

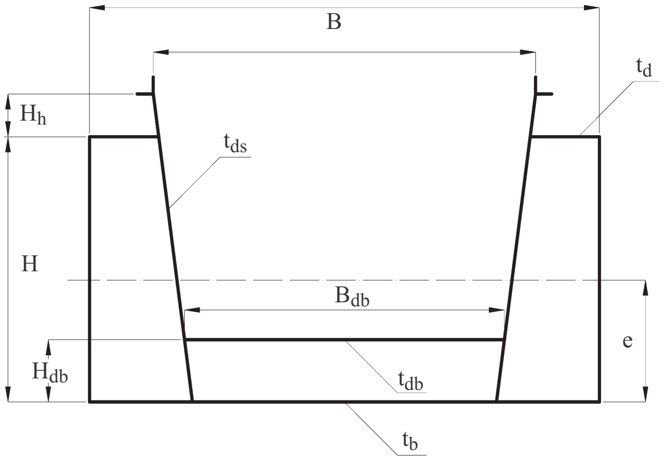

Fig. 2. *Schematic diagram of the generalized midship section of inland navigation ships*

The considered research problem consists in formulation of a mathematical model for analytical transforming the ship characteristics known at preliminary design stage, namely :

- ship numerical parameters $\overline{x} \equiv (L, B, H, T, C_B, ...)$ describing : ship main dimensions, hull form, structural material properties
- qualitative attributes $\overline{p} \equiv (K, R)$ identifying : ship functional type, its class and midship section topology
- into values of the hull structure mass *m* and mass centre height z_g , to be determined :

$$m(\overline{x}) = m(L, B, T, H, C_B, p_1, ..., p_n) \qquad (1)$$

$$z_g(\overline{x}) = z(L, B, T, H, C_B, p_1, ..., p_n) \qquad (2)$$

The hull structural elements should satisfy a number of strength requirements imposed by the classification institution rules. In the algorithm in question dimensioning the scantlings is carried out on the basis of overall and local strength criteria.

ALGORITHM FOR DETERMINING HULL STRUCTURAL SCANTLINGS

Qualitative identification attributes of hull structures

Two functional types of ships, identified by means of the symbolic index K, are considered :

- K = 1 dry cargo ships
- K = 0 liquid cargo ships.

Three classes of ships determined by restricted areas of navigation and identified by the symbolic index R [10], are distinguished :

- R = 1 − navigation area on which waves of the height $h_{1/10} \le 2.0$ [m] can be encountered (e.g. Bay of Gdańsk)
- R = 2 − navigation area on which waves of the height $h_{1/10} \le 1.2$ [m] can be encountered (e.g. Vistula Bay, Włocławek Bay)
- R = 3 − navigation area on which waves of the height $h_{1/10} \le 0.6$ [m] can be encountered - rivers, channels and lakes, which are rated, by the administration, among the inland waterways of Poland.

Numerical identifiers of hull structures

Determination of ship hull scantlings and its structural designing is associated with knowledge of ship hull form which – at early design phases – is identified by : ship dimensions, hull space subdivision, hull form coefficients etc. In the algorithm in question the following numerical parameters identifying the hull were assumed :

L - ship length [m]
B - ship breadth [m]
H - ship depth to upper deck [m]
T - ship design draught [m]
C_B - hull block coefficient [-].

Design loads

The longitudinal hull bending moment M_{FW} is the sum of the still water bending moment M_F and wave bending moment M_W. In accordance with the requirements [9] :

- the still water bending moments were determined as that not less than :

$$M_F = 0.07 B \cdot H \cdot L^2 \ \text{[kNm]} \qquad (3)$$

- for determination of the wave bending moment the following approximate formula was used :

$$M_W = k_1(R) \cdot k_2(T) \cdot A_1(R, L) \bullet$$
$$\bullet h_1(R) \cdot C_B \cdot B \cdot L^2 \ \text{[kNm]}$$

where : $h_1(R)$ - design wave height.

The correction coefficients $k_1(R)$, $k_2(T)$, $A_1(R,L)$ in [9] are defined by means of tabulated discrete values, rather inconvenient in coding computer algorithms. Therefore the relationships were approximated by using the following analytical functions :

$$h_1(R) \cong h(R) = 3 - 1.1R + 0.1R^2 \qquad (4)$$

$$k_1(R) \cong f_1(R) = 0.81 + 0.095R - 0.055R^2 \qquad (5)$$

$$k_2(T) \cong f_2(T) = 2.2 + 0.014T^2 - 1.85T^{0.2} \qquad (6)$$

$$A_1(R, L) \cong f_3(R, L) = 0.37 - 0.0115R + \\ - 0.0016L - 0.00063R \cdot L \qquad (7)$$

The design bending moment is the sum of the moments :

$$M_C \equiv M_{FW} = M_F + M_W \ \text{[kNm]} \qquad (8)$$

Permissible stresses

Ship hull structure exposed to external loads due to action of environment during building and operation of the ship, should provide an appropriate level of its resistance against :

- loss of integrity of structural elements
- excessive geometrical deformation of the structure
- permanent change of dimensions of the structure.

Scantlings of structural elements should be so selected as to fulfil the above mentioned criteria at given material properties, that can be realized by an appropriately low level of internal loads within the structure.

The level of permissible stresses in the structure was defined by means of the coefficient k < 1 related to the structural material yield stress σ_P [MPa] . Hence the required strength modulus of midship section can be described by the following formula :

$$W_1 = 10 \frac{M_C}{k \cdot \sigma_P} \ \text{[cm}^2\text{m]} \qquad (9)$$

As the approximating formulas usually are of a nonstructural character hence they are provided with appropriate units of measure.

Description of midship section geometry is identified by the set of parameters :

- e - distance from the neutral axis [m]
- B_h - breadth of cargo hatches [m]
- B_{db} - breadth of inner bottom [m]
- H_h - height of hatch coamings [m]
- H_{db} - depth of double bottom [m]
- t_b - thickness of outer bottom and side plating [cm]
- t_d - deck plating thickness [cm]
- t_{db} - thickness of inner bottom [cm]
- t_{ds} - thickness of inner side plating [cm]
- t_{lb} - thickness of longitudinal bulkhead plating [cm]
- S - midship cross-section area [m^2]
- W_C - minimum midship section modulus [cm^2m]

Minimum thickness values of the elements taken into account in the section modulus W_1 cannot be smaller than the minimum ones defined in [9], where a - frame spacing [m] :

minimum thickness of deck plating :

$$t_d = a(0.01L + 0.5) \text{ [cm]} \tag{10}$$

minimum thickness of outer bottom and side plating :

$$t_b = a(0.01L + 0.65) \text{ [cm]} \tag{11}$$

minimum thickness of inner bottom plating :

$$t_{db} = a(0.01L + 0.45) \text{ [cm]} \tag{12}$$

thickness of inner side plating :

$$t_{ds} = 1.77a(0.082L + 2.5) \text{ [cm]} \tag{13}$$

thickness of longitudinal bulkheads :

$$t_{lb} = 5a\sqrt{H} + 0.1 \text{ [cm]} \tag{14}$$

The midship section modulus at minimum thickness of deck plating is determined as follows :

$$W_2 = t_d^{min} \frac{2.4H^2}{f_4(\cdot)\left(1 + 2.1\frac{H_h}{H}\right)} \text{ [cm}^2\text{m]} \tag{15}$$

The midship section modulus at minimum thickness of bottom plating is determined by means of the following formula :

$$W_3 = t_d^{min} \frac{2.4H^2}{f_4(\cdot)\left(1 + 2.1\frac{H_h}{H}\right)} \cdot \frac{f_5(\cdot)}{1 - f_5(\cdot)} \cdot \frac{B}{B - B_h} \text{ [cm}^2\text{m]} \tag{16}$$

The value of the dimensioning section modulus W_C is the largest out of the following ones :

$$\min(W_C) = \max(W_1, W_2, W_3) \tag{17}$$

Mass of hull structure stiffeners

The functions f_4 and f_5 which represent magnitude and distribution of mass of hull plating stiffeners, given in [5] by means of diagrams (rather inconvenient for coding computer programs) are described by the relationships :

$$f_4(\cdot) = f_4\left(\frac{B - B_h}{H}, \frac{B}{H}\right) \tag{18}$$

where : $\frac{B - B_h}{H}$ – independent variable

$\frac{B}{H}$ – discretely changeable parmeter.

$$f_5(\cdot) = f_5\left(\frac{B_{db}}{B - B_h} \cdot \frac{t_{db}}{t_d}, \frac{H_{db}}{H}\right) \tag{19}$$

where : $\frac{B_{db}}{B - B_h} \cdot \frac{t_{db}}{t_d}$ – independent variable

$\frac{H_{db}}{H}$ – discretely changeable parameter.

The relationships were approximated with the use of the analytical functions :

$$f_4(\cdot) = \left[ds\left(0.05 + \frac{0.95}{\frac{B - B_h}{H}} + \frac{0.82}{\frac{B}{H}}\right) + (1 - ds)\left(0.145 + \frac{1.68}{\frac{B - B_h}{H}}\right) \right] \cdot 10^{-2} \tag{20}$$

where : ds = {0,1}

If ds = 1 then inner side structures are taken into account in the hull section modulus.

$$f_5(\cdot) = db\left(0.25 + \frac{0.125}{\frac{B_{db}}{B - B_h} \cdot \frac{t_{db}}{t_d}} + 0.55\frac{H_{db}}{H}\right) + 0.5(1 - db) \tag{21}$$

where : db = {0,1}

If db = 1 then inner bottom structure is taken into account in the hull section modulus, and in the case of single bottom hull : $f_5(\cdot) = 0.5$.

Mass and mass centre height

The cross-section area corresponding with the midship section modulus W_C is determined by means of the formula consisting functions which account for stiffeners. In the case of a double bottom hull, the cross-section area of midship section is determined by means of the relationship :

$$S_{DB} = f_6\left(\frac{B - B_h}{H}, \frac{B}{H}\right)\frac{W_C}{H}\left(1 + 2.1\frac{H_h}{H}\right) + f_7\left(\frac{B}{H}, \frac{t_{ds} + t_d}{t_{db}}\right)B_{db} \cdot t_{db} \text{ [m}^2\text{]} \tag{22}$$

In the case of a single bottom hull, the cross-section area of midship section is determined by the formula :

$$S_{NB} = f_6\left(\frac{B - B_h}{H}, \frac{B}{H}\right)\frac{W_C}{H}\left(1 + 2.1\frac{H_h}{H}\right) \cdot \left(1 + 1.34\frac{H}{B}\right) + 0.027H(t_{ds} + t_d) \text{ [m}^2\text{]} \tag{23}$$

In [5] the functions f_6 and f_7 are defined by means of the diagrams expressing the relationship :

$$f_6(\cdot)=f_6\left(\frac{B-B_h}{H},\frac{B}{H}\right) \qquad (24)$$

where : $\frac{B-B_h}{H}$ - independent variable

$\frac{B}{H}$ - discretely changeable parameter.

$$f_7(\cdot)=f_7\left(\frac{B}{H},\frac{t_{ds}+t_{lb}}{t_{db}}\right) \qquad (25)$$

where : $\frac{B}{H}$ - independent variable

$\frac{t_{ds}+t_{lb}}{t_{db}}$ - discretely changeable parameter.

The relationships were approximated by using the following analytical functions :

$$f_6(\cdot)=\left[\begin{array}{l} ds\left(1.38+0.25\frac{B-B_h}{H}-0.1\frac{B}{H}\right)+ \\ +(1-ds)\left(1.7+0.1\frac{B-B_h}{H}\right)\end{array}\right]\cdot 10^{-4} \qquad (26)$$

$$f_7(\cdot)=\left(\begin{array}{l} 1.22-0.125\frac{B}{H}+3.14\frac{t_{ds}+t_{lb}}{t_{db}}+ \\ -0.375\frac{B}{H}\cdot\frac{t_{ds}+t_{lb}}{t_{db}}\end{array}\right)\cdot 10^{-2} \qquad (27)$$

The total mass of hull structure is expressed by the formula :

$$m(\overline{x},\overline{p})=\rho_m\cdot S(\overline{x},\overline{p})L\cdot f_8(K,R)\,[t] \qquad (28)$$

where :

$f_8(\cdot)$ - a function for correcting mass distribution in hull end regions

ρ_m [tm^{-3}] - structural material density.

The function $f_8(\cdot)$ defined in [5] by means of tabulated values, was approximated by using the analytical function :

$$f_8(K,R)=1.92+0.167K-0.225R \qquad (29)$$

The height of hull mass centre $z_g(\cdot)$ is defined by the relationship :

$$e=z_g(\cdot)=H\cdot f_5(\cdot)=H\cdot \qquad (30)$$

$$\cdot\left[db\left(0.25+\frac{0.125}{\frac{B_{db}}{B-B_h}\cdot\frac{t_{db}}{t_d}}+0.55\frac{H_{db}}{H}\right)+0.5(1-db)\right]$$

where : the function $f_5(\cdot)$ is defined by the formula (21).

PRELIMINARY VERIFICATION OF THE ALGORITHM

The preliminary verification of the algorithm was performed by using – as an example – SINE 207 ship designed in the frame of the Eureka E!3065 INCOWATRANS project. The selected ship is intended for carrying general cargo and containers : one tier in the hold and another on the deck hatch covers.

Main parameters of the SINE 207 ship

overal ship lenght	L_{OA} = 56.50 m
ship lenght between perpendiculars	L_{BP} = 55.30 m
ship breadth	B = 9.00 m
ship depth to upper deck	H = 3.00 m
design draught	T_D = 1.00 m
deadweight at T_D	P_D = 280 t
scantling draught	T_S = 1.60 m
deadweight at T_S	P_S = 580 t
container capacity	Cc = 18/36 TEU
power	N = 620 kW
speed	v = 15 km/h

In the ship's design documentation, the outfitted ship mass equal to 144.5 t was estimated on the basis of the longitudinal distribution curve of ship mass. The abscissa of mass centre was estimated equal to 27.66 m, and mass centre height equal to 1.95 m. Because of lack of information on a navigation area assumed in the design of the ship, the verifying calculations were performed for three areas of navigation : R=1, R=2 and R=3. The verified ship has been distinguished by lack of a large superstructure on the main deck. Only a small deckhouse accomodating ship's wheelhouse, has been provided on its bow. Calculation results obtained by means of the algorithm in question deals solely with hull structure mass, without outfitting, therefore the verification serves only as an estimation of prediction credibility.

Tab. 1. *Results of verifying calculations*

Verified quantities		Values estimated by using the algorithm					
Mass [t]	Mass centre (MC) height [m]	Navigation area R=1		Navigation area R=2		Navigation area R=3	
		Mass [t]	MC height [m]	Mass [t]	MC height [m]	Mass [t]	MC height [m]
144.5	**1.95**	**168.6**	**1.27**	**143.4**	**1.27**	**123.7**	**1.27**

The verifying calculations were performed by using Excel calculation sheet.

RECAPITULATION

- The presented algorithm for estimating hull structure mass of inland navigation ships can be useful in the preliminary design stage of inland navigation ships intended for carrying general cargo, dry and liquid bulk cargoes. In the case of ships of different construction, e.g. those for carrying heavy roll-on – roll-off cargo, fitted with heavy decks, results obtained by means of the algorithm may significantly differ from real masses as structural designing such ships is carried out in a different way.
- The performed verifying calculations showed convergent results of estimated masses, and, under the assumption that the SINE 207 ship construction satisfies the requirements for the navigation area R = 2 , the obtained estimation can be deemed very correct.
- The large difference of estimation of mass centre height results from not accounted for ship's outfitting.

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Miscellanea

The Academic Computer Centre in Gdańsk (CI TASK)

Founded in 1994 by the State Committee for Scientific Research (KBN), Academic Computer Centre (CI TASK) in Gdańsk is an inter-university unit that manages one of the biggest and most modern metropolitan area networks (MAN) in Poland.

The TASK network covers the territory of the whole so-called Tri-City, i.e. Gdańsk-Sopot-Gdynia. It connects 70 LAN networks of various research institutes in which over 6000 computers of PC class, workstations, and servers are installed. The network has about 16000 users (excluding students). The TASK network is connected to the national network thus enabling remote access to the Centre resources, the usage of all networks services, multimedial transmissions, interactive work, teaching and learning through the network. The Centre co-operates closely with four other supercomputer centres in Poland, and participates in creation of national metacomputing system. It also has a link to the TEN-155 panEuropean research network which provides extension of the service to the USA and other overseas regions.

A concise characteristics of the Centre main departments is as follows :

The Network Group serves as the design and supervising centre of the whole Tri-City network. Now the network operates in ATM and FDDI technologies. It consists of three FDDI rings, each with five to eight FDDI nodes connected with links operating in ATM technology. The group maintains all the network services and servers, monitors secure network operation, and gathers network statistics, both within TASK, cooperating MANs, and worldwide transmissions. Network supervising is highly automated with such tools as SUN Net Manager, Cisco Works, and Cisco Net-Flow Analyzer. Lately, the Network Group has offered creation of the Virtual LAN facility. A pilot VLAN configuration has been established for the University of Gdańsk.

The Supercomputers Group maintains and manages all the computers (IBM, SGI and SUN) installed in CI TASK equipped with a high-capacity archivisation system (ATL, HP, and EXABYTE). 34 profesional software packages make it possible to perform large scale calculations in various fields of science and technology. The group also delivers expert advice in software application and security of servers. Its latest attainment is the SGI cluster project that resulted in effective supercomputer workload.

The Inter-Disciplinary Group of Mathematical Modelling was established as a group for mathematical modelling of theoretical and applied research. Its main fields of interest include: Quantum Chemistry, Plasma Physics, Atomic Physics, Biomolecular Modelling, Mechanics, Medicine, and Electrodynamics. The Group publishes papers of its interests in the TASK Quarterly Scientific Bulletin. The journal makes it possible to present papers and exchange of views on applied numerical methods for solving a variety of problems in science and engineering by using high performance computers. Contributors are invited to send their proposals to :

quarterly@task.gda.pl

In 1999, in recognition of the Centre's achievements in metacomputing technologies based on SGI servers, a special prize was awarded to it by the KBN (The State Committee for Scientific Research).

Notation :

ATM - Asynchronous Transfer Mode
FDDI - Fiber Distributed Data Interface
LAN - Local Area Network
MAN - Metropolitan Area Network
VLAN - Virtual Local Area Network
ATL, EXABYTE, HP, IBM, SGI, SUN - firm names