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OS	CHIRICĂ, Ionel; MUŞAT, Sorin Dumitru; CHIRICĂ, Raluca and BEZNEA, Elena-Felicia. Torsional behaviour of the ship hull composite model. *Comput. Mater. Sci.* 50 (4). 2011. p.1381–1386.
OA	ION, Raluca, MUŞAT, Sorin Dumitru, CHIRICĂ, Ionel, BOAZU, Doina, and BEZNEA, Elena Felicia. Torsion analysis of ship hull made of composite materials. *Materiale Plastice*. 47(3). 2010. p.364-369.

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Retraction Notice

Retraction notice to "Torsional behaviour of the ship hull composite model" [Comput. Mater. Sci. 50 (4) (2011) 1381–1386]

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This article has been retracted: please see Elsevier Policy on Article Withdrawal (http://www.elsevier.com/locate/withdrawalpolicy).

This article has been retracted at the request of the Editor-in-Chief.

It has come to our attention that there is very substantial duplication of text and content between this Computational Materials Science article and an earlier paper by the same authors in Torsion Analysis of Ship Hull Made of Composite Materials, Materiale Plastice, Vol. 47, Issue 3, pp. 364–369, 2010. One of the conditions of submission of a paper for publication is that authors declare explicitly that their work is original and has not appeared in a publication elsewhere. Re-use of any data should be appropriately cited. As such this article represents a severe abuse of the scientific publishing system. The scientific community takes a very strong view on this matter and apologies are offered to readers of the journal that this was not detected during the submission process.

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Torsion Analysis of Ship Hull Made of Composite Materials

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The paper deals with a methodology based on a macroelement model proposed for torsional behaviour of the ship hull made of composite material. A computer program TORS has been developed for the elastic analysis of linear torsion. The results are compared with the FEM based licensed soft COSMOS/M results and measurements on the scale model (1:50) of a container ship, made of composite materials.

Keywords: composites, torsion, FEM

The fibre-reinforced laminated composites have found increasing application in many engineering fields, such as marine structures, aircraft, automobiles etc. This is mainly due to their high specific strength and specific stiffness. However, these new materials also induce some new problems. In recent years the improved design, fabrication and mechanical performance of low-cost composites has led to increase in the use of composites for large patrol boats, hovercraft, mine hunters and corvettes. Currently, there are all-composite naval ships up to 80-90 m long, and this trend continues. It is predicted that hulls for mid-sized warships, such as frigates that are typically 120-160 m long, may be constructed in composite materials from 2020. The proliferation of the specialized literature, mainly in the form of journal/proceedings papers [1- 5], and the activity in terms of workshops devoted to this topic attests this interest [7, 9, 10]. A decisive factor that has fueled this growing activity was generated by high diversity and severity of demands and operating conditions imposed on structural elements involved in the advanced technology. In order to be able to survive and fulfill their mission in the extreme environmental conditions in which they operate, new materials and new structural paradigms are required. The estimation of the torsion strength of the ship hull is very important for its structural safety against applied loads [6, 11, 15, 16]. Various methodologies have been developed to evaluate the torsion hull girder capacity, [8, 17]. The torsion strength obtained by various methods is compared with experimental results and it appears that the proposed methodology is simple yet robust in estimating hull girder torsion strength. Different analytical tools have so far been developped by researches to successfully predict the torsion behaviour associated with ship hull subject to different loading conditions. The use of finite-elements analysis for investigation of torsion problem of ship hull is becoming popular due to the improvement in computational hardware and emergence of highly specialized software. There has been a growing interest in the foundation of the theory of thin-walled composite beams and of their incorporation in civil and naval constructions in the last two decades or so. To ensure safe design of a ship hull, traditionally, the longitudinal strength of the ship hull with length exceeding 60 m must be assessed during the design stage. The longitudinal failure of ship hulls made of composite materials is usually easier due to the relative low stiffness and relative thin structures. With the trend that the size of ship hull from composite materials is larger and larger it is becoming necessary to study the longitudinal strength of ship hull made of this type of advanced materials. Ship hull structure can be considered as thin-walled structures. Plates and shells have one physical dimension, their thickness, small in comparison with their other two. In thin/thick walled beams all three dimensions are of different order of magnitude. For such structures the wall thickness is small compared with any other characteristic dimension of the cross-section, whereas the linear dimensions of the cross-section are small, compared with the longitudinal dimension. Ship hulls in composite materials can usually be regarded as assemblies of a series of thin walled stiffened composite panels. Thus, knowing the strength of stiffened composite panels it is possible to estimate the longitudinal strength of ship hulls in composite materials. Due to their wide applications in civil, aeronautical/aerospace and naval engineering, and due to the increased use in their construction of advanced composite material systems, a comprehensive theory of thin/thick walled beams has to be developed: this is one of the aims of this paper.

The aim of the work is to analyze the influence of the very large open decks on the torsion behaviour of the ship hull made of composite materials.

Model of macroelement

The outline of the macroelement section is considered as polygonal one. In the theory, the material is considered as an orthotropic one. For a straight line portion of cross section outline is corresponding a longitudinal strip plate (fig. 1). Due to the torsion of the thin walled beam, in the strip plate the stretching-compression, bending and shearing occur. The strip plate is treated as an Euler-Bernoulli plate. The stiffness matrix of the macro-element is obtained by assembling the stiffness matrices of the strips.

Two coordinate systems are used:

- global system O_oXYZ having the axis OoX along the torsion centers line of the cross sections of the beam.
- local system attached to each strip plate k ($F_k^0 x_k y_k z_k$) having the axis $F_k^0 x_k$ parallel with the global axis O_oX.

The torsion behaviour of the thin-walled beam is depending on the section type. So, the methodology presented in this paper is treating in different ways and different hypothesis, depending on the type of cross section: open and closed.

The open cross section is treated based on the hypothesis of the Vlasov theory:

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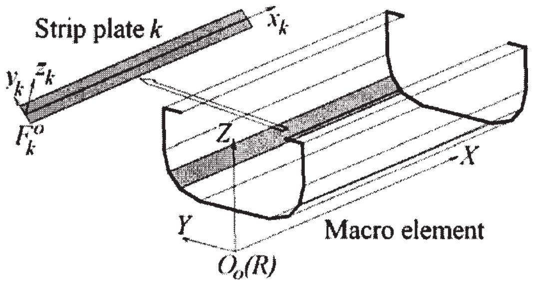

Fig. 1. Thin walled beam macro element

- the material is linear-elastic, homogeneous, isotropic generally, having the coordinate system $F_k^0 x_k y_k z_k$ as the main orthotropic axis;

- the shear stresses occurring in the beam cross section are parallel with the median line Γ.

During the deformation the median line Γ does not remain plane. The projection of the median line on the cross section plane remains the same as its initial shape (non-deformed outline hypothesis). For small displacements, the displacement v of the current point F placed on the median line has the equation

$$\mathrm{v}(x,s)=\tilde{r}(s)\,\varphi(x)\,. \tag{1}$$

- the displacement u along the axis O_oX of the point F is considered as constant on the wall thickness. The displacement u is considered to be in the form

$$u(x,s)=-\omega(s)\,\varphi'(x)\,. \tag{2}$$

The sectorial coordinate is defined as

$$\omega(s)=\int_\Gamma \tilde{r}(s)\,\mathrm{d}s\,. \tag{3}$$

The torsion of the thin-walled beam generates the torsion of the strips and the loading of the strips in their plane (fig. 2).

Using the equations (1) and (2) for a strip k, it may be written

$$\mathrm{v}_k(x,s)=\tilde{r}_k\,\varphi(x)\,; \tag{4}$$
$$u_k(x,y_k)=-\omega(y_k)\,\varphi'(x)\,. \tag{5}$$

For the displacement u, due to the tension-compression loading of the strip k the approach function is a parabolic one, having the form

$$u_k(\xi)=P_1(\xi)u_i^k+P_2(\xi)u_{ij}^k+P_3(\xi)u_j^k\,. \tag{6}$$

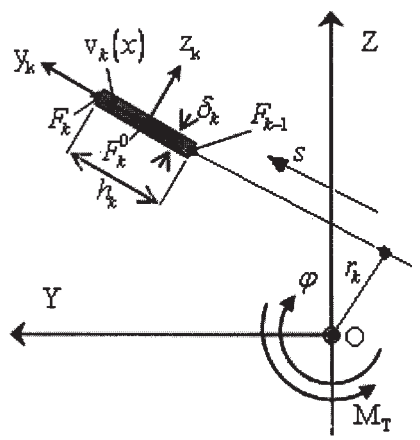

Fig. 2. Strip element details

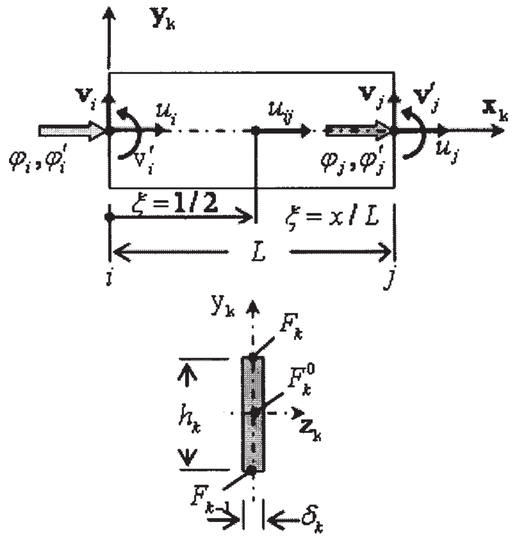

Fig. 3. Finite strip element

For the case of closed section, is considered that u is proportional to the generalized sectorial co-ordinate $\hat{\omega}$ evaluated related to O and O^* (fig. 4).

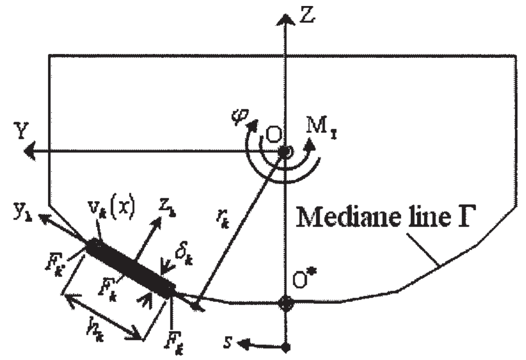

Fig. 4. Polygonal closed cross section

Benscoter theory, it is consider that u is proportional to the rate of twist

$$u(x,s)=-\hat{\omega}(s)\,\varphi'(x)\,. \tag{7}$$

The generalized sectorial coordinate is defined as

$$\hat{\omega}=\omega-\tilde{\omega}\,; \tag{8}$$

were:

$$\omega(s)=\int_0^s r(s)\,\mathrm{d}s\,,\ \tilde{\omega}=\omega_0\tilde{s}/\tilde{S}\,,\ \omega_0=\int_\Gamma r(s)\,ds\,;$$

$$\tilde{s}=\int_0^s\frac{\mathrm{d}s}{\delta(s)}\,;$$

-the double of the area surrounded by Γ is

$$\tilde{S}=\int_\Gamma\frac{\mathrm{d}s}{\delta(s)}=\sum_{k=1}^{n}\frac{h_k}{\delta_k}\,;$$

where n is the number of strip-plates. The torsion loading of the beam generates an in-plane loading of the strip-plate. For each strip-plate, it may be written

$$\mathrm{v}_k(x)=r_k\,\varphi(x)\,; \tag{9}$$
$$u_k(x,y_k)=-\hat{\omega}(y_k)\,\varphi'(x)\,. \tag{10}$$

These equations define the displacement field for each strip-plate. The continuity of the displacement *u* along the jointing edges between two strip-plates is embedded in above relation. The linear variation of $\bar{\omega}_k$, the generalized sectorial co-ordinate along the axis *yk* (in the reference system $F_k x_k y_k z_k$ associated to strip-plate *k*) may be expressed as

$$\hat{\omega} = \hat{\omega}_k + (\hat{\omega}_{k'} - \hat{\omega}_k)\eta; \quad \text{where } -1/2 \le \eta = y_k / h_k < 1/2. \tag{11}$$

The coordinates $\bar{\omega}_k$, $\bar{\omega}_{k'}$, $\bar{\omega}_{k''}$ characterize the points, F_k, F_k' and F_k''. The dependent equation between these coordinates is

$$\bar{\omega}_k = (\bar{\omega}_{k'} + \bar{\omega}_{k''})/2$$

For the longitudinal displacement one obtains

$$u(x, y_k) = -[\ \hat{\omega}_k + (\hat{\omega}_{k''} - \hat{\omega}_{k'})\ \eta\ ]\ \varphi'(x). \tag{12}$$

Using the hypothesis, the strain generated in the strip-plate *k* are

$$\varepsilon_k = \frac{\partial u_k}{\partial x} = -[\ \hat{\omega}_k + (\hat{\omega}_{k''} - \hat{\omega}_{k'})\ \eta\ ]\ \varphi''(x); \tag{13}$$

$$\gamma_k = \frac{\partial u_k}{\partial y} + \frac{\partial v_k}{\partial x} = \Delta_k \varphi'(x); \tag{14}$$

where: $\Delta_k = \omega_0 / (\tilde{S}\delta_k)$.

Normal stresses σk appear in each strip-plate *k* due to the warping, having the equation

$$\sigma_k(x, y_k) = -E\,\hat{\omega}(y_k)\varphi''(x). \tag{15}$$

In each cross-section, these stresses perform a system of distributed forces in self-equilibrium. The tangential stresses τ_k associates with the deformations γ_k may be determined with the equation

$$\tau_k(x) = G\gamma_k = \frac{G\omega_0}{\tilde{S}}\frac{1}{\delta_k}\varphi'(x). \tag{16}$$

The flow of these stresses, $\tau_k\delta_k$, is constant for each section of thin-walled beam. The differential equation of the twist angle φ obtained by the Ritz method is

$$E I_{\hat{\omega}}\varphi''' - G I_T\,\varphi' = -M_T(x); \tag{17}$$

where

$$I_{\hat{\omega}} = \sum_{k=1}^{n} I_{\hat{\omega}k};\ I_{\hat{\omega}k} = h_k\delta_k[\hat{\omega}_k^2 + (\hat{\omega}_{k'} - \hat{\omega}_{k''})^2/12]$$

is sectorial moment of inertia;

and

$$I_T = \omega_0^2 / \tilde{S};$$

is conventional polar moment of inertia;

M_T is the transmitted torque. The differential equation reveals two components of the transmitted torque:

- Saint Venant torque

$$M_\gamma = GI_T\varphi';$$

- warping torque

$$M_\varepsilon = -EI_{\hat{\omega}}\varphi'''.$$

The component M_γ of the transmitted torque is the part associated with the strain γ_k and stress τ_k (Saint Venant torsion). The component *Mz* is the part of the transmitted torque associated with the shear forces by strip-plates bending generated can by obtained only from equilibrium condition. For the displacements $\varphi(\xi)$ and $v_k(\xi)$ third order polynomial functions are chosen:

$$\varphi(\xi) = H_1(\xi)\varphi_i + LH_3(\xi)\varphi'_i + H_2(\xi)\varphi_j + LH_4(\xi)\varphi'_j \tag{18}$$

$$v_k(\xi) = H_1(\xi)v_i^k + LH_3(\xi)\theta_i^k + H_2(\xi)v_j^k + LH_4(\xi)\theta_j^k \tag{19}$$

For bending and torsion, the well known matrices of the beam are used

$$\mathbf{k}_v^k = \frac{EI_k}{L^3}\begin{bmatrix} 12 & 6L & -12 & 6L \\ & 4L^2 & -6L & 2L^2 \\ & & 12 & -6L \\ \text{symm.} & & & 4L^2 \end{bmatrix}; \tag{20}$$

$$\mathbf{k}_\varphi^k = \frac{GI_{T_k}}{L}\begin{bmatrix} 6/5 & L/10 & -6/5 & L/10 \\ & 2L^2/15 & -L/10 & -L^2/10 \\ & & 6/5 & -L/10 \\ \text{symm.} & & & 2L^2/15 \end{bmatrix}. \tag{21}$$

Equivalent stiffness characteristics of the composite shell

In the methodology, the classical thin-walled beam theory for isotropic materials was used. Due to the material used in the fabrication of the ship hull, the orthotropy of the material is to consider.

The orthotropy system of the strips is considered $F_k^0 x_k y_k z_k$.. Also, is considered that the stack of layers may be different from one to other layer. Is considered that the stack is a symmetric one, 2*ns* being the number of layers.

The equivalent stiffness coefficients for the tension-compression, bending and shearing loading of the strip *k* are determined according to the equation of static equilibrium.

The points placed in a layer are considered in a plane state in the plane $F_k^0 x_k y_k$.

The hypothesis of un-deformed cross section (σ_y =0), leads to the following equation for the strip *k* and layer *i*.

$$\begin{pmatrix}\sigma_x \\ \tau_{xy}\end{pmatrix}_{i,k} = \begin{pmatrix}\bar{Q}_{11} & 0 \\ 0 & \bar{Q}_{66}\end{pmatrix}_{i,k}\begin{pmatrix}\varepsilon_x \\ \gamma_{xy}\end{pmatrix}_{i,k}. \quad \text{So} \quad (\bar{Q}_{11})_{i,k} = E_{i,k},\ (\bar{Q}_{66})_{i,k} = G_{i,k}. \tag{22}$$

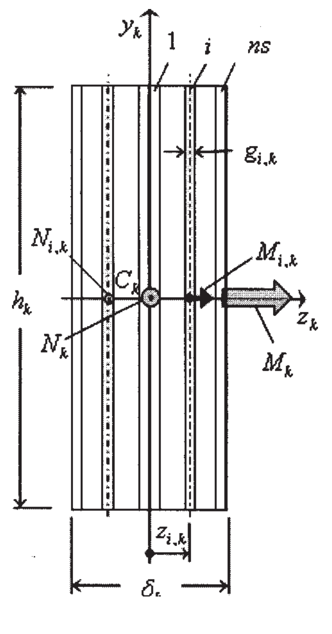

Fig. 5. Determination of equivalent bending stiffness

For the tension-compression of a strip k (fig. 5) (having the longitudinal displacement u_k) the following equations may be written:

- for each layer i

$$A_{i,k} = g_{i,k} h_k, \quad N_{i,k} = E_{i,k} A_{i,k} u'_k ;$$

- for the strip considered as homogeneous one,

$$N_k = (EA)_k u'_k ;$$

From the condition of equivalence of the axial force

$$N_k = 2\sum_{i=1}^{ns} N_{i,k} ;$$

the equivalent bending stiffness is obtained

$$(EA)_k = 2\sum_{i=1}^{ns} (E_{i,k} g_{i,k}) h_k . \quad (23)$$

For the bending of a strip k (fig. 5) (having the transversal displacement vk) the following equations may be written:

-for each layer i

$$I_{i,k} = \frac{g_{i,k} h_k^3}{12}, \quad M_{i,k} = -E_{i,k} I_{i,k} \mathrm{v}''_k ;$$

- for the strip considered as homogeneous one,

$$M_k = -(EI)_k \mathrm{v}''_k ;$$

- From the condition of equivalence of the bending moment

$$M_k = 2\sum_{i=1}^{ns} M_{i,k} ;$$

the equivalent bending moment is obtained

$$(EI)_k = 2\sum_{i=1}^{ns} E_{i,k} I_{i,k} . \quad (24)$$

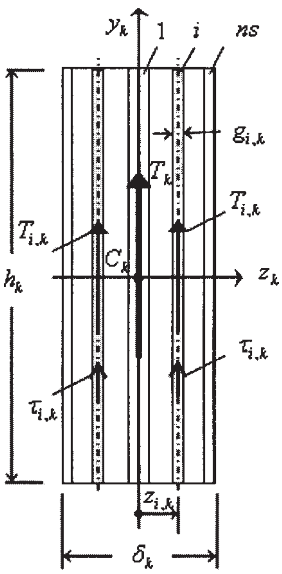

Fig. 6. Determination of equivalent shear stiffness

For the shearing of the strip k (fig. 6) the following equations may be written:

- for each layer i

$$\tau_{i,k} = G_{i,k} \gamma_k, \quad T_{i,k} = G_{i,k} g_{i,k} h_k \gamma_k ;$$

- for the strip considered as homogeneous one,

$$T_k = (GA)_k \gamma_k ;$$

- from the condition of equuivalence of the shear force

$$T_k = 2\sum_{i=1}^{ns} T_{i,k} .$$

the equivalent shearing stiffness is obtained

$$(GA)_k = 2\sum_{i=1}^{ns} G_{i,k} g_{i,k} h_k . \quad (25)$$

By introducing the hypothesis of the same geometry of the equivalent section (same h_k and δ_k) from (24) is resulting the equivalent Young's modulus for strip

$$E_k = \frac{2}{\delta_k} \sum_{i=1}^{ns} E_{i,k} g_{i,k} , \quad (26)$$

and from (25) the equivalent shear modulus for strip k,

$$G_k = \frac{2}{\delta_k} \sum_{i=1}^{ns} G_{i,k} g_{i,k} . \quad (27)$$

Numerical analysis

A soft (named TORS) based on the theory presented above was done. In the same time, a 3-D model with 4-node SHELL4L composite elements of COSMOS/M was used. The ship hull model is loaded by a torque M_x applied in the midship. Due to this fact, the real ship has a much stiffened structure on the both ends, the model is, from point of view of torsion, considered as clamped at the ends. The ship model has the main characteristics: length L=2.4m, breadth B=0.4m, depth D=0.2m. The material is E-glass/polyester having the symmetric stack. The stack of the shell is according to the topologic code [A/B]3s. The stack of the deck and bulkheads is according to the topologic code [A/B/A/B/A/B/A/B/A]s. The layers made of material A, have the thickness of 0.25 mm and characteristics: E_x=80 GPa, E_y=80 GPa, G_{xy}=10 GPa, μ_{xy}=0.2 The layers made of material B, have the thickness of 0.1 mm and characteristics: E_x=3.4 GPa, E_y=3.4 GPa, G_{xy}=1.3 GPa, μ_{xy}=0.3. According to the upper equations, the equivalent mechanical characteristics of the composite are E_x=58.11 GPa; E_y=58.11 GPa; G_{xy}=7.51 GPa; μ_{xy} = 0.228. To fulfill the hypothesis of no deformability of the cross section, transversal bulkheads are placed at every 200 mm.

Experimental part

The experimental analysis of the ship model was done with a system concerning the clamping system and loading rig (fig. 8) used to carry out torque tests. In figure 7, the experimental rig for torsion of the ship hull model is

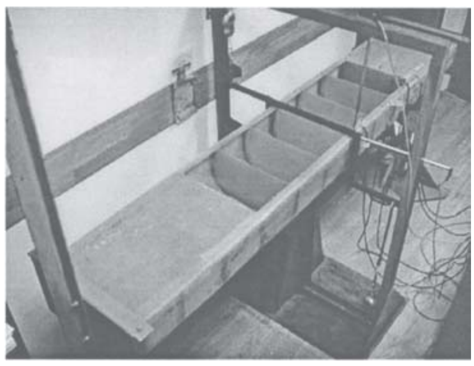

Fig. 7. Torsion rig for experiment

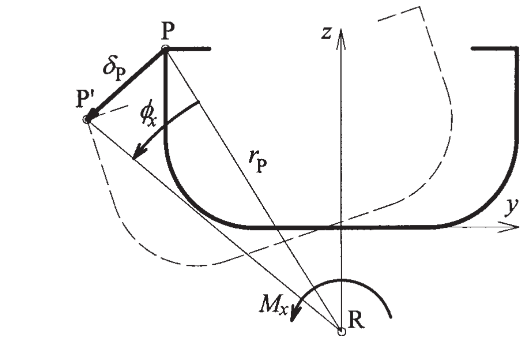

Fig. 8. Torsion angle calculus

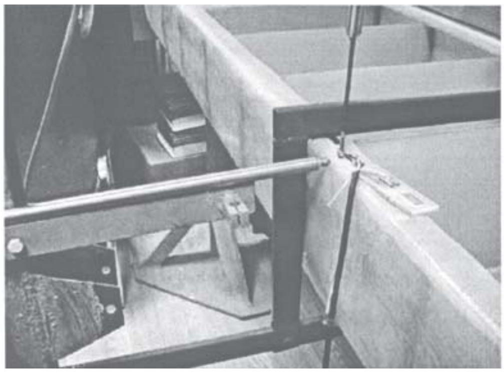

Fig. 10. Displacements measurementy rig

Fig. 9. Torsion loading rig

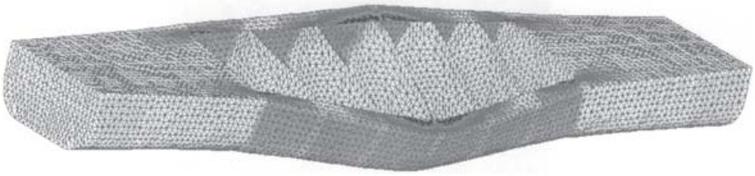

Fig.11. Ship model deformed due to torsion

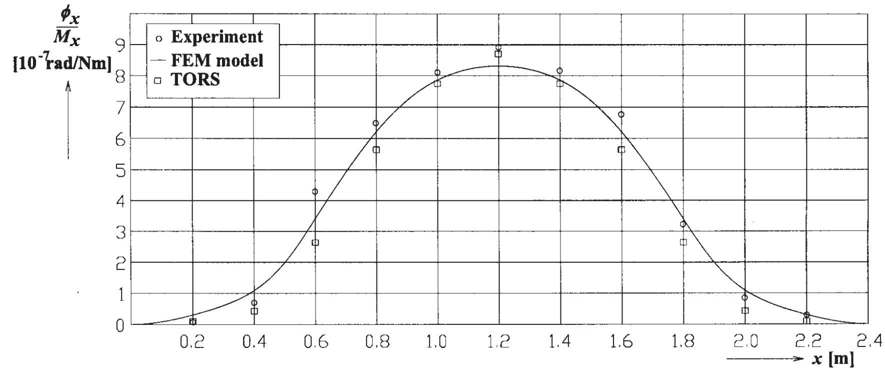

Fig. 12. Relative torsion angle along the ship model

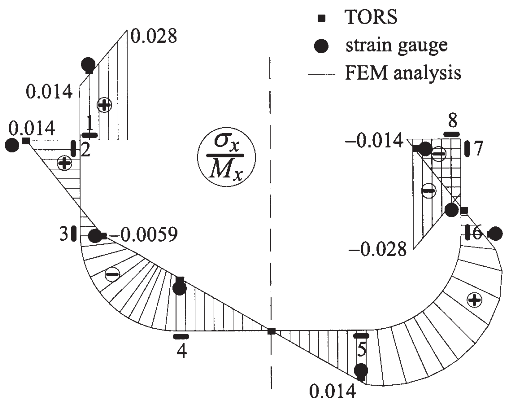

Fig. 13. Relative normal stress in the midship open section

presented.

The stress state in the ship hull was determined by the strain gauges measurements. 20 strain gauges have been used for the measurements, with the strain gauge equipment concerning a bridge equipment Spider. The strain gauges were placed along the strip deck in the open area and in the closed section (on the deck side and bottom).

The torsion angle of the ship hull model cross sections was determined by taking into account the displacements of the points placed on the outline, according to the rotation of the cross section as a rigid body (thin-walled beam hypothesis) (fig. 8).

The vertical and horizontal displacements of the point placed at the intersection between deck and side shell were determined with LVDT system (fig. 9).

Conclusions

The methodology presented in this paper, is concerning to a proposed macroelement model of thin walled beam for torsion analysis of ship hull made of composite material. The assumptions concerning the material properties and the stress distribution in the beam have been made.

A finite element computer program TORS has been developed for the elastic analysis of linear torsion. For this program, the ship hull beam is divided into a number of macroelements. Each macroelement is divided into a number of strip elements, each of which has a cubic variation of the twist rotation φ along its length. The data for each strip element consists of the characteristics of composite (stack and material).

Each element may have a uniformly distributed torque per unit length m_x, while concentrated torques *M* and bimoments *B* may act at the nodes between macro elements. Each node may have restraints which prevent twist rotation and/or warping. The numerical results obtained with the code TORS, based on this method are compared with the results obtained with FEM analysis COSMOS/M and experimental results on the model of a ship with large open deck.

In the figure 11, the deformed ship hull numerical model, according to the numerical calculus done with COSMOS/M is shown. Due to the variation of the cross section shape of the model, a coupled torsion with lateral bending occurred.

In the spite of fact the torque is applied so that can provide a pure torsion, warping of the sections occurs. Warping of the section is only depending on the section geometry which means that along the model exist free warping and restrained warping sections.

The values obtained with FE analysis and according to the strain gauges measurements are presented.

The variation of the relative normal stress in the midship open section and the results obtained with TORS (macroelement model) FEM analysis and in experimental tests for the 8 points are presented in figure 13. Due to the fact that the variation of the normal stress is linear type, the variation of the ratio (σ_x/M_x) was plotted with continuous line. The values of the stresses obtained with strain gauges were plotted in the figure.

The variation of the relative torsion angle (ϕ_x/M_x) along the ship model obtained so in FEM analysis, macroelement model and experimental measurements are presented in figure 12. Due to the closed section type in the ends, the torsion stiffness of the model in these areas is much higher than in the middle part. As it is seen in figure 12, the maximum value of the relative torsion angle (ϕ_x/M_x) in the midship is almost 2 times more than the maximum torsion angle in the closed area.

The results obtained by the three methods (macro-element model, FEM and experiment tests) are in a good agreement. The simple mode to introduce the input data for defining the cross section, the macroelement model and base code recommend the methodology as a good tool for torsion analysis of ship hull made of composite materials.

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