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ASPECTS ON STRUCTURAL SCATLINGS OF SMALL CRAFTS BUILD FROM COMPOSITE MATERIALS

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Abstract: *Development and improvement of manufacturing technologies for composite materials with more and more improved characteristics, resulted in use of these materials in shipbuilding as well, and particularly in boatbuilding. Scantling calculations of strength structures for these boats are carried out based on the Rules of Classification Societies for ships and recently according to ISO 12215 series of standards. In this article, are presented results of such scantling calculations of structural elements of one leisure boat, based on relevant standard, using CraftSoft software. This software, developed by authors in EXCEL, can calculate the required scantling structural properties for boats constructed of aluminum alloys, steel, wood and fiber reinforced plastic, single skin and sandwich laminates, according to ISO 12215-5 standard.*
Keywords: *composite material, small craft, scantling*

1. INTRODUCTION

Traditional materials used in shipbuilding are steel and aluminum, but due to development and improvement of manufacturing technologies for composite materials with improved characteristics, these materials commenced to replace more and more the traditional ones as a consequence of their advantages: low density, high endurance to mechanical actions, corrosion and fatigue resistance, high capacity to attenuate vibrations, special magnetic proprieties, low energy consumption and lower cost installations for manufacturing.

But usage of composite materials, due to lower mechanical proprieties in comparison with metals, is limited to construction of small and medium ships, up to 70 meters and construction of some structures onboard large ships where effective stresses do not reach big values, e.g. superstructures or their inner bulkheads, or other fittings or arrangements onboard.

The most used composite materials for building small ships are those fibre glass reinforced and those of sandwich type whose characteristics are prescribed by following standards:

1. ISO 12215-1: 2003 Small craft. Hull construction and scantlings. Part 1: Materials: Thermosetting resins, glass fibre reinforcement, reference laminate;
2. ISO 12215-2: 2003 Small craft. Hull construction and scantlings. Part 2 : Materials: Core materials for sandwich construction, embedded materials,

as well as by the Rules of some classification societies for ships, e.g. Lloyd’s Register (LR), American Bureau of Shipping (ABS), DNV –GL, Bureau Veritas (BV), etc.

Recently, in the construction of ship’s strength structures, the unrestricted use of a new combination of materials based on SPS (sandwich plate system) concept have commenced, materialized in steel sandwich panels which consists of three layers: two external layers of steel and one internal core layer, see figure 1.

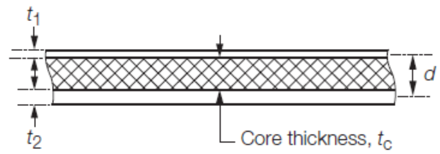


Figure 1: Steel sandwich panel

Regulations for fabrication, characteristics and scantling of this new composite material could be found at some classification societies as LR, DNV-GL, etc.

2. SCANTLING OF HULLS BUILT IN COMPOSITE MATERIALS

Boats are small crafts with length less than 24 meters, with broad scope of use, from performing commercial services to leisure or sport activities. Scantling of those boats, built in composite materials, is done based on Rules of classification societies, but now, this scantling could be done as well according to following recent standards:

1. ISO 12215-5: 2008 Small craft. Hull construction and scantlings. Part 5: Design pressures for monohulls, design stresses, scantlings determination;
2. ISO 12215-6: 2008 Small craft. Hull construction and scantlings. Part 6 : Structural arrangements and details.

In principle, scantling of structural elements of boats based on these regulations is carried out according to a general scheme indicated in figure 2:

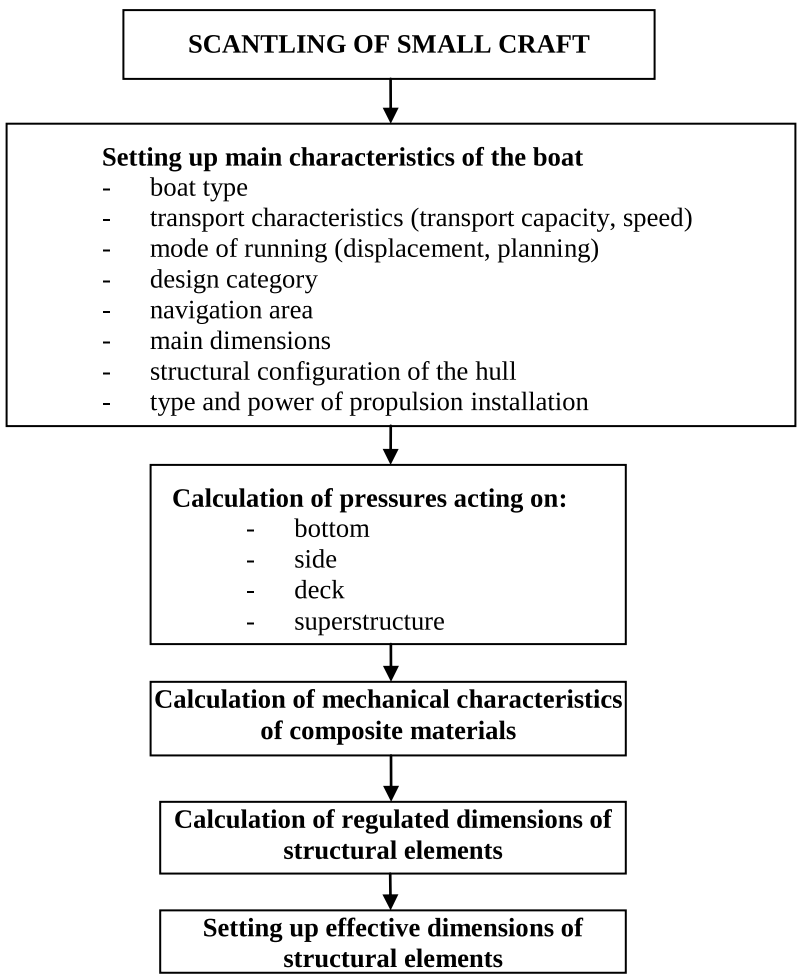


Figure 2: Scheme of boat scantling

Figure 3 presents the results of some comparative scantling calculations for boats made of composite materials according to the Rules of some classification societies and according to ISO 12215-5 : 2008, reproduced from [3]. We can conclude that boats dimensioned according to this standard are lighter than those dimensioned according to the Rules of main classification societies (LR, ABS, GL, BV or RINA).

Scantling of structural elements subject to concentrated loads could be performed through direct calculations, including finite element method.

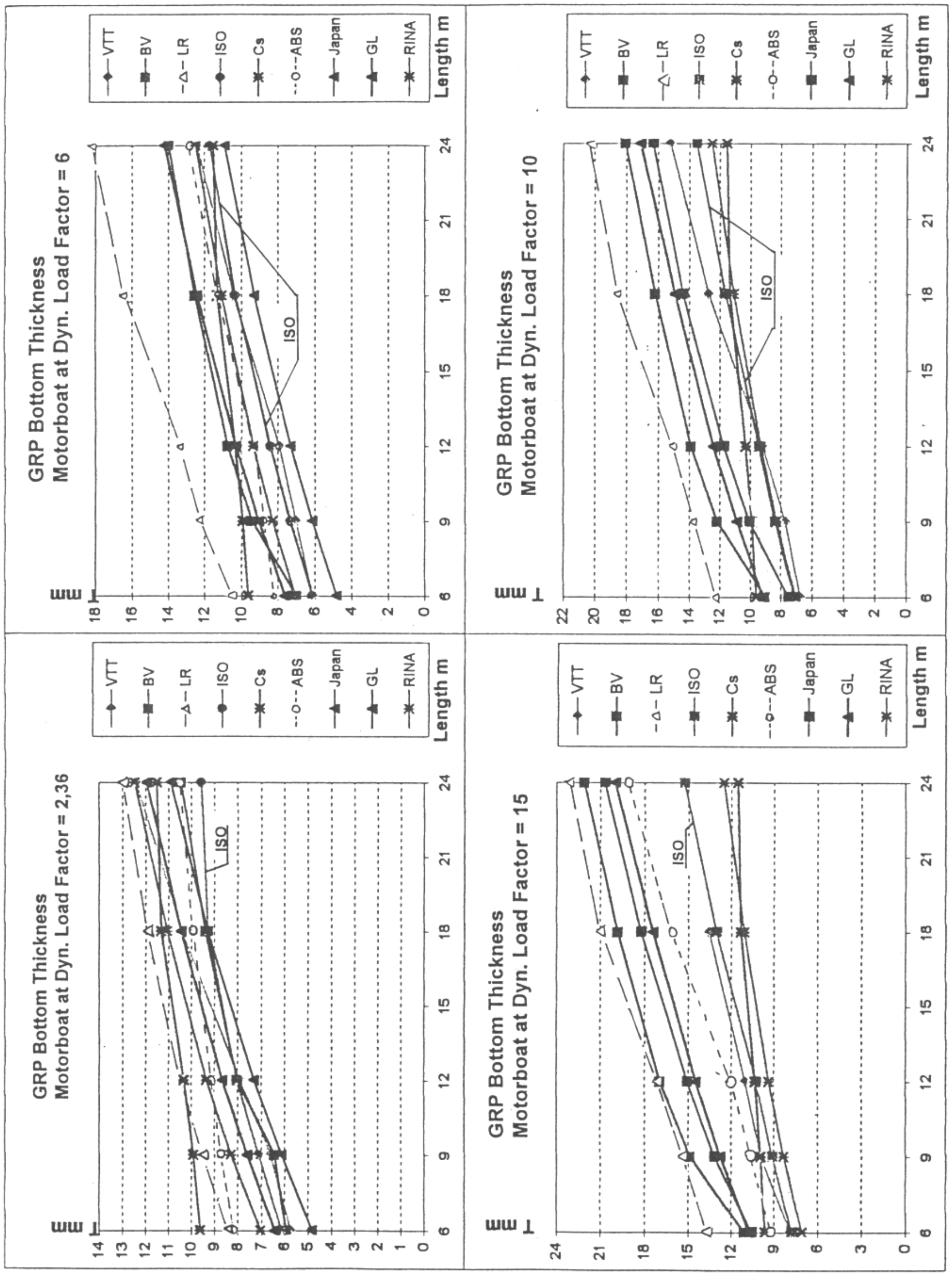
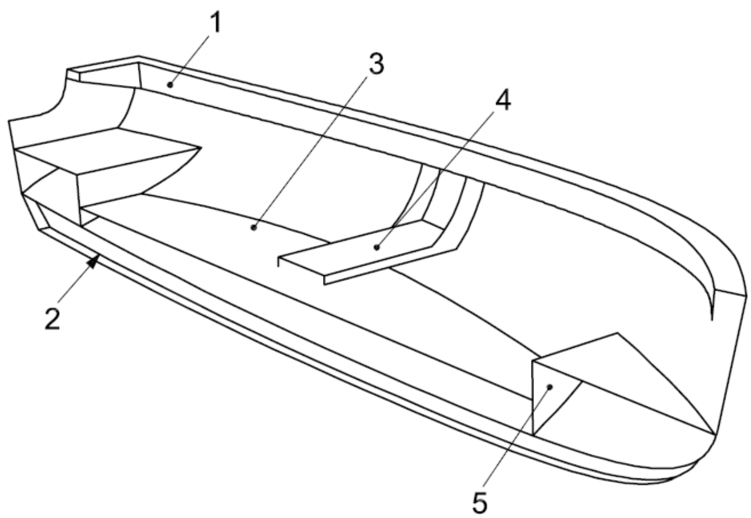


Figure 3: Comparative calculations for small craft scantlings

3. SCANTLING CALCULATIONS FOR A BOAT BASED ON INTERNATIONAL STANDARD ISO 12215-5:2008 USING CRAFTSOFT SOFTWARE

Based on standard ISO 12215-5 : 2008, a leisure boat in serial production was dimensioned, in order to fulfill essential requirements of Directive 94/25/EC, see figure 4. The characteristics of this boat are given in table 1.



Key

1 gunwale stringer
2 keel
3 structural sole
4 thwarts
5 deep floor

Figure 4: Structural arrangement of dimensioned boat

Table 1: Boat particulars

Craft Type	Motor boat MFS-MB3
Design Category	D
Material	GRP single-skin laminates and GRP sandwich composites
Displacement, m_{LDC}	625.00 kg
Length of Hull, L_H	4.50 m
Hull Beam, B_H	1.40 m
Loaded Waterline Length, L_{WL}	4.00 m
Loaded Waterline Beam, B_{WL}	1.30 m
Chine Beam, B_C	1.20 m
Depth of Bulkhead, D_b	0.53 m
Deadrise Angle, $b_{0.4}$	17.00 ^{o}
Maximum speed, V	9.50 kts

Because scantling calculations based on relevant ISO standard, are laborious and complex, a software named CraftSoft was developed in Excel. With its help, following calculations for structural elements of respective boat were performed, as indicated in the tables hereinafter:

Table 2: General calculation

Dynamic Load Factor, n_{CG}	0.916	
Design Category Factor, k_{DC}	0.400	
Base Bottom Displacement Pressure, $P_{BMD\ BASE}$	40.084	kN/m^2
Base Bottom Planning Pressure, $P_{BMP\ BASE}$	20.567	kN/m^2
Minimum Bottom Pressure, $P_{BM\ MIN}$	5.279	kN/m^2
Minimum Side Pressure, $P_{SM\ MIN}$	1.440	kN/m^2
Base Deck Pressure, $P_{DM\ BASE}$	16.000	kN/m^2
Minimum Deck Pressure, $P_{DM\ MIN}$	5.000	kN/m^2

Table 3: GRP laminates properties for single-skin panels and stiffeners

Fabrication procedures	Hand-laminated combened chopped strand mat (CSM)/woven roving (WR)		
Composite Evaluation Level		EL-c	
Multiplied factor, K_M		0.800	
Glass content in mass, ψ		0.250	
Ultimate tensile strength, σ_{ut}		53.600	N/mm^2
Ultimate compressive strength, σ_{uc}		87.600	N/mm^2
Ultimate flexural strength, σ_{uf}		110.700	N/mm^2
Ultimate in-plane shear strength, τ_u		46.400	N/mm^2
Interlaminar (out of plane) shear strength, $\tau_{u\ inter}$		14.500	N/mm^2
In-plane modulus, E		3600.000	N/mm^2
In-plane shear modulus, G		2132.000	N/mm^2

Table 4: GRP sandwich properties for transom panel

Fabrication procedures	Wood core covered by an outer GRP laminate and an inner GRP laminate		
Wood core properties of sandwich			
Wood type		Fir	
Wood density, ρ_c		0.470	kg/m^3
Ultimate tensile strength, σ_{ut}		80.000	N/mm^2
Ultimate compressive strength, σ_{uc}		40.000	N/mm^2
Ultimate flexural strength, σ_{uf}		68.000	N/mm^2
Ultimate transverse shear strength, τ_u		10.000	N/mm^2
Young's modulus parallel to fibres, E_L		10000.000	N/mm^2
Young's modulus perpendicular to fibres, E_T		800.000	N/mm^2
Shear modulus, G		600.000	N/mm^2
Transverse contraction, μ_{TL}		0.330	
Outer and inner GRP laminates properties of sandwich			
Composity Evaluation Level of laminates		EL-c	
Multiplied factor for laminates, K_M		0.800	
Glass content in mass of laminates, ψ		0.250	
Ultimate tensile strength, σ_{ut}		53.600	N/mm^2
Ultimate compressive strength, σ_{uc}		87.600	N/mm^2
Ultimate flexural strength, σ_{uf}		110.700	N/mm^2
Ultimate in-plane shear strength, τ_u		46.400	N/mm^2
Interlaminar (out of plane) shear strength, $\tau_{u\ inter}$		14.500	N/mm^2
In-plane modulus, E		3600.000	N/mm^2
In-plane shear modulus, G		2132.000	N/mm^2

Table 5: GRP single-skin panel geometry

Item	**Dimension and Location**							
	Length l [mm]	Width b [mm]	Aspect Ratio l/b	Longit. pos. x [m]	Location	z [m]	h [m]	c [mm]
Bottom Panel	2700	1400	1.929	2.500	Bottom	-	-	530
Side Panel	2700	1400	1.929	2.500	Side	0.230	0.115	530

Table 6: GRP single-skin panel calculations & results

Item	Calculations to ISO 12215-5 standard									
	k_L	k_{AR}	k_2	k_3	k_C	k_z	P [kN/m^2]	t [mm]	t_{min} [mm]	$t_{adopted}$ [mm]
Bottom Panel	1.000	0.250	0.495	0.028	0.500	-	5.279	4.81	3.81	5.00
Side Panel	1.000	0.250	0.495	0.028	0.500	0.5	2.804	3.50	3.81	5.00

Table 7: GRP sandwich panel geometry

Item	Dimension and Location							
	Length l [mm]	Width b [mm]	Aspect Ratio l/b	Longit. pos. x [m]	Location	z [m]	h [m]	Curvature c [mm]
Trasom Panel	920	300	3.067	0.000	Transom	0.300	0.150	0.000

Table 8: GRP sandwich panel calculations

Item	Calculations to ISO 12215-5 standard									
	k_L	k_{AR}	k_2	k_3	k_C	k_{KSH}	k_z	P [kN/m^2]	M_d Nmm/mm	F_d [N/mm]
Trasom Panel	0.501	0.579	0.489	0.028	1.000	0.485	0.5	3.256	23.8563	0.4737

Table 9: GRP sandwich panel results

Item	Required						Adopted						
	I [cm^4/cm]	SM_o [cm^3/cm]	SM_i [cm^3/cm]	t_{omin} [mm]	t_{imin} [mm]	t_s [mm]	t_c [mm]	t_o [mm]	t_i [mm]	t_s [mm]	I [cm^4/cm]	SM_o [cm^3/cm]	SM_i [cm^3/cm]
Trasom Panel	0.00335	0.0089	0.00545	0.57	0.40	0.095	43.0	5.2	1.8	50	2.903	1.994	0.819

Table 10: Minimum sandwich skin fibre mass

Item	Required					Adopted	
	k_4	k_5	k_6	w_{os} [kg/m^2]	w_{is} [kg/m^2]	w_{os} [kg/m^2]	w_{is} [kg/m^2]
Trasom Panel	0.900	1.000	1.000	0.198	0.139	1.799	0.623

Table 11: GRP stiffner geometry

Item	Dimension and Location						
	Length l_u [mm]	Spacing s [mm]	Longit. pos. x [m]	Location	z [m]	h [m]	Curvature c_u [mm]
Keel	2700	600	2.500	Bottom	-	-	0
Gunwale stringer	2700	500	2.500	Side	0.230	0.230	475

Table 12: GRP single-skin panel calculations & results

Label	Calculations to ISO 12215-5 standard								Required			Adopted		
	k_L	k_{AR}	k_z	k_{CS}	k_{SA}	P [kN/m^2]	M_d [Nm]	F_d [N]	A_W [cm^2]	SM [cm^3]	I [cm^4]	A_W [cm^2]	SM [cm^3]	I [cm^4]
Keel	1.0	0.25	-	1.000	5.000	5.279	1924.2	4276.1	1.843	71.798	90.056	3.500	76.32	1100.0
Gunwale stringer	1.0	0.25	0.0	0.514	7.500	1.600	249.9	1080.0	0.698	9.324	8.386	3.000	10.04	34.38

From the boats dimensioned this way, and being in use, we did not received complaints, which means that their design and construction were correct.

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