UDK 629.5.02-036.5:629.5.024:629.5.011

PRORAČUN ELEMENATA STRUKTURE TRUPA MALOGA PUTNIČKOG PLOVILA
SMALL CRAFT STRUCTURAL ELEMENTS SCANTLINGS

Jasmin PERIĆ – Albert ZAMARIN – Tin MATULJA

Sažetak: *Prikazan je primjer proračuna elemenata strukture stakloplastičnog plovila prema pravilima i propisima klasifikacijskog društva Lloyd´s Register. Nakon toga je izvršena kontrola proračuna pomoću softverskog paketa Special Service Craft, 5,0 istoga klasifikacijskog društva. Namjera je odrediti dimenzije osnovnih strukturnih elemenata za predmetno stakloplastično plovilo, te izraditi nacrt glavnog rebra i uzdužnog presjeka na kojem će, osim prorčunatih dimenzija poprečnih i uzdužnih elemenata strukture trupa, biti vidljiva osnovna strukturalna toplogija i razmještaj. Tako dobivene dimenzije i nacrt strukturnih elemenata predstavljaju osnovu za daljnju tehnološku razradu u smislu izrade laminat-plana i detalja strukture.*

Ključne riječi:
- konstrukcija broda
- dimenzioniranje strukturnih elemenata
- pravila i propisi klasifikacijskog društva
- malo putničko plovilo
- stakloplastika

Summary: In this paper, an example of small craft structural elements scantlings calculations is presented, with relevance to *Lloyd's Register* classification rules. Afterwards, calculations have been checked with the *Lloyd's Special Service Craft, 5,0* software. The intent was to define the dimensions of major structural scantling elements for the small GRP craft considered and also to design a midship section and longitudinal section drawings on which would be visible, except for the calculated dimensions of transversal and longitudinal elemental structures of the hull, the main structural topology and disposition. Such attained dimensions and drawings of structural elements are basic to the further technological breakdown in the sense of defining a laminate plan and structural details.

Key words:
- ship construction
- structural elements scantlings
- rules and regulations of the classification society
- small craft
- glass reinforced plastic

1. UVOD

Brodograđevna povijest dijeli se u dva dijela, drvenu i željeznu. Drvo je stoljećima bilo osnovni brodograđevni materijal. Razvojem industrije čelik je postao glavni materijal za izgradnju većih brodova, osobito trgovačkih. Razvojem kemijske industrije i pronalaskom plastičnih masa započinje prodor plastike u sva područja ljudskog života. Njezina rasprostranjenost danas opravdana je zbog niske cijene, brze i automatizirane izrade, mogućnosti oblikovanja i bojenja. U maloj brodogradnji SOP (staklom ojačana plastika) plovila zauzimaju najveći dio proizvodnje [1], i to zbog mnogih prednosti: jednostavnije izrade, zadovoljavajuće čvrstoće i relativno malih troškova održavanja. Danas postoji više načina izrade stakloplastičnih plovila.

1. INTRODUCTION

Shipbuilding history can be divided in two major periods, wooden shipbuilding and shipbuilding with steel. Hence, wood was the basic shipbuilding material for centuries. With industrial build-up, steel has become the major shipbuilding material for larger ships, especially merchant ships. Within the development of the chemical industry and discovery of plastic materials, plastic began its ingress into all aspects of modern living. Plastic can be found everywhere, its distribution is logical due to its low cost, automated production, easy shaping and colouring. GRP (glass reinforced plastic) crafts in small shipbuilding present the major part of small shipbuilding production [1] for a number of advantages; simple production, satisfactory strength, lower production costs and relatively low maintenance costs.

U početku se koristio isključivo ručni kontaktni postupak, međutim zahtjevi za većom čvrstoćom uz manju težinu, te zahtjevi za smanjivanjem emisije stirena doveli su do novih načina izrade. Prije svih treba spomenuti postupak vakumske infuzije, gdje se na suho posložena staklena ojačanja mata (pusta) i rovinga (hasure), nakon zatvaranja folijom (pokrivačem) pušta smola, te crpkama isisava višak zraka i smole.
Izradi stakloplastičnog plovila prethodi proračun strukturnih elemenata [2]. Masovna izrada i primjena stakloplastičnih plovila dovela je do potrebe podizanja kvalitete i sigurnosti plovila, pa tako nova pravila za statutarnu certifikaciju brodica i jahti zahtjevaju proračun strukture za plovila veća od 2,5m duljine trupa.
Proračun konstrukcije bazira se na empirijskim formulama danima od strane klasifikacijskog društva pod kojim se plovilo gradi. Danas se koriste i softverski paketi klasifikacijskih društava, koji prema ulaznim parametrima: glavnim dimenzijama, vrsti plovila, području plovidbe i brzini, proračunavaju minimalne zahtijevane dimenzije strukturnih elemenata.
U ovom radu prikazan je proračun elemenata strukture deplasmanskoga stakloplastičnog plovila, sl. 1, a glavne dimenzije prikazane su u tablici 1.

Tablica 1. Glavne dimenzije broda

Duljina preko svega	L_{oa} = 21,00 m
Širina konstrukcijska	B = 6,40 m
Visina konstrukcijska	H = 2,80 m
Gaz na KVL	T = 1,60 m
Brzina u službi	v = 10,0 čv
Istisnina	D = 75 t
Broj putnika	140

2. PRORAČUN KONSTRUKCIJE STAKLOPLASTIČNOG PLOVILA

2.1. Tijek proračuna

Prikazana je izrada proračuna stukturnih elemenata predmetnoga stakloplastičnog plovila, pri čemu se koriste pravila i propisi klasifikacijskog društva "Lloyd´s Register of Shipping – Special Service Craft", [3].
Proračun započinje iskustvenim formulama za dobivanje mehaničkih karakteristika staklenog ojačanja, koje će kasnije služiti za uspoređivanje sa stvarnim naprezanjima u elementima. Na isti se način izračunavaju svojstva materijala, odnosno debljine pojedinih slojeva unutar laminata, a s obzirom na gramaturu staklenog ojačanja.

There are several current methods by which to build a craft from glass reinforced plastic. In the beginning, a manual contact procedure was exclusively carried out, however requirements for greater strength and lower weight and also requirements for lower stiren emission, have led to new production procedures. One of the more important of such methods is where the resin is pumped onto previously placed and reinforced dry glass *mat* and *roving* reinforcements. Afterward sealing the foil, extra resin and air is pumped out.
Before actual craft production, structural element calculations should be conducted [2]. Mass production of such crafts has resulted in the necessity for the quality and safety of vessels. Hence, new regulations for the certification of small crafts and yachts demand structural calculations for all crafts over 2.5m in hull length.
Calculation of small craft structure is based on empirical equations provided by the classification society under which the craft is build. Nowdays, specialised software packages from the classification societies are used, which with relevance to the input parameters; main dimensions, craft type, area of navigation, speed, etc., the minimal required dimensions of structural elements are calculated.
In this paper, the structural elements calculation for a displacement craft made from GRP is presented, as seen in Figure 1. The main dimensions are shown in Table 1.

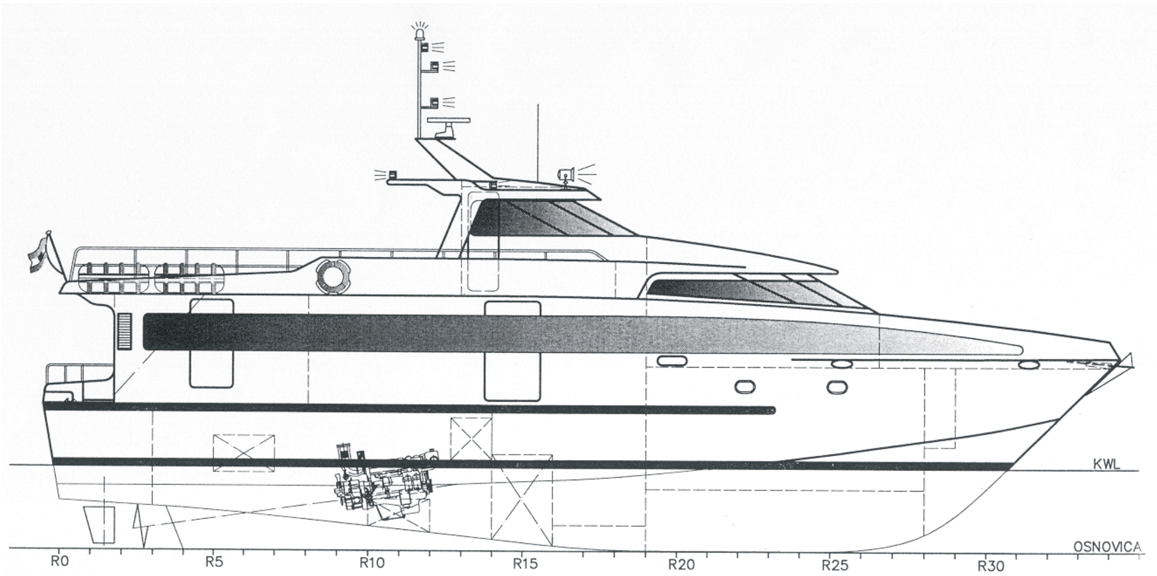
Table 1. Main dimensions of small craft

Overall length	L_{oa} = 21,00 m
Breadth	B = 6,40 m
Height	H = 2,80 m
Draught	T = 1,60 m
Speed in service	v = 10,0 čv
Displacement	D = 75 t
Number of passengers	140

2. STRUCTURAL CALCULATION FOR GRP CRAFTS

2.1. Calculation procedure

In this paper, the development of structural elements calculation of a given GRP craft is presented, where the rules and regulations of "Lloyd's Register of Shipping - Special Service Craft", [3] classification society were used. Calculation is begun with empirical equations for defining the mechanical characteristics of glass reinforcement, which will later serve for comparison with real stress in the elements. Based on the same principle, material characteristics are calculated, and thereafter the thickness of particular layers inside the laminate is calculated, with respect to the structure of the glass reinforcement.



Slika 1. Opći plan maloga putničkog plovila
Figure 1. General plan of small craft

Da bi se počelo s proračunom elemenata, potrebno je odrediti opterećenja koja se javljaju zbog eksploatacije broda pa se tako, također pomoću empirijskih formula dobivaju konstrukcijska opterećenja koja ovise o glavnim dimenzijama plovila, području plovidbe, brzini i sl.
Nakon što su određene vrijednosti opterećenja može se pristupiti izračunu vrijednosti momenata savijanja u području ispod ukrepljenja i na sredini panela (odnosno polovini razmaka ukrepa). Za dobivanje momenata savijanja najvažniji parametri su opterećenja i razmak ukrepljenja. Potom je potrebno izračunati minimalne debljine laminata oplate. Da bi se one dobile, potrebno je poznavati razmak između ukrepa, opterećenje na promatranom dijelu i modul elastičnosti laminata.
Isto tako potrebno je izračunati tlačna i vlačna naprezanja u zadnjem sloju laminata. Da bi se to odredilo, uz momente savijanja i modul elastičnosti potrebno je izračunati i udaljenost neutralne osi laminata od njegove vanjske površine. Time se završava proračun opločenja, a započinje proračun ukrepljenja, koji se izvodi istim redoslijedom kao i za opločenje, samo su iskustvene formule prilagođene ukrepljenju.

In order to begin elements calculation, determination of loads during navigation is required, and thus with the application of empirical equations, the structural load regarding craft main dimensions, area of navigation, speed, etc. is determined. When the structural load has been determined, the bending moment in areas under the stiffeners and in the middle of panels (half the distance between the stiffeners) can be calculated. In determining the bending moment, the most crucial parameters are the structural loads and the stiffener spacing. Later, the minimal thickness of the hull laminate is to be calculated. In order to calculate it, an spacing between stiffeners, the load on the considered area and the laminate modulus of elasticity must be known.
Also, compression and tensile stress in the last laminate layer should be calculated. In order to do so, besides the bending moments and modulus of elasticity, the distance from the neutral axis of the laminate to its surface should be calculated. Thereby, calculation of the hull laminate is complete and the calculation for stiffeners is consequent, which is conducted in the same manner as for the hull but with adjusted empirical equations.

2.2. Mehaničke osobine

Mehaničke osobine mata računaju se na osnovi postotaka staklenog ojačanja G_C, koje se u njemu nalazi, a ovisi o odabranoj vrsti materijala [3], [4]. Odabran je materijal koji ima G_C = 0,33, [3]. Mehaničke se osobine zatim izračunavaju prema sljedećim izrazima:

2.2. Mechanical properties

The mechanical characteristics of the matt are calculated on the basis of its glass reinforcement ratio G_C, which depends on the chosen type of material [3], [4]. In this paper, the chosen material has G_C = 0,33, [3]. The mechanical characteristics are then calculated according to the following equations:

- Vlačna čvrstoća,

- Tensile strength,

$$200G_C + 25 = 91{,}0\,\text{Nmm}^{-2}.$$

- Modul elastičnosti, E - Modulus of elasticity, E

$$(15 \cdot G_C + 2) \cdot 10^3 = (15 \cdot 0{,}33 + 2) \cdot 10^3 = 6950\,\text{Nmm}^{-2}.$$

- Tlačna čvrstoća, - Compression strength,

$$150 G_C + 72 = 150 \cdot 0{,}33 + 72 = 121{,}5\ \text{Nmm}^{-2}.$$

- Smična čvrstoća, - Shear strength,

$$80 G_C + 38 = 80 \cdot 0{,}33 + 38 = 64{,}4\,\text{Nmm}^{-2}.$$

- Modul smika, G - Modulus of shear, G

$$(1{,}7 G_C + 2{,}24) \cdot 10^3 = (1{,}7 \cdot 0{,}33 + 2{,}24) \cdot 10^3 = 2801\,\text{Nmm}^{-2}$$

Mehaničke osobine rovinga računaju se na osnovi postotaka staklenog ojačanja G_C, koje se u njemu nalazi, a ovisi o odabranoj vrsti materijala. Odabran je materijal koji ima G_C = 0,5 [3]. Mehaničke se osobine zatim izračunavaju prema sljedećim izrazima:

The mechanical characteristics of rowing are calculated regarding the glass reinforcement ratio G_C, which depends on the chosen type of material. In this paper, the choosen material has G_C = 0,5 [3]. The mechanical characteristics are then calculated according to the following equations:

- Vlačna čvrstoća -Tensile strength,

$$400 G_C - 10 = 400 \cdot 0{,}5 - 10 = 190{,}0\ \text{Nmm}^{-2}$$

- Modul elastičnosti, E - Modulus of elasticity, E

$$(30 G_C - 0{,}5) \cdot 10^3 = (30 \cdot 0{,}5 - 0{,}5) \cdot 10^3 = 14500\ \text{Nmm}^{-2}$$

- Tlačna čvrstoća - Compression strength,

$$150 G_C + 72 = 150 \cdot 0{,}5 + 72 = 147\ \text{Nmm}^{-2}$$

- Smična čvrstoća - Shear strength,

$$80 \cdot G_C + 38 = 80 \cdot 0{,}5 + 38 = 78{,}0\ \text{Nmm}^{-2}$$

- Modul smika, G - Modulus of shear, G

$$(1{,}7 G_C + 2{,}24) \cdot 10^3 = (1{,}7 \cdot 0{,}5 + 2{,}24) \cdot 10^3 = 3090\ \text{Nmm}^{-2}$$

Minimalna debljina svakoga pojedinog sloja u laminatu određuje se prema izrazu:

Minimal thickness of each particular laminate layer is determined according to:

$$t_i = \frac{m_{Fi}\left[\dfrac{\int_{Fi}}{f_{Ci}} - \left(\int_{Fi} - \int_{Ri}\right)\right]}{1000 \int_{Fi} \int_{Ri}},\ \text{mm} \tag{1}$$

gdje je:
m_{Fi} - gramatura staklenog ojačanja, a koeficijenti
$\int_{Fi} = 2{,}56$
$\int_{Ri} = 1{,}2$ - preuzeti iz [3].
$f_{Ci} = 0{,}33$

where:
m_{Fi} - structure of glass reinforcement, and coefficients
$\int_{Fi} = 2{,}56$
$\int_{Ri} = 1{,}2$ - taken from [3].
$f_{Ci} = 0{,}33$

Za pust gramature 450 gm^{-2} slijedi:
t_i = 0,937 mm.
Za hasuru gramature 610 gmm^{-2} i $f_{Ci} = 0{,}5$ slijedi:
t_i = 0,747 mm.

For a matt structure of 450 gm^{-2} it follows:
t_i = 0,937 mm.
For a roving structure of 610 gmm^{-2} , $f_{Ci} = 0{,}5$ it follows:
t_i = 0,747 mm.

2.3. Opterećenja brodske konstrukcije

Pojedine proračunske komponente vanjskog opterećenja trupa prikazane su u tablici 2, a prema [3].

Tablica 2. Komponente vanjskog opterećenja

Hidrodinamičko opterećenje	P_w	13,78 kNm^{-2}
Opterećenje uslijed posrtanja	P_p	26,15 kNm^{-2}
Opterećenje dna	P_{dh}	10,49 kNm^{-2}
Pritisak na pramčani dio strukture	P_f	22,11 kNm^{-2}
Hidrostatski pritisak vanjske oplate dna	P_{hl}	11,1 kNm^{-2}

Tako definirana vanjska opterećenja služe kao baza za određivanje konstrukcijskih opterećenja za promatrani dio trupa. Dobivaju se upotrebom dodatnih faktora vezanih za položaj na trupu, a prikazana su tablici 3.

Tablica 3. Konstrukcijska opterećenja za promatrani dio trupa

Područje	Konstrukcijski pritisak, kNm^{-2}	
	opločenje	ukrepljenje
Dno	37,25	29,8
Bok	27,45	21,96
Paluba	8,72	primarni elementi: 3,2 sekundarni elementi: 5,23
Nadgrađe		
Bok	3,73	2,98
Prednja strana	4,66	3,73
Stražnja strana	2,33	1,86
Kormilarnica		
Bok	2,98	2,38
Krov	2,33	1,86
Prednja strana	4,66	3,73
Stražnja strana	2,33	1,86

2.3. Structural loads

Particular components of external hull loads are shown in Table 2, according to [3].

Table 2. External load components

Hydrodynamic load	P_w	13,78 kNm^{-2}
Pitching load	P_p	26,15 kNm^{-2}
Hull bottom load	P_{dh}	10,49 kNm^{-2}
Pressure on bow structure	P_f	22,11 kNm^{-2}
Hydrostatic pressure on bottom shell	P_{hl}	11,1 kNm^{-2}

Such defined external loads are the basis for structural loads determination for the considered part of the hull. They are determined with the use of additional factors relating to the position on hull and are shown in Table 3.

Table 3. Structural loads for particular position on hull

Position	Strucural load, kNm^{-2}	
	shell	stiffeners
Bottom	37,25	29,8
Side	27,45	21,96
Deck	8,72	Primary elements: 3,2 Secondary elements: 5,23
Superstructure		
Side	3,73	2,98
Front side	4,66	3,73
Back side	2,33	1,86
Wheelhouse		
Side	2,98	2,38
Top	2,33	1,86
Front side	4,66	3,73
Back side	2,33	1,86

2.4. Dimenzioniranje opločenja i ukrepljenja

Dimenzije opločenja na pojedinom dijelu strukture, kao i dimenzije ukrepnih elemenata završno se određuju na osnovi dvaju zahtjeva. Prvi je minimalna debljina opločenja, tj. laminata u milimetrima za promatrani dio strukture, uz prethodno proračunato projektno opterećenje p, razmak ukrepa b i modul elastičnosti svih slojeva laminata E_{tp} prema izrazu:

2.4. Plate and stiffener dimensioning

Plate dimensions on particular parts of structure, as well as the dimensions of the stiffeners, are finally calculated in relation to two requirements. The first is the minimal thickness of shell, i.e. the thickness of the laminate in millimetres for the considered part of the structure, with the previously calculated design load p, stiffener indent b and modulus of elasticity of all the laminate layers E_{tp} according to:

$$t = 0{,}146 \cdot b \cdot \sqrt[3]{\frac{p}{E_{tp}}} \quad \text{, mm} \tag{2}$$

Drugi zahtjev vezan je za provjeru stvarnoga vlačnog i tlačnog naprezanja u vanjskom sloju laminata, u odnosu prema dozvoljenom naprezanju, prema izrazima za vlačno naprezanje

The second requirement is related to verification of real tensile and compression stress in the outside laminate layer, regarding allowed stress, and according to equations for tensile stress

$$\delta_{t1} \le \delta_{dop}$$

$$\delta_{ti} = \frac{0{,}1 \cdot E_{ti} \cdot y_i \cdot M}{\sum (E_i \cdot I_i)} \text{ , Nmm}^{-2}, \tag{3}$$

odnosno za tlačno naprezanje:

respectively for compressive stress:

$$\delta_{c1} \le \delta_{dop}$$

$$\delta_{c1} = \frac{0{,}1 \cdot E_{ci} \cdot y_i \cdot M}{\sum (E_i \cdot I_i)} \text{ , Nmm}^{-2} \tag{4}$$

gdje je:
i – ide od 1 – ukupnog broja slojeva laminata,
E_{t1}, E_{c1} – modul elastičnosti vanjskog sloja laminata za tlak, odnosno vlak, u Nmm^{-2} ,
y_i - udaljenost neutralne osi od unutarnjeg/vanjskog sloja,
I_i – moment inercije površine presjeka sloja laminata, I_1 za mat i I_2 za roving,

where:
i – from 1 to the total number of laminate layers,
E_{t1}, E_{c1} – modulus of elasticity of the outside laminate layer for compression, respectively tension, in Nmm^{-2},
y_i–distance from neutral axis to the inner/outer laminate layer
I_i – momentum of inertia cross sectional area of laminate layer I_1 for mat and I_2 for rowing,

$$I_1 = \frac{b \cdot h^3}{12} = 7{,}8 \cdot 10^{-3}\ \text{m}^4,$$

$$I_2 = \frac{b \cdot h^3}{12} = 6{,}225 \cdot 10^{-3}\ \text{m}^4,$$

M – moment savijanja na oplati unutar panela računa se prema izrazu, a na poziciji ispod ukrepe

M – bending moment on shell inside of panel under the stiffener is calculated according to,

$$M_b = \frac{kpb^2}{12} \cdot 10^{-5} \text{ , Nm}$$

odnosno na sredini panela:

and respectively at the middle of the panel:

$$M_C = \frac{(1{,}5 - k)p \cdot b^2}{12} \cdot 10^{-5} \text{ , Nm}$$

gdje je:

where:

$$k = \frac{y^3 + 1}{y + 1}, \qquad y = \frac{b_W}{b} = 0{,}2 \,,$$

b_w - širina baze ukrepljenja,
b - nepoduprti raspon,
k - koeficijent utjecaja momenta savijanja.

b_w – stiffener base width,
b – unstiffened span,
k – coefficient of bending moment influence.

Osim toga potrebno je izračunati i položaj težišta po duljini laminata:

Besides this, the position of the laminate longitudinal centre of mass is calculated:

$$x_L = \frac{\sum (E_i \cdot t_i \cdot x_i)}{\sum (E_i \cdot t_i)} \text{ , mm} \tag{5}$$

Prilikom dimenzioniranja ukrepljenja vrijede iste postavke dane kroz izraze (2) – (5) s tom razlikom što se moment savijanja na ukrpeljenju određuje prema izrazu:

While dimensioning the stiffeners, the same equations given from (2) – (5) are applied with the exception that the bending moment on stiffeners is determined according to the following equation:

$$M_s = \Phi_M \cdot s \cdot l_e^2 \cdot p \text{ , Nm} \tag{6}$$

gdje je:

s - razmak ukrepljenja,

l_e - efektivni raspon ukrepljenja,

$\Phi_M = 0{,}0833$.

Udaljenost neutralne osi ukrepljenja od površine laminata se određuje prema izrazu:

where:

s - stiffeners spacing,

l_e - effective stiffeners span,

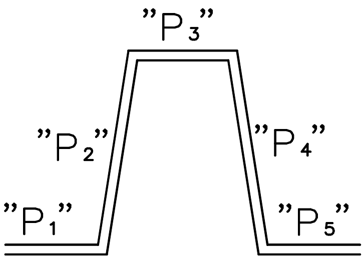
$\Phi_M = 0{,}0833$.

Distance from neutral axis to the laminate surface is calculated according to:

$$x_s = \frac{\sum(E_i \cdot t_i \cdot b_i \cdot x_i)}{(E_i \cdot t_i \cdot b_i)} \text{ , mm} \tag{7}$$

uz podjelu poprečnog presjeka na površine prema slici 2.

with the cross section segmentation as seen in Figure 2.



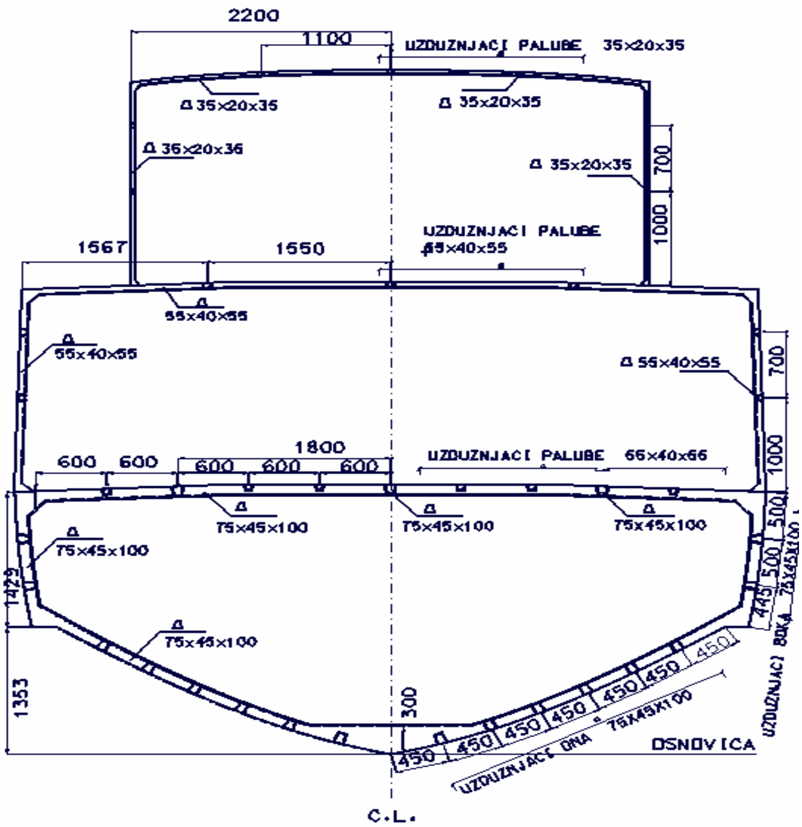
Slika 2. Shema podjela površina za proračun položaja neutralne linije ukrepljenja
Figure 2. Cross section segmentation for calculating neutral axis position of stiffeners

Prikazani zahtjevi, kroz izraze (1) – (8), rezultirali su usvajanjem konačnih dimenzija strukture, opločenja u tablici 4 i ukrepljenja u tablici 5, a prikazani su na glavnom rebru (slika 3), te na uzdužnom presjeku u središnjoj uzdužnoj vertikalnoj ravnini, (slika 4).

The presented requirements from (1) to (8) have defined the final dimensions of the shell structure, in Table 4, and stiffeners structure in Table 5, and these are shown on the midship section in Figure 3., and also on the longitudinal section in the central line, Figure 4.

Tablica 4. Prikaz provjere konačnih dimenzija opločenja
Table 4. Verification of final plate dimensions

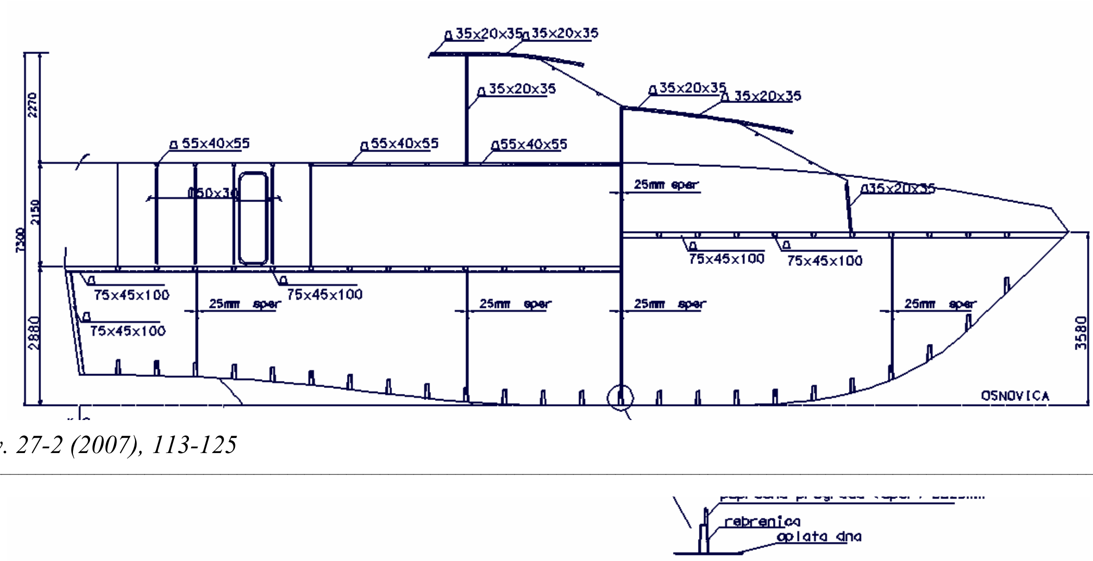
Područje *Position*	Moment savijanja, *Bending moment*, *M*, Nm		Minimalna debljina, *Minimal thickness* t_i, mm	Stvarno naprezanje *Actual stress*, δ_i, Nmm^{-2}		Dozvoljeno naprezanje, *Permissible stress*, δ_{dop}, Nmm^{-2}	
	Sredina panela *Mid-panel*	Ispod ukrepljenja *Under stiffener*		vlak *tension*	tlak *compression*	vlak *tension*	tlak *compression*
Dno *Bottom*	2,88	3,66	8,4	31,8	30,9	91,0	121,0
Bok *Side*	2,66	3,53	7,6	30,6	29,8	91,0	121,0
Paluba *Deck*	0,95	1,47	5,8	11,1	10,8	91,0	121,0
Nadgrađe *Superstructure*							
Bok *Side*	1,55	2,60	4,6	23,0	22,3	91,0	121,0
Krov *Top*	2,34	4,10	5,0	35,4	34,3	91,0	121,0
Kormilarnica *Wheelroom*							
Bok *Side*	1,19	2,12	3,9	17,0	16,4	91,0	121,0
Krov *Top*	1,16	2,13	3,9	17,0	16,4	91,0	121,0



Slika 3. Nacrt glavnog rebra
Figure 3. Midship section

Tablica 5. Prikaz provjere konačnih dimenzija ukrepljenja
Table 5. Verification of final stiffener dimensions

Područje *Position*	Moment savijanja, *Bending moment,* *M*, Nm	Udaljenost od N.L, *Distance from. N.A.* x_L, mm	Stvarno naprezanje, *Actual stress,* δ_{li}, Nmm^{-2}		Dozvoljeno naprezanje, *Permissibile stress,* δ_{dop}, Nmm^{-2}	
			vlak *tension*	tlak *compression*	vlak *tension*	tlak *compression*
Dno, ukrepa tip1 *Bottom, stiffener type 1* 75x45x100	716	41,2	74,8	75,5	91,0	121,0
Bok, ukrepa tip1 *Side, stiffener type 1* 75x45x100	556	41,2	57,2	58,6	91,0	121,0
Paluba, ukrepa tip2 *Deck, stiffener type 2* 55x40x55	223	22,6	77,6	76,9	91,0	121,0
Nadgrađe, ukrepa tip2 *Superstructure, stiffener type 2* 55x40x55	106	22,6	36,7	36,3	91,0	121,0
Kormilarnica, ukrepa tip3 *Wheelhouse stiffener type 3* 35x20x35	70	11,8	69,1	69,6	91,0	121,0



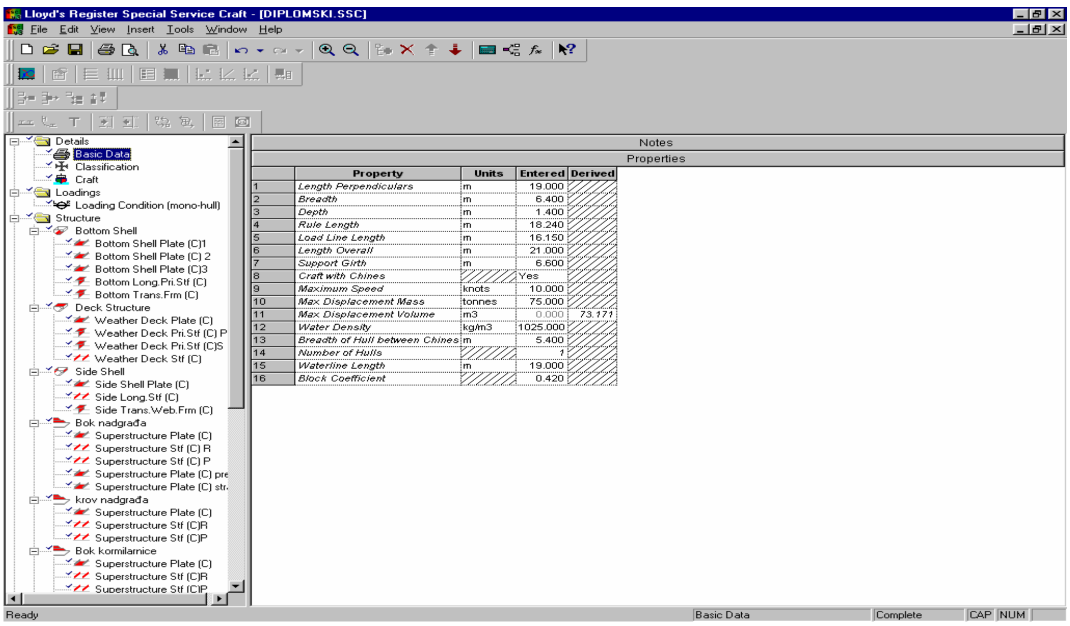
Slika 4. Uzdužni presjek u C.L.
Figure 4. Longitudinal section in C.L.

3. PROVJERA DIMENZIJA STRUKTURNIH ELEMENATA POMOĆU SOFTVERSKOG PAKETA LR-SSC 5.0

Završna provjera dimenzija strukturnih elemenata izvršena je prema programu *LR-SSC 5.0* [5]. Na slici 5 može se vidjeti glavni izbornik koji se nalazi s lijeve strane dok je desna strana rezervirana za tablicu koja se odabere u izborniku, prva odabrana tablica upravo je i prikazana i ona služi za opisivanje forme, odnosno glavnih dimenzije broda. Nakon opisivanja forme potrebno je upisati i hidrostatske karakteristike.

3. STRUCTURAL ELEMENTS DIMENSION VERIFICATION WITH SOFTWARE PACKAGE LR-SSC 5.0

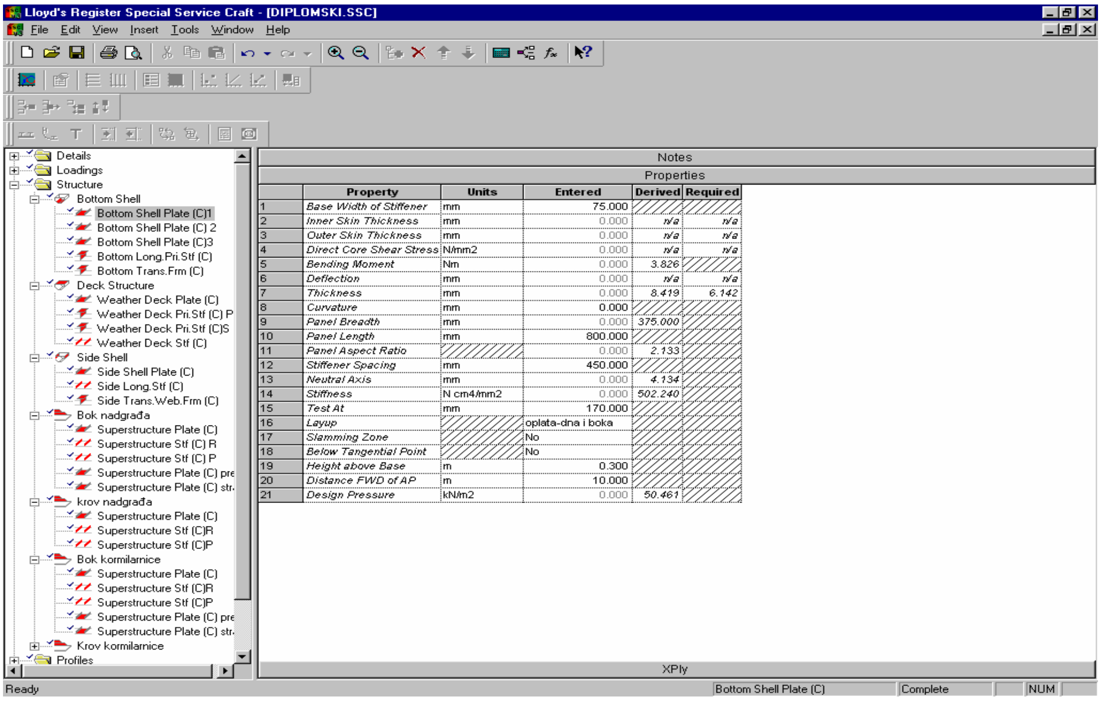
Final verification of the structural elements dimensions according to *LR-SSC 5.0* is performed. Details can be found in [5]. In Figure 5, the main toolbar is seen on the left side, while the right side is reserved for the table which is chosen from the menu. The first chosen table is actually shown and it serves for defining the form, and respectively the main ship dimensions. After defining the craft form, the hydrostatic characteristics should be entered.



Slika 5. Prikaz izbornika za unos osnovnih podataka o plovilu
Figure 5. Menu for input of basic craft data

Kada je brod definiran glavnim dimenzijama i hidrostatikom, slijedi određivanje materijala gradnje, budući da ovaj softver dozvoljava upotrebu različitih materijala gradnje trupa. Odabirom stakloplastičnog materijala ulazi se u područje definiranja gramature staklenog ojačanja i postotka stakla unutar pojedinog sloja laminata. Za mat je odabrano, prema zahtjevima Lloyd's Registera 33% stakla, dok je za roving zahtijevano 50% stakla.

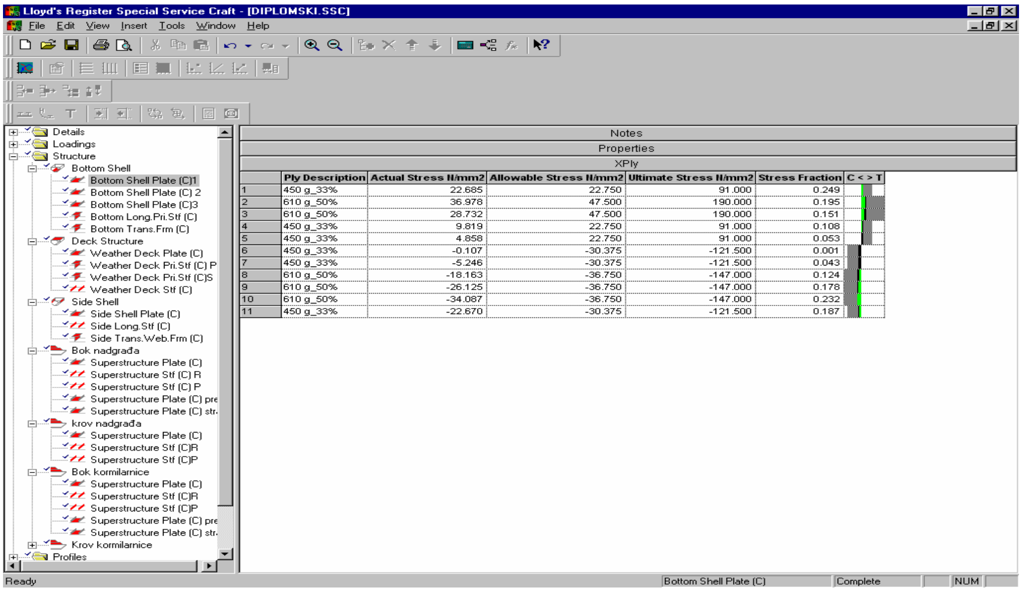
After the craft has been defined with the main dimensions and hydrostatics, definition of the shipbuilding material follows, since this software allows for the use of different materials. With the selection of GRP material, the density of glass reinforcement and glass ratio in a particular laminate layer should be defined. For Matt, according Lloyd's Register, 33% glass is chosen, while for Rowing 50% glass is chosen.



Slika 6. Prikaz izbornika za definiranje proračunskih parametara oplate dna
Figure 6. Menu for defining calculated parameters of bottom shell

Nakon definiranja pojedinih slojeva potrebno je složiti laminate koji će se upotrebljavati u strukturi. Na gotovo isti način definiraju se i ukrepljenja, s tom razlikom što je kod njih potrebno definirati veličinu ukrepe i materijal ispune (u ovom slučaju poliuretanska pjena). Kad su svi materijali i njihove karakteristike definirani, može se pristupiti slaganju konstruktivnih elemenata. Tako se na slici 6 vidi što je sve potrebno za definiranje oplate dna.
To je uz već definirani laminat, razmak uzdužnih i poprečnih elemenata, pozicija mjesta koje promatramo u odnosu na osnovicu i, naravno, projektno opterećenje. Nakon što su ti parametri ubačeni, softver računa naprezanja u svakom pojedinom sloju laminata i uspoređuje ih s dozvoljenim naprezanjima, slika 7. Ako su naprezanja manja od dozvoljenih, laminat je zadovoljio proračun. Isti princip kao za laminat koristi se i za provjeru naprezanja u ukrepljenjima, odnosno slojevima laminata oko ukrepljenja. Izlist rezultata dobivenih proračunom može se naći u [6].

After defining particular layers, the laminate, which will be used in structure, should be arranged. Stiffeners are defined on the same principle except that the size of the stiffeners and the material of the core should be defined (in this case polyurethane foam). When all materials and their characteristics have been defined, the arrangement of the structural elements can be conducted. Figure 6 shows what is needed for defining the bottom shell. It is made up of: laminate, the distance between the transversal and longitudinal elements, the position of the considered plate related to the baseline and the design load. After these parameters have been entered into the software program, it calculates stresses in each laminate layer and compares them with the allowed stresses, Figure 7. If those stresses are lower than allowed, the laminate is satisfactory calculated. The same principle as for laminate is also used for stress verification in stiffeners, and respectively in the laminate layers around stiffeners. A list of results can be found in [6].



Slika 7. Prikaz tablice usporedbe stvarnih i dozvoljenih naprezanja
Figure 7. Comparison between actual and allowed stresses

4. ZAKLJUČAK

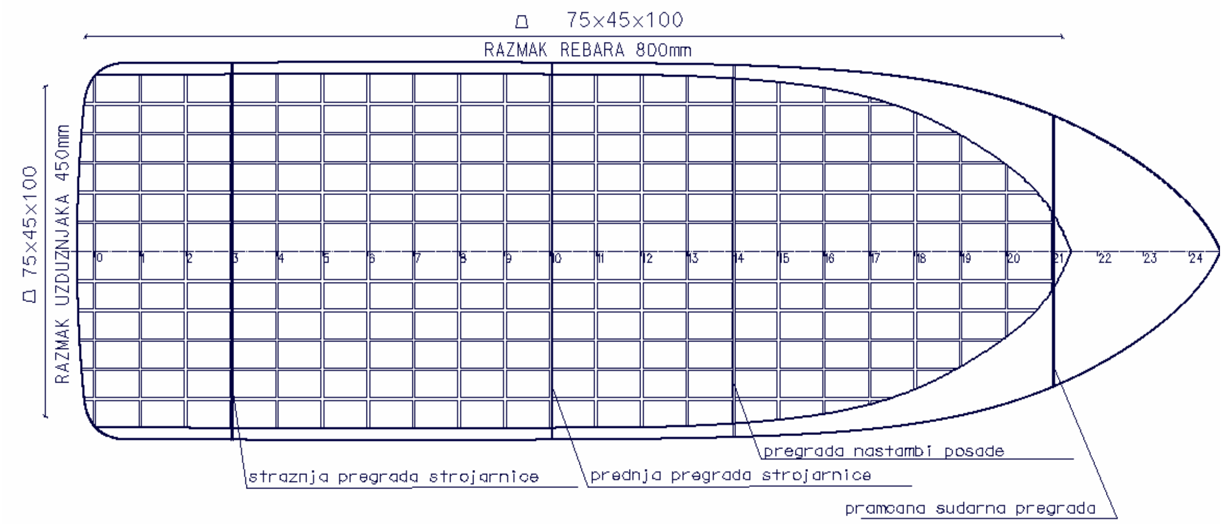
Projektiranje plovila zahtjevan je zadatak zbog velikog broja utjecajnih faktora, čije su implikacije u fazi izrade projekta ponekad nepoznate. U ovom su radu podaci o formi i hdrostatskim karakteristikama plovila, što uključuje duljinu, visinu, širinu, te istisninu, gaz i sl preuzeti od netom izgrađenoga motornog broda, izgrađenog od brodograđevnog čelika kao osnovnog materijala i ovdje su poslužili kao predložak.
Dimenzioniranje strukture trupa izvršeno je pomoću pravila i propisa klasifikacijskog društva “Lloyd's Register of Shipping” s dodatnim pravilima prilagođenima manjim radnim plovilima “Special Service Craft”. Kao i u pravilima ostalih klasifikacijskih društava i ovdje se za izračune minimalnih dozvoljenih vrijednosti elemenata strukture trupa koriste iskustvene formule, koje su izvođene i dopunjavane godinama.
Osim klasične metode dimenzioniranja strukture danas se sve više koriste računalni programi s istom svrhom. Tako je i u ovom radu upotrijebljen računalni program “Lloyd's Register of Shipping – Special Service Craft 5,0”, pomoću kojega je izvršena kontrola prethodno dobivenih vrijednosti. Prilikom usporedbe vrijednosti dobivenih dvjema metodama došlo se do sljedećih zaključaka: vrijednosti mehaničkih karakteristika staklenog ojačanja, svojstva materijala, konstrukcijskih opterećenja i momenata savijanja za opločenje i ukrepljenje iste su bez obzira na metodu računanja. Međutim, kako je i pretpostavljeno do razlike dolazi pri računanju minimalne zahtijevane debljine laminata i to u korist klasične metode do približno 10%, a na koju izravno utječe razmak ukrepljenja. Prema preporukama klasifikacijskog društva projektant strukture odabire one vrijednosti koje su dobivene upotrebom računalnog programa. Prema tim

4. CONCLUSION

Ship design is a demanding procedure because of a large number of influencing factors, whose implications during the preliminary design phase are not always fully known. Therefore, each phase must be correct and compatible with the following phases. In this paper, hull form and hydrostatic characteristics have been taken from a motorboat, which is built from steel as the basic material, and these have been used as a template.
Hull structure dimensioning is performed according to the rules and regulations of “Lloyd’s Register of Shipping”, with additional rules for small service crafts, “Special Service Craft. For the purpose of calculation of the minimal allowed values of hull structural elements, empirical equations have been used, and as with those of other classification societies, they have been derived and supplemented for years.
Today, except for the traditional methods for structural dimensioning, special software is often used for this same purpose. Such software has been used in this paper, “Lloyd’s Register of Shipping - Special Service Craft 5,0”, by which verification of the previously calculated values has been performed. Comparing the calculated values with those of the two methods, the following conclusion has been made: the values of the mechanical characteristics of glass reinforcement, materials attributes, and structural loads and bending moments for shell and stiffeners are the same regardless of the applied method. However, as it is assumed, there are differences in the values of the required minimal laminate thickness, of approximately 10 % with the traditional method, which is directly influenced by stiffeners indent. Lloyd’s Register anticipates that such differences will emerge, so they have emphasized that if two methods of calculations

se uputama i postupilo u ovom radu te su vrijednosti dobivene upotrebom računalnog programa i usvojene, primijenjene u izradi nacrta glavnog rebra, uzdužnog presjeka, te nacrta strukture dna (slika 8). Svi su nacrti rezultat dimenzioniranja strukture trupa, te je na navedenim nacrtima prikazan i njihov strukturni raspored. Sljedeća je faza priprema dokumentacije za rad u radionici, odnosno izrada laminat-plana, detalja izrade spojeva, raznih tehnoloških uputa, gantograma aktivnosti, te, naravno, opremanja [7].
Klasična metoda proračuna daje projektantu dobar uvid u participiranje pojedinih parametara u konačnome rezultatu, dok upotreba softvera dodatno omogućava velik broj izmjena i varijacije različitih strukturnih rasporeda sve dok se ne nađe optimalan, u odnosu na ukupnu masu strukture i troškova proizvodnje.

are used, the designer should chose the one that is made with software. According to this direction, authors have chosen values calculated with the use of software, and that are used for the midship section, longitudinal section and bottom structural drawings, Figure 8. All drawings are the result of hull structure dimensioning and therefore the drawings also show its structural arrangement.
The next phase of the design process includes the preparation of workshop documentation, the laminate plan, and details of joining procedures, different technological instructions, gantograms and outfitting [7].
The traditional calculation method gives the designer a good perspective regarding the influence of each parameter on the final result, while the use of software additionally enables a large number of changes and testing of different scenarios of structural arrangements until the optimal one is obtained, with respect to the total mass of the structure and the production costs.



Slika 8. Nacrt strukture dna
Figure 8. Bottom structure drawing

5. POPIS OZNAKA

5. LIST OF SYMBOLS

debljina laminata	t - mm	laminate thickness
vanjsko opterećenje	p - Nmm^{-2}	external load
moment inercije	I - m^4	moment of inertia
modul elastičnosti	E - Nmm^{-2}	modulus of elasticity
moment savijanja	M - Nm	bending moment
naprezanje	δ - Nmm^{-2}	stress
udaljenost neutralne osi presjeka	y - mm	vertical position of neutral axis
razmak ukrepa	s - mm	spacing of stiffener
raspon ukrepa	l - mm	span of stiffener
širina baze ukrepljenja	b - mm	stiffener base width

LITERATURA
REFERENCES

[1] Kunej, W.: *Poliesterski kompoziti*, Metalmineral d.d. Zagreb, Zagreb, 2003.
[2] du Plessis, H.: *Fibreglass Boat – Fitting Out, Maintenance and Repair*, International Marine / McGraw-Hill, Camden, 1996.
[3] Rules and Regulations for the Classification of Special Service Craft, Lloyd´s Register of Shiping, London, 2004.
[4] Geer, D.: *Elements of boat strength*, International Marine / McGraw-Hill, 2000.
[5] User manual SSC 5.0, Lloyd's Register of Shipping, London, 2005.
[6] Perić, J.: *Dimenzioniranje strukturnih elemnata malog putničkog plovila*, Diplomski rad, Tehnički fakultet Sveučilišta u Rijeci, 2006.
[7] Lozica, Ž.: *Konstrukcija broda od stakloplastike*, Fakultet strojarstva i brodogradnje Zagreb, Zagreb, 1976.

Strukovni prilog

Technical note

Adresa autora/Author adress:
Jasmin Perić, ing. brodogradnje
doc. dr. sc. Albert Zamarin, dipl. ing brodogradnje
asist. Tin Matulja, dipl. ing. brodogradnje
Tehnički fakultet Sveučilišta u Rijeci
Vukovarska 58
HR-51000 Rijeka, Hrvatska