PROCJENA STABILITETA I OTPORA 5-METARSKE JEDRILICE

Bašić, Marija

SVEUČILIŠTE U RIJECI

TEHNIČKI FAKULTET

Preddiplomski sveučilišni studij brodogradnje

Završni rad

PROCJENA STABILITETA I OTPORA

5-METARSKE JEDRILICE L5

Rijeka, rujan 2024. Marija Bašić

00690943838

SVEUČILIŠTE U RIJECI

TEHNIČKI FAKULTET

Preddiplomski sveučilišni studij brodogradnje

Završni rad

PROCJENA STABILITETA I OTPORA 5-METARSKE JEDRILICE L5

Mentor: prof. dr. sc. Anton Turk

Komentor: prof. dr. sc. Roko Dejhalla

Rijeka, rujan 2024

Marija Bašić

00690943838

SVEUČILIŠTE U RIJECI
TEHNIČKI FAKULTET
POVJERENSTVO ZA ZAVRŠNE ISPITE

Rijeka, 13.03.2024.

Zavod: Zavod za brodogradnju i inženjerstvo morske tehnologije
Predmet: Plovnost i stabilitet broda

ZADATAK ZA ZAVRŠNI RAD

Pristupnik: **Marija Bašić (0069094383)**
Studij: Sveučilišni prijediplomski studij brodogradnje (1020)

Zadatak: **PROCJENA STABILITETA I OTPORA 5-METARSKE JEDRILICE / ASSESSMENT OF THE STABILITY AND RESISTANCE OF A 5-METRE SAILBOAT**

Opis zadatka:

Na temelju postojećeg 3D modela 5-metarske jedrilice tipa L5, potrebno je: - odrediti hidrostatičke značajke trupa, - izraditi preliminarnu procjenu mase i težišta, - izraditi proračun stabiliteta prema EN ISO 12217-3:2017, - izraditi proračun otpora za odabrano stanje opterećenja.

Rad mora biti napisan prema Uputama za pisanja diplomskih / završnih radova koje su objavljene na mrežnim stranicama studija.

Zadatak uručen pristupniku: 20.03.2024.

Mentor:
izv. prof. dr. sc. Anton Turk

Komentor:
prof. dr. sc. Roko Dejhalla

Predsjednik povjerenstva za završni ispit:
prof. dr. sc. Roko Dejhalla

Izjava

Sukladno čl. 9 *Pravilnika o završnom radu , završnom ispitu i završetku sveučilišnih prijediplomskih studija* izjavljujem da sam samostalno izradila rad pod naslovom *Procjena stabiliteta i otpora 5-metarske jedrilice tipa L5*, konzultirajući se s mentorom i komentorom te primjenjujući znanja stečena tijekom prijediplomskog studija.

Rijeka, rujan 2024.

____

Marija Bašić

Zahvala

Želim se zahvaliti svom mentoru prof. dr. sc. Antonu Turku na savjetima i znanju prenesenom tijekom studija i tijekom izrade ovoga rada.

Želim se zahvaliti mojim roditeljima i sestri na beskrajnoj podršci, strpljenju i razumijevanju.

Najveće hvala mom komentoru prof. dr. sc. Roku Dejhalli.

Hvala Vam na svakoj kritici, svakom savjetu, izdvojenom vremenu i ogromnoj posvećenosti.

Hvala Vam na svakom održanom predavanju.

Hvala Vam što ste nam nesebično prenosili znanje i željeli da razumijemo.

Hvala Vam na svakom razgovoru koji se nije ticao otpora i propulzije, a značio mi je.

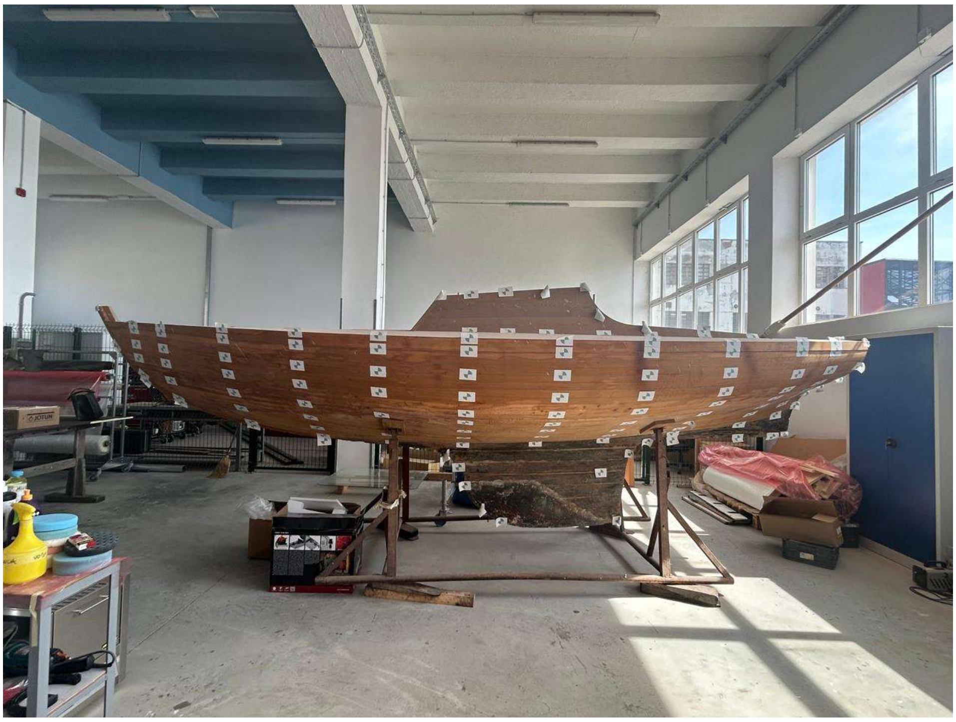
Profesore, hvala Vam na svemu.

Sadržaj

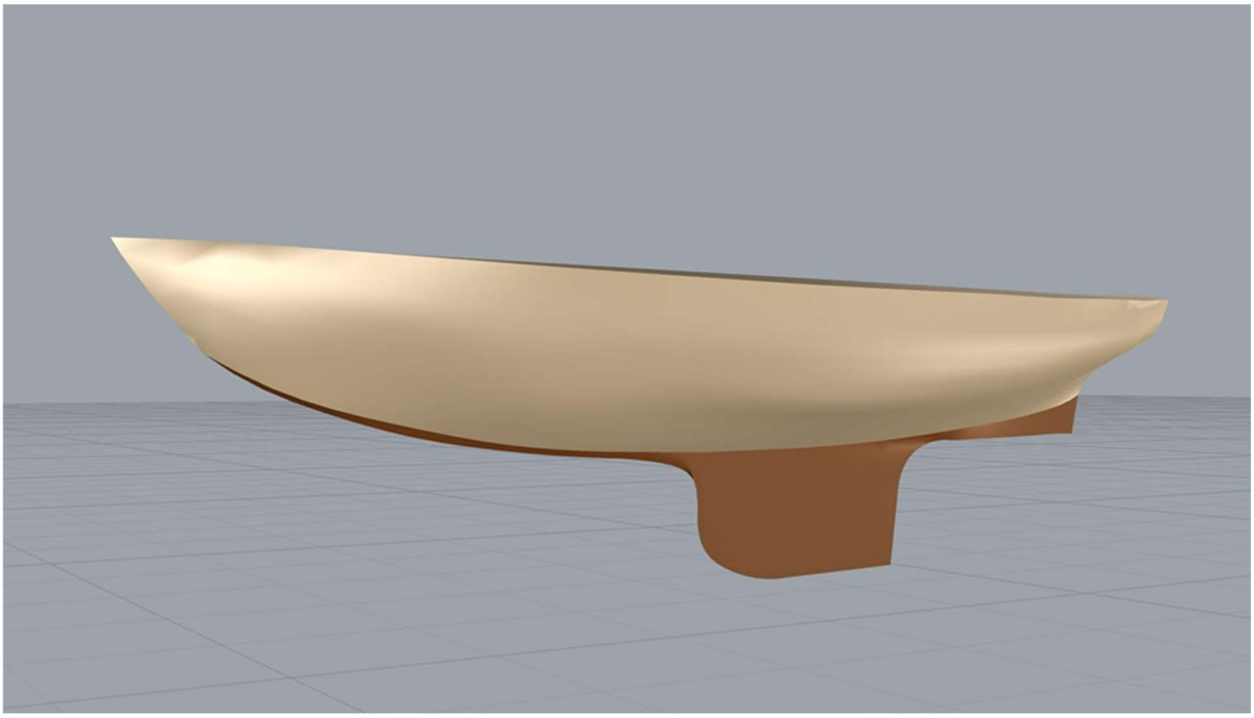
1. Uvod

Jedrilica je plovilo koje funkcionira kroz dva medija: zrak i vodu. Trenutno postoji veliki broj različitih vrsta jedrilica koje se razlikuju po: veličini, namjeni, konstrukciji trupa, vrsti kobilice, rasporedu jedara i izboru jarbola. Upotrebljavajući relativno gibanje između vode i zraka jedrilica stvara silu koja je potrebna za njeno vlastito gibanje. Jedrilica mora biti u mogućnosti izdržati opterećenja koja nastaju zbog jedra i kobilice. Kobilica je temeljni element koji osigurava stabilnost plovila.

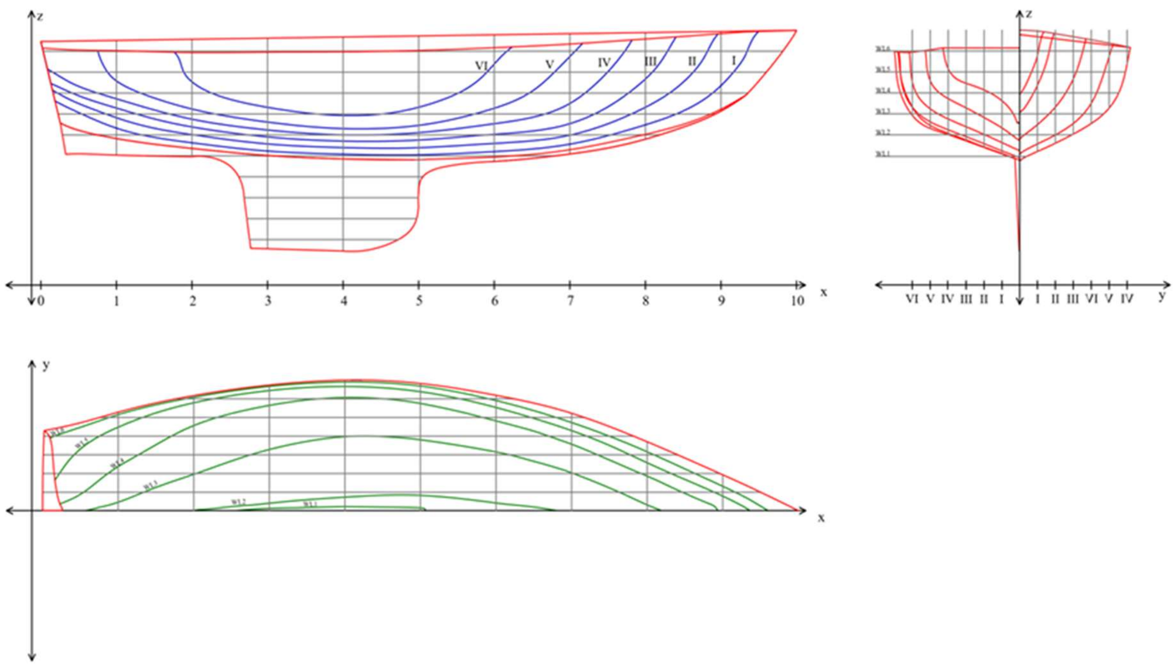
Ovaj rad se temelji na procjeni stabiliteta i otpora zadane jedrilice L5, slika 1. Procjena stabiliteta napravljena je prema normi EN ISO 12217:2017, uz pomoć propratnog alata *Rhinoceros 7*, koji je korišten za izradu digitalnog modela same forme (slika 1.1), te dodatka *Orca 3D* za dobivanje podataka o hidrostatičkim značajkama plovila. Proračun procjene otpora je izvršen za raspon brzina prema metodi „Delft Systematic Yacht Hull Series“, kako bi se prikazalo ponašanje zadane forme pri promjeni brzine.



Slika 1. Jedrilica L5-slikano u prostoru edukativne radionice „Torpedo“



Slika 1.1 Model jedrilice izrađen u programu Rhinoceros 7



Slika 1.2 Nacrt linija jedrilice klase L5

2. Opći podaci jedrilice

U tablici 2. nalaze se relevantni podaci koji opisuju glavne karakteristike jedrilice tipa L5.

Dužina trupa L_H	=	6,17m
Širina trupa B_H	=	2,04m
Maksimalna širina trupa B_{MAX}	=	2,04m
Vrsta pogona	:	jedra
Površina jedra	=	21,9 m^2
Maksimalna snaga pomoćnog motora	:	8 kW
Broj osoba	:	pet
Projektna kategorija	:	C

Tablica 2. Glavne izmjere i opći podaci jedrilice

2.1. Procjena masa i težišta

U tablici 2.1 prikazane su raspodjele masa za tri različita stanja opterećenja definirana prema normi ISSO 12217.

Masa praznog plovila m_{EC}	=	910 kg
Trup	=	500 kg
Jarbol i deblenjak	=	54 kg
Oputa	=	15 kg
Glavno jedro	=	15 kg
Prednje jedro	=	5 kg

Kobilica	=	315 kg
Kormilo	=	5 kg
Standardna oprema	=	60 kg
(sidro, sidreno uže, lanac, izvanbrodski motor)		
Masa praznog opremljenog plovila m_{LC}	=	970 kg
Masa osoba	=	375 kg (5 osoba)
(masa jedne osobe 75kg)		
Provijant + osobne stvari	=	100 kg
Pitka Voda	=	0,0
Gorivo	=	18 kg
Izvanbrodski motor	=	40 kg
Zalihe, rezervni dijelovi	=	20 kg
Splav za spašavanje	=	35 kg
Maksimalno opterećenje plovila	=	548 kg
Masa maksimalnog opterećenog plovila m_{LDC}	=	1517 kg
Masa plovila u stanju najmanjeg opterećenja m_{MO}	=	1090 kg
(uključena 1osoba, oprema uobičajeno na plovilu, masa splava za spašavanje)		
Masa koja se mora odbiti za plovilo u dolasku	=	20 kg
Masa plovila u dolasku m_{LA}	=	1497 kg
Najveće opterećenje plovila	=	510 kg (za pločicu graditelja)

Tablica 2.1 raspodjela masa za tri stanja opterećenja

U tablicama 2.1.1, 2.1.2, 2.1.3 prikazan je izračun momenata masa za tri različita stanja opterećenja i koordinate težišta masa sustava za ista stanja opterećenja, prema normi ISO 12217.

Raspodjela masa i koordinate težišta za maksimalno stanje opterećenja									
	mi, kg	xi, m	yi, m	zi, m	mi*xi, kg*m	mi*yi, kg*m	mi*zi, kg*m		
trup	500,0	2,640	0,000	1,280	1320,000	0,000	640,000		
standardna oprema	20,0	5,000	0,000	1,500	100,000	0,000	30,000		
Σ	520,0				1420,000	0,000	670,000		
								xG, m	2,731
								yG, m	0,000
								zG, m	1,288
Osobe #1	75,0	3,080	0,000	1,600	231,000	0,000	120,000		
#2	75,0	3,080	0,000	1,600	231,000	0,000	120,000		
#3	75,0	3,080	0,000	1,600	231,000	0,000	120,000		
#4	75,0	3,080	0,000	1,600	231,000	0,000	120,000		
#5	75,0	3,080	0,000	1,600	231,000	0,000	120,000		
Provijant + osobne stvari	100,0	3,000	0,000	0,900	300,000	0,000	90,000		
Tank goriva	18,0	5,500	0,000	1,200	99,000	0,000	21,600		
zalihe, rezervni djelovi	20,0	3,080	0,000	0,900	0,000	0,000	18,000		
jarbol i deblenjak	54,0	0,650	0,000	4,780	0,000	0,000	258,120		
oputa	15,0	4,000	0,000	5,000	0,000	0,000	75,000		
izvanbrodski motor	40,0	-0,300	0,000	1,400	-12,000	0,000	56,000		
glavno jedro	15,0	2,000	0,000	2,150	30,000	0,000	32,250		
prednje jedro	5,0	6,000	0,000	1,600	30,000	0,000	8,000		
kobilica	315,0	2,500	0,000	0,150	0,000	0,000	47,250		
splav	35,0	3,080	0,000	0,900	1,000	0,000	31,500		
kormilo	5,0	0,200	0,000	0,600	0,600	0,000	3,000		
Σ	997,0				1603,600	0,000	1240,720		
								xG, m	1,608
								yG, m	0,000
								zG, m	1,244
Σ Ukupno	1517,0				3023,600	0,000	1910,720		
							LCG	xG, m	1,993
							TCG	yG, m	0,000
							VCG	zG, m	1,260

Tablica 2.1.1 Raspodjela masa i koordinate težišta za maksimalno stanje opterećenja

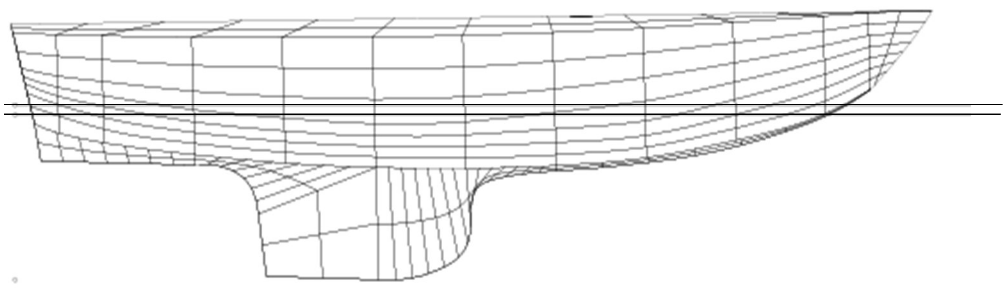
Raspodjela masa i koordinate težišta za stanje opterećenja plovila u dolasku									
	mi, kg	xi, m	yi, m	zi, m	mi*xi, kg*m	mi*yi, kg*m	mi*zi, kg*m		
trup	500,0	2,640	0,000	1,280	1320,000	0,000	640,000		
standardna oprema	20,0	5,000	0,000	1,500	100,000	0,000	30,000		
Σ	520,0				1420,000	0,000	670,000		
								xG, m	2,731
								yG, m	0,000
								zG, m	1,288
Osobe #1	75,0	3,080	0,000	1,600	231,000	0,000	120,000		
#2	75,0	3,080	0,000	1,600	231,000	0,000	120,000		
#3	75,0	3,080	0,000	1,600	231,000	0,000	120,000		
#4	75,0	3,080	0,000	1,600	231,000	0,000	120,000		
#5	75,0	3,080	0,000	1,600	231,000	0,000	120,000		
Provijant + osobne stvari	100,0	3,000	0,000	0,900	300,000	0,000	90,000		
Tank goriva	18,0	5,500	0,000	1,200	99,000	0,000	21,600		
jarbol i deblenjak	54,0	0,650	0,000	4,780	0,000	0,000	258,120		
oputa	15,0	4,000	0,000	5,000	0,000	0,000	75,000		
izvanbrodski motor	40,0	-0,300	0,000	1,400	-12,000	0,000	56,000		
glavno jedro	15,0	2,000	0,000	2,150	30,000	0,000	32,250		
prednje jedro	5,0	6,000	0,000	1,600	30,000	0,000	8,000		
kobilica	315,0	2,500	0,000	0,150	0,000	0,000	47,250		
splav	35,0	3,080	0,000	0,900	1,000	0,000	31,500		
kormilo	5,0	0,200	0,000	0,600	0,600	0,000	3,000		
Σ	977,0				1603,600	0,000	1222,720		
								xG, m	1,641
								yG, m	0,000
								zG, m	1,252
Σ Ukupno	1497,0				3023,600	0,000	1892,720		
							LCG	xG, m	2,020
							TCG	yG, m	0,000
							VCG	zG, m	1,264

Tablica 2.1.2 Raspodjela masa i koordinate težišta za stanje opterećenja plovila u dolasku

Raspodjela masa i koordinate težišta za minimalno radno stanje									
	mi, kg	xi, m	yi, m	zi, m	mi*xi, kg*m	mi*yi, kg*m	mi*zi, kg*m		
trup	500,0	2,640	0,000	1,280	1320,000	0,000	640,000		
standardna oprema	20,0	5,000	0,000	1,500	100,000	0,000	30,000		
Σ	520,0				1420,000	0,000	670,000		
								xG, m	2,731
								yG, m	0,000
								zG, m	1,288
Osobe #1	75,0	3,080	0,000	1,600	231,000	0,000	120,000		
Provijant + osobne stvari	10,0	3,000	0,000	0,900	30,000	0,000	9,000		
jarbol i deblenjak	54,0	0,650	0,000	4,780	0,000	0,000	258,120		
oputa	15,0	4,000	0,000	5,000	0,000	0,000	75,000		
izvanbrodski motor	40,0	-0,300	0,000	1,400	-12,000	0,000	56,000		
glavno jedro	15,0	2,000	0,000	2,150	30,000	0,000	32,250		
prednje jedro	5,0	6,000	0,000	1,600	30,000	0,000	8,000		
kobilica	315,0	2,500	0,000	0,150	0,000	0,000	47,250		
splav	35,0	3,080	0,000	0,900	1,000	0,000	31,500		
kormilo	5,0	0,200	0,000	0,600	0,600	0,000	3,000		
Σ	569,0				310,600	0,000	640,120		
								xG, m	0,546
								yG, m	0,000
								zG, m	1,125
Σ Ukupno	1089,0				1730,600	0,000	1310,120		
							LCG	xG, m	1,589
							TCG	yG, m	0,000
							VCG	zG, m	1,203

Tablica 2.1.3Raspodjela masa i koordinate težišta za minimalno radno stanje

Položaj vodnih linija za maksimalno opterećeno plovilo (m_{LDC} =1517 kg), plovilo u dolasku (m_{LA} =1497 kg) i plovilo u stanju minimalnog opterećenja (m_{MO} =1090 kg) prikazan je na slici 2.2.



Slika 2.2 Položaj vodnih linija (VL) za masu istisnine od 1517 kg, 1497 kg i 1090 kg.

3. Proračun stabiliteta prema EN ISO 12217-2017

Proračun stabiliteta plovila napravljen je prema Sailing boats of hull lenght greater than or equal to 6m (EN ISO 12217-2017 small craft – Stability buoyancy assessment and categorization – Part 2). Popunjene tablice nalaze se u prilogu 1.

3.1 Odabir opcije za proračun stabiliteta

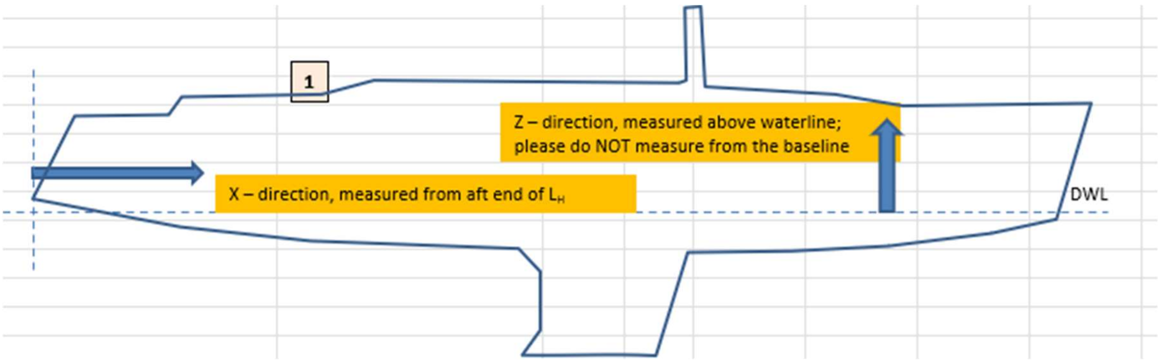
Za provjeru stabiliteta odabrana je opcija 5 (EN ISO 12217-1, Tablica 2) koja je primjenjiva za:

- plovila C ili D kategorije

- bilo koja plovila osim onih kod kojih vodoravna projekcija linije razme obuhvaća bilo koju kombinaciju vodonepropusne palube, odnosno brzopraznećeg kokpita prema zahtjevima (EN ISO 11812:2018) Small craft-Watertight cockpits and quick-draining cockpits.

- Prema opciji pet potrebno je ispuniti:

- Radni list broj 3 („downflooding height“). Kao otvor za naplavljivanje utvrđena je visina pražnice kokpita na mjestu gdje se pražnica spaja s pramčanom palubicom, na lijevom i desnom boku plovila, slika 3.1.1. Minimalna visina otvora za naplavljivanje (EN ISO 12217-1, točka 6.1.2.2) iznad vodne linije maksimalno opterećenog plovila, određena je prema metodi iz EN ISO 12217-1, Fig. 2. i iznosi 0.736.



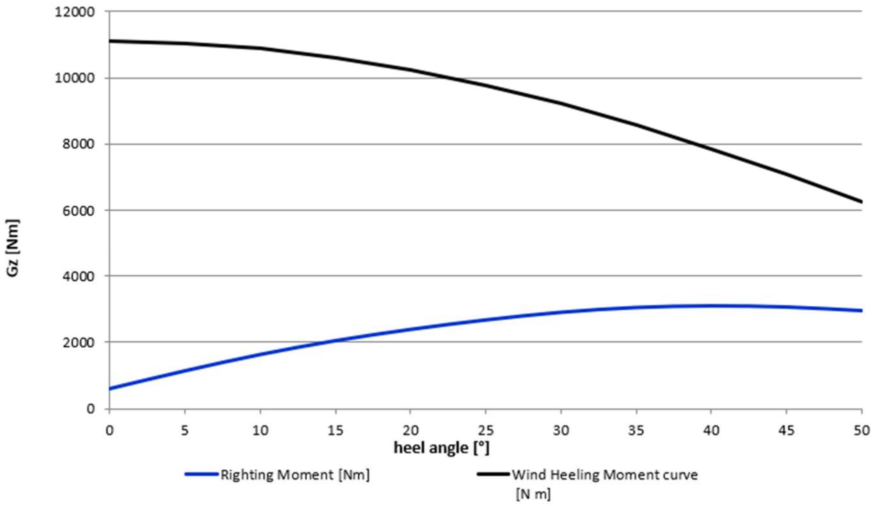
Slika 3.1.1. Visina h_d, visina otvora za naplavljivanje

- Radni list 9, („wind stiffness test“). Potrebno je ispuniti zahtjeve korištenjem teorijske metode, te se moraju ispuniti zahtjevi brzine vjetra za kategoriju C, tablica 7.

Wind speed in metres per second		
Design category	**C**	**D**
Option 5	13	8
Option 6	11	6

Tablica 7. prilog 1.

- Radni list 9a prikazuje odnos krivulje momenta nagiba zbog vjetra i momenta koji vraća jedrilicu u uspravni položaj, ove dvije krivulje se do kuta od 50 stupnjeva ne sijeku, slika 3.1.2

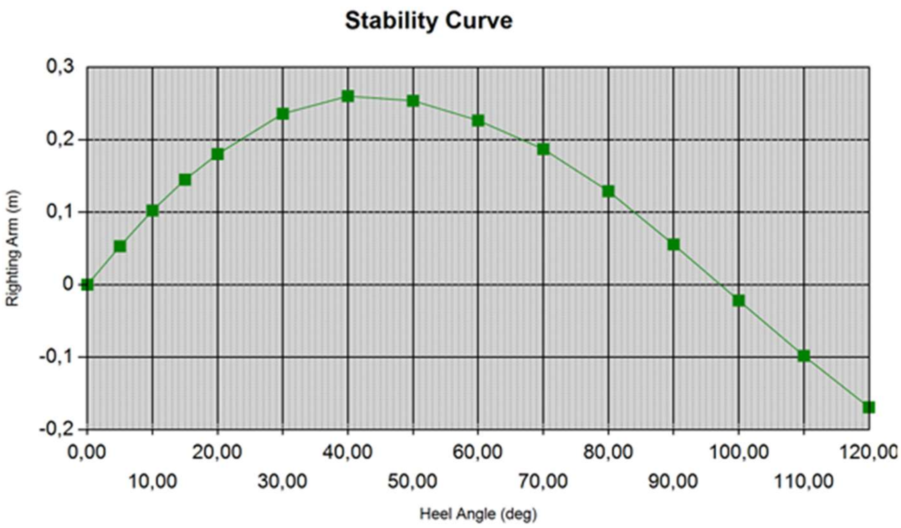


Slika 3.1.2. Dijagram momenta nagiba zbog vjetra i momenta koji vraća jedrilicu u uspravan položaj

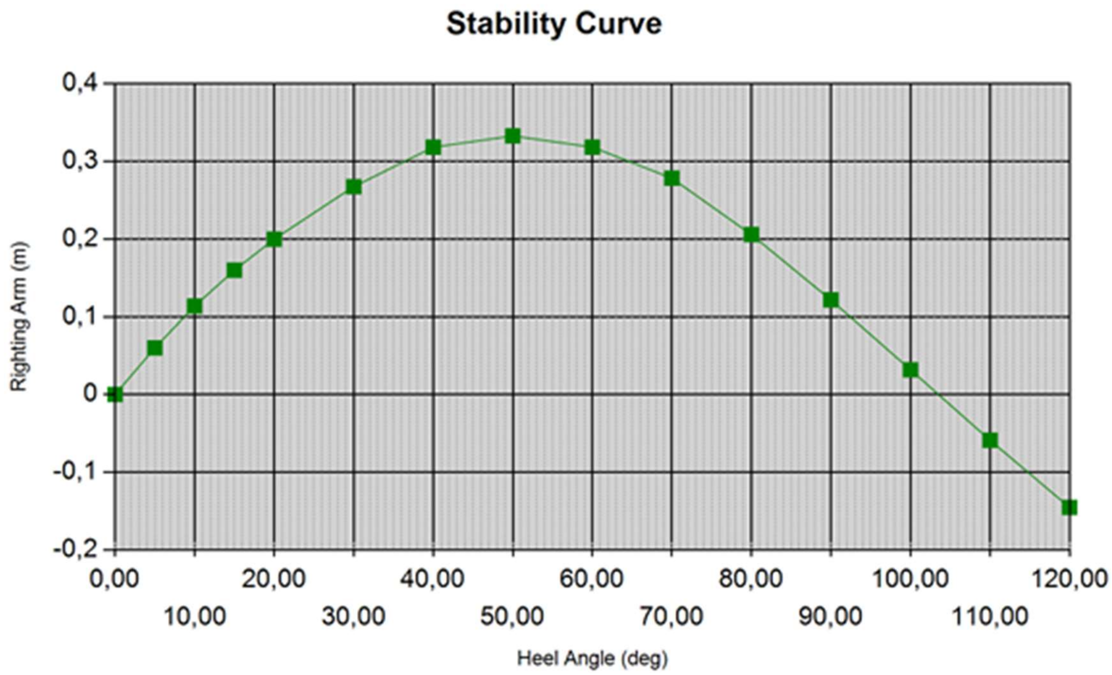
U prilogu 1 nalazi se popunjeni tablični kalkulator sa svim unesenim veličinama i potvrdom zadovoljavanja kriterija.

3.2 Poluga stabiliteta

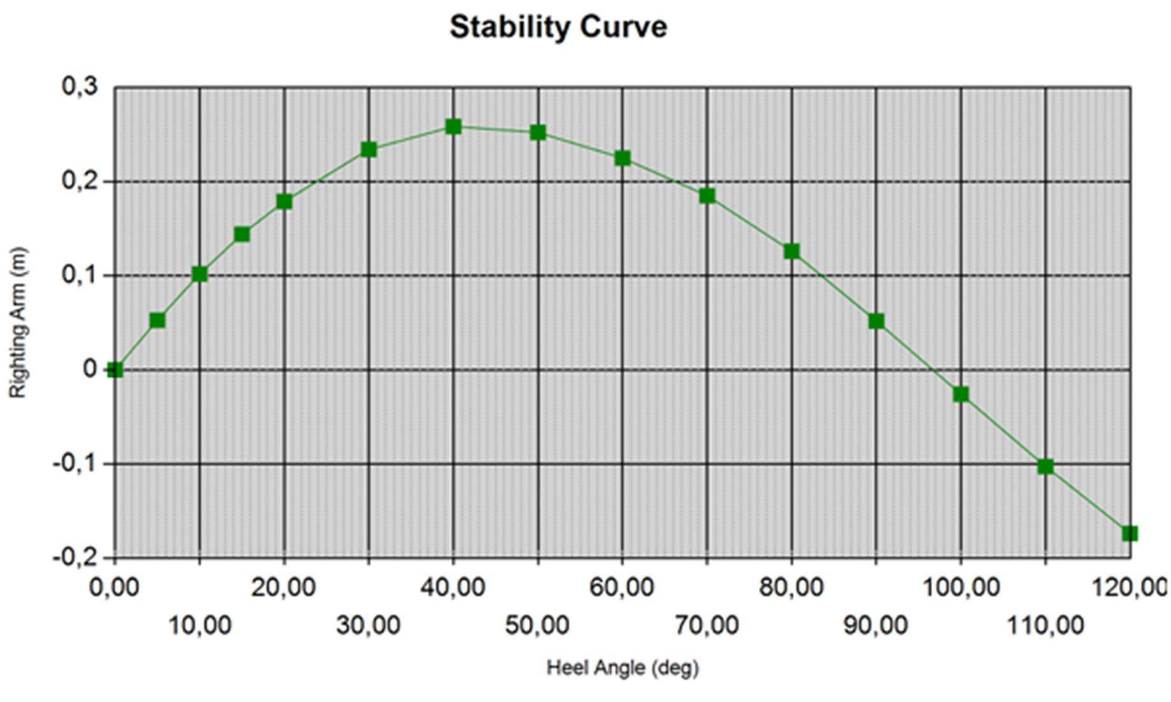
Poluge stabiliteta zadane forme za pojedine slučajeve opterećenja prikazane su na slikama: stanje punog opterećenja (slika 3.2.1), minimalnog radnog stanja (slika 3.2.2) i stanje plovila u dolasku (slika 3.2.3) dobivene su primjenom Orca 3D, unutar programskog paketa Rhinoceros 7.



Slika 3.2.1 Poluga stabiliteta za stanje punog opterećenja (engl. Loaded Displacement Condition)



Slika 3.2.2 Poluga stabiliteta za minimalno radno stanje (engl. Minimum Operating Condition)



Slika 3.2.3 Poluga stabiliteta za stanje plovila u dolasku (engl. Loaded Aarrival Condition)

4. Određivanje hidrodinamičkih značajki trupa

Za određivanje hidrodinamičkih značajki zadanog trupa korištena je metoda „Delft Systematic Yacht Hull Series“. Procjene otpora su izračunate za raspon brzina prema vrijednostima Froudovih brojeva zadanih u metodi. Raspon brzina primijenjen u proračunu zadan je u tablici 4.

Fn	V m/s
0,1	2,3154
0,15	2,8358
0,2	3,2745
0,25	3,6610
0,3	4,0105
0,35	4,3318
0,4	4,6309
0,45	4,9118
0,5	5,1775
0,55	5,4302
0,6	5,6717

Tablica 4. raspon brzina za proračun

4.1 Ulazni parametri

U tablici 4.1.1 nalazi se popis ulaznih podataka u metričkom sustavu.

Veličina	Simbol	
Dužina vodne linije	Lwl	5.467 m
Širina vodne linije	Bwl	1.838 m
Gaz golog trupa	Tc	0.364 m
Volumen istisnine golog trupa	Vc	1.421 m^3
Uzdužni položaj težišta uzgona	LCB	2.611 m
Uzdužni položaj težišta vodne linije	LCF	2.619 m
Prizmatični koeficjent	Cp	0.546
Koeficjent glavnog rebra	Cm	0.72
Površina vodne linije	Awl	6.776 m^2

Tablica 4.1.1. Ulazni podaci za proračun

U tablici 4.1.2 nalazi se popis raspona parametara trupa ispitanih u DSYHS-u. Izračunate vrijednosti za zadanu jedrilicu tipa L5 se nlaze unutar intervala određenih prema serijama ispitanih modela.

	Raspon parametara	Vrijednosti za L5
$\frac{Lwl}{Bwl}$	2.73 - 5.00	2.97
$\frac{Bwl}{Tc}$	2.46 - 19.38	5.049
$\frac{Lwl}{\nabla c^{\frac{1}{3}}}$	4.34 - 8.5	4.86
LCB	0% - (-8.2%)	-7.6%
LCF	-1.8% - (-9.5%)	-7.47%
Cp	0.52 - 0.6	0.546
Cm	0.65 - 0.78	0.72
$\frac{Aw}{\nabla c^{\frac{2}{3}}}$	3.78 - 12.67	5.36

Tablica 4.1.2 Popis omjera veličina i raspona parametara prema DSYHS-u i za jedrilicu tipa L5

4.2 Metoda

„Delft Systematic Yacht Hull Series“ (DSYHS) je opsežna metoda koja je testirala 50 modela i razvila jednadžbe koje se koriste kao aproksimativna metoda za procijenu najbitnijih sila koje djeluju na jedrilicu. Ovom metodom hidrodinamičke sile su rastavljene na zasebne komponenete:

- Otpor golog trupa u uspravnom stanju Rrh
- Otpor kobilice u uspravnom stanju Rrk
- Otpor golog trupa sa nagibom Rrhφ
- Otpor kobilice sa nagibom Rrkφ

Ukupni otpor se računa kao zbroj otpora trenja golog trupa, preostalog otpora golog trupa, promjene otpora trenja golog tupa, promjene preostalog otpora, otpora trenja privjesaka, preostalog otpora privjesaka, dodtaka za otpor zbog viskoznosti kod privjesaka i promjene preostalog otpora privjesaka. Ukupni otpor se računa prema jednadžbi:

$$Rt\varphi = Rfh + Rrh + \Delta Rfh\varphi + \Delta Rrh\varphi + Rfk + Rrk + Rv + \Delta Rrk\varphi \qquad (4.20)$$

Izračun procjene otpora golog trupa u uspravnom stanju je početak proračuna, u ovom stanju se izračunavaju otpor trenja i preostali otpor. Zatim se određuju „delte“ otpora trenja i preostalog otpora koje su u funkciji kuta nagiba. Navede veličine su u proračunu izračunate za raspon brzina izračunatih kao funkcije raspona Froudovih brojeva zadanih u metodi.

4.3 Otpor trenja golog trupa na mirnoj vodi

Prepostavlja se potpuno turbulentno strujanje duž trupa. Pri izračunu Reynoldsovog broja uzima se 70% duljine vodne linije, a koeficjent otpora trenja se određuje metodom ITTC-57.

Korelacijska krivulja prema ITTC-u je definirana formulom:

$$Cf = \frac{0.075}{(\log(Rn) - 2)^2} = \frac{0.075}{(\log(9927853) - 2)^2} = 0.003 \qquad (4.30)$$

Reynoldsov broj Rn se računa prema formuli:

$$Rn = \frac{V * 0.7 * Lwl}{\nu} \tag{4.31}$$

Kinematički viskozitet ν i gustoća vode ρ se uzimaju za morsku vodu pri tempereaturi od 15°C.
$\nu = 1.18831 * 10^{-6}$ m²/s

ρ = 1025.9 kg/m³

Za određivanje otpra trenja Rfh koristi se izraz:

$$Rfh = \frac{1}{2} * \rho * V^2 * Sc * Cf \tag{4.32}$$

Uronjena površina golog trupa Sc se računa prema izrazu:

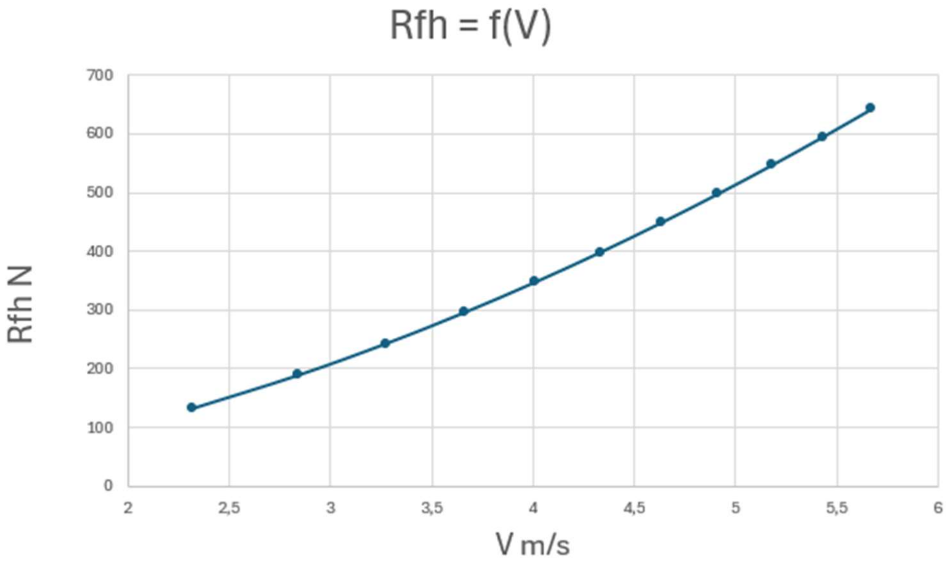
$$Sc = \left(1.97 + 0.171 * \frac{Bwl}{Tc}\right) * \left(\frac{0.65}{Cm}\right) * (\nabla c * Lwl)^{\frac{1}{2}} = \tag{4.32}$$

$$\left(1.97 + 0.171 * \frac{1.838}{0.364}\right) * \left(\frac{0.65}{0.72}\right) * (1.421 * 5.46)^{\frac{1}{2}} = 7{,}62 \text{ m}^2$$

Otpor trenja golog trupa u uspravnom stanju računa se za sve brizine koje su u funkciji Froudovih brojeva zadanih prema metodi, rezultati otpora se nalaze u tablici 4.3.1. Na slici 4.3.1 prikazan je dijagram otpora trenja Rfh za zadane brzine.

Fn	V	Rn	log Rn	Cf	Rfh
	m/s	/	/	/	N
0,1	2,315447161	277502,6	5,443267	0,006326	132,6991
0,15	2,835832035	339869,9	5,531313	0,006014	189,2467
0,2	3,274536778	392448	5,593782	0,005807	243,6329
0,25	3,661043415	438770,2	5,642237	0,005654	296,4921
0,3	4,010472125	480648,7	5,681828	0,005533	348,18
0,35	4,331804987	519159,9	5,715301	0,005433	398,9234
0,4	4,630894322	555005,3	5,744297	0,00535	448,8786
0,45	4,911805167	588672	5,769873	0,005277	498,1596
0,5	5,17749725	620514,7	5,792752	0,005214	546,853
0,55	5,430204927	650801,4	5,813448	0,005157	595,0267
0,6	5,671664071	679739,8	5,832343	0,005107	642,7352

Tablica 4.3.1 Izračunat Reynoldsov broj, bezdimenzijski koeficjent otpora trenja i otpor trenja za zadani raspon brzina



Slika 4.3.1 Dijagram Rfh u funkcij raspona brzina

4.4 Preostali otpor golog trupa

Preostali otpor golog trupa Rrh određuje se prema jednadžbi:

$$\frac{Rrh}{\nabla c * \rho * g} = (a_0 + \left(a_1 * \frac{LCB_{fpp}}{Lwl} + a_3 * \frac{\nabla c^{\frac{2}{3}}}{Aw} + a_4 * \frac{Bwl}{Lwl}\right) * \frac{\nabla c^{\frac{1}{3}}}{Lwl} + \left(a_5 * \frac{\nabla c}{Sc} + a_6 * \frac{LCB_{fpp}}{LCF_{fpp}} + a_7 * \left(\frac{LCB_{fpp}}{Lwl}\right)^2 + a_8 * Cp^2\right) * \frac{\nabla c^{\frac{1}{3}}}{Lwl} \quad (4.40)$$

Koeficjenti *a* ovog polinomskog izraza određeni su pri konstantnim brzinama i prikazani su za niz Froudeovih brojeva korištenjem metode najmanjeg kvadrata. Koeficjenti u ovisnosti o Fn su prikazani u tablici 4.4.1.

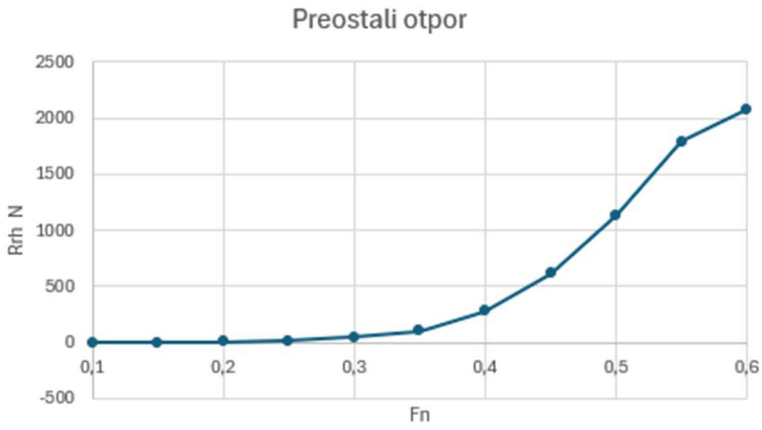
Fn	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
a0	-0,0014	0,0004	0,0014	0,0027	0,0056	0,0032	-0,0064	-0,0171	-0,0201	0,0495	0,0808
a1	0,0403	-0,1808	-0,1071	0,0463	-0,8005	-0,1011	2,3095	3,4017	7,1576	1,5618	-5,3233
a2	0,047	0,1793	0,0637	-0,1263	0,4891	-0,0813	-1,5152	-1,9862	-6,3304	-6,0661	-1,1513
a3	-0,0227	-0,0004	0,009	0,015	0,0269	-0,0382	0,0751	0,3242	0,5829	0,8641	0,9663
a4	-0,0119	0,0097	0,0153	0,0274	0,0519	0,032	-0,0858	-0,145	0,163	1,1702	1,6084
a5	0,0061	0,0118	0,0011	-0,0299	-0,0313	-0,1481	-0,5349	-0,8043	-0,3966	1,761	2,7459
a6	-0,0086	-0,0055	0,0012	0,011	0,0292	0,0837	0,1715	0,2952	0,5023	0,9176	0,8491
a7	-0,0307	0,1721	0,1021	-0,0595	0,7314	0,0223	-2,455	-3,5284	-7,1579	-2,1191	4,7129
a8	-0,0553	-0,1728	-0,0648	0,122	-0,3619	0,1587	1,1865	1,3575	5,2534	5,4281	1,1089

Tablica 4.4.1 koeficjenti polinoma za preostali otpor golog trupa

Izračunate vrijednosti polinomskog izraza u ovisnosti o Froudeovom broju su prikazane u tablici 4.4.2. Rezultati su grafički prikazani na dijagramu, slika 4.4.1

Fn	Rrh (N)
0.1	-2.6059
0.15	2.7711
0.20	7.0292
0.25	18.1405
0.30	45.9277
0.35	105.446
0.40	276.609
0.45	615.374
0.50	1138.83
0.55	1791.45
0.60	2077.28

Tablica 4.4.2 Izračunate vrijednosti otpora trenja Rrh u funkcije Fn



Slika 4.4.1 Dijagram preostalog otpora golog trupa Rrh u funkciji Fn

4.5 Promjena otpora u ovisnosti o nagibu

Kada se jedrilica nagne dolazi do promjene u otporu. U realnim okolnostima nagib je uzrokovan silama na jedrima, što podrazumjeva sile uzgona na trup i privjeske. Da bi se inducirani otpor mogao izračunati računa se promjena otpora uzrokovana promjenom nagiba. Promjena otpora se računa zasebno za otpor trenja i preostali otpor.

4.5.1 Promjena otpora trenja

Promjena otpora trenja uzrokovanog promjenom nagiba je ovisna o promjeni uronjenog dijela trupa. Na temelju hidrostatičkih proračuna koji su provedeni za različite modele prema DSYHS-u promjena uronjenog dijela trupa može se aproksimirati s visokim stupnjem točnosti prema jednadžbi:

$$Sc\varphi = Sc_{\varphi=0} * (1 + \frac{1}{100} * (s_0 + s_1 * \frac{Bwl}{Tc} + s_2 * \left(\frac{Bwl}{Tc}\right)^2 + s_3 * Cm) \quad (4.5.1)$$

U tablici 4.5.1.1 prikazane su vrijednosti koeficjenta polinomskog izraza za izračun promjene površine uronjenog dijela trupa.

ϕ	5	10	15	20	25	30	35
s0	-4,112	-4,522	-3,291	1,85	6,51	12,334	14,648
s1	0,054	-0,132	-0,389	-1,2	-2,305	-3,911	-5,182
s2	-0,027	-0,077	-0,118	-0,109	-0,066	0,024	0,102
s3	6,329	8,738	8,949	5,364	3,443	1,767	3,497

Tablica 4.5.1.1 koeficjenati polinoma za površinu uronjenog dijela trupa

u ovisnosti o nagibu

Izračunate vrijednosti polinomskog izraza su prikazane u tablici 4.5.1.2

Sc ϕ (m^2)	Φ °
7.5885	5
7.5622	10
7.4890	15
7.3893	20
7.2973	25
7.2060	30
7.1397	35

Tablica 4.5.1.2 Vrijednosti površine uronjenog dijela trupa

ovisno o kutu nagiba

Koristeći formulu za izračun otpora trenja (4.32) izračunate su vrijednosti za otpor trenja golog trupa za zadane kuteve. Dobijene vrijednosti su navedene u stablici 4.5.1.

V	Cf	Rfh ϕ5	Rfh ϕ10	Rfh ϕ15	Rfh ϕ20	Rfh ϕ25	Rfh ϕ 30	Rfh ϕ35
m/s		N	N	N	N	N	N	N
2,315447	0,00632586	132,014173	131,5566	130,28321	128,5488	126,9483	125,36	124,2066
2,835832	0,00601435	188,2698968	187,6174	185,801312	183,3278	181,0453	178,7801	177,1352
3,274537	0,00580708	242,3753779	241,5354	239,197365	236,013	233,0745	230,1584	228,0408
3,661043	0,0056536	294,9616577	293,9394	291,094136	287,2188	283,6428	280,0941	277,517
4,010472	0,00553266	346,3827948	345,1823	341,841042	337,2902	333,0908	328,9233	325,897
4,331805	0,00543342	396,8642622	395,4888	391,6606	386,4465	381,6351	376,8602	373,3929
4,630894	0,00534959	446,5615994	445,0139	440,706308	434,8392	429,4253	424,0526	420,151
4,911805	0,00527725	495,5882227	493,8706	489,090097	482,5789	476,5706	470,608	466,2781
5,177497	0,00521378	544,030282	542,1448	536,896987	529,7494	523,1537	516,6083	511,8552
5,430205	0,00515734	591,9553038	589,9037	584,193618	576,4163	569,2397	562,1177	556,9458
5,671664	0,00510661	639,4175525	637,2015	631,033544	622,6327	614,8806	607,1876	601,601

Tablica 4.5.1 Vrijednosti otpora trenja za zadane kuteve u funkciji raspona brzina

4.5.2 Promjena preostalog otpora

Zbog asimetrije trupa uzrokovane nagibom dolazi do promjene u raspodjeli istisninskog volumena a time i preostalog otpora. Promjena preostalog otpora trupa zbog nagiba izvedena je iz mjerenja na nula i 20 stupnjeva nagiba, oduzimanjem od otpora u uspravnom stanju nagnuti otpor. Promjena preostalog otpora zbog nagiba određena je iz izmjerenih podataka i izračun je pretpostavljen polinomskom jednadžbom za ΔRrh.

Preostali otpor izmjeren na nagibu od 20 stupnjeva se računa po jednadžbi:

$$\frac{\Delta Rrh_{\varphi=20}}{\nabla c * \rho * g} = u_0 + u_1 * \frac{Lwl}{Bwl} + u_3 * \left(\frac{Bwl}{Tc}\right)^2 + u_4 * LCB + u_5 * LCB^2 \qquad (4.5.2)$$

U tablici 4.5.1.3 prikazane su vrijednosti koeficjenta polinomskog izraza za izračun promjene preostalog otpora na nagibu od 20 stupnjeva u funkciji Froudovog broja.

Fn	0,25	0,3	0,35	0,4	0,45	0,5	0,55
u0	-0,0000268	0,0006628	0,0016533	-0,0008659	-0,0032715	-0,000198	0,00158
u1	-0,0000014	-0,0000632	-0,0002144	-0,0000354	0,0001372	-0,000148	-0,0004
u2	-0,0000057	-0,0000699	-0,000164	0,0002226	0,0005547	-0,000659	-0,0007
u3	0,0000016	0,0000069	0,0000199	0,0000188	0,0000268	0,000186	0,00021
u4	-0,000007	0,0000459	-0,000054	-0,00058	-0,0010064	-0,000749	-0,0005
u5	-0,0000017	-0,0000004	-0,0000268	-0,0001133	-0,0002026	-0,000165	-0,0001

Tablica 4.5.1.3 koeficjenti za polinomski izraz promjene otpora trupa na nagibu od 20 stupnjeva

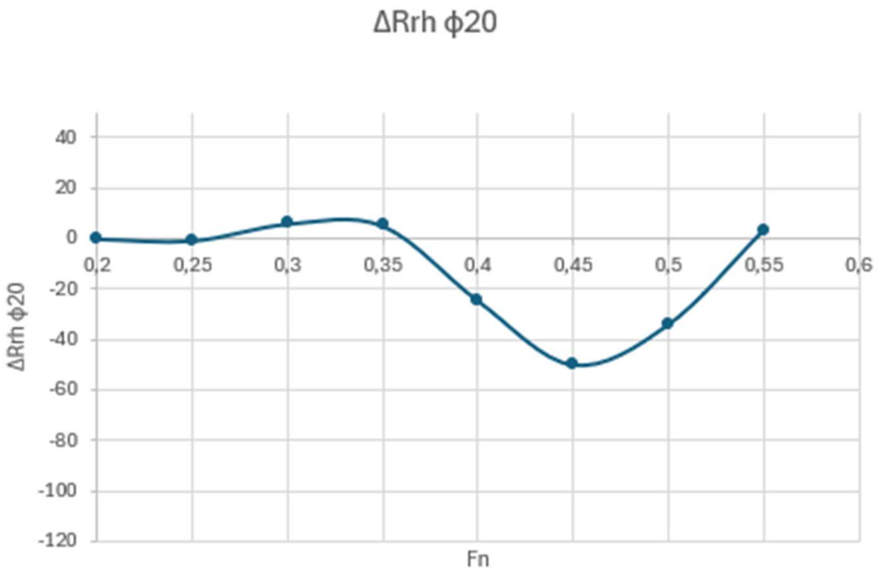
Izračunate vrijednosti polinomskog izraza promjene otpora pri nagibu od 20 stupnjeva prikazane su u tablici 4.5.1.4.

Fn	ΔRrh φ20 (N)
0.25	-0.70924
0.30	5.9663
0.35	5.1783
0.40	-24.4945
0.45	-49.9266
0.50	-34.0046
0.50	3.38756

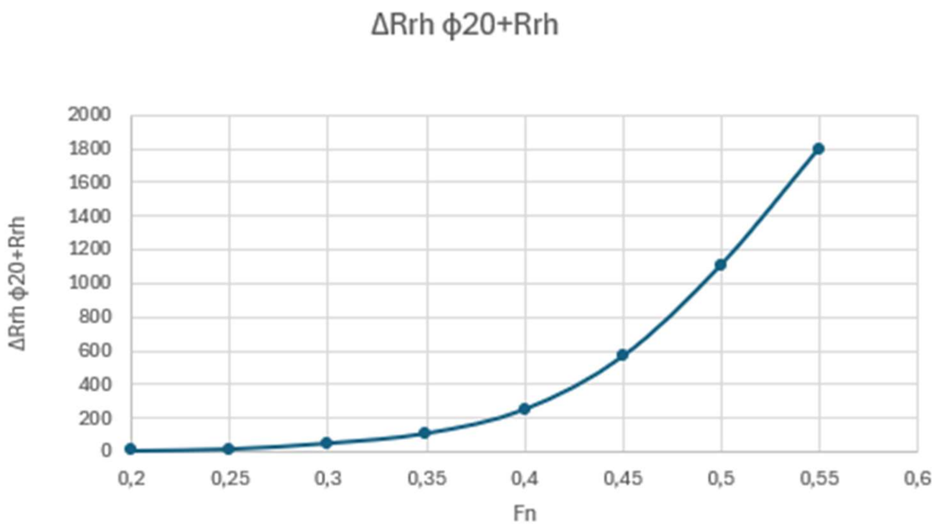
Tablica 4.5.1.4 Promjena preostalog otpora pri kutu od 20° u funkciji Froudovog broja

Promjena preostalog otpora pri nagibu od 20 stupnjeva grafički je prikazana na dijagramu, slika 4.5.2.

Na slici 4.5.3 prikazan je dijagram preostalog otpora pri nagibu od 20 stupnjava , krivulja je prikazana u funkciji Froudovog broja.



Slika 4.5.2 Dijagram promjene preostalog otpora pri kutu od od 20° u funkciji Froudovog broja



Slika 4.5.3 Dijagram preostalog otpora pri kutu od od 20° u funkciji Froudovog broja

Promjena otpora ovisno o bilo kom kutu se računa kao ekvivalent kuta nagiba na potenciji 1.7. Kut nagiba se računa u radijanima.

$$\Delta Rrh_{\varphi} = \Delta Rrh_{\varphi=20} + 6.0 * \varphi^{1.7} \quad (4.5.3)$$

4.6 Otpor privjesaka

Otpor golog trupa i privjesaka izračunati su zasebno. Utvrđeno je da otpor zbog viskoznosti privjesaka ne ovisi o kutu nagiba. Na temelju DSYHS eksperimenata sa sustavnim varijacijama kobilice ispod trupova različite forme zaključeno je da je preostali otpor privjesaka značajno pod utjecajem prisutnosti slobodne površine i zbog toga ovisi o nagibu. Prvo se određuje preostali otpor privjesaka u uspravnom stanju, a nakon toga promjena otpora zbog kuta nagiba.

4.6.1 Dodatak *Rv*

Dodatak za otpor zbog viskoznosti smatra se zbrojem otpora trenja i „drugih“ viskoznih učinaka koji se obračunavaju uvođenjem faktora forme.

$$Rv = Rf * (1 + k) \tag{4.6.1}$$

Otpor trenja *Rf* se računa pomoću izraza:

$$Rf = \frac{1}{2} * \rho * V^2 * S * Cf \tag{4.32}$$

Površina kobilice iznosi 2.436 m^2

Za izračun faktora forme (1+k) koristi se Hoernerova formulacija „Fluid Dynamic Drag“, koja faktor oblika određuje kao funkciju relativne debljine presjeka.

$$(1 + k) = \left(1 + 2 * \frac{t}{c} + 60 * \left(\frac{t}{c}\right)^4\right) = (1 + 2 * 15 + 60 * 0.15^4) = 1.33 \tag{4.6.1.1}$$

Glavni parametri kobilice iz DSYHS-ovih standarda za izabrani Model 1 su zadani u tablici 4.6

AR – 0.65
TR – 0.63
Λ – 45
t/c – 0.15

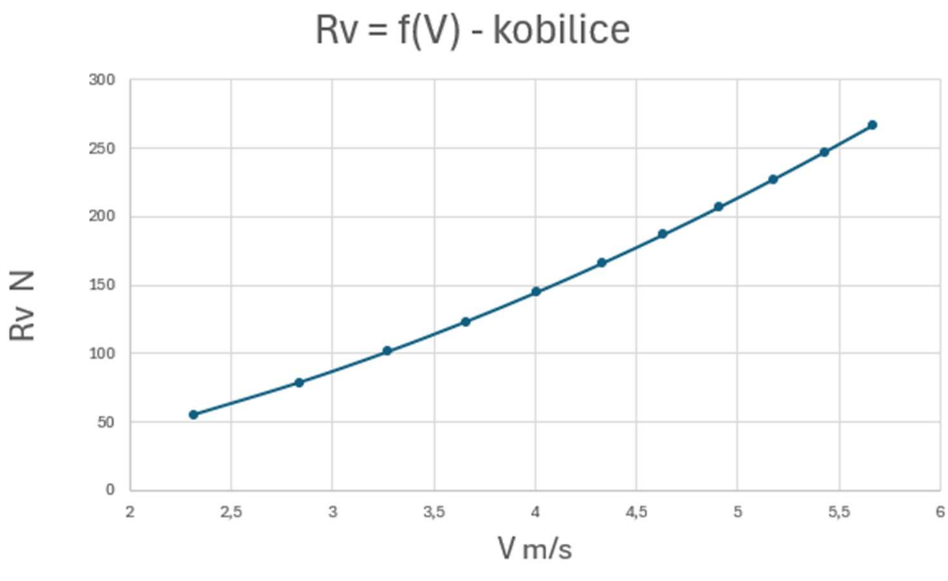
Tablica 4.6 glavni parametri kobilice izabranog Modela 1

U tablici 4.6.1. su navedene izračunate vrijednosti dodatka za otpor na kobilici zbog viskoznosti, vrijednosti su izračunate za raspon brzina prema zadanim Froudovim brojevima.

Fn	V	Rn	log Rn	Cf	Rfh	Rv
	m/s	/	/	/	N	N
0,1	2,31545	277503	5,44327	0,00633	42,3781	55,0916
0,15	2,83583	339870	5,53131	0,00601	60,4369	78,568
0,2	3,27454	392448	5,59378	0,00581	77,8054	101,147
0,25	3,66104	438770	5,64224	0,00565	94,6862	123,092
0,3	4,01047	480649	5,68183	0,00553	111,193	144,551
0,35	4,3318	519160	5,7153	0,00543	127,398	165,618
0,4	4,63089	555005	5,7443	0,00535	143,352	186,357
0,45	4,91181	588672	5,76987	0,00528	159,09	206,817
0,5	5,1775	620515	5,79275	0,00521	174,64	227,032
0,55	5,4302	650801	5,81345	0,00516	190,025	247,032
0,6	5,67166	679740	5,83234	0,00511	205,261	266,839

Tablica 4.6.1 Dodatak za otpor za zadane brzine

Dijagram koji prikazuje krivulju dodatka za otpor u funkciji brzine prikazan je na slici 4.6.1



Slika 4.6.1. Dijagram dodatka za otpor u funkciji brzina

4.6.2 Preostali otpor kobilice

Preostali otpor Rrk se izračunava pomoću izraza:

$$\frac{Rrk}{\nabla k * \rho * g} = A0 + A1 * \frac{T}{Bwl} + A2 * \frac{Tc + Zcbk}{\nabla k^{\frac{1}{3}}} + A4 * \frac{\nabla c}{\nabla k} \quad (4.6.2)$$

vk – uronjeni volumen kobilice m^3

T – ukupan gaz m

Zcbk – vertikalna pozicija centra uzgona kobilice m

U tablici 4.6.2.1 su prikazani koeficjenti polinomskog izraza za izračun preostalog otpora kobilice.

Fn	0,2	0,25	0,3	0,35	0,4	0,45	0,5	0,55	0,6
A0	-0,001	-0,0055	-0,0111	-0,0071	-0,03581	-0,0047	0,00553	0,04822	0,01021
A1	0,00172	0,00597	0,01421	0,02632	0,08649	0,11592	0,07371	0,0066	0,14173
A2	0,00117	0,0039	0,00069	-0,0023	0,00999	-0,0006	0,05991	0,07048	0,6409
A3	-8E-05	-9E-05	0,00021	0,00039	0,00017	0,00035	-0,0011	-0,0004	-0,0019

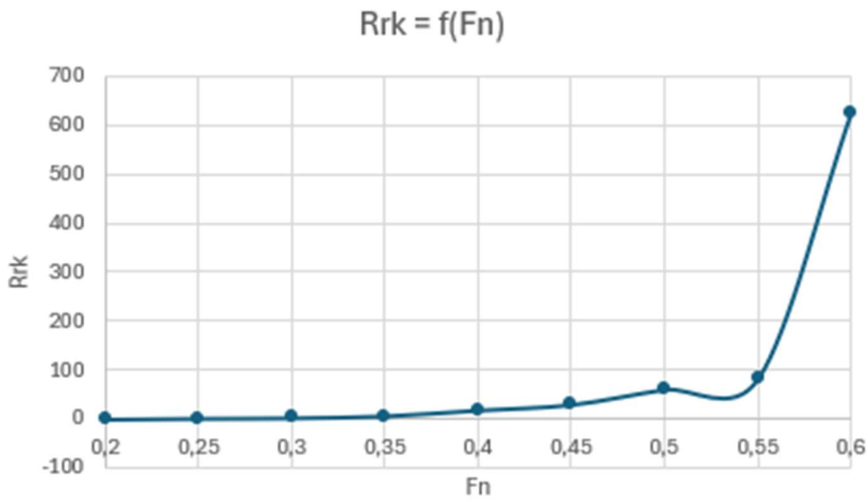
Tablica 4.6.2.1 koeficjenti polinomskog izraza za izračun preostalog otpora kobilice

U tablici 4.6.2.2. su navedene izračunate vrijednosti preostalog otpora kobilice za zadane Froudove brojeve.

Fn	Rrk (N)
0.20	-0.0148
0.25	1.7469
0.30	2.7291
0.35	6.7954
0.40	18.595
0.45	29.897
0.50	60.8187
0.55	82.941
0.60	626.163

Tablica 4.6.2.2 Preostali otpor kobilice

Dijagram koji prikazuje krivulju preostalog otpora kobilice u funkciji Froudovog broja prikazan je na slici 4.6.2



Slika 4.6.2 Dijagram preostalog otpora kobilice

4.6.3 Promjena otpora kobilice u ovisnosti o kutu nagiba

Pretpostavlja se da na viskozni otpor privjesaka ne utječe naginjanje jedrilice, međutim bitan utjecaj na ukupan otpor privjesaka ima preostali otpor, na koji utječe činjenica da se volumen kobilice približava slobodnoj površini, što ovisi o kutu nagiba i brzini jedrilice tj. Froudeovom broju.

Izraz koji se koristi za aproksimaciju otpora privjesaka pod određenim kutem se definira jednadžbom:

$$\frac{\Delta Rrk\varphi}{\nabla k * \rho * g} = Ch * Fn^2 * \varphi \qquad (4.6.3)$$

$$Ch = H1 * \frac{Tc}{T} + H2 * \frac{Bwl}{Tc} + H3 * \frac{Tc}{T} * \frac{Bwl}{Tc} + H4 * \frac{Lwl}{\nabla c^{\frac{1}{3}}} = \qquad (4.6.4)$$

$$-3.5837 * \frac{0.364}{1.122} + (-0.0518) * \frac{1.838}{0.364} + 0.5958 * \frac{0.364}{1.122} * \frac{1.838}{0.364} + 0.2055 * \frac{5.467}{1.421^{\frac{1}{3}}}$$

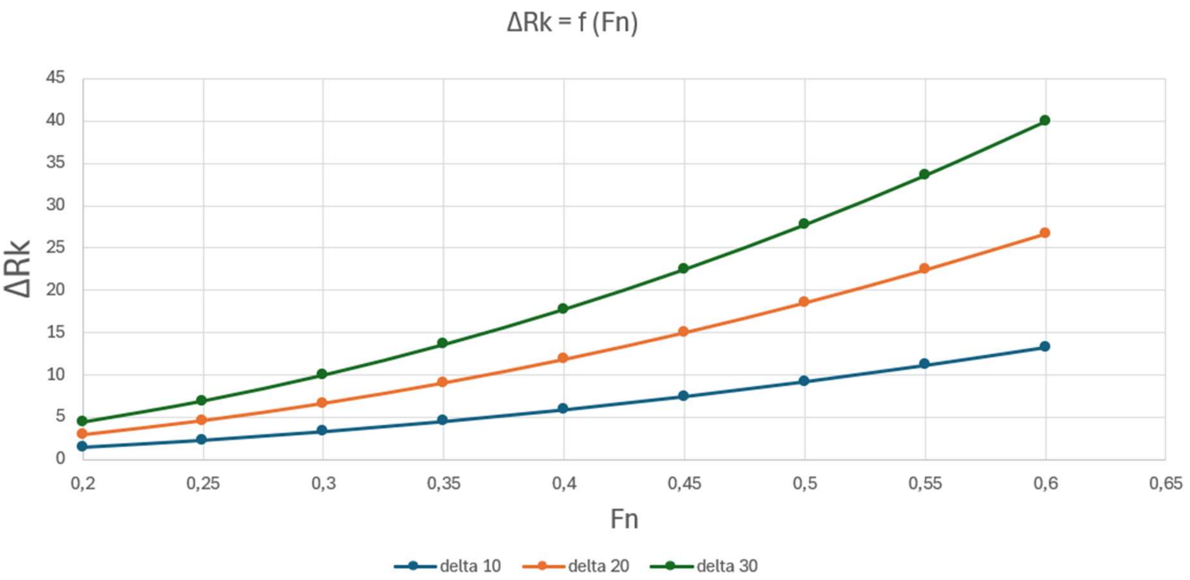
$$Ch = 0.5498$$

Vrijednosti promjena otpora kobilice u ovisnosti o kutu nagiba prikazane su u tablici 4.6.3.

Fn	ΔRkϕ10	ΔRkϕ20	ΔRkϕ30
0,2	1,47767	2,96383	4,4415
0,25	2,30886	4,63098	6,93984
0,3	3,32475	6,66861	9,99337
0,35	4,52536	9,07672	13,6021
0,4	5,91067	11,8553	17,766
0,45	7,48069	15,0044	22,4851
0,5	9,23543	18,5239	27,7594
0,55	11,1749	22,414	33,5888
0,6	13,299	26,6745	39,9735

Tablica 4.6.3. Promjena otpora kobilce za kuteve nagiba u funkcij Fn

Dijagram na slici 4.6.3 prikazuje krivulje promjene otpora kobilice za kuteve od deset, dvadeset i trideset stupnjeva. Krivulje su prikazane u funkciji Froudovog broja.



Slika 4.6.3 Dijagram promjene otpora kobilice za nagibe od 10°, 20° i 30°

5. Zaključak

U ovom radu izvršena je procjena stabiliteta i otpora jedrilice kategorije L5. Odabrana forma trupa prethodno je modelirana u programskom paketu Rhinoceros 7 i određene su hidrostatičke značajke trupa pomoću paketa Orca 3D za tri stanja opterećenja.

Izrađen je proračun stabiliteta prema ISO 12217-2:2017 , prilog 1. Određene su hidrodinamičke značajke trupa za stanje golog trupa i kobilice u uspravnom stanju, kao i značajke golog trupa i kobilice pod određenim kutem. Izračunate vrijednosti su prikazane tablično za zadani raspon brzina i pomoću dijagrama. Aproksimacija hidrodinamičkih sila jedrilice temeljena je na metodi „Delft Systematic Yacht Hull Serije“

„DSYHS“ metoda se tijekom godina proširivala, a danas sadrži informacije o otporu golog trupa, otporu trupa sa privjescima u ravnom i nagnutom stanju te porastu otpora zbog momenta trima jedara, porastu otpora zbog bočne sile pri različitim brzinama broda i kutovima nagiba. Nove formulacije za relevantne hidrodinamičke sile u funkciji geometrije trupa su izvedene da bi se pokrilo što više različitih oblika trupa i dizajna privjesaka.

Omjeri parametara zadane jedrilice L5 su se nalazili unutar intervala parametara koji su zadani metodom testirajući 50 različitih modela, pa se metoda DSYHS pokazala kao relevantna za aproksimaciju i procjenu otpora zadane jedrilice tipa L5 za zadani raspon brzina.

Literatura

[1] International Marine Certification Institute, »CALCULATION TOOLS & CHECKLISTS,« [Mrežno]. Available: https://www.imci.org/52. [Pokušaj pristupa 20.05.2024]

[2] J.A. Keuning and U.B. Sonnenberg, Approxximation of the Hydrodynamic Forces on a Sailing Yacht based on the “Delf Systematic Yacht Hull Series”, Delft university of Technology, Amsterdam, 16. November 1998.

POPIS SLIKA

POPIS TABLICA

Sažetak

Ovaj rad se temelji na procjeni stabiliteta i otpora jedrilice klase L5. Model je bio zadan u programu *Rhinoceros 7*. Stabilitet plovila procjenjen je prema normi ISO 12217-2:2017 koristeći dostupan tablični kalkulator. Hidrostatičke značajke plovila su dobivene koristeći dodatak *Orca 3D*. Procjena otpora je analizirana metodom " Delft Systematic Yacht Hull Series" autora J. A. Keuning i U. B. Sonnenberg. Prepostavljeni su otpori za određeni interval brzina. Rezultati su prikazani tablično i grafički.

Ključne riječi: jedrilica, stabilitet, hidrostatske značajke, otpor trenja, preostali otpor, promjena otpora.

Summary

This paper focuses on the assessment of the stability and resistance of an L5 class sailing boat. The model of the sailing boat was created using Rhinoceros 7 software. The vessel's stability was assessed according to the ISO 12217-2:2017 standard using an available spreadsheet calculator. The hydrostatic characteristics of the vessel were obtained using the Orca 3D. The resistance evaluation was conducted using "Delft Systematic Yacht Hull Series" method developed by J. A. Keuning and U. B. Sonnenberg, with assumed resistance values for specific speed range. The results are presented in both tabular and graphical formats.

Keywords: Sailing boat, stability, hydrostatic characteristics, frictional resistance, residual resistance, resistance variation.

INTERNATIONAL MARINE CERTIFICATION INSTITUTE (UK)
INTERNATIONAL MARINE CERTIFICATION INSTITUTE
53 Rodney Street, Liverpool L1 9ER, United Kingdom
+44-151-528 3096 info@imci-uk.org imci-uk.org
Rue Abbé Cuypers 3, B-1040 Brussels, Belgium
+32-2-741 6836 info@imci.org imci.org

ISO 12217-2:2017 SAILING BOATS OF LENGTH GREATER THAN OR EQUAL TO 6m

Monohulls only

Manufacturer:	ZAVRŠNI RAD
Signatory, Name:	MARIJA BAŠIĆ
Signatory, Title:	
Phone:	
Email:	
WWW:	
CIN Model Year:	
Model Name:	SAILING BOAT L5-CLASS

This calculation sheet is provided by IMCI "as is" and any express or implied warranties, including, but not limited to, the implied warranties of fitness for a particular purpose are disclaimed.

blue cells are derived values	yellow cells require data input

Please make sure to set your signature on the summary! (worksheet 16)
either digitally or print summary, sign and attach scan

- most worksheets have additional comments / remarks / other calculations beside the printout area; please take into account.

- If curves or righting moments are required, please fill in worksheets 6a and 6b or attach curve of righting moments for both loading conditions to the documentation.

- For boats with quick-draining cockpit the cockpit calculation according to ISO 11812 shall be enclosed to the documentation.

- Please attach other detailed information as appropriate, e.g. photos, sketches etc. for sill height, openings, companion way doors, location of flooding points, practical tests etc.

- Please think before printing the complete workbook; often some of the worksheets are not needed. In this case please print out only single worksheets

- When entering data, please use the correct separator for your Excel version, many application problems are the result of incorrect separators (, or .)

- Please be aware that there is NO technical difference between the requirements of ISO 12217-2:2015 and ISO 12217-2:2017; change of the name is just because of the harmonisation process; for FDIS ISO 12217-2:2020 the main change is exclusion of optional equipment from the maximum load and the result of the "maximum recommended load for builder's plate" (With ISO 14945 and ISO 14946 renamed to "maximum load for the builder's plate, m_{MBP}") which exludes OB engine weights and the optional equipment.

ISO 12217-2:2017 SAILING BOATS OF LENGTH GREATER THAN OR EQUAL TO 6m
CALCULATION WORKSHEET No. 1

ISO 12217-2:2017 en240408

ZAVRŠNI RAD SAILING BOAT L5-CLASS

Design Category intended: C		Monohull / multihull: Monohull		
Item	**Symbol**	**Unit**	**Value**	**Ref.**
Length of hull as in ISO 8666	L_H	m	6,17	3.4.1
Length of waterline in loaded arrival condition	L_{wl}	m	5,47	3.4.2
Empty Craft condition mass	m_{EC}	kg	910,0	3.5.1
standard equipment		kg	60,0	3.6.12
water ballast in tanks which are notified in the owner's manual to be filled when the boat is afloat		kg	0,0	3.5.2
Light craft condition mass	m_{LC}	kg	970,0	3.5.2
Mass of:				
Desired crew limit	CL	----	5	3.6.3
Mass of:				
desired crew limit at 75 kg each		kg	375,0	'3.5.4
provisions + personal effects		kg	100,0	'3.5.4
drinking water		kg	0,0	'3.5.4
fuel		kg	17,6	'3.5.4
lubricating and hydraulic oils		kg	0,0	'3.5.4
black water		kg	0,0	'3.5.4
grey water		kg	0,0	'3.5.4
water ballast		kg	0,0	'3.5.4
other fluids carried aboard		kg	0,0	'3.5.4
stores, spare gear and cargo (if any)		kg	20,0	'3.5.4
inflatable life raft(s) in excess of essential safety equipment		kg	35,0	'3.5.4
other small boats carried aboard		kg	0,0	'3.5.4
Maximum load = sum of above masses (**ISO 12217-2:2020)**	m_L	kg	547,6	'3.5.4
optional equipment and fittings not included in basic outfit		kg	0,0	'3.5.4
Maximum load = sum of above masses using **ISO 12217-2:2017**	m_L	kg	547,6	'3.5.4
Maximum Load condition mass	m_{LDC}	kg	1517,6	'3.5.5
mass to be removed for loaded arrival condition		kg	20,0	'3.5.6
Loaded Arrival condition mass	m_{LA}	kg	1497,6	'3.5.6
Mass of:				
minimum number of crew according to 3.5.3		kg	75	3.5.3a)
non-consumable stores and equipment normally aboard		kg	10,0	3.5.3b)
inflatable life raft		kg	35,0	'3.5.3
Load to be included in Minimum Operating Condition	m'_L	kg	120,0	'3.5.3
Light craft condition mass	m_{LC}	kg	970,0	'3.5.2
Mass in the Minimum Operating Condition	m_{MO}	kg	1090,0	'3.5.3
Maximum load for the builder's plate using EN ISO 14945:2021 and EN ISO 14946:2021 (if manually reduced on Worksheet 1b the reduced value is shown)	m_{MBP}	kg	510,0	ISO 14945 ISO 14946
Is boat sail or non-sail? nominal sail area	A_S	m^2	21,9	'3.4.8
sail area / displacement ratio = $A_S / (m_{LDC})^{2/3}$		-----	0,1655	3.1.2
CLASSIFIED AS [non-sail if AS / (mLDC)2/3 < 0.07]	SAIL/NON-SAIL ?		**SAIL**	3.1.2

NB If SAIL, continue using these worksheets, if NON-SAIL, use ISO 12217-1

ISO 12217-2:2017 / ISO 14945:2021 CALCULATION WORKSHEET No.1b Builder's plate

ZAVRŠNI RAD SAILING BOAT L5-CLASS

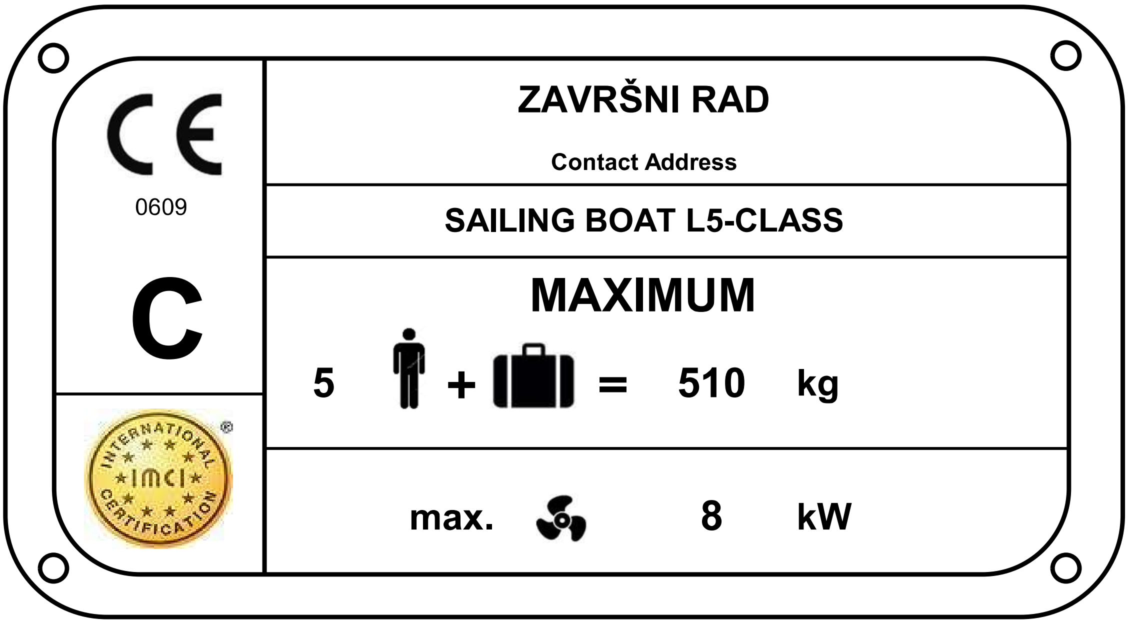
Since 2021-12-09 EN ISO 14945:2021 and EN ISO 14946:2021 are harmonised!
*The formely 'Maximum recommended load for builder's plate' became '**Maximum load for the builder's plate', m_{MBP}.***
m_{MBP} does not include the optinonal equipment anymore; also the weight of outboard engines is excluded from m_{MBP} and can be shown in a seperated line on the plate.
Below you find an example for the builder's plate with the maxium value for m_{MBP} calcuated from the stability calculation on worksheet 1.
For portable tanks, please change the default 'yes' on the right side in 'no, portable tank'; the weight of the tank will be included in m_{MBP}
Please be aware that ISO 14946:2021 allowes in clause 6 that the maximum recommended load can be downrated or limited by the manufacturer at any time. Therefore you find a extra cell to enter a manual reduced value for the maximum load for the builder's plate.

Please be also aware that the design of these plates is just a proposal from EN ISO 14945, the manufacturer is free to change the design as long all requirements of the standard are fulfilled.

Item	Value	Unit	Ref.
Manually reduced value for the 'Maximum load for the builder's plate m_{MBP}	510	kg	EN ISO 14945, cl. 6, note 2
Maximum engine power of a single engine	8	kW	
number of engines	1		

Please see builder's plate example with values calculated from worksheet 1 entries on next page:

Builder's plate information for craft powered by inboard or sterndrive engines



ISO 12217-2:2017 CALCULATION WORKSHEET No.2 TESTS TO BE APPLIED

ZAVRŠNI RAD SAILING BOAT L5-CLASS

Question	Symbol	Unit	Answer	Ref.
Is boat fully enclosed? (see definition in ref.)		Yes / No	No	3.1.8
Is boat a catamaran or trimaran?		Yes / No	No	3.1.3, 3.1.4
If NO, choose from options 1 to 7.				
Length of hull	L_H	m	6,17	3.4.1
Beam of Hull	B_H		2,04	
If boat is a multihull: Beam between centres of buoyancy of sidehulls	B_{CB}	m	1,80	3.4.5
Is ratio $L_H / B_{CB} > 5$		Yes / No	No	7.1
If YES, treat the boat as a monohull, and choose from options 1 to 7. If NO, use option 8; use multihull excel calcuation template				
Mass in the minimum operating condition	m_{MO}	kg	1090	3.5.3
Mass in the loaded arrival condition	m_{LA}	kg	1498	3.5.6

Choose any ONE of the following options and use all the worksheets indicated for that option.

		All boats except catamarans and trimarans with $L_H / B_{CB} > 5$							Multih.
Option		1	2	3	4	5	6	7	8
categories possible		A + B	C + D	C + D	C + D	C + D	C + D	C + D	A – D
decking or covering		fully enclosed	fully enclosed	any amount	any amount	any amount	any amount	any amount	see note a
downflooding openings		3	3	3	3	3	3		3
downflooding angle		3	3						
downflooding height test	all boats	3	3	3		3			3
	full method	4	4	4		4			4
recess size		5[b]				5[c]	5[c]		5[d]
minimum energy		6	6						
angle of vanishing stability		6	6						
stability index		7	7						
knockdown-recovery test				8	8				
wind stiffness test						9	9		
flotation requirement					10		10		10[d]
capsize recovery test								11	
bare poles speed									12
wind speed limits									13
stability requirements									14
habitable multihulls									14[e]
detection & removal of water		15	15	15	15	15	15	15	15
SUMMARY		16	16	16	16	16	16	16	16

a Fully enclosed if category A or B, otherwise any amount.
b Only applicable to boats for category B using 6.5.2 and having $\phi_V < 90°$.
c Only applicable to boats of design category C that are fully enclosed.
d Applicable for category A,B and boats of design category C that are fully enclosed
e Only applicable if boat is defined as habitable according to 3.1.9, and is deemed to be vulnerable to inversion when used in design category – see 7.11.2 & 7.11.3.

Option selected	5

ISO 12217-2:2017 CALCULATION WORKSHEET No. 3 DOWNFLOODING

ZAVRŠNI RAD SAILING BOAT L5-CLASS

Downflooding Openings:

Question	Answer	Ref.
Have all appropriate downflooding openings been identified?	Yes	6.2.1
Have potential downflooding openings within the boat been identified?	Yes	6.2.1.4
Do all closing appliances satisfy ISO 12216?	Yes	6.2.1.1
Hatches or opening type appliances are not fitted below minimum height above waterline? *	Yes	6.2.1.2
Seacocks comply with requirements?	Yes	6.2.1.3
Are all openings on design category A or B boats fitted with closing appliances? **	No	6.2.1.5
Categories possible: A or B if all are YES, C or D if first five are YES	C	6.2.1

* Except for emergency escape hatches on design category C boats, where 0,1 m is allowable ** Except openings for ventilation and engine combustion

Exemptions Downflooding Openings:

Question	Answer	Ref.
Drains from quick-draining recesses or watertight recesses acc. to cl. 6.1.1.6 b) are either:		
1) freeing ports with non-return flaps which are watertight from the exterior (degree 3) **or**		6.2.1.6 b)
2) have a drainage area smaller than three times the minimum area required of ISO 11812		6.2.1.6 b)
		6.2.1.6 b)
Opening appliances (e.g. side doors) in the topsides which comply with ISO 12216 are		
1) referenced in the owner's manual as watertight closure to be kept shut when under way, **and**		6.2.1.6 d)
2) marked inboard with "KEEP SHUT WHEN ..." in upper case letters not less than 4,8 mm high, **and**		6.2.1.6 d)
3) the hight above waterline of the lowest part is > 50% of required downflooding height		6.2.1.6 d)
		6.2.1.6 d)
All other exemtions of cl. 6.2.1.6 checked and requirements fullfilled?	Yes	6.2.1.6
		6.2.1.6

Downflooding angle:

Item	Symbol	Unit	Value	Ref.
Required value:				6.2.3
Cats. A + B = 40°, Cat. C = 35°, Cat. D = 30°	$\phi_{D(R)}$	degrees	**35**	Table 3
Actual Downflooding Angle: any opening at m_{MO}	ϕ_D	degrees	**69,40**	3.3.2
Actual Downflooding Angle: any opening at m_{LA}	ϕ_D	degrees	**67,80**	3.3.2
Method used to determine ϕ_D:				Annex B
Category possible on Downflooding Angle ϕ_D:			**n.a.**	6.2.3
Actual downflooding angle: to non-quickdraining recess at m_{MO}	ϕ_{DC}	degrees	**69,4**	3.3.2
Actual downflooding angle: to non-quickdraining recess at m_{LA}	ϕ_{DC}	degrees	**67,8**	3.3.2
Actual downflooding angle: to main hatchway at m_{MO}	ϕ_{DH}	degrees	**69,4**	3.3.2
Actual downflooding angle: to main hatchway at m_{LA}	ϕ_{DH}	degrees	**67,8**	3.3.2

Downflooding Height:

Requirement			Basic requirement	Reduced value for small openings
Applicable to			options 1-3, 5 and 8	options 1-3,5 and 8, but only if fig. 2 is used
Ref.			6.1.2.2 a)	6.1.2.2 d)
obtained from Fig. 2 or annex A?			fig. 2	= basic x 0.75
Maximum area of small openings ($50L_H^2$) (mm²) =			1903	
Required downflooding height $h_{D(R)}$	Fig. 2 / ann. A	Category A		
	Fig. 2 / ann. A	Category B		
	Fig. 2 / ann. A	Category C	**0,36**	**0,27**
	Fig. 2 / ann. A	Category D		
Actual Downflooding Height h_D	Ref. 6.2.2.1		**0,736**	**0,736**
Design Category possible			**C**	**C**
Design Category possible on Downflooding Height = lowest of above				**C**

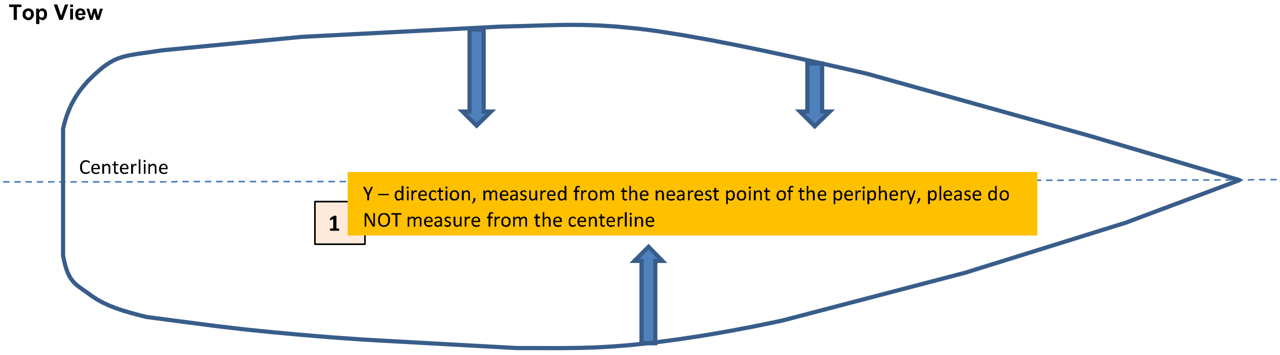
ISO 12217-2:2017 CALCULATION WORKSHEET No.3a DOWNFLOODING OPENINGS / CLOSING APPLIANCES

ZAVRŠNI RAD SAILING BOAT L5-CLASS

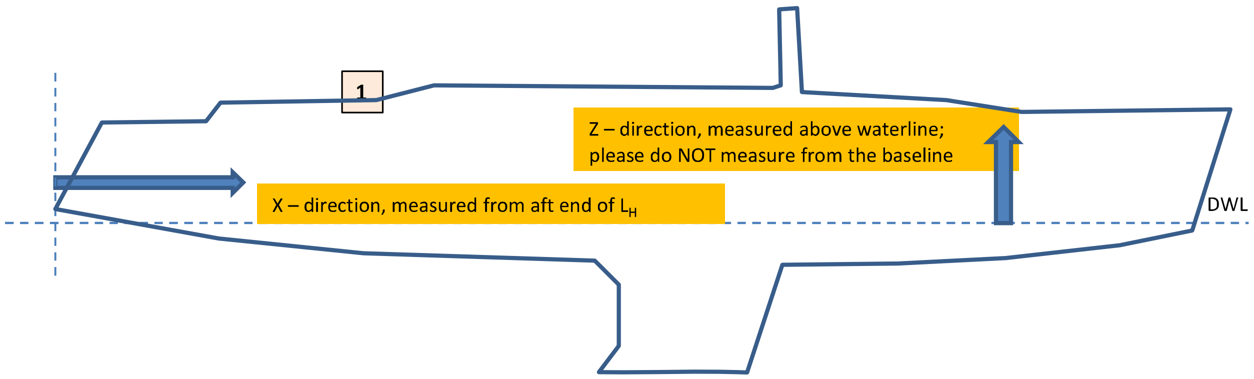
General overview downflooding openings and closing appliances

NOTE: All drawings are not blocked by a password, so please replace with own drawings if at hand.
NOTE: See X,Y, Z coordinates for worksheet 3b as illustrated below

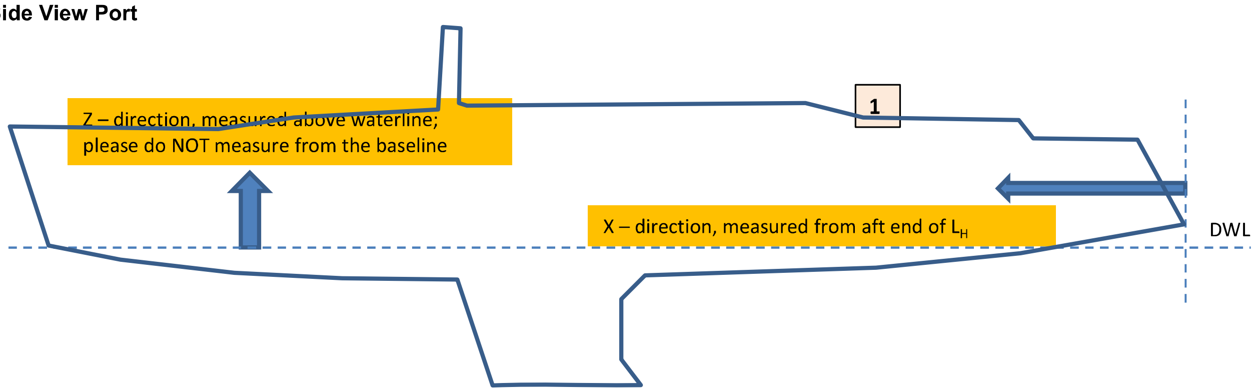
Top View



Side View Starboard



Side View Port



Please insert a short describtion and measurements of downflooding openings and closing appliances under the corresponding number on worksheet 3b

ISO 12217-2:2017 CALCULATION WORKSHEET No.3b DOWNFLOODING OPENINGS

ZAVRŠNI RAD SAILING BOAT L5-CLASS

General overview downflooding openings and closing appliances

NOTE: Please submit for every pre-fabricated closing appliance a declaration of conformity (DoC) of the product.
Please submit for every non pre-fabricated closing appliance a calculation acc. to ISO 12216 (see IMCI template).
For both a watertightness test must be done!

Description of the downflooding opening / closing appliance	Nr.	$X^{(a)}$ [m]	Y [m]	Z (=h_D) [m]	watertighness test done?	opening type[(b)]
sheerline	1	2,50	0,73	0,74	n.a.	downflooding opening
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					
	10					
	11					
	12					
	13					
	14					
	15					
	16					
	17					
	18					
	19					
	20					
	21					
	22					

(a) Please be aware that X is measured from the aft end of $L_{H.}$
In Annex A calculations x_D is measured from the bow or stern, whichever is nearest
(b) opening typs are: normal downflooding openings without any opening appliances; pre-fabricated opening appliances; non-pre-fabricated opening appliances and other devices

ISO 12217-2:2017 CALCULATION WORKSHEET No.4 DOWNFLOODING HEIGHT

ZAVRŠNI RAD SAILING BOAT L5-CLASS

Calculation using normativ annex A (options 1-3 and 5 only)

Item	Symbol	Unit	Opening 1	Opening 2	Opening 3	Opening 4
Position of openings						
Least longitudinal distance from bow/stern	x_D	m				
Least travers distance from gunwale	y_D	m				
F_1 = greater of $(1 - x_D / L_H)$ or $(1 - y_D / B_H)$	F_1	----	1,00	1,00	1,00	1,00
Size of openings:						
Combined area of openings to top of any down-flooding opening	a	mm^2				
Longitudinal distance of opening from tip of bow	x'_D	m				
Limiting value of a = $(30L_H)^2$		mm^2	34262	34262	34262	34262
If $a \geq (30L_H)^2$, F_2 = 1,0 If $a < (30L_H)^2$, $F_2 = 1 + \frac{x'_D}{L_H}\left(\frac{\sqrt{a}}{75\ L_H} - 0{,}4\right)$	F_2	----	1,00	1,00	1,00	1,00
Size of recesses:						
Volume of recesses which are not self-draining in accordance with ISO 11812	V_R	m^3				
Freeboard amidships (see 3.4.6)	F_M	m				
Is opening not a recess? Is recess quickdraining? Is recess not quickdraining?						
$k = V_R/(L_H B_H F_M)$	k	----				
If opening is not a recess, $F_3 = 1$ If recess is quickdraining, $F_3 = 0.7$ If recess is not quick draining, $F_3 = (0.7 + k^{0.5})$	F_3	----	1,20	1,20	1,20	1,20
Displacement:						
Loaded displacement volume (see 3.5.7)	V_D	m^3	1,48			
$B = B_H$ for monohulls	B	m	2,04			
$F_4 = [(10\ V_D)/(L_H\ B^2)]^{1/3}$	F_4	----	0,83			
Flotation:						
For boats using option 4 or 6, $F_5 = 0.8$ For all other boats, $F_5 = 1.0$	F_5	----	1			
Required calculation height: = $F_1 F_2 F_3 F_4 F_5 L_H/15$	$h_{D(R)}$	m	0,41	0,41	0,41	0,41
Required downfooding height with limits applied (see annex A, Table A.1) – Category A	$h_{D(R)}$	m				
Category B	$h_{D(R)}$	m				
Category C	$h_{D(R)}$	m	0,3	0,3	0,3	0,3
Category D	$h_{D(R)}$	m				
Measured Downflooding Height:	h_D	m				
Design Category possible:						
Lowest of above =						**Fail**

ISO 12217-2:2017 CALCULATION WORKSHEET No. 5 RECESS SIZE

ZAVRŠNI RAD SAILING BOAT L5-CLASS

NB: This sheet is to be completed for the Loaded Arrival Condition. calculation not applicable

Further exemptions according to 6.5.1

Angle of vanishing stability > 90° ?	YES/NO	Yes	6.3.1a)
Over at least 35% of the periphery is the depth of the recess less than 3% of the max. breadth of the recess (e.g. toe rails, low bulwarks)	YES/NO		6.3.1b)
At least 5% of the bulwark area positioned within the lowest 25% of the bulwark height drains overboard and the bulwark height is less than 12,5% of the maximum breadth of the recess *(attention, req. 1) and 2) below must get also a "Yes" to fullfill all requirements)*	YES/NO		6.3.1c)
Unobstructed drainage area from the recess on each side of the boat centreline	m²		6.3.1d)
Volume of the recess to the recess retention level	m³		
Drainage area per side (m²) divided by recess volume (m³)			6.3.1d)
Height position of drainage area (lowest 25% / lowest 50% / full depth)			6.3.1d)
Requirements of 6.3.1.d) fullfilled? *(attention, req. 1) and 2) below must get also a "Yes")*	YES/NO		6.3.1d)
1) the lower edge of the drainage openings are not more than 10 mm above recess sole height for at least 70 % of the width of each opening?	YES/NO		6.3.1 c) & d)
2) If drainage area is provided by an open or partially open transom, are the openings extend to the outboard sides of the recess sole on both sides?	YES/NO		6.3.1 c) & d)

Is recess exempt from size limit? If "yes", no further calculation required.			6.3.1

Calculation methods:

Item	Symbol	Unit	Value	Ref.
SIMPLIFIED METHOD: Use 1), 2) or 3) below.				
Average freeboard to loaded waterline at aft end of recess	F_A	m		6.3.2.1
Average freeboard to loaded waterline at sides of recess	F_S	m		6.3.2.1
Average freeboard to loaded waterline at forward end of recess	F_F	m		6.3.2.1
Waterline length at mLA	L_{WL}	m		
Waterline breadth at mLA	B_{WL}	m		
Maximum length of recess at the retention level (see 3.5.11)	l	m		6.3.2.4
Maximum breadth of recess at the retention level (see 3.5.11)	b	m		6.3.2.4

- In case of assymetric recesses please insert length and breadth of each area below; this allows a more exact calculation using simplified method 1) or 2)

	max. length	*max. breadth*	*Unit*	*% loss GMT (option 1)*	*% loss GMT (option 2)*	Ref.
Maximum length and breadth of recess part A			m			6.3.2.2/3
Maximum length and breadth of recess part B			m			6.3.2.2/3
Maximum length and breadth of recess part C			m			6.3.2.2/3
Maximum length and breadth of recess part D			m			6.3.2.2/3
Maximum length and breadth of recess part E			m			6.3.2.2/3
Maximum length and breadth of recess part F			m			6.3.2.2/3
Maximum length and breadth of recess part G			m			6.3.2.2/3
Maximum length and breadth of recess part H			m			6.3.2.2/3
Maximum length and breadth of recess part I			m			6.3.2.2/3

to be continued on page 2

ISO 12217-2:2017 CALCULATION WORKSHEET No. 5 RECESS SIZE

	Symbol	Unit	Value	Ref.
Average freeboard to recess periphery $= (F_A + 2F_S + F_F) / 4$	F_R	m	0	6.3.2.1
Category A permitted percentage loss in metacentric height $(GM_T) = 250\ F_R / L_H$			n.a.	6.3.2.1
Category B permitted percentage loss in metacentric height $(GM_T) = 550\ F_R / L_H$			n.a.	6.3.2.1
Category C permitted percentage loss in metacentric height $(GM_T) = 1\ 200\ F_R / L_H$			0	6.3.2.1

SIMPLIFIED METHOD: Use 1), 2) or 3) below.				
1) Loss of GM_T used?				6.3.2.2
Second moment of area of free-surface of recess	SMA_{RECESS}	m^4	0	6.3.2.2
Metacentric height of boat at m_{LA}	GM_T	m		6.3.2.2
Calculated percentage loss in metacentric height $(GM_T) =$	$\frac{102\ 500 \times SMA_{RECESS}}{m_{LA} \times GM_T}$			6.3.2.2
2) Second moment of areas used?				6.3.2.3
Second moment of area of free-surface of recess	SMA_{RECESS}	m^4	0	6.3.2.3
Second moment of area of waterplane of boat at m_{LA}	SMA_{WP}	m^4	0	6.3.2.3
Calculated percentage loss in metacentric height $(GM_T) =$	$\left(\frac{245 \times SMA_{RECESS}}{SMA_{WP}}\right)$			6.3.2.3
3) Recess dimensions used?				6.3.2.4
Maximum length of recess at the retention level (see 3.6.11)	l	m	0	6.3.2.4
Maximum breadth of recess at the retention level (see 3.6.11)	b	m	0	6.3.2.4
Calculated percentage loss in metacentric height $(GM_T) =$	$270\left(\frac{l \times b^3}{L_H \times B_H{}^3}\right)^{0,7}$			6.3.2.4

Requirement: from results above, applied design category possible?	**n.a.**	6.3.2.1

DIRECT CALCULATION METHOD used?			6.3.3
percentage full of water = 60 – 240 F/L_H			6.3.3a)
actual residual righting moment up to ϕD, ϕV or 90° whichever is least	N·m		6.3.3b)
required residual righting moment up to ϕD, ϕV or 90° whichever is least	N·m	3144,9075	6.3.3b)
design category possible		Fail	

ISO 12217-2:2017 CALCULATION WORKSHEET No. 6

MINIMUM RIGHTING ENERGY & ANGLE OF VANISHING STABILITY

ZAVRŠNI RAD SAILING BOAT L5-CLASS

Minimum righting energy: **Design categories A and B only**

Item	Symbol	Unit	m_{MO}	Ref.
Mass in minimum operating condition	m_{MO}	kg	1090	3.5.3
Area under GZ curve up to Φ_V m_{MO}	A_{GZ}	m deg	20,41	6.4
Righting energy up to Φ_V = m_{MO} A_{GZ}	E_{GZ}	kg m deg	22249	6.4
Requirement: For Category A: $E_{GZ} \geq 172\,000$; for Category B: $E_{GZ} \geq 57\,000$.				Table 4
Category possible on minimum energy:				

Angle of vanishing stability:

Item	Symbol	Unit	m_{MO}	m_{LA}	Ref.
Required value of angle of vanishing stability: Category A = (130 – m/500) but ≥ 100° Category B = (130 – m/200) but ≥ 95° Category C = 90° Category D = 75°	$\Phi_{V(R)}$	degree	90,00	90,00	6.5 Table 5
Actual angle of vanishing stability:	Φ_V	degree	98,48	100,00	3.4.10
Category possible on angle of vanishing stability:			**C**	**C**	6.5.1

Alternative for Design Category B only: method used? **No**

Item	Symbol	Unit	m_{MO}	m_{LA}	Ref.
Mass of boat in each condition	m_{MO} or m_{LA}	kg	1090	1497,575	3.5.3 or 3.5.6
Required value of ϕ_V = (130 - 0,005m) but always ≥ 75°	$\Phi_{V(R)}$	degree	124,55	122,51213	6.5.2a)
Actual angle of vanishing stability:	Φ_V	degree	98,48	100,00	3.4.10
Is required value of ϕ_V attained?		Yes / No	**No**	**No**	6.5.2a)
Volume of buoyancy calculated according to annex D	V_B	m^3	0		annex D
Mass of boat in maximum load condition	m_{LDC}	kg	1517,575		3.5.5
Is V_B > (m_{LDC}/850) ?		Yes / No	**No**		6.5.2b)
Are accesses to non-habitable compartments fitted with hatches or doors watertight to degree 2 and marked "Keep shut when under way" ?		Yes / No			6.5.2c)
Do flotation elements (where fitted) comply with annex E ?		Yes / No			6.5.2d)
Is stability information required by 6.5.2e) supplied ?		Yes / No			6.5.2e)
Are safety signs according to Figure 3 displayed ?		Yes / No			6.5.2f)
Can boat be assigned Design Category B?			**NO**		6.5.2

ISO 12217-2:2017 CALCULATION WORKSHEET No. 6a curve of righting moment m

ZAVRŠNI RAD SAILING BOAT L5-CLASS

insert curve of righting moment in 5° steps in one of following units:

N m *kg m* *m*

chosen unit **m**

heeling angle[°]	insert Heeling Arm/Moment [Nm, kg m, m]	Heeling Moment [Nm]	Heeling Moment [kg m]	Arm Gz [m]
0	0	0	0	0,000
5	0,06	641	65	0,060
10	0,114	1.218	124	0,114
15	0,16	1.710	174	0,160
20	0,2	2.138	218	0,200
25	0,235	2.512	256	0,235
30	0,268	2.865	292	0,268
35	0,297	3.174	324	0,297
40	0,318	3.399	347	0,318
45	0,33	3.527	360	0,330
50	0,333	3.559	363	0,333
55	0,33	3.527	360	0,330
60	0,318	3.399	347	0,318
65	0,278	2.971	303	0,278
70	0,244	2.608	266	0,244
75	0,206	2.202	225	0,206
80	0,165	1.764	180	0,165
85	0,122	1.304	133	0,122
90	0,077	823	84	0,077
95	0,032	342	35	0,032
100	-0,014	-150	-15	-0,014
105		0	0	0,000
110		0	0	0,000
115		0	0	0,000
120		0	0	0,000
125		0	0	0,000
130		0	0	0,000
135		0	0	0,000
140		0	0	0,000
145		0	0	0,000
150		0	0	0,000
155		0	0	0,000
160		0	0	0,000

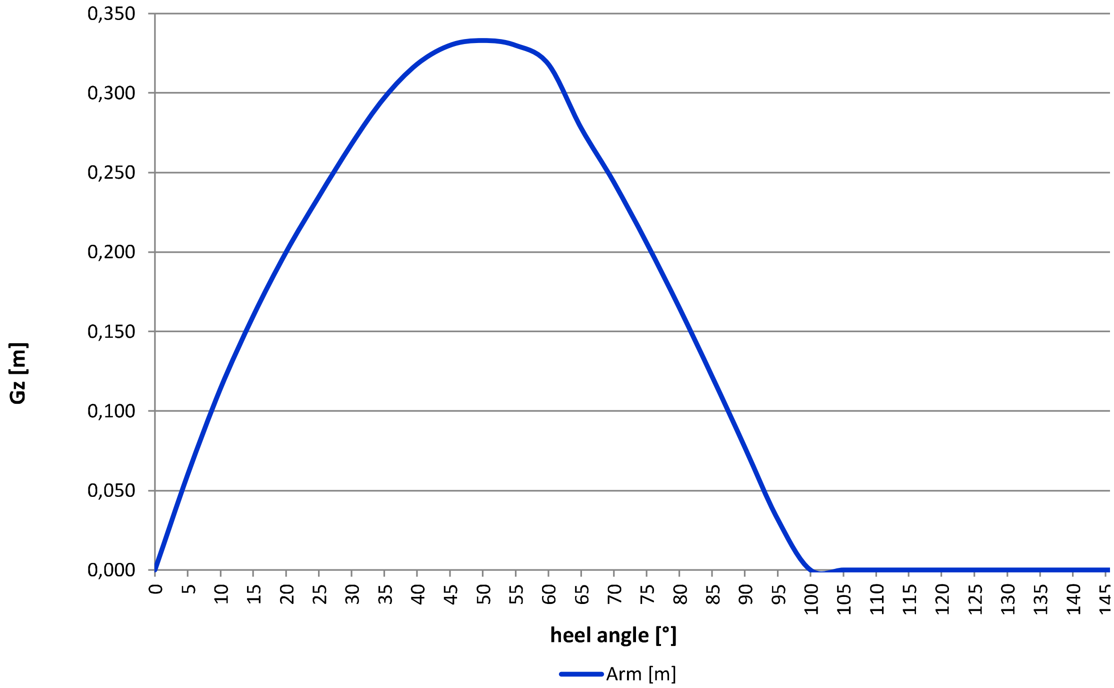
Angle of vanishing stability		Area under GZ curve	
98,48	degrees	20,4118	m deg

ISO 12217-2:2017 CALCULATION WORKSHEET No. 6a curve of righting moment m

INTERNATIONAL MARINE CERTIFICATION INSTITUTE

INTERNATIONAL NON-PROFIT ASSOCIATION

Heeling arm curve m_{MO} ZAVRŠNI RAD SAILING BOAT L5-CLASS



ISO 12217-2:2017 CALCULATION WORKSHEET No. 6b curve of righting moment m

ZAVRŠNI RAD SAILING BOAT L5-CLASS

insert curve of righting moment in 5° steps in one of following units:

N m ***kg m*** ***m***

chosen unit **m**

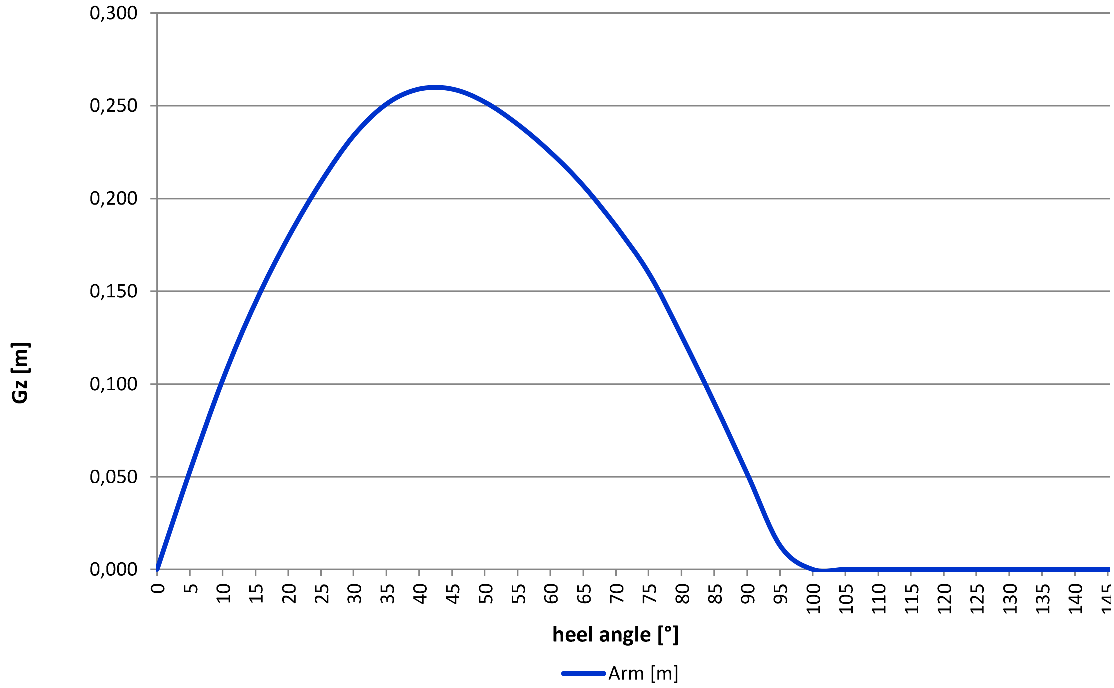
heeling angle[°]	insert Heeling Arm/Moment [Nm, kg m, m]	Heeling Moment [Nm]	Heeling Moment [kg m]	Arm Gz [m]
0	0	0	0	0,000
5	0,053	778	79	0,053
10	0,102	1.498	153	0,102
15	0,144	2.115	216	0,144
20	0,179	2.629	268	0,179
25	0,209	3.069	313	0,209
30	0,234	3.436	350	0,234
35	0,251	3.686	376	0,251
40	0,259	3.803	388	0,259
45	0,259	3.803	388	0,259
50	0,252	3.701	377	0,252
55	0,24	3.524	359	0,240
60	0,225	3.304	337	0,225
65	0,207	3.040	310	0,207
70	0,185	2.717	277	0,185
75	0,16	2.350	240	0,160
80	0,126	1.850	189	0,126
85	0,09	1.322	135	0,090
90	0,052	764	78	0,052
95	0,013	191	19	0,013
100		0	0	0,000
105		0	0	0,000
110		0	0	0,000
115		0	0	0,000
120		0	0	0,000
125		0	0	0,000
130		0	0	0,000
135		0	0	0,000
140		0	0	0,000
145		0	0	0,000
150		0	0	0,000
155		0	0	0,000
160		0	0	0,000

Angle of vanishing stability		Area under GZ curve	
100,00	degrees	16,2	m deg

ISO 12217-2:2017   CALCULATION WORKSHEET No. 6b   curve of righting moment m

INTERNATIONAL MARINE CERTIFICATION INSTITUTE
INTERNATIONAL NON-PROFIT ASSOCIATION

Heeling arm curve m_{LA} ZAVRŠNI RAD   SAILING BOAT L5-CLASS



ISO 12217-2:2017 CALCULATION WORKSHEET No. 7a STABILITY INDEX

ZAVRŠNI RAD SAILING BOAT L5-CLASS

Stability Index (STIX): **complete both columns**

Factor	Item	Symbol	Unit	m_{MO}	m_{LA}	Ref.
FDS (6.6.2)	Positive area under GZ curve to Φ_V	A_{GZ}	m deg.	20,4118	16,2	6.6.2
	Length of hull	L_H	m	6,17		3.4.1
	Factor as calculated = A_{GZ} /(15,81 $(L_H)^{0,5}$)	FDS	—	0,520	0,413	6.6.2
	FDS when limited to the range 0,5 to 1,5	FDS	—	**0,520**	**0,500**	6.6.2
FIR (6.6.3)	Angle of vanishing stability	Φ_V		98,48	100,00	3.4.10
	If m<40.000, FIR = Φ_V / (125 - m / 1600) If m>40.000. FIR = Φ_V / 100	FIR		0,792	0,806	6.6.3
	FIR when limited to the range 0,4 to 1,5	FIR		**0,792**	**0,806**	6.6.3
FKR (6.6.4)	Righting lever at 90° heel	GZ_{90}	m	0,077	0,052	6.6.4
	Reference sail area (see ISO 8666)	A_S	m^2	21,85		3.4.8
	Height of centre of area of A_S above waterline	h_{CE}	m	3,636	3,6	6.6.4
	Calculate F_R = $(GZ_{90}\ m)/(2\ A_S\ h_{CE})$	F_R	—	0,528	0,495	6.6.4
	If $F_R \geq 1,5$, FKR = (0,875 + 0,0833 F_R) If F_R < 1,5, FKR = (0,5 + 0,333 F_R) If Φ_V < 90°, FKR = 0,5	FKR	—	0,674	0,663	6.6.4
	FKR when limited to the range 0,5 to 1,5	FKR	—	**0,674**	**0,663**	6.6.4
FDL (6.6.5)	Length waterline	L_{WL}	m	5,33	5,47	3.4.2
	Length base size L_{BS} = (2 L_{WL} + L_H) / 3	L_{BS}	m	5,61	5,70	6.6.5
	Calculate $F_L = (L_{BS}/11)^{0,2}$	F_L	—	0,874	0,877	6.6.5
	Calculate FDL = $\left\{0,6+\left[\frac{15mF_L}{L_{BS}^3(333-8L_{BS})}\right]\right\}^{0,5}$	FDL	—	0,939	0,985	6.6.5
	FDL when limited to the range 0,75 to 1,25	FDL	—	**0,939**	**0,985**	6.6.5
FBD (6.6.6)	Beam of Hull	B_H	m	2,04		3.4.3
	Beam Waterline	B_{WL}	m	1,75	1,84	3.4.4
	Calculate $F_B = 3,3\ B_H / (0,03\ m)^{1/3}$	F_B	—	2,105	1,894	6.6.6
	If F_B > 2,20 FBD = $[13,31\ B_{WL} / (B_H\ F_B^3)]^{0,5}$ If F_B < 1,45 FBD = $[B_{WL} F_B^2 / (1,682\ B_H)]^{0,5}$ Otherwise FBD = $1,118\ (B_{WL}/B_H)^{0,5}$	FDB	—	1,036	1,061	6.6.6
	FBD when limited to the range 0,75 to 1,25	FDB	—	**1,036**	**1,061**	6.6.6
FWM (6.6.7)	Downflooding angle = lesser of Φ_{DC} and Φ_{DH}	Φ_{DW}	degree	69,4	67,8	3.3.2
	If $\Phi_{DW} \geq 90°$ (see worksheet 3) then FWM = 1,0 , If Φ_{DW} is less than 90° then:					
	Righting lever at downflooding angle	GZ_{DW}	m	0,2508	0,1982	6.6.7
	Lever from centre of sail area to underwater profile	$h_{CE} + h_{LP}$	m	4	4	6.6.7
	Calc. wind speed at which serious flooding occurs = $\{13\ m\ GZ_{DW} / [A_S\ (h_{CE}+h_{LP})\ \lvert\cos\Phi_{DW}\rvert^{1,3}\ ]\ \}^{0,5}$	v_{AW}	m / s	12,6	12,5	6.6.7
	If Φ_{DW} < 90°, FWM = v_{AW}/17; if $\Phi_{DW} \geq 90°$, FWM = 1,0	FWM	—	0,740	0,736	6.6.7
	FWM when limited to the range 0,5 to 1,0	FWM	—	**0,740**	**0,736**	6.6.7

to be continued on worksheeet 7b

ISO 12217-2:2017 CALCULATION WORKSHEET No. 7b (continued) STABILITY INDEX

ZAVRŠNI RAD SAILING BOAT L5-CLASS

Stability Index (STIX): **complete both columns**

Factor	Item	Symbol	Unit	m_{MO}	m_{LA}	Ref.
FDF (6.6.8)	Downflooding angle to non-quickdraining cockpit	Φ_{DC}	degree	69,4	67,8	3.3.2
	Downflooding angle to main access hatch	Φ_{DH}	degree	69,4	67,8	3.3.2
	Total area of openings for findig Φ_{DA} = (1,2 L_H B_H F_M)		cm^2	0,000		3.3.2
	Downflooding angle at which above area is immersed	Φ_{DA}	degree			3.3.3
	Angle of vanishing stability	Φ_V	degree	98,5	100,0	3.4.10
	Least of the above four angles	Φ_{DF}	degree	69,4	67,8	6.6.8
	Then $FDF_1 = \Phi_{DF} / 90$			0,77	0,75	6.6.8
	FDF_1 when limited to the range 0,5 to 1,25	FDF_1		0,77	0,75	6.6.8
	Does boat float acc. to 6.5.2.b) and also when flooded have GZ90 > 0 ?		Yes / No	No	No	6.6.8
	If Yes, calculate final FDF = 1,2 FDF_1, otherwise FDF = FDF_1	FDF		**0,77**	**0,75**	6.6.8

Calculation oft STIX and ssignment oft Design Category:

Item	Symbol	Unit	m_{MO}	m_{LA}	Ref.
Length base size $L_{BS} = (2 L_{WL} + L_H) / 3$	L_{BS}	m	5,610	5,701	6.6.9
Product of all 7 factors = FDS x FIR x FKR x FDL x FBD x FWM x FDF	F	—	0,154	0,155	
STIX = (7 + 2,25 L_{BS}) x $F^{0,5}$	$STIX$	—	7,70	7,80	
Design category possible on STIX: **A when STIX >32, B when STIX > 23, C when STIX > 14 and D when STIX >5**			**D**	**D**	Table 5

ISO 12217-2:2017 CALCULATION WORKSHEET No. 8 KNOCKDOWN-RECOVERY TEST

ZAVRŠNI RAD SAILING BOAT L5-CLASS

Design Categories C and D only

method used:

Item	Symbol	Cat C	Cat D	Ref.
Experimental method: Crew Limit	CL			3.6.3
Is boat prepared and persons positioned as in 6.7.2 ?	Yes / No			6.7.2
Is water or other weight used instead of persons, if so which?				6.7.2
Masthead taken to		waterline	horizontal	6.7.3; 6.7.4
Masthead held in position for		60s	10s	6.7.3; 6.7.5
Boat recovers when released ?	Yes / No			6.7.3; 6.7.6
Boat floats so it can be pumped or bailed out ?	Yes / No			6.7.3; 6.7.7
If boat achieves YES to each of above, Design Category is OK				
Alternative theoretical method:				
Is GZ positive at heel angle as defined in 6.7.5 ?	Yes / No			6.7.5
Design category given:		**Fail**	**Fail**	

ISO 12217-2:2017 CALCULATION WORKSHEET No. 9 WINDS TIFFNESS TEST

ZAVRŠNI RAD SAILING BOAT L5-CLASS

Design Categories C and D using option 5 or 6 only

Method used: **Theoretical**

Experimental method:

Item	Symbol	Unit	Un-reefed	Reefed	Ref.
Boat prepared and weight positioned as in 6.8.2		Yes / No			6.8.2.1
Final tension in pull-down line	T	kg			6.8.2.3
Perpendicular lever between pull-down and mooring lines (see fig. 5)	h	m			6.8.2.3
Final angle of heel observed	Φ_T	degree			6.8.2.3
Beam of hull	B_H	m	2,04		3.4.3
Actual profile projected area of sails, including overlaps	A'_S	m²			3.4.9
Lever from centre of sail area to underwater profile (see fig. 6)	$h_{CE} + h_{LP}$	m			6.8.2.4
Calculated wind speed = $\sqrt{\dfrac{13hT + 390B_H}{A'_S(h'_{CE} + h_{LP})(\cos\phi_T)^{1,3}}}$	v_W	m/s	#DIV/0!	#DIV/0!	6.8.2.4
Is reefed sail plan used?		Yes / No			6.8.4.2
Design Category given according to Table 7					Table 5

NB: Safety signs in accordance with Figure 7 must be affixed to the boat.

Alternative theoretical method:

Item	Symbol	Unit	Un-reefed	Reefed	Ref.
Righting moment curve increased by one crew to windward		Yes / No	Yes		6.8.3.2
Option (from worksheet 2) being used			5		Table 2
Design Category intended			C	C	
Relevant calculation wind speed taken from Table 7	v_W	m/s	13,00	13,00	Table 6
Actual profile projected area of sails, including overlaps	A'_S	m²	21,90		3.4.9
Upright lever from centre of sail area to underwater profile (see fig. 6)	$h_{CE} + h_{LP}$	m	4,00		6.8.2.4
Calculated 0,75 v_W^2 A'$_S$ (h'_{CE} h_{LP})	M_{W0}	Nm	11103	0	6.8.2.4
From righting moment curve and wind heeling curve [= M $_{W0}$ (cosΦ)^{1,3}] resulting angle of heel =	Φ	degree	#N/A		6.8.3.4
Is Φ < Φ_D (see Worksheet 3) and < 45°?		Yes / No	#N/A		
Is reefed sail plan used?		Yes / No	No		6.8.4.2
Design Category given according to Table 7			**#N/A**		Table 5

ISO 12217-2:2017 CALCULATION WORKSHEET No. 9a

curve of righting moment vs. wind heeling curve

ZAVRŠNI RAD SAILING BOAT L5-CLASS

insert curve of righting moment in 5° steps in one of following units:

N m ***kg m*** ***m***

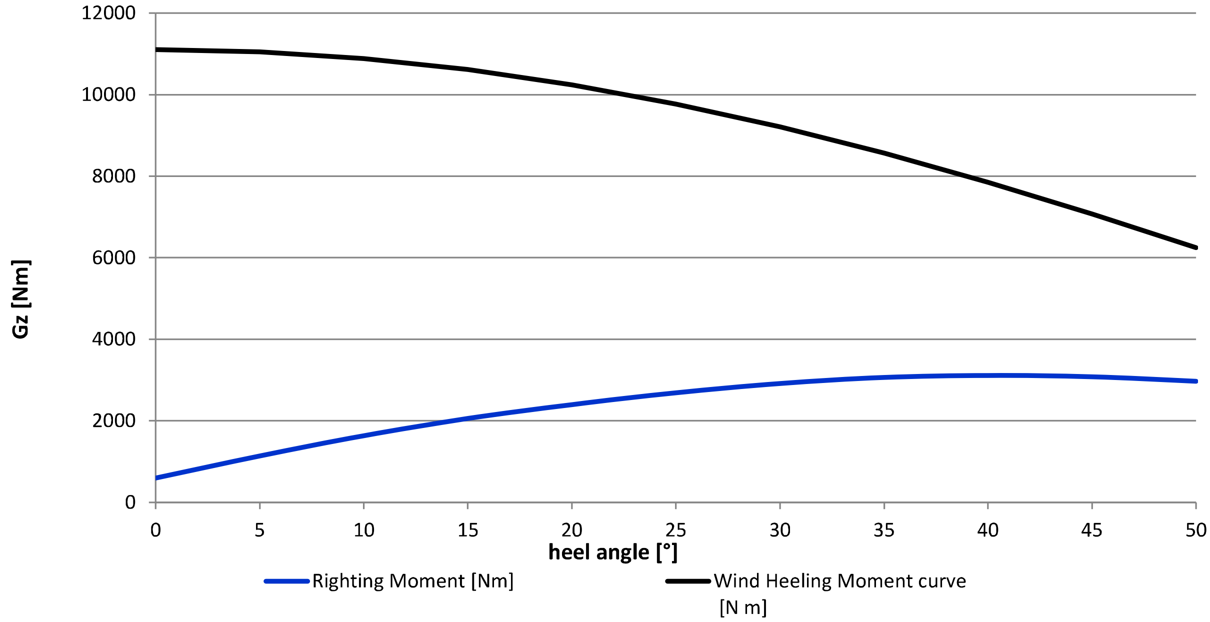
m	chosen unit
unreefed	chose if reefed or unreefed sail combination used

heeling angle[°]	insert righting Arm / Moment [Nm, kg m, m]	Righting Moment [Nm]	Righting Moment [kg m]	Righting Arm Gz [m]	Wind Heeling moment curve [N m]	Righting moment curve increased by one crew windward
0	0	0	0	0,00	11103	600
5	0,053	543	55	0,05	11048	1141
10	0,102	1.045	107	0,10	10885	1636
15	0,144	1.476	150	0,14	10614	2055
20	0,179	1.834	187	0,18	10241	2398
25	0,209	2.142	218	0,21	9770	2685
30	0,234	2.398	245	0,23	9210	2917
35	0,251	2.572	262	0,25	8567	3063
40	0,259	2.654	271	0,26	7852	3113
45	0,259	2.654	271	0,26	7076	3078
50	0,252	2.582	263	0,25	6251	2968

point of intersection of righting moment curve and wind heeling moment curve

Φ_C	
#N/A	degree

Curve of righting moment increased by one person windward vs wind heeling moment



završen kalkulator

ISO 12217-2:2017 CALCULATION WORKSHEET No. 10 FLOTATION REQUIREMENT

ZAVRŠNI RAD SAILING BOAT L5-CLASS

Annex D
Objective: to show that the buoyancy available from the hull structure, fittings and flotation elements equals or exceeds that required to support the loaded boat.

Item	Mass [kg]	Density [kg/m³]	Volume [m³]	Ref.
Hull structure				
GRP Laminate		1500		Table D.1
Foam core materials		80		Table D.1
Balsa core materials		150		Table D.1
Plywood		600		Table D.1
Other timber		600		Table D.1
Permanent balast		7800		Table D.1
Fastenings and other metalwork		5000		Table D.1
Windows		2300		Table D.1
Engines and other fittings an equipment				
Diesel engines		5000		Table D.1
Petrol engines		4000		Table D.1
Outboard engines		3000		Table D.1
Sail-drive or stern-drive		4000		Table D.1
Mast(s) and Spar(s)		2700		Table D.1
Stowed sails and ropes		1200		Table D.1
Food and other stores		2000		Table D.1
Miscellaneous equipment		2000		Table D.1
Non-integral fuel tanks				Table D.1
Non-integral water tanks				Table D.1
Gross volumes of fixed tanks and air containers				D.2.2
Fuel tanks				D.2.2
Water tanks				D.2.2
Other tanks				D.2.2
Air tanks or container meeting the requirement of annex E				D.2.2

Total volume of hull, fittings and equipment, V_B Sum			0	
Mass in the maximum load condition	m_{LDC}	kg	1517,575	3.5.5
		calculate ratio m_{LDC} / V_B	#DIV/0!	
	For options 4 and 6	m_{LDC} / V_B < 850 ?	**#DIV/0!**	

ISO 12217-2:2017 CALCULATION WORKSHEET No.11 CAPSIZE-RECOVERY TEST

ZAVRŠNI RAD SAILING BOAT L5-CLASS

Design Categories C and D only

Objective: to demonstrate that a boat can be returned to the upright after a capsize by the actions of the crew using their body action and/or righting devices purposely designed and permanently fitted to the boat, that it will subsequently float, and to verify that the recommended minimum crew mass is sufficient for the recovery method used.

Item	Unit	Value	Ref.
Minimum number of crewrequired	---		6.10.7
Minimum mass of crew required	kg		6.10.7
Is boat prepared as in 6.10.2 to 6.10.5 ?	Yes / No		6.10.2-5
Does boat float for > 5 min when fully capsized ?	Yes / No		6.10.6
Time required to right the boat (least time of 1 to 3 attempts)	minutes		6.10.8
Is this time less than 5 min?	Yes / No		6.10.8
With one 75 kg person aboard, boat floats so it can be pumped or bailed out ?	Yes / No		6.10.10
With full Crew Limit aboard, without bailing, boat floats approx. level with at least 2/3 periphery showing, for more than 5 min ?	Yes / No		6.10.11
INFORMATION FOR OWNER'S MANUAL: **Likelihood of capsize occuring in normal use:**			
Righting technique which is most successful:			
Minimum number of crew required?	Minimum mass of crew required (kg):		
Design category recommended by the builder:	C		

ISO 12217-2:2017 CALCULATION WORKSHEET No. 15 **DETECTION + REMOVAL OF WATER**

ZAVRŠNI RAD **SAILING BOAT L5-CLASS**

Item	response	Ref.
The internal arrangement facilitates the drainage of water to bilge suction point(s), to a location from which it can be bailed rapidly, or directly overboard?	Yes	6.11.1
Is boat provided with a means of removing water from the bilges in accordance with 15083?	Yes	6.11.2
Table 2 option used for assessment:	5	6.11.3
Can water in boat be detected from helm position?	Yes	6.11.3
For boats in design cat C using option 3,5 or 7: option (see worksheet 2):	5	6.11.3
Methods used: direct visual inspection		6.11.3
transparent inspection panels		6.11.3
bilge alarms		6.11.3
indication of the operation of automatic bilge pumps		6.11.3
other means (specify):		6.11.3

ISO 12217-2:2017 en240408 CALCULATION WORKSHEET No.16 **SUMMARY**

Design Description:	ZAVRŠNI RAD SAILING BOAT L5-CLASS				
Design Category intended:	C	Crew Limit:	5	Date:	2024-09-08

Sheet	Item	Symbol	Unit	Value
1	Length of hull: (as in ISO 8666)	L_H	m	**6,17**
	Length of waterline	L_{WL}	m	**5,47**
	Beam of hull: (as in ISO 8666)	B_H	m	**2,04**
	Mass:			
	Empty craft mass	m_{EC}	kg	**910**
	Maximum load	m_L	kg	**548**
	Maximum load for the builder's plate acc to ISO 14945:2021	m_{MBP}	kg	**510**
	Light craft condition mass	m_{LC}	kg	**970**
	Maximum Loaded condition mass = m_{LC} + m_{ML}	m_{LDC}	kg	**1518**
	Loaded arival condition mass	m_{LA}	kg	**1498**
	Minimum operating condition mass	m_{MO}	kg	**1090**
1	**Is boat sail or non-sail?**		SAIL/NON-SAIL	**SAIL**
2	**Option selected:**			**5**

Sheet	Item		Unit	Required	Actual		Pass/Fail
3	**Downflooding openings:**	Are all requirements met?					**Pass**
		Watertighness test for closing appliances done successful?					**Pass**
		Exemptions ok or openings considered as possible downflooding openings?					**PASS**
	Downflooding angle:			**Required**	**m_{MO}**	**m_{LA}**	**Pass/Fail**
		to any opening Φ_{DA}	degrees	> 35	**69,4**	**67,8**	**n.a.**
		to non-quickdraining opening Φ_{DC}	degrees		**69,4**	**67,8**	
		to main access hatchway Φ_{DH}	degrees		**69,4**	**67,8**	
3 & 4	**Downflooding height:**	Worksheet employed for basic height					
	basic requirement		m	0,36		**0,74**	**Pass**
	reduced height for small openings (only using figures)		m	0,27		**0,74**	**Pass**
5	**Recess size:** (option 1 using 6.5.2, and option 5,6 except cat D)						
	Simplified method: max reduction in GM_T		%	≤ 0	not used		**n.a.**
	Direct calculation: margin righting moment over heeling moment		N m		0		
6	**Minimum righting energy:** (option 1 only)		kg m degree	n.a.	**22.249**		**n.a.**
6	**Angle of vanishing stability:** (option 1 & 2 only)		degrees	90,0	**98,48**	**100,00**	**n.a.**
	Alternative to AVS (option 1 cat B only)		requirements of 6.5.2 fullfilled?				
7	**Stability index:** (otion 1 & 2 only)		STIX	> 14	**8**	**7,80**	**n.a.**
8	**Knockdown-recovery test:** (options 3 + 4 only)			method used?	0,00		
				are allrequirements met ?			**n.a.**

to be continued on page 2

9	**Wind stiffness test:** (options 5 & 6 only)			#N/A
	was reefed sail area used (i.e. are warning labels required?)		Yes	
10	**Flotation requirement:** options 4,6 and 8 only	ratio m_{LDC}/V_B < 850		
11	**Capsisze recovery test:** (option 7only)	are all requirements met?	Yes / No	**n.a.**
	Design category recommended by the builder		C	
15	**Detection & removal of water:** Are all requirements satisfied?		Yes / No	**Yes**
NB: Boat must pass all requirements applicable to selected option to be given intended Design Category.				
Design Category given:	**C**	Assessed by:	Marija Bašić	

Doc. of downflooding opening / closing appliance attached? ☐

If applicable, cockpit calculation according to ISO 11812 attached ? ☐

If applicable, curve of righting moments in m_{MO} and m_{LA} attached ? ☐

Appropriate add. information attached (e.g. photos, drawings,…) ? ☐

Signature: ____________________________