Structural Design of 38m Special Purpose Vessel in Aluminium Alloy

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presented in partial fulfillment
of the requirements for the double degree:
"Advanced Master in Naval Architecture" conferred by University of Liege
"Master of Sciences in Applied Mechanics, specialization in Hydrodynamics, Energetics and Propulsion" conferred by Ecole Centrale de Nantes
developed at University of Genoa in the framework of the

"EMSHIP"
Erasmus Mundus Master Course
in "Integrated Advanced Ship Design"

Ref. 159652-1-2009-1-BE-ERA MUNDUS-EMMC

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Genoa, February 2013

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Where I have consulted the published work of others, this is always clearly attributed.

Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

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ABSTRACT

The design of aluminium hull structure must satisfy strength, weight and productivity requirements. Since these requirements often conflict each other, there are a number of possible designs. This thesis reports the investigation of this process which includes below stages:

- Preliminary design of the vessel is executed such as general arrangement and hull form design, capacity planning, stability analysis, hull resistance prediction, etc. At this stage, the general arrangement is generated by considering the customer requirements. Then the hull form is designed by Maxsurf software by taking into account service performance. Stability calculations are performed by Hydromax software and submitted to representative of the customer and Classification Society to demonstrate that the vessel has stability in accordance with requirements of Classification Society and Flag Authority and at any case in accordance with IMO Resolution A749 (18). Hull resistance prediction is made by Savitsky method, afterwards final data on performance is confirmed by CFD calculations based on relative displacement between the agreed configurations.
- The structural design of the vessel is satisfied with the rules and regulations of RINA (Registro Italiano Navale) for aluminium alloy High-Speed Craft. Longitudinal strength calculations are, as a rule, is carried out at the midship section and the scantlings of hull structures (plating, stiffeners, and primary supporting members) are determined. Buckling strength calculations are made for some critical members such as plating and primary members of bottom and deck structures by taking into account critical buckling stresses defined by rules.
- Direct finite element analysis of main machinery foundations which have significant influence on structure is performed. Due to there is not any remarkable rules for aluminium alloy structured engine foundations, this kind of analysis was unavoidable. This analysis is performed by ANSYS Mechanical software. The results of FEA are examined for deflection and stress distribution and these are compared with permissible values imposed by rules.

1. INTRODUCTION

The initial design stage has significant importance on all over the project, including the structural design, as the decisions are here taken fundamental to reach design objectives by establishing basic ship characteristics.

The general objective of the thesis is to carry out the structural design process of a high speed special purpose vessel which is a supply unit for offshore platforms, suitable for transporting technical personnel, cargo on deck and liquid cargo: fresh water and gasoil with a flash point above 60°C.

The design is developed in Rodriquez Cantieri Navali Spa. which has good experience with aluminium alloy vessels. Although the thesis aims to investigate the structural design of the vessel, it is needed to follow from preliminary design stages by providing its main particulars, hull form, capacity plan, stability analysis as well as the general arrangement.

2. PROJECT DESCRIPTION

The ship will be a Special Purpose Vessel (SPV), which is a supply unit for offshore platforms, suitable for transporting technical personnel, cargo on deck and liquid cargo: fresh water and gasoil with a flash point above 60°C.

The ship will have Italian flag and will be enrolled in RINA (Registro Italiano Navale).

The hull and superstructure will be in aluminium according to the philosophy of the project.

2.1. Principal Characteristics and Specifications

The ship will have the following main characteristics:

Main dimensions

- Length overall	38,4 meters
- Breadth overall	8,6 meters
- Moulded depth	3,95 meters
- Gross Tonnage	295

Propulsion

- Main Engines	3 (three) x Cummins KTA 50 M2; 1343 Kw@1900 rpm
- Propellers	3 (three) x 4 blade (fixed pitch)

Gearbox

The gearboxes will be at single speed, reverse gear and the PTO is: the reduction ratio is determined as 3 (three).

Load capacity

- Passengers	40 technical
- Deck cargo	40 tonnes with a maximum height of the CG of 1,2 meter from the cargo deck
- Cargo area	60 m^2 (max 1,5 tonne/m^2)
- Weight distributed on deck	1,5 tonne/m^2 for loading area and 1,0 tonne/m^2 for remaining areas
- Deadweight	134 tonnes (difference between the displacement at full load and Lightship)

Service Performance

At the displacement calculated with 40% fuel and fresh water aboard ship, without loading, the ship will be able to achieve the following performance:

- Maximum speed (@100% RPM)	26 knots
- Minimum speed (@90% RPM)	23 knots

2.2. Classification and Certification

The vessel, including its machinery, equipment and outfitting, will be constructed in accordance with rules and regulations of the RINA (Registro Italiano Navale) in order to obtain the class notation:

RINA C ✠, Special Service - Light Ship, Special Navigation - International Operations with Service within 100 miles from shore

The structural design of the vessel will be satisfied with the rules and regulations of **RINA for the Classification of High-Speed Craft** and, as applicable, and only concerns of the mentioned above classification, will also satisfy the following rules and regulations:

- International Load Line Convention, 1966 and subsequent amendments
- International Convention for Tonnage Measurements, 1969 and subsequent amendments
- International Convention for Safety of Life at Sea, SOLAS 1974/78 and subsequent amendments
- International Convention for the Prevention of Pollution, MARPOL 1973/78 annex I, IV, VI and subsequent amendments (if required)
- International Labour Organization (ILO) Convention 92 (Supplement 133 an Recommendation 140)
- International Labor Organization (ILO) Convention 152 (for shipboard lifting appliances)
- International Convention for Preventing Collision at Sea (COLREG), 1972 and subsequent amendments
- Recommendation on general requirements for Electronic Navigation Aid, RES A 574 (14)
- International Electro-technical Commission (IEC) Publication 92
- International Telecommunication Convention (GMDSS)

- Code of Safety for Special Purpose Ships carrying more than 12 p. (SPS), implemented by Authority of Italian Flag in IMO Resolutions RES A 534 (13) in 1994 and MSC 266 (84) 2008
- Noise level on board of ships rules (IMO RES A 468)

2.3. Hull Design & General Arrangement

The customer has another vessel which has similar service type with 46 m length and the vessel's performance is satisfied by customer. Therefore, the customer requested to have similar hull lines under chine for new vessel also.

The new hull is developed by Maxsurf software based on the lines plan of reference vessel and general arrangement drawing of new project which was already made by company and proposed to the customer before this work started.

Fig.2.1 Preliminary 3D model of the vessel

The hull below deck was divided by watertight bulkheads by considering rules and regulations according to below assessment of spaces:

- Rudder room (Frames: 0-2)
- Local for auxiliaries (Frames: 2-7)
- Engine room (Frames: 7-14)
- Machinery room (Frames: 14-18)
- Crew quarters (Frames: 18-28)
- Local for bow thrusters (Frames: 28-33)
- Fore peak area (Frames: 33-38)

On the main deck, arrangement included the following:

- Bow mooring area
- Locker room

- Passengers’ saloon
- Cargo area
- Aft mooring area

On the upper deck, arrangement included the following:

- Wheelhouse
- Rescue boat area

Below figures present some sections of the vessel from general arrangement which you can see main divisions:

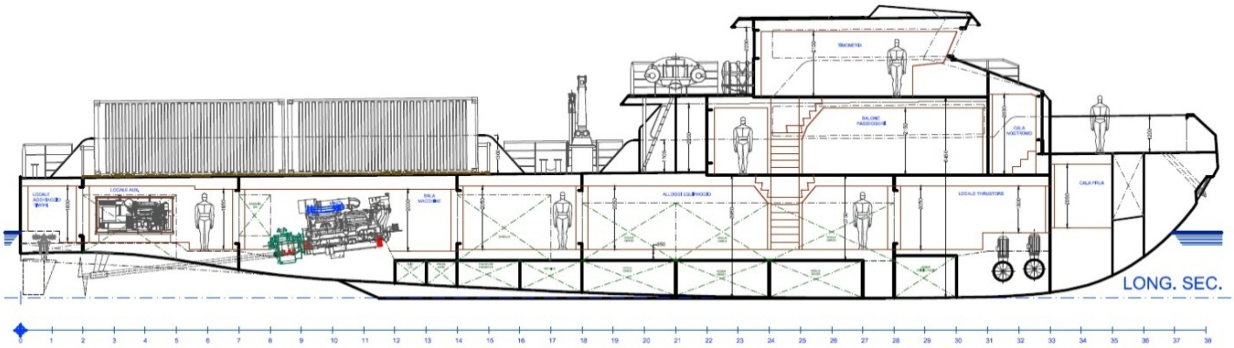


Fig.2.2 Longitudinal section

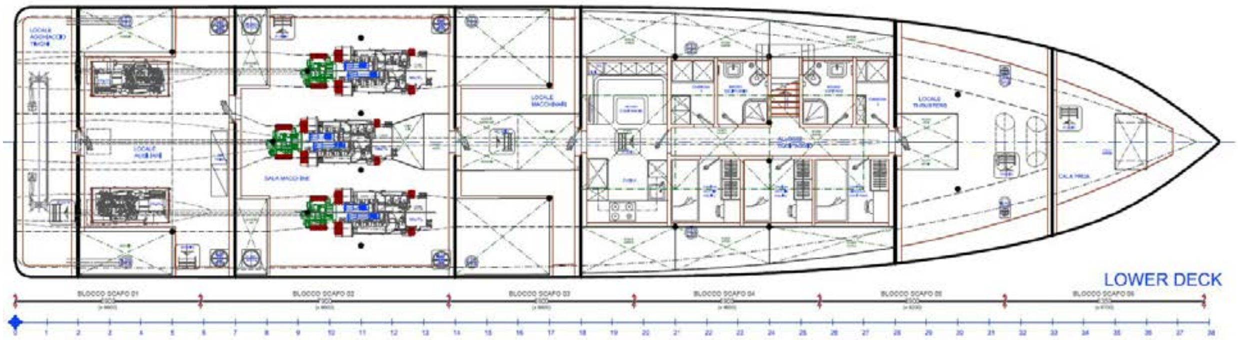


Fig.2.3 Lower deck

Hydrostatics data is enclosed in Full Master Thesis: Appendix-1.

Lines plan is enclosed in Full Master Thesis: Appendix-3.

General arrangement (design by A. Battistini) is enclosed in Full Master Thesis: Appendix-4.

2.4. Tank Arrangement & Capacity Plan

The number and location of transverse and longitudinal watertight tank bulkheads intended for the carriage of rig water to the oil platforms are comply with the subdivision requirements which are mentioned on next chapter.

By considering regulations, required cofferdams between gasoil tanks, rig water tanks and lubricating oil tanks are provided.

Below table presents total capacities of considered tanks.

Table 2.1 Tank capacities

Tank Name	Intact Permeability	Damage Permeability	Fluid Type	Volume	Specific Gravity	Weight
	%	%		[m^3]	[kg/m^3]	[kg]
Rig water	98	95	Rig water	45,17	1,00	45,17
Gasoil	98	95	Gasoil	43,00	0,8524	36,65
Daily oil	98	95	Gasoil	6,42	0,8524	5,47
Overflow	98	95	Gasoil	1,34	0,8524	1,14
Sludge	98	95	Sludge	1,34	1,00	1,34
Lubricating oil	98	95	Lube Oil	0,95	0,92	0,87
Bilge	98	95	Bilge	2,97	1,00	2,97
Fresh water	98	95	Fresh Water	6,71	1,00	6,71
Black water	98	95	Black water	1,69	1,00	1,69
Grey water	98	95	Grey water	1,69	1,00	1,69

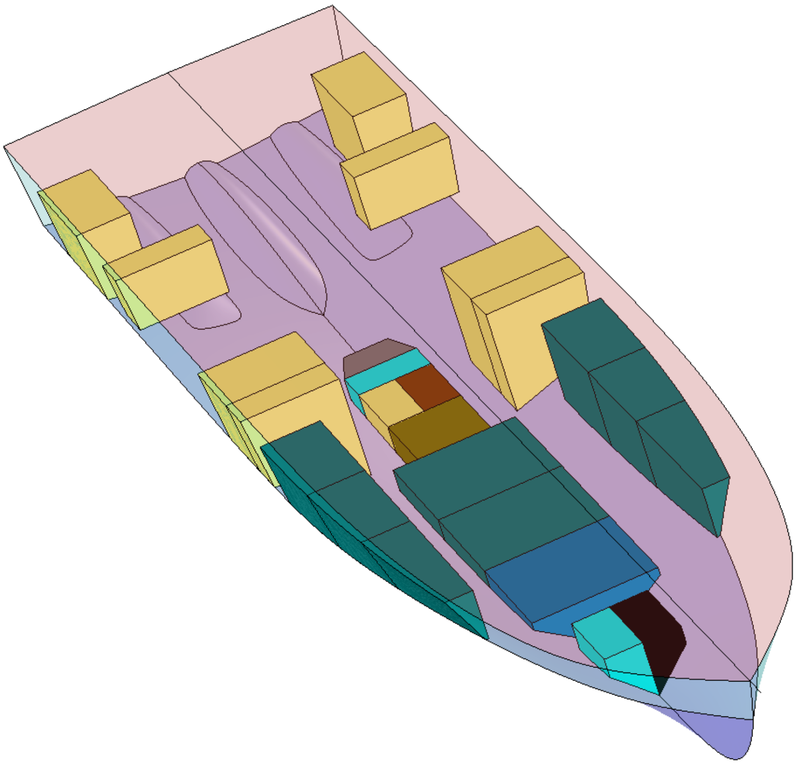


Fig.2.4 Tank arrangement by Hydromax

Capacity plan drawing is enclosed in Full Master Thesis: Appendix-5.

2.5. Stability Design Criteria

Stability calculations are performed by Hydromax software and submitted to representative of the customer and Classification Society to demonstrate that the vessel has stability in accordance with requirements of Classification Society and Flag Authority and at any case in accordance with IMO Resolution A749 (18).

The intact stability criteria specified in this chapter are complied with for the loading conditions mentioned in C2.5.3. These criteria set minimum values, but no maximum values are recommended.

2.5.1. General Intact Stability Criteria

i. GZ curve area

The area under the righting lever curve (GZ curve) is to be not less than 0,055 m.rad up to θ = 30° angle of heel and not less than 0,09 m.rad up to θ = 40° or the angle of down flooding θ_f if this angle is less than 40°. Additionally, the area under the righting lever curve between the angles of heel of 30° and 40° or between 30° and θ_f, if this angle is less than 40°, is to be not less than 0,03 m.rad.

ii. Minimum righting lever

The righting lever GZ is to be at least 0,20 m at an angle of heel equal to or greater than 30°.

iii. Angle of maximum righting lever

The maximum righting lever is to occur at an angle not less than 25°.

iv. Initial metacentric height

The initial metacentric height GM_o is to be not less than 0,15 m.

2.5.2. Severe Wind and Rolling Criterion

The ability of the vessel to withstand the combined effects of beam wind and rolling is demonstrated for each loading condition, with reference to Fig.2.1 as follows:

- The ship is subjected to a steady wind pressure acting perpendicular to the ship's centerline which results in a steady wind heeling lever (l_{w1});
- From the resultant angle of equilibrium (θ_o), the ship is assumed to roll owing to wave action to an angle of roll (θ_1) to windward. The angle of heel under action of steady wind (θ_o) is not to exceed 16° or 80° of the angle of deck immersion, whichever is less;
- The ship is then subjected to a gust wind pressure which results in a gust wind heeling lever (1_{w2});
- Under these circumstances, area "b" is to be be equal to or greater than area "a", as indicated in Fig.2.5 are defined as follows:
  - θ_o : angle of heel under action of steady wind
  - θ_1 : angle of roll to windward due to wave action
  - θ_2 : angle of downflooding (θ_f) or 50° or θ_c, whichever is less,

    Where;
    - θ_f : angle of heel at which openings in the hull, superstructures or deckhouses which cannot be closed weathertight immerse. In applying this criterion, small openings through which progressive flooding cannot take place need not be considered as open;
    - θ_c : angle of second intercept between wind heeling lever l_{w2} and GZ curves.

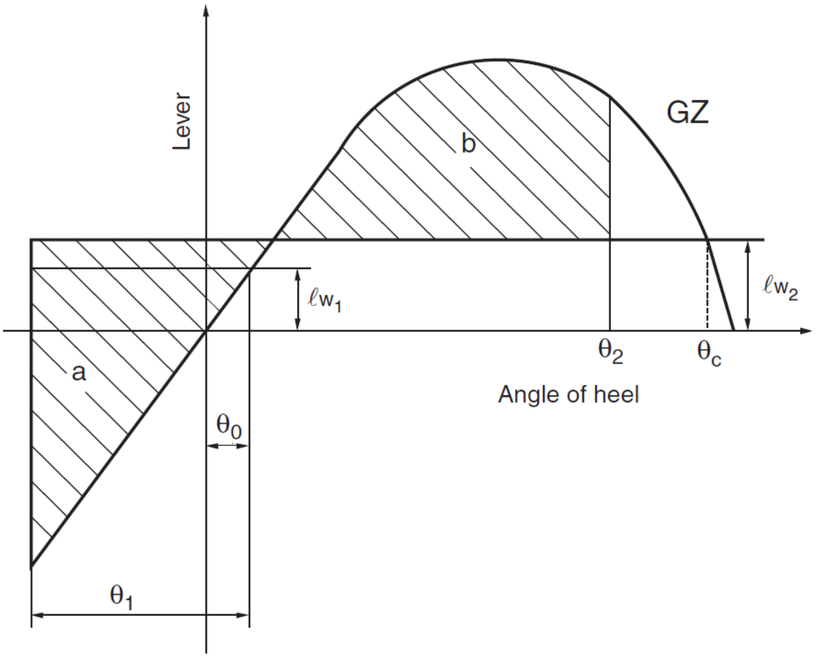


Fig.2.5 Severe wind and rolling

The wind heeling levers l_{w1} and l_{w2}, in m, referred above are constant values at all angles of inclination and should be calculated as follows:

$$l_{w1} = \frac{P.A.Z}{1000.g.\Delta} \quad (1)$$

And

$$l_{w2} = 1{,}5.\, l_{w1} \quad (2)$$

Where;

P : wind pressure of 504 Pa. The value of P used for ships in restricted service may be reduced subject to the approval of the Society;

A : projected lateral area in m^2 of the portion of the ship and deck cargo above the waterline;

Z : vertical distance, in m, from the center of A to the center of the underwater lateral area or approximately to a point at one half the mean draught;

Δ : displacement, in tonnes;

g : gravitational acceleration of 9,81 m/s^2.

Intact stability data is enclosed in Full Master Thesis: Appendix-2.

2.5.3. Loading Conditions

Table 2.2 Trial condition

Item Name	Quantity	Sounding (m)	Unit Mass (tonnes)	Total Mass (tonnes)	Long. Arm (m)	Trans. Arm (m)	Vert. Arm (m)
Lightship	1		134,00	134,00	17,00	0,00	3,30
Deck cargo	0		45,00	0,00	5,50	0,00	5,00
Crew	5		0,14	0,70	26,00	0,00	5,00
Passengers	0		0,14	0,00	26,00	0,00	5,00
Consumable	0,2		3,00	0,60	21,00	0,00	1,60
Rig water-S1	0%	0,00	6,58	0,00	19,47	3,33	2,21
Rig water-S2	0%	0,00	5,15	0,00	22,41	3,24	2,29
Rig water-S3	0%	0,00	3,62	0,00	25,64	3,07	2,44
Rig water-P1	0%	0,00	6,58	0,00	19,47	-3,33	2,21
Rig water-P2	0%	0,00	5,15	0,00	22,41	-3,24	2,29
Rig water-P3	0%	0,00	3,62	0,00	25,64	-3,07	2,44
Rig water-C1	0%	0,00	7,17	0,00	19,52	0,00	0,78
Rig water-C2	0%	0,00	7,30	0,00	22,49	0,00	0,76
Gasoil-S1	90%	1,83	6,03	5,43	3,50	3,47	2,28
Gasoil-S2	10%	0,56	8,19	0,82	15,01	2,40	1,19
Gasoil-S3	10%	0,57	4,10	0,41	16,50	2,39	1,16
Gasoil-P1	90%	1,83	6,03	5,43	3,50	-3,47	2,28
Gasoil-P2	10%	0,56	8,19	0,82	15,01	-2,40	1,19
Gasoil-P3	10%	0,57	4,10	0,41	16,50	-2,39	1,16
Daily oil-S	99%	1,39	2,74	2,71	7,50	2,97	2,60
Daily oil-P	99%	1,39	2,74	2,71	7,50	-2,97	2,60
Overflow	10%	0,23	1,14	0,11	15,13	0,24	0,44
Sludge	5%	0,18	1,34	0,07	15,19	-0,17	0,40
Lub. oil	5%	0,13	0,87	0,04	12,57	0,00	0,52
Bilge	5%	0,19	2,97	0,15	17,15	0,00	0,32
F.W.	40%	0,72	6,71	2,69	25,43	0,00	0,49
B.W.	5%	0,28	1,69	0,08	28,91	-0,11	0,18
G.W.	5%	0,28	1,69	0,08	28,91	0,11	0,18
Sea chest	0%	0,00	1,22	0,00	13,51	0,00	0,85
Total				157,27	15,93	0,00	3,12

Table 2.3 Arrival condition

Item Name	Quantity	Sounding (m)	Unit Mass (tonnes)	Total Mass (tonnes)	Long. Arm (m)	Trans. Arm (m)	Vert. Arm (m)
Lightship	1		134,00	134,00	17,00	0,00	3,30
Deck cargo	0		45,00	0,00	5,50	0,00	5,00
Crew	5		0,14	0,70	26,00	0,00	5,00
Passengers	0		0,14	0,00	26,00	0,00	5,00
Consumable	10%		3,00	0,30	21,00	0,00	1,60
Rig water-S1	10%	0,44	6,58	0,66	19,35	3,08	1,37
Rig water-S2	10%	0,47	5,15	0,52	22,17	3,03	1,48
Rig water-S3	10%	0,49	3,62	0,36	25,06	2,95	1,71
Rig water-P1	10%	0,44	6,58	0,66	19,35	-3,08	1,37
Rig water-P2	10%	0,47	5,15	0,52	22,17	-3,03	1,48
Rig water-P3	10%	0,49	3,62	0,36	25,06	-2,95	1,71
Rig water-C1	10%	0,32	7,17	0,72	19,59	0,00	0,32
Rig water-C2	10%	0,34	7,30	0,73	22,49	0,00	0,26
Gasoil-S1	10%	0,30	6,03	0,60	3,50	3,35	1,49
Gasoil-S2	10%	0,56	8,19	0,82	15,01	2,40	1,19
Gasoil-S3	10%	0,57	4,10	0,41	16,50	2,39	1,16
Gasoil-P1	10%	0,30	6,03	0,60	3,50	-3,35	1,49
Gasoil-P2	10%	0,56	8,19	0,82	15,01	-2,40	1,19
Gasoil-P3	10%	0,57	4,10	0,41	16,50	-2,39	1,16
Daily oil-S	99%	1,39	2,74	2,71	7,50	2,97	2,60
Daily oil-P	99%	1,39	2,74	2,71	7,50	-2,97	2,60
Overflow	30%	0,39	1,14	0,34	15,05	0,37	0,54
Sludge	90%	0,85	1,34	1,21	15,02	-0,42	0,78
Lub. oil	10%	0,17	0,87	0,09	12,55	0,00	0,55
Bilge	90%	0,93	2,97	2,67	17,01	0,00	0,73
F.W.	10%	0,35	6,71	0,67	25,43	0,00	0,24
B.W.	90%	1,26	1,69	1,52	28,97	-0,38	0,79
G.W.	90%	1,26	1,69	1,52	28,97	0,38	0,79
Sea chest	0%	0,00	1,22	0,00	13,51	0,00	0,85
Total				156,62	16,97	0,00	3,04

Table 2.4 Half load condition

Item Name	Quantity	Sounding (m)	Unit Mass (tonnes)	Total Mass (tonnes)	Long. Arm (m)	Trans. Arm (m)	Vert. Arm (m)
Lightship	1		134,00	134,00	17,00	0,00	3,30
Deck cargo	0,14		45,00	6,30	5,50	0,00	5,00
Crew	5		0,14	0,70	26,00	0,00	5,00
Passengers	41		0,14	5,74	26,00	0,00	5,00
Consumable	0,5		3,00	1,50	21,00	0,00	1,60
Rig water-S1	90%	1,83	6,58	5,92	19,46	3,32	2,12
Rig water-S2	10%	0,47	5,15	0,52	22,17	3,03	1,48
Rig water-S3	10%	0,49	3,62	0,36	25,06	2,95	1,71
Rig water-P1	90%	1,83	6,58	5,92	19,46	-3,32	2,12
Rig water-P2	10%	0,47	5,15	0,52	22,17	-3,03	1,48
Rig water-P3	10%	0,49	3,62	0,36	25,06	-2,95	1,71
Rig water-C1	90%	1,03	7,17	6,45	19,51	0,00	0,74
Rig water-C2	10%	0,34	7,30	0,73	22,49	0,00	0,26
Gasoil-S1	99%	1,99	6,03	5,97	3,50	3,47	2,36
Gasoil-S2	20%	0,79	8,19	1,64	15,00	2,63	1,34
Gasoil-S3	20%	0,80	4,10	0,82	16,50	2,61	1,32
Gasoil-P1	99%	1,99	6,03	5,97	3,50	-3,47	2,36
Gasoil-P2	20%	0,79	8,19	1,64	15,00	-2,63	1,34
Gasoil-P3	20%	0,80	4,10	0,82	16,50	-2,61	1,32
Daily oil-S	99%	1,39	2,74	2,71	7,50	2,97	2,60
Daily oil-P	99%	1,39	2,74	2,71	7,50	-2,97	2,60
Overflow	30%	0,39	1,14	0,34	15,05	0,37	0,54
Sludge	50%	0,54	1,34	0,67	15,03	-0,40	0,62
Lub. oil	50%	0,44	0,87	0,44	12,54	0,00	0,70
Bilge	50%	0,59	2,97	1,49	17,02	0,00	0,56
F.W.	50%	0,80	6,71	3,36	25,43	0,00	0,54
B.W.	50%	0,88	1,69	0,85	28,95	-0,33	0,58
G.W.	50%	0,88	1,69	0,85	28,95	0,33	0,58
Sea chest	0%	0,00	1,22	0,00	13,51	0,00	0,85
Total				199,28	16,38	0,00	2,98

Table 2.5 Full load condition

Item Name	Quantity	Sounding (m)	Unit Mass (tonnes)	Total Mass (tonnes)	Long. Arm (m)	Trans. Arm (m)	Vert. Arm (m)
Lightship	1		134,00	134,00	17,00	0,00	3,30
Deck cargo	0,58		45,00	26,10	6,00	0,00	5,00
Crew	5		0,14	0,70	26,00	0,00	5,00
Passengers	40		0,14	5,60	26,00	0,00	5,00
Consumable	1		3,00	3,00	21,00	0,00	1,60
Rig water-S1	99%	1,97	6,58	6,52	19,46	3,32	2,20
Rig water-S2	99%	1,90	5,15	5,10	22,40	3,23	2,28
Rig water-S3	99%	1,69	3,62	3,58	25,63	3,07	2,43
Rig water-P1	99%	1,97	6,58	6,52	19,46	-3,32	2,20
Rig water-P2	99%	1,90	5,15	5,10	22,40	-3,23	2,28
Rig water-P3	99%	1,69	3,62	3,58	25,63	-3,07	2,43
Rig water-C1	99%	1,10	7,17	7,10	19,51	0,00	0,78
Rig water-C2	99%	1,16	7,30	7,22	22,49	0,00	0,76
Gasoil-S1	99%	1,99	6,03	5,97	3,50	3,47	2,36
Gasoil-S2	99%	2,47	8,19	8,11	15,00	2,89	2,23
Gasoil-S3	99%	2,49	4,10	4,06	16,50	2,88	2,22
Gasoil-P1	99%	1,99	6,03	5,97	3,50	-3,47	2,36
Gasoil-P2	99%	2,47	8,19	8,11	15,00	-2,89	2,23
Gasoil-P3	99%	2,49	4,10	4,06	16,50	-2,88	2,22
Daily oil-S	99%	1,39	2,74	2,71	7,50	2,97	2,60
Daily oil-P	99%	1,39	2,74	2,71	7,50	-2,97	2,60
Overflow	10%	0,23	1,14	0,11	15,13	0,24	0,44
Sludge	5%	0,18	1,34	0,07	15,19	-0,17	0,40
Lub. oil	99%	0,77	0,87	0,86	12,54	0,00	0,86
Bilge	5%	0,19	2,97	0,15	17,15	0,00	0,32
F.W.	99%	1,18	6,71	6,65	25,46	0,00	0,77
B.W.	5%	0,28	1,69	0,09	28,91	-0,11	0,18
G.W.	5%	0,28	1,69	0,09	28,91	0,11	0,18
Sea chest	0%	0,00	1,22	0,00	13,51	0,00	0,85
Total				263,82	16,22	0,00	3,00

Table 2.6 Equilibrium conditions

	Unit	Trial	Arrival	Half-Load	Full-Load
Draft Amidships	m	1,63	1,66	1,83	2,09
Displacement	tonnes	157,30	156,60	199,30	263,80
Heel to Starboard	degrees	0,00	0,00	0,00	0,00
Draft at FP	m	1,49	1,68	1,82	2,10
Draft at AP	m	1,77	1,64	1,84	2,08
Draft at LCF	m	1,66	1,65	1,83	2,09
Trim (+ve by stern)	m	0,28	-0,05	0,02	-0,01
WL Length	m	36,24	36,46	36,62	36,91
WL Breadth	m	8,07	8,04	8,09	8,15
Wetted Area	m^2	262,62	265,82	282,38	306,14
Waterline Area	m^2	229,50	233,72	239,56	247,13
Prismatic Coefficient	-	0,67	0,64	0,67	0,70
Block Coefficient	-	0,33	0,31	0,36	0,41
Midship Area Coefficient	-	0,55	0,55	0,60	0,64
Water plane Area Coefficient	-	0,78	0,80	0,81	0,82
LCB from zero pt. (+ve fwd)	m	15,91	16,97	16,38	16,22
LCF from zero pt. (+ve fwd)	m	14,65	14,93	15,20	15,55
KB	m	1,22	1,21	1,33	1,48
KG solid	m	3,12	3,04	2,98	3,00
BMt	m	6,89	7,05	5,76	4,56
BML	m	117,86	124,26	103,04	83,79
GMt corrected	m	4,90	5,02	3,95	3,04
GML corrected	m	115,86	122,23	101,22	82,27
KMt	m	8,11	8,26	7,09	6,04
KML	m	119,08	125,47	104,36	85,27
Immersion (TPc)	tonne/cm	2,35	2,40	2,46	2,53
MTc	tonne.m	4,94	5,19	5,47	5,88
RM at 1deg = GMt.Disp.sin(1)	tonne.m	13,44	13,71	13,73	13,98
Max deck inclination	degrees	0,4	0,1	0	0
Trim angle (+ve by stern)	degrees	0,4	-0,1	0	0

2.6. Hull Resistance Prediction

At preliminary stages of the design, the hull resistance prediction has significant importance for developing hull lines.

In the design initial steps, indeed, it is necessary to evaluate the resistance characteristics of different possible solutions and later the design is more and more retouched and corrected as more precise data are available; this method involves the execution of several resistance estimates which must be carried out in short times and which, even when the time factor is not a problem, would lead to prohibitive financing charges if done using towing tank tests.[1]

For resistance predictions, Hullspeed module of Maxsurf software is used. Many different approaches exist to predict the resistance of a vessel. Hullspeed implements several different resistance algorithms, each applicable to various families of hull shapes. Hullspeed read the input data from the Maxsurf design and automatically measure the surface shape. Since the algorithms are designed for specific hull types, they will be more accurate when certain conditions are satisfied. These conditions are:

1. Hull shape: Hard chine hull in pre-planing regime ($1,0 < Fn_V < 3,0$). In this speed range the dynamic lift begins to have some effects, but has still a modest entity.
2. Speed range: The resistance prediction algorithms are useful only within certain speed ranges; these limits are:

Table 2.7 Speed ranges for different algorithms

Algorithm	Low – speed limit	Actual (For trial condition)	High – speed limit
Savitsky (pre-planing)	$Fn_V = 1,0$	1,86	$Fn_V = 2,0$
Savitsky (planing)	$Fn_b = 1,0$	1,51	-
Lahtiharju (hard chine)	$Fn_V = 1,5$	1,86	$Fn_V = 5,0$
Holtrop	$Fn_L = 0,0$	0,70	$Fn_L = 0,8$

Where;

Fn_b : beam Froude number

Fn_V : volume Froude number

Fn_L : length Froude number

3. Dimensions: The resistance prediction algorithms are useful only within certain limits of hull dimensions. After measurements, it is seen that only Savitsky algorithm can be used for this hull. Below table presents the limits for this algorithm:

Table 2.8 Dimension limits for Savitsky algorithm

Dimensions	Minimum	Actual (For trial condition)	Maximum
L/(V^1/3)	3,07	6,90	12,40
ie	3,70	15,78	28,60
L/B	2,52	4,53	28,26
B/T	1,70	4,94	9,80
At/Ax	0	0,37	1
LCG/L	-0,016	0,062	0,066

Where;

L : length on the waterline

B : beam on the waterline

T : draft of hull

At : transom sectional area

Ax : maximum sectional area

V : displaced volume

ie : half angle of entrance

LCG : longitudinal centre of gravity, measured from amidships, positive is aft.

Due to hull has no fully-planning features, Savitsky pre-planing method is performed. This method calculates components as following table:

Table 2.9 Components for Savitsky pre-planing method calculations [2]

R_T	Total resistance; either expressed as: $R_T = R_R + R_F + R_{Cor} + R_{App} + R_{Air}$ or $R_T = R_W + R_V + R_{Cor} + R_{App} + R_{Air}$
R_{Cor}	Correlation allowance resistance; additional resistance for correlation from model to ship scale
R_{App}	Appendage resistance; resistance of appendages such as rudder, etc.
R_{Air}	Air resistance; wind resistance of above-water hull and superstructure

This power prediction assumes 100% propulsive efficiency, and will need to be reduced to get an accurate engine power estimate. The overall efficiency is determined as 55%. Then the power, P, is calculated as follows:

$$P = \frac{R.V}{\eta} \tag{3}$$

Where;

V : ship velocity

η : the efficiency

R : the resistance

Table 2.10 Savitsky Pre-Planing method results for different conditions

	Trial Condition		Arrival Condition		Half-Load Condition		Full-Load Condition	
Speed	Resistance	Power	Res.	Power	Res.	Power	Res.	Power
[kn]	[kN]	[kW]	[kN]	[kW]	[kN]	[kW]	[kN]	[kW]
10,0	--	--	--	--	--	--	--	--
10,5	--	--	--	--	--	--	--	--
11,0	--	--	--	--	--	--	--	--
11,5	--	--	--	--	--	--	--	--
12,0	--	--	--	--	--	--	--	--
12,5	--	--	--	--	--	--	--	--
13,0	--	--	--	--	--	--	--	--
13,5	--	--	--	--	--	--	--	--
14,0	41,69	545,87	--	--	--	--	--	--
14,5	46,94	636,64	49,07	665,48	--	--	--	--
15,0	52,20	732,40	54,72	767,73	69,32	972,61	--	--
15,5	57,46	832,99	60,37	875,27	77,82	1128,27	101,22	1467,43
16,0	62,68	938,03	65,77	984,24	86,33	1291,97	115,21	1724,23
16,5	67,91	1048,04	71,17	1098,33	93,48	1442,78	129,21	1994,20
17,0	72,71	1156,24	76,37	1214,29	100,28	1594,51	142,35	2263,45
17,5	77,00	1260,39	80,77	1322,05	107,08	1752,68	152,41	2494,72
18,0	81,29	1368,64	85,17	1434,00	112,38	1892,14	162,48	2735,49
18,5	85,01	1471,08	89,25	1544,42	117,45	2032,37	171,94	2975,25
19,0	88,43	1571,63	92,81	1649,39	122,52	2177,43	177,98	3162,93
19,5	91,86	1675,47	96,37	1757,78	127,00	2316,49	184,02	3356,34
20,0	95,97	1795,30	100,31	1876,55	131,45	2459,00	190,04	3555,02
20,5	100,20	1921,28	104,54	2004,45	135,89	2605,75	195,76	3753,67
21,0	104,33	2049,29	108,76	2136,40	140,09	2751,67	201,49	3957,78
21,5	106,82	2148,15	111,75	2247,30	144,29	2901,62	207,21	4167,05
22,0	109,31	2249,44	114,33	2352,73	148,40	3053,73	211,21	4346,30
22,5	111,77	2352,23	116,92	2460,69	151,35	3185,29	215,22	4529,39
23,0	**114,10**	**2454,72**	**119,34**	**2567,34**	**154,31**	**3319,71**	**219,23**	**4716,34**
23,5	116,44	2559,50	121,75	2676,10	157,27	3456,83	222,37	4887,96

24,0	118,68	2664,29	124,14	2786,65	160,17	3595,65	225,46	5061,33
24,5	120,81	2768,60	126,34	2895,17	163,09	3737,31	228,56	5237,71
25,0	122,95	2875,02	128,55	3005,88	165,94	3880,41	232,08	5426,84
25,5	125,36	2990,14	130,90	3122,11	168,59	4021,07	235,66	5620,90
26,0	**127,92**	**3110,93**	**133,57**	**3248,42**	**171,24**	**4164,34**	**239,25**	**5818,44**
26,5	130,48	3234,24	136,26	3377,36	174,09	4315,14	242,47	6010,17
27,0	132,80	3353,83	138,79	3505,06	177,44	4481,22	245,60	6202,61
27,5	135,09	3474,80	141,17	3631,15	180,80	4650,57	248,74	6398,11
28,0	--	--	143,55	3759,60	183,98	4818,31	252,53	6613,68
28,5	--	--	--	--	186,82	4980,26	256,57	6839,47
29,0	--	--	--	--	189,68	5145,01	260,61	7069,17
29,5	--	--	--	--	--	--	264,14	7288,50
30,0	--	--	--	--	--	--	267,41	7503,61

As the engine models, hence total capacity, are determined by customer and service performance is identified on technical specifications of project, there is just needed to confirm first results with requirements. After preliminary resistance predictions by Hullspeed software, the hull lines of the vessel are evaluated by computational fluid dynamics analysis software ANSYS-CFX. The aim was to have quick comparison with Savitsky method whether the results of this method are logical or not for this kind of hull. If so, hull resistance prediction could be made by Savitsky method in order to get results very quickly when an update on hull lines is necessity.

Computational fluid dynamics analysis is performed at fixed conditions to get convergence in a short time, hence different draft and trim values are adopted. For these analyses, trial condition is performed at 26 knots which is to be achieved according to contract agreement.

Table 2.11 Savitsky method and CFD analysis comparison

Data from Savitsky Method				Data from CFD				Difference	
Speed	Trim	Disp.	RT	Aft draft	Trim	Disp.	RT	Disp.	RT
[kn]	[deg]	[tonnes]	[kN]	[m]	[deg]	[tonnes]	[kN]	[%]	[%]
26	0,4	157,3	127,92	1,55	0,25	171,37	133,81	8,21	4,40
26	0,4	157,3	127,92	1,50	0,25	153,23	112,86	-2,65	-13,35
26	0,4	157,3	127,92	1,53	0,28	155,32	111,84	-1,27	-14,38
26	0,4	157,3	127,92	1,52	0,30	153,62	110,35	-2,40	-15,92
26	0,4	157,3	127,92	1,53	0,30	154,88	110,09	-1,56	-16,19
26	0,4	157,3	127,92	1,55	0,40	165,90	127,24	5,19	-0,54
26	0,4	157,3	127,92	1,65	1,00	165,93	115,03	5,17	-11,25
26	0,4	157,3	127,92	1,63	1,00	162,10	113,01	2,93	-13,23
26	0,4	157,3	127,92	1,63	1,00	158,00	109,30	0,41	-17,07

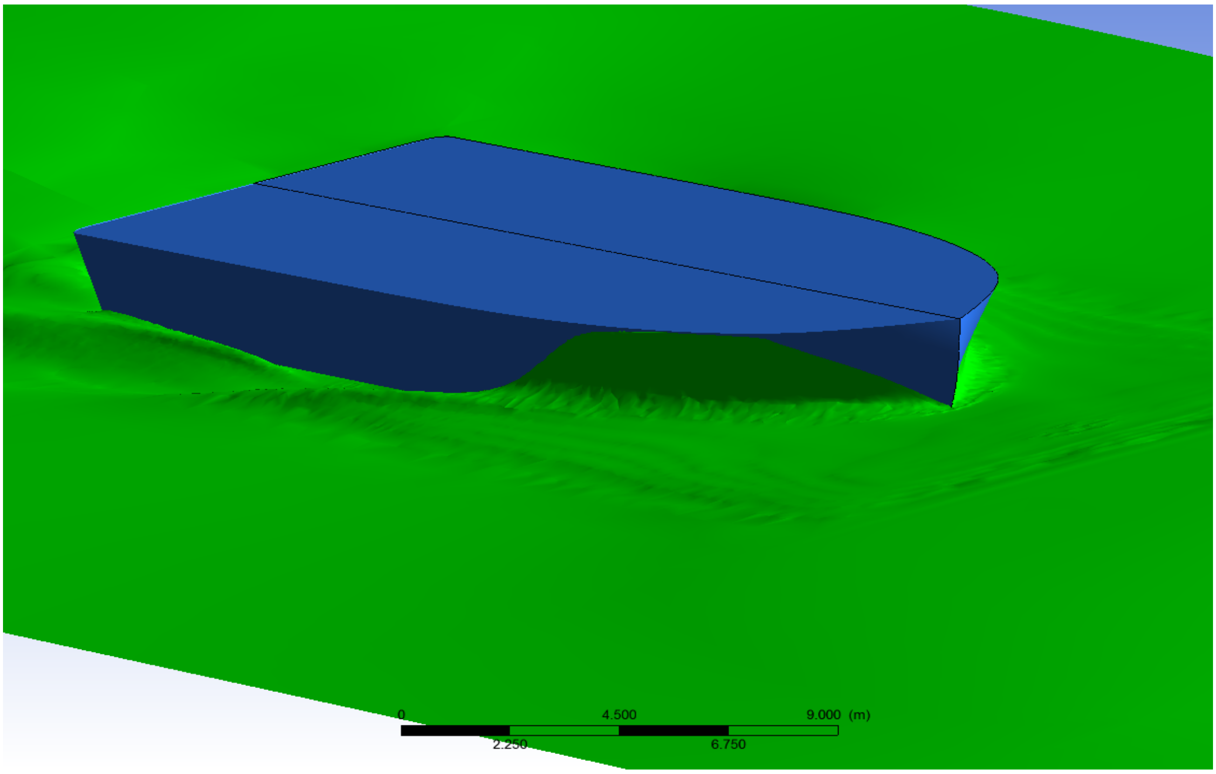


Fig.2.6a Wave elevations

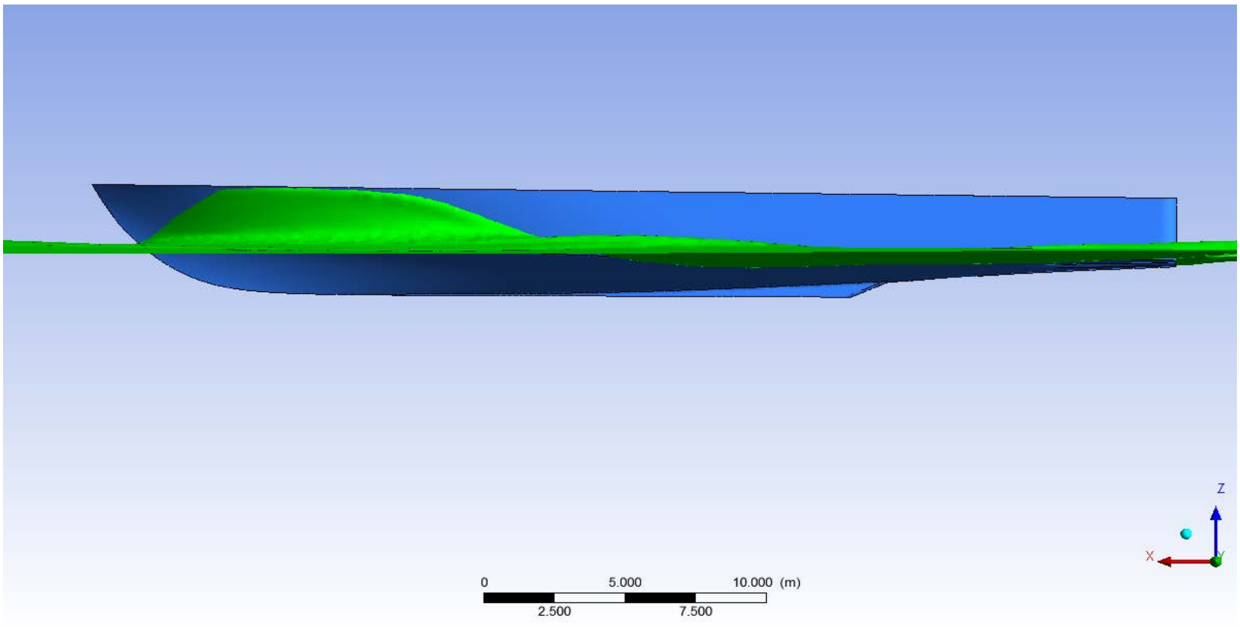


Fig.2.6b Wave elevations

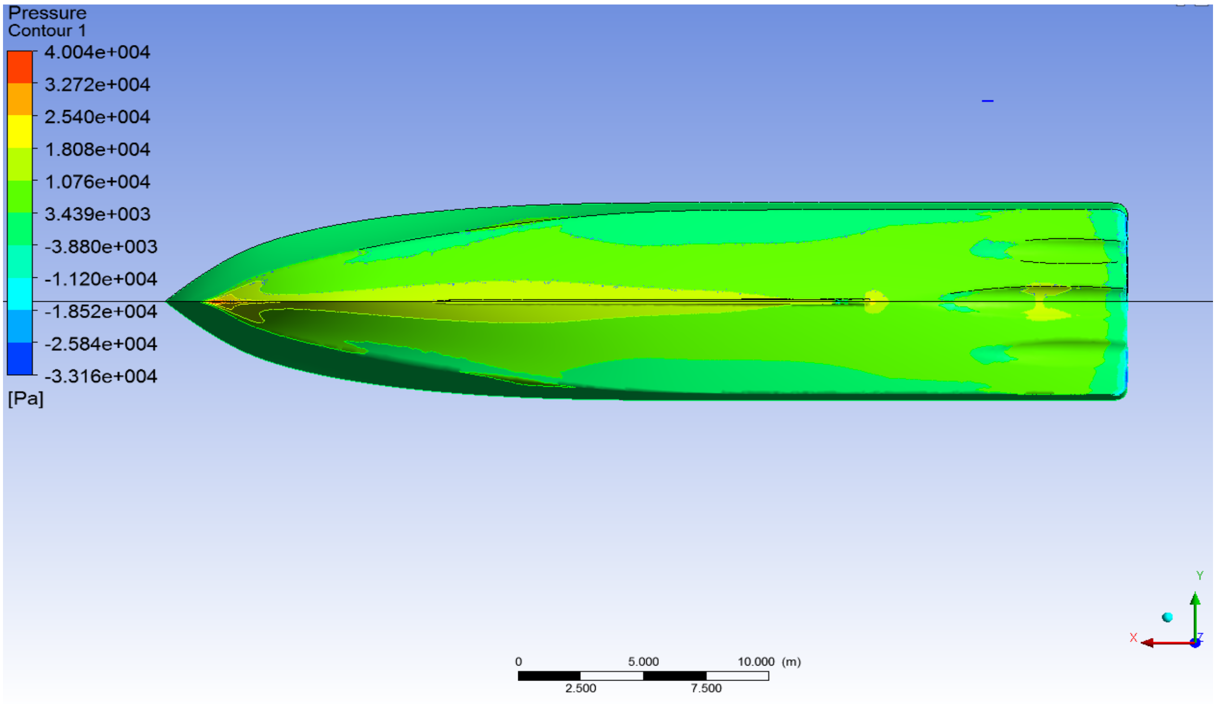


Fig.2.7 Pressure distribution on bottom

As seen from Table 2.11, CFD results give an idea as this vessel can achieve 26 knots by selected engines which have 4029 kW power in total. Therefore, this hull design is adopted for scantlings without going on further changing at this stage.

3. STRUCTURE DESIGN BY RULES

The weight of aluminium material is 2660 kg/m^3 while steel weighs 7850 kg/m^3. At one third of the weight of steel, the lower lightship displacement of the aluminium structure will reduce the fuel costs dramatically and allows faster speeds.

The basic principles for structural design with aluminium are similar to those for design with steel. Consideration is made for the reduced elastic modulus of aluminium, which means reduced buckling strength and stiffness.[3]

3.1. General

The structural elements of the vessel are determined with the rules and regulations of RINA Rules for the Classification of High-Speed Craft. This chapter contains the requirements for structural scantlings of the craft to which these Rules apply, i.e. to craft for which $V \geq 7{,}16\ \Delta^{1/6}$.

Table 3.1 Main dimensions for structure design

Dimension	Value	Unit	Definition
L	36,91	m	Rule length equal to L_{WL} where L_{WL} is the waterline measured with craft at rest in calm water
FP	0,00	m	Forward perpendicular, i.e. the perpendicular at the intersection of the waterline at draught and foreside of the stern
AP	36,91	m	Aft perpendicular, i.e. the perpendicular located at a distance L abaft of the forward perpendicular
B	8,60	m	The greatest moulded breadth of the craft
B_W	8,15	m	The greatest moulded breadth measured on waterline at draught T
D	3,95	m	Depth measured vertically in the transverse section at the middle of length L from the moulded base line of the hull to the top of the deck beam at one side of the main deck
T	2,09	m	Draught of the craft measured vertically in the transverse section at the middle of length L from the moulded baseline of the hull to the full load waterline, with the craft at rest calm water
Δ	263,8	tonnes	Moulded displacement at draught T in sea water
C_B	0,41		Total block coefficient
V	26,00	knots	Maximum service speed
g	9,81	m/s^2	Acceleration of gravity
LCG	16,22	m	Longitudinal center of gravity of the craft

3.2. Materials and Connections

Aluminum for hull construction is used in two basic product forms, plates and extrusions. Aluminum structural shapes are produced by the extrusion process, where hot metal is pressed through a die to form the structural profile. This process is rather versatile, and a new shape can be easily designed and extruded. For this reason, there are a variety of different extrusions used in marine construction, but few to any standard cross-section.[4]

Hull and superstructure is made of aluminum approved by the Classification Society:

Plates	5083 series aluminum alloy
Profiles	5083 & 6082 series aluminum alloy
Filler material	5183 series aluminum alloy

3.2.1. Some Features of 5083 Series Aluminium Alloy[5]

Aluminium alloy 5083 contains 5.2% magnesium, 0.1% manganese and 0.1% chromium. In the tempered condition, it is strong, and retains good formability due to excellent ductility. 5083 has high resistance to corrosion, and is used in marine applications. It has the low density and excellent thermal conductivity common to all aluminium alloys.

Corrosion Resistance Alloy 5083 has excellent resistance to general corrosion, and is used in marine applications. Resistance is excellent in aqueous solutions in the pH range 4 – 9. The corrosion resistance of aluminium alloys relies on a protective surface oxide film, which when damaged is readily repaired by the rapid reaction between aluminium and oxygen. However, the high reactivity of the base metal can give rapid corrosion if the film cannot be repaired, so aluminium alloys are not suitable for use with reducing media. Alloy 5083 can be anodized to improve the corrosion resistance by thickening the protective surface film.

Fabrication Aluminium 5083 is readily cold formable, as it is ductile. Forming loads and tool & press wear are generally less than with carbon steel. For piercing and blanking the punch to die clearance should be about 7% of the thickness per side for temper O, 7.5% for other tempers.

Welding Alloy 5083 is readily welded by the TIG and MIG processes using 5183, 5356 or 5556 filler alloys. Welding the H116 temper will reduce the tensile and yield strengths in the heat affected zone to those of the annealed condition. Aluminium must be very dry & clean to avoid contamination & porosity of the weld. It is essential that all traces of flux used in welding or brazing are removed by scrubbing with hot water.

Heat Treatment Alloy 5083 is annealed at 350°C, time at temperature and cooling rate are unimportant. Stress relief is rarely required, but can be carried out at about 220°C. If loss of strength is of concern, stress relief tests should be conducted.

Table 3.2 General mechanical characteristics of used aluminium alloys

Aluminium alloy				Unwelded condition		Welded condition	
Alloy	Temper	Products	Thickness [mm]	$R_{p\,0,2}$ [N/mm^2]	R_m [N/mm^2]	$R_{p\,0,2}$' [N/mm^2]	R_m' [N/mm^2]
5083	H111	Rolled	$t \leq 50$	125	275	125	275
5083	H321	Rolled	$t \leq 40$	215	305	125	275
6082	T6	extruded	$t \leq 15$	255	310	115	170

* $R_{p\,0,2}$ and $R_{p\,0,2}$' are the minimum guaranteed yield stresses at 0,2% in unwelded and welded condition respectively.

* R_m and R_m' are the minimum guaranteed tensile strengths in unwelded and welded condition respectively.

3.2.2. *Material factor K for scantlings of aluminium alloy structures*

The value of the material factor K is introduced into formulae for checking scantlings of structural members, given in this chapter is determined by the following equation:

$$K = \frac{100}{R'_{lim}} = 0{,}80 \text{ (For 5083 series aluminium alloy)} \tag{4}$$

Where;

R'_{lim} = 125 N/mm^2, minimum guaranteed yield stress of the parent metal in welded condition $R'_{p0,2}$, but not greater than 70% of the minimum guaranteed tensile strength of the parent metal in welded condition R'_m, in N/mm^2 (see Table 3.2).

3.3. Design Acceleration

3.3.1. *Vertical acceleration at LCG*

The design vertical acceleration at LCG, a_{CG} (expressed in g), corresponds to the average of the 1 per cent highest accelerations in the most severe sea conditions expected, in addition to the gravity acceleration.

$$a_{CG} = foc.Soc.\frac{V}{\sqrt{L}} = 1{,}46g \tag{5}$$

Where;

V = 26 knots

L = 36,91 m

foc = 1 for supply vessels

Soc = C_f for open sea service ($H_s \geq 4{,}0$ m)

$$C_F = 0{,}2 + \frac{0{,}6}{V/\sqrt{L}} = 0{,}34 \geq 0{,}32 \tag{6}$$

The longitudinal distribution of vertical acceleration along the hull is given by:

$$a_V = k_V . a_{CG} \tag{7}$$

Where;

k_V : longitudinal distribution factor described in Fig.3.1.

$k_V = 1$ for $x/L \leq 0{,}5$

$k_V = 2 . x/L$ for $x/L > 0{,}5$

a_{CG} = 1.46g design acceleration at LCG

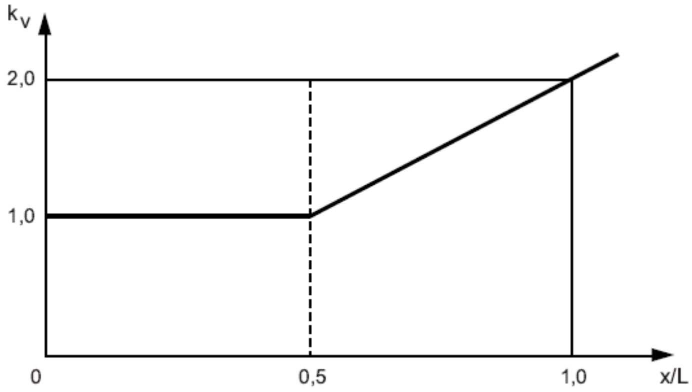


Fig.3.1 Longitudinal distribution of vertical acceleration

3.3.2. *Transverse acceleration*

Transverse acceleration is defined on the basis of results of model tests and full-scale measurements, considering their characteristic value. In the absence of such results, transverse acceleration, in g, at the calculation point of the craft is obtained from:

$$a_t = 2{,}5.\frac{H_{sl}}{L}.\left(1 + 5.\left(1 + \frac{V/\sqrt{L}}{6}\right)^2.\frac{r}{L}\right) = 0{,}69g \tag{8}$$

Where;

H_{sl} = 5,62 m permissible significant wave height at maximum service speed V (see C3.3.3)

r = 2,03 m height above axis of the roll (0,5D for monohull craft).

3.3.3. Assessment of limit operating conditions

“Limit operating conditions” in this paragraph are taken to mean sea states (characterized only by their significant wave heights) compatible with the structural design parameters of the craft, i.e. the sea states in which the craft operate depending on its actual speed.

It is assumed that, on the basis of weather forecast, the craft does not encounter, within the time interval required for the voyage, sea states with significant heights, in m, greater than the following:

$$H_{sm} = 5.\frac{a_{CG}}{V/\sqrt{L}}.\frac{L}{6+0,14.L} = 5,62\ m \tag{9}$$

Where, vertical acceleration a_{CG} is defined above.

3.4. Overall Loads

As a rule, only longitudinal vertical bending moment and shear force are considered for monohulls.

3.4.1. Bending moment due to still water loads, wave induced loads and impact loads

$$M_{blH} = M_{blS} = 0,55.\Delta.L.(C_B + 0,7).(1 + a_{CG}) = 14586\ kN.m \tag{10}$$

Where;

Δ = 263,8 tonnes

L = 36,91 m

C_B = 0,41

a_{CG} = 1,46g

3.4.2. Bending moment due to still water loads and wave induced loads

$$M_{blH} = M_{sH} + 0,60.Soc.C.L^2.B.C_B \tag{11}$$

$$M_{blS} = M_{sS} + 0,35.Soc.C.L^2.B.(C_B + 0,7) = 13248\ kN.m \tag{12}$$

Where;

M_{sH} : still water hogging bending moment

M_{sS} = 104,74 (t.m) x 9,81 = 1027,5 kN.m, still water sagging bending moment (see section v)

Soc : parameter indicated above for the considered type of service

C = 6+0,02.L

For the purpose of this calculation, C_B is taken as 0,6.

3.4.3. Total shear force

$$T_{bl} = \frac{3{,}2.M_{bl}}{L} = 1265\ kN \tag{13}$$

Where;

M_{bl} = 14586 kN.m

3.4.4. Longitudinal distribution of total bending moment

The longitudinal distribution of the total bending moments is given by:

K_M . M_{blH} in hogging

K_M . M_{blS} in sagging

Where;

K_M : longitudinal distribution factor as shown on Fig.3.2

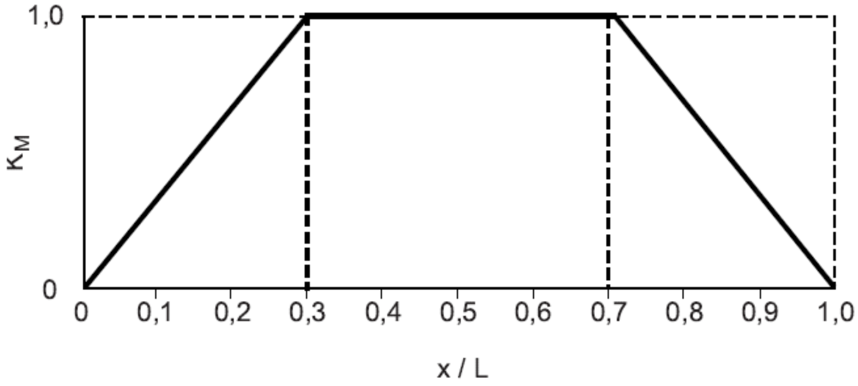


Fig.3.2 Longitudinal distribution of total bending moment

3.4.5. Bending moment and shear force taking into account the actual distribution of weights

The distribution of quasi-static bending moment and shear force due to still water loads is determined from the difference in weight and buoyancy distributions for Full-Load condition envisaged.

Longitudinal strength analysis is made by Hydromax software and the results are presented on below table:

Table 3.3 Longitudinal strength results for Full-Load condition

Name	Long. Pos.	Buoyancy	Weight	Net Load	Shear	Moment
	[m]	[t/m]	[t/m]	[t/m]	[t]	[t.m]
Section-1	1	6,18	4,58	-1,60	-1,56	-0,78
Section-2	2	6,24	12,66	6,42	-3,21	-3,16
Section-3	3	6,40	12,30	5,90	2,96	-3,25
Section-4	4	6,66	11,95	5,28	8,55	2,55
Section-5	5	7,01	7,58	0,58	13,49	13,63
Section-6	6	7,42	7,21	-0,21	13,68	27,27
Section-7	7	7,88	12,26	4,38	13,06	40,70
Section-8	8	8,32	6,47	-1,86	17,02	55,81
Section-9	9	8,58	6,10	-2,49	14,84	71,78
Section-10	10	8,81	5,72	-3,09	12,05	85,26
Section-11	11	9,04	5,35	-3,68	8,66	95,65
Section-12	12	9,25	4,59	-4,67	4,69	102,37
Section-13	13	9,47	3,88	-5,59	0,09	**104,74**
Section-14	14	9,67	11,95	2,28	-5,62	101,99
Section-15	15	9,85	11,96	2,11	-3,43	97,47
Section-16	16	10,02	11,86	1,84	-1,40	95,07
Section-17	17	10,15	3,72	-6,44	0,36	94,56
Section-18	18	10,23	10,44	0,21	-6,13	91,67
Section-19	19	10,23	10,34	0,10	-5,97	85,63
Section-20	20	10,12	10,13	0,01	-5,91	79,69
Section-21	21	9,89	12,81	2,93	-5,94	73,76
Section-22	22	9,55	10,33	0,78	-3,05	69,26
Section-23	23	9,12	9,78	0,65	-2,34	66,57
Section-24	24	8,63	9,17	0,53	-1,75	64,54
Section-25	25	8,09	8,50	0,41	-1,27	63,04
Section-26	26	7,50	7,80	0,30	-0,92	61,95
Section-27	27	6,88	5,04	-1,84	-0,67	61,16
Section-28	28	6,23	3,72	-2,50	-2,48	59,57
Section-29	29	5,54	3,60	-1,95	-4,71	55,92
Section-30	30	4,83	3,40	-1,43	-6,37	50,33
Section-31	31	4,10	2,82	-1,28	-7,49	43,35

Section-32	32	3,34	2,76	-0,57	-8,42	35,34
Section-33	33	2,56	2,71	0,15	-8,63	26,75
Section-34	34	1,75	2,65	0,90	-8,11	18,32
Section-35	35	0,94	2,59	1,65	-6,84	10,79
Section-36	36	0,26	2,53	2,27	-4,86	4,89
Section-37	37	0,00	2,47	2,47	-2,44	1,22
Section-38	38	0,00	0,00	0,00	0,00	0,00

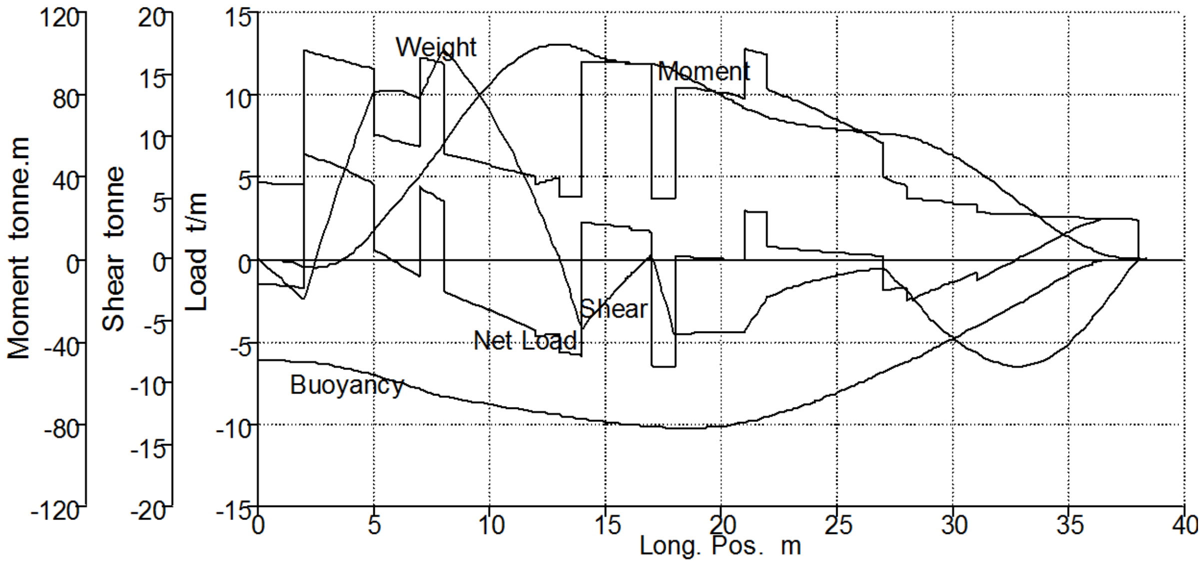


Fig.3.3 Longitudinal strength diagram

3.5. Local Loads

Design loads defined at this part are used for the resistance checks and obtain scantlings of structural elements of hull and deckhouses.

3.5.1. Loads

The following loads are considered in determining scantlings of hull structure:

- Impact pressures due to slamming,
- Sea pressures due to hydrostatic heads and wave loads,
- Internal loads.

External pressure determines scantlings of side and bottom structures, internal loads determine scantlings of deck structures.

3.5.2. Load points

Pressure on panels and strength members is considered uniform and equal to the pressure at the following load points:

- For panels:
  Lower edge of the plate, for pressure due to hydrostatic head and wave load
  Geometrical center of the panel, for impact pressure
- For strength members:
  Center of the supported area supported by the element.

3.5.3. Impact pressure on the bottom of hull

When slamming is expected to occur, the impact pressure, in kN/m^2, considered as acting on the bottom of hull is not less than:

$$p_{sl} = 70.\frac{\Delta}{S_r}.K_1.K_2.K_3.a_{CG} \qquad (14)$$

Where;

S_r : reference area equal to:

$$S_r = 0{,}7.\frac{\Delta}{T} = 88{,}4\ m^2 \qquad (15)$$

Δ = 263,8 tonnes, displacement

T = 2,09 m, draught of the craft

a_{CG} = 1,46g, design vertical acceleration at LCG

K_1 : longitudinal bottom impact pressure distribution factor:

- For $x/L < 0{,}5$: $K_1 = 0{,}5 + x/L$
- For $0{,}5 \leq x/L \leq 0{,}8$: $K_1 = 1{,}0$
- For $x/L > 0{,}8$: $K_1 = 3{,}0 - 2{,}5.x/L$

Where, x is the distance, in m, from the aft perpendicular to the load point.

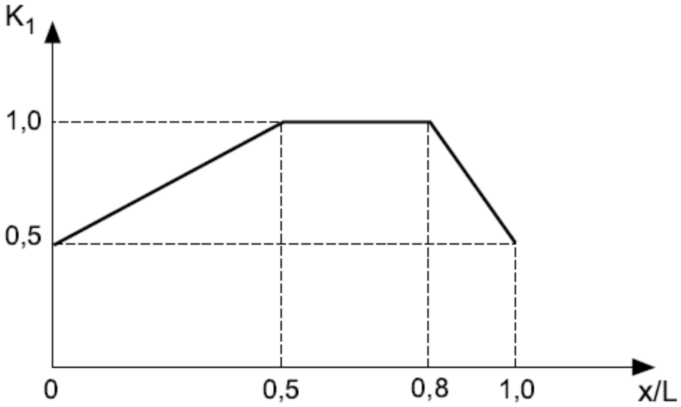


Fig.3.4 Longitudinal distribution of bottom impact pressure

K_2 : factor accounting for impact area, equal to:

$$K_2 = 0{,}455 - 0{,}35.\frac{u^{0{,}75}-1{,}7}{u^{0{,}75}+1{,}7} \gg \begin{matrix} 0{,}67\ for\ plating \\ 0{,}66\ for\ longitudinals \end{matrix} \qquad (16)$$

With:

- $K_2 \geq 0{,}50$ for plating,
- $K_2 \geq 0{,}45$ for stiffeners,
- $K_2 \geq 0{,}35$ for girders and floors,

$$u = 100.\frac{s}{S_r} \gg \begin{matrix} 0{,}31\ for\ plating \\ 0{,}34\ for\ longitudinals \end{matrix} \qquad (17)$$

Where;

s = 0,27 m^2, area supported by plating

s = 0,30 m^2, area supported by longitudinals

K_3, factor accounting for shape and deadrise of the hull, equal to:

$$K_3 = \frac{70-\alpha_d}{70-\alpha_{dCG}} = 1 \qquad (18)$$

Where;

$\alpha_{dCG} = 18{,}77^o$, deadrise angle measured at LCG,

$\alpha_d = 18{,}77^o$, deadrise angle between horizontal line and straight line joining the edges of respective area measured at the longitudinal position of the load point.

3.5.4. Sea pressures on side shell

The sea pressure, in kN/m^2, considered as acting on the bottom and side shell is not less than p_{smin}, defined in Table 3.4, nor less than:

- For $z \leq T$:

$$p_s = 10.\left(T + 0{,}75.S - \left(1 - 0{,}25.\frac{S}{T}\right).z\right) \qquad (19)$$

- For $z > T$:

$$p_s = 10.(T + S - z) \tag{20}$$

Where;

z: vertical distance, in m, from the moulded base line to load point. z is taken positively upwards.

S: as given, in m, in Table 3.4 with C_B taken not greater than 0,5.

Table 3.4 Sea pressure formulation

	S	p_{smin}
$x/L \geq 0{,}9$	$T \leq 0{,}36.a_{CG}.\frac{\sqrt{L}}{C_B} \leq 3{,}5.T$	$20 \leq \frac{L+75}{5} \leq 35$
$x/L \leq 0{,}5$	$T \leq 0{,}60.a_{CG}.\sqrt{L} \leq 2{,}5.T$	$10 \leq \frac{L+75}{5} \leq 20$

Between midship area and fore end ($0{,}5 < x/L < 0{,}9$), p_s varies in a linear way as follows:

$$p_s = p_{sFP} - \left(2{,}25 - 2{,}5.\frac{x}{L}\right).(p_{sFP} - p_{sM}) \tag{21}$$

3.5.5. *Sea pressures on deckhouses*

The pressure, in kN/m^2, considered as acting on walls of deckhouses is not less than:

$$p_{su} = K_{su}.\left(1 + \frac{X_1}{2.L(C_B + 0{,}1)}\right).(1 + 0{,}045.L - 0{,}38.z_1) \tag{22}$$

Where;

K_{su} : coefficient equal to:

- $K_{su} = 6{,}0$ for front walls of a deckhouse located directly on the main deck not at the fore end
- $K_{su} = 5{,}0$ for unprotected walls of the second tier, not located at the fore end
- $K_{su} = 1{,}5 + 3{,}5.b/B$ (with $3 \leq K_{su} < 5$) for sides of deckhouses, b being the breadth, in m, of the considered deckhouse
- $K_{su} = 3{,}0$ for the other walls

$x_1 = 11$ m, distance, from front walls or from wall elements to the midship perpendicular (for front walls or side walls aft of the midship perpendicular, x_1 is equal to 0)

$z_1 = 6{,}5$ m, distance from load point to waterline at draught T.

The minimum values of p_{su}, in kN/m^2, are considered are:

- For the front walls of the lower tier: $p_{su} = 6,5 + 0,06.L$
- For the sides and aft walls of the lower tier: $p_{su} = 4,0$
- For the other walls or sides: $p_{su} = 3,0$

3.5.6. Deck loads

The pressure, in kN/m^2, considered as acting on decks is given by formula:

$$p_d = p.(1 + 0,4.a_v) \qquad (23)$$

Where;

p : uniform pressure due to load carried, in kN/m^2.

a_v : design vertical acceleration defined in C3.3.1

- For weather decks and exposed areas without deck cargo:
  If $z_d \leq 2$: p = 6,0 kN/m^2
  If $z_d \geq 3$: p = 3,0 kN/m^2
- For weather decks and exposed areas with deck cargo:
  If $z_d \leq 2$: p = (p_c + 2) = 16,7 kN/m^2
- For enclosed accommodation decks not carrying goods:
  p = 3,0 kN/m^2

Where;

z_d = 1,86 m the vertical distance from deck to waterline at draught T.

p_c = 1,5 t/m^2 = 14,7 kN/m^2 uniform pressure due to deck cargo load is defined by customer.

Note: p can be reduced by 20% for primary supporting members and pillars under decks located at least 4 m above the waterline at draught T, excluding embarkation areas.

3.5.7. Pressures on tank structures

The pressure, in kN/m^2, considered as acting on tank structures is not less than the greater of:

$$p_{t1} = 9,81.h_1.\rho.(1 + 0,4.a_v) + 100.p_v \qquad (24)$$

$$p_{t2} = 9,81.h_2 \qquad (25)$$

Where;

h_1 : distance, in m, from load point to tank top

h_2 : distance, in m, from load point to top of over-flow or to a point located 1,5 m above the tank top, whichever is greater

ρ : liquid density, in t/m^3 (1,0 t/m^3 for water)

p_v : setting pressure, in bars, of pressure relief valve, when fitted (1,01 bars)

3.5.8. Pressures on subdivision bulkheads

The pressure, in kN/m^2, considered as acting on subdivision bulkheads is not less than:

$$p_{sb} = 9{,}81.h_3 \tag{26}$$

Where;

h_3 : distance, in m, from load point to bulkhead top.

3.6. Minimum Scantling Requirements

This chapter stipulates requirements for the scantlings of hull structures such as plating, stiffeners, and primary supporting members. The loads acting on such structures are calculated in accordance with the provision of C3.5.

The definitions and symbols used are presented on the following table:

Table 3.5 Definitions used in hull scantlings

Symbol	Value	Unit	Definition
s	0,30	m	spacing of stiffeners measured along the plating
l	1,0	m	overall span of stiffeners i.e. the distance between the supporting elements at the ends of the stiffeners
S	1,0	m	conventional scantling span of primary supporting members
b	0,90	m	actual surface width of the load bearing on primary supporting members
K	0,80	-	material factor defined in C3.2.2
μ	1,0	-	defined in below, which needs not be taken greater than 1,0

$$\mu = \sqrt{1{,}1 - 0{,}5.\left(\frac{s}{l}\right)^2} = 1{,}03 \tag{27}$$

Table 3.6 Design parameters for scantling calculations

	Pressure	Element	Material	σ_{am} (N/mm^2)	τ_{am} (N/mm^2)
Bottom	impact pressure p_{sl} as defined in C3.5.3	Plating	H321-5083	95/K = 118,75	-
		Ord. stiffeners	H111-5083	70/K = 87,50	45/K = 56,25
		Floors	H321-5083	70/K = 87,50	45/K = 56,25
Side	p : sea pressure p_s as defined in C3.5.5	Plating	H321-5083	85/K = 106,25	-
		Ord. stiffeners	H111-5083	70.C_A/K = 87,50	45/K = 56,25
		Stringers	H321-5083	70/K–σ_a = 87,50	45/K = 56,25
Deck	p : deck pressure p_d as defined in C3.5.6	Plating	H321-5083	85/K = 106,25	-
		Ord. stiffeners	H111-5083	70.C_A/K = 26,25	45/K = 56,25
		Deck transverses	H321-5083	70/K = 87,50	45/K = 56,25
		Deck girders		70.C_A/K = 26,25	
Deckhouse walls	p : sea pressure p_{su} as defined in C3.5.5	Plating	H321-5083	85/K = 106,25	-
		Ord. stiffeners	H111-5083	70/K = 87,50	45/K = 56,25
		Girders	H111-5083	70/K = 87,50	45/K = 56,25
Tank bulkheads	p_t : pressure on tank structure as defined in C3.5.7	Plating	H321-5083	85/K = 106,25	-
		Ord. stiffeners	H111-5083	70/K = 87,50	45/K = 56,25
		Girders	H321-5083	70/K = 87,50	45/K = 56,25
Subdivision bulkheads	p_{sb} : pressure on subdivision bulkhead as defined in C3.5.8	Plating	H321-5083	95/K = 118,75	-
		Vertical stiffeners	H111-5083	95/K = 118,75	55/K = 68,75
		Vertical girders	H111-5083	95/K = 118,75	55/K = 68,75

Where;

σ_a = 0,015 N/mm^2 being the stress induced by the normal force in side transverses due to deck loads transmitted by deck beams,

e : ratio between permissible and actual hull girder longitudinal bending stresses as:

$$e = \sigma_p/\sigma_{bI} \tag{28}$$

$$C_A = 1{,}3 - \frac{1}{e} \leq 1 \tag{29}$$

Table 3.7 Coefficients e and C_A

Position	e	C_A
Bottom	1,00	0,30
z above	3,45	1,00
Deck	1,00	0,30

3.6.1. Longitudinal strength

For craft with length less than or equal to 65 m, longitudinal strength calculations are, as a rule, is carried out at the midship section.

Longitudinal stress, in N/mm^2, in each point of the structures contributing to the craft longitudinal strength is obtained from the following equations:

- At bottom:

$$\sigma_{bI} = \frac{M_{bI}}{W_b}.10^{-3} = 105{,}46\ N/mm^2 \tag{30}$$

- At main deck:

$$\sigma_{bI} = \frac{M_{bI}}{W_d}.10^{-3} = 105{,}46\ N/mm^2 \tag{31}$$

- At height z above the bottom:

$$\sigma_{bI} = M_{bI}.\left(\frac{1}{W_b} - \left(\frac{1}{W_b} + \frac{1}{W_d}\right).\frac{z}{D}\right).10^{-3} = 25{,}36\ N/mm^2 \tag{32}$$

Where;

z = 1,5 m,

M_{bI} = 14586 kN.m, total bending moment defined in C3.4.

W_b, W_d = 0,1383 m^3, rule section modulus respectively at bottom and main deck at the stress calculation point of the craft section under consideration.

The values of σ_{bI} are not to exceed σ_p, with:

$$\sigma_p = \frac{70}{K} = 87{,}50\ N/mm^2 \tag{33}$$

Therefore, σ_{bI} = 87,50 N/mm^2 is taken into account for bottom and deck structures.

3.6.2. Plating

The thickness, in mm, required for the purposes of resistance to design pressure, is given by the formula:

$$t = 22{,}4.\mu.s.\sqrt{\frac{p}{\sigma_{am}}} \tag{34}$$

Considerations:

- The thickness of plates connected to the stern frame, or in way of propeller shaft brackets is adopted as 1,5 times the thickness of the adjacent plating.

- Where tanks are arranged on sides, the biggest design pressure is taken into account between sea pressure and tank bulkhead pressure.
- The thickness of the collision bulkhead is calculated from the formula given above, multiplied by 1,15.

Table 3.8 Plating thicknesses

	x	z	p Design pressure	t_{min} Min. thickness	t_{req} Min. required thickness	t Chosen value
Unit	[m]	[m]	[kN/m^2]	[mm]	[mm]	[mm]
Bottom shell	18,46	0,25	200,69	4,5	8,75	10
Sea intakes	14,00	0,25	173,75	4,5	7,91	10
Side shell	18,46	1,50	125,39*	3,8	5,48	7
Deck	18,46	3,95	26,43	2,5	3,35	10
Deck (Fr.22 - Fr.33)	24,00	3,95	10,54	2,5	2,12	6
Deckhouse	24,00	6,45	5,27	2,5	2,87**	5
Deckhouse boundary walls	24,00	5,25	7,15	2,5	3,34**	5
Deckhouse front walls	33,00	5,75	8,72	2,5	3,69**	5
Bridge deck	24,00	8,95	5,27	2,5	2,87**	5
Bridge deck boundary walls	24,00	7,50	3,00	2,5	2,17**	5
Subdivision bulkheads	18,00	0,25	37,28	2,5	3,03	6
Collision bulkhead	33,00	0,20	43,65	2,88	3,28	7
Tank bulkheads	18,46	1,06	132,22	2,5	5,62	6
Tank tops	18,46	3,05	101,33	2,5	4,92	5
Bulwark	24,00	4,05	40,46	3,8	5,53***	7
Transom	0	1,20	-	-	-	12
Tunnels	2,00	1,20	-	-	13,10	15

* Tank bulkhead pressure is taken into account.
** Stiffener spacing is 600 mm.
*** Stiffener spacing is 400 mm.

3.6.3. *Ordinary stiffeners*

The section modulus Z, in cm^3, and the shear area A_t, in cm^2, required for the purpose of supporting the design pressure transmitted by the plating, are given by the following formula:

$$Z = 1000.\frac{l^2.s.p}{m.\sigma_{am}} \tag{35}$$

$$A_t = 5.\frac{l.s.p}{\tau_{am}} \tag{36}$$

Where m is a coefficient depending on the type of stiffener and on whether there are rule brackets at the end of each individual span. The values for m are indicated in Table 3.9.

Table 3.9 Coefficient m

Type of stiffener	m
Continuous longitudinal stiffeners without Rule brackets at the ends of span	12
Longitudinal and transverse stiffeners with Rule brackets at the ends of span	19
Longitudinal and transverse stiffeners with Rule brackets at one end of span	15
Non-continuous longitudinal stiffeners and transverse stiffeners without Rule brackets at the ends of span	8

m = 15 is adopted for longitudinal structures.

Considerations:

- These formulae are valid for a stiffener whose web is perpendicular to the plating, or forms an angle to the plating of less than 15°. In the case of stiffeners whose web forms an angle $\alpha>15°$ to the perpendicular to the plating, the required modulus and shear area is obtained from the same formulae, dividing the values of Z and A_t by Cos(α).
- The section modulus of ordinary stiffeners is calculated in association with an effective width of plating equal to the spacing of the stiffeners, without exceeding 20 per cent of the span.

  Hence 0,2.*l* = 0,2 m effective width l_b = 0,2 m is adopted.
- For aluminium alloy stiffeners, the web thickness is not less than:
  - 1/15 of the depth, for flat bars,
  - 1/35 of the depth, for other sections,
- And the thickness of the face plate is to not less than 1/20 of its width.
- All longitudinals are continuous through the transverse elements. Where they are interrupted at a transverse watertight bulkhead, continuous brackets are positioned through the bulkhead so as to connect the ends of longitudinals.
- The section modulus, shear area and welding section required for the ordinary stiffeners of the collision bulkhead are calculated from the formulae given above, considering σ_{am} and τ_{am} divided respectively by 1,15 and 1,05.

In general, the resistant weld section A_w, in cm^2, connecting the ordinary stiffeners to the web of primary members, is not less than:

$$A_w = \varphi.p.s.l.K.10^{-3} \tag{37}$$

Where;

φ : coefficient as indicated below:

If the weld is parallel to the reaction on primary member, $\varphi = 200$

If the weld is perpendicular to the reaction on primary member, $\varphi = 160$

p : design pressure, in kN/m^2, acting on the secondary stiffeners, as defined on Table 3.6 for various hull regions,

s : spacing of ordinary stiffeners, in m,

l : span of ordinary stiffeners, in m,

K : greatest material factor of ordinary stiffener and primary member, defined in C3.2.2.

Table 3.10 Ordinary stiffeners

	x	z	p Design Press.	Z Req. sec. Mod.	A_t Req. shear area	A_w Res. weld sec.	Chosen Typical T Bar	Z Sec. mod.	A_t Shear area
Unit	[m]	[m]	[kN/m^2]	[cm^3]	[cm^2]	[cm^2]	[mm]	[cm^3]	[cm^2]
Bottom	18,46	0,25	203,40	46,50	5,42	9,76	100x5+50x9	54,4	9,05
Side	18,46	1,50	54,45	12,44	1,45	1,61	60x60x4	18,1	4,65
Deck	18,46	3,95	26,43	20,14	0,70	1,27	100x5+50x9	54,4	9,05
Deck (After Fr.22)	24,00	3,95	10,54	8,03	0,28	0,51	60x60x4	19,1	4,65
Deckhouse	24,00	6,45	5,27	10,1*	0,28	0,51	60x40x5 - L	15,6	4,75
Deckhouse walls	24,00	5,25	7,15	4,08*	0,38	0,69	60x40x5 - L	15,6	4,75
Deckhouse front walls	33,00	5,75	8,72	4,98*	0,47	0,84	60x40x5 - L	15,6	4,75
Bridge deck	24,00	8,95	5,27	10,1*	0,28	0,51	60x40x5 - L	15,6	4,75
Bridgedeck walls	24,00	7,70	3,00	1,71*	0,16	0,29	60x40x5 - L	15,6	4,75
Subdivision bulkheads	18,00	0,25	37,28	6,28	0,81	1,79	60x60x4	17,8	4,65
Tank bulkheads	18,46	1,50	125,39	28,66	3,34	6,02	80x5+50x7	33,7	7,15
Tank tops	18,46	3,05	101,33	18,28**	2,70	4,86	60x60x4	17,5	4,65
Bulwark	24,00	4,05	40,46	12,33 ***	1,44	2,59	60x40x5 - L	16,3	4,75
Transom	0	1,20	-	-	-	-	80x5+50x7	36,3	7,15

*Stiffener spacing is 600 mm and without rule brackets (m=12)

**With rule brackets at 2 ends of the span (m=19).

***Stiffener spacing is 400 mm.

3.6.4. Primary supporting members

The primary supporting members (floors, frames, beams) are to form continuous transverse frames.

The section modulus Z, in cm^3, and the shear area A_t, in cm^2, required for the purpose of supporting the design pressure transmitted by the ordinary stiffeners, are given by the following formula:

$$Z = 1000.\frac{S^2.b.p}{m.\sigma_{am}} \tag{38}$$

$$A_t = 5.\frac{S.b.p}{\tau_{am}} \tag{39}$$

Where m is a coefficient depends on support conditions at the ends of the girder span, assumed to be equal to:

- 10 for floors, bottom girders, side frames, deck beams and girders, vertical webs of superstructures
- 12 for side stringers.

Considerations:

- The section modulus of primary supporting members is calculated in association with attached plating as l_b = 0,3 m.
- For aluminium stiffeners, the following geometric ratios are adopted, where the compressive stress not known:
  - The web thickness is not less than 1/35 of web depth,
  - The face plate thickness is not less than 1/20 of face plate breadth (1/10 for face plates which are not symmetrical with respect to the web).
- In way of main machinery seatings, girders are positioned extending from the bottom to the foundation plate of main engines. In this longitudinally framed bottom as B > 8 m, side girders are positioned in such a way to divide the floor span into approximately equal parts.
- The section modulus, shear area and welding section required for the primary supporting members of the collision bulkhead are calculated from the formulae given above, considering σ_{am} and τ_{am} divided respectively by 1,3 and 1,2.

Table 3.11 Primary supporting members

	x	z	p Design pressure	Z Required section modulus	A_t Required shear area	Chosen Typical T Bar	Z Section modulus	A_t Shear area
Unit	[m]	[m]	[kN/m^2]	[cm^3]	[cm^2]	[mm]	[cm^3]	[cm^2]
Bottom girders	18,46	0,25	203,40	209,21	16,27	255x7+70x5	281,5	24,5
Floors	18,46	0,25	203,40	209,21	16,27	305x7+70x5	213,2	21,0
Side stringers	18,46	1,50	125,39*	86,85	8,11	165x70x5	93,3	11,5
Frames	18,46	1,50	125,39*	86,85	8,11	165x70x5	93,3	11,5
Deck girders	18,46	3,95	26,43	90,61	2,11	165x70x5	96,6	11,5
Deck transverses	18,46	3,95	26,43	27,18	2,11	165x70x5	96,6	11,5
Deckhouse girders	24,00	6,45	5,27	36,15**	0,84	100x5+50x9	54,4	9,05
Deckhouse transverses	24,00	6,45	5,27	10,85**	0,84	100x5+50x9	54,4	9,05
Deckhouse boundary walls	24,00	5,25	7,15	12,25**	1,14	100x5+50x9	54,4	9,05
Deckhouse front walls	33,00	5,75	8,72	14,95**	1,40	100x5+50x9	54,4	9,05
Bridge deck girders	24,00	8,95	5,27	36,15**	0,84	100x5+50x9	54,4	9,05
Bridge deck transverses	24,00	8,95	5,27	10,85**	0,84	100x5+50x9	54,4	9,05
Bridge deck boundary walls	24,00	7,70	3,00	5,14**	0,48	100x5+50x9	54,4	9,05
Subdivision bulkheads	18,00	0,25	37,28	28,25	2,44	80x5+50x7	33,9	7,15
Tank bulkheads	18,46	1,80	120,73	82,79***	6,44	165x70x5	91,9	11,5
Tank tops	18,46	3,05	101,33	69,48***	5,40	165x70x5	90,3	11,5
Transom	0	1,20	-	-	-	165x70x5	98,3	11,5

*Tank bulkhead pressure is taken into account.
**Primary supporting members spacing, b = 1800 mm.
***Primary supporting members spacing, b = 600 mm.

3.6.5. Pillars

i. Loads on pillars

Where pillars are aligned, the compressive load Q, in kN, is equal to the sum of loads supported by the pillar considered and those supported by the pillars located above, multiplied by a weighting factor.

The weighting factor depends on the relative position of each pillar with respect to that considered. This coefficient is equal to:

- 1,0 for the pillar considered,
- 0,9 for the pillar immediately above (first pillar of the line),
- $0,81 = 0,9^2$ for the following pillar (second pillar of the line),
- $0,729 = 0,9^3$ for the third pillar of the line,
- In general, $0,9^n$ for the n^{th} pillar of the line, but not less than $0,9^7 = 0,478$.

ii. Critical stress for overall buckling of pillars

For global buckling behavior of pillars made of aluminium alloy (without heat treatment), the critical stress, σ_C, in N/mm^2, is given by the formula:

$$\sigma_c = \frac{R'_{p\,0,2}}{0,85+0,25.\left(\frac{f.l}{r}\right)}.C = 28,92\ N/mm^2 \tag{40}$$

Where:

$R'_{p\ 0,2} = 115\ N/mm^2$ minimum as-welded guaranteed yield stress of 6082 series aluminium alloy used,

l = 2,65 m, length of the pillar,

A = 28,27 cm^2, area of the pillar cross section,

I = 290 cm^4, minimum moment of inertia of the pillar cross section,

r : minimum radius of gyration of the pillar cross section, equal to:

$$r = \sqrt{I/A} = 3,20\ cm \tag{41}$$

f = 1 coefficient given in Fig.3.5 depending on the conditions of fixing of the pillar.

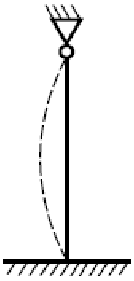
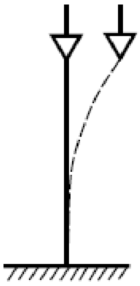
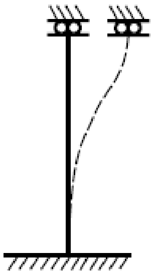
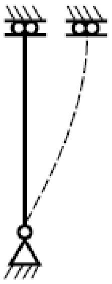
Conditions of fixity					
f	0,7	1,0	2,0	1,0	2,0

Fig.3.5 Coefficient f

C : coefficient is equal to:

- For alloys without heat treatment:

$$C = \frac{1}{1+\lambda+\sqrt{(1+\lambda)^2-(0{,}68.\lambda)}} = 0{,}24 \tag{42}$$

- For alloys with heat treatment:

$$C = \frac{1}{1+\lambda+\sqrt{(1+\lambda)^2-(3{,}2.\lambda)}} = 0{,}32 \tag{43}$$

$$\sigma_E = \frac{69{,}1}{\left(\frac{f.l}{r}\right)^2} = 100{,}94\ N/mm^2 \tag{44}$$

$$\lambda = \frac{R'_{p\,0{,}2}}{\sigma_E} = 1{,}14 \tag{45}$$

iii. Critical stress for local buckling of pillars

For local buckling behavior of a pillars made of aluminium alloy, the admissible stress σ_{cl}, in N/mm^2, is given by the formula:

$$\sigma_{cI} = 2.R'_{p\,0{,}2}.C = 101{,}6\ N/mm^2 \tag{46}$$

Where;

C : coefficient for alloys without heat treatment:

$$C = \frac{1}{1+\lambda+\sqrt{(1+\lambda)^2-(0{,}68.\lambda)}} = 0{,}41 \tag{47}$$

$$\lambda = \frac{R'_{p\,0{,}2}}{\sigma_{EI}} = 0{,}27 \tag{48}$$

For tubular pillars with a circular cross-section, the stress σ_{EI}, in N/mm^2, is given by:

$$\sigma_{EI} = 43000.\left(\frac{t}{D}\right)^2 = 430\ N/mm^2 \tag{49}$$

D = 100 mm, outer diameter,

t = 10 mm, plating thickness.

iv. Scantlings of pillars

The scantlings of pillars are to comply with the following requirements:

$\sigma \leq \sigma_c$

$\sigma \leq \sigma_{cl}$

Where;

σ : compressive stress, in N/mm^2, in the pillar due to load Q,

$$\sigma = 10.\mathrm{Q}/\mathrm{A} \tag{50}$$

A = 28,27 cm^2, being the cross-sectional area of the pillars,

σ_c = 28,92 N/mm^2, overall buckling critical stress, as defined above,

σ_{cl} = 101,6 N/mm^2, local buckling critical stress, as defined above.

The maximum allowable axial load for alloys without heat treatment is the smaller of the following two values:

$$P_c = \sigma_c.A.10^{-1} = 81{,}77\ kN \tag{51}$$

$$P_{cI} = \sigma_{cI}.A.10^{-1} = 287{,}28\ kN \tag{52}$$

3.6.6. Main machinery seatings

The scantling of main machinery seatings and thrust bearings are adequate in relation to the weight and power of engines and static and dynamic forces transmitted by the propulsive installation.

Transverse and longitudinal members supporting the seatings are located in line with floors and bottom girders.

They are so arranged as to avoid discontinuity and ensure sufficient accessibility for welding of joints and for surveys and maintenance.

Seatings are located above the floors and adequately connected to the latter and to the girders located below.

Two girders are fitted in way of each main engine.

Due to there is no any remarkable rules for aluminium alloy structured engine foundations, scantling is created by previous experiences, afterwards this approach is approved by finite element analysis which will be expressed on next chapter.

Adopted scantling for machinery seatings:

Bedplate flange: 250x25 mm (net cross-sectional area is 62,5 cm^2)

Bedplate net thickness: 25 mm

Total web net thickness of girders: 12x2 = 24 mm

Web net thickness of floors: 10 mm

Where the engine has following futures:

P = 1343 kW, maximum power of the engine,

n_r = 1900 rpm, number of revolutions per minute of the engine shaft at power equal to P,

L_E = 2,5 m, effective length of the engine foundation plate required for bolting the engine to the seatings.

3.6.7. Design section modulus

Section modulus for midship section is calculated by considering all the elements contributing to longitudinal strength after determining all members at the midship section.

Table 3.12 Design section modulus

Symbol	Value	Unit	Definition
$\sum A_i$	297560	mm^2	Total cross sectional area
$\sum G$	7,14E+08	mm^3	Total static moment
Z_g	2400	mm	Neutral axis from moulded base line
$\sum I_{total}$	6,04E+11	mm^4	Total moment of inertia
W_d	0,3922	m^3	Design section modulus at main deck
W_b	0,2455	m^3	Design section modulus at bottom deck
W_b, W_d	0,1383	m^3	Rule section modulus respectively at bottom and main deck

3.7. Buckling Strength Control

These requirements are applied to alloy plates and girders subjected to compressive load, to calculate their buckling strength.

3.7.1. *For deck plate subjected to cargo load*

Elastic buckling and shear stresses of deck plate:

$$\sigma_E = 0{,}9.m_c.E.\varepsilon.\left(\frac{t}{1000.a}\right)^2 = 308\ N/mm^2 \tag{53}$$

$$\tau_E = 0{,}9.m_t.E.\left(\frac{t}{1000.a}\right)^2 = 399\ N/mm^2 \tag{54}$$

Where;

E = 70000 N/mm^2, Young's modulus for aluminium alloy structures,

m_c = 4, for uniform compression (Ψ=1) it is equal to: $(1+\Upsilon^2)^2$

m_t = 5,34 +4 (a / b)^2 = 5,7

Ψ : ratio between smallest and largest compressive stresses when the stress presents a linear variation across the panel (0 ≤ Ψ ≤ 1),

ϒ = c/d = 1,

t = 10 mm, plate thickness,

a = 0,3 m, shorter side of plate,

b = 1,0 m, longer side of plate.

c = 1 m, unloaded side of plate,

d = 1 m, loaded side of plate,

ε : for edge d stiffened by angle or T-section:

- If ϒ ≥ 1 : ε = 1,1
- If ϒ < 1 : ε = 1,25

The critical buckling stress σ_c :

$$if\ \sigma_E \le \frac{R_{p0,2}}{2},\quad \sigma_c = \frac{\sigma_E}{SF_1} = 308\ N/mm^2 \tag{55}$$

$$if\ \sigma_E > \frac{R_{p0,2}}{2},\quad \sigma_c = \frac{R_{p0,2}}{SF_1}.\left(1-\frac{R_{p0,2}}{4.\sigma_E}\right) = 177{,}5\ N/mm^2 \tag{56}$$

The critical buckling stress τ_c :

$$if\ \tau_E \le \frac{R_{p0,2}}{2\sqrt{3}},\quad \tau_c = \frac{\tau_E}{SF_1} = 399\ N/mm^2 \tag{57}$$

$$if\ \tau_E > \frac{R_{p0,2}}{2\sqrt{3}},\quad \tau_c = \frac{R_{p0,2}}{SF_1.\sqrt{3}}.\left(1-\frac{R_{p0,2}}{4.\tau_E.\sqrt{3}}\right) = 114{,}5\ N/mm^2 \tag{58}$$

Where;

$R_{p\ 0,2}$ = 215 N/mm^2, minimum guaranteed yield stress of H321-5083 series aluminum alloy, in delivery conditions,

SF_1 = 1,0 safety factor defined as:

Table 3.13 Safety factors

	Local loads	Overall loads
Plating	1,00	1,00
Secondary stiffeners	1,00	1,33
Primary structure	1,00	1,53

By using general formulations, actual compressive values of σ and τ are obtained as presented on following table:

Table 3.14 Actual compressive values for deck plate panel

Symbol	Value	Unit	Definition
M_{bIS}	14586E+06	N.mm	Hull girder bending moment due to still water loads and wave induced loads as defined in C3.4.1
I_{total}	6,04E+11	mm^4	Total moment of inertia of the midship section
Z_g	2400	mm	Neutral axis from moulded base line
y	1600	mm	Distance of the centroid of the area from neutral axis
W	3,775E+08	mm^3	Section modulus
σ_1	38,64	N/mm^2	Primary response due to hull girder bending
p	0,0215	N/mm^2	Dynamic load due to vertical acceleration
s	300	mm	Stiffener spacing
l	1000	mm	Frame spacing
t	10	mm	Plate thickness
σ_3	9,68	N/mm^2	Tertiary response due to local plate bending (at the center)
σ	48,32	N/mm^2	Actual compressive stress on deck plate panel
T_{bI}	1265000	N	Total shear force acting on midship section as defined in C3.4.3
A_{sh}	1258333	mm^2	Hull girder shear area
τ_1	1,01	N/mm^2	Hull girder shear stress (negligible)
F_i	6450	N	Dynamic load due to vertical acceleration (over 0,3 m^2)
A_i	3000	mm^2	Cross sectional area of plate
τ_2	2,15	N/mm^2	Local shear stress
τ	3,16	N/mm^2	Shear stress acting on deck plate panel (negligible)

Where;

p = 0,0215 N/mm^2, the vertical component of dynamic load due to vertical acceleration is obtained by the following equation:

$$F_V = m.a_v \tag{59}$$

m = 450 kg over 0,3 m^2 plate area, design load as defined in C.2.1

a_v = 1,46g, vertical acceleration as defined in C3.3.1.

σ_3 : The maximum local bending strength of plate is equal to:

$$\sigma = \frac{\beta.p.s^2}{t^2} \tag{60}$$

If the aspect ratio of the plate (*l/s=0,33*) is higher than 2, β = 0,5 is used as correction factor for the aspect ratio.[6]

A_{sh} : hull girder shear area is equal to:

$$A_{sh} = I_{total}.\frac{t}{m} \tag{61}$$

t = 10mm, thickness of the structure at given distance from the neutral-axis of the total cross-sectional area,

m = 48E+05, static moment about neutral axis of the cumulative cross-sectional area starting from shear stress free end to the given distance from neutral axis,

Comparison of actual compressive values and critical stresses for deck plate:

$$\sigma = 48{,}32 \text{ N/mm}^2 \ll \sigma_c = 177{,}5 \text{ N/mm}^2$$

$$\tau = 3{,}16 \text{ N/mm}^2 \ll \tau_c = 114{,}5 \text{ N/mm}^2$$

3.7.2. For bottom plate subjected to impact pressure

By using same approach, below results are obtained for bottom plate.

The critical buckling stress σ_c :

$$if\ \sigma_E \leq \frac{R_{p0,2}}{2}, \quad \sigma_c = \frac{\sigma_E}{SF_1} = 308\ N/mm^2 \tag{62}$$

$$if\ \sigma_E > \frac{R_{p0,2}}{2}, \quad \sigma_c = \frac{R_{p0,2}}{SF_1}.\left(1 - \frac{R_{p0,2}}{4.\sigma_E}\right) = 177{,}5\ N/mm^2 \tag{63}$$

The critical buckling stress τ_c :

$$if\ \tau_E \leq \frac{R_{p0,2}}{2\sqrt{3}}, \quad \tau_c = \frac{\tau_E}{SF_1} = 399\ N/mm^2 \tag{64}$$

$$if\ \tau_E > \frac{R_{p0,2}}{2\sqrt{3}}, \quad \tau_c = \frac{R_{p0,2}}{SF_1.\sqrt{3}}.\left(1 - \frac{R_{p0,2}}{4.\tau_E.\sqrt{3}}\right) = 114{,}5\ N/mm^2 \tag{65}$$

Where;

$R_{p0,2}$ = 215 N/mm^2, minimum guaranteed yield stress of H321-5083 series aluminum alloy, in delivery conditions,

σ_E = 308 N/mm^2,

τ_E = 399 N/mm^2,

SF_1 = 1,0 safety factor as defined on Table 3.13

Table 3.15 Actual compressive values for bottom plate panel

Symbol	Value	Unit	Definition
M_{bIS}	14586E+06	N.mm	Hull girder bending moment due to still water loads and wave induced loads as defined in C3.4.1
$\sum I_{total}$	6,04E+11	mm^4	Total moment of inertia of the midship section
Z_g	2400	mm	Neutral axis from moulded base line
y	2170	mm	Distance of the centroid of the area from neutral axis
W	2,784E+08	mm^3	Section modulus
σ_1	52,40	N/mm^2	Primary response due to hull girder bending
p	0,2	N/mm^2	Dynamic pressure due to impact load (for full-load condition at V=26kn)
s	300	mm	Stiffener spacing
l	1000	mm	Frame spacing
t	10	mm	Plate thickness
σ_3	90	N/mm^2	Tertiary response due to local plate bending (at the center)
σ	142,4	N/mm^2	Actual compressive stress on deck plate panel
T_{bI}	1265000	N	Total shear force as defined in C3.4.3
A_{sh}	927803	mm^2	Hull girder shear area
τ_1	1,36	N/mm^2	Hull girder shear stress (negligible)
F_i	60000	N	Dynamic pressure due to impact load (over 0,3 m^2)
A_i	3000	mm^2	Cross sectional area of plate
τ_2	20	N/mm^2	Local shear stress
τ	21,36	N/mm^2	Shear stress acting on deck plate panel

Comparison of actual compressive values and critical stresses for bottom plate:

$$\sigma = 142{,}4 \text{ N/mm}^2 \ll \sigma_c = 177{,}5 \text{ N/mm}^2$$

$$\tau = 21{,}36 \text{ N/mm}^2 \ll \tau_c = 114{,}5 \text{ N/mm}^2$$

3.7.3. For deck girder

The elastic flexural buckling stress σ_E :

$$\sigma_E = 69{,}1.\left(\frac{r}{1000.c}\right)^2.m.10^4 = 5366\ N/mm^2 \tag{66}$$

Where;

r : gyration radius, equal to:

$$r = 10\sqrt{\frac{I}{S+\varphi.t.10^{-2}}} = 62{,}3\ mm \tag{67}$$

I = 1223 cm^4, moment of inertia of the girder, calculated with a plate flange of width equal to φ,

φ = 200 (smaller of 800.a and 200.c)

S = 11,5 cm^2, area of the cross section of the stiffener excluding attached plating.

m = 2, coefficient depending on boundary conditions:

- m = 1 for a stiffener simply supported at both ends,
- m = 2 for a stiffener simply supported at one end and fixed at the other one,
- m = 4 for a stiffener fixed at both ends.

Local elastic buckling stress σ_E, for built up stiffeners with symmetrical flange:

- Web:

$$\sigma_E = 27.\left(\frac{t_w}{h_w}\right)^2.10^4 = 264\ N/mm^2 \tag{68}$$

- Flange:

$$\sigma_E = 11.\left(\frac{t_f}{h_f}\right)^2.10^4 = 561\ N/mm^2 \tag{69}$$

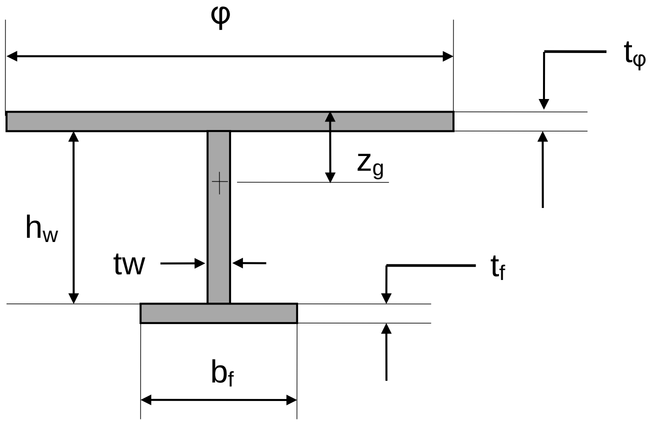
Where;

h_w = 160 mm, web height,

t_w = 5 mm, web thickness,

b_f = 70 mm, flange width,

t_f = 5 mm, flange thickness.



The critical buckling stress σ_c :

$$if\ \sigma_E \le \frac{R_{p0,2}}{2},\quad \sigma_c = \frac{\sigma_E}{SF_1} = 172\ N/mm^2 \tag{70}$$

$$if\ \sigma_E > \frac{R_{p0,2}}{2},\quad \sigma_c = \frac{R_{p0,2}}{SF_1}.\left(1-\frac{R_{p0,2}}{4.\sigma_E}\right) = 72\ N/mm^2 \tag{71}$$

Where;

$R'_{p0,2}$ = 125 N/mm^2, minimum as-welded guaranteed yield stress of H321-5083 series aluminum alloy,

σ_E = 264 N/mm^2, either overall elastic buckling stress or local buckling stress, whichever is the less.

SF_1 = 1,53 safety factor defined on Table 3.13

Table 3.16 Actual compressive values for deck girder

Symbol	Value	Unit	Definition
M_{bIS}	14586E+06	N.mm	Hull girder bending moment due to still water loads and wave induced loads as defined in C3.4.1
$\sum I_{total}$	6,04E+11	mm^4	Total moment of inertia of the midship section
Z_g	2400	mm	Neutral axis from moulded base line
Z	1475	mm	Distance of the centroid of the area from neutral axis
W	4,1E+08	mm^3	Section modulus
σ_1	35,62	N/mm^2	Primary response due to hull girder bending
p	0,0215	N/mm^2	Dynamic pressure due to cargo load
s	300	mm	Stiffener spacing
l	1000	mm	Frame spacing
M_i	5,38E+05	N.mm	Local bending moment
Z_i	139,5	mm	Neutral axis of considered beam
I_{x1}	1,347E+07	mm^4	Moment of inertia of considered beam
σ_2	5,57	N/mm^2	Secondary response due to local bending of girder
σ	41,19	N/mm^2	Actual compressive stress on deck girder

Where;

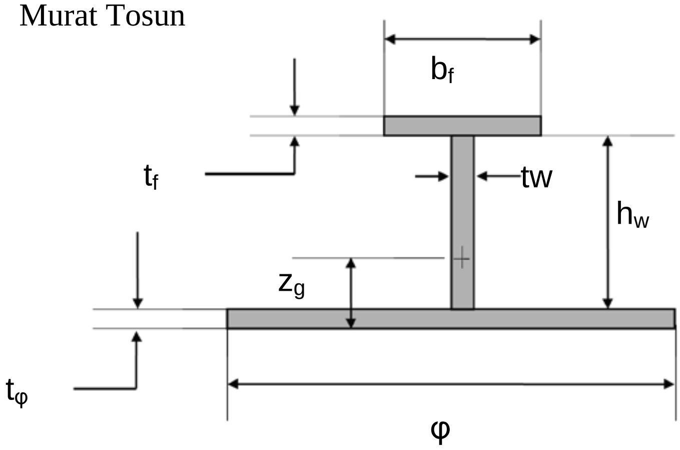
M_i : the maximum local bending moment considering the girder is fixed at both ends:

$$M_i = \frac{p.s.l^2}{12} \tag{72}$$

Comparison of actual compressive load and critical stress for deck girder:

$$\sigma = 41{,}19 \text{ N/mm}^2 \ll \sigma_c = 72 \text{ N/mm}^2$$

3.7.4. *For bottom side girder*



h_w = 300 mm, web height,

t_w = 7 mm, web thickness,

b_f = 70 mm, flange width,

t_f = 5 mm, flange thickness.

By using same approach, below results are obtained for bottom side girder.

The critical buckling stress σ_c :

$$if\ \sigma_E \leq \frac{R_{p0,2}}{2}, \quad \sigma_c = \frac{\sigma_E}{SF_1} = 96{,}1\ N/mm^2 \tag{73}$$

$$if\ \sigma_E > \frac{R_{p0,2}}{2}, \quad \sigma_c = \frac{R_{p0,2}}{SF_1}.\left(1 - \frac{R_{p0,2}}{4.\sigma_E}\right) = 64{,}3\ N/mm^2 \tag{74}$$

Where;

$R'_{p0,2}$ = 125 N/mm^2, minimum as-welded guaranteed yield stress of H321-5083 series aluminum alloy,

σ_E = 147 N/mm^2,

SF_1 = 1,53 safety factor defined on Table 3.13

Table 3.17 Actual compressive values for bottom side girder

Symbol	Value	Unit	Definition
M_{bIS}	14586E+06	N.mm	Hull girder bending moment due to still water loads and wave induced loads as defined in C3.4.1
$\sum I_{total}$	6,04E+11	mm^4	Total moment of inertia of the midship section
Z_g	2400	mm	Neutral axis from moulded base line
Z	1730	mm	Distance of the centroid of the area from neutral axis
W	3,49E+08	mm^3	Section modulus
σ_1	41,78	N/mm^2	Primary response due to hull girder bending
p	0,2	N/mm^2	Dynamic pressure due to impact load (for full-load condition at V=26kn)
s	300	mm	Stiffener spacing
l	1000	mm	Frame spacing
M_i	5,0E+06	N.mm	Local bending moment
Z_i	84,5	mm	Neutral axis of considered beam
I_{x1}	6,5E+07	mm^4	Moment of inertia of considered beam
σ_2	6,51	N/mm^2	Secondary response due to local bending of girder
σ	48,29	N/mm^2	Actual compressive stress on bottom side girder

Comparison of actual compressive load and critical stress for bottom side girder:

$$\sigma = 48{,}29\ \text{N/mm}^2 \ll \sigma_c = 64{,}3\ \text{N/mm}^2$$

3.8. Propeller Pockets Design

Tunnels which are also called as “propeller pockets” are provided in ship hulls to accommodate propellers under reduced draught conditions, thereby avoiding reduction of propeller diameter and consequent loss of efficiency.[7]

After preliminary design of propulsion system, high shaft angle is appeared on the hull. To prevent loss of efficiency of the propulsion system, propeller pockets are provided at the bottom of the hull.

A partial tunnel allows large-diameter propellers to be fitted which may reduce cavitation or reduce shaft angle to minimize the variation in hydrodynamic blade angle.

The propeller and tunnel design process must be integrated as they are hydrodynamically mutually interactive; the tunnel delivers water flow to the propeller and influences the exit velocity distribution. The propeller induces flow from the tunnel as it develops propulsive thrust and greatly influences both dynamic and steady pressures on the surface of the tunnel in the vicinity of the propeller.

Tunnel design detail is especially important with regard to longitudinal placement of the propeller within the tunnel, propeller tip clearance and longitudinal distribution of cross-sectional area in the tunnel exit. For craft with high design operating speeds, the tunnel depth should be kept to the minimum consistent with operational requirements. Tunnel depth and shaft angle are design variables for optimization and integration of the propulsion system with the vessel to satisfy operational requirements.[8]

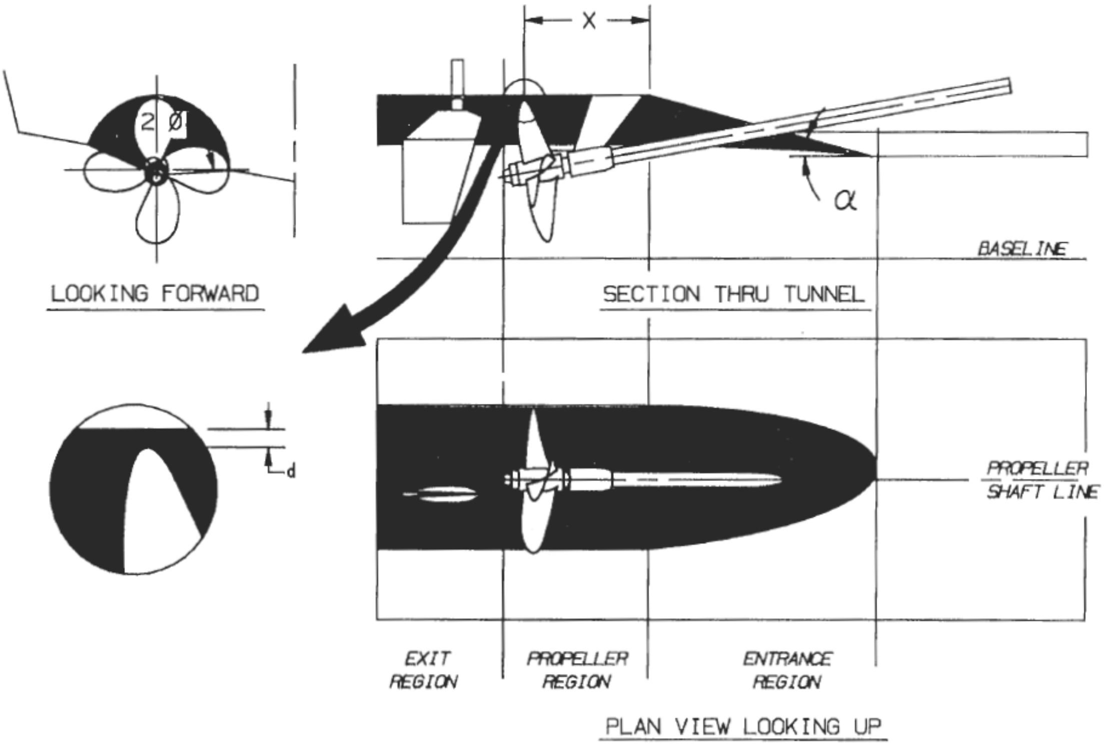


Fig.3.6 Tunnel geometry description

While propeller tip clearance, d/D, has both geometric and hydrostatic advantages (reduced tip clearance permits small tunnel radius to minimize lost buoyancy) it has a significant influence on propulsive efficiency. The small clearance tends to permit the propeller to operate with increased efficiency due to reduced tip loses and operation in a more favourable wake.[9]

For preliminary design of hull, target is to achieve 6° of shaft line with 1,28 m diameter and 4-bladed propeller. By considering experimental studies and recommendations of suppliers, following details are determined: the longitudinal position of tunnels is between aft peak and 9th frame; tunnel depth is not to exceed 1,5 m from baseline; 15% propeller tip clearance. As mentioned above, main parameters are tunnel depth and tip clearance. However relatively bigger tip clearance is chosen to prevent threats due to propeller-induced vibrations.

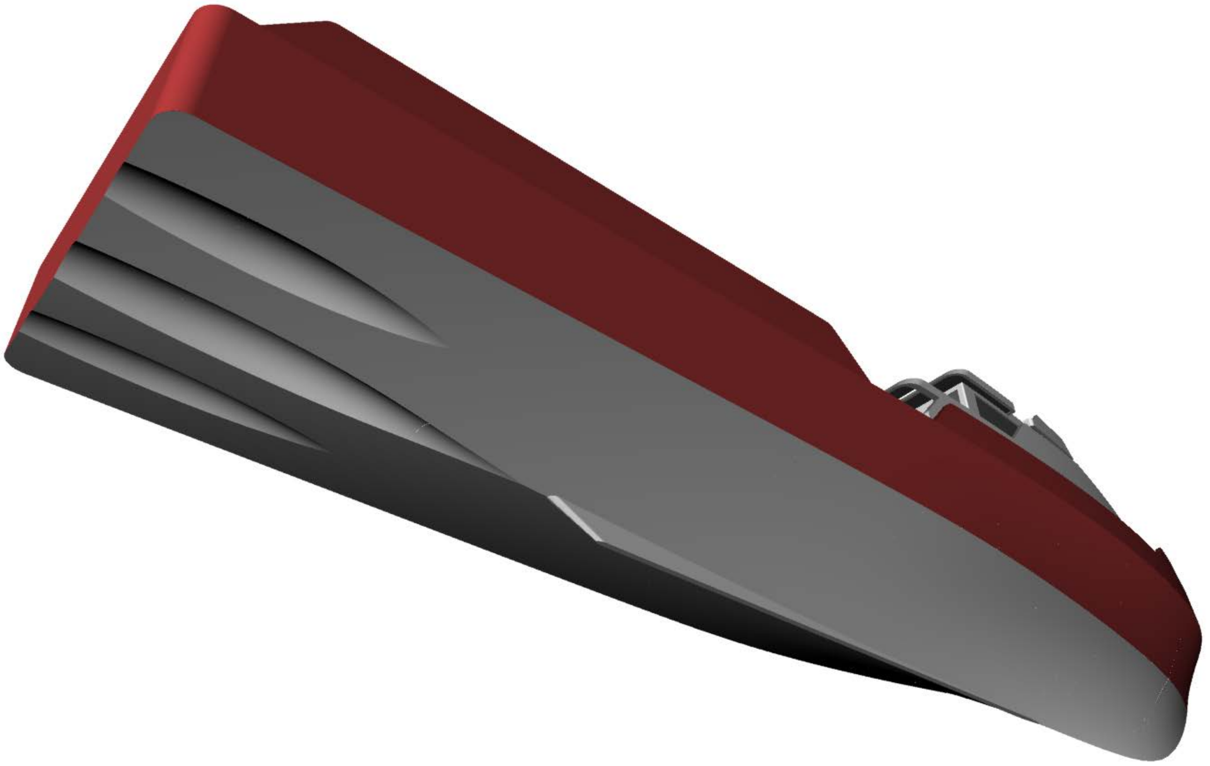


Fig.3.7 3D visualization of preliminary propeller pockets

Eventually, the enhancement achieved by using partial tunnels include reducing the shaft angle approximately 3°, decreasing navigational draft and allowing the propulsion machinery to move aft for an appropriate longitudinal center of gravity location and improved arrangements.

3.9. Structure Weight

The design of aluminium hull structure must satisfy strength, weight and productivity requirements. Hence this structure design is developed by classification rules which have a conservative approach; the weight of the structure should be controlled in order to meet requirements and have low production costs.

Table 3.18 Weight of used plating

	Thickness	Plate Area	Weight
	[mm]	[m^2]	[kg]
Hull deck	10	189	5320,00
Hull deck (Fr.22 - Fr.33)	6	102	1452,36

Hull bottom	10	243	6474,44
Hull side	7	182	3386,98
Transom	12	19	590,52
Side tunnel	15	19	750,12
Center tunnel	15	11	450,87
Bulkheads	6	117	1867,32
Collision bulkhead	7	15	279,30
Tank bulkhead	6	53	845,88
Tank inner side	6	87	1388,52
Tank centerline	6	15	239,40
Tank top	5	92	1223,60
Lubricating oil tank - sea chest	10	8	212,80
Deckhouse	5	82	1090,60
Deckhouse boundary wall	5	75	997,50
Deckhouse front wall	5	24	319,20
Deckhouse inside wall	5	16	212,80
Bridge deck	5	38	505,40
Bridge deck boundary wall	5	50	665,00
Bulwark	7	86	1601,32
Bulwark caprail	10	18	478,80
Fore part centerline	7	9	167,58
Engine seating girder web	10	7	186,20
Engine seating girder web	12	21	670,32
Engine seating bedplate	25	6	399,00
Engine seating bedplate	15	2	59,85
Engine seating bedplate	10	3	79,80
Engine seating transverse	10	36	957,60
Rudder room girder web	12	4	127,68
Machinery room girder web	10	13	345,80
Rudder-machinery room transverse	7	40	744,80
Skeg	10	6	159,60
Stairs	5	15	199,50
Brackets (0.08 m2, 3000 pc)	5	240	3192,00
SUB-TOTAL			37642,46

Table 3.19 Weight of used typical stiffeners

	Section area	Length	Weight
	[mm^2]	[m]	[kg]
Main deck: 100x5+50x9	905	428	1030,32
Main deck (after Fr.22): 60x60x4	464	242	298,69
Bottom: 100x5+50x9	905	384	924,40
Side: 60x60x4	464	278	343,12
Transom: 80x5+50x7	715	52	98,90
Bulkhead: 60x60x4	464	288	355,46
Bulkhead girder: 80x5+50x7	715	144	273,87
Bulkhead hor. Girder 80x5+50x7	715	40	76,08
Tank side: 80x5+50x7	715	116	220,62
Tank inner side: 80x5+50x7	715	116	220,62
Tank bulkhead: 80x5+50x7	715	138	262,46
Tank top: 60x60x4	464	232	286,34
Deckhouse: 60x40x5	475	88	111,19
Deckhouse girder: 100x5+50x9	905	40	96,29
Deckhouse beam: 100x5+50x9	905	60	144,44
Deckhouse boundary wall: 60x40x5	475	102	128,88
Deckhouse boundary wall transverse: 100x5+50x9	905	46	110,74
Deckhouse front wall: 60x40x5	475	11	13,90
Deckhouse front wall girder: 100x5+50x9	905	11	26,48
Deckhouse front wall transverse: 100x5+50x9	905	14	33,70
Bridge deck: 60x40x5	475	42	53,07
Bridge deck girder: 100x5+50x9	905	7	16,85
Bridge deck beam: 100x5+50x9	905	35	84,26
Bridge deck boundary wall: 60x40x5	475	42	53,07
Bridge deck boundary wall transverse: 100x5+50x9	905	35	84,26
Bulwark: 60x40x5	475	176	222,38
Pillar: 100x10	2827	55	413,59
SUB-TOTAL			5983,96

Table 3.20 Weight of plating used for primary supporting members

	Width	Thickness	Section	Length	Plate	Weight
	[mm]	[mm]	[mm^2]	[m]	[m^2]	[kg]
Main deck girder flange	70	5	350	306	21,42	284,89
Main deck girder web	160	5	800	306	48,96	651,17
Main deck beam flange	70	5	350	244	17,08	227,16
Main deck beam web	160	5	800	244	39,04	519,23
Side stringer flange	70	5	350	78	5,46	72,62
Side stringer web	160	5	800	78	12,48	165,98
Side transverse flange	70	5	350	85	5,95	79,14
Side transverse web	160	5	800	85	13,60	180,88
Bottom side girder flange	70	5	350	78	5,46	72,62
Bottom side girder web	300	7	2100	78	23,40	435,71
Floor flange	70	5	350	104	7,28	96,82
Floor web	250	7	1750	104	26,00	484,12
Transom girder flange	70	5	350	14	0,98	13,03
Transom girder web	160	5	800	14	2,24	29,79
Transom hor. girder flange	70	5	350	7	0,49	6,52
Transom hor. girder web	160	5	800	7	1,12	14,90
Tank stringer flange	70	5	350	46	3,22	42,83
Tank stringer web	160	5	800	46	7,36	97,89
Tank top girder flange	70	5	350	60	4,20	55,86
Tank top girder web	160	5	800	60	9,60	127,68
Tank transverse flange	70	5	350	111	7,77	103,34
Tank transverse web	160	5	800	111	17,76	236,21
Tank bulkhead girder flange	70	5	350	18	1,26	16,76
Tank bulkhead girder web	160	5	800	18	2,88	38,30
Tank bulkhead hor. girder flange	70	5	350	20	1,40	18,62
Tank bulkhead hor. girder web	160	5	800	20	3,20	42,56
Tank centerline hole flange	70	5	350	28	1,99	26,44
Sea-chest hole flange	70	7	490	2	0,14	2,61
Engine room transverse flange	70	5	350	82	5,74	76,34
Engine room center girder flange	120	7	840	5.5	0,66	12,29

Rudder-machinery room girder flange	70	7	490	43	3,01	56,05
Rudder-machinery room transverse flange	70	7	490	123	8,61	160,32
SUB-TOTAL						4448,66

Table 3.21 Total structure weight

	Thickness [mm]	Plate area [m^2]	Weight [kg]
PLATINGS	5 (H321-5083 series aluminum alloy)	880	11703
	6 (H321-5083 series aluminum alloy)	363	5793
	7 (H321-5083 series aluminum alloy)	394	7331
	10 (H321-5083 series aluminum alloy)	534	14215
	12 (H321-5083 series aluminum alloy)	44	1389
	15 (H321-5083 series aluminum alloy)	32	1261
	25 (H321-5083 series aluminum alloy)	6	399
	Typical Profile	Length [m]	Weight [kg]
PROFILES	60x40x5 (H111-5083 series aluminum alloy)	461	582
	60x60x4 (H111-5083 series aluminum alloy)	1040	1284
	80x5+50x7 (H111-5083 series aluminum alloy)	606	1153
	100x5+50x9 (H111-5083 series aluminum alloy)	1060	2552
	Ø100x10 (T6-6082 series aluminum alloy)	55	414
SUBTOTAL			48075
Welding	5183 series aluminum alloy	3%	1442
TOTAL			**49517**

Note: Fenders, watertight doors, hatch covers, windows frames, escape stairs, ventilation tubes, bow thruster foundation, anchoring equipment area, deck container basement, lower deck basement, living room doors and walls, crane foundation reinforcements, etc. are not included in this calculation.

In compliance with experiences of the shipyard, this total structure weight, 50 tonnes, satisfies the predictions.

Structure drawings are enclosed in Full Master Thesis: Appendix-6.

4. STRUCTURAL STRENGTH ANALYSIS BY FEM

4.1. Objective and Scope

Direct analysis for high-speed crafts provides enhanced structural evaluation capabilities to assess the adequacy of a structural design. In principle, a minimum requirement of direct analysis is that the preliminary design of the structure be in accordance with the criteria of Classification Society. Should the direct analysis results indicate the need to increase basic scantlings, this increase is to be accomplished to meet the acceptance criteria of the direct analysis.[10]

Structural direct analysis is a strength assessment methodology based on first principles approach. In this regard, checking criteria are applied to verify that predicted stress levels do not exceed a specified percentage of yield strength and buckling strength.

The analysis procedures in applying direct analysis include the following steps:

i. Structural finite element (FE) model development
ii. Specification of the load cases
iii. Determining of boundary conditions
iv. Strength analysis
v. Application of the checking criteria

Main machinery foundations of the hull are investigated in detail for the structural analysis of the craft to ensure continuity of the reinforced elements to maximize strength:

4.2. Finite Element Model

3D model is created on Rhinoceros3D software, and then model exported to ANSYS Design Modeler. Material is defined as aluminium alloy and thicknesses are established. Software workbench considers all surfaces as shell element and defines the element type as SHELL181. SHELL181 is suitable for analyzing thin to moderately-thick shell structures. It is a four-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. (If the membrane option is used, the element has translational degrees of freedom only). The degenerate triangular option should only be used as filler elements in mesh generation.

SHELL181 is well-suited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness is accounted for in nonlinear analyses. In the element domain, both full and reduced integration schemes are supported. SHELL181 accounts for follower (load stiffness) effects of distributed pressures.

The element formulation is based on logarithmic strain and true stress measures. The element kinematics allow for finite membrane strains (stretching). However, the curvature changes within a time increment are assumed to be small.

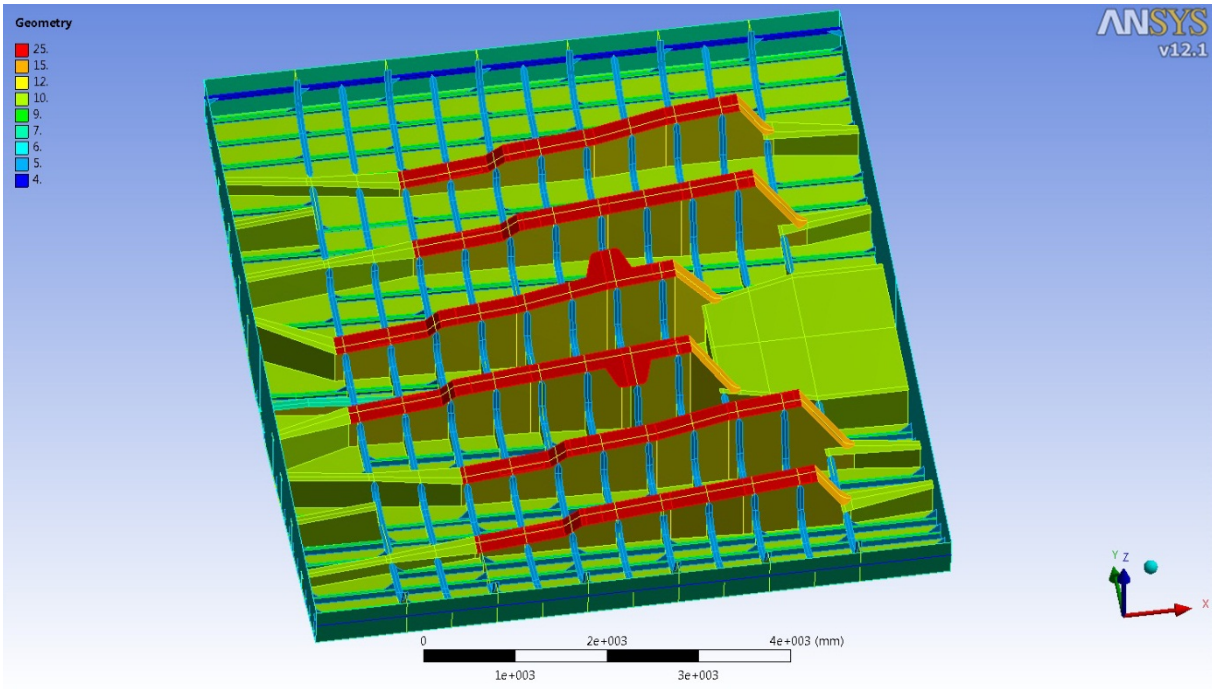


Fig.4.1 Geometry display with shell thicknesses

Above figure presents FE model with given different thicknesses. There are 6 main girders for 3 engines and center engine girders are connected to lubricating oil tank and this tank is situated by the side of sea chest. Due to object is to verify the scantling of engine seatings, bulkheads and side shells are not fully-modeled.

Global mesh is created with following features:

- Mesh method: Quadrilateral dominant
- Advanced size function: On curvature
- Element size: 8,6 mm – 43 mm
- Number of nodes: 383201
- Number of elements: 384878

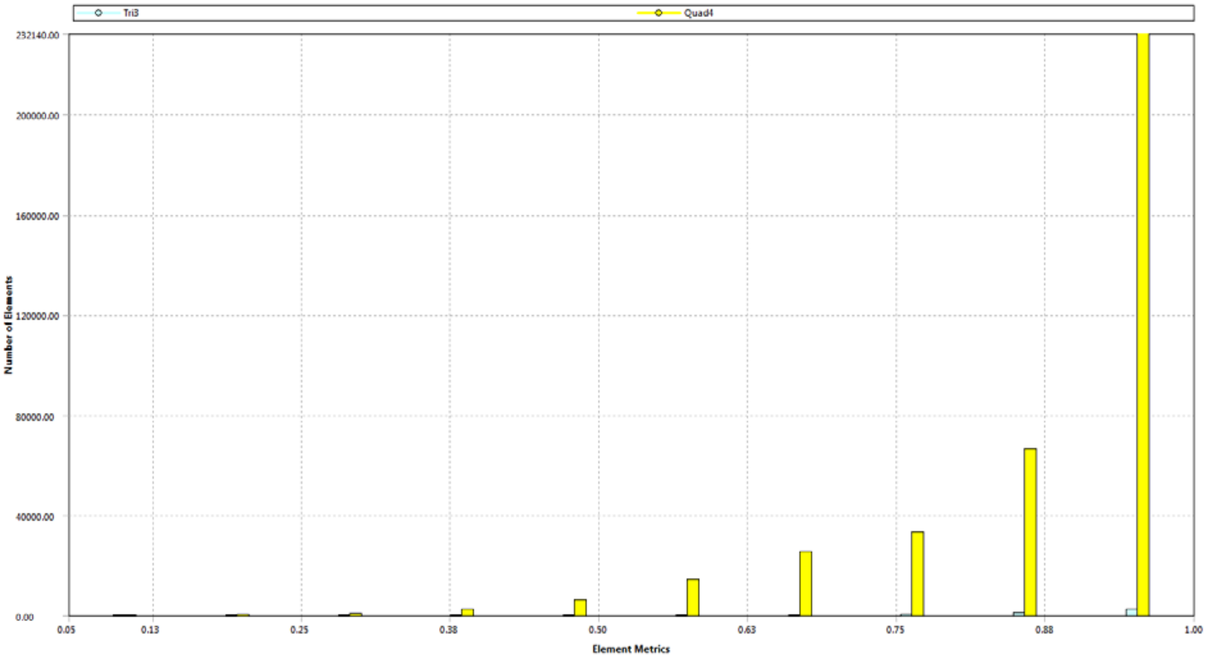


Fig.4.2 Mesh element quality

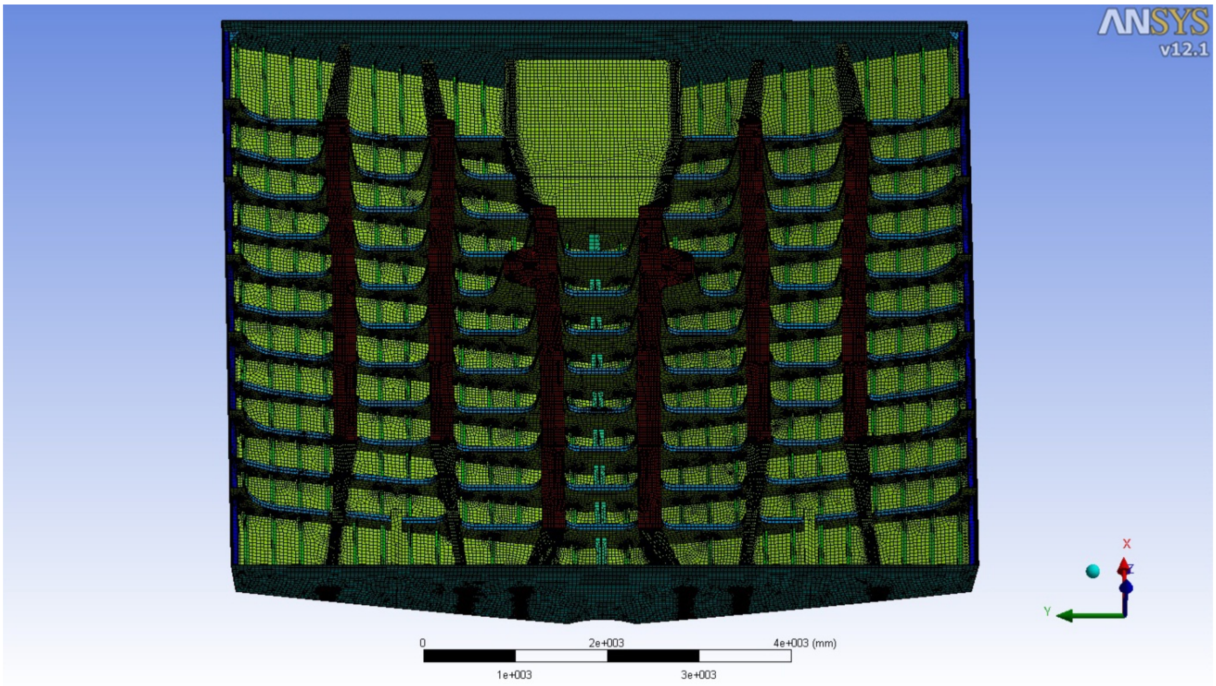


Fig.4.3a Meshed model

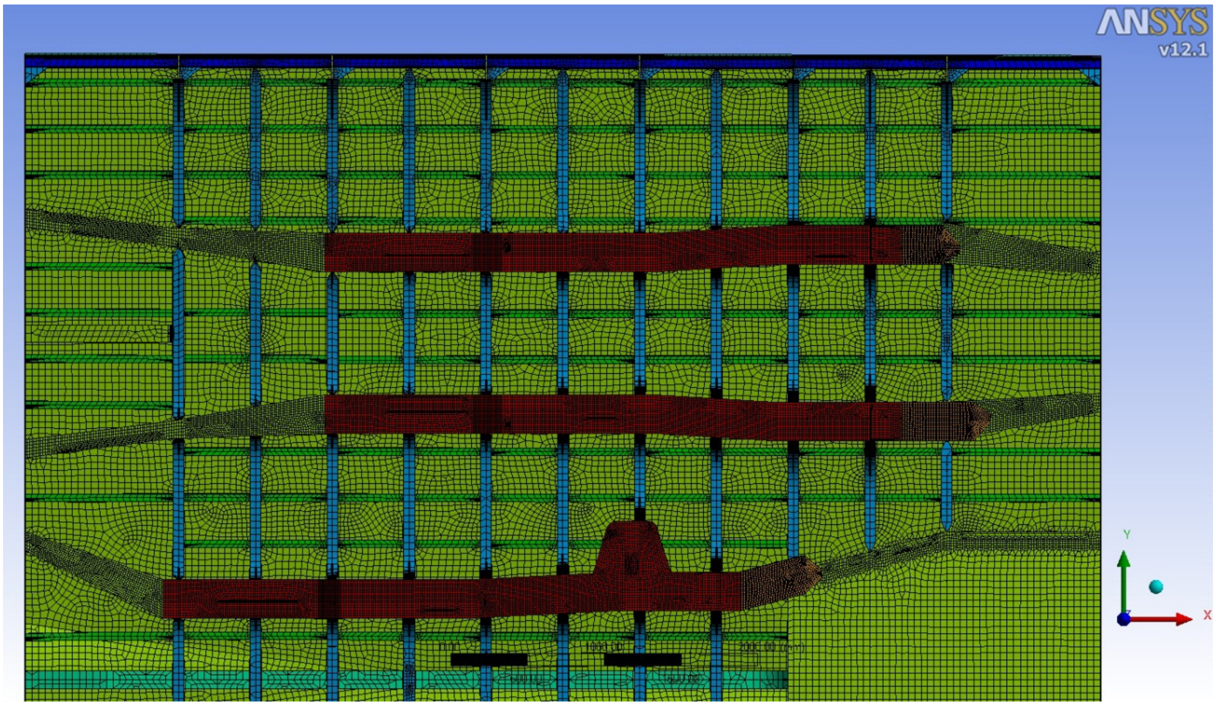


Fig.4.3b Meshed half model top view

For more accurate results, refinements are made for engine seating meshes.

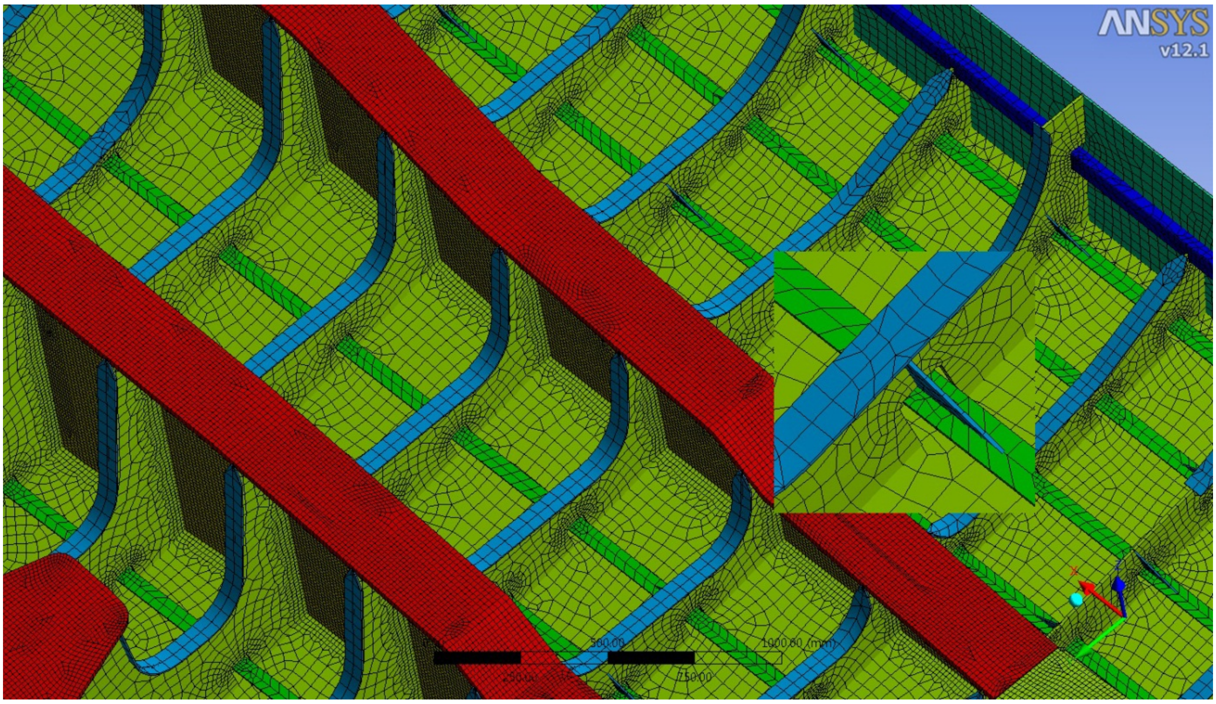


Fig.4.3c Detailed meshed model

4.3. Load Cases

The following loading conditions are considered:

4.3.1. Loading condition in still water

The following loads are considered:

- Forces caused by engine weights and pillars through standard earth gravity

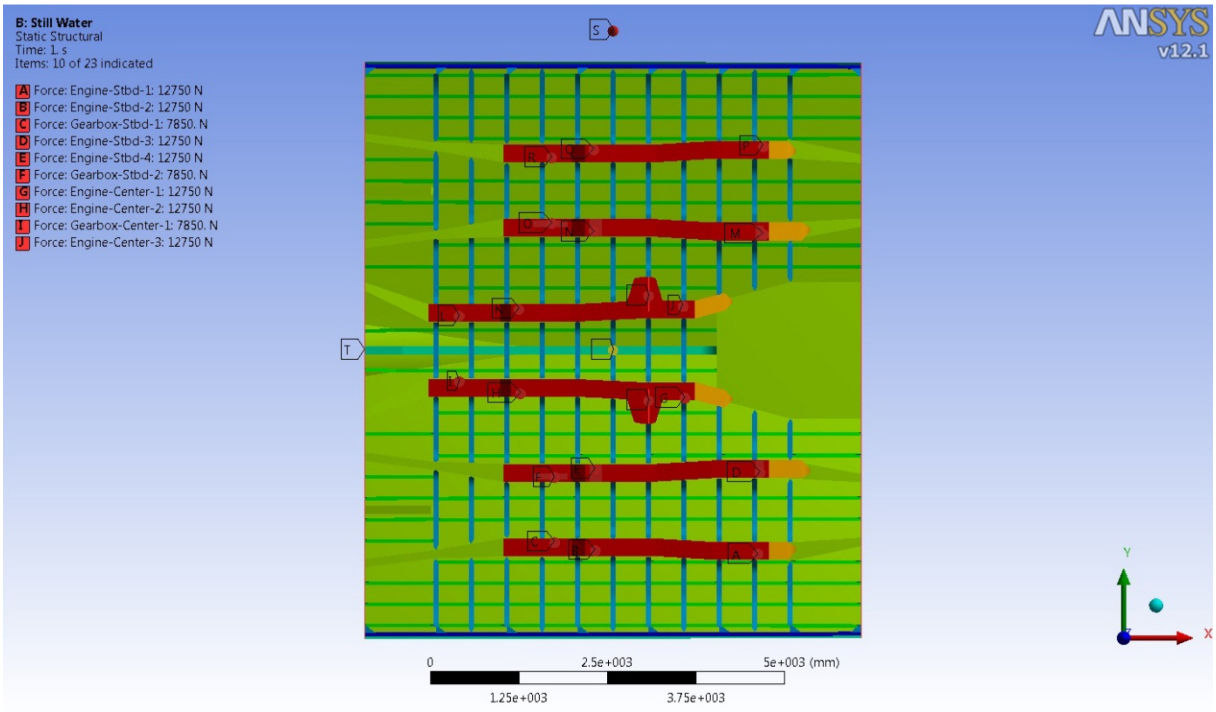


Fig.4.4 Loads under still water loading condition

This part of the craft situated under deck cargo area. To maintain continuity of this deck part, 2 pillars are settled at two sides of center engine at Frame-11. For each pillar, transmitted force is presumed as 30000 N.

Gearbox weight ≈ 1600 kg ≈ 15700 N / 2 = 7850 N over one connection

Engine weight ≈ 5200 kg ≈ 51000 N / 4 = 12750 N over one bedplate connection.

Due to no current information regarding to center of gravity of the engine, engine weight is divided to 4 equal forces which are applied on 4 bedplate connections as seen on below figure which has same type of engine and foundation:

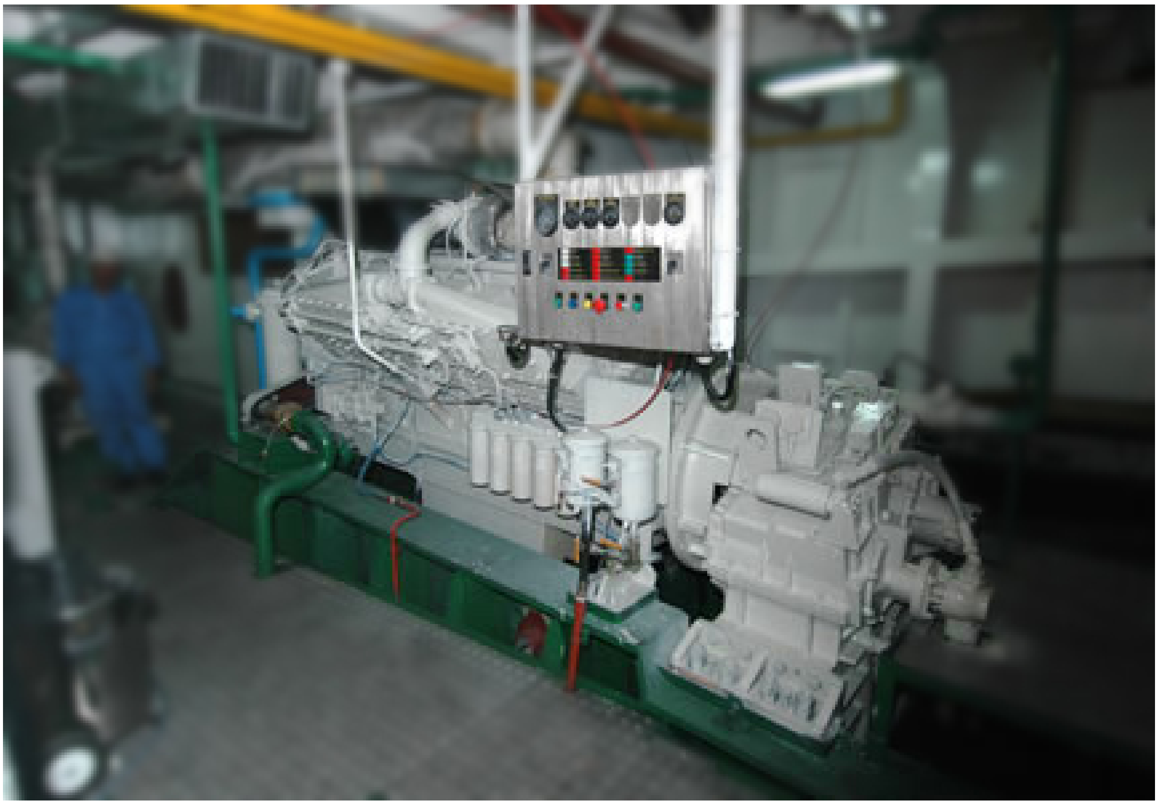


Fig.4.5 Sample engine foundation

- Outer hydrostatic load in still water

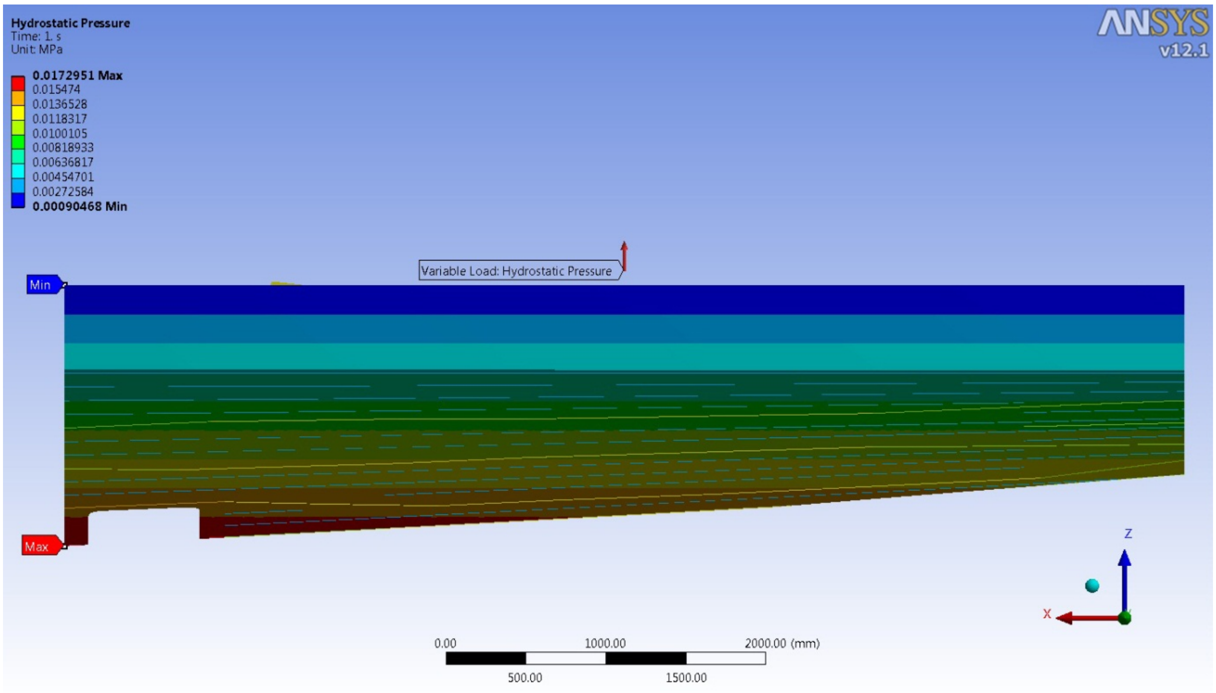


Fig.4.6 Variable load: Hydrostatic pressure

4.3.2. Combined loading condition

The following loads are to be considered:

- Forces of inertia due to the vertical acceleration a_v of the craft, considered in a downward direction. The vertical acceleration is calculated as stipulated in C3.3.1.
- Forces caused by engine weights and pillars through vertical acceleration

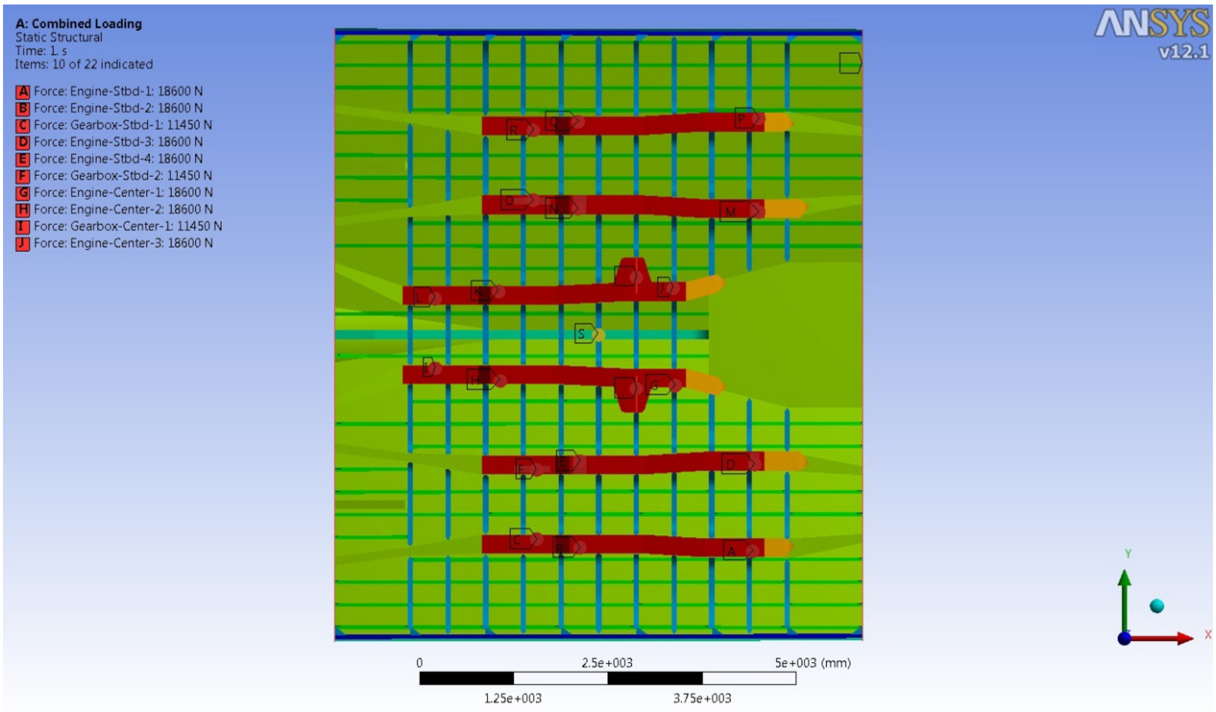


Fig.4.7 Loads under combined loading condition

For each pillar, transmitted force is presumed as 30000 N.

For one bedplate connection of the engine,

$$F_V = m.a_v = 1300x1.46g \approx 18600\ N \tag{75}$$

By similar approach, for one connection of the gearbox, F = 11450 N is taken into account.

Hence inertial forces have more effect when the craft is at maximum speed; hydrostatic pressure was not taken into account in this combined loading condition.

4.4. Boundary Conditions

In order to calculate a solution, ANSYS requires data at the boundaries of each sub-task's domain of definition. This means that boundary conditions will be required both along external boundaries (boundary sets) and along internal boundaries between subdomains that belong to different sub-tasks.

All longitudinal edges on bulkheads are fixed on X, Y and Z directions, rotations however are permitted.

Table 4.1 Boundary conditions

Location of Independent Point	Translational			Rotational		
	X	Y	Z	φx	φy	φz
Longitudinals edges on bulkhead	Fixed	Fixed	Fixed	Free	Free	Free
Bulkhead edges	Fixed	Fixed	Fixed	Free	Free	Free

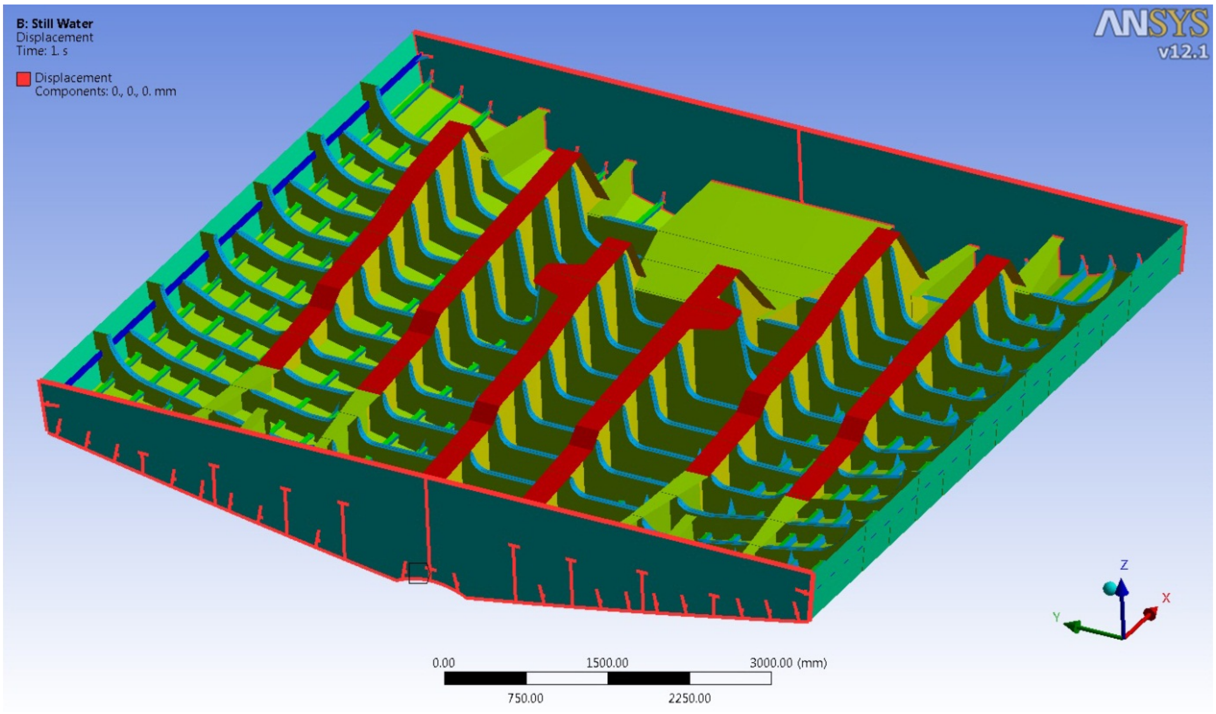


Fig.4.8 Boundary conditions

4.5. Analysis of Local Structures

4.5.1. Loading condition in still water

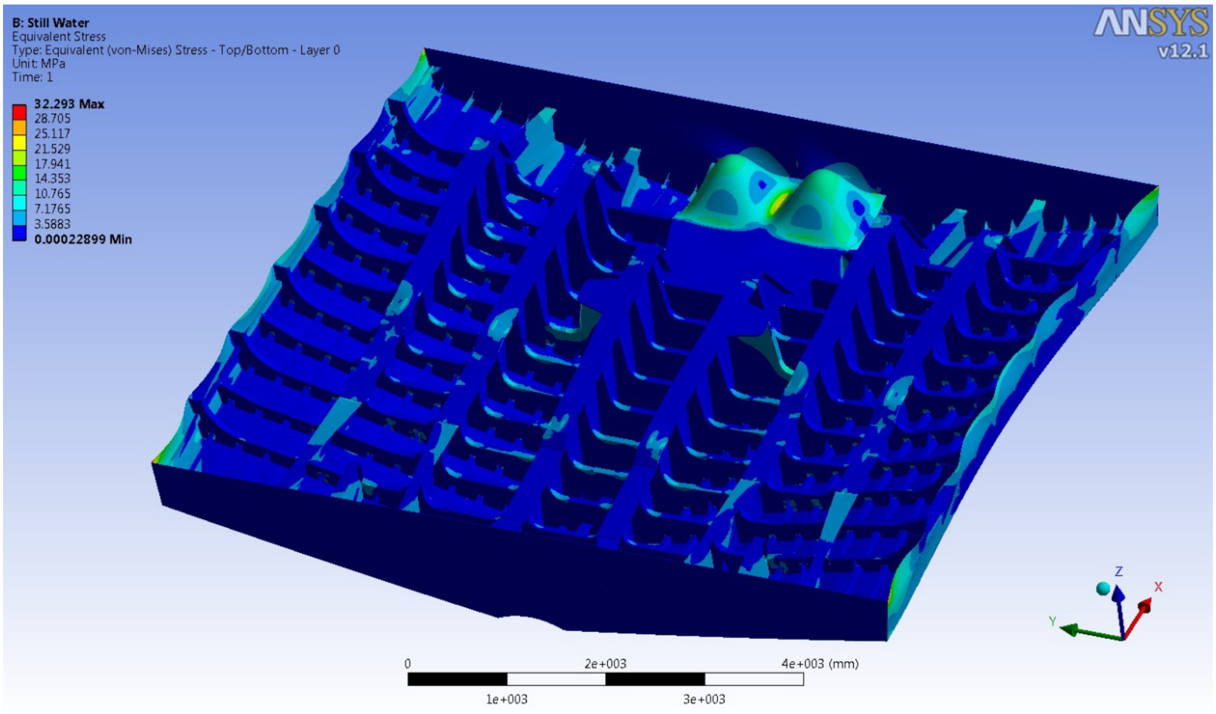


Fig.4.9 Equivalent stress distribution under still water loading condition

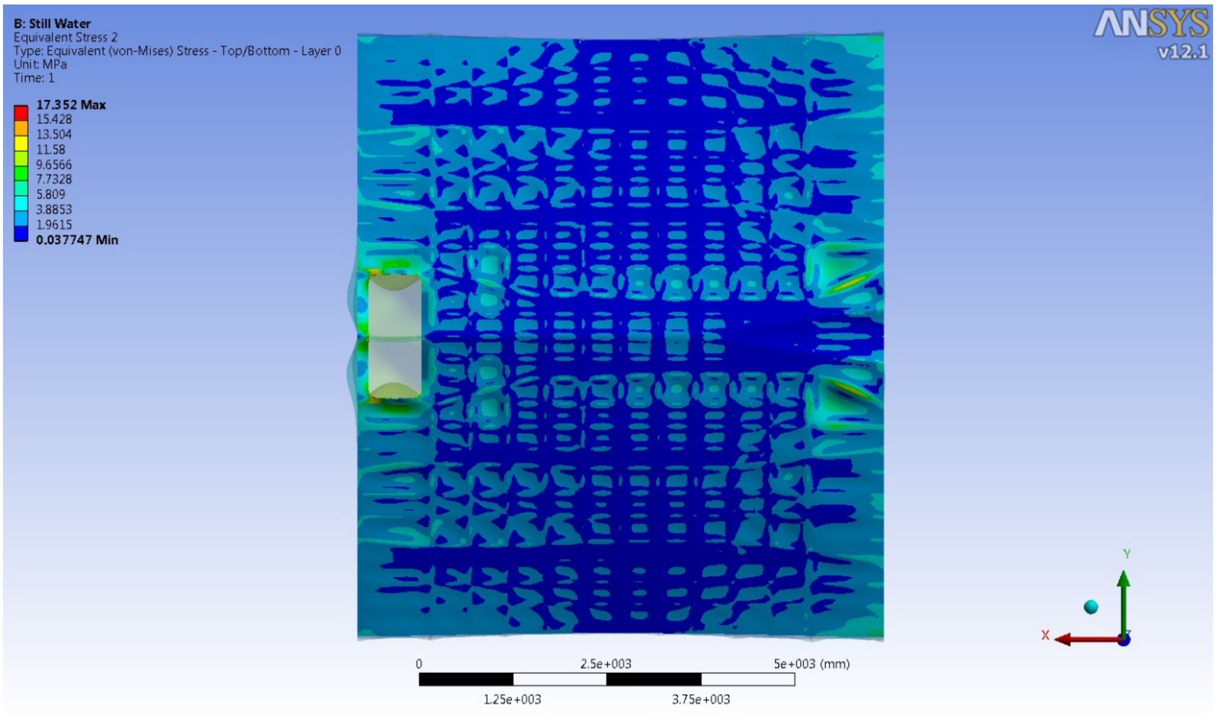


Fig.4.10 Equivalent stress distribution for bottom plate under still water loading condition

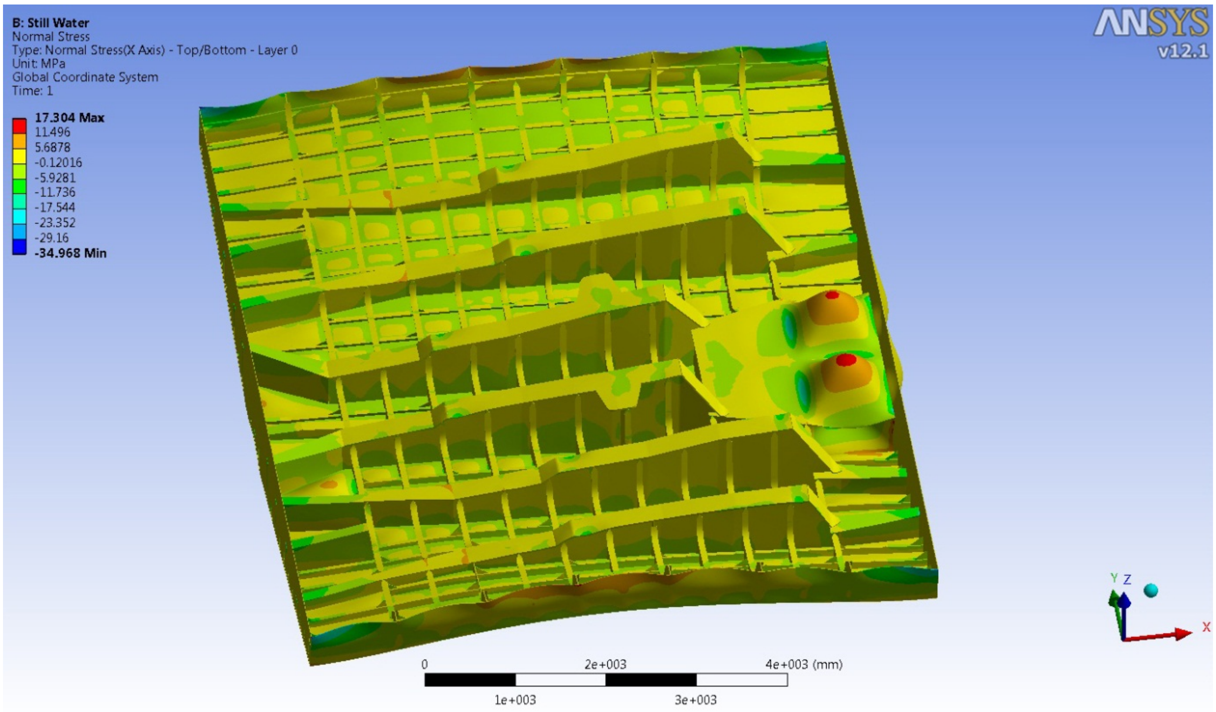


Fig.4.11 Normal stress distribution under still water loading condition

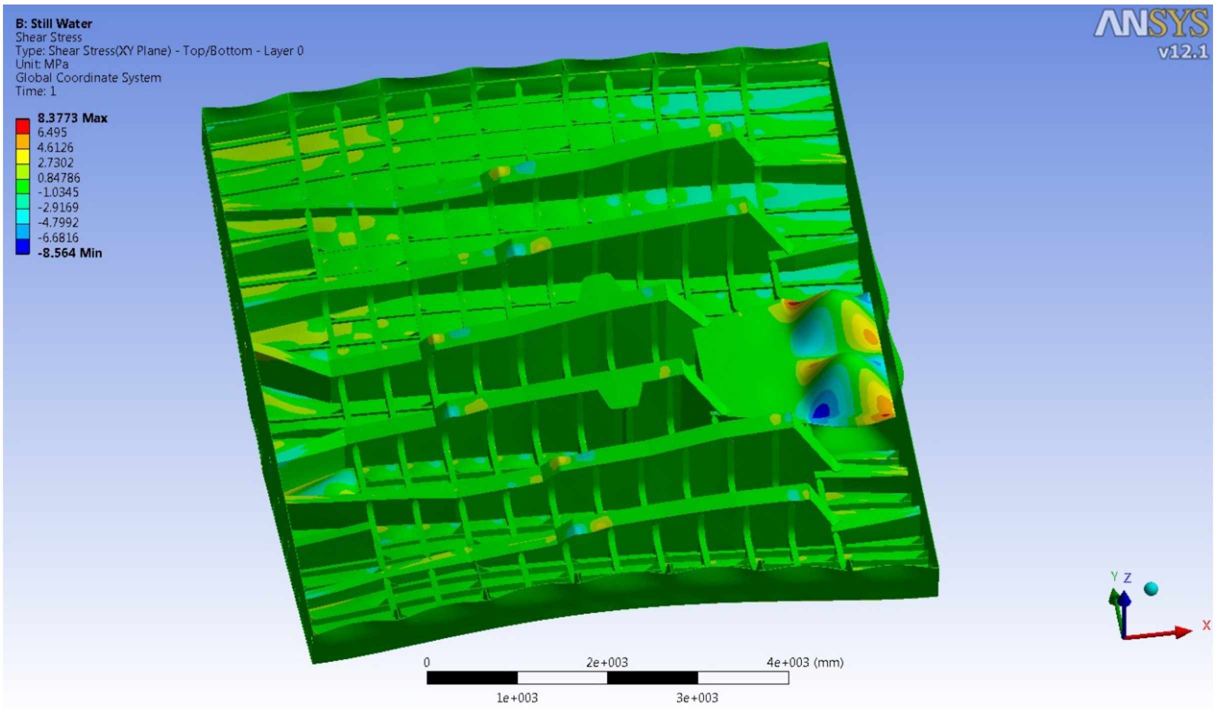


Fig.4.12 Shear stress distribution under still water loading condition

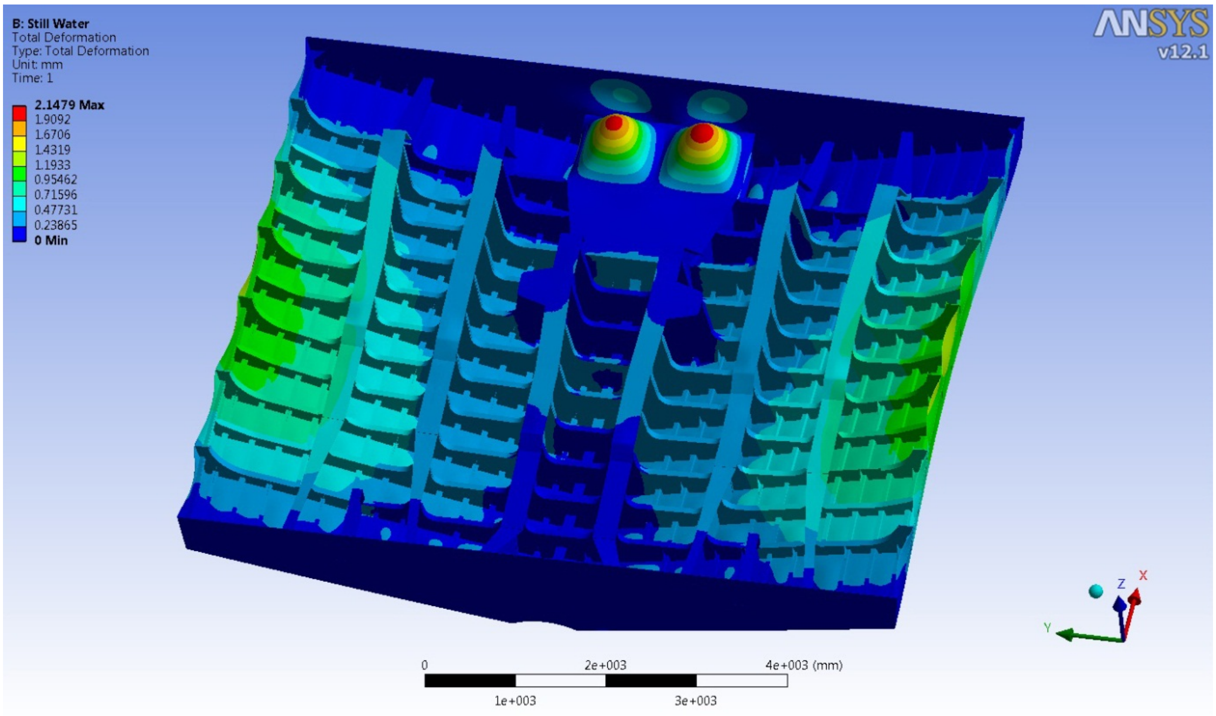


Fig.4.13 Total deformation under still water loading condition

4.5.2. Combined loading condition

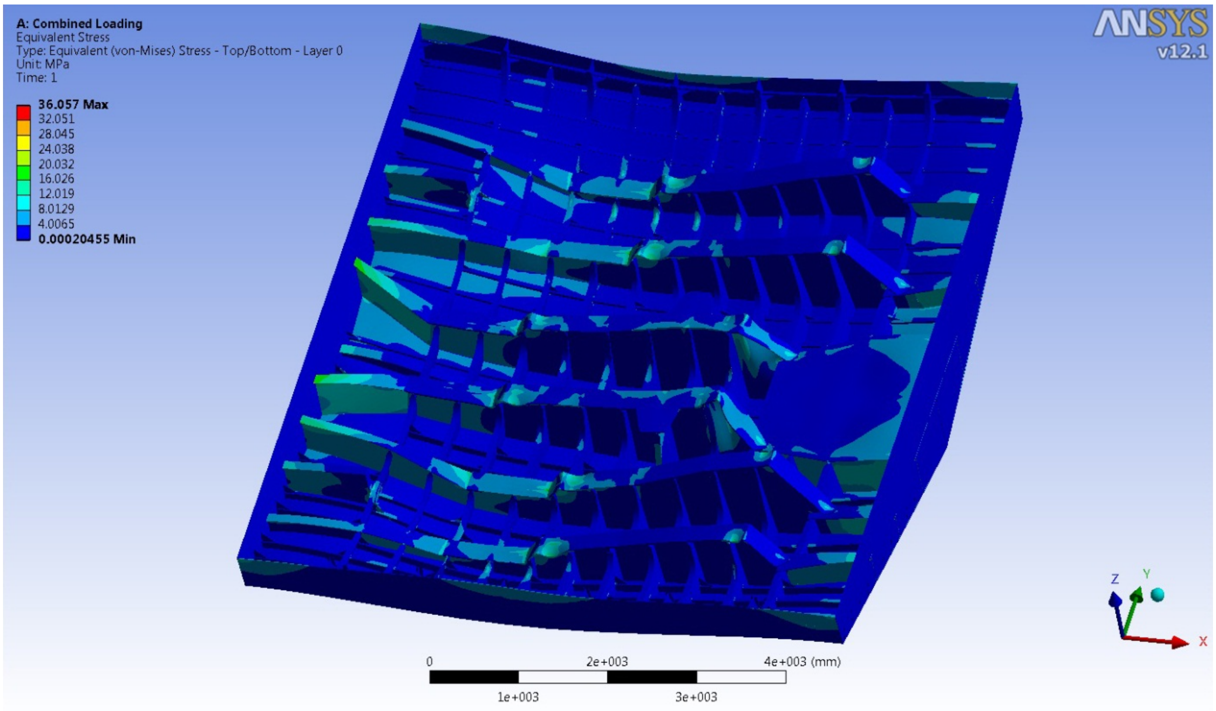


Fig.4.14 Equivalent stress distribution under combined loading condition

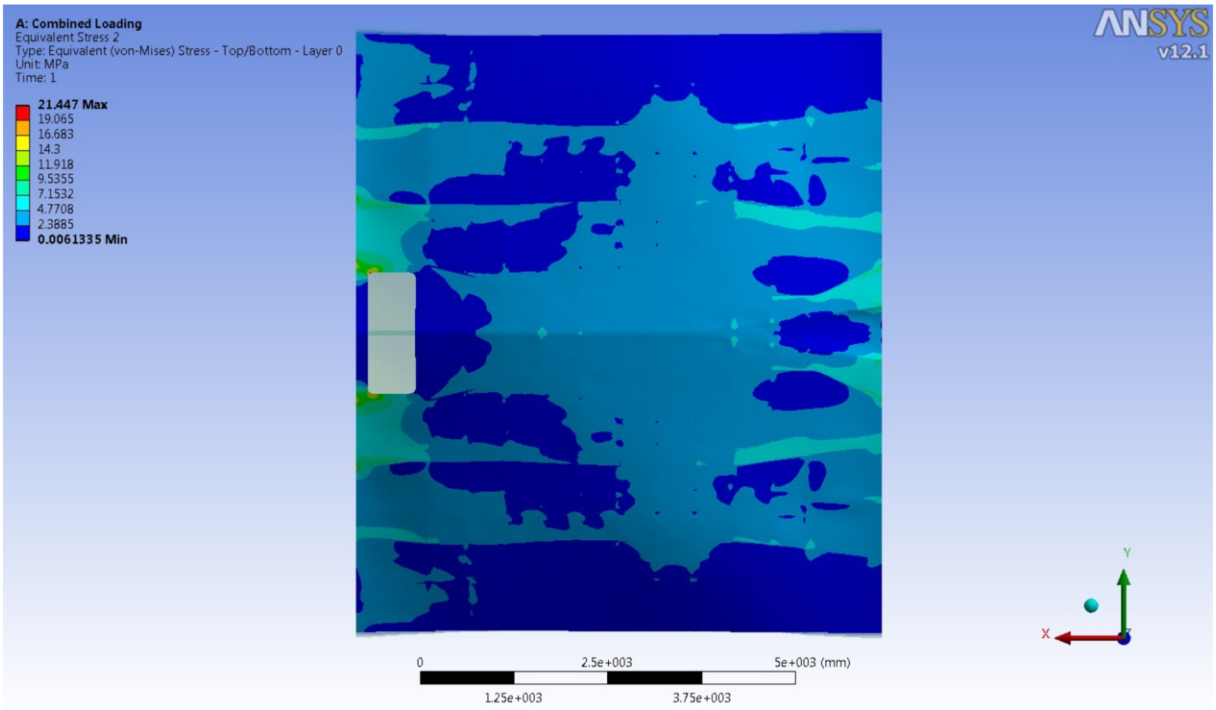


Fig.4.15 Equivalent stress distribution for bottom plate under combined loading condition

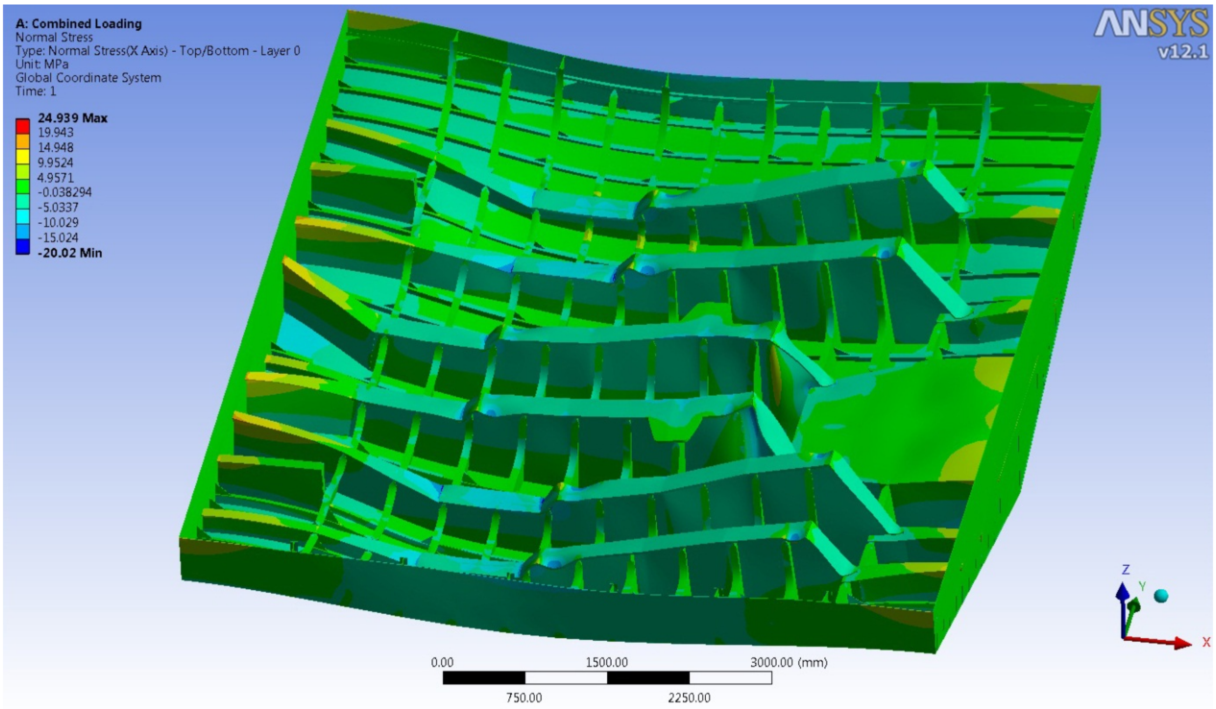


Fig.4.16 Normal stress distribution under combined loading condition

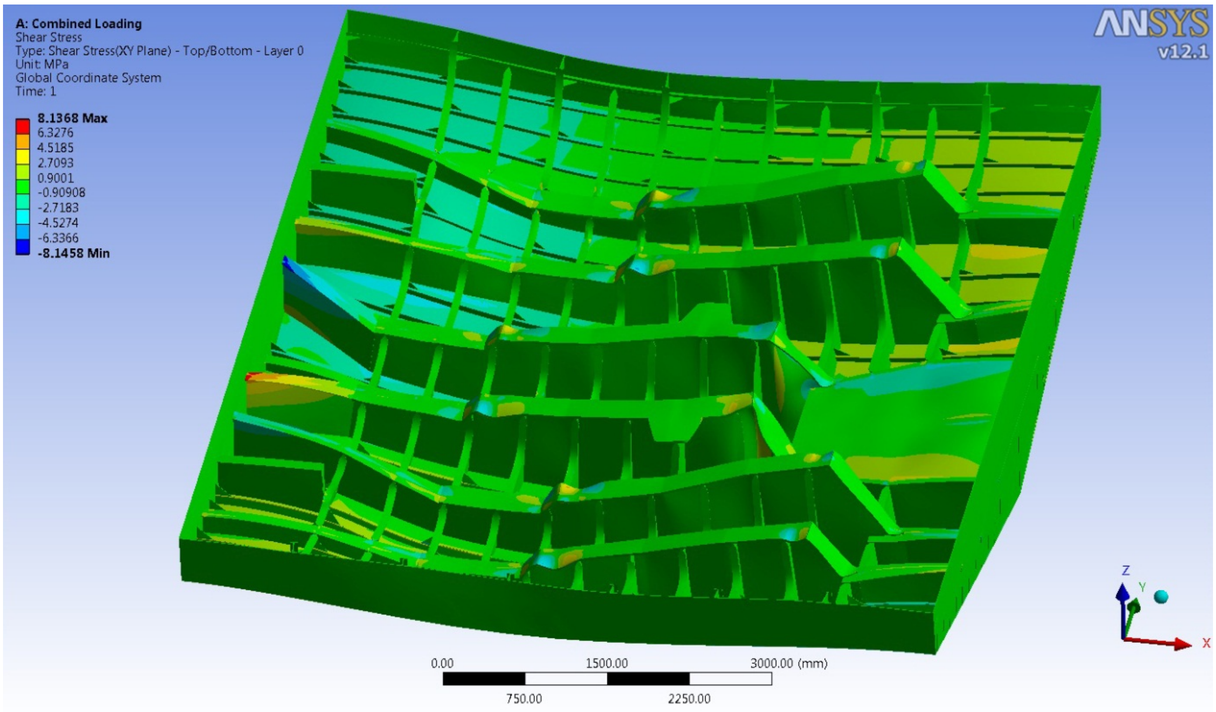


Fig.4.17 Shear stress distribution under combined loading condition

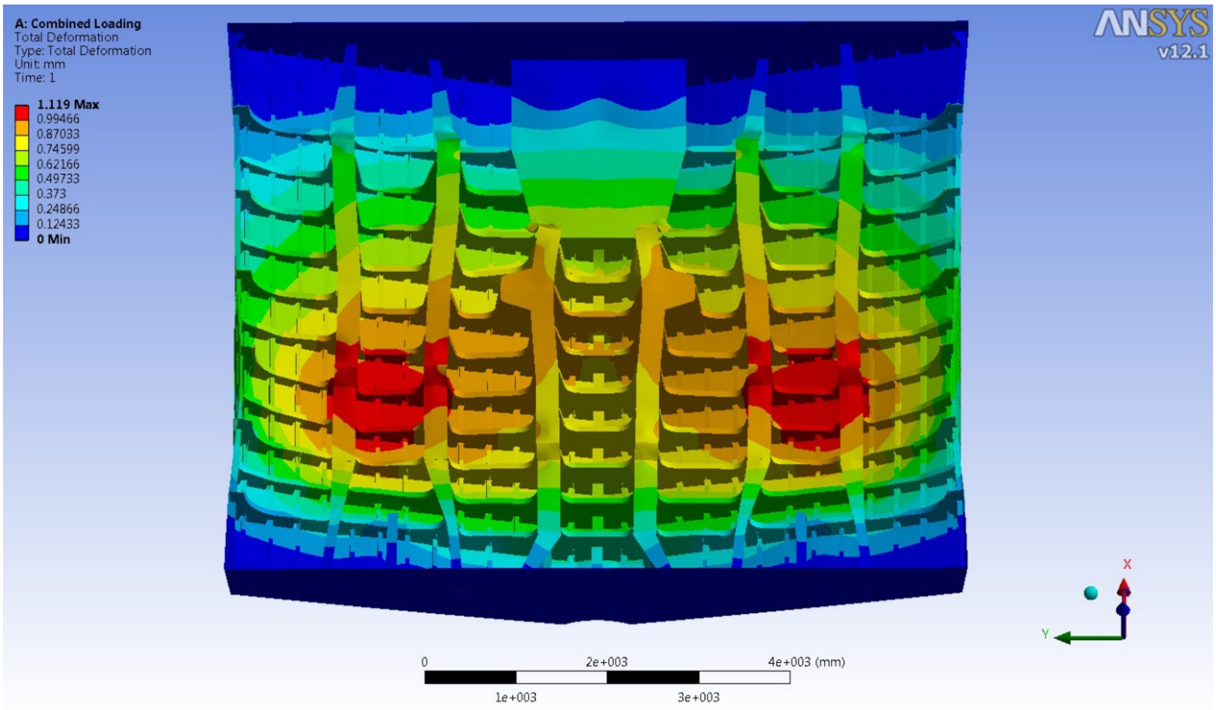


Fig.4.18 Total deformation under combined loading condition

4.6. Checking Criteria

The stresses given by the above analyses are not greater than the following allowable values:

- Normal stress:

$$\sigma_{am} = \frac{150}{K.f'_m.f_s} \gg \begin{matrix} 69{,}77\ N/mm^2 for\ still\ water\ loading \\ 87{,}21\ N/mm^2\ for\ combined\ loading \end{matrix} \tag{76}$$

- Shear stress:

$$\tau_{am} = \frac{90}{K.f'_m.f_s} \gg \begin{matrix} 41{,}86\ N/mm^2 for\ still\ water\ loading \\ 52{,}33\ N/mm^2\ for\ combined\ loading \end{matrix} \tag{77}$$

- Von-Mises equivalent bending stress:

$$\sigma_{eq.\ am} = \frac{190}{K.f'_m.f_s} \gg \begin{matrix} 88{,}37\ N/mm^2 for\ still\ water\ loading \\ 110{,}47\ N/mm^2\ for\ combined\ loading \end{matrix} \tag{78}$$

Where;

K = 0,80 material factor defined in C3.2.2

f'_m = 2,15 coefficient for aluminium alloy structures

f_s : safety coefficient assumed as:

- 1,25 for loading condition in still water,
- 1,00 for combined loading condition.

Comparing the occurring stress with the admissible stress gives the safety factor that is applied:

$$Safety\ Factor = \frac{admissible\ stress\ variation}{actual\ stress\ variation} \tag{79}$$

Table 4.2 Finite element analysis results

Still water loading condition	**Highest stress [N/mm^2]**	**Check [N/mm^2]**	**Safety factor**
Normal stress	17,30	69,77	4,03
Shear stress	8,56	41,86	4,89
Von-Mises equivalent bending stress	32,29	88,37	2,74
Combined loading condition	**Highest stress [N/mm^2]**	**Check [N/mm^2]**	**Safety factor**
Normal stress	24,94	87,21	3,49
Shear stress	8,15	52,33	6,42
Von-Mises equivalent bending stress	36,06	110,47	3,06

By taking into account maximum equivalent stresses, below figures are obtained:

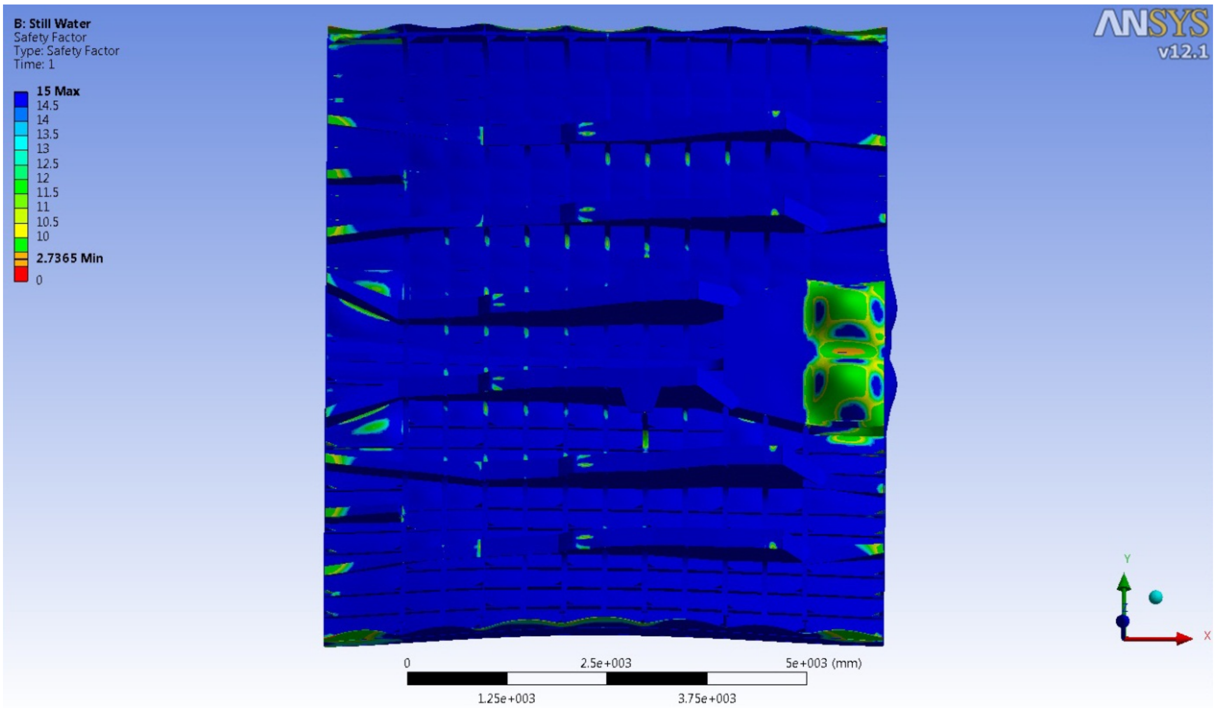


Fig.4.19 Safety factor for still water loading condition

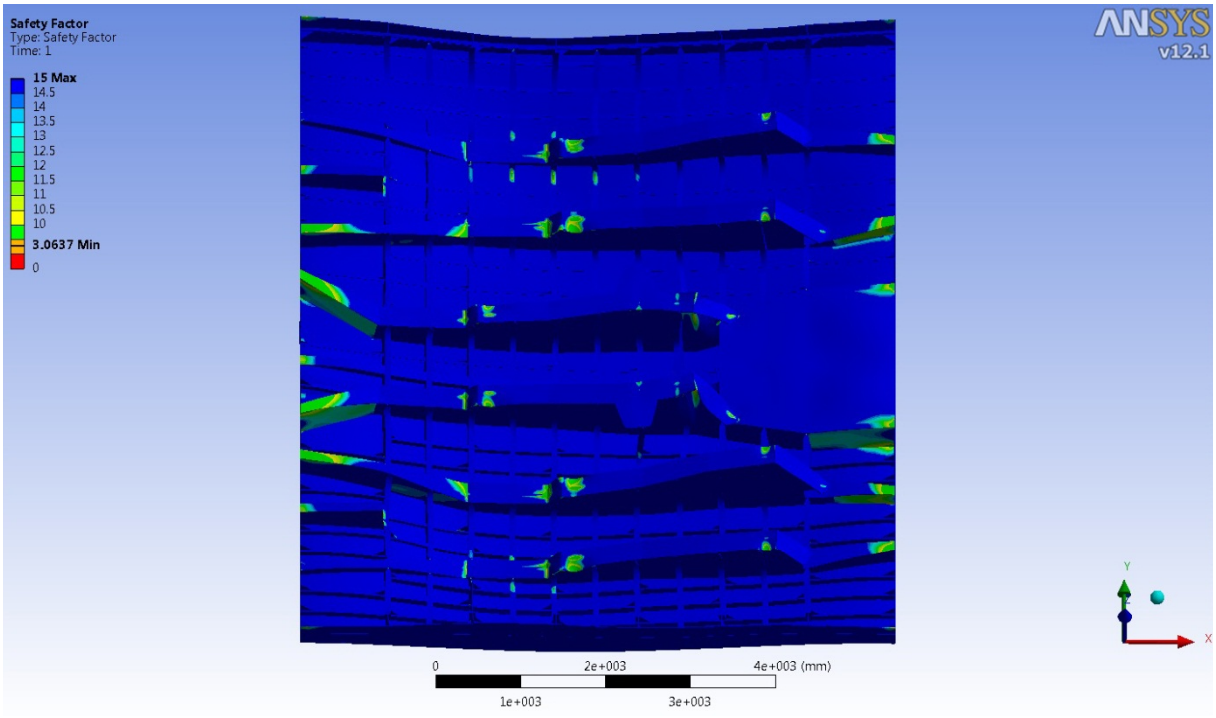


Fig.4.20 Safety factor for combined loading condition

5. CONCLUSIONS

The use of aluminum for the structure of high speed crafts seems a natural fit due to the weight savings that using aluminum can provide. However, the success of an aluminum ship design depends on many factors related to hull shape, the various properties of aluminum alloys, structure design approach, etc. After analyzing all the data produced through this thesis including preliminary design processes, structure design and local direct analyses, it could be concluded by highlighting some points:

- For high speed crafts, hull shape has significant importance. Therefore the hull resistance prediction is essentially momentous for developing hull lines at preliminary stages of the design. For this purpose Savitsky Method is applied primarily, and then some modifications are made on the hull lines. By CFD applications, more accurate results are obtained and these results are compared with previous method. Meanwhile spray flow over the hull is observed even resistance values are in a good range. To prevent this, using of “spray rails” also called as “spray strips” under the chine is proposed. A spray strip is a relatively narrow strip, of small cross-section, attached to the hull for the purpose of controlling or diverting spray and reduces the wetted area. It has also effects as increasing the lift.
- Although the vessel is a high speed craft, it will work as a supply unit for offshore platforms to transport technical personnel, cargo on deck and liquid cargo. On the other hand, the structure design is developed according to High Speed Craft rules by directives of Classification Society. In spite of the rules give convincing scantling requirements; there were conflicts between shipyard and representative of the customer for choosing elements which are based on stock of the shipyard. Therefore, higher thicknesses are adopted for some elements based on customer’s old vessel which has similar service type with 46 m length by charge of representative of the customer.
- Hence the structure design is developed by classification rules which have a conservative approach; the weight of the structure needed to be checked in order to meet requirements and have low production costs. In compliance with experiences of the shipyard, total structure weight, 50 tonnes, satisfied the predictions.
- Tunnel design detail is especially important with regard to longitudinal placement of the propeller within the tunnel, propeller tip clearance and longitudinal distribution of

cross-sectional area in the tunnel exit. Eventually, the enhancement is achieved by using partial tunnels include reducing the shaft angle approximately 3°, decreasing navigational draft and allowing the propulsion machinery to move aft for an appropriate longitudinal center of gravity location and improved arrangements. As the propeller and tunnel design process must be integrated due to these are hydrodynamically mutually interactive; this preliminary tunnel design should be analyzed by CFD analysis together with propellers later on.

- Direct finite element analysis of main machinery foundations which have significant influence on structure is performed. Due to there is not any remarkable rules for aluminium alloy structured engine foundations, this kind of analysis was unavoidable. Regarding to instructions of Classification Society, this analysis is performed for two loading conditions. Eventually high safety margins are gained for the scantling which is generated on the strength of previous projects of the shipyard. Due to some uncertainties of working conditions such as not using of flexible couplings for engines and gearbox seatings by charge of representative of the customer, the scantling of foundations is kept as analysed at this stage of the project.

6. ACKNOWLEDGEMENTS

I am deeply indebted to my supervisor Prof. Dario Boote from University of Genoa whose help, stimulating suggestions and encouragement helped me in all the time of research for and writing of this thesis. Besides my supervisor, I would like to thank also Tatiana Pais for assisting me in this period.

I would like to express my gratitude to all those who gave me the possibility to complete this thesis. I want to thank the Intermarine & Rodriquez Cantieri Navali Spa for giving me assistance to commence this thesis in the first instance, to do the necessary research work and to use departmental data. I have furthermore to thank engineers Alessio Battistini and Roberto Rossi who showed me immeasurable patience during my internship at company and assisted me on my thesis.

Note: This thesis was developed in the frame of the European Master Course in “Integrated Advanced Ship Design” named “EMSHIP” for “European Education in Advanced Ship Design”, Ref.: 159652-1-2009-1-BE-ERA MUNDUS-EMMC.

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