UNIVERSITY OF LISBON

INSTITUTO SUPERIOR TECNICO

DESIGN OF SHIP STRUCTURES

Project work

Student: Davide Melozzi 102230

Professor: Yordan Garbatov

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SUMMARY

The current project work was completed as part of the Design of Ship Structures course, and it comprises of a structural analysis of a ship's midship section.

The major goal of this project is to assist the student in understanding the subject given in the course so that they may fulfill their knowledge of structural analysis. This structural project will be completed in accordance with DnV, or Common Structural Rules (DnV, 2014).

In this case, a different ship was used in the type, function and constituent geometry of the main section than the one used in the AEN project, in order to obtain an all-round knowledge of design skills with reference to building geometries directly functional for bulk transport.

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1. Introduction

The main objective of this project is to preliminarily carry out the design of a Midship section using guidelines consisting of methods certified by the DnV classification register.
As a result, a method will be employed to accomplish that. This will be an iterative process because when a number is fixed or amended, it is critical to test if that value changes in the final results while still adhering to the standards.
All processes will be carried out in accordance with DnV, Common Structural Rules, and an analysis will be carried out using Bureau Veritas – Mars 2000 software to validate that all analytical data acquired are correct.
The calculations were carried out in Excel, and the 2D midship portion was designed in AutoCAD.

- The MARS2000 program will be used to check the scantlings of plate and stiffeners in the midship section.
- The CS guidelines will also be used to build one transverse bulkhead.
- The fatigue strength of a butt welded joint on the ship's deck is to be evaluated using the criteria of Fatigue Assessment of Ship Structures No. 30.7, DNV (2014).
- The ultimate strength will be determined using MARS2000 software.

2. Ship Dimensions

2.1.Basic Dimensions

The main dimensions of the ship where given in the last work project and are given in the following table:

Main Charateristics		
Lbp	231	[m]
B	34.6	[m]
D	18.1	[m]
T	13.2	[m]
v	18.2	[kn]
Cb	0.78	[-]

Tab.1 – Main dimensions of the ship

Where:

- Lbp: length between perpendiculars of the ship
- B: breadth of the ship
- D: depth of the ship
- T: draught
- v: cruise speed of the ship
- Cb: block coefficient

There will be critical constants employed, such as the acceleration gravity, g, the salt water density, ρsw, and the cargo density, which are required to compute various pressures in plates and stiffeners. The values of these constants are listed in the table below.

Data for calculations		
LCB	0.027	[m]
ΔL	11.55	[m]
R_b	2.82	[m]
g	9.810	[m^2/s]
ρ_sw	1.025	[t/m^3]
ρ_cargo	0.800	[t/m^3]

Tab.2 Values obtained to help the calculation procedure

When commencing to build a new midship section, DNV has specific requirements that must be followed. These rules are shown in table 3 below, where it is feasible to see if they are followed.

DNV Rules			
	Rule	Real	
Lbp	< 350	231.000	[m]
L/B	> 5	6.676	[-]
B/D	< 2.5	1.912	[-]
Cb	> 0.6	0.780	[-]

Tab.3 Rules to apply

To construct the midship section, the space frame, s, (spaces between stiffeners), and the span, L, which is the length of the frames, must be calculated. The minimum to ensure safety, according to project support appointments, should be 0.6 m, whereas the maximum may be computed as:

$$s = (2.08Lbp+438) \quad \text{mm}$$

This number can vary between $0.6 \leq s \leq 1$ m and s(+/- 15%), which are values that are 15% more or less than the optimal value. These two techniques are both legitimate, however the lowest will be specified as a value of two, and the maximum will be defined as a value of two as well, in order to maintain as much safety as possible.

It is critical to note that the spacing between stiffeners were kept lower than the maximum estimated value to maintain the structure's security. To assist construction, the distance technique was offered by employing the same value spaces of the stiffeners for the same plate.

The stiffener span should be between 3s and 5s m, hence a value of 4L will be assumed. Spaces between stiffeners, for example, are provided a lower value than the limit for plate length to maintain structural security.

The results obtained after rules restrictions are shown in the following table:

Restriction of parameters				
Parameter	Min	Max	Unit	Description
B1	0.000	3.244	[m]	Lenght of Bottom Tank
B2	4.325	6.055	[m]	Lenght of bilge tank
S	600	918	[mm]	Space Framing
h2	1.2	1.8	[m]	Longitudinal Hatch
B3	17.3	-	[m]	Cargo Hatch
l	2754.000	4590	[mm]	Stiffner Span

Tab.4 Application of DNV rules

2.2. Midship Section

This project's planned midship portion is for a bulk carrier with a single side skin, a double bottom, and an open hatch. Geometric calculations were used to determine specifications such as bottom tank width and height, bilge tank width, and deck tank width. However, as seen in the image below, the height of the bilge/deck will vary due to the varying angles. Alpha must be less than or equal to 30° for this project, and beta must be between 45° and 55°. Furthermore, the height h1 will be 0.8m and the height h2 will be 1.5m.
One of the plates subject to constraints is the keel plate, which has a minimum breadth according to DnV regulations C201 in Section 6 (Bottom Structures). The shear strake plate must also report a minimum and maximum value in Section 7 (Side Structures) of DnV regulation C201. Finally, under Section 8 (Deck Structures), the strength deck plating must conform to a minimum and maximum breadth specified by regulation C101.
The midship section may now be shown in figure 1, below, with the stiffeners and plates labeled. Recognize that the stiffeners have their'head' turned below, since cargo readily turns to the tanks' ground.

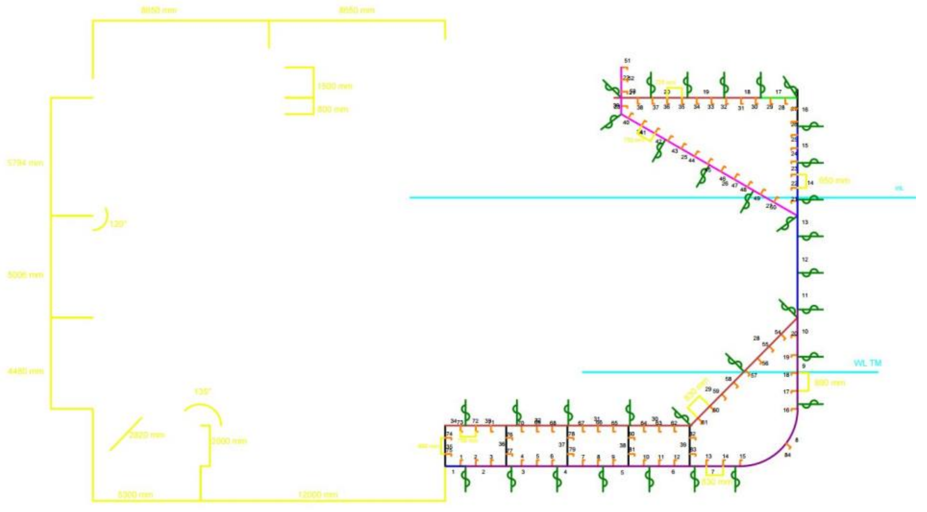


Fig.1 Midship section with measures

When developing the midship section, an engineer must also adhere to the market plates. Furthermore, before deciding on the size of the plates and the number of stiffeners, welding requirements must be considered. It is critical to provide at least 50 mm of space between the two pieces being welded in order to avoid weakening the plate's structure. This might be two or more plates, or the weld and a stiffener. Figures a and b provide examples of these two scenarios. The stiffener amount in a strake is similarly easy to calculate. First, the frame spacing must be within the stated range (0.6≤s≤0.918 m). Second, they must adhere to the previously stated welding restrictions.

Plate Restrictions		
	Min Lenght [mm]	Max Lenght [mm]
Keel	1955	-
Bottom	1955	-
Inner Bottom	1955	-
Bilge	1955	-
Side	1955	1800
Deck	1955	1800

Tab.5 Plate Restrictions

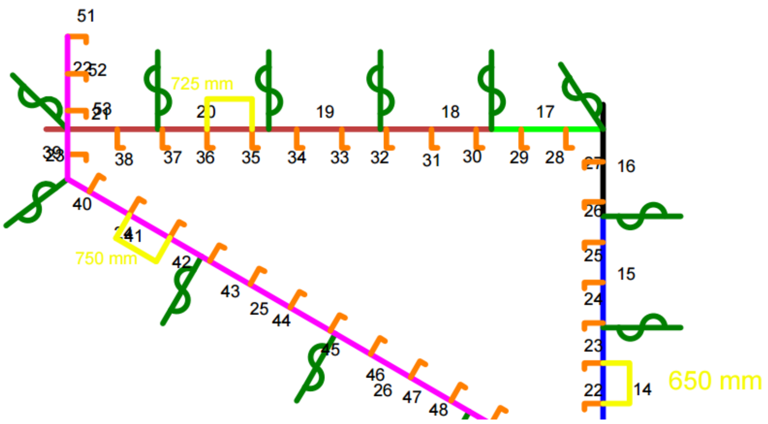


Fig.2 Example distance plates and welding marks

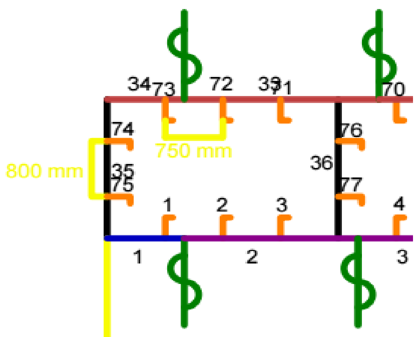


Fig.3 Example men’s hole and distances

3. Material Properties

The Class Society Rules are considered when selecting materials. Steels with a greater mechanical resistance in the bottom and deck might be employed in this situation if subjected to a larger bending moment strain. However, if the Classification Society Rules do not require the use of that sort of material, and also to make computations easier.

3.1. Hull Structure

The hull structure of this project will be totally constructed of steel. However, as mentioned in the DNV standards, there are numerous grades of steel with varied mechanical qualities, and their selection is based on two factors: plate thickness and hull region. This relationship is illustrated in the picture below, where A, B, D, and E represent NS-steel grades while AH, DH, and EH represent HS-steel grades. Furthermore, while deciding on a steel grade, two other factors must be considered: pricing and welding. To begin with, high strength structural steel is more costly than standard strength structural steel.
As a consequence, a ship cannot be built entirely of the finest steel since, while this makes the structure safer, it is too expensive to manufacture. As a reason, the steel will be chosen with the current strains in each plate and stiffener in mind. Second, keep in mind that the plates and stiffeners must be welded together, and the greater the thickness of the components, the longer it will take to weld them. As a response, plates thicker than 20 mm should be avoided since welding would take too long. As a result, the steel grade can be altered to meet this constraint.

Once there are no side tanks, a different sort of material, more expensive and resistant, will be utilized for security reasons. This occurs because any stroke in the side of the hull, for whatever reason, makes it more difficult to have a leak.

It is also crucial to note that steel with better resistance is more expensive, raising production costs. The following table lists the typical steel properties:

Table B1 Material classes

Thickness in mm	*Class*			
	I	*II*	*III*	*IV*
$t \leq 15$	A/AH	A/AH	A/AH	A/AH
$15 < t \leq 20$	A/AH	A/AH	A/AH	B/AH
$20 < t \leq 25$	A/AH	A/AH	B/AH	D/DH
$25 < t \leq 30$	A/AH	A/AH	D/DH	D/DH
$30 < t \leq 35$	A/AH	B/AH	D/DH	E/EH
$35 < t \leq 40$	A/AH	B/AH	D/DH	E/EH
$40 < t \leq 50$*)	B/AH	D/DH	E/EH	E/EH

*) Plating of Class III or IV and with a thickness between 50 mm < t ≤ 150 mm, shall be of grade E/EH.
For other cases, D/DH (according to Class II) will be minimum quality for thicknesses above 50 mm

The table below shows the many types of steel and their qualities that will be considered in this project. It is expected that the Young Modulus for all of them will be 206 GPa.

Material Selection- Hull structural steel			
	Yield Stress [N/mm2]	Grade	f1

NV-NS	235	A,B,D, E	1
NV-27	265	-	1.08
NV-32	315	-	1.28
NV-36	355	-	1.39
NV-40	390	-	1.47
Ref	S2-B201	S2-B202	S2-B203

Tab.6 DNV restrictions of material selection

The references on the left are the DnV rules that were utilized, where the first argument is the needed section.

Rhull and Rside are for NV-NS, which is for normal strength structural steel with a yield point lot less than 235 N/mm2 and NV-NS, which stands for normal strength structural steel with a yield point lot less than 315 N/mm3.

The material factor, f1, for the hull and side of the NV-NS and NV-32, respectively. E is the steel's modulus of elasticity.

3.2. Corrosion Additions for Steel

Several structural metals erode simply from exposure to moisture in the air, but the process may be greatly influenced by particular compounds. Corrosion can be localized locally, forming a pit or fracture, or it can spread across a large region, corroding the surface more or less evenly. Corrosion happens on exposed surfaces because it is a diffusion-controlled process. As a result, the thickness of the plate decreases with time. As a result, a corrosion margin is added to the net thickness to ensure the structure's safety. Because the ambient pressures fluctuate alongside the ship, the increased margin corrosion is mostly determined by the placement of the plate. Contact with saline water, ballast, cargo oil, and so on, for example. It is critical to understand that in tanks for fuel oil and ballast water, corrosion additives must enhance the scantlings of the steel structure. As a result, the plates and stiffeners will have corrosion added to their thicknesses, tk.

Figure below depicts these values (Table D1 from Section 2, DnV rules):

Table D1 Corrosion addition t_k in mm

Internal members and plate boundary between spaces of the given category	*Tank/hold region* Within 1.5 m below weather deck tank or hold top	*Tank/hold region* Elsewhere
Ballast tank 1)	3.0	1.5
Cargo oil tank only	2.0	1.0 (0) 2)
Hold of dry bulk cargo carriers 4)	1.0	1.0 (3) 5)
Plate boundary between given space categories	*Within 1.5 m below weather deck tank or hold top*	*Elsewhere*
Ballast tank 1)/Cargo oil tank only	2.5	1.5 (1.0) 2)
Ballast tank 1)/Hold of dry bulk cargo carrier 4)	2.0	1.5
Ballast tank 1)/Other category space 3)	2.0	1.0
Cargo oil tank only/ Other category space 3)	1.0	0.5 (0) 2)
Hold of dry bulk cargo carrier 4) /Other category space 3)	0.5	0.5

1) The term ballast tank also includes combined ballast and cargo oil tanks, but not cargo oil tanks which may carry water ballast according to Regulation 13(3), of MARPOL 73/78.

2) The figure in brackets refers to non-horizontal surfaces.

3) Other category space denotes the hull exterior and all spaces other than water ballast and cargo oil tanks and holds of dry bulk cargo carriers.

4) Hold of dry bulk cargo carriers refers to the cargo holds, including ballast holds, of vessels with class notations **Bulk Carrier** and **Ore Carrier**, see Pt.5 Ch.2 Sec.5.

5) The figure in brackets refers to webs and bracket plates in lower part of main frames in bulk carrier holds.

The next table will represent a partial representation of corrosion addition thicknesses in plates and stiffeners on midship section.

Corrosion addition tk on number of components				
Plates			Stiffeners	
Number	tk [mm]		Number	tk [mm]
1	1		1	1.5
2	1		2	1.5
3	1		3	1.5
4	1		4	1.5
5	1		5	1.5
6	1		6	1.5
7	1		7	1.5
8	1		8	1.5
9	1		9	1.5
10	1		10	1.5
11	0.5		11	1.5
12	0.5		12	1.5
13	0.5		13	1.5
14	1		14	1.5
15	1		15	1.5
16	2		16	1.5
17	2		17	1.5
18	2		18	1.5
19	2		19	1.5
20	2		20	1.5
21	2		21	1.5
22	2		22	1.5

Tab.7 Corrosion addition thicknesses

4. Design Loads

This section explains all of the loads used in the ship's construction. Because the goal of this project is to design the midship section, there is no need to do a thorough load analysis. This indicates that just a subset of the computations are validated in this section.

It should be noted that for wave-induced ship movements and accelerations, as well as lateral pressure, and that the specified design wave coefficient is a basic parameter for longitudinal strength calculations. Because the ship's movements and accelerations are provided as extreme values, the probability level is 10^-8.
Recognize that design pressures induced by the sea, liquid cargoes, dry cargoes, ballast, and bunkers are based on severe situations, but are reduced to equal values corresponding to the stress levels specified in DnV standards.
Furthermore, the analysis excludes impact forces induced by the sea (slamming, bow impact).

4.1. Ship Motions and Accelerations

According to the DNV regulations, acceleration, sea pressures, and hull girder loads have all been linked to a wave coefficient, C_W, given by the following table:

Table B1 Wave coefficient C_W	
L	C_W
$L \leq 100$	$0.0792\ L$
$100 < L < 300$	$10.75 - [\ (300 - L)/100\ ]^{3/2}$
$300 \leq L \leq 350$	10.75
$L > 350$	$10.75 - [\ (L - 350)/150\ ]^{3/2}$

And following formula:

$$C_W = 10.75 - \left(\frac{300 - L_{bp}}{100}\right)^{\frac{3}{2}},\ 100 < L < 300$$

Where a common acceleration parameter a0 is given by:

$$a_0 = \frac{3C_w}{L_{bp}} + C_V C_{V1}$$

$$C_V = \frac{\sqrt{L_{bp}}}{50},\ maximum\ 0.2$$

$$C_{V1} = \frac{v}{\sqrt{L_{bp}}},\ minimum\ 0.88$$

Using the aforementioned equations, it is feasible to compute the values of the parameters:

Parameters for calculation			
Cw	10.18	[-]	S4-B201
Cv	0.2	[-]	S4-B203
Cv1	1.20	[-]	S4-B203
a0	0.37	[-]	S4-B203

Tab.8 Basic ship motion and acceleration characteristics

4.1.2. Surge, sway /yaw and heave accelerations

The surge, sway and heave accelerations are given respectively by:

$$a_x = 0.2\, g\, a_0 \sqrt{C_b}$$

$$a_y = 0.3\, g\, a_0$$

$$a_z = 0.7\, g \frac{a_0}{\sqrt{C_b}}$$

The results obtained through these equations are resumed in the following table:

Surge,Sway/Yaw and Heave accelerations			
Surge Acceleration			
a_x	0.644	[m/s^2]	S4-B301
Combined Sway/Yaw Acceleration			
a_y	1.094	[m/s^2]	S4-B302
Heave Acceleration			
a_z	2.890	[m/s^2]	S4-B303

Tab.9 Surge, sway and heave accelerations

4.1.3. Roll motion and acceleration

The roll angle, the period of roll and the tangential roll acceleration are expressed by:

$$\phi = 50 * \frac{c}{B+75}\ (roll\ angle\ in\ rad)$$

$$T_R = 2 * \frac{k_r}{\sqrt{GM_t}}\ (period\ of\ roll\ in\ s)$$

$$a_r = \phi * \left(2 * \frac{\pi}{T_R}\right)^2 * R_r$$

Where:

- c = (1.25-0.025*Tr) *k and k = 1.2 (ships without bilge keel)
- kr = 0.25*B, which is the roll radius in m (for ships loaded with ore between - longitudinal bulkheads)
- GMt = 0.12*B for tankers and bulk carriers.
- Rroll = the smaller of (0.25D+0.5T; 0.5D)

Roll motion and acceleration			
T_roll	8.490	[s]	S4 - B 402
ϕ	0.473	[rad]	
a_roll	1.711	[m/s^2]	S4 - B 403
R_roll	6.6	[m]	
GM	4.152	[m]	S4 - B 402
kr	8.65	[m]	
k	1	[-]	S4 - B 401
c	1.038	[-]	

Tab.10 Roll accelerations

4.1.4. Pitch motion and acceleration

The formulas for calculating pitch angle, period of pitch and acceleration, as well as their results, are illustrated with the following equations:

$$\theta = 0.25 * \frac{a_0}{\sqrt{C_B}} \ (pitch\ angle\ in\ rad)$$

$$T_p = 1.8 * \sqrt{\frac{L}{g}} \ (period\ of\ pitch\ in\ s)$$

$$a_p = \theta * \left(2 * \frac{\pi}{T_p}\right)^2$$

Pitch motion and acceleration			
T_pitch	8.735	[s]	S4 - B 502
θ	0.119	[rad]	S4 - B 501
a_pitch	0.407	[m/s^2]	S4 - B 503
R_pitch	6.6	[m]	

Tab.11 Pitch motion and acceleration

4.2. Combined acceleration

The midship section's multiple combined accelerations (vertical, transverse, and longitudinal) may be estimated using the calculations:

$$a_v = k_v * g * \frac{a_0}{C_B}$$

Where kv is 0.7 between 0.3L and 0.6L for the midship section

$$a_t = \sqrt{a_y^2 + \left(gsen(\phi) + a_{roll}\right)^2}$$

$$a_l = \sqrt{a_x^2 + \left(gsen(\theta) + a_{pitch}\right)^2}$$

Combined Acceleration			
Combined Vertical Acceleration			
a(vert)	3.272	[m/s^2]	S4 - B 601
k(vert)	0.7	[-]	
Combined Transverse Acceleration			
a(trans)	6.280	[m/s^2]	S4 - B 701
Combined Longitudinal Acceleration			
a(long)	1.699	[m/s^2]	S4 - B 801

Tab.12 Combined acceleration

5. Lonngitudinal Strenght

This section specifies the criteria for longitudinal hull girder scantlings in terms of bending and shear. Recognize that the wave bending moments and shear forces are stated as design values with a 10^-8 chance of exceeding. These numbers are used to calculate the section modulus and shear area of the hull girder, as well as to regulate buckling and ultimate strength.

It is significant to remember that this only applies to ships that have complained about the limits specified.

5.1. Still Water Conditions

The design Stillwater bending moments, Ms, and Stillwater shear forces, Qs, must be calculated throughout the ship length for the design cargo situation after greater tensions are created in the ship. It is feasible to account for ballast condition as well, but because this project is intended to help the ship bear larger stresses, there is no need to do so. Downward loads are considered to be positive in these calculations and must be integrated in the forward direction from the aft and end of length. Figure below depicts the sign conventions of Qs and Ms:

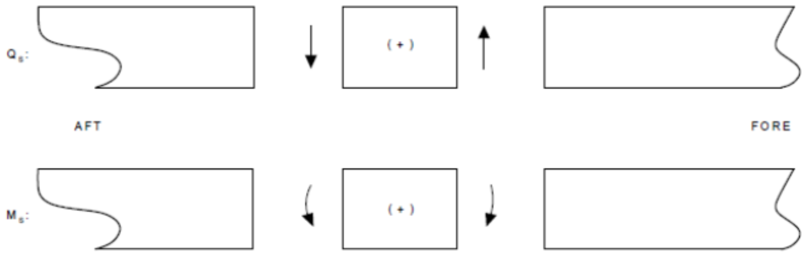


Fig. Conventions to apply

5.1.1. Still Water Bending Moments

The Stillwater bending moments amidships for sagging and hogging are provided by the following formulae:

$$M_{SO_{sagging}} =- 0.065\, C_W\, L_{bp}^2\, B\left(C_b + 0.7\right)$$

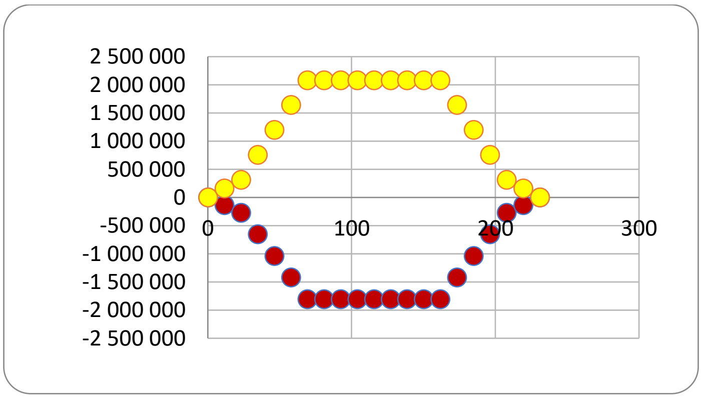
$$M_{SO_{hogging}} = C_W\, L^2\, B\,(0.1225 - 0.015\, C_b)$$

And the maximum bending moment in each station in calculated following:

$$M_s = k_{sm} * M_{so}$$

ksm is1.0 within 0.4Lbp amidships 0.15 at 0.1Lbp from AP of FP 0 at FP and AP

According on this numerical simulations, the class society limits for the bending moment for each component of the ship for both still water and moving water circumstances could be generated.



Cw	Ms Sag [kN*m]	Ms Hog [kN*m]
10.18	-1 807 541	2 081 867

5.1.2. Still water Shear Forces

For sagging and hogging circumstances, the Stillwater shear forces throughout the length of the ship are given by:

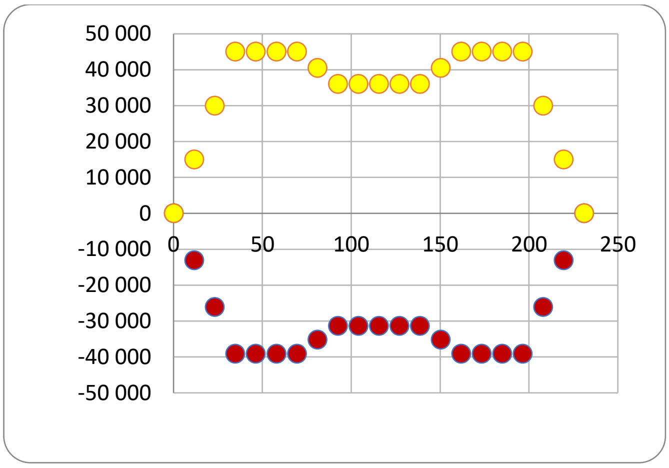
$$Q_S = k_{sq} Q_{SO}$$

$$Q_{SO} = 5 \frac{M_{SO}}{L_{bp}}$$

The values of ksq throughout the ship's length are provided by:

k_{sq} = 0 at A.P. and F.P.
= 1.0 between 0.15 L and 0.3 L from A.P.
= 0.8 between 0.4 L and 0.6 L from A.P.
= 1.0 between 0.7 L and 0.85 L from A.P.

According on this computer modelling, the classification society limitations on shear force for each portion of the ship were generated for both still water and moving water circumstances. This is illustrated below



Q Sag [kN*m]	Q Hog [kN*m]
-39 124	45 062

5.2. Wave Load Conditions

The ship is subjected to the effect of waves of varying lengths, frequencies, and amplitudes when navigating offshore. This interaction changes the forces exerted on the hull and, as a result, the tensions along the structure. Sagging and hogging are the two options. The first occurs when the top section of the ship beam is compressed while the bottom part is extended, and the second is the inverse.

5.2.1. Vertical Wave Bending Moment

The wave load condition at the midship for sagging and hogging is given by:

$$M_{WO_{sagging}} = -0.11\,\alpha\,C_W\,L_{bp}^2\,B\,(C_b + 0.7)$$

$$M_{WO_{hogging}} = 0.19\,\alpha\,C_W\,L_{bp}^2\,B\,C_b$$

The greatest value α is obtained when the factor is supplied by the figure below for seagoing circumstances.

α = 1.0 for seagoing conditions
= 0.5 for harbour and sheltered water conditions (enclosed fjords, lakes, rivers).

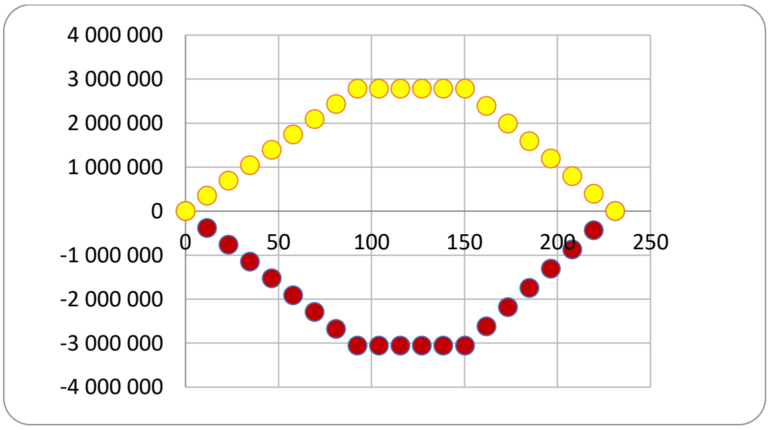
The following equation describes the wave load situation along the ship.

$$M_W = k_{wm}\,M_{WO}$$

With factor

k_{wm} = 1.0 between 0.40 L and 0.65 L from A.P.
= 0.0 at A.P. and F.P.

According on this computer modelling, the classification society limitations on shear force for each portion of the ship in both wave circumstances could be generated.



Ms Sag [kN*m]	Ms Hog [kN*m]
-3 058 916	2 784 590

5.2.2. Vertical Wave Shear Force

A positive shear force and a negative shear force are supplied as rule values for vertical wave shear forces throughout the length of the ship to be utilized when positive and negative water shear force:

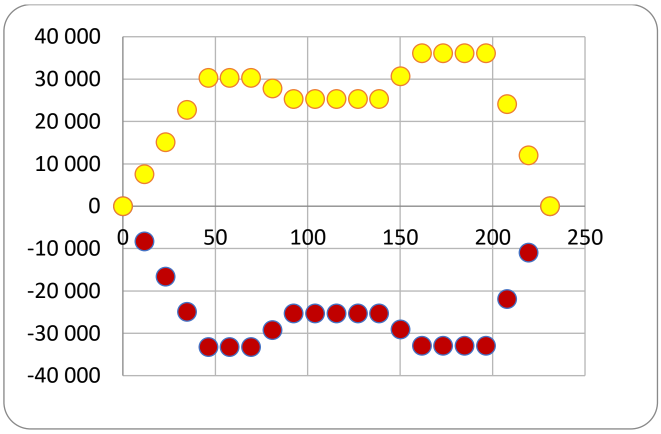
$$Q_{WP} = 0.3\,\beta\,k_{wqp}\,C_W\,L_{bp}\,B\,(C_b + 0.7)$$

$$Q_{WN} = -\,0.3\,\beta\,k_{wqp}\,C_W\,L_{bp}\,B\,(C_b + 0.7)$$

When there is a buoyancy surplus forward of section, shear force is positive; when there is a weight surplus forward of section, shear force is negative.
The values of the constants are explained in the following table:

β	=	1.0 for seagoing conditions
	=	0.5 for harbour and sheltered water conditions (enclosed fjords, lakes, rivers)
k_{wqp}	=	0 at A.P. and F.P.
	=	1.59 $C_B/(C_B + 0.7)$ between 0.2 L and 0.3 L from A.P.
	=	0.7 between 0.4 L and 0.6 L from A.P.
	=	1.0 between 0.7 L and 0.85 L from A.P.
k_{wqn}	=	0 at A.P. and F.P.
	=	0.92 between 0.2 L and 0.3 L from A.P.
	=	0.7 between 0.4 L and 0.6 L from A.P.
	=	1.73 $C_B/(C_B + 0.7)$ between 0.7 L and 0.85 L from A.P.

According on this computer modelling, the classification society limitations on shear force for each portion of the ship in both wave circumstances could be generated



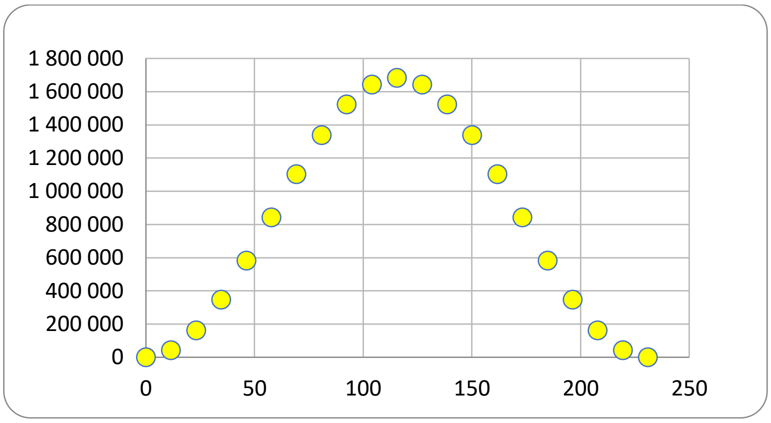
Q Neg [kN*m]	Q Pos [kN*m]
-36 115	36 115

5.2.3. Horizontal Wave Bending Moment

The horizontal wave bending moments throughout the ship's length are given by

$$M_{WH} = 0.22\, L_{bp}^{\frac{9}{4}}\, (T + 0.3\, B)\, C_b \left(1 - \cos \cos \left(360 \frac{x}{L_{bp}}\right)\right)$$

Where x is the distance in meters between the A.P and the segment under consideration.



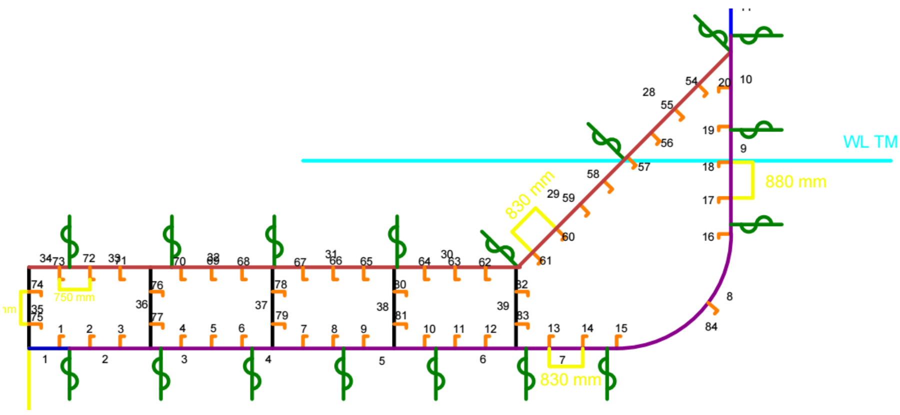
6. Bottom Structures

This section's requirements relate to bottom structures and define the bottom structure's initial scantling procedure, which includes the keel plate, bottom and bilge plating, inner bottom plating, longitudinal girders plating, bottom longitudinal and girder stiffeners.

Note that it is show only half of the breadth of the plates 1 and 34, since it is half for each half midship section.

It is critical to provide the local loads on the bottom structure before detailing plates and stiffeners. The table below shows the pressures to which a plate and stiffeners are subjected (table B1 from Section 6, DnV rules)

Structure	*Load type*	*p (kN/m²)*
Outer bottom	Sea pressure	$p_1 = 10\,T + p_{dp}$ (kN/m²) 1)
	Net pressure in way of cargo tank or deep tank	$p_2 = \rho(g_0 + 0.5\,a_v)\,h_s - 10\,T_M$ $p_3 = \rho\, g_0\, h_s + p_0 - 10\,T_M$
Inner bottom	Dry cargo in cargo holds	$p_4 = \rho(g_0 + 0.5\,a_v)\,H_C$
	Ballast in cargo holds	$p_5 = (10 + 0.5a_v)h_s$ $p_6 = 6.7(h_s + \phi b) - 1.2\sqrt{H\,\phi b_t}$ 2) $p_7 = 0.67(10h_p + \Delta p_{dyn})$ $p_8 = 10h_s + p_0$
	Liquid cargo in tank above	$p_9 = \rho(g_0 + 0.5a_v)\,h_s$ $p_{10} = \rho g_0[0.67(h_s + \phi b) - 0.12\sqrt{H\,\phi b_t}]$ 2) $p_{11} = 0.67(\rho g_0 h_p + \Delta p_{dyn})$ $p_{12} = \rho g_0 h_s + p_0$
Inner bottom, floors and girders	Pressure on tank boundaries in double bottom	$p_{13} = 0.67\,(10\,h_p + \Delta\, p_{dyn})$ $p_{14} = 10\,h_s + p_0$
	Minimum pressure	$p_{15} = 10\,T$
1) For ships with service restrictions the last term in p_1 may be reduced by the percentages given in Sec.4 B202. 2) p_6 and p_{10} to be used in tanks/holds with largest breadth > 0.4 B.		



Some assumptions and constants should be determined before utilizing the formulas from C200 to C906 to specify all the key parameters from the elements. The formulas may be found in the DNV regulations and are presented in the table below. As suggested by the professor in class, the neutral axis height was estimated to be D/3.

Constant values			
p0	15	kN/m^2	S4 - C 302
t0	6	mm	S6 C402
ka	1.08	[-]	S6 - A 201
f2b	0.868	[-]	
Zb	3.19E+07	[cm^3]	
I	1.93E+10	[cm^4]	S5-C401
Tm	4.62	[m]	S6 - C 402
ks	2	[-]	S4-C201
f	4.9	[m]	S4 - C 201
Z_NA	6.03	[m]	p

Total loads must be considered in direct stress calculations on double bottom structures as differences between internal and exterior pressures. The table below represents these loads (table B1 from Section 6, DNV rules). For design purposes, the top air pipe will be considered to be 1.5m above the strength deck or 19.6m above the baseline.

6.1 Plates

6.1.1. Keel Plate

The keel plate, represented by plate 1 in Figure 16, will be developed using the equations C201 and C202. These equations, which are provided below, yield the plate's minimal breadth and minimum thickness.

$$b_{min} = 800 + 5\,L_{bp}$$

$$t_{min} = 7.0 + \frac{0.05\,L_{bp}}{\sqrt{f_1}} + t_k$$

Where tk is the increased margin corrosion from table and f1 is the factor from the steel chosen.

As a result, the primary dimensions of the keel plate are reflected in the table below.

Because there is only one plate with an integer number, the ultimate thickness was rounded up.

Keel Plate						
Plate	Breadth [m]	Breadth [m]	Material	Thickness [mm]	ICM [mm]	Gross Thickness [mm]
nº	b_min	b	f1	t_min	tk	t
1	1.955	2	1.39	17.80	1	18
	S6 - C 201			S6 - C 202		

6.1.2. Bottom and Bilge Plating

These plates, which correspond to plates 2 through 10 in the picture, will be created using the equations C301, C302, and C304. These equations, which are provided below, yield the plate's minimal breadth, needed thickness, and minimum thickness. The ultimate thickness is the rounded upward number between the minimum and necessary thicknesses.

The width of the strakes in the longitudinal bulkhead and bilge strake, which must be of a steel grade higher than A, must not be less than the following equation.

The thickness of the plates representing the minimum and necessary thicknesses, treq, respectively. The valid thickness is the greater of two values.

$$b_{min} = 800 + 5\,L_{bp}$$

$$t_{req} = \frac{15.8\,k_a\,s\sqrt{p}}{\sqrt{\sigma}} + t_k$$

Where:

- p = highest pressure value between p1 and p3
- ka = 1, (for dry cargo vessels)
- σ = 175f1-120f2b, (maximum 120f1 when transverse frames, within 0.4Lbp)
- f2b stress factor is given by $f_{2b} = \frac{5.7\left(M_S + M_W\right)}{Z_B}$
- Where MS is is the the still water bending moment, MW is the hogging still water bending moment, and ZB is the bottom midship section modulus in cm3 given by

$$Z_B = \frac{I}{Z_{NA}\,100}$$

- Where I is the midship section moment of inertia about the transverse NA (Neutral Axis) and Z_{NA} is the neutral axis height, it was possible to use 1/3 of the depth value, this approximation, seems to be more correct. The midship section moment of inertia about the transverse neutral axis shall not be less than

$$I = 3\,C_W\,L_{bp}^3\,B\,(C_b + 0.7)$$

- The expression for the minimum thickness required for the outer bottom plating

$$t_{min} = 5.0 + \frac{0.04\,L_{bp}}{\sqrt{f_1}} + t_k$$

Bottom and bilge plates																			
Plate	Breadth [m]	Thickness [mm]	Breadth [m]	Thickness [mm]		s	p1	p2	p3	p	σ	pdp	pl	y	z	kf	hs	Material
nº	b	t	b_min	t_min	t_req	[m]	[kN/m^2]	[kN/m^2]	[kN/m^2]	[kN/m^2]	[-]	[kN/m^2]	[-]	[m]	[m]	[m]	[m]	f1
2	2.25	15	1.955	14.3	13.8	0.75	152.1	-22.7	-11.1	152.1	139.0	20.1	25.3	8.65	0	4.9	2	1.39
3	2.25	15	1.955	14.3	13.8	0.75	152.1	-22.7	-11.1	152.1	139.0	20.1	25.3	8.65	0	4.9	2	1.39
4	2.25	15	1.955	14.3	13.8	0.75	152.1	-22.7	-11.1	152.1	139.0	20.1	25.3	8.65	0	4.9	2	1.39
5	2.25	15	1.955	14.4	13.8	0.75	152.3	-22.7	-11.1	152.3	139.0	20.3	25.3	8.875	0	4.9	2	1.39
6	2.25	15	1.955	14.5	13.8	0.75	155.1	-22.7	-11.1	155.1	139.0	23.1	25.3	11.125	0	4.9	2	1.39
7	2.00	17	1.955	16.0	13.8	0.83	157.7	-22.7	-11.1	157.7	139.0	25.7	25.3	13.25	0	4.9	2	1.39
8	4.89	17	1.955	16.3	13.8	0.83	162.7	0.7	9.0	162.7	139.0	30.7	25.3	16.475	0.826	4.9	4	1.39
9	2.33	17	1.955	16.7	13.6	0.88	167.8	-8.7	1.0	167.8	153.0	35.8	25.3	17.3	4.2125	4.9	3.2	1.47
10	2.33	17	1.955	16.8	13.6	0.88	170.6	-34.5	-21.1	170.6	153.0	38.6	25.3	17.3	6.5375	4.9	1	1.47

6.1.3. Inner Bottom Plating

The inner bottom plate thicknesses are specified by an equation that reflects the required thickness corresponding to lateral pressure and an expression that defines the minimum thickness.

These plates, numbered 28 to 34 in the image, will be created using the equations C401 and C402. These equations, which are provided below, yield the needed and minimum thickness of the plate.

$$t_{req} = \frac{15.8\,k_a\,s\sqrt{p}}{\sqrt{\sigma}} + t_k$$

Where:

- p = highest pressure value between p13 and p15 and p14
- ka=1, (for dry cargo vessels)
- σ=200f1-100f2b, (maximum 140f1 when transverse frames, within 0.4Lbp)

And the minimum thickness is given by the following equation:

$$t_{min} = t_0 + \frac{0.03 L_{bp}}{\sqrt{f_1}} + t_k$$

Inner bottom plates																
Plate	Breadth [m]	Thickness [mm]	Breadth [m]	Thickness [mm]		s	p4	p13	p14	p15	p	σ	pdp	pl	y	z
nº	b	t	b_min	t_min	t_req	[m]	[kN/m^2]	[kN/m^2]	[kN/m^2]	[kN/m^2]	[kN/m^2]	[-]	[kN/m^2]	[-]	[m]	[m]
28	3.73	15	1.955	14.11	13.22	0.83	158.38	108.54	88.00	132.00	158.38	198.47	36.32	25.25	16	6
29	3.73	15	1.955	14.59	13.22	0.83	170.70	123.95	124.00	132.00	170.70	198.47	29.88	25.25	13.4	3.3
30	3.025	14	1.955	13.94	13.22	0.75	188.89	134.67	158.90	132.00	188.89	198.47	24.75	25.25	10.5	2
31	3.025	14	1.955	13.94	13.22	0.75	188.89	134.67	176.00	132.00	188.89	198.47	22.47	25.25	8.65	2
32	2.525	14	1.955	13.94	13.22	0.75	188.89	134.67	176.00	132.00	188.89	198.47	22.47	25.25	8.65	2
33	2.525	14	1.955	13.94	13.22	0.75	188.89	134.67	176.00	132.00	188.89	198.47	22.47	25.25	8.65	2
34	2	14	1.955	13.94	13.22	0.75	188.89	134.67	176.00	132.00	188.89	198.47	22.47	25.25	8.65	2

6.1.4. Double Bottom Longitudinal Girder

These plates, numbered 35 to 39 in the picture, will be created using the equations C501 and C502. These equations, which are provided below, yield the needed and minimum thickness of the plate. The ultimate thickness is the rounded upward number between the minimum and necessary thicknesses. The thickness needed for twin bottom tank floors and longitudinal girders is determined by the following equation:

$$t_{req} = \frac{15.8\, k_a\, s \sqrt{p}}{\sqrt{\sigma}} + t_k$$

- p = highest pressure value p13,p14,p15
- ka=1, (for dry cargo vessels)
- σ=130f1, (longitudinal stiffened)

And the thickness of longitudinal girders, flooring, and supporting plates must be at least:

$$t_{min} = 6.0 + \frac{k}{\sqrt{f_1}} + t_k$$

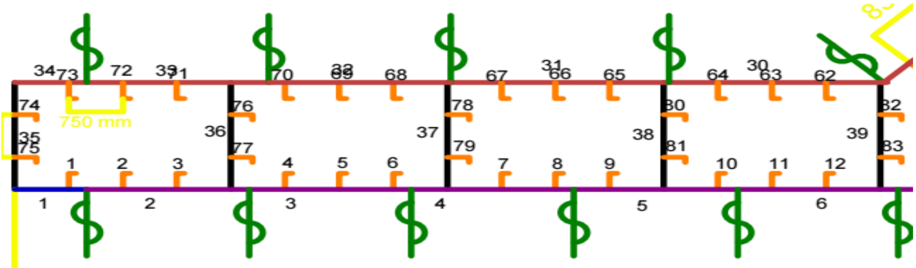
Where k=0.02Lbp, for other girders and remaining part of centre girder

Longitudinal Girders															
Plate	Breadth [m]	Thickness [mm]	Thickness [mm]		k	s	p13	p14	p15	p	σ	hp	Δpdyn	hs	Material
nº	b	t	t_min	t_req	[-]	[m]	[kN/m^2]	[kN/m^2]	[kN/m^2]	[kN/m^2]	[-]	[m]	[kN/m^2]	[m]	f1
35	2	16	15.22	11.42	4.62	0.8	141.37	25.00	132.00	141.37	139.04	18.6	25	1	1.39
36	2	16	15.22	11.42	4.62	0.8	141.37	25.00	132.00	141.37	139.04	18.6	25	1	1.39
37	2	16	15.22	11.42	4.62	0.8	141.37	25.00	132.00	141.37	139.04	18.6	25	1	1.39
38	2	16	15.22	11.42	4.62	0.8	141.37	25.00	132.00	141.37	139.04	18.6	25	1	1.39
39	2	16	15.22	11.42	4.62	0.8	141.37	25.00	132.00	141.37	139.04	18.6	25	1	1.39

6.3. Stiffeners

The optimum stiffener is determined by computing three parameters: the thickness of the web/flange (t), the requisite section modulus (Z), and the area (A). The first two are determined using DNV-rules, whereas the third is calculated using A=0.68*Z^2/3. This is true once all of the stiffeners are bulb-profile.

Furthermore, the final thickness is the maximum rounded upward value of all the minimum thicknesses, and the final area is the maximum area of all the minimum areas. This is done in this manner to make selecting stiffeners easier. The more equal the stiffeners, the easier the construction.



6.2.1. Bottom Longitudinal

The necessary section modulus and the minimum thickness of web and flange are specified by S6-701 and S6-703, respectively, according to the standards, as indicated below.

The minimal sectional area and minimum thickness are required to determine the right longitudinal. Bulb-profile stiffeners will be used for the bottom longitudinals. The sectional area is defined as follows:

$$A = 0.68\sqrt[3]{Z^2}$$

With Z sectional modulus required

$$Z = \frac{83\, l^2\, s\, p\, w_k}{\sigma}$$

Where:

- s = spacing of the stiffener
- l = stiffener span (equal to 4*s)
- p = highest pressure from p1 to p3
- wk = 1+0.06*tk (S3-C 1004)
- k = 0.015*Lpp, maximum of 5
- σ= 225 f1 – 130 f2b – 0.7 σdb (maximum of 160*f1), where σdb = 50*f1
- tk = thickness considered the corrosion

And the tickness of web and flange shall not be less than:

$$t = 4.5 + k + t_k$$

Where k = 0.015Lbp, (5 maximum)

The final thickness is the greatest rounded upward value of the minimum thicknesses, and the final area is the greatest area of all the minimum areas. This is done in this manner to make selecting stiffeners easier. The more equal the stiffeners, the easier the construction.

In the next parts of this study, requirements will be utilized in relation to the market database of bulb-profile stiffeners.

Bottom longitudinals														
Stiffener	Section Modulus [cm^3]	Thickness [mm]	Area [cm^2]	t_min	A_min	l	k	s	wk	σ	p1	p2	p3	P
nº	Z_req	t	A	[mm]	[cm^2]	[m]	[-]	[m]	[-]	[-]	[kN/m2]	[kN/m2]	[kN/m2]	[kN/m2]
1	1068	10	85.2	9.465	71.0	3.672	3.465	0.75	1.09	130.3	152.1	-22.7	-11.1	152.1
2	1068	10	85.2	9.465	71.0	3.672	3.465	0.75	1.09	130.3	152.1	-22.7	-11.1	152.1
3	1068	10	85.2	9.465	71.0	3.672	3.465	0.75	1.09	130.3	152.1	-22.7	-11.1	152.1
4	1068	10	85.2	9.465	71.0	3.672	3.465	0.75	1.09	130.3	152.1	-22.7	-11.1	152.1
5	1068	10	85.2	9.465	71.0	3.672	3.465	0.75	1.09	130.3	152.1	-22.7	-11.1	152.1
6	1068	10	85.2	9.465	71.0	3.672	3.465	0.75	1.09	130.3	152.1	-22.7	-11.1	152.1
7	1068	10	85.2	9.465	71.0	3.672	3.465	0.75	1.09	130.3	152.1	-22.7	-11.1	152.1
8	1068	10	85.2	9.465	71.0	3.672	3.465	0.75	1.09	130.3	152.1	-22.7	-11.1	152.1
9	1068	10	85.2	9.465	71.0	3.672	3.465	0.75	1.09	130.3	152.1	-22.7	-11.1	152.1
10	1077	10	85.2	9.465	71.5	3.672	3.465	0.75	1.09	130.3	153.4	-22.7	-11.1	153.4

6.2.2. Inner Bottom Longitudinal

The necessary section modulus and the minimum thickness of web and flange are specified by S6-701 and S6-703, respectively, according to the standards, as indicated below.

$$Z = \frac{83 * l^2 * s * p * w_k}{\sigma}$$

And

$$t = 4.5 + k + t_k$$

Where:

- s = spacing of the stiffener
- l = stiffener span (equal to 4*s)
- p = highest pressure from p4, p13, p14 and p15
- wk = 1+0.06*tk (S3-C 1004)
- k = 0.015*Lpp, maximum of 5
- σ= 225 f1 – 100 f2b – 0.7 σdb (maximum of 160*f1), where σdb = 50*f1
- tk = thickness with margin corrosion

Inner Bottom Longitudinals											
Stiffener	Section Modulus [cm^3]	Thickness [mm]	Area [cm^2]	t_min	A_min	l	k	s	wk	σ	P
nº	Z_req	t	A	[mm]	[cm^2]	[m]	[-]	[m]	[-]	[-]	[kN/m2]
50	1026	10	70	9.47	69	3.672	3.465	0.83	1.09	130.3	132
51	1026	10	70	9.47	69	3.672	3.465	0.83	1.09	130.3	132
52	1026	10	70	9.47	69	3.672	3.465	0.83	1.09	130.3	132
53	1026	10	70	9.47	69	3.672	3.465	0.83	1.09	130.3	132
54	1026	10	70	9.47	69	3.672	3.465	0.83	1.09	130.3	132

55	1026	10	70	9.47	69	3.672	3.465	0.83	1.09	130.3	132
56	1026	10	70	9.47	69	3.672	3.465	0.83	1.09	130.3	132
57	1027	10	70	9.47	69	3.672	3.465	0.83	1.09	130.3	132.191
58	1035	10	70	9.47	70	3.672	3.465	0.75	1.09	130.3	147.4248
59	1035	10	70	9.47	70	3.672	3.465	0.75	1.09	130.3	147.4248
60	1035	10	70	9.47	70	3.672	3.465	0.75	1.09	130.3	147.4248
61	1035	10	70	9.47	70	3.672	3.465	0.75	1.09	130.3	147.4248

6.2.3. Double Bottom Longitudinal Stiffeners

The general section modulus requirements of stiffeners on longitudinal girders forming the border of double bottom tanks are provided by the necessary section modulus and the minimum thickness of web and flange are specified by S6-901 and S6-603, respectively, according to the standards, as indicated below.

$$Z = \frac{100 * l^2 * s * p * w_k}{\sigma}$$

$$t = 4.5 + k + t_k$$

Where:

- s = spacing of the stiffener
- l = stiffener span (equal to 4*s)
- p = highest pressure from p13, p14 and p15
- wk = 1+0.06*tk (S3-C 1004)
- k = 0.015*Lpp, maximum of 5
- σ= 225 f1 – 110 f2b (maximum of 160*f1)
- tk = thickness of corrosion margin

Stiffeners of girders											
Stiffener	Section Modulus [cm^3]	Thickness [mm]	Area [cm^2]	t_min	A_min	l	k	s	wk	σ	P
nº	Z_req	t	A	[mm]	[cm^2]	[m]	[-]	[m]	[-]	[-]	[kN/m2]
70	936	10.0	67	9.5	65	3.672	3.465	0.8	1.09	174.2	138.69
71	972	10	67	9.5	67	3.672	3.465	0.8	1.09	174.2	144.05
72	936	10	67	9.5	65	3.672	3.465	0.8	1.09	174.2	138.69
73	972	10	67	9.5	67	3.672	3.465	0.8	1.09	174.2	144.05
74	936	10	67	9.5	65	3.672	3.465	0.8	1.09	174.2	138.69
75	972	10	67	9.5	67	3.672	3.465	0.8	1.09	174.2	144.05
76	936	10	67	9.5	65	3.672	3.465	0.8	1.09	174.2	138.69
77	972	10	67	9.5	67	3.672	3.465	0.8	1.09	174.2	144.05
78	936	10	67	9.5	65	3.672	3.465	0.8	1.09	174.2	138.69
79	972	10	67	9.5	67	3.672	3.465	0.8	1.09	174.2	144.05

6.2.4 Selection of the longitudinals

To make the ship's construction easier, one stiffener pattern was chosen for each piece of the bottom structure. This implies that the bottom, bilge, and keel plate will be stiffened in one way, the inner bottom in another, and so forth. To pick the desired, the stiffener with the highest section modulus and thickness of each portion was used. For example, stiffener 20 will have the properties of the bottom, bilge, and keel plate. Following this, pick one among the ones accessible from shipbuilding industry that meets the needed requirements.

Requirements Maximum				
Structure	SecMudul. [cm^3]	Thickness [mm]	Area [cm^2]	Longitudinal
	Z	t	A	
Outer Bottom	1404	10	86	HP400 X 16
Inner Bottom	1036	10	70	HP370 X 15
Double Bottom	973	10	67	HP340 x 12

7. Side Structure

This section will go through how to size the side structures using the formulas provided in Pt3. Ch1. Section 7 of the DNV Rules. Side plating (plates 11 to 15), shear strake plate (plate 16), longitudinal (stiffeners 21 to 27), and transverse stiffeners are all part of it (located in plates 11 to 13).

This section will go through the first scantling of the side structure, which comprises the side plating, shear strake plate, longitudinals, and main frame.

It is critical to show the local loads on the bottom structure before discussing plates and stiffeners.

Total loads must be considered in direct stress calculations on side structures as differences between internal and exterior pressures. The table below represents these loads (table B1 from Section 7, DNV rules). The same theory that was used for hp from bottom structures is used here.

Load type		*P (kN/m²)*
External	Sea pressure below summer load waterline	$p_1 = 10\,h_0 + p_{dp}$ 1)
	Sea pressure above summer load waterline	$p_2 = (p_{dp} - (4 + 0.2\,k_s)\,h_0)$ 1) minimum $6.25 + 0.025\,L_1$
Internal	Ballast, bunker or liquid cargo in side tanks in general	$p_3 = \rho\,(g_0 + 0.5\,a_v)\,h_s - 10\,h_b$ $p_4 = \rho\,g_0\,h_s - 10\,h_b + p_o$ $p_5 = 0.67\,(\rho\,g_0\,h_p + \Delta\,p_{dyn}) - 10\,h_b$
	Above the ballast waterline at ballast, bunker or liquid cargo tanks with a breadth > 0.4 B	$p_6 = \rho g_0[0.67(h_s + \phi b) - 0.12\sqrt{H\phi b_t}]$
	Above the ballast waterline and towards ends of tanks for ballast, bunker or liquid cargo with length > 0.15 L	$p_7 = \rho g_0[0.67(h_s + \theta l) - 0.12\sqrt{H\theta l_t}]$
	In tanks with no restriction on their filling height 2)	$p_8 = \rho\left[3 - \frac{B}{100}\right]b_b$

1) For ships with service restrictions, p_2 and the last term in p_1 may be reduced by the percentages given in Sec.4 B202.

2) For tanks with free breadth $b_s > 0.56$ B the design pressure will be specially considered according to Sec.4 C305.

Some assumptions and constants should be determined before utilizing the formulas from C200 to C906 to specify all the key parameters from the elements. The formulas may be found in the DNV regulations and are presented in the table below.

Constant values			
H	17.6	[m]	S7 - B 101
bt	17.3	[m]	
hb	4.62	[m]	
ks	2	[-]	S4-C201
p0	15	kN/m^2	S4 - C 302
	25		
ka	1.08	[-]	
b	25.95	m	S7 - B 101
f2d	1.74	[-]	
T ballast	4.62	[m]	S6 - C 402

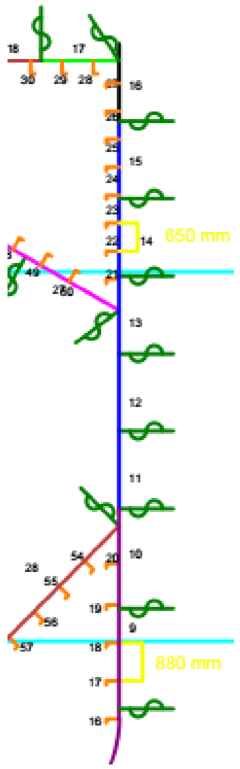


Fig. Side representation

7.1. Plates

7.1.1. Side Plates

These plates, which correspond to plates 11 to 15, will be created using the equations C101 and C102. These equations, which are provided below, yield the needed and minimum thicknesses of the plate. It was discovered that the ultimate thickness is the rounded upward value between the minimum and necessary thicknesses.

$$t_{req} = \frac{15.8\, k_a\, s \sqrt{p}}{\sqrt{\sigma}} + t_k \qquad t_{min} = 5.0 + \frac{k\, L_{bp}}{\sqrt{f_{1_{side}}}} + t_k$$

Where,

- s = stiffener spacing
  - Plate 11 to 13: spacing from transverse stiffener (s=918 mm)
  - Plate 14 and 15: spacing from longitudinal stiffener
- p = highest value from
  - Plate 11 to 13: pressure p1, p6 and p8
  - Plate 14 and 15: pressure p2 and p6
- σ is equal to
  - Plate 11 to 13: 120*f1
  - Plate 14 and 15: 140*f1
- k = 0.01
- tk = thickness of corrosion margin

Side Plates													
Plate	Breadth [m]	Thickness [mm]	t_min	t_req	k	σ	s	p	p1	p2	p6	p8	pdp
nº	b	t	[mm]	[mm]	[-]	[-]	[m]	[kN/m^2]	[kN/m^2]	[kN/m^2]	[kN/m^2]	[kN/m^2]	[KN/m^2]
11	1.8	14	7.54	13.30	0.01	153.6	0.918	103	78	-	103	73	32
12	1.8	13	7.54	12.70	0.01	153.6	0.918	94	62	-	94	73	34
13	1.8	13	7.54	12.07	0.01	153.6	0.918	84	46	-	84	73	36
14	1.8	11	8.04	10.02	0.01	179	0.725	96	-	34	96	-	37
15	1.8	10	8.04	9.43	0.01	179	0.725	84	-	28	84	-	37

7.1.2. Shear Strake

The equations C201 and C202 will be used to create this plate, which is number 16. These equations, which are provided below, yield the plate's minimal breadth and minimum thickness. The ultimate thickness is the rounded upward number between the minimum and necessary thicknesses. This value was acquired when the strength deck was designed.

The following equations yield the minimal breadth and thickness;

$$b_{min} = 800 + 5\,L_{bp},$$

$$t_{min} = \frac{t_1+t_2}{2}$$

Where:

- t1 = required side plating in mm (equation with the same design as plates 14 and 15)
- t2 = required deck plating in mm

Shear Strake								
Plate	Breadth [m]	Thickness [mm]	t1	t2	k	σ	s	p
nº	b	t	[mm]	[mm]	[-]	[-]	[m]	[kN/m^2]
16	1.8	11	9.79	12	0.01	195	0.725	78

7.2. Stiffeners

The optimum stiffener is determined by computing three parameters: the thickness of the web/flange (t), the requisite section modulus (Z), and the area (A). The first two are produced using DNV-rules, while the third is computed using A=0.68*Z23. This is true once all of the stiffeners are bulb-profile.
Furthermore, the final thickness is the maximum rounded upward value of all the minimum thicknesses, and the final area is the maximum area of all the minimum areas. This is done in this manner to make selecting stiffeners easier. The more equal the stiffeners, the easier the construction.
To make the ship's construction easier, one stiffener pattern was chosen for each piece of the side structure. This means that the stiffener on the side and shear plate will be the same (longitudinal or transverse). To pick the desired, the stiffener with the highest section modulus and thickness of each portion was used. Following this, pick one among the ones accessible from shipbuilding industry that meets the needed requirements. The table below summarizes these two phases.

Requirements Maximum				
Structure	SecMudul. [cm^3]	Thickness [mm]	Area [cm^2]	Longitudinal
	Z	t	A	
Side	276	10	29	HP220 X 10
Shear Strake	214	10	29	HP220 X 10
Strength Deck	438	10	40	HP260 x 12

7.2.1. Side Longitudinals

The necessary section modulus and the minimum thickness of web and flange are specified by S7-301 and S7-302, respectively, according to the standards, as indicated below.
The minimum sectional area and minimum thickness must be computed in order to define the longitudinals.

$$Z = \frac{83 * l^2 * s * p * w_k}{\sigma}$$

$$t = 4.5 + k + t_k$$

Where:

- s = spacing of the stiffener
- l = stiffener span (equal to 4*s)
- p = highest pressure from p2, p6 and p8
- wk = 1+0.06*tk (S3-C 1004)
- k = 0.01*Lpp, maximum of 5

- sigma= 225*f1 – 130 f2d*zn-za/zn (maximum of 160*f1). Zn must be taken as D/3 as done in section 6 and Za is the height of the element from the baseline
- tk = thickness of corrosion margin

Stiffener	SecMudul. [cm^3]	Thickness [mm]	Area [cm^2]	t_min	A_req	l	s	wk	σ	p
nº	Z	t	A	[mm]	[cm^2]	[m]	[m]	[-]	[-]	[KN/m^2]
21	276	10	29	8	29	2.9	0.725	1.09	205	102
22	263	10	29	8	28	2.9	0.725	1.09	205	98
23	250	10	29	8	27	2.9	0.725	1.09	205	93
24	236	10	29	8	26	2.9	0.725	1.09	205	88
25	223	10	29	8	25	2.9	0.725	1.09	205	83
26	227	10	29	10	25	2.9	0.725	1.18	205	78
27	213	10	29	10	24	2.9	0.725	1.18	205	73

7.2.2. Transverse main frame

The needed section modulus is supplied by S7-C401, as indicated below, according to the requirements.

The main structure is positioned outside the peak tanks and extends to the lowest deck. It is attached to the floors, double bottom, and hopper tanks.

The required section modulus is determined by:

$$Z = \frac{C\, l^2\, s\, p\, w_k}{f_{1_{side}}}$$

Where:

- s = spacing of the stiffener
- l = stiffener span (equal to 4*s)
- p = highest pressure from p3 to p6.
- wk = 1+0.06*tk (S3-C 1004)
- C = 0.43

Main frame							
Frame	Section Modulus [cm^3]	Area [cm^2]	C	l	s	wk	P
	Z	A	[-]	[m]	[m]	[-]	[kN/m2]
f	426	38	0.43	3.672	0.918	1.090	94

8. Deck Structures

The criteria in this section relate to the ship deck structure, with the plating and stiffener equations based on structural design principles. This scantling consists of the strength deck, deck plating below and above the strength deck, and longitudinals.

Deck scantling, as shown in bottom and side structures, is an iterative process. This means that anything can alter following any midship section design calculations.

This section will examine deck structural dimensioning using the calculations provided in Pt3. Ch1. Section 8 of the DNV Rules.

It consists of the stringer plating (plate 17), the strength deck plate (plates 18–21), the plates under and above the strength deck (plates 22–27), and the longitudinal stiffeners (stiffener 28 to 49).

Some assumptions and constants should be determined before utilizing the formulas from C100 to C404 to specify all the key parameters from the elements. The formulas may be found in the DNV regulations and are presented in the table below. The height of the neutral axis is the same as in the bottom constructions.

Total loads must be considered in direct stress calculations on deck structures as discrepancies between internal and exterior pressures. The table below represents these loads (table B1 from Section 8, DNV rules). The same theory that was used for hp from bottom structures is used here.

Structure	*Load type*	*p (kN/m²)*
Weather decks [1]	Sea pressure	$p_1 = a(p_{dp} - (4 + 0,2k_s)h_0)$ [2], minimum 5.0
	Deck cargo	$p_2 = (g_0 + 0.5\,a_v)\,q$
Cargo 'tweendecks	Deck cargo	$p_3 = \rho_c\,(g_0 + 0.5\,a_v)\,H_C$
Platform deck in machinery spaces	Machinery and equipment	$p_4 = 1.6\,(g_0 + 0.5\,a_v)$
Accommodation decks	Accommodation in general	$p_5 = 0.35\,(g_0 + 0.5\,a_v)$, see also Sec.4 C401
Deck as tank bottom in general	Ballast, bunker or liquid cargo	$p_6 = \rho\,(g_0 + 0.5\,a_v)\,h_s$ $p_7 = 0.67\,(\rho\,g_0\,h_p + \Delta\,p_{dyn})$ $p_8 = \rho\,g_0\,h_s + p_0$
Deck as tank top in general		$p_7 = 0.67\,(\rho\,g_0\,h_p + \Delta\,p_{dyn})$ $p_8 = \rho\,g_0\,h_s + p_0$
Deck as tank boundary in tanks with breadth > 0.4 B		$p_9 = \rho g_0[0.67(h_s + \phi b) - 0.12\sqrt{H\,\phi b_t}]$
Deck as tank boundary towards ends of tanks with length > 0.15 L		$p_{10} = \rho g_0[0.67(h_s + \theta l) - 0.12\sqrt{H\,\theta l_t}]$
Deck as tank boundary in tanks with breadth > 0.4 B [3]		$p_{11} = \rho\left(3 - \frac{B}{100}\right) b_b$
Deck as tank boundary in tanks with length > 0.1 L [4]		$p_{12} = \rho\left(4 - \frac{L}{200}\right) l_b$
Watertight decks submerged in damaged condition [5]	Sea pressure	$p_{13} = 10\,h_b$

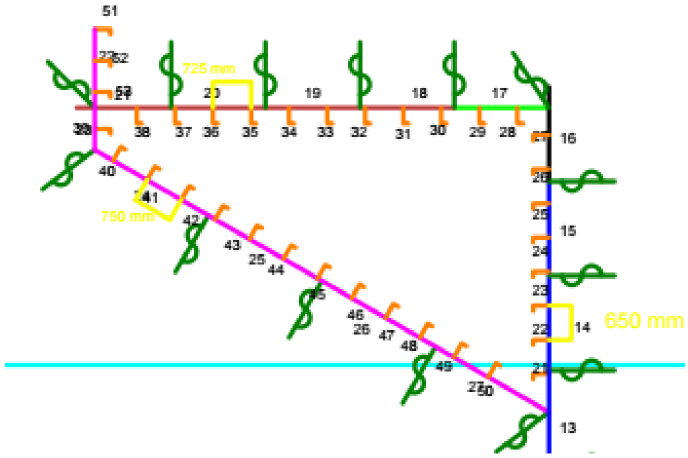
1) On weather decks combination of the design pressures p_1 and p_2 may be required for deck cargo with design stowage height less than 2.3 m.

2) For ships with service restrictions p_1 may be reduced with the percentages given in Sec.4 B202. C_W should not be reduced.

3) To be used for strength members located less than 0.25 b_b away from tank sides in tanks with no restrictions on their filling height. For tanks with free breadth (no longitudinal wash bulkheads) b_b > 0.56 B the design pressure will be specially considered according to Sec.4 C305

4) To be used for strength members located less than 0.25 l_b away from tank ends in tanks with no restrictions on their filling height. For tanks with free length (no transverse wash bulkheads or transverse web frames in narrow tanks) l_b > 0.13 L the design pressure will be specially considered according to Sec.4 C305

5) The strength may be calculated with allowable stresses for plating, stiffeners and girders increased by 60 f_1.



Constant values			
a	0.8	[-]	S8 - B 101
f2d	1.737	[-]	S8 - A 201
ZD	1.60E+07	[cm^3]	
I	1.93E+10	[cm^4]	S5-C401
Z_NA	6.03	[m]	
ka	1.08		
ks	2	[-]	S4-C201
p0	15	kN/m^2	S4 - C 302
f	4.9	[m]	S4 - C 201

8.1. Plates

8.1.1. Stringer and Strength Deck Plate

The plates 17 to 21 in figure will be created using the equations C101, C102, and C104. These equations, which are provided below, determine the minimum breadth, needed thickness, and minimum thickness of the plate. It was discovered that the ultimate thickness is the rounded upward value between the minimum and necessary thicknesses.

$$b = 800 + 5L_{bp},$$

$$t_{req} = \frac{15.8\, k_a\, s \sqrt{p}}{\sqrt{\sigma}} + t_k$$

$$t_{min} = t_0 \frac{k\, L_{bp}}{\sqrt{f_1}} + t_k$$

Where:

- s = stiffener spacing
- p = highest value from p1, p7 and p8 in this case
- σ =120 $f1 - 100f2b$
- tk = thickness of corrosion margin
- t0 is 5.5
- k is 0.02

Strength deck plates													
Plate	Breadth [m]	Thickness [mm]	t_min	t_req	t0	k	s	σ	p	p1	p7	p8	pdp
nº	b	t	[mm]	[mm]	[-]	[-]	[m]	[-]	[KN/m^2]	[KN/m^2]	[KN/m^2]	[KN/m^2]	[KN/m^2]
17	1.8	12	11.42	8.82	5.5	0.02	0.865	166.8	26.9	19.1	26.9	15.0	45
18	1.8	12	11.42	8.82	5.5	0.02	0.865	166.8	26.9	17.3	26.9	15.0	43
19	1.8	12	11.42	8.82	5.5	0.02	0.865	166.8	26.9	15.6	26.9	15.0	41
20	1.8	12	11.42	8.82	5.5	0.02	0.865	166.8	26.9	13.8	26.9	15.0	39
21	1.8	12	11.42	8.82	5.5	0.02	0.865	166.8	26.9	12.0	26.9	15.0	37

8.1.2. Below and Above Plates from Strenght Deck

These plates, which are plates 22–27 in the picture, will be created using the equations C101 and C202. These equations, which are provided below, yield the needed and minimum thickness of the plate. It was discovered that the final thickness is greatest when the rounded upward.
Steel decks must have a minimum thickness of:

$$t_{min} = t_0 + \frac{kL_{bp}}{\sqrt{f_1}} + t_k$$

Where:

- t0=5.5, for unsheathed weather
- k=0.02, in vessels with single continuouse deck

Plates of deck below and above strength deck													
Plate	Breadth [m]	Thickness [mm]	t_min	t_req	t0	k	s	σ	p	p7	p8	pdp	pl
nº	b	t	[mm]	[mm]	[-]	[-]	[m]	[-]	[KN/m^2]	[KN/m^2]	[KN/m^2]	[KN/m^2]	[-]
22	1.5	12	11.58	2.00	5.5	0.02	0.75	204.8	0.0	0.0	0.0	36	25
23	0.8	12	11.58	4.58	5.5	0.02	0.4	204.8	29.6	29.6	19.0	36	25
24	2.5	12	11.58	8.53	5.5	0.02	0.91	204.8	36.4	36.4	29.3	37	25
25	2.5	12	11.08	8.74	5.5	0.02	0.91	204.8	44.9	44.9	41.9	40	25
26	2.5	12	11.08	9.48	5.5	0.02	0.91	204.8	54.4	53.3	54.4	43	25
27	2.5	12	11.08	10.35	5.5	0.02	0.91	204.8	67.0	61.7	67.0	45	25

8.2. Stiffeners

The optimum stiffener is determined by computing three parameters: the thickness of the web/flange (t), the requisite section modulus (Z), and the area (A). The first two are produced using DNV-rules, while the third is computed using A=0.68*Z^2/3. This is true once all of the stiffeners are bulb-profile.
Furthermore, the final thickness is the maximum rounded upward value of all the minimum thicknesses, and the final area is the maximum area of all the minimum areas. This is done in this manner to make selecting stiffeners easier. The more equal the stiffeners, the easier the construction.

To make the ship's construction easier, one stiffener pattern was chosen for each portion of the deck structure. To pick the desired, the stiffener with the highest section modulus and thickness of each portion was used. Following this, pick one from the various shipbuilding industry that meets the essential characteristics. The table below summarizes these two phases.

Requirements Maximum				
Structure	SecMudul. [cm^3]	Thickness [mm]	Area [cm^2]	Longitudinal
	Z	t	A	
Strength Deck	438	10	40	HP260 x 12
Below Deck	1207	10	78	HP370 X 13
Above Deck	87	9	14	HP140 X 10

8.2.1. Strenght Deck Longitudinals

The minimum sectional area and minimum thickness are required to define the suitable longitudinals. Deck longitudinals, such as those found in the bottom and side components, are bulb-profile stiffeners.
The required section modulus and minimum thickness of web and flange are specified by S8-301 and S8-303, respectively, according to the standards, as indicated below. The sectional area is defined by the following equation, and the modulus required is supplied by the following equation:

$$Z = \frac{83\, l^2\, s\, p\, w_k}{\sigma}$$

$$t = 4.5 + k + t_k$$

Where:

- s = spacing of the stiffener
- l = stiffener span (equal to 4*s)
- p = highest pressure from p1, p6, p7 and p8
- wk = 1+0.06*tk (S3-C 1004)
- k = 0.01*Lpp, maximum of 5
- σ= 225*f1-130*f2d, maximum of 160*f1
- tk = thickness of corrosion margin

Strength Deck										
Stiffener	SecMudul. [cm^3]	Thickness [mm]	Area [cm^2]	t_min	A_req	l	s	wk	σ	p
nº	Z	t	A	[mm]	[cm^2]	[m]	[m]	[-]	[-]	[KN/m^2]
28	438	10	40	9.81	39	3.46	0.865	1.18	62.2	27
29	438	10	40	9.81	39	3.46	0.865	1.18	62.2	27
30	438	10	40	9.81	39	3.46	0.865	1.18	62.2	27
31	438	10	40	9.81	39	3.46	0.865	1.18	62.2	27
32	438	10	40	9.81	39	3.46	0.865	1.18	62.2	27
33	438	10	40	9.81	39	3.46	0.865	1.18	62.2	27
34	438	10	40	9.81	39	3.46	0.865	1.18	62.2	27
35	438	10	40	9.81	39	3.46	0.865	1.18	62.2	27
36	438	10	40	9.81	39	3.46	0.865	1.18	62.2	27

8.2.2. Below and Above Longitudinal from Strength Deck

The required section modulus and minimum thickness of web and flange are specified by S8-301 and S8-303, respectively, according to the standards, as indicated below.

$$Z = \frac{83 * l^2 * s * p * w_k}{\sigma}$$

$$t = 4.5 + k + t_k$$

Where:

- s = spacing of the stiffener
- l = stiffener span (equal to 4*s)
- p = highest pressure from p6, p7 and p8
- wk = 1+0.06*tk (S3-C 1004)
- k = 0.01*Lpp, maximum of 5
- σ= 225*f1-130*f2d, maximum of 160*f1
- tk = ICM thickness

Below Deck and Above Deck										
Stiffener	SecMudul. [cm^3]	Thickness [mm]	Area [cm^2]	t_min	A_req	l	s	wk	σ	p
nº	Z	t	A	[mm]	[cm^2]	[m]	[m]	[-]	[-]	[KN/m^2]
37	48	10	78	9.81	9	1.6	0.4	1.18	62.2	30
38	670	10	78	9.81	52	3.64	0.91	1.18	62.2	35
39	673	9	78	8.31	52	3.64	0.91	1.09	62.2	38
40	727	9	78	8.31	55	3.64	0.91	1.09	62.2	41
41	780	9	78	8.31	58	3.64	0.91	1.09	62.2	45
42	834	9	78	8.31	60	3.64	0.91	1.09	62.2	48
43	888	9	78	8.31	63	3.64	0.91	1.09	62.2	51
44	966	9	78	8.31	66	3.64	0.91	1.09	62.2	55

9. Neutral Axis Correction

This section is intended to determine essential midship section characteristics using all available data, such as the true neutral axis height, moment of inertia, section modulus of various portions of the ship, and so on. The following process was applied for each plate and stiffener to compute everything, and the results are displayed below.

The neutral axis is an axis in the cross section of a beam (or shaft) that has no longitudinal stresses or strains. The neutral axis lies at the geometric centroid if the section is symmetric, isotropic, and not curved before the bend. All fibers on one side of the neutral axis are tense, while those on the other are compressed.

One of the goals of this chapter is to find the proper value using an iterative procedure. This method starts with a correction of the neutral axis, ZNA, knowing that buckling control will change the thickness of some plates, which will modify the neutral axis again. Following the buckling control analysis, the ultimate neutral axis height may be determined.

The neutral axis height is given by:

$$Z_{NA} = \frac{\Sigma S_i}{\Sigma A_i}$$

Where S is the initial moment of area and A is the transverse section area of the plates, as defined by the equations below:

$$S = A.Z_{bottom}$$

$$A = h.b$$

Take note that h represents the thickness of the plates and b represents the breadth in meters. The minimal midship section modulus, Z0, the inertia of neutral axis moment, INA, the midship section modulus on the bottom, Wbottom, and the midship section modulus on the deck, Wdeck are all critical characteristics. These paramiters are provided, in turn, by:

$$Z_0 = \frac{C_{wo}}{f_1} L_{bp}^2 B (C_b + 0.7)$$

Cwo denotes the midship section modulus about the transverse neutral axis, which is given by:

$$C_{WO} = 10.75 - \left(\frac{300 - L_{bp}}{100}\right)^{\frac{3}{2}} \quad for\ L_{bp} < 300$$

$$I_{NA} = 2\left(\sum I_i - \sum A_i Z_{NA}^2\right)$$

By the parallel axis theorem, I is the moment of inertia about the base line. And Io is the area moment of inertia about a reference system of axis.

$$I_0 = \frac{1}{12} h^3 b$$

$$W_{bottom} = \frac{I_{NA}}{Z_{NA}\, 10^4}$$

$$W_{deck} = \frac{I_{NA}}{(D - Z_{NA})\, 10^4}$$

Considerind the following parameters we can obtain a table that resume all the charateristics:

Parameters			
	A	A*z	I
Plate	1.19	7.46	53.45
Stiffner	0.53	2.92	22.09
Total	1.72	10.38	75.54

Midship Characteristics			
Parameter	Value	Unit	Description
Z_NA	6.04	m	Neutral Axis Height
I_NA	151	m^4	Inertion of neutral axis moment
W min	278 083	cm^2*m	Minimum midship section modulus
W bottom	250 106	cm^2*m	Bottom section modulus
W deck	125 284	cm^2*m	Deck section modulus

10. Buckling Control

Buckling can occur when a structure is exposed to compressive stress. Buckling is defined as an abrupt lateral deflection of a structural element. This can happen even though the stresses that arise in the structure are much below those required to cause the material of which the structure is made to break. As the applied stress on a member, such as a column, increases, it eventually becomes big enough to cause the member to become unstable, and it is said to have buckled. Further loading will result in severe and perhaps unexpected deformations, potentially resulting in the member's full loss of load-carrying ability.

If the deformations generated by buckling do not cause the member to completely collapse, the member will continue to withstand the load that caused it to buckle. If the buckled member is part of a larger assemblage of components, such as a building, any additional load imparted to the buckled element of the structure will be redistributed within the structure.

Buckling is a mathematical bifurcation in the solution of the equations of static equilibrium. After a certain point, any additional load can be borne in one of two states of equilibrium: a strictly compressed state (with no lateral deviation) or a laterally-deformed state.

Buckling control includes plating susceptible to in-plate compressive and shear loads, axially compressed stiffeners and pillars, as well as panel ultimate strength. Buckling strength requirements are connected to shear stresses based on the design values of still water and wave bending moments, as well as shear forces and axial forces supporting bulkheads and plating beams based on the rule loads.

The axial compressive stress applied to the midship section plate panels will be investigated in this study. To accomplish so, the initial neutral axis height adjustment must be determined.

The axial compressive stress imparted to the plate panels of the midship section will be investigated in this study. The approach used to keep a plate from buckling is the same as outlined in Section 13 of the DNV standards and is briefly discussed below.

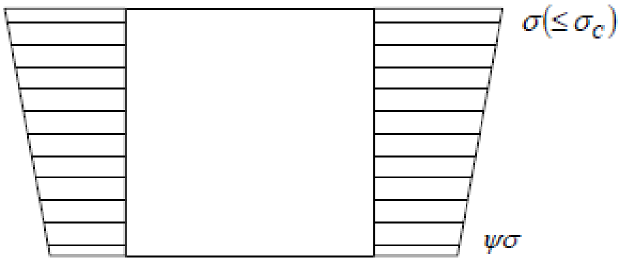
The ideal elastic buckling stress may be taken as:

$$\sigma_{el} = 0.9\, k\, E \left(\frac{t - t_k}{1000\, s}\right)^2$$

Where k denotes the plating with longitudinal stiffeners, and is given by (in compressive stress direction):

$$k = k_l = \frac{8.4}{\psi + 1.1} \quad for\ (0 \leq \psi \leq 1)$$

And ψ as seen in the figure below, is the ratio between the smaller and bigger compressive stresses assuming linear variation:



In this situation, to simplify computations, it will be assumed to be a constant ratio, 1.
The critical buckling stress, c, is calculated as follows:

$$\sigma_c = \sigma_{el} \quad when\, \sigma_{el} < \frac{\sigma_f}{2}$$

$$\sigma_f = \sigma_{el} \quad when\, \sigma_{el} > \frac{\sigma_f}{2}$$

The longitudinal stress on plate panels, sigma (al), is given by:

$$\sigma_{al} = \frac{M_S + M_W}{I_N}\left(z_n - z_a\right) 10^5$$
$$= minimum\ 30\, f_1 \frac{N}{mm^2}\ at\ side$$

And the critical buckling might be related to the actual compressive stress:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

Where, c is the critical buckling stress and a is the calculated compressive stress in plate panels theta is equal to 1.0 for deck, single bottom and longitudinally stiffened side platin and 0.9 for bottom, inner bottom and transversely stiffened side plating.

If the conditions are not met, the thickness should be raised until the condition is met. However, if the thickness becomes impractical (t>=50 mm), the plate/stiffener material and stiffener size can be modified.

More information on material characteristics can be found in the excell file dedicated to buckling calculations.

The following table shows the final findings for the plates and stiffeners:

Before the iteration in MARS					
		Thicknesses			Material
	Plate	t_plate	t_buckling	t_final	f1
	nº	[mm]	[mm]	[mm]	-
Outer Bottom	1	18	15	18	1.39
	2	15	15	15	1.39
	3	15	15	15	1.39
	4	15	15	15	1.39
	5	15	15	15	1.39
	6	15	15	15	1.39
	7	17	16	17	1.39
	8	17	15	17	1.39
	9	17	15	17	1.47
	10	17	15	17	1.47
Inner Bottom	28	15	15	15	1.47
	29	15	15	15	1.47
	30	14	14	14	1.47
	31	14	14	14	1.47
	32	14	14	14	1.47
	33	14	14	14	1.47
	34	14	14	14	1.47
Double Bottom	35	16	14	16	1.39
	36	16	14	16	1.39
	37	16	14	16	1.39
	38	16	14	16	1.39
	39	16	14	16	1.39
Side	11	14	16	16	1.28
	12	13	16	16	1.28
	13	13	18	18	1.28
	14	11	18	18	1.39
	15	10	25	25	1.39
Shear Strake	16	11	25	25	1.47
Strength Deck	17	12	25	25	1.47
	18	12	25	25	1.47
	19	12	25	25	1.47
	20	12	25	25	1.47
	21	12	25	25	1.47
Above Deck	22	12	24	24	1.47
Below Deck	23	12	24	24	1.47
	24	12	24	24	1.47
	25	12	24	24	1.47
	26	12	24	24	1.47
	27	12	24	24	1.47

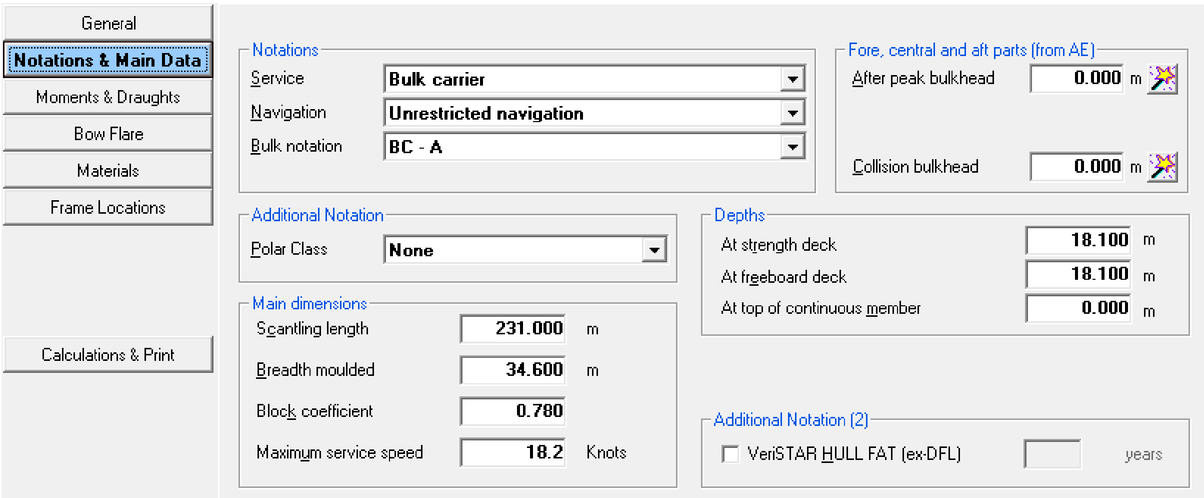
11. Mars 2000

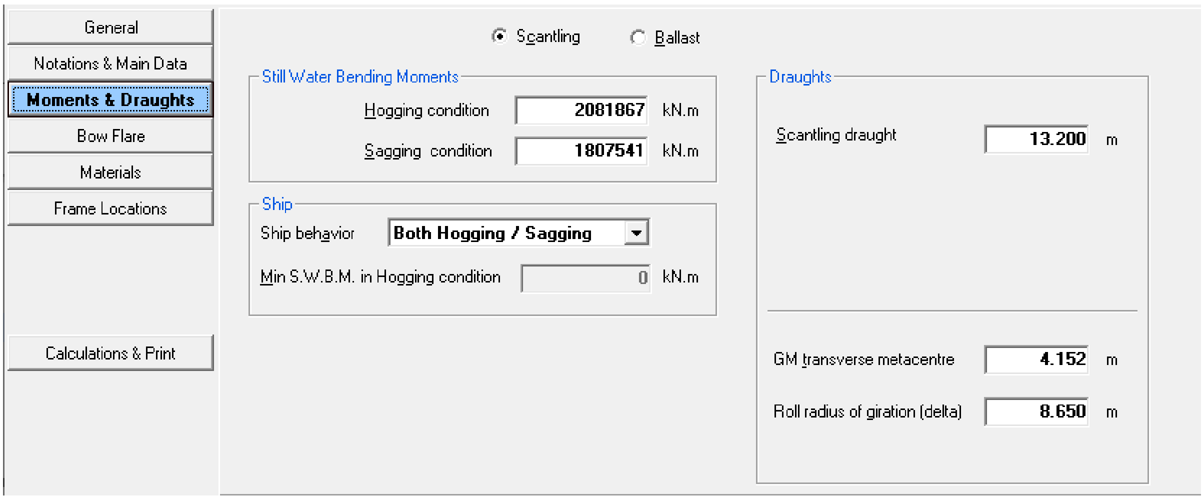
MARS 2000 is a program that ensures oil tankers and bulk carriers follow uniform structural rules. This tool allows you to create a section based on the Bureau Veritas Rules for Steel Ship Classification and it checks: the strength parameters of the hull girder;

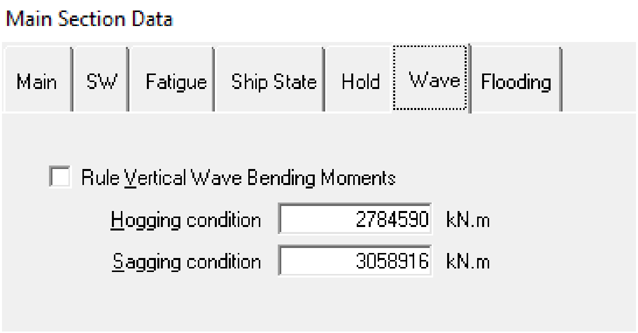
- Scanning of continuous longitudinal members;
- strakes and longitudinal ordinary stiffeners;
- Scanning of transverse ordinary stiffeners;

This program is capable of doing calculations at any portion along the length of the ship, however for this project, just the midship section in the center of the ship will be examined. Before doing the computations, two stages must be completed: setting the parameters in the Basic Ship Data (BSD) and constructing the section to be evaluated using MarsIn.
The Basic Ship Data module accepts generic data that is shared by all transverse sections, bulkhead configurations, and torsion models. It also conducts any calculations that can be performed on the data.
MarsIn accepts input from any segment of the ship's length. Longitudinal components contributing to hull girder strength, transverse stiffeners, and compartments comprise the section.
Furthermore, section geometry is panel oriented: the section must be divided into multiple panels, each of which corresponds to a physical entity such as the exterior shell, strong deck, inner bottom, or longitudinal bulkhead. Each panel is made up of two node-described contiguous segments. Once the panels have been thoroughly specified, welding connections and longitudinal stiffeners (complete with scantling) may be discovered. Transverse stiffening zones can also be defined if necessary.

Aside from the ship's fundamental dimensions (Lpp, B, and D), the BSD demands the still water bending moment of sagging and hogging, as well as one still water shear force condition (sagging or hogging) as design parameters. As a result, the values acquired, were utilized as input, with a probability level of 10^-8, which are extreme values. As a result, if the structures handle these values, it is assumed that all operational values are safe. The figures below depict all of the additional inputs.



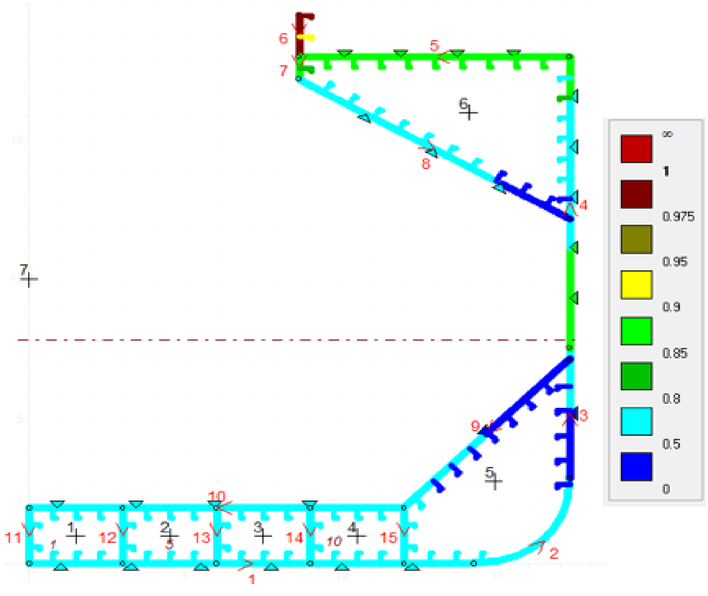




11.1. Hull Girder Strenght

It is feasible to test the material's ability to sustain elongating loads in this section. The ultimate strength of a material is assessed here by the utmost stress that it can sustain while being stretched before breaking.
When assessing the strength of a ship, it is typical to examine three strengths: longitudinal strength, transverse strength, and local strength. The most fundamental and vital strength to assure the safety of a ship structure is longitudinal strength, often known as hull girder strength. If the vessel is subjected to primary loads that exceed this critical value while hogging and sagging, the hull girder may collapse, resulting in catastrophic losses.

MARS 2000 understands the Ultimate Strength Assessment of the midship section hull, and it is possible to see the hull girder strength in the picture above:

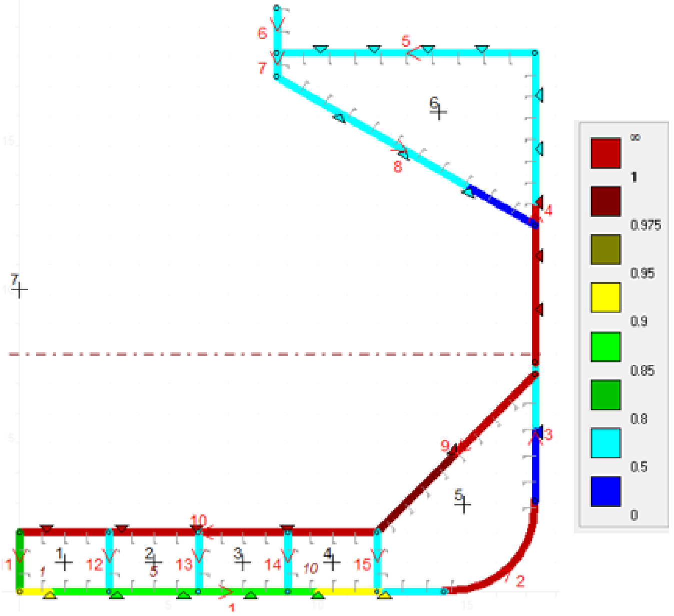


Following are some conclusions: First and foremost, the bottom, portion of the side, and below strength deck structures appear to be overdesigned, since the ratio of real tension to yield stress does not exceed 0.8. (cyan color). This might be because the plates are thicker, the material is stronger, or the stiffeners are larger than required. As a result, if the goal is to improve the midship portions, these regions should be prioritized. However, it is crucial to remember that the midship is safe for the times when the regulations are followed.
Second, as seen in the previous section, there exist plates with thicknesses more than 20 mm.

This occurred for a variety of reasons. The first reason is because additional stiffener elements, such as longitudinal/transverse girders and brackets, were overlooked when calculating plate thickness and stiffener sizes. They would strengthen the components surrounding them, making the deck structure more resistant to high stresses. Brackets, for example, postpone the creation of end hinges and therefore a collapse mechanism in the joint region by giving a large value of the plastic section modulus, so enhancing the ultimate strength. As a result, thick plates would not be required.
It has been discovered that residual stresses reduce the initial yielding point of the structural reaction and hence the final strength.

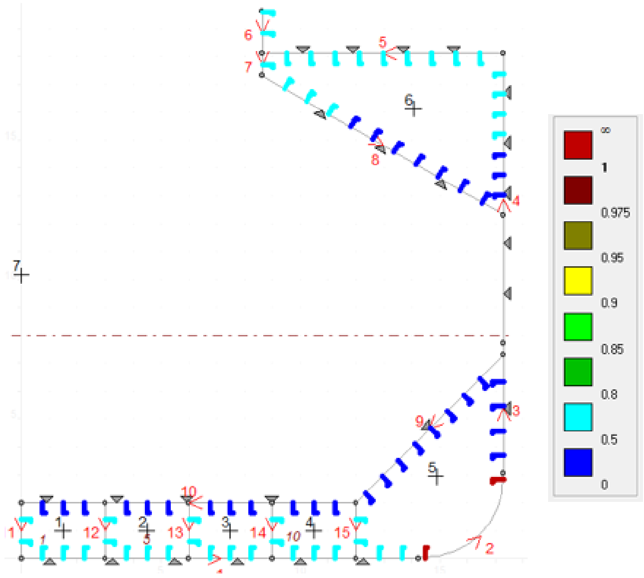
11.2. Local Strenght- Strakes

Local strength, on the other hand, is concerned with determining the strength of a limited structure, like as a girder or a longitudinal, for loads encountered locally. These loads can include the hydrostatic pressure, cargo load, wave pressure, and so forth. Because the loads are different and this study takes into consideration the buckling control, the pattern differs from the hull girder strength. As a result, the ratio greater than one at the inner bottom may be explained since they are the plates that support the entire column of cargo above it.
In the instance of the bilge plate, one method to reduce stress would be to add a bilge keel, which would help to raise the plate's section minimum and so reduce stress.



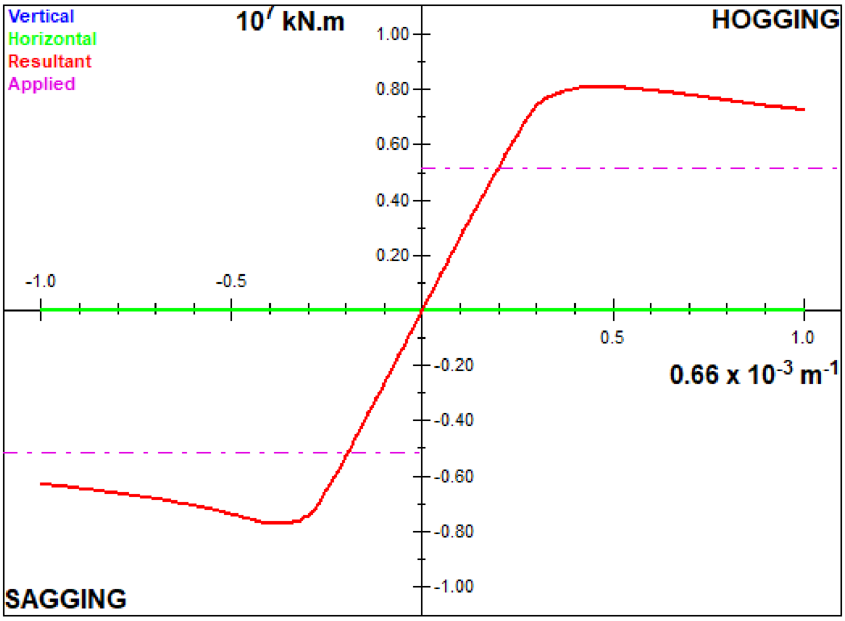
11.3. Local Strenght – Stiffeners

The pattern shown in the hull girder strength is followed in the picture below. With a few exceptions, the construction appears to be adequately constructed for safety.



11.4. Ultimate Bending Moment

Having said that, we may identify our study's most crucial representative graph: Ultimate Bending Moment.
The ultimate bending moment is the maximum bending moment that a beam can withstand before failing. As seen in the figures below, the scantling of the midship section meets all of the requirements from ultimate.
The Ultimate Strength is represented in figure bellow:



11.5. Comparison between Mars2000 and Excel calculations

Next chapter will contrast the findings acquired in EXCEL with the ones obtained in MARS 2000. To accomplish this, the whole procedure described in Section 9 of this project was performed for the increased thickness and stiffeners produced from the buckling control.
It is possible to confirm that there are not in conflicts between the MARS and Excel findings. This is because the initial stiffeners were redimensioned. To accomplish this, the final stiffeners were all far smaller than the first ones. This reduces the effective area of cross-section, which influences the remaining values.

The calculations from the heights z and area moments I for each element can explain the discrepancy in the findings. This is due to the fact that the parameters Z NA, I NA, W bottom, and W deck are all reliant on these two. With this knowledge, the errors become plausible and acceptable.

The following table compares the two options:

MARS VS EXCEL	EXCEL	MARS	Difference [%]
Effective area of cross-section	4.239	4.237	0.04
Moment of inertia/GY axis	226	225	0.45
Neutral axis (above base line)	7.56	7.98	5.54
Section modulus at bottom	29.93	28.23	5.68
Section modulus at deck	21.45	22.24	3.67

12. Transversal Bulkhead

A transverse bulkhead is a partition wall of planking or plate that runs across a section or the whole breadth of a ship in an athwartship direction. Its primary role is to partition the ship into a number of watertight compartments, ensuring that any breach of the shell does not result in the vessel's loss.
The transverse bulkhead comes in two varieties: a plate with longitudinals and a corrugated plate. The bulkhead is made up of stools, which are made up of the lower stool and the top stool.

In this scenario, the transverse bulkhead is made up of two corrugated portions that run vertically to resist the pressure exerted by the cargo load. Transverse stiffeners are required in the inner hull areas. The following figure depicts the corrugated dimensions in a transverse bulkhead:

203 For corrugated bulkheads the following definition of spacing applies (see Fig.1):

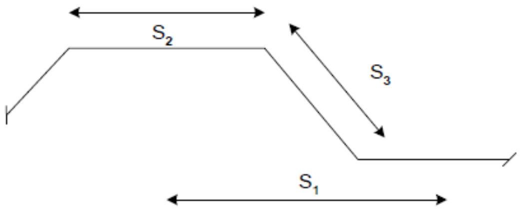


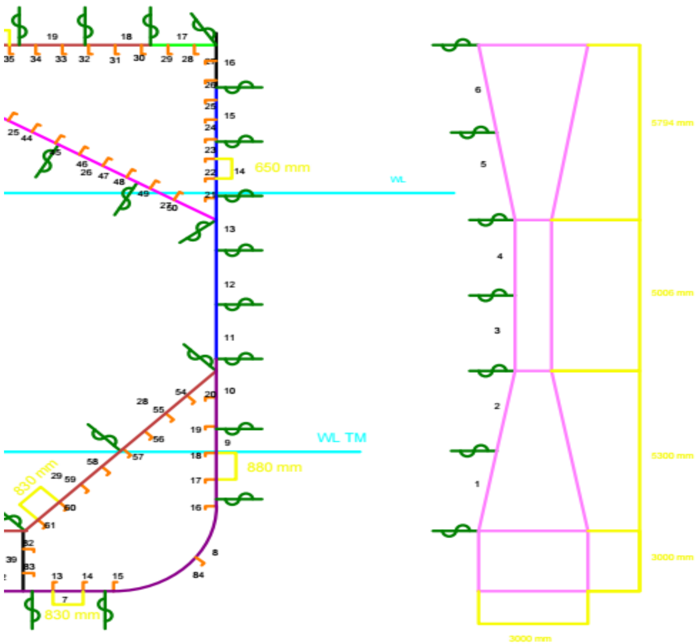
Fig. 1
Corrugated bulkhead

s = s_1 for section modulus calculations
= 1.05 s_2 or 1.05 s_3 for plate thickness calculations in general
= s_2 or s_3 for plate thickness calculation when 90 degrees corrugations.

The pressure in the load point is used to design the bulkhead plates. This is the point at which thickness is determined. The inner hull tanks' transverse stiffeners are also determined.

The following table and graphic show the key dimensions and representations of the transversal bulkhead design:

Main Charateristics		
tank breadth	34.6	[m]
s1 / sc	1.44	[m]
s2 / a	0.94	[m]
s3 / c	1.12	[m]
α	1.11	[rad]
d	1	[m]
Height of lower ends	5.3	[m]
Height of upper end	5.794	[m]



The thickness at each plate is represented in the table below by the formulae below.

Plate	Breadth	Final thickness	corrugated thickness	required thickness	minimum thickness	P	σ	s	t_k	tn
nº	[m]	[mm]	[mm]	[mm]	[mm]	[kN/m²]	[-]	[m]	[mm]	[mm]
1	2.7	17	16.1	14.6	10.4	163	305.8	1.17	1.5	14
2	2.7	17	16.1	14.6	10.4	163	305.8	1.17	1.5	14
3	2.5	17	16.1	14.6	10.4	163	305.8	1.17	1.5	14
4	2.5	17	16.1	14.6	10.4	163	305.8	1.17	1.5	14
5	2.94	17	16.1	14.6	10.4	163	305.8	1.17	1.5	14
6	2.94	17	16.1	14.6	10.4	163	305.8	1.17	1.5	14

The corrugated thickness is given by:

$$t_{corr} = \sqrt{\frac{500\, s^2 p}{\sigma} - t_n^2} + t_k$$

Where:

- t_n is the thickness in mm of the neighbouring plate flange, not to be taken greater than t
- p is the higher value of $p_1$and p_2
- σ=220 f_1, for watertight bulkheadswhen $p_1$is applied
- t_k=1.5 mm

Structure		*Load type*	*p (kN/m²)*
Watertight bulkheads		Sea pressure when flooded or general dry cargo minimum	$p_1 = 10\, h_b$
Cargo hold bulkheads		Dry bulk cargo	$p_2 = \rho_c\,(g_0 + 0.5\, a_v)\, K\, h_c$
Tank bulkheads in general		Ballast, bunker or liquid cargo	$p_3 = \rho\,(g_0 + 0.5\, a_v)\, h_s$ $p_4 = 0.67\,(\rho\, g_0\, h_p + \Delta p_{dyn})$ $p_5 = \rho\, g_0\, h_s + p_0$
Longitudinal bulk-heads as well as transverse bulkheads at sides in wide tanks	In tanks with breadth > 0.4 B		$p_6 = \rho g_0 [0,67(h_s + \phi b) - 0,12\sqrt{H\, \phi\, b_t}]$
	Note 1)		$p_7 = \rho\left[3 - \frac{B}{100}\right] b_b$
Transverse bulkheads and longitudinal bulkheads at ends in long tanks	In tanks with length > 0.15 L		$p_8 = \rho g_0 [0,67(h_s + \theta l) - 0,12\sqrt{H\, \theta\, l_t}]$
	Note 2)		$p_9 = \rho\left[4 - \frac{L}{200}\right] l_b$
Longitudinal wash bulkheads			$p_7 = \rho\left[3 - \frac{B}{100}\right] b_b$
Transverse wash bulkheads			$p_9 = \rho\left[4 - \frac{L}{200}\right] l_b$

1) To be used for strength members located less than 0.25 b_b away from tank sides in tanks with no restrictions on their filling height. For tanks with free breadth (no longitudinal wash bulkheads) b_b > 0.56 B the design pressure will be specially considered according to Sec.4 C305.

2) To be used for strength members located less than 0.25 l_b away from tank ends in tanks with no restrictions on their filling height. For tanks with free length (no transverse wash bulkheads or transverse web frames in narrow tanks) l_b > 0.13 L the design pressure will be specially considered according to Sec.4 C305.

The required thickness and minimum thickness are given by:

$$t_{req} = \frac{15.8\, k_a\, s \sqrt{p}}{\sqrt{\sigma}} + t_k$$

$$t\_ = 5.0 + \left(\frac{k\, L_{bp}}{\sqrt{f_1}}\right) + t_k$$

With k = 0.02 for transversal skin longitudinal bulkhead

The following formulae are used to compute transverse stiffeners.
For simple stiffeners and corrugations, the section modulus need is given by:

$$Z = \frac{1000\, l^2\, s\, p\, w_k}{\sigma\, m}$$

Where:

- P is the highest value from p_1 and p_2 from Table B1 from the DNV rules section 9.
- σ is 160*f_1
- m=10

Following the completion of several constraints, the selection of transverse stiffeners is determined, with the profile and characteristics shown in the table below:

Structure	SecMudul. [cm^3]	Thickness [mm]	Area [cm^2]	Longitudinal
	Z	t	A	
Trans. Bulkhead	1018	14	65.54	HP 340x14

13. Fatigue Analysis

Fatigue is the weakening of a material caused by repetitive stresses. When a material is subjected to cyclic stress, it develops gradual and localized structural degradation. The nominal maximum stressvalues that cause such damage may be substantially lower than the material's strength, which is commonly reported as the ultimate tensile stress limit or the yield stress limit.
It happens when a substance is repeatedly loaded and unloaded. If the loads exceed a particular threshold, small fractures will occur at stress concentrators such as the surface, persistent slip bands, component interfaces in composites, and grain interfaces in metals. A crack will eventually reach a critical size, propagate rapidly, and the structure will shatter. The structure's shape has a significant impact on fatigue life; square holes or sharp corners cause elevated local stresses where fatigue cracks can form. Round holes and smooth transitions or fillets will boost the structure's fatigue strength.

The fatigue analysis was based on the example in Reference 3 Appendix C. As a result, several assumptions stated in the article were deemed legitimate since they were also true. The weld connection at the junction of the strength deck and stringer will be analyzed. Furthermore, the midship section described in section 3 will be evaluated, with geometric values obtained from MARS 2000.

The observed results have an impact on how the calculations are performed:

- This project assumes that the plate and bracket have a service life of 25 years and 15 years of effective corrosion protection.

- The analysis must be carried out in accordance with the simplified process outlined in Section 4 of Reference 3 and utilizing the simplified formulae for load and stress calculations provided in Sections 5 and 6 of Reference 3.

- Torsion is not accounted for.

- The bending moments supplied in this project component are used to calculate the local and global loads.

- Only load condition will be analyzed.

13.1. Initial Data

The tables below show the input data for this issue. It consists of the primary dimensions of the ship as well as the definition of load conditions.
Scantlings and stiffener characteristics of the geometry will take into account a strength deck plate with two stiffeners and a stringer plate with two stiffeners as well. The fundamental parameters are presented below.

C-1 The example ship's main dimensions			
Length of ship	L	231	m
Breadth of ship	B	34.60	m
Block coefficient	Cb	0.78	-
Design speed	Vs	18.20	knots
Depth of ship	D	18.10	m
Moment of inertia of hull cross-section about transverse neutral axis	I N	226	m^4
Neutral axis above keel	Z NA	7.56	m

C-2 Definition of load conditions		
	Fully loaded	
Stillwater bending moment Hogging	2 081 867	kN*m
Stillwater bending moment Sagging	-1 807 541	kN*m
Draught	13.2	m
Metacentric height	4.152	m
Roll radius of gyration	8.65	m
Part of time in load condition	0.65	-
Part of time in ballast condition	0.2	-

C-4 Scantlings and properties of stiffener considered			
Total Stiffener sectional modulus at top of flange	Zs	5160000	mm^3
Quantity in plate	nº	4	stiffener
Stiffener sectional modulus at top of flange	Z	1290000	mm^3
Distance above keel	z	17.84	m
Effective span length	l	3460	mm
Distance from end of stiffener to hot spot	x	0	mm

Web frame spacing	ls	3460	mm
Stiffener spacing	s	865	mm
Thickness of plate (plate 18)	tp	25	mm
Height of stiffener	h	370	mm
Thickness of web	tw	15	mm

The stress concentration factor is an essential metric in fatigue analysis. The stress concentration factor is used to represent the increase in notch stress caused by local geometry, weld geometry, and craftsmanship. Before the hot spot stresses can be estimated, the value of the K-factor for the examined detail must be determined. The following formula can be used for a butt weld, and the results are displayed in the table below. The other parameters (Kg and K axial) were likewise derived from reference 3s tables A-2.

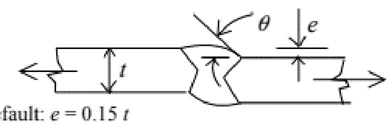
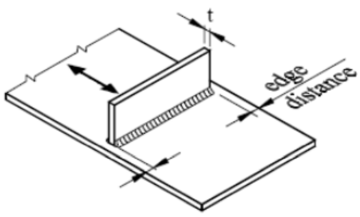
2	Welding from both sides:  Default: $e = 0.15\,t$	The eccentricity between welded plates may be accounted for in the calculation of stress concentration factor. The following formula applies for a butt weld in an unstiffened plate or for a pipe butt weld with a large radius: $$K_{te} = 1 + \frac{3(e - e_0)}{t}$$ where e is eccentricity (misalignment) and t is plate thickness. $e_0 = 0.1t$ is misalignment inherent in the S-N data for butt welds. $K_{t\alpha}$ from 1

Table A-3 K–factors for stiffeners welded to a plate		
No.	*Geometry*	*K-factor*
1		$K_g = 1.13$ if $t \le 25$ mm $K_g = 1.27$ if $t > 25$ mm

K-Factor					
Misalignment	Misalignment inherent	Plate thickness	Factor		
e	e_0	t	Kte	Kg	Kaxial
[mm]	[mm]	[mm]	[-]	[-]	[-]
3.75	2.5	25	1.15	1.13	1.4

13.2. Calculation of the local stresses due to stiffener bending

To calculate the stresses caused by stiffener bending in the appropriate loading circumstances, multiply the bending stress by the corresponding dynamic pressure. For an external pressure load (pressure acting on the plate side of the panel), compression stress will exist at the considered position, and hence the negative sign applies. As a result, the following formulas may be used to determine the combined stresses.

For the internal pressure and external:

$$\sigma_{2A} = K_{te} * K_g * M * \frac{10^{-3}}{Zs}\ [MPa]$$

Where:

- Zs is the total section modulus from the stiffeners given in table
- M is the bending moment in kN*m calculated by
- M=p*s*l^2/12 [kN*m]
- P is the maximum dynamic pressure in the deck stiffener in kN*m
- S is the stiffener spacing and l the stiffener span given in table

In this project, it is presumed that the tank under consideration is a ballast tank. Because there is no ballast in the tank during the load situation, the internal pressure is zero. Furthermore, it will be regarded that the tank will not be occupied with fresh water. While the external is equal to the stiffener's maximum pdp value in the deck structure. The outcomes are displayed in the table below.

Local Stress		
K	1.2995	-
Me	3.93E+07	N*mm
pe	45.50	kN/m^2
rp	1	-
Sigma 2A	12.85	N/mm^2
Delta Sigma 1	25.7	N/mm^2

13.3. Stresses from global loads and combine hot-spot stresses

Since the horizontal bending moment is zero, the vertical bending moments provide the following stress ranges. The 0.464 in the formula is used to convert the bending moments from Section 5 with a probability of 10^-8 to those with a probability of 10^-4.

$$\Delta\sigma_v = K_{axial} * \left(M_{SW,H} - M_{SW,S}\right) * 0.464 * 10^{-3} * \frac{z-zn}{Ina}\ \Delta\sigma_g = \Delta\sigma_v$$

Global hull stresses		
Δσv	114.9	N/mm^2
Δσhg	0	N/mm^2
ρvh	0.1	-
Δσg	114.9	N/mm^2

The total local and global stress range is provided below as a formula, and because the plates are in the deck, the correction factor is one.

$$\Delta\sigma = 1 * \left(\Delta\sigma_g + 0.6 * \Delta\sigma_1\ 0.6 * \Delta\sigma_g + \Delta\sigma_1\right)[MPa]$$

Combined hot spot stresses		
a	0.6	-
b	0.6	-
Δσ	130.3	N/mm^2

13.4. Long term distribution

The Weibull distribution can describe the long-term distribution of stress ranges at small details. As a result, various Weibull distribution parameters, such as ha, h0, and h, must be determined.

ha=0.05 h0=2.21-0.54*Lpp h=h0, for deck longitudinals

C.6.8 Long term distribution	
ha	0.05
h0	0.934
h	0.934

13.6. Fatigue part damage

The part damage in the fully loaded state throughout the design life of 20 years is computed using the:

Non-corrosive environment:

$$D = v_0 T_d \left[\frac{q^{m_1}}{\bar{a}_1} \Gamma\left(1+\frac{m_1}{h}; \left(\frac{S_1}{q}\right)^h\right) + \frac{q^{m_2}}{\bar{a}_2} \gamma\left(1+\frac{m_2}{h}; \left(\frac{S_1}{q}\right)^h\right)\right]$$

Corrosive enviroment:

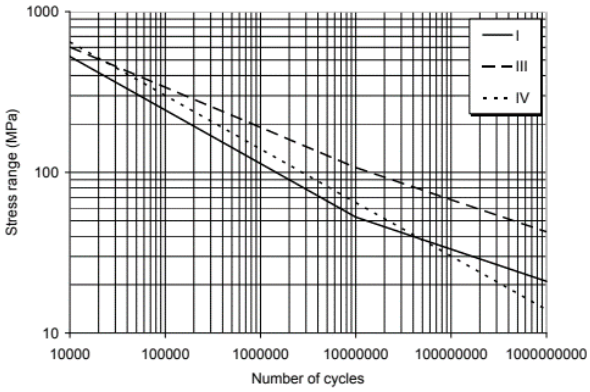
D corrosive=2*D non corrosive

Where:

- v0Td=20*365*24*3600/4*Lpp (the number of cycles during 20 years)
- q=n0) 1h (the Weibull scale parameter)
- a1 and m1 = S-N parameters for N<10^7 cycles
- a2 and m2 = S-N parameters for N>10^7 cycles
- S1 = Stress range for which change of slope occur

From the following figures the parameters a1 ,m1, a2, m2 and S1 can be found and the results are show in the table below.

S-N Curve	*Material*	$N \leq 10^7$		$N > 10^7$	
		$\log \bar{a}$	m	$\log \bar{a}$	m
I	Welded joint	12.164	3.0	15.606	5.0
III	Base Material	15.117	4.0	17.146	5.0



S-N parameters for N </= 10^7 cycles			S-N parameters for N >/= 10^7 cycles			Stress range
log (a)	a barra 1	m1	log (a)	a barra 2	m2	S1 [Mpa]
12.164	1.46E+12	3	15.606	4.04E+15	5	50

The variable D non-corrosive may be discovered using these parameters and the values of the gama and incomplete gama functions, and the results are presented below.

Auxiliary Table	
alfa 1	4.2132
x1	3.7666
Γ(α1,x1)	4.13847
alfa 2	6.35533
x2	3.7666
γ(α1,x1)	31.3944
(q^m1)/a barra 1	1.21E-09
(q^m2)/a barra 2	6.37E-11

Fatigue part damage		
T d	25	years
v0 Td	83389321.8	cycles
n0	10000	-
q	12.08064631	N/mm^2
D non corrosive	0.584	-
D corrosive	1.168	-
T c	15	years

Based on a corrosion protection term of 15 years, the fatigue damage for the full load situation is as follows.

$$D_{load} = \rho_{load} * (D_{non\ corrosive} * \frac{Tc}{Td} + D_{corrosive} * \frac{Td-Tc}{Td})$$

According to the article's standards, if Dload is less than 1.0, the detail has an adequate fatigue life for 25 years of operation in the North Atlantic wave environment. As a result, after entering the numbers into the calculation and assuming a ro(load) of 0.65, the D load equals 0.732, which is acceptable.

Some factors might have influenced these results. One of these is most likely the stiffener. Because the damage is proportional to the stress range Δσ0, which is inversely related to the stiffener size, the stiffener may be overdesigned. As a result, a smaller stiffener may have been employed. Additionally, the type of connection might have an effect on fatigue damage. If there was a bracket nearby, the rigidity of the plate, indicated by the section modulus, would rise, lowering the local stresses. Another crucial consideration is residual stress and weld quality. Once the strength of the plates is reduced, this might have an effect on the outcomes.

D full load	D total	T Fatigue	D acceptable
0.734	0.734	34.2	1

14. Conclusions

The primary goal of this study is to design the scantling of a midship section and the transverse bulkhead in accordance with DNV standards. This comprises plate dimensioning, longitudinal stiffeners, ship movements and accelerations, buckling control, and so on. Following that, a classification society program, MARS 2000, was utilized to test the structure's safety for the excessive levels of bending moment prescribed by the standards. Thus, being able to analyze the many stressors in addition to the scantling, such as global and local stress, as well as the final strength. A fatigue study for the connection between the stringer plate and the strength deck was completed at the conclusion of this report.

The major findings reveal a portion of the construction that may withstand the strains induced by the excessive levels. However, it appears that the building is overbuilt to support these attempts. Thus, because ship design is an iterative process, this is critical because it directs which changes should be made, such as evaluating smaller reinforcements, the existence of girders and brackets, thinner plates, and so on.

Furthermore, this project was critical for the student since it provided advanced understanding about ship structural design and how to deal with classification society rules.

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