Universidade de Lisboa – Instituto Superior Técnico

Licenciatura em Engenharia Naval e Oceânica

Comportamento de Estruturas Navais

BEHAVIOUR OF SHIP STRUCTURES

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Appendix A

Initial Values

Initial data about the tanker ship was needed to carry out this project. As such, values for deadweight, general ship size (length between perpendiculars, breadth, draft and molded depth), ship speed, minimum draft (equal to propeller size), block coefficient, longitudinal center of buoyancy, crew size and autonomy, were provided. These values are displayed in **Table 1**.

Table 1 – Initial Values

DWT/1000 [t]	LBP [m]	B [m]	D [m]	d [m]	v [kn]	dmin [m]	Cb	LCB	n [crew]	A [days]
30	187	26.1	13.7	9.9	16.5	8	0.77	0.029	22	30

Firstly, to calculate the general shape of the hull, the Series-60 method will be applied, breaking the ship into three distinct sections, namely run, cylindrical body and entrance, as observed in **Figure 1**.

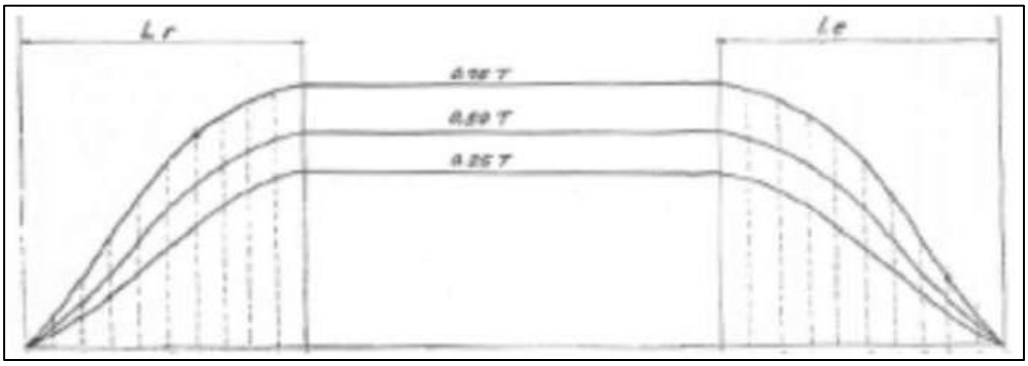


Figure 1- "Run", "entrance", and cylindrical parts of the ship hull.

Thus, the following formulas will be used, where **Lx** is the cylindrical section, **Le** is the entrance and **Lr** is the run section:

$$L_x = L_{BP}(1.81C_B - 1.148)$$
$$L_E = L_{BP}(a - b * LCB)$$
$$L_R = L_{BP} - L_x - L_E$$

Simultaneously, it is also possible to calculate the following parameters, **a** and **b**, as well as **dL**, defined as one-twentieth of the LBP:

$$a = 0.9803 - 0.6424C_B - 0.2368C_B^2$$
$$b = 0.0531 - 1.172C_B + 0.0786C_B^2$$

Results are presented in **Table 2**.

Table 2 -Values of parameters and Sections

LX	45.9459	a	0.345253
LE	68.68678295	b	-0.76054
LR	72.36731705	dL	9.35

Finally, to be able to determine the correct values for the offset table, the following coefficients must be calculated. To figure out the value of $\left(\frac{C_{PE}}{C_{PR}}\right)$, the value is interpolated using the given LCB of 0.029 and the graph below (**Figure 2**).

$$C_{PE} = \left(\frac{C_{PE}}{C_{PR}}\right) C_{PR}$$

$$C_{PR} = \frac{C_M * L_{BP} - L_x}{L_E\left(\frac{C_{PE}}{C_{PR}}\right) + L_R}$$

$$C_M = 0.96C_B + 0.038$$

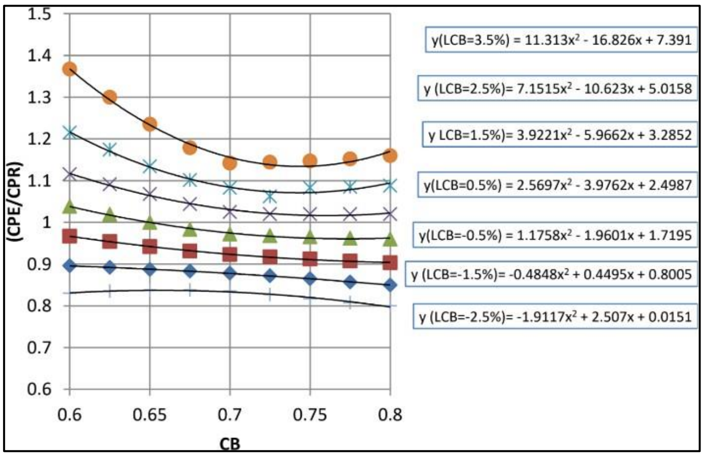


Figure 2 - Graph of relationship between CB and (CPE/CPR).

In the end, we are left with the following values presented in **Table 3**.

Table 3 - Coefficient Values

Cpe	0.739989
Cpr	0.671063
CM	0.7772

Offset Table

Now having the values of the coefficients, and using the corresponding Series-60 graphs, an offset table can be obtained, recording the value of the breath for the corresponding waterline-station pair. In this process a set of 10 stations for each run and Entrance set is used, to increase the resolution. Thus, **Table 4** is obtained.

Table 4 - Relative Offset Table

S/T	0.000	0.075d	0.25d	0.5d	0.75d	1d	1.25d	1.5d
AP	0.000	0.000	0.000	0.000	0.000	0.085	0.270	0.425
R-1	0.020	0.060	0.080	0.090	0.135	0.330	0.545	0.690
R-2	0.065	0.165	0.215	0.270	0.365	0.570	0.730	0.840
R-3	0.170	0.300	0.370	0.470	0.595	0.750	0.860	0.930
R-4	0.320	0.455	0.540	0.655	0.775	0.870	0.945	0.985
R-5	0.490	0.610	0.700	0.810	0.895	0.950	0.980	0.995
R-6	0.650	0.755	0.830	0.920	0.960	0.990	0.995	1.000
R-7	0.800	0.870	0.920	0.980	0.990	0.995	1.000	1.000
R-8	0.915	0.950	0.975	0.995	1.000	1.000	1.000	1.000
R-9	0.995	0.995	0.995	1.000	1.000	1.000	1.000	1.000
E-9	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000
E-8	0.970	0.975	0.985	0.995	1.000	1.000	1.000	1.000
E-7	0.905	0.930	0.960	0.985	0.990	0.990	0.995	1.000
E-6	0.795	0.865	0.920	0.950	0.970	0.980	0.980	0.990
E-5	0.650	0.760	0.840	0.895	0.920	0.935	0.945	0.960
E-4	0.475	0.595	0.735	0.800	0.830	0.855	0.875	0.905
E-3	0.320	0.510	0.595	0.665	0.695	0.720	0.745	0.790
E-2	0.170	0.345	0.430	0.485	0.505	0.520	0.550	0.610
E-1	0.055	0.170	0.225	0.250	0.260	0.275	0.305	0.365
FP	0.000	0.000	0.000	0.000	0.000	0.000	0.035	0.080

In order to create the offset table, these values must be multiplied by half of the ship breadth and interpolate the values for the real waterlines. This way **Table 5**, and the three following graphs (**Figures 3-5**) are obtained.

Table 5 - Offset table

Table Multiplied by B/2										
	d	0.000	0.075	0.250	0.500	0.750	1.000	1.250	D	1.500
X[m]	R/T	0.000	0.743	2.475	4.950	7.425	9.900	12.375	13.700	14.850
0.000	AP	0.000	0.000	0.000	0.000	0.000	1.109	3.524	4.606	5.546
8.041	R-1	0.261	0.783	1.044	1.175	1.762	4.307	7.112	8.125	9.005
16.082	R-2	0.848	2.153	2.806	3.524	4.763	7.439	9.527	10.295	10.962
24.122	R-3	2.219	3.915	4.829	6.134	7.765	9.788	11.223	11.712	12.137
32.163	R-4	4.176	5.938	7.047	8.548	10.114	11.354	12.332	12.612	12.854
40.204	R-5	6.395	7.961	9.135	10.571	11.680	12.398	12.789	12.894	12.985
48.245	R-6	8.483	9.853	10.832	12.006	12.528	12.920	12.985	13.020	13.050
56.286	R-7	10.440	11.354	12.006	12.789	12.920	12.985	13.050	13.050	13.050

64.327	R-8	11.941	12.398	12.724	12.985	13.050	13.050	13.050	13.050	13.050
72.367	R-9	12.985	12.985	12.985	13.050	13.050	13.050	13.050	13.050	13.050
118.313	E-9	12.985	13.050	13.050	13.050	13.050	13.050	13.050	13.050	13.050
125.945	E-8	12.659	12.724	12.854	12.985	13.050	13.050	13.050	13.050	13.050
133.577	E-7	11.810	12.137	12.528	12.854	12.920	12.920	12.985	13.020	13.050
141.209	E-6	10.375	11.288	12.006	12.398	12.659	12.789	12.789	12.859	12.920
148.841	E-5	8.483	9.918	10.962	11.680	12.006	12.202	12.332	12.437	12.528
156.473	E-4	6.199	7.765	9.592	10.440	10.832	11.158	11.419	11.628	11.810
164.104	E-3	4.176	6.656	7.765	8.678	9.070	9.396	9.722	10.037	10.310
171.736	E-2	2.219	4.502	5.612	6.329	6.590	6.786	7.178	7.597	7.961
179.368	E-1	0.718	2.219	2.936	3.263	3.393	3.589	3.980	4.399	4.763
187.000	FP	0.000	0.000	0.000	0.000	0.000	0.000	0.457	0.771	1.044

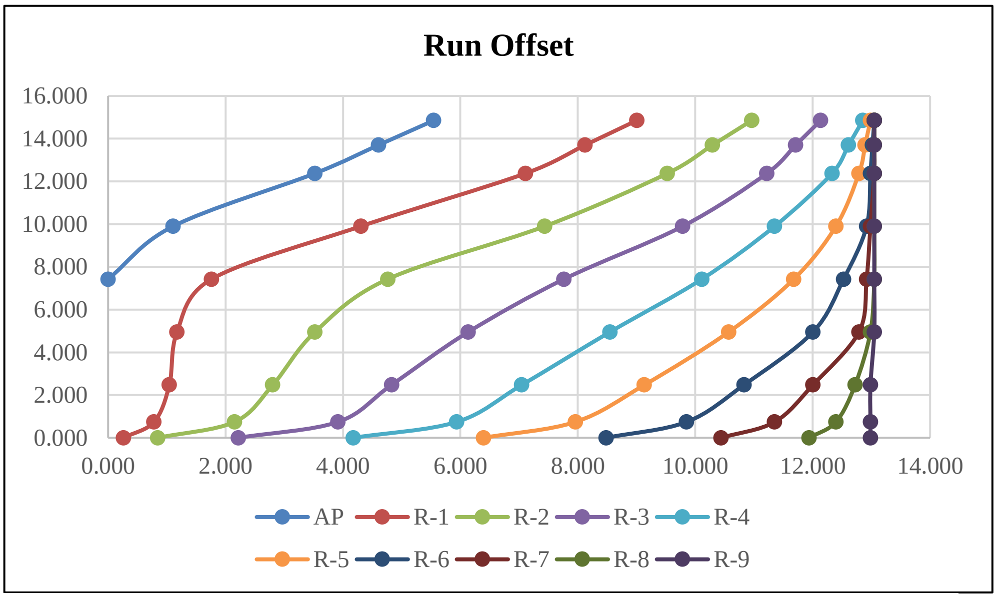


Figure 3 - Run Offset

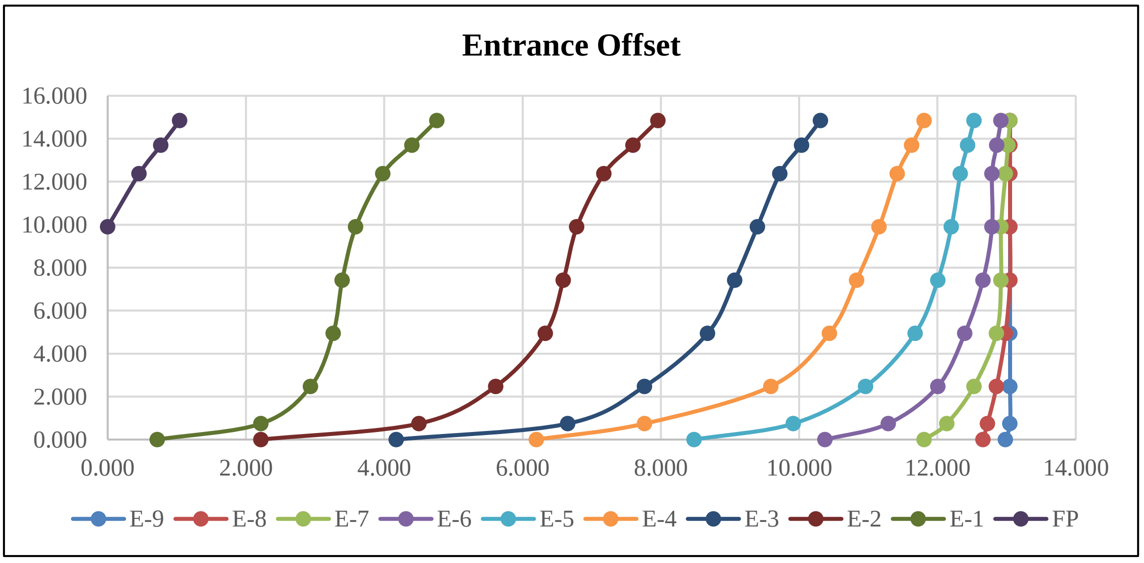


Figure 4 - Entrance Offset

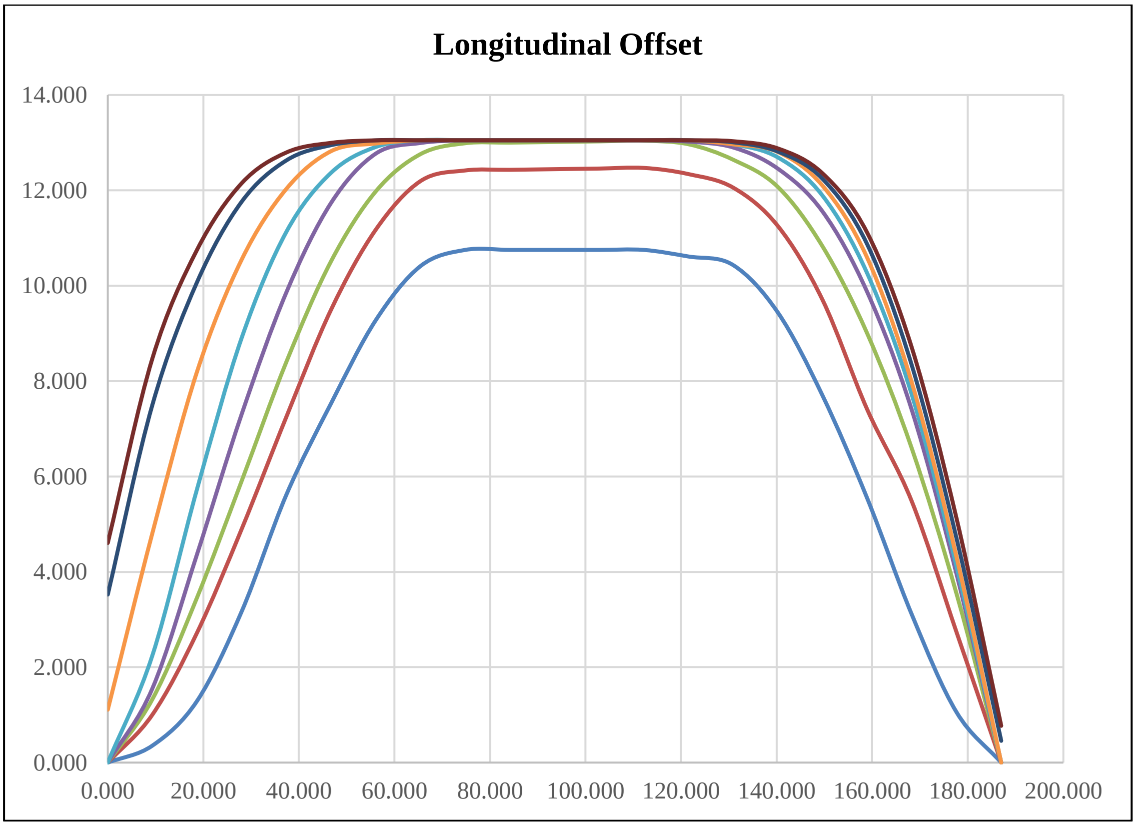


Figure 5 - Longitudinal Offset

Appendix B

Midship Section

The general arrangement of the ship was based on the model presented for this project (**Figure 6**), with adjustments made to the parameters and measurements as needed.

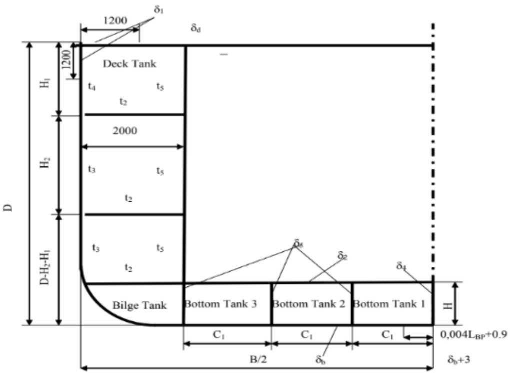


Figure 6 - Project Midship Section

Given an outer tank size of 2m, the final dimensions for the bottom tanks were determined to be most suitable with a configuration of 4 tanks, resulting in the C1 value presented below (**Table 6**).

Table 6 - Final dimension of C1

C1 [m]	2.7625

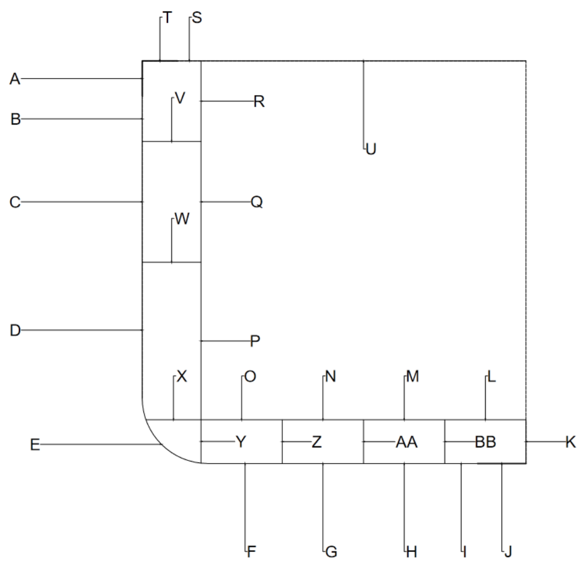


Figure 7 - Final Midship Section

After defining the general bottom tank size, the next step is to determine the bilge radius, using the following formula:

$$R = K_t \times \sqrt{B \times T}$$

and using the following graph (**Figure 8**) for the value of **Kt**.

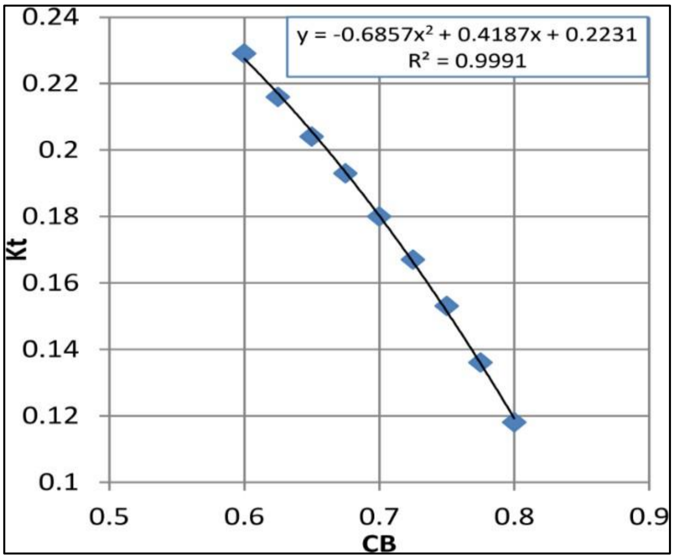


Figure 8 - Coefficient Kt as a function of CB

Hence, the results in **Table 7** are obtained.

Table 7 - Values of R and Kt

Kt	0.13
R	2.23

Finaly, the remaining side tank dimensions and bottom tank height are calculated (**Table 8**).

Table 8 - Midship section length values

H [m]	H1 [m]	H2 [m]	H3 [m]
1.49	2.74	4.11	6.85

Now having a model of the Midship section, the initial thicknesses values for each section were also calculated, resulting in the values presented in **Table 9**.

Table 9 - Sheet thicknesses for different midsection sections

δd	δb	δdb	δbt	δ1	δ2
11.545	13.48	9.24	7.39	15.01	17.52
δ4	δ5	t2	t3	t4	t5
12.132	13.48	16.176	9.236	12.132	10

Having these thicknesses, the value for **Wmin** can be calculated, using the following equations:

$$W_{min} = 0.01C_{\square} \times L_{BP}^2 \times B \times (C_B + 0.7)$$

$$C_{\square} = 10.75 - \left(\frac{300 - L_{BP}}{100}\right)^{1.5}$$

Finaly, having calculated these values, a final table can be obtained. Using the **Wmin** and **Wdeck** values, the real thicknesses of the plates can be determined (**Table 10**). To achieve this, the solver program is utilized, ensuring that the difference between **Wmin** and **Wdeck** is 0 (**Table 12**).

Table 10 - Real plate thicknesses

Plate	δ (mm)	δ (m)	c	area	z	Io	A*z	A*Z^2	Izz
A	19.69	0.01969	1.2	0.023626514	13.1	0.002835182	0.309507	4.054546	4.057381206
B	15.91525	0.01592	1.54	0.024509488	11.73	0.004843892	0.287496	3.372331	3.377175355
C	12.11616	0.01212	4.11	0.049797421	8.905	0.070098585	0.443446	3.948887	4.018985541
D	12.11616	0.01212	4.62	0.055976663	4.54	0.099565691	0.254134	1.153769	1.253334285
E	17.68361	0.01768	3.503	0.062286685	1.12	0.499992106	0.069559	0.077681	0.577672642
F	17.68361	0.01768	2.5325	0.04478375	0	1.16703E-06	0	0	1.16703E-06
G	17.68361	0.01768	2.7625	0.048850981	0	1.27302E-06	0	0	1.27302E-06
H	17.68361	0.01768	2.7625	0.048850981	0	1.27302E-06	0	0	1.27302E-06
I	17.68361	0.01768	1.1145	0.019708387	0	5.13584E-07	0	0	5.13584E-07
J	20.68361	0.02068	1.648	0.034086594	0	1.21522E-06	0	0	1.21522E-06
K	15.91525	0.01592	1.49	0.023713725	0.745	0.004387237	0.017667	0.013162	0.017548947
L	22.99	0.02299	2.7625	0.063506275	1.49	2.79682E-06	0.094624	0.14099	0.140993078
M	22.99	0.02299	2.7625	0.063506275	1.49	2.79682E-06	0.094624	0.14099	0.140993078
N	22.99	0.02299	2.7625	0.063506275	1.49	2.79682E-06	0.094624	0.14099	0.140993078
O	22.99	0.02299	2.7625	0.063506275	1.49	2.79682E-06	0.094624	0.14099	0.140993078
P	10	0.01000	5.36	0.0536	4.17	0.128325547	0.223512	0.932045	1.060370587
Q	10	0.01000	4.11	0.0411	8.905	0.057855443	0.365996	3.25919	3.31704537
R	10	0.01000	2.74	0.0274	12.33	0.017142353	0.337842	4.165592	4.182734213
S	15.1452	0.01515	0.8	0.012116161	13.7	2.31598E-07	0.165991	2.274082	2.27408247
T	19.69	0.01969	1.2	0.023626514	13.7	7.6323E-07	0.323683	4.43446	4.434461129
U	15.1452	0.01515	11.05	0.167354472	13.7	3.19894E-06	2.292756	31.41076	31.41076412
V	21.22034	0.02122	2	0.042440671	10.96	1.5926E-06	0.46515	5.098041	5.098042898
W	21.22034	0.02122	2	0.042440671	6.85	1.5926E-06	0.290719	1.991422	1.991423978
X	21.22034	0.02122	2	0.042440671	1.49	1.5926E-06	0.063237	0.094223	0.094224126
Y	17.68361	0.01768	1.4781	0.026138148	0.745	0.004758841	0.019473	0.014507	0.019266167
Z	17.68361	0.01768	1.49	0.026348583	0.745	0.00487	0.01963	0.01462	0.01949883
AA	17.68361	0.01768	1.49	0.026348583	0.745	0.00487	0.01963	0.01462	0.01949883
BB	17.68361	0.01768	1.49	0.026348583	0.745	0.00487	0.01963	0.01462	0.01949883
Total	-	-	-	1.24792	-	-	6.367554	66.90253	67.80698728

Table 11 – Initial vs. final plate thicknesses

δd	11.545	15.1452
δb	13.48	17.68361
δdb	9.236	12.11616
δbt	7.3888	9.692929
δ1	15.0085	19.68876
δ2	17.524	22.9887
δ4	12.132	15.91525
δ5	13.48	17.68361
t2	16.176	21.22034
t3	9.236	12.11616
t4	12.132	15.91525
t5	10	10

Table 12 - Real plate thicknesses

Wdeck	Wbottom	ZNA	INA	k	Wdeck - Wmin	Wmin
128111.9	215860.8	5.102537	110.1437575	1.311840721	0.00	128111.9252

Longitudinal Sections

To define the total number of tanks, the LBP of the ship is divided into four sections: *Afterpeak* (L_a), Machine Room (L_{er}), Cargo tanks Section (L_i) and *Forepeak* (L_f).

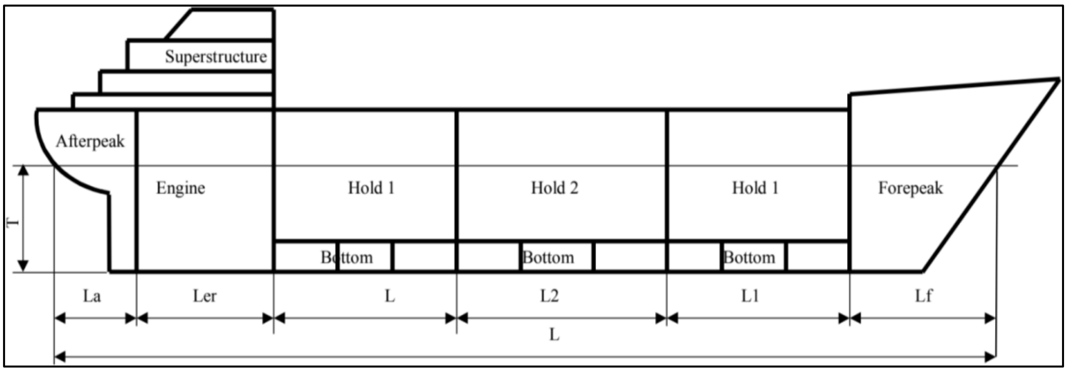


Figure 9 - Longitudinal Ship Sections

The maximum and minimum dimensions for each of the mentioned sections are first calculated (**Table 13**).

Table 13 - Allowed Section Values

Min	-	Max p
9.35	Lf	14.96
18.7	Li	46.75
	Li	30
	Li	25.7
28.05	Ler	46.75
	La	9.35

As a result, an arrangement consisting of a total of 8 cargo tanks is obtained (**Table 14**).

Table 14 - Final Section Distribution

Stations	[AP:S1]	[S1:S2]	[S2:S3]	[S3:S4]	[S4:S5]	[S5:S6]	[S6:S7]	[S7:S8]	[S8:S9]	[S9:S10]	[S10:S11]	[S11:S12]	[S12:S13]	[S13:S14]	[S14:S15]	[S15:S16]	[S16:S17]	[S17:S18]	[S18:S19]	[S19:FP]
X [m]	9.35	18.7	28.05	37.4	46.75	56.1	65.45	74.8	84.15	93.5	102.85	112.2	121.55	130.9	140.25	149.6	158.95	168.3	177.65	187
Space	L_a	L_{ER}			H1		H2		H3		H4		H5		H6		H7		H8	L_f
Lenght	9.35	28.05			18.7		18.7		18.7		18.7		18.7		18.7		18.7		9.35	9.35
Nr of DI	1	3			2		2		2	0	2		2		2		2		1	1

Bonjean Curves

Bonjean curves are plots of the section areas versus draft for different stations in the hull of a vessel. As such, these curves facilitate the calculation of the immersed volume for waterlines not parallel to the ship baseline. In this project these were calculated using integration by the trapeze method. This was done for each pairing of 8 waterlines and 20 stations, calculating the relative error for the process (**Table 15**). Finaly, these values were normalized (**Table 16**) for the ship draft, allowing to present the Bonjean curves (**Table 17**) in the following graphs (**Figures 10-11**) in an intuitive manner.

Table 15 – Waterlines and stations

		Waterlines [m]							
Stations	X [m]	0.000	0.743	2.475	4.950	7.425	9.900	12.375	13.700
AP	0.000	0.000	0.000	0.000	0.000	0.000	1.373	7.106	12.492
1.000	9.350	0.000	0.506	2.530	6.104	10.816	19.561	34.809	45.398
2.000	18.700	0.000	1.493	6.856	16.556	29.072	46.327	68.952	82.755
3.000	28.050	0.000	2.999	12.367	28.733	48.812	72.899	100.516	116.361
4.000	37.400	0.000	4.780	18.347	40.959	66.945	95.614	126.135	142.979
5.000	46.750	0.000	6.325	23.665	51.206	81.041	112.217	144.108	161.297
6.000	56.100	0.000	7.594	27.652	58.280	90.060	122.104	154.318	171.608
7.000	65.450	0.000	8.392	30.009	61.880	94.109	126.408	158.707	175.998
8.000	74.800	0.000	8.601	30.609	62.832	95.130	127.429	159.728	177.019
9.000	84.150	0.000	8.606	30.637	62.876	95.175	127.473	159.772	177.063
10.000	93.500	0.000	8.611	30.665	62.920	95.219	127.518	159.817	177.108
11.000	102.850	0.000	8.616	30.693	62.965	95.263	127.562	159.861	177.152
12.000	112.200	0.000	8.621	30.721	63.009	95.308	127.607	159.905	177.197
13.000	121.550	0.000	8.522	30.445	62.607	94.871	127.170	159.469	176.760
14.000	130.900	0.000	8.349	29.745	61.354	93.363	125.452	157.593	174.843
15.000	140.250	0.000	7.681	27.886	58.237	89.355	120.908	152.611	169.632
16.000	149.600	0.000	6.460	24.244	51.941	80.955	110.639	140.759	157.055
17.000	158.950	0.000	4.806	19.016	42.364	67.272	93.068	119.617	134.178
18.000	168.300	0.000	3.182	13.623	30.908	49.586	68.975	89.127	100.402
19.000	177.650	0.000	1.406	6.839	16.109	26.091	36.512	47.660	54.165
FP	187.000	0.000	0.000	0.000	0.000	0.000	0.000	0.565	1.379

Table 16 - Normalization

		WL Normalized [m]							
Stations	X [m]	0.000	0.054	0.181	0.361	0.542	0.723	0.903	1.000
AP	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.040	0.070
1.000	9.350	0.000	0.003	0.014	0.034	0.061	0.110	0.196	0.256
2.000	18.700	0.000	0.008	0.039	0.093	0.164	0.261	0.389	0.467
3.000	28.050	0.000	0.017	0.070	0.162	0.275	0.411	0.567	0.657
4.000	37.400	0.000	0.027	0.104	0.231	0.378	0.540	0.712	0.807
5.000	46.750	0.000	0.036	0.134	0.289	0.457	0.633	0.813	0.910
6.000	56.100	0.000	0.043	0.156	0.329	0.508	0.689	0.871	0.968
7.000	65.450	0.000	0.047	0.169	0.349	0.531	0.713	0.896	0.993
8.000	74.800	0.000	0.049	0.173	0.355	0.537	0.719	0.901	0.999
9.000	84.150	0.000	0.049	0.173	0.355	0.537	0.719	0.902	0.999
10.000	93.500	0.000	0.049	0.173	0.355	0.537	0.720	0.902	0.999
11.000	102.850	0.000	0.049	0.173	0.355	0.538	0.720	0.902	1.000
12.000	112.200	0.000	0.049	0.173	0.356	0.538	0.720	0.902	1.000
13.000	121.550	0.000	0.048	0.172	0.353	0.535	0.718	0.900	0.998
14.000	130.900	0.000	0.047	0.168	0.346	0.527	0.708	0.889	0.987
15.000	140.250	0.000	0.043	0.157	0.329	0.504	0.682	0.861	0.957
16.000	149.600	0.000	0.036	0.137	0.293	0.457	0.624	0.794	0.886
17.000	158.950	0.000	0.027	0.107	0.239	0.380	0.525	0.675	0.757
18.000	168.300	0.000	0.018	0.077	0.174	0.280	0.389	0.503	0.567
19.000	177.650	0.000	0.008	0.039	0.091	0.147	0.206	0.269	0.306
FP	187.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.008

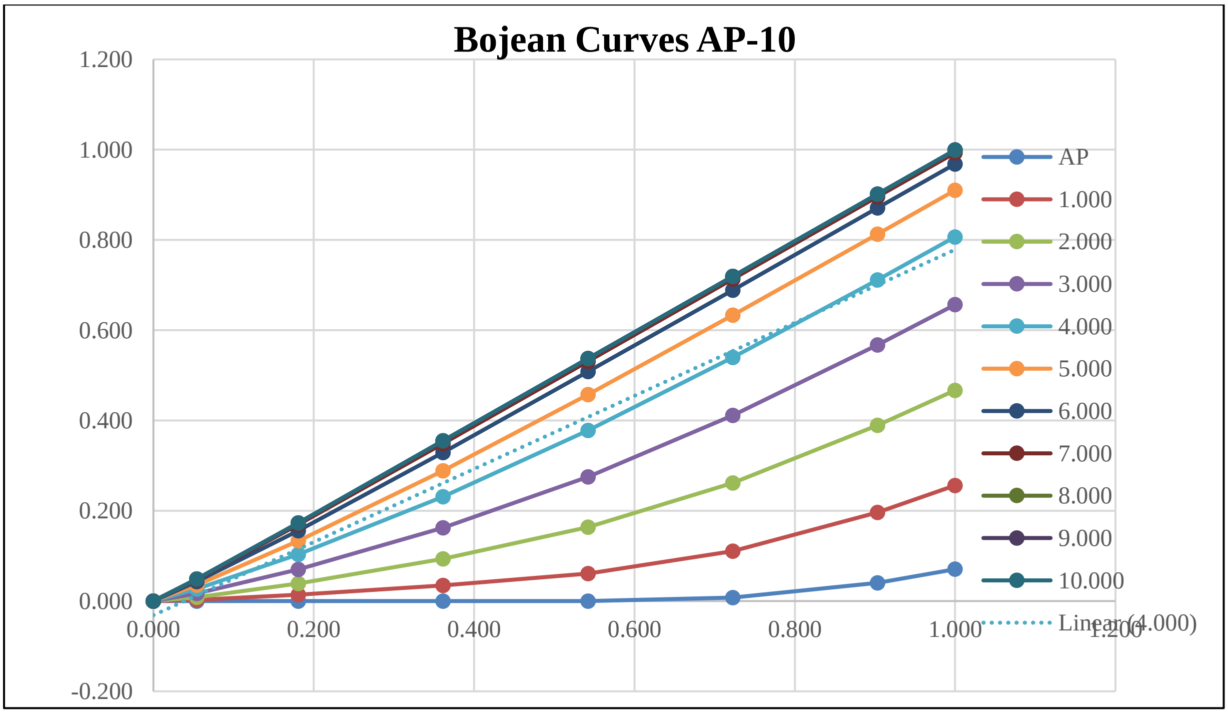


Figure 10 – Bojean curves AP-10

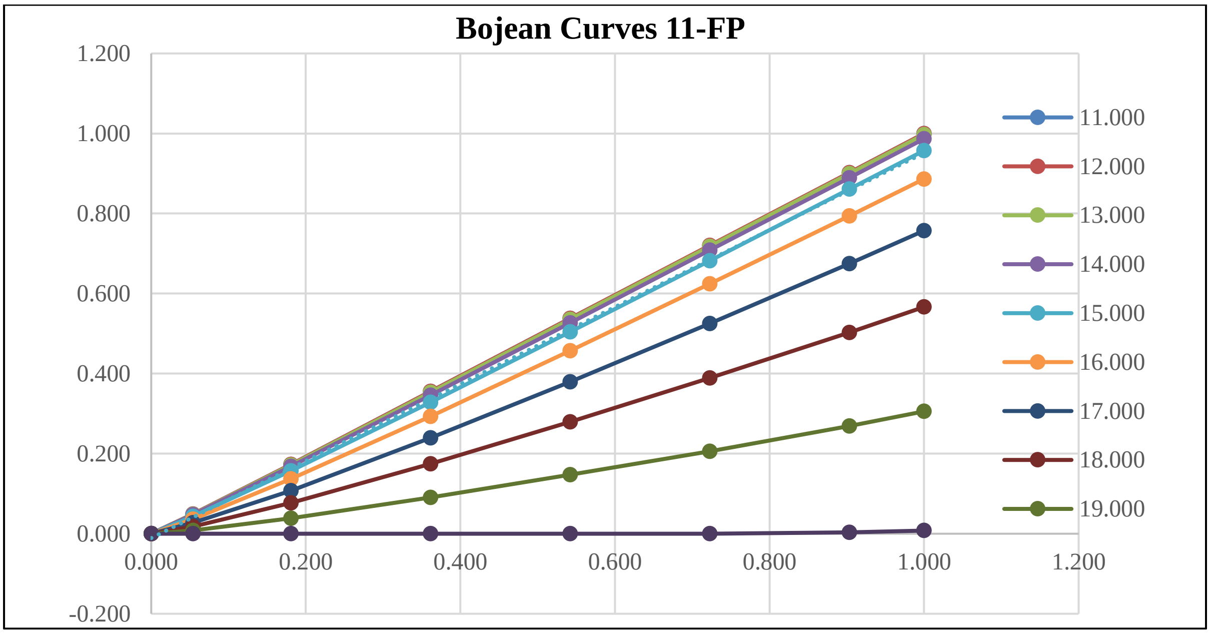


Figure 11 – Bojean curves 11-FP

Table 17 – Bonjean Coefficients

Bonjean Coefficients						Comparison		
Stations	(T/D)^4	(T/D)^3	(T/D)^2	(T/D)^1	b	Bonjean sum	Areas	Difference
AP	0.2153	-0.1718	0.0249	0.0025	-0.0001	0.0710	0.0705	-0.0005
1	0.0570	0.1867	-0.0813	0.0956	-0.0009	0.2580	0.2562	-0.0018
2	-0.0479	0.2272	0.0926	0.1968	-0.0011	0.4687	0.4670	-0.0017
3	-0.0406	0.0509	0.3174	0.3299	-0.0007	0.6577	0.6567	-0.0010
4	0.0216	-0.1678	0.4573	0.4964	-0.0005	0.8074	0.8069	-0.0005
5	0.1083	-0.3668	0.5102	0.6593	-0.0005	0.9110	0.9103	-0.0007
6	0.1777	-0.4765	0.4742	0.7938	-0.0006	0.9692	0.9685	-0.0007
7	0.1450	-0.3612	0.3174	0.8930	-0.0007	0.9942	0.9932	-0.0010
8	0.1461	-0.3479	0.2839	0.9179	-0.0008	1.0000	0.9990	-0.0010
9	0.1464	-0.3476	0.2824	0.9191	-0.0008	1.0003	0.9992	-0.0011
10	0.1467	-0.3473	0.2809	0.9203	-0.0008	1.0006	0.9995	-0.0011
11	0.1470	-0.3471	0.2794	0.9215	-0.0008	1.0008	0.9997	-0.0011
12	0.1473	-0.3468	0.2780	0.9226	-0.0008	1.0011	1.0000	-0.0011
13	0.1510	-0.3614	0.2983	0.9107	-0.0008	0.9986	0.9975	-0.0011
14	0.1453	-0.3594	0.3171	0.8845	-0.0006	0.9876	0.9867	-0.0009
15	0.1463	-0.3845	0.3803	0.8162	-0.0007	0.9583	0.9573	-0.0010
16	0.1923	-0.5077	0.5221	0.6806	-0.0007	0.8873	0.8863	-0.0010
17	0.2507	-0.6404	0.6487	0.4992	-0.0007	0.7582	0.7572	-0.0010
18	0.2474	-0.6029	0.5829	0.3403	-0.0008	0.5676	0.5666	-0.0010
19	0.2091	-0.4682	0.4104	0.1553	-0.0006	0.3065	0.3057	-0.0008
FP	0.0684	-0.0971	0.0419	-0.0054	0.0001	0.0077	0.0078	0.0001

Error [%]	-0.094

Lightweight

Ships' Lightweight is calculated as a sum of multiple weights of a ship, specifically, the weight of the machinery, the superstructure, the equipment and the hull. As such, it can be described by the following equation:

$$LW = P_m + P_{ss} + P_{eq} + P_{hull}$$

For this project, the weights of each of these were based on a provided document, using the formulas and methods described.

Weight of Machinery

For calculating the distribution of machinery in a tanker ship, the following figure was used as a reference (**Figure 12**).

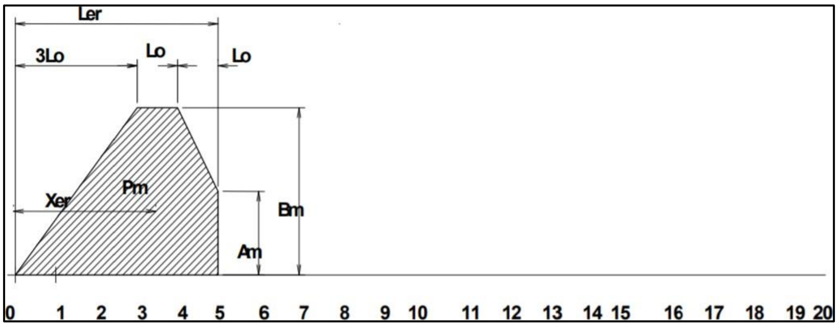


Figure 12 - Machinery Weight Distribution

The formulas used to obtain the machinery parameters were:

$$A_m = \frac{5}{8}\frac{P_m}{L_{er}}\left(45\frac{X_{er}}{L_{er}} - 26\right)$$

$$B_m = \frac{5}{16}\frac{P_m}{L_{er}}\left(14 - 15\frac{X_{er}}{L_{er}}\right)$$

$$N_{eff} = 0.4612L^2 - 42.254L + 2013.3$$

$$P_m = 0.1N_{eff}$$

$$X_{ER} = 0.6L_{ER}$$

Having obtained the values in **Table 12**.

Table 10 - Machinery parameters

Lo (m)	7.48	Pm (t)	1023.95048
Ler (m)	28.05	Am (t/m)	17.11147193
Xer (m)	22.44	Bm (t/m)	42.77867981
Neff (hp)	10239.5048		

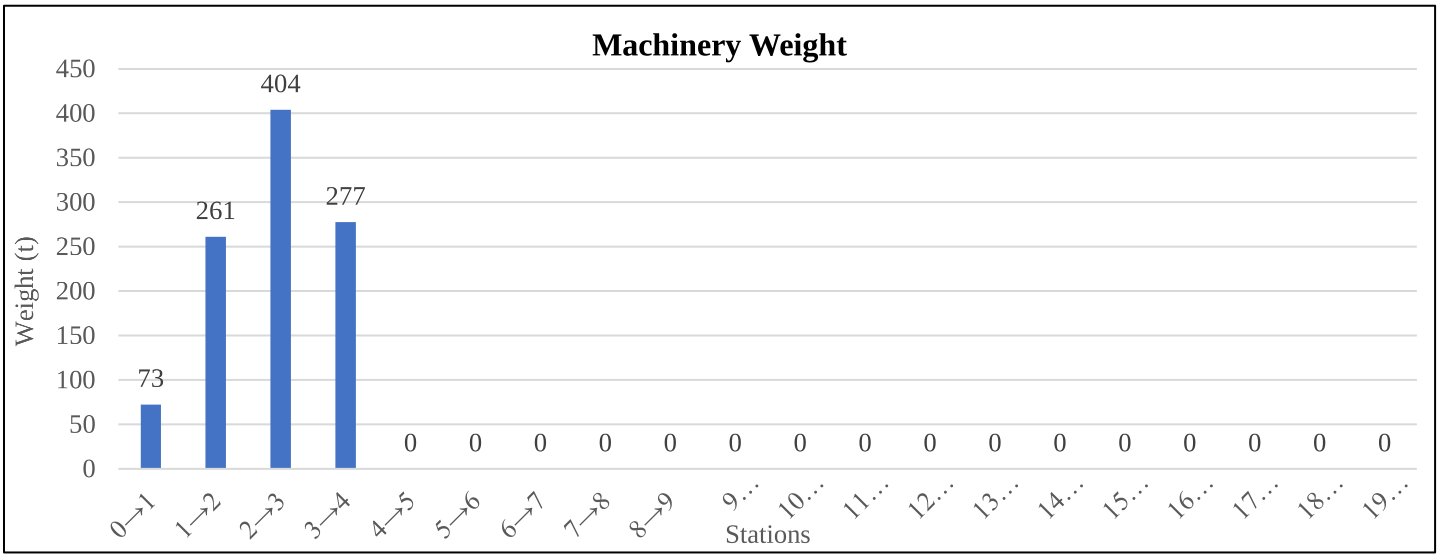


Figure 13 - Machine Weight Distribution by Station

Weight of the superstructure

For this section, the distribution in **Figure 14** was used.

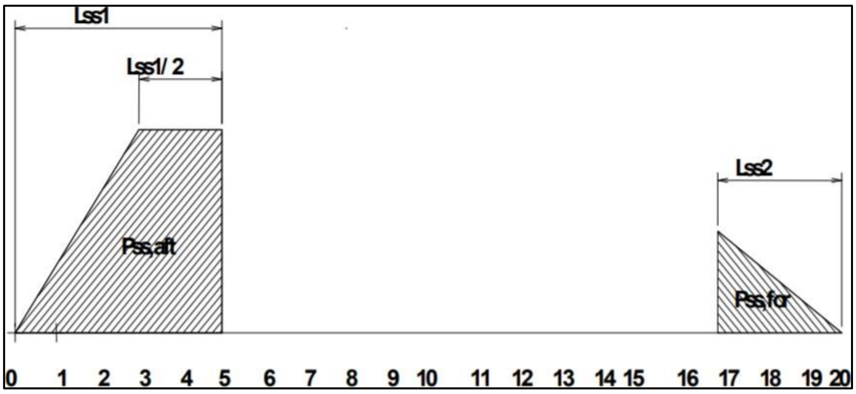


Figure 14 - Superstructure Weight Distribution

The formulas used to calculate the necessary parameters were:

$$P_{ss,aft} = 0.5L_{er}B$$

$$P_{ss,for} = 0.008LB$$

The obtained results are presented in **Table 13**.

Table 11 - Superstructure Weight by section

Pss, aft [t]	488.070
Pss, for [t]	39.046

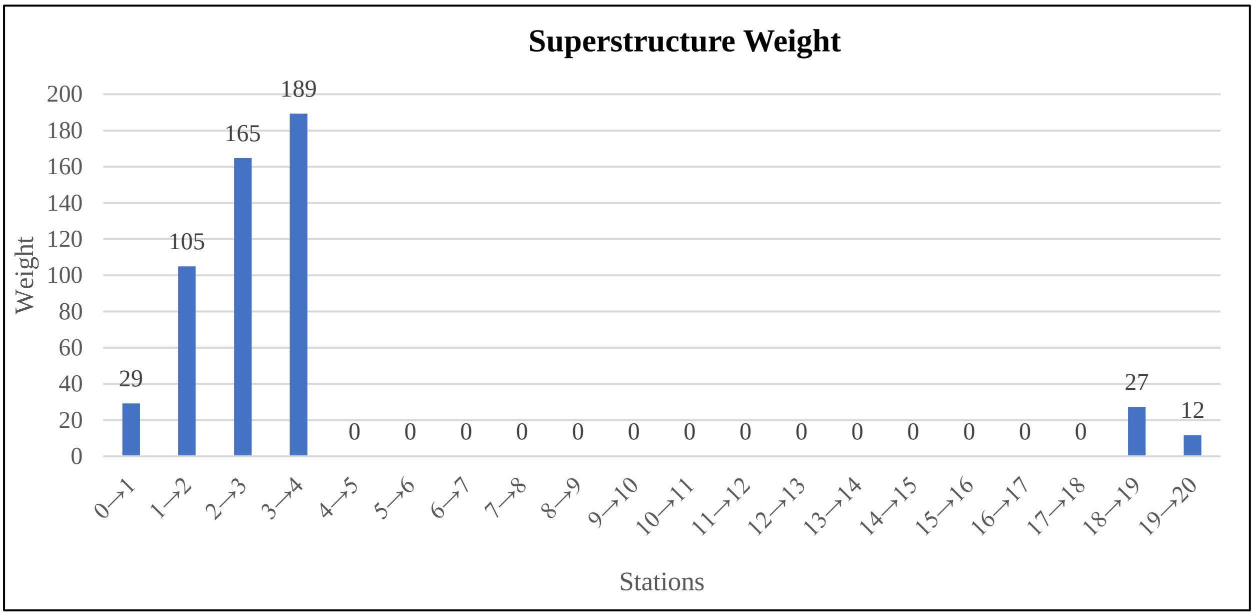


Figure 15 - Superstructure Weight (tons) by station

Weight of Hull

For the weight of the hull, the distribution is presented in **Figure 16**.

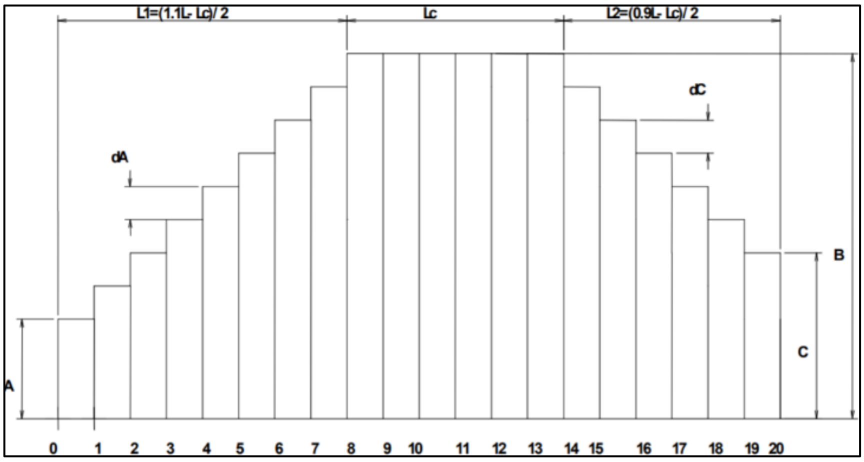


Figure 16 – Weight of the hull distribution

The formulas used to calculate the hull weight were the following:

$$DW = 4 \times 10^{-6} L^{3.1019}$$

$$k_{DW} = -2 \times 10^{-6} x^2 + 0.0016x + 0.6001$$

$$k_{hull} = 2.206 \times 10^{-6} \times L_{BP}{}^2 - 0.001183 L_{BP} + 0.2763$$

$$P_{hull,ss} = \Delta k_{hull}$$

$$\Delta = \frac{DW}{k_{DW}}$$

$$X_{\text{hull}} = \frac{L_c}{L} - 0.7$$

$$P_{hull} = P_{hull,ss} - P_{ss}$$

Leading to the results shown in **Table 14**.

Table 14 – Hull weight

kDW	0.830
DW	44574.40
khull,ss	0.12
Δ	53745.40
Phull,ss	6548.23
Pss	527.12
Phull	6021.12
Xhull	-0.40
Lc	56.10
Lc/L	0.30
Phull/L	32.20

Now that these values have been calculated, the appropriate formulas to calculate **A, B, C, dA** and **dC** can be applied. In this case Lc/L is equal to 0.3, so the corresponding formulas are used, as shown in **Figure 17**.

L_c / L	0.1	0.2	0.3
$B/(P_{hull}/L)$	1.27	1.24	1.21
$A/(P_{hull}/L)$	$0.755-0.266(x_{hull}/\Delta L)$	$0.738-0.279(x_{hull}/\Delta L)$	$0.726-0.296(x_{hull}/\Delta L)$
$C/(P_{hull}/L)$	$0.699+0.325(x_{hull}/\Delta L)$	$0.668+0.349(x_{hull}/\Delta L)$	$0.637+0.381(x_{hull}/\Delta L)$
L_c / L	0.4	0.5	0.6
$B/(P_{hull}/L)$	1.18	1.15	1.12
$A/(P_{hull}/L)$	$0.711-0.319(x_{hull}/\Delta L)$	$0.704-0.350(x_{hull}/\Delta L)$	$0.704-0.392(x_{hull}/dL)$
$C/(P_{hull}/L)$	$0.606+0.426(x_{hull}/\Delta L)$	$0.574+0.490(x_{hull}/dL)$	$0.544+0.588(x_{hull}/dL)$

Figure 17 – Used equations

The results using these equations are shown in **Table 15**.

Table 15 – Results for , B, C, dA and dC

A	23.78
B	38.96
C	19.99
dA	1.90
dC	3.16

Applying the distribution of weights, the graph in **Figure 18** is obtained.

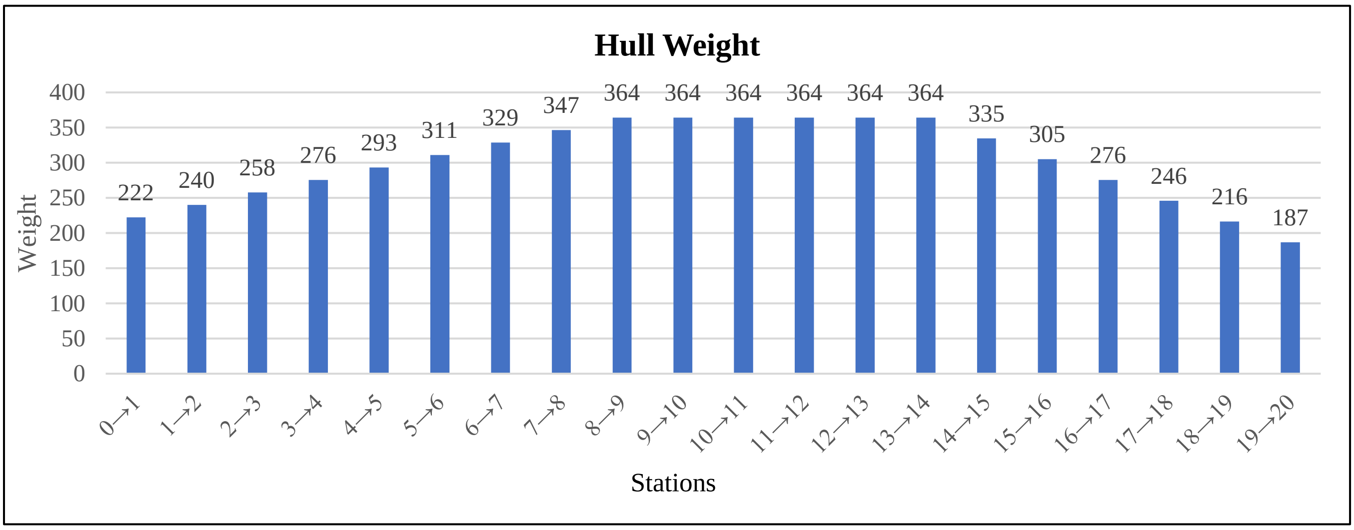


Figure 18 – Hull Weight (tons) by station

Weight of equipment

For the weight of the equipment, the distribution is presented in **Figure 19**.

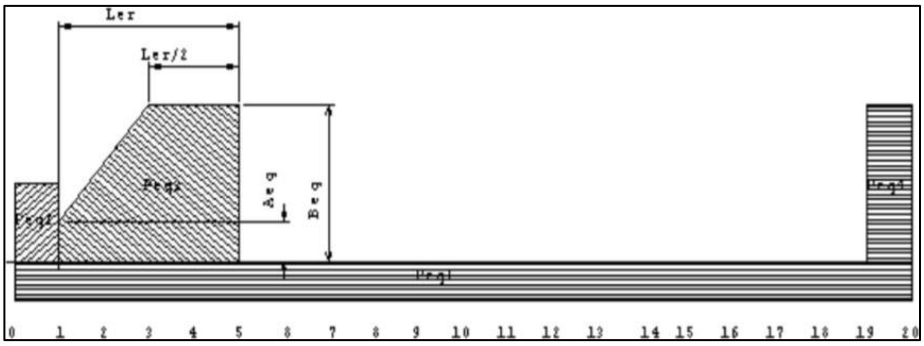


Figure 19 – Equipment weight distribution

The formulas used to calculate the weight of the equipment were the following:

$$P_{eq} = P_{eq,1} + P_{eq,2} + P_{eq,3} + P_{eq,4}$$

$$P_{eq,1} = 0.5P_{eq}$$

$$P_{eq,2} = 0.03P_{eq}$$

$$P_{eq,3} = 0.4P_{eq}$$

$$P_{eq,4} = 0.07P_{eq}$$

$$P_{eq} = LW - Phull + Pss + Pm$$

$$LW = \Delta - DW$$

$$A_{eq} = B_{eq}/3$$

$$B_{eq} = \frac{\frac{P_{eq3}}{\left(\frac{10}{3}\right)}}{\Delta \mathrm{L}}$$

Leading to the results shown in **Table 16**.

Table 16 – Equipment weight

W [t]	9170.0
Peq [t]	1602.6
Peq 1 [t]	801.3
Peq 2 [t]	48.1
Peq 3 [t]	641.0
Peq 4 [t]	112.2
Aeq [t/m]	6.9
Beq [t/m]	20.6

Thus, the following graph is obtained (**Figure 20**).

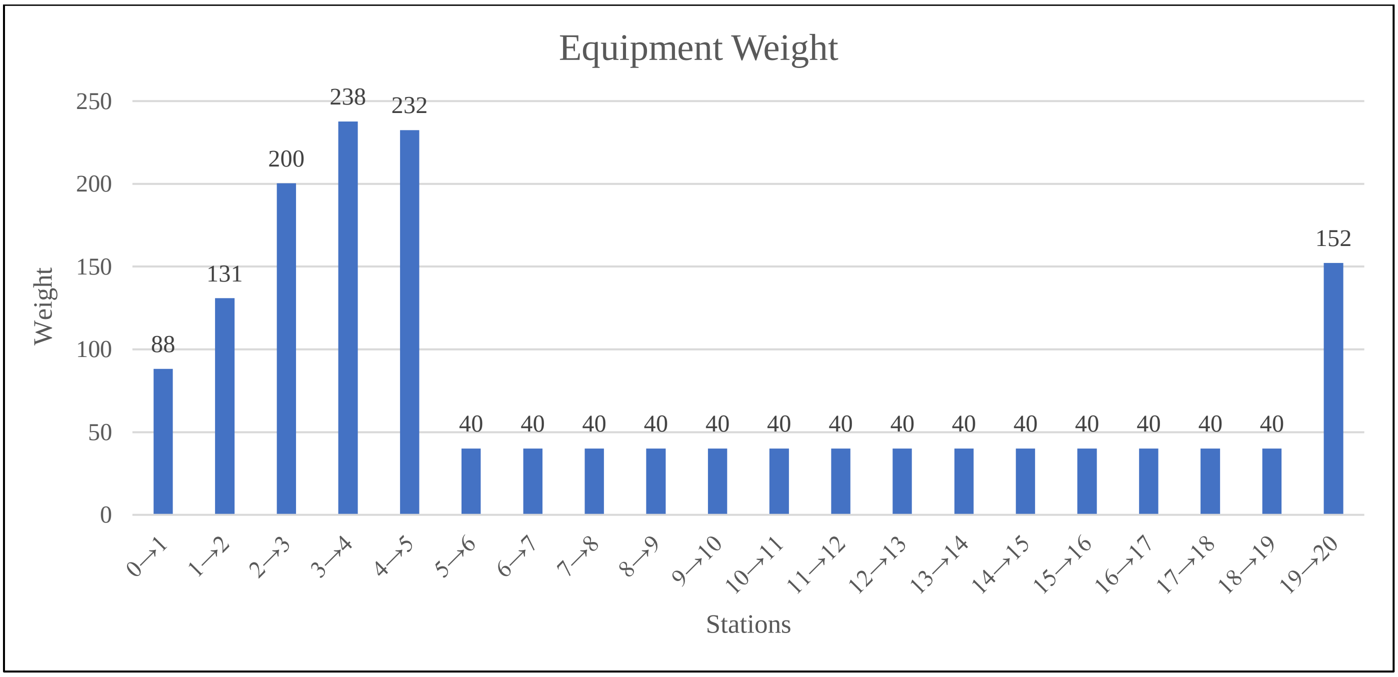


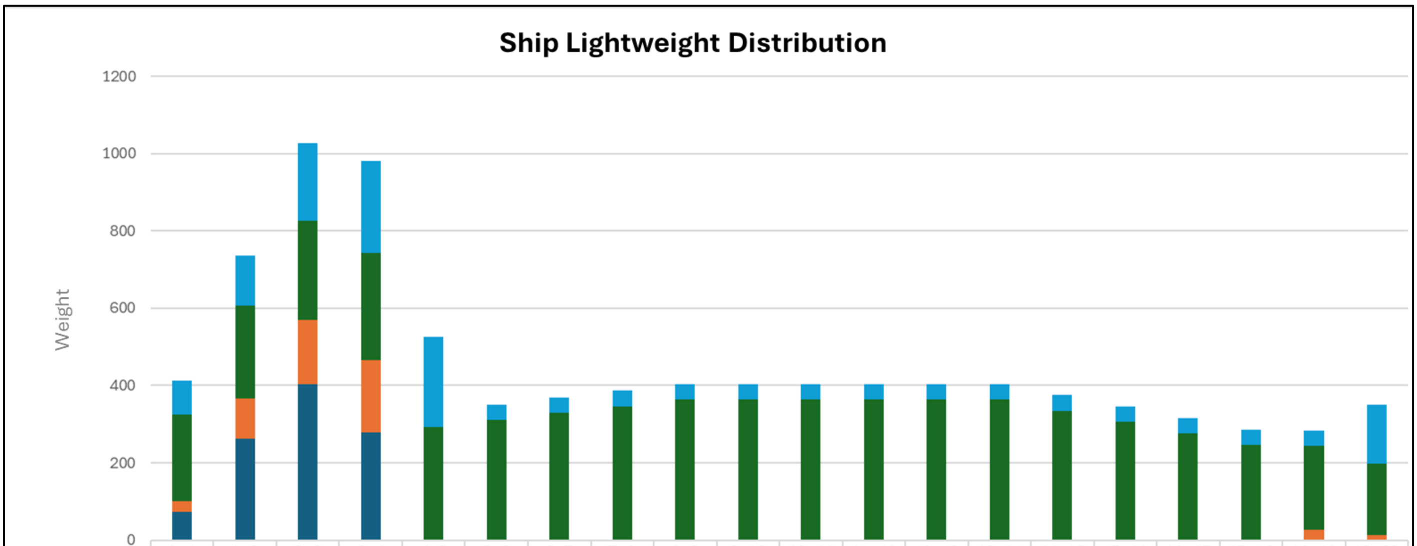
Figure 20 – Equipment Weight (tons) by station

Total Lightweight

Creating a final table for all the lightweight (**Table 17**) allows us to do a final sum of all the values. From this table we also observe that most of the impact comes from the weight of the hull itself, rather than the remaining structures or equipment.

Table 17 – All lightweight

Stations	Machinery (t)	Superstructure (t)	Hull (t)	Equipment (t)	Total
0→1	73	29	222	88	412
1→2	261	105	240	131	737
2→3	404	165	258	200	1027
3→4	277	189	276	238	980
4→5	0	0	293	232	526
5→6	0	0	311	40	351
6→7	0	0	329	40	369
7→8	0	0	347	40	387
8→9	0	0	364	40	404
9→10	0	0	364	40	404
10→11	0	0	364	40	404
11→12	0	0	364	40	404
12→13	0	0	364	40	404
13→14	0	0	364	40	404
14→15	0	0	335	40	375
15→16	0	0	305	40	345
16→17	0	0	276	40	316
17→18	0	0	246	40	286
18→19	0	27	216	40	284
19→20	0	12	187	152	351
Total	1015.2	527.1	6026.1	1602.6	9171.0



	0→1	1→2	2→3	3→4	4→5	5→6	6→7	7→8	8→9	9→10	10→11	11→12	12→13	13→14	14→15	15→16	16→17	17→18	18→19	19→20
Equipment	88	131	200	238	232	40	40	40	40	40	40	40	40	40	40	40	40	40	40	152
Hull	222	240	258	276	293	311	329	347	364	364	364	364	364	364	335	305	276	246	216	187
Superstructure	29	105	165	189	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	12
Machinery	73	261	404	277	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Stations

Figure 21 – Ship lightweight distribution (tons)

Tanks

Tank Capacity

The tanker ship being designed in this project will have 4 types of tanks, namely, Bottom Tanks, Side Tanks, Deck tanks and Bilge Tanks. To determine the volume of each one, we will use the Midship section plan as a base, taking the measurements from the previous calculated drawing, and calculating the corresponding area.

Now, after also calculating the total area of the midship section, we calculate the corresponding ratio of tank to total area, allowing us to estimate the area at each station, and consequently, the volume of each tank. As such, in the following table (**Table 18**), we have the area and ratios displayed.

Table 18 – Tank areas as ratios of midsection area

	Area/2 [m^2]	Area [m^2]	Ratio
Cargo Hold	134.9205	269.841	0.759185
Deck Tank	5.48	10.96	0.030835
Side Tank 1	8.22	16.44	0.046253
Side Tank 2	10.6891	21.3782	0.060147
Bilge tank	1.9445	3.889	0.010942
Bottom Tank 4	4.1152	8.2304	0.023156
Bottom Tank 3	4.1161	8.2322	0.023161
Bottom Tank 2	4.1161	8.2322	0.023161
Bottom Tank 1	4.1161	8.2322	0.023161
Total	177.7176	355.4352	1

And with these values, it is possible to calculate the volume and number of tanks in between each station, as shown below in the next two tables (**Tables 19-20**).

Table 19 – Tank volume

Tank Volume/ 2																					
Stations	[AP:S1]	[S1:S2]	[S2:S3]	[S3:S4]	[S4:S5]	[S5:S6]	[S6:S7]	[S7:S8]	[S8:S9]	[S9:S10]	[S10:S11]	[S11:S12]	[S12:S13]	[S13:S14]	[S14:S15]	[S15:S16]	[S16:S17]	[S17:S18]	[S18:S19]	[S19:FP]	Total
V_total [m^3]	541.273188	1198.23728	1861.74	2424.83	2844.98	3112.65744	3250.11386	3300.70896	3310.67126	3311.5	3312.33	3313.16	3309.49	3287.49	3220.85	3054.53	2723.03	2193.33	1445.21	519.338	51535.5
V_cargo [m^3]	-	-	-	-	2159.86	2363.0822	2467.43703	2505.84806	2513.41129	2514.04	2514.67	2515.3	2512.52	2495.81	2445.22	2318.95	2067.29	1665.14	1097.18	-	34155.8
V_deck [m^3]	-	-	-	-	87.7261	95.9801548	100.218684	101.778806	102.085998	102.112	102.137	102.163	102.05	101.371	99.3162	94.1878	83.966	67.6323	44.5636	-	1387.29
V_Side1 [m^3]	-	-	-	-	131.589	143.970232	150.328026	152.668209	153.128997	153.167	153.206	153.244	153.074	152.057	148.974	141.282	125.949	101.448	66.8454	24.021	2104.95
V_Side2 [m^3]	-	-	-	-	171.116	187.215597	195.483127	198.526247	199.125445	199.175	199.225	199.275	199.054	197.731	193.723	183.719	163.781	131.921	86.9242	31.2364	2737.23
V_bilge [m^3]	-	-	-	-	31.1284	34.0571918	35.5611735	36.1147606	36.2237632	36.2328	36.2419	36.251	36.2109	35.9701	35.241	33.4212	29.7941	23.9983	15.8128	5.68234	497.942
V_bottom4 [m^3	-	-	-	-	65.8778	72.0761921	75.2591109	76.4306829	76.6613682	76.6806	76.6998	76.719	76.6341	76.1245	74.5814	70.7302	63.0542	50.7884	33.465	12.0257	1053.81
V_bottom3 [m^3	-	-	-	-	65.8922	72.0919553	75.2755702	76.4473984	76.6781342	76.6973	76.7166	76.7358	76.6508	76.1412	74.5977	70.7457	63.0679	50.7995	33.4723	12.0283	1054.04
V_bottom2 [m^3	-	-	-	-	65.8922	72.0919553	75.2755702	76.4473984	76.6781342	76.6973	76.7166	76.7358	76.6508	76.1412	74.5977	70.7457	63.0679	50.7995	33.4723	12.0283	1054.04
V_bottom [m^3]	-	-	-	-	65.8922	72.0919553	75.2755702	76.4473984	76.6781342	76.6973	76.7166	76.7358	76.6508	76.1412	74.5977	70.7457	63.0679	50.7995	33.4723	12.0283	1054.04
Sum tanks	0	0	0	0	2844.98	3112.65744	3250.11386	3300.70896	3310.67126	3311.5	3312.33	3313.16	3309.49	3287.49	3220.85	3054.53	2723.03	2193.33	1445.21	109.05	45099.1
Diff	541.273188	1198.23728	1861.74	2424.83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	410.287	6436.36

Table 20 – Tank number

Tank Number																				
Stations	[AP:S1]	[S1:S2]	[S2:S3]	[S3:S4]	[S4:S5]	[S5:S6]	[S6:S7]	[S7:S8]	[S8:S9]	[S9:S10]	[S10:S11]	[S11:S12]	[S12:S13]	[S13:S14]	[S14:S15]	[S15:S16]	[S16:S17]	[S17:S18]	[S18:S19]	[S19:FP]
Cargo	-	-	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-
Deck	-	-	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	-
Side	-	-	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Bildge	-	-	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Bottom	-	-	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

As such, we can create the following diagram (**Figure 22**), of the ship tanks' position and volume.

		Tank Capacity																					
		Afterpeak	Machine room			1		2		3		4		5		6		7		8	Forepeak		
		[AP:S1]	[S1:S2]	[S2:S3]	[S3:S4]	[S4:S5]	[S5:S6]	[S6:S7]	[S7:S8]	[S8:S9]	[S9:S10]	[S10:S11]	[S11:S12]	[S12:S13]	[S13:S14]	[S14:S15]	[S15:S16]	[S16:S17]	[S17:S18]	[S18:S19]	[S19:FP]	Volume Total [m^3]	45099.1
Port	Deck	-	-	-	-	43.86306	47.99008	50.10934	50.8894	51.043	51.05579	51.06858	51.08137	51.02481	50.68557	49.65812	47.09388	41.98299	33.81613	22.2818	-	Deck	Port
	Side 1	-	-	-	-	65.79459	71.98512	75.16401	76.3341	76.5645	76.58369	76.60287	76.62206	76.53722	76.02835	74.48719	70.64082	62.97448	50.7242	33.4227	12.01051	Side 1	
	Side 2	-	-	-	-	85.55778	93.6078	97.74156	99.26312	99.56272	99.58767	99.61262	99.63757	99.52724	98.86553	96.86143	91.85971	81.89057	65.96059	43.46212	15.61819	Side 2	
	Bilge	-	-	-	-	15.56418	17.0286	17.78059	18.05738	18.11188	18.11642	18.12096	18.1255	18.10543	17.98505	17.62048	16.71059	14.89707	11.99917	7.90638	2.841172	Bilge	
	Bottom 4	-	-	-	-	32.93892	36.0381	37.62956	38.21534	38.33068	38.34029	38.3499	38.3595	38.31703	38.06227	37.29071	35.3651	31.52708	25.39419	16.73249	6.012852	Bottom 4	
	Bottom 3	-	-	-	-	32.94612	36.04598	37.63779	38.2237	38.33907	38.34867	38.35828	38.36789	38.32541	38.07059	37.29887	35.37283	31.53397	25.39974	16.73615	6.014167	Bottom 3	
	Bottom 2	-	-	-	-	32.94612	36.04598	37.63779	38.2237	38.33907	38.34867	38.35828	38.36789	38.32541	38.07059	37.29887	35.37283	31.53397	25.39974	16.73615	6.014167	Bottom 2	
	Bottom 1	-	-	-	-	32.94612	36.04598	37.63779	38.2237	38.33907	38.34867	38.35828	38.36789	38.32541	38.07059	37.29887	35.37283	31.53397	25.39974	16.73615	6.014167	Bottom 1	
	Suoerestrutura		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Superestrutura	
	Carga	-	-	-	-	2159.863	2363.082	2467.437	2505.848	2513.411	2514.041	2514.671	2515.301	2512.516	2495.811	2445.219	2318.953	2067.287	1665.142	1097.179	-	Carga	
Starboard	Bottom 1	-	-	-	-	32.94612	36.04598	37.63779	38.2237	38.33907	38.34867	38.35828	38.36789	38.32541	38.07059	37.29887	35.37283	31.53397	25.39974	16.73615	6.014167	Bottom 1	Starboard
	Bottom 2	-	-	-	-	32.94612	36.04598	37.63779	38.2237	38.33907	38.34867	38.35828	38.36789	38.32541	38.07059	37.29887	35.37283	31.53397	25.39974	16.73615	6.014167	Bottom 2	
	Bottom 3	-	-	-	-	32.94612	36.04598	37.63779	38.2237	38.33907	38.34867	38.35828	38.36789	38.32541	38.07059	37.29887	35.37283	31.53397	25.39974	16.73615	6.014167	Bottom 3	
	Bottom 4	-	-	-	-	32.93892	36.0381	37.62956	38.21534	38.33068	38.34029	38.3499	38.3595	38.31703	38.06227	37.29071	35.3651	31.52708	25.39419	16.73249	6.012852	Bottom 4	
	Bilge	-	-	-	-	15.56418	17.0286	17.78059	18.05738	18.11188	18.11642	18.12096	18.1255	18.10543	17.98505	17.62048	16.71059	14.89707	11.99917	7.90638	2.841172	Bilge	
	Side 2	-	-	-	-	85.55778	93.6078	97.74156	99.26312	99.56272	99.58767	99.61262	99.63757	99.52724	98.86553	96.86143	91.85971	81.89057	65.96059	43.46212	15.61819	Side 2	
	Side 1	-	-	-	-	65.79459	71.98512	75.16401	76.3341	76.5645	76.58369	76.60287	76.62206	76.53722	76.02835	74.48719	70.64082	62.97448	50.7242	33.4227	12.01051	Side 1	
	Deck	-	-	-	-	43.86306	47.99008	50.10934	50.8894	51.043	51.05579	51.06858	51.08137	51.02481	50.68557	49.65812	47.09388	41.98299	33.81613	22.2818	-	Deck	
	Total	0	0	0	0	2844.977	3112.657	3250.114	3300.709	3310.671	3311.501	3312.331	3313.16	3309.492	3287.488	3220.848	3054.53	2723.035	2193.329	1445.207	109.0504	Total	
		[AP:S1]	[S1:S2]	[S2:S3]	[S3:S4]	[S4:S5]	[S5:S6]	[S6:S7]	[S7:S8]	[S8:S9]	[S9:S10]	[S10:S11]	[S11:S12]	[S12:S13]	[S13:S14]	[S14:S15]	[S15:S16]	[S16:S17]	[S17:S18]	[S18:S19]	[S19:FP]		
		Afterpeak	Machine room			1		2		3		4		5		6		7		8	Forepeak		

Figure 22 – Ship tanks' position and volume

Tank Mapping

In the next phase of this work, it is necessary to calculate the ship's deadweight, so attributing and distributing the provisions of freshwater, fuel, oil and cargo are fundamental for this process. For our project, two different loading conditions will be studied, referred to as Cargo condition and Ballast Condition.

The distribution of these materials was a result of multiple iterations of calculations and changes, arriving at the final arrangement, that guarantees the availability of the necessary provisions while maintaining ship stability.

Cargo Conditions

Table 21 – Cargo condition Tank placement

		Cargo Condition																					
		Afterpeak	Machine room			1		2		3		4		5		6		7		8	Forepeak		
		[AP:S1]	[S1:S2]	[S2:S3]	[S3:S4]	[S4:S5]	[S5:S6]	[S6:S7]	[S7:S8]	[S8:S9]	[S9:S10]	[S10:S11]	[S11:S12]	[S12:S13]	[S13:S14]	[S14:S15]	[S15:S16]	[S16:S17]	[S17:S18]	[S18:S19]	[S19:FP]	Volume Total [m^3]	
Port	Deck	-	-	-	-	FW	FW	FW														Deck	Port
	Side 1	-	-	-	-	FW	FW	FW														Side 1	
	Side 2	-	-	-	-	Fuel	Fuel	Fuel													B	Side 2	
	Bilge	-	-	-	-	Fuel	Fuel	Fuel													B	Bilge	
	Bottom 4	-	-	-	-	Fuel	Fuel	Fuel	Fuel												B	Bottom 4	
	Bottom 3	-	-	-	-	Fuel	Fuel	Fuel	Fuel	B		B									B	Bottom 3	
	Bottom 2	-	-	-	-	Fuel	Fuel	Fuel	Fuel	B	B	B								B	B	Bottom 2	
	Bottom 1	-	-	-	-	Fuel	Fuel	Fuel	Fuel	B	B	B	B	B	B				B	B	B	Bottom 1	
	Suoerestrutura																					Superestrutura	
	Carga					Cargo	Cargo	Cargo	Cargo	Cargo	Cargo	Cargo	Cargo	Cargo	Cargo	Cargo	Cargo	Cargo	Cargo	Cargo		Carga	

Ballast Conditions

Table 22 – Ballast Condition Tank Placement

		Balast Condition																					
		Afterpeak	Machine room			1		2		3		4		5		6		7		8	Forepeak		
		[AP:S1]	[S1:S2]	[S2:S3]	[S3:S4]	[S4:S5]	[S5:S6]	[S6:S7]	[S7:S8]	[S8:S9]	[S9:S10]	[S10:S11]	[S11:S12]	[S12:S13]	[S13:S14]	[S14:S15]	[S15:S16]	[S16:S17]	[S17:S18]	[S18:S19]	[S19:FP]	Volume Total [m^3]	
Port	Deck	-	-	-	-	FW	FW	FW	B	B	B	B	B	B								Deck	Port
	Side 1	-	-	-	-	FW	FW	FW	B	B	B	B	B	B	B							Side 1	
	Side 2	-	-	-	-	Fuel	Fuel	Fuel	B	B	B	B	B	B	B	B						Side 2	
	Bilge	-	-	-	-	Fuel	Fuel	Fuel	B	B	B	B	B	B	B	B			B	B	B	Bilge	
	Bottom 4	-	-	-	-	Fuel	Fuel	Fuel	Fuel	B	B	B	B	B	B	B		B	B	B	B	Bottom 4	
	Bottom 3	-	-	-	-	Fuel	Fuel	Fuel	Fuel	B	B	B	B	B	B	B	B	B	B	B	B	Bottom 3	
	Bottom 2	-	-	-	-	Fuel	Fuel	Fuel	Fuel	B	B	B	B	B	B	B	B	B	B	B	B	Bottom 2	
	Bottom 1	-	-	-	-	Fuel	Fuel	Fuel	Fuel	B	B	B	B	B	B	B	B	B	B	B	B	Bottom 1	
	Suoerestrutura	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Superestrutura	
	Carga	-	-	-	-	B	B			B	B			B	B			B	B	B		Carga	

Deadweight

In this section, we will focus on calculating the remaining weights of the ship, as until now we have only focused on the fixed loads, that are integral parts of the ship, and as such, don't change. So, the focus will be on the contents of the tanks, and on the weights of the crew and their provisions.

Crew and Provisions

The following distribution (**Figure 23**) was used, that concentrates the weight in the superstructure segment of the ship.

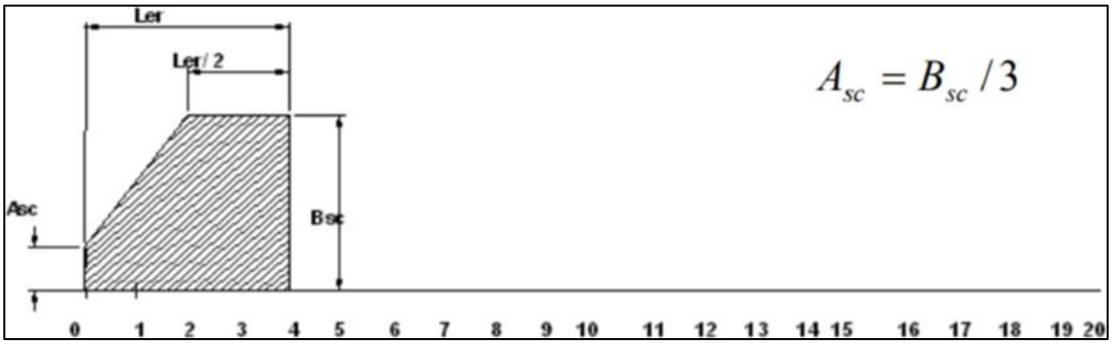


Figure 23 –Distribution of crew and provisions weight

As such, the following formulas were used.

$$P_{sc} = 0.15n$$
$$B_{sc} = P_{sc}/\left(\frac{10}{3}\right)/\Delta L$$
$$A_{sc} = B_{sc}/3$$

Leading to the results shown in **Table 23** and **Figure 24**.

Table 23 – Crew and provisions parameters

P,sc [t]	3.3
A,sc [t/m]	0.035294118
B,sc [t/m]	0.105882353

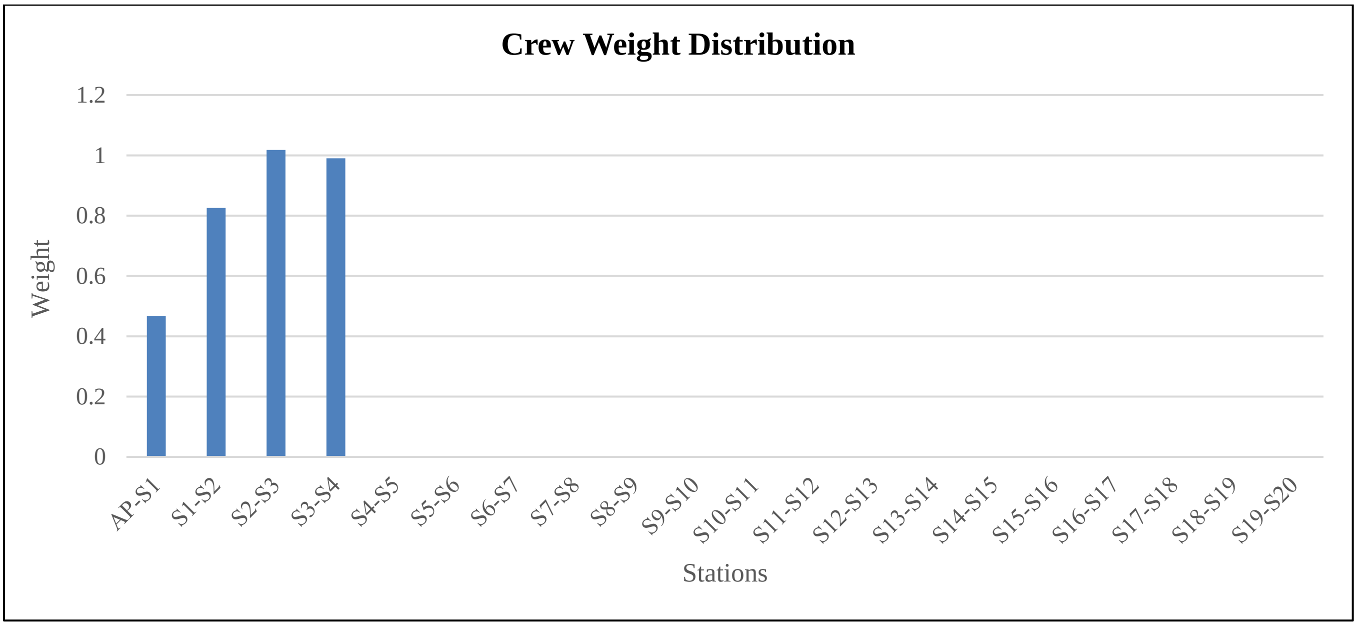


Figure 24 –Distribution of crew and provisions weight

Fresh Water

To determine the range of possible freshwater weights, the following expression was used:

$$P_{fw} = [0.015 \div 0.02]\ DW$$

As such, two values are obtained, one for the maximum and one for the minimum, as seen below (**Table 23**).

Table 23 –Fresh Water Parameters

ρ [t/m^3]	1
Pfw, min [t]	668.62
Pfw, max [t]	891.4879274
Pfw, real [t]	709.8123916

Now having the necessary weight, instead of using a predetermined distribution, we use the tank plan to correctly place the mass of each in the correct position.

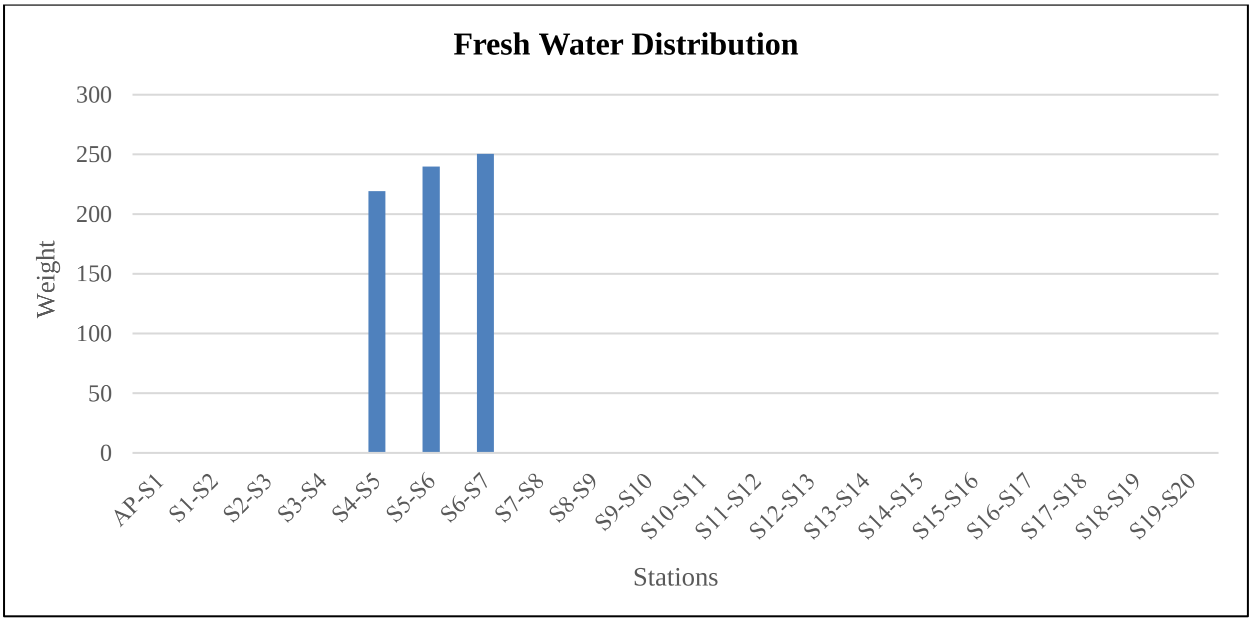


Figure 25 – Distribution of fresh water

Fuel, oil and cooling water

For this calculation, the following formula is used:

$$P_{foc} = 0.0002 N_{eff} T$$

Hence, the results in **Table 24** are obtained.

Table 24 – Fuel, Oil and Cooling Water parameters

Neff [Horse]	10240
T [Hours]	720
A [Days]	30
Pfoc [t]	1474.488691
ρfuel [t/m^3]	0.86
Vfoc, min [t]	1714.521734
Pfoc, real [t]	1559.460634

For the weight distribution, the method used was, just like in the case of freshwater distribution, the position of these tanks within the ship.

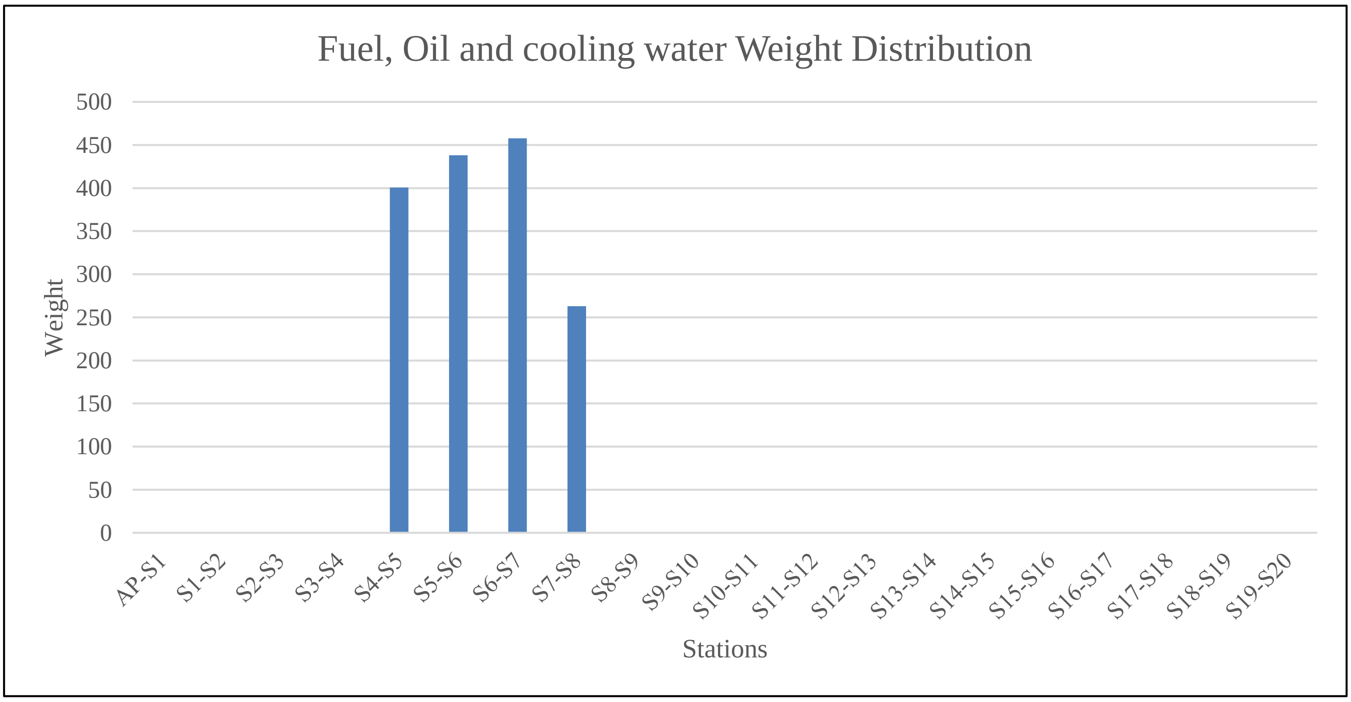


Figure 26 –Fuel, Oil and Cooling Water distribution

Ballast Weight

For Ballast weight, the range of values was calculated with the following expression:

$$P_b = [0.15 \div 0.4]\ DW$$

The results obtained are displayed in **Table 25**.

Table 25 –Ballast Weight Parameters

Pb, min [t]	6686.159456
Pb, max [t]	17829.75855
ρ [t/m^3]	1.025

By applying the previous method, the cargo condition and ballast condition ballast weight distributions were obtained (**Figures 27-28**).

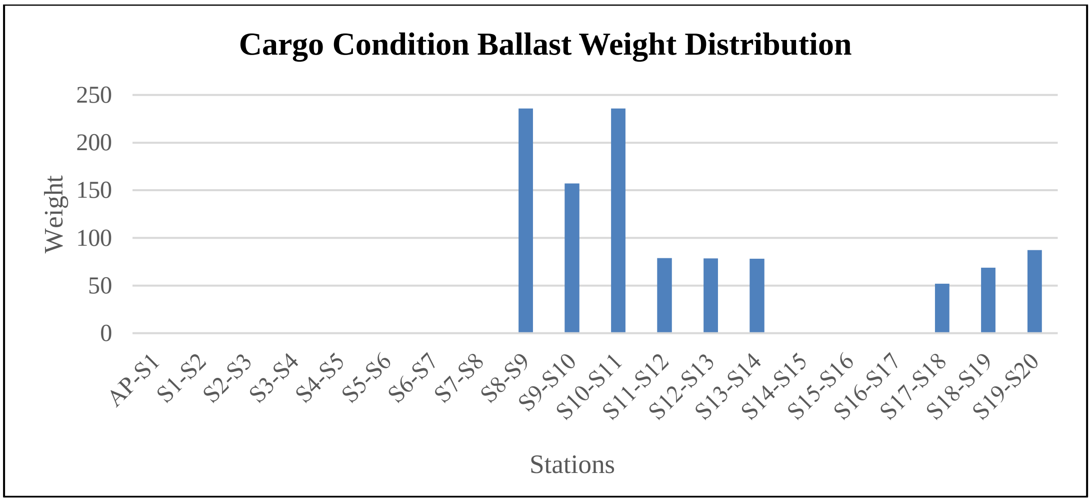


Figure 27 – Cargo Condition Ballast Distribution

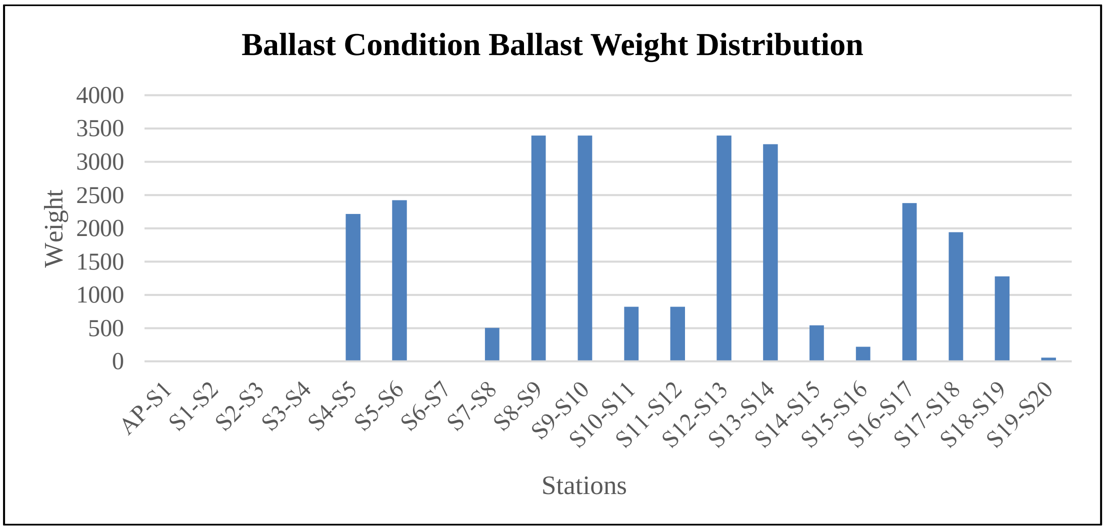


Figure 28 – Ballast Condition Weight Distribution

Cargo Weight

As there won't be carried any cargo in the Ballast Condition, the only distribution shown will be the cargo Condition, giving us the following distribution (**Figure 29**).

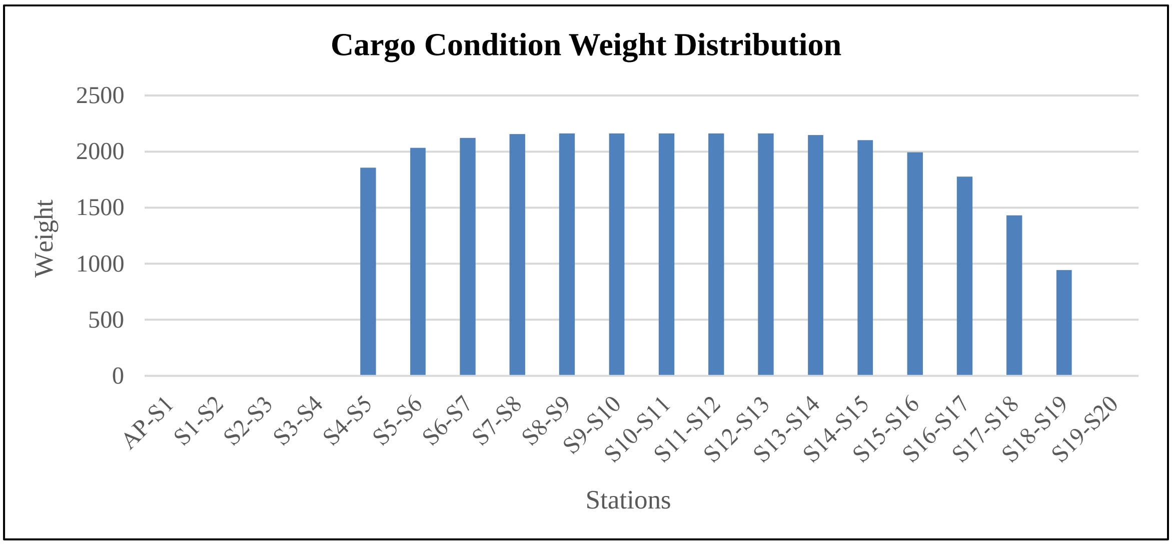


Figure 29 – Cargo Distribution

Total Deadweight

The value of deadweight corresponds to the sum of all the previously calculated variable weights. As such, the two tables shown below each correspond to a different loading condition.

Deadweight – Cargo Condition

Table 26 – Deadweight Cargo Condition

Section	Weight
AP-S1	0.4675
S1-S2	0.825
S2-S3	1.0175
S3-S4	0.99
S4-S5	2477.384547
S5-S6	2710.478449
S6-S7	2830.174463
S7-S8	2417.99401
S8-S9	2397.31897
S9-S10	2319.304953
S10-S11	2398.520503
S11-S12	2241.812919
S12-S13	2239.33056
S13-S14	2224.442082
S14-S15	2102.887977
S15-S16	1994.299173
S16-S17	1777.866568
S17-S18	1484.091804
S18-S19	1012.192562
S19-S20	87.15516271

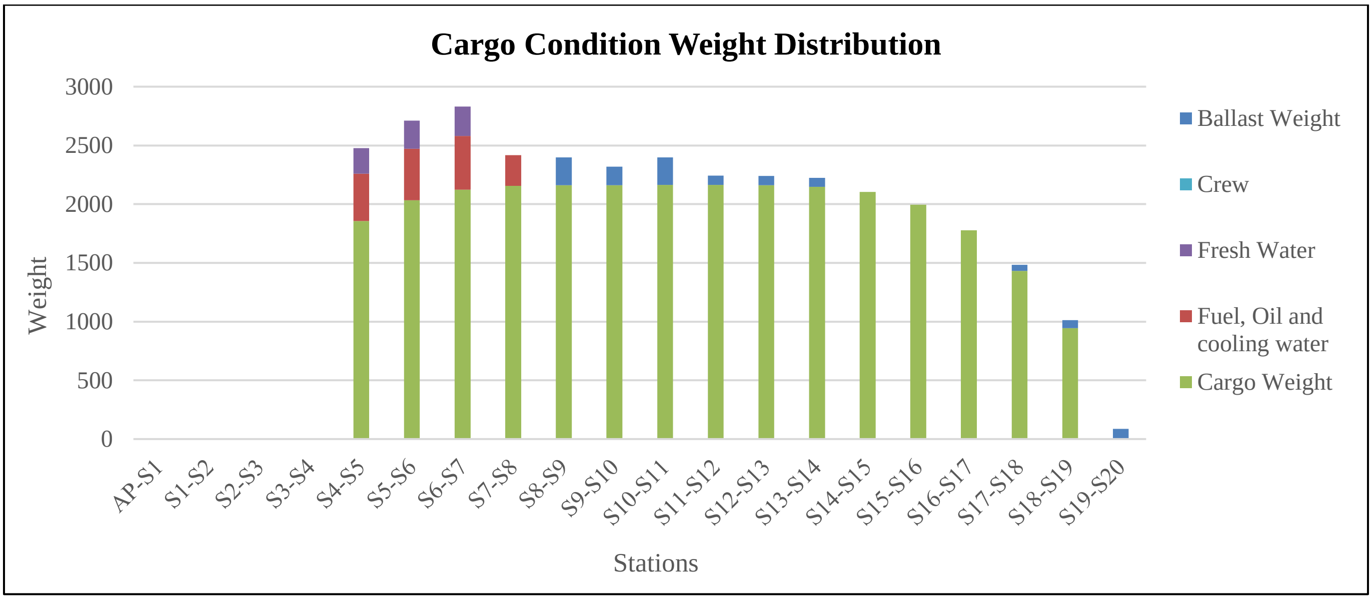


Figure 30 – Deadweight Distribution Graph CC

Deadweight - Ballast Condition

Table 27 – Deadweight ballast condition

Section	Weight
AP-S1	0.4675
S1-S2	0.825
S2-S3	1.0175
S3-S4	0.99
S4-S5	2833.762
S5-S6	3100.387
S6-S7	708.1786
S7-S8	764.2799
S8-S9	3393.438
S9-S10	3394.288
S10-S11	817.601
S11-S12	817.8058
S12-S13	3392.229
S13-S14	3265.77
S14-S15	540.5219
S15-S16	217.5429
S16-S17	2377.533
S17-S18	1939.636
S18-S19	1278.046
S19-S20	55.13787

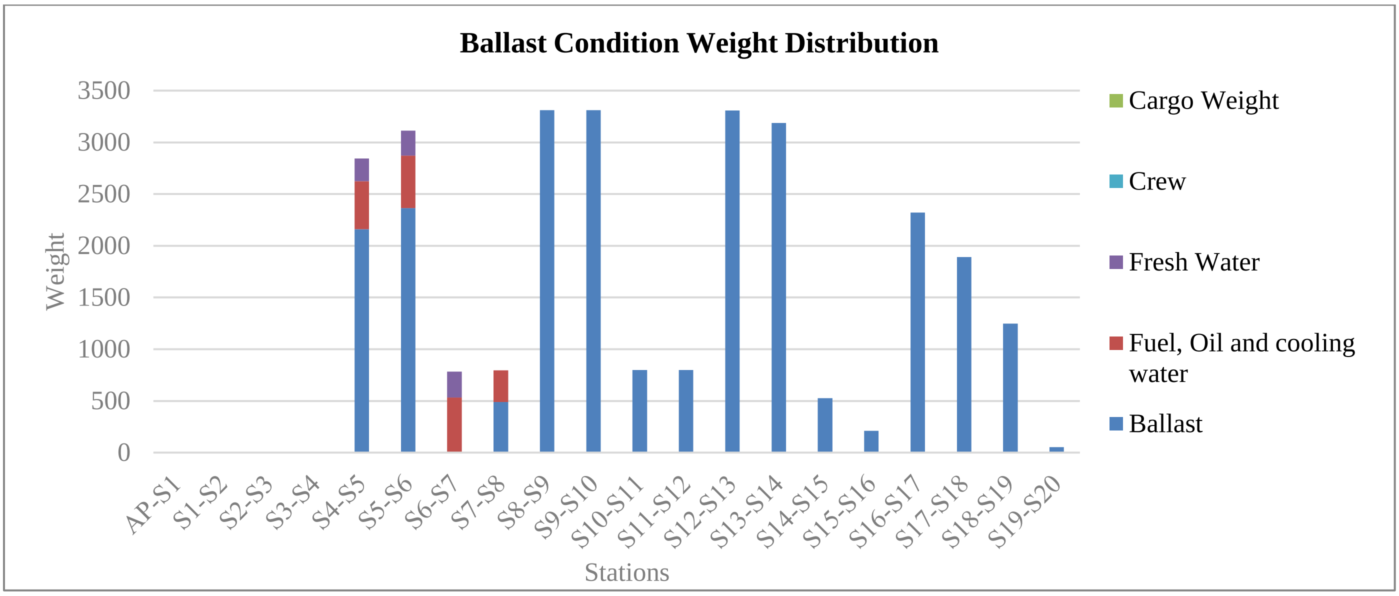


Figure 31 – Deadweight distribution Graph BC

Total Ship Weight and Longitudinal Center of Gravity

The total weight of the ship depends on if it's in a cargo or ballast condition, and as such, so will the Longitudinal Center of Gravity. For the calculation of this positional value, we will use the following formula:

$$X_{cg} = \Delta L \frac{\Sigma k \cdot (LW + DWT)}{\Sigma(LW + DWT)}$$

Total Weight Ballast Condition

Table 28 – Total Weight BC

LW +DW (Ballast Condition)					
Stations	LW	DW	Total Weight	k	k*Total Weight
[AP-S1]	412.227	0.468	412.695	-9.500	-3920.601
[S1-S2]	737.137	0.825	737.962	-8.500	-6272.676
[S2-S3]	1026.907	1.018	1027.924	-7.500	-7709.432
[S3-S4]	980.041	0.990	981.031	-6.500	-6376.704
[S4-S5]	525.703	2833.762	3359.465	-5.500	-18477.057
[S5-S6]	351.130	3100.387	3451.517	-4.500	-15531.827
[S6-S7]	368.868	708.179	1077.046	-3.500	-3769.661
[S7-S8]	386.605	764.280	1150.885	-2.500	-2877.212
[S8-S9]	404.342	3393.438	3797.780	-1.500	-5696.670
[S9-S10]	404.342	3394.288	3798.631	-0.500	-1899.315
[S10-S11]	404.342	817.601	1221.943	0.500	610.972
[S11-S12]	404.342	817.806	1222.148	1.500	1833.222
[S12-S13]	404.342	3392.229	3796.571	2.500	9491.428
[S13-S14]	404.342	3265.770	3670.112	3.500	12845.392
[S14-S15]	374.774	540.522	915.295	4.500	4118.829
[S15-S16]	345.205	217.543	562.748	5.500	3095.113
[S16-S17]	315.636	2377.533	2693.169	6.500	17505.602
[S17-S18]	286.067	1939.636	2225.703	7.500	16692.773
[S18-S19]	283.787	1278.046	1561.833	8.500	13275.578
[S19-FP]	350.869	55.138	406.007	9.500	3857.063
Total	-	-	38070.466	-	10794.814

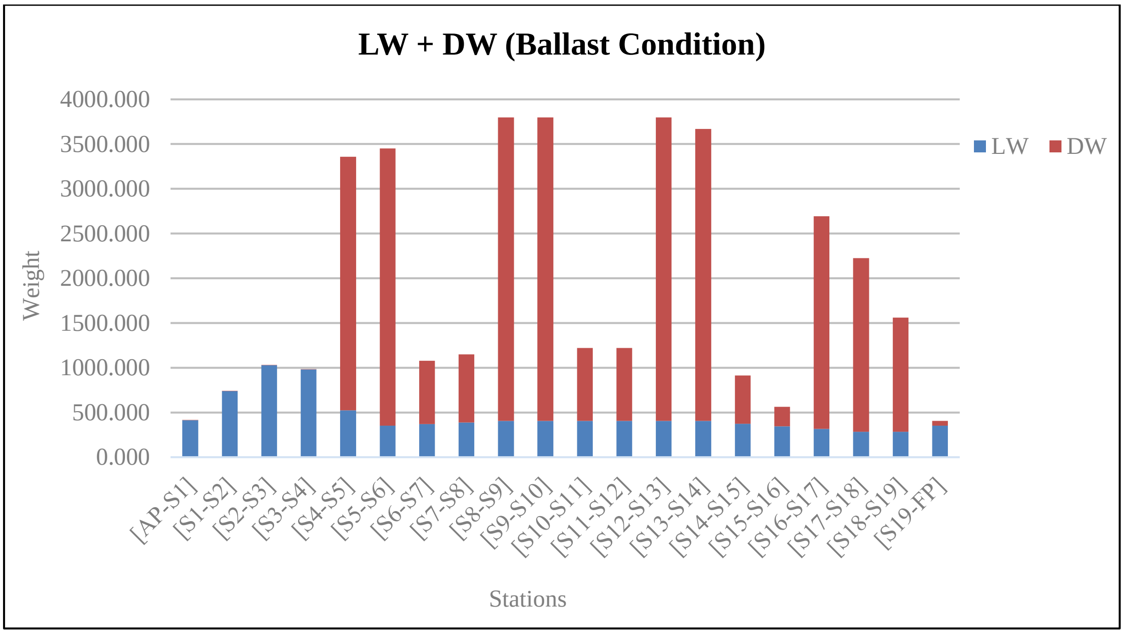


Figure 32 – Total Weight Distribution BC

Table 29 – LCG and Displacement BC

Longitudinal Center of Gravity (Ballast Condition)	2.65
Displacement	38070.47

Total Weight Cargo Condition

Table 30 – Total Weight CC

LW +DW (Cargo Condition)					
Stations	LW	DW	Total Weight	k	k*Total Weight
[AP-S1]	412.227	0.468	412.695	-9.500	-3920.601
[S1-S2]	737.137	0.825	737.962	-8.500	-6272.676
[S2-S3]	1026.907	1.018	1027.924	-7.500	-7709.432
[S3-S4]	980.041	0.990	981.031	-6.500	-6376.704
[S4-S5]	525.703	2477.385	3003.087	-5.500	-16516.981
[S5-S6]	351.130	2710.478	3061.609	-4.500	-13777.239
[S6-S7]	368.868	2830.174	3199.042	-3.500	-11196.647
[S7-S8]	386.605	2417.994	2804.599	-2.500	-7011.497
[S8-S9]	404.342	2397.319	2801.661	-1.500	-4202.492
[S9-S10]	404.342	2319.305	2723.647	-0.500	-1361.824
[S10-S11]	404.342	2398.521	2802.863	0.500	1401.431
[S11-S12]	404.342	2241.813	2646.155	1.500	3969.233
[S12-S13]	404.342	2239.331	2643.673	2.500	6609.182
[S13-S14]	404.342	2224.442	2628.784	3.500	9200.745
[S14-S15]	374.774	2102.888	2477.661	4.500	11149.477
[S15-S16]	345.205	1994.299	2339.504	5.500	12867.272
[S16-S17]	315.636	1777.867	2093.503	6.500	13607.768
[S17-S18]	286.067	1484.092	1770.159	7.500	13276.195
[S18-S19]	283.787	1012.193	1295.979	8.500	11015.824
[S19-FP]	350.869	87.155	438.024	9.500	4161.227
Total	-	-	41889.563	-	8912.260

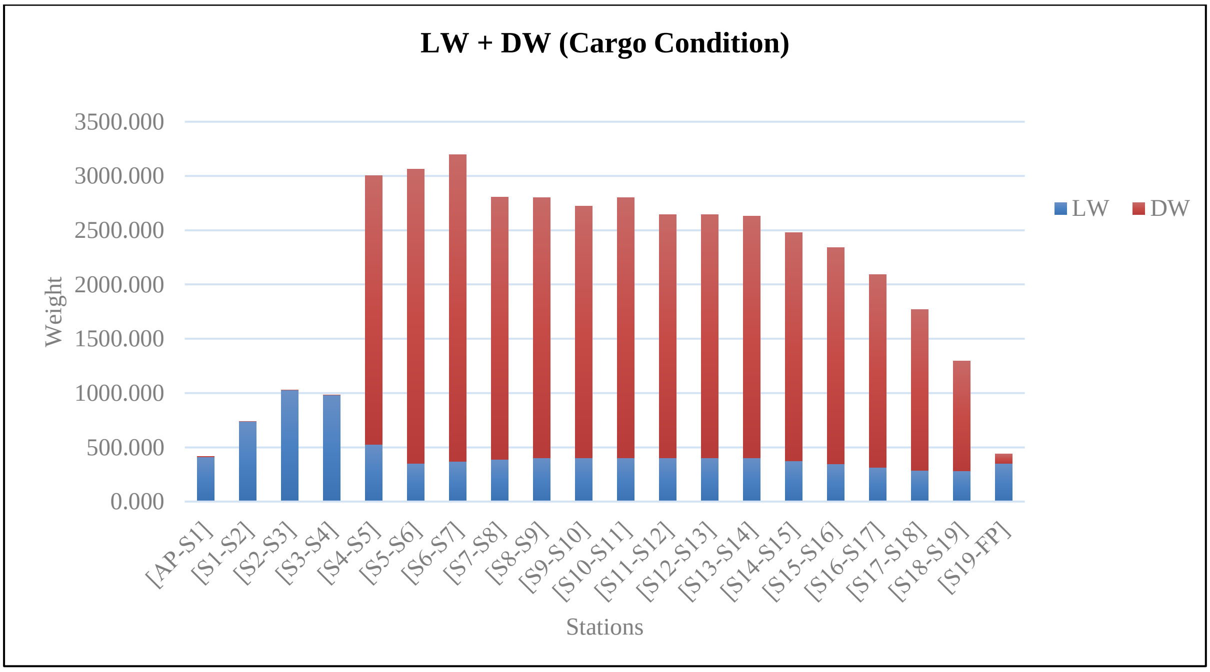


Figure 33 – Total Weight Distribution CC

Table 31 – LCG and Displacement CC

Longitudinal Center of Gravity (Ballast Condition)	**1.99**
Displacement	**41889.56**

Still Water

Buoyancy

In order to calculate the Buoyancy of the ship, at a specific incline, we will resort to the use of Bonjean Curves. However, as the value of the incline isn't known, we will abide to being restricted between two parallel waterlines, distant by D/10. Beyond those restrictions, we also define the following conditions:

$$L_{CG} = L_{CB}$$
$$\Delta = P_{\text{total}}$$
$$T_{aft} \geq T_{for}$$

In order to obtain the final values, the tank positions were adjusted in an iterative method, applying the solver addon to facilitate the calculations. As such, the following graphs were obtained (**Figures 34-35**).

Cargo Conditions

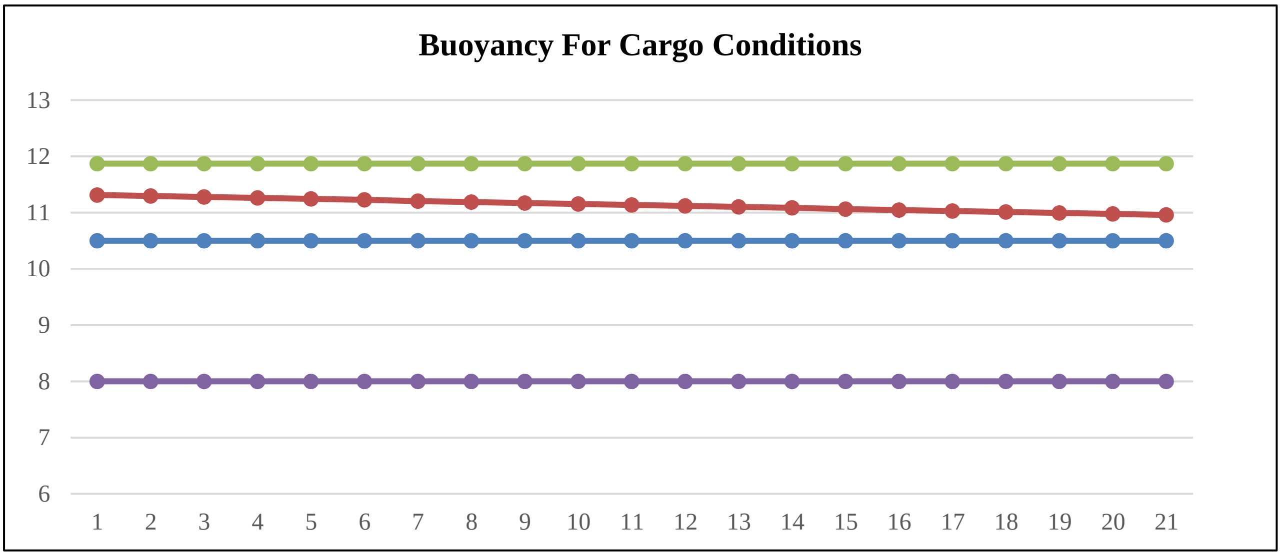


Figure 34 – Buoyancy for Cargo Conditions

The final ship incline is 0.35m.

Ballast Conditions

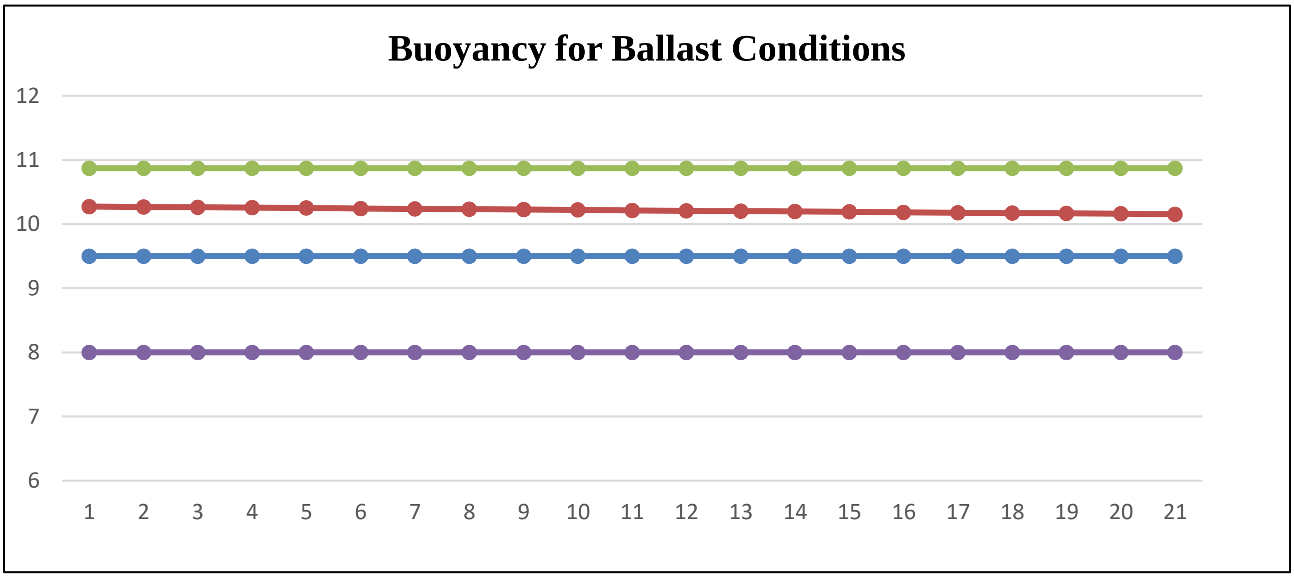


Figure 35 – Buoyancy for Ballast Conditions

The final ship incline is equal to 0.12m.

Shear Forces and Bending Moment

Cargo Conditions

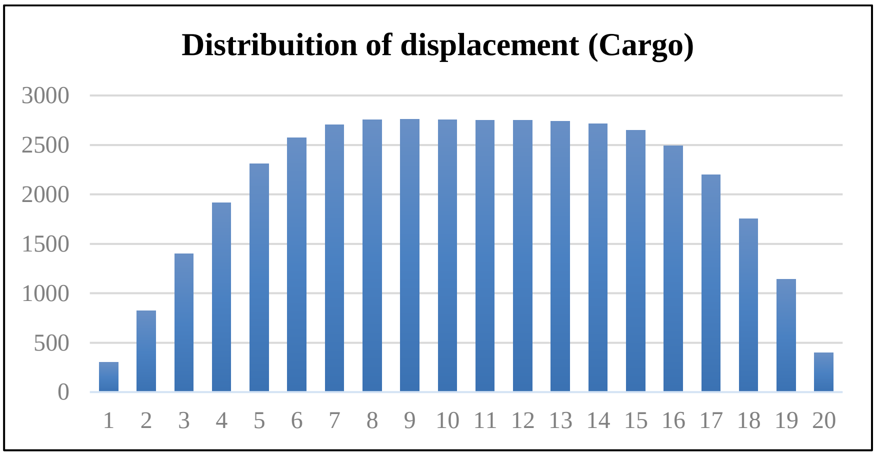


Figure 36 – Distribution of Displacement CC

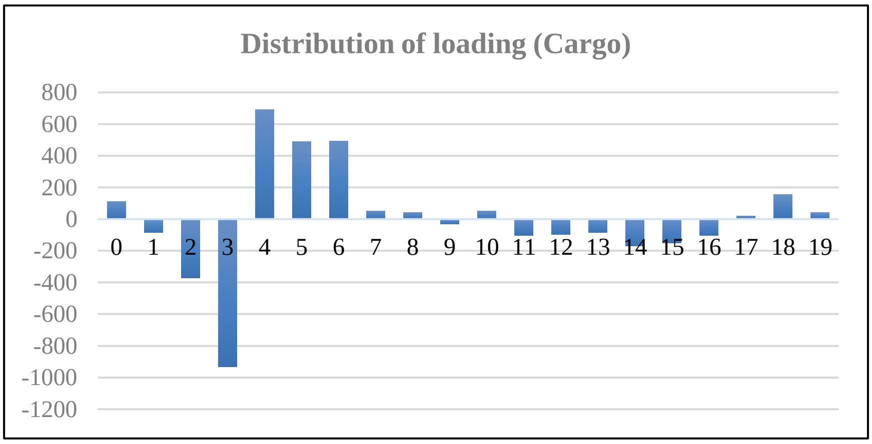


Figure 37 – Distribution of Displacement Loading CC

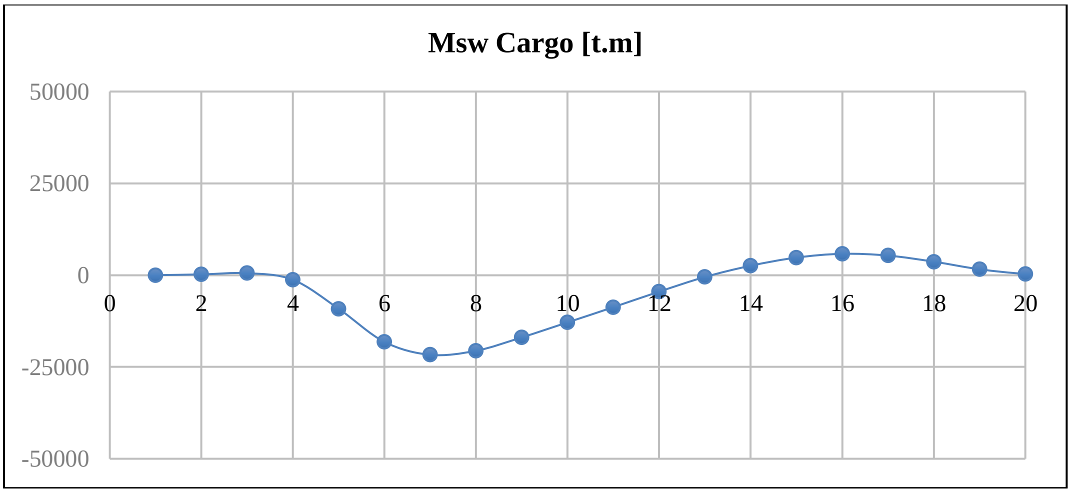


Figure 38 – Moment Cargo Condition

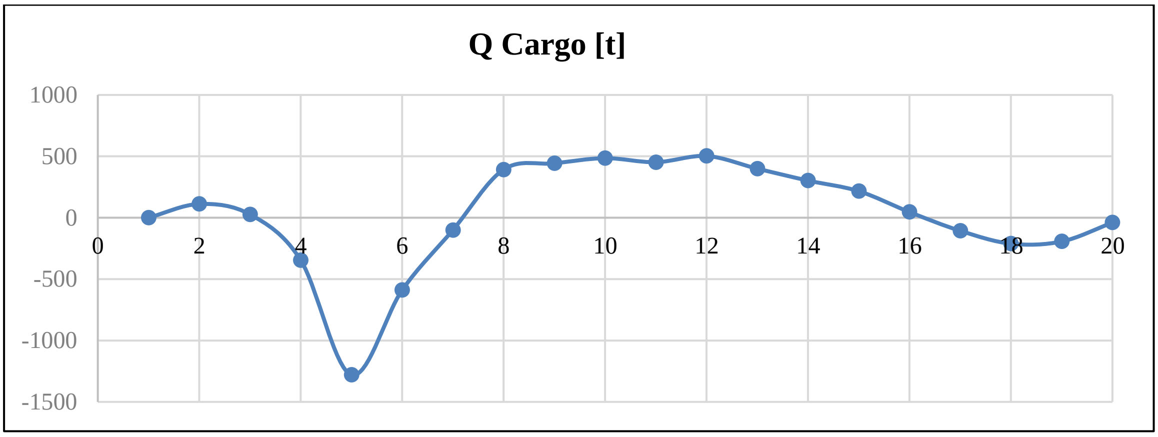


Figure 39 – Shear Forces CC

Ballast Condition

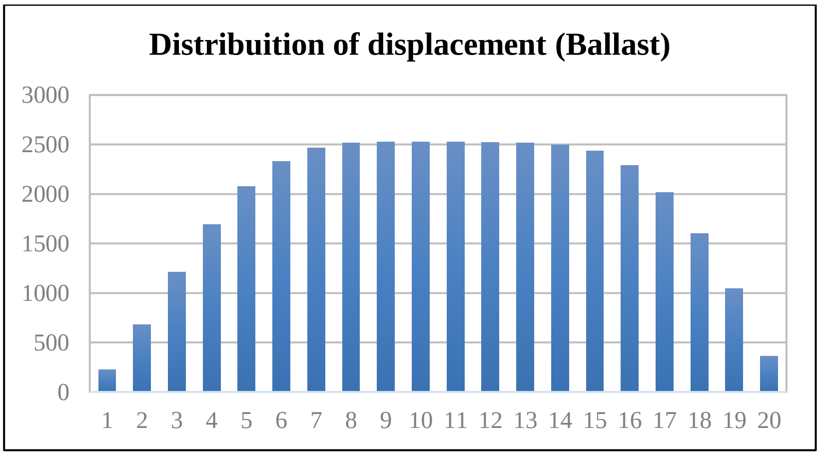


Figure 40 – Distribution of Displacement BC

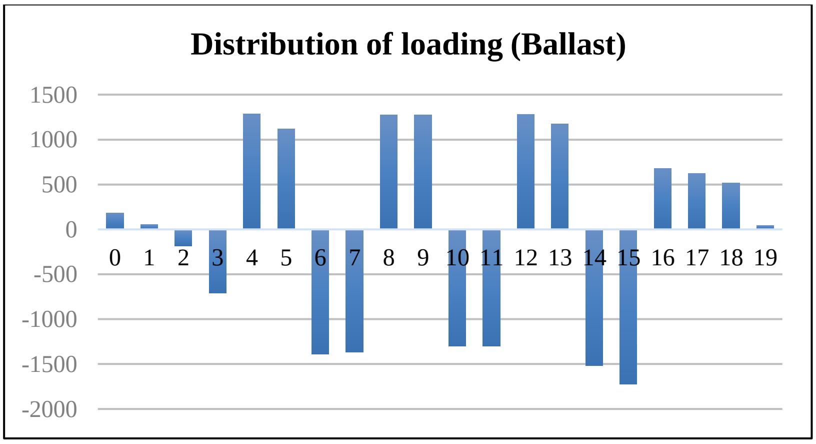


Figure 41 – Distribution of Loading BC

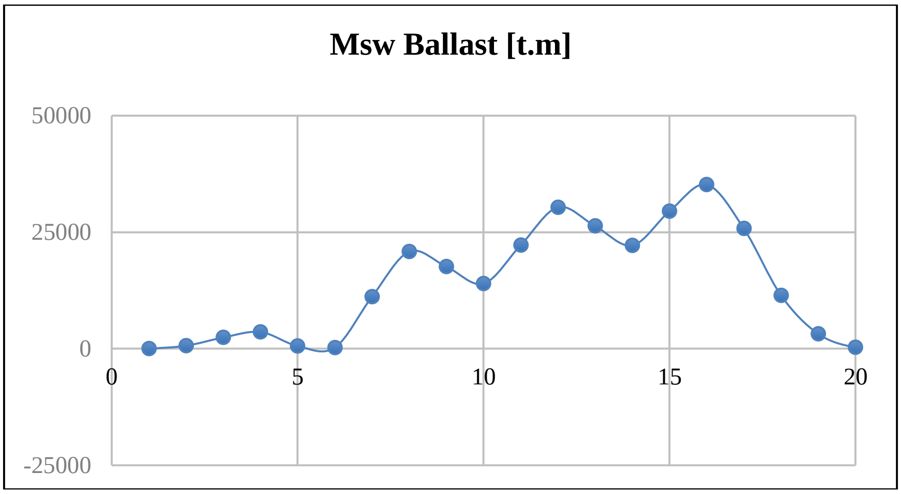


Figure 42 – Moment Ballast Condition

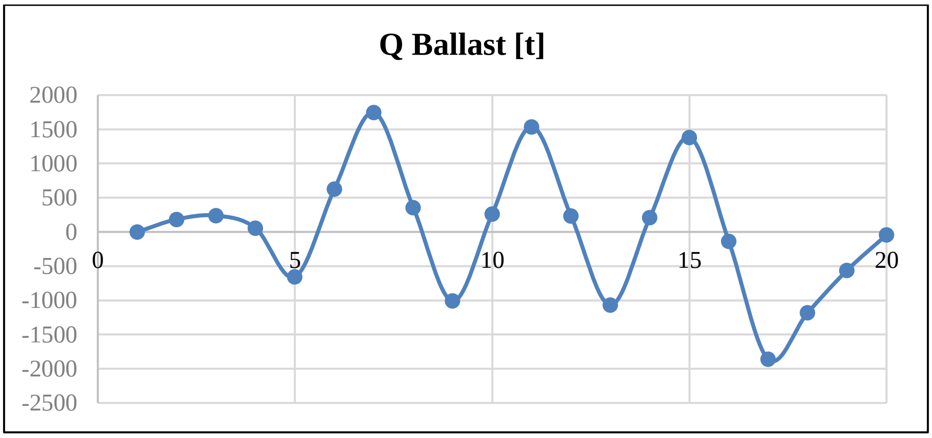


Figure 43 – Shear Forces BC

Induced Waves

In this phase of the project, we also subjected the ship to an induced wave, to study it the distribution needs to be adjusted further. Consequently, the ship was subjected to a wave of height 1m, of a wavelength equal to the ships LBP, while keeping the original ship displacement the same. This test was repeated for both cargo conditions, and for sagging and hogging scenarios.

Sagging

In sagging conditions, the deck is usually in compression, and the bottom of the ship in traction.

Cargo Conditions

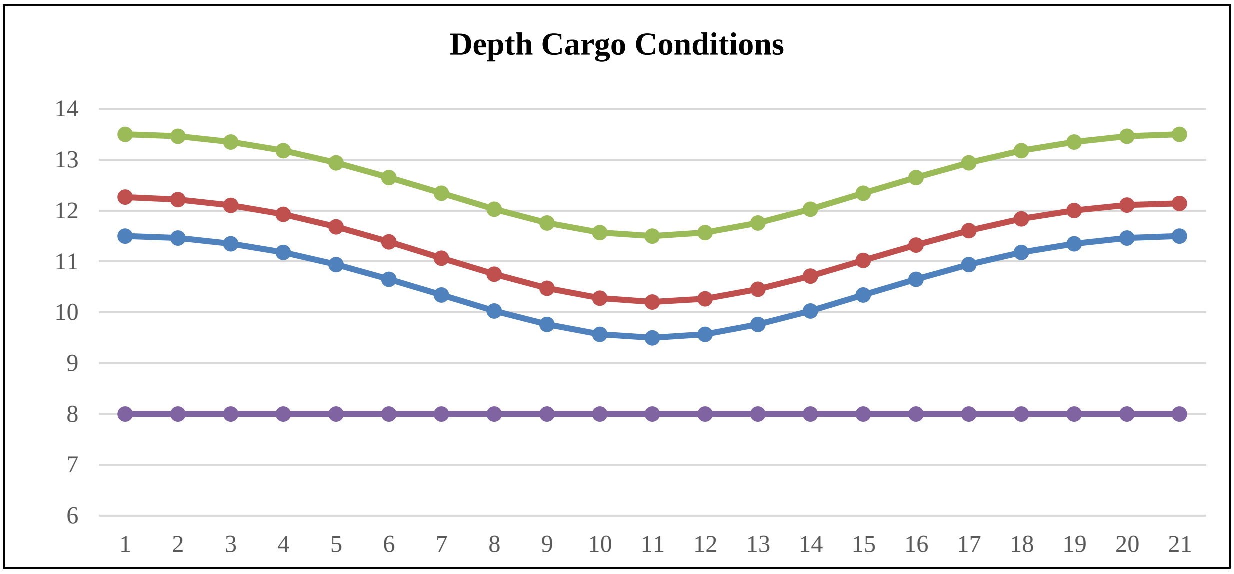


Figure 44 – Depth in cargo conditions Sagging

The incline of the ships is 0.12m.

Ballast Conditions

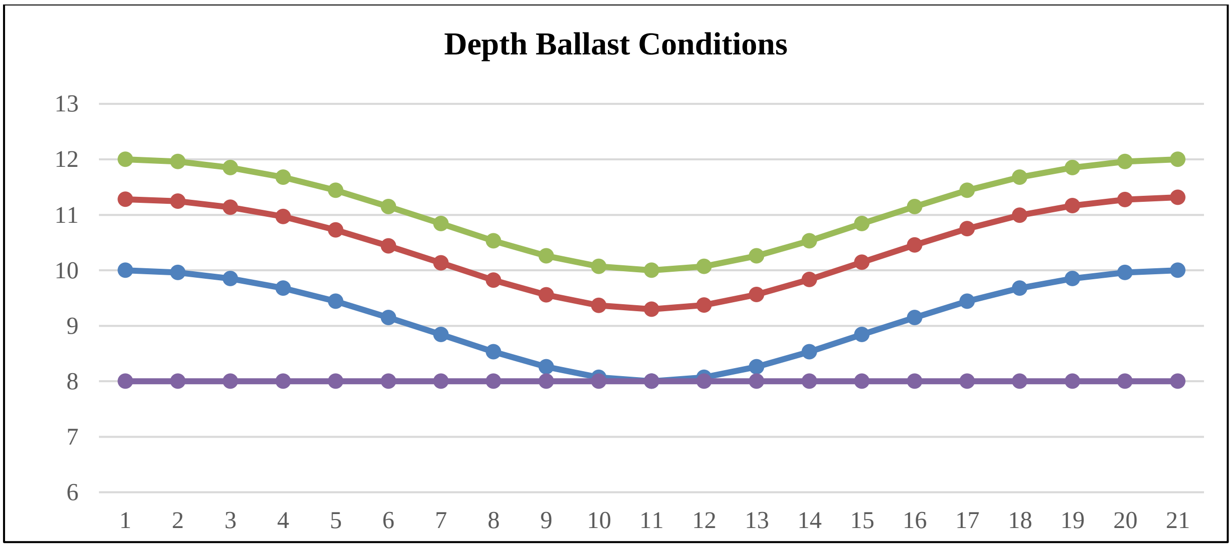


Figure 44 – Depth in Ballast Conditions Sagging

The incline of the ships is 0.03m.

Shear Forces and Bending Moment

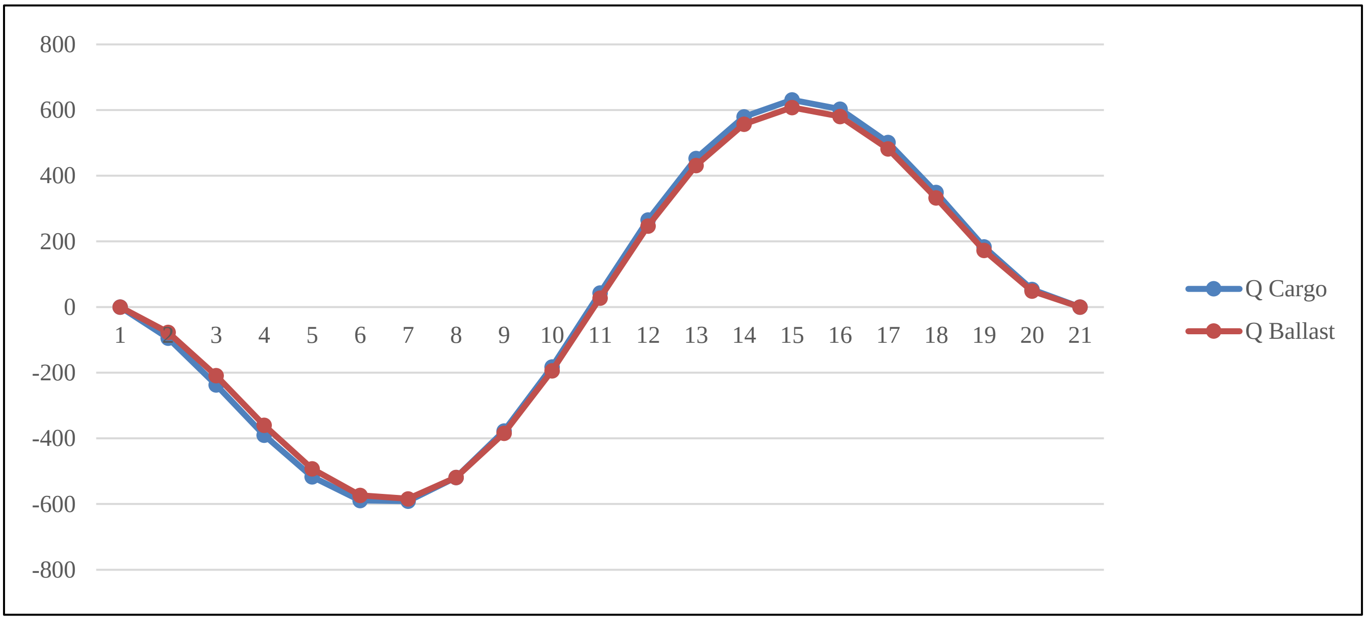


Figure 45 – Shear Forces Sagging

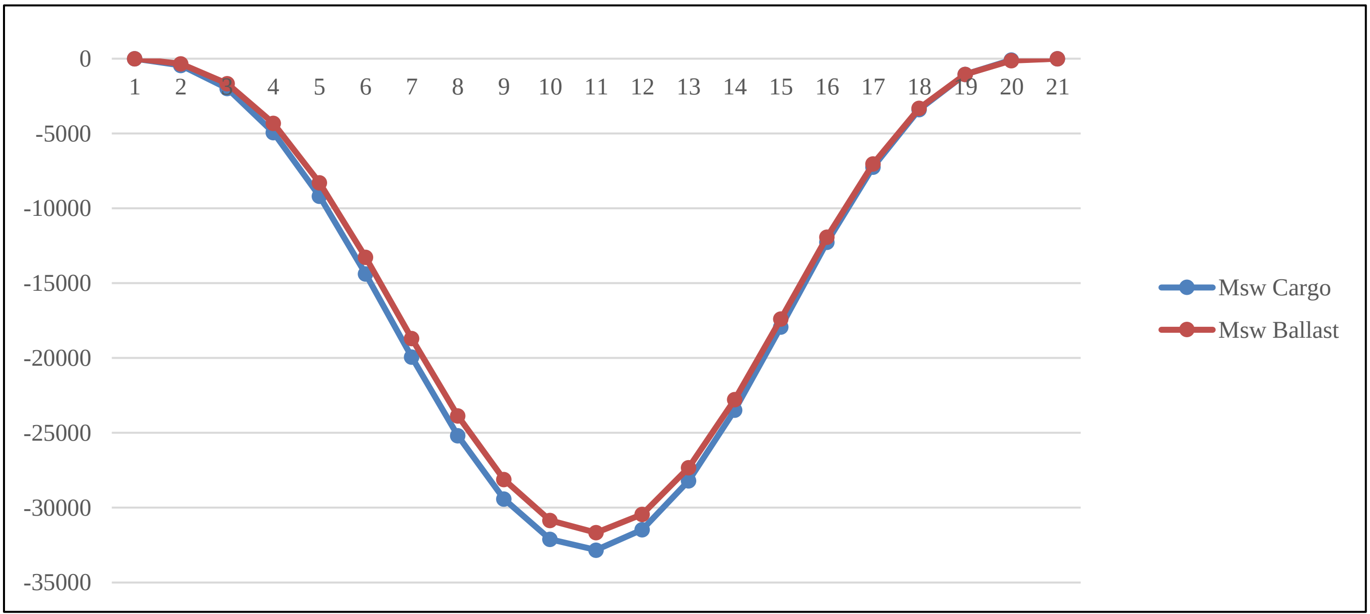


Figure 46 – Bending Moments Sagging

Hogging

In sagging conditions, the deck is usually in compression, and the bottom of the ship in traction.

Cargo Conditions

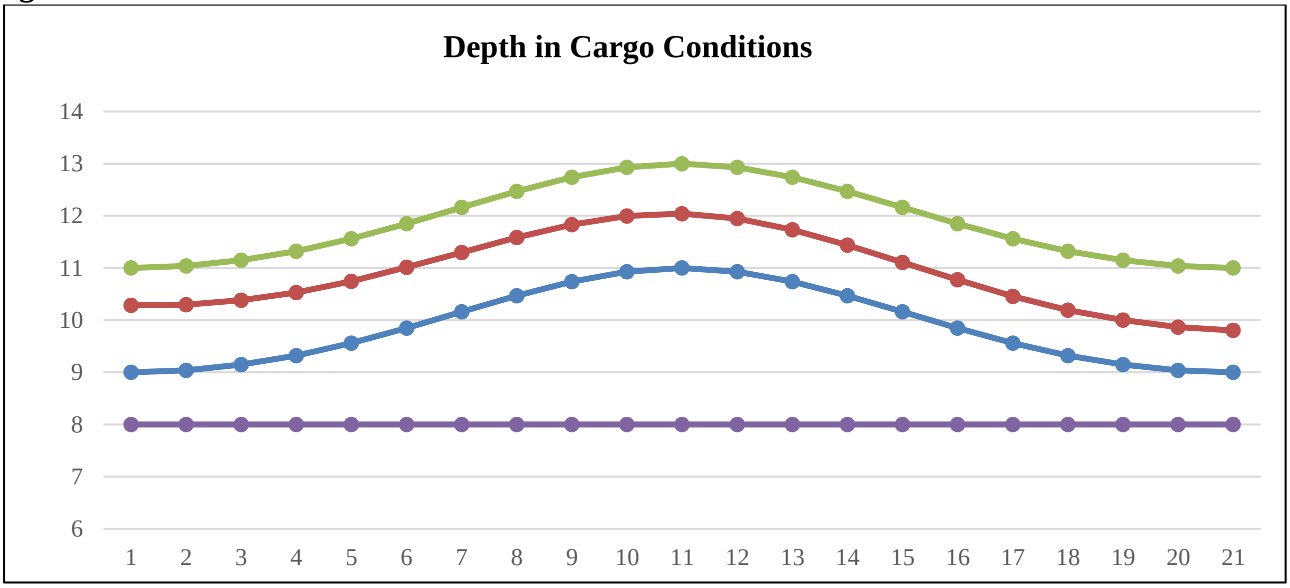


Figure 47 – Depth in cargo Conditions Hogging

The incline of the ships is 0.48m

Ballast Conditions

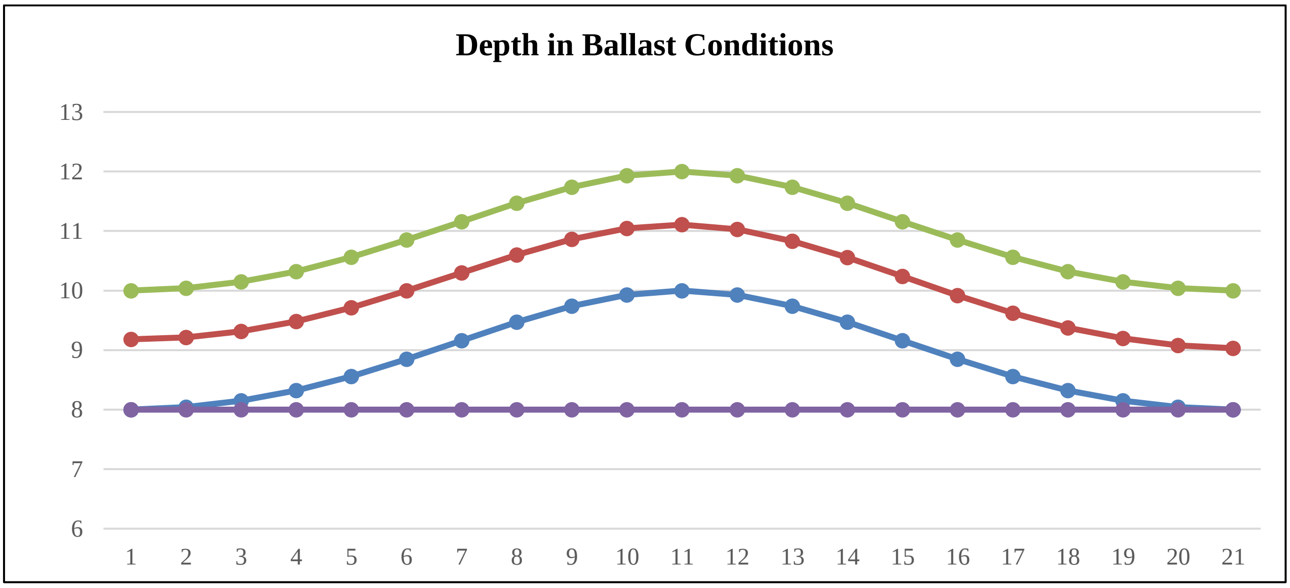


Figure 48 – Depth in Ballast Conditions Hogging

The incline of the ships is 0.15m

Shear Forces and Bending Moment

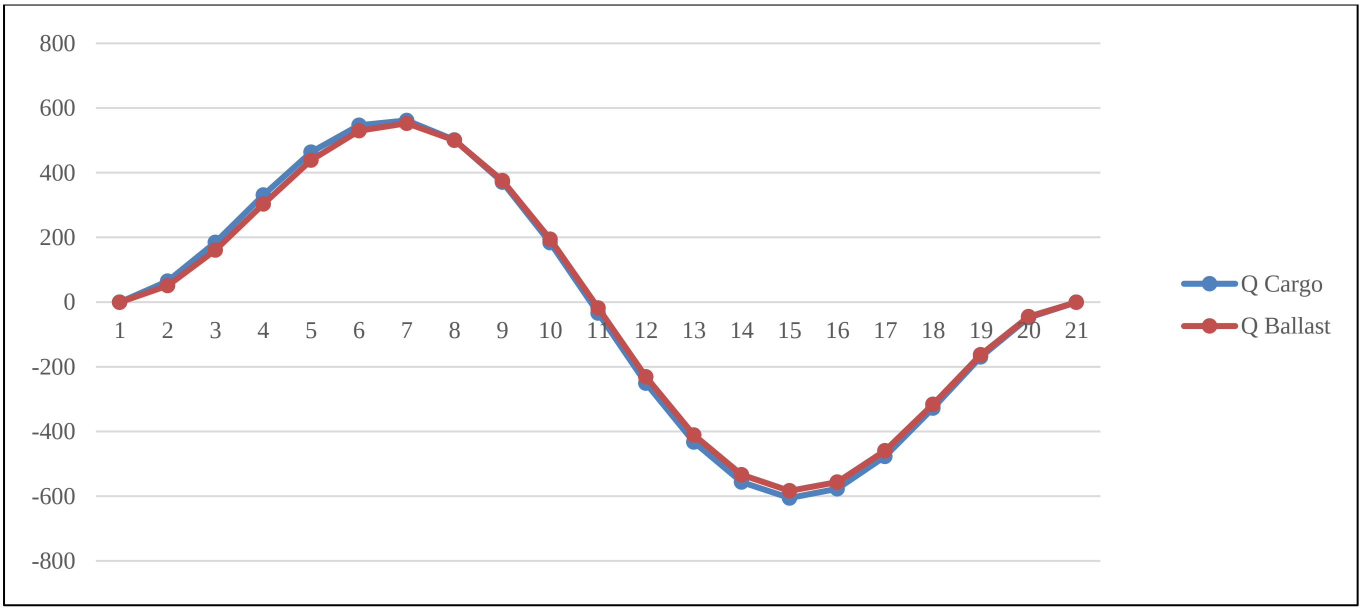


Figure 49 – Shear Forces Hogging

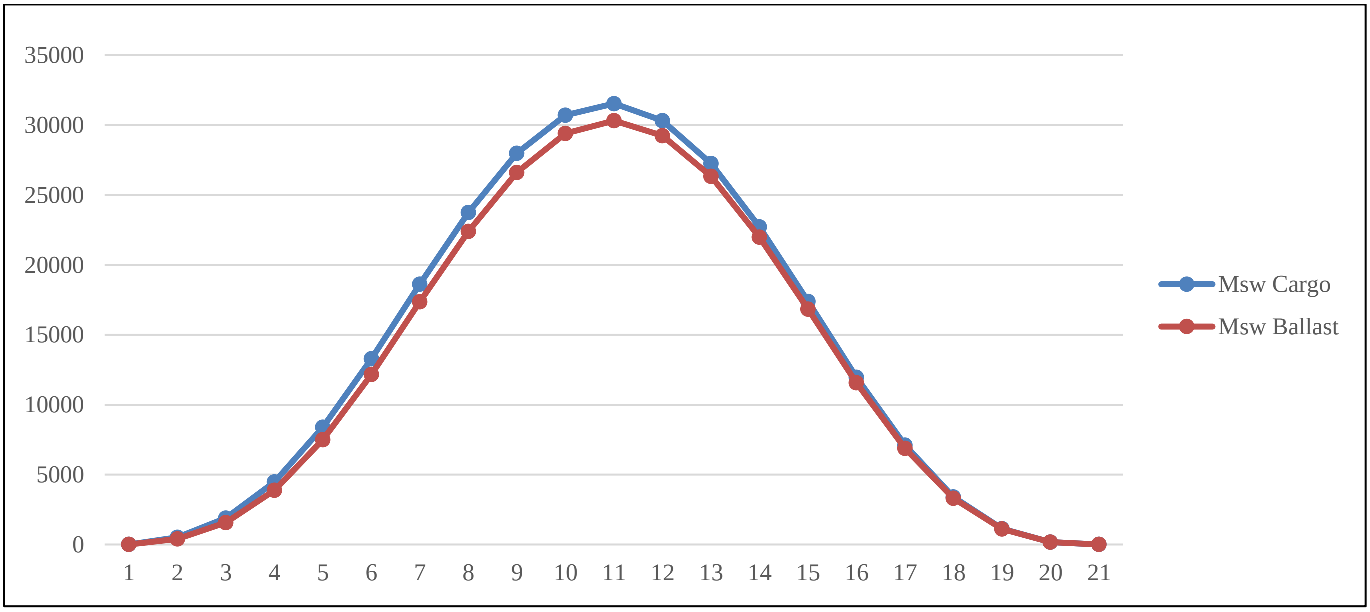


Figure 50 – Bending Moments Hogging

Classification Societies

The classification societies are responsible for assuring safety and guaranteeing that the rules of ship construction are followed. As such, in the following section, obtained shear forces and bending moments will be compared to those established by the classification society, guaranteeing that they are up to the specifications.

Still Water

Shear Forces

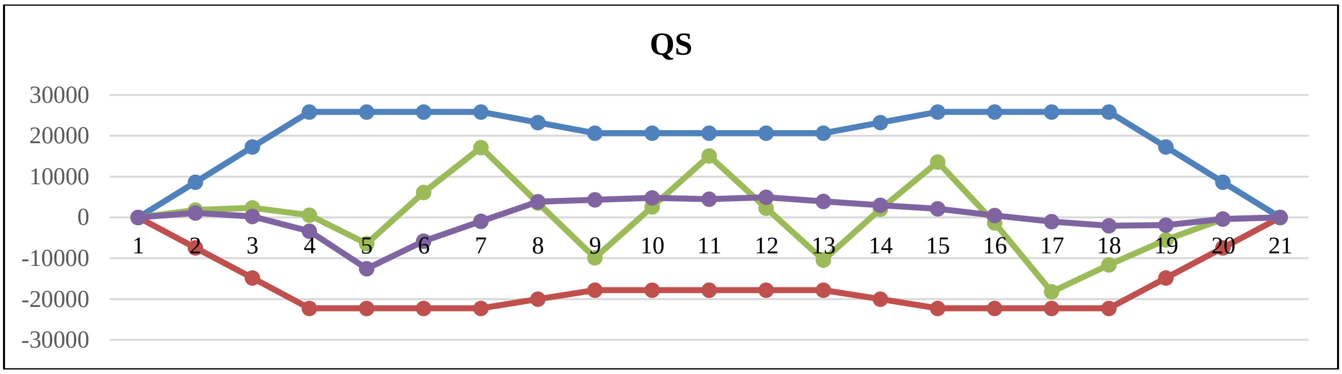


Figure 51 – Shear Forces and Classification Limits

Bending Moment

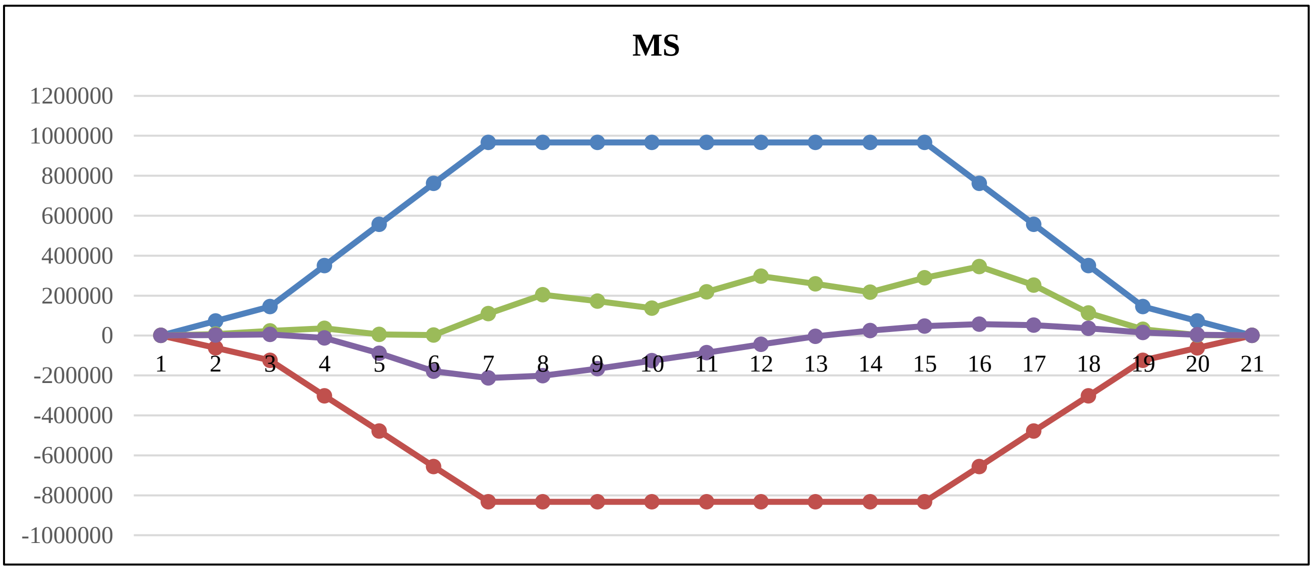


Figure 52 – Bending Moment and Classification Limits

Induced Waves

Shear Forces

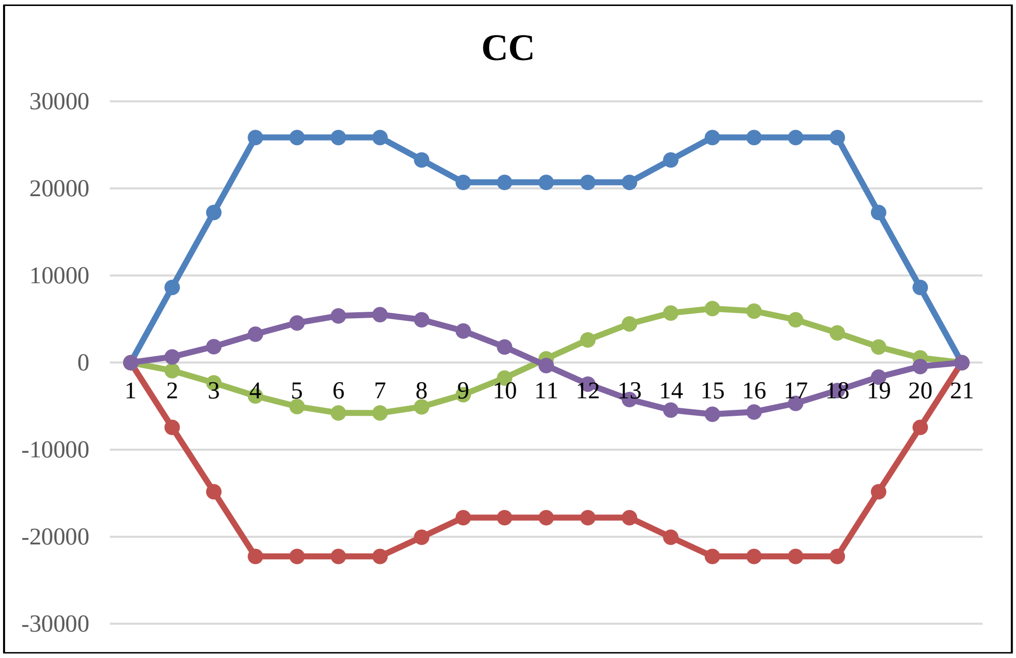


Figure 53 – Shear Forces Cargo Condition Wave

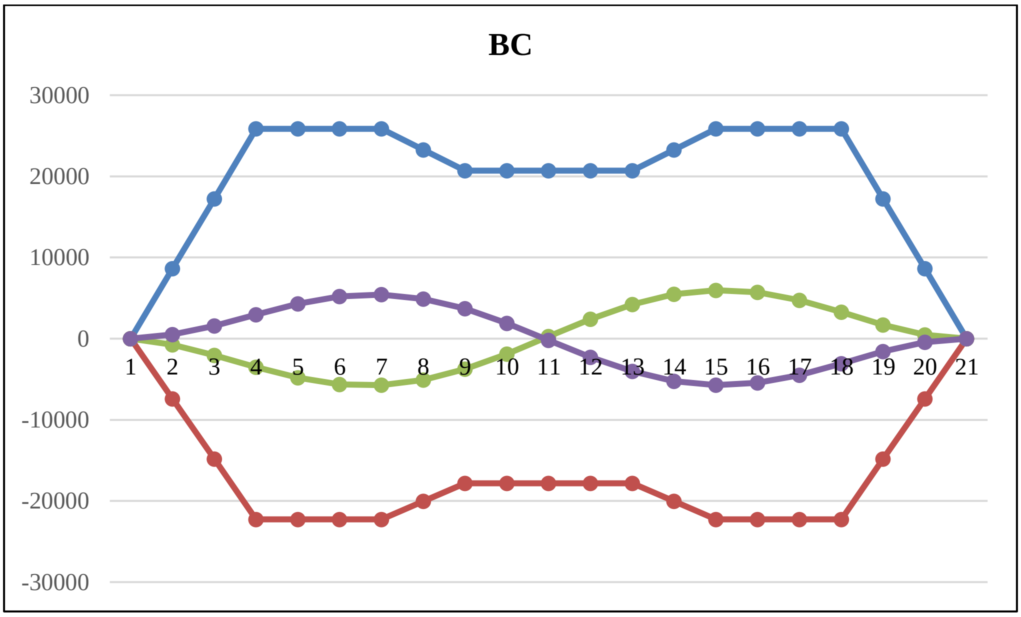


Figure 54 – Shear Forces Ballast Condition Wave

Bending Moments

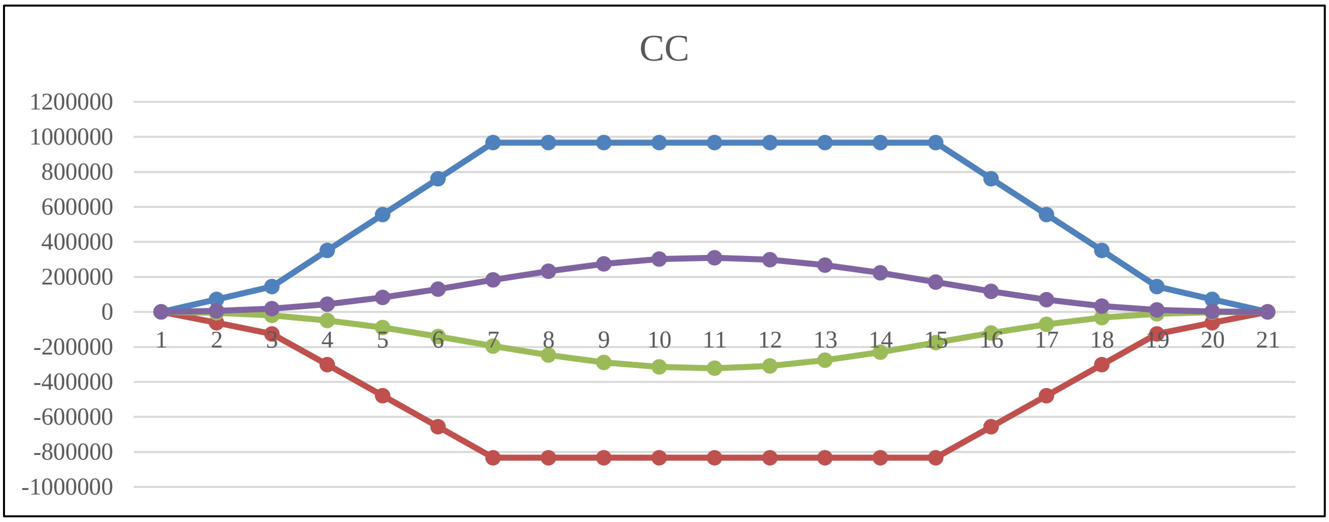


Figure 55 – Bending Moments Cargo Condition Wave

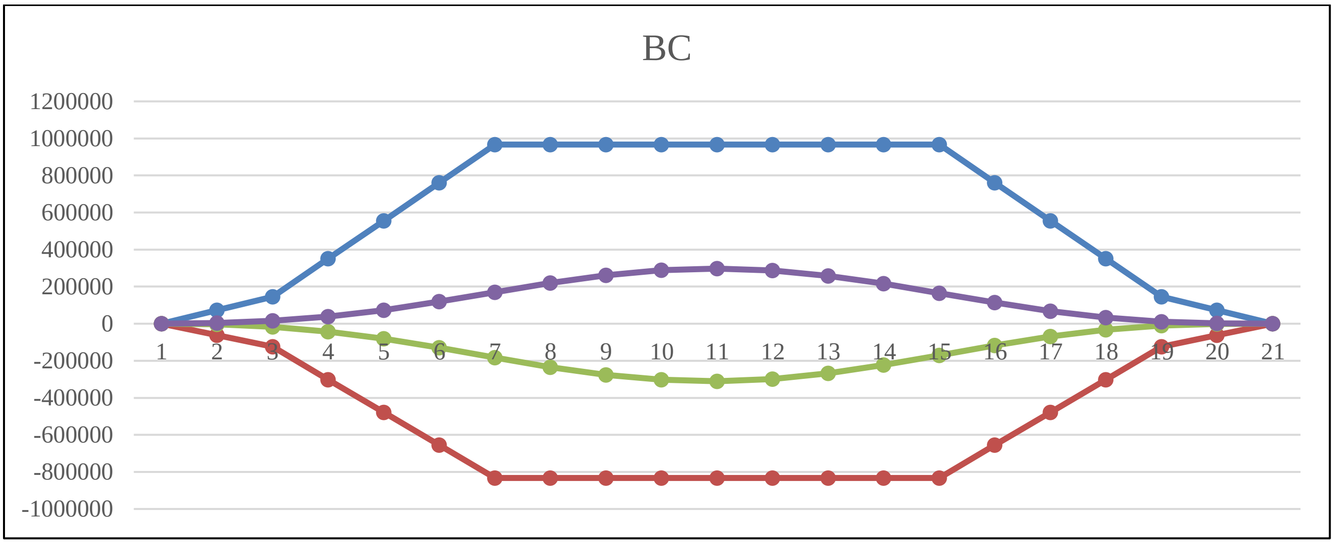


Figure 56 – Bending Moment Ballast Condition

Normal Stress

From the previously calculated maximum bending moments and maximum shear forces, it is possible to calculate the maximum Normal Stress values for the ship midsection. As such, those values correspond to the ones displayed in **Table 32**.

Table 32 – Bending Moment Table

Condição de Carga		Condição de Lastro	
Msw + Msag [kN.m]	Msw + Mhog [kN.m]	Msw + Msag [kN.m]	Msw + Mhog [kN.m]
0	0	0	0
74469.28821	-60505.77588	78838.34373	-56136.7204
150257.4397	-119692.6885	168698.5898	-101251.538
338107.7391	-314271.7373	385675.357	-266704.119
466115.0763	-568693.7483	561653.0183	-473155.806
583050.5945	-834187.5784	763918.7964	-653319.376
754174.5185	-1045493.003	1076506.03	-723161.491
764925.9799	-1034741.541	1171308.247	-628359.275
800668.2689	-998999.2522	1139777.165	-659890.356
840744.1254	-958923.3957	1103994.184	-695673.337
881338.4162	-918329.1049	1185011.792	-614655.729
922831.19	-876836.3311	1264751.928	-534915.593
961993.4105	-837674.1106	1225106.901	-574560.62
992061.2791	-807606.242	1184421.253	-615246.268
1013804.271	-785863.2499	1256241.469	-543426.052
818408.9775	-598829.1954	1106851.649	-310386.524
608294.6774	-426514.1473	808753.2182	-226055.606
386457.1122	-265922.3642	462710.5097	-189668.967
160720.6686	-109229.4596	176383.7429	-93566.3853
75878.75546	-59096.30862	75308.7985	-59666.2656
0	0	0	0

And from these values, it is further possible to calculate both the maximum shear forces of cargo conditions (**Table 33**) and of ballast conditions (**Table 34**).

Table 33 – Maximum Shear Forces Cargo Conditions

Cargo Condition			
Sagging		Hogging	
σdeck [MPa]	σbottom [MPa]	σdeck [MPa]	σbottom [MPa]
79.13426243	-46.96565307	-81.60778169	48.43367013
13.7	0	13.7	0

Table 34 – Maximum Shear Forces Ballast Conditions

Ballast Condition			
Sagging		Hogging	
σdeck [MPa]	σbottom [MPa]	σdeck [MPa]	σbottom [MPa]
98.72241991	-58.59109292	-56.44763275	33.50129078
13.7	0	13.7	0

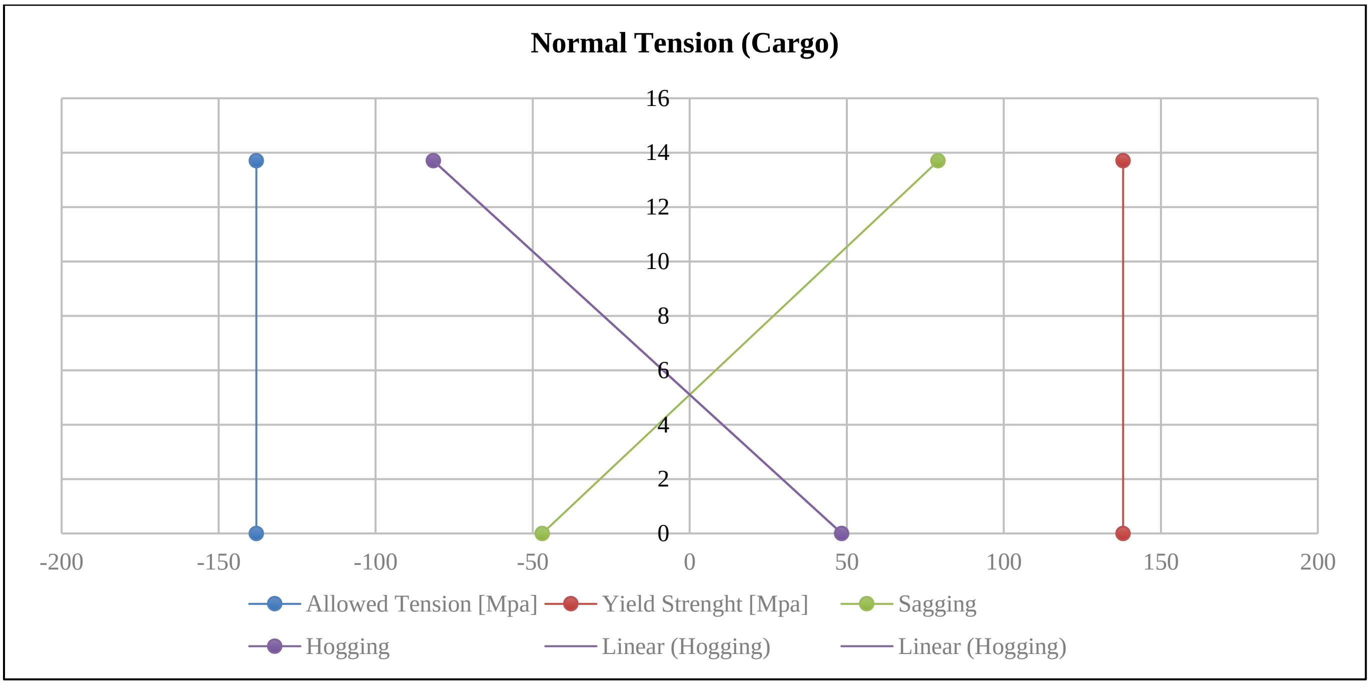


Figure 57 – Normal Stress Cargo

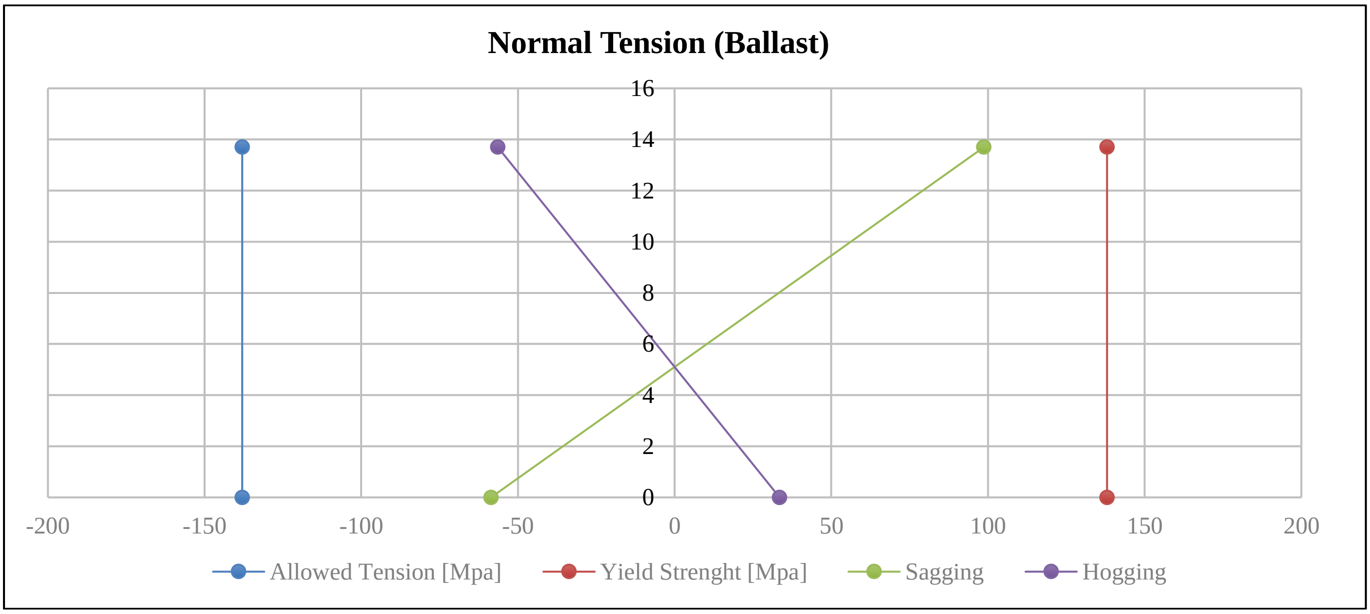


Figure 58 – Normal Stress Ballast

Vertical Displacement

In order to calculate the ships' vertical displacement, we assume the behavior of a beam, with a Young Modulus of 210 GPa. Since the values are in the range of 200mm, they are within spec for a ship of this length, as they take a positive value in hogging conditions, and negative in sagging conditions.

Cargo Condition

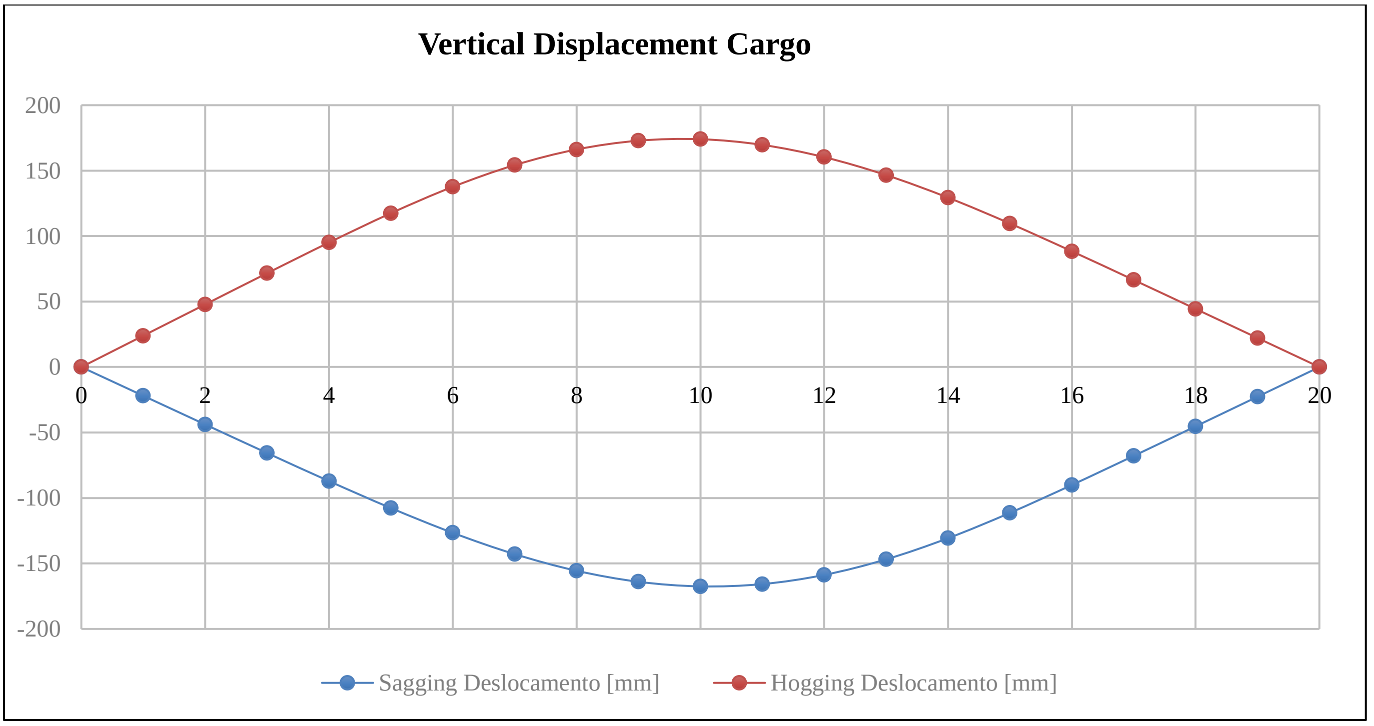


Figure 59 – Vertical Displacement Cargo

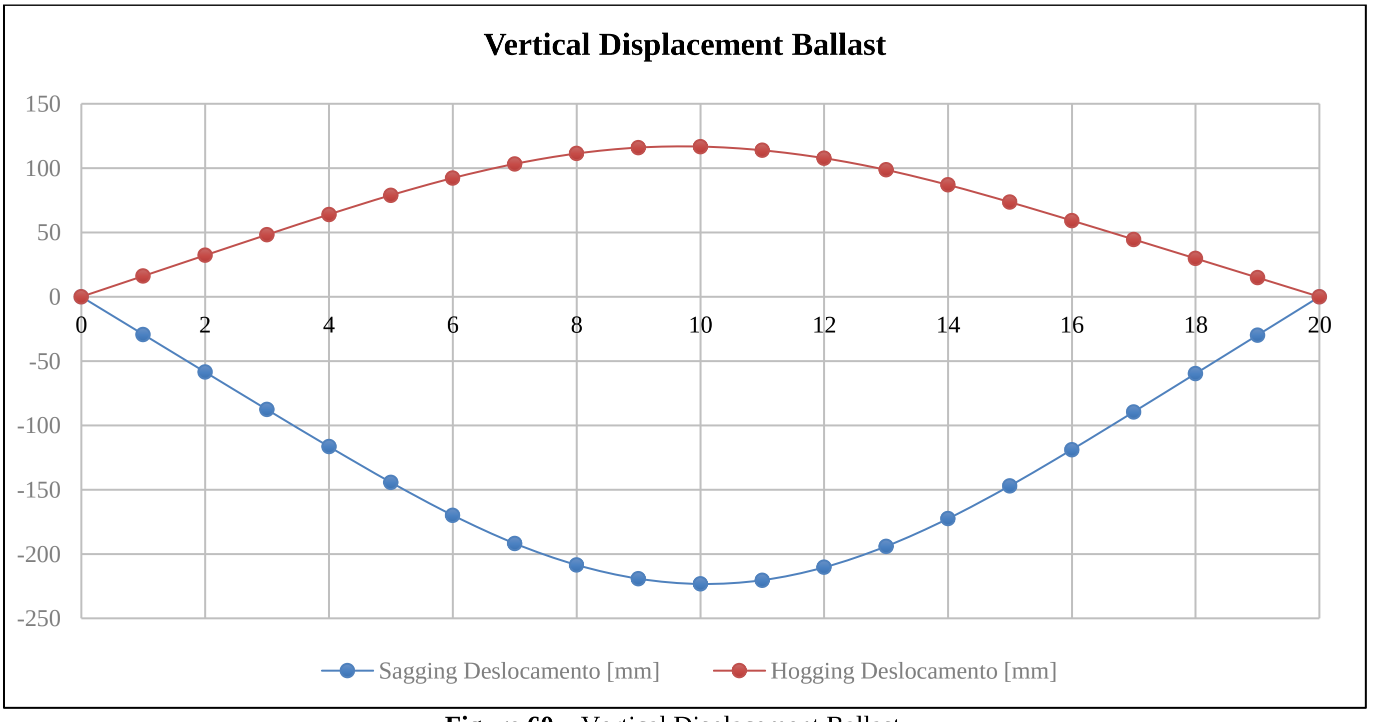


Figure 60 – Vertical Displacement Ballast

Shear Stress Distribution

To facilitate the distribution of Shear stress calculations, the number of plates used was simplified.

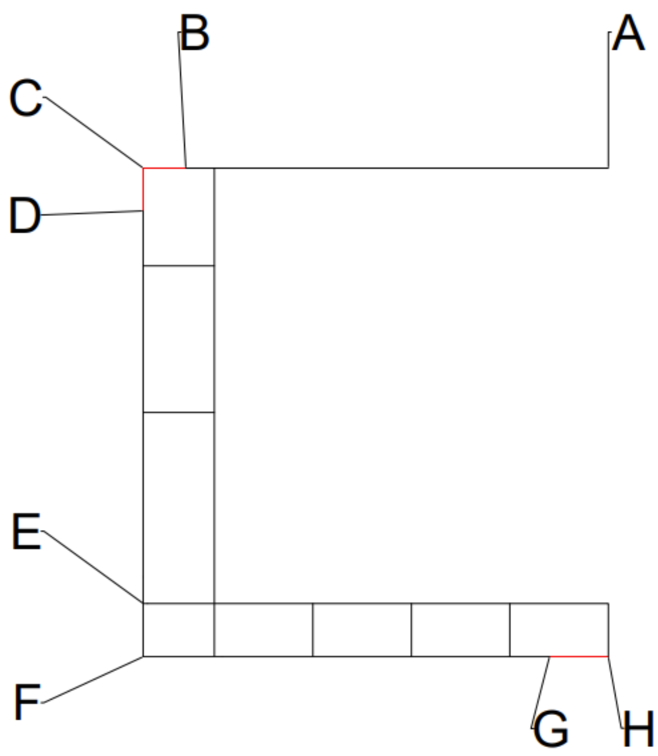


Figure 61 – New Simplified Plate Positions

From this simplification, I was able to create a table of the values of Inertia of each new plate, taking the preexisting table (**Table 35**) to create the new one (**Table 36**).

Table 35 – Total Plate Characteristics

Plates	δ (m)	c	area	z	Io	A*z	A*Z^2	Izz
A	0.02	1.20	0.02	13.10	0.00	0.31	4.05	4.06
B	0.02	1.54	0.02	11.73	0.00	0.29	3.37	3.38
C	0.01	4.11	0.05	8.91	0.07	0.44	3.95	4.02
D	0.01	4.62	0.06	4.54	0.10	0.25	1.15	1.25
E	0.02	3.50	0.06	1.12	0.50	0.07	0.08	0.58
F	0.02	2.53	0.04	0.00	0.00	0.00	0.00	0.00
G	0.02	2.76	0.05	0.00	0.00	0.00	0.00	0.00
H	0.02	2.76	0.05	0.00	0.00	0.00	0.00	0.00
I	0.02	1.11	0.02	0.00	0.00	0.00	0.00	0.00
J	0.02	1.65	0.03	0.00	0.00	0.00	0.00	0.00
K	0.02	1.49	0.02	0.75	0.00	0.02	0.01	0.02
L	0.02	2.76	0.06	1.49	0.00	0.09	0.14	0.14
M	0.02	2.76	0.06	1.49	0.00	0.09	0.14	0.14
N	0.02	2.76	0.06	1.49	0.00	0.09	0.14	0.14

O	0.02	2.76	0.06	1.49	0.00	0.09	0.14	0.14
P	0.01	5.36	0.05	4.17	0.13	0.22	0.93	1.06
Q	0.01	4.11	0.04	8.91	0.06	0.37	3.26	3.32
R	0.01	2.74	0.03	12.33	0.02	0.34	4.17	4.18
S	0.02	0.80	0.01	13.70	0.00	0.17	2.27	2.27
T	0.02	1.20	0.02	13.70	0.00	0.32	4.43	4.43
U	0.02	11.05	0.17	13.70	0.00	2.29	31.41	31.41
V	0.02	2.00	0.04	10.96	0.00	0.47	5.10	5.10
W	0.02	2.00	0.04	6.85	0.00	0.29	1.99	1.99
X	0.02	2.00	0.04	1.49	0.00	0.06	0.09	0.09
Y	0.02	1.48	0.03	0.75	0.00	0.02	0.01	0.02
Z	0.02	1.49	0.03	0.75	0.00	0.02	0.01	0.02
AA	0.02	1.49	0.03	0.75	0.00	0.02	0.01	0.02
BB	0.02	1.49	0.03	0.75	0.00	0.02	0.01	0.02
Total	-	-	1.25	-	-	6.37	66.90	67.81

Table 36 – New Plate Characteristics

Chapas	b [m]	δ [m]	A[m^2]	z [m]	Io [m^4]	A*z [m^3]	A*z^2 [m^4]	Izz [m^4]
AB	13.05000	0.01515	0.19764	13.99243	0.00000	2.76553	38.69650	38.69650
BC	1.20000	0.01969	0.02363	0.00000	0.00284	0.00000	0.00000	0.00284
CD	1.20000	0.01969	0.02363	12.20000	0.00284	0.28824	3.51657	3.51941
DE	11.01000	0.01592	0.17523	6.09500	1.77009	1.06801	6.50951	8.27959
EF	1.49000	0.01768	0.02635	1.14500	0.00487	0.03017	0.03454	0.03942
FG	11.40200	0.01768	0.20163	0.76884	0.00001	0.15502	0.11919	0.11919
GH	1.64800	0.02068	0.03409	0.77034	0.00000	0.02626	0.02023	0.02023
Total	-	-	0.68219	-	-	4.33323	-	50.67718

And from these values, it is further possible to calculate the maximum stress at each node, using the Maximum Shear stress (**Table 37**), obtaining the results (**Table 38**).

Table 37 – Shear stress

Q	kN
Qsw (CC)	5000.86376
Qsw (BC)	3136.63717
Qsg (CC)	1665.23084
Qhg (CC)	-2643.40692
Qsg (BC)	966.96350
Qhg (BC)	-2050.66177
Max	5000.86376

Table 38 – Shear stress at points

E'	1.64734
D'	1.74493
C'	1.66953

Conclusion

This project allowed me to have a greater grasp on the concepts of the stability and behaviour of a ship in two different loading conditions, a area of Naval architecture that I hadn't had much contact with before.

This work will allow me to have a greater understanding of these mechanisms in the future and improve my capabilities of noticing mistakes in these kinds of calculations.

Bibliography

- YG_CEN_project support
- CEN PROJECT 2024 - 2025