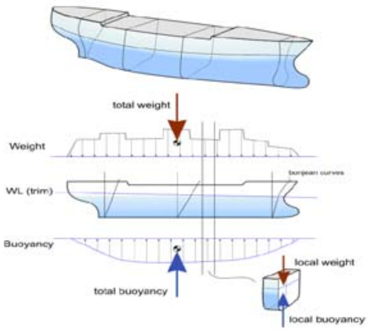
Comportamento de Estruturas Navais

Behaviour of Ship Structures

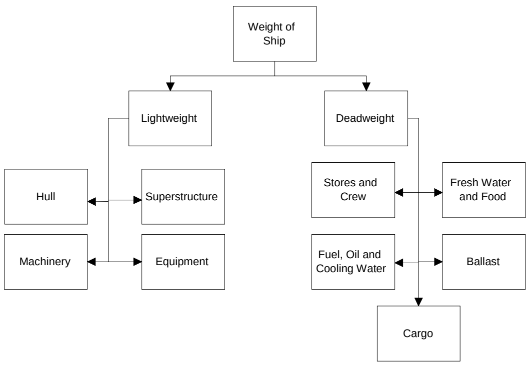
(supporting information for the project work)

Yordan Garbatov

Weight of the ship and its contents



Weight of the ship and its contents



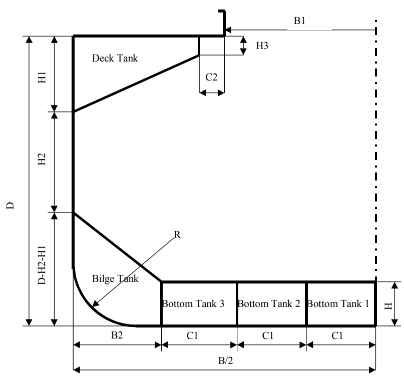
Weight of the ship and its contents

The information regarding weights is of a discrete nature and must be gathered together and entered into a "Table of Weight" or some other suitable form of information storage.

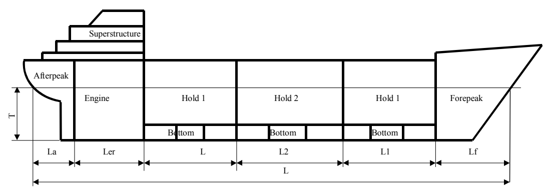
The formulations that are going to be presented here is applied to a bulk carrier.

Length of Ship, L	120.00	[m]
Breadth, B	18.00	[m]
Block Coefficient, C_B	0.68	[-]
Depth, D	10.00	[m]

Weight of the ship and its contents



Weight of the ship and its contents



Weight of the ship and its contents

In specifying the distribution of individual weights, it is used some approximations and idealisations.

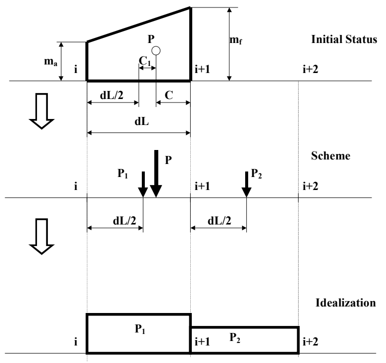
Nearly all items can be represented in terms of one or more of the three basic types of distribution:

- **Point,**
- **Uniform and**
- **Trapezoidal distribution.**

In addition, for cargo and ballast, an alternative approach is possible.

For a trapezoid with a length, *dL* the relevant information may be specified by a total mass *P*, with a specified position of centre of gravity C_1.

Weight of the ship and its contents



Weight of the ship and its contents

The formulas for converting from one form of distribution to another one are:

$$P = \frac{dL(m_f + m_a)}{2}$$

$$C_1 = \frac{dL}{6}\left[\frac{m_f - m_a}{m_f + m_a}\right]$$

$$C = \frac{dL}{2} - C_1$$

$$P_1 = P\left(\frac{1}{2} + \frac{C}{dL}\right) \qquad P_2 = P\left(\frac{1}{2} - \frac{C}{dL}\right)$$

$$P = P_1 + P_2$$

Weight of machinery

The weight per unit length is related to the product of the sectional area of the relevant space times the mass density.

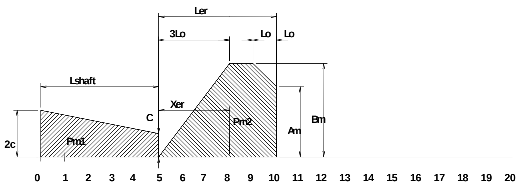
The weight of LW may be presented as a sum of the following components:

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

Weight of machinery

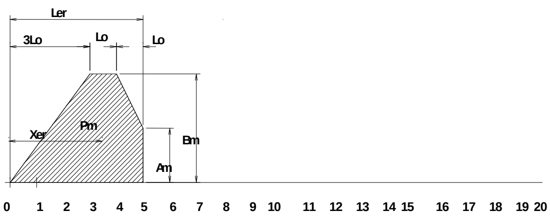
Weight of machinery

Typical approximation of weight of machinery depends on the location of the engine room.



Weight of machinery

Weight distribution of machinery (aft of midship)



Weight of machinery

The weight parameters are described as:

$$P_{m1} = 2L_{shaft}$$

$$P_{m2} = P_m - P_{m1}$$

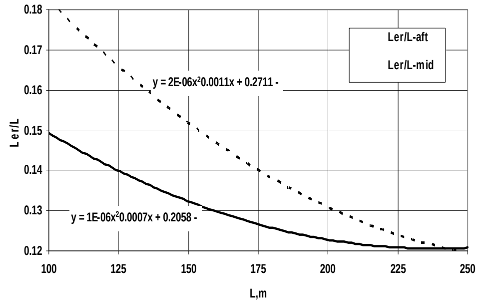
$$0.59L_{er} \le X_{er} \le 0.62L_{er}$$

where:

P_{m1} is the weight of the shaft and the propeller,
P_{m2} is the weight of the mechanisms in the engine room,
L_{shaft} is the length of the shaft and
X_{er} is the position of the longitudinal centre of gravity of the weight of mechanisms in the engine room.

Weight of machinery

Relative length of the engine room



Weight of machinery

The descriptors of the weight distribution are given as:

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

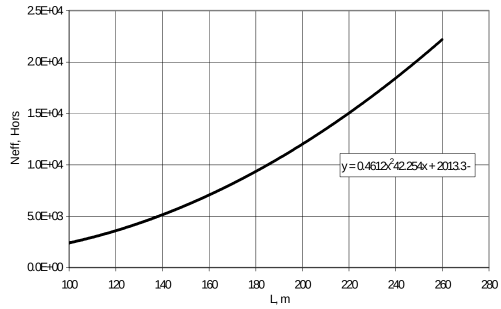
$$B_m = \frac{5}{16}\frac{P_m}{L_{er}}\left(14 - 15\frac{X_{er}}{L_{er}}\right)$$

$$P_m = 0.1N_{eff}$$

where L_{er} is the length of the engine room and N_{eff} is the effective power of the main engine.

Weight of machinery

Effective main engine powers as a function of the length of ship

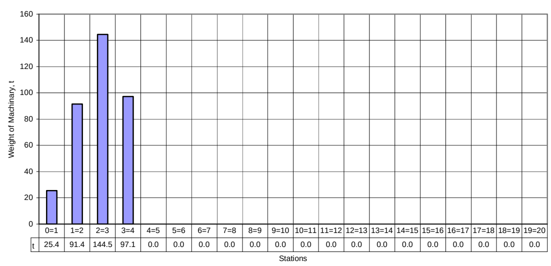


Calculation of the weight of machinery

L_{er}/L=2E-6 L^2-0.0011 L+0.2711	0.168	[-]
L_{er}	24.000	[m]
X_{er}=0.6 L_{er}	14.400	[m]
N_{eff}=0.4612 L^2 - 42.254 L + 2013.3	3584.10	[Horse]
P_m=0.1 N_{eff}	358.410	[t]
A_m=5/8 P_m/L_{er} (45 X_{er}/L_{er}-26)	9.334	[t/m]
B_m=5/16 P_m/L_{er} (14-15 X_{er}/L_{er})	23.334	[t/m]
$L_o=L_{er}/5$	4.800	[m]
$B_1=B_m$ (ΔL/(3 L_o))	9.722	[t/m]
$B_2=B_m$((2 ΔL)/(3 L_o))	19.445	[t/m]
$B_3=B_m$	23.334	[t/m]
$B_4=A_m$	9.334	[t/m]
c_1=ΔL/3	2.000	[m]
$m_1=B_1$ ΔL/2	29.167	[t]
$M_{11}=m_1(1/2+c_1/ΔL)$	24.306	[t]
$M_{12}=m_1(1/2-c_1/ΔL)$	4.861	[t]
c_2=ΔL/2-ΔL/6((B_2-B_1)/(B_2+B_1))	2.667	[m]
m_2=ΔL(B_2+B_1)/2	87.502	[t]
$M_{22}=m_2(1/2+c_2/ΔL)$	82.641	[t]
$M_{23}=m_2(1/2-c_2/ΔL)$	4.861	[t]
c_3=ΔL/2-ΔL/6((B_3-B_2)/(B_3+B_2))	2.909	[m]
m_3=ΔL(B_3+B_2)/2	128.337	[t]
$M_{33}=m_3(1/2+c_3/ΔL)$	126.392	[t]
$M_{34}=m_3(1/2-c_3/ΔL)$	1.944	[t]
c_4=ΔL/2-ΔL/6((B_3-B_4)/(B_3+B_4))	2.571	[m]
m_4=ΔL(B_3+B_4)/2	98.003	[t]
$M_{44}=m_4(1/2+c_4/ΔL)$	91.003	[t]
$M_{43}=m_4(1/2-c_4/ΔL)$	7.000	[t]

Weight of machinery

Weight distribution of machinery



Weight of superstructure

The distribution function of the weight of the superstructures is described by the following parameters:

$$L_{ss,2} = 0.05L + 3$$

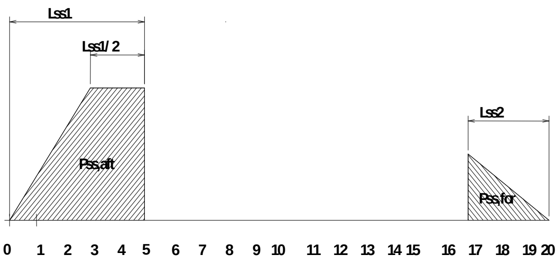
$$a = 0.003L + 0.48$$

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

$$P_{ss,for} = 0.008L\,B$$

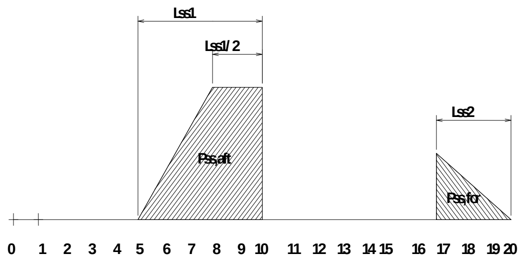
Weight of superstructure

Weight distribution of superstructures (aft midship)



Weight of superstructure

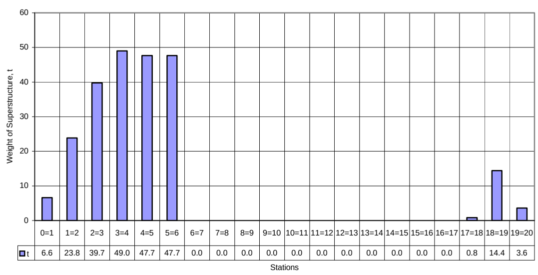
Weight distribution of superstructures (midship)



Weight of superstructures

$P_{ss,aft}$=0.5 L_{er}B	216.000	[t]
$P_{ss,for}$=0.008LB	17.280	[t]
a=0.03L+0.48	4.080	[m]
$L_{ss,1}$=L_{er}+2a	36.000	[m]
$L_{ss,2}$=0.05L+3	12.000	[m]
m_{aft}=4/3$P_{ss,aft}$/L_{ss1}	8.000	[t/m]
m_{for}=2$P_{ss,for}$/L_{ss2}	2.880	[t/m]
B_1=dL/L_{ss1}/2m_{aft}	2.667	[t/m]
B_2=2dL/L_{ss1}/2m_{aft}	5.333	[t/m]
B_3=m_{aft}	8.000	[t/m]
B_4=m_{aft}	8.000	[t/m]
B_5=m_{aft}	8.000	[t/m]
B_6=m_{aft}	8.000	[t/m]
c_1=ΔL/3	2.000	[m]
m_1=B_1ΔL/2	8.000	[t]
M_{11}=m_1(1/2+c_1/ΔL)	6.667	[t]
M_{12}=m_1(1/2-c_1/ΔL)	1.333	[t]
c_2=ΔL/2-ΔL/6((B_2-B_1)/(B_2+B_1))	2.667	[t]
m_2=ΔL(B_2+B_1)/2	24.000	[t]
M_{22}=m_2(1/2+c_2/ΔL)	22.667	[t]
M_{23}=m_2(1/2-c_2/ΔL)	1.333	[t]
c_3=ΔL/2-ΔL/6((B_3-B_2)/(B_3+B_2))	2.800	[t]
m_3=ΔL(B_3+B_2)/2	40.000	[t]
M_{33}=m_3(1/2+c_3/ΔL)	38.667	[t]
M_{34}=m_3(1/2-c_3/ΔL)	1.333	[t]
m_4=ΔLB_4	48.000	[t]
M_{44}=m_4	48.000	[t]
m_5=ΔLB5	48.000	[t]
M_{55}=m_5	48.000	[t]
m_6=ΔLB_6	48.000	[t]
M_{66}=m_6	48.000	[t]
B_{18}=m_{for}	2.880	[t/m]
B_{19}=ΔL/$L_{ss2}$$m_{for}$	1.440	[t]
c_{19}=ΔL/3	2.000	[m]
m_{19}=B_{19}ΔL/2	4.320	[t]
M_{1919}=m_{19}(1/2+c_{19}/ΔL)	3.600	[t]
M_{1918}=m_{19}(1/2-c_{19}/ΔL)	0.720	[t]
c_{18}=ΔL/2-ΔL/6((B_{18}-B_{19})/(B_{18}+B_{19}))	2.667	[m]
m_{18}=ΔL(B_{18}+B_{19})/2	14.640	[t]
M_{1818}=m_{18}(1/2+c_{18}/ΔL)	13.827	[t]
M_{1817}=m_{18}(1/2-c_{18}/ΔL)	0.813	[t]

Weight of superstructure



Weight of hull

The major item of the weight distribution is the hull. A useful first approximation of the hull weight distribution is defined as:

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

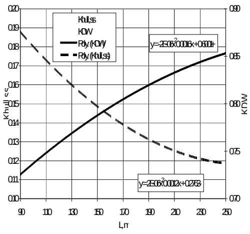
where:

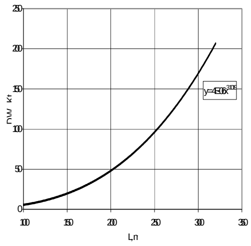
$$P_{hull,ss} = \Delta\, k_{hull,ss}$$

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

Weight of hull

The coefficients $k_{hull,ss}$ and k_{DW} and *DW* as a function of the length of the ship is given as





Weight of hull

The distribution of the weight may differ depending on the position of the engine room. When the engine room is located at the middle of the ship, the parameters determining the distribution are:

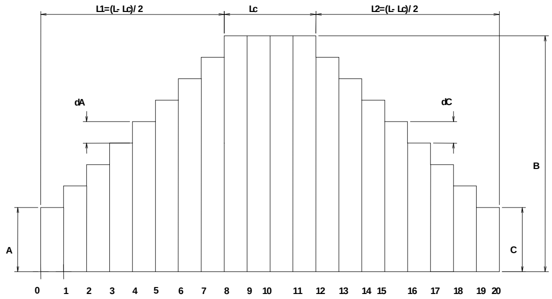
$$dA = 2\Delta L \frac{B-A}{L-L_c}$$

$$B = \left[1 + C_b\left(1 - \frac{L_c}{L}\right)\right] P_{hull}$$

$$dC = 2\Delta L \frac{B-C}{L-L_c}$$

Weight of hull

Hull weight distribution (midship).



Weight of hull

Hull weight distribution parameters (midship)

L_c / L	0.1	0.2	0.3
$B/(P_{hull}/L)$	1.27	1.24	1.21
$A/(P_{hull}/L)$	$0.730 - 0.293\,(x_{hull}/\Delta L)$	$0.707 - 0.310\,(x_{hull}/\Delta L)$	$0.685 - 0.333\,(x_{hull}/\Delta L)$
$C/(P_{hull}/L)$	$0.730 + 0.293\,(x_{hull}/\Delta L)$	$0.707 + 0.310\,(x_{hull}/\Delta L)$	$0.685 + 0.333\,(x_{hull}/\Delta L)$
L_c / L	0.4	0.5	0.6
$B/(P_{hull}/L)$	1.18	1.15	1.12
$A/(P_{hull}/L)$	$0.667 - 0.365\,(x_{hull}/\Delta L)$	$0.650 - 0.408\,(x_{hull}/\Delta L)$	$0.640 - 0.476\,(x_{hull}/\Delta L)$
$C/(P_{hull}/L)$	$0.667 + 0.365\,(x_{hull}/\Delta L)$	$0.650 + 0.408\,(x_{hull}/\Delta L)$	$0.640 + 0.476\,(x_{hull}/\Delta L)$

Weight of hull

When the engine room is located at the aft of the midship, then the distribution of the weight is defined by:

$$dA = 2\Delta L \frac{B-A}{1.1L-L_c}$$

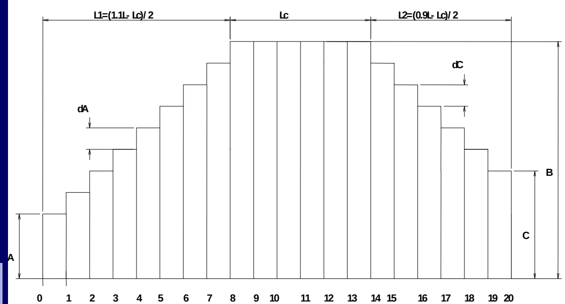
$$B = \left[1 + C_b\left(1 - \frac{L_c}{L}\right)\right] \frac{P_{hull}}{L}$$

$$dC = 2\Delta L \frac{B-C}{0.9L-L_c}$$

$$\frac{x_{hull}}{\Delta L} = \left[\left(\frac{L_c}{L} - 0.7\right) \div 0.5\right]$$

Weight of hull

Hull weight distribution (aft a midship)



Weight of hull

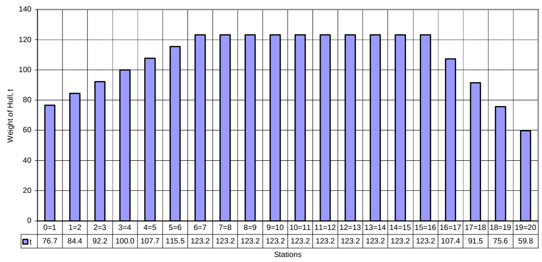
Hull weight distribution parameters (aft a midship)

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
$A/(P_{hull}/L)$	$0.711-0.319(x_{hull}/\Delta L)$	$0.704-0.350(x_{hull}/\Delta L)$	$0.704-0.392(x_{hull}/dL)$
$C/(P_{hull}/L)$	$0.606+0.426(x_{hull}/\Delta L)$	$0.574+0.490(x_{hull}/dL)$	$0.544+0.588(x_{hull}/dL)$

Weight of hull

k_{DW}= -2E-6x² + 0.0016x + 0.6001	0.763	[-]
DW=4E-06 $L^{3.1019}$	11258.287	[t]
Δ=DW/k_{DW}	14749.491	[t]
LW=Δ-DW	3491.205	[t]
$k_{hull,ss}$= 2E-06 L^2 – 0.0012 L + 0.2763	0.161	[-]
$P_{hull,ss}$=Δ k_{hull}	2376.14	[t]
P_{ss}	233.300	[t]
P_{hull}=$P_{hull,ss}$-P_{ss}	2142.84	[t]
L_c/L	0.500	[-]
L_1=(1.1 L-L_c)/2	36.000	[m]
L_c	60.000	[m]
L_2=(0.9 L-L_c)/2	24.000	[m]
P_{hull}/L	17.857	[m]
X_{hull}=L_c/L-0.7	-0.200	[t/m]
A=(P_{hull}/L) ((0.704-0.350 (X_{hull}/ΔL))	12.780	[t/m]
B=(P_{hull}/L) 1.15	20.536	[t/m]
C=(P_{hull}/L) ((0.574+0.490 (X_{hull}/ΔL))	9.958	[t/m]
dA=2 ΔL (B-A)/(1.1 L-L_c)	1.293	[t/m]
dC=2 ΔL (B-C)/(0.9 L-L_c)	2.644	[t/m]

Weight of hull



Weight of equipment

The weight of equipment is presented as:

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

$$P_{eq,1} = [0.4 \div 0.6] P_{eq}$$

$$P_{eq,2} = [0.02 \div 0.05] P_{eq}$$

$$P_{eq,3} = [0.3 \div 0.45] P_{eq}$$

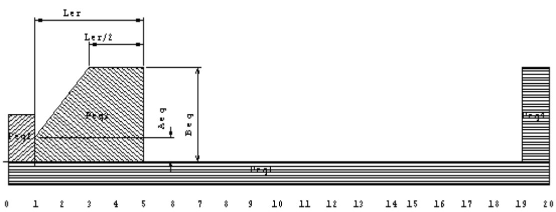
$$P_{eq,4} = [0.05 \div 0.1] P_{eq}$$

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

$$LW = \Delta - DW$$

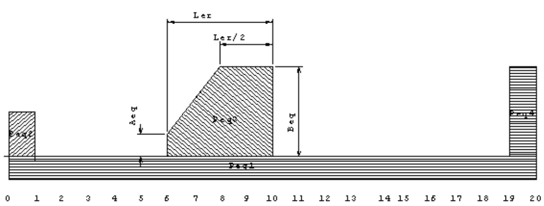
Weight of equipment

Weight distribution of equipment (aft of a midship)



Weight of equipment

Weight distribution of equipment (midship)



Weight of equipment

The weight of equipment may be approximated as:

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

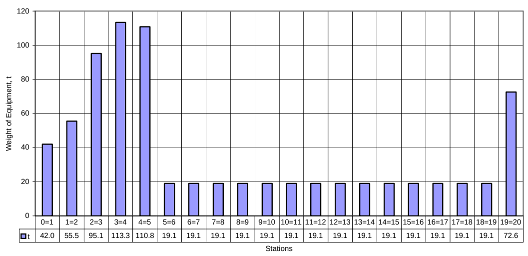
$$P_{eq,\,for} = 0.008 LB$$

Weight of equipment

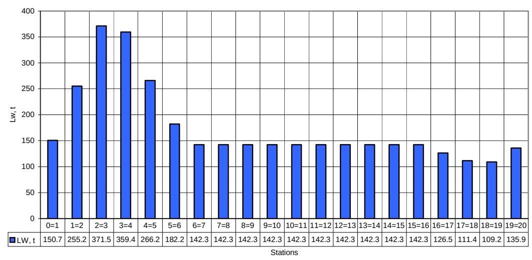
LW	3491.205	[t]
P_{hull}	2142.848	[t]
P_{ss}	233.291	[t]
P_m	358.410	[t]
P_{eq}=LW-P_{hull}-P_{ss}-P_m	756.656	[t]
L_{er}	24.000	[m]
$P_{eq1}=0.5P_{eq}$	378.328	[t]
$P_{eq2}=0.03P_{eq}$	22.700	[t]
$P_{eq3}=0.4P_{eq}$	302.662	[t]
$P_{eq4}=0.07P_{eq}$	52.966	[t]
$A_{eq}=B_{eq}/3$	5.044	[t/m]
$B_{eq}=P_{eq3}/(10/3)/\ \Delta L$	15.133	[t/m]
$B_1=A_{eq}$	5.044	[t/m]
$B_2=2B_{eq}/3$	10.089	[t/m]
$B_3=B_{eq}$	15.133	[t/m]
$B_4=B_{eq}$	15.133	[t/m]
$c_1=\Delta L/2-\Delta L/6((B_2-B_1)/(B_2+B_1))$	2.667	[m]
$m_1=(B_1+B_2)\ \Delta L/2$	38.169	[t]
$M_{11}=m_1(1/2+c_1/\Delta L)$	36.048	[t]
$M_{12}=m_1(1/2-c_1/\Delta L)$	2.120	[t]
$c_2=\Delta L/2-\Delta L/6((B_3-B_2)/(B_3+B_2))$	2.800	[m]
$m_2=\Delta L(B_3+B_2)/2$	75.666	[t]
$M_{22}=m_2(1/2+c_2/\Delta L)$	73.143	[t]
$M_{23}=m_2(1/2-c_2/\Delta L)$	2.522	[t]
$M_{33}=B_3\Delta L$	90.799	[t]
$M_{44}=B_4\Delta L$	90.799	[t]

Weight of equipment

Weight distribution of equipment



Weight distribution of LW



Dead-weight

The *DW* of merchant ships is the difference between the full-load displacement weight Δ and the lightship weight:

$$DW = \Delta - LW$$

$$\Delta = \nabla \rho$$

The actual cargo dead weight is obtained by deducting the weight of fuel, stores, fresh water, water (or other removable ballast), crew and stores, which the ship may carry.

$$DW = P_{sc} + P_{fw} + P_{foc} + P_b + P_c$$

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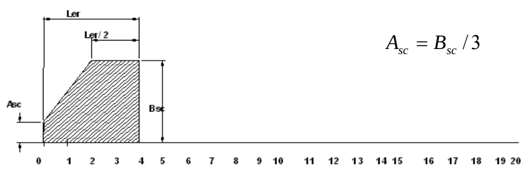
Weight of stores and crew

The weight of the stores and crew may be approximated as:

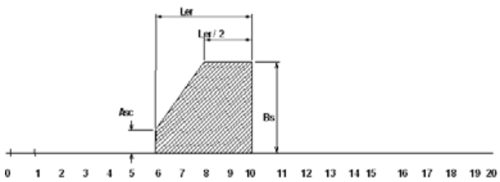
$$P_{sc} = 0.15n$$

where *n* is the number of the members of the crew



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

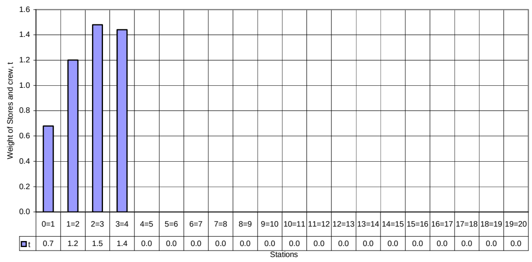
Weight of stores and crew



Weight of stores and crew

n	32	[ps]
P_{sc}=0.15 n	4.800	[t]
$A_{sc}=B_{sc}/3$	24.000	[t/m]
$B_{sc}=P_{sc3}/(10/3)/\ \Delta L$	0.080	[t/m]
$B_1=A_{sc}$	0.240	[t/m]
$B_2=2*B_{sc}/3$	0.080	[t/m]
$B_3=B_{sc}$	0.160	[t/m]
$B_4=B_{sc}$	0.240	[t/m]
$c_1=\Delta L/2-\Delta L/6\ ((B_2-B_1)/(B_2+B_1))$	0.240	[m]
$m_1=(B_1+B_2)\ \Delta L/2$	2.667	[t]
$M_{11}=m_1\ (1/2+c_1/\Delta L)$	0.720	[t]
$M_{12}=m_1\ (1/2-c_1/\Delta L)$	0.680	[t]
$c_2=\Delta L/2-\Delta L/6\ ((B_3-B_2)/(B_3+B_2))$	0.040	[m]
$m_2=\Delta L\ (B_3+B_2)/2$	2.800	[t]
$M_{22}=m_2\ (1/2+c_2/\Delta L)$	1.200	[t]
$M_{23}=m_2\ (1/2-c_2/\Delta L)$	1.160	[t]
$M_{33}=B_3\ \Delta L$	0.040	[t]
$M_{44}=B_4\ \Delta L$	1.440	[t]

Weight of stores and crew



Fresh water capacity

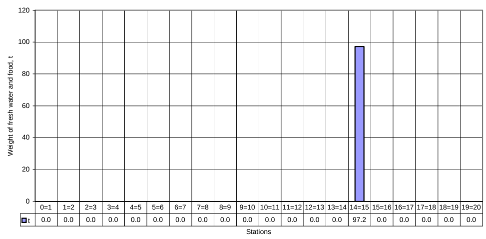
Fresh water capacity will depend upon whether the water is to be obtained ashore and carried to the length of the voyage or the ship's distilling plant can meet all requirements at sea.

In the latter case requisite capacity for fresh water will be much reduced. The weight of fresh water and food may be described as

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

Fresh water capacity

n	32	[ps]
P_w	105.600	[t]
γ_{water}	1.000	[t/m³]
$P_{w,real}$	97.200	[t]



Fuel, oil and cooling water

The necessary weight of fuel, oil and cooling water is a matter for specific estimating to the particular machinery installation. An approximated expression may be taken as:

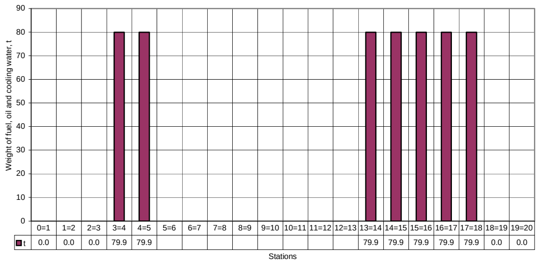
$$P_{foc} = 0.0002\, N_{eff}\, T$$

where T is the duration of the voyage in hours.

$N_{eff}=0.4612\ L^2 - 42.25\ L + 2013.3$	3584.100	[Horse]
T=24 A	720.000	[Hours]
A	30.000	[days]
$P_{foc}=0.0002\ N_{eff}\ T$	516.110	[t]
γ_{fuel}	1.000	[t/m³]
$P_{foc,real}$	559.623	[t]

Fuel, oil and cooling water

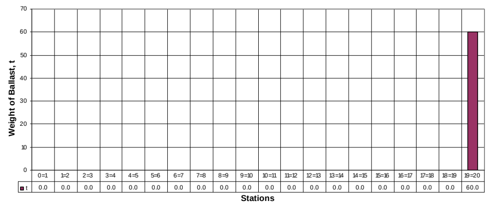
Weight distribution of fuel, oil and cooling water



Ballast

The required ballast will be dependent upon trim and stability consideration, which in the first approximation can be taken as:

$$P_b = (0.15 \div 0.4)DW$$



Weight of Cargo

Detail information has to be taken to determine the weight of cargo. In the preliminary design phase, approximation to weight may be adequate. When the design is finalised exact methods should be used. The cargo weight may be presented as:

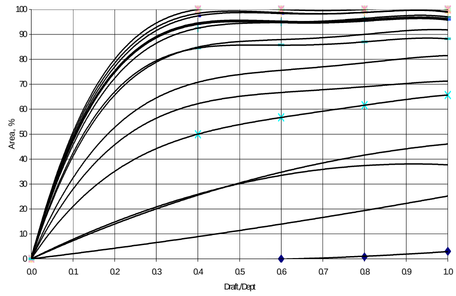
$$P_c = DW - P_{wc} - P_{foc} - P_b$$

The distribution functions of cargo and ballast require knowing the volume capacities on the ship.

In order to construct the plane of the volume capacities of tanks and holds is required the information for the hull arrangement and the relative to the midship sectional floating area at different states.

Weight of Cargo

Relative net sectional area



Weight of Cargo

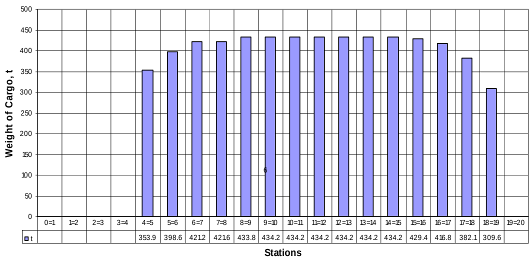
$$
\begin{Bmatrix}
\bar{A}_{\%}(0)\\ \bar{A}_{\%}(1)\\ \bar{A}_{\%}(2)\\ \bar{A}_{\%}(3)\\ \bar{A}_{\%}(4)\\ \bar{A}_{\%}(5)\\ \bar{A}_{\%}(6)\\ \bar{A}_{\%}(7)\\ \bar{A}_{\%}(8)\\ \bar{A}_{\%}(9)\\ \bar{A}_{\%}(10)\\ \bar{A}_{\%}(11)\\ \bar{A}_{\%}(12)\\ \bar{A}_{\%}(13)\\ \bar{A}_{\%}(14)\\ \bar{A}_{\%}(15)\\ \bar{A}_{\%}(16)\\ \bar{A}_{\%}(17)\\ \bar{A}_{\%}(18)\\ \bar{A}_{\%}(19)\\ \bar{A}_{\%}(20)
\end{Bmatrix}
=
\begin{bmatrix}
0 & 0 & 7.943 & -5.043\\
0 & 0 & 4.877 & 20.315\\
0 & 0 & -29.590 & 75.660\\
-141.670 & 417.500 & -462.330 & 252.200\\
-255.210 & 750.000 & -811.040 & 397.750\\
-384.380 & 1088.000 & -1125.400 & 512.800\\
-453.130 & 1262.500 & -1284.400 & 572.000\\
-477.080 & 1346.200 & -1381.200 & 611.100\\
-520.830 & 1458.300 & -1479.200 & 641.670\\
-520.830 & 1458.300 & -1479.200 & 641.670\\
-520.830 & 1458.300 & -1479.200 & 641.670\\
-520.830 & 1458.300 & -1479.200 & 641.670\\
-520.830 & 1458.300 & -1479.200 & 641.670\\
-520.830 & 1458.300 & -1479.200 & 641.670\\
-520.830 & 1458.300 & -1479.200 & 641.670\\
-502.080 & 1410.000 & -1435.900 & 626.900\\
-453.130 & 1262.500 & -1284.400 & 572.000\\
-433.330 & 1209.200 & -1221.900 & 534.000\\
-196.880 & 597.080 & -669.000 & 349.200\\
0 & 0 & -45.154 & 82.877\\
0000.000 & 0000.0000 & 0000.0000 & 52.000
\end{bmatrix}
\begin{Bmatrix}
\left(\frac{T}{D}\right)^4\\
\left(\frac{T}{D}\right)^3\\
\left(\frac{T}{D}\right)^2\\
\left(\frac{T}{D}\right)
\end{Bmatrix}
$$

Weight of Cargo

DW	11258.287	[t]
$P_{water,real}$	97.200	[t]
$P_{fuel,real}$	559.623	[t]
$P_{ballast,real}$	60.000	[t]
$P_{cargo}=DW-P_{water,real}-P_{fuel,real}-P_{ballast,real}$	10541.463	[t]
Δ	14749.491	[t]
B_1=0.5 B	9.000	[m]
h_1=0.2 D	2.000	[m]
h_2=0.3 D	3.000	[m]
b_2=0.15 B	2.700	[m]
$C_1=2.25*((L+30)/80)^{0.25}$	2.000	[m]
C_2+B1=0.6 B	12.600	[m]
H_3=1	1.000	[m]
H=(L-40)/0.57+40 B+3500 T/L, [mm]	1.110	[m]
γ_{cargo}	1.000	[t/m^3]
Deck tank	97.200	[m^3]
Bilge tank	77.760	[m^3]
Bottom tank 1	26.649	[m^3]
Bottom tank 2	26.649	[m^3]
Bottom tank 3	26.649	[m^3]
Area		
Deck tank	16.200	[m^2]
Bilge tank	12.960	[m^2]
Bottom tank 1	4.441	[m^2]
Bottom tank 2	4.441	[m^2]
Bottom tank 3	4.441	[m^2]

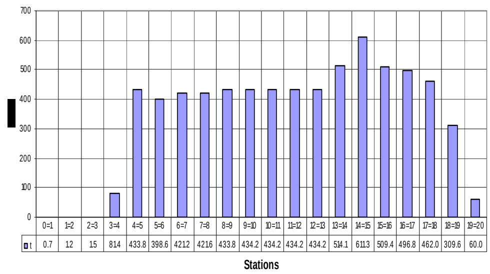
Weight of Cargo

Weight distribution of cargo



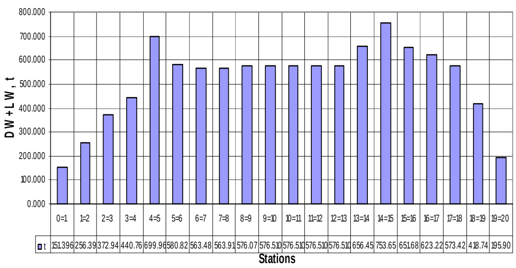
Weight of DW

Weight distribution of DW



Centre of gravity of DW and LW

Weight distribution of DW+LW



Centre of gravity of DW and LW

Stations	Stores	Water	Fuel	Ballast	Cargo	DW	LW	DW+LW	k	[9] [10]
	[1]	[2]	[3]	[4]	[5]	[6]	[8]	[9]	[10]	[11]
0=1	0.680	0.000	0.000	0.000	0.000	0.7	150.716	151.396	-9.500	-1438.262
1=2	1.200	0.000	0.000	0.000	0.000	1.2	255.196	256.396	-8.500	-2179.366
2=3	1.480	0.000	0.000	0.000	0.000	1.5	371.466	372.946	-7.500	-2797.098
3=4	1.440	0.000	79.946	0.000	0.000	81.4	359.383	440.769	-6.500	-2865.001
4=5	0.000	0.000	79.946	0.000	353.867	433.8	266.152	699.965	-5.500	-3849.810
5=6	0.000	0.000	0.000	0.000	398.589	398.6	182.235	580.824	-4.500	-2613.707
6=7	0.000	0	0.000	0.000	421.167	421.2	142.317	563.484	-3.500	-1972.194
7=8	0.000	0.000	0.000	0.000	421.601	421.6	142.317	563.918	-2.500	-1409.795
8=9	0.000	0.000	0.000	0.000	433.759	433.8	142.317	576.076	-1.500	-864.113
9=10	0.000	0.000	0.000	0.000	434.193	434.2	142.317	576.510	-0.500	-288.255
10=11	0.000	0.000	0.000	0.000	434.193	434.2	142.317	576.510	0.500	288.255
11=12	0.000	0.000	0.000	0.000	434.193	434.2	142.317	576.510	1.500	864.765
12=13	0.000	0.000	0.000	0.000	434.193	434.2	142.317	576.510	2.500	1441.274
13=14	0.000	0.000	79.946	0.000	434.193	514.1	142.317	656.456	3.500	2297.596
14=15	0.000	97.200	79.946	0.000	434.193	611.3	142.317	753.656	4.500	3391.452
15=16	0.000	0.000	79.946	0.000	429.417	509.4	142.317	651.680	5.500	3584.239
16=17	0.000	0.000	79.946	0.000	416.825	496.8	126.450	623.222	6.500	4050.941
17=18	0.000	0.000	79.946	0.000	382.090	462.0	111.391	573.427	7.500	4300.706
18=19	0.000	0.000	0.000	0.000	309.580	309.6	109.161	418.740	8.500	3559.292
19=20	0.000	0.000	0.000	60.000	0.000	60.0	135.904	195.904	9.500	1861.084

$$x_p = \Delta L \frac{\sum_{11}}{\sum_{9}}$$

Water buoyancy

In order to calculate the still water buoyancy distribution the location of the still waterline of the vessel must be determined based on the two overall equilibrium requirements.

It is also necessary to define the weight distribution, *m* (*x*) or at least the overall weight and the location of the longitudinal centre of gravity.

Thus, once the water line of a ship has been specified, the still water buoyancy is fixed and calculable, and the still water load, shear force and bending moment depend entirely on the weight distribution.

Water buoyancy

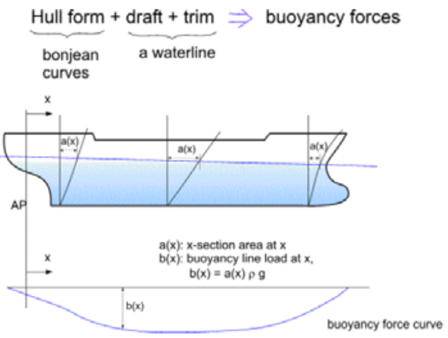
The overall static equilibrium requires that the total upward buoyant force equals the weight of the ship and that these two vertical forces coincide that the longitudinal centre of buoyancy (LCB) must coincide with the longitudinal centre of gravity (LCG). Using this notation, the first requirement is:

$$\rho g \int_o^L a(x) dx = g \int_o^L m(x) dx = g\Delta$$

Similarly, the equilibrium of moments requires that:

$$\rho g \int_o^L x\, a(x) dx = g \int_o^L x\, m(x) dx = g\Delta\, l_G$$

Water buoyancy



Water buoyancy

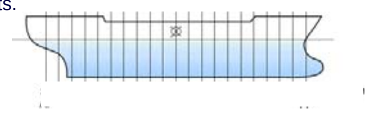
To satisfy the above requirements must be determined the drafts at FP and AP, which needs the information about the mean moulded draft (Tm), the longitudinal centre of buoyancy (*LCB*), the longitudinal metacentric radius (BML) and the longitudinal centre of gravity (*LCG*):

$$T_{FP} = T_m + \left(\frac{L}{2} - x_f\right)\frac{LCG - LCB}{BM_L}$$

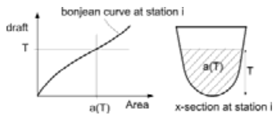
$$T_{AP} = T_m - \left(\frac{L}{2} + x_f\right)\frac{LCG - LCB}{BM_L}$$

Water buoyancy

Bonjean curves show the relationship between local draft and submerged cross-sectional area. There is one Bonjean curve for each station. There are typically 21 stations from the FP to the AP, with 0 being the AP. This divides the L_{bp} into 20 segments.

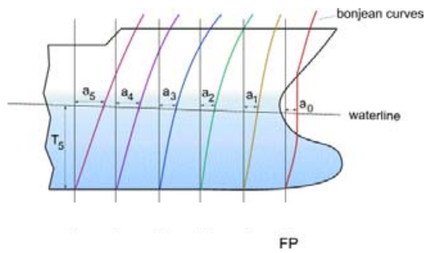


At each station we can draw a Bonjean curve of the x-section area



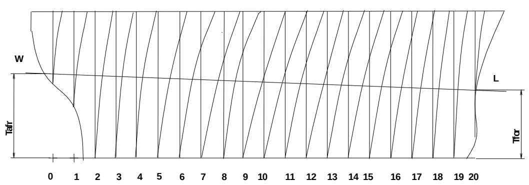
Water buoyancy

For the typical 21 station ship, we divide the ship into 21 slices, each extending fore and aft of its station. Using the Bonjean curve for each station we calculate the total displacement at our draft/trim;



Water buoyancy

Having the drafts at FP and AP and using the Bonjean curves the floated net-sections can be defined and the displacement and longitudinal centre of buoyancy may be calculated. The procedure has to be repeated until the difference between the position of the longitudinal centre of gravity and the longitudinal centre of buoyancy is acceptable.



Water buoyancy

It is well known that the floated section of the Bonjean curves may be approximated by a line between two neighbour water lines at a distance of 0.1*T*.

It is considered that $LCB = x_f$ and $BML = L$ then an analytical method for estimating the *LCB* and displacement can be used.

For that purpose an additional water line WL_C above the waterline WL_O on a distance of 0.1*T* has to be plotted.

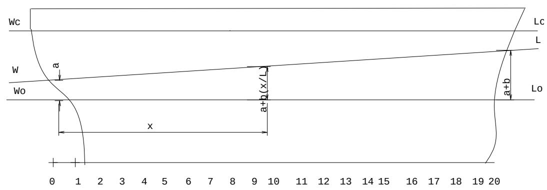
If the estimated waterline takes place between WL_O and WL_C then the immersed cross sectional area of any state may be calculated as:

$$a_i = a_{oi} + \frac{a_{ci} - a_{oi}}{\varepsilon}\left(a + b\frac{x}{L}\right)$$

Water buoyancy

Stations	T_{WLo}, m	T_{WL}, m	T_{WLc}, m	$Area_{WLo}$, %	$Area_{WL}$ %	$Area_{WLc}$ %	$Area_{mid}$, m^2	$Area_{WLo}$, m^2	$Area_{WL}$, m^2	$Area_{WLc}$, m^2
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
0	7.00	7.44	7.50	0.36	0.64	0.69	153.74	0.39	0.69	0.74
1	7.00	7.44	7.50	16.61	17.81	17.98	153.74	17.88	19.17	19.35
2	7.00	7.44	7.50	38.46	39.91	40.10	153.74	41.39	42.95	43.15
3	7.00	7.44	7.50	59.19	60.25	60.40	153.74	63.69	64.84	65.00
4	7.00	7.44	7.50	76.99	77.66	77.76	153.74	82.85	83.58	83.68
5	7.00	7.44	7.50	88.41	88.87	88.94	153.74	95.14	95.64	95.72
6	7.00	7.44	7.50	95.28	95.70	95.77	153.74	102.54	102.99	103.06
7	7.00	7.44	7.50	98.18	98.34	98.38	153.74	105.66	105.83	105.87
8	7.00	7.44	7.50	99.51	99.60	99.63	153.74	107.08	107.19	107.22
9	7.00	7.44	7.50	99.51	99.60	99.63	153.74	107.08	107.19	107.22
10	7.00	7.44	7.50	99.51	99.60	99.63	153.74	107.08	107.19	107.22
11	7.00	7.44	7.50	99.51	99.60	99.63	153.74	107.08	107.19	107.22
12	7.00	7.44	7.50	99.51	99.60	99.63	153.74	107.08	107.19	107.22
13	7.00	7.44	7.50	99.51	99.60	99.63	153.74	107.08	107.19	107.22
14	7.00	7.44	7.50	99.51	99.60	99.63	153.74	107.08	107.19	107.22
15	7.00	7.44	7.50	98.32	98.43	98.46	153.74	105.81	105.93	105.96
16	7.00	7.44	7.50	95.28	95.70	95.77	153.74	102.54	102.99	103.06
17	7.00	7.44	7.50	85.78	86.14	86.20	153.74	92.31	92.70	92.77
18	7.00	7.44	7.50	74.16	75.06	75.18	153.74	79.80	80.77	80.91
19	7.00	7.44	7.50	35.89	36.67	36.76	153.74	38.62	39.46	39.56
20	7.00	7.44	7.50	0.00	1.00	2.00	153.74	0.00	1.08	2.15

Water buoyancy

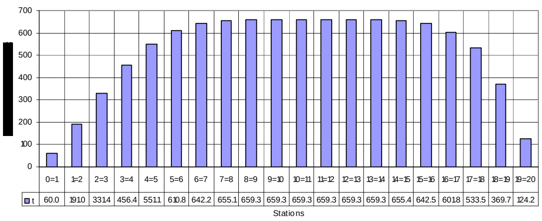


Immersed sectional area - still water

Stations	k	$Area_{WLo}$	[2][3]	$Area_{WLc}$	[5]-[3]	[6][2]	[7][2]	a/ε+b/εk/20	[6][9]	[3]+[10]	[11][2]
	-	m^2	m^2	m^2	m^2	m^2	m^2	-	m^2	m^2	m^2
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
0	0.0	0.2	0.0	0.4	0.2	0.0	0.0	0.9	0.2	0.3	0.0
1	1.0	17.9	17.9	19.3	1.5	1.5	1.5	0.9	1.3	19.2	19.2
2	2.0	41.4	82.8	43.2	1.8	3.5	7.0	0.9	1.6	42.9	85.9
3	3.0	63.7	191.1	65.0	1.3	3.9	11.7	0.9	1.1	64.8	194.5
4	4.0	82.9	331.4	83.7	0.8	3.3	13.2	0.9	0.7	83.6	334.3
5	5.0	95.1	475.7	95.7	0.6	2.9	14.4	0.9	0.5	95.6	478.2
6	6.0	102.5	615.2	103.1	0.5	3.1	18.8	0.9	0.5	103.0	618.0
7	7.0	105.7	739.6	105.9	0.2	1.5	10.3	0.9	0.2	105.8	740.9
8	8.0	107.1	856.7	107.2	0.1	1.1	8.4	0.9	0.1	107.2	857.6
9	9.0	107.1	963.8	107.2	0.1	1.2	10.7	0.9	0.1	107.2	964.8
10	10.0	107.1	1070.8	107.2	0.1	1.3	13.2	0.9	0.1	107.2	1072.0
11	11.0	107.1	1177.9	107.2	0.1	1.4	15.9	0.9	0.1	107.2	1179.2
12	12.0	107.1	1285.0	107.2	0.1	1.6	19.0	0.9	0.1	107.2	1286.4
13	13.0	107.1	1392.1	107.2	0.1	1.7	22.2	0.9	0.1	107.2	1393.6
14	14.0	107.1	1499.2	107.2	0.1	1.8	25.8	0.9	0.1	107.2	1500.8
15	15.0	105.8	1587.1	106.0	0.2	2.3	34.9	0.9	0.1	105.9	1589.2
16	16.0	102.5	1640.7	103.1	0.5	8.3	133.4	0.9	0.5	103.0	1648.0
17	17.0	92.3	1569.4	92.8	0.5	7.7	131.3	0.9	0.4	92.7	1576.1
18	18.0	79.8	1436.5	80.9	1.1	19.9	358.6	0.9	1.0	80.8	1454.0
19	19.0	38.6	733.8	39.6	0.9	17.8	338.1	0.9	0.8	39.4	749.5
20	20.0	0.0	0.0	1.1	1.1	21.5	430.5	0.9	0.9	0.9	18.9

Weight distribution of displacement

$\Delta=\gamma\ \Delta L\ \Sigma_{11}$	10384.90	[t]
$x_b=\Delta L\ \Sigma_{12}/\Sigma_{11}-L/2$	3.11	[m]
x_p	3.10	[m]
P	10384.90	[t]



Basic relationships

The principal assumption for a load, shear forces and bending moment calculations are listed hereunder:

- There is only one independent variable, longitudinal position, *x*.
- The loads and deflection have a single value at any cross section.
- The hull girder remains elastic, its deflection is small, and the longitudinal strain due to bending varies linearly over the cross section, about some transverse axis of zero strain (neutral axis).
- Dynamic effects may be either neglected or accounted for by equivalent static loads.
- Since the bending strain is linear, the horizontal and vertical bending of the hull girder may be defined separately and superimposed.

Basic relationships

In elastic, small-deflection beam theory the governing equation for the bending moment is:

$$\frac{d^2M}{dx^2} = q(x)$$

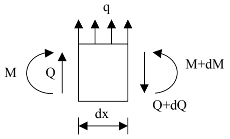
where q (x) is the loading on the beam, expressed as a distributed vertical force, t/m.

For a ship, this is a net distributed force that is resultant of the buoyancy force and the weight force.

In the sign convention adopted herein, forces are positive upward, but an exception is made for the weight force, which is conventionally regarded as positive. The net force is:

$$q(x) = b(x) - p(x)$$

Basic relationships



The solution for requires two integrations. The first yields the transverse shear force, and it is obtained by imposing vertical force equilibrium of a differential element considered as a free body:

$$Q + q dx - Q - dQ = 0$$

$$q = \frac{dQ}{dx}$$

$$Q(x) = \int_o^x q(x) dx + \lambda$$

Basic relationships

The equilibrium of moment yields:

$$M + Qdx + q\,dx\,\frac{dx}{2} - M - dM = 0$$

The dx^2 term of the second order is neglected and therefore:

$$Q = \frac{dM}{dx}$$

$$M(x) = \int_o^x Q(x) dx + \lambda$$

Basic relationships

In order to calculate the load on the hull girder it is necessary to calculate both the distributed buoyancy force and the distributed weight force.

The still water buoyancy is a completely static quantity and it depends mainly on the shape of the immersed hull.

The additional buoyancy force due to waves is markedly different from the buoyancy force in still water, being essentially both dynamic and probabilistic.

Basic relationships

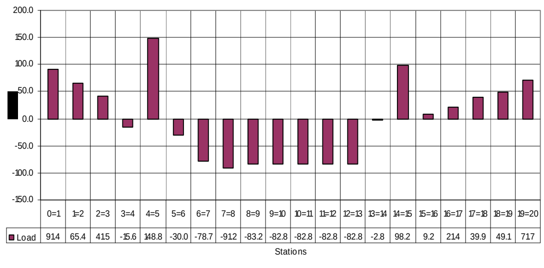
Stations	Area	Sum-par of [2]	Displacement [t], 0.5 γ [3] ΔL	Weight, [t]	Loading, [t], [5]-[4]	Sum from up	Integration of [7]	dQ, [t], $-[7]_{20}$[1]/20	Q, [t], [7]+[9]	0.5 ΔL [8]	dMsw=$-[11]_{20}$[1]/20	Msw=[11]+[12]
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]
0						0	0	0	0	0	0	0
1												
2												
3												
4												
…												
18												
19												
20						$[7]_{20}$		$-[7]_{20}$	0.0	$[11]_{20}$	$-[11]_{20}$	0

Shear forces and bending moment in still water

Stations	Area	Sum-par	Displ [t]	Weight, [t]	Load, [t]	Sum from up	Integration	dQ, [t]	Q, [t]		dMsw, [t.m]	Msw, [t.m]
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]
0	0.3	19.5	60.0	151.4	91.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0E+00
1	19.2	62.1	191.0	256.4	65.4	91.4	91.4	-0.2	91.2	274.1	-12.1	2.6E+02
2	42.9	107.8	331.4	372.9	41.5	156.8	339.5	-0.4	156.4	1018.6	-24.3	9.9E+02
3	64.8	148.4	456.4	440.8	-15.6	198.3	694.6	-0.6	197.7	2083.7	-36.4	2.0E+03
4	83.6	179.2	551.1	700.0	148.8	182.7	1075.5	-0.8	181.9	3226.6	-48.6	3.2E+03
5	95.6	198.6	610.8	580.8	-30.0	331.5	1589.7	-1.0	330.5	4769.1	-60.7	4.7E+03
6	103.0	208.8	642.2	563.5	-78.7	301.5	2222.7	-1.2	300.3	6668.1	-72.9	6.6E+03
7	105.8	213.0	655.1	563.9	-91.2	222.8	2747.0	-1.4	221.4	8240.9	-85.0	8.2E+03
8	107.2	214.4	659.3	576.1	-83.2	131.6	3101.4	-1.6	130.0	9304.1	-97.1	9.2E+03
9	107.2	214.4	659.3	576.5	-82.8	48.4	3281.3	-1.8	46.6	9844.0	-109.3	9.7E+03
10	107.2	214.4	659.3	576.5	-82.8	-34.4	3295.3	-2.0	-36.4	9886.0	-121.4	9.8E+03
11	107.2	214.4	659.3	576.5	-82.8	-117.2	3143.8	-2.2	-119.4	9431.3	-133.6	9.3E+03
12	107.2	214.4	659.3	576.5	-82.8	-199.9	2826.7	-2.4	-202.3	8480.0	-145.7	8.3E+03
13	107.2	214.4	659.3	656.5	-2.8	-282.7	2344.0	-2.6	-285.3	7032.1	-157.9	6.9E+03
14	107.2	213.1	655.4	753.7	98.2	-285.5	1775.8	-2.8	-288.3	5327.3	-170.0	5.2E+03
15	105.9	208.9	642.5	651.7	9.2	-187.3	1302.9	-3.0	-190.3	3908.8	-182.1	3.7E+03
16	103.0	195.7	601.8	623.2	21.4	-178.1	937.5	-3.2	-181.3	2812.5	-194.3	2.6E+03
17	92.7	173.5	533.5	573.4	39.9	-156.7	602.7	-3.4	-160.1	1808.0	-206.4	1.6E+03
18	80.8	120.2	369.7	418.7	49.1	-116.8	329.2	-3.6	-120.4	987.5	-218.6	7.7E+02
19	39.4	40.4	124.2	195.9	71.7	-67.7	144.7	-3.8	-71.5	434.1	-230.7	2.0E+02
20	0.9					4.0	81.0	-4.0	0.0	242.9	-242.9	0.0E+00

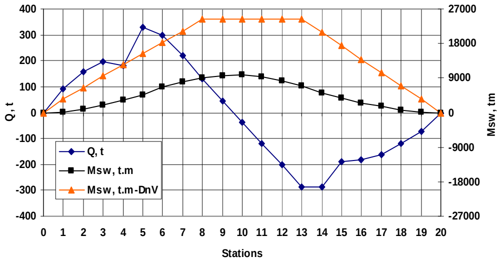
Shear forces and bending moment in still water

Loading distribution



Shear forces and bending moment in still water

Distribution of shear forces and still water bending moment.



Requirement of classification societies

Still water loads result from the action of the self-weight of the ship, the cargo or dead weight and the buoyancy.

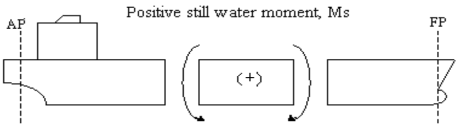
The variation of still water load depends to a large extent on the dead weight since the light ship weight is almost constant during the ship's lifetime and the buoyancy force is always equal to the sum of the other two components.

Therefore, the value of the still water effects is governed at each time by the amount of cargo and its distribution along the given ship.

Requirement of classification societies

The CS Rules calculate the design bending moment distribution along the ship length covering:

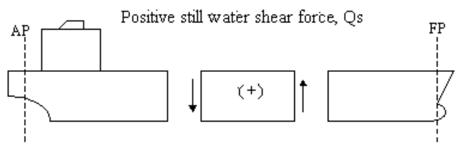
- The design still water bending moments in seagoing condition,
- Design wave bending moments in seagoing condition,
- Speed/flare corrected design wave bending moments in seagoing condition,
- A minimum hull girder section modulus requirement, and
- Maximum allowable still water bending moments in harbour.



Requirement of classification societies

The CS Rules calculate the design shear force distribution along the ship length covering:

- Design still water shear forces in seagoing condition,
- Design wave shear forces in seagoing condition.



Requirement of classification societies

The design still water bending moments amidships M_s (sagging and hogging) are normally not to be taken less than:

$M_s = M_{so}$, (kNm)

$M_{so} = -0.065\ C_{wu}\ L^2\ B\ (C_b + 0.7)$ in sagging,(kNm)

$M_{so} = C_{wu}\ L^2\ B\ (0.1225 - 0.015\ C_b)$, in hogging, (kNm)

$C_{wu} = C_w$

$$Cw = \begin{cases} 0.0792L & for\ \ L \le 100m \\ 10.75 - \left[\dfrac{(300-L)}{100}\right]^{3/2} & for\ \ 100 < L < 300m \\ 10.75 & for\ \ 300 \le L \le 350m \\ 10.75 - \left[\dfrac{(L-350)}{150}\right]^{3/2} & for\ \ L > 350m \end{cases}$$

Requirement of classification societies

When required in connection with stress analysis or buckling control, the still water bending moments at arbitrary positions along the length of the ship are normally not to be taken less than:

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

k_{sm}=1.0 within 0.4 L amidships

k_{sm}=0.15 at 0.1 L from AP or FP

k_{sm}=0 at FP and AP

Requirement of classification societies

The design values of still water shear forces along the length of the ship are normally not to be taken less than:

$Q_s = k_{sq} \, Q_{so}$, (kN)

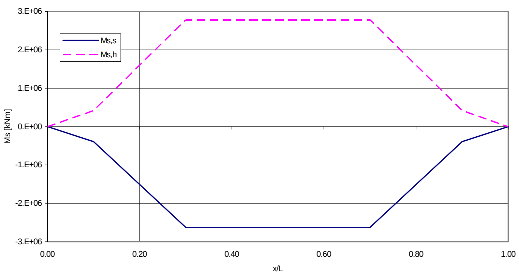
$Q_{so} = 5 \, M_{so}/L$, (kN)

where:

- k_{sq}=0 at AP and FP
- k_{sq}=1 between 0.15 L and 0.3 L from AP
- k_{sq}=0.8 between 0.4 L and 0.6 L from AP
- k_{sq}=1 between 0.7 L and 0.85 L from AP

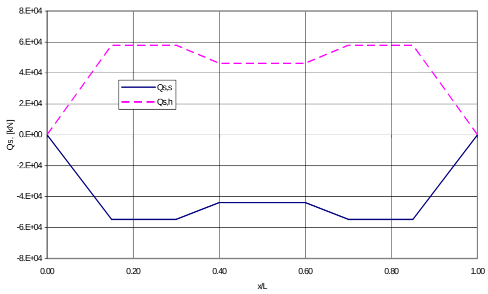
Requirement of classification societies

The design still water bending moments



Requirement of classification societies

Design shear forces in Stillwater



Wave-induced loads for ship structural analysis

It is generally accepted for the purposes of ship structural design and analysis that both hydrostatic and self-weight loads can be determined for a given ship condition with a high degree of confidence.

The underwater shape of the hull is determined from detailed knowledge of the hull offsets, enabling the buoyancy distribution to be calculated.

Detailed weight lists, including knowledge of stores, cargo and fuel enable the self-weight distribution to be calculated.

Load calculation methods

A ship is a freely floating body on the surface of the water and it is subjected to a combination of hydrostatic and hydrodynamic forces depending on whether either the ship or the free surface is moving.

At the overall or global level, if the ship is considered as a rigid body (a beam or girder), then Newton's second law must be satisfied, that is:

$$\vec{F} = \frac{\delta\left(m\vec{v}\right)}{\delta t} = m\vec{a}$$

Static-balance method

Typically the still water load is not the most severe overall loading case, as the effects of dynamic wave loading must be superimposed upon the still water case.

An exception to this is very large ships such as bulk carriers, where during loading or unloading, the overall bending moment may be large enough to bring about hull girder collapse.

Until recently, the usual approach has been to imagine the ship momentarily balanced upon a design wave, such that the net force and moment on the ship is zero, and to calculate the corresponding shear force and bending moment distributions.

Static-balance method

The static-balance is an idealised representation and does not directly allow for dynamic effects so it will not provide a true assessment of the actual stress distribution within the structure.

It is a very valuable tool in the 'Rules' approach to ship design. The ship is designed to 'Rules' such that calculated stresses are less than or equal to a specified maximum when the ship is balanced on the design wave.

This enables minimum sectional modulus to be determined and should be followed up later on with more detailed and specific calculations, such as analysis of stiffened panels or deck openings.

Static-balance method

Calculated stresses, using the design wave approach, may be used for comparison purposes throughout the life of the ship, but it should always be recognized that the calculated stress level is indicative only.

It is considered that this approach is conservative in terms of overall hull girder strength, and have been shown that bending moments predicted by the static-balance method are greater than those calculated from solutions to the equations of motion.

Static-balance method

The weight and 'static wave' buoyancy distributions are needed to determine the shear force and bending moment distribution along the length of the ship.

1. The ship is typically broken down into at least twenty sections for these calculations.
2. The weight distribution comes from design calculations.
3. The buoyancy distribution is calculated through an iterative procedure.

To calculate the buoyancy distribution, the waterline takes on the shape of the assumed wave profile (usually trochoidal) of height, *H* and of length, *λ*, which is the most commonly taken as $\lambda = L_{BP}$ although sometimes $\lambda = 0.9\, L_{BP}$ may be used.

Static-balance method

With the crest (hogging case) or trough (sagging case) of the wave at amidships, the trim and the submergence of the ship is iteratively adjusted until the force and moment equations are balanced:

For shear forces

$$\int_{-L/2}^{L/2} \left[w(x) - b(x) \right] dx = 0$$

Bending moments

$$\int_{-L/2}^{L/2} x \left[w(x) - b(x) \right] dx = 0$$

Once these equations are balanced, the shear force and bending moment distributions are determined through integration of the sectional forces along the hull.

Static-balance method

There has been much discussion as to suitable methods for specifying design wave height, and historical accounts of standard wave height. Probably the most common formula is:

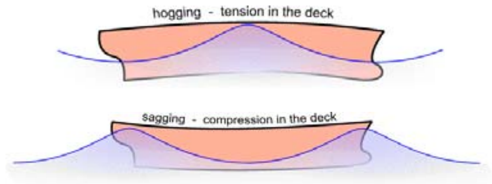
$$h_w = \frac{L}{20}$$

Although this is less commonly used, particularly for higher wave lengths,

$$h_w = 0.6\sqrt{L}$$

Static-balance method

Design wave forces are considered to be quasi-static. As a wave passes by a vessel, the worst hogging moment will occur when the midbody is on the crest of a wave and the bow and stern is in the troughs. The worst sagging moment will happen when the bow and stern are on two crests, with the midbody in the trough between.



Static-balance method

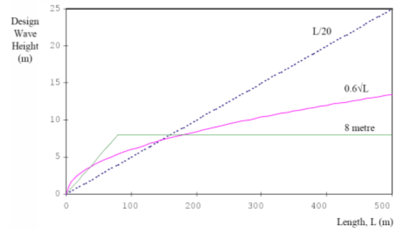
Whether for sagging or hogging, the worst condition will occur when the wavelength is close to the vessel length. If the waves are much shorter,

or much longer than the vessel, the bending moments will be less than if the wavelength equals the ship length.

Static-balance method

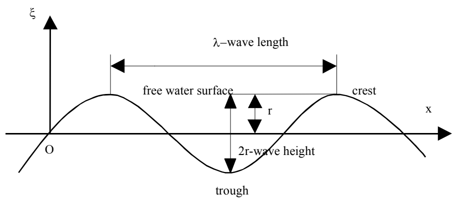
The '8m' wave is given by SSCP23. An increase of 15% is recommended if the ship operates solely in the North Atlantic.

$$h_w = \begin{cases} \frac{L}{10}\ m & ; L \le 80m \\ 8\ m & ; L > 80m \end{cases}$$



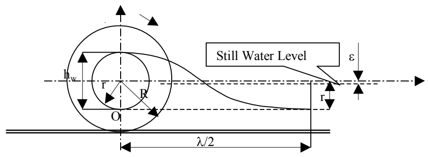
Static-balance method

Laying out the wave profile on that of the ship so that heights for reading the Bonjean curves may be obtained makes the buoyancy curve. The trochoidal-wave profile may be constructed



Static-balance method

Trochoidal-wave profile



The variation of the load of the ship as a result of the wave profile is:

$$q = -\gamma B(x)\left(\varsigma \mp r\cos\frac{2\pi x}{\lambda}\right)$$

Static-balance method

The condition of equilibrium may be written as:

$$\int_{-L/2}^{L/2} q\,dx = 0$$

leading to

$$\varsigma = \pm\frac{r\int_{-L/2}^{L/2} B(x)\cos\frac{2\pi x}{\lambda}dx}{A_{WP}}$$

Introducing

$$\int_{-L/2}^{L/2} B(x)\cos\frac{2\pi x}{\lambda}dx = \varphi BL$$

Static-balance method

Taken into account that the water plane area can be calculated as:

$$A_{WP} = \alpha_{WP} BL$$

leading to

$$\varsigma = \pm\frac{\varphi}{\alpha_{WP}}$$

Static-balance method

The additional vertical bending moment as a result of redistributing the buoyancy is:

$$M_W = \int_{-L/2}^{x}\int_{-L/2}^{x} q\,dx\,dx$$

Making superposition of additional load for the vertical bending moment is written:

$$M_W \mp \gamma r B L^2 \int_{-L/2}^{x}\int_{-L/2}^{x}\left(\frac{\varphi}{\alpha_{WP}} - \cos\frac{2\pi x}{\lambda}\right)\frac{B(x)}{B}\left[d\left(\frac{x}{L}\right)\right]^2$$

The sign (-) present the wave is in a wave trough (sagging) and (+) is for a wave crest (hogging).

Static-balance method

Finally the additional vertical bending moment that is taken into consideration of quasi static loading of the ship on the wave surface is: $M_W \mp \gamma r B L^2 k\left(\frac{L}{\lambda}, \alpha_{WP}, x\right)$

$$k = \int_{-L/2}^{x}\int_{-L/2}^{x}\left(\frac{\varphi}{\alpha_{WP}} - \cos\frac{2\pi x}{\lambda}\right)\frac{B(x)}{B}\left[d\left(\frac{x}{L}\right)\right]^2$$

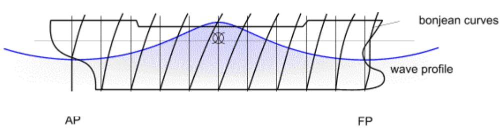
The additional vertical bending moment at the midship section (x=0) may be calculated as:

$$M_W(0) = -\int_{-L/2}^{0} xq\,dx$$

$$M_W(0) = \mp\gamma r B L^2 k_0$$

Static-balance method

We can now calculate the wave bending moments by placing the ship on the design wave. We can use the Bonjean curves to determine the buoyancy forces due to the quasi-static effects of the wave;



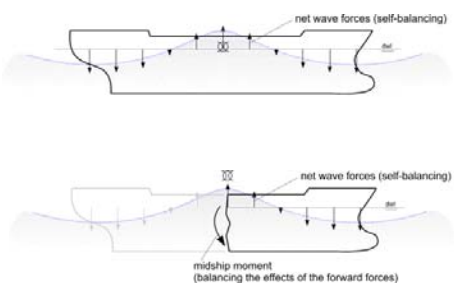
Static-balance method

The steps to determine the wave bending moment are;

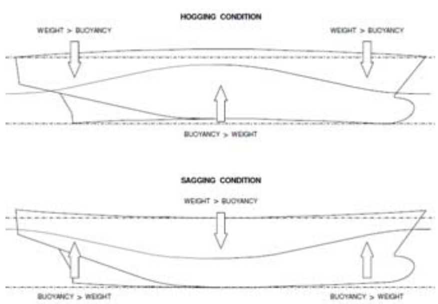
1. Obtain Bonjean curves
2. At each station determine the still water buoyancy forces.
3. At each station determine the total buoyancy forces
4. The net wave buoyancy forces are the difference between wave and still water.

This gives us a set of station buoyancy forces due to the wave (net of still water). These forces should be in equilibrium (no net vertical force).

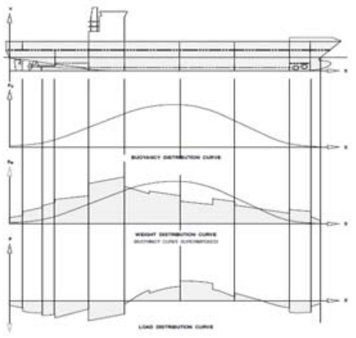
Static-balance method



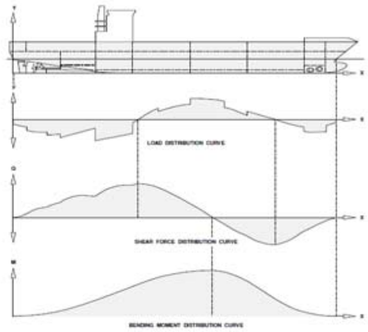
Static-balance method



Static-balance method

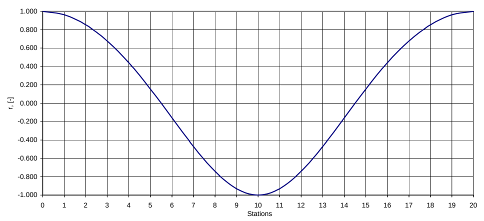


Static-balance method



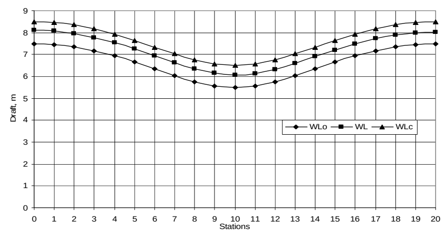
Wave-induced load – sagging

Wave ordinates - sagging



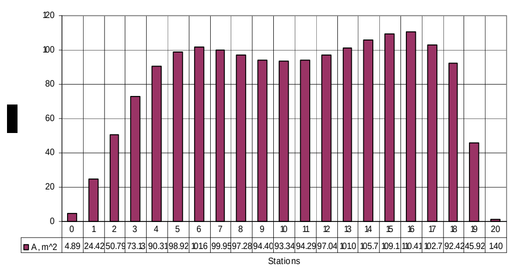
Static-balance method

Waterline positions – sagging



Static-balance method

Immersed section area – sagging



Bonjean plan - sagging

	Relative wave draft	T_{Wave}, [m]	T_{WLo}, [m]	T_{WL}, [m]	T_{WLc}, [m]	$Area_{Wlo}$, [%]	$Area_{WL}$, [%]	$Area_{WLc}$, [%]	$Area_{Mid}$, [m^2]	$Area_{Wlo}$, [m^2], [10][7][4]/D/100	$Area_{WL}$, [m^2], [10][8][5]/D/100	$Area_{WLc}$, [m^2], [10][9][6]/D/100
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]
0	1.00	1.00	7.50	8.12	8.50	6.11	7.71	8.80	153.74	7.04	9.62	11.50
1	0.96	0.96	7.46	8.07	8.46	17.88	19.58	20.69	153.74	20.51	24.31	26.91
2	0.85	0.85	7.35	7.96	8.35	39.64	41.48	42.56	153.74	44.81	50.77	54.65
3	0.68	0.68	7.18	7.78	8.18	59.62	61.07	62.02	153.74	65.78	73.05	77.97
4	0.44	0.44	6.94	7.54	7.94	76.90	77.82	78.50	153.74	82.06	90.21	95.83
5	0.15	0.15	6.65	7.25	7.65	88.12	88.66	89.13	153.74	90.15	98.80	104.88
6	-0.16	-0.16	6.34	6.93	7.34	94.90	95.23	95.60	153.74	92.53	101.50	107.91
7	-0.47	-0.47	6.03	6.62	7.03	98.36	98.18	98.19	153.74	91.19	99.87	106.12
8	-0.74	-0.74	5.76	6.34	6.76	100.20	99.73	99.54	153.74	88.69	97.22	103.42
9	-0.93	-0.93	5.57	6.15	6.57	100.37	99.86	99.61	153.74	85.91	94.37	100.58
10	-1.00	-1.00	5.50	6.08	6.50	100.43	99.92	99.64	153.74	84.92	93.32	99.57
11	-0.93	-0.93	5.57	6.14	6.57	100.37	99.87	99.61	153.74	85.91	94.26	100.58
12	-0.74	-0.74	5.76	6.33	6.76	100.20	99.74	99.54	153.74	88.69	96.98	103.42
13	-0.47	-0.47	6.03	6.59	7.03	99.96	99.59	99.51	153.74	92.66	100.95	107.54
14	-0.16	-0.16	6.34	6.90	7.34	99.73	99.51	99.56	153.74	97.23	105.58	112.38
15	0.15	0.15	6.65	7.21	7.65	98.36	98.35	98.55	153.74	100.62	109.00	115.97
16	0.44	0.44	6.94	7.49	7.94	95.24	95.76	96.31	153.74	101.63	110.30	117.57
17	0.68	0.68	7.18	7.72	8.18	85.91	86.45	87.04	153.74	94.79	102.66	109.42
18	0.85	0.85	7.35	7.90	8.35	74.88	76.03	77.05	153.74	84.66	92.31	98.95
19	0.96	0.96	7.46	8.00	8.46	36.70	37.41	37.80	153.74	42.11	46.02	49.18
20	1.00	1.00	7.50	8.04	8.50	0.00	1.00	2.00	153.74	0.00	1.24	2.61

Immersed sectional area - sagging

Stations	Coefficient	$Area_{WLo}$	[2][3]	$Area_{WLc}$	[5]-[3]	[6][2]	[7][2]	a/ε+b/e[1]/20	[6][9]	[3]+[10]	[11][2]
	-	m²	m²	m²	m²	m²	m²	-	m²	m²	m²
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
0	0.00	3.52	0.00	5.75	2.23	0.00	0.00	0.62	1.37	4.89	0.00
1	1.00	20.51	20.51	26.91	6.40	6.40	6.40	0.61	3.91	24.42	24.42
2	2.00	44.81	89.63	54.65	9.84	19.68	39.37	0.61	5.97	50.79	101.57
3	3.00	65.78	197.33	77.97	12.19	36.57	109.72	0.60	7.35	73.13	219.39
4	4.00	82.06	328.25	95.83	13.77	55.08	220.31	0.60	8.25	90.31	361.24
5	5.00	90.15	450.73	104.88	14.74	73.68	368.42	0.60	8.77	98.92	494.58
6	6.00	92.53	555.17	107.91	15.38	92.27	553.61	0.59	9.09	101.62	609.70
7	7.00	91.19	638.30	106.12	14.93	104.52	731.64	0.59	8.76	99.95	699.66
8	8.00	88.69	709.56	103.42	14.72	117.77	942.18	0.58	8.58	97.28	778.22
9	9.00	85.91	773.23	100.58	14.66	131.96	1187.61	0.58	8.49	94.40	849.63
10	10.00	84.92	849.15	99.57	14.65	146.51	1465.15	0.58	8.42	93.34	933.40
11	11.00	85.91	945.06	100.58	14.66	161.28	1774.08	0.57	8.37	94.29	1037.15
12	12.00	88.69	1064.34	103.42	14.72	176.66	2119.90	0.57	8.35	97.04	1164.50
13	13.00	92.66	1204.64	107.54	14.88	193.43	2514.62	0.56	8.38	101.04	1313.54
14	14.00	97.23	1361.28	112.38	15.15	212.05	2968.75	0.56	8.47	105.70	1479.82
15	15.00	100.62	1509.29	115.97	15.35	230.22	3453.30	0.56	8.52	109.14	1637.06
16	16.00	101.63	1626.05	117.57	15.94	255.11	4081.72	0.55	8.79	110.41	1766.61
17	17.00	94.79	1611.39	109.42	14.63	248.71	4228.04	0.55	8.00	102.79	1747.44
18	18.00	84.66	1523.82	98.95	14.29	257.29	4631.18	0.54	7.76	92.42	1663.53
19	19.00	42.11	800.08	49.18	7.07	134.31	2551.92	0.54	3.81	45.92	872.47
20	20.00	0.00	0.00	2.61	2.61	52.27	1045.41	0.54	1.40	1.40	27.96

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Loading condition - sagging

$\Delta = \Delta L\ \Sigma[11]\ \gamma$	10389	[t]
$Xc = \Delta L\ \Sigma[12]/\Sigma[11] - L/2$	3.16	[m]

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Shear forces and vertical bending moment - sagging

Stations	Immersed sectional area, still water, m²	Immersed sectional area, wave, m²	[2]-[3]	$[4]_i+[4]_{i-1}+[5]_{i-1}$	$[5]_i+[5]_{i-1}+[6]_{i-1}$	$0.5\gamma\Delta L[5]$	$dQw=-[7]_{20}\,[1]/20$, t	Qw=[7]+[8], t	$0.25\gamma\Delta L^2[6]$	$dMw=-[10]_{20}[1]/20$, tm	Mw= [10]+[11], tm
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
0	0.35	4.89	-4.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	19.17	24.42	-5.25	-9.79	-9.79	-30.12	-0.59	-30.70	-90.35	-102.22	-192.57
2	42.94	50.79	-7.84	-22.89	-42.48	-70.39	-1.17	-71.56	-391.87	-204.43	-596.31
3	64.84	73.13	-8.29	-39.03	-104.40	-120.00	-1.76	-121.76	-963.05	-306.65	-1269.70
4	83.58	90.31	-6.73	-54.04	-197.47	-166.19	-2.35	-168.53	-1821.62	-408.87	-2230.49
5	95.65	98.92	-3.27	-64.04	-315.55	-196.93	-2.93	-199.86	-2910.98	-511.09	-3422.06
6	103.00	101.62	1.38	-65.93	-445.52	-202.73	-3.52	-206.25	-4109.96	-613.30	-4723.26
7	105.84	99.95	5.89	-58.65	-570.10	-180.35	-4.10	-184.46	-5259.20	-715.52	-5974.72
8	107.20	97.28	9.92	-42.84	-671.59	-131.72	-4.69	-136.41	-6195.43	-817.74	-7013.17
9	107.20	94.40	12.80	-20.12	-734.54	-61.86	-5.28	-67.13	-6776.16	-919.95	-7696.11
10	107.20	93.34	13.86	6.54	-748.12	20.12	-5.86	14.25	-6901.38	-1022.17	-7923.55
11	107.20	94.29	12.91	33.32	-708.26	102.45	-6.45	96.00	-6533.69	-1124.39	-7658.07
12	107.20	97.04	10.16	56.39	-618.55	173.40	-7.04	166.36	-5706.14	-1226.61	-6932.75
13	107.20	101.04	6.16	72.71	-489.46	223.58	-7.62	215.95	-4515.22	-1328.82	-5844.04
14	107.20	105.70	1.50	80.37	-336.38	247.12	-8.21	238.91	-3103.13	-1431.04	-4534.17
15	105.94	109.14	-3.19	78.67	-177.35	241.91	-8.80	233.12	-1636.01	-1533.26	-3169.27
16	103.00	110.41	-7.41	68.06	-30.61	209.30	-9.38	199.91	-282.39	-1635.47	-1917.86
17	92.71	102.79	-10.08	50.57	88.03	155.52	-9.97	145.55	812.05	-1737.69	-925.64
18	80.78	92.42	-11.64	28.86	167.46	88.73	-10.56	78.18	1544.80	-1839.91	-295.11
19	39.45	45.92	-6.47	10.74	207.05	33.03	-11.14	21.88	1910.08	-1942.13	-32.05
20	0.95	1.40	-0.45	3.81	221.61	11.73	-11.73	0.00	2044.34	-2044.34	0.00

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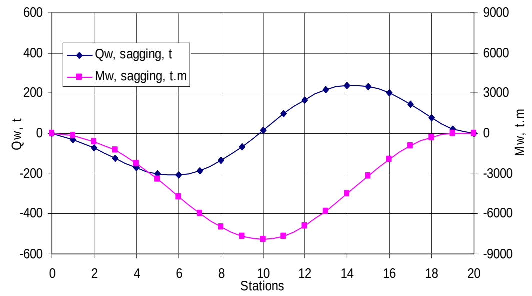
Static-balance method

Distribution of shear forces and wave induced bending moment, sagging



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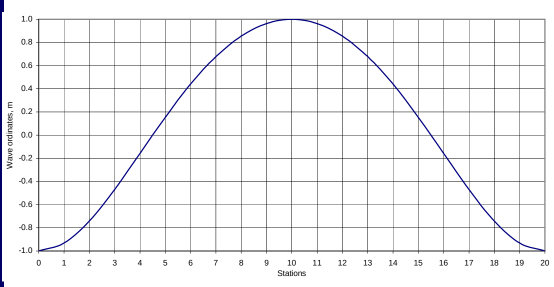
Wave-induced load – hogging

Wave ordinates, hogging



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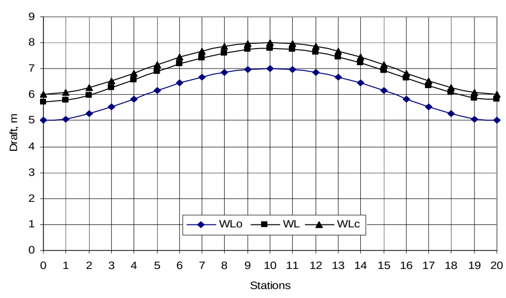
Static-balance method

Waterline positions, hogging



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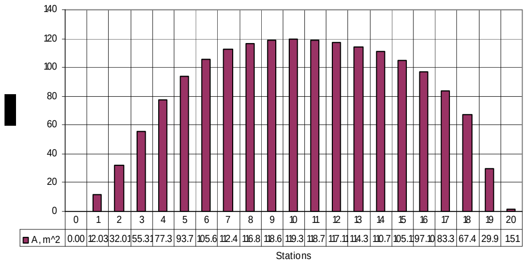
Static-balance method

Immersed sectional area, hogging



Bonjean plan, hogging

Stations	Relative draft of Wave	T_W, m	T_{WLo}, m	T_{WL}, m	T_{WLc}, m	$Area_{WLo}$, [%]	$Area_{WL}$, [%]	$Area_{WLc}$, [%]	$Area_{Mid}$, m²	$Area_{WLo}$, m², [10][7][4]/D/100	$Area_{WL}$, m², [10][8][5]/D/100	$Area_{WLc}$, m², [10][9][6]/D/100
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]
0	-1.00	-1.00	5.00	5.72	6.00	0.00	0.00	0.00	153.74	0.00	0.00	0.00
1	-0.93	-0.93	5.07	5.79	6.07	11.55	13.41	14.12	153.74	9.00	11.94	13.17
2	-0.74	-0.74	5.26	5.99	6.26	31.60	34.70	35.76	153.74	25.54	31.94	34.40
3	-0.47	-0.47	5.53	6.27	6.53	55.44	57.38	58.04	153.74	47.13	55.26	58.26
4	-0.16	-0.16	5.84	6.58	6.84	75.38	76.40	76.76	153.74	67.70	77.31	80.74
5	0.15	0.15	6.15	6.90	7.15	87.81	88.32	88.56	153.74	83.08	93.67	97.40
6	0.44	0.44	6.44	7.19	7.44	94.94	95.45	95.70	153.74	94.01	105.52	109.48
7	0.68	0.68	6.68	7.43	7.68	98.17	98.34	98.49	153.74	100.77	112.36	116.25
8	0.85	0.85	6.85	7.61	7.85	99.52	99.69	99.85	153.74	104.86	116.69	120.56
9	0.96	0.96	6.96	7.73	7.96	99.51	99.76	99.94	153.74	106.52	118.52	122.34
10	1.00	1.00	7.00	7.77	8.00	99.51	99.79	99.97	153.74	107.08	119.20	122.95
11	0.96	0.96	6.96	7.74	7.96	99.51	99.77	99.94	153.74	106.52	118.69	122.34
12	0.85	0.85	6.85	7.63	7.85	99.52	99.70	99.85	153.74	104.86	117.01	120.56
13	0.68	0.68	6.68	7.46	7.68	99.56	99.61	99.73	153.74	102.20	114.27	117.70
14	0.44	0.44	6.44	7.23	7.44	99.67	99.53	99.60	153.74	98.69	110.65	113.94
15	0.15	0.15	6.15	6.95	7.15	98.60	98.32	98.34	153.74	93.29	105.04	108.16
16	-0.16	-0.16	5.84	6.64	6.84	94.75	95.04	95.17	153.74	85.10	97.05	100.10
17	-0.47	-0.47	5.53	6.34	6.53	85.60	85.55	85.58	153.74	72.77	83.31	85.91
18	-0.74	-0.74	5.26	6.07	6.26	70.40	72.28	72.67	153.74	56.91	67.42	69.91
19	-0.93	-0.93	5.07	5.88	6.07	30.40	33.13	33.66	153.74	23.69	29.96	31.40
20	-1.00	-1.00	5.00	5.82	6.00	0.00	1.00	2.00	153.74	0.00	0.89	1.84

Immersed sectional area, hogging

Stations	Coefficient	$Area_{WLo}$	[2][3]	$Area_{WLc}$	[5]-[3]	[6][2]	[7][2]	a/ε+b/e[2] /20	[6][9]	[3]+[10]	[11][2]
	-	m²	m²	m²	m²	m²	m²	-	m²	m²	
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00
1	1.00	9.00	9.00	13.17	4.18	4.18	4.18	0.73	3.03	12.03	12.03
2	2.00	25.54	51.09	34.40	8.86	17.72	35.44	0.73	6.47	32.01	64.02
3	3.00	47.13	141.39	58.26	11.13	33.40	100.19	0.74	8.18	55.31	165.94
4	4.00	67.70	270.79	80.74	13.05	52.18	208.73	0.74	9.65	77.35	309.40
5	5.00	83.08	415.39	97.40	14.32	71.61	358.03	0.75	10.67	93.75	468.73
6	6.00	94.01	564.08	109.48	15.47	92.81	556.85	0.75	11.60	105.61	633.68
7	7.00	100.77	705.39	116.25	15.48	108.33	758.31	0.76	11.68	112.45	787.18
8	8.00	104.86	838.91	120.56	15.70	125.60	1004.81	0.76	11.93	116.80	934.37
9	9.00	106.52	958.68	122.34	15.82	142.40	1281.56	0.77	12.10	118.62	1067.61
10	10.00	107.08	1070.85	122.95	15.86	158.62	1586.24	0.77	12.21	119.30	1192.99
11	11.00	106.52	1171.72	122.34	15.82	174.04	1914.43	0.78	12.26	118.78	1306.60
12	12.00	104.86	1258.37	120.56	15.70	188.40	2260.82	0.78	12.25	117.11	1405.32
13	13.00	102.20	1328.62	117.70	15.50	201.51	2619.69	0.79	12.17	114.37	1486.81
14	14.00	98.69	1381.71	113.94	15.25	213.45	2988.24	0.79	12.04	110.74	1550.34
15	15.00	93.29	1399.29	108.16	14.87	223.05	3345.81	0.80	11.82	105.11	1576.61
16	16.00	85.10	1361.55	100.10	15.01	240.09	3841.52	0.80	12.00	97.10	1553.63
17	17.00	72.77	1237.16	85.91	13.14	223.35	3796.97	0.81	10.58	83.35	1416.96
18	18.00	56.91	1024.34	69.91	13.00	234.07	4213.31	0.81	10.53	67.44	1213.94
19	19.00	23.69	450.10	31.40	7.71	146.58	2785.06	0.82	6.29	29.98	569.56
20	20.00	0.00	0.00	1.84	1.84	36.90	737.94	0.82	1.51	1.51	30.26

Loading status - hogging

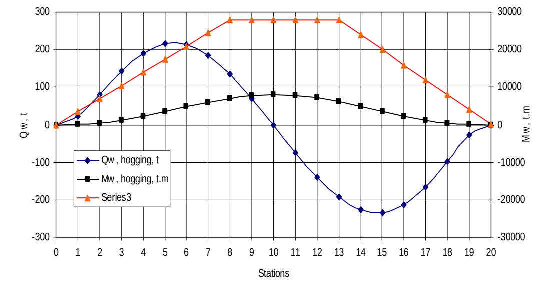
Δ=γ ΔL Σ[11] γ	10132.35	[t]
Xc=ΔL Σ[12]/Σ[11]-L/2	3.05	[m]

Shear forces and vertical wave bending moment - hogging

Stations	Immersed area, still water, m²	Immersed area, wave, m²	[2]-[3]	[4]i+[4]i-1+[5]i-1	[5]i+[5]i-1+[6]i-1	0.5γΔL[5]	dQw=-[7]20[1]/20, t	Qw=[7]+[8], t	0.25γΔL²[6]	dMw=-[10]20[1]/20, tm	Mw=[10]+[11], tm
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
0	0.35	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	19.17	12.03	7.15	7.49	7.49	23.04	0.00	23.05	69.12	39.37	108.50
2	42.94	32.01	10.93	25.57	40.56	78.62	0.01	78.63	374.12	78.75	452.87
3	64.84	55.31	9.53	46.03	112.15	141.53	0.01	141.54	1034.58	118.12	1152.69
4	83.58	77.35	6.23	61.78	219.96	189.98	0.02	190.00	2029.10	157.49	2186.59
5	95.65	93.75	1.90	69.91	351.65	214.98	0.02	215.00	3243.98	196.86	3440.85
6	103.00	105.61	-2.61	69.20	490.76	212.79	0.03	212.81	4527.28	236.24	4763.52
7	105.84	112.45	-6.61	59.97	619.94	184.42	0.03	184.45	5718.90	275.61	5994.51
8	107.20	116.80	-9.60	43.77	723.68	134.59	0.03	134.62	6675.92	314.98	6990.91
9	107.20	118.62	-11.42	22.75	790.20	69.95	0.04	69.99	7289.55	354.36	7643.91
10	107.20	119.30	-12.10	-0.77	812.17	-2.37	0.04	-2.33	7492.29	393.73	7886.02
11	107.20	118.78	-11.58	-24.45	786.95	-75.19	0.05	-75.14	7259.62	433.10	7692.72
12	107.20	117.11	-9.91	-45.94	716.56	-141.27	0.05	-141.22	6610.24	472.47	7082.71
13	107.20	114.37	-7.17	-63.02	607.59	-193.79	0.06	-193.73	5605.05	511.85	6116.90
14	107.20	110.74	-3.54	-73.73	470.84	-226.71	0.06	-226.65	4343.54	551.22	4894.76
15	105.94	105.11	0.84	-76.43	320.69	-235.02	0.06	-234.96	2958.32	590.59	3548.92
16	103.00	97.10	5.90	-69.70	174.56	-214.32	0.07	-214.25	1610.31	629.97	2240.27
17	92.71	83.35	9.36	-54.43	50.43	-167.38	0.07	-167.31	465.21	669.34	1134.55
18	80.78	67.44	13.34	-31.73	-35.74	-97.58	0.08	-97.51	-329.69	708.71	379.02
19	39.45	29.98	9.47	-8.93	-76.40	-27.46	0.08	-27.38	-704.82	748.08	43.27
20	0.95	1.51	-0.57	-0.03	-85.36	-0.09	0.09	0.00	-787.46	787.46	0.00

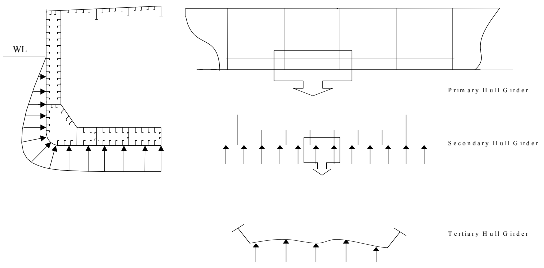
Static-balance method

Distribution of shear forces and wave induced bending moment, hogging



Primary hull girder stresses

Primary secondary and tertiary hull girder components



Primary direct stress

Elementary **Bernoulli-Euler** beam theory is usually used in computing the primary stress or deflection due to vertical or lateral hull bending loads.

Considerations related to the applicability of beam theory:

- **The beam is prismatic, i.e. all cross sections are the same.**
- **Plane cross sections remain plane and merely rotate as the beam deflects.**
- **Transverse (Poisson) effects on strain are neglected.**
- **The material behaves elastically, the moduli of elasticity in tension and compression being equal.**
- **Shear effect (stresses, strains) can be separated from and do not influence bending stresses or strains.**

Primary direct stress

The elastic curve equation under assumptions of the elementary beam theory may be obtained by equating the resisting moment to the bending moment, at section *x*:

$$EI\frac{d^2z}{dx^2} = M(x)$$

This may be written in terms of the load per unit length, $q(x)$ as:

$$EI\frac{d^4z}{dx^4} = q(x)$$

Primary direct stress

Integrating for the deflection of the ship hull as a beam with variable net section may be written.

$$z(x) = \frac{M_{mid}L^2}{EI_{mid}}\left[\int_0^x\int_0^x \frac{M(x)}{M_{mid}}\frac{I_0}{I(x)}d\left(\frac{x}{L}\right)d\left(\frac{x}{L}\right) + a\frac{x}{L} + b\right]$$

If it is assumed that:

$$\frac{x}{L} = \xi \qquad \frac{d^2z}{dx^2} = \frac{1}{L}\frac{d^2z}{d\xi^2} \qquad \frac{M(x)I_{mid}}{M_{mid}I(x)} = f(\xi)$$

Primary direct stress

$$z = \frac{M_{mid}L^2}{EI_{mid}}\left[\int_0^\xi\int_0^\xi f(\xi)d\xi^2 - \xi\int_0^1\int_0^\xi f(\xi)d\xi^2\right]$$

where

$$\int_0^\xi f(\xi)d\xi = \frac{1}{n}\sum_{i=0}^{m-1}(f_i + f_{i+1}) = \frac{1}{2n}S_m$$

$$\int_0^\xi\int_0^\xi f(\xi)d\xi^2 = \frac{1}{n^2}\sum_{m=0}^{k-1}(S_m + S_{m+1})$$

Primary direct stress

The calculation of the deflection has to be performed taking into account that:

$$M_{mid} = M_{sw} + M_{vw}$$

The maximum deflection can be evaluated by:

$$z_{max} = \frac{M_{max}L^2}{kI_{max}}$$

where the coefficient *k* depends on the distribution of the moment of inertia and vertical bending moment

Primary direct stress

The longitudinal stress in section *x* is related to the bending moment by the following equation:

$$\sigma(x,z) = \frac{M(x)}{I(x)} z$$

The extreme stresses are found at the top or bottom of the beam where ***z*** takes on its numerically largest values.

The quantity $W(x)=I(x)/z$ is termed the section modulus of the beam. The extreme stress at the deck or bottom is given by:

$$\sigma(x,z) = \frac{M(x)}{W(x,z)}$$

Calculation of section modulus

The section modulus to the deck or bottom is obtained by deriving the moment of inertia by the distance from the neutral axes to the moulded deck line at the side or to the baseline, respectively.

The following items may be included, provided they are continuously or effectively developed:

- Deck plating (strength deck and other effective decks)
- Shell and inner-bottom plating,
- Deck and bottom girders.
- Plating and longitudinal stiffeners of longitudinal bulkheads.
- All longitudinals of deck, sides, bottom and inner bottom.
- Continuous longitudinal hatch comings.

Calculation of section modulus

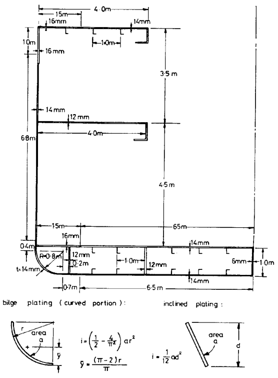
The section modulus calculation for the cargo ship is based on the following formula for the moment of inertia of any composite girder section:

$$I = 2\left[I_{zz} - Ah_{NA}^2\right] = 2\left[\sum\left(i + ah^2\right) - Ad_{NA}^2\right]$$

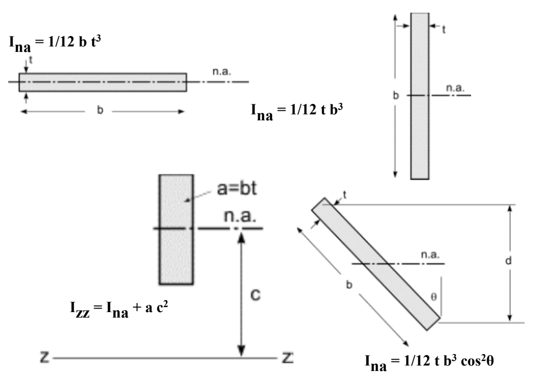
If the assumed axis be assigned an arbitrary location, the known or directly determinable values may be obtained:

$$h_{NA} = \frac{\sum ah}{\sum a} = \frac{\sum ah}{A}$$

Calculation of section modulus



Calculation of section modulus



Section modulus

Item	Scantlings [m•mm]	Area a[m²]	Height h[m]	Moment ah[m³]	Second Moment ah²[m⁴]	Local Second moment i[m⁴]
Strength deck plating	2.5•14	0.0350	9	0.3150	2.835	
Strength deck stringer plate	1.5•16	0.0240	9	0.2160	1.944	
Strength deck longitudinals	W160•14; f40•14	0.0084	8.9	0.0748	0.666	
Sheer strike	1.0•16	0.0160	8.5	0.1360	1.156	0.001
Side plating	7.2•14	0.1008	4.4	0.4435	1.951	0.435
Second deck plating	4.0•12	0.0480	5.5	0.2640	1.452	
Bilge (curved portion)	R=0.8; t=14	0.0176	0.29	0.0051	0.001	0.001
Inner bottom plating	6.5•14	0.0910	1.0	0.0910	0.091	
Inner bottom margin plate	1.5•16	0.0240	1.0	0.0240	0.024	
Inner bottom longitudinals	W200•10; F66•15	0.0150	0.86	0.0129	0.011	
Side girders	1.0•12	0.0240	0.5	0.0120	0.006	0.002
Centre girder (1/2)	1.0•6	0.0060	0.5	0.0030	0.001	0.001
Bottom plating	7.2•14	0.1008	0.0	0	0	
Bottom longitudinals	W200•10; F66•15	0.0150	0.14	0.0021	0.000	
Upper hatch side girder	W0.5•24; F0.4•25	0.0225	8.64	0.1944	1.680	
Lower hatch side girder	W0.5•25; F0.4•25	0.0225	5.14	0.1157	0.595	
Totals		0.5706		1.9095	12.413	0.440

Section modulus

The distance of the neutral axis above the keel is:

$$h_{NA} = \frac{\sum a_i h_i}{\sum a_i} = \frac{1.9095}{0.5706} = 3.346\ [m]$$

$$I = I_{zz} - Ah_{NA}^2 = (12.413 + 0.440) - 6.390 = 6.463\ [m^4]$$

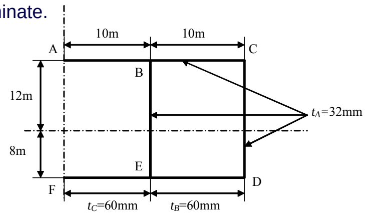
$$W_d = \frac{I}{h_D - h_{NA}} = \frac{12.93}{9.00 - 3.346} = 2.287\ [m^3]$$

$$W_b = \frac{I}{h_{NA}} = \frac{12.93}{3.346} = 3.864\ [m^3]$$

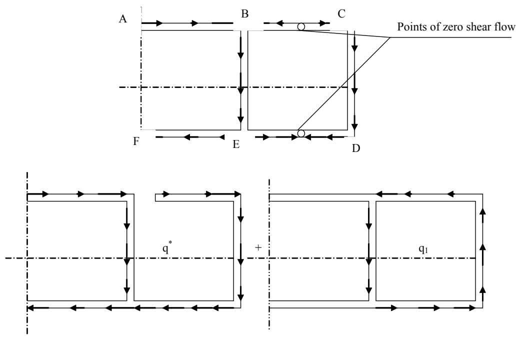
Shear stress in ship structure - multicell

In the definition of S^* was assumed that the line integral was always commenced at a point of zero shear flow.

Consequently for the tanker, the value of S^* can only be calculated along AB and FE; it cannot be calculated anywhere around the perimeter of the wing tank BCDEB –statically indeterminate.



Shear stress in ship structure - multicell



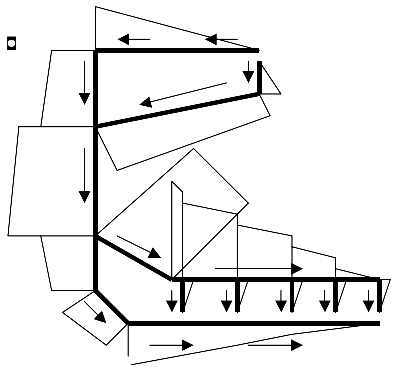
Shear stress in ship structure - multicell

The standard technique consists of two main steps:

A-Remove a sufficient number of restraints resulting in a statistically determinate problem. The artificial model has displacements at the restraint points which should be zero.

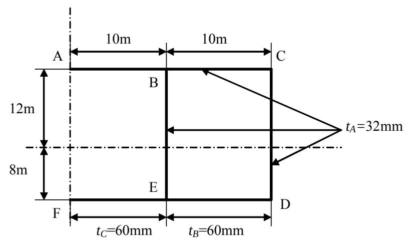
B-For each such restraint point impose the geometric condition that the displacement should be zero.

Shear stress in ship structure - multicell



Shear flow calculation of multicell section

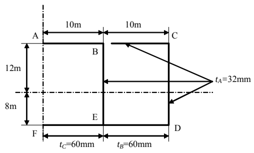
The shear flow will be calculated for the idealised tanker. The thickness will be expressed in terms of a reference thickness, t_A , instead of substituting their numerical values.



Shear flow calculation of multicell section

Step 1. Calculation of *S**

Branch BCDE:



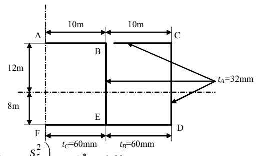
BC $\quad S^* = \int_o^{s_1} 12t_A ds_1 = 12t_A s_1,\ S_C^* = 120t_A$

CD $\quad S^* = S_C^* + \int_o^{s_2} (12 - s_2) t_A ds_2 = 120t_A + \left(12s_2 - \frac{s_2^2}{2}\right) t_A,\ S_D^* = 160t_A$

DE $\quad S^* = S_D^* + \int_o^{s_3} (-8) t_B ds_3 = 160t_A - 8t_B s_3,\ S_E^* = 160t_A - 80t_B = \left(160 - 80\frac{68}{32}\right) t_A = -10t_A$

Shear flow calculation of multicell section

Branch ABE



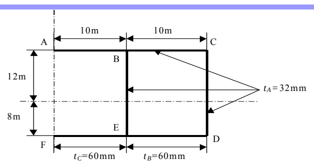
AB $\quad S^* = \int_o^{s_4} 12t_A ds_4 = 12t_A s_4,\ S_B^* = 120t_A$

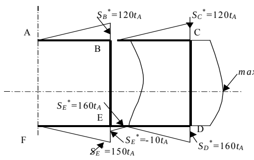
BE $\quad S^* = S_B^* + \int_o^{s_5} (12 - s_5) t_A ds_5 = 120t_A + \left(12s_5 - \frac{s_5^2}{2}\right) t_A,\ S_E^* = 160t_A$

Branch FE

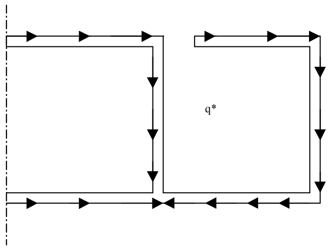
FE $\quad S^* = \int_o^{s_6} (8) t_C ds_6 = 8t_C s_6,\ S_E^* = 80t_C = 80\frac{60}{32} t_A = 150t_A$

Shear flow calculation of multicell section



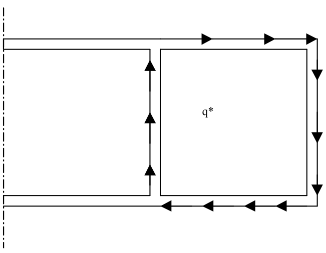


Shear flow calculation of multicell section

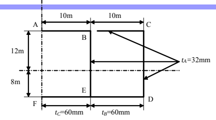


Shear flow calculation of multicell section

Step 2 Cyclic integration $\oint \frac{S^*}{t} ds$



Shear flow calculation of multicell section



BC $\quad \int_o^{10} \frac{12t_A s_1}{t_A} ds_1 = 600$

CD $\quad \int_o^{20} \frac{\left(120 + 12s_2 - \frac{s_2^2}{2}\right) t_A}{t_A} ds_2 = \left[120s_2 + 6s_2^2 - \frac{s_2^3}{6}\right]_0^{20} = 3467$

DE $\quad \int_o^{10} \frac{(160t_A - 8t_B s_3)}{t_B} ds_3 = \int_o^{10} \left(160\frac{32}{68} - 8s_3\right) ds_3 = 353$

EB $\quad \int_o^{20} \frac{-\left(120 + 12s_4 - \frac{s_4^2}{2}\right) t_A}{t_A} ds_4 = -\left[120s_4 + 6s_4^2 - \frac{s_4^3}{6}\right]_0^{20} = -3467$

(negative because the integration is against the flow)

$$\oint \frac{S^*}{t} ds = 600 + 3467 + 353 - 3467 = 953$$

Shear flow calculation of multicell section

Step 3. Cyclic integration $\oint \frac{ds}{t}$

BCD, DE and EB:

$$\left\{\begin{aligned} \int_0^{30} \frac{ds}{t_A} &= \frac{30}{t_A} \\ \int_0^{10} \frac{ds}{t_B} &= \frac{10}{t_B} \\ \int_0^{20} \frac{ds}{t_A} &= \frac{20}{t_A} \end{aligned}\right\} \qquad \oint \frac{ds}{t} = \frac{30 + 10\left(\frac{32}{68}\right) + 20}{t_A} = \frac{54.71}{t_A}$$

Shear flow calculation of multicell section

Step 4: Calculation of corrective shear flow

$$q_1 = -\frac{Q}{I}\frac{\oint \frac{S^*}{t} ds}{\oint \frac{ds}{t}} = -\frac{Q}{I}\frac{953}{54.71} = -\frac{Q}{I}\left(17.42 t_A\right)$$

A negative value indicates that corrective shear flow is counter clockwise.

Step 5. Total shear flow

$$q = q^* + q_1 = \frac{Q}{I}\left(S^* - 17.42 t_A\right)$$