Innovative Ship and Offshore Plant Design

Part I. Ship Design

Ch. 10 Structural Design

Spring 2019

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Ch. 10 Structural Design

1. General & Materials

(1) Stress Transmission
(2) Principal Dimensions
(3) Criteria for the Selection of Plate Thickness, Grouping of Longitudinal Stiffener
(4) Material Factors

(1) Stress Transmission

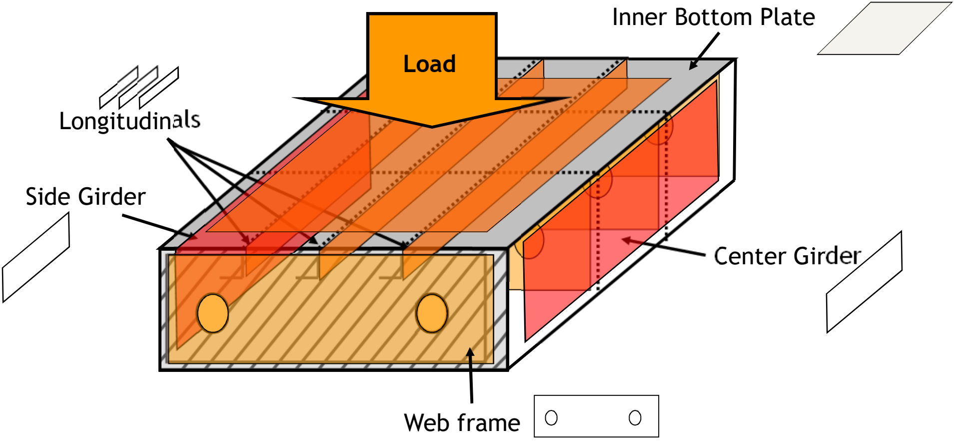


Plate ➡ Longi. ➡ Web frame ➡ Girder

➡ : Stress Transmission

DNV Rules, Jan. 2004, Pt. 3 Ch. 1 Sec. 1 101

(2) Principal Dimensions

The following principal dimensions are used in accordance with DNV rule.

1) Rule length (L or L_s)

: Length of a ship used for rule scantling procedure

$$\boxed{0.96 \cdot L_{WL} < L < 0.97 \cdot L_{WL}}$$

- Distance on the summer load waterline (L_{WL}) from the fore side of the stem to the axis of the rudder stock
- Not to be taken less than 96%, and need not be taken greater than 97%, of the extreme length on the summer load waterline (L_{WL})
- Starting point of rule length: F.P

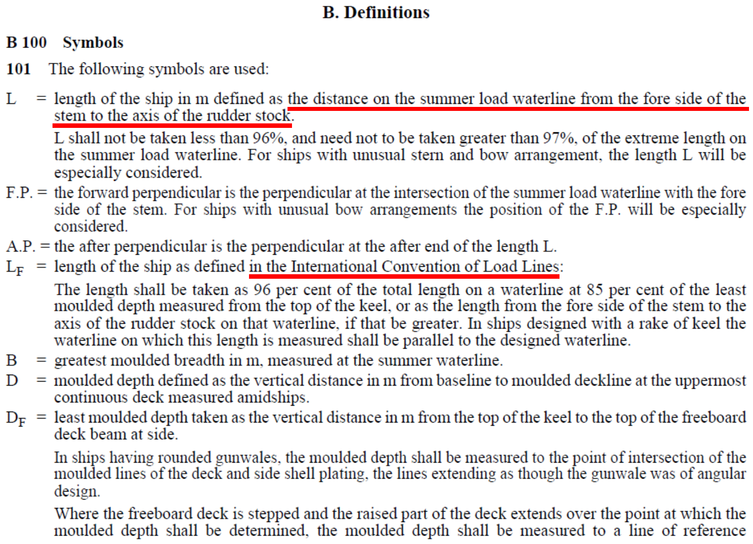
Ex.

L_{BP}	L_{WL}	$0.96 \cdot L_{WL}$	$0.97 \cdot L_{WL}$	L
250	261	250.56	253.17	250.56
250	258	247.68	250.26	250.00
250	255	244.80	247.35	247.35

2) Breadth

: Greatest moulded breadth in [m], measured at the summer load waterline

(DNV Pt.3 Ch.1 Sec.1 B101), 2011



B. Definitions

B 100 Symbols

101 The following symbols are used:

L = length of the ship in m defined as the distance on the summer load waterline from the fore side of the stem to the axis of the rudder stock.
L shall not be taken less than 96%, and need not to be taken greater than 97%, of the extreme length on the summer load waterline. For ships with unusual stern and bow arrangement, the length L will be especially considered.

F.P. = the forward perpendicular is the perpendicular at the intersection of the summer load waterline with the fore side of the stem. For ships with unusual bow arrangements the position of the F.P. will be especially considered.

A.P. = the after perpendicular is the perpendicular at the after end of the length L.

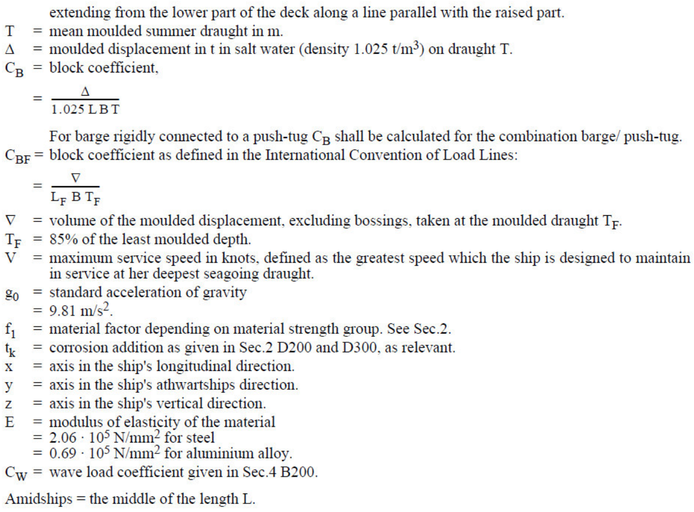
L_F = length of the ship as defined in the International Convention of Load Lines:
The length shall be taken as 96 per cent of the total length on a waterline at 85 per cent of the least moulded depth measured from the top of the keel, or as the length from the fore side of the stem to the axis of the rudder stock on that waterline, if that be greater. In ships designed with a rake of keel the waterline on which this length is measured shall be parallel to the designed waterline.

B = greatest moulded breadth in m, measured at the summer waterline.

D = moulded depth defined as the vertical distance in m from baseline to moulded deckline at the uppermost continuous deck measured amidships.

D_F = least moulded depth taken as the vertical distance in m from the top of the keel to the top of the freeboard deck beam at side.
In ships having rounded gunwales, the moulded depth shall be measured to the point of intersection of the moulded lines of the deck and side shell plating, the lines extending as though the gunwale was of angular design.
Where the freeboard deck is stepped and the raised part of the deck extends over the point at which the moulded depth shall be determined, the moulded depth shall be measured to a line of reference

(DNV Pt.3 Ch.1 Sec.1 B101), 2011



extending from the lower part of the deck along a line parallel with the raised part.

T = mean moulded summer draught in m.

Δ = moulded displacement in t in salt water (density 1.025 t/m^3) on draught T.

C_B = block coefficient,

$$= \frac{\Delta}{1.025\, L B T}$$

For barge rigidly connected to a push-tug C_B shall be calculated for the combination barge/ push-tug.

C_{BF} = block coefficient as defined in the International Convention of Load Lines:

$$= \frac{\nabla}{L_F\, B\, T_F}$$

∇ = volume of the moulded displacement, excluding bossings, taken at the moulded draught T_F.

T_F = 85% of the least moulded depth.

V = maximum service speed in knots, defined as the greatest speed which the ship is designed to maintain in service at her deepest seagoing draught.

g_0 = standard acceleration of gravity
= 9.81 m/s^2.

f_1 = material factor depending on material strength group. See Sec.2.

t_k = corrosion addition as given in Sec.2 D200 and D300, as relevant.

x = axis in the ship's longitudinal direction.

y = axis in the ship's athwartships direction.

z = axis in the ship's vertical direction.

E = modulus of elasticity of the material
= $2.06 \cdot 10^5$ N/mm^2 for steel
= $0.69 \cdot 10^5$ N/mm^2 for aluminium alloy.

C_W = wave load coefficient given in Sec.4 B200.

Amidships = the middle of the length L.

DNV Rules, Jan. 2004, Pt. 3 Ch. 1 Sec. 1 101

(2) Principal Dimensions

3) Depth (D)

: Moulded depth defined as the vertical distance in [m] from baseline to moulded deck line at the uppermost continuous deck measured amidships

4) Draft (T)

: Mean moulded summer draft (**scantling draft**) in [m]

5) Brock coefficient (C_B)

: To be calculated based on the rule length

$$C_B = \frac{\Delta}{1.025 \cdot L \cdot B \cdot T}$$, (Δ : moulded displacement in salt water on draft T)

DNV Rules, Jan. 2004, Pt. 3 Ch. 1 Sec. 1 101

(3) Criteria for the Selection of Plate Thickness, Grouping of Longitudinal Stiffener

1) Criteria for the selection of plate thickness

➡ When selecting plate thickness, use the provided plate thickness.

(1) 0.5 mm interval
(2) Above 0.25 mm: 0.5 mm
(3) Below 0.25 mm: 0.0 mm

Ex) 15.75 mm ➡ 16.0 mm
15.74 mm ➡ 15.5 mm

2) Grouping of longitudinal stiffener

For the efficiency of productivity, each member is arranged by grouping longitudinal stiffeners. The grouping members should satisfy the following rule.

Average value but not to be taken less than 90% of the largest individual requirement (DNV).

Ex) The longitudinal stiffeners have design thickness of 100, 90, 80, 70, 60 mm. The average thickness is given by 80 mm×5. However, the average value is less than 100mm×90% = 90 mm of the largest individual requirement, 100 mm.
Therefore, the average value should be taken 90 mm×5.

(4) Material Factors

1) DNV Rules, Jan. 2004, Pt. 3 Ch. 1 Sec.2

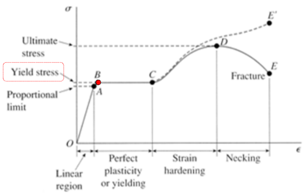
2) James M. Gere, Mechanics of Materials 7th Edition, Thomson, Chap.1, pp.15~26

- The material factor f_1 is included in the various formulae for scantlings and in expressions giving allowable stresses.1)

Material Designation	Yield Stress (N/mm^2)	$\frac{\sigma}{\sigma_{NV-NS}}$	Material Factor (f_1)
NV-NS	235	235/235 = 1.00	1.00
NV-27	265	265/235 = 1.13	1.08
NV-32	315	315/235 = 1.34	1.28
NV-36	355	355/235 = 1.51	1.39
NV-40	390	390/235 = 1.65	1.47

* NV-NS: Normal Strength Steel (Mild Steel)

* NV-XX: High Tensile Steel



* Yield Stress (σ_y) [N/mm^2] or [MPa]: The magnitude of the load required to cause yielding in the beam.2)

* High tensile steel: A type of alloy steel that provides better mechanical properties or greater resistance to corrosion than carbon steel. They have a carbon content between 0.05-0.25% to retain formability and weldability, including up to 2.0% manganese, and other elements are added for strengthening purposes.

* A: 'A' grade 'Normal Strength Steel'

* AH: 'A' grade 'High Tensile Steel'

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2. Global Hull Girder Strength (Longitudinal Strength)

(1) Generals
(2) Still Water Bending Moment (Ms)
(3) Vertical Wave Bending Moment (Mw)
(4) Section Modulus

Interest of "Ship Structural Design"

- Ship Structural Design

What is designer's major interest?

- Safety:

Won't 'it' fail under the load?

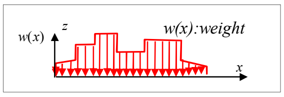
a ship } global

a stiffener
a plate } local

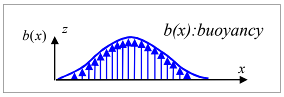
Let's consider the safety of the ship from the point of global strength first.

Dominant Forces Acting on a Ship

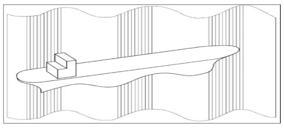
What are dominant forces acting on a ship in view of the longi. strength?



weight of light ship, weight of cargo, and consumables



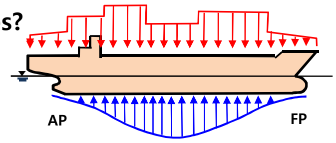
hydrostatic force (buoyancy) on the submerged hull



hydrodynamic force induced by the wave

What is the direction of the dominant forces?

The forces act in vertical (lateral) direction along the ship's length.



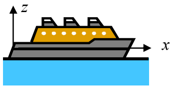
Longitudinal Strength

: Overall strength of ship's hull which resists the bending moment, shear force, and torsional moment acting on a hull girder.

Longitudinal strength loads

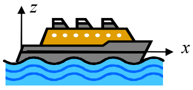
: Load concerning the overall strength of the ship's hull, such as the bending moment, shear force, and torsional moment acting on a hull girder

longitudinal loads



Loads are caused by
in longitudinal direction in the still water
condition

longitudinal loads



Loads are induced by

¹⁾ Okumoto,Y., Design of Ship Hull Structures, Springers, 2009, P.17

Idealization of the Ship Hull Girder Structure

How can we idealize a ship as a structural member?

- **Structural member according to the types of loads**

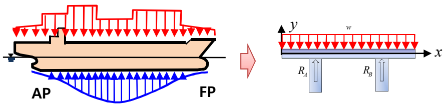
  ① Axially loaded bar: structural member which supports forces directed along the axis of the bar

  ② Bar in torsion: structural member which supports torques (or couples) having their moment about the longitudinal axis

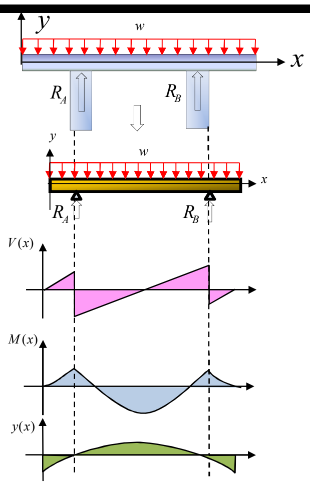
  ③ Beam: structural members subjected to lateral loads, that is, forces or moments perpendicular to the axis of the bar

Since a ship has a slender shape and subject to lateral loads, it will behave like a beam from the point view of structural member.

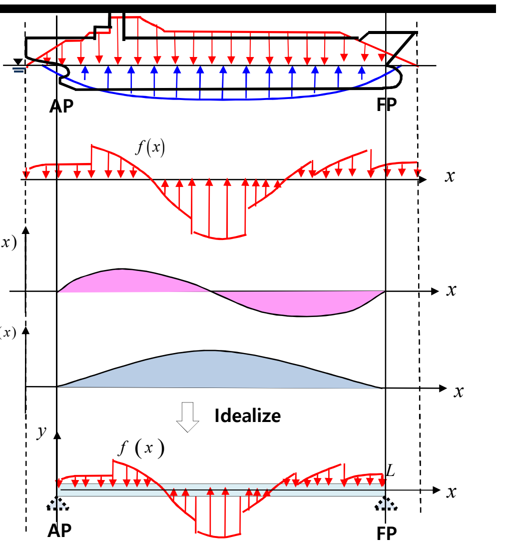
Ship is regarded as a .



Applying Beam Theory to a Ship



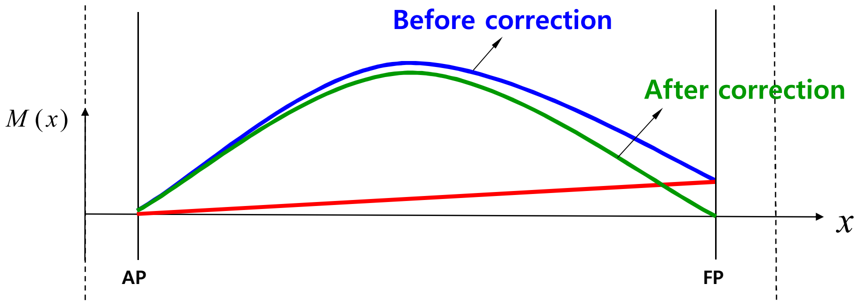
If there are supports at the ends, deflection and slope of the beam occur.



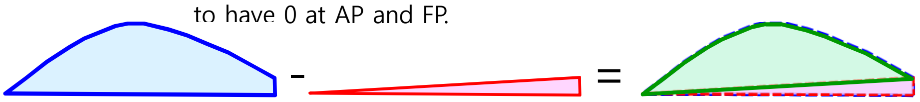
Actually, there are no supports at the ends of the ship.
However, the deflection and slope could occur due to inequality of the buoyancy and the weight of a ship. For this problem, we assume that there are simple supports at the A.P and the F.P.

* James M. Gere, Mechanics of Materials, 6th Edition, Thomson, Ch. 4, p. 292

Correction of a Bending Moment Curve



What if the bending moment is not zero at FP?
➡ The deflection and slope of the beam occur at FP.
➡ Thus, we correct the bending moment curve to have 0 at AP and FP.



* James M. Gere, Mechanics of Materials, 6th Edition, Thomson, Ch. 4, p. 292

Actual Stress ≤ Allowable Stress
- Bending Stress and Allowable Bending Stress

1) DNV Rules, Pt. 3 Ch. 1 Sec. 5, Jan. 2004

The ($\sigma_{act.}$) shall not be greater than the (σ_l).

M_S : Largest SWBM among all loading conditions and class rule
M_W : Calculated by class rule or direct calculation

$$\boxed{\sigma_{act.} = \frac{|M_S + M_W|}{Z} 10^3 \ \ [kg/cm^2]}$$

(DNV Pt.3 Ch.1 Sec. 5 C303)

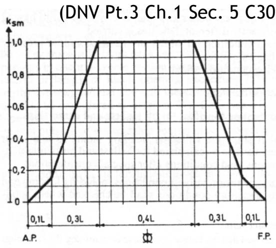


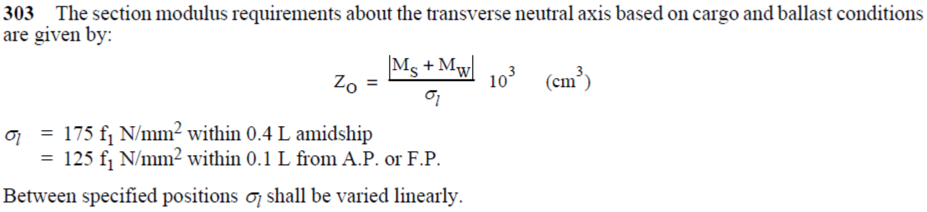
Fig. 2
Stillwater bending moment

$$\sigma_l = \sigma_{allow} = 175 f_1 \ [N/mm^2]$$ within 0.4L amidship

$$= 125 f_1 \ [N/mm^2]$$ within 0.1L from A.P. or F.P.

(f_1: Material factor. Ex. Mild steel 1.0, HT-32 1.28, HT-36 1.39)

(DNV Pt.3 Ch.1 Sec.5 C303), 2011



303 The section modulus requirements about the transverse neutral axis based on cargo and ballast conditions are given by:

$$Z_O = \frac{|M_S + M_W|}{\sigma_l} 10^3 \quad (cm^3)$$

σ_l = 175 f_1 N/mm^2 within 0.4 L amidship
= 125 f_1 N/mm^2 within 0.1 L from A.P. or F.P.

Between specified positions σ_l shall be varied linearly.

(DNV Pt.3 Ch.1 Sec.5 C304), 2011

304 The midship section modulus about the vertical neutral axis (centre line) is normally not to be less than:

$$Z_{OH} = \frac{5}{f_1} L^{9/4} (T + 0.3B)\, C_B \quad (\mathrm{cm}^3)$$

The above requirement may be disregarded provided the combined effects of vertical and horizontal bending stresses at bilge and deck corners are proved to be within 195 f_1 N/mm^2.

The combined effect may be taken as:

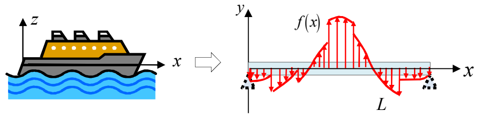
$$\sigma_s + \sqrt{\sigma_w^{\ 2} + \sigma_{wh}^{\ 2}}$$

σ_s = stress due to M_S
σ_w = stress due to M_W
σ_{wh} = stress due to M_{WH}, the horizontal wave bending moment as given in B205.

Criteria of Structural Design (1/2)

- **Ship Structural Design**

a ship



The **actual bending stress** ($\sigma_{act.}$) shall not be greater than the **allowable bending stress** (σ_l).

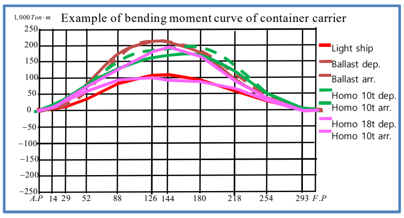
$$\boxed{\sigma_{act.} \le \sigma_l}\ ,\ \sigma_{act.} = \frac{M}{I_{N.A}/y} = \frac{|M_S + M_W|}{I_{N.A}/y}$$

M_S : Largest SWBM among all loading conditions and class rule
M_W : VWBM calculated by class rule or direct calculation

σ_l **: allowable stress**

For instance, allowable bending stresses by DNV rule are given as follows:

$\sigma_l = 175 f_1 \ [N/mm^2]$ within 0.4L amidship
$= 125 f_1 \ [N/mm^2]$ within 0.1L from A.P. or F.P.



Actual bending moments at aft and forward area are smaller than that at the midship.

What is, then, the f_1?

Criteria of Structural Design (2/2)

$$\boxed{\sigma_{act.} \le \sigma_l}$$

$$\sigma_{act.} = \frac{M}{I_{N.A}/y} = \frac{|M_S + M_W|}{I_{N.A}/y}$$

(1) Still Water Bending Moment (Ms)
(2) Vertical Wave Bending Moment (Mw)
(3) Section Modulus ($I_{N.A}/y$)

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(1) Still Water Bending Moment (Ms)

Still Water Bending Moment (Ms)

$$\boxed{\sigma_{act.} \le \sigma_l} \quad , \sigma_{act.} = \frac{M}{I_{N.A}/y} = \frac{|M_S + M_W|}{I_{N.A}/y}$$

, { M_S: Still water bending moment
M_W: Vertical wave bending moment

Hydrostatic loads along ship's length
caused by the weight & the buoyancy

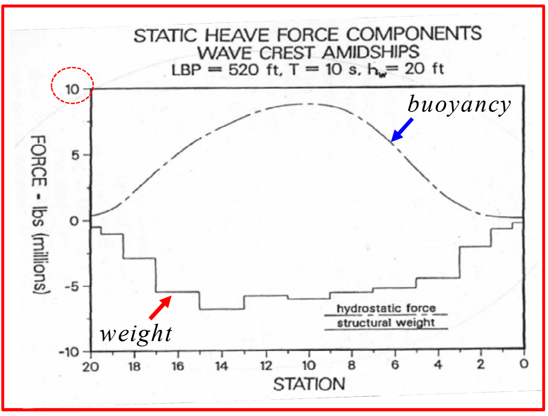
$f_S(x)$: distributed loads in longitudinal direction in still water

$V_S(x)$: still water shear force

$$V_S(x) = \int_0^x f_S(x)dx$$

$M_S(x)$: still water bending moment

$$M_S(x) = \int_0^x V_S(x)dx$$



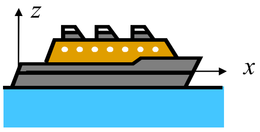
Distributed Loads in Longitudinal Direction

$$f(x) = f_S(x) + f_W(x)$$

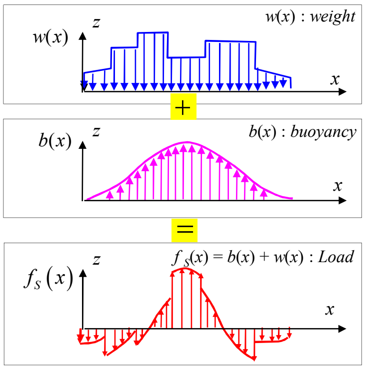
$f(x)$: Distributed loads in longitudinal direction

$f_S(x)$: **Static longitudinal loads** in longitudinal direction
$f_W(x)$: **Hydrodynamic longitudinal loads** induced by wave

In still water



$$f_S(x) = b(x) + w(x)$$



$b(x)$: Distributed buoyancy in longitudinal direction
$w(x) = LWT(x) + DWT(x)$
- $w(x)$: Weight distribution in longitudinal direction
- $LWT(x)$: Lightweight distribution
- $DWT(x)$: Deadweight distribution

Distributed Loads in Still Water

Load Curve, $f_S(x)$ → **Actual Still Water Shear Force, $V_S(x)$** → **Actual Still Water Bending Moment, $M_S(x)$**

Weight, $w(x)$
Buoyancy, $b(x)$

$V_S(x) = \int_0^x f_S(x)dx$

$M_S(x) = \int_0^x V_S(x)dx$

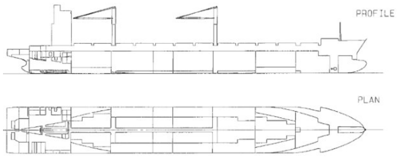
✓ Example of a 3,700 TEU Container Ship in Homogeneous 10 ton Scantling Condition

- Principal Dimensions & Plans

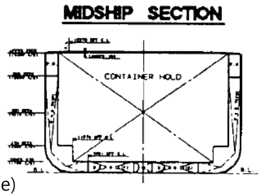
Principal dimension

LENGTH O. A.	257. 368 M
LENGTH B. P.	245. 240 M
BREADTH MOULDED	32. 20 M
DEPTH MOULDED	19. 30 M
DESIGNED DRAUGHT MOULDED	10. 10 M
SCANTLING DRAUGHT MOULDED	12. 50 M

Profile & plan



Midship section



- Loading Condition: Homogeneous 10 ton Scantling Condition (Sailing state)

* Frame space: 800mm

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                        SAILING    STATE

DRAUGHT  F.P         =     12.260 M   K.M.T                    =      14.889 M
DRAUGHT  MIDSHIP     =     12.457 M   KG  (SOLID)              =      13.586 M
DRAUGHT  A.P         =     12.654 M   GM  (SOLID)              =       1.303 M
TRIM BY STERN        =       .394 M   FREE SURF. CORR.(GGo)    =        .059 M
PROPELLER I/D        =      160.3 %   GoM  (FLUID)             =       1.244 M
DISPLACEMENT         =    66813.6 T   KGo ACTUAL  (FLUID)      =      13.645 M

DRAUGHT AT LCF       =     12.483 M   TRIM  (DIS*A)/(MTC*100)  =        .394 M
LCB FROM A.P         =    115.677 M   FREE SURF. MOM.          =        3921 T-M
LCG FROM A.P         =    115.045 M   M.T.C.                   =      1072.0 T-M
TRIM LEVER :  A      =       .632 M   LCF FROM A.P             =     106.275 M

DEGREE   =   .0    5.0   10.0   15.0   20.0   30.0   40.0   50.0   60.0   75.0
KN       = .000  1.296  2.591  3.882  5.168  7.614  9.592 10.930 11.697 11.959
KGo*SINθ = .000  1.189  2.369  3.532  4.667  6.823  8.771 10.453 11.817 13.180
GZ       = .000   .107   .222   .350   .501   .791   .821   .477  -.120 -1.221
```

Distributed Loads in Still Water - Lightweight

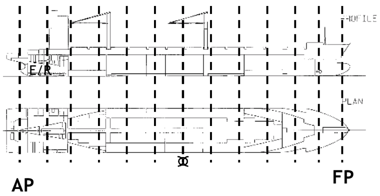
Load Curve, $f_S(x)$ → **Actual Still Water Shear Force, $V_S(x)$** → **Actual Still Water Bending Moment, $M_S(x)$**

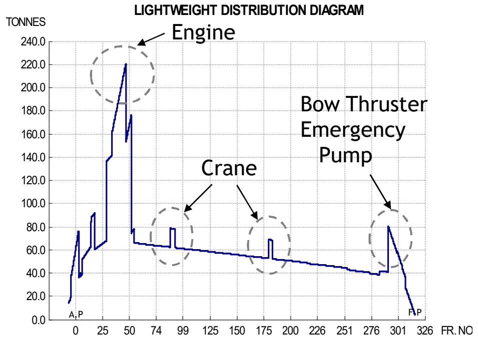
Weight, $w(x)$
Buoyancy, $b(x)$

$V_S(x) = \int_0^x f_S(x)dx$

$M_S(x) = \int_0^x V_S(x)dx$

Example of a 3,700 TEU Container Ship

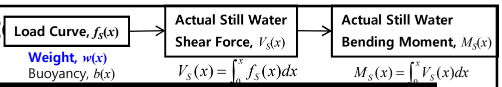




```
             L I G H T   W E I G H T   S U M M A R Y

Hull No. :     1329.    3,700 TEU CONTAINER VESSEL
------------------------------------------------------------------
  NO    AFT END   FORE END     WEIGHT        L.C.G        MOMENT
------------------------------------------------------------------
   1    -5.000     14.350     616.00        7.000       4312.0
   2    14.350     43.400    1387.10       31.400      43554.9
   3    43.400    232.320    7591.50      128.620     976418.7
   4   232.320    252.240     732.30      239.280     175224.7
   5    27.200     41.600     476.40       35.800      17055.1
   6      .000    245.240      30.00      122.620       3678.6
   7    43.400    232.320     340.00      134.200      45628.0
   8    -3.600    232.320     119.00      114.400      13613.6
   9    -3.400      2.400     151.90         .000           .0
  10      .000    252.240     224.00      120.000      26880.0
  11   202.240    232.320     137.90      217.000      29924.3
  12    43.400    202.240    1053.00      121.700     128150.1
  13   143.280    146.680      55.00      144.980       7973.9
  14    70.480     73.880      55.00       72.180       3969.9
  15    14.350    232.320     115.90      114.360      13254.3
  16    -3.600    232.320     128.00      114.360      14638.1
  17   232.320    245.240     118.30      238.600      28226.4
  18    36.000    170.000       3.00       81.000        243.0
  19    -5.000      4.000      50.00        -.500        -25.0
  20    29.000     41.600      15.50       37.100        575.0
  21    -3.500      4.000      19.20         .000           .0
  22     4.000     11.200      34.30        7.600        260.7
  23    41.600    173.900      62.50      105.760       6610.0
  24   226.160    232.320      20.40      229.240       4676.5
  25   239.000    243.000       5.40      241.000       1301.4
  26    11.200    232.320      39.20      121.700       4770.6
  27    11.200    232.320     191.30      121.700      23281.2
  28    27.200     41.600     214.50       36.000       7722.0
  29    23.230     37.600     979.00       30.400      29761.6
  30    11.200     41.600     289.50       22.000       6369.0
  31     5.000     23.230     111.30       11.200       1246.6
  32    12.000     41.600     150.70       28.000       4219.6
  33    11.200     41.600     158.60       28.000       4440.8
  34    11.200     41.600      95.90       28.000       2685.2
  35    11.200    218.480     165.00      114.240      18849.6
  36    27.200     41.600       8.50       36.000        306.0
  37    11.200     41.600      43.00       30.000       1290.0
  38    27.200     41.600       4.30       36.000        154.8
  39    27.200     41.600       5.70       36.000        205.2
------------------------------------------------------------------
LIGHT  SHIP  TOTAL =           15998.10      103.228    1651446.5
------------------------------------------------------------------
```

Distributed Loads in Still Wat
- Deadweight



Load Curve, $f_S(x)$ → Actual Still Water Shear Force, $V_S(x)$ → Actual Still Water Bending Moment, $M_S(x)$

Weight, $w(x)$

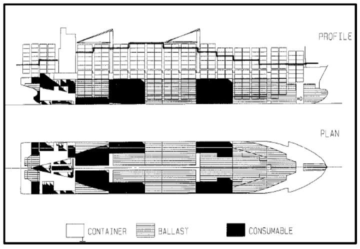
Buoyancy, $b(x)$

$$V_S(x)=\int_0^x f_S(x)dx$$

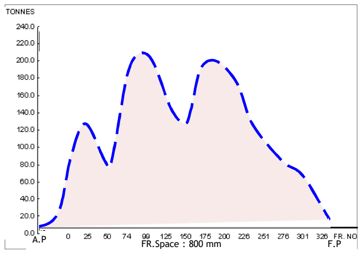
$$M_S(x)=\int_0^x V_S(x)dx$$

Example of a 3,700 TEU Container Ship

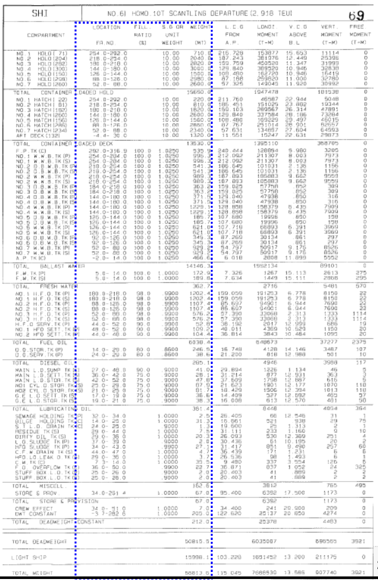
- Loading plan in homogenous 10 ton scantling condition



- Deadweight distribution curve in homogenous 10 ton scantling condition



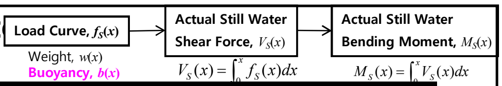
Deadweight distribution in longitudinal direction in homogenous 10 ton scantling condition



SHI | NO.6) HOMO.10T SCANTLING DEPARTURE (2,918 TEU) | 69

COMPARTMENT	LOCATION FR.NO.	FILL RATIO (%)	S.G OR UNIT WEIGHT	WEIGHT (MT)	L.C.G FROM A.P.	LONGI. MOMENT (T-M)	V.C.G ABOVE B.L	VERT. MOMENT (T-M)	FREE MOMENT (T-M)
NO.1 HOLD(71)	254.0-292.0		10.00	710.0	216.728	153877	15.653	11114	0
NO.2 HOLD(204)	218.0-254.0		10.00	2040.0	187.243	381976	12.449	25396	0
NO.3 HOLD(282)	180.0-218.0		10.00	2820.0	159.759	450520	11.347	31999	0
NO.4 HOLD(300)	144.0-180.0		10.00	3000.0	129.840	389520	10.946	32838	0
NO.5 HOLD(150)	126.0-144.0		10.00	1500.0	108.480	162720	10.946	16419	0
NO.6 HOLD(298)	88.0-126.0		10.00	2980.0	87.188	259820	11.000	32780	0
NO.7 HOLD(260)	52.0- 88.0		10.00	2600.0	57.325	149045	11.920	30992	0
TOTAL CONTAINER LOADED HOLD				15650.0		1947478		181538	0
NO.1 HATCH(22)	254.0-292.0		10.00	220.0	211.760	46587	22.944	5048	0
NO.2 HATCH(81)	218.0-254.0		10.00	810.0	186.451	151025	23.882	19344	0
NO.3 HATCH(182)	180.0-218.0		10.00	1820.0	159.103	289567	26.314	47891	0
NO.4 HATCH(260)	144.0-180.0		10.00	2600.0	129.840	337584	28.186	73284	0
NO.5 HATCH(156)	126.0-144.0		10.00	1560.0	108.480	169229	29.497	46015	0
NO.6 HATCH(286)	88.0-126.0		10.00	2860.0	87.767	251014	28.901	82657	0
NO.7 HATCH(234)	52.0- 88.0		10.00	2340.0	57.631	134857	27.604	64593	0
AFT DECK(132)	-4.4- 30.0		10.00	1320.0	11.551	15247	22.631	29873	0
TOTAL CONTAINER LOADED DECK				13530.0		1395110		388705	0
F.P.TK(C)	292.0-316.9	100.0	1.0250	535.9	240.444	128854	5.980	3205	0
NO.1 W.W.B.TK(P)	254.0-284.0	100.0	1.0250	996.3	212.092	211307	8.003	7973	0
NO.1 W.W.B.TK(S)	254.0-284.0	100.0	1.0250	996.3	212.092	211307	8.003	7973	0
NO.2 D.B.W.B.TK(P)	218.0-254.0	100.0	1.0250	541.3	186.645	101031	2.136	1156	0
NO.2 D.B.W.B.TK(S)	218.0-254.0	100.0	1.0250	541.3	186.645	101031	2.136	1156	0
NO.2 W.W.B.TK(P)	218.0-254.0	100.0	1.0250	989.3	187.893	185883	9.662	9559	0
NO.2 W.W.B.TK(S)	218.0-254.0	100.0	1.0250	989.3	187.893	185883	9.662	9559	0
NO.3 D.B.W.B.TK(P)	184.0-218.0	100.0	1.0250	363.2	159.025	57758	.852	309	0
NO.3 D.B.W.B.TK(S)	184.0-218.0	100.0	1.0250	363.2	159.025	57758	.852	309	0
NO.4 D.B.W.B.TK(P)	144.0-180.0	100.0	1.0250	371.5	129.040	47938	.850	316	0
NO.4 D.B.W.B.TK(S)	144.0-180.0	100.0	1.0250	371.5	129.040	47938	.850	316	0
NO.4 W.W.B.TK(P)	144.0-180.0	100.0	1.0250	1229.1	128.858	158379	6.435	7909	0
NO.4 W.W.B.TK(S)	144.0-180.0	100.0	1.0250	1229.1	128.858	158379	6.435	7909	0
NO.5 D.B.W.B.TK(P)	126.0-144.0	100.0	1.0250	185.7	107.680	19996	.850	158	0
NO.5 D.B.W.B.TK(S)	126.0-144.0	100.0	1.0250	185.7	107.680	19996	.850	158	0
NO.5 W.W.B.TK(P)	126.0-144.0	100.0	1.0250	621.0	107.718	66893	6.391	3969	0
NO.5 W.W.B.TK(S)	126.0-144.0	100.0	1.0250	621.0	107.718	66893	6.391	3969	0
NO.6 D.B.W.B.TK(P)	92.0-126.0	100.0	1.0250	345.3	87.269	30134	.861	297	0
NO.6 D.B.W.B.TK(S)	92.0-126.0	100.0	1.0250	345.3	87.269	30134	.861	297	0
NO.7 W.W.B.TK(P)	52.0- 88.0	100.0	1.0250	929.2	54.797	50917	9.176	8526	0
NO.7 W.W.B.TK(S)	52.0- 88.0	100.0	1.0250	929.2	54.797	50917	9.176	8526	0
A.P.TK(C)	-2.0- 14.0	100.0	1.0250	466.6	6.018	2808	11.899	5552	0
TOTAL BALLAST WATER				14146.3		1592134		89101	0
F.W.TK(P)	5.0- 14.0	100.0	1.0000	172.9	7.326	1267	15.113	2613	275
F.W.TK(S)	5.0- 14.0	100.0	1.0000	189.8	7.634	1449	15.111	2868	295
TOTAL FRESH WATER				362.7		2716		5481	570
NO.1 H.F.O.TK(P)	180.0-218.0	98.0	.9900	1202.4	159.059	191253	6.778	8150	22
NO.1 H.F.O.TK(S)	180.0-218.0	98.0	.9900	1202.4	159.059	191253	6.778	8150	22
NO.2 H.F.O.TK(P)	88.0-126.0	98.0	.9900	1107.4	85.697	94901	6.944	7690	22
NO.2 H.F.O.TK(S)	88.0-126.0	98.0	.9900	1107.4	85.697	94901	6.944	7690	22
NO.3 H.F.O.TK(P)	52.0- 88.0	98.0	.9900	576.2	57.390	33068	2.313	1333	1114
NO.3 H.F.O.TK(S)	52.0- 88.0	98.0	.9900	576.2	57.390	33068	2.313	1333	1114
H.F.O SERV.TK(P)	44.0- 52.0	90.0	.9900	52.8	38.192	2017	12.999	686	19
NO.1 HFO SETT.TK(P)	48.0- 52.0	90.0	.9900	109.2	40.011	4369	10.520	1150	20
NO.2 HFO SETT.TK(P)	44.0- 48.0	90.0	.9900	104.4	36.814	3843	10.484	1095	20
TOTAL FUEL OIL				6038.4		848673		37277	2375
D.O.STOR.TK(P)	14.0- 29.0	80.0	.8600	246.5	16.748	4128	14.146	3487	107
D.O.SERV.TK(P)	24.0- 29.0	80.0	.8600	38.6	21.200	818	12.988	501	10
TOTAL DIESEL OIL				285.1		4946		3988	117
MAIN L.O.SUMP TK(C)	27.0- 48.0	90.0	.9000	41.0	29.894	1226	1.134	46	5
MAIN L.O.SETT.TK(S)	36.0- 42.0	75.0	.9000	28.1	31.214	877	12.931	363	3
MAIN L.O.STOR.TK(S)	42.0- 52.0	75.0	.9000	47.8	37.609	1798	12.887	616	5
NO1 CYL.O.STOR.TK(S)	25.0- 29.0	75.0	.9000	87.9	21.623	1901	12.177	1070	118
NO2 CYL.O.STOR.TK(S)	21.0- 25.0	75.0	.9000	81.7	18.429	1506	12.394	1013	118
G.E L.O.SETT.TK(S)	17.0- 19.0	75.0	.9000	36.6	14.409	527	12.692	465	57
G.E L.O.STOR.TK(S)	19.0- 21.0	75.0	.9000	38.3	16.008	613	12.570	481	58
TOTAL LUBRICATING OIL				361.4		8448		4054	364
SEWAGE HOLDING TK(P)	32.0- 34.0		1.0000	2.5	26.405	66	12.546	31	1
BILGE HOLDING TK(C)	14.0- 25.0		1.0000	31.3	16.861	521	.938	29	75
S.T L.O. DRAIN TK(C)	24.0- 25.0		.9000	1.3	19.600	25	1.313	2	1
RESIDUE TK(S)	29.0- 44.0		1.0000	7.5	31.111	233	1.160	9	10
DIRTY OIL TK(S)	29.0- 36.0		1.0000	20.3	26.093	530	12.389	251	4
L.O.SLUDGE TK(P)	37.0- 39.0		.9000	2.0	30.436	61	10.195	20	2
HFO SLUDGE TK(P)	34.0- 43.0		.9900	27.1	31.417	851	9.490	257	60
C.F.W.DRAIN TK(S)	44.0- 47.0		1.0000	4.7	36.439	171	1.231	6	6
HFO.LO.LEAK O.TK(S)	29.0- 36.0		1.0000	3.7	26.536	98	1.493	6	1
C.W.TK(C)	7.3- 14.0		1.0000	35.5	9.480	337	3.554	126	6
F.O. OVERFLOW TK(S)	36.0- 50.0		.9900	22.7	36.871	837	1.052	24	325
STUFF.BOX.L.O.TK(P)	25.0- 26.0		.9000	2.0	20.403	41	.889	2	2
STUFF.BOX.L.O.TK(S)	25.0- 26.0		.9000	2.0	20.403	41	.889	2	2
TOTAL MISCELL.				162.6		3812		765	495
STORE & PROV.	34.0-251.4		1.0000	67.0	95.400	6392	17.500	1173	0
TOTAL STORE & PROVISION				67.0		6392		1173	0
CREW EFFECT	34.0- 51.0		1.0000	7.0	34.400	241	29.900	209	0
DWT CONSTANT	-3.7-282.6		1.0000	205.0	122.620	25137	20.850	4274	0
TOTAL DEADWEIGHT CONSTANT				212.0		25378		4483	0
TOTAL DEADWEIGHT				50815.5		6035087		896565	3921
LIGHT SHIP				15998.1	103.228	1651452	13.200	211175	0
TOTAL WEIGHT				66813.6	115.045	7686539	13.586	907740	3921

Distributed Loads in Still Wat
- Buoyancy Curve



Load Curve, $f_S(x)$ → Actual Still Water Shear Force, $V_S(x)$ → Actual Still Water Bending Moment, $M_S(x)$

Weight, $w(x)$

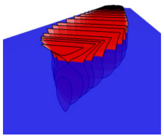
Buoyancy, $b(x)$

$$V_S(x)=\int_0^x f_S(x)dx$$

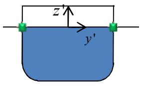
$$M_S(x)=\int_0^x V_S(x)dx$$

Example of a 3,700 TEU Container Ship

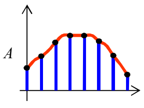
✓ Calculation of buoyancy



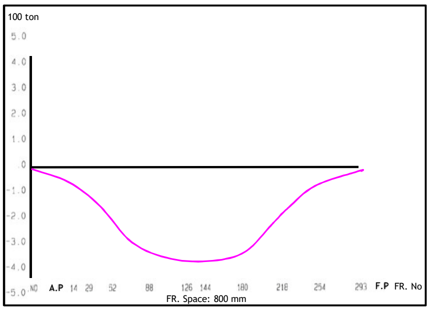
(1) Calculation of sectional area below waterline

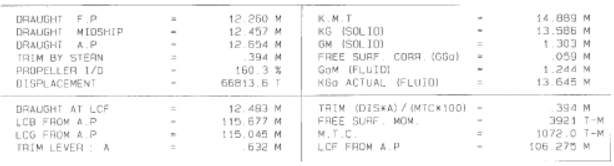


(2) Integration of sectional area over the ship's length



✓ Buoyancy Curve in Homogeneous 10 ton Scantling Condition





DRAUGHT F.P	=	12.250 M	K.M.T	=	14.889 M
DRAUGHT MIDSHIP	=	12.457 M	KG (SOLID)	=	13.586 M
DRAUGHT A.P	=	12.654 M	GM (SOLID)	=	1.303 M
TRIM BY STERN	=	.394 M	FREE SURF. CORR. (GGo)	=	.059 M
PROPELLER I/D	=	160.3 %	GoM (FLUID)	=	1.244 M
DISPLACEMENT	=	66813.6 T	KGo ACTUAL (FLUID)	=	13.645 M
DRAUGHT AT LCF	=	12.483 M	TRIM (DIS*A)/(MTC*100)	=	.394 M
LCB FROM A.P	=	115.677 M	FREE SURF. MOM.	=	3921 T-M
LCG FROM A.P	=	115.045 M	M.T.C.	=	1072.0 T-M
TRIM LEVER : A	=	.632 M	LCF FROM A.P	=	106.275 M

Distributed Loads in Still Water - Load Curve

Load Curve, $f_S(x)$ → **Actual Still Water Shear Force, $V_S(x)$** → **Actual Still Water Bending Moment, $M_S(x)$**

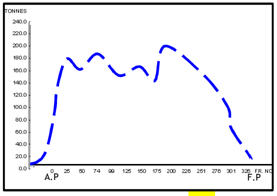
Weight, $w(x)$
Buoyancy, $b(x)$

$V_S(x)=\int_0^x f_S(x)dx$ $M_S(x)=\int_0^x V_S(x)dx$

Load Curve $f_S(x)$:

Weight Curve = Lightweight + Deadweight

in homogenous 10ton scantling condition



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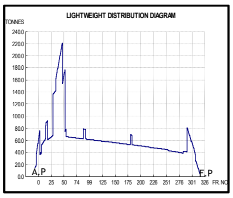
Lightweight Distribution Curve



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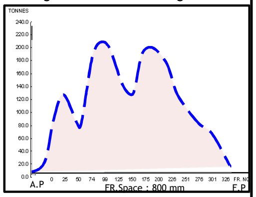
Deadweight Distribution Curve

in homogenous 10 ton scantling condition



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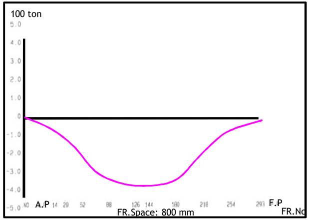
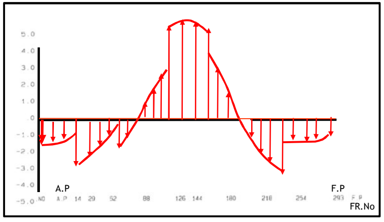
Buoyancy Curve

in homogenous 10 ton scantling condition



Load Curve = Weight $w(x)$ + Buoyancy $b(x)$

in homogenous 10 ton scantling condition



Actual Still Water Shear Force

Actual Still Water Shear Force & Actual Still Water Bending Moment

Load Curve, $f_S(x)$ → **Actual Still Water Shear Force, $V_S(x)$** → **Actual Still Water Bending Moment, $M_S(x)$**

Weight, $w(x)$
Buoyancy, $b(x)$

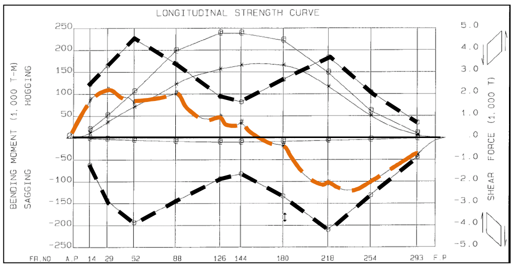
$V_S(x)=\int_0^x f_S(x)dx$ $M_S(x)=\int_0^x V_S(x)dx$

Example of a 3,700TEU Container Ship

Load Curve $f_S(x)=b(x)+w(x)$

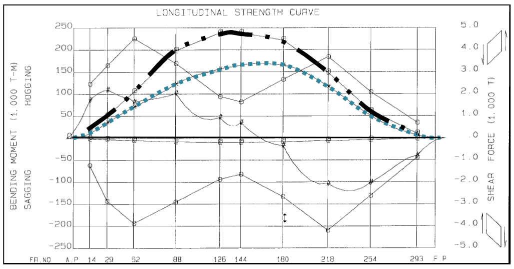
Actual Still Water Shear Force $V_S(x)=\int_0^x f_S(x)dx$

Actual still water shear force
Design still water shear force



Actual Still Water Bending Moment $M_S(x)=\int_0^x V_S(x)dx$

Actual still water bending moment
Design still water bending moment



Rule Still Water Bending Moment by the Classification Rule

Recently, actual still water bending moment based on the loading conditions is used for still water bending moment, because the rule still water bending moment is only for the tanker.

- The design still water bending moments to be taken less than

(DNV Pt. 3 Ch. 1 Sec. 5 A105)

$$\boxed{M_S = M_{SO}\ [kNm]}$$

(**rule still water bending moment**)

$$M_{SO} = \underline{-0.065}C_{WU}L^2B(C_B + 0.7) \quad \text{[kNm] in sagging}$$

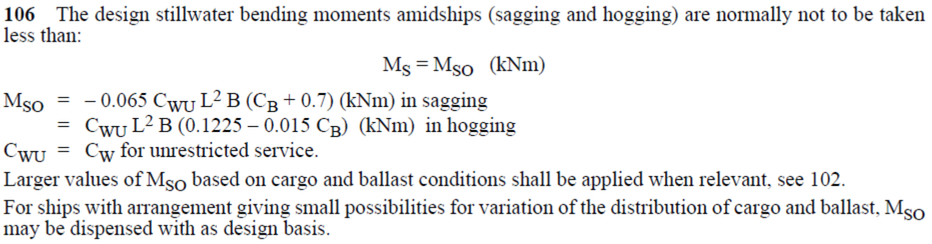
$$= C_{WU}L^2B(0.1225 - 0.015C_B) \quad \text{[kNm] in hogging}$$

C_{WU}: Wave coefficient for unrestricted service

The design still water bending moment shall not be less than the large of: the largest actual still water bending moment based on the loading conditions and the rule still water bending moment.

Design SWBM = Max(Actual SWBM, Rule SWBM) + margin

(DNV Pt.3 Ch.1 Sec. 5 A106), 2011



106 The design stillwater bending moments amidships (sagging and hogging) are normally not to be taken less than:

$$M_S = M_{SO} \quad \text{(kNm)}$$

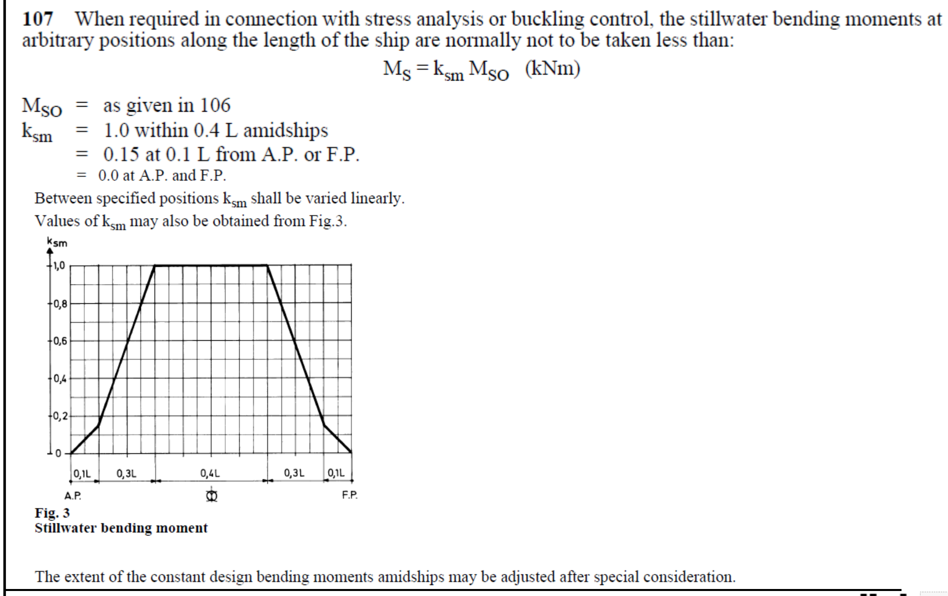
M_{SO} = $-0.065\ C_{WU}\ L^2\ B\ (C_B + 0.7)$ (kNm) in sagging
= $C_{WU}\ L^2\ B\ (0.1225 - 0.015\ C_B)$ (kNm) in hogging

C_{WU} = C_W for unrestricted service.

Larger values of M_{SO} based on cargo and ballast conditions shall be applied when relevant, see 102.

For ships with arrangement giving small possibilities for variation of the distribution of cargo and ballast, M_{SO} may be dispensed with as design basis.

(DNV Pt.3 Ch.1 Sec. 5 B107), 2011



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

$$M_S = k_{sm} M_{SO} \quad (kNm)$$

M_{SO} = as given in 106

k_{sm} = 1.0 within 0.4 L amidships

= 0.15 at 0.1 L from A.P. or F.P.

= 0.0 at A.P. and F.P.

Between specified positions k_{sm} shall be varied linearly.

Values of k_{sm} may also be obtained from Fig.3.

Fig. 3
Stillwater bending moment

The extent of the constant design bending moments amidships may be adjusted after special consideration.

Rule Still Water Shear Force by the Classification Rule

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

(Dnv Pt.3 Ch.1 Sec. 5 B107)

(**rule still water shear force**)

$$\boxed{Q_S = k_{sq} Q_{SO} (kN)}$$

$$Q_{SO} = 5\frac{M_{SO}}{L}(kN)$$

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

$M_{SO} = -0.065 C_{WU} L^2 B (C_B + 0.7)$ [kNm] in sagging

$= C_{WU} L^2 B (0.1225 - 0.015 C_B)$ [kNm] in hogging

C_{WU}: wave coefficient for unrestricted service

The design still water shear force shall not be less than the large of: the largest actual still water shear forces based on loading conditions and the rule still water shear force.

Design SWSF = Max(Actual SWSF, Rule SWSF) + margin

(DNV Pt.3 Ch.1 Sec. 5 B108), 2011

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

$$Q_S = k_{sq}\, Q_{SO} \quad (\text{kN})$$

$$Q_{SO} = 5\frac{M_{SO}}{L} \quad (\text{kN})$$

M_{SO} = design stillwater bending moments (sagging or hogging) given in 106.

Larger values of Q_S based on load conditions ($Q_S = Q_{SL}$) shall be applied when relevant, see 102. For ships with arrangement giving small possibilities for variation in the distribution of cargo and ballast, Q_{SO} may be dispensed with as design basis

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

Between specified positions k_{sq} shall be varied linearly.

Sign convention to be applied:

— when sagging condition positive in forebody, negative in afterbody
— when hogging condition negative in forebody, positive in afterbody.

(2) Vertical Wave Bending Moment (Mw)

Vertical Wave Bending Moment (Mw)

$$\boxed{\sigma_{act.} \le \sigma_l} \quad , \sigma_{act.} = \frac{M}{Z} = \frac{|M_S + M_W|}{Z}$$

, { M_S: Still water bending moment
M_W: Vertical wave bending moment

Hydrodynamic loads induced by waves along ship's length

$f_W(x)$: distributed loads induced by waves
= Froude-Krylov force + diffraction force
+ added mass force + damping force

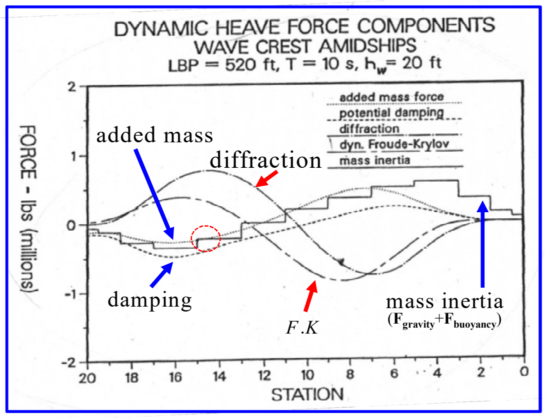
$$\begin{aligned} \mathbf{M}\ddot{\mathbf{r}} &= \sum \mathbf{F} = (Body\ \ Force) + (Surface\ \ Force) \\ &= \mathbf{F}_{gravity}(\mathbf{r}) \quad + \quad \mathbf{F}_{Fluid}(\mathbf{r}, \dot{\mathbf{r}}, \ddot{\mathbf{r}}) \\ &= \mathbf{F}_{gravity} + \mathbf{F}_{Buoyancy}(\mathbf{r}) + \mathbf{F}_{F.K}(\mathbf{r}) + \mathbf{F}_D(\mathbf{r}) \\ &\quad + \mathbf{F}_{R,Damping}(\mathbf{r}, \dot{\mathbf{r}}) + \mathbf{F}_{R,Mass}(\mathbf{r}, \ddot{\mathbf{r}}) \end{aligned}$$

$V_W(x)$: vertical wave shear force

$$V_W(x) = \int_0^x f_W(x)dx$$

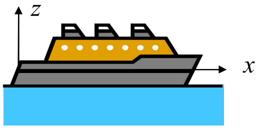
$M_W(x)$: vertical wave bending moment

$$M_W(x) = \int_0^x V_W(x)dx$$



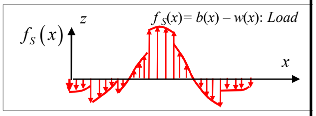
Dynamic Longitudinal Loads

In still water



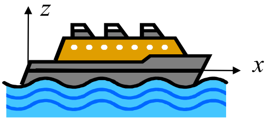
$$f_S(x) = b(x) + w(x)$$

$f(x)$: Distributed loads in longitudinal direction
$f_S(x)$: **Static longitudinal loads** in longitudinal direction
$f_W(x)$: **Hydrodynamic longitudinal loads** induced by wave



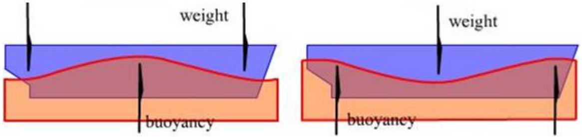
+

In wave



✓ Dynamic longitudinal loads
: Loads are induced by waves

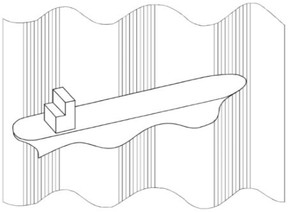
Vertical bending due to waves

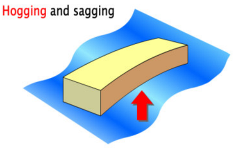


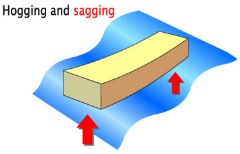
Hogging

Sagging

- Ship in oblique waves

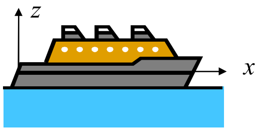






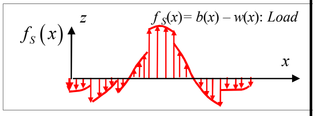
Dynamic Longitudinal Loads
- Direct Calculation of Dynamic Longitudinal Loads (1/2)

In still water



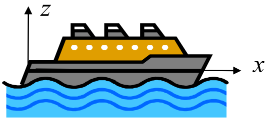
$$f_S(x) = b(x) + w(x)$$

$f(x)$: Distributed loads in longitudinal direction
$f_S(x)$: **Static longitudinal loads** in longitudinal direction
$f_W(x)$: **Hydrodynamic longitudinal loads** induced by wave

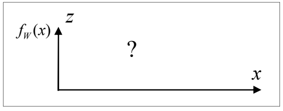


+

In wave

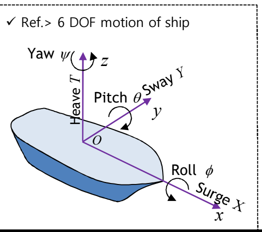


- ✓ Dynamic longitudinal loads
  : Loads are induced by waves



- ✓ Direct calculation of dynamic longitudinal loads
  - from 6DOF motion of ship

$$\mathbf{x} = [X, Y, T, \phi, \theta, \psi]^T$$



$$f(x) = f_S(x) \quad + f_W(x)$$
$$= b(x) + w(x) + \boxed{f_{F.K}(x) + f_D(x) + f_R(x)}$$

additional loads in wave

where,

$$f_R(x) = -a(x)\boxed{\ddot{\mathbf{x}}} - b(x)\boxed{\dot{\mathbf{x}}}$$

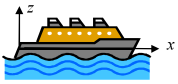
$f_D(x)$: Diffraction force at x
$f_R(x)$: Radiation force at x by damping and added mass
$f_{F.K}(x)$: Froude-Krylov force at x

In order to calculate loads in waves, first we have to determine $\ddot{\xi}_3$, $\dot{\xi}_3$.

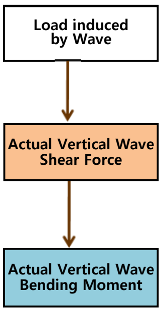
How to determine $\ddot{\xi}_3$, $\dot{\xi}_3$?

Dynamic Longitudinal Loads
- Direct Calculation of Dynamic Longitudinal Loads (2/2)

In wave



- ✓ Direct calculation of dynamic longitudinal loads



Load induced by Wave

$$f_W(x) = f_{F.K}(x) + f_D(x) + f_R(x)$$

where, $f_R(x) = -a(x)\,\ddot{\mathbf{x}} - b(x)\,\dot{\mathbf{x}}$

Actual Vertical Wave Shear Force

$$Q_W(x) = \int_0^x f_W(x)dx$$

Actual Vertical Wave Bending Moment

$$M_W(x) = \int_0^x Q_W(x)dx$$

Rule Values of Vertical Wave Bending Moments

✓ Direct calculation of dynamic longitudinal loads

- Loads are induced by waves

Actual Vertical Wave Shear Force $Q_W(x) = \int_0^x f_W(x)dx$

↓

Actual Vertical Wave Bending Moment $M_W(x) = \int_0^x Q_W(x)dx$

Recently, rule values of vertical wave moments are used, because of the uncertainty of the direct calculation values of vertical wave bending moments.

Design VWBM = Min(Actual VWBM, Rule VWBM) + margin

The rule vertical wave bending moments amidships are given by:

$$\boxed{M_W = M_{WO} \quad [kNm]}$$

(DNV Pt.3 Ch.1 Sec.5 B201)

L	C_W
$L \le 100$	$0.0792 \cdot L$
$100 < L < 300$	$10.75 - [(300-L)/100]^{3/2}$
$300 \le L \le 350$	10.75
$L > 350$	$10.75 - [(L-350)/150]^{3/2}$

$M_{WO} = -0.11\alpha C_W L^2 B(C_B + 0.7)$ [kNm] in sagging

$= 0.19\alpha C_W L^2 B C_B$ [kNm] in hogging

$\alpha = 1.0$ for seagoing condition

$= 0.5$ for harbor and sheltered water conditions (enclosed fiords, lakes, rivers)

C_W: wave coefficient

C_B: block coefficient, not be taken less than 0.6

Direct calculation values of vertical wave bending moments can be used for design vertical wave bending moment instead of the rule values of vertical wave moments, if the value of the direct calculation is smaller than that of the rule value.

Rule Values of Vertical Wave Shear Forces

✓ Direct calculation of dynamic longitudinal loads

- Loads are induced by waves

Load induced by Wave $f_W(x) = f_D(x) + f_{F.K}(x) + f_R(x)$

where, $f_R(x) = -a(x)\,\ddot{\mathbf{x}} - b(x)\,\dot{\mathbf{x}}$

↓

Actual Vertical Wave Shear Force $Q_W(x) = \int_0^x f_W(x)dx$

Design VWSF = Min(Actual VWSF, Rule VWSF) + margin

The rule values of vertical wave shear forces along the length of the ship are given by:

(DNV Pt.3 Ch.1 Sec.5 B203)

Positive shear force: $\boxed{Q_{WP} = 0.3\beta k_{wqp} C_W LB(C_B + 0.7)}$

Negative shear force: $\boxed{Q_{WN} = -0.3\beta k_{wqn} C_W LB(C_B + 0.7)}$

β: coefficient according to operating condition

k_{wqp}, k_{wqn}: coefficients according to location in lengthwise

C_W: wave coefficient

Direct calculation values of vertical wave shear forces can be used for vertical wave shear force instead of the rule values of vertical shear forces, if the value of the direct calculation is smaller than that of the rule value.

[Example] Rule Values of Still Water Bending Moments (Ms) and Vertical Wave Bending Moment (Mw)

Calculate L_S, $C_{B,SCANT}$, and vertical wave bending moment (M_W) at amidships (0.5L) of a ship in hogging condition for sea going condition.

Given: $L_{OA} = 332.0\,m, L_{BP} = 317.2\,m, L_{EXT} = 322.85\,m, B = 43.2m, T_s = 14.5\,m,\ \Delta = 140,960\,ton$

$$\boxed{M_S = M_{SO}(kNm)}$$
$$M_{SO} = -0.065C_{WU}L^2B(C_B + 0.7),\ _{(in\,sagging)}$$
$$= C_{WU}L^2B(0.1225 - 0.015C_B),\ _{(in\,hogging)}$$
$$\boxed{M_w = M_{WO} \quad (kNm)}$$
$$M_{WO} = -0.11\alpha C_W L^2B(C_B + 0.7),\ _{(in\,sagging)}$$
$$= 0.19\alpha C_W L^2BC_B,\ _{(in\,hogging)}$$

(Sol.) $L_s = 0.97 \times L_{EXT} = 0.97 \times 322.85 = 313.16$

$$C_{B,SCANT} = \Delta / (1.025 \times L_s \times B \times T_s) = \frac{140,906}{1.025 \times 313.16 \times 43.2 \times 14.5} = 0.701$$

$\alpha = 1.0$, for sea going condition,

$C_W = 10.75$, if $300 \le \text{L} \le 350$ (wave coefficient)

$k_{wm} = 1.0$ between 0.4L and 0.65 L from A.P(=0.0) and F.P

$$M_{WO} = 0.19 \times \alpha \times C_W \times L^2 \times B \times C_{B,SCANT} \ (kNm)$$
$$= 0.19 \times 1.0 \times 10.75 \times 313.16^2 \times 43.2 \times 0.701 = 6,066,303 \ (kNm)$$

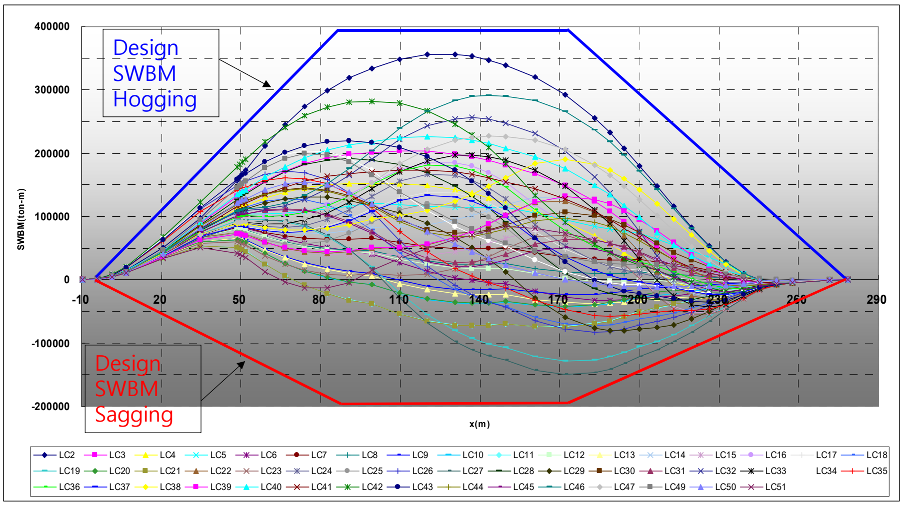
at 0.5L, $k_{wm} = 1.0$

$M_W = 1.0 \times M_{WO}$

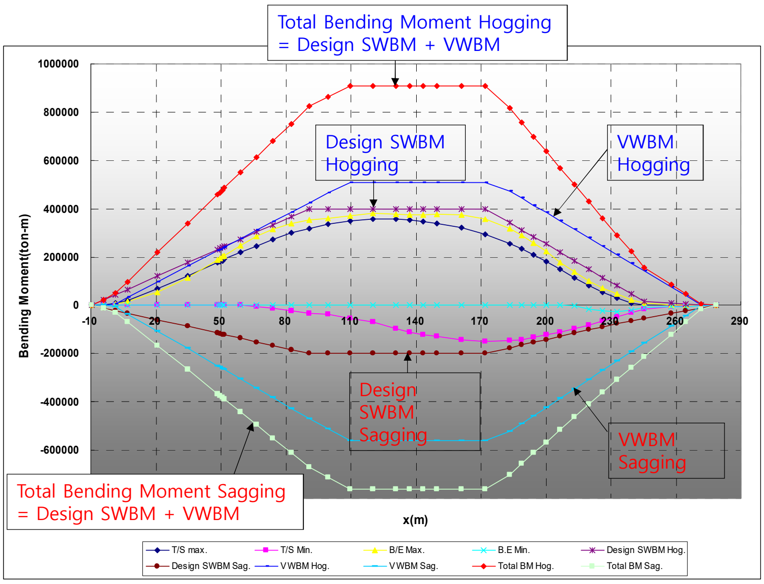
So, $M_W = 1.0 \times M_{WO} = 6,066,303 \ (kNm)$

1) DSME, Ship Structural Design, 5-2 Load on Hull Structure, Example 4, 2005

Still Water Bending Moment Curve (T&S Booklet)



Total Bending Moment Curve



Total Bending Moment Hogging
= Design SWBM + VWBM

Design SWBM
Hogging

VWBM
Hogging

Design
SWBM
Sagging

VWBM
Sagging

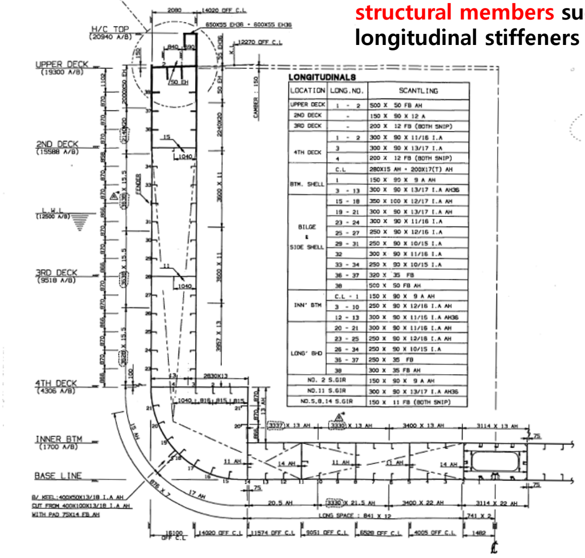
Total Bending Moment Sagging
= Design SWBM + VWBM

---

(3) Section Modulus

Example of Midship Section of a 3,700 TEU Container Ship

1) First, determine the dimensions of the longitudinal structural members such as longitudinal plates and longitudinal stiffeners by rule local scantling.



LONGITUDINALS

LOCATION	LONG.NO.	SCANTLING
UPPER DECK	1 - 2	500 X 50 FB AH
2ND DECK	-	150 X 90 X 12 A
3RD DECK	-	200 X 12 FB (BOTH SNIP)
4TH DECK	1 - 2	300 X 90 X 11/16 I.A
	3	300 X 90 X 13/17 I.A
	4	200 X 12 FB (BOTH SNIP)
BTM. SHELL	C.L	280X15 AH + 200X17(T) AH
	1	150 X 90 X 9 A AH
	3 - 13	300 X 90 X 13/17 I.A AH36
BILGE & SIDE SHELL	15 - 18	350 X 100 X 12/17 I.A AH
	19 - 21	300 X 90 X 13/17 I.A AH
	23 - 24	300 X 90 X 11/16 I.A
	25 - 27	250 X 90 X 12/16 I.A
	29 - 31	250 X 90 X 10/15 I.A
	32	300 X 90 X 11/16 I.A
	33 - 34	250 X 90 X 10/15 I.A
	36 - 37	320 X 35 FB
	38	500 X 50 FB AH
INN' BTM	C.L - 1	150 X 90 X 9 A AH
	3 - 10	250 X 90 X 12/16 I.A AH
	12 - 13	300 X 90 X 11/16 I.A AH36
LONG' BHD	20 - 21	300 X 90 X 11/16 I.A AH
	23 - 25	250 X 90 X 12/16 I.A AH
	26 - 34	250 X 90 X 10/15 I.A
	36 - 37	250 X 35 FB
	38	300 X 35 FB AH
NO. 2 S.GIR		150 X 90 X 9 A AH
NO.11 S.GIR		300 X 90 X 13/17 I.A AH36
NO.5,8,14 S.GIR		150 X 11 FB (BOTH SNIP)

Vertical Location of Neutral Axis about Baseline

2) Second, calculate the moment of sectional area about the base line.

$$\sum h_i A_i$$

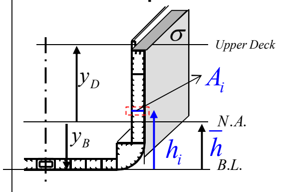
h_i : vertical center of structural member
A_i : area of structural member

3) Vertical location of neutral axis from base line ($\bar{h}$) is, then, calculated by dividing the moment of area by the total sectional area.

$$\bar{h} = \frac{\sum h_i A_i}{A}$$

$\bar{h}$: vertical location of neutral axis
A : total area

<Midship section>



By definition, neutral axis pass through the centroid of the cross section.

Midship Section Moment of Inertia about N.A

- The midship section moment of inertia about base line ($I_{B.L}$)

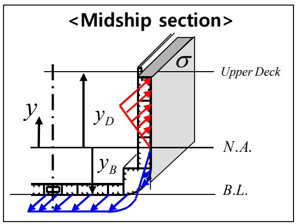
$$I_{B.L} = I_{N.A.} + A\,\bar{h}^2$$

- then calculate the midship section moment of inertia about neutral axis ($I_{N.A}$) using $I_{B.L}$.

$$I_{N.A.} = I_{B.L} - A\,\bar{h}^2$$

$\boxed{\sigma \le \sigma_l}$, $\sigma = \dfrac{M}{I_{N.A}/y} = \dfrac{M}{Z}$

Calculation of Section Modulus and Actual Stress at Deck and Bottom


<Midship section>

σ: bending stress
M_T: Total bending moment
A: Total Area
$I_{N.A.}$: Inertia *moment* of the midship section area about neutral axis (N.A.)
B.L : Base Line

Section modulus

$$\frac{I_{N.A.}}{y_D} = Z_D, \qquad \frac{I_{N.A.}}{y_B} = Z_B$$

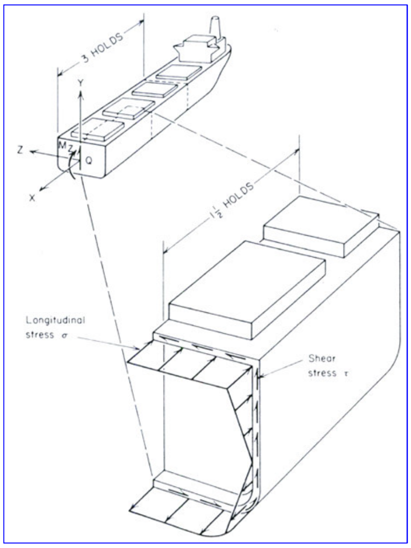
Calculation of Actual Stress at Deck and Bottom

$$\sigma_{Deck} = \frac{M}{I_{N.A}/y_D} = \frac{M}{Z_D}$$

$$\sigma_{Bottom} = \frac{M}{I_{N.A}/y_B} = \frac{M}{Z_B}$$

$\boxed{\sigma \le \sigma_l}$, $\sigma = \dfrac{M}{I_{N.A}/y} = \dfrac{M}{Z}$

Global Hull Girder Strength (Longitudinal Strength) - Definition of the Longitudinal Strength Members



Application of hull girder load effects

※ Example of Requirement for Longitudinal Structural Member

DNV Rules for Classification of Ships
Part 3 Chapter 1 HULL STRUCTUREALDESIGN SHIPS WITH LENGTH 100 METERS AND ABOVE
Sec. 5 Longitudinal Strength
C 300 Section modulus

301 The requirements given in 302 and 303 will normally be satisfied when calculated for the midship section only, provided the following rules for tapering are complied with:

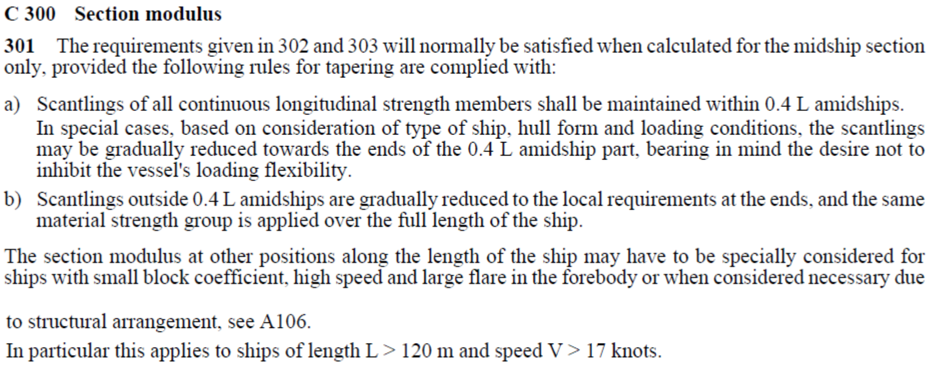
a) **Scantlings of all continuous longitudinal strength members shall be maintained within 0.4 L amidships**.

b) **Scantlings outside 0.4 L amidships are gradually reduced** to the local requirements at the ends, and the same material strength group is applied over the full length of the ship.

The section modulus at other positions along the length of the ship may have to be specially considered for ships with small block coefficient, high speed and large flare in the fore body or when considered necessary due to structural arrangement, see A106.

* Hughes, Ship Structural Design, John Wiley & Sons, 1983

(DNV Pt.3 Ch.1 Sec. 5 C300), 2011



C 300 Section modulus

301 The requirements given in 302 and 303 will normally be satisfied when calculated for the midship section only, provided the following rules for tapering are complied with:

a) Scantlings of all continuous longitudinal strength members shall be maintained within 0.4 L amidships. In special cases, based on consideration of type of ship, hull form and loading conditions, the scantlings may be gradually reduced towards the ends of the 0.4 L amidship part, bearing in mind the desire not to inhibit the vessel's loading flexibility.

b) Scantlings outside 0.4 L amidships are gradually reduced to the local requirements at the ends, and the same material strength group is applied over the full length of the ship.

The section modulus at other positions along the length of the ship may have to be specially considered for ships with small block coefficient, high speed and large flare in the forebody or when considered necessary due to structural arrangement, see A106.

In particular this applies to ships of length L > 120 m and speed V > 17 knots.

The Minimum Required Midship Section Modulus and Inertia Moment by DNV Rule

DNV Rules, Jan. 2004, Pt.3 Ch.1 Sec.5

The **midship section modulus** about the transverse neutral axis shall not be less than:

(Pt.3 Ch.1 Sec.5 C302)

$$Z_O = \frac{C_{WO}}{f_1} L^2 B(C_B + 0.7) \quad [\mathrm{cm}^3]$$

C_{WO}: wave coefficient

L	C_{WO}
$L < 300$	$10.75 - [(300 - L)/100]^{3/2}$
$300 \le L \le 350$	10.75
$L > 350$	$10.75 - [(L - 350)/150]^{3/2}$

C_B is in this case not to be taken less than 0.60

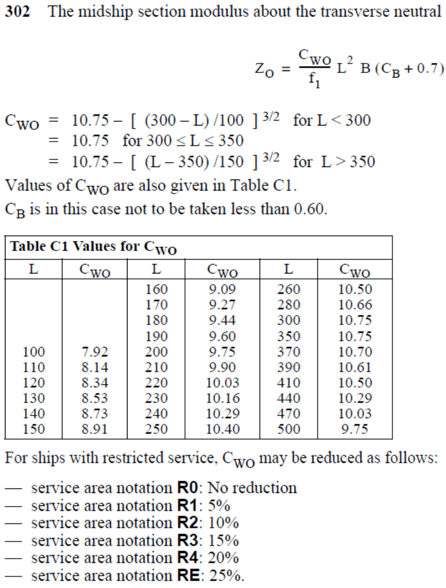
The midship section moment of **inertia** about the transverse neutral axis shall not be less than:

(Pt.3 Ch.1 Sec.5 C400)

$$I_{ship} = 3C_W L^3 B(C_B + 0.7) \quad [cm^4]$$

* DNV Rules, Jan. 2004, Pt.3 Ch.1 Sec.5

(DNV Pt.3 Ch.1 Sec.5 C302), 2011



302 The midship section modulus about the transverse neutral axis shall not be less than:

$$Z_O = \frac{C_{WO}}{f_1} L^2 B(C_B + 0.7) \quad (\mathrm{cm}^3)$$

C_{WO} = $10.75 - [(300 - L)/100]^{3/2}$ for $L < 300$
= 10.75 for $300 \le L \le 350$
= $10.75 - [(L - 350)/150]^{3/2}$ for $L > 350$

Values of C_{WO} are also given in Table C1.

C_B is in this case not to be taken less than 0.60.

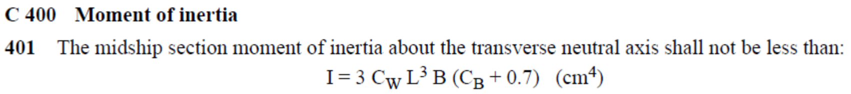
Table C1 Values for C_{WO}

L	C_{WO}	L	C_{WO}	L	C_{WO}
		160	9.09	260	10.50
		170	9.27	280	10.66
		180	9.44	300	10.75
		190	9.60	350	10.75
100	7.92	200	9.75	370	10.70
110	8.14	210	9.90	390	10.61
120	8.34	220	10.03	410	10.50
130	8.53	230	10.16	440	10.29
140	8.73	240	10.29	470	10.03
150	8.91	250	10.40	500	9.75

For ships with restricted service, C_{WO} may be reduced as follows:

— service area notation **R0**: No reduction
— service area notation **R1**: 5%
— service area notation **R2**: 10%
— service area notation **R3**: 15%
— service area notation **R4**: 20%
— service area notation **RE**: 25%.

(DNV Pt.3 Ch.1 Sec.5 C401), 2011



C 400 Moment of inertia

401 The midship section moment of inertia about the transverse neutral axis shall not be less than:

$$I = 3\ C_W\ L^3\ B\ (C_B + 0.7)\quad (\text{cm}^4)$$

Material Factors (f_1)

1) DNV Rules, Jan. 2004,Pt.3 Ch.1 Sec.2

2) James M. Gere, Mechanics of Materials 7th Edition, Thomson, Chap.1, pp.15~26

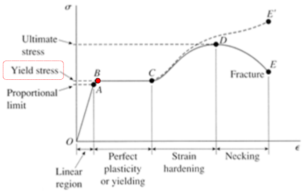
- The material factor f_1 is included in the various formulae for scantlings and in expressions giving allowable stresses.1)

Material Designation	Yield Stress (N/mm^2)	$\frac{\sigma}{\sigma_{NV-NS}}$	Material Factor (f_1)
NV-NS	235	235/235 = 1.00	1.00
NV-27	265	265/235 = 1.13	1.08
NV-32	315	315/235 = 1.34	1.28
NV-36	355	355/235 = 1.51	1.39
NV-40	390	390/235 = 1.65	1.47

* NV-NS: Normal Strength Steel (Mild Steel)

* NV-XX: High Tensile Steel

* High tensile steel: A type of alloy steel that provides better mechanical properties or greater resistance to corrosion than carbon steel. They have a carbon content between 0.05-0.25% to retain formability and weldability, including up to 2.0% manganese, and other elements are added for strengthening purposes.



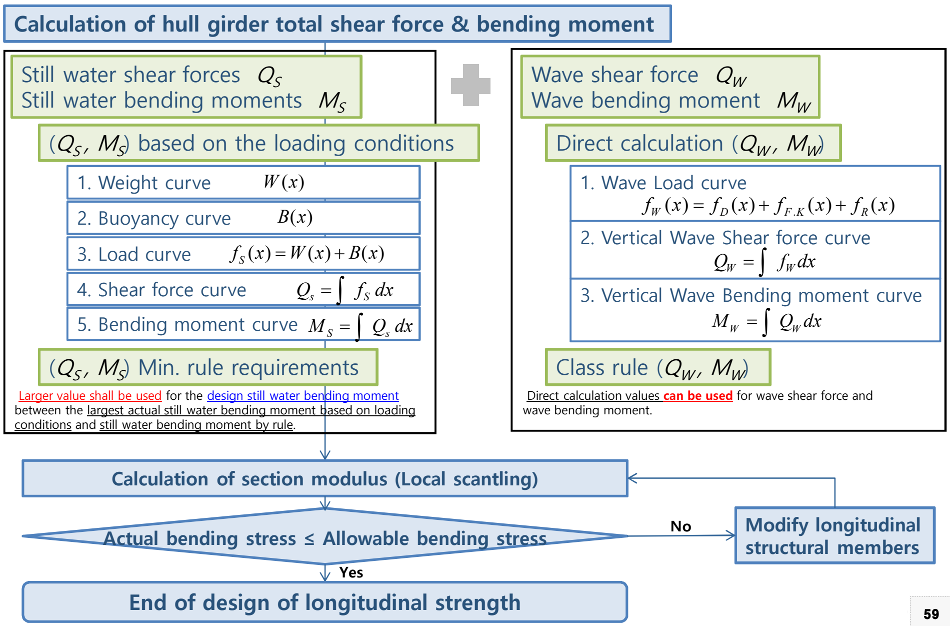
* Yield Stress (σ_y) [N/mm^2] or [MPa]: The magnitude of the load required to cause yielding in the beam.2)

* A: 'A' grade 'Normal Strength Steel'

* AH: 'A' grade 'High Tensile Steel'

Summary of Longitudinal Strength

$\boxed{\sigma \le \sigma_l}$, $\sigma = \frac{M}{I_{N.A}/y} = \frac{M}{Z}$



Calculation of hull girder total shear force & bending moment

Still water shear forces Q_S
Still water bending moments M_S

(Q_S, M_S) based on the loading conditions

1. Weight curve $W(x)$
2. Buoyancy curve $B(x)$
3. Load curve $f_S(x) = W(x) + B(x)$
4. Shear force curve $Q_s = \int f_S \, dx$
5. Bending moment curve $M_S = \int Q_s \, dx$

(Q_S, M_S) Min. rule requirements

Larger value shall be used for the design still water bending moment between the largest actual still water bending moment based on loading conditions and still water bending moment by rule.

✚

Wave shear force Q_W
Wave bending moment M_W

Direct calculation (Q_W, M_W)

1. Wave Load curve
$f_W(x) = f_D(x) + f_{F.K}(x) + f_R(x)$
2. Vertical Wave Shear force curve
$Q_W = \int f_W dx$
3. Vertical Wave Bending moment curve
$M_W = \int Q_W dx$

Class rule (Q_W, M_W)

Direct calculation values **can be used** for wave shear force and wave bending moment.

Calculation of section modulus (Local scantling)

Actual bending stress ≤ Allowable bending stress

No

Modify longitudinal structural members

Yes

End of design of longitudinal strength

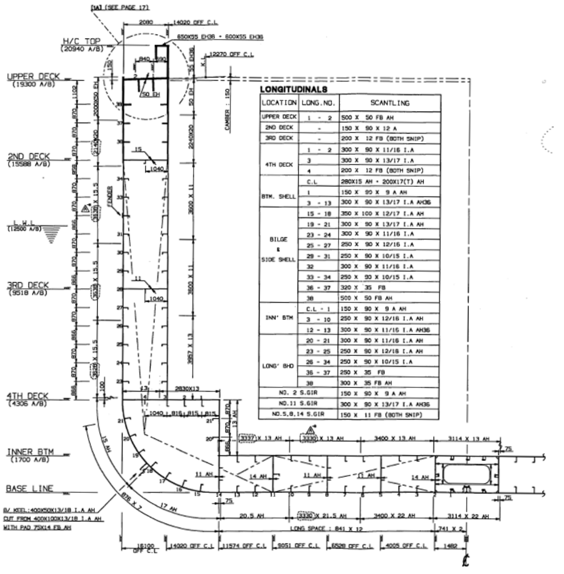
---

3. Structural Design of Midship Section of a 3,700 TEU Container Ship

(1) Data for Structural Design
(2) Longitudinal Strength

(1) Data for Structural Design

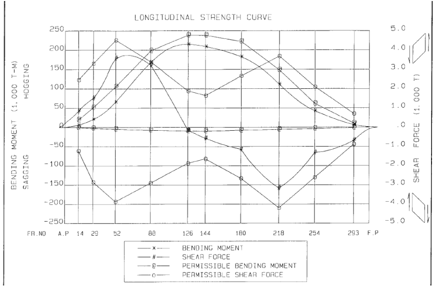
Midship Section for 3,700 TEU Container Ship

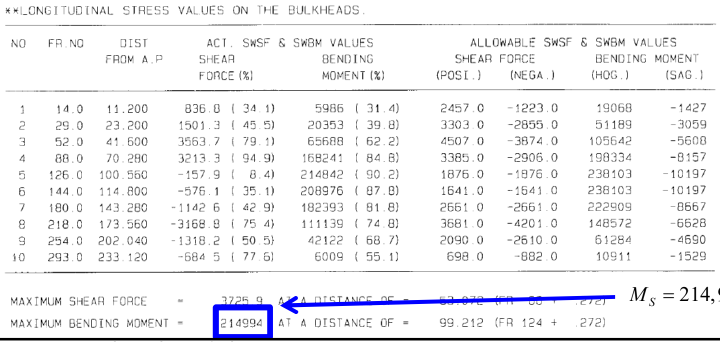


LONGITUDINALS

LOCATION	LONG.NO.	SCANTLING
UPPER DECK	1 - 2	500 X 50 FB AH
2ND DECK	-	150 X 90 X 12 A
3RD DECK	-	200 X 12 FB (BOTH SNIP)
4TH DECK	1 - 2	300 X 90 X 11/16 I.A
	3	300 X 90 X 13/17 I.A
	4	200 X 12 FB (BOTH SNIP)
BTM. SHELL	C.L	280X15 AH + 200X17(T) AH
	1	150 X 90 X 9 A AH
	3 - 13	300 X 90 X 13/17 I.A AH36
BILGE & SIDE SHELL	15 - 18	350 X 100 X 12/17 I.A AH
	19 - 21	300 X 90 X 13/17 I.A AH
	23 - 24	300 X 90 X 11/16 I.A
	25 - 27	250 X 90 X 12/16 I.A
	29 - 31	250 X 90 X 10/15 I.A
	32	300 X 90 X 11/16 I.A
	33 - 34	250 X 90 X 10/15 I.A
	36 - 37	320 X 35 FB
	38	500 X 50 FB AH
INN' BTM	C.L - 1	150 X 90 X 9 A AH
	3 - 10	250 X 90 X 12/16 I.A AH
	12 - 13	300 X 90 X 11/16 I.A AH36
LONG' BHD	20 - 21	300 X 90 X 11/16 I.A AH
	23 - 25	250 X 90 X 12/16 I.A AH
	26 - 34	250 X 90 X 10/15 I.A
	36 - 37	250 X 35 FB
	38	300 X 35 FB AH
NO. 2 S.GIR		150 X 90 X 9 A AH
NO.11 S.GIR		300 X 90 X 13/17 I.A AH36
NO.5,8,14 S.GIR		150 X 11 FB (BOTH SNIP)

Design Still Water Bending Moment for Ballast Arrival Condition





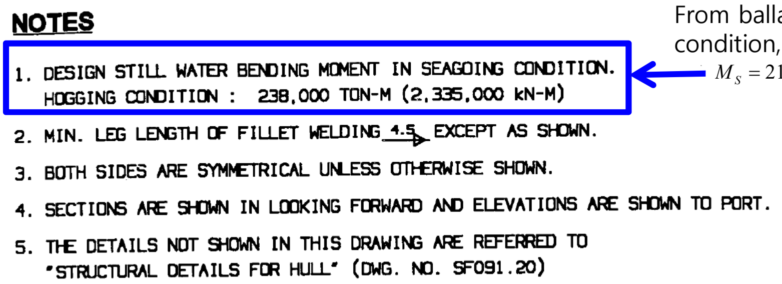
**LONGITUDINAL STRESS VALUES ON THE BULKHEADS.

NO	FR.NO	DIST FROM A.P	ACT. SWSF & SWBM VALUES		ALLOWABLE SWSF & SWBM VALUES			
			SHEAR FORCE (%)	BENDING MOMENT (%)	SHEAR FORCE		BENDING MOMENT	
					(POSI.)	(NEGA.)	(HOG.)	(SAG.)
1	14.0	11.200	836.8 (34.1)	5986 (31.4)	2457.0	-1223.0	19068	-1427
2	29.0	23.200	1501.3 (45.5)	20353 (39.8)	3303.0	-2855.0	51189	-3059
3	52.0	41.600	3563.7 (79.1)	65688 (62.2)	4507.0	-3874.0	105642	-5608
4	88.0	70.280	3213.3 (94.9)	168241 (84.8)	3385.0	-2906.0	198334	-8157
5	126.0	100.560	-157.9 (8.4)	214842 (90.2)	1876.0	-1876.0	238103	-10197
6	144.0	114.800	-576.1 (35.1)	208976 (87.8)	1641.0	-1641.0	238103	-10197
7	180.0	143.280	-1142.6 (42.9)	182393 (81.8)	2661.0	-2661.0	222909	-8667
8	218.0	173.560	-3168.8 (75.4)	111139 (74.8)	3681.0	-4201.0	148572	-6628
9	254.0	202.040	-1318.2 (50.5)	42122 (68.7)	2090.0	-2610.0	61284	-4690
10	293.0	233.120	-684.5 (77.6)	6009 (55.1)	698.0	-882.0	10911	-1529

MAXIMUM SHEAR FORCE = 3725.9 AT A DISTANCE OF = 53.072 (FR 66 + .272)
MAXIMUM BENDING MOMENT = 214994 AT A DISTANCE OF = 99.212 (FR 124 + .272)

$M_S = 214,994[ton \cdot m]$

Design Still Water Bending Moment



NOTES

1. DESIGN STILL WATER BENDING MOMENT IN SEAGOING CONDITION.
   HOGGING CONDITION : 238,000 TON-M (2,335,000 kN-M)
2. MIN. LEG LENGTH OF FILLET WELDING 4.5 EXCEPT AS SHOWN.
3. BOTH SIDES ARE SYMMETRICAL UNLESS OTHERWISE SHOWN.
4. SECTIONS ARE SHOWN IN LOOKING FORWARD AND ELEVATIONS ARE SHOWN TO PORT.
5. THE DETAILS NOT SHOWN IN THIS DRAWING ARE REFERRED TO "STRUCTURAL DETAILS FOR HULL" (DWG. NO. SF091.20)

From ballast arrival condition,
$M_S = 214,994[ton \cdot m]$

By calculating the section modulus and stress factor of the basis ship, we can assume the stress factor for the design ship.

(2) Longitudinal Strength

Example of Midship Scantling
- Midship Scantling for 3,700 TEU Container Ship

<Calculation of Design Bending Moment (Hogging)>

- Still water bending moment
  - Larger value shall be used for still water bending moment between the largest actual still water bending moment based on loading conditions and design still water bending moment by rule.

✓Design still water bending moment by rule[1]

$$C_{WU} = C_W = 10.75 - [(300 - L)/100]^{3/2} = 10.75 - [(300 - 247.64)/100]^{3/2} = 10.37$$

$$M_{SO} = C_{WU} L^2 B (0.1225 - 0.015 C_B) = 10.37 \times 247.64^2 \times 32.2 \times (0.1225 - 0.015 \times 0.6581) = \boxed{2,364,171.77 (kN \cdot m)}$$

$$M_S = k_{sm} M_{SO} = 1.0 \times 2,364,171.77 = \boxed{2,364,171.77 (kN \cdot m)}$$

✓Largest actual still water bending moment based on the loading conditions

- At ballast arrival condition

$$M_S = \boxed{2,109,290 (kN \cdot m)} = 214,994 (ton \cdot m)$$

- Wave bending moment[2]

$$M_{WO} = 0.19 \alpha C_{WU} L^2 B C_B = 0.19 \times 1.0 \times 10.37 \times 247.64^2 \times 32.2 \times 0.6581 = 2,560,481.90 (kN \cdot m)$$

$$M_W = k_{wm} M_{WO} = 1.0 \times 2,560,481.90 = 2,560,481.90 (kN \cdot m)$$

$$\therefore M_S = 2,364,171.77 (kNm)$$

$$M = M_S + M_W = 2,364,171.77 + 2,560,481.90 =$$

<Calculation of Design Bending Moment (Sagging)>

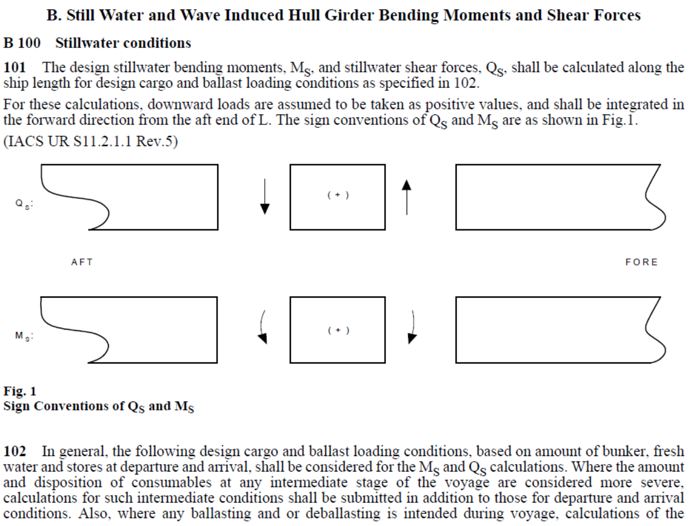
- Design bending moment at sagging condition is calculated in the same way.

$$M_S = -1,807,679.05 (kN \cdot m)$$
$$M_W = -3,059,149.16 (kN \cdot m)$$
$$M = M_S + M_W = -1,807,679.05 - 3,059,149.16 =$$

[1] DNV Rules, Pt. 3 Ch. 1 Sec. 5 B100, Jan. 2004

[2] DNV Rules, Pt. 3 Ch. 1 Sec. 5 B200, Jan. 2004

(DNV Pt. 3 Ch. 1 Sec. 5 B101), 2011



B. Still Water and Wave Induced Hull Girder Bending Moments and Shear Forces

B 100 Stillwater conditions

101 The design stillwater bending moments, M_S, and stillwater shear forces, Q_S, shall be calculated along the ship length for design cargo and ballast loading conditions as specified in 102.

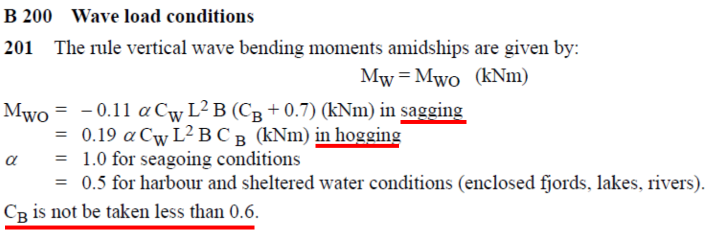
For these calculations, downward loads are assumed to be taken as positive values, and shall be integrated in the forward direction from the aft end of L. The sign conventions of Q_S and M_S are as shown in Fig.1.

(IACS UR S11.2.1.1 Rev.5)

Fig. 1
Sign Conventions of Q_S and M_S

102 In general, the following design cargo and ballast loading conditions, based on amount of bunker, fresh water and stores at departure and arrival, shall be considered for the M_S and Q_S calculations. Where the amount and disposition of consumables at any intermediate stage of the voyage are considered more severe, calculations for such intermediate conditions shall be submitted in addition to those for departure and arrival conditions. Also, where any ballasting and or deballasting is intended during voyage, calculations of the

(DNV Pt. 3 Ch. 1 Sec. 5 B201), 2011



B 200 Wave load conditions

201 The rule vertical wave bending moments amidships are given by:

$$M_W = M_{WO} \quad \text{(kNm)}$$

M_{WO} = $-0.11\, \alpha\, C_W\, L^2\, B\, (C_B + 0.7)$ (kNm) in sagging

= $0.19\, \alpha\, C_W\, L^2\, B\, C_B$ (kNm) in hogging

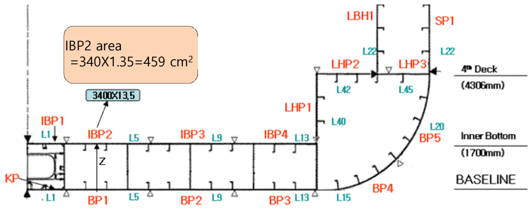
α = 1.0 for seagoing conditions

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

C_B is not be taken less than 0.6.

Example of Midship Scantling
- Midship Scantling for 3,700 TEU Container Ship

Plates at Bottom Structure



<Bottom Structure Plate>

	Name	Width (cm)	Thickness (cm)	Area (cm^2)	Vertical center of IBP (cm)	1st moment of IBP area about base line (cm^3)	2nd moment of IBP area about base line (cm^4)	Moment of inertia of IBP area(Ix) (cm^4)
Plate	KP	155.70	2.05	319	0.0	0	0.000E+00	1.118E+02
	BP1	340.00	1.60	544	0.0	0	0.000E+00	1.161E+02
	BP2	333.00	1.60	533	0.0	0	0.000E+00	1.137E+02
	BP3	326.20	1.60	522	0.0	0	0.000E+00	1.113E+02
	BP4	350.40	2.15	753	34.3	25,825	8.853E+05	2.902E+02
	BP5	350.40	2.15	753	27.8	20,943	5.822E+05	2.902E+02
	IBP1	155.70	1.35	210	170.0	35,733	6.075E+06	3.192E+01
	IBP2	340.00	1.35	459	170.0	78,030	1.327E+07	6.971E+01
	IBP3	333.00	1.35	450	170.0	76,424	1.299E+07	6.828E+01
	IBP4	326.20	1.35	440	170.0	74,863	1.273E+07	6.688E+01
	Name	Width (cm)	Thickness (cm)	Area (cm^2)	Vertical center of IBP (cm)	1st moment of IBP area about base line (cm^3)	2nd moment of IBP area about base line (cm^4)	Moment of inertia of IBP area(Ix) (cm^4)
girder	L0	1.10	170.00	187	85.0	15,895	1.351E+06	4.504E+05
	L2	1.40	170.00	238	85.0	20,230	1.720E+06	5.732E+05
	L5	1.25	170.00	213	85.0	18,063	1.535E+06	5.118E+05
	L8	1.25	170.00	213	85.0	18,063	1.535E+06	5.118E+05
	L11	1.25	170.00	213	85.0	18,063	1.535E+06	5.118E+05
	L14	1.25	170.00	213	85.0	18,063	1.535E+06	5.118E+05

IBP (inner bottom plate) area (A)
= Width of IBP X Thickness of IBP

Ex. Area of IBP2 $= 340 \times 1.35 = 459\ cm^2$

1st moment of IBP area about base line
= Area of IBP (A) X Vertical center of IBP (b)

Ex. 1st moment of Area of IBP2

$$= 459 \times 170 = 78,030\ cm^3$$

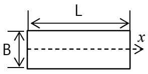
2nd moment of IBP area about base line
= Area of IBP (A) X Vertical center of IBP (b)^2

Ex. 2nd moment of Area of IBP2

$$= 459 \times 170^2 = 1.327e^{07} cm^4$$

Moment of inertia of IBP area (I_x)

Ex. Moment of inertia of IBP2 area

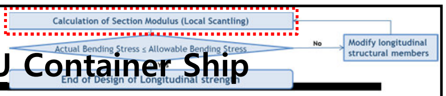


$$= \frac{LB^3}{12} = \frac{340 \times 1.35^3}{12} = 6.971e^{01} cm^4$$

Moment of inertia of IBP area about base line ($I_{x'}$) is obtained by using the parallel-axis theorem.

$$I_{x'} = I_x + b^2 A$$

Example of Midship Scantling
- Midship Scantling for 3,700 TEU Container Ship



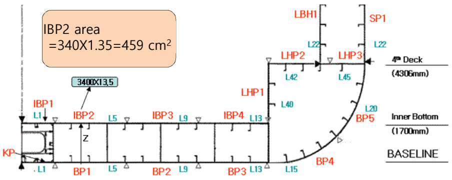
Stiffeners at Bottom Structure

<Bottom Structure Stiffener Web Plate>

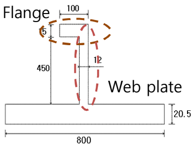
	Name	Width (cm)	Thickness (cm)	Area (cm^2)	Vertical center of IBP (cm)	1st moment of IBP area about base line (cm^3)	2nd moment of IBP area about base line (cm^4)	Moment of inertia of IBP area(Ix) (cm^4)
Bottom Longi. Web	L1	1.20	45.00	54	22.5	1,215	2.734E+04	9.113E+03
	L3	1.20	55.00	66	27.5	1,815	4.991E+04	1.664E+04
	L4	1.20	55.00	66	27.5	1,815	4.991E+04	1.664E+04
	L6	1.20	55.00	66	27.5	1,815	4.991E+04	1.664E+04
	L7	1.20	55.00	66	27.5	1,815	4.991E+04	1.664E+04
	L9	1.20	55.00	66	27.5	1,815	4.991E+04	1.664E+04
	L10	1.20	55.00	66	27.5	1,815	4.991E+04	1.664E+04
	L12	1.20	55.00	66	27.5	1,815	4.991E+04	1.664E+04
	L13	1.20	55.00	66	27.5	1,815	4.991E+04	1.664E+04
InnerBTM Longi.Web	Inner Bottom	In case of Inner Bottom 1.20	35.00	378	152.5	57,645	8.791E+06	3.859E+04
	Name	Width (cm)	Thickness (cm)	Area (cm^2)	Vertical center of IBP (cm)	1st moment of IBP area about base line (cm^3)	2nd moment of IBP area about base line (cm^4)	Moment of inertia of IBP area(Ix) (cm^4)
Bilge Longi. Web	L15	1.20	45.00	54	362.5	19,575	7.096E+06	9.113E+03
	L16	1.20	45.00	54	278.0	19,183	4.173E+06	9.113E+03
	L17	1.20	45.00	54	200.1	13,810	2.162E+06	9.113E+03
	L18	1.20	40.00	48	131.9	8,310	8.351E+05	6.400E+03
	L19	1.20	40.00	48	75.9	4,782	2.765E+05	6.400E+03
	L20	1.20	35.00	42	34.3	1,954	4.941E+04	4.288E+03
	L21	1.20	35.00	42	8.7	493	3.179E+03	4.288E+03

<Bottom Structure Stiffener Flange>

	Name	Width (cm)	Thickness (cm)	Area (cm^2)	Vertical center of IBP (cm)	1st moment of IBP area about base line (cm^3)	2nd moment of IBP area about base line (cm^4)	Moment of inertia of IBP area(Ix) (cm^4)
Bottom Longi. Flange	L1	10.00	1.50	15	45.0	675	3.038E+04	2.813E+00
	L3	50.00	1.50	75	55.0	4,125	2.269E+05	1.406E+01
	L4	50.00	1.50	75	55.0	4,125	2.269E+05	1.406E+01
	L6	50.00	1.50	75	55.0	4,125	2.269E+05	1.406E+01
	L7	50.00	1.50	75	55.0	4,125	2.269E+05	1.406E+01
	L9	50.00	1.50	75	55.0	4,125	2.269E+05	1.406E+01
	L10	10.00	1.50	15	55.0	825	4.538E+04	2.813E+00
	L12	10.00	1.50	15	55.0	825	4.538E+04	2.813E+00
	L13	10.00	1.50	15	55.0	825	4.538E+04	2.813E+00
InnerBTM Longi.F	Inner Bottom	In case of Inner Bottom 10.00	1.50	135	166.5	22,478	3.743E+06	2.531E+01
	Name	Width (cm)	Thickness (cm)	Area (cm^2)	Vertical center of IBP (cm)	1st moment of IBP area about base line (cm^3)	2nd moment of IBP area about base line (cm^4)	Moment of inertia of IBP area(Ix) (cm^4)
Bilge Longi. Flange	L15	1.20	45.00	69	362.5	25,013	9.067E+06	9.113E+03
	L16	1.20	45.00	69	278.0	19,183	5.333E+06	9.113E+03
	L17	1.20	45.00	69	200.1	13,810	2.764E+06	9.113E+03
	L18	1.20	40.00	63	131.9	8,310	1.096E+06	6.400E+03
	L19	1.20	40.00	63	75.9	4,782	3.629E+05	6.400E+03
	L20	1.20	35.00	57	34.3	1,954	6.699E+04	4.288E+03
	L21	1.20	35.00	57	8.7	493	4.268E+03	4.288E+03
Toal				7,519		590,637	87,554,496	3,350,227



For convenience of calculation of moment of inertia of the stiffener area about base line, we consider that the stiffener is actually composed of flange and web plate and thus the stiffener is assumed as the flange and web plate.



Neutral axis of bottom structure
= Total 1st moment of area about base line / Total area

$$= \frac{590,637}{7,519} = 78.55\ [cm]$$

Example of Midship Scantling
- Midship Scantling for 3,700 TEU Container Ship

Calculation of moment of inertia of sectional area from neutral axis

Area, neutral axis, 1st moment & 2nd moment about baseline, and moment of inertia of side structure, bulkhead structure, deck structure are calculated in the same way and the results are as follows:

Structure	Area	Neutral axis	1st moment of area about baseline	2nd moment of area about baseline	Moment of inertia of area
Bottom	7,519	79	5.906E+05	8.755E+08	2.627E+07
Side	3,135	1,158	3.630E+06	4.203E+09	1.261E+08
Bulkhead	5,273	1,250	6.592E+06	8.242E+09	2.472E+08
Deck	2,200	2,130	5.015E+06	1.208E+10	3.624E+08
Total	18,127		1.583E+07	2.540E+10	7.620E+08

Vertical location of neutral axis of midship section from baseline ($\bar{h}$) is calculated by using the above table.

$\bar{h} =$ **Total 1st moment of area about baseline / Total area**

$$= \frac{1.583e^{07}}{18,127} = 873.2[cm]$$

Moment of inertia of area about neutral axis of midship section:

$$I_{Base,Total} = I_{N.A.,Total} + \bar{h}^2 \sum A_i \Rightarrow$$

(Parallel-axis theorem)

$$\begin{aligned} I_{N.A.,Total} &= I_{Base,Total} - \bar{h}^2 \sum A_i \\ &= \sum\left(I_{Local,i} + A_i h_i^2\right) - \bar{h}^2 \sum A_i \Leftarrow I_{Base,Total} = \sum\left(I_{Local,i} + A_i h_i^2\right) \\ &= \boxed{\sum I_{Local,i}} + \boxed{\sum A_i h_i^2} - \bar{h}^2 \sum A_i \\ &= \left(7.620e^{08} + 2.540e^{10}\right) - 873.2^2 \times 18,127 = 1.234e^{10}\,[cm^4] \end{aligned}$$

$I_{N.A.}$: moment of inertia of midship section area about neutral axis (cm^3)
I_{Base} : moment of inertia of midship section area about base line (cm^3)
h_i : vertical center of structural member (cm)
A_i : area of structural member (cm)

Example of Midship Scantling
- Midship Scantling for 3,700 TEU Container Ship

$$f_{2b,2d} = \frac{5.7(M_S + M_W)}{Z_{b,d}}$$

① Assume section modulus

- Bottom stress factor of the basis ship

$Z_B = 2.595e^7 \ cm^3$

- Deck stress factor of the basis ship

$Z_D = 2.345e^7 \ cm^3$

② Actual section modulus

- Bottom section modulus

$Z_B = 2 \times I / y_B$ (port & starboard)

$= 2 \times 1.234e^{10} / 873.2$

$= 2.826e^7 \, [cm^3]$

(y_B: Vertical distance from N.A to bottom = 873.2cm)

Because the section modulus at bottom is larger than that of the basis ship, the stress factor should be decreased.

- Bottom Stress Factor

$$f_{2b} = \frac{5.7(M_S + M_W)}{f_1 \times Z_B} = \frac{5.7 \times 4,924,653.67}{1.0 \times 2.826e^7} =$$

- Deck section modulus

$Z_D = 2 \times I / y_D$ (port & starboard)

$= 2 \times 1.234e^{10} / 1,226.8$

$= 2.012e^7 \, [cm^3]$

(y_D: Vertical distance from N.A to deck=2094-873.2 = 1,226.8 cm)

Because the section modulus at deck is smaller than that of the basis ship, the stress factor will be increased. However, if HT-36 is used, then the stress factor can be decreased.

- Deck Stress Factor

$$f_{2d} = \frac{5.7(M_S + M_W)}{f_1 \times Z_D} = \frac{5.7 \times 4,924,653.67}{1.39 \times 2.012e^7} =$$

③ Because the stress factor (f_{2b}) is decreased, the allowable stress is increased.

$$\sigma = 225 f_1 - 130 f_{2b} - 0.7\sigma_{db}$$

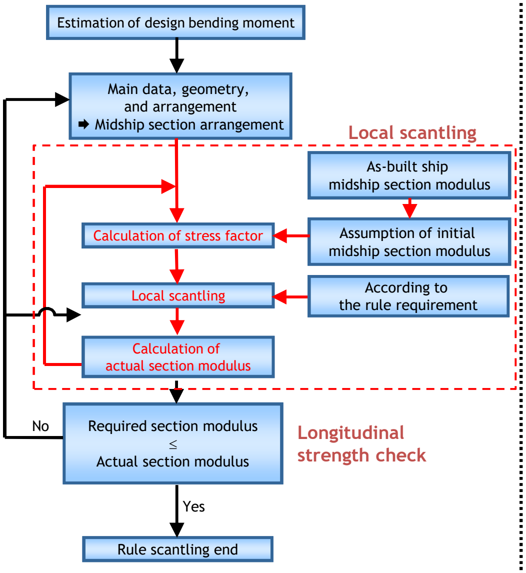
e.g., Allowable stress for longitudinals at inner bottom

④ Because the allowable stress is increased, the required section modulus is decreased. So, we can reduce the size of the structure member.

$$\boxed{Z = \frac{83 l^2 spw_k}{\sigma} \ [cm^3]}$$

e.g., Required section modulus for longitudinals at inner bottom

Example of Midship Scantling
- Midship Scantling for 3,700 TEU Container Ship



Estimation of design bending moment

Main data, geometry, and arrangement
➡ Midship section arrangement

Local scantling

As-built ship midship section modulus

Assumption of initial midship section modulus

Calculation of stress factor

According to the rule requirement

Local scantling

Calculation of actual section modulus

No

Required section modulus ≤ Actual section modulus

Longitudinal strength check

Yes

Rule scantling end

The local scantling is determined assuming that initial midship section modulus of the design ship is equal to that of the basis ship.

The midship section modulus of the basis ship:

$$Z_B = 2.595e^7\ cm^3$$
$$Z_D = 2.345e^7\ cm^3$$

The actual bending stress ($\sigma_{act.}$) shall not be greater than the allowable bending stress (σ_l).

Therefore, we have to repeat the calculation.