Innovative Ship and Offshore Plant Design

Part I. Ship Design

Ch. 5 Freeboard Calculation

Spring 2019

Myung-Il Roh

Department of Naval Architecture and Ocean Engineering
Seoul National University

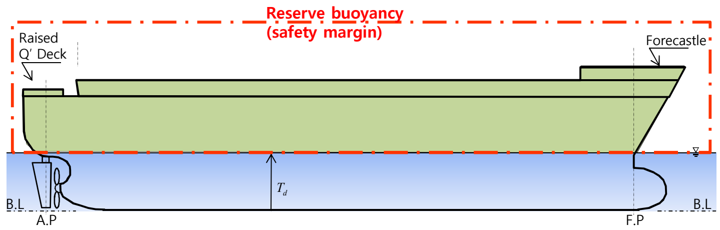
Contents

Ch. 5 Freeboard Calculation

1. Concept

Purpose

▪ The purpose of the freeboard



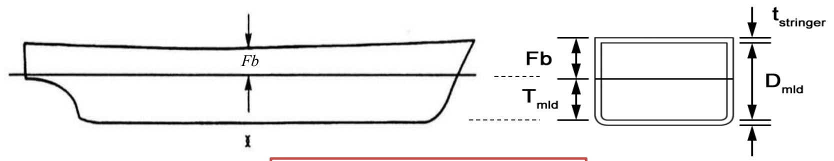
- The ship needs an additional safety margin to maintain buoyancy and stability while operating at sea.
- This safety margin is provided by   of the hull located above the water surface (   ).

▪ The regulation of the freeboard

- International Convention on Load Lines 1966 (   )

Definition (1/2)

▪ Freeboard (Fb)



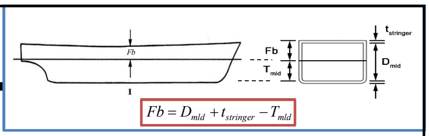
$$Fb = D_{mld} + t_{stringer} - T_{mld}$$

- Definition: The freeboard is the   measured at the deck edge at the mid-length between the perpendiculars. It includes the thickness of stringer plate.[1)]
- In other word, the   between the   and the   (at the deck line). It includes the thickness of stringer.

▪ Molded Depth (D_{mld}): The molded depth is the vertical distance measured from the top of the keel to the top of the freeboard deck beam at side.
▪ Depth for freeboard (D_f): The depth for freeboard is the molded depth amdiships, plus the stringer thickness at side.
$D_f = D_{mld} + t_{stringer}$, $t_{stringer}$: Thickness of the stringer

1) International Convention on Load Lines 1966, ANNEX1 Chapter 1, Reg.3-(9), 2003

Definition (2/2)



▪ Freeboard (Fb)

$$D_f - T_{mld} \geq Fb_{req.}$$

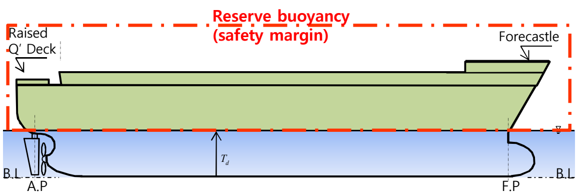
- **Requirement**

: Actual freeboard should not be less than the required freeboard of ICLL 1966.

Effect of Freeboard on Ships' Characteristics (1/3)

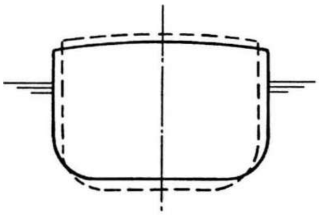
: The freeboard influences the following ship's characteristics.

1. Dryness of deck. .
   (a) because walking on wet deck can be dangerous
   (b) as a safety measure against water entering through deck openings
   (c) to prevent violent seas destroying the superstructure
2. in damaged condition.
3. (characteristics of righting arm curve).
4. .



Effect of Freeboard on Ships' Characteristics (2/3)

▪ Large Freeboard



Greater freeboard at the expense of breadth decreases stability.

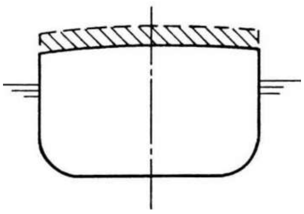
In general, a large freeboard improves stability.

However, it is difficult to consider this factor in the design. Since for reasons of cost, the necessary minimum underdeck volume should not be exceeded and the length is based on economic considerations, only a decrease in breadth would compensate for an increase in freeboard and depth.

* H. Schneekluth, V. Bertram, Ship Design for Efficiency and Economy, pp. 15, 1998

Effect of Freeboard on Ships' Characteristics (3/3)

▪ Increasing Freeboard



Freeboard increased by additional superstructure

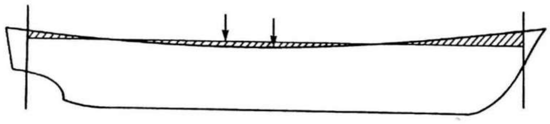
Increasing depth and decreasing breadth would decrease both the initial stability and the righting arm curve.

The stability would only be improved if the underwater form of the ship and the height of the centre of gravity remained unchanged and the freeboard were increased.

* H. Schneekluth, V. Bertram, Ship Design for Efficiency and Economy, pp. 16, 1998

Effect of Sheer

- **Advantages and Disadvantages of a Construction 'Without Sheer'**



Ship with and without sheer with same underdeck volume
(the differences in freeboard are exaggerated in the diagram)

Advantages of a construction 'without sheer'

+ Better stowage of containers in holds and on deck
+ Cheaper construction method, easier to manufacture
+ Greater carrying capacity with constant underdeck volume

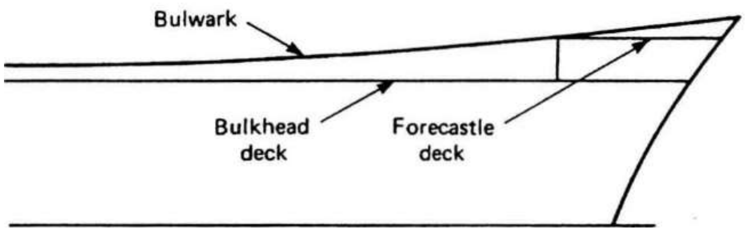
Disadvantages of a construction 'without sheer'

- If the forecastle is not sufficiently high, reduced seakeeping ability
- Less aesthetic in appearance

* H. Schneekluth, V. Bertram, Ship Design for Efficiency and Economy, pp. 16, 1998

Freeboard and Sheer

- **Compensation for a Lack of Sheer**



Visual sheer effect using the line of the bulwark

The 'upper edge of bulwark' line can be extended to **give the appearance of sheer.**

* H. Schneekluth, V. Bertram, Ship Design for Efficiency and Economy, pp. 17, 1998

2. International Convention on Load Lines (ICLL) 1966

Regulation of the International Convention on Load Lines (ICLL) 1966

- **The ICLL 1966 is structured as follows:**

Chapter I – General

- **Terms and concepts** are defined.
  All the definitions of terms and concepts associated with freeboard and the freeboard calculation, and a description of how the freeboard is marked.

Chapter II – Conditions for the assignment of freeboard

- **Structural requirements** are defined.
  Conditions for the assignment of freeboard structural requirements under which freeboard is assigned.

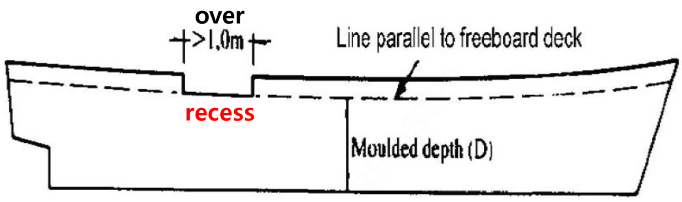
Chapter III – Freeboards

- **Procedure of freeboard calculation** is described.
  The freeboard tables and the regulations for correcting the basis values given by the tables. This is **the central part** of the freeboard regulations.

The agreement is valid for cargo ships over 24 m in length and for non-cargo-carrying vessels, e.g. floating dredgers.
Warships are not subject to the freeboard regulations.

1. General Definitions (1/5)

▪ Freeboard Deck[1)]



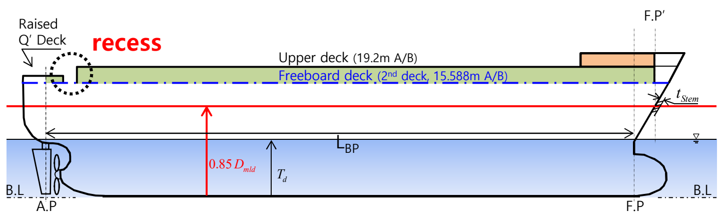
(a) The freeboard deck is normally the uppermost complete deck exposed to weather and sea, which has permanent means of closing all openings in the weather part thereof, and below which all openings in the sides of the ship are fitted with permanent means of watertight closing.

(b) Where a recess in the freeboard deck extends to the sides of the ship and is in excess of one meter in length, the lowest line of the exposed deck and the continuation of that line parallel to the upper part of the deck is taken as the freeboard deck.

1) International Convention on Load Lines 1966, ANNEX1 Chapter 1, Reg.3-(9), 2003

1. General Definitions (2/5)

Ex) Freeboard of 3,700TEU Container Carrier



- There is a recess in the upper deck of the container carrier.
  In other words, the upper deck is discontinuous.

- This 3,700TEU container carrier is designed to assign 2nd deck as freeboard deck considering other design factors.

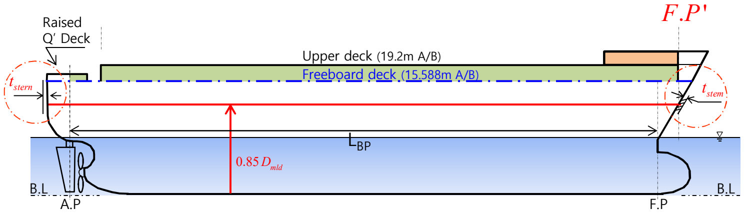
- Quarter deck: deck at after part, in general, at ¼ of the ship's length after

1. General Definitions (3/5)

3,700TEU Container Carrier

D_{mld} (freeboard deck)	15.588 m
$0.85D_{mld}$	13.250 m

▪ Freeboard Length (L_f): $L_f = \max(L_1, L_2)$



L_1 : 96% of the total length (including thickness of stem and stern) on a measured from the top of the keel

※ Perpendicular: In the freeboard regulation, the forward perpendicular is located at the point of the intersection of the waterline at 85% depth with the forward edge of the stem.

Example) L_1 of 3,700TEU container carrier

$$L_1 = (t_{stern} + L_{Aft,0.85D} + L_{BP} + L_{Forward,0.85D} + t_{stem}) \times 0.96$$
$$= (0.015 + 5.0 + 245.24 + 0.024 + 0.015) \times 0.96$$
$$= 250.294 \times 0.96 = 240.282[m]$$

$L_{Aft,0.85D}$: 5.0m
$L_{Foward,0.85D}$: 0.024m
t_{stern}: 0.015m
t_{stem}: 0.015m
L_{BP}: 245.24m

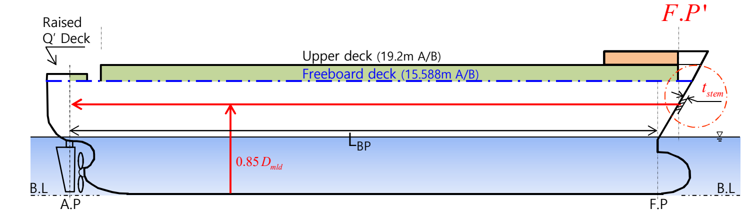
* International Convention on Load Lines 1966, ANNEX1 Chapter 1, Reg.3-(1), 2003

1. General Definitions (4/5)

3,700TEU Container Carrier

D_{mld} (freeboard deck)	15.588 m
$0.85D_{mld}$	13.250 m

▪ Freeboard Length (L_f): $L_f = \max(L_1, L_2)$



L_2 : The length on a from the fore side of the to

Example) L_2 of 3,700TEU container carrier

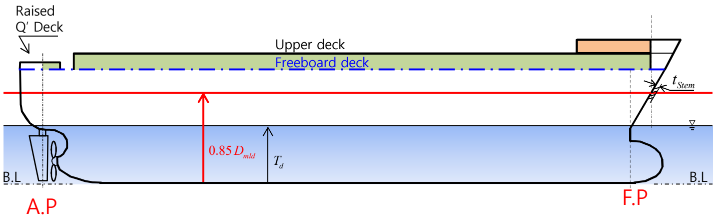
$$L_2 = L_{BP} + L_{Forward,0.85D} + t_{stem}$$
$$= 245.24 + 0.024 + 0.015 = 245.279[m]$$
$$L_f = \max(L_1, L_2)$$
$$= \max(240.282, 245.279) = 245.279[m](L_2)$$

$L_{Aft,0.85D}$: 5.0m
$L_{Foward,0.85D}$: 0.024m
t_{stern}: 0.015m
t_{stem}: 0.015m
L_{BP}: 245.24m

* International Convention on Load Lines 1966, ANNEX1 Chapter 1, Reg.3-(1), 2003

1. General Definitions (5/5)

- **Perpendiculars**



Why do we use perpendiculars at $0.85D_{mld}$ instead of T_d?

The aft perpendicular is established using the rudder axis. This somewhat anomalous approach due to the forward perpendicular makes sense, because the draft (to which usually the length is related) is not available as an input value.

In case the draft is not determined, the draft is only known after the freeboard calculation is finished.

2. Structural Requirements

The requirement for the assignment of freeboard is that the ship is sufficiently safe and has adequate strength. The requirements in detail are:

- The particular structural requirements of the freeboard regulation must be satisfied. Particular attention should be given to : external doors, sill heights and ventilator heights, hatches and openings of every kind plus their sealing arrangements on decks and sides.

(e.g. engine room openings, side windows, scuppers[1)], freeing ports[2)] and pipe outlets)

1) Scupper: Openings in the shell plating just above deck plating to allow water to run overboard.
2) Freeing ports: An opening in the bulwark or rail for discharging large quantities of water, when thrown by the sea upon the ship's deck.
(http://www.libertyship.com/html/glossary/glosbody.htm : Project Liberty Ship - Glossary of Nautical and Shipbuilding Terms)

3. Required Data for the Calculation of Freeboards

To calculate the freeboard of a ship in accordance with ICLL 1966, some data and plans are required as follows:

- Lines or Offset Table (Fared Lines)
- General Arrangement Plan (G/A)
- Hydrostatic Table
- Midship Section Plan (M/S)
- Shell Expansion Plan
- Construction Profile & Decks Plan
- Superstructure Construction Plan,
- Aft body Construction, Fore body Construction Plans

3. Procedure of Freeboard Calculation

Types of Ships

For the purpose of freeboard calculation, ships shall be divided into type 'A' and type 'B'.

- **Type 'A' ships**
  : A type 'A' ship is designed to .

  Example) Crude Oil Carrier, LNG Carrier, etc.

  - The type 'A' ship has a high integrity of the exposed deck with only small access openings to cargo compartments, closed by watertight gasketed covers of steel or equivalent material.
  - The type 'A' ship has low permeability of loaded cargo compartments.

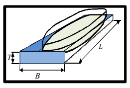
- **Type 'B' ships**
  :
  shall be considered as type 'B' ships.

  Example) Container Carrier, Bulk Carrier, Ore Carrier, etc.

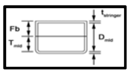
  ∗ 3,700TEU container carrier is a type 'B' ship.

Freeboard Calculation Procedure

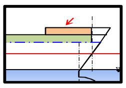
1. Tabular freeboard (F_t) calculation
2. Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)



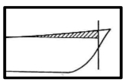
3. Correction for depth ($D_f \neq L_f/15$)



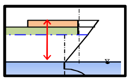
4. Deduction for superstructure and trunks



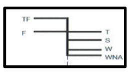
5. Correction for sheer (sheer ≠ standard sheer)



6. Minimum bow height



7. Maximum molded summer draft



(1) Tabular Freeboard (F_t) Calculation

1. Tabular freeboard(F_t) calculation
2. Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3. Correction for depth ($D_f \neq L_f/15$)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

$L_f = \max(L_1, L_2) = 245.279[m]$

Length of ship (m)	Freeboard (mm)
240	3690
241	3705
242	3720
243	3735
244	3750
245	3765
246	3780
247	3795
248	3808
249	3821
250	3835
⋮	

[Table 1] Freeboard table for type 'B' ships

The tabular freeboard for type 'B' ships shall be for type 'B' ships.

Freeboards at intermediate lengths of ship shall be obtained by linear interpolation.

Example 3,700TEU Container Carrier)

$$L_f = 245.279[m]$$

$$\therefore F_t = \frac{3,765\cdot(246-245.279)+3,780\cdot(245.279-245)}{(245.279-245)+(246-245.279)}$$

$$= 3,770[mm]$$

(2) Correction for Block Coefficient (C_B)

1. Tabular freeboard(F_t) calculation
2. Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3. Correction for depth ($D_f \neq L_f/15$)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

- **Block coefficient (C_B) at 0.85D_{mld}**

$$C_{B,0.85\cdot Dmld} = \frac{\nabla}{L_f \cdot B \cdot 0.85 D_{mld}}$$

Where, the volume (∇) of the molded displacement of the ship is taken at a molded draft of $0.85D_{mld}$.

3,700TEU Container Carrier

D_{mld} (freeboard deck)	15.588 m
$0.85D_{mld}$	13.250 m
$C_{B,0.85Dmld}$	0.6705

If the block coefficient exceeds 0.68, the tabular freeboard specified in Regulation 28 shall be multiplied by the factor.

$$C_{B,0.85\cdot D_{mld}} \geq 0.68 \quad \text{Correction for block coefficient} = F_t \cdot \frac{(C_{B,0.85\cdot D_{mld}}+0.68)}{1.36}$$

$$C_{B,0.85\cdot D_{mld}} < 0.68 \quad \text{There is no correction for block coefficient.}$$

Example 3,700TEU Container Carrier)

$$C_{B,0.85\cdot Dmld} = 0.6705 < 0.68$$

$$\rightarrow \text{There is no correction for block coefficient.}$$

(3) Correction for Depth (D_f)

$L_f = \max(L_1, L_2) = 245.279[m]$

$D_f = D_{mld} + t_{stringer}$

1. Tabular freeboard(F_t) calculation
2. Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3. Correction for depth ($D_f \neq L_f/15$)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

▪ Depth for freeboard (D_f)

$$D_f = D_{mld} + t_{stringer}$$ (where, freeboard deck = upper deck)

$t_{stringer}$: Thickness of the freeboard deck

3,700TEU Container Carrier

D_{mld} (freeboard deck)	15.588 m
$t_{stringer}$	0.013m
D_f	15.601 m

$D_f \le L_f / 15$

There is no correction for depth.

$D_f > L_f / 15$

$$\text{Correction for depth} = (D_f - L_f / 15) \cdot R$$

$$R = L_f / 0.48 : L_f < 120\,m$$

$$R = 250 : L_f \ge 120\,m$$

Example 3,700TEU Container Carrier)

$D_f \neq D_{mld} + t_{stringer}$ (∵ freeboard deck ≠ upper deck)

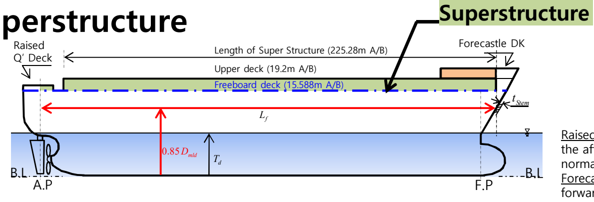
$D_f = 15.601[m],\ L_f / 15 = 245.279 / 15 = 16.352[m]$

$\therefore D_f < L_f / 15 \rightarrow$ There is no correction for depth.

(4) Deduction for Superstructure and Trunks (1/6)

1. Tabular freeboard(F_t) calculation
2. Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3. Correction for depth ($D_f \neq L_f/15$)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

▪ Superstructure



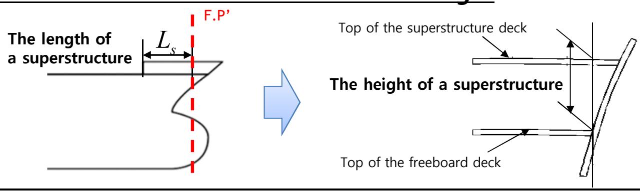
Raised Q' Deck: Superstructure which extends forward from the after perpendicular, generally has a height less than a normal superstructure, and has an intact front bulkhead

Forecastle DK: Superstructure which extends from the forward perpendicular aft to a point which is forward of the forward perpendicular

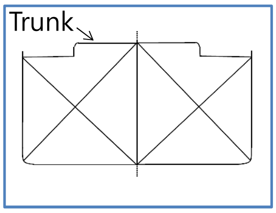
A superstructure is a decked structure on the freeboard deck, extending from side to side of the ship or with the side plating not being inboard of the shell plating more than 4% of the breadth.

The height of a superstructure: The least vertical height measured at side from the top of the superstructure deck beams to the top of the freeboard deck beams.

The length of a superstructure (L_S): The mean length of the part of the superstructure which lies within the freeboard length.



[Appendix] Regulations for Superstructure, Trunk, and Raised Quarter Deck

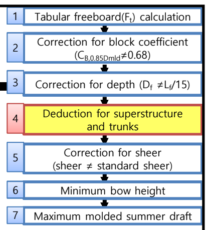


- There are special regulations for trunks (Reg. 36) which are not covered here. E = S for an enclosed superstructure of standard height.
- S is the superstructure's length within L.

- If the superstructure is set in from the sides of the ship, E is modified by a factor b/B_s, where b is the superstructure width and B_s the ship width, both at the middle of the superstructure length (Reg. 35).

- For superstructures ending in curved bulkheads, S is specially defined by Reg. 34. If the superstructure height d_v is less than standard height d_s (Table 1.5a), E is modified by a factor d_v/d_s.
- The effective length of a raised quarter deck (if fitted with an intact front bulkhead) is its length up to a maximum of 0.6L.
- Otherwise the raised quarterdeck is treated as a poop of less than standard height.

(4) Deduction for Superstructure and Trunks (2/6)



3,700TEU Container Carrier

Item	Mean length (m)	Height (m)
Superstructure	225.28	3.71
Raised Q' Deck	11.20	1.24

▪ Effective length of superstructure (L_E)

L_E = Mean Length × [min(Standard Height, Actual Height)] / Standard Height

If the height of an enclosed superstructure is
① higher than the standard height, the effective length of an enclosed superstructure of standard height shall be its length.
② less than the standard height, the effective length shall be its length reduced in the ratio of the actual height to the standard height.

The standard height of a superstructure shall be as given in the following table:

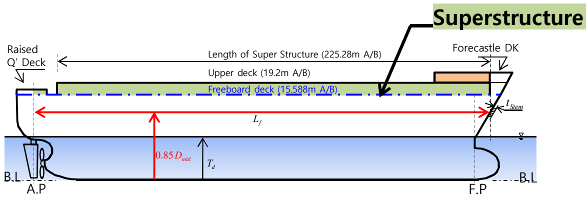
L_f (m)	Raised quarterdeck (m)	All other superstructures (m)
30 or less	0.90	1.80
75	1.20	1.80
125 or more	1.80	2.30

The standard heights at intermediate lengths of the ship shall be obtained by linear interpolation.

(4) Deduction for Superstructure and Trunks (3/6)

1. Tabular freeboard(F_t) calculation
2. Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3. Correction for depth ($D_f \neq L_f/15$)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

L_E = Mean Length × [min(Standard Height, Actual Height)] / Standard Height



3,700TEU Container Carrier

Item	Mean length (m)	Height (m)
Superstructure	225.28	3.71
Raised Q' Deck	11.20	1.24

L_f (m)	Raised quarterdeck (m)	All other superstructures (m)
30 or less	0.90	1.80
75	1.20	1.80
125 or more	1.80	2.30

Example 3,700TEU Container Carrier)

L_t: Length of a superstructure

$$L_{E,\text{superstructure}} = 225.28 \cdot 2.30 / 2.30\ [m] \quad (\because 3.71 > 2.30)$$

$$L_{E,Rasied\,Q'deck} = L_{s,Rasied\,Q'deck} \cdot H_{Rasied\,Q'deck} / H_{\text{standard}}$$

$$= 11.20 \cdot 1.24 / 1.80 \quad (\because 1.24 < 1.80)$$

$$= 7.72\ [m]$$

$$\therefore L_E = L_{E,Rasied\,Q'deck} + L_{E,\text{superstructure}} = 7.72 + 225.28 = 233.00[m]$$

(4) Deduction for Superstructure and Trunks (4/6)

1. Tabular freeboard(F_t) calculation
2. Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3. Correction for depth ($D_f \neq L_f/15$)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

$L_f = \max(L_1, L_2) = 245.279[m]$

$L_E = 233.00[m]$

▪ Deduction from the freeboard

Where the effective length (L_E) of superstructures and trunk is

① 1.0 L_f

Deduction from the freeboard =
$$\begin{cases} 350mm & : L_f = 24m \\ 860mm & : L_f = 85m \\ 1{,}070mm & : L_f \geq 122m \end{cases}$$

② less than 1.0L_f, the deduction shall be a percentage obtained from the following table:
Percentage of deduction for type 'A' and 'B' ships

	Total Effective Length Superstructures and Trunks										
	0	0.1 L	0.2 L	0.3 L	0.4 L	0.5 L	0.6 L	0.7 L	0.8 L	0.9 L	1.0 L
Percentage of deduction for all types of superstructures	0	7	14	21	31	41	52	63	75.3	87.7	100

Percentages at intermediate lengths of superstructures and trunks shall be obtained by linear interpolation.

(4) Deduction for Superstructure and Trunks (5/6)

$L_f = \max(L_1, L_2) = 245.279[m]$
$L_E = 233.00[m]$

▪ Deduction from the freeboard

Example 3,700TEU Container Carrier)

$$L_f = 245.279[m]$$
$$L_E = 233.00[m]$$
$$\therefore L_E < L_f$$

Where the effective length (L_E) of superstructures and trunk is less than 1.0L_f, the deduction shall be a percentage obtained form the following table:

$$L_E / L_f = 0.95$$

	Total Effective Length Superstructures and Trunks										
	0	0.1 L	0.2 L	0.3 L	0.4 L	0.5 L	0.6 L	0.7 L	0.8 L	0.9 L	1.0 L
Percentage of deduction for all types of superstructures	0	7	14	21	31	41	52	63	75.3	87.7	100

Percentage of deduction for superstructures

$$= 87.7 + (100 - 87.7)\ X\ (0.05/0.1) = 93.85\%$$

(4) Deduction for Superstructure and Trunks (6/6)

$L_f = \max(L_1, L_2) = 245.279[m]$

Percentage of deduction for superstructures $= 93.85\%$

▪ Deduction from the freeboard

Example 3,700TEU Container Carrier)

$$L_f = 245.279[m]$$

Deduction from the freeboard = $\begin{cases} 350mm & : L_f = 24m \\ 860mm & : L_f = 85m \\ 1{,}070mm & : L_f \geq 122m \end{cases}$

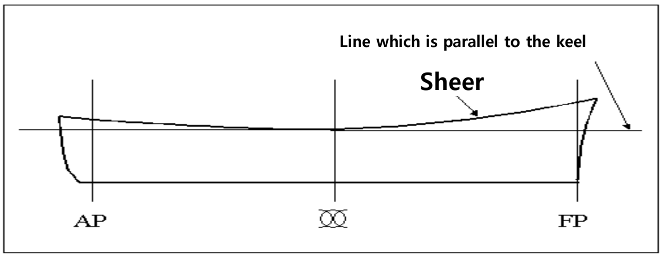
The deduction from the freeboard is multiplied by the percentage of deduction for superstructure.

Deduction from the freeboard $= 1{,}070 \cdot 0.9385 = 1{,}004[mm]$

(5) Correction for Sheer (1/7)

1. Tabular freeboard(F_t) calculation
2. Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3. Correction for depth ($D_f \neq L_f/15$)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

▪ Sheer



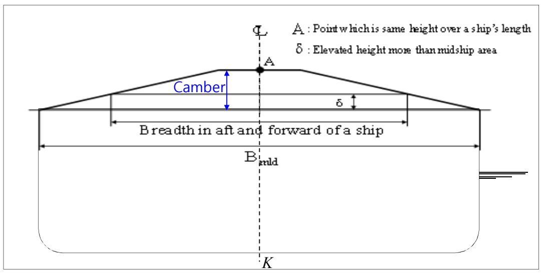
Sheer is   of a ship's deck from mid length towards the bow and stern.

The sheer gives the ship extra   at the stem and the stern.

(5) Correction for Sheer (2/7)

1. Tabular freeboard(F_t) calculation
2. Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3. Correction for depth ($D_f \neq L_f/15$)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

▪ Camber



Camber is the   .

The curvature helps to ensure sufficient drainage of any water on deck.

For ships with camber of beam, care must be taken that the deck without sheer do not become too humped at the ends as a result of the deck beam. In other words, the deck 'centre-line' should have no sheer and the deck edge line should be raised.

(5) Correction for Sheer (3/7)

1 Tabular freeboard(F_t) calculation
2 Correction for block coefficient ($C_{B,0.85Dmld}$≠0.68)
3 Correction for depth (D_f ≠L_f/15)
4 Deduction for superstructure and trunks
5 Correction for sheer (sheer ≠ standard sheer)
6 Minimum bow height
7 Maximum molded summer draft

▪ Correction for sheer

$$\text{Correction for shear} = (S_o - S)\cdot(0.75 - 0.5r_1)$$

- S_o: Standard height of sheer (mm)
- S : Mean height of actual sheer (mm)
- r_1: The effective length (L_E) of superstructures divided by freeboard length (L_f)

$$r_1 = L_E / L_f$$

- If $S_0 > S$, **the tabular freeboard is added to the correction for sheer.**
- If $S_0 < S$, **the tabular freeboard is subtracted to the correction for sheer.**

(5) Correction for Sheer (4/7)

1 Tabular freeboard(F_t) calculation
2 Correction for block coefficient ($C_{B,0.85Dmld}$≠0.68)
3 Correction for depth (D_f ≠L_f/15)
4 Deduction for superstructure and trunks
5 Correction for sheer (sheer ≠ standard sheer)
6 Minimum bow height
7 Maximum molded summer draft

(a) Excess or deficiency of sheer

➡ **Design ship has no sheer.**

$L_f = 245.279[m]$

Station		Standard* Height (mm)	Standard* Ordinate	Standard* Factor	Standard* Product	Actual Height (mm)	Actual Ordinate	Actual Factor	Actual Product
After half	A.P	25.0(L_f/3+10)	2,294	1	2,294	S1	0	1	0
	L_f/6(from A.P)	11.1(L_f/3+10)	1,019	3	3,057	S2	0	3	0
	L_f/3(from A.P)	2.8(L_f/3+10)	257	3	771	S3	0	3	0
	Amidiship	0	0	1	0	S4	0	1	0
	Mean height	S_A = 8.34(L_f/3 + 10)			765	S_a			0
Forward half	Amidship	0	0	1	0	S4	0	1	0
	L_f/3(from F.P)	5.6(L_f/3+10)	514	3	1,542	S5	0	3	0
	L_f/6(from F.P)	22.2(L_f/3+10)	2,037	3	6,111	S6	0	3	0
	F.P	50.0(L_f/3+10)	4,588	1	4,588	S7	0	1	0
	Mean height	S_F = 16.68(Lf/3 +10)			1,526	S_f			0

(2,294+3,057+771+0)/(1+3+3+1)=765

(0+1,542+6,111+4,588)/(1+3+3+1)=1,526

Standard height of sheer (S_o): (S_A+S_F)/2 = 1,146 mm

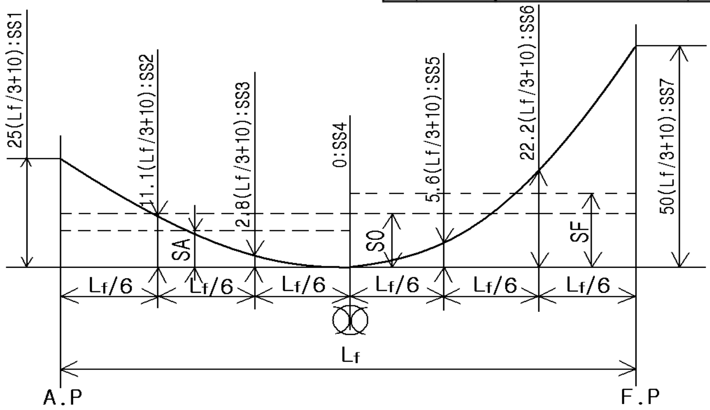
Mean height of actual sheer (S): (S_a+S_f)/2 = 0 mm

(5) Correction for Sheer (5/7)

1. Tabular freeboard(F_T) calculation
2. Correction for block coefficient ($C_{B\,0.85Dmld} \neq 0.68$)
3. Correction for depth ($D_f \neq L_f/15$)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

* Standard height of sheer

Station		Standard*			
		Height (mm)	Ordinate	Factor	Product
After half	A.P	$25.0(L_f/3+10)$	2,294	1	2,294
	$L_f/6$(from A.P)	$11.1(L_f/3+10)$	1,019	3	3,057
	$L_f/3$(from A.P)	$2.8(L_f/3+10)$	257	3	771
	Amidiship	0	0	1	0
	Mean height	$S_A = 8.34(L_f/3 + 10)$			765
Forward half	Amidship	0	0	1	0
	$L_f/3$(from F.P)	$5.6(L_f/3+10)$	514	3	1,542
	$L_f/6$(from F.P)	$22.2(L_f/3+10)$	2,037	3	6,111
	F.P	$50.0(L_f/3+10)$	4,588	1	4,588
	Mean height	$S_F = 16.64(Lf/3 +10)$			1,526



(5) Correction for Sheer (6/7)

1. Tabular freeboard(F_T) calculation
2. Correction for block coefficient ($C_{B\,0.85Dmld} \neq 0.68$)
3. Correction for depth ($D_f \neq L_f/15$)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

(b) Sheer credit for superstructure

If the forward half of sheer profile or the after half of sheer profile **are greater than the standard**, sheer credit is given for a poop or forecastle. The sheer credit is the following:

$$s = \frac{Y}{3} \cdot \frac{L'}{L_f}$$

s : Sheer credit
Y : Difference between actual and standard height of superstructure at the after or forward perpendicular (= min(0, h_a-h_s))
L' : Mean enclosed length of poop or forecastle up to a maximum length of 0.5L

① Sheer credit for forecastle

$$s_f = \frac{Y_f}{3} \cdot \frac{L'}{L_f} = \frac{h_a - h_s}{3} \cdot \frac{L'}{L_f} = \frac{3,200 - 2,300}{3} \cdot \frac{25.3}{245.279} = 31$$

$$\rightarrow S'_f = S_f + s_f = 0 + 31 = 31\ [mm]$$

$L_f = 245.279[m]$
h_a(actual height of forecastle) = 3,200 [mm]
$h_s = 2,300$ [mm]
L' (length of forecastle) = 25.3 [m]
$S_a = 0$
$S_f = 0$

S': Actual height of sheer corrected by sheer credit

② Sheer credit for poop

$$s_p = \frac{Y_p}{3} \cdot \frac{L'}{L_f} = \frac{0 - 2,300}{3} \cdot \frac{0}{245.279} = 0$$

$$\rightarrow S'_a = S_a + s_p = 0 + 0 = 0\ [mm]$$

No poop deck for design ship ($Y_p = 0$)

L_f (m)	Raised quarterdeck (m)	All other superstructures (m)
30 or less	0.90	1.80
75	1.20	1.80
125 or more	1.80	2.30

(5) Correction for Sheer (7/7)

1 Tabular freeboard(F_t) calculation
2 Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3 Correction for depth ($D_f \neq L_f/15$)
4 Deduction for superstructure and trunks
5 Correction for sheer (sheer ≠ standard sheer)
6 Minimum bow height
7 Maximum molded summer draft

(c) Correction for sheer

Mean height of actual sheer (S):

$$S = \frac{(S'_a + S'_f)}{2} = \frac{(0+31)}{2} = 15.5\ [mm]$$

$$\text{Correction for shear} = (S_o - S)\cdot(0.75 - 0.5r_1)$$
$$= (1{,}146 - 15.5)\cdot(0.75 - 0.5\cdot 0.95)$$
$$= 311\ [mm]$$

Standard height of sheer (S_o)
: 1,146 mm

$S'_f = 31\ [mm]$

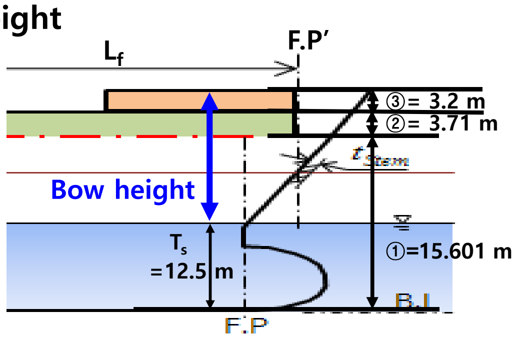
$S'_a = 0\ [mm]$

$r_1 = L_E / L_f = 0.95$

(6) Minimum Bow Height (1/3)

1 Tabular freeboard(F_t) calculation
2 Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3 Correction for depth ($D_f \neq L_f/15$)
4 Deduction for superstructure and trunks
5 Correction for sheer (sheer ≠ standard sheer)
6 Minimum bow height
7 Maximum molded summer draft

- **Bow height**



Bow height (Hb) is defined as the
between the water surface corresponding to the assigned summer freeboard and the designed trim and the top of the exposed deck at side.

Example 3,700TEU Container Carrier)

Actual bow height = D_f(①) + Superstructure height(②) +Forecastle at F.P(③)-Ts
= 15.601 + 3.71 + 3.2 – 12.5
= 10.011 [m]

(6) Minimum Bow Height (2/3)

1 Tabular freeboard(F_t) calculation
2 Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3 Correction for depth ($D_f \neq L_f/15$)
4 Deduction for superstructure and trunks
5 Correction for sheer (sheer ≠ standard sheer)
6 Minimum bow height
7 Maximum molded summer draft

▪ Minimum bow height

$$Minimm\ bow\ height = \left[6{,}075\left(\frac{L_f}{100}\right) - 1{,}875\left(\frac{L_f}{100}\right)^2 + 200\left(\frac{L_f}{100}\right)^3\right] \times$$

$$[2.08 + 0.609 C_{B0.85D} - 1.603 C_{WF} - 0.0129\left(\frac{L_f}{D_f}\right)]\ [mm]$$

where,

C_{WF}: freeboard water plane coefficient for $L_f/2$ forward

$$C_{WF} = \frac{A_{WF}}{(L_f/2) \times B}$$

A_{WF}: Water plane area for $L_f/2$ forward

- **Actual bow height should be larger than minimum bow height.**

Example 3,700TEU Container Carrier)

$L_f = 245.279[m]$
$B = 32.2[m]$
$C_{B,0.85D} = 0.6705$
$A_{WF} = 26{,}695[m^2]$
$D_f = 15.601[m]$
$Actual\ bow\ height = 10.011[m]$

$$Minimm\ bow\ height = \left[6{,}075\left(\frac{245.279}{100}\right) - 1{,}875\left(\frac{245.279}{100}\right)^2 + 200\left(\frac{245.279}{100}\right)^3\right]$$

$$\times [2.08 + 0.609 \cdot 0.6705 - 1.603 \cdot \left(\frac{26{,}695}{\left(\frac{245.279}{2}\right) \cdot 32.2}\right) - 0.0129\left(\frac{245.279}{15.601}\right)]\ [mm]$$

$= 7{,}899$ [mm]

$\therefore Actual\ bow\ height > Minimum\ bow\ height$

(6) Minimum Bow Height (3/3)

1 Tabular freeboard(F_t) calculation
2 Correction for block coefficient ($C_{B,0.85Dmld} \neq 0.68$)
3 Correction for depth ($D_f \neq L_f/15$)
4 Deduction for superstructure and trunks
5 Correction for sheer (sheer ≠ standard sheer)
6 Minimum bow height
7 Maximum molded summer draft

▪ Correction for bow height

If actual bow height

① is larger than minimum bow height.

$$Correction\ \ for\ bow\ height = 0$$

② is less than minimum bow height

$$Correction\ \ for\ bow\ height = Minimum\ bow\ height - Actual\ bow\ height$$

(7) Maximum Molded Summer Draft (1/2)

1. Tabular freeboard(F_t) calculation
2. Correction for block coefficient ($C_{B,0.85Dmld}$≠0.68)
3. Correction for depth (D_f ≠L_f/15)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

- **Maximum molded summer draft (d_s)**

$$d_s = D_f - fs$$

* fs (Calculated summer freeboard)
= Tabular freeboard + Correction for block coefficient
+ Correction for depth − Deduction for superstructure
± Correction for Sheer + Correction for minimum bow height

= 3,770 + 0 + 0 − 1,004 + 311 + 0

= 3,077 [mm]

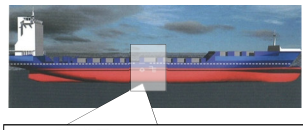
Tabular freeboard	3,770	mm
Correction for block coefficient	0	mm
Correction for depth (D_f)	0	mm
Deduction for superstructure and trunks	-1,004	mm
Correction for Sheer	311	mm
Correction for minimum bow height	0	mm
Depth for freeboard (D_f)	15.601	m
Molded summer draft required by owner (Ts)	12.50	m

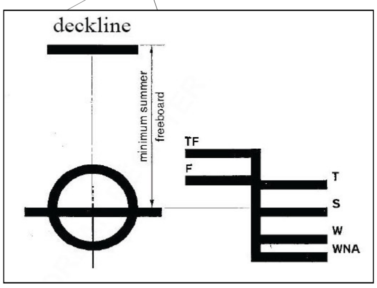
$$d_s = 15.601 - 3.077$$
$$= 12.524\ [m] > 12.5\ [m]$$

(7) Maximum Molded Summer Draft (2/2)

1. Tabular freeboard(F_t) calculation
2. Correction for block coefficient ($C_{B,0.85Dmld}$≠0.68)
3. Correction for depth (D_f ≠L_f/15)
4. Deduction for superstructure and trunks
5. Correction for sheer (sheer ≠ standard sheer)
6. Minimum bow height
7. Maximum molded summer draft

- **Freeboard Mark**





Explanation of abbreviations used on the mark:

TF: Tropical Fresh (for water with a density of 1.000 t/m³)
F: Fresh (ditto)
T: Tropical (for water with a density of 1.025 t/m³)
S: Summer freeboard (ditto)
W: Winter (ditto)
WNA : Winter North Atlantic (ditto), only for ships, less than 100 meter
GL/NK/ LR: Germanischer Lloyd / Nippon Kaiji Kyokai / Lloyd's Register

The Plimsoll[1)] mark or Freeboard Mark is a symbol indicating the   of the ship in the water, leaving a minimal freeboard for safety.

The freeboard is marked according to the result of the freeboard calculation, where the summer freeboard in salt water (d_S) is established.

- Tropical draft

$$d_T = d_S + d_S / 48$$

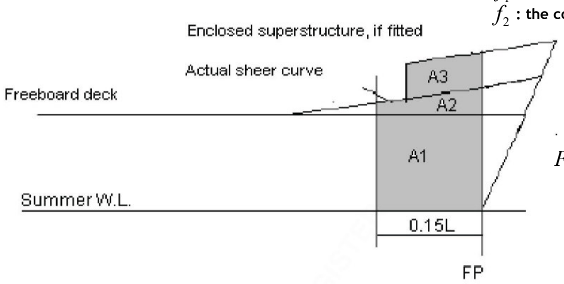
- Winter draft

$$d_W = d_S - d_S / 48$$

* Samuel Plimsoll (1825.2.10~1898.6.3) was a British politician and social reformer, now best remembered for having devised the Plimsoll line.

(8) Reserve Buoyancy[1)]

F_0 : the tabular freeboard [mm]
f_1 : the correction for block coefficient [mm]
f_2 : the correction for depth [mm]



$$F_{\min} = F_0 \cdot f_1 + f_2$$

All ships assigned a type 'B' freeboard, other than oil tankers*, chemical tankers* and gas carriers*, shall have additional reserve buoyancy in the fore end.

The regulation is satisfied as follows:

$$A_1 + A_2 \geq (0.15 \cdot F_{\min} + 4 \cdot (L/3+10)) \cdot L/1000$$

and

$$A_3 \geq (0.15 \cdot F_{\min} + 4 \cdot (L/3+10)) \cdot L/1000$$

* International Convention on Load Lines 1966, ANNEX1 Chapter 1, Reg.3-(5), 2003

(9) Summary

Example 3,700TEU Container Carrier)

Tabular freeboard	**3,770** mm
Correction for block coefficient	**0** mm
Correction for depth (D_f)	**0** mm
Deduction for superstructure and trunks	**-1,004** mm
Correction for sheer	**311** mm
Correction for minimum bow height	**0** mm
Calculated summer freeboard (f_s)	**3,077** mm
Depth for freeboard (D_f)	**15.601** m
Maximum molded summer draft (d_s)	**12.524** m
Molded summer draft required by owner (T_s)	**12.500** m
Margin	**24** mm

$*d_s = D_f - fs$

$*\text{Margin} = d_s - T_s$