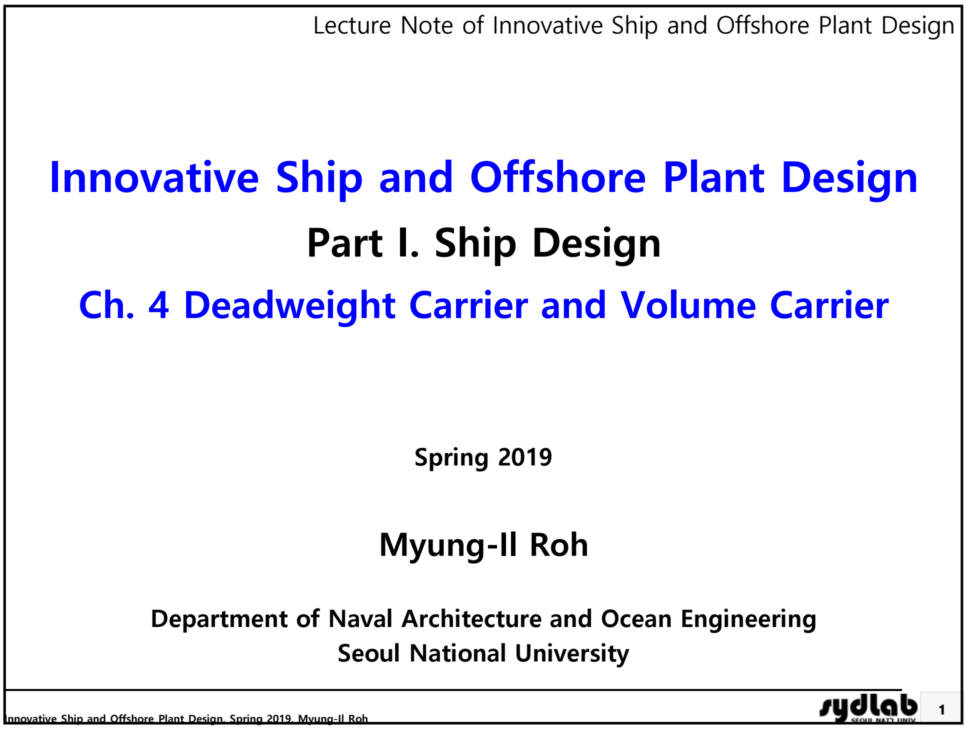

Lecture Note of Innovative Ship and Offshore Plant Design

Innovative Ship and Offshore Plant Design

Part I. Ship Design

Ch. 4 Deadweight Carrier and Volume Carrier

Spring 2019

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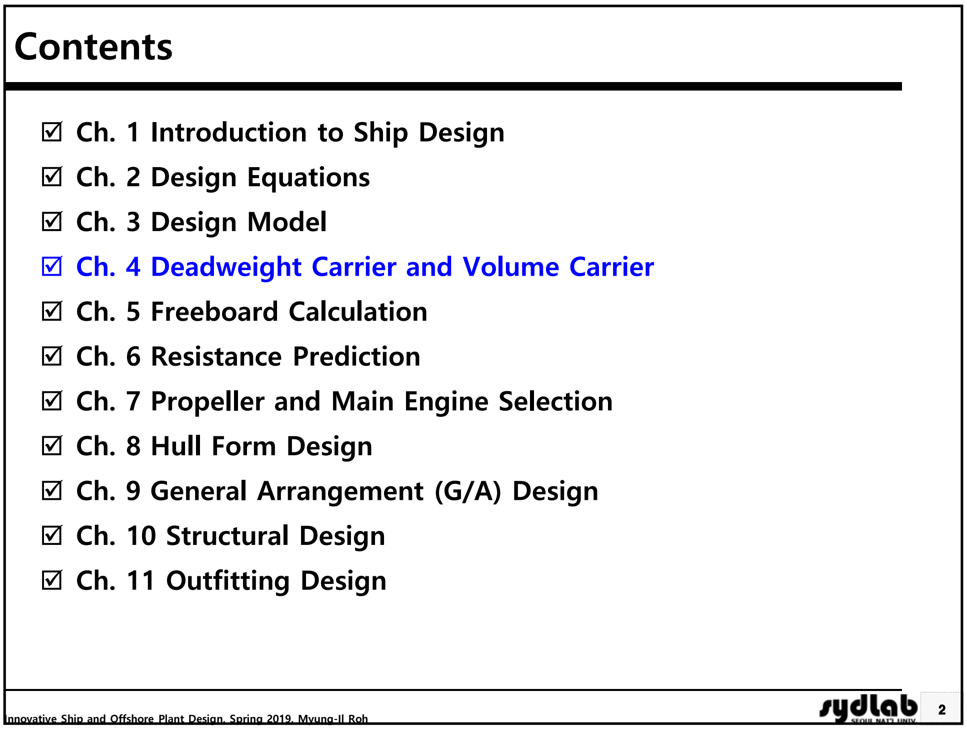

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Ch. 4 Deadweight Carrier and Volume Carrier

1. Characteristics of Deadweight Carrier and Volume Carrier
2. Procedures of the Determination of Principal Dimensions for Deadweight Carrier and Volume Carrier
3. Examples of Determination of the Principal Dimensions of Deadweight Carrier and Volume Carrier

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1. Characteristics of Deadweight Carrier and Volume Carrier

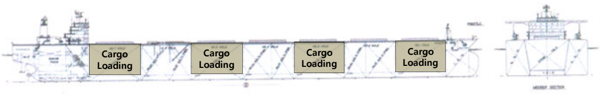
Deadweight Carrier vs. Volume Carrier

is a ship whose is **a critical factor** when the cargo to be carried is “**heavy**” in relation to the space provided for it.

Ore Carrier

The ship will be **weight critical** when the ship carries a cargo which has a density greater than or inversely lesser than **1.29 m³/ton**.

For an example, an ore carrier loads the iron ore (density ≈ 7.85 ton/m³) in alternate holds, **“alternated loading”**, therefore this kind of ship needs less than a half of the hold volume.



<Alternated loading in ore carrier>

※ **Approximate formula of roll periods (T_r)**

$$T_r = \frac{2k \cdot B}{\sqrt{GM}}$$

GM : Metacentric height
B : Breadth,
k : 0.32~0.39 for full loading
0.37~0.40 for ballast condition

is a ship whose **is a critical factor** when the cargo to be carried is “ ” in relation to the space provided for it.

Membrane-type LNG Carrier

Examples of Volume Carriers

Containers are arranged in bays in lengthwise, rows in beam wise, tiers in depth wise.
Therefore, length, breadth and depth of a container carrier vary according to the number and size of containers.

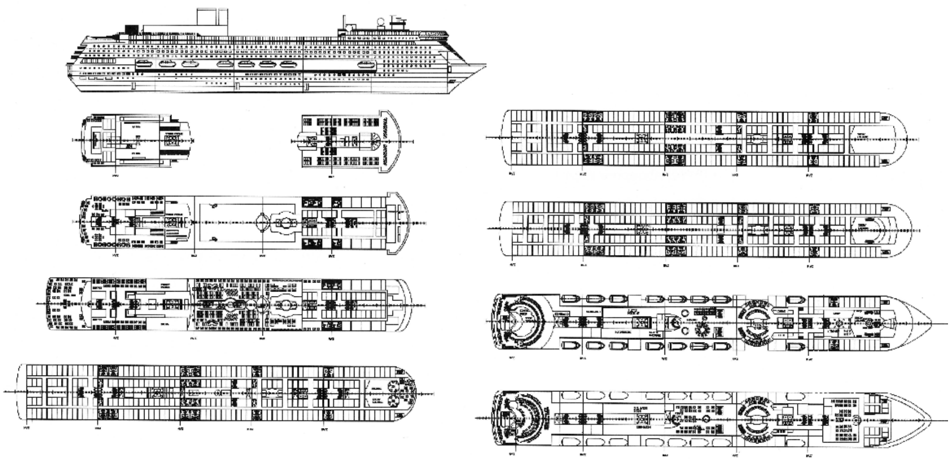
Container Carrier

Moreover, container carrier loads containers on deck, and that causes **to be the ultimate criterion**.

Cruise ship is a kind of **volume carrier** because it has **many decks and larger space for passengers.**
And the which becomes the critical criterion on cruise ship.

Cruise Ship

An Example of General Arrangement (G/A) of a Cruise Ship (Volume Carrier)



Example of Deadweight Carrier - Bulk Carrier

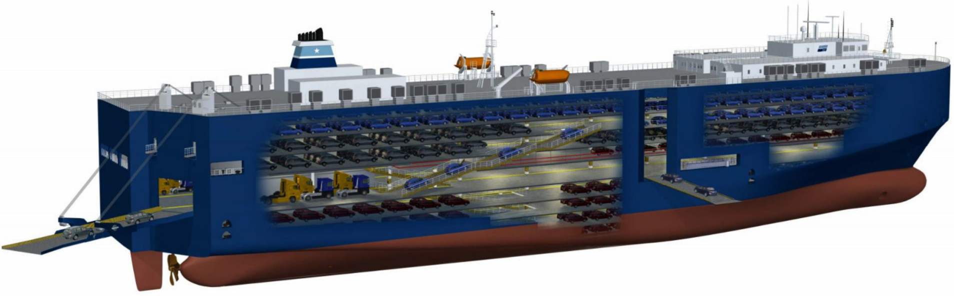
* Reference: Thomas Schneider

Example of Volume Carrier
- Container Carrier

Large size container carrier

Small size container carrier

Example of Volume Carrier
- PCTC (Pure Care and Truck Carrier, RO-RO)



* Reference: Thomas Schneider

Example of Weight and Volume Carrier
- MPCV (Multi Purpose Cargo Vessel)

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2. Procedures of the Determination of Principal Dimensions for Deadweight Carrier and Volume Carrier

Procedure of the Determination of Principal Dimensions for a Deadweight Carrier

1	•**At first**, the principal dimensions such as *L, B, T, C_B are determined* according to the .	**Weight Equation (Physical Constraint)** $\rho \cdot L \cdot B \cdot T \cdot C_B \cdot (1+\alpha) = DWT + LWT$ ✓**Given: DWT (owner's requirements)** ✓**Find: L, B, T, C_B**
2	•**Next**, the depth is determined considering the required cargo hold capacity according to the .	**Volume Equation (Economical Constraints)** $V_{CH} = f(L, B, D)$ ✓**Given: L, B, V_{CH} (owner's requirements)** ✓**Find: D**
3	•Then, it should be checked **lastly** that whether the depth and draft satisfy the .	**Freeboard Calculation (Regulatory Constraints)** $D \geq T + Fb(L, B, D, C_B)$ ✓**Given: L, B, D, T, C_B** ✓**Check: Whether the chosen depth is equal or greater than the draft plus required freeboard or not.**

Procedure of the Determination of Principal Dimensions for a Volume Carrier

1	•**At first**, the principal dimensions such as *L, B, D are determined* to provide the required cargo hold capacity according to the .	**Volume Equation (Economical Constraints)** $V_{CH} = f(L, B, D)$ ✓**Given: V_{CH} (owner's requirements)** ✓**Find: L, B, D**
2	•**Next**, the principal dimensions such as *T, C_B are determined* according to the .	**Weight Equation (Physical Constraint)** $\rho \cdot L \cdot B \cdot T \cdot C_B \cdot (1+\alpha) = DWT + LWT$ ✓**Given: L, B, DWT (owner's requirements)** ✓**Find: T, C_B**
3	•Then, it should be checked **lastly** that whether the depth and draft satisfy the .	**Freeboard Calculation (Regulatory Constraints)** $D \geq T + Fb(L, B, D, C_B)$ ✓**Given: L, B, D, T, C_B** ✓**Check: Whether the chosen depth is equal or greater than the draft plus required freeboard or not.**

3. Examples of Determination of the Principal Dimensions of Deadweight Carrier and Volume Carrier

Determination of the Principal Dimensions of a 297,000 ton Deadweight VLCC based on a 279,500 ton Deadweight VLCC (Deadweight Carrier)

Example of the Principal Particulars of the Basis Ship of 279,500 ton Deadweight VLCC and Owner's Requirements of the Design Ship of 297,000 ton Deadweight VLCC

Design Ship: 297,000 Ton Deadweight VLCC (Very Large Crude oil Carrier)

		Basis Ship	Owner's Requirements	Remark
Principal Dimensions	Loa	abt. 330.30 m		
	Lbp	314.00 m		
	B,mld	58.00 m		
	Depth,mld	31.00 m		
	Td(design)	20.90 m	**21.50 m**	
	Ts(scant.)	22.20 m	**22.84 m**	
Deadweight (scant)		301,000 ton	**320,000 ton**	
Deadweight (design)		279,500 ton	**297,000 ton**	
Speed (at design draft 90% MCR (with 15% Sea Margin)		15.0 knots	**16.0 knots**	
M/E	TYPE	B&W 7S80MC		
	MCR	32,000 PS x 74.0 RPM		
	NCR	28,800 PS x 71.4 RPM		
FOC	SFOC	122.1 g/BHP·h		Based on NCR
	DFOC	84.4 ton/day		
Cruising Range		26,000 N/M	**26,500 N/M**	
Shape of Midship Section		Double side / Double bottom	Double side / Double bottom	
Capacity	Cargo Hold	abt. 345,500 m³	**abt. 360,000 m³**	
	H.F.O.	abt. 7,350 m³		
	D.O.	abt. 490 m³		
	Fresh Water	abt. 460 m³		
	Ballast	abt. 103,000 m³		Including Peak Tanks

Basis Ship

- **Dimensional Ratios**

$$L/B = 5.41,$$
$$B/T_d = 2.77,$$
$$B/D = 1.87,$$
$$L/D = 10.12$$

- **Hull Form Coefficient**

$$C_{B\_d} = 0.82$$

- **Lightweight (=41,000 ton)**
  - Structural weight ≈ 36,400 ton (88%)
  - Outfit weight ≈ 2,700 ton (6.6%)
  - Machinery weight ≈ 1,900 ton (4.5%)

$$\text{Cargo density} = \frac{\text{Deadweight}_{scant}}{\text{Cargo hold capacity}} = \frac{301{,}000}{345{,}500} = 0.87\,[ton/m^3] > 0.77$$

Deadweight Carrier

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Determination of the Principal Dimensions of 297,000 ton Deadweight VLCC
Step 1: Weight Equation

Step 1: Weight Equation → **Step 2: Volume Equation** → **Step 3: Freeboard Calculation**

Step 1: The principal dimensions such as L, B, T_d, and $C_{B,d}$ are determined by the .

$$\boxed{\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT}$$

ρ: density of sea water = 1.025 ton/m³

α: a fraction of the shell appendage allowance = 0.0023

$$\left(1+\alpha = \frac{Displacement}{Moulded\ Displaced\ Volume}\bigg|_{basis} = \frac{313{,}007}{312{,}269} = 1.0023\right)$$

✓ **Given:** $DWT_d = \mathbf{297{,}000}\,[ton]$, $T_d = \mathbf{21.5}[m]$, $V_s = \mathbf{16}[knots]$

✓ **Find:** L, B, $C_{B,d}$

***Subscript d: at design draft**

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Step 1: Weight Equation
- Method 2 for the Total Weight Estimation (1/4)

Step 1: Weight Equation → Step 2: Volume Equation → Step 3: Freeboard Calculation

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT$$

Given: $DWT_d = 297{,}000\ [ton]$, $T_d = 21.5 [m]$
Find: L, B, $C_{B,d}$

Method 2: Assume that the total weight (W) is proportional to the deadweight.

$$W = \frac{W_{Basis}}{DWT_{d,Basis}} \cdot DWT_d$$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = W$$

Design ship and basis ship are assumed to have the same ratio of the deadweight to the total weight.

Therefore, the total weight of the design ship can be estimated by the ratio of the deadweight to the total weight of the basis ship.

$$\frac{DWT_{d,Basis}}{W_{Basis}} = \frac{DWT_d}{W} \Rightarrow W = \frac{W_{Basis}}{DWT_{d,Basis}} \cdot DWT_d$$

$$= \frac{320{,}500}{279{,}500} \cdot 297{,}000$$

$$= 340{,}567\ [ton]$$

Step 1: Weight Equation
- Method 2 for the Total Weight Estimation (2/4)

Step 1: Weight Equation → Step 2: Volume Equation → Step 3: Freeboard Calculation

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT$$

Given: $DWT_d = 297{,}000\ [ton]$, $T_d = 21.5 [m]$
Find: L, B, $C_{B,d}$

Method 2: $W = \frac{W_{Basis}}{DWT_{d,Basis}} \cdot DWT_d$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = W$$

$$L \cdot B \cdot 21.5 \cdot C_{B,d} \cdot 1.025 \cdot (1+0.002) = 340{,}567$$

$$\boxed{L \cdot B \cdot C_{B,d} \cdot 22.08 = 340{,}567 \cdots (5.2)}$$

There are 3 unknown variables (L, B, $C_{B,d}$) with one given equation.

➡

Therefore, we have to assume two variables to solve this indeterminate equation.

The values of the dimensional ratio L/B and $C_{B,d}$ can be obtained from the basis ship.

$$L/B = L_{Basis} / B_{Basis} = 314/58 = 5.413$$

$$C_{B,d} = C_{B,d,Basis} = 0.8213$$

Step 1: Weight Equation
- Method 2 for the Total Weight Estimation (3/4)

Step 1: Weight Equation → Step 2: Volume Equation → Step 3: Freeboard Calculation

$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + \boxed{LWT}$

Given: $DWT_d = 297{,}000$ [ton], $T_d = 21.5$[m]
Find: $L, B, C_{B,d}$

Method 2: $W = \frac{W_{Basis}}{DWT_{d,Basis}} \cdot DWT_d$

$L \cdot B \cdot C_{B,d} \cdot 22.08 = 340{,}567 \cdots (5.2)$

$L/B = 5.413,\ C_{B,d} = 0.8213$

Substituting the ratio obtained from the basis ship into the equation (5.2), the equation can be converted to a quadratic equation in L.

$$L \cdot \left(L/\left(L/B\right)\right) \cdot C_{B,d} \cdot 22.08 = 340{,}567$$

$$L(L/5.143) \cdot 0.8213 \cdot 22.08 = 340{,}567$$

$$L^2 \cdot 3.349 = 340{,}567$$

$$\therefore L = 318.85[m]$$

Step 1: Weight Equation
- Method 2 for the Total Weight Estimation (4/4)

Step 1: Weight Equation → Step 2: Volume Equation → Step 3: Freeboard Calculation

$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + \boxed{LWT}$

Given: $DWT_d = 297{,}000$ [ton], $T_d = 21.5$[m]
Find: $L, B, C_{B,d}$

Method 2: $W = \frac{W_{Basis}}{DWT_{d,Basis}} \cdot DWT_d$

$L = 318.85[m]$

We can obtain B from the ratio L/B of the basis ship.

$$\begin{aligned} B &= L/(L/B) \\ &= 318.85/5.413 \\ &= 58.90\ [m] \end{aligned}$$

$$\therefore L = 318.85[m],\ \ B = 58.90[m],\ C_{B,d} = 0.8213$$

Then, the is determined considering the required cargo hold capacity by .

And it should be checked lastly that whether the .

Determination of the Principal Dimensions of 297,000 ton Deadweight VLCC - Step 2: Volume Equation (1/2)

Step 1: Weight Equation → **Step 2:** Volume Equation → **Step 3:** Freeboard Calculation

Step 2: Next, the depth is determined considering the required cargo hold capacity by the .

$$\boxed{V_{CH} = f(L, B, D)}$$

- ✓ **Given:** $L = \mathbf{318.85}[m]$, $B = \mathbf{58.90}[m]$, $V_{CH} = \mathbf{360{,}000}[m^3]$
- ✓ **Find:** D

Determination of the Principal Dimensions of 29 - Step 2: Volume Equation (2/2)

Step 1: Weight Equation → **Step 2:** Volume Equation → **Step 3:** Freeboard Calculation

$V_{CH} = f(L, B, D)$
Given: L=318.85[m], B=58.90[m], V_{CH} = 360,000[m^3]
Find: D

Assume that the cargo hold capacity is proportional to $L{\cdot}B{\cdot}D$.

$$f(L, B, D) = C_{CH} \cdot L \cdot B \cdot D$$

$$V_{CH} = C_{CH} \cdot L \cdot B \cdot D$$

The coefficient C_{CH} can be obtained from the basis ship.

$$C_{CH} = \left.\frac{V_{CH}}{L \cdot B \cdot D}\right|_{Basis} = \frac{345{,}500}{314 \cdot 58 \cdot 31} = 0.612$$

We use the same coefficient C_{CH} for the determination of depth.

$$V_{CH} = C_{CH} \cdot L \cdot B \cdot D$$

$$360{,}000 = 0.612 \times 318.85 \times 58.90 \times D$$

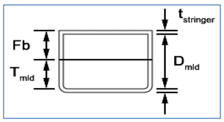
$$\therefore D = 31.32[m]$$

Determination of the Principal Dimensions of 297,000 ton Deadweight VLCC
- Step 3: Freeboard Calculation (1/2)

Step 1: Weight Equation → Step 2: Volume Equation → **Step 3: Freeboard Calculation**

Step 3: Then, it should be checked whether the depth and draft satisfy the freeboard regulation.

$$\boxed{D_{Fb} \geq T_s + Fb(L, B, D_{mld}, C_{B,d})}$$



$$\left(D_{Fb} = D_{mld} + t_{stringer}\right)$$

- ✓ **Given**: $L = \mathbf{318.85}[m]$, $B = \mathbf{58.90}[m]$, $D\ (=D_{mld}) = \mathbf{31.32}[m]$, $T_{s,Req.} = \mathbf{22.84}[m]$, $C_{B,d,Basis} = \mathbf{0.8213}$, $t_{stringer,Basis} = \mathbf{0.02}[\mathrm{m}]$

- ✓ **Check**: **The freeboard of the ship should be larger than the required freeboard.**

Determination of the Principal Dimensions of 29
- Step 3: Freeboard Calculation (2/2)

Step 1: Weight Equation → Step 2: Volume Equation → **Step 3: Freeboard Calculation**

$$D_{Fb} \geq T_s + Fb(L, B, D_{mld}, C_{B,d})$$

Given: L=318.85[m], B=58.90[m], D (=D_{mld})=31.32[m], T_s=22.84[m], $C_{B,d}$=0.8213, $t_{stringer}$=0.02[m]

Check: Freeboard of the ship should be larger than that in accordance with the freeboard regulation.

At the early design stage, there are few data available for estimation of required freeboard. Thus, the required freeboard can be estimated from the basis ship.

Assume that the freeboard is proportional to the depth.

$$Fb(L, B, D_{mld}, C_{B,d}) = C_{Fb} \cdot D_{mld}$$

$$D_{Fb} \geq T_s + C_{Fb} \cdot D_{mld}$$

The coefficient C_{Fb} can be obtained from the basis ship.

$$C_{Fb} = \left.\frac{Fb}{D_{mld}}\right|_{Basis} = \frac{7.84}{31} = 0.253$$

Check: Freeboard of the design ship

$$D_{Fb} \geq T_s + C_{Fb} \cdot D_{mld}$$

$$D_{mld} + t_{stringer} \geq T_s + C_{Fb} \cdot D_{mld}$$

$$31.32 + 0.02 \geq 22.84 + 0.253 \cdot 31.32$$

$31.34 \geq 30.76$ **: Satisfied**

It is satisfied. However, this method is used for a rough estimation. Thus, after the principal dimensions are determined more accurately, freeboard needs to be calculated more accurately in accordance with ICLL 1966.

Step 1: Weight Equation
- Method 3 for the Lightweight Estimation (1/3)

Step 1: Weight Equation → Step 2: Volume Equation → Step 3: Freeboard Calculation

$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT$

Given: $DWT_d = 297{,}000\ [ton]$, $T_d = 21.5[m]$

Find: L, B, $C_{B,d}$

Method 3: Assume that the lightweight could vary as the volume of the vessel represented by $\underline{L \cdot B \cdot D}$.

$$LWT = C_{LWT} L \cdot B \cdot D$$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + C_{LWT} \cdot L \cdot B \cdot D$$

The coefficient C_{LWT} can be obtained from the basis ship.

$$C_{LWT} = \left. \frac{LWT}{L \cdot B \cdot D} \right|_{Basis} = \frac{41{,}000}{314 \cdot 58 \cdot 31} = 0.072$$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + C_{LWT} \cdot L \cdot B \cdot D$$

$$L \cdot B \cdot 21.5 \cdot C_{B,d} \cdot 1.025 \cdot (1+0.002) = 297{,}000 + 0.072 \cdot L \cdot B \cdot D$$

$$L \cdot B \cdot C_{B,d} \cdot 22.08 = 297{,}000 + 0.072 \cdot L \cdot B \cdot D \cdots (5.3)$$

There are 4 unknown variables (L, B, D, $C_{B,d}$) with one given equation.

➡ **Nonlinear indeterminate equation!**

Step 1: Weight Equation
- Method 3 for the Lightweight Estimation (2/3)

Step 1: Weight Equation → Step 2: Volume Equation → Step 3: Freeboard Calculation

$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT$

Given: $DWT_d = 297{,}000[ton]$, $T_d = 21.5[m]$

Find: L, B, $C_{B,d}$

Method 3: $LWT = C_{LWT} L \cdot B \cdot D$

$$L \cdot B \cdot C_{B,d} \cdot 22.08 = 297{,}000 + 0.072 \cdot L \cdot B \cdot D \cdots (5.3)$$

Therefore, we have to assume three variables to solve this indeterminate equation.

The values of the dimensional ratios L/B, B/D and $C_{B,d}$ can be obtained from the basis ship.

$$L/B = L_{Basis}/B_{Basis} = 314/58 = 5.413$$

$$B/D = B_{Basis}/D_{Basis} = 58/31 = 1.871$$

$$C_{B,d} = C_{B,d,Basis} = 0.8213$$

Substituting the ratios obtained from the basis ship into the equation (5.3), the equation can be converted to a cubic equation in L.

$$L \cdot \big(L/(L/B)\big) \cdot C_{B,d} \cdot 22.08 = 297{,}000 + 0.072 \cdot L \cdot \big(L/(L/B)\big) \cdot \big(L/(L/B)/(B/D)\big)$$

Step 1: Weight Equation
- Method 3 for the Lightweight Estimation (3/3)

$$L\cdot\left(L/\left(L/B\right)\right)\cdot C_{B,d}\cdot 22.08=297{,}000+0.072\cdot L\cdot\left(L/\left(L/B\right)\right)\cdot\left(L/\left(L/B\right)/\left(B/D\right)\right)$$
$$L(L/5.143)\cdot 0.8213\cdot 22.08=297{,}000+0.072\cdot L\cdot\left(L/5.413\right)\cdot\left(\left(L/5.413\right)/1.871\right)$$
$$L^2\cdot 3.349=297{,}000+L^3\cdot 0.0013$$

$$\therefore L=318.48\ [m]$$

Then B is calculated from the ratio L/B of the basis ship.

$$B=L/(L/B)$$
$$=318.48/5.413$$
$$=58.82[m] \qquad \therefore L=318.48[m],\quad B=58.82[m],\quad C_{B,d}=0.8213$$

Then, the is determined considering the required cargo hold capacity by .

And it should be checked lastly whether the depth and draft satisfy the freeboard regulation.

Step 1: Weight Equation
- Method 4 for the Lightweight Estimation in Components (1/7)

Step 1: Weight Equation → Step 2: Volume Equation → Step 3: Freeboard Calculation

$$\rho\cdot L\cdot B\cdot T_d\cdot C_{B,d}\cdot(1+\alpha)=DWT_d+\boxed{LWT}$$

Given: DWT_d = 297,000 [*ton*], T_d = 21.5[*m*], V_S = 16 [knots]

Find: L, B, $C_{B,d}$

Method 4: Estimate the .

$$LWT=W_s+W_o+W_m$$

$$L\cdot B\cdot T_d\cdot C_{B,d}\cdot\rho\cdot(1+\alpha)=DWT_d+W_s+W_o+W_m$$

(W_s) is estimated as follows:

$$W_s=C_s\cdot L^{1.6}\cdot(B+D)$$

The coefficient C_s can be obtained from the basis ship.

$$C_s=\left.\frac{W_s}{L^{1.6}\cdot(B+D)}\right|_{Basis}=\frac{36{,}400}{314^{1.6}\cdot(58+31)}=0.0414$$

Step 1: Weight Equation - Method 4 for the Lightweight Estimation in Components (2/7)

Step 1: Weight Equation → **Step 2: Volume Equation** → **Step 3: Freeboard Calculation**

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + \boxed{LWT}$$

Given: $DWT_d = 297{,}000\,[ton]$, $T_d = 21.5[m]$, $V_S = 16$ [knots]
Find: $L, B, C_{B,d}$

Method 4: $LWT = W_s + W_o + W_m$

(W_o) is estimated as follows:

$$W_o = C_o \cdot L \cdot B$$

The coefficient C_o can be obtained from the basis ship.

$$C_o = \left.\frac{W_o}{L \cdot B}\right|_{Basis} = \frac{2{,}700}{314 \cdot 58} = 0.1483$$

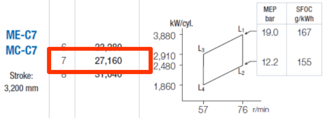
(W_m) is estimated as follows:

$$W_m = C_m \cdot NMCR$$

The coefficient C_m can be obtained from the basis ship.

$$C_m = \left.\frac{W_m}{NMCR}\right|_{Basis} = \frac{1{,}900}{36{,}952} = 0.0514$$

Main engine of basis ship : 7S80MC-C



$$NMCR = 27{,}160[kW]$$
$$= 36{,}952[PS]$$

$NMCR$ can be estimated based on the resistance estimation, power prediction, and main engine selection. However, there are few data available for estimation of the $NMCR$ at the early design stage. Thus, <u>$NMCR$ can be estimated using ‘Admiralty formula’</u>.

Step 1: Weight Equation - Method 4 for the Lightweight Estimation in Components (3/7)

Step 1: Weight Equation → **Step 2: Volume Equation** → **Step 3: Freeboard Calculation**

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + \boxed{LWT}$$

Given: $DWT_d = 297{,}000\,[ton]$, $T_d = 21.5[m]$, $V_S = 16$ [knots]
Find: $L, B, C_{B,d}$

Method 4: $LWT = W_s + W_o + \boxed{W_m}$

$$W_m = C_m \cdot \boxed{NMCR}$$

$$NMCR = \frac{1}{\text{Engine Margin}} \cdot \frac{1}{\text{Derating ratio}} \cdot NCR$$

$$(\text{Engine Margin} = 0.9,\ \textit{Assumed}\ \text{Derating ratio} = 0.9)$$

$$NMCR = 1.265 \cdot NCR$$

By applying the ‘ ’ to the NCR, the NCR also can be estimated.

$$NCR = \frac{\Delta^{2/3} \cdot V_s^{\,3}}{C_{ad}}$$

The coefficient C_{ad} can be obtained from the basis ship.

$$C_{ad} = \left.\frac{\Delta^{2/3} \cdot V_s^{\,3}}{NCR}\right|_{Basis} = \frac{320{,}500^{2/3} \cdot 15^3}{28{,}800} = 548.82 \qquad \left(V_{s,\,at\ design\ draft} = 15[knots]\right)$$

$$NCR = \frac{\Delta^{2/3} \cdot V_s^{\,3}}{548.82}$$

$$NMCR = 1.265 \cdot \frac{\Delta^{2/3} \cdot V_s^{\,3}}{548.82}$$
$$= 0.0022 \cdot \Delta^{2/3} \cdot V_s^{\,3}$$

Step 1: Weight Equation - Method 4 for the Lightweight Estimation in Components (4/7)

Step 1: Weight Equation → **Step 2: Volume Equation** → **Step 3: Freeboard Calculation**

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + \boxed{LWT}$$

Given: DWT_d= 297,000 [ton], T_d = 21.5[m], V_S = 16 [knots]
Find: L, B, $C_{B,d}$

Method 4: $LWT = W_s + W_o + \boxed{W_m}$

$$W_m = C_m \cdot \boxed{NMCR}$$

$W_s = C_s \cdot L^{1.6} \cdot (B+D)$ $\qquad C_s = 0.0414$
$W_o = C_o \cdot L \cdot B$ $\qquad C_o = 0.1483$
$W_m = C_m \cdot NMCR$ $\qquad C_m = 0.0514$
$NMCR = 0.0022 \cdot \Delta^{2/3} \cdot V_s^3$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + W_s + W_o + W_m$$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + C_s \cdot L^{1.6} \cdot (B+D) + C_o \cdot L \cdot B + C_m \cdot NMCR$$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + C_s \cdot L^{1.6} \cdot (B+D) + C_o \cdot L \cdot B + C_m \cdot (0.0022 \cdot \Delta^{2/3} \cdot V_s^3)$$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + C_s \cdot L^{1.6} \cdot (B+D) + C_o \cdot L \cdot B + C_m \cdot (0.0022 \cdot \left(L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha)\right)^{2/3} \cdot V_s^3)$$

$$L \cdot B \cdot 21.5 \cdot C_{B,d} \cdot 1.025 \cdot (1+0.002) = 297{,}000 + 0.0414 \cdot L^{1.6} \cdot (B+D) + 0.1483 \cdot L \cdot B + 0.0514 \cdot (0.0022 \cdot \left(L \cdot B \cdot 21.5 \cdot C_{B,d} \cdot 1.025 \cdot (1+0.002)\right)^{2/3} \cdot 16^3)$$

Step 1: Weight Equation - Method 4 for the Lightweight Estimation in Components (5/7)

$$L \cdot B \cdot 21.5 \cdot C_{B,d} \cdot 1.025 \cdot (1+0.002) = 297{,}000 + 0.0414 \cdot L^{1.6} \cdot (B+D) + 0.1483 \cdot L \cdot B + 0.0514 \cdot (0.0022 \cdot \left(L \cdot B \cdot 21.5 \cdot C_{B,d} \cdot 1.025 \cdot (1+0.002)\right)^{2/3} \cdot 16^3)$$

$$\boxed{L \cdot B \cdot C_{B,d} \cdot 22.08 = 297{,}000 + 0.0414 \cdot L^{1.6} \cdot (B+D) + 0.1483 \cdot L \cdot B + 0.00012 \cdot (L \cdot B \cdot C_{B,d} \cdot 22.08)^{2/3} \cdot 16^3 \cdots (5.4)}$$

There are 4 unknown variables (L, B, D, $C_{B,d}$) with one equation.

➡ Nonlinear indeterminate equation!

Therefore, we have to assume three variables to solve this indeterminate equation.

The values of the dimensional ratios L/B, B/D, and $C_{B,d}$ can be obtained from the basis ship.

$$L/B = L_{Basis}/B_{Basis} = 314/58 = 5.413$$

$$B/D = B_{Basis}/D_{Basis} = 58/31 = 1.871$$

$$C_{B,d} = C_{B,d,Basis} = 0.8213$$

Step 1: Weight Equation - Method 4 for the Lightweight Estimation in Components (6/7)

Step 1: Weight Equation → Step 2: Volume Equation → Step 3: Freeboard Calculation

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + \boxed{LWT}$$

Given: ***DWT***$_d$**= 297,000 [*ton*], *T*$_d$ = 21.5[*m*], V$_S$ = 16 [knots]**
Find: ***L, B, C***$_{B,d}$

Method 4: $LWT = W_s + W_o + \boxed{W_m}$

$$W_m = C_m \cdot \boxed{NMCR}$$

$$L \cdot B \cdot C_{B,d} \cdot 22.08 = 297{,}000 + 0.0414 \cdot L^{1.6} \cdot (B+D) + 0.1494 \cdot L \cdot B$$
$$+0.00012 \cdot (L \cdot B \cdot C_{B,d} \cdot 22.08)^{2/3} \cdot 16^3 \cdots (5.4)$$

$$L/B = 5.413,\ B/D = 1.871, C_{B,d} = 0.8213$$

Substituting the ratios obtained from the basis ship into the equation (5.4), the equation can be converted to a cubic equation in L.

$$L \cdot (L/(L/B)) \cdot C_{B,d} \cdot 22.08 = 297{,}000 + 0.0414 \cdot L^{1.6} \cdot ((L/(L/B)) + (L/(L/B)/(B/D))$$
$$+0.1483 \cdot L \cdot (L/(L/B))$$
$$+0.00012 \cdot (L \cdot (L/(L/B)) \cdot C_{B,d} \cdot 22.08)^{2/3} \cdot 16^3$$
$$L \cdot (L/5.413) \cdot 0.8213 \cdot 22.08 = 297{,}000 + 0.0414 \cdot L^{1.6} \cdot ((L/5.413) + (L/5.413/1.871))$$
$$+0.1483 \cdot L \cdot (L/5.413)$$
$$+0.00012 \cdot (L \cdot (L/5.413) \cdot 0.8213 \cdot 22.08)^{2/3} \cdot 16^3$$
$$L^2 \cdot 3.349 = 297{,}000 + 0.0414 \cdot L^{1.6} \left(0.185 \cdot L + 0.099 \cdot L\right)$$
$$+0.0274 \cdot L^2 + 0.00012 \cdot (L^2 \cdot 3.349)^{2/3} \cdot 16^3$$
$$\therefore L = 318.57\ \ [m]$$

Step 1: Weight Equation - Method 4 for the Lightweight Estimation in Components (7/7)

Step 1: Weight Equation → Step 2: Volume Equation → Step 3: Freeboard Calculation

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + \boxed{LWT}$$

Given: ***DWT***$_d$**= 297,000 [*ton*], *T*$_d$ = 21.5[*m*], V$_S$ = 16 [knots]**
Find: ***L, B, C***$_{B,d}$

Method 3: $LWT = W_s + W_o + \boxed{W_m}$

$$W_m = C_m \cdot \boxed{NMCR}$$

$$L = 318.57\ \ [m]$$

Then, B is calculated from the ratio L/B of the basis ship.

$$B = L/(L/B)$$
$$= 318.57/5.413$$
$$= 58.84\ \ [m]$$

$$\therefore L = 318.57[m],\ \ B = 58.84[m],\ \ C_{B,d} = 0.8213$$

Then, the depth is determined considering the required cargo hold capacity by the volume equation.

And it should be checked lastly whether the depth and draft satisfy the freeboard regulation.

Determination of Principal Dimensions of a 160,000 m³ LNG Carrier based on a 138,000 m³ LNG Carrier (Volume Carrier)

Example of the Principal Particulars of a Basis Ship of 138,000 m³ LNG Carrier and Owner's Requirements of a 160,000 m³ LNG Carrier

Design Ship: 160,000 m³ LNG Carrier

		Basis Ship	Owner's Requirements	Remark
Principal Dimensions	L_{OA}	277.0 m		
	L_{BP}	266.0 m		
	B_{mld}	43.4 m		
	D_{mld}	26.0 m		
	T_d (design)	11.4 m	11.4 m	
	T_s (scant)	12.1 m	**12.1 m**	
Cargo Hold Capacity		138,000 m³	**160,000 m³**	
Service Speed		19.5 knots	**19.5 knots**	
Main Engine	Type	**Steam Turbine**	**2 Stroke Diesel Engine (×2)**	
	DMCR	36,000 PS × 88 RPM		With Engine Margin 10%
	NCR	32,400 PS × 85 RPM		With Sea Margin 21%
SFOC		180.64 g/BHP·h		
Deadweight (design)		69,000 ton	**80,000 ton**	
DFOC		154.75 ton/day		
Cruising Range		13,000 N/M	**11,400 N/M**	

Basis Ship

- **Dimensional Ratios**

$$L/B = 6.31,$$
$$B/T_d = 3.81,$$
$$B/D = 1.67,$$
$$L/D = 10.23$$

- **Hull Form Coefficient**

$$C_{B\_d} = 0.742$$

- **Lightweight (=31,000 ton)**
  - Structural weight ≈ 21,600 ton (≈70%)
  - Outfit weight ≈ 6,200 ton (≈ 20%)
  - Machinery weight ≈ 3,200 ton (≈ 10%)

$$\text{Cargo density} = \frac{\text{Deadweight}}{\text{Cargo hold capacity}} = \frac{69{,}000}{138{,}000} = 0.5\ [ton/m^3] < 0.77$$

Volume Carrier

Determination of the Principal Dimensions of 160,000 m³ LNG Carrier
- Step 1: Volume Equation (1/4)

Step 1: Volume Equation → Step 2: Weight Equation → Step 3: Freeboard Calculation

Step 1: The principal dimensions such as L, B, D are determined considering the required cargo hold capacity by the .

$$\boxed{V_{CH} = f(L, B, D)}$$

- ✓ **Given:** $V_{CH} = 160{,}000[m^3]$
- ✓ **Find:** $L,\ B,\ D$

Determination of the Principal Dimensions
- Step 1: Volume Equation (2/4)

Step 1: Volume Equation → Step 2: Weight Equation → Step 3: Freeboard Calculation

$V_{CH} = f(L,B,D)$
Given: $V_{CH} = 160{,}000[m^3]$
Find: $L,\ B,\ D$

Assume that the cargo hold capacity is proportional to $L \cdot B \cdot D$.

$$f(L,B,D) = C_{CH} \cdot L \cdot B \cdot D$$

$$V_{CH} = C_{CH} \cdot L \cdot B \cdot D$$

Coefficient C_{CH} can be obtained from the basis ship.

$$C_{CH} = \left.\frac{V_{CH}}{L \cdot B \cdot D}\right|_{Basis} = \frac{138{,}000}{266 \cdot 43.4 \cdot 26} = 0.460$$

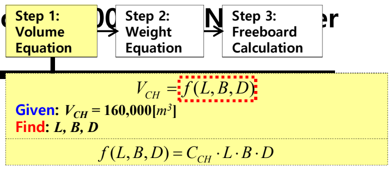
$$V_{CH} = C_{CH} \cdot L \cdot B \cdot D$$

$$\boxed{160{,}000 = 0.460 \cdot L \cdot B \cdot D \cdots (6.1)}$$

There are 3 unknown variables (L, B, D) with one equation.

➡ **Nonlinear indeterminate equation!**

Determination of the Principal Dimensions
- Step 1: Volume Equation (3/4)



Step 1: Volume Equation → **Step 2: Weight Equation** → **Step 3: Freeboard Calculation**

$$V_{CH} = \boxed{f(L,B,D)}$$

Given: $V_{CH} = 160{,}000[m^3]$
Find: L, B, D

$$f(L,B,D) = C_{CH} \cdot L \cdot B \cdot D$$

$$160{,}000 = 0.460 \cdot L \cdot B \cdot D \cdots (6.1)$$

Therefore, we have to assume two variables to solve this indeterminate equation.

The values of the dimensional ratios L/B and B/D can be obtained from the basis ship.

$$L/B = L_{Basis} / B_{Basis} = 266/43.4 = 6.129$$

$$B/D = B_{Basis} / D_{Basis} = 43.4/26 = 1.670$$

Substituting the ratios obtained from basis ship into the equation (6.1), the equation can be converted to a cubic equation in L.

$$160{,}000 = 0.460 \cdot L \cdot (L/(L/B)) \cdot (L/(L/B)/(B/D))$$

$$160{,}000 = 0.460 \cdot L \cdot (L/6.129) \cdot (L/6.129/1.670)$$

$$160{,}000 = 0.007 \cdot L^3$$

$$\therefore L = 279.4[m]$$

Determination of the Principal Dimensions of 160,000 m³ LNG Carrier
- Step 1: Volume Equation (4/4)

$$L = 279.4\ [m]$$

We can obtain B and D from the ratios L/B and B/D of the basis ship.

$$B = L/(L/B) = 279.4/6.129 = 45.6\ [m]$$

$$D = L/(L/B)/(B/D) = 279.4/6.129/1.669 = 27.3\ [m]$$

$$\therefore L = 279.4[m], \quad B = 45.6[m], \quad D = 27.3[m]$$

Determination of the Principal Dimensions of 160,000 m³ LNG Carrier - Step 2: Weight Equation

Step 1: Volume Equation → **Step 2: Weight Equation** → Step 3: Freeboard Calculation

Step 2: Then, block coefficient ($C_{B,d}$) is determined by the .

$$\boxed{\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT}$$

ρ : density of sea water = 1.025 ton/m³
α : a fraction of the shell appendage allowance = 0.002

- ✓ **Given:** $L = 279.4[m]$, $B = 45.6[m]$, $D = 27.3[m]$, $T_d = 11.4[m]$, $DWT_d = 80{,}000[ton]$, $V_s = 19.5[knots]$
- ✓ **Find:** $C_{B,d}$

***Subscript d: at design draft**

Step 2: Weight Equation - Method 4 for the Lightweight Estimation in Components (1/5)

Step 1: Volume Equation → **Step 2: Weight Equation** → Step 3: Freeboard Calculation

$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT$
Given: $L = 279.4[m]$, $B = 45.6[m]$, $D = 27.3[m]$, $T_d = 11.4[m]$, $DWT_d = 80{,}000[ton]$, $V=19.5[knots]$
Find: $C_{B,d}$

Method 4: Estimate the structural weight (W_s), outfit weight (W_o), and machinery weight (W_m) in components.

$$LWT = W_s + W_o + W_m$$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + W_s + W_o + W_m$$

Structural weight (W_s) is estimated as follows:

$$W_s = C_s \cdot L^{1.6} \cdot (B+D)$$

The coefficient C_s can be obtained from the basis ship.

$$C_s = \left.\frac{W_s}{L^{1.6} \cdot (B+D)}\right|_{Basis} = \frac{21{,}600}{266^{1.6} \cdot (43.4+26)} = 0.0410$$

Step 2: Weight Equation
- Method 4 for the Lightweight Estimation in Components (2/5)

Step 1: Volume Equation → Step 2: Weight Equation → Step 3: Freeboard Calculation

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + \boxed{LWT}$$

Given: $L = 279.4[m]$, $B = 45.6[m]$, $D = 27.3[m]$, $T_d = 11.4[m]$, $DWT_d = 80{,}000[ton]$, V=19.5$[knots]$

Find: $C_{B,d}$

Method 4: $LWT = W_s + W_o + W_m$

Outfit weight (W_o) **is estimated as follows:**

$$W_o = C_o \cdot L \cdot B$$

The coefficient C_o can be obtained from the basis ship.

$$C_o = \left.\frac{W_o}{L \cdot B}\right|_{Basis} = \frac{6{,}200}{266 \cdot 43.4} = 0.5371$$

Machinery weight (W_m) **is estimated as follows:**

$$W_m = C_m \cdot NMCR$$

The coefficient C_m can be obtained from the basis ship.

$$C_m = \left.\frac{W_m}{NMCR}\right|_{Basis} = \frac{3{,}200}{36{,}000} = 0.089$$

Because the main engine of the basis ship is steam turbine, NMCR of the basis ship is equal to MCR of that.

$$NMCR_{basis} = MCR_{basis}$$
$$= 36{,}000[PS]$$

At the early design stage, *NMCR* can be estimated by 'Admiralty formula'.

Step 2: Weight Equation
- Method 4 for the Lightweight Estimation in Components (3/5)

Step 1: Volume Equation → Step 2: Weight Equation → Step 3: Freeboard Calculation

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + \boxed{LWT}$$

Given: $L = 279.4[m]$, $B = 45.6[m]$, $D = 27.3[m]$, $T_d = 11.4[m]$, $DWT_d = 80{,}000[ton]$, V=19.5$[knots]$

Find: $C_{B,d}$

Method 4: $LWT = W_s + W_o + W_m$

$$NMCR = \frac{1}{\text{Engine Margin}} \cdot \frac{1}{\text{Derating ratio}} \cdot NCR$$

$$(\text{Engine Margin} = 0.9,\ \text{Derating ratio} = 0.9)$$

$$NMCR = 1.265 \cdot NCR$$

By applying the 'Admiralty formula' to the NCR, the NMCR also can be estimated.

$$NCR = \frac{\Delta^{2/3} \cdot V_s^3}{C_{ad}}$$

The coefficient C_{ad} can be obtained from the basis ship.

$$C_{ad} = \left.\frac{\Delta^{2/3} \cdot V_s^3}{NCR}\right|_{Basis} = \frac{100{,}000^{2/3} \cdot 19.5^3}{32{,}400} = 493.05 \quad \left(V_{s,\,at\ design\ draft} = 19.5[knots]\right)$$

$$NCR = \frac{\Delta^{2/3} \cdot V_s^3}{493.05}$$

$$NMCR = 1.265 \cdot \frac{\Delta^{2/3} \cdot V_s^3}{493.05}$$
$$= 0.0025 \cdot \Delta^{2/3} \cdot V_s^3$$

Step 2: Weight Equation - Method 4 for the Lightweight Estimation in Components (4/5)

Step 1: Volume Equation → **Step 2: Weight Equation** → **Step 3: Freeboard Calculation**

$$\rho\cdot L\cdot B\cdot T_d\cdot C_{B,d}\cdot(1+\alpha)=DWT_d+\boxed{LWT}$$

Given: $L=279.4[m]$, $B=45.6[m]$, $D=27.3[m]$, $T_d=11.4[m]$, $DWT_d=80{,}000[ton]$, V=19.5$[knots]$

Find: $C_{B,d}$

Method 4: $LWT=W_s+W_o+W_m$

$W_s=C_s\cdot L^{1.6}\cdot(B+D)$ $C_s=0.0410$

$W_o=C_o\cdot L\cdot B$ $C_o=0.5371$

$W_m=C_m\cdot NMCR$ $C_m=0.089$

$NMCR=0.0025\cdot\Delta^{2/3}\cdot V_s^{\,3}$

$$L\cdot B\cdot T_d\cdot C_{B,d}\cdot\rho\cdot(1+\alpha)=DWT_d+W_s+W_o+W_m$$

$$L\cdot B\cdot T_d\cdot C_{B,d}\cdot\rho\cdot(1+\alpha)=DWT_d+C_s\cdot L^{1.6}\cdot(B+D)+C_o\cdot L\cdot B+C_m\cdot NMCR$$

$$\begin{aligned}L\cdot B\cdot T_d\cdot C_{B,d}\cdot\rho\cdot(1+\alpha)=DWT_d&+C_s\cdot L^{1.6}\cdot(B+D)+C_o\cdot L\cdot B\\&+C_m\cdot(0.0025\cdot\Delta^{2/3}\cdot V_s^{\,3})\end{aligned}$$

$$\begin{aligned}L\cdot B\cdot T_d\cdot C_{B,d}\cdot\rho\cdot(1+\alpha)=DWT_d&+C_s\cdot L^{1.6}\cdot(B+D)+C_o\cdot L\cdot B\\&+C_m\cdot(0.0025\cdot\left(L\cdot B\cdot T_d\cdot C_{B,d}\cdot\rho\cdot(1+\alpha)\right)^{2/3}\cdot V_s^{\,3})\end{aligned}$$

$$\begin{aligned}279.4\cdot45.6\cdot11.4\cdot C_{B,d}\cdot1.025\cdot(1+0.002)=&80{,}000+0.0410\cdot279.4^{1.6}\cdot(45.6+27.3)+0.5371\cdot279.4\cdot45.6\\&+0.089\cdot(0.0025\cdot\left(279.4\cdot45.6\cdot11.4\cdot C_{B,d}\cdot1.025\cdot(1+0.002)\right)^{2/3}\cdot19.5^3)\end{aligned}$$

$$\begin{aligned}149{,}175\cdot C_{B,d}=&80{,}000+24{,}554+6{,}843\\&+0.089\cdot(0.0025\cdot\left(149{,}175\cdot C_{B,d}\right)^{2/3}\cdot19.5^3)\end{aligned}$$

Step 2: Weight Equation - Method 4 for the Lightweight Estimation in Components (5/5)

Step 1: Volume Equation → **Step 2: Weight Equation** → **Step 3: Freeboard Calculation**

$$\rho\cdot L\cdot B\cdot T_d\cdot C_{B,d}\cdot(1+\alpha)=DWT_d+\boxed{LWT}$$

Given: $L=279.4[m]$, $B=45.6[m]$, $D=27.3[m]$, $T_d=11.4[m]$, $DWT_d=80{,}000[ton]$, V=19.5$[knots]$

Find: $C_{B,d}$

Method 4: $LWT=W_s+W_o+W_m$

$$149{,}175\cdot C_{B,d}=80{,}000+24{,}554+6{,}843+0.089\cdot(0.0025\cdot\left(149{,}175\cdot C_{B,d}\right)^{2/3}\cdot19.5^3)$$

$$149{,}175\cdot C_{B,d}=80{,}000+24{,}554+6{,}843+4{,}634\cdot C_{B,d}^{\ \ 2/3}$$

$$149{,}175\cdot C_{B,d}=111{,}397+4{,}634\cdot C_{B,d}^{\ \ 2/3}$$

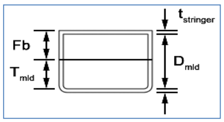
$$\therefore C_{B,d}=0.773$$

Determination of the Principal Dimensions of 160,000 m³ LNG Carrier - Step 3: Freeboard Calculation (1/2)

Step 1: Volume Equation → Step 2: Weight Equation → **Step 3: Freeboard Calculation**

Step 3: Then, it should be checked lastly whether the depth and draft satisfy the freeboard regulation.

$$\boxed{D_{Fb} \geq T_s + Fb(L, B, D_{mld}, C_{B,d})}$$



$$\left(D_{Fb} = D_{mld} + t_{stringer}\right)$$

- ✓ **Given**: L=279.4[m], B=45.6[m], D (=D_{mld})=27.3[m], T_s = 12.1[m], $C_{B,d}$=0.773, $t_{stringer}$=0.02[m]
- ✓ **Check**: The freeboard of the ship should be larger than the required freeboard.

Determination of the Principal Dimensions - Step 3: Freeboard Calculation (2/2)

Step 1: Volume Equation → Step 2: Weight Equation → **Step 3: Freeboard Calculation**

$D_{Fb} \geq T_s + Fb(L, B, D_{mld}, C_{B,d})$

Given: L = 279.4[m], B = 45.6[m], D(=D_{mld}) = 27.3[m], T_s = 12.1[m], $C_{B,d}$ = 0.773, $t_{stringer}$ = 0.02[m]

Check: Freeboard of the ship should be larger than that in accordance with the freeboard regulation.

At the early design stage, there are few data available for estimation of required freeboard. Thus, the required freeboard can be estimated from the basis ship.

Assume that the freeboard is proportional to the depth.

$$Fb(L, B, D_{mld}, C_{B,d}) = C_{Fb} \cdot D_{mld}$$

$$D_{Fb} \geq T_s + C_{Fb} \cdot D_{mld}$$

The coefficient C_{Fb} can be obtained from the basis ship.

$$C_{Fb} = \left.\frac{Fb}{D_{mld}}\right|_{Basis} = \frac{6.68}{26} = 0.257$$

Check: Freeboard of the design ship

$$D_{Fb} \geq T_s + C_{Fb} \cdot D_{mld}$$

$$D_{mld} + t_{stringer} \geq T_s + C_{Fb} \cdot D_{mld}$$

$$27.3 + 0.02 \geq 12.1 + 0.257 \cdot 27.3$$

$$27.32 \geq 19.11$$ **: Satisfied**

It is satisfied. However, this method is used for a rough estimation. So, after the main dimensions are determined more accurately, freeboard needs to be calculated more accurately through the freeboard regulation.

Determination of Principal Dimensions of a 4,100 TEU Container Carrier based on a 3,700 TEU Container Carrier (Volume Carrier)

Example of the Principal Particulars of a Basis Ship of 3,700 TEU Container Carrier and Owner's Requirements of a 4,100 TEU Container Carrier

Design Ship: 4,100 TEU Container Carrier

	Basis Ship	Owner's requirements
Principal Dimensions		
LOA	257.4 m	less than **260.0 m**
LBP	245.24 m	
Bmld	32.2 m	less than **32.25 m**
Dmld	19.3 m	
Td /Ts (design / scant)	10.1 / 12.5 m	abt. **11.0 / 12.6 m**
Deadweight (design / scant)	34,400 / 50,200 ton	**40,050 / 49,000 ~ 51,000 ton**
Capacity		
Container on Deck / in Hold	2,174 TEU / 1,565 TEU	**abt. 4,100 TEU**
Ballast Water	13,800 m^3	**abt. 11,500 m^3**
Heavy Fuel Oil	6,200 m^3	
Main Engine & Speed		
M/E Type	Sulzer 7RTA84C	
MCR (BHP x rpm)	38,570 BHP × 102 RPM	
NCR (BHP x rpm)	34,710 BHP × 8.5 RPM	
Service Speed at NCR (Td, 15% SM)	22.5 knots (at 11.5 m) at 30,185 BHP	**24.5 knots (at 11.0 m)**
DFOC at NCR	103.2 ton	
Cruising Range	20,000 N/M	abt. 20,000 N/M
Complement (Crew)	30 Person	**30 Person**

* TEU: Twenty-foot Equivalent Units

Basis Ship

- **Dimensional Ratios**

$$L/B = 7.62$$
$$B/T_d = 3.19$$
$$B/D = 1.67$$
$$L/D = 12.71$$

- **Hull Form Coefficient**

$$C_{B\_d} = 0.62$$

- **Lightweight (=16,000 ton)**
  - Structural weight ≈ 11,000 ton (≈68%)
  - Outfit weight ≈ 3,200 ton (≈ 20%)
  - Machinery weight ≈ 1,800 ton (≈ 12%)

$$\text{Cargo density} = \frac{\text{Deadweight}_{\text{scant}}}{\text{Cargo hold capacity}} = \frac{\text{Deadweight}_{\text{scant}}}{V_{\text{container}} \times N_{\text{container}}} = \frac{50,200}{46.9 \cdot 3,739} = 0.29\ [ton/m^3] < 0.77$$

$$\Downarrow$$

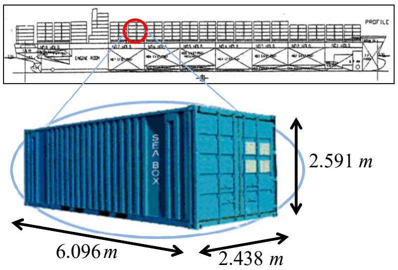
Volume Carrier

4,100 TEU Container Carrier Design based on the 3,700 TEU Container Carrier (1/4)

N_L: Number of bays
N_B: Number of rows
N_D: Number of tiers

Example 2: 160,000 m^3 LNG Carrier Design based on 138,000 m^3 LNG Carrier	Example 3: 4,100TEU Container Carrier Design based on 3,700TEU Container Carrier
$\boxed{V_{CH} = f(L,B,D)}$	$\boxed{V_{CH} = f(L,B,D)}$
✓ **Given**: $V_{CH} = 160{,}000[m^3]$	✓ **Given**: $N_{C\_req} = 4{,}100\ TEU$
✓ **Find**: L, B, D	✓ **Find**: L, B, D

Containers are arranged in bays in lengthwise, rows in beam wise, tiers in depth wise.
It means that the principal dimensions are determined .



Example) 20' ISO Container size

Therefore, length, breadth, and depth of container carrier vary according to the number and size of containers in cargo hold.

$$L = f(N_L) \quad B = f(N_B) \quad D = f(N_D)$$

$$\boxed{\begin{aligned} &L = L_H + L_{APT} + L_{ER} + L_{FPT} = \left(L_{clear,con} + 2L_{container} + L_{clear,hold}\right)\cdot\frac{N_L}{2} + L_{APT} + L_{ER} + L_{FPT} \\ &B = B_H + B_{D.S} = \left(B_{clearance} + B_{container}\right)\cdot N_B - B_{clearance} + 2\cdot(B_{D.S} + B_{clearance,D.S}) \\ &D = D_H + D_{D.B} - D_{H.C} = \left(D_{clearance} + D_{container}\right)\cdot N_D + D_{D.B} - D_{H.C} \end{aligned}}$$

$$\Rightarrow N_{C\_req} = f(N_L, N_B, N_D)$$

4,100 TEU Container Carrier Design based on the 3,700 TEU Container Carrier (2/4)

* **Size of Container** ($L \times B \times D$)
20' ISO Container: $6.096\,m \times 2.438\ m \times 2.591\ m$
40' ISO Container: $12.192\,m \times 2.438\ m \times 2.591\ m$

Length, breadth and depth of container carrier vary stepwise according to the number and size of containers.

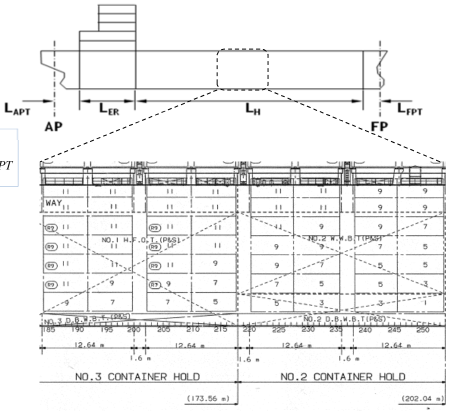
1) Length

$$\boxed{L = L_H + L_{APT} + L_{ER} + L_{FPT}}$$

$$L_H = \left(L_{clear,con} + 2L_{container} + L_{clear,hold}\right)\cdot\frac{N_L}{2}$$

$$L = \left(L_{clear,con} + 2L_{container} + L_{clear,hold}\right)\cdot\frac{N_L}{2} + L_{APT} + L_{ER} + L_{FPT}$$

L_H: Length of cargo hold
L_{APT}: Length between aft perpendicular to aft bulkhead
L_{ER}: Length of engine room
L_{FPT}: Length between forward perpendicular to collision bulkhead
N_L: Number of bays
$L_{clear,con}$: Clearance between containers
$L_{clear,hold}$: Clearance between cargo holds
$L_{container}$: Length of 20' container



Example)

$L_{clear,con} = 0.564[m]$, $L_{clear,hold} = 1.6[m]$,
$L_{APT} = 11.2[m]$, $L_{ER} = 30.4[m]$,
$L_{FPT} = 12.92[m]$, $L_{container} = 6.096[m]$

$$\rightarrow L = 7.14 \cdot N_L + 54.52$$

4,100 TEU Container Carrier Design based on the 3,700 TEU Container Carrier (3/4)

* Size of Container ($L \times B \times D$)
20' ISO Container: $6.096m \times 2.438\ m \times 2.591\ m$
40' ISO Container: $12.192m \times 2.438\ m \times 2.591\ m$

Length, breadth and depth of container carrier vary stepwise according to the number and size of containers.

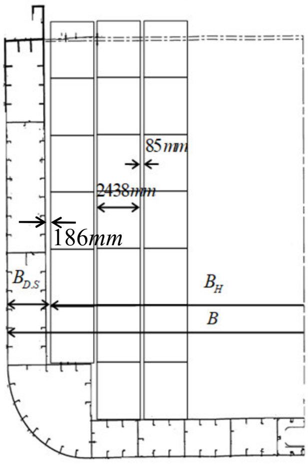
2) Breadth

$$\boxed{B = B_H + 2 \cdot (B_{D.S} + B_{clearance,D.S})}$$

$$B_H = \left(B_{clearance} + B_{container}\right) \cdot N_B - B_{clearance}$$

$$B = \left(B_{clearance} + B_{container}\right) \cdot N_B - B_{clearance} + 2 \cdot (B_{D.S} + B_{clearance,D.S})$$

B_H: Breadth of cargo hold
$B_{D.S}$: Breadth of double side wing tank = 2.08m
N_B: Number of rows
$B_{clearance}$: Clearance between containers
$B_{clearance,D.S}$: Clearance between container and double side wing tank
$B_{container}$: Breadth of 20' container



Example)

$B_{clearance} = 0.085[m]$, $B_{container} = 2.438[m]$

$B_{D.S} = 2.08[m]$, $B_{clearance,D.S} = 0.186[m]$

$$\rightarrow B = 2.523 \cdot N_B + 4.447$$

4,100 TEU Container Carrier Design based on the 3,700 TEU Container Carrier (4/4)

* Size of Container ($L \times B \times D$)
20' ISO Container: $6.096m \times 2.438\ m \times 2.591\ m$
40' ISO Container: $12.192m \times 2.438\ m \times 2.591\ m$

Length, breadth and depth of container carrier vary stepwise according to the number and size of containers.

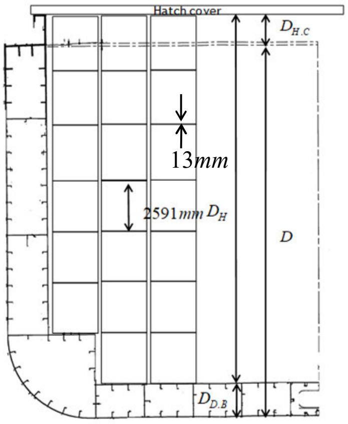
3) Depth

$$\boxed{D = D_H + D_{D.B} - D_{H.C}}$$

$$D_H = \left(D_{clearance} + D_{container}\right) \cdot N_D$$

$$D = \left(D_{clearance} + D_{container}\right) \cdot N_D + D_{D.B} - D_{H.C}$$

D_H: Depth of cargo hold
$D_{D.B}$: Depth of double bottom
$D_{H.C}$: Hatch coaming height
N_D: Number of tiers (in hold)
$D_{clearance}$: Clearance between containers
$D_{container}$: Depth of 20' container



Example)

$D_{clearance} = 0.013[m]$, $D_{container} = 2.591[m]$

$D_{D.B} = 1.7[m]$, $D_{H.C} = 0.628[m]$

$$\rightarrow D = 2.604 \cdot N_D + 1.072$$

Determination of the Principal Dimensions of 4,100 TEU Container Carrier - Step 1: Volume Equation (1/11)

Step 1: Volume Equation → Step 2: Weight Equation → Step 3: Freeboard Calculation

Step 1: The length, breadth, and depth of container carrier are determined to a great extent

$$\boxed{N_{C\_req} = f(N_L, N_B, N_D)}$$

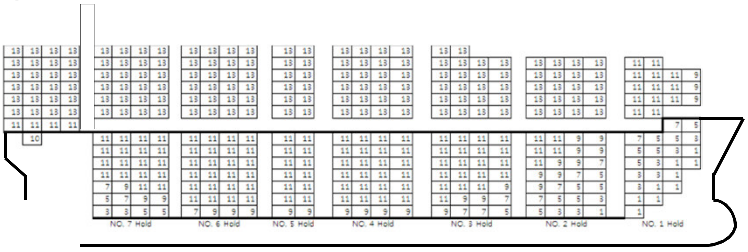
✓ **Given: The number of containers to be required** $= 4{,}100\ [TEU]$

✓ **Find:** $N_L,\ N_B,\ N_D$

Determination of the Principal Dimensions of 4,100 TEU Container Carrier - Step 1: Volume Equation (2/11)

1. The number of additional containers to satisfy owner's requirement (4,100 TEU**)**

Basis ship (3,700 TEU Container Carrier)



In Hold: 1,565 TEU
On Deck: 2,174 TEU
Total: 3,739 TEU

➡ **The number of additional containers to be required: 361** TEU **(= 4,100 – 3,739** TEU**)**

Determination of the Principal Dimensions of 4,
- Step 1: Volume Equation (3/11)

Step 1: Volume Equation → **Step 2:** Weight Equation → **Step 3:** Freeboard Calculation

Given: Number of Container = 4,100 [*TEU*]
Find: N_L, N_B, N_D
Number of additional containers to be required: 361 *TEU*

$B = 2.523 \cdot N_B + 4.447$

2.

1) Available breadth of the design ship

Main dimensions for ships in Panama Canal

L_{max}	289.5 m
B_{max}	32.3 m
T_{max}	12.04 m

	Basis Ship	Owner's requirements
Bmld	32.2 m	Less than 32.25 m

$$B_{available} = B_{\text{limit}} - B_{basis}$$
$$= 32.25 - 32.2$$
$$= 0.05[m]$$

$B_{avialable}$: Available breadth of design ship
B_{limit} : Breadth limited by owner's requirement
B_{basis} : Breadth of basis ship

Because 2.523 m is needed to increase 1 row in hold, it is not possible to increase the breadth.

$$\rightarrow \boxed{N_B = N_{B,basis} = 11 \ [Rows]}$$

Determination of the Principal Dimensions of 4,
- Step 1: Volume Equation (4/11)

Step 1: Volume Equation → **Step 2:** Weight Equation → **Step 3:** Freeboard Calculation

Given: Number of Container = 4,100 [*TEU*]
Find: N_L, N_B, N_D
Number of additional containers to be required: 361 *TEU*

$L = 7.14 \cdot N_L + 54.52$

3.

1) Available length of the design ship

Main dimensions for ships in Panama Canal

L_{max}	289.5 m
B_{max}	32.3 m
T_{max}	12.04 m

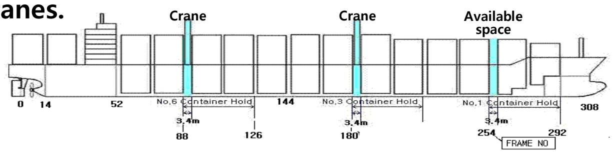
	Basis Ship	Owner's Requirements
LOA	257.4 m	less than 260.0 m
LBP	245.24 m	

$$L_{OA,available} = L_{OA,\text{limit}} - L_{OA,basis}$$
$$= 260 - 257.4$$
$$= 2.6[m]$$

$L_{OA,available}$: Available LOA of design ship
$L_{OA,limit}$: L_{OA} limited by owner's requirement
$L_{OA,basis}$: L_{OA} of basis ship

Because 7.14 m is needed to increase 1 bay in hold, it is not possible to increase the length.

However, because there is no requirement of cranes in the design ship, we can increase 1 bay in hold by utilizing the space of two occupied cranes.



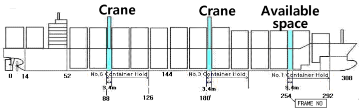
Basis ship (3,700 *TEU* Container Carrier)

Determination of the Principal Dimensions of 4,100 TEU Container Carrier - Step 1: Volume Equation (5/11)

2) Available length of the design ship

$$L = 7.14 \cdot N_L + 54.52$$

$$L_{crane} = (L_{space\ of\ crane} - L_{lashing\ bridge}) \cdot N_{space\ of\ crane}$$
$$= (3.4 - 1.6) \cdot 3$$
$$= 5.4[m]$$



L_{crane}: Available length of design ship by utilizing the space of crane
$L_{space\ of\ crane}$: Crane and available space
$L_{lashing\ bridge}$: Space of lashing bridge (= Clearance between cargo holds, $L_{clear,hold}$)
$N_{space\ of\ crane}$: Number of crane and available space

3) Total available length of design ship in lengthwise

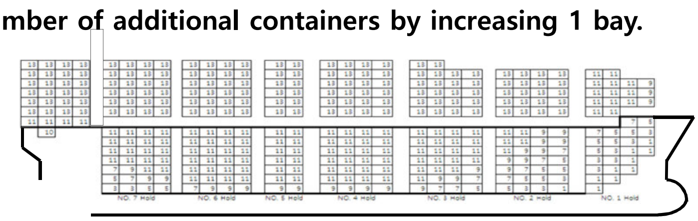
$$= L_{OA,available} + L_{crane}$$
$$= 2.6 + 5.4$$

$= 8[m] > 7.14[m] \rightarrow$ **It is possible to increase 1 bay in hold.**

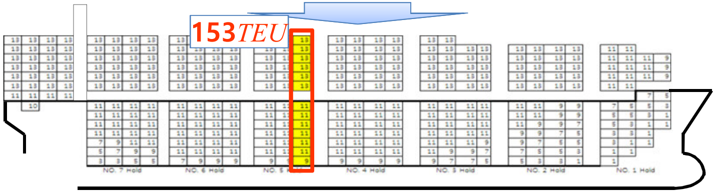
$$\Rightarrow N_L = N_{L,basis} + 1 = 26 + 1$$
$$= 27 \ \text{[Bays]}$$

Determination of the Principal Dimensions of 4,100 TEU Container Carrier - Step 1: Volume Equation (6/11)

4) Number of additional containers by increasing 1 bay.



Basis ship (3,700 *TEU* Container Carrier)

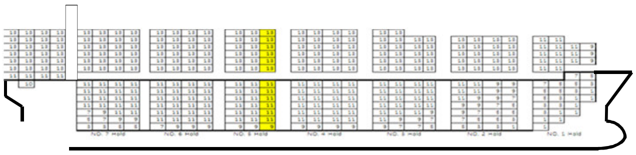


Basis ship + 1 bay

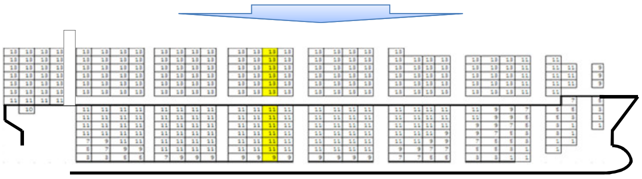
→ **Number of additional containers: 153 *TEU***
→ **Number of total containers: 3,892 *TEU***
→ **Number of additional containers to be required: 208 *TEU***

Determination of the Principal Dimensions of 4,100 TEU Container Carrier
- Step 1: Volume Equation (7/11)

In general, the container carriers load two 40 ft containers in a hold.
So, the containers of the design ship are arranged as follows:



Basis ship + 1 bay



Basis ship + 1 bay

Determination of the Principal Dimensions of 4,1
- Step 1: Volume Equation (8/11)

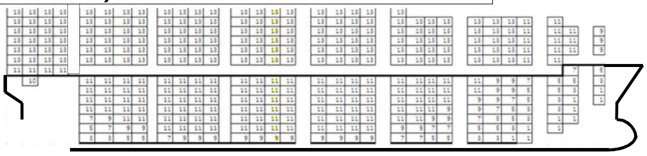
Step 1: Volume Equation → **Step 2: Weight Equation** → **Step 3: Freeboard Calculation**

Given: Number of Container = 4,100 [*TEU*]
Find: N_L, N_B, N_D
Number of additional containers to be required: 361 *TEU*

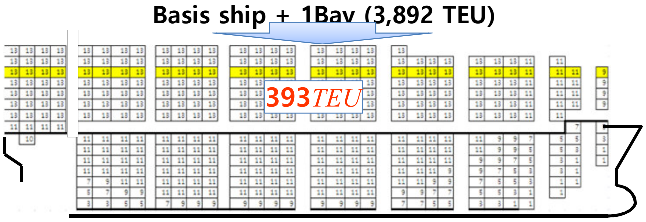
4.

- There are two methods for increasing the tiers.

Method 1) Increase of the tiers on deck



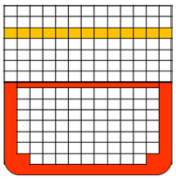
Basis ship + 1Bay (3,892 TEU)



Basis ship + 1 bay + 1 tier on deck (4,285 TEU)

$$N_D = N_{D,basis}$$
$$= 7 \ \text{[Tiers]}$$

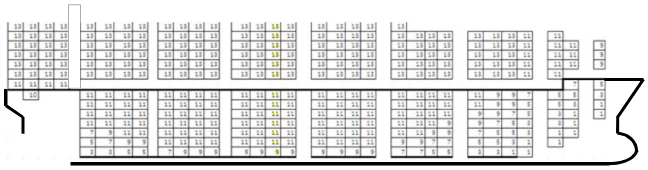
In hold



→ Number of additional containers: 393 *TEU*
→ Number of total containers: 4,285 *TEU*
→ Number of containers to be exceeded: 185 *TEU*

Determination of the Principal Dimensions of 4,100 TEU Container Carrier - Step 1: Volume Equation (9/11)

Method 2) Increase of the tiers in hold

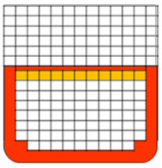


Basis ship + 1 bay (3,892 *TEU)*

$$N_D = N_{D,basis} + 1 = 7 + 1 = 8 \text{ [Tiers]}$$

Basis ship + 1 bay + 1 tier in hold (4,161 *TEU*)

In hold

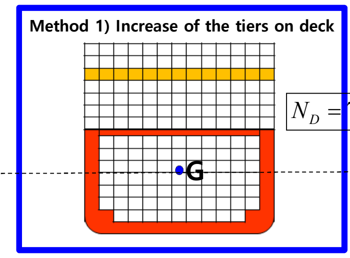


→ Number of additional containers: 269 *TEU*
→ Number of total containers: 4,161 *TEU*
→ Number of containers to be exceeded: 61 *TEU*

Determination of the Principal Dimensions of 4,100 TEU Container Carrier - Step 1: Volume Equation (10/11)

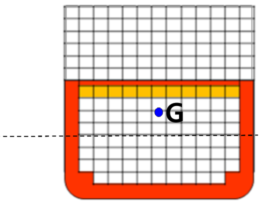
Comparison between two methods:

Method 1) Increase of the tiers on deck



$N_D = 7$ [Tiers]

Method 2) Increase of the tiers in hold



$N_D = 8$ [Tiers]

The center of mass of the containers in the methods 1 and 2 are almost same. However, the center of lightweight in the method 2 is higher than that in the method 1. So, the center of total mass in the method 2 is higher than that in method 1.

$\rightarrow KG_{method\,1} < KG_{method\,2}$

$GM = KB + BM - KG$

$GM_{method\,1} > GM_{method\,2}$

$GZ = GM \sin\phi$

$GZ_{method\,1} > GZ_{method\,2}$

KG: Distance from keel to vertical center of mass of container carrier
GM: Distance from vertical center of mass of container carrier to metacenter
KB: Distance from keel to center of buoyancy
BM: Distance from center of buoyancy to metacenter
GZ: Righting Arm

Therefore, for giving the ship better stability, Method 1 is selected.

Determination of the Principal Dimensions of 4,100 TEU Container Carrier - Step 1: Volume Equation (11/11)

5. Principal dimensions (L, B, D) determined by the arrangement of containers in cargo hold (N_L, N_D, N_B):

$N_L = 27$ [Bays]	$N_B = 11$ [Rows]	$N_D = 7$ [Tiers]
$L = 7.14 \cdot N_L + 54.52$	$B = 2.523 \cdot N_B + 4.447$	$D = 2.604 \cdot N_D + 1.072$
$= 7.14 \cdot 27 + 54.52$	$= 2.523 \cdot 11 + 4.447$	$= 2.604 \cdot 7 + 1.072$
$= 247.76[m]$	$= 32.2[m]$	$= 19.3[m]$

$$\therefore L = 247.76[m], \qquad B = 32.2[m], \qquad D = 19.3[m]$$

Determination of the Principal Dimensions of 4,100 TEU Container Carrier - Step 2: Weight Equation

Step 1: Volume Equation → **Step 2: Weight Equation** → Step 3: Freeboard Calculation

Step 2: Then, block coefficient ($C_{B,d}$) is determined by the .

$$\boxed{\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT}$$

ρ: density of sea water = 1.025 ton/m^3

α: a fraction of the shell appendage allowance = 0.0029

$$\left(1+\alpha = \left. \frac{Displacement}{Moulded\ Displaced\ Volume} \right|_{basis} = \frac{49,848.7}{49,652.7} = 1.0039 \right)$$

- ✓ **Given:** $L = 247.76[m]$, $B = 32.2[m]$, $D = 19.3[m]$, $T_d = 11.0[m]$, $DWT_d = 40,050[ton]$, $V_s = 24.5[knots]$
- ✓ **Find:** $C_{B,d}$

***Subscript d: at design draft**

Step 2: Weight Estimation
Method 4 for the Lightweight Estimation in Components (1/5)

Step 1: Volume Equation → **Step 2: Weight Equation** → Step 3: Freeboard Calculation

$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT$

Given: $L = \mathbf{247.76}[m]$, $B = \mathbf{32.2}[m]$, $D = \mathbf{19.3}[m]$, $T_d = \mathbf{11.0}[m]$, $DWT_d = \mathbf{40{,}050}[ton]$, $V = \mathbf{24.5}[knots]$

Find: $C_{B,d}$

Method 4: Estimate the structural weight (W_s), outfit weight (W_o), and machinery weight (W_m) in components.

$$LWT = W_s + W_o + W_m$$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + W_s + W_o + W_m$$

Structural weight (W_s) is estimated as follows:

$$W_s = C_s \cdot L^{1.6} \cdot (B+D)$$

The coefficient C_s can be obtained from the basis ship.

$$C_s = \left. \frac{W_s}{L^{1.6} \cdot (B+D)} \right|_{Basis} = \frac{11{,}000}{245.24^{1.6} \cdot (32.2+19.3)} = 0.032$$

Step 2: Weight Estimation
Method 4 for the Lightweight Estimation in Components (2/5)

Step 1: Volume Equation → **Step 2: Weight Equation** → Step 3: Freeboard Calculation

$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT$

Given: $L = \mathbf{247.76}[m]$, $B = \mathbf{32.2}[m]$, $D = \mathbf{19.3}[m]$, $T_d = \mathbf{11.0}[m]$, $DWT_d = \mathbf{40{,}050}[ton]$, $V = \mathbf{24.5}[knots]$

Find: $C_{B,d}$

Method 4: $LWT = W_s + W_o + W_m$

Outfit weight (W_o) is estimated as follows:

$$W_o = C_o \cdot L \cdot B$$

The coefficient C_o can be obtained from the basis ship.

$$C_o = \left. \frac{W_o}{L \cdot B} \right|_{Basis} = \frac{3{,}200}{245.24 \cdot 32.2} = 0.405$$

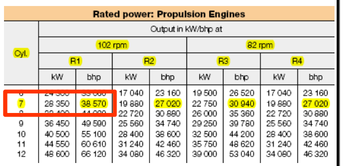
Machinery weight (W_m) is estimated as follows:

$$W_m = C_m \cdot NMCR$$

The coefficient C_m can be obtained from the basis ship.

$$C_m = \left. \frac{W_m}{NMCR} \right|_{Basis} = \frac{1{,}800}{38{,}570} = 0.047$$

Main engine of basis ship : Sulzer 7RTA84C



Rated power: Propulsion Engines

Cyl.	Output in kW/bhp at							
	102 rpm				82 rpm			
	R1		R2		R3		R4	
	kW	bhp	kW	bhp	kW	bhp	kW	bhp
6	24 300	33 060	17 040	23 160	19 500	26 520	17 040	23 160
7	28 350	38 570	19 880	27 020	22 750	30 940	19 880	27 020
8	32 400	44 080	22 720	30 880	26 000	35 360	22 720	30 880
9	36 450	49 590	25 560	34 740	29 250	39 780	25 560	34 740
10	40 500	55 100	28 400	38 600	32 500	44 200	28 400	38 600
11	44 550	60 610	31 240	42 460	35 750	48 620	31 240	42 460
12	48 600	66 120	34 080	46 320	39 000	53 040	34 080	46 320

$$NMCR = 38{,}570[PS]$$

At the early design stage, *NMCR* can be estimated by 'Admiralty formula'.

Step 2: Weight Estimation Method 4 for the Lightweight Estimation in Components (3/5)

Step 1: Volume Equation → **Step 2: Weight Equation** → **Step 3: Freeboard Calculation**

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT$$

Given: $L = \mathbf{247.76}[m]$, $B = \mathbf{32.2}[m]$, $D = \mathbf{19.3}[m]$, $T_d = \mathbf{11.0}[m]$, $DWT_d = \mathbf{40{,}050}[ton]$, $V = \mathbf{24.5}[knots]$

Find: $C_{B,d}$

Method 4: $LWT = W_s + W_o + W_m$

$$NMCR = \frac{1}{\text{Engine Margin}} \cdot \frac{1}{\text{Derating ratio}} \cdot NCR$$

$$\downarrow (\text{Engine Margin} = 0.9,\ \text{Derating ratio} = 0.9)$$

$$NMCR = 1.265 \cdot NCR$$

By applying the 'Admiralty formula' to the NCR, the NMCR also can be estimated.

$$NCR = \frac{\Delta^{2/3} \cdot V_s^3}{C_{ad}}$$

The coefficient C_{ad} can be obtained from the basis ship.

$$C_{ad} = \left.\frac{\Delta^{2/3} \cdot V_s^3}{NCR}\right|_{Basis} = \frac{50{,}400^{2/3} \cdot 23.17^3}{34{,}710} = 488.96 \quad \left(V_{s,\,at\ design\ draft} = 23.17[knots]\right)$$

$$NCR = \frac{\Delta^{2/3} \cdot V_s^3}{488.96}$$

$$NMCR = 1.265 \cdot \frac{\Delta^{2/3} \cdot V_s^3}{488.96}$$

$$= 0.0025 \cdot \Delta^{2/3} \cdot V_s^3$$

Step 2: Weight Estimation Method 4 for the Lightweight Estimation in Components (4/5)

Step 1: Volume Equation → **Step 2: Weight Equation** → **Step 3: Freeboard Calculation**

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT$$

Given: $L = \mathbf{247.76}[m]$, $B = \mathbf{32.2}[m]$, $D = \mathbf{19.3}[m]$, $T_d = \mathbf{11.0}[m]$, $DWT_d = \mathbf{40{,}050}[ton]$, $V = \mathbf{24.5}[knots]$

Find: $C_{B,d}$

Method 4: $LWT = W_s + W_o + W_m$

$W_s = C_s \cdot L^{1.6} \cdot (B+D)$ $\quad C_s = 0.032$

$W_o = C_o \cdot L \cdot B$ $\quad C_o = 0.405$

$W_m = C_m \cdot NMCR$ $\quad C_m = 0.047$

$NMCR = 0.0025 \cdot \Delta^{2/3} \cdot V_s^3$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + W_s + W_o + W_m$$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + C_s \cdot L^{1.6} \cdot (B+D) + C_o \cdot L \cdot B + C_m \cdot NMCR$$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + C_s \cdot L^{1.6} \cdot (B+D) + C_o \cdot L \cdot B$$
$$+ C_m \cdot (0.0025 \cdot \Delta^{2/3} \cdot V_s^3)$$

$$L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha) = DWT_d + C_s \cdot L^{1.6} \cdot (B+D) + C_o \cdot L \cdot B$$
$$+ C_m \cdot (0.0025 \cdot \left(L \cdot B \cdot T_d \cdot C_{B,d} \cdot \rho \cdot (1+\alpha)\right)^{2/3} \cdot V_s^3)$$

$$247.76 \cdot 32.2 \cdot 11.0 \cdot C_{B,d} \cdot 1.025 \cdot (1+0.0039) = 40{,}050 + 0.032 \cdot 247.76^{1.6} \cdot (32.2+19.3) + 0.405 \cdot 247.76 \cdot 32.2$$
$$+ 0.047 \cdot (0.0025 \cdot \left(247.76 \cdot 32.2 \cdot 11.0 \cdot C_{B,d} \cdot 1.025 \cdot (1+0.0039)\right)^{2/3} \cdot 24.5^3)$$

$$90{,}306 \cdot C_{B,d} = 40{,}050 + 11{,}181 + 3{,}233$$
$$+ 0.047 \cdot (0.0025 \cdot \left(90{,}306 \cdot C_{B,d}\right)^{2/3} \cdot 24.5^3)$$

Step 2: Weight Estimation Method 4 for the Lightweight Estimation in Components (5/5)

Step 1: Volume Equation → **Step 2: Weight Equation** → Step 3: Freeboard Calculation

$$\rho \cdot L \cdot B \cdot T_d \cdot C_{B,d} \cdot (1+\alpha) = DWT_d + LWT$$

Given: $L = \mathbf{247.76}[m]$, $B = \mathbf{32.2}[m]$, $D = \mathbf{19.3}[m]$, $T_d = \mathbf{11.0}[m]$, $DWT_d = \mathbf{40{,}050}[ton]$, $V = \mathbf{24.5}[knots]$

Find: $C_{B,d}$

Method 4: $LWT = W_s + W_o + W_m$

$$90,306 \cdot C_{B,d} = 40,050 + 11,181 + 3,233 + 0.047 \cdot (0.0025 \cdot \left(90,306 \cdot C_{B,d}\right)^{2/3} \cdot 24.5^3)$$

$$90,306 \cdot C_{B,d} = 40,050 + 11,181 + 3,233 + 3,488 \cdot {C_{B,d}}^{2/3}$$

$$90,306 \cdot C_{B,d} = 54,464 + 3,488 \cdot {C_{B,d}}^{2/3}$$

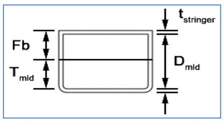
$$\therefore C_{B,d} = 0.632$$

Determination of the Principal Dimensions of 4,100 TEU Container Carrier - Step 3: Freeboard Calculation (1/2)

Step 1: Volume Equation → Step 2: Weight Equation → **Step 3: Freeboard Calculation**

Step 3: Then, it should be checked lastly whether the depth and draft satisfy the freeboard regulation.

$$D_{Fb} \geq T_s + Fb(L, B, D_{mld}, C_{B,d})$$



$$\left(D_{Fb} = D_{mld} + t_{stringer}\right)$$

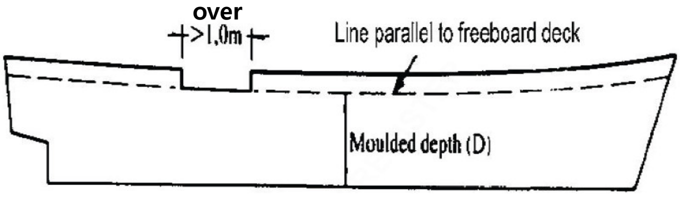
- ✓ **Given**: $L = \mathbf{247.76}[m]$, $B = \mathbf{32.2}[m]$, $D(=D_{mld}) = \mathbf{19.3}\ [m]$, $T_s = \mathbf{11.0}[m]$, $C_{B,d} = \mathbf{0.632}$, $t_{stringer} = \mathbf{0.05}[\mathrm{m}]$
- ✓ **Check: The freeboard of the ship should be larger than the required freeboard.**

Definition of Freeboard Deck

Freeboard Deck (D_f)$^{1)}$:

(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.



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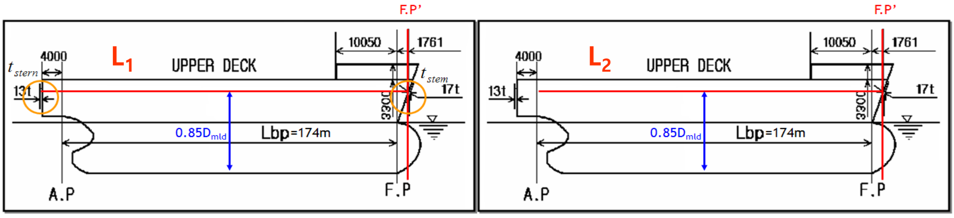
1) International Convention on Load Lines 1966, ANNEX1 Chapter 1, Reg.3-(9), 2003

Definition of Freeboard Length

Freeboard Length (L_f)$^{2)}$:

(a) The length shall be taken as 96% of the total length on a waterline at 85% of the least moulded depth measured from the top of the keel (L_1), or as the length from the fore side of the stem to the axis of the rudder stock on that waterline (L_2), if that be greater.

(b) For ships without a rudder stock, the length (L) is to be taken as 96% of the waterline at 85% of the least molded depth.



$$L_f = \max(L_1, L_2)$$

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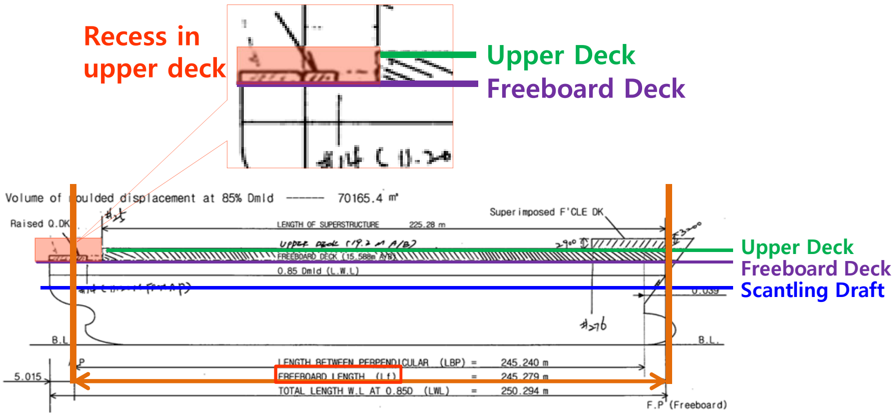
2) International Convention on Load Lines 1966, ANNEX1 Chapter 1, Reg.3-(1), 2003

Determination of Freeboard Deck

The freeboard deck of the container carrier:

- Because there is a recess in the upper deck of the container carrier, the upper deck is discontinuous.



Therefore, the freeboard deck of the container carrier is the second deck.

Determination of the Principal Dimensions of 4,
- Step 3: Freeboard Calculation (2/2)

Step 1: Volume Equation → **Step 2:** Weight Equation → **Step 3:** Freeboard Calculation

$$D_{Fb} \ge T_s + Fb(L, B, D_{mld}, C_{B,d})$$

Given: $L = 247.76[m]$, $B = 32.2[m]$, $D(=D_{mld}) = 19.3\ [m]$, $T_d = 11.0[m]$, $C_{B,d} = 0.632$, $t_{stringer} = 0.013[m]$

Check: Freeboard of the ship should be larger than that in accordance with the freeboard regulation.

At the early design stage, there are few data available for estimation of required freeboard. Thus, the required freeboard can be estimated from the basis ship.

Assume that the freeboard is proportional to the depth.

$$Fb(L, B, D_{mld}, C_{B,d}) = C_{Fb} \cdot D_{mld}$$

$$D_{Fb} \ge T_s + C_{Fb} \cdot D_{mld}$$

The coefficient C_{Fb} can be obtained from the basis ship.

$$C_{Fb} = \left.\frac{Fb}{D_{mld}}\right|_{Basis} = \frac{3.101}{19.3} = 0.161$$

Check: Freeboard of the design ship

$$D_{Fb} \ge T_s + C_{Fb} \cdot D_{mld}$$

$$D_{\text{second deck}} + t_{stringer} \ge T_s + C_{Fb} \cdot D_{mld}$$

$$15.588 + 0.013 \ge 12.6 + 0.161 \cdot 19.3$$

$$15.601 \not\ge 15.707$$ **: Not satisfied**

$D_{second\ deck}$: Depth of the second deck
$t_{stringer}$: Thickness of second deck

It is not satisfied. However, this method is used for a rough estimation. So, after the main dimensions are determined more accurately, freeboard needs to be calculated more accurately through the freeboard regulation.