Ship Stability

Ch. 10 Hydrostatic Values and Curves

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Contents

- Ch. 1 Introduction to Ship Stability
- Ch. 2 Review of Fluid Mechanics
- Ch. 3 Transverse Stability Due to Cargo Movement
- Ch. 4 Initial Transverse Stability
- Ch. 5 Initial Longitudinal Stability
- Ch. 6 Free Surface Effect
- Ch. 7 Inclining Test
- Ch. 8 Curves of Stability and Stability Criteria
- Ch. 9 Numerical Integration Method in Naval Architecture
- Ch. 10 Hydrostatic Values and Curves
- Ch. 11 Static Equilibrium State after Flooding Due to Damage
- Ch. 12 Deterministic Damage Stability
- Ch. 13 Probabilistic Damage Stability
Ch. 10 Hydrostatic Values and Curves

1. Hydrostatic Values
2. Trim and Stability Calculation of a 3,700TEU Container Ship Including Hydrostatic Values
3. More Examples

Introduction

In general, the document which contains the following list is submitted to ship owner and classification society, and get approval from them 9 months before steel cutting.

- Principle particulars
- General arrangement
- Midship section plan
- Lines plan
- Hydrostatic table
- Bonjean table
- Tank capacity table
- Light weight summary
- Allowable Minimum GM Curve
- Trim & stability calculation (Intact stability)
- Damage stability calculation
- Freeboard Calculation
- Visibility Check
- Equipment number calculation

Today’s main subject!
1. Hydrostatic Values

- Draft<sub>Mld</sub>, Draft<sub>Scant</sub>: Draft from base line, moulded / scantling (m)
- Volume<sub>Mld</sub>(V), Volume<sub>Ext</sub>: Displacement volume, moulded / extreme (m³)
- Displacement<sub>Mld</sub>(Δ), Displacement<sub>Ext</sub>: Displacement, moulded / extreme (ton)
- LCB: Longitudinal center of buoyancy from midship (Sign: - Aft / + Forward)
- LCF: Longitudinal center of floatation from midship (Sign: - Aft / + Forward)
- VCB: Vertical center of buoyancy above base line (m)
- TCB: Transverse center of buoyancy from center line (m)
- KM<sub>T</sub>: Transverse metacenter height above base line (m)
- KM<sub>L</sub>: Longitudinal metacenter height above base line (m)
- MTC: Moment to change trim one centimeter (ton-m)
- TPC: Increase in Displacement<sub>Mld</sub> (ton) per one centimeter immersion
- WSA: Wetted surface area (m²)
- C<sub>p</sub>: Block coefficient
- C<sub>WP</sub>: Water plane area coefficient
- C<sub>M</sub>: Midship section area coefficient
- C<sub>P</sub>: Prismatic coefficient
- Trim: Trim(= after draft – forward draft) (m)
Hydrostatic Curve

Hydrostatic curve: Curve for representing hydrostatic values

Example of Hydrostatic Curve

Water Plane Area ($A_{WP}$), Tones Per 1cm Immersion ($TPC$), Longitudinal Moment of Area ($L_{WP}$), Longitudinal Center of Floatation ($LCF$)

- Water plane area
  $$A_{WP} = \int b(x) \, dx$$

- Tones Per 1 Cm immersion ($TPC$)
  $$TPC = \frac{1}{\rho_{sw}} \cdot \frac{1}{100} \cdot A_{WP}$$
  where \(\rho_{sw}\) is the density of sea water.

- 1\textsuperscript{st} moment of water plane area about y axis
  $$M_{WP} = M_y = \int x \, dA = \int x \, dy$$

- Longitudinal Center of Floatation
  $$LCF = \frac{M_{WP}}{A_{WP}}$$
Sectional Area \((A)\), Displacement Volume \((V)\)

- **Sectional area**
  \[
  A(x) = \int dy\,dz
  \]
- **Displacement volume**
  \[
  V = \int dx\,dy\,dz
  = \int \left( \int dy\,dz \right) \,dx \\
  \Rightarrow A(x)
  \]
  \[
  \therefore V = \int A(x)\,dx
  
  \text{After calculating each sectional area, displacement volume can be calculated by integration of section area over the length of a ship.}
  
Longitudinal Moment of Displacement Volume \((M_{VL})\) and Longitudinal Center of Buoyancy \((LCB)\)

- **Longitudinal moment of displacement volume**
  \[
  M_{VL} = M_V = \int x\,dV \\
  = \int \left( \int x\,dy\,dz \right) \,dx \\
  \Rightarrow M_{A,L} \\
  M_{A,L}: \text{Longitudinal moment of area about y axis}
  \]
  \[
  \therefore M_{VL} = \int M_{A,L}\,dx
  
  \text{After calculating each longitudinal moment of sectional area about the y axis } (M_{A,L}) \text{, longitudinal moment of displacement volume can be calculated by integration of longitudinal moment of section area over the length of ship.}
  
- **Longitudinal Center of Buoyancy**
  \[
  LCB = \frac{M_{VL}}{V}
  \]
Vertical Moment of Displacement Volume \( (M_{V,r}) \) and Vertical Center of Buoyancy \( (V_{CB} \text{ or } K_B) \)

\[
M_{V,r} = M_{wz} = \int \int z \, dx \, dy \, dz \quad \Rightarrow M_{A,r} \quad \text{Vertical moment of area about } y \text{-axis}
\]

\[
V_{CB} = \frac{M_{V,r}}{V} = \frac{M_{A,r}}{x} \quad \text{(negative)}
\]

\[
K_B = T_e + V_{CB}
\]

After calculating each vertical moment of sectional area about the y axis \( (M_{A,r}) \), vertical moment of displacement volume can be calculated by integration of vertical moment of section area over the length of ship.

Transverse Moment of Displacement Volume \( (M_{V,t}) \) and Transverse Center of Buoyancy \( (T_{CB}) \)

\[
M_{V,t} = M_{wy} = \int \int y \, dx \, dy \, dz \quad \Rightarrow M_{A,t} \quad \text{Vertical moment of area about } z \text{-axis}
\]

\[
T_{CB} = \frac{M_{V,t}}{V}
\]

After calculating each transverse moment of sectional area about the z axis \( (M_{A,t}) \), transverse moment of displacement volume can be calculated by integration of transverse moment of section area over the length of a ship.
Block Coefficient ($C_B$) and Water Plane Area Coefficient ($C_{WP}$)

$C_B = \frac{\nabla}{L \cdot B_{mld} \cdot T}$

$C_{WP} = \frac{A_{WP}}{L \cdot B_{mld}}$

Midship Section Coefficient ($C_M$) and Prismatic Coefficient ($C_p$)

$C_M = \frac{A_M}{B_{mld} \cdot T}$

$C_p = \frac{\nabla}{L_{BP} \cdot A_M} \Rightarrow \frac{\nabla}{L_{BP} \cdot B_{mld} \cdot T \cdot C_M} = \frac{C_B}{C_M}$
### Transverse Metacentric Radius ($BM$), Longitudinal Metacentric Radius ($BML$), Moment to change Trim 1 Cm ($MTC$), and Trim

**BM**

Transverse righting moment:

$$\Delta GZ = \Delta GM \cdot \sin \theta$$

$$GM = KB \times BM = KG$$

$$BM_m = \frac{L}{V} (1 + \tan^2 \theta)$$

$$BM = \frac{L}{V}$$

- ($\theta$: Angle of heel)
- ($\Delta GZ$, $GM$, $KB$, $BM$, $KG$)
- ($BM_m$, $BM$)
- Without considering the change of the center of buoyancy in vertical direction

**BML**

Longitudinal righting moment:

$$\Delta GZ = \Delta GM \cdot \sin \theta$$

$$GM = KB \times BM = KG$$

$$BML_m = \frac{L}{V} (1 + \tan^2 \theta)$$

$$BML = \frac{L}{V}$$

- ($\theta$: Angle of trim)
- ($\Delta GZ$, $GM$, $KB$, $BM$, $KG$)
- ($BML_m$, $BML$)
- Without considering the change of the center of buoyancy in vertical direction

**MTC**

Moment to change Trim 1 Cm:

$$MTC = \Delta GM \times \frac{1}{L_{BP} \cdot 100}$$

$$GM = KB \times BM = KG$$

- ($\Delta GM$)
- ($MTC$)
- Without considering the change of the center of buoyancy in vertical direction
- ($\theta$: Angle of trim)

**Trim**

Transverse Moment Arm = $L_{CB} - L_{CG}$

$$\text{Trim}[m] = \frac{\Delta \cdot \text{Trim Lever}}{MTC \cdot 100}$$

$$MTC = \frac{\rho \cdot I_T}{L_{BP} \cdot 100}$$

### Generation of Hydrostatic Tables and Hydrostatic Curves

**Given:** Offsets table, Formulas for calculating hydrostatic values

**Find:** Hydrostatic tables as function of draft, Hydrostatic curves

- Calculation of hydrostatic values as function of draft
  - **<Hydrostatic Tables>**
    - **<Hydrostatic Curves>**
      - Generated curve using B-spline
      - Calculated values with respect to draft in the hydrostatic tables

**Draft [m]**

<table>
<thead>
<tr>
<th>Δ</th>
<th>LCB</th>
<th>TCB</th>
<th>KB</th>
<th>KM</th>
<th>L BP</th>
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<td>1</td>
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<td>3</td>
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<tr>
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<td>5</td>
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</tr>
</tbody>
</table>
Example of Offsets Table of a 6,300TEU Container Ship

<table>
<thead>
<tr>
<th>Waterline</th>
<th>* Unit: mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half-Breadth</td>
<td></td>
</tr>
<tr>
<td>Stations</td>
<td></td>
</tr>
</tbody>
</table>

Example of Lines of a 6,300TEU Container Ship
- Fore Body
Example of Lines of a 6,300TEU Container Ship - After Body

Relationship Between Lines and Offsets Table (1/2)

Lines

Generation of offsets table from the lines

Offsets table
Relationship Between Lines and Offsets Table (2/2)

- Half-breadth for St. 18
- Waterline at 18m
- Half-breadth for St. 19
- Waterline at 18m

Example of Hydrostatic Tables of a 6,300TEU Container Ship (1/2)

<table>
<thead>
<tr>
<th>DRAFT (M)</th>
<th>Disp. (M3)</th>
<th>Disp. (ExT) (M3)</th>
<th>VCB (M)</th>
<th>LCF (M)</th>
<th>KM (T)</th>
<th>KM M</th>
<th>MTC (T)</th>
<th>WSA (M2)</th>
<th>Cm</th>
<th>Cm</th>
<th>Cm</th>
<th>Cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.000</td>
<td>22354.0</td>
<td>22728.3</td>
<td>1.471</td>
<td>2.732</td>
<td>1.546</td>
<td>3.137</td>
<td>916.651</td>
<td>795.5</td>
<td>68.5</td>
<td>7478.0</td>
<td>0.5248</td>
<td>0.6332</td>
</tr>
<tr>
<td>4.050</td>
<td>22206.7</td>
<td>22664.5</td>
<td>1.489</td>
<td>2.774</td>
<td>1.555</td>
<td>3.154</td>
<td>916.847</td>
<td>798.0</td>
<td>68.7</td>
<td>7505.7</td>
<td>0.5263</td>
<td>0.6499</td>
</tr>
<tr>
<td>4.100</td>
<td>22172.2</td>
<td>22619.5</td>
<td>1.485</td>
<td>2.807</td>
<td>1.582</td>
<td>3.198</td>
<td>907.286</td>
<td>802.4</td>
<td>68.9</td>
<td>7514.1</td>
<td>0.5275</td>
<td>0.6507</td>
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<tr>
<td>4.150</td>
<td>22150.3</td>
<td>22676.4</td>
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<td>2.850</td>
<td>1.611</td>
<td>3.208</td>
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<td>812.8</td>
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<td>4.300</td>
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<td>22497.2</td>
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<td>2.260</td>
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<td>69.7</td>
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<td>4.350</td>
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<td>1.465</td>
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<td>4.400</td>
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<td>2.308</td>
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</table>

Naval Architectural Calculations, Spring 2016, Myung-Il Roh
Example of Hydrostatic Tables of a 6,300TEU Container Ship (2/2)

<table>
<thead>
<tr>
<th>DRAFT (M)</th>
<th>DISPL. (M^3)</th>
<th>DISPL. (Ton)</th>
<th>VCB (M)</th>
<th>LCB (M)</th>
<th>LCF (M)</th>
<th>KM (M)</th>
<th>KM (T)</th>
<th>MTC (T)</th>
<th>TPC (Ton)</th>
<th>WSA (M^2)</th>
<th>Cg</th>
<th>Cm</th>
<th>Cn</th>
<th>Cme</th>
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</thead>
<tbody>
<tr>
<td>11.750</td>
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<td>450346</td>
<td>1547.2</td>
<td>88.1</td>
<td>125959.4</td>
<td>0.695</td>
<td>0.814</td>
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<td>18.912</td>
<td>450328</td>
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<td>88.2</td>
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<tr>
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<td>0.694</td>
<td>0.814</td>
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<td>0.963</td>
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</table>

Example of Hydrostatic Curves of a 6,300TEU Container Ship
Example of Programming for Calculation of the Hydrostatics - Example of Hydrostatic Tables of a 320K VLCC (1/2)

Example of Programming for Calculation of the Hydrostatics - Example of Hydrostatic Tables of a 320K VLCC (2/2)
2. Trim and Stability Calculation of a 3,700TEU Container Ship Including Hydrostatic Values
### Naval Architectural Calculation, Spring 2016, Myung-Il Roh

#### Name Specific Gravity Filling Ratio

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Heavy Fuel Oil</td>
<td>0.990</td>
<td>96%</td>
</tr>
</tbody>
</table>

#### HEAVY FUEL OIL TANKS

<table>
<thead>
<tr>
<th>COMPARTMENT</th>
<th>LOCATION</th>
<th>NAME</th>
<th>L.G.</th>
<th>W.C.</th>
<th>V.C.</th>
<th>VOLUME</th>
<th>WEIGHT</th>
<th>L.C.G.</th>
<th>W.C.G.</th>
<th>V.C.G.</th>
<th>FROM</th>
<th>ABOVE FREEBOARD</th>
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<td>NO.1 H.F.O. TK (F)</td>
<td>180-2181</td>
<td>1239.3</td>
<td>159.066</td>
<td>6.942</td>
<td>622.0</td>
<td>1,214.6</td>
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<td>1,202.4</td>
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<tr>
<td>NO.2 H.F.O. TK (F)</td>
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<td>159.066</td>
<td>6.942</td>
<td>622.0</td>
<td>1,214.6</td>
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<td>1,202.4</td>
<td></td>
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<tr>
<td>NO.1 H.F.O. TK (B)</td>
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</tr>
<tr>
<td>NO.2 H.F.O. TK (B)</td>
<td>180-2229</td>
<td>1214.5</td>
<td>159.066</td>
<td>6.942</td>
<td>391.0</td>
<td>1,214.6</td>
<td>0.990</td>
<td>1,202.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*In general, heavy fuel oil is not fully loaded in the tank because of the vaporized gas, that is, oil mist.

\[
\text{GG}_i = \sum \rho_i \cdot V_i
\]

where \( \rho \) is the specific gravity and \( V \) is the volume.

**Example:**

\[
1,214.6 \times 0.99 = 1,202.4
\]

\[
1,118.6 \times 0.99 = 1,107.4
\]

---

### Tank Summary Table (1/2)

<table>
<thead>
<tr>
<th>Name</th>
<th>Specific Gravity</th>
<th>Filling Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Ballast Tank</td>
<td></td>
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</tr>
<tr>
<td>Fresh Water Tank</td>
<td></td>
<td></td>
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<tr>
<td>Heavy Fuel Oil Tank</td>
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<tr>
<td>Diesel Oil Tank</td>
<td></td>
<td></td>
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<tr>
<td>Lubrication Oil Tank</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miscellaneous Tank</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To be used for calculation of FSM (Free Surface Moment)
Tank Summary Table (2/2)

1. \[ LCG_{DWT} = \sum \frac{LCG_i \times \rho_i V_i}{DWT} \]

   - \( LCG_{DWT} \): Longitudinal center of gravity of cargo
   - \( \rho \): Density of cargo
   - \( V_i \): Volume of cargo

2. \[ LCG_{LWT} = \sum \frac{LCG_j \times W_j}{LWT} \]

   - \( LCG_{LWT} \): Longitudinal center of lightweight
   - \( W_j \): Distributed lightweight in longitudinal direction

- \( LCG_{DWT} \): Variable load based on loading condition
- \( LCG_{LWT} \): Location of \( LCG_{LWT} \) is fixed.

\[ \Delta = LCG_{DWT} \times DWT + LCG_{LWT} \times LWT \]

*Lightweight* reflects the weight of vessel being ready to go to sea without cargo and loads. And lightweight can be composed of:
- \( DWT \): Structural weight + Ballast weight + Machinery weight
- \( LW \): Weight that a ship can load till the maximum allowable immersion (at the scantling draft\(c_0\)).

And deadweight can be composed of:
- \( DWT\): Payload + Fuel oil + Diesel oil + Fresh water + Ballast water + etc.

Lightweight Summary

<table>
<thead>
<tr>
<th>Ball No.</th>
<th>1299</th>
<th>2/2000</th>
<th>MW</th>
<th>LW</th>
<th>LCG</th>
<th>NORT |</th>
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</tbody>
</table>

- MW: Static load
- LW: Dynamic load
- LCG: Location of LCG

Lightweight Distribution Diagram

- Engine
- Bow Thruster
- Emergency Pump

\[ \sum_{i=1}^{n} LCG_i \times \rho_i V_i = LCG_{DWT} \times DWT \]

\[ \sum_{j=1}^{m} LWT_j = \sum_{i=1}^{n} LCG_i \times W_j \]

\[ \Delta = LCG_{DWT} \times DWT + LCG_{LWT} \times LWT \]
Hydrostatic Values

- Draft_{Mld}, Draft_{Scant}: Draft from base line, moulded / scantling (m)
- Volume_{Mld}(V), Volume_{Ext}: Displacement volume, moulded / extreme (m³)
- Displacement_{Mld}(\Delta), Displacement_{Ext}: Displacement, moulded / extreme (ton)
- LCB: Longitudinal center of buoyancy from midship (Sign: - Aft / + Forward)
- LCF: Longitudinal center of floatation from midship (Sign: - Aft / + Forward)
- VCB: Vertical center of buoyancy above base line (m)
- TCB: Transverse center of buoyancy from center line (m)
- KM_t: Transverse metacenter height above base line (m)
- KM_L: Longitudinal metacenter height above base line (m)
- MTC: Moment to change trim one centimeter (ton-m)
- TPC: Increase in Displacement_{Mld} (ton) per one centimeter immersion
- WSA: Wetted surface area (m²)
- C_B: Block coefficient
- C_{WP}: Water plane area coefficient
- C_M: Midship section area coefficient
- C_P: Prismatic coefficient
- Trim: Trim(= after draft – forward draft) (m)

- Buoyancy due to appendages should be included.
- Thickness of hull should be included.

Constant "c" = 1.025

Hydrostatic Tables

<table>
<thead>
<tr>
<th>DRAFT</th>
<th>W</th>
<th>L</th>
<th>D</th>
<th>Sp</th>
<th>Ext(T)</th>
<th>WBD</th>
<th>LCB</th>
<th>LCF</th>
<th>HAT</th>
<th>XWL</th>
<th>MTC</th>
<th>TPC</th>
<th>WSA</th>
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</tr>
<tr>
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<td>16400.8</td>
<td>2.025</td>
<td>0.674</td>
<td>1.590</td>
<td>21.069</td>
<td>828.08</td>
<td>525.64</td>
<td>49.70</td>
<td>5602.12</td>
<td>6072.8</td>
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<td>5421.9</td>
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<td>830.42</td>
<td>528.66</td>
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<td>0.712</td>
<td>1.630</td>
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<td>0.727</td>
<td>1.652</td>
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<td>50.10</td>
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<td>0.739</td>
<td>1.675</td>
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<td>50.30</td>
<td>5719.87</td>
<td>5719.00</td>
<td>6216.70</td>
<td>5462.00</td>
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</tbody>
</table>
Loading Conditions

- A ship can be operated at various loading conditions.
- According to the loading condition, the displacement of the ship varies.
  - This means that LCG and KG varies as well.
- In accordance with IACS UR S1, the commercial ship’s loading conditions which should be calculated are as follows.
  - Lightship condition
  - Ballast condition (Departure/Arrival)
  - Homogeneous loading condition (Departure/Arrival)
  - Special condition required by the Owner

Loading Conditions: Lightship Condition (1/6)

- Lightship condition: Condition that loaded nothing (no cargo, imaginary condition)
By linear interpolation, draft at $L_C F = 3.871 \text{ m}$, $V_C B = K_B = 2.087 \text{ m}$, $K_M L = 818.61 \text{ [m]}$

$$M_T C = \frac{\Delta \times G M_L}{100 \times L_B P} = \frac{15,998.1 \times 816.52}{100 \times 245.24} = 532.7 \text{ [ton-m]}$$

Let’s calculate this!
**Loading Conditions: Lightship Condition (4/6)**

### Calculation of Trim forward, Trim aft

Given the draft and displacement, calculate the trim angles for lightship condition.

\[
\delta_a = \frac{LCF \times \text{Trim}}{LBP}
\]

\[
d_a = d_{eq} + \delta_a = d_{eq} + \frac{LCF \times \text{Trim}}{LBP}
\]

\[
\delta_T = \frac{d_T}{\text{Trim}} \times \frac{LCF}{LBP}
\]

\[
d_T = d_a - \text{Trim}
\]

\[
d_T = 6.086 - 4.560 = 1.526 [m]
\]

**Loading Conditions: Lightship Condition (5/6)**

### Calculation of \( GM, KG \)

- \( KG \): Calculation from the distribution of \( LWT \) and \( DWT \)

\[
KG = 13.2 [m]
\]

- \( GM = KM_T - KG \)

\[
GM = 21.296 - 13.2 = 8.096 [m]
\]

- \( GG_a = 0 \) (No liquid cargo in lightship condition)

\[
KG_a = KG = 13.2 [m]
\]
Loading Conditions: Lightship Condition (6/6)

Stability check

**IMO A-749(18) CHAP. 3.1 CRITERION**

<table>
<thead>
<tr>
<th>MIN. GmH</th>
<th>0.096</th>
<th>0.150 M</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA 0-30</td>
<td>0.049</td>
<td>0.055 M</td>
</tr>
<tr>
<td>AREA 0-40</td>
<td>0.236</td>
<td>0.090 M</td>
</tr>
<tr>
<td>AREA 0-10</td>
<td>0.367</td>
<td>0.030 M</td>
</tr>
<tr>
<td>MAX. G2</td>
<td>2.352</td>
<td>0.200 M</td>
</tr>
<tr>
<td>MAX. G2 OCCURS AT</td>
<td>27.2</td>
<td>25.00 DEG</td>
</tr>
<tr>
<td>FLOODING ANGLE IS</td>
<td>99.6</td>
<td>DEG</td>
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**IMO A-749(18) CHAP. 3.2 CRITERION**

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<td>Z</td>
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<tr>
<td>ROLLING PERIOD</td>
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<tr>
<td>AREA a</td>
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<td>50.2</td>
</tr>
<tr>
<td>8c</td>
<td>8.4</td>
<td>29.3 DEG</td>
</tr>
<tr>
<td>8c</td>
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<td>75.1 DEG</td>
</tr>
</tbody>
</table>

Loading Conditions: Ballast Departure Condition (1/6)

- Ballast departure condition: Condition that loaded ballast water and consumable cargo
Loading Conditions: Ballast Departure Condition (2/6)

**Calculation of MTC**

<table>
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<tbody>
<tr>
<td>6.0</td>
<td>3.002</td>
<td>2.022</td>
<td>3.892</td>
<td>116.92</td>
<td>118.53</td>
<td>15.763</td>
<td>496.0</td>
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<td>56.4</td>
<td>476.2</td>
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<td>660.4</td>
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<td>598.0</td>
<td>916.9</td>
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</tbody>
</table>

By linear interpolation, draft at LCF = 7.044 [m], \( VCB = KB \) = 3.826 [m], \( KM_I = 495.55 [m] \)

\[
MTC = \frac{\Delta \times GM_L}{100 \times LBP} = \frac{32,980.1 \times 491.724}{100 \times 245.24} = 661.3 [ton \cdot m]
\]

Let’s calculate this!

Loading Conditions: Ballast Departure Condition (3/6)

**Calculation of Trim**

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<td>578.6</td>
<td>598.0</td>
<td>916.9</td>
<td></td>
</tr>
</tbody>
</table>

Let’s calculate this!

1. **Trim Lever = LCB - LCG = 118.910 - 113.116 = 5.794 [m]**
2. **Trim [m] = \( \frac{\Delta \times \text{Trim Lever}}{MTC \times 100} \) = \( \frac{32,980.1 \times 5.794}{661.3 \times 100} = 2.890 [m] \)**

Let’s calculate this!
Loading Conditions: Ballast Departure Condition (4/6)

Calculation of Trim forward, Trim aft

\[
\delta_a = \frac{LCF \times \text{Trim LBP}}{LBP}
\]

\[
d_a = d_{aq} + \delta_a = d_{aq} + \frac{LCF \times \text{Trim LBP}}{LBP}
\]

\[
= 7.044 + \frac{118.707}{2.890} = 245.24
\]

\[
= 8.443 \text{[m]}
\]

\[
d_f = d_a - \text{Trim}
\]

\[
= 8.443 - 2.890 = 5.553 \text{[m]}
\]

Loading Conditions: Ballast Departure Condition (5/6)

Calculation of GM, KG

KMT: Given in hydrostatic tables (KMT = 15.728 [m])

KG: Calculation from distribution of LWT and DWT

\[
KG = 9.584 \text{[m]}
\]

\[
GM = KMT - KG = 15.728 - 9.584 = 6.144 \text{[m]}
\]

\[
GG_o = 0.177
\]

\[
\therefore KG_o = KG + GG_o = 9.584 + 0.177 = 9.761 \text{[m]}
\]
Stability check

**WING A-749** (18) CHAP. 3.1 CRITERION

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</tr>
<tr>
<td>AREA 30-40</td>
<td>0.077</td>
</tr>
<tr>
<td>MAX Gz</td>
<td>4.056</td>
</tr>
<tr>
<td>MAX Gz OCCURS AT 54.1 28.00 DEG</td>
<td></td>
</tr>
</tbody>
</table>

**WING A-749 (18) CHAP. 3.2 CRITERION**

| WIND AREA | 4283 M² |
| Z         | 13.173 M |
| ROLLING PERIOD | 16.1 SEC |
| AREA a   | 0.525   | 1.935 M-RAD |
| 2w1     | 1.132   | 0.155 M    |
| b1      | 1.0     | 23.2 DEG   |
| b2      | 50.0    | 90.0 DEG   |

3. More Examples
A box-shaped barge (L x B x D: 100m x 20m x 12m) is floating in freshwater on an even keel at draft of 6m. Vertical center of mass of the barge is 4m from baseline. When an external moment about x axis of 3,816 ton-m is applied on the ship, calculate an angle of heel.

**[Example] Calculation of an Angle of Heel (1/2)**

$$r_e = 3,816 \text{ton-m}$$

**[Example] Calculation of an Angle of Heel (2/2)**

Given:
L: 100m, B: 20 m, D: 12m, T: 6m, KG: 4m

Find: Angle of heel

$$r_e = F_h \cdot GM \cdot \sin \phi$$

$$\Rightarrow \sin \phi = \frac{r_e}{F_h \cdot GM}$$

$$\Rightarrow \phi = \sin^{-1} \left( \frac{r_e}{F_h \cdot GM} \right)$$

$$F_h = \rho \cdot L \cdot B \cdot T$$

$$GM = KB + BM - KG$$

$$BM = \frac{T}{2}$$

In case of box shaped barge

$$BM = \frac{(L-B)/12}{L \cdot B \cdot T} = \frac{(100-20)/12}{100 \cdot 20 \cdot 6} = 5.6 \text{[m]}$$

$$KB = T/2 = 3 \text{[m]}$$

$$\rho = 1 \text{[ton/m}^3\text{]}$$

$$\phi = \sin^{-1} \left( \frac{3,816}{(\rho \cdot L \cdot B \cdot T) \cdot (KB + BM - KG)} \right)$$

$$= \sin^{-1} \left( \frac{3,816}{(1 \cdot 100 \cdot 20 \cdot 6) \cdot (3 + 5.6 - 4)} \right)$$

$$= 3^\circ$$
A barge with 100m length, 20m breadth and 10m depth is floating having a draft of 5m. The center of mass, G, is located 7m above base line. A 1,000ton cargo will be loaded as in the figure below. The load will be on center line, 20m in front of the center of the ship and 4m above baseline. Calculate the draft at the aft perpendicular of the ship when the cargo is loaded.

**[Example] Calculation of a Trim of a Ship**

Given:
- L: 100m, B: 20m, D: 10m, T: 5m, KG: 7m
- Cargo Load: 1,000ton
  (At 20m in front of the center of the ship and 4m above the baseline)

Find:
- The draft at the aft perpendicular of the ship
[Example] Calculation of Trim of a Ship
- Calculation of the Approximate Solution by Using Linearization (1/7)

**Given:**
L: 100m, B: 20m, D: 10m, T: 5m, KG: 7m
Cargo Load: 1,000ton (At 20m in front of the center of the ship and 4m above the baseline)

**Find:** The draft at the aft perpendicular of the ship

---

**[Example] Calculation of Trim of a Ship
- Calculation of the Approximate Solution by Using Linearization (2/7)**

**Given:**
L: 100m, B: 20m, D: 10m, T: 5m, KG: 7m
Cargo Load: 1,000ton (At 20m in front of the center of the ship and 4m above the baseline)

**Find:** The draft at the aft perpendicular of the ship

---

In calculating TPC, is it reasonable to assume as below?

\[ A_{TPC} \approx L_B - B_t \]
### [Example] Calculation of Trim of a Ship

- **Calculation of the Approximate Solution by Using Linearization (3/7)**

**Given:**
- L: 100m, B: 20m, D: 10m, T: 5m, KG: 7m
- Cargo Load: 1,000ton
- (At 20m in front of the center of the ship and 4m above the baseline)

**Find:** The draft at the aft perpendicular of the ship

**[Elevation View]**

#### Trim Moment

\[
\text{Trim Moment} = w \cdot L \cdot \cos \theta \approx w \cdot L \\
\text{Trim Moment} = 20,000 \text{ton-m}
\]

#### Calculation of trim

1. **Trim moment:**
   \[
   \text{Trim moment} = w \cdot L \cdot \cos \theta \approx w \cdot L = 1,000 \cdot 20 = 20,000 \text{ton-m}
   \]

2. **Calculation of \( GM_M \)**
   \[
   KB_1 = \frac{T_1}{2} = \frac{5.488}{2} = 2.744 \text{m} \\
   KG_1 = 10,250 \text{ton} \\
   W_L = \Delta_L = 10,250 \text{ton} \\
   W_W = \Delta_W = 1,000 \text{ton} \\
   KG_1 = \frac{10,250 - 1,000}{11,250} = 6.73 \text{m}
   \]

Is it reasonable that \( KB_1 \) is equal to \( T_1/2 \)?

---

### [Example] Calculation of Trim of a Ship

- **Calculation of the Approximate Solution by Using Linearization (4/7)**

**Given:**
- L: 100m, B: 20m, D: 10m, T: 5m, KG: 7m
- Cargo Load: 1,000ton
- (At 20m in front of the center of the ship and 4m above the baseline)

**Find:** The draft at the aft perpendicular of the ship

**[Elevation View]**

#### Calculation of trim

1. **Trim moment:** 20,000ton-m

2. **Calculation of \( GM_M \)**
   \[
   KB_1 = 2.744 \text{m}, \quad KG_1 = 6.73 \text{m} \\
   BM_{M_1} = \frac{I_{x_1}}{V} \quad \text{For the calculation of } \beta, \text{the inclined water plane area should be known. However, we do not know it until the inclination angle is determined. The inclination angle (trim), however, can only be determined when } \text{the inclined water plane area (BM}_{M_1}\text{) is known. To solve this kind of “nonlinear” problem, we assume that “the inclined water plane area” is approximately equal to “the known water plane area” from previous state.} \\
   I_{x_1} = \int x^2 \, dx \\
   \geq I_{x_1} = \frac{B \cdot L^3}{12} = \frac{20 \cdot 100^3}{12} = 1,666,667 \text{m}^4 \\
   BM_{M_1} = \frac{1,666,667}{11,250/1.025} = 151.9 \text{m} \\
   \therefore GM_{M_1} = KB_1 + BM_{M_1} - KG_1 \\
   = 2.74 + 151.9 - 6.73 \\
   = 147.91 \text{m}
   \]
[Example] Calculation of Trim of a Ship
- Calculation of the Approximate Solution by Using Linearization (5/7)

Given:
L: 100m, B: 20m, D: 10m, T: 5m, KG: 7m
Cargo Load: 1,000ton
(A: 20m in front of the center of the ship and 4m above the baseline)

Find: The draft at the aft perpendicular of the ship

\[ \text{Trim Moment} = \frac{\Delta \cdot GM_{xx}}{L_{xx} - 100} \]
\[ = \frac{11,250 \cdot 147.91}{100 - 100} = 1,660 \text{ton} \cdot \text{m/cm} \]

In case of the box-shaped ship, the LCF is located at the midship:

\[ \text{Trim} = \frac{\text{Trim Moment}}{MTC} = \frac{20,000}{166} \approx 1.2 \text{m} \]

[Example] Calculation of Trim of a Ship
- Calculation of the Approximate Solution by Using Linearization (6/7)

Given:
L: 100m, B: 20m, D: 10m, T: 5m, KG: 7m
Cargo Load: 1,000ton
(A: 20m in front of the center of the ship and 4m above the baseline)

Find: The draft at the aft perpendicular of the ship

\[ \text{Trim Moment} = \frac{\Delta \cdot GM_{xx}}{L_{xx} - 100} \]
\[ = \frac{11,250 \cdot 147.91}{100 - 100} = 1,660 \text{ton} \cdot \text{m/cm} \]

Calculation of the change of the draft (T)
\[ T_i = 5.488 \text{m} \]

Calculation of the trim
\[ \text{Trim} = 1.2 \text{m} \]

Calculation of the draft at the aft perpendicular of the ship
\[ T_{A,T} = T_i + \frac{\text{Trim}}{2} \]
\[ = 5.488 + \frac{1.2}{2} = 6.088 \text{m} \]

Draft at the aft perpendicular
\[ = T_i + \frac{\text{Trim}}{2} = 5.488 + \frac{1.2}{2} = 6.088 \text{m} \]
[Example] Calculation of Trim of a Ship
- Calculation of the Approximate Solution by Using Linearization (7/7)

Given:
- L: 100m, B: 20m, D: 10m, T: 5m, KG: 7m
- Cargo Load: 1,000ton
- JA: 20m in front of the center of the ship and 4m above the baseline

Find:
- The draft at the aft perpendicular of the ship

There will be some difference between the approximate solution and exact solution, because of the following approximate terms.
- Trim Moment
- $I_L$:
- $A_{WP}:
- TPC:
- $K_B$:
- $L_{CB}$:

This calculation has to be “repeated” using “the inclined current water plane” until the difference between the approximate solution and exact solution becomes to zero.

[Example] Calculation of Trim for a Barge Ship When the Cargo is Moved

A barge ship is 20m length, 12m breadth, 4m depth, and is floating at 2m draft in the fresh water. When a 10ton cargo which is loaded on the center of the deck is moved to 4m in the direction of the forward perpendicular and 2m in the direction of the starboard, determine the draft at the forward perpendicular (FP), after perpendicular (AP), portside, and starboard of the ship. KG of the ship is given as 2m.
[Example] Calculation of Trim for a Barge Ship When the Cargo is Moverd

Given:
L: 20m, B: 12m, D: 4m, T: 2m, KG: 2m
Movement of the 10ton cargo
(From the center of the deck to 4m in the direction of the forward perpendicular and 2m in the direction of the starboard)

Find: The draft at the forward perpendicular (FP), after perpendicular (AP), portside, and starboard of the ship

\[ F = Ax \]

A problem that force (moment) acting on the ship is given, and the change in position and orientation is calculated.

Load of the cargo

The change of the force (moment) is given.

Problem to calculate the change of the position

\[ \text{Given:} \]
L: 20m, B: 12m, D: 4m, T: 2m, KG: 2m
Movement of the 10ton cargo
(From the center of the deck to 4m in the direction of the forward perpendicular and 2m in the direction of the starboard)

Find: Draft at the forward perpendicular (FP), after perpendicular (AP), portside, and starboard of the ship

\[ \text{Calculation of the approximate solution by linearizing the problem} \]

1. Change of draft caused by trim
   ① Calculation of the trim
   \[ \text{Trim} = \sum \text{Trim Moment} \]
   ①-1) Trim Moment : (weight of the cargo) \times \text{distance}
   ①-2) \text{Trim} = \text{KG} \times \text{B} \times \text{T}
   ①-3) \Delta \text{GM} \cdot \text{T} \cdot \text{L}

2. Change of draft caused by heel
   ① Calculation of the change of the draft caused by the heel
   \[ \text{Heel} = B \cdot \tan \phi \]
   ①-1) Calculation of the change of the center of gravity in the transverse direction
   ①-2) \Delta \text{GM} \cdot \text{B} \cdot \Delta \text{L} \cdot \text{T}
   ①-3) Calculating the heeling angle
   \[ \Delta \text{L} \cdot \cos \phi = \Delta \text{GM} \cdot \sin \phi \]

3. Calculation of draft at each port and starboard of the FP and AP
   ① Calculation of the draft at each port and starboard of the FP and AP respectively
   \[ T_{\text{FP}} = \frac{\text{Trim} + \text{Heel}}{2} \]
[Example] Calculation of Trim for a Barge Ship When the Cargo is Moved
- Calculation of the Approximate Solution by Using Linearization (2/7)

Given:
L: 20m, B: 12m, D: 4m, T: 2m, KG: 2m
Movement of the 10ton cargo
(from the center of the deck to 4m in the direction of the forward perpendicular and 2m in the direction of the starboard)

Find: The draft at the forward perpendicular (FP), after perpendicular (AP), portside, and starboard of the ship

\[
F = Ax
\]
Force (moment)
Position and Orientation

A problem that force (moment) acting on the ship is given, and the change in position and orientation is calculated.

Displacement volume and displacement of the ship:
\[
V = L \cdot B \cdot T = 20 \cdot 12 \cdot 2 = 480 \text{ m}^3
\]
\[
\Delta = V \cdot \rho_w = 480 \cdot 10 \cdot 480 \text{ ton}
\]

1. Changed draft caused by trim

\[
\text{Trim Moment} = 10 \cdot 4 \cdot \cos \theta = 40 \text{ ton} \cdot m
\]
\[
GM_1 = KB + BM_1 - KG
\]
\[
KB = \frac{T}{2} = \frac{2}{2} = 1 \text{ m}
\]
\[
BM_1 = \frac{L}{V} \cdot \frac{BL}{V} = \frac{12 \cdot 20}{12} = 16.67 \text{ m}
\]
\[
KG = 2 \text{ m}
\]
\[
GM_1 = KB + BM_1 - KG = 1 + 16.67 - 2 = 15.67 \text{ m}
\]

[Example] Calculation of Trim for a Barge Ship When the Cargo is Moved
- Calculation of the Approximate Solution by Using Linearization (3/7)

1. Change of draft caused by trim

\[
\text{Trim Moment} = 10 \cdot 4 \cdot \cos \theta = 40 \text{ ton} \cdot m
\]
\[
GM_1 = KB + BM_1 - KG
\]
\[
KB = \frac{T}{2} = \frac{2}{2} = 1 \text{ m}
\]
\[
BM_1 = \frac{L}{V} \cdot \frac{BL}{V} = \frac{12 \cdot 20}{12} = 16.67 \text{ m}
\]
\[
KG = 2 \text{ m}
\]
\[
GM_1 = KB + BM_1 - KG = 1 + 16.67 - 2 = 15.67 \text{ m}
\]

2. Change of draft caused by heel

\[
\text{Heel} = \tan \phi
\]
\[
\phi' = \phi + \Delta \phi
\]
\[
\Delta \phi = \frac{\Delta L}{L} = \frac{\Delta L}{100\text{cm}}
\]
\[
\Delta L = \frac{\text{Trim Moment}}{100\text{ ton} \cdot m} \cdot \frac{100\text{ cm}}{100}
\]
\[
T = \frac{\text{Trim Moment}}{100\text{ ton} \cdot m}
\]
\[
\Delta \phi = \frac{40}{3.7608} = 10.64 \text{ cm}
\]
\[
\Delta L = 10.64 \times 100 = 1064 \text{ m}
\]

3. Calculation of drafts at each portside and starboard of the FP and AP

\[
L_{FP} = \frac{L}{2}
\]
\[
L_{AP} = \frac{L}{2} + \Delta L
\]
\[
L_{Port} = \frac{L}{2} + \Delta L
\]
\[
L_{Stb} = \frac{L}{2} + \Delta L
\]

\[
\text{Location of the cargo}
\]
2. Changed draft caused by the heel

- Change of the center of gravity

\[ \delta y_g' = \frac{w \Delta}{L} = \frac{10 \cdot 2}{480} = 0.04 \text{ m} \]

\[
GM = KB + BM - KG
\]

\[
KB = \frac{T}{2} = \frac{2}{2} = 1 \text{ m}
\]

\[
BM = \frac{I}{V} = \frac{L^2}{12} = \frac{20 \cdot 12^2}{12} = 6 \text{ m}
\]

\[
KG = 2 \text{ m}
\]

\[
GM = KB + BM - KG = 1 + 6 - 2 = 5 \text{ m}
\]
3. Calculation of the drafts at the each portside and starboard of the FP and AP

- The drafts at the each portside and starboard of the FP and AP are calculated considering the direction of forward perpendicular and starboard as follows:

\[
T_{FP-Portside} = T + \frac{B}{2} \tan \phi = T + \frac{0.1064}{2} - 0.0482 = 2.0050m
\]

\[
T_{AP-Portside} = T - \frac{B}{2} \tan \phi = T - \frac{0.1064}{2} + 0.0482 = 1.9950m
\]

\[
T_{FP-Starboard} = T + \frac{B}{2} \tan \phi = T + \frac{0.1064}{2} + 0.0482 = 2.1014m
\]

\[
T_{AP-Starboard} = T - \frac{B}{2} \tan \phi = T - \frac{0.1064}{2} - 0.0482 = 1.8986m
\]

3. Calculation of drafts at each portside and starboard of the FP and AP

If the inclination angles are small, the difference of the approximate solution and exact solution will be small. The linearized terms in the solving procedure

- Trim moment \( w \cdot \cos \theta \cdot I_1 \)
- \( I_{11} \) \( I_{12} \) \( I_{13} \)
- \( A WP \)
- TPC, MTC
- \( KB_1 \)
- LCB_1
- Vertical center of buoyancy at the previous state
- Longitudinal center of buoyancy at the previous state

- Because of linearization, there is a difference between the obtained solution and exact solution. If the inclination angles are small, an acceptable solution can be obtained. If the inclination angles are large, however, this calculation has to be repeated using the inclined current water plane until the difference between the approximate solution and exact solution becomes to zero.
A ship is floating in fresh water as seen in the figure below. Answer the following questions. The density of the after part, cargo hold part, and forward part is $\rho_m = 1.0 \text{ton/m}^3$.

1. Calculate the displacement ($\Delta$) of the ship.
2. Calculate the LCF, LCB, LCG, and KG of the ship.
3. If all compartments (No.1~No.5 for port and starboard, total 10 cargo holds) are fully loaded, with a load whose density is 0.6ton/m$^3$, calculate the deadweight (DWT) and lightweight (LWT).
4. When the cargo is loaded and unloaded, the shape of the water plane changes. Explain how to calculate the change of the trim in this case.

---

**[Example] Calculation of Trim of a Ship (1/7)**

A ship is floating in fresh water as seen in the figure below. Answer the following questions. The density of the after part, cargo hold part, and forward part is $\rho_m = 1.0 \text{ton/m}^3$.

1. Calculate the displacement ($\Delta$) of the ship.
2. Calculate the LCF, LCB, LCG, and KG of the ship.
3. If all compartments (No.1~No.5 for port and starboard, total 10 cargo holds) are fully loaded, with a load whose density is 0.6ton/m$^3$, calculate the deadweight (DWT) and lightweight (LWT).
4. When the cargo is loaded and unloaded, the shape of the water plane changes. Explain how to calculate the change of the trim in this case.

---

**[Example] Calculation of Trim of a Ship (2/7)**

A problem that force (moment) acting on the ship is given, and the change in position and orientation is calculated.

---

**Given:**

- L: 180m, B: 30m, D: 10m, T: 8m
- Density of the ship material $\rho_m = 1.0 \text{ton/m}^3$
- The ship is floating in fresh water

**Find:**

1. Displacement ($\Delta$)
2. LCF, LCB, LCG, KG
3. When the all cargo hold are full with the load whose density is 0.6ton/m$^3$ homogeneously, DWT and LWT?
4. How do we calculate the change of the trim when the cargo is loaded or unloaded?
[Example] Calculation of Trim of a Ship (3/7)

Given:
- L: 180m, B: 30m, D: 10m, T: 8m
- Density of the ship material ρ_m = 1.0 ton/m³
- The ship is floating in fresh water.

Find:
1. Displacement (Δ)
2. LCF, LCB, LCG, KG
3. When the cargo hold is fully loaded, with a load having a density of 0.6 ton/m³ homogeneously. What is the DWT and LWT?
4. How do we calculate the change of the trim when the cargo is loaded or unloaded?

Calculation of the approximate solution by linearizing the problem

1. Displacement (Δ)
   \[ Δ = V \cdot ρ \]
   \[ V = A_p \cdot T \]  (Since the water plane area does not change)

2. LCF, LCB, LCG, KG
   \[ LCF = \frac{M_{CF}}{V} = \frac{\int x \cdot dx \cdot dy}{\int dx \cdot dy} \]
   \[ LCB = \frac{M_{CB}}{V} = \frac{\int x' \cdot dx' \cdot dy'}{\int dx' \cdot dy'} \]

Because the water plane area is not changed in the vertical direction, LCF = LCG

3. When the cargo hold is fully loaded, with a load having a density of 0.6 ton/m³ homogeneously. What is the DWT and LWT?
   \[ DWT = A_p \cdot D \cdot ρ_{m} \]
   \[ LWT = Δ - DWT \]

4. How do we calculate the change of the trim when the cargo is loaded or unloaded?

[Example] Calculation of Trim of a Ship (4/7)

Given:
- L: 180m, B: 30m, D: 10m, T: 8m
- Density of the ship material ρ_m = 1.0 ton/m³
- The ship is floating in fresh water.

Find:
1. Displacement (Δ)
2. LCF, LCB, LCG, KG
3. When the all cargo hold are full with the load whose density is 0.6 ton/m³ homogeneously, DWT and LWT?
4. How do we calculate the change of the trim when the cargo is loaded or unloaded?

Calculation of the approximate solution by linearizing the problem

1. Displacement (Δ)
   \[ Δ = V \cdot ρ \]
   \[ V = A_p \cdot T \]

If the water plane areas for after part, cargo hold part, and fore part are A_p, A_k, A_f respectively,

\[ A_p = (30 + 10) \cdot 20 \cdot 0.5 = 400 \text{ m}^2 \]
\[ A_k = 150 \cdot 30 = 4.500 \text{ m}^2 \]
\[ A_f = 0.5 \cdot 30 \cdot 10 = 150 \text{ m}^2 \]

\[ V = (A_p + A_k + A_f) \cdot T = 40,400 \text{ m}^3 \]

\[ \therefore Δ = V \cdot ρ_m = 40,400 \cdot 1.0 = 40,400 \text{ ton} \]
[Example] Calculation of Trim of a Ship (5/7)

Given:
L: 180m, B:30m, D:10m, T:8m
Density of the ship material $\rho_m = 1.0\text{ton/m}^3$.
The ship is floating in fresh water.

Find:
① Displacement ($\Delta$)
② LCF, LCB, LCG, KG
③ When the all cargo hold are full with the load whose density is 0.6ton/m$^3$ homogeneously, DWT and LWT?
④ How do we calculate the change of the trim when the cargo is loaded or unloaded?

Because the ship is in the “even keel” state and the water plane area is not changed in the vertical direction

LCF = LCB = LCG = 0.73m

Because the water plane area is not changed in the z axis direction

$KG = \frac{D}{2} = \frac{10}{2} = 5\text{m}$, $KB = \frac{T}{2} = \frac{8}{2} = 4\text{m}$

[Example] Calculation of Trim of a Ship (6/7)

Given:
L: 180m, B:30m, D:10m, T:8m
Density of the ship material $\rho_m = 1.0\text{ton/m}^3$.
The ship is floating in fresh water.

Find:
① Displacement ($\Delta$)
② LCF, LCB, LCG, KG
③ When the all cargo hold are full with the load whose density is 0.6ton/m$^3$ homogeneously. What is the DWT and LWT?
④ How do we calculate the change of the trim when the cargo is loaded or unloaded?

DWT = $\Delta$ + $\rho_{cargo} \times D$ 
LWT = $\Delta$ - DWT

The deadweight (DWT) and lightweight (LWT) of the ship

$DWT = \Delta \times \rho_m$

$\Delta = 4,500 \times 10 - 0.6$

$= 27,000\text{ton}$

$LWT = \Delta - DWT$

$= 40,400 - 27,000$

$= 13,400\text{ton}$
④ How do we calculate the change of trim when the cargo is loaded or unloaded?

The trim at the first stage is calculated by the moment caused by loading/unloading the cargo and MTC in the even keel state. However, the water plane area, center of gravity, and buoyancy of the ship can change by loading/unloading the cargo. Therefore, to calculate the trim of the ship, the MTC has to be obtained after trimming and we have to iterate the following calculation until a constant value is obtained.

At first, we calculate the MTC in the current state by using the trim obtained in first stage. And then, we calculate the trim at the second stage by using this MTC. And then, we iterate this calculation procedure until the error of the displacement and trim is smaller than the allowable value.

---

### [Example] Calculation of Trim of a Ship (7/7)

**Given:**
- L: 180m, B: 30m, D: 10m, T: 8m
- Density of the ship material \( \rho_m = 1.0 \text{ton/m}^3 \)
- The ship is floating in fresh water.

**Find:**
- ① Displacement (Δ)
- ② LCF, LCB, LCG, KG
- ③ When the all cargo hold are full with the load whose density is 0.6ton/m³ homogeneously, DWT and LWT?
- ④ How do we calculate the change of the trim when the cargo is loaded or unloaded?

---

### [Example] Calculation of Barge Ship’s Trim and Heel Angles (1/18)

A barge ship of 28m length, 18m breadth, 9m height, 1m shell plate thickness, density of shell plate \( \rho_m = 1.0 \text{ton/m}^3 \) is shown below.

① Calculate ship’s lightweight and draft in fresh water under the condition of “light ship” loading condition. And if the barge ship is floating in sea water, what is the draft?

② The barge ship floats in fresh water and it carries the loads as shown in the table.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Mass</th>
<th># of Cargoes</th>
<th>Loading position(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight 1</td>
<td>100ton</td>
<td>3</td>
<td>0 0 1</td>
</tr>
<tr>
<td>Freight 2</td>
<td>150ton</td>
<td>2</td>
<td>5 0 1</td>
</tr>
</tbody>
</table>

Calculate the ship’s ⑤ deadweight (DWT) ⑥ TPC ⑦ MTC ⑧ Trim ⑨ Fore and after drafts ⑩ LCB ⑪ LCG.

③ From the result of the question ②, if the freight 2 is unloaded from the barge ship, calculate LCB and LCG.

④ From the result of the question ③, if the freight 1 moves 5m along the positive y direction. calculate the barge ship’s heel angle.
Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρm = 1.0 ton/m³

Find:
① LWT, Draft in fresh water (Tfw), Draft in sea water (Tsw)
② When the freight 1 and 2 are loaded in fresh water, calculate a) Deadweight (DWT) ⒞ TPC ⓒ MTC ⓓ Trim ⓔ Fore and after drafts ⒞ LCB ⓖ LCG.
③ Freight 2 is unloaded from ②, calculate LCB, LCG.
④ Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

Load freight
- The change in force (moment) is given. And the problem is calculation of position and orientation of the ship

Unload freight
- The change in force (moment) is given. And the problem is calculation of position and orientation of the ship

Move freight
- The change in force (moment) is given. And the problem is calculation of position and orientation of the ship

Calculation of the approximate solution by linearizing the problem

Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρm = 1.0 ton/m³
[Example] Calculation of Barge Ship’s Trim and Heel Angles (4/18)

**Given**
- L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
- Density of the shell plate: $\rho_m = 1.0 \text{ton/m}^3$

**Find**
1. LWT, Draft in fresh water ($T_{FW}$), Draft in sea water ($T_{SW}$)
2. When the freight 1 and 2 are loaded in fresh water, calculate:
   - Deadweight (DWT)
   - TPC
   - MTC
   - Trim
   - Fore and after drafts
   - LCB
   - LCG.
3. Freight 2 is unloaded from 2, calculate LCB, LCG.
4. Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

**Calculation of the approximate solution by linearizing the problem**

- Freight 2 is unloaded from ①, calculate LCB, LCG.
- $LCB = \frac{M_{c,l}}{V}$
- $LCG = \frac{w_1}{W}L$

- From the condition ③, freight 1 moves 5m along the positive y direction. Calculate heel angle.
- $\delta \gamma'_y \cos \phi + \delta \gamma'_z \sin \phi = \frac{GM}{A} \sin \phi$
- $\delta \gamma'_x = \frac{w_1}{A}$
- $\frac{GM}{A} = KB + BM - KG$

[Example] Calculation of Barge Ship’s Trim and Heel Angles (5/18)

**Given**
- L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
- Density of the shell plate: $\rho_m = 1.0 \text{ton/m}^3$

**Find**
1. LWT, Draft in fresh water ($T_{FW}$), Draft in sea water ($T_{SW}$)
2. When the freight 1 and 2 are loaded in fresh water, calculate:
   - Deadweight (DWT)
   - TPC
   - MTC
   - Trim
   - Fore and after drafts
   - LCB
   - LCG.
3. Freight 2 is unloaded from ②, calculate LCB, LCG.
4. Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

**Example Calculation**

- $\Delta = (30 \cdot 20 - 10 \cdot 9) \cdot 1.0 \text{ton} = 1,464 \text{ton}$
- $T_{FW} = \frac{\Delta_{SW}}{\Delta} = \frac{1,464}{30-20} = 2.44 \text{m}$
- Thus, the draft is $T_{FW} = 2.44 \text{m}$
- In sea water, the draft for light ship condition is given by:
  - $\Delta = 2.8 \cdot T_{SW} \cdot \rho_w$
  - Thus, the draft is $T_{SW} = \frac{1.464}{2.8 \cdot 1.025} = 2.39 \text{m}$
When the freight 1 and 2 are loaded in fresh water,

- Deadweight (DWT)
- TPC
- MTC
- Trim
- Fore and after drafts
- LCB
- LCG

Before loading the freight, the ship’s displacement is equal to lightweight (LWT):

\[ \Delta = LWT = 1,464 \text{ ton} \]

Thus the ship’s deadweight (DWT) is

\[ DWT = 3 \times 100 + 2 \times 150 = 600 \text{ ton} \]

After loading the freights, the ship’s displacement becomes

\[ \Delta = LWT + DWT = 2,064 \text{ ton} \]
[Example] Calculation of Barge Ship’s Trim and Heel Angles (8/18)

**Given:**
- L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
- Density of the shell plate: $\rho_m = 1.0 \text{ ton/m}^3$

**Find:**
1. LWT, Draft in fresh water ($T_{f\text{w}}$), Draft in sea water ($T_{s\text{w}}$)
2. When the freight 1 and 2 are loaded in fresh water, calculate:
   - Deadweight (DWT)
   - TPC
   - MTC
   - Trim
   - Fore and after drafts
   - LCB
   - LCG
3. Freight 2 is unloaded from 2, calculate LCB, LCG.
4. Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

After loading the freight, the changed center of buoyancy becomes:

$$KB = \frac{T}{2} = \frac{1.72}{2} = 0.86 \text{ m}$$

And the changed center of gravity about the base line, that is $z=0$, is expressed as follows:

$$KG = \frac{\Delta LBM}{L_{BP}} = \frac{1.72}{2} = 0.86 \text{ m}$$

**[Example] Calculation of Barge Ship’s Trim and Heel Angles (9/18)**

**Given:**
- L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
- Density of the shell plate: $\rho_m = 1.0 \text{ ton/m}^3$

**Find:**
1. LWT, Draft in fresh water ($T_{f\text{w}}$), Draft in sea water ($T_{s\text{w}}$)
2. When the freight 1 and 2 are loaded in fresh water, calculate:
   - Deadweight (DWT)
   - TPC
   - MTC
   - Trim
   - Fore and after drafts
   - LCB
   - LCG
3. Freight 2 is unloaded from 2, calculate LCB, LCG.
4. Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

After loading the freight, the changed center of buoyancy becomes:

$$KB = \frac{T}{2} = \frac{1.72}{2} = 0.86 \text{ m}$$

And the changed center of gravity about the base line, that is $z=0$, is expressed as follows:

$$KG = \frac{\Delta LBM}{L_{BP}} = \frac{1.72}{2} = 0.86 \text{ m}$$

$$I_z = \frac{B \cdot L^3}{12} = \frac{20 \cdot 30^3}{12} = 45,000 \text{ m}^4$$

$$BM_L = I_z = \frac{45,000}{2.064 / 1.0} = 21.8 \text{ m}$$

$$GM_L = KB + BM_L - KG = 0 + 21.8 - 2.09 = 19.71 m$$
[Example] Calculation of Barge Ship’s Trim and Heel Angles (10/18)

**Given:**
- L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
- Density of the shell plate: \( \rho_m = 1.0 \text{ton/m}^3 \)

**Find:**
- ① LWT, Draft in fresh water (\( T_{fw} \)), Draft in seawater (\( T_{sw} \))
- ② When the freight 1 and 2 are loaded in fresh water, calculate ① Deadweight (DWT) ② TPC ③ MTC ④ Trim ⑤ Fore and after drafts ⑥ LCB ⑦ LCG.
- ③ Freight 2 is unloaded from ②, calculate LCB, LCG.
- ④ Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

Therefore, MTC (moment to trim 1 cm) is

\[
MTC = \frac{\Delta GM}{100} = \frac{2,064 - 21.43}{100} = 442.32 \text{ ton} \cdot \text{m/cm}
\]

[Example] Calculation of Barge Ship’s Trim and Heel Angles (11/18)

**Given:**
- L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
- Density of the shell plate: \( \rho_m = 1.0 \text{ton/m}^3 \)

**Find:**
- ① LWT, Draft in fresh water (\( T_{fw} \)), Draft in seawater (\( T_{sw} \))
- ② When the freight 1 and 2 are loaded in fresh water, calculate ① Deadweight (DWT) ② TPC ③ MTC ④ Trim ⑤ Fore and after drafts ⑥ LCB ⑦ LCG.
- ③ Freight 2 is unloaded from ②, calculate LCB, LCG.
- ④ Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

Loading of the freight 2 leads to

\[
\text{Trim Moment} = -5 \cdot (150 - 2) = -1,500 \text{ ton} \cdot \text{m}
\]

\[
\text{Trim} = \frac{\text{Trim Moment}}{MTC} = -3.39 \text{ cm} = -0.0339 \text{ m}
\]

Using the trim, the fore and after drafts are expressed as follow:

Draft at fore part \( T = \frac{1}{2} \cdot 0.0339 = 3.42 \text{ m} \)

Draft at after part \( T = \frac{1}{2} \cdot 0.0339 = 3.46 \text{ m} \)
[Example] Calculation of Barge Ship’s Trim and Heel Angles (12/18)

Given:
- L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
- Density of the shell plate: \( \rho_m = 1.0 \text{ton/m}^3 \)

Find:
1. LWT, Draft in fresh water (\( T_{fW} \)), Draft in sea water (\( T_{sw} \))
2. When the freight 1 and 2 are loaded in fresh water, calculate: Deadweight (DWT) \( \rho_f \), TPC \( \Theta \), MTC \( \psi \), Trim \( z \) \( x \)
3. Freight 2 is unloaded from 2, calculate LCB, LCG.
4. Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

About the midship section, longitudinal moment of the volume of submerged wedge leads to

\[
\frac{1}{2} (L - T_f) \left( \frac{L}{2} \right) - \frac{1}{2} \cdot 2 \cdot 3 \cdot L - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2} - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2} - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2}
\]

Therefore, total longitudinal moment of displaced volume, \( M_L \), is calculated as follows

\[
M_L = -2 \left( \frac{1}{2} \left( \frac{L}{2} \right) (T_f - T_f) \right) \left( \frac{L}{2} \right) - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2} - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2} - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2}
\]

Where, the change in center of buoyancy in vertical direction is disregarded.

[Example] Calculation of Barge Ship’s Trim and Heel Angles (13/18)

Given:
- L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
- Density of the shell plate: \( \rho_m = 1.0 \text{ton/m}^3 \)

Find:
1. LWT, Draft in fresh water (\( T_{fW} \)), Draft in sea water (\( T_{sw} \))
2. When the freight 1 and 2 are loaded in fresh water, calculate: Deadweight (DWT) \( \rho_f \), TPC \( \Theta \), MTC \( \psi \), Trim \( z \) \( x \)
3. Freight 2 is unloaded from 2, calculate LCB, LCG.
4. Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

About the midship section, longitudinal moment of the volume of emerged wedge leads to

\[
\frac{1}{2} (L - T_f) \left( \frac{L}{2} \right) - \frac{1}{2} \cdot 2 \cdot 3 \cdot L - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2} - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2} - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2}
\]

Therefore, total longitudinal moment of displaced volume, \( M_L \), is calculated as follows

\[
M_L = -2 \left( \frac{1}{2} \left( \frac{L}{2} \right) (T_f - T_f) \right) \left( \frac{L}{2} \right) - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2} - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2} - \frac{1}{2} \cdot \frac{L}{2} \cdot \frac{L}{2}
\]

Where, the change in center of buoyancy in vertical direction is disregarded.
Consequently, trim moment due to loading freights is expressed as follows:

\[
\text{Trim moment} = 2,064 - 0.73 \times 5 \times (150 - 2)
\]

We have to calculate this.

\[\text{Given:}\]
- L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
- Density of the shell plate: \( \rho_m = 1.0 \text{ton/m}^3 \)

\[\text{Find:}\]
1. LWT, Draft in fresh water (\( T_{FW} \)), Draft in sea water (\( T_{SW} \))
2. When the freight 1 and 2 are loaded in fresh water, calculate:
   - Deadweight (DWT)
   - TPC
   - MTC
   - Trim
   - Fore and after drafts
   - LCB @ LCG
3. Freight 2 is unloaded from 2, calculate LCB, LCG.
4. Freight 1 moves 5m along the positive \( y \) direction. Calculate the heel angle.

\[\text{[Example] Calculation of Barge Ship’s Trim and Heel Angles (15/18)}\]

If the freight 2 is unloaded from the condition 2, the ship’s trim becomes zero. Hence LCB=LCG=0. At this time, the displacement \( \Delta \) is 1,764ton, draft is 1,764/(30\times20)=2.94m.
Freight 1 moves 5m along the positive y direction. Calculate the heel angle.  

Heeling moment \( w \cdot d \cdot \cos \phi \)  
Restoring moment \( \Delta \cdot GZ \approx \Delta \cdot GM \cdot \sin \phi \)  
The freight 1 moves 5m along the positive y direction from centerline, total center of gravity \( G \) moves perpendicularly to \( G' \).  
Thus from Heeling arm \( w \cdot d \frac{\Delta}{\Delta} \cos \phi \)  
\( GG' = \frac{w \cdot d}{\Delta} \frac{(100-3)-5}{1.764} = 0.85 \text{ m} \)

**[Example] Calculation of Barge Ship’s Trim and Heel Angles (16/18)**

**Given:**
- \( L: 30\text{ m}, B: 20\text{ m}, D: 10\text{ m}, \) Shell plate thickness: 1m
- Density of the shell plate: \( \rho = 1.0\text{ ton/m}^3 \)

**Find:**
1. \( \text{LWT, Draft in fresh water (}T_{fw}\text{)}, \) Draft in sea water \( T_{sw} \)
2. When the freight 1 and 2 are loaded in fresh water, calculate \( \text{i) Deadweight (DWT)}, \text{ ii) TPC} \)
3. MTC \( \oplus \) Trim \( \oplus \) Fore and after drafts \( \oplus \) LCB \( \oplus \) LCG.
4. Freight 2 is unloaded from \( \text{2}, \) calculate LCB, LCG.
5. Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

**[Example] Calculation of Barge Ship’s Trim and Heel Angles (17/18)**

**Given:**
- \( L: 30\text{ m}, B: 20\text{ m}, D: 10\text{ m}, \) Shell plate thickness: 1m
- Density of the shell plate: \( \rho = 1.0\text{ ton/m}^3 \)

**Find:**
1. \( \text{LWT, Draft in fresh water (}T_{fw}\text{)}, \) Draft in sea water \( T_{sw} \)
2. When the freight 1 and 2 are loaded in fresh water, calculate \( \text{i) Deadweight (DWT)}, \text{ ii) TPC} \)
3. MTC \( \oplus \) Trim \( \oplus \) Fore and after drafts \( \oplus \) LCB \( \oplus \) LCG.
4. Freight 2 is unloaded from \( \text{2}, \) calculate LCB, LCG.
5. Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

Restoring moment is obtained using the following equation.  
\( GZ = GM \cdot \sin \phi = (KB + BM - KG) \cdot \sin \phi \)  
Because the barge ship’s shape is box-shape,  
\( KB = \frac{T}{2} = \frac{2.94}{2} = 1.47 \text{ m} \)  
\( BM = \frac{I}{V} = \frac{LB^2 / 12}{V} = 11.34 \text{ m} \)  
\( KG = 30 - 20 - 10 - 4 - 28 - 18 - 9 - 4.5 + 100 - 3 - 1 \)  
\( = 2.20 \text{ m} \)  
\( GM = KB + BM - KG = 1.47 + 11.34 - 2.20 \)  
\( = 10.61 \text{ m} \)
Naval Architectural Calculation, Spring 2016, Myung-Il Roh

Heel angle is calculated as

\[ \sin \phi \cos \phi = \frac{wd}{GM} \]

\[ \tan \phi = \frac{wd}{\Delta GM} \]

\[ \phi = \tan^{-1} \left( \frac{GG'}{GM} \right) = \tan^{-1} \left( \frac{0.85}{10.61} \right) \approx 4.58^\circ \]

**[Example] Calculation of Barge Ship’s Trim and Heel Angles (18/18)**

**Given:**
- L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
- Density of the shell plate: \( \rho_m = 1.0 \text{ton/m}^3 \)

**Find:**
1. LWT, Draft in fresh water \( (T_{fw}) \), Draft in salt water \( (T_{sw}) \)
2. When the freight 1 and 2 are loaded in fresh water, calculate \( \Delta \) Deadweight (DWT) \( \Delta \) TPC
   - LCB \( \Delta \) Trim \( \Delta \) Fore and after drafts
3. Freight 2 is unloaded from 2, calculate LCB,
4. Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

**[Example] Practical Calculation of a Ship’s Fore and Aft Drafts (1/9)**

A bulk carrier of which the length between perpendiculars \( (LBP) \) is 264m and deadweight is 150,000ton (DWT 150K) floats in sea water. The ship is fully loaded and the fore and after drafts are 16.9m (even keel condition).

After unloading the load 16,032ton from No. 1 Cargo Hold, calculate the fore and after drafts using the ship’s hydrostatic table. For reference, the freight’s center of gravity is located in centerline in transverse direction, and 107.827m from midship in longitudinal direction.
Given: 150k Bulk Carrier (9 Cargo Hold)
Hydrostatic Table
L: 264m, TAFT: 16.9m, TFORE: 16.9m,
No.1 Cargo Hold: 16,032ton unloaded
(Cargo hold position in longitudinal direction: 107.827m)

Find:
Fore and after drafts

---

Calculation of the approximate solution by linearizing the problem

1. Calculation of trim

\[ \text{Trim}[\text{m}] = \sum \text{Trim Moment} \]

\[ \text{MPC} \cdot 100 \]

\[ \Delta \]

At the initial state, the ship is on an even keel.
Thus, LGG = LCB.
After unloading, LCG becomes

\[ \text{LCG} = \frac{W}{G} \]

LCB after unloading: At first, calculate the changed displacement. And then, the changed LCB is calculated by interpolating the values in the table.

\[ \Delta \]

\[ \text{MPC} \cdot \frac{\Delta}{L} \cdot \text{LCF} \]

2. Calculation of the changed draft

\[ T_{\text{trim}} = \frac{L}{L - \text{LCF} \cdot \text{trim}} \]

\[ T_{\text{unchanged}} = \frac{L}{L - \text{LCF} \cdot \text{trim}} \]

---
Since the ship is on an even keel at initial state, initial LCG and initial LCB are the same. The value of LCB at draft \(d=16.9\) m is listed in the hydrostatic table.

\[
8.547 \text{ m} \\
\text{LCB} = +8.547 \text{ m} \\
\text{LCG} = LCB = +8.547 \text{ m}
\]

(From midship: +fore, -after)

**[Example] Practical Calculation of a Ship's Fore and Aft Drafts (4/9)**

**Given:** 150k Bulk Carrier (9 Cargo Hold)

Hydrostatic Table

L: 264m, \(T_{FWT}\): 16.9m, \(T_{FORE}\): 16.9m,

No.1 Cargo Hold: 16,032 ton unloaded

(Cargo hold position in longitudinal direction: 107.827 m)

**Find**

Fore and after drafts

\[
\begin{align*}
\text{L:} & \quad 264 \text{ m} \\
\text{TAFT:} & \quad 16.9 \text{ m} \\
\text{TFORE:} & \quad 16.9 \text{ m} \\
\text{No.1 Cargo Hold:} & \quad 16,032 \text{ ton unloaded} \\
\text{(Cargo hold position in longitudinal direction:} & \quad 107.827 \text{ m})
\end{align*}
\]

**1. Calculation of trim**

\[
\text{Trim(m)} = \sum \frac{\text{Trim Moment}}{\text{MTC}} - 100
\]

(1-1) Trim Moment: \((\text{LCG} - \text{LCB}) \cdot \Delta\)

Since the ship is on an even keel at initial state, initial LCG and initial LCB are the same. The value of LCB at draft \(d=16.9\) m is listed in the hydrostatic table.

\[
LCB = +8.547 \text{ m} \quad \text{(From midship: +fore, -after)}
\]

\[
LCG = LCB = +8.547 \text{ m} \quad \text{(From midship: +fore, -after)}
\]

**[Example] Practical Calculation of a Ship's Fore and Aft Drafts (5/9)**

**Given:** 150k Bulk Carrier (9 Cargo Hold)

Hydrostatic Table

L: 264m, \(T_{FWT}\): 16.9m, \(T_{FORE}\): 16.9m,

No.1 Cargo Hold: 16,032 ton unloaded

(Cargo hold position in longitudinal direction: 107.827 m)

**Find**

Fore and after drafts

**1. Calculation of trim**

\[
\text{Trim(m)} = \sum \frac{\text{Trim Moment}}{\text{MTC}} - 100
\]

(1-1) Trim Moment: \((\text{LCG} - \text{LCB}) \cdot \Delta\)

Calculate the changed displacement and LCG after unloading. The value of LCB at draft \(d=16.9\) m is listed in the hydrostatic table.

i) Full loading condition

Ship's total weight at full loading condition: \(\Delta = 168,962 \text{ ton}\)

Moment in longitudinal direction: \(\Delta \times \text{LCG} = 168,962 \times (+8.547) = 1,444,118 \text{ ton m}\)

ii) Unloading of freight

Weight of the unloaded freight: \(w = -16,032 \text{ ton}\)

\[
\text{LCG} = +107.827 \text{ m}
\]

Moment in longitudinal direction: \(w \times l = -16,032 \times (+107.827) = -1,728,770 \text{ ton m}\)
[Example] Practical Calculation of a Ship’s Fore and Aft Drafts (6/9)

Given: 150k Bulk Carrier (9 Cargo Hold)
Hydrostatic Table
L: 264m, \( T_{TAF} \): 16.9m, \( T_{CB} \): 16.9m,
No.1 Cargo Hold: 16,032ton unloaded
(Cargo hold position in longitudinal direction: 107.827m)

Find:
Fore and after drafts

1. Calculation of trim

\[
\text{Trim}[m] = \frac{\sum \text{Trim Moment}}{\text{MTC - 100}}
\]

(1-1) Trim Moment: (LCG-LCB) \( \cdot \) \( \Delta \)

Calculate changed displacement and LCG after unloading.
The value of LCB at draft \( d=16.9m \) is listed in the hydrostatic tables.

iii) Longitudinal moment about midship due to the ship’s total weight after unloading

\[
\text{Weight} = \text{Weight at full loading condition}
- \text{Weight of the unloaded freight}
\]

iv) Ship’s total weight and center of gravity in longitudinal direction after unloading

[Example] Practical Calculation of a Ship’s Fore and Aft Drafts (7/9)

Given: 150k Bulk Carrier (9 Cargo Hold)
Hydrostatic Table
L: 264m, \( T_{TAF} \): 16.9m, \( T_{CB} \): 16.9m,
No.1 Cargo Hold: 16,032ton unloaded
(Cargo hold position in longitudinal direction: 107.827m)

Find:
Fore and after drafts

1. Calculation of trim

\[
\text{Trim}[m] = \frac{\sum \text{Trim Moment}}{\text{MTC - 100}}
\]

(1-1) Trim Moment: (LCG-LCB) \( \cdot \) \( \Delta \)

To obtain LCB and average draft corresponding to the changed total weight, 152,929 ton, the hydrostatic tables are used.
Thus using the values of the two drafts, the draft, LCB, MTC, and LCF corresponding to the weight, 152,929 ton, can be calculated by interpolation.

\[
\text{Displacement} (\Delta) = 152,929 \text{ ton}
\]

\[
\text{Draft}(d) = 15.440 - 15.420 = (152,929 - 152,832) / 15.420
\]

\[
= 15.429 \text{ m}
\]

\[
\]

\[
= 9.342 \text{ m} \text{ (Forward from midship)}
\]

\[
\text{MTC} = 1.805 - 1.829 = (152,929 - 152,832) / 1.829
\]

\[
= 1.818 \text{ m} \text{ (Forward from midship)}
\]
[Example] Practical Calculation of a Ship's Fore and Aft Drafts (8/9)

Given: 150k Bulk Carrier (9 Cargo Hold)
Hydrostatic Table
L: 264m, TAF: 16.9m, TCG: 16.9m,
No.1 Cargo Hold: 16,032ton unloaded
(Cargo hold position in longitudinal direction: 107.827m)

Find:
Fore and after drafts

### 1. Calculation of trim

\[
\text{Trim(m)} = \frac{\sum \text{Trim Moment}}{\text{MTC}} \\
\text{Distance between LCB and LCG} = 9.342 \text{m}
\]

\[
\text{Trim Moment} = 152,929 \times 9.342 = 1,713,276 \text{ ton m}
\]

### 2. Calculation of the changed draft

Change in trim: \( \delta t = 8.937 \text{ m} \)

Fore draft:
\[
df = \frac{L + LCF}{L} \times \delta t = \frac{264 + 1.818}{264} \times (-8.937) = 19.959 \text{ m}
\]

After draft:
\[
df = \frac{L - LCF}{L} \times \delta t = \frac{264 - 1.818}{264} \times (-8.937) = 11.022 \text{ m}
\]
During a voyage, a cargo ship uses up 320 ton of consumable stores (H.F.O: Heavy Fuel Oil), located 88 m forward of the midships.

Before the voyage, the forward draft marks at forward perpendicular recorded 5.46 m, and the after marks at the after perpendicular, recorded 5.85 m.

At the mean draft between forward and after perpendicular, the hydrostatic data show the ship to have LCF after of midship = 3 m, Breadth = 10.47 m, moment of inertia of the water plane area about transverse axis through point F = 6,469,478 m^4, Cwp = 0.8.

Calculate the draft mark the readings at the end of the voyage, assuming that there is no change in water density (ρ = 1.0 ton/m^3).

**Example**

**Calculation of Draft Change Due to Fuel Consumption (1/4)**

During a voyage, a cargo ship uses up 320 ton of consumable stores (H.F.O: Heavy Fuel Oil), located 88 m forward of the midships.

Before the voyage, the forward draft marks at forward perpendicular recorded 5.46 m, and the after marks at the after perpendicular, recorded 5.85 m.

At the mean draft between forward and after perpendicular, the hydrostatic data show the ship to have LCF after of midship = 3 m, Breadth = 10.47 m, moment of inertia of the water plane area about transverse axis through point F = 6,469,478 m^4, Cwp = 0.8.

Calculate the draft mark the readings at the end of the voyage, assuming that there is no change in water density (ρ = 1.0 ton/m^3).

**Example**

**Calculation of Draft Change Due to Fuel Consumption (2/4)**

**Calculation of parallel rise (draft change)**

- **Tones per 1 cm immersion (TPC)**
  \[ TPC = \rho \cdot d \cdot \frac{A_{wp}}{100} = 1 \text{[ton/m^3]} \cdot 1,633.3 \text{[m^2]} \cdot \frac{1}{100 \text{[cm/m]}} \]
  \[ = 20.4165 \text{[ton/cm]} \]

- **Parallel rise**
  \[ \delta d = \frac{\text{weight}}{TPC} = \frac{320 \text{[ton]}}{20.4165 \text{[ton/cm]}} = 15.6736 \text{[cm]} = 0.1567 \text{[m]} \]
[Example] Calculation of Draft Change Due to Fuel Consumption (3/4)

② Calculation of trim

- Trim moment: \( \tau_{\text{trim}} = 320[\text{ton}] \cdot 88[\text{m}] = 28,160[\text{ton} \cdot \text{m}] \)
- Moment to trim 1 cm (MTC)
  \[
  \text{MTC} = \frac{\rho \cdot I_1}{100 \cdot L_{\text{agp}}} = \frac{1[\text{ton} \cdot \text{m}^2]}{100[\text{cm} / \text{m}] \cdot 195[\text{m}]} = 6,469,478[\text{ton} \cdot \text{cm}] = 331.7949[\text{ton} \cdot \text{cm}] \]
- Trim
  \[
  \text{Trim} = \frac{\tau_{\text{trim}}}{\text{MTC}} = \frac{28,160[\text{ton} \cdot \text{m}]}{331.7949[\text{ton} \cdot \text{cm}]} = 84.8785[\text{cm}] = 0.8488[\text{m}] 
  \]

[Example] Calculation of Draft Change Due to Fuel Consumption (4/4)

③ Calculation of changed draft at F.P and A.P

- Draft change at F.P due to trim: \( \frac{195}{2} \times 3 \times 0.8488 = -0.4375[\text{m}] \)
- Draft change at A.P due to trim: \( \frac{195}{2} \times 3 \times 0.8488 = 0.4113[\text{m}] \)
- Changed Draft at F.P: draft - parallel rise - draft change due to trim
  \( = 5.46[\text{m}] - 0.1567[\text{m}] - 0.4375[\text{m}] = 4.8688[\text{m}] \)
- Changed Draft at A.P: draft - parallel rise + draft change due to trim
  \( = 5.85[\text{m}] - 0.1567[\text{m}] + 0.4113[\text{m}] = 6.1046[\text{m}] \)