Ship Stability

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Ship Stability

Ch. 10 Hydrostatic Values

Hydrostatic Values

Trim and Stability Calculation of a 3,700TEU Container Ship Including Hydrostatic Values

More Examples

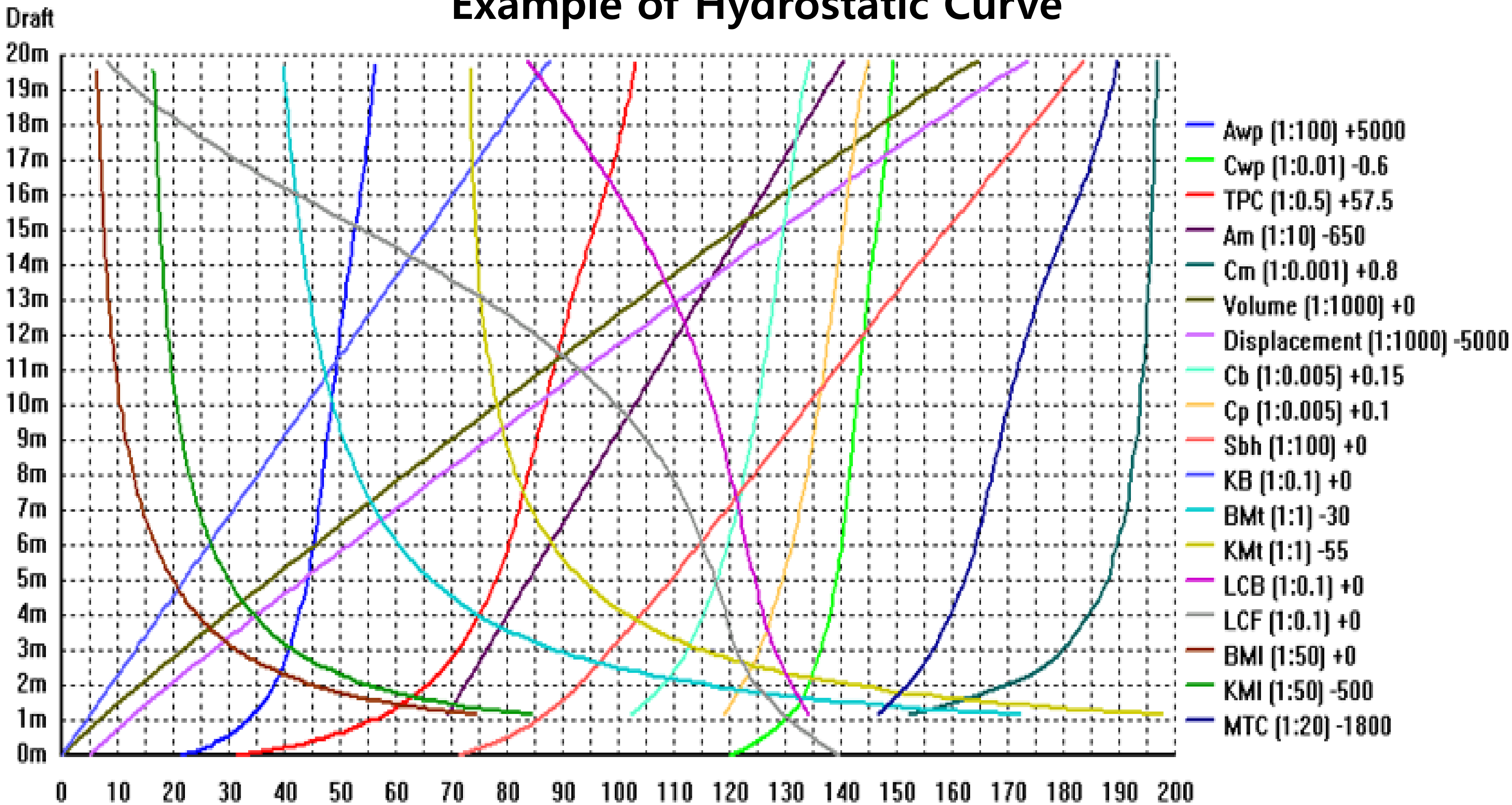
Hydrostatic Values

Hydrostatic Values

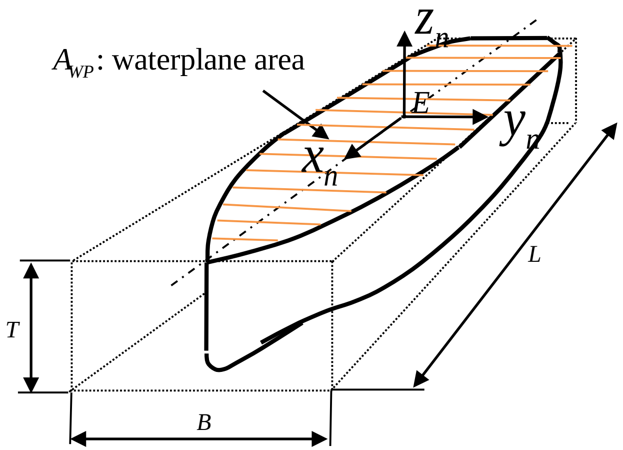
- ☑ $Draft_{Mld}$, $Draft_{Scant}$: Draft from base line, moulded / scantling (m)
- ☑ $Volume_{Mld}(\nabla)$, $Volume_{Ext}$: Displacement volume, moulded / extreme (m^3)
- ☑ $Displacement_{Mld}(\Delta)$, $Displacement_{Ext}$: Displacement, moulded / extreme (ton)
- ☑ LCB: Longitudinal center of buoyancy 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 (m^2)
- ☑ 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)

☑ **Hydrostatic curve: Curve for representing hydrostatic values**

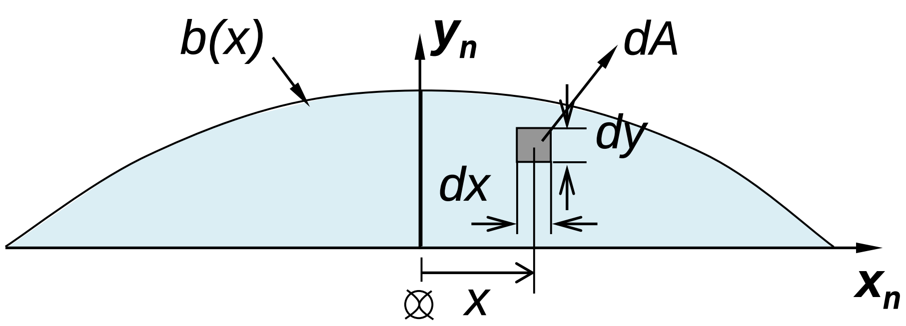
Example of Hydrostatic Curve



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



$b(x)$: Half breadth of each section
ρ_{sw}: Density of sea water(1.025[ton/m^3])



$Ex_ny_nz_n$: Water plane fixed frame

✓ **Water plane area**

$$A_{WP} = \int dA = 2 \cdot \int_0^L b(x)\,dx$$

✓ **Tones Per 1cm Immersion (TPC)**

$$TPC = \rho_{sw} \cdot A_{WP} \cdot \frac{1}{100}$$

ρ_{sw} : density of sea water

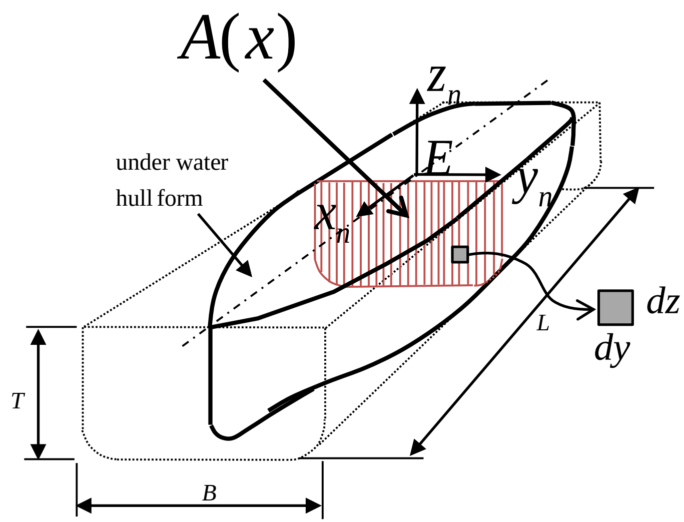
✓ **1st moment of water plane area about y axis**

$$M_{WP} = \int x\,dA = \iint x\,dx\,dy$$

✓ **Longitudinal Center of Floatation**

$$LCF = \frac{M_{WP}}{A_{WP}}$$

Sectional Area(A), Displacement Volume(∇)



✓ **Sectional Area**

$$A(x) = \int dA = \iint dy\,dz$$

✓ **Displacement volume**

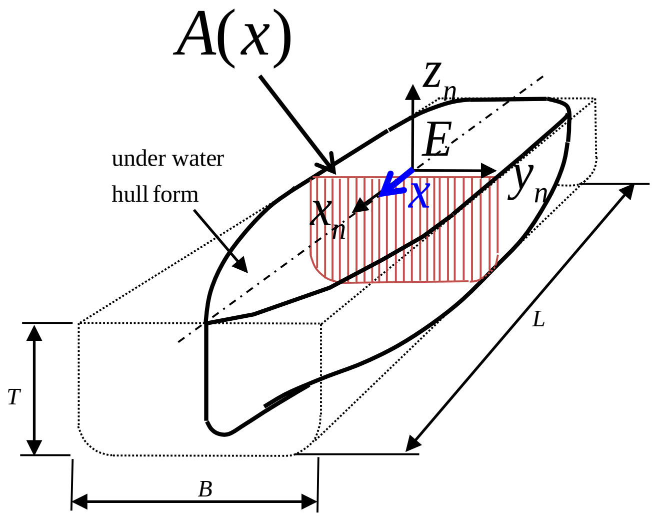
$$\nabla = \int dV = \iiint dx\,dy\,dz$$
$$= \int \left(\iint dy\,dz \right) dx$$
$$\Rightarrow A(x)$$

$$\therefore \nabla = \int A(x)dx$$

After calculating each sectional area, displacement volume can be calculated by integration of section area over the length of a ship.

$Ex_ny_nz_n$: Water plane fixed frame

Longitudinal Moment of Displacement Volume ($M_{\nabla,L}$) and Longitudinal Center of Buoyancy (LCB)



$Ex_ny_nz_n$: Water plane fixed frame

✓ **Longitudinal moment of displacement volume**

$$M_{\nabla,L} = \int x\,dV = \iiint x\,dx\,dy\,dz = \int \left(\iint x\,dy\,dz \right) dx$$

$$\Rightarrow M_{A,L}$$

$M_{A,L}$: Longitudinal moment of area about y axis

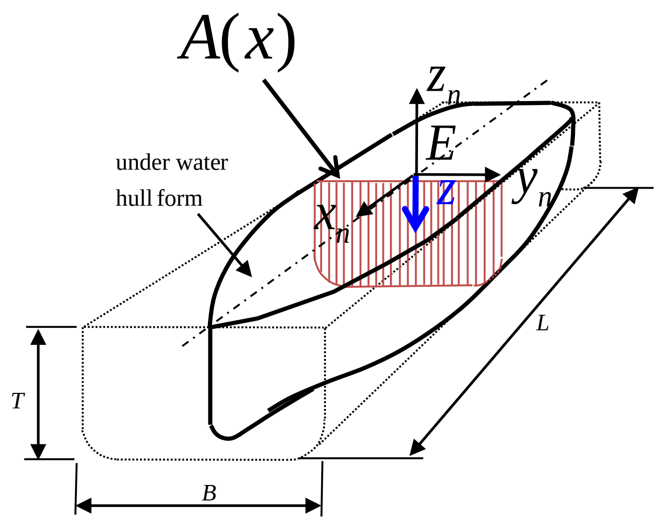
$$\therefore M_{\nabla,L} = \int M_{A,L}\,dx$$

After calculating each longitudinal moment of sectional area about the y axis($M_{A,L}$), 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**

$$LCB = \frac{M_{\nabla,L}}{\nabla}$$

Vertical Moment of Displacement Volume ($M_{\nabla,V}$) and Vertical Center of Buoyancy (VCB or KB)



$Ex_ny_nz_n$: Water plane fixed frame

✓ **Vertical moment of displacement volume**

$$M_{\nabla,V} = \int z\, dV = \iiint z\, dx\, dy\, dz = \int \left(\iint z\, dy\, dz \right) dx$$

$$\Rightarrow M_{A,V}$$

$M_{A,V}$: Vertical moment of area about y axis

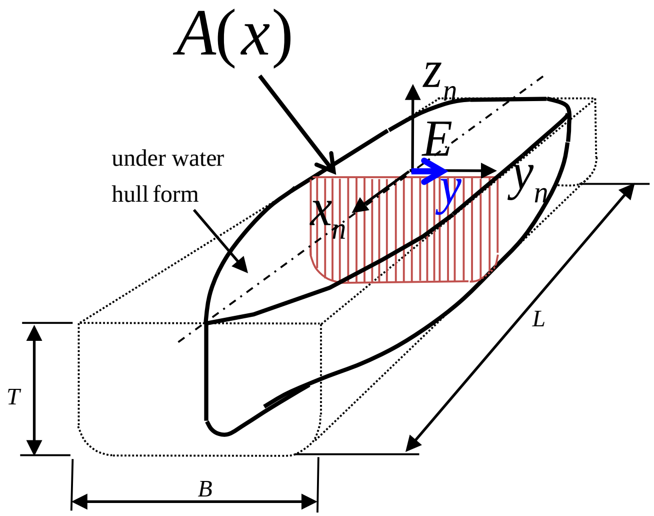
$$\therefore M_{\nabla,V} = \int M_{A,V}\, dx$$

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

✓ **Vertical Center of Buoyancy**

$$VCB = KB = \frac{M_{\nabla,V}}{\nabla}$$

Transverse Moment of Displacement Volume ($M_{\nabla,T}$) and Transverse Center of Buoyancy (TCB)



✓ **Transverse moment of displacement volume**

$$M_{\nabla,T} = \int y\,dV = \iiint y\,dx\,dy\,dz = \int \left(\iint y\,dy\,dz \right) dx$$

$$\Rightarrow M_{A,T}$$

$M_{A,T}$: Vertical moment of area about z axis

$$\therefore M_{\nabla,T} = \int M_{A,T}\,dx$$

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.

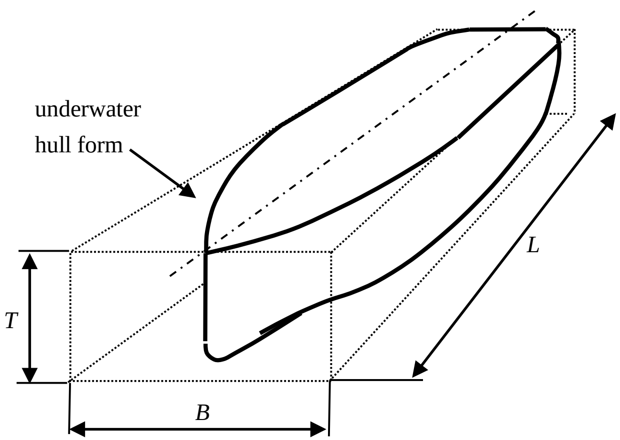
✓ **Transverse Center of Buoyancy**

$$TCB = \frac{M_{\nabla,T}}{\nabla}$$

$Ex_ny_nz_n$: Water plane fixed frame

Block Coefficient(C_B) and Water Plane Area Coefficient(C_{WP})

C_B(Block coefficient)



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

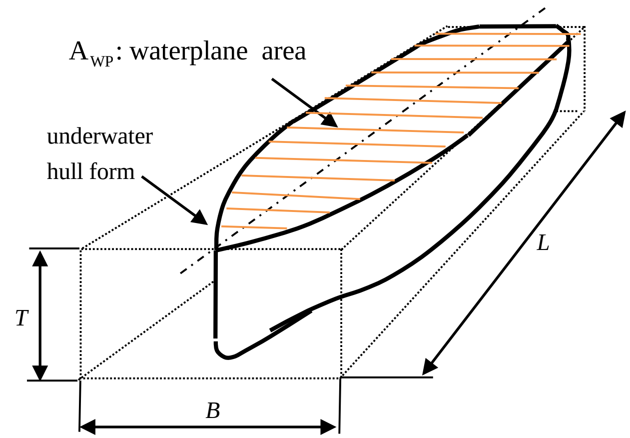
∇: Moulded volume of displacement

L: Length (L_{WL} or L_{BP})

B_{mld}: Moulded breadth

T_{mld}: Moulded draft

C_{WP}(Water Plane Area Coefficient)



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

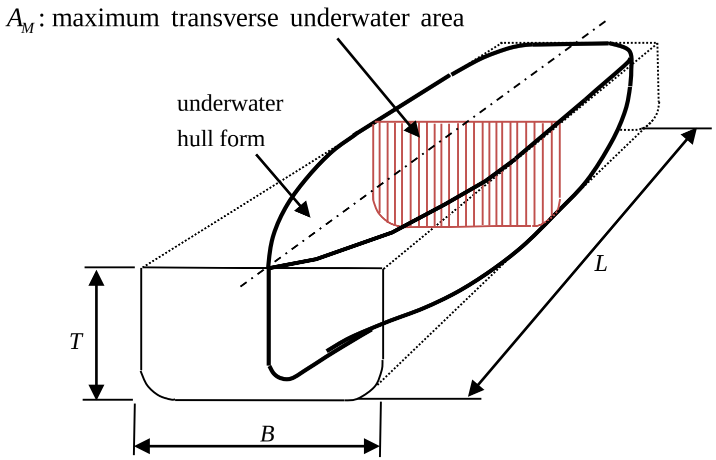
A_{WP}: Water plane area

L: Length (L_{WL} or L_{BP})

B_{mld}: Moulded breadth

Midship Section Coefficient(C_M) and Prismatic Coefficient (C_P)

C_M (Midship Section Coefficient)



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

B_{mld}: Moulded breadth

T_{mld}: Moulded draft

A_M: Sectional area at midship

C_P(Prismatic Coefficient)

$$C_P = \frac{\nabla}{L_{BP} \cdot A_M} = \frac{\nabla}{L_{BP} \cdot B_{mld} \cdot T \cdot C_M} = \frac{C_B}{C_M}$$

∇: Moulded volume of displacement

L: Length (L_{WL} or L_{BP})

B_{mld}: Moulded breadth

T_{mld}: Moulded draft

C_M: Midship section coefficient

C_B: Block coefficient

Transverse Metacentric Radius(BM), Longitudinal Metacentric Radius(BM_L), Moment to change Trim 1 cm(MTC), and Trim

BM

Transverse righting moment = $\Delta \cdot GZ \approx \Delta \cdot GM \cdot \sin\phi$

$$GM = KB + BM - KG$$

$$BM_0 = \frac{I_T}{\nabla}\left(1 + \tan^2\phi\right)$$

(ϕ : Angle of heel)
: Considering the change of the center of buoyancy in vertical direction

$$BM = \frac{I_T}{\nabla}$$

: Without considering the change of the center of buoyancy in vertical direction

GM : Transverse metacentric height
KB : Vertical center of displaced volume
BM : Transverse metacentric Radius
KG : Vertical center of gravity

BM$_L$

Longitudinal righting moment = $\Delta \cdot GZ_L = \Delta \cdot GM_L \cdot \sin\theta$

$$GM_L = KB + BM_L - KG$$

$$BM_{L0} = \frac{I_L}{\nabla}\left(1 + \tan^2\theta\right)$$

(θ : Angle of trim)
: Considering the change of the center of buoyancy in vertical direction

$$BM_L = \frac{I_L}{\nabla}$$

: Without considering the change of the center of buoyancy in vertical direction

GM_L : Longitudinal metacentric height
KB : Vertical center of displaced volume
BM_L : Longitudinal metacentric Radius
KG : Vertical center of gravity

MTC

Moment to change Trim 1 Cm

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

(Unit conversion for centimeter)

$$GM_L = KB + BM_L - KG$$

If we assume that KB, KG are small than BM$_L$

$$GM_L \approx BM_L$$

$$\therefore MTC = \Delta \cdot BM_L \cdot \frac{1}{L_{BP} \cdot 100}$$

Trim

$$\text{Transverse Moment Arm} = LCB - LCG$$

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

$$MTC = \frac{\Delta \cdot GM_L}{100 \cdot L_{BP}}$$

Generation of Hydrostatic Tables and Hydrostatic Curves

Given: Offsets table, Formulas for calculating hydrostatic values
Find: Hydrostatic tables as function of draft, Hydrostatic curves

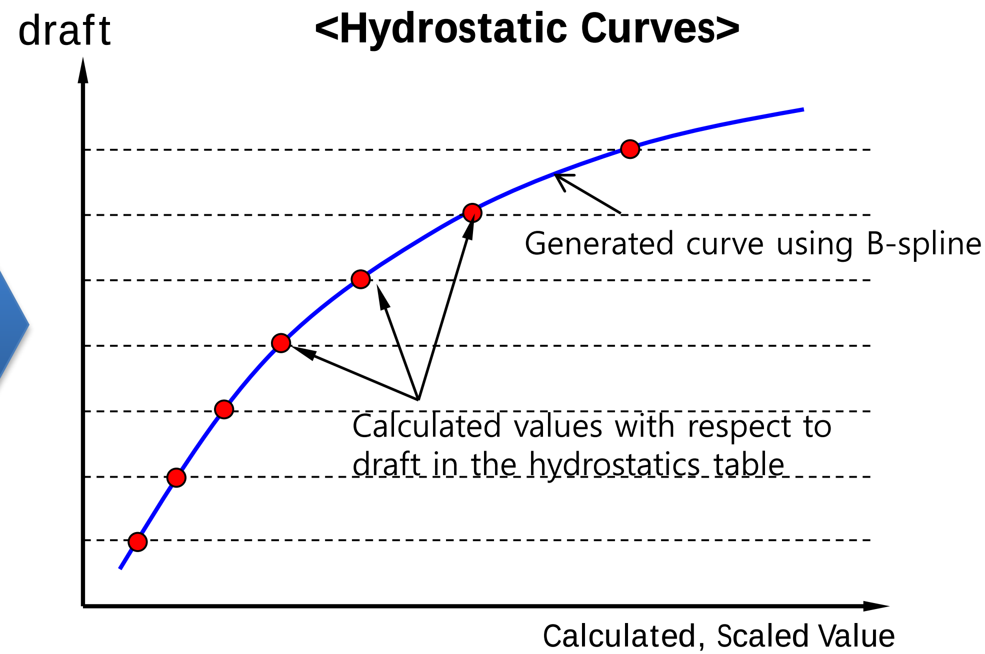
✓ **Calculation of hydrostatic values as function of draft**

<Hydrostatic Tables>

Draft [m] ↓

	Δ	LCB	TCB	KB	KM_T	...
0	...	...	...	...	...	...
1	...	...	...	...	...	...
2	...	...	...	...	...	...
3	...	...	...	...	...	...
4	...	...	...	...	...	...
5	...	...	...	...	...	...
...	...	...	...	...	...	...

<Hydrostatic Curves>



Example of Offsets Table of a 6,300TEU Container Ship

→ **Waterline**

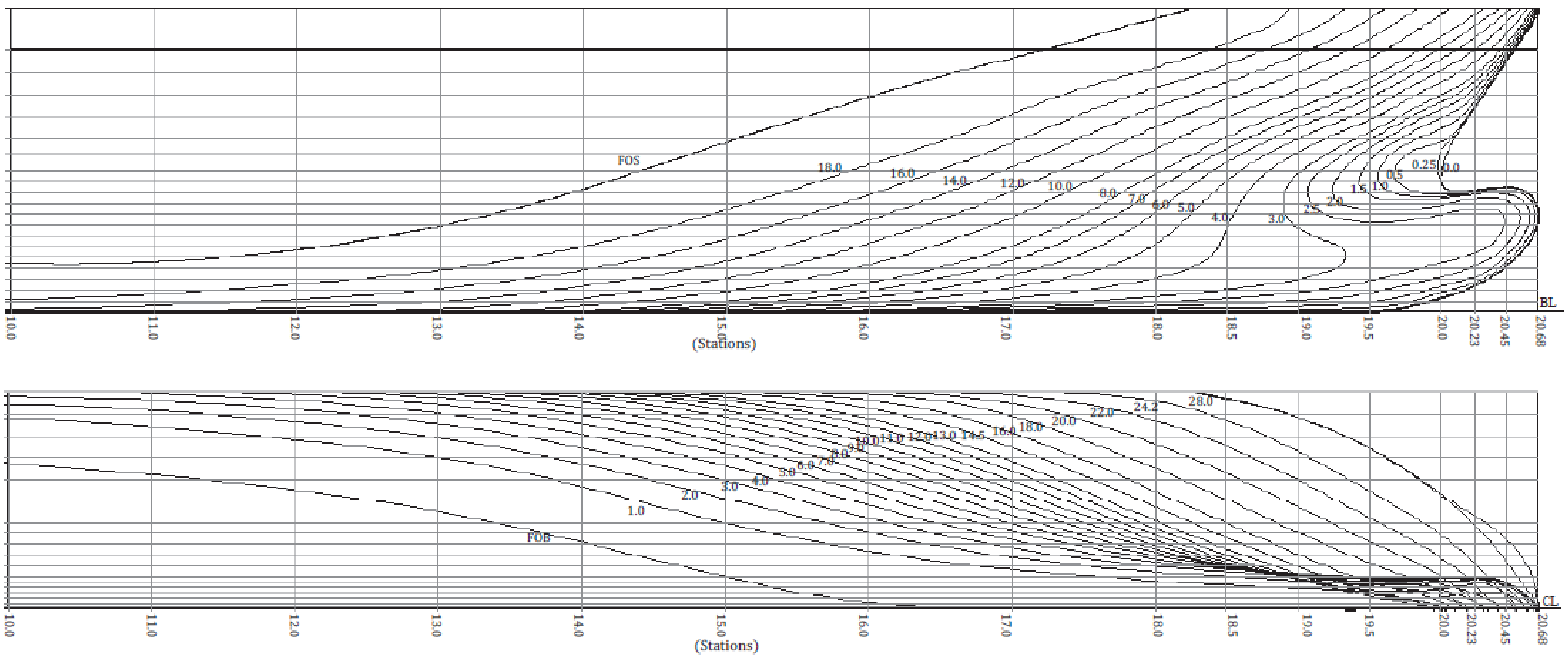
* Unit: mm

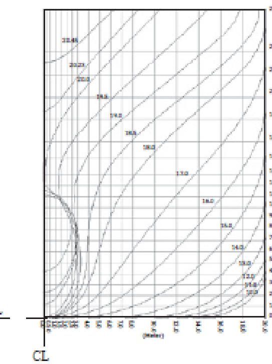
Stations ↓

Half-Breadth

Station NO.	HALF BREADTH FROM CENTER LINE																				Station NO.
	BOTTOM LINE	1 W.L	2 W.L	3 W.L	4 W.L	5 W.L	6 W.L	7 W.L	8 W.L	9 W.L	10 W.L	11 W.L	12 W.L	13 W.L	14.5 W.L	16 W.L	18 W.L	20 W.L	22 W.L	24.2 W.L	
Trans. (-0.38)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14450	18262	19780	20000	20000	Trans. (-0.38)
-0.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10525	15955	18890	19944	20000	*	-0.19
AP	-	-	-	-	-	-	-	-	-	-	-	-	-	2627	12572	16765	19204	19994	20000	*	AP
0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	8474	14763	17871	19596	20000	*	*	0.25
0.5	-	-	-	-	-	-	-	-	-	-	-	-	3283	11746	16178	18456	19824	20000	*	*	0.5
0.75	-	-	-	487	933	530	-	-	-	-	0	1846	8680	13817	17230	18948	19956	20000	*	*	0.75
1	-	93	1802	1870	1462	863	397	183	280	895	2275	5061	12168	15561	18071	19440	20000	*	*	*	1
1.5	49	1879	2372	2520	2446	2215	2059	2283	2919	4288	9026	13623	16033	17687	19196	19906	20000	*	*	*	1.5
2	534	2677	3363	3734	3932	4029	4250	5085	7289	10680	13943	16341	17896	18937	19811	20000	*	*	*	*	2
3	2025	5058	6294	7228	8182	9483	11583	14000	16000	17469	18517	19244	19735	19990	20000	*	*	*	*	*	3
4	3974	8451	10473	12071	13627	15218	16635	17938	18937	19594	19941	20000	20000	20000	*	*	*	*	*	*	4
5	6091	12054	14349	16032	17344	18359	19152	19729	19996	20000	20000	*	*	*	*	*	*	*	*	*	5
6	8152	14697	16708	18069	19011	19627	19952	20000	20000	*	*	*	*	*	*	*	*	*	*	*	6
7	10187	16515	18101	19113	19728	19985	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	7
8	12286	17500	18738	19502	19915	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	8
9	13900	17562	18720	19408	19815	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9
10	13517	17469	18718	19466	19926	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	10
11	12406	16799	18306	19265	19873	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	11
12	11001	15632	17338	18464	19316	19887	20000	20000	*	*	*	*	*	*	*	*	*	*	*	*	12
13	9018	14029	15875	17152	18138	18941	19528	19922	20000	20000	20000	20000	*	*	*	*	*	*	*	*	13
14	6196	11304	13404	14934	16146	17141	17974	18650	19199	19622	19886	19994	20000	20000	20000	*	*	*	*	*	14
15	2993	7980	10216	11870	13217	14356	15353	16246	17038	17740	18354	18882	19312	19633	19929	20000	20000	*	*	*	15
16	583	5356	7103	8420	9598	10677	11684	12651	13581	14471	15328	16159	16935	17624	18572	19322	19877	20000	20000	*	16
17	124	3602	4805	5656	6434	7181	7919	8674	9438	10248	11052	11859	12734	13663	15032	16321	17837	19014	19797	20000	17
18	100	2577	3442	3967	4341	4643	4932	5224	5554	5931	6346	6845	7479	8235	9516	10921	13033	15277	17449	19250	18
18.5	110	2286	2979	3414	3673	3815	3893	3951	4012	4115	4320	4603	4959	5458	6511	7872	10049	12543	15057	17488	18.5
19	112	1982	2596	2988	3195	3258	3215	3104	2954	2804	2723	2710	2780	3087	3833	4987	7036	9433	11867	14527	19
19.5	-	1538	2160	2550	2778	2891	2894	2784	2569	2231	1760	1385	1247	1279	1685	2532	4262	6237	8428	10884	19.5
FP	-	-	1195	1825	2310	2652	2859	2901	2768	2497	2060	1301	-	29	148	603	1551	2981	4700	6815	FP
20.23	-	-	-	1353	2045	2481	2753	2893	2890	2686	2125	697	-	-	-	-	-	1590	3135	5042	20.23
20.45	-	-	-	-	-	1300	1910	2258	2420	2400	2110	1320	-	-	-	-	-	-	-	2343	20.45
20.68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.68

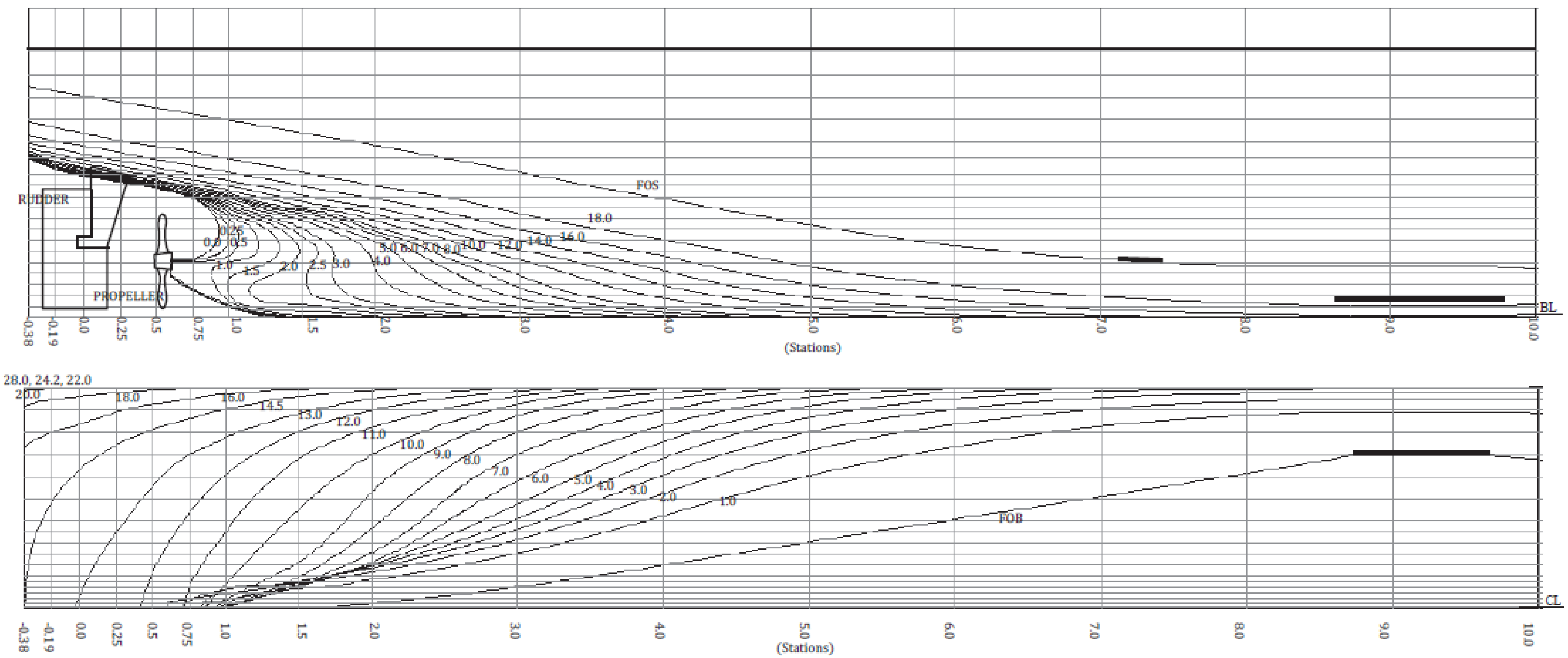
Example of Lines of a 6,300TEU Container Ship
- Fore Body

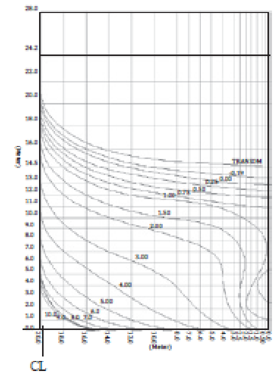




GENERAL PARTICULARS	
L.O.A (m)	278.05
L.B.P (m)	264.05
B mld (m)	40.0
D mld (m)	24.2
Td mld (m)	12
Ts mls (m)	14.5

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

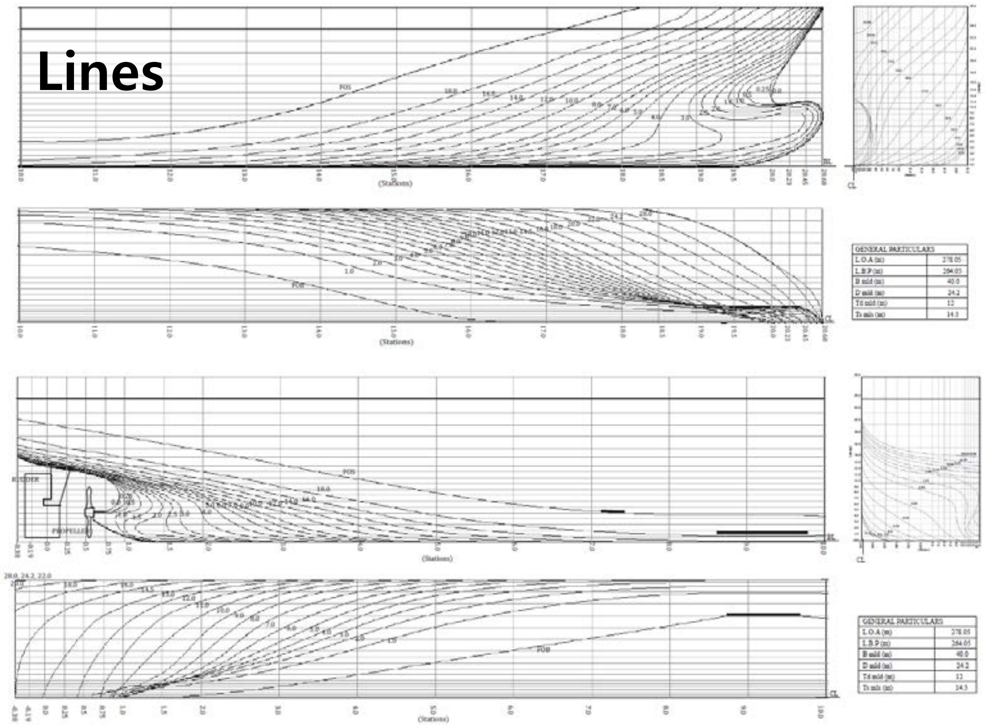




GENERAL PARTICULARS	
L.O.A (m)	278.05
L.B.P (m)	264.05
B mld (m)	40.0
D mld (m)	24.2
Td mld (m)	12
Ts mls (m)	14.5

Relationship Between Lines and Offsets Table (1/2)

Lines

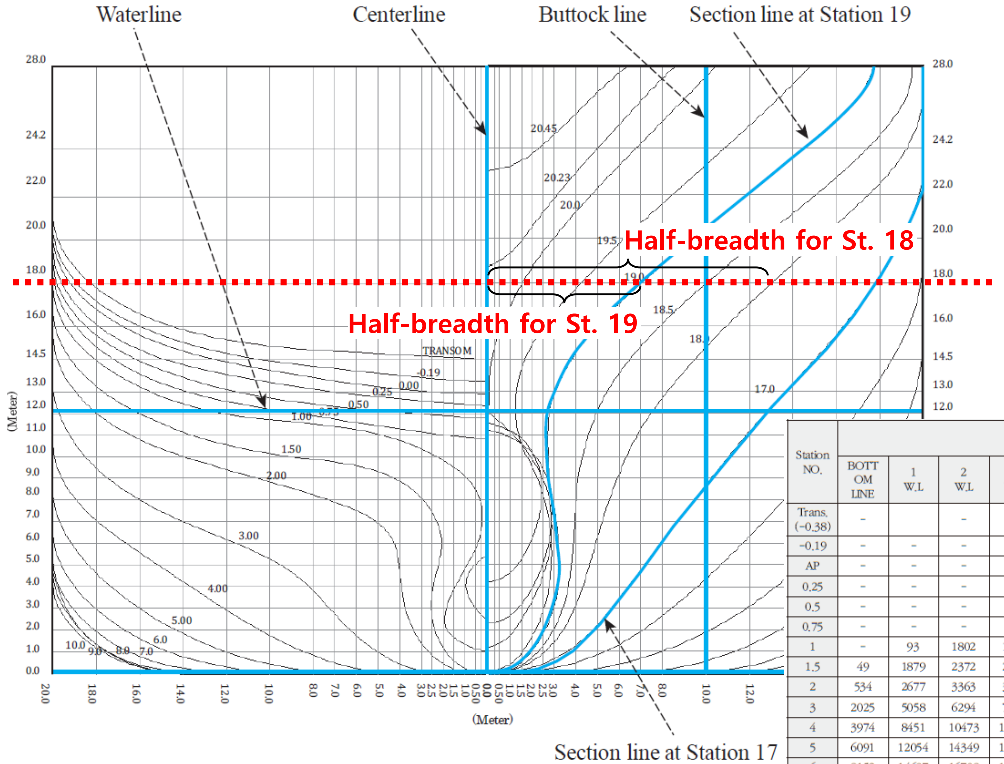


Generation of offsets table from the lines

Offsets table

Station NO.	BOTTOM LINE	1 W.L	2 W.L	3 W.L	4 W.L	5 W.L	6 W.L	7 W.L	8 W.L	9 W.L	10 W.L	11 W.L	12 W.L	13 W.L	14.5 W.L	16 W.L	18 W.L	20 W.L	22 W.L	24.2 W.L	Station NO.
	HALF BREADTH FROM CENTER LINE																				
Trans. (-0.38)	-		-	-	-	-	-	-	-	-	-	-	-	-	-	14450	18262	19780	20000	20000	Trans. (-0.38)
-0.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10525	15955	18890	19944	20000	*	-0.19
AP	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	2627	12572	16765	19204	19994	20000	*	AP
0.25	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	8474	14763	17871	19596	20000	*	*	0.25
0.5	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	3283	11746	16178	18456	19824	20000	*	*	0.5
0.75	-	-	-	487	933	530	-	-	-	-	0	1846	8680	13817	17230	18948	19956	20000	*	*	0.75
1	-	93	1802	1870	1462	863	397	183	280	895	2275	5061	12168	15561	18071	19440	20000	*	*	*	1
1.5	49	1879	2372	2520	2446	2215	2059	2283	2919	4288	9026	13623	16033	17687	19196	19906	20000	*	*	*	1.5
2	534	2677	3363	3734	3932	4029	4250	5085	7289	10680	13943	16341	17896	18937	19811	20000	*	*	*	*	2
3	2025	5058	6294	7228	8182	9483	11583	14000	16000	17469	18517	19244	19735	19990	20000	*	*	*	*	*	3
4	3974	8451	10473	12071	13627	15218	16635	17938	18937	19594	19941	20000	20000	20000	*	*	*	*	*	*	4
5	6091	12054	14349	16032	17344	18359	19152	19729	19996	20000	20000	*	*	*	*	*	*	*	*	*	5
6	8152	14697	16708	18069	19011	19627	19952	20000	20000	*	*	*	*	*	*	*	*	*	*	*	6
7	10187	16515	18101	19113	19728	19985	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	7
8	12286	17500	18738	19502	19915	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	8
9	13900	17562	18720	19408	19815	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9
10	13517	17469	18718	19466	19926	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	10
11	12406	16799	18306	19265	19873	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	11
12	11001	15632	17338	18464	19316	19887	20000	20000	*	*	*	*	*	*	*	*	*	*	*	*	12
13	9018	14029	15875	17152	18138	18941	19528	19922	20000	20000	20000	20000	*	*	*	*	*	*	*	*	13
14	6196	11304	13404	14934	16146	17141	17974	18650	19199	19622	19886	19994	20000	20000	20000	*	*	*	*	*	14
15	2993	7980	10216	11870	13217	14356	15353	16246	17038	17740	18354	18882	19312	19633	19929	20000	20000	*	*	*	15
16	583	5356	7103	8420	9598	10677	11684	12651	13581	14471	15328	16159	16935	17624	18572	19322	19877	20000	20000	*	16
17	124	3602	4805	5656	6434	7181	7919	8674	9438	10248	11052	11859	12734	13663	15082	16321	17887	19014	19797	20000	17
18	100	2577	3442	3967	4341	4643	4932	5224	5554	5931	6346	6845	7479	8235	9516	10921	13033	15277	17449	19250	18
18.5	110	2286	2979	3414	3673	3815	3893	3951	4012	4115	4320	4603	4959	5458	6511	7872	10049	12543	15057	17488	18.5
19	112	1982	2596	2988	3195	3258	3215	3104	2954	2804	2723	2710	2780	3087	3833	4987	7036	9433	11867	14527	19
19.5	-	1538	2160	2550	2778	2891	2894	2784	2569	2231	1760	1385	1247	1279	1685	2532	4262	6237	8428	10884	19.5
FP	-	-	1195	1825	2310	2652	2859	2901	2768	2497	2060	1301	-	29	148	603	1551	2981	4700	6815	FP
20.23	-	-	-	1353	2045	2481	2753	2893	2890	2686	2125	697	-	-	-	-	-	1590	3135	5042	20.23
20.45	-	-	-	-	-	1300	1910	2258	2420	2400	2110	1320	-	-	-	-	-	-	-	2343	20.45
20.68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.68

Relationship Between Lines and Offsets Table (2/2)



Waterline at 18m

Station NO.	HALF BREADTH FROM CENTER LINE BOTTOM LINE	1 W.L	2 W.L	3 W.L	4 W.L	5 W.L	6 W.L	7 W.L	8 W.L	9 W.L	10 W.L	11 W.L	12 W.L	13 W.L	14.5 W.L	16 W.L	18 W.L	20 W.L	22 W.L	24.2 W.L	Station NO.
Trans. (-0.38)	-		-	-	-	-	-	-	-	-	-	-	-	-	-	14450	18262	19780	20000	20000	Trans. (-0.38)
-0.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10525	15955	18890	19944	20000	*	-0.19
AP	-	-	-	-	-	-	-	-	-	-	-	-	-	2627	12572	16765	19204	19994	20000	*	AP
0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	8474	14763	17871	19596	20000	*	*	0.25
0.5	-	-	-	-	-	-	-	-	-	-	-	-	3283	11746	16178	18456	19824	20000	*	*	0.5
0.75	-	-	-	487	933	530	-	-	-	-	0	1846	8680	13817	17230	18948	19956	20000	*	*	0.75
1	-	93	1802	1870	1462	863	397	183	280	895	2275	5061	12168	15561	18071	19440	20000	*	*	*	1
1.5	49	1879	2372	2520	2446	2215	2059	2283	2919	4288	9026	13623	16033	17687	19196	19906	20000	*	*	*	1.5
2	534	2677	3363	3734	3932	4029	4250	5085	7289	10680	13943	16341	17896	18937	19811	20000	*	*	*	*	2
3	2025	5058	6294	7228	8182	9483	11583	14000	16000	17469	18517	19244	19735	19990	20000	*	*	*	*	*	3
4	3974	8451	10473	12071	13627	15218	16635	17938	18937	19594	19941	20000	20000	20000	*	*	*	*	*	*	4
5	6091	12054	14349	16032	17344	18359	19152	19729	19996	20000	20000	*	*	*	*	*	*	*	*	*	5
6	8152	14697	16708	18069	19011	19627	19952	20000	20000	*	*	*	*	*	*	*	*	*	*	*	6
7	10187	16515	18101	19113	19728	19985	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	7
8	12286	17500	18738	19502	19915	20000	*	*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*	*	*	*	8
9	13900	17562	18720	19408	19815	20000	*	*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*	*	*	*	9
10	13517	17469	18718	19466	19926	20000	*	*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*	*	*	*	10
11	12406	16799	18306	19265	19873	20000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	11
12	11001	15632	17338	18464	19316	19887	20000	20000	*	*	*	*	*	*	*	*	*	*	*	*	12
13	9018	14029	15875	17152	18138	18941	19528	19922	20000	20000	20000	20000	*	*	*	*	*	*	*	*	13
14	6196	11304	13404	14934	16146	17141	17974	18650	19199	19622	19886	19994	20000	20000	20000	*	*	*	*	*	14
15	2993	7980	10216	11870	13217	14356	15353	16246	17038	17740	18354	18882	19312	19633	19929	20000	20000	*	*	*	15
16	583	5356	7103	8420	9598	10677	11684	12651	13581	14471	15328	16159	16935	17624	18572	19322	19877	20000	20000	*	16
17	124	3602	4805	5656	6434	7181	7919	8674	9438	10248	11052	11859	12734	13663	15032	16321	17837	19014	19797	20000	17
18	100	2577	3442	3967	4341	4643	4932	5224	5554	5931	6346	6845	7479	8235	9516	10921	**13033**	15277	17449	19250	18
18.5	110	2286	2979	3414	3673	3815	3893	3951	4012	4115	4320	4603	4959	5458	6511	7872	10049	12543	15057	17488	18.5
19	112	1982	2596	2988	3195	3258	3215	3104	2954	2804	2723	2710	2780	3087	3833	4987	**7036**	9433	11867	14527	19
19.5	-	1538	2160	2550	2778	2891	2894	2784	2569	2231	1760	1385	1247	1279	1685	2532	4262	6237	8428	10884	19.5
FP	-	-	1195	1825	2310	2652	2859	2901	2768	2497	2060	1301	-	29	148	603	1551	2981	4700	6815	FP
20.23	-	-	-	1353	2045	2481	2753	2893	2890	2686	2125	697	-	-	-	-	-	1590	3135	5042	20.23
20.45	-	-	-	-	-	1300	1910	2258	2420	2400	2110	1320	-	-	-	-	-	-	-	2343	20.45
20.68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.68

Half-breadth for each station at 18m waterline

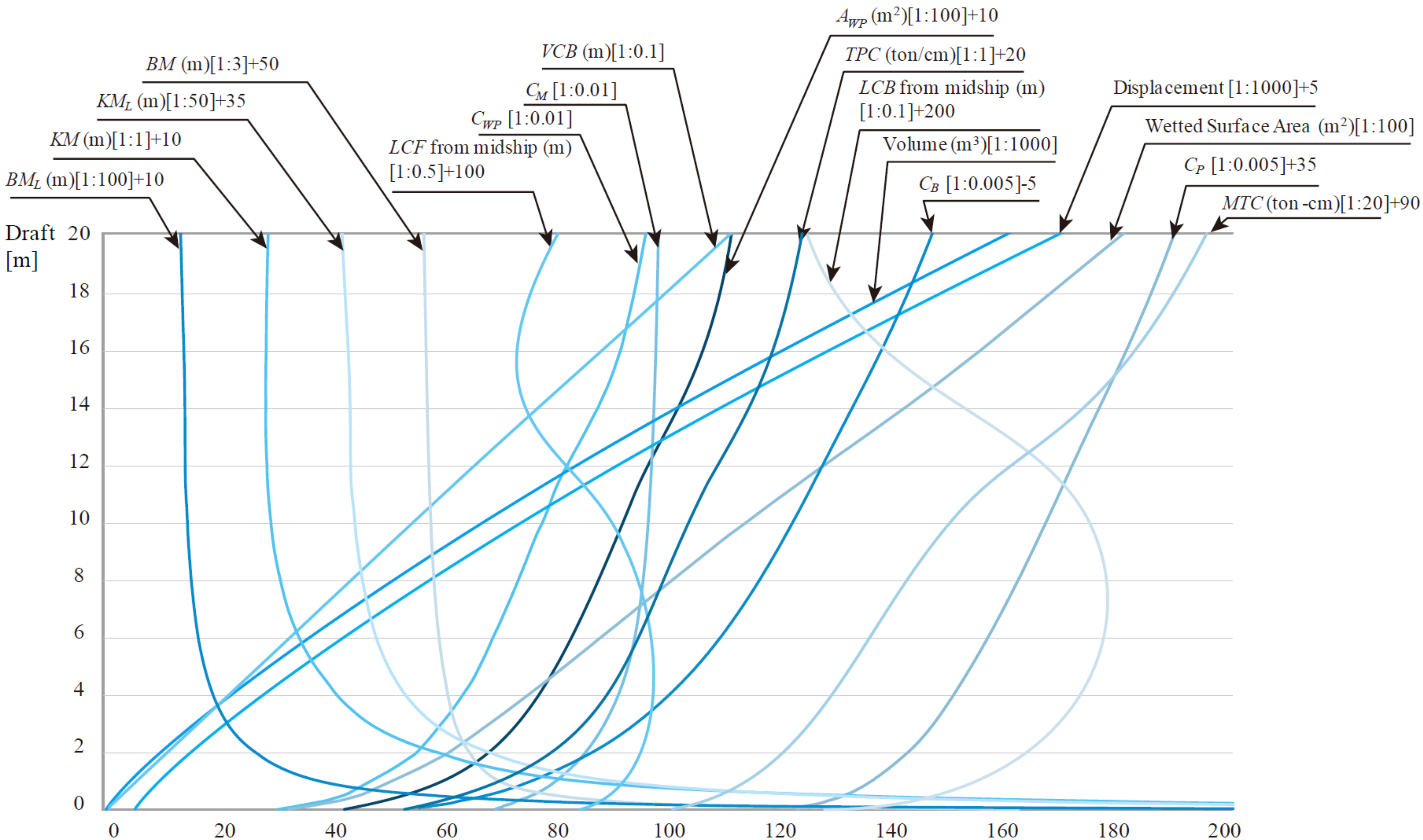
Example of Hydrostatic Tables of a 6,300TEU Container Ship (1/2)

DRAFT (M)	DISP MLD(M^3)	DISP EXT(Ton)	*VCB* (M)	*LCB* (M)	*LCF* (M)	*KM* (M)	KM_L (M)	*MTC* (T-M)	*TPC* (Ton)	*WSA* (M^2)	C_B	C_W	C_P	C_M
4.000	22054.0	22720.3	2.171	-2.732	-1.546	31.537	926.651	795.5	68.5	7474.0	0.5248	0.6332	0.5769	0.9097
4.050	22389.1	23064.3	2.199	-2.714	-1.535	31.314	916.847	798.9	68.7	7507.8	0.5261	0.6349	0.5777	0.9107
4.100	22726.2	23410.3	2.226	-2.697	-1.523	31.098	907.266	802.4	68.9	7541.5	0.5275	0.6367	0.5786	0.9118
4.150	23053.3	23756.4	2.253	-2.680	-1.511	30.889	897.964	805.9	69.1	7575.3	0.5288	0.6384	0.5794	0.9128
4.200	23400.4	24102.4	2.281	-2.663	-1.500	30.686	888.93	809.3	69.3	7609.1	0.5302	0.6402	0.5802	0.9138
4.250	23737.5	24448.5	2.308	-2.646	-1.488	30.490	880.152	812.8	69.5	7642.9	0.5314	0.6420	0.5810	0.9147
4.300	24077.3	24797.2	2.336	-2.630	-1.476	30.300	871.537	816.3	69.7	7676.7	0.5327	0.6437	0.5818	0.9157
4.350	24419.0	25148.0	2.363	-2.614	-1.465	30.115	863.102	819.8	69.9	7710.5	0.5341	0.6454	0.5826	0.9166
4.400	24760.7	25498.8	2.391	-2.598	-1.453	29.936	854.9	823.3	70.1	7744.3	0.5354	0.6472	0.5835	0.9176
4.450	25102.4	25849.6	2.418	-2.582	-1.441	29.762	846.921	826.7	70.3	7778.1	0.5366	0.6489	0.5843	0.9185
...														
7.500	47233.9	48564.4	4.087	-2.084	-2.217	21.918	560.803	1023.9	78.2	9736.7	0.5979	0.7224	0.6283	0.9517
7.550	47615.8	48956.4	4.115	-2.086	-2.257	21.852	558.143	1027.2	78.3	9768.7	0.5988	0.7235	0.6290	0.9520
7.600	47999.0	49349.6	4.142	-2.088	-2.302	21.785	555.428	1030.3	78.4	9800.7	0.5996	0.7246	0.6296	0.9523
7.650	48382.1	49742.8	4.170	-2.090	-2.348	21.722	552.756	1033.4	78.6	9832.7	0.6004	0.7256	0.6303	0.9527
7.700	48765.2	50136.0	4.197	-2.092	-2.393	21.659	550.126	1036.6	78.7	9864.6	0.6013	0.7267	0.6309	0.9530
7.750	49148.4	50529.3	4.224	-2.094	-2.438	21.598	547.537	1039.7	78.8	9896.6	0.6021	0.7277	0.6316	0.9533
7.800	49533.1	50924.1	4.252	-2.097	-2.483	21.538	544.992	1042.9	78.9	9928.6	0.6029	0.7288	0.6322	0.9536
7.850	49919.1	51320.2	4.279	-2.100	-2.527	21.481	542.488	1046.1	79.0	9960.7	0.6037	0.7298	0.6329	0.9539
7.900	50305.0	51716.3	4.307	-2.104	-2.571	21.424	540.023	1049.2	79.1	9992.8	0.6045	0.7309	0.6335	0.9542
7.950	50690.9	52112.3	4.334	-2.107	-2.615	21.369	537.595	1052.4	79.2	10024.8	0.6053	0.7319	0.6342	0.9544
...														

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

DRAFT (M)	DISP MLD(M^3)	DISP EXT(Ton)	VCB (M)	LCB (M)	LCF (M)	KM (M)	KM_L (M)	MTC (T-M)	TPC (Ton)	WSA (M^2)	C_B	C_W	C_P	C_M
11.750	81677.2	83912.8	6.431	-3.298	-8.607	18.919	430.346	1347.2	88.1	12595.4	0.6593	0.8134	0.6803	0.9692
11.800	82107.4	84354.3	6.459	-3.326	-8.710	18.912	430.028	1353.1	88.2	12631.3	0.6600	0.8148	0.6809	0.9693
11.850	82539.1	84797.3	6.487	-3.355	-8.816	18.905	429.787	1359.4	88.4	12667.6	0.6606	0.8162	0.6815	0.9695
11.900	82970.8	85240.4	6.515	-3.384	-8.923	18.900	429.549	1365.5	88.5	12703.9	0.6613	0.8176	0.6820	0.9696
11.950	83402.4	85683.4	6.543	-3.413	-9.030	18.894	429.313	1371.9	88.7	12740.2	0.6620	0.8190	0.6826	0.9697
12.000	83634.1	86126.4	6.571	-3.442	-9.136	18.889	429.081	1378.1	88.8	12776.5	0.6626	0.8204	0.6832	0.9698
12.050	84267.9	86571.6	6.599	-3.471	-9.233	18.879	428.885	1384.5	89.0	12812.5	0.6633	0.8218	0.6838	0.9700
12.100	84703.3	87018.4	6.627	-3.501	-9.323	18.866	428.717	1391.0	89.1	12848.3	0.6639	0.8231	0.6844	0.9701
12.150	85138.6	87465.1	6.655	-3.531	-9.413	18.853	428.551	1397.5	89.3	12884.0	0.6646	0.8245	0.6850	0.9702
12.200	85573.9	87911.9	6.683	-3.561	-9.503	18.840	428.387	1404.0	89.4	12919.8	0.6652	0.8258	0.6856	0.9703
12.250	86009.2	88358.7	6.711	-3.591	-9.593	18.826	428.224	1410.5	89.5	12955.6	0.6659	0.8271	0.6862	0.9705
...														
14.250	104062.4	106885.2	7.843	-4.937	-12.788	18.585	423.63	1683.1	95.4	14391.6	0.6924	0.8808	0.7105	0.9746
14.300	104528.0	107363.1	7.872	-4.973	-12.837	18.604	423.328	1689.2	95.5	14426.2	0.6931	0.8819	0.7111	0.9747
14.350	104995.0	107842.2	7.901	-5.008	-12.880	18.683	423.056	1695.6	95.6	14461.0	0.6938	0.8831	0.7117	0.9748
14.400	105451.9	108321.3	7.929	-5.042	-12.940	18.683	422.786	1701.9	95.7	14495.8	0.6944	0.8843	0.7123	0.9749
14.450	105928.8	108800.4	7.958	-5.077	-12.992	18.682	422.519	1708.2	95.9	14530.6	0.6951	0.8854	0.7129	0.9750
14.500	106395.7	109279.6	7.986	-5.112	-13.043	18.682	422.255	1714.5	96.0	14565.4	0.6957	0.8866	0.7135	0.9751
14.550	106864.4	109760.5	8.015	-5.147	-13.090	18.682	422.01	1720.9	96.1	14600.3	0.6964	0.8878	0.7141	0.9751
14.600	107334.5	110242.8	8.043	-5.182	-13.133	18.681	421.779	1727.4	96.2	14635.1	0.6971	0.8889	0.7148	0.9752
14.650	107804.5	110725.1	8.072	-5.217	-13.176	18.681	421.55	1733.9	96.4	14970.0	0.6977	0.8901	0.7154	0.9753
14.700	108274.5	111207.4	8.101	-5.251	-13.219	18.681	421.323	1740.3	96.5	14704.9	0.6984	0.8912	0.7160	0.9754

Example of Hydrostatic Curves of a 6,300TEU Container Ship



Hydrostatics Table

Draft	Awp	Cwp	TPC	Am	Cm	Disp. Vol.	Dispacement	Cb	Cp	
1	13969.707634	0.727589	143.189503	57.595373	0.959923	13274.704872	13606.572494	0.691391	0.720257	0
2	14665.449669	0.763826	150.320859	117.023844	0.975199	27625.670041	28316.311792	0.719418	0.737715	1
3	15077.051700	0.785263	154.539780	176.973600	0.983187	42515.292743	43578.175062	0.738113	0.750735	1
4	15357.591332	0.799875	157.415311	236.973600	0.987390	57741.104204	59184.631810	0.751837	0.761439	2
5	15581.372337	0.811530	159.709066	296.973600	0.989912	73212.579375	75042.893859	0.762631	0.770403	2
6	15749.689195	0.820296	161.434314	356.973600	0.991593	88884.693834	91106.811180	0.771569	0.778110	3
7	15875.551257	0.826852	162.724400	416.973600	0.992794	104697.883311	107315.330393	0.779002	0.784656	3
8	15995.591849	0.833104	163.954816	476.973600	0.993695	120634.354919	123650.213792	0.785380	0.790363	4
9	16108.202427	0.838969	165.109075	536.973600	0.994396	136685.843246	140102.989327	0.791006	0.795464	4
10	16220.139230	0.844799	166.256427	596.973600	0.994956	152848.654175	156669.870529	0.796087	0.800123	5
11	16334.646305	0.850763	167.430125	656.973600	0.995415	169122.501317	173350.563850	0.800769	0.804458	5
12	16456.300612	0.857099	168.677081	716.973600	0.995797	185509.431357	190147.167141	0.805162	0.808561	6
13	16586.144990	0.863862	170.007986	776.973600	0.996120	202010.815322	207061.085705	0.809338	0.812491	6
14	16733.101975	0.871516	171.514295	836.973600	0.996397	218662.950551	224129.524315	0.813478	0.816420	7
15	16880.258424	0.879180	173.022649	896.973600	0.996637	235526.994120	241415.168973	0.817802	0.820561	7
16	17033.256489	0.887149	174.590879	956.973600	0.996848	252548.055106	258861.756483	0.822097	0.824696	8
17	17190.202935	0.895323	176.199580	1016.973600	0.997033	269669.514686	276411.252553	0.826193	0.828652	8
18	17330.470220	0.902629	177.637320	1076.973600	0.997198	286937.720924	294111.163948	0.830260	0.832593	9
19	17450.827341	0.908897	178.870980	1136.973600	0.997345	304340.487982	311949.000181	0.834267	0.836487	9
20	17554.763112	0.914311	179.936322	1196.973600	0.997478	321853.728657	329900.071874	0.838161	0.840280	10
21	17654.425395	0.919501	180.957860	1256.973600	0.997598	339467.205809	347953.885955	0.841933	0.843960	10
22	17745.043330	0.924221	181.886694	1316.973600	0.997707	357175.445606	366104.831746	0.845586	0.847529	11
23	17829.121813	0.928600	182.748499	1376.973600	0.997807	374971.328289	384345.611496	0.849120	0.850986	11
24	17906.567070	0.932634	183.542312	1436.973600	0.997898	392848.739497	402669.957984	0.852536	0.854332	12
25	17977.456424	0.936326	184.268928	1496.973600	0.997982	410799.466249	421069.452905	0.855832	0.857562	12
26	18042.453063	0.939711	184.935144	1556.973600	0.998060	428815.884445	439536.281557	0.859006	0.860676	13
27	18109.462826	0.943201	185.621994	1616.973600	0.998132	446896.925743	458069.348887	0.862070	0.863683	14
28	18169.982624	0.946353	186.242322	1676.973600	0.998199	465040.875432	476666.897318	0.865031	0.866592	14
29	18227.152414	0.949331	186.828312	1736.973600	0.998261	483242.386920	495323.446593	0.867892	0.869404	15
30	18281.613265	0.952167	187.386536	1796.973600	0.998319	501498.412094	514035.872397	0.870657	0.872123	15

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Example of Programming for Calculation of the Hydrostatics - Example of Hydrostatic Tables of a 320K VLCC (2/2)

Hydrostatics Table

KB	BMt	KMt	LCB	LCF	BMl	KMl	MTC	Wetted Surface Area
0.509932	249.279769	249.789701	17.634696	16.988722	5579.686819	5580.196750	2314.646744	14102.067144
1.025653	131.559866	132.585519	17.124977	16.375976	2962.881019	2963.906672	2557.861669	15079.444762
1.543595	89.894069	91.437664	16.785825	15.944990	2045.756860	2047.300456	2717.998493	15882.807875
2.060474	68.385545	70.446019	16.518405	15.612685	1570.949684	1573.010157	2834.636543	16618.776733
2.576277	55.320467	57.896744	16.287570	15.207640	1281.933552	1284.509829	2932.926936	17331.697356
3.092244	46.498881	49.591125	16.069941	14.941734	1081.449552	1084.541796	3003.884761	18026.084613
3.607174	40.131690	43.738864	15.890147	14.769625	932.964856	936.572030	3052.482676	18706.387874
4.121509	35.310328	39.431836	15.716638	14.383665	824.011114	828.132622	3106.376536	19367.844148
4.635703	31.535720	36.171423	15.530695	13.873811	739.817809	744.453512	3160.081909	20026.661200
5.150036	28.499889	33.649925	15.320611	13.206166	673.530311	678.680346	3217.131299	20688.395322
5.664717	26.007295	31.672012	15.078149	12.389904	620.434826	626.099544	3279.046555	21355.594668
6.179868	23.940218	30.120085	14.798156	11.426314	577.378964	583.558831	3347.163851	22031.346533
6.695516	22.197901	28.893417	14.478059	10.313393	542.171603	548.867119	3422.641486	22719.069067
7.213571	20.701056	27.914627	14.108800	8.961314	514.225484	521.439055	3513.814422	23436.142778
7.736683	19.395506	27.132189	13.686550	7.550015	490.042460	497.779143	3606.819609	24153.666246
8.261164	18.253453	26.514617	13.221739	6.036404	469.665833	477.926997	3706.662270	24885.589906
8.784388	17.250265	26.034653	12.711991	4.427362	452.305205	461.089592	3811.653906	25648.473411
9.309007	16.358312	25.667320	12.168722	3.027873	435.400427	444.709435	3904.150199	26390.817987
9.834664	15.558514	25.393178	11.610030	1.874104	418.610230	428.444894	3981.251301	27121.767720
10.360640	14.833239	25.193879	11.052104	0.949584	402.322606	412.683246	4046.532211	27828.171680
10.886729	14.168543	25.055272	10.508656	0.314228	387.475682	398.362411	4110.477717	28519.892075
11.412880	13.555606	24.968487	9.990360	-0.119337	373.550750	384.963631	4169.473618	29205.249360
11.939003	12.987957	24.926960	9.503047	-0.379617	360.593551	372.532554	4225.382593	29882.641610
12.465035	12.463030	24.928065	9.049601	-0.523423	348.430560	360.895595	4277.515818	30554.971648
12.990852	11.977942	24.968794	8.629644	-0.588068	336.938839	349.929691	4325.446727	31223.264679
13.516351	11.528007	25.044358	8.242049	-0.578749	326.080741	339.597092	4369.643798	31887.840180
14.041601	11.109971	25.151572	7.887679	-0.442092	316.247188	330.288788	4416.559250	32557.540530
14.566638	10.721379	25.288016	7.565974	-0.286588	306.814475	321.381113	4458.789754	33226.725389
15.091404	10.360160	25.451564	7.274229	-0.103187	297.903898	312.995302	4498.743464	33896.183818
15.615903	10.023641	25.639544	7.010481	0.115336	289.495842	305.111745	4536.928276	52901.394845

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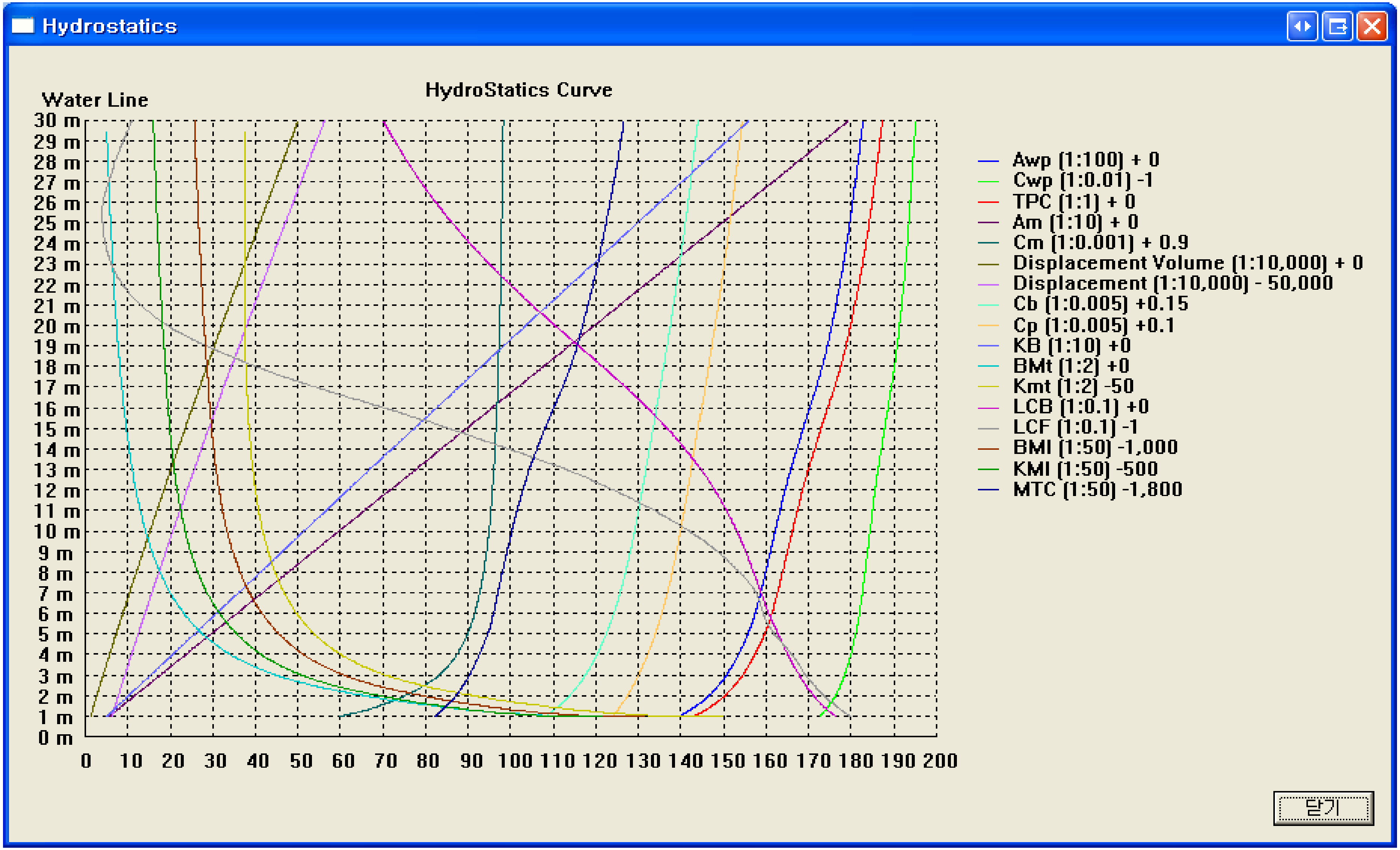
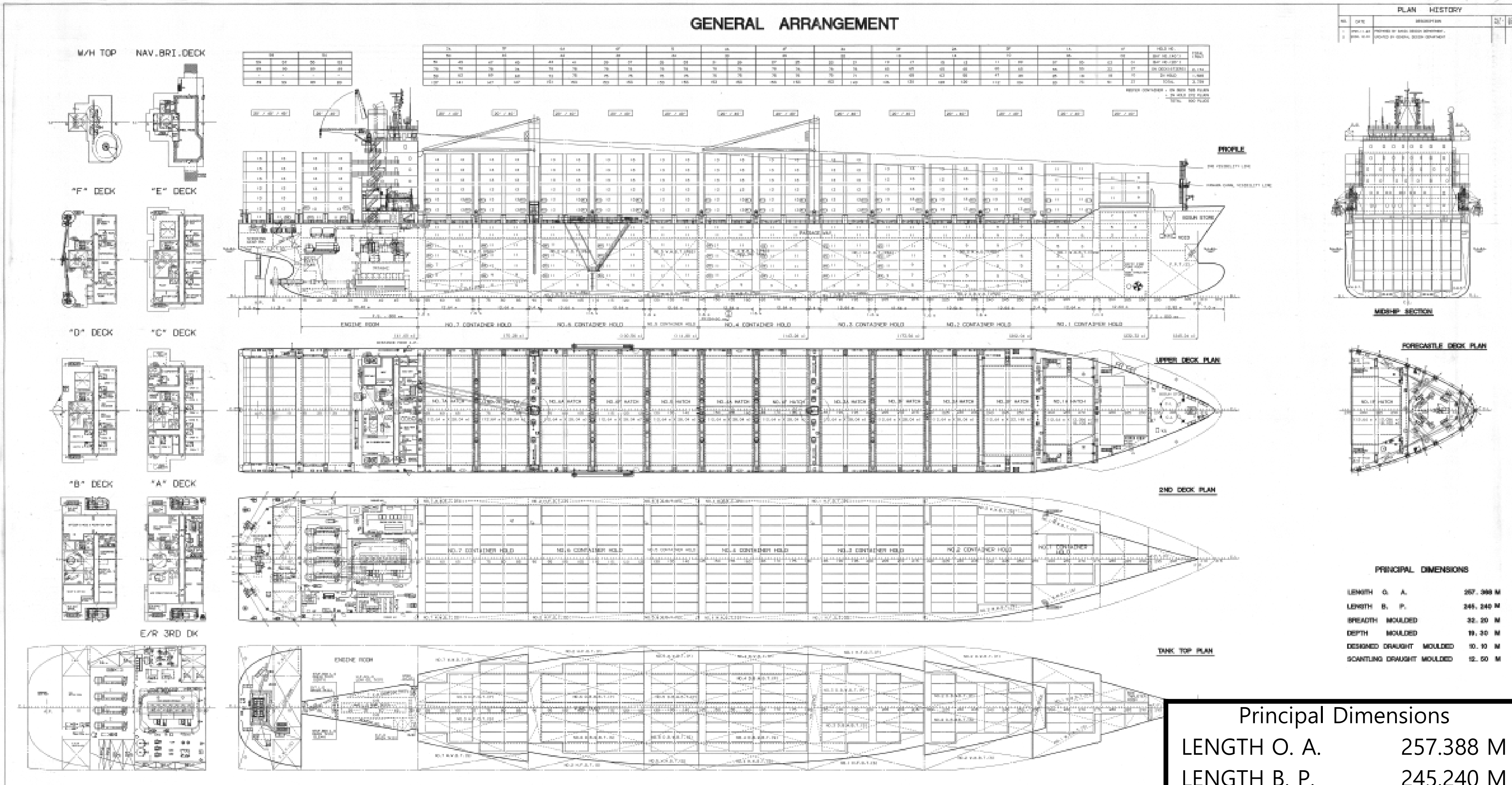
Example of Programming for Calculation of the Hydrostatics
- Example of Hydrostatic Curves of a 320K VLCC



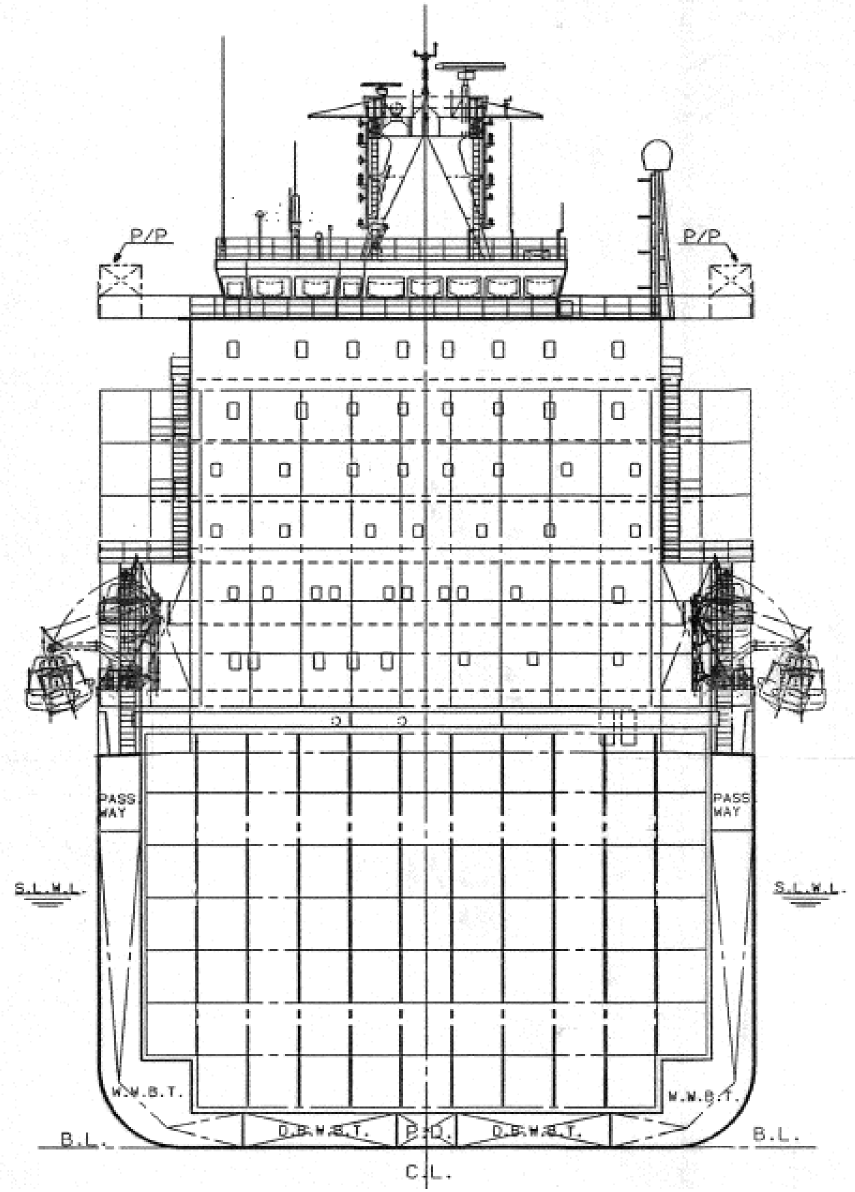
Trim and Stability Calculation of a 3,700TEU Container Ship Including Hydrostatic Values

General Arrangement(G/A) of a 3,700TEU Container Ship



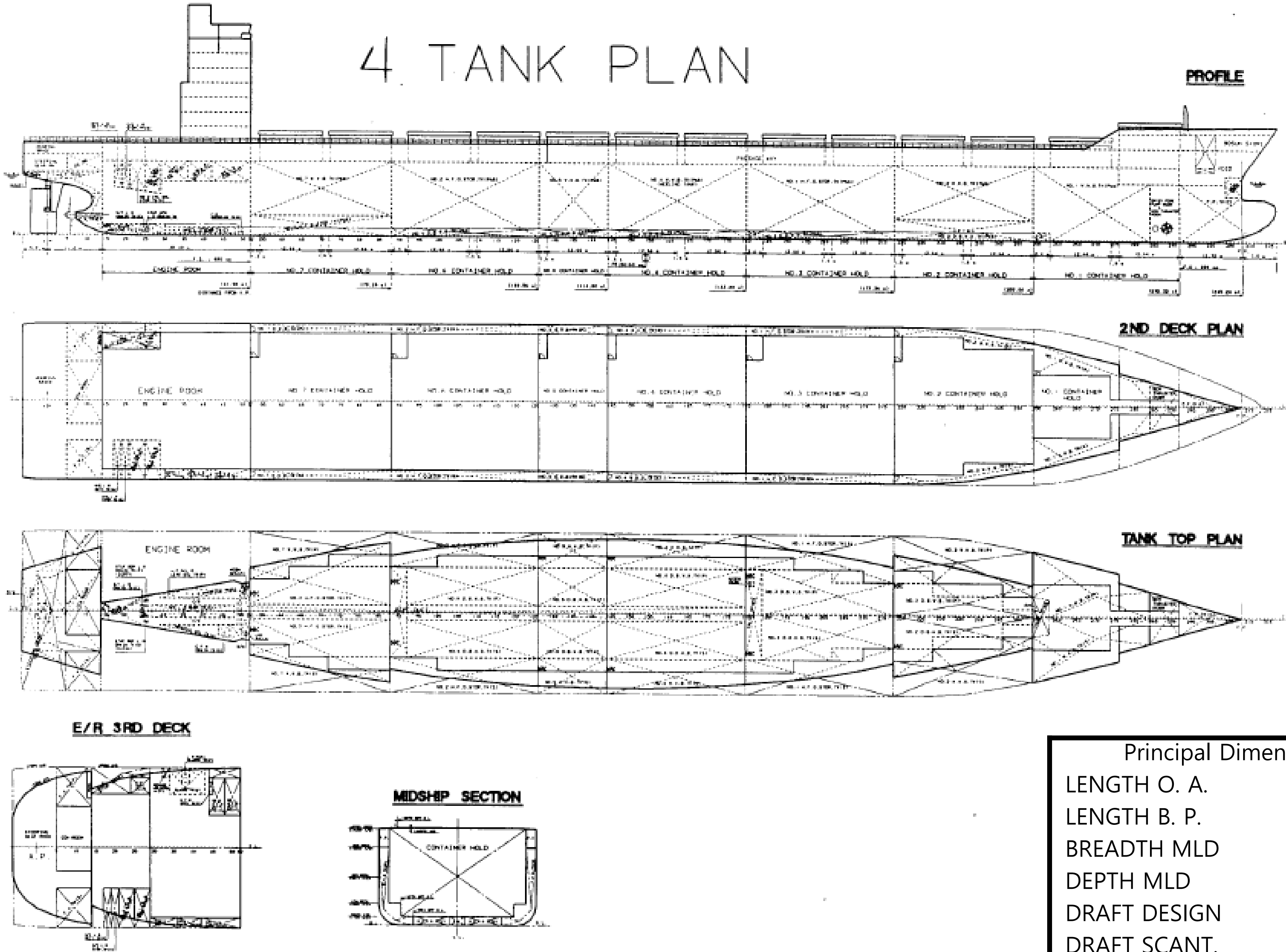
Principal Dimensions	
LENGTH O. A.	257.388 M
LENGTH B. P.	245.240 M
BREADTH MLD	32.20 M
DEPTH MLD	19.30 M
DRAFT DESIGN	10.10 M
DRAFT SCANT.	12.50 M

Midship Section in G/A



Principal Dimensions	
LENGTH O. A.	257.388 M
LENGTH B. P.	245.240 M
BREADTH MLD	32.20 M
DEPTH MLD	19.30 M
DRAFT DESIGN	10.10 M
DRAFT SCANT.	12.50 M

Tank Plan



Principal Dimensions	
LENGTH O. A.	257.388 M
LENGTH B. P.	245.240 M
BREADTH MLD	32.20 M
DEPTH MLD	19.30 M
DRAFT DESIGN	10.10 M
DRAFT SCANT.	12.50 M

Tank Summary Table (1/2)

$$GG_0 = \frac{\sum \rho_F \cdot i_T}{\rho_{SW} \nabla}$$: Free surface moment

Name	Specific Gravity	Filling Ratio*
Heavy Fuel Oil	**0.990**	**98%**

Ex) $1,214.6 \times 0.99 = 1,202.4$

$1,118.6 \times 0.99 = 1,107.4$

HEAVY FUEL OIL TANKS

(S.G.= .990)

COMPARTMENT	LOCATION (FR.NO.)	CAPACITIES: VOLUME 100%FULL (M**3)	CAPACITIES: VOLUME 98%FULL (M**3)	CAPACITIES: WEIGHT 98%FULL (TONNES)	100% FULL: L.C.G FROM A.P (M)	100% FULL: V.C.G ABOVE B.L(M)	MAX. MT OF INERTIA (M**4)
NO.1 H.F.O TK (P)	180-218	1239.3	1214.6	1202.4	159.046	6.949	622
NO.1 H.F.O TK (S)	180-218	1239.3	1214.6	1202.4	159.046	6.949	622
NO.2 H.F.O TK (P)	88-126	1141.5	1118.6	1107.4	85.692	7.112	395
NO.2 H.F.O TK (S)	88-126	1141.5	1118.6	1107.4	85.692	7.112	395
NO.3 H.F.O TK (P)	52- 88	593.9	582.0	576.2	57.377	2.352	1126
NO.3 H.F.O TK (S)	52- 88	593.9	582.0	576.2	57.377	2.352	1126
HFO SERV. TK(P)	44- 52	59.3	58.1	57.5	38.213	13.142	19
NO.1 HFO SETT. TK(P)	48- 52	122.5	120.0	118.8	40.010	10.887	112
NO.2 HFO SETT. TK(P)	44- 48	117.2	114.9	113.7	36.813	10.850	112
T O T A L		6248.4	6123.4	6062.0			

To be used for calculation of FSM(Free Surface Moment)

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

Water Ballast Tank

(S.G.= 1.025)

COMPARTMENT	LOCATION (FR.NO)	CAPACITIES VOLUME 100% FULL (M**3)	CAPACITIES WEIGHT 100% FULL (TONNES)	100% FULL L.C.G FROM A.P (M)	100% FULL V.C.G ABOVE B.L(M)	MAX. MT OF INERTIA (M**4)
F.P TK (C)	292-317	522.9	535.9	240.444	5.980	109
NO.1 W.W.B TK (P)	254-284	972.0	996.3	212.092	8.003	312
NO.1 W.W.B TK (S)	254-284	972.0	996.3	212.092	8.003	312
NO.2 D/B W.B TK (P)	218-254	528.1	541.3	186.645	2.136	868
NO.2 D/B W.B TK (S)	218-254	528.1	541.3	186.645	2.136	868
NO.2 W.W.B TK (P)	218-254	965.2	989.3	187.893	9.662	578
NO.2 W.W.B TK (S)	218-254	965.2	989.3	187.893	9.662	578
NO.3 D/B W.B TK (P)	184-218	354.3	363.2	159.025	.852	1253
NO.3 D/B W.B TK (S)	184-218	354.3	363.2	159.025	.852	1253
NO.4 D/B W.B TK (P)	144-180	362.4	371.5	129.040	.850	1029
NO.4 D/B W.B TK (S)	144-180	362.4	371.5	129.040	.850	1029
NO.4 W.W.B TK (P)	144-180	1199.1	1229.1	128.858	6.435	475
NO.4 W.W.B TK (S)	144-180	1199.1	1229.1	128.858	6.435	475
NO.5 D/B W.B TK (P)	126-144	181.2	185.7	107.680	.850	515
NO.5 D/B W.B TK (S)	126-144	181.2	185.7	107.680	.850	515
NO.5 W.W.B.TK (P)	126-144	605.8	621.0	107.718	6.391	250
NO.5 W.W.B.TK(S)	126-144	605.8	621.0	107.718	6.391	250
NO.6 D/B W.B TK (P)	92-126	336.9	345.3	87.269	.861	971
NO.6 D/B W.B TK (S)	92-126	336.9	345.3	87.269	.861	971
NO.7 W.W.B TK (P)	52- 88	906.6	929.2	54.797	9.176	767
NO.7 W.W.B TK (S)	52- 88	906.6	929.2	54.797	9.176	767
A.P TK (C)	-2- 14	455.2	466.6	6.018	11.899	3897
T O T A L		13801.3	14146.3			

Fresh Water Tank

(S.G.= 1.000)

COMPARTMENT	LOCATION (FR.NO.)	CAPACITIES VOLUME 100% FULL (M**3)	CAPACITIES WEIGHT 100% FULL (TONNES)	100% FULL L.C.G FROM A.P (M)	100% FULL V.C.G ABOVE B.L(M)	MAX. MT OF INERTIA (M**4)
F.W TK (P)	5- 14	172.9	172.9	7.326	15.113	275
F.W TK (S)	5- 14	189.8	189.8	7.634	15.111	295
T O T A L		362.7	362.7			

Heavy Fuel Oil Tank

(S.G.= .990)

COMPARTMENT	LOCATION (FR.NO.)	CAPACITIES VOLUME 100%FULL (M**3)	CAPACITIES VOLUME 98%FULL (M**3)	CAPACITIES WEIGHT 98%FULL (TONNES)	100% FULL L.C.G FROM A.P (M)	100% FULL V.C.G ABOVE B.L(M)	MAX. MT OF INERTIA (M**4)
NO.1 H.F.O TK (P)	180-218	1239.3	1214.6	1202.4	159.046	6.949	622
NO.1 H.F.O TK (S)	180-218	1239.3	1214.6	1202.4	159.046	6.949	622
NO.2 H.F.O TK (P)	88-126	1141.5	1118.6	1107.4	85.692	7.112	395
NO.2 H.F.O TK (S)	88-126	1141.5	1118.6	1107.4	85.692	7.112	395
NO.3 H.F.O TK (P)	52- 88	593.9	582.0	576.2	57.377	2.352	1126
NO.3 H.F.O TK (S)	52- 88	593.9	582.0	576.2	57.377	2.352	1126
HFO SERV. TK(P)	44- 52	59.3	58.1	57.5	38.213	13.142	19
NO.1 HFO SETT. TK(P)	48- 52	122.5	120.0	118.8	40.010	10.887	112
NO.2 HFO SETT. TK(P)	44- 48	117.2	114.9	113.7	36.813	10.850	112
T O T A L		6248.4	6123.4	6062.0			

Diesel Oil Tank

(S.G.= .860)

COMPARTMENT	LOCATION (FR.NO.)	CAPACITIES VOLUME 100%FULL (M**3)	CAPACITIES VOLUME 98%FULL (M**3)	CAPACITIES WEIGHT 98%FULL (TONNES)	100% FULL L.C.G FROM A.P (M)	100% FULL V.C.G ABOVE B.L(M)	MAX. MT OF INERTIA (M**4)
D.O SERV. TK (P)	14- 29	56.1	55.0	47.3	21.200	13.421	12
D.O STOR. TK (P)	24- 29	358.3	351.2	302.0	16.855	15.000	125
T O T A L		414.4	406.2	349.3			

Lubrication Oil Tank

(S.G.= .900)

COMPARTMENT	LOCATION (FR.NO.)	CAPACITIES VOLUME 100%FULL (M**3)	CAPACITIES VOLUME 98%FULL (M**3)	CAPACITIES WEIGHT 98%FULL (TONNES)	100% FULL L.C.G FROM A.P (M)	100% FULL V.C.G ABOVE B.L(M)	MAX. MT OF INERTIA (M**4)
M/E L.O SUMP TK(C)	27- 48	50.6	49.6	44.6	29.278	1.222	22
M/E L.O SETT. TK(S)	36- 42	41.7	40.8	36.8	31.211	13.462	4
M/E L.O STOR. TK(S)	42- 52	70.8	69.4	62.5	37.607	13.427	6
NO.1 CYL.OIL TK(S)	25- 29	130.2	127.6	114.9	21.617	12.865	131
NO.2 CYL.OIL TK(S)	21- 25	121.1	118.7	106.8	18.422	13.041	131
G/E L.O SETT. TK(S)	17- 19	54.2	53.1	47.8	14.407	13.279	65
G/E L.O STOR. TK(S)	19- 21	56.8	55.7	50.1	16.006	13.182	65
T O T A L		525.4	514.9	463.5			

Miscellaneous Tank

COMPARTMENT	LOCATION FRAMES	CAPACITIES VOLUME 100% FULL (M**3)	100% FULL L.C.G FROM A.P (M)	100% FULL V.C.G ABOVE B.L(M)	MAX. MT OF INERTIA (M**4)
SEWAGE HOLDING TK(P)	32- 34	8.3	26.402	13.452	1
BILGE HOLDING TK(C)	14- 25	62.9	16.279	1.478	75
S/T L.O DRAIN TK(C)	24- 25	3.0	19.600	1.695	1
RESIDUE TK(S)	29- 44	25.0	30.577	1.754	10
DIRTY OIL TK (S)	29- 36	46.0	26.042	13.549	4
L.O SLUDGE TK(P)	37- 39	4.4	30.422	10.570	2
HFO SLUDGE TK(P)	32- 43	58.8	31.176	10.148	61
C.F.W DRAIN TK(S)	44- 47	9.4	36.433	1.666	6
HFO/LO LEAK O.TK(P)	29- 36	7.4	26.438	1.836	1
C.W TK (C)	7.3- 14	35.5	9.480	3.554	6
F.O OVERFLOW TK	36- 50	45.9	35.974	1.525	328
STUFF.L.O DRAIN TK(P)	25- 26	4.4	20.403	1.428	2
STUFF.L.O DRAIN TK(S)	25- 26	4.4	20.403	1.428	2
T O T A L		315.4			

Tank Summary Table (2/2)

① $$LCG_{DWT} = \frac{\sum LCG_i \times \rho_i V_i}{DWT}$$ ←

LCG_i : Longitudinal center of gravity of cargo

ρ_i : Density of cargo

V_i : Volume of cargo

② $$LCG_{LWT} = \frac{\sum LCG_j \times W_j}{LWT}$$ ←

LCG_j : Longitudinal center of lightweight

W_j : Distributed lightweight in longitudinal direction

- LCG_{DWT} : Variable based on Loading Condition
- LCG_{LWT} : Location of LCG_{LWT} is fixed.

$$\therefore LCG = \frac{LCG_{DWT} \times DWT + LCG_{LWT} \times LWT}{\Delta}$$

***Lightweight**(*LWT*) reflects the weight of vessel being ready to go to sea without cargo and loads. And lightweight can be composed of:

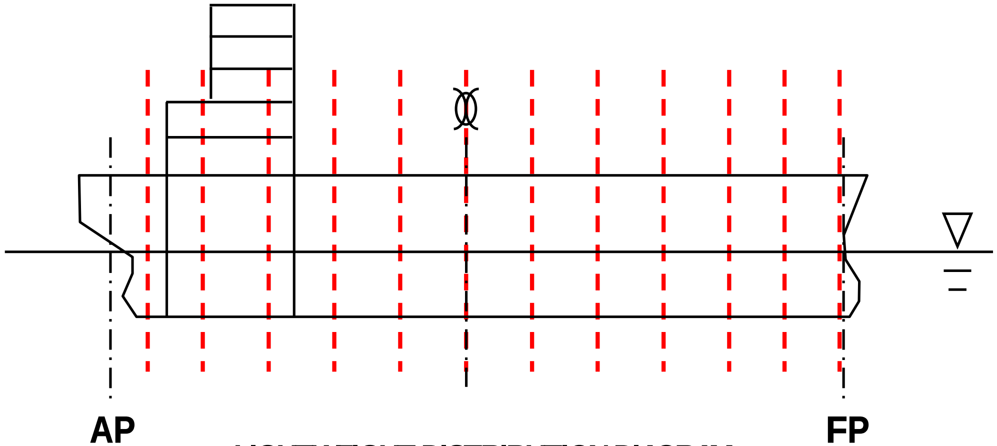
LWT = Structural weight + Outfit weight + Machinery weight

***Deadweight**(*DWT*) is the weight that a ship can load till the maximum allowable immersion(at the scantling draft(T_s)).

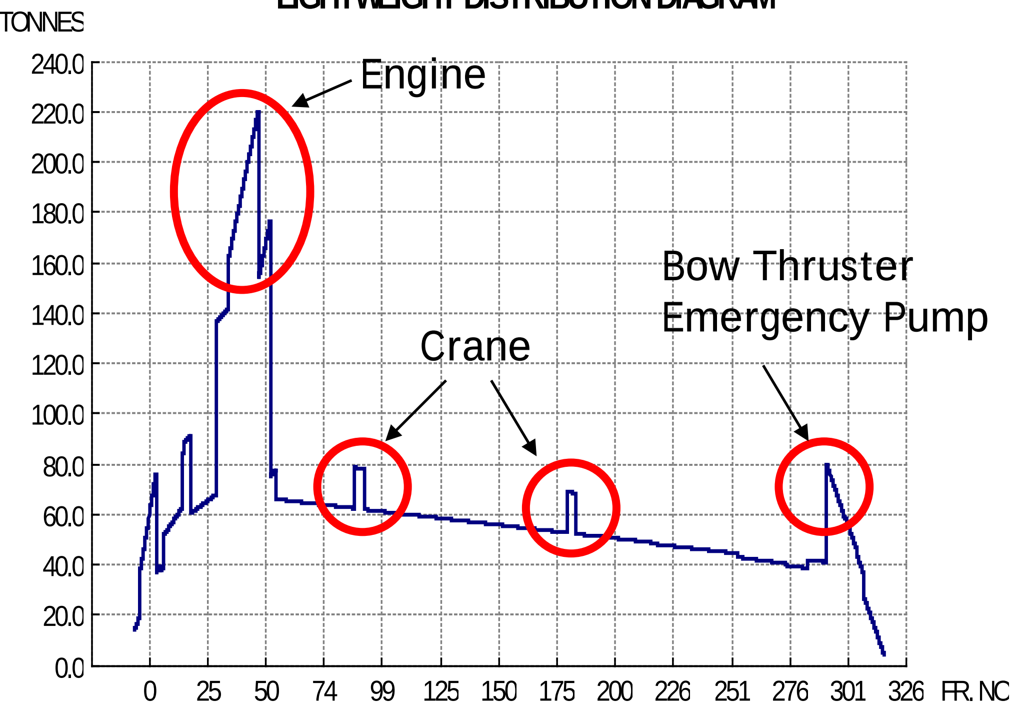
And deadweight can be composed of:

DWT= Payload+ Fuel oil + Diesel oil+ Fresh water +Ballast water + etc.

Lightweight Summary



LIGHTWEIGHT DISTRIBUTION DIAGRAM



$$LCG_{LWT} = \frac{\sum LCG_j \times W_j}{LWT}$$

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

Hull No. : 1329. 3,700 TEU CONTAINER VESSEL

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

Hydrostatic Values

- ☑ $Draft_{Mld}$, $Draft_{Scant}$: Draft from base line, moulded / scantling (m)
- ☑ $Volume_{Mld}(\nabla)$, $Volume_{Ext}$: Displacement volume, moulded / extreme (m^3)
- ☑ $Displacement_{Mld}(\Delta)$, $Displacement_{Ext}$: 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 (m^2)
- ☑ 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)

Hydrostatics Table

DRAFT MLD [M]	DISP MLD [M3]	DISP EXT [T]	LCF [M]	LCB [M]	VCB [M]	TPC [T]	MTC [T-M]	KML [M]	KMT [M]	WSA [M2]	CB	CP	CW	CM
3,00	11326,7	11693,7	-3,33	-3,32	1,63	46,7	479,2	1016,5	23,83	5114,7	0,474	0,506	0,572	0,937
3,05	11562,7	11936,2	-3,31	-3,32	1,66	46,9	482,1	1001,8	23,57	5145,3	0,475	0,507	0,574	0,938
3,10	11798,8	12178,7	-3,30	-3,32	1,68	47,1	484,9	987,7	23,32	5175,8	0,477	0,509	0,576	0,938
3,15	12034,9	12421,2	-3,28	-3,32	1,71	47,2	487,7	974,1	23,08	5206,3	0,479	0,510	0,578	0,939
3,20	12271,0	12663,6	-3,26	-3,31	1,74	47,4	490,5	961,0	22,86	5236,8	0,481	0,512	0,580	0,940
3,25	12507,1	12906,1	-3,25	-3,31	1,77	47,5	49							
3,30	12743,2	13148,6	-3,23	-3,31	1,79	47,7	49							
3,35	12979,2	13391,1	-3,21	-3,31	1,82	47,9	49							
3,40	13215,3	13633,6	-3,20	-3,30	1,85	48,0	50							
3,45	13451,4	13876,1	-3,18	-3,30	1,88	48,2	50							
3,50	13687,5	14118					50							
3,55	13923,6	14361					51							
3,60	14159,7	14603,5	-3,1		1,96	48,6	51							
3,65	14395,7	14846,0	-3,11	-3,29	1,99	48,8	515,9	862,6	21,18	5511,4	0,495	0,522	0,597	0,947
3,70	14631,8	15088,5	-3,10	-3,29	2,02	49,0	518,8	853,4	21,02	5541,9	0,496	0,523	0,599	0,948
4,40	18047,3	18596,3	-2,94	-3,24	2,40	50,9	554,2	740,4	19,16	5960,4	0,514	0,538	0,623	0,956
4,45	18297,2	18852,9	-2,93	-3,24	2,43	51,1	556,5	733,4	19,05	5989,9	0,516	0,539	0,625	0,956
4,50	18547,1	19109,5	-2,92	-3,23	2,46	51,2	558,8	726,6	18,94	6019,3	0,517	0,540	0,626	0,957
4,55	18796,9	19366,1	-2,91	-3,23	2,48	51,3	561,1	720,0	18,84	6048,7	0,518	0,541	0,628	0,957
4,60	19046,8	19622,7	-2,91	-3,22	2,51	51,4	563,4	713,5	18,74	6078,2	0,519	0,542	0,629	0,958
4,65	19296,7	19879,3	-2,90	-3,22	2,54	51,6	565,7	707,3	18,64	6107,6	0,520	0,543	0,631	0,958
4,70	19546,6	20135,9	-2,89	-3,21	2,57	51,7	568,0	701,1	18,54	6137,1	0,522	0,544	0,632	0,959
4,75	19796,4	20392,5	-2,88	-3,21	2,60	51,8	570,3	695,2	18,45	6166,5	0,523	0,545	0,634	0,959
4,80	20046,3	20649,1	-2,87	-3,21	2,62	51,9	572,6	689,4	18,36	6195,9	0,524	0,546	0,635	0,959
4,85	20296,2	20905,7	-2,87	-3,20	2,65	52,1	574,9	683,7	18,27	6225,4	0,525	0,547	0,637	0,960
4,90	20546,1	21162,3	-2,86	-3,20	2,68	52,2	577,3	678,2	18,19	6254,8	0,526	0,548	0,639	0,960
4,95	20795,9	21418,9	-2,85	-3,19	2,71	52,3	579,6	672,8	18,11	6284,3	0,527	0,549	0,640	0,961
5,00	21045,8	21675,5	-2,84	-3,19	2,73	52,4	581,9	667,5	18,03	6313,7	0,528	0,549	0,642	0,961
5,05	21306,9	21943,6	-2,85	-3,18	2,76	52,5	584,0	661,8	17,94	6342,6	0,529	0,550	0,643	0,961
5,10	21568,0	22211,7	-2,85	-3,18	2,79	52,7	586,1	656,3	17,85	6371,5	0,530	0,551	0,644	0,962
5,15	21829,1	22479,8	-2,85	-3,18	2,82	52,8	588,3	650,8	17,76	6400,4	0,532	0,553	0,646	0,962
5,20	22090,2	22747,9	-2,85	-3,17	2,84	52,9	590,4	645,5	17,68	6429,2	0,533	0,554	0,647	0,963

$\times 1.025 \times c$

Constant “c”

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

DRAFT (M)	DISP MLD(M3)	DISP EXT(T)	VCB (M)	LCB (M)	LCF (M)	KMT (M)	KML (M)	MTC (T-M)	TPC (TON)	WSA (M2)	C B	C W	C P	C M
3.75	14919.7	15400.8	2.025	118.394	119.002	21.691	838.95	525.6	49.7	5602.1	.5072	.6127	.5421	.9356
3.80	15160.8	15648.4	2.051	118.403	119.048	21.524	830.42	528.6	49.9	5631.7	.5086	.6145	.5431	.9364
3.85	15401.8	15896.1	2.076	118.412	119.093	21.362	822.15	531.6	50.0	5661.4	.5099	.6163	.5441	.9372
3.90	15644.8	16145.8	2.103	118.422	119.132	21.201	813.71	534.3	50.1	5690.8	.5113	.6180	.5451	.9380
3.95	15891.1	16398.8	2.133	118.434	119.159	21.037	804.83	536.7	50.3	5719.8	.5127	.6196	.5462	.9388

DRAFT MLD [M]	DISP MLD [M3]	DISP EXT [T]	LCF [M]	LCB [M]	VCB [M]	TPC [T]	MTC [T-M]	KML [M]	KMT [M]	WSA [M2]	CB	CP	CW	CM
5,25	22351,3	23016,0	-2,85	-3,17	2,87	53,0	592,5	640,4	17,59	6458,1	0,534	0,555	0,648	0,963
5,30	22612,4	23284,1	-2,86	-3,17	2,90	53,1	594,6	635,3	17,51	6487,0	0,535	0,556	0,649	0,963
5,35	22873,5	23552,2	-2,86	-3,16	2,93	53,2	596,8	630,4	17,44	6515,9	0,536	0,557	0,651	0,964
5,40	23134,6	23820,3	-2,86	-3,16	2,95	53,3	598,9	625,6	17,36	6544,8	0,537	0,557	0,652	0,964
5,45	23395,7	24088,4	-2,86	-3,16	2,98	53,4	601,0	620,8	17,29	6573,7	0,538	0,558	0,653	0,964
								616,2	17,22	6602,6	0,539	0,559	0,655	0,965
								611,7	17,15	6631,4	0,540	0,560	0,656	0,965
								607,3	17,09	6660,3	0,542	0,561	0,657	0,965
								603,0	17,02	6689,2	0,543	0,562	0,659	0,966
								598,8	16,96	6718,1	0,544	0,563	0,660	0,966
								594,6	16,90	6747,0	0,544	0,564	0,661	0,966
								590,6	16,84	6775,9	0,545	0,564	0,663	0,966
								586,6	16,79	6804,7	0,546	0,565	0,664	0,967
5,90	25745,6	26501,3	-2,88	-3,12	3,23	54,4	620,1	582,7	16,73	6833,6	0,547	0,566	0,665	0,967
5,95	26006,7	26769,4	-2,88	-3,12	3,26	54,5	622,3	578,9	16,68	6862,5	0,548	0,567	0,667	0,967
6,65	29794,8	30658,9	-3,28	-3,12	3,64	55,9	653,3	531,4	16,02	7265,9	0,562	0,579	0,684	0,971
6,70	30066,2	30937,5	-3,31	-3,12	3,67	56,0	655,6	528,4	15,98	7294,7	0,563	0,580	0,685	0,971
6,75	30337,5	31216,0	-3,34	-3,12	3,70	56,1	657,8	525,5	15,94	7323,5	0,564	0,580	0,687	0,971
6,80	30608,8	31494,6	-3,37	-3,12	3,72	56,2	660,0	522,7	15,91	7352,3	0,565	0,581	0,688	0,971
6,85	30880,1	31773,2	-3,40	-3,12	3,75	56,3	662,2	519,9	15,87	7381,1	0,565	0,582	0,689	0,972
6,90	31151,4	32051,7	-3,43	-3,12	3,78	56,4	664,5	517,2	15,84	7409,9	0,566	0,583	0,690	0,972
6,95	31422,7	32330,3	-3,46	-3,12	3,81	56,5	666,7	514,5	15,81	7438,7	0,567	0,583	0,692	0,972
7,00	31694,0	32608,9	-3,49	-3,12	3,84	56,6	668,9	511,8	15,78	7467,5	0,568	0,584	0,693	0,972
7,05	31975,1	32897,5	-3,54	-3,13	3,86	56,7	671,2	509,1	15,74	7496,5	0,569	0,585	0,694	0,972
7,10	32256,2	33186,1	-3,59	-3,13	3,89	56,8	673,5	506,5	15,71	7525,4	0,570	0,586	0,695	0,973
7,15	32537,3	33474,7	-3,64	-3,14	3,92	56,9	675,8	503,9	15,67	7554,3	0,571	0,587	0,697	0,973
7,20	32818,4	33763,3	-3,69	-3,15	3,95	57,0	678,2	501,3	15,64	7583,3	0,572	0,588	0,698	0,973
7,25	33099,5	34051,9	-3,75	-3,15	3,97	57,1	680,5	498,8	15,61	7612,2	0,573	0,588	0,699	0,973
7,30	33380,6	34340,4	-3,80	-3,16	4,00	57,2	682,8	496,4	15,58	7641,2	0,573	0,589	0,700	0,973
7,35	33661,7	34629,0	-3,85	-3,17	4,03	57,3	685,1	493,9	15,55	7670,1	0,574	0,590	0,701	0,974
7,40	33942,8	34917,6	-3,90	-3,17	4,06	57,4	687,4	491,6	15,52	7699,0	0,575	0,591	0,703	0,974
7,45	34223,9	35206,2	-3,95	-3,18	4,08	57,5	689,7	489,2	15,49	7728,0	0,576	0,592	0,704	0,974

Loading Conditions

☑ A ship can be operated at various loading conditions.

☑ According to the loading condition, the displacement of the ship varies.

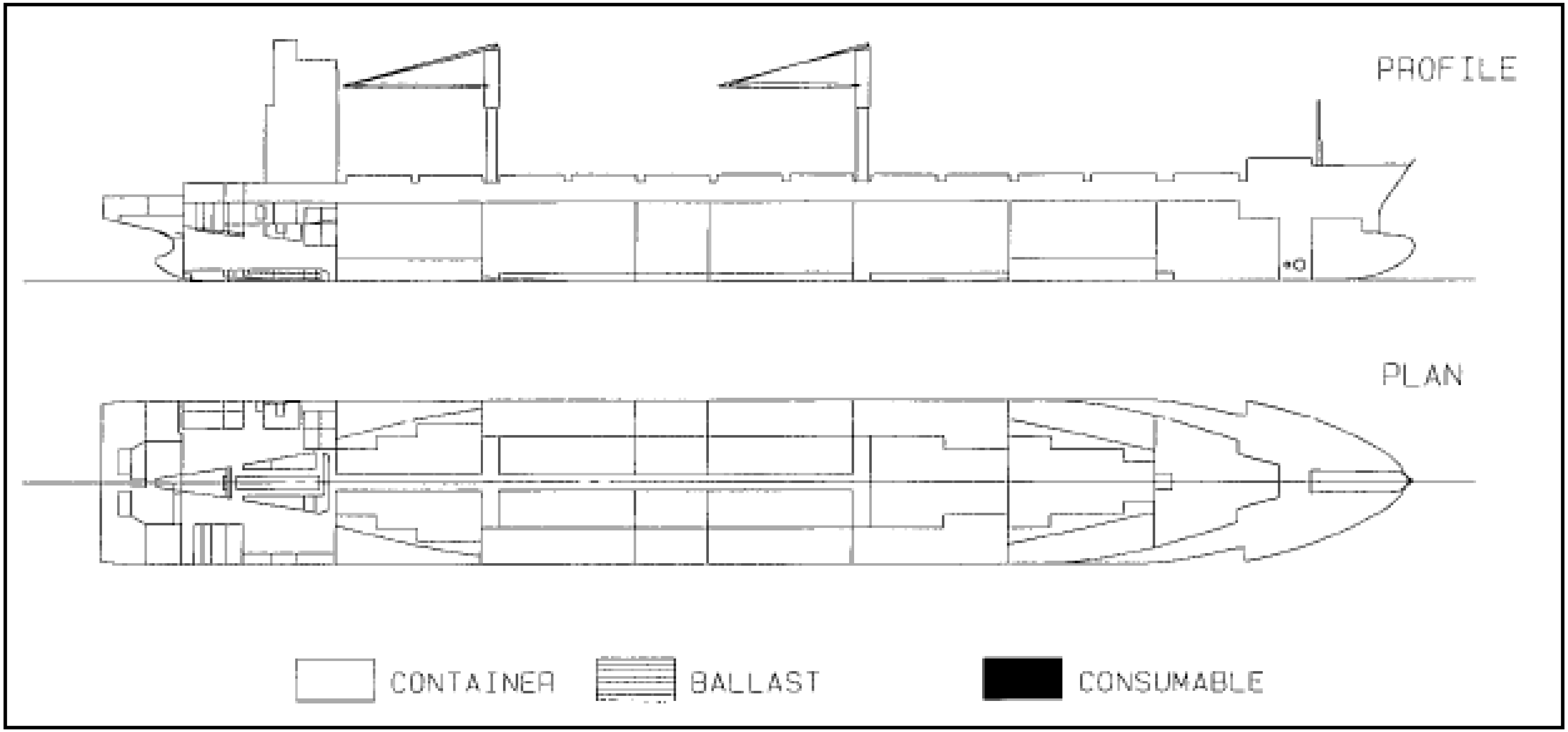
- This means that LCG and KG varies as well.

☑ 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)**



Loading Conditions: Lightship Condition (2/6)

■ Calculation of *MTC*

DRAUGHT F.P	=	1.526	M
DRAUGHT MIDSHIP	=	3.806	M
DRAUGHT A.P	=	6.086	M
TRIM BY STERN	=	4.560	M
PROPELLER I/D	=	74.0	%
DISPLACEMENT	=	15998.1	T
DRAUGHT AT LCF	=	3.871	M
LCB FROM A.P	=	118.416	M
LCG FROM A.P	=	103.228	M
TRIM LEVER : A	=	15.188	M

K.M.T	=	21.296	M
KG (SOLID)	=	13.200	M
GM (SOLID)	=	8.096	M
FREE SURF. CORR.(GGo)	=	.000	M
GoM (FLUID)	=	8.096	M
KGo ACTUAL (FLUID)	=	13.200	M
TRIM (DIS*A)/(MTC*100)	=	4.560	M
FREE SURF. MOM.	=	0	T-M
① M.T.C.	=	532.8	T-M
LCF FROM A.P	=	119.110	M

Let's calculate this!

① In hydrostatics table

DRAFT (M)	DISP MLD(M3)	DISP EXT(T)	VCB (M)	LCB (M)	LCF (M)	KMT (M)	KML (M)	MTC (T-M)	TPC (TON)	WSA (M2)	C B	C W	C P	C M
3.75	14919.7	15400.8	2.025	118.394	119.002	21.691	838.95	525.6	49.7	5602.1	.5072	.6127	.5421	.9356
3.80	15160.8	15648.4	2.051	118.403	119.048	21.524	830.42	528.6	49.9	5631.7	.5086	.6145	.5431	.9364
3.85	15401.8	15896.1	2.076	118.412	119.093	21.362	822.15	531.6	50.0	5661.4	.5099	.6163	.5441	.9372
3.90	15644.8	16145.8	2.103	118.422	119.132	21.201	813.71	534.3	50.1	5690.8	.5113	.6180	.5451	.9380
3.95	15891.1	16398.8	2.133	118.434	119.159	21.037	804.83	536.7	50.3	5719.8	.5127	.6196	.5462	.9388

By linear interpolation, draft at LCF= 3.871[m], $VCB(=KB)=2.087[m],\ KM_L=818.61[m]$

$$\left(BM_L = KM_L - KB = 818.61 - 2.09 = 816.52\right)$$

$$MTC = \frac{\Delta \times GM_L}{100 \times LBP} \approx \frac{\Delta \times BM_L}{100 \times LBP} = \frac{15{,}998.1 \times 816.52}{100 \times 245.24} = 532.7[ton \cdot m]$$

Loading Conditions: Lightship Condition (3/6)

■ Calculation of *Trim*

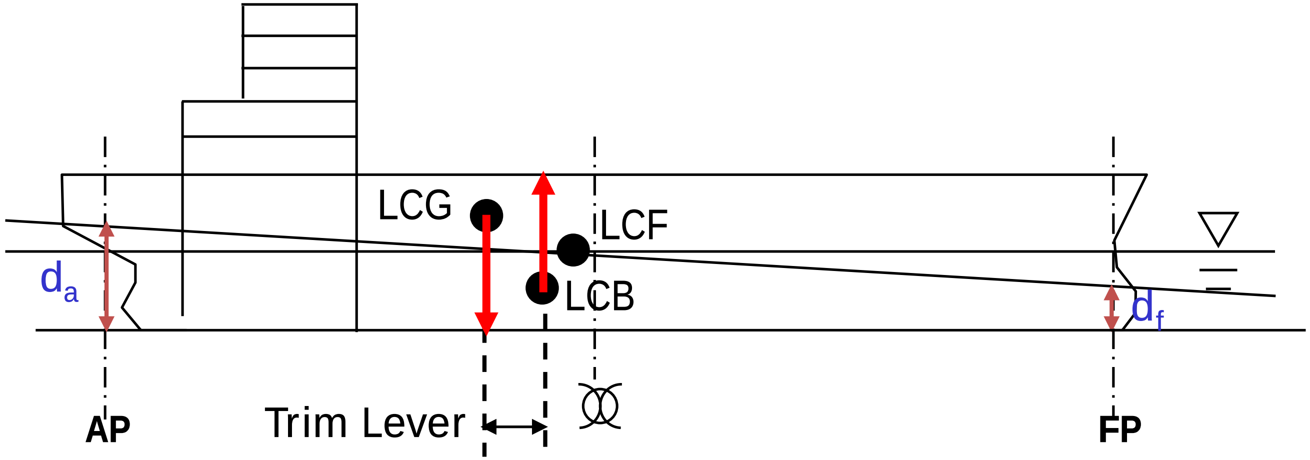
DRAUGHT F.P	=	1.526	M	K.M.T	=	21.296	M
DRAUGHT MIDSHIP	=	3.806	M	KG (SOLID)	=	13.200	M
DRAUGHT A.P	=	6.086	M	GM (SOLID)	=	8.096	M
TRIM BY STERN	=	4.560	M	FREE SURF. CORR.(GGo)	=	.000	M
PROPELLER I/D	=	74.0	%	GoM (FLUID)	=	8.096	M
DISPLACEMENT	=	15998.1	T	③ KGo ACTUAL (FLUID)	=	13.200	M
② DRAUGHT AT LCF	=	3.871	M	TRIM (DIS*A)/(MTC*100)	=	4.560	M
LCB FROM A.P	=	118.416	M	FREE SURF. MOM.	=	0	T-M
LCG FROM A.P	=	103.228	M	M.T.C.	=	532.8	T-M
TRIM LEVER : A	=	15.188	M	LCF FROM A.P	=	119.110	M

Let's calculate this! (③ TRIM)

Let's calculate this! (② LCB, LCG, TRIM LEVER)

② $Trim\ Lever = LCB - LCG = 118.416 - 103.228 = 15.188[m]$

③ $Trim[m] = \dfrac{\Delta \times Trim\,Lever}{MTC \times 100} = \dfrac{15{,}998.1 \times 15.188}{532.8 \times 100} = 4.560[m]$



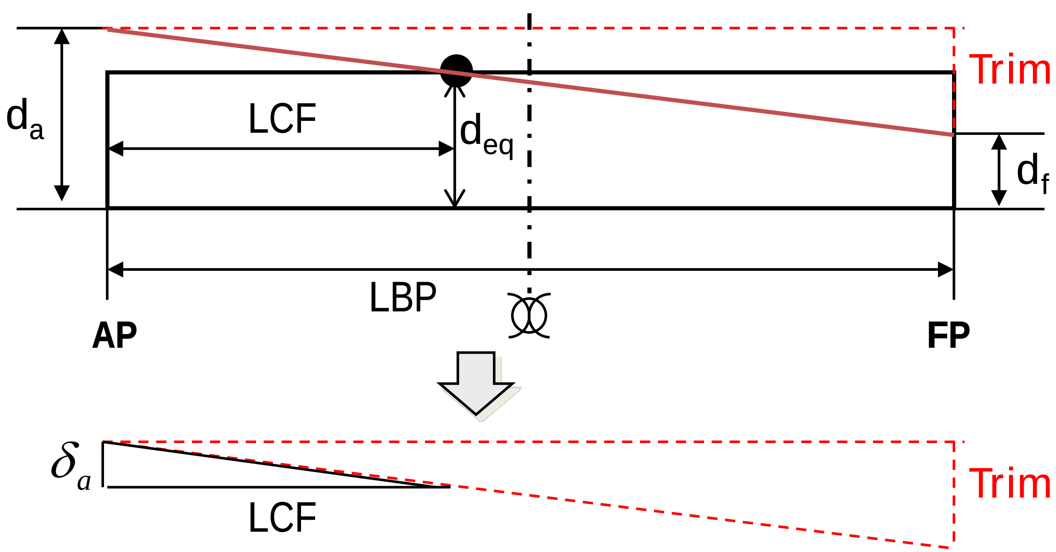
Loading Conditions: Lightship Condition (4/6)

■ Calculation of *Trim forward, Trim aft*

④ Let's calculate this!

DRAUGHT F.P	= 1.526 M	K.M.T	= 21.296 M
DRAUGHT MIDSHIP	= 3.806 M	KG (SOLID)	= 13.200 M
DRAUGHT A.P	= 6.086 M	GM (SOLID)	= 8.096 M
TRIM BY STERN	= 4.560 M	FREE SURF. CORR.(GGo)	= .000 M
PROPELLER I/D	= 74.0 %	GoM (FLUID)	= 8.096 M
DISPLACEMENT	= 15998.1 T	KGo ACTUAL (FLUID)	= 13.200 M
DRAUGHT AT LCF	= 3.871 M	TRIM (DIS*A)/(MTC*100)	= 4.560 M
LCB FROM A.P	= 118.416 M	FREE SURF. MOM.	= 0 T-M
LCG FROM A.P	= 103.228 M	M.T.C.	= 532.8 T-M
TRIM LEVER : A	= 15.188 M	LCF FROM A.P	= 119.110 M

④



$$LBP : Trim = LCF : \delta_a$$

$$\delta_a = \frac{LCF}{LBP} \times Trim$$

$$d_a = d_{eq} + \delta_a = d_{eq} + \frac{LCF}{LBP} \times Trim$$

$$= 3.871 + \frac{119.110}{245.24} \times 4.560$$

$$= 6.086[m]$$

$$d_f = d_a - Trim$$

$$= 6.086 - 4.560 = 1.526[m]$$

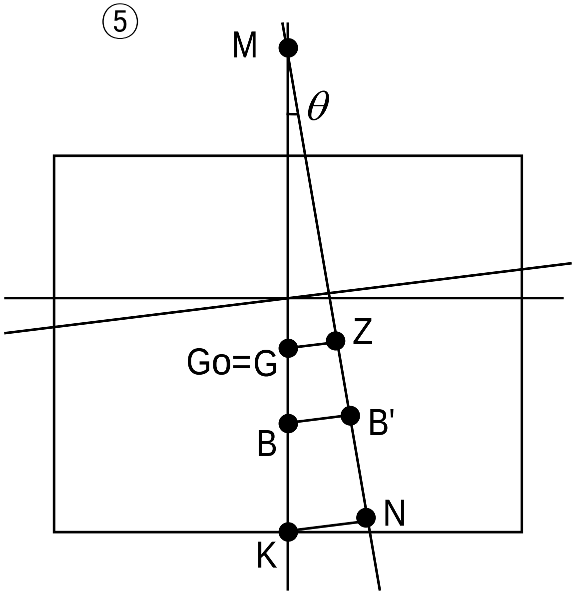
Loading Conditions: Lightship Condition (5/6)

■ Calculation of *GM, KG*

Let's calculate this!

			⑤		
DRAUGHT F.P	=	1.526 M	K.M.T	=	21.296 M
DRAUGHT MIDSHIP	=	3.806 M	KG (SOLID)	=	13.200 M
DRAUGHT A.P	=	6.086 M	GM (SOLID)	=	8.096 M
TRIM BY STERN	=	4.560 M	FREE SURF. CORR. (GGo)	=	.000 M
PROPELLER I/D	=	74.0 %	GoM (FLUID)	=	8.096 M
DISPLACEMENT	=	15998.1 T	KGo ACTUAL (FLUID)	=	13.200 M
DRAUGHT AT LCF	=	3.871 M	TRIM (DIS*A)/(MTC*100)	=	4.560 M
LCB FROM A.P	=	118.416 M	FREE SURF. MOM.	=	0 T-M
LCG FROM A.P	=	103.228 M	M.T.C.	=	532.8 T-M
TRIM LEVER : A	=	15.188 M	LCF FROM A.P	=	119.110 M

⑤



KM_T : Given in hydrostatic tables (KM_T = 21.296 [m])

KG : Calculation from the distribution of *LWT* and *DWT*

(KG = 13.2 [m])

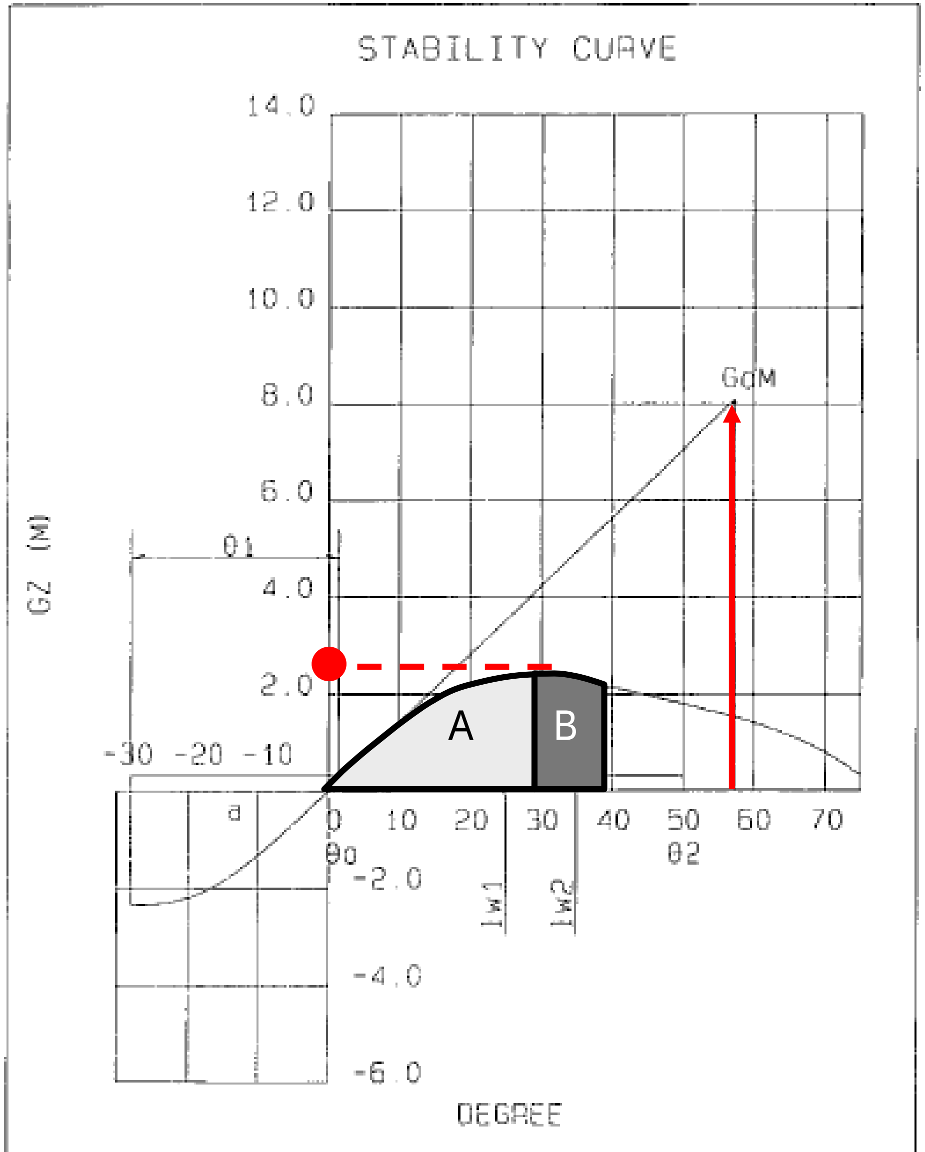
$GM = KM_T - KG$ (GM = 21.296 – 13.2 = 8.096 [m])

$GGo = 0$ (∵ No liquid cargo in lightship condition)

∴ $KGo = KG = 13.2$ [m]

Loading Conditions: Lightship Condition (6/6)

■ Stability check



IMO A-749(18) CHAP.3.1 CRITERION

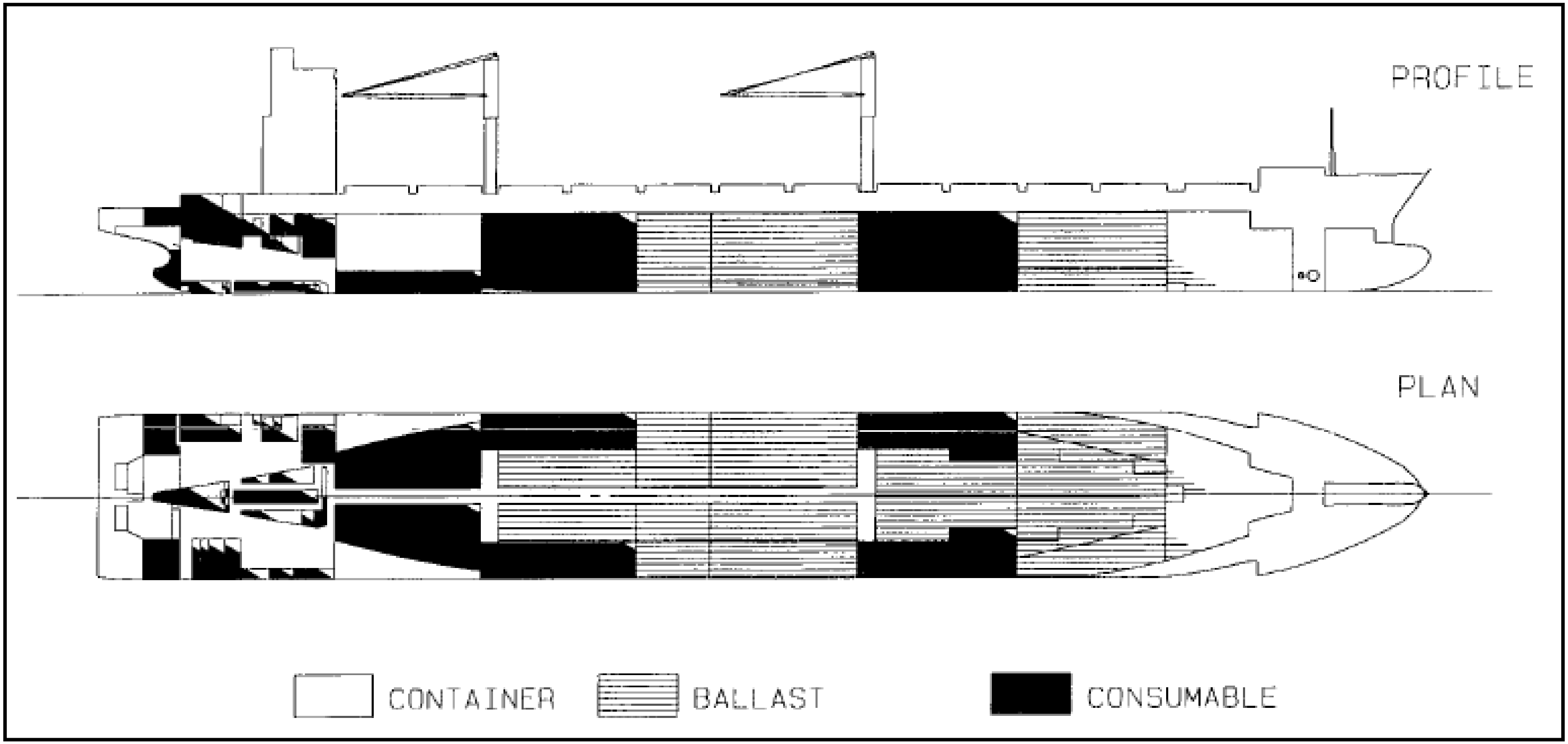
	ACTUAL	REQ.	
MIN. GoM	8.096	0.150	M
AREA 0-30	.849	0.055	M-RAD
AREA 0-40(θf)	1.236	0.090	M-RAD
AREA 30-40(θf)	.387	0.030	M-RAD
MAX. GZ	2.352	0.200	M
MAX. GZ OCCURS AT	27.2	25.00	DEG.
FLOODING ANGLE IS	90.0		DEG.

IMO A-749(18) CHAP.3.2 CRITERION

WIND AREA				4849	M^2
Z =				13.017	M
ROLLING PERIOD				10.4	SEC.
AREA a =	.914	,	b =	1.323	M-RAD
lw1 =	.203	,	lw2 =	.304	M
θo =	1.4	,	θ1 =	29.3	DEG.
θ2 =	50.0	,	θc =	75.1	DEG.

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*

DRAUGHT F.P	=	5.553 M	K.M.T	=	15.728 M
DRAUGHT MIDSHIP	=	6.998 M	KG (SOLID)	=	9.584 M
DRAUGHT A.P	=	8.443 M	GM (SOLID)	=	6.144 M
TRIM BY STERN	=	2.890 M	FREE SURF. CORR.(GGo)	=	.177 M
PROPELLER I/D	=	105.1 %	GoM (FLUID)	=	5.967 M
DISPLACEMENT	=	32980.1 T	KGo ACTUAL (FLUID)	=	9.761 M
DRAUGHT AT LCF	=	7.044 M	① TRIM (DIS*A)/(MTC*100)	=	2.890 M
LCB FROM A.P	=	118.910 M	FREE SURF. MOM.	=	5847 T-M
LCG FROM A.P	=	113.116 M	M.T.C.	=	661.3 T-M
TRIM LEVER : A	=	5.794 M	LCF FROM A.P	=	118.707 M

① In hydrostatics table

Let's calculate this!

DRAFT (M)	DISP MLD(M3)	DISP EXT(T)	VCB (M)	LCB (M)	LCF (M)	KMT (M)	KML (M)	MTC (T-M)	TPC (TON)	WSA (M2)	C B	C W	C P	C M
7.00	31782.0	32730.5	3.802	118.912	118.753	15.763	498.01	659.6	56.4	7422.2	.5770	.6945	.5976	.9655
7.05	32056.1	33012.2	3.829	118.910	118.701	15.724	495.22	661.5	56.5	7450.0	.5779	.6956	.5983	.9658
7.10	32332.2	33296.0	3.858	118.907	118.639	15.686	492.45	663.4	56.5	7478.0	.5787	.6966	.5991	.9660
7.15	32608.3	33579.8	3.886	118.903	118.577	15.649	489.74	665.3	56.6	7506.0	.5796	.6977	.5998	.9662
7.20	32884.4	33863.6	3.914	118.900	118.516	15.613	487.07	667.2	56.7	7534.1	.5804	.6987	.6005	.9665

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

$$\left(BM_L = KM_L - KB = 495.55 - 3.83 = 491.72\right)$$

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

Loading Conditions: Ballast Departure Condition (3/6)

■ Calculation of *Trim*

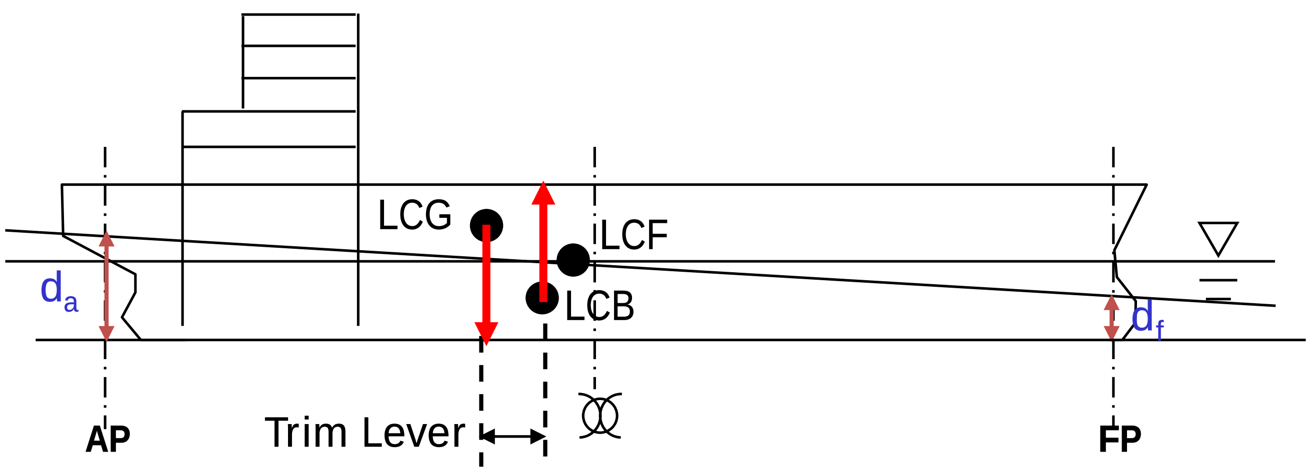
DRAUGHT F.P	= 5.553 M		K.M.T	= 15.728 M
DRAUGHT MIDSHIP	= 6.998 M		KG (SOLID)	= 9.584 M
DRAUGHT A.P	= 8.443 M		GM (SOLID)	= 6.144 M
TRIM BY STERN	= 2.890 M		FREE SURF. CORR.(GGo)	= .177 M
PROPELLER I/D	= 105.1 %		GoM (FLUID)	= 5.957 M
DISPLACEMENT	= 32980.1 T	③	KGo ACTUAL (FLUID)	= 9.761 M
② DRAUGHT AT LCF	= 7.044 M		TRIM (DIS×A)/(MTC×100)	= 2.890 M
LCB FROM A.P	= 118.910 M		FREE SURF. MOM.	= 5847 T-M
LCG FROM A.P	= 113.116 M		M.T.C.	= 661.3 T-M
TRIM LEVER : A	= 5.794 M		LCF FROM A.P	= 118.707 M

Let's calculate this! (③)

Let's calculate this! (②)

② $Trim\ Lever = LCB - LCG = 118.910 - 113.116 = 5.794[m]$

③ $Trim[m] = \dfrac{\Delta \times Trim\ Lever}{MTC \times 100} = \dfrac{32{,}980.1 \times 5.794}{661.3 \times 100} = 2.890[m]$

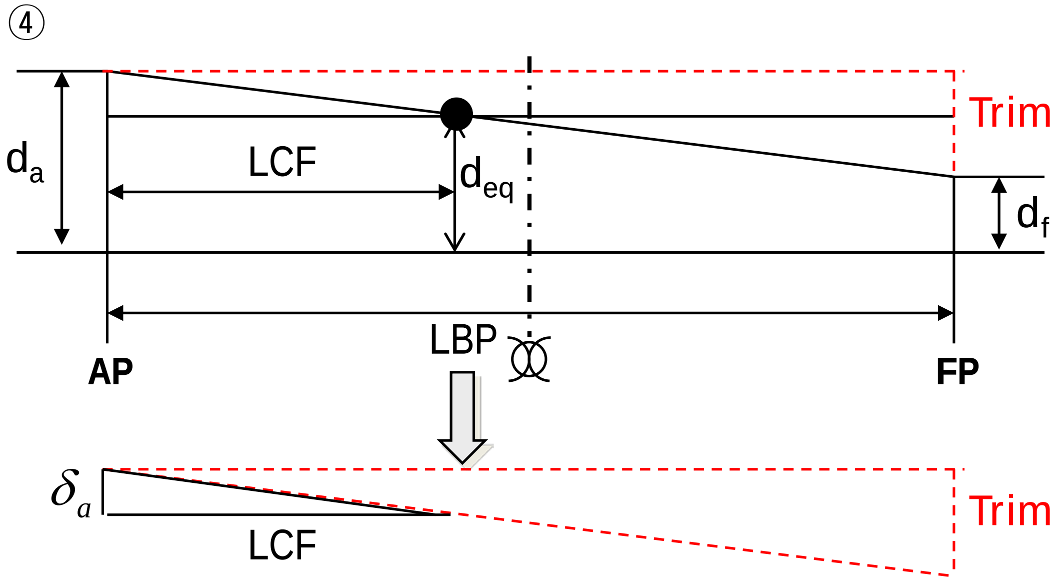


Loading Conditions: Ballast Departure Condition (4/6)

■ Calculation of *Trim forward, Trim aft*

④ Let's calculate this!

DRAUGHT F.P	= 5.553 M	K.M.T	= 15.728 M
DRAUGHT MIDSHIP	= 6.998 M	KG (SOLID)	= 9.584 M
DRAUGHT A.P	= 8.443 M	GM (SOLID)	= 6.144 M
TRIM BY STERN	= 2.890 M	FREE SURF. CORR.(GGo)	= .177 M
PROPELLER I/D	= 105.1 %	GoM (FLUID)	= 5.967 M
DISPLACEMENT	= 32980.1 T	KGo ACTUAL (FLUID)	= 9.761 M
DRAUGHT AT LCF	= 7.044 M	TRIM (DIS*A)/(MTC*100)	= 2.890 M
LCB FROM A.P	= 118.910 M	FREE SURF. MOM.	= 5847 T-M
LCG FROM A.P	= 113.116 M	M.T.C.	= 661.3 T-M
TRIM LEVER : A	= 5.794 M	LCF FROM A.P	= 118.707 M



$$LBP : Trim = LCF : \delta_a$$

$$\delta_a = \frac{LCF}{LBP} \times Trim$$

$$d_a = d_{eq} + \delta_a = d_{eq} + \frac{LCF}{LBP} \times Trim$$

$$= 7.044 + \frac{118.707}{245.24} \times 2.890$$

$$= 8.443[m]$$

$$d_f = d_a - Trim$$

$$= 8.443 - 2.890 = 5.553[m]$$

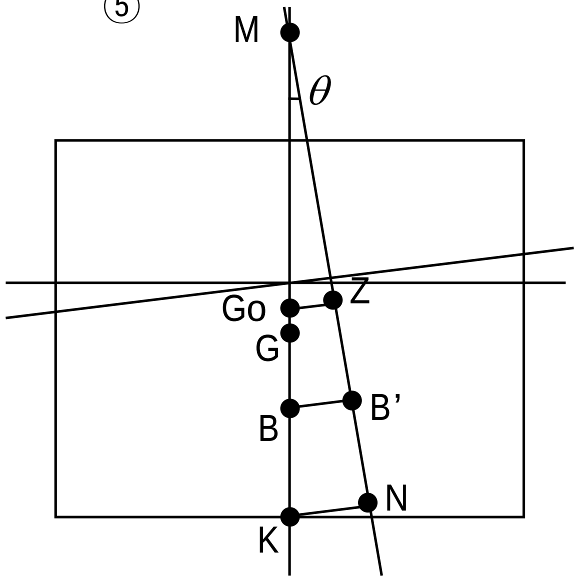
Loading Conditions: Ballast Departure Condition (5/6)

■ Calculation of *GM, KG*

Let's calculate this!

DRAUGHT F.P	=	5.553 M	⑤ K.M.T	=	15.728 M
DRAUGHT MIDSHIP	=	6.998 M	KG (SOLID)	=	9.584 M
DRAUGHT A.P	=	8.443 M	GM (SOLID)	=	6.144 M
TRIM BY STERN	=	2.890 M	FREE SURF. CORR.(GGo)	=	.177 M
PROPELLER I/D	=	105.1 %	GoM (FLUID)	=	5.967 M
DISPLACEMENT	=	32980.1 T	KGo ACTUAL (FLUID)	=	9.761 M
DRAUGHT AT LCF	=	7.044 M	TRIM (DIS*A)/(MTC*100)	=	2.890 M
LCB FROM A.P	=	118.910 M	FREE SURF. MOM.	=	5847 T-M
LCG FROM A.P	=	113.116 M	M.T.C.	=	661.3 T-M
TRIM LEVER : A	=	5.794 M	LCF FROM A.P	=	118.707 M

⑤



KMT : Given in hydrostatics table (KM_T = 15.728 [m])

KG : Calculation from distribution of *LWT* and *DWT*

(*KG* = 9.584 [m])

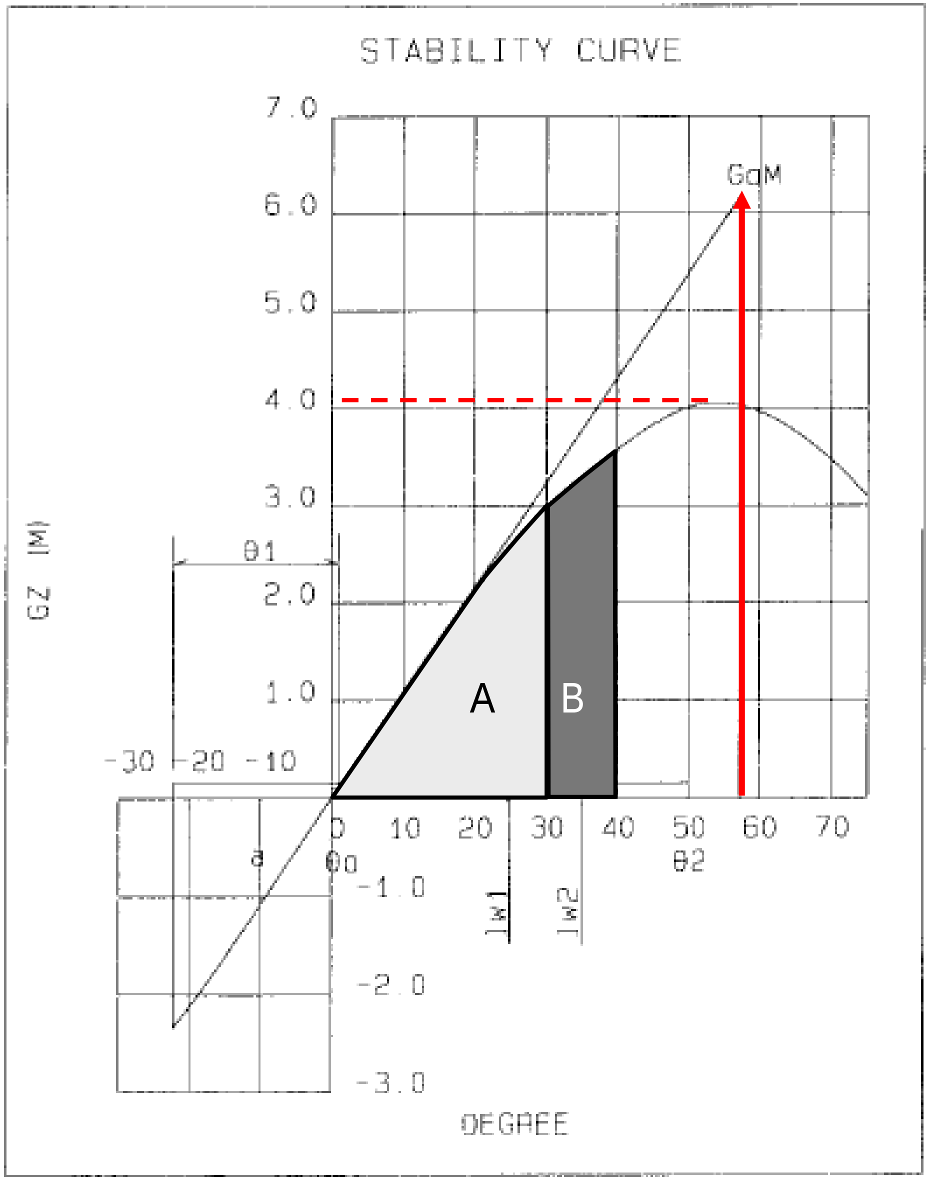
$GM = KM_T - KG$ (GM = 15.728 – 9.584 = 6.144 [m])

GGo = 0.177

∴ *KGo* = *KG* + *GGo* = 9.584 + 0.177 = 9.761 [m]

Loading Conditions: Ballast Departure Condition (6/6)

■ Stability check



IMO A-749(18) CHAP.3.1 CRITERION

	ACTUAL	REQ.	
MIN. GoM	6.177	0.150	M
AREA 0-30	.827	0.055	M-RAD
AREA 0-40 (θf)	1.404	0.090	M-RAD
AREA 30-40 (θf)	.577	0.030	M-RAD
MAX. GZ	4.056	0.200	M
MAX. GZ OCCURS AT	54.1	25.00	DEG.
FLOODING ANGLE IS	77.0		DEG.

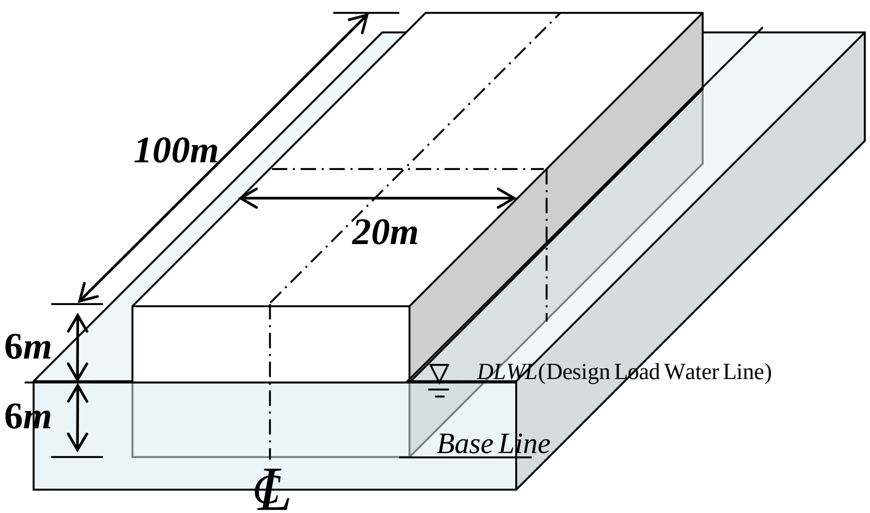
IMO A-749(18) CHAP.3.2 CRITERION

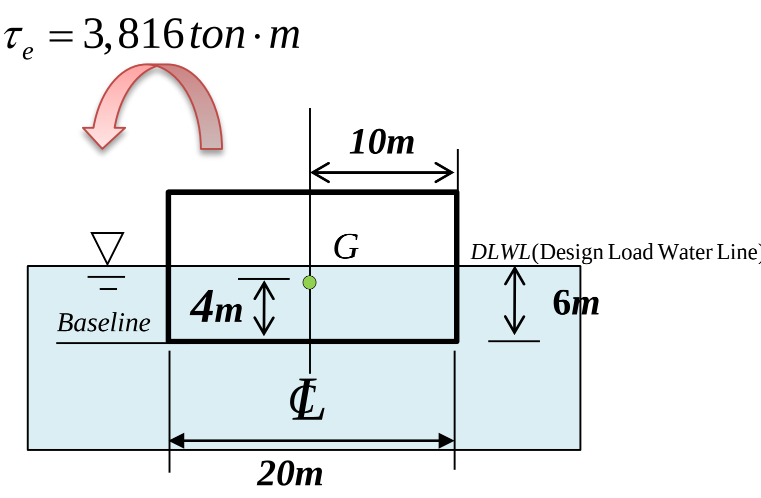
WIND AREA					4283	M^2
Z	=				13.173	M
ROLLING PERIOD					10.1	SEC.
AREA a	=	.525	, b	=	1.935	M-RAD
lw1	=	.103	, lw2	=	.155	M
θo	=	1.0	, θ1	=	23.2	DEG.
θ2	=	50.0	, θc	=	90.0	DEG.

More Examples

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

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 3,816ton-m is applied on the ship, **calculate an angle of heel**.





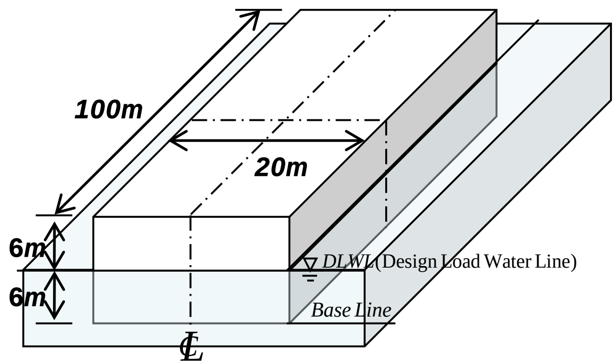
< Front View>

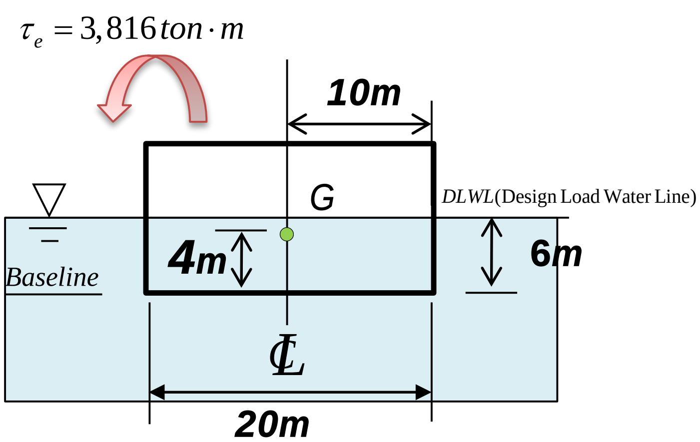
예제6.1

[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**





<Front View>

$$\boxed{\tau_e = F_B \cdot GM \cdot \sin\phi}$$

$$\rightarrow \sin\phi = \frac{\tau_e}{F_B \cdot GM}$$

$$\rightarrow \phi = \sin^{-1}\left(\frac{\tau_e}{F_B \cdot GM}\right)$$

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

$$GM = KB + BM - KG$$

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

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

$$= 4^\circ$$

$$BM = \frac{I_T}{\nabla}$$

In case of box shaped barge

$$= \frac{(L \cdot B^3)/12}{L \cdot B \cdot T}$$

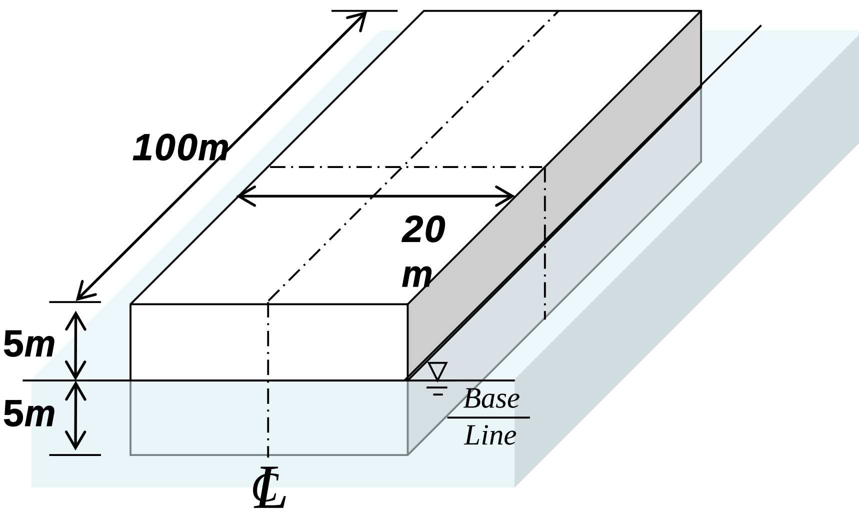
$$= \frac{(100 \cdot 20^3)/12}{100 \cdot 20 \cdot 6} = 5.6[m]$$

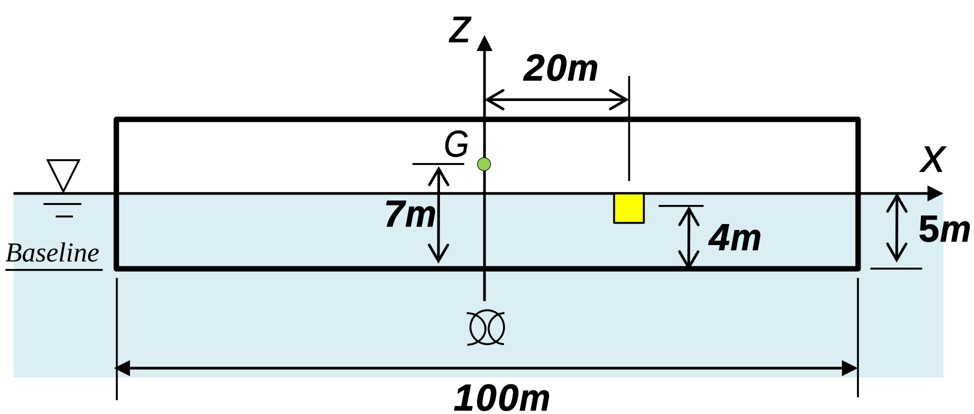
$$KB = T/2 = 3[m]$$

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

[Example] Calculation of a Trim of a Ship

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**.



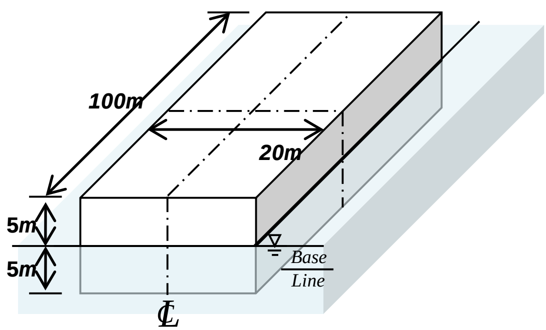


<Elevation View>

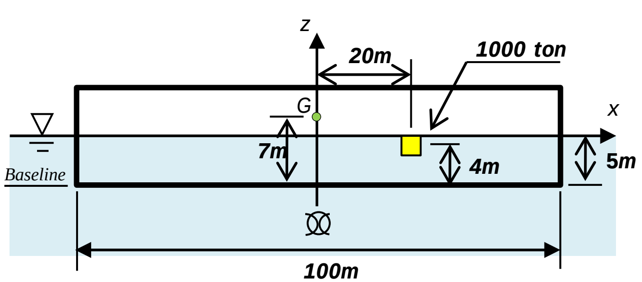
[Example] Calculation of a Trim of a Ship

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



<Three Dimensional View>



<Elevation View>

$$\mathbf{F} = \mathbf{A}\mathbf{x}$$

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.

Given:
Load of the 1,000 ton cargo
(At 20m in front of the center of the ship and 4m above the baseline)

Load of the cargo
➡ The change of the force(moment) is given.

Find: The draft at the aft perpendicular of the ship

Problem to calculate the change of the position

<Notation>

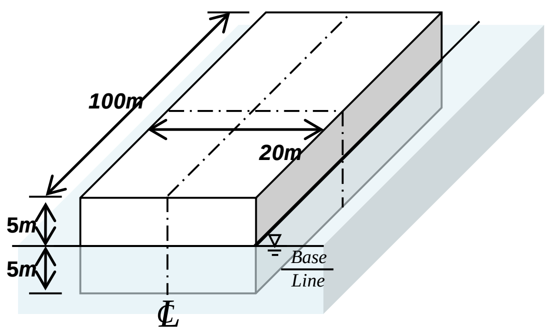
$\square_0$: Sub Index 0 – State before the change of position

$\square_1$: Sub Index 1 – State after the change of position

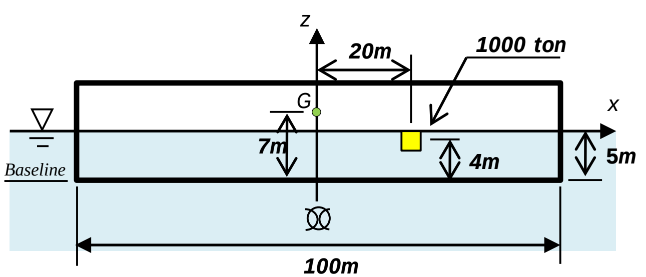
[Example] Calculation of Trim of a Ship
- Calculation of the Approximate Solution by Using Linearization (1/7)

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



<Three Dimensional View>



<Elevation View>

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

Calculation of the approximate solution by linearizing the problem

① Calculation for change of draft

$\delta\Delta = TPC \cdot \delta T \qquad T_1 = T_0 + \delta T$ (δT: change of draft)

② Calculation of trim

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

②-1) Trim Moment: w (weight of the cargo) × l (distance)
(Linearized trim moment. How can we calculate the actual trim moment?)

②-2) $\overline{GM_L} = \overline{KB} + \overline{BM_L} - \overline{KG}$

②-3) $MTC = \frac{\Delta \cdot \overline{GM_L}}{100 \cdot L_{BP}}$

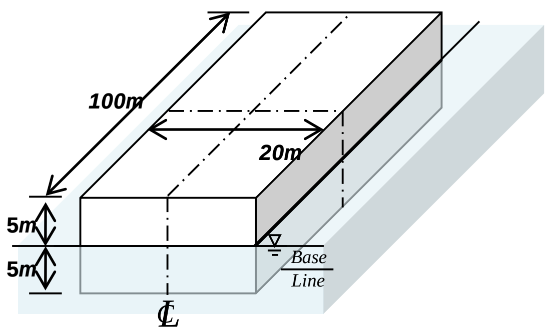
③ Calculation of draft at the aft perpendicular of the ship

$T_{Aft,Fore} = T_1 \pm \frac{\text{trim}}{2}$ (when LCF is located at the middle point of L_{BP})

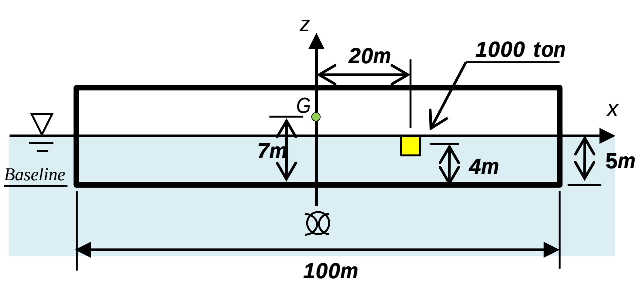
[Example] Calculation of Trim of a Ship
- Calculation of the Approximate Solution by Using Linearization (2/7)

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



<Three Dimensional View>



<Elevation View>

① $T_1 = T_0 + \delta T$
$\delta\Delta = TPC \cdot \delta T$

① Calculation of the change of the draft (T)

$$\delta\Delta = TPC \cdot \delta T$$

$$TPC = \frac{A_{WP\_0} \cdot \rho}{100} = \frac{L_0 \cdot B_0 \cdot 1.025}{100} = \frac{100 \cdot 20 \cdot 1.025}{100}$$

$$= 20.5 \text{ ton/cm}$$

$$\delta\Delta = 1,000 \text{ ton}$$

$$\delta T = \frac{\delta\Delta}{TPC} = \frac{1,000}{20.5} = 48.8 \text{ cm} = 0.488 \text{ m}$$

$$T_1 = T_0 + \delta T = 5 + 0.488 = 5.488\,m$$

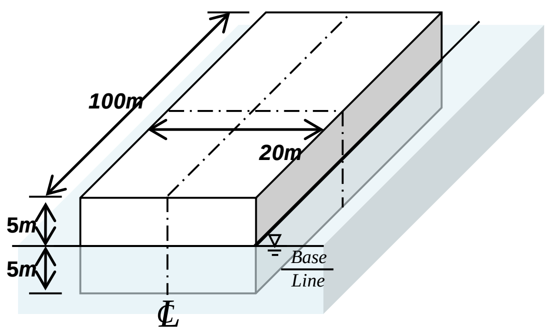
In calculating TPC, is it reasonable to assume as below?

$$A_{WP\_0} = L_0 \cdot B_0$$

[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



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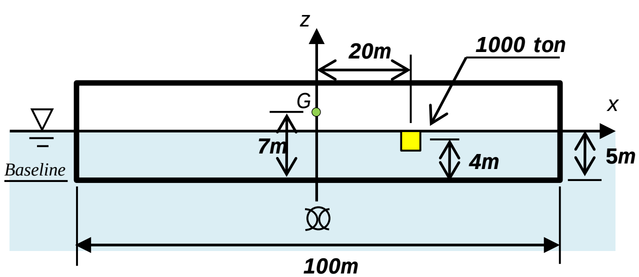


<Elevation View>

① $T_1 = T_0 + \delta T$
$\delta\Delta = TPC \cdot \delta T$

② $\text{Trim[m]} = \dfrac{\sum \text{Trim Moment}}{MTC \cdot 100}$

$\text{Trim Moment} = w \cdot l \qquad MTC = \dfrac{\Delta \cdot \overline{GM_L}}{100 \cdot L_{BP}}$

$\overline{GM_L} = \overline{KB} + \overline{BM_L} - \overline{KG}$

③ $T_{Aft,Fore} = ①T \pm \dfrac{②\text{trim}}{2}$

② Calculation of trim

②-1) Trim moment

$$\text{Trim moment} = w \cdot l \cdot \cos\theta \cong w \cdot l$$ (By assuming that θ is small)

$$= 1,000 \cdot 20 = 20,000 \text{ ton-m}$$

②-2) Calculation of GM_{L1}

$$KB_1 = \frac{T_1}{2} = \frac{5.488}{2} = 2.744\,\text{m}$$

$$W_0 = \Delta_0 = \rho \cdot L_0 \cdot B_0 \cdot T_0 = 100 \cdot 20 \cdot 5 \cdot 1.025$$

$$= 10,250\,\text{ton}(\text{exactly Mg})$$

$$W_1 = \Delta_1 = \Delta_0 + w = 10,250 + 1,000 = 11,250\,\text{ton}$$

$$KG_1 = \frac{W_0 \cdot KG_0 + w \cdot z_{c\_w}}{W_1}$$

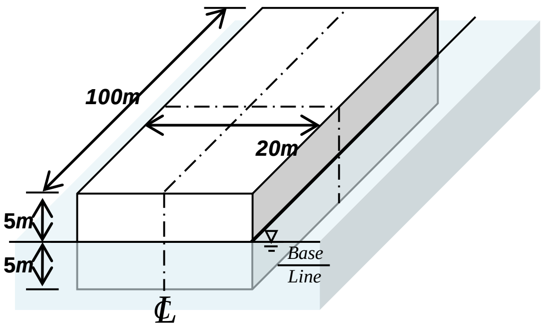
$$KG_1 = \frac{10,250 \cdot 7 + 1,000 \cdot 4}{11,250} = 6.73\,\text{m}$$

Is it reasonable that KB_1 is equal to $T_1/2$?

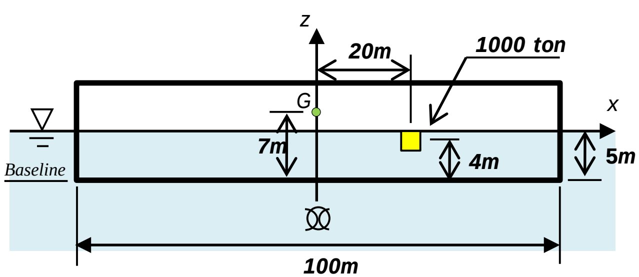
[Example] Calculation of Trim of a Ship
- Calculation of the Approximate Solution by Using Linearization (4/7)

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



<Three Dimensional View>



<Elevation View>

①$T_1 = T_0 + \delta T$
$\delta\Delta = TPC \cdot \delta T$

②$\text{Trim[m]} = \dfrac{\sum \text{Trim Moment}}{MTC \cdot 100}$

$\text{Trim Moment} = w \cdot l \quad MTC = \dfrac{\Delta \cdot \overline{GM}_L}{100 \cdot L_{BP}}$

$\overline{GM}_L = \overline{KB} + \overline{BM}_L - \overline{KG}$

③$T_{Aft,Fore} = ①T \pm \dfrac{②\text{trim}}{2}$

② Calculation of trim

②-1) Trim moment: 20,000ton-m

②-2) Calculation of GM_{L1}

$$KB_1 = 2.744\,\text{m}, KG_1 = 6.73\,\text{m}$$

$$BM_{L1} = \frac{I_{L1}}{\nabla}$$

$$I_{L1} = \iint_{A_{WP}} x^2 dA$$

For the calculation of I_{L1}, "the inclined water plane area" should be known. However, we do not know it until the inclination angle is determined. The inclination angle, however, can only be determined, when "the inclined water plane area" 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.

$$\cong I_{L0} \cong \frac{B_0 \cdot L_0^3}{12} = \frac{20 \cdot 100^3}{12} = 1,666,667\,\text{m}^4$$

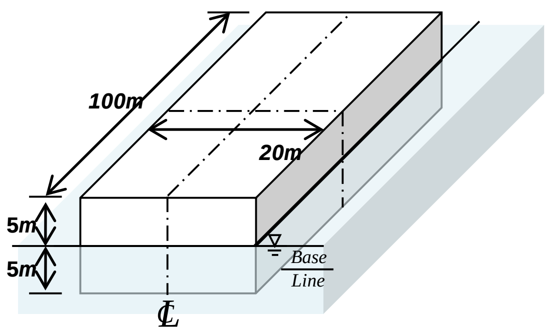
$$BM_{L1} = \frac{1,666,667}{11,250/1.025} = 151.9\,\text{m}$$

$$\therefore GM_{L1} = KB_1 + BM_{L1} - KG_1$$
$$= 2.74 + 151.9 - 6.73$$
$$= 147.91\,\text{m}$$

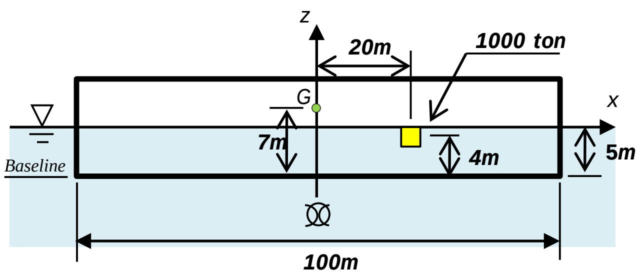
[Example] Calculation of Trim of a Ship
- Calculation of the Approximate Solution by Using Linearization (5/7)

Given:
L: 100m, B: 20m, D: 10m, T: 5m, KG: 7m
Cargo Load: 1,000ton
(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



<Three Dimensional View>



<Elevation View>

$$①T_1 = T_0 + \delta T$$
$$\delta\Delta = TPC \cdot \delta T$$

$$②\text{Trim}[m] = \frac{\sum \text{Trim Moment}}{MTC \cdot 100}$$
$$\text{Trim Moment} = w \cdot l \qquad MTC = \frac{\Delta \cdot \overline{GM}_L}{100 \cdot L_{BP}}$$
$$\overline{GM}_L = \overline{KB} + \overline{BM}_L - \overline{KG}$$

$$③T_{Aft,Fore} = ①T \pm \frac{②\text{trim}}{2}$$

② Calculation of trim

②-1) Trim moment: 20,000ton-m

②-2) Calculation of GM_{L1}: 147.91m

②-3) Calculation of *MTC*

$$MTC = \frac{\Delta \cdot GM_L}{L_{BP} \cdot 100} = \frac{\Delta \cdot GM_{L1}}{L_0 \cdot 100} = \frac{11,250 \cdot 147.91}{100 \cdot 100}$$
$$= 166\text{ton} \cdot \text{m/cm}$$

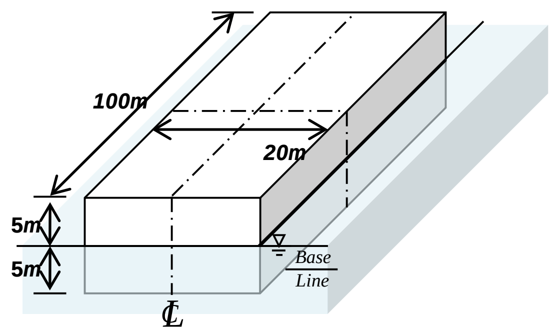
In case of the box-shaped ship, the LCF is located at the midship.

$$\therefore \text{Trim} = \frac{\text{Trim Moment}}{MTC \cdot 100} = \frac{20,000}{166 \cdot 100} = 1.2\text{m}$$

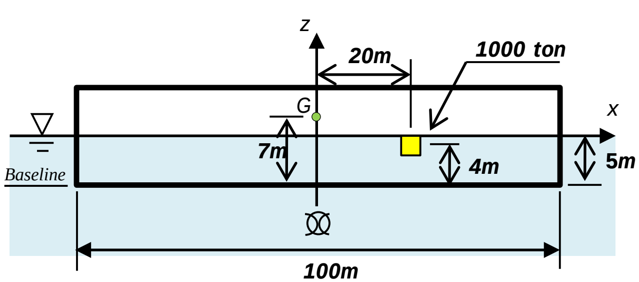
[Example] Calculation of Trim of a Ship
- Calculation of the Approximate Solution by Using Linearization (6/7)

Given:
L: 100m, B: 20m, D: 10m, T: 5m, KG: 7m
Cargo Load: 1,000ton
(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



<Three Dimensional View>



<Elevation View>

① $T_1 = T_0 + \delta T$
$\delta\Delta = TPC \cdot \delta T$

② $\text{Trim[m]} = \dfrac{\sum \text{Trim Moment}}{MTC \cdot 100}$

$\text{Trim Moment} = w \cdot l \quad MTC = \dfrac{\Delta \cdot \overline{GM_L}}{100 \cdot L_{BP}}$

$\overline{GM_L} = \overline{KB} + \overline{BM_L} - \overline{KG}$

③ $T_{Aft,Fore} = ①T \pm \dfrac{②\text{trim}}{2}$

① Calculation of the change of the draft (T)

$$T_1 = 5.488\,m$$

② Calculation of the trim

$$\text{Trim} = 1.2\text{ m}$$

③ Calculation of the draft at the aft perpendicular of the ship

$$T_{Aft,Fore} = T_1 \pm \frac{\text{trim}}{2}$$

Draft at the aft perpendicular

$$= T_1 - \frac{\text{trim}}{2} = 5.488 - \frac{1.2}{2} = 4.888\text{m}$$

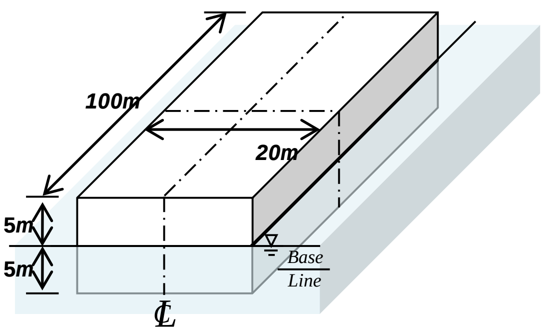
Draft at the forward perpendicular

$$= T_1 + \frac{\text{trim}}{2} = 5.488 + \frac{1.2}{2} = 6.088\text{ m}$$

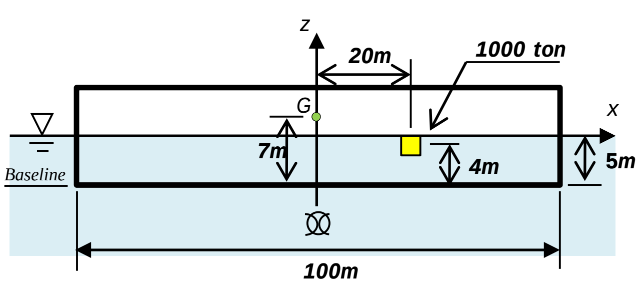
[Example] Calculation of Trim of a Ship
- Calculation of the Approximate Solution by Using Linearization (7/7)

Given:
L: 100m, B: 20m, D: 10m, T: 5m, KG: 7m
Cargo Load: 1,000ton
(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



<Three Dimensional View>



<Elevation View>

① $T_1 = T_0 + \delta T$, $\delta\Delta = TPC \cdot \delta T$

② $\text{Trim[m]} = \dfrac{\sum \text{Trim Moment}}{MTC \cdot 100}$

$\text{Trim Moment} = w \cdot l \qquad MTC = \dfrac{\Delta \cdot \overline{GM_L}}{100 \cdot L_{BP}}$

$\overline{GM_L} = \overline{KB} + \overline{BM_L} - \overline{KG}$

③ $T_{Aft,Fore} = ①T \pm \dfrac{②\text{trim}}{2}$

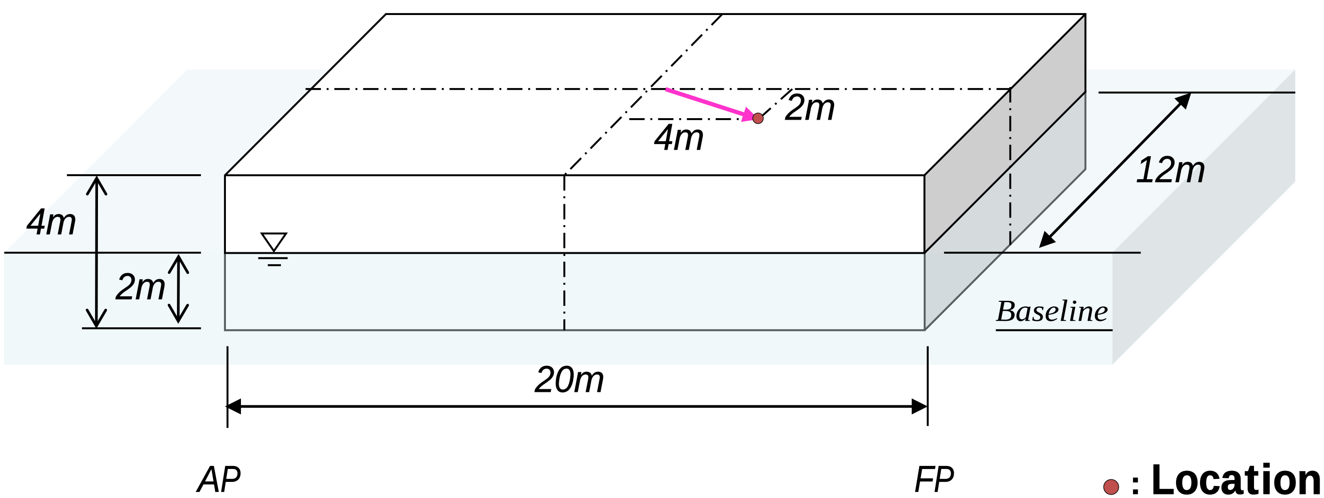
There will be some difference between the approximate solution and exact solution, because of the following approximate terms.

- Trim moment $w \cdot l \cdot \cos\theta \cong w \cdot l$
- I_L $I_{L1} \cong I_{L0}$
- A_{WP} $\iint dx\,dy \cong A_{WP0} = L_0 \cdot B_0$
- TPC Linearized A_{WP0}
- KB_1 Vertical center of buoyancy at the previous state
- LCB_1 Longitudinal center of buoyancy at the previous state

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.

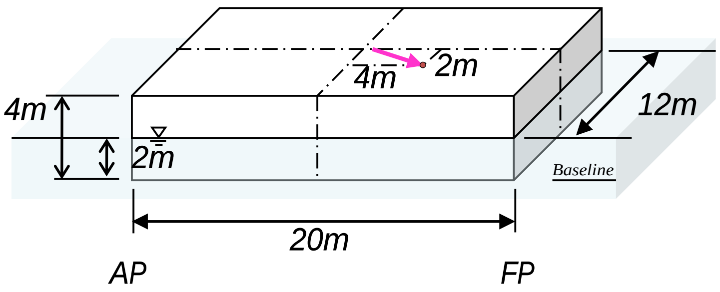


● : **Location of the cargo**

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

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



• : **Location of the cargo**

$$\mathbf{F} = \mathbf{A}\mathbf{x}$$

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.

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

⇐ Load of the cargo
➡ The change of the force(moment) is given.

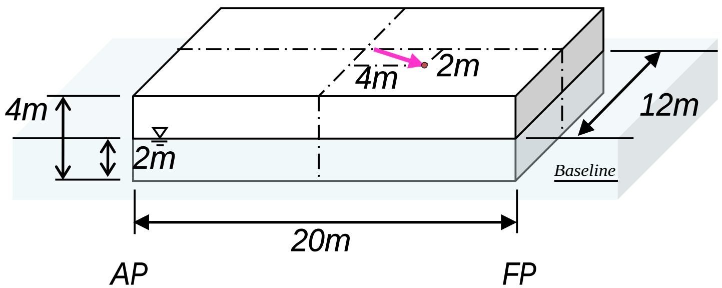
Find:
Draft at the forward perpendicular(FP), after perpendicular(AP), portside, and starboard of the ship

⇐ Problem to calculate the change of the position

[Example] Calculation of Trim for a Barge Ship When the Cargo is Moved - Calculation of the Approximate Solution by Using Linearization (1/7)

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



● : **Location of the cargo**

Calculation of the approximate solution by linearizing the problem

1. Change of draft caused by trim

① Calculation of the trim

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

①-1) Trim Moment : *w*(weight of the cargo) × *l*(distance)

①-2) $\overline{GM_L} = \overline{KB} + \overline{BM_L} - \overline{KG}$

①-3) $MTC = \dfrac{\Delta \cdot \overline{GM_L}}{100 \cdot L_{BP}}$

2. Change of draft caused by heel

② Calculation of the change of the draft caused by the heel

$$\text{Heel[m]} = B \cdot \tan\phi \quad \left(\delta y_G' \cos\phi + \delta z_G' \sin\phi = \overline{GM} \sin\phi\right)$$

②-1) Calculation of the change of the center of the gravity in the transverse direction $\delta y_G' = \dfrac{w \cdot l_T}{\Delta}$

②-2) $\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG}$

②-3) Calculating of the heeling angle

$$\delta y_G' \cos\phi + \delta z_G' \sin\phi = \overline{GM} \sin\phi$$

3. Calculation of draft at each port and starboard of the FP and AP

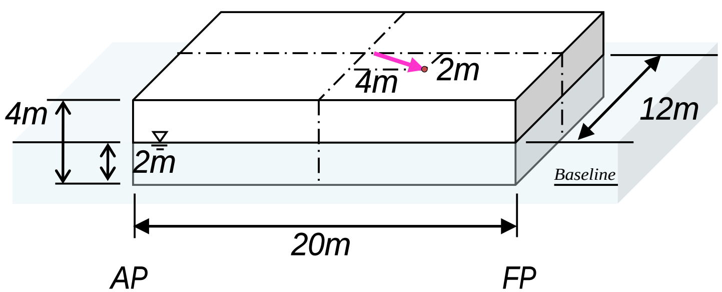
③ Calculation of the draft at the each port and starboard of the FP and AP, respectively

$$T_{Fwd,Aft,Port,Stb'd} = T \pm \frac{\text{Trim}}{2} \pm \frac{\text{Heel}}{2}$$

[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



● : **Location of the cargo**

$$\mathbf{F} = \mathbf{A}\mathbf{x}$$

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:

$$\nabla = L \cdot B \cdot T = 20 \cdot 12 \cdot 2 = 480\, m^3$$

$$\Delta = \nabla \cdot \rho_{fw} = 480 \cdot 1.0 = 480\, ton$$

1. Changed draft caused by trim

$$① \text{Trim}[\text{m}] = \frac{\text{Trim Moment}}{MTC \cdot 100}$$

- Trim moment produced by moving the cargo in the forward direction

$$\text{Trim Moment} = 10 \cdot 4 \cdot \cos\theta \approx 40\, ton \cdot m$$

$$GM_L = KB + BM_L - KG$$

$$KB = \frac{T}{2} = \frac{2}{2} = 1m$$

$$BM_L = \frac{I_L}{\nabla} = \frac{BL^3/12}{\nabla} = \frac{12 \cdot 20^3/12}{480} \approx 16.67m$$

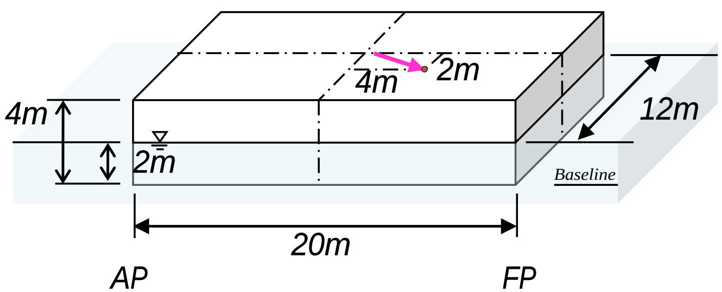
$$KG = 2\, m$$

$$GM_L = KB + BM_L - KG = 1 + 16.67 - 2 = 15.67\, m$$

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

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



● : **Location of the cargo**

1. Change of draft caused by trim	2. Change of draft caused by heel	3. Calculation of drafts at each portside and starboard of the FP and AP
① $\text{Trim}[m] = \frac{\text{Trim Moment}}{MTC \cdot 100}$ $\text{Trim Moment} = w \cdot l_L$ $\overline{GM}_L = \overline{KB} + \overline{BM}_L - \overline{KG}$ $MTC = \frac{\Delta \cdot \overline{GM}_L}{100 \cdot L_{BP}}$	② $\text{Heel}[m] = B \cdot \tan\phi$ $\delta y_G' = \frac{w \cdot l_T}{\Delta}$ $\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG}$ $\delta y_G' \cos\phi + \delta z_G' \sin\phi = \overline{GM} \sin\phi$	$T_{Fwd,Aft,Port,Stb'd} = T \pm \frac{\text{Trim}}{2} \pm \frac{\text{Heel}}{2}$

1. Changed draft caused by trim

$$① \text{Trim}[m] = \frac{\text{Trim Moment}}{MTC \cdot 100}$$

- Trim moment caused by moving the cargo in the direction of the forward perpendicular

$$\text{Trim Moment} = 10 \cdot 4 \cdot \cos\theta \approx 40\, ton \cdot m$$

$$GM_L = KB + BM_L - KG = 1 + 16.67 - 2 = 15.67\, m$$

$$MTC = \frac{\Delta \cdot GM_L}{100L} = \frac{480 \cdot 15.67}{100 \cdot 20} = 3.7608\, ton \times m / cm$$

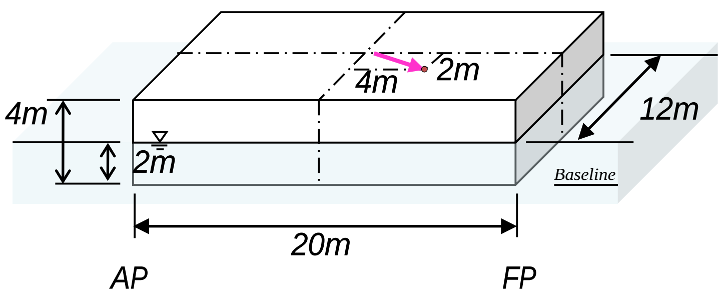
$$\therefore t = \frac{Trim\ Moment}{100 \cdot MTC} = \frac{40}{3.7608} = 10.64\, cm = 0.1064\, m$$

[Example] Calculation of Trim for a Barge Ship When the Cargo is Moved - Calculation of the Approximate Solution by Using Linearization (4/7)

1. Change of draft caused by trim	2. Change of draft caused by heel	3. Calculation of drafts at each portside and starboard of the FP and AP
①$\text{Trim}[m] = \dfrac{\text{Trim Moment}}{MTC \cdot 100}$ $\text{Trim Moment} = w \cdot l_L$ $\overline{GM}_L = \overline{KB} + \overline{BM}_L - \overline{KG}$ $MTC = \dfrac{\Delta \cdot \overline{GM}_L}{100 \cdot L_{BP}}$	②$\text{Heel}[m] = B \cdot \tan\phi$ $\delta y'_G = \dfrac{w \cdot l_T}{\Delta}$ $\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG}$ $\delta y'_G \cos\phi + \delta z'_G \sin\phi = \overline{GM} \sin\phi$	$T_{Fwd,Aft,Port,Stb'd}$ $= T \pm \dfrac{\text{Trim}}{2} \pm \dfrac{\text{Heel}}{2}$

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



● : Location of the cargo

2. Changed draft caused by the heel

- Change of the center of gravity

$$\delta y'_G = \frac{w \cdot l_T}{\Delta} = \frac{10 \cdot 2}{480} = 0.04\,m$$

$$\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG}$$

$$KB = \frac{T}{2} = \frac{2}{2} = 1\,m$$

$$BM = \frac{I_T}{\nabla} = \frac{LB^3/12}{\nabla} = \frac{20 \cdot 12^3/12}{480} = 6\,m$$

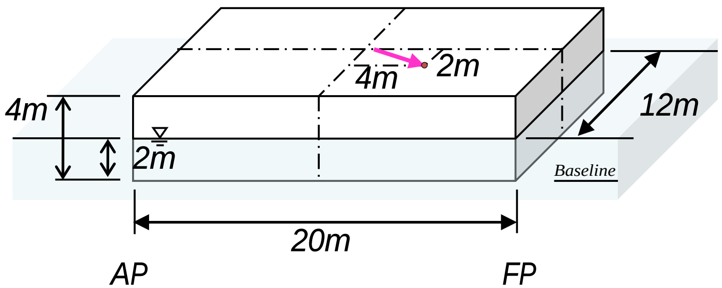
$$KG = 2\,m$$

$$\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG} = 1 + 6 - 2 = 5\,m$$

[Example] Calculation of Trim for a Barge Ship When the Cargo is Moved - Calculation of the Approximate Solution by Using Linearization (5/7)

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



● : **Location of the cargo**

1. Change of draft caused by trim	2. Change of draft caused by heel	3. Calculation of drafts at each portside and starboard of the FP and AP
① $\text{Trim}[\text{m}] = \frac{\text{Trim Moment}}{MTC \cdot 100}$ $\text{Trim Moment} = w \cdot l_L$ $\overline{GM}_L = \overline{KB} + \overline{BM}_L - \overline{KG}$ $MTC = \frac{\Delta \cdot \overline{GM}_L}{100 \cdot L_{BP}}$	② $\text{Heel}[\text{m}] = B \cdot \tan\phi$ $\delta y'_G = \frac{w \cdot l_T}{\Delta}$ $\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG}$ $\delta y'_G \cos\phi + \delta z'_G \sin\phi = \overline{GM} \sin\phi$	$T_{Fwd,Aft,Port,Stb'd}$ $= T \pm \frac{\text{Trim}}{2} \pm \frac{\text{Heel}}{2}$

2. Changed draft caused by the heel

- Change of the center of gravity

$$\delta y'_G = \frac{w \cdot l_T}{\Delta} = 0.04\,m$$

- Transverse metacentric height

$$\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG} = 1 + 6 - 2 = 5\,m$$

- Heeling angle

$$\delta y'_G \cos\phi + \delta z'_G \sin\phi = GZ \approx \overline{GM} \sin\theta$$

$$\tan\phi = \frac{\delta y'_G}{\overline{GM}} = \frac{0.04}{5} = 0.008$$

$$\phi = \tan^{-1}\left(\frac{\delta y'_G}{\overline{GM}}\right) = \tan^{-1}\left(\frac{0.04}{5}\right) \approx 0.46^\circ$$

- Changed draft caused by heel

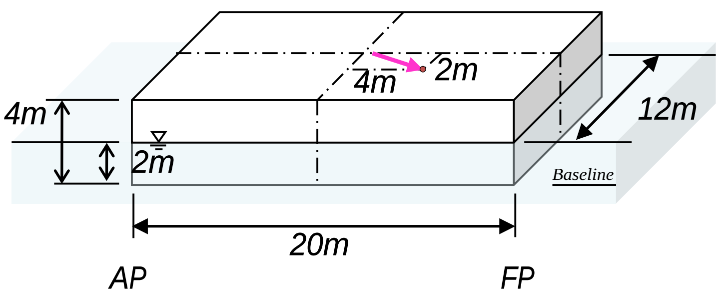
$$Starboard = +\frac{B}{2} \cdot \tan\phi = 6 \cdot \tan 0.46^\circ \approx 0.0482\,m$$

$$Port = -\frac{B}{2} \cdot \tan\phi = -6 \cdot \tan 0.46^\circ \approx -0.0482\,m$$

[Example] Calculation of Trim for a Barge Ship When the Cargo is Moved - Calculation of the Approximate Solution by Using Linearization (6/7)

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



● : **Location of the cargo**

1. Change of draft caused by trim

$$①\text{Trim}[m] = \frac{\text{Trim Moment}}{MTC \cdot 100}$$

$$\text{Trim Moment} = w \cdot l_L$$

$$\overline{GM_L} = \overline{KB} + \overline{BM_L} - \overline{KG}$$

$$MTC = \frac{\Delta \cdot \overline{GM_L}}{100 \cdot L_{BP}}$$

2. Change of draft caused by heel

$$②\text{Heel}[m] = B \cdot \tan\phi$$

$$\delta y'_G = \frac{w \cdot l_T}{\Delta}$$

$$\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG}$$

$$\delta y'_G \cos\phi + \delta z'_G \sin\phi = \overline{GM} \sin\phi$$

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

$$T_{Fwd,Aft,Port,Stb'd} = T \pm \frac{\text{Trim}}{2} \pm \frac{\text{Heel}}{2}$$

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:

$$T_{\text{Fore-Starboard}} = T + \frac{Trim}{2} + \frac{B}{2}\tan\phi = T + \frac{0.1064}{2} + 0.0482 = 2.1014\,m$$

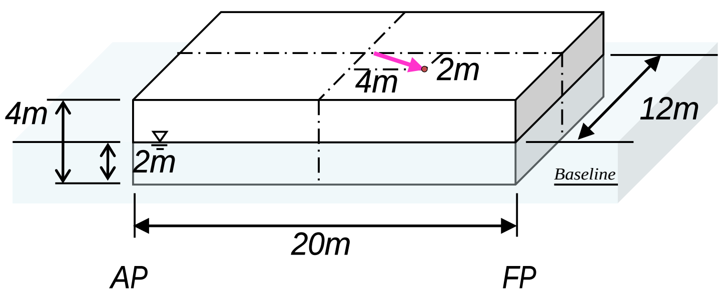
$$T_{\text{Fore-Portside}} = T + \frac{Trim}{2} - \frac{B}{2}\tan\phi = T + \frac{0.1064}{2} - 0.0482 = 2.0050\,m$$

$$T_{\text{Aft-Portside}} = T - \frac{Trim}{2} - \frac{B}{2}\tan\phi = T - \frac{0.1064}{2} - 0.0482 = 1.8986\,m$$

$$T_{\text{Aft-Starboard}} = T - \frac{Trim}{2} + \frac{B}{2}\tan\phi = T - \frac{0.1064}{2} + 0.0482 = 1.9950\,m$$

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



● : **Location of the cargo**

1. Change of draft caused by trim

$$①\text{Trim}[m] = \frac{\text{Trim Moment}}{MTC \cdot 100}$$

$$\text{Trim Moment} = w \cdot l_L$$

$$\overline{GM}_L = \overline{KB} + \overline{BM}_L - \overline{KG}$$

$$MTC = \frac{\Delta \cdot \overline{GM}_L}{100 \cdot L_{BP}}$$

2. Change of draft caused by heel

$$②\text{Heel}[m] = B \cdot \tan\phi$$

$$\delta y'_G = \frac{w \cdot l_T}{\Delta}$$

$$\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG}$$

$$\delta y'_G \cos\phi + \delta z'_G \sin\phi = \overline{GM}\sin\phi$$

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

$$T_{Fwd,Aft,Port,Stb'd} = T \pm \frac{\text{Trim}}{2} \pm \frac{\text{Heel}}{2}$$

3. Calculation of the drafts at the 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 $w \cdot l \cdot \cos\theta \cong w \cdot l$
- I_L, I_T $I_{L1} \cong I_{L0}$, $I_{T1} \cong I_{T0}$
- AWP $\iint dx\,dy \cong A_{WP0} = L_0 \cdot B_0$
- TPC, MTC Linearized A_{WP0}, Linearized I ,
- KB_1 Vertical center of buoyancy at the previous state
- LCB_1 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.

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

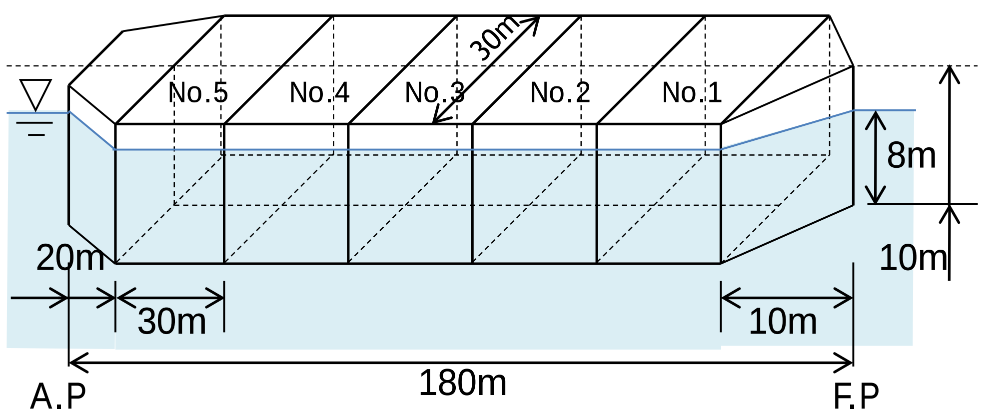
A ship is floating in fresh water as seen in the figure below. Answer the following questions. The density of the after part, cargo hold part, and forward part is ρ_m=1.0ton/m^3.

① Calculate the displacement(Δ) 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).

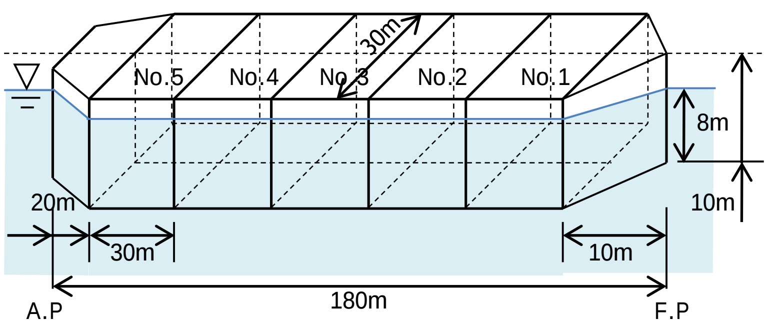
④ When the cargo is loaded and unloaded, the shape of the water plane changes. Explain how to calculate the change of the trim in this case.



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

Given:
L: 180m, B:30m, D:10m, T:8m
Density of the ship material ρ_m= 1.0ton/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/m^3 homogeneously, DWT and LWT?
④ How do we calculate the change of the trim when the cargo is loaded or unloaded?



$$\mathbf{F} = \mathbf{A}\mathbf{x}$$

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.

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

Cargo Loading/Unloading
➡ The change of the force(moment) is given.

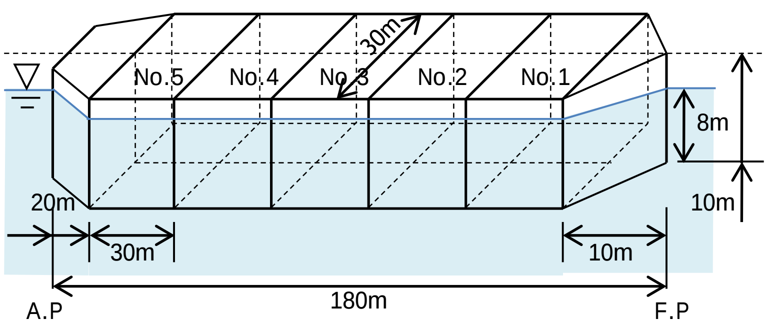
Find:
① Displacement (Δ)
② LCF, LCB, LCG, KG
③ When the all cargo hold are full with the load whose density is 0.6 ton/m^3 homogeneously.
What is the DWT and LWT?
④ How do we calculate the change of the trim when the cargo is loaded or unloaded?

Problem to calculate the change of the position

[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= 1.0ton/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/m^3 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)

$$\Delta = \nabla \cdot \rho$$

$$\nabla = A_{WP} \cdot T$$ (Since the water plane area does not change)

② LCF, LCB, LCG, KG

$$LCF = \frac{M_{Awp,y'}}{A_{WP}} = \frac{\iint x'\,dx'\,dy'}{\iint dx'\,dy'}$$

(1st moment of the water plane area about y axis though the center of the ship)

$$LCB = \frac{M_{\nabla,y'}}{\nabla} = \frac{\iiint x'\,dx'\,dy'\,dz'}{\iint dx'\,dy'\,dz'}$$

(1st moment of the displacement about y axis though the center of the ship)

Because the water plane area is not changed in the vertical direction $LCF = LCB$

Because the ship is in the even keel state $LCB = LCG$

③ When the cargo hold is fully loaded, with a load having a density of 0.6 ton/m^3 homogeneously. What is the DWT and LWT?

$$DWT = A_h \cdot D \cdot \rho_{cargo}$$

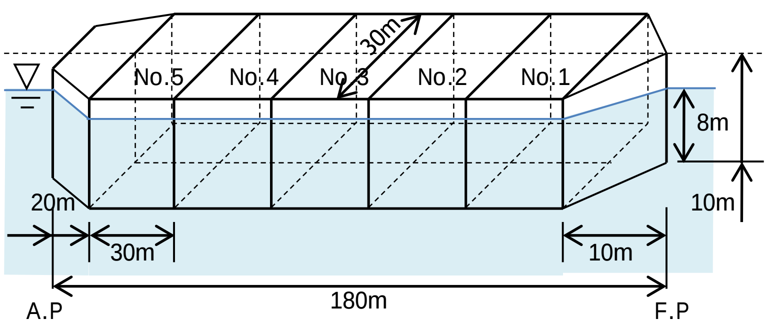
$$LWT = \Delta - DWT$$

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= 1.0ton/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 0.6ton/m³ homogeneously, DWT and LWT?
④ How do we calculate the change of the trim when the cargo is loaded or unloaded?



① Displacement(Δ) $\Delta = \nabla \cdot \rho \,, \nabla = A_{WP} \cdot T$

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

$$A_a = (30+10)\cdot 20 \cdot 0.5 = 400\, m^2$$

$$A_h = 150 \cdot 30 = 4,500\, m^2$$

$$A_f = 0.5 \cdot 30 \cdot 10 = 150\, m^2$$

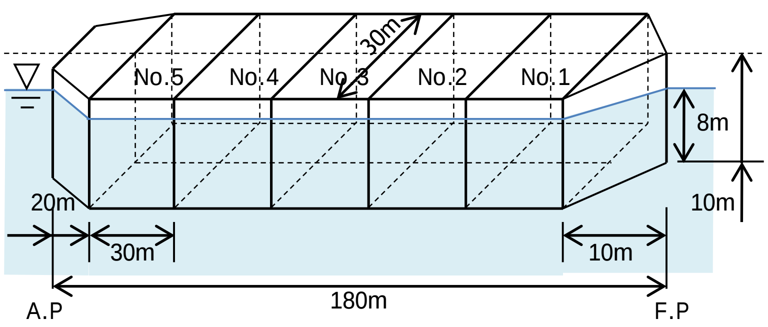
$$\nabla = (A_a + A_h + A_f)\cdot T = 40,400\, m^3$$

$$\therefore \Delta = \nabla \cdot \rho_{fw} = 40,400 \cdot 1.0 = 40,400\, ton$$

[Example] Calculation of Trim of a Ship (5/7)

Given:
L: 180m, B:30m, D:10m, T:8m
Density of the ship material ρ_m= 1.0ton/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/m^3 homogeneously, DWT and LWT?
④ How do we calculate the change of the trim when the cargo is loaded or unloaded?



② LCF, LCB, LCG, KG

$$LCF = \frac{M_{Awp,y'}}{A_{WP}} = \frac{\iint x'\,dx'\,dy'}{\iint dx'\,dy'}$$

$$LCB = \frac{M_{\nabla,y'}}{\nabla} = \frac{\iiint x'\,dx'\,dy'\,dz'}{\iint dx'\,dy'\,dz'}$$

1st moment of the water plane area about y axis though the center of the ship(M_L)

$$M_L = -A_a \cdot (8.3333+70) + A_f \cdot (\frac{10}{3}+80) + A_h \cdot (5)$$

$$\approx 3,666.68\,m^3$$

$$LCF = \frac{M_L}{A_a + A_h + A_f} = \frac{3,666.68}{5,050}$$

$$\approx 0.73\,m$$

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

$$LCF = LCB = LCG = 0.73\,m$$

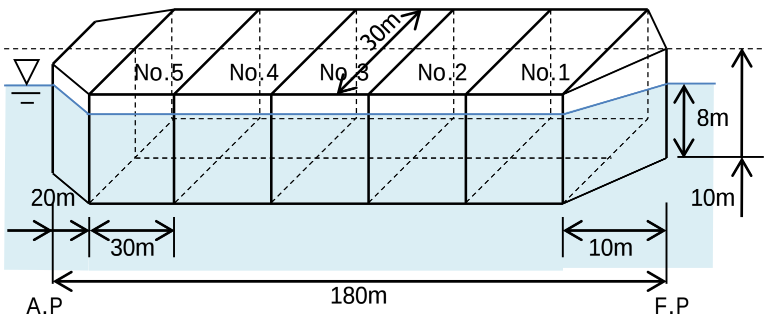
Because the water plane area is not changed in the z axis direction

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

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

Given:
L: 180m, B:30m, D:10m, T:8m
Density of the ship material ρ_m= 1.0ton/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/m^3 homogeneously, DWT and LWT?
④ How do we calculate the change of the trim when the cargo is loaded or unloaded?



③ When the all cargo hold are full with the load whose density is 0.6ton/m³ homogeneously. What is the DWT and LWT?

$$DWT = A_{WP\_Hold} \cdot D \cdot \rho_{\text{cargo}}$$
$$LWT = \Delta - DWT$$

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

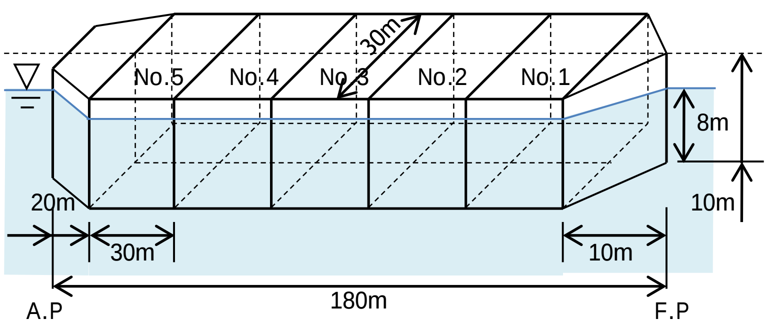
$$\begin{aligned} DWT &= A_h \cdot D \cdot \rho_{cargo} \\ &= 4,500 \cdot 10 \cdot 0.6 \\ &= 27,000\,ton \end{aligned}$$

$$\begin{aligned} LWT &= \Delta - DWT \\ &= 40,400 - 27,000 \\ &= 13,400\,ton \end{aligned}$$

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

Given:
L: 180m, B:30m, D:10m, T:8m
Density of the ship material ρ_m= 1.0ton/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/m^3 homogeneously, DWT and LWT?
④ How do we calculate the change of the trim when the cargo is loaded or unloaded?



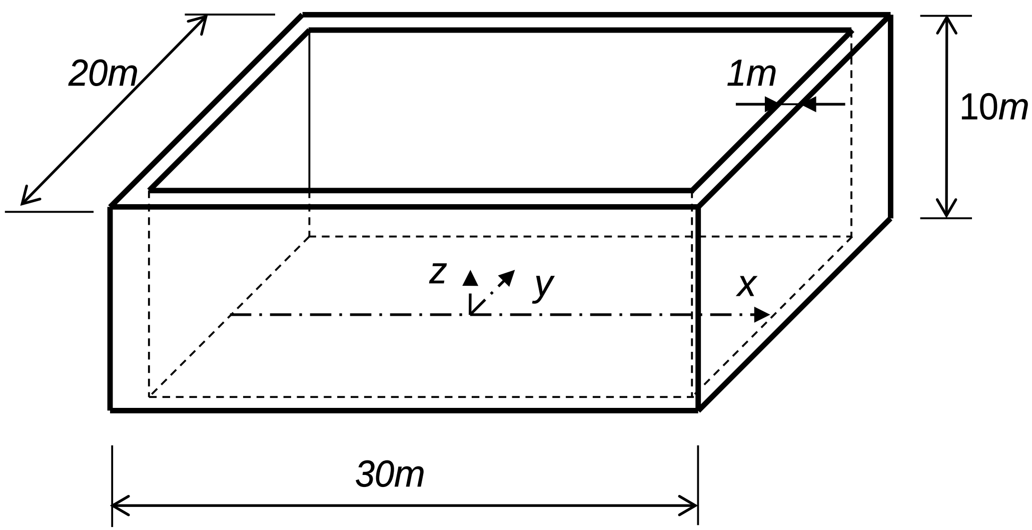
④ How do we calculate the change of trim when the cargo is loaded or unloaded?

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 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 ρ_m=1.0ton/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.

Item	Unit Mass	# of Cargoes	Loading position(m)		
			x	y	z
Freight 1	100ton	3	0	0	1
Freight 2	150ton	2	-5	0	1

Calculate the ship's ⓐ deadweight(DWT) ⓑ TPC ⓒ MTC ⓓ Trim ⓔ Fore and after drafts ⓕ LCB ⓖ 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.

[Example] Calculation of Barge Ship's Trim and Heel Angles (2/18)

Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρ_m=1.0ton/m^3

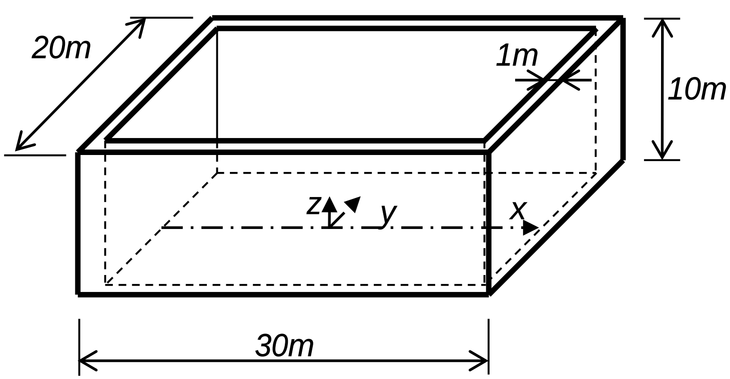
Find:

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.



$$\mathbf{F} = \mathbf{A}\mathbf{x}$$

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.

Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρ_m=1.0 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.

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

③ Freight 2 is unloaded from ②, calculate LCB, LCG.

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

④ Freight 1 moves 5m along the positive y direction. Calculate heel angle.

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

[Example] Calculation of Barge Ship's Trim and Heel Angles (3/18)

Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρ_m=1.0ton/m^3

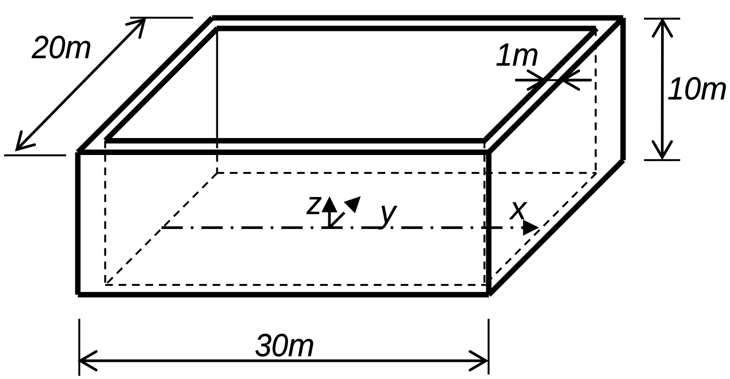
Find:

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

① LWT, Draft in fresh water(T_{fw}), Draft in sea water(T_{sw})

$$\Delta_{LWT} = A_{WP} \cdot T_{fw} \cdot \rho_{fw} \longrightarrow T_{fw} = \frac{\Delta_{LWT}}{A_{WP} \cdot \rho_{fw}}$$

$$\Delta_{LWT} = A_{WP} \cdot T_{sw} \cdot \rho_{sw} \longrightarrow T_{sw} = \frac{\Delta_{LWT}}{A_{WP} \cdot \rho_{sw}}$$

② When the freight 1 and 2 are loaded in fresh water, ⓐ Deadweight(DWT) ⓑ TPC ⓒ MTC ⓓ Trim ⓔ Fore and after drafts ⓕ LCB ⓖ LCG

ⓐ $\Delta = LWT + DWT$

ⓑ $TPC = \dfrac{A_{WP} \cdot \rho_{f.w}}{100}$

ⓒ $MTC = \dfrac{\Delta \cdot \overline{GM_L}}{L_{BP} \cdot 100}$

$\overline{GM_L} = \overline{KB} + \overline{BM_L} - \overline{KG}$

ⓓ $\text{Trim[m]} = \dfrac{\text{Trim Moment}}{MTC \cdot 100}$

ⓔ $T_{Aft,Fore} = T \pm \dfrac{\text{trim}}{2}$

ⓕ $LCB = \dfrac{M_{\nabla,y'}}{\nabla} = \dfrac{\iiint x'\,dx'\,dy'\,dz'}{\iiint dx'\,dy'\,dz'}$

ⓖ $LCG = \dfrac{w}{W} l_L$

[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: ρ_m=1.0ton/m^3

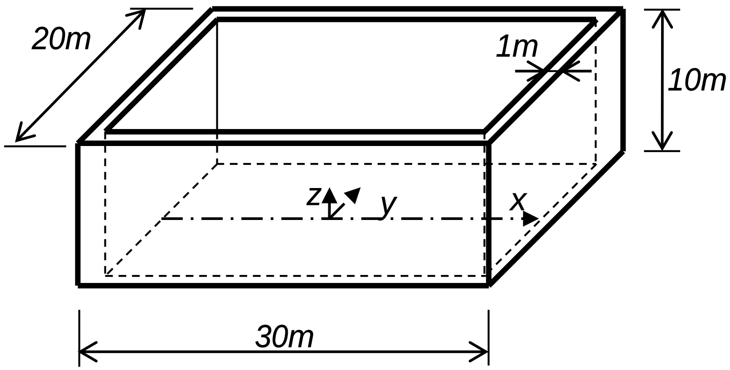
Find:

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

③ Freight 2 is unloaded from ②, calculate LCB, LCG.

$$LCB = \frac{M_{\nabla,y'}}{\nabla} = \frac{\iiint x'\,dx'\,dy'\,dz'}{\iiint dx'\,dy'\,dz'}$$

$$LCG = \frac{w}{W} l_L$$

④ From the condition ③, freight 1 moves 5m along the positive y direction. Calculate heel angle.

$$\delta y'_G \cos\phi + \delta z'_G \sin\phi = \overline{GM}\sin\phi$$

$$\delta y'_G = \frac{w \cdot l_T}{\Delta}$$

$$\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG}$$

[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: ρ_m=1.0ton/m^3

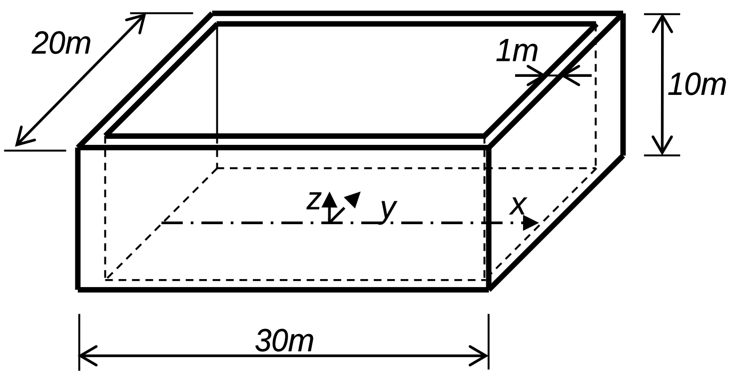
Find:

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.



$$\Delta_{LWT} = (30 \cdot 20 \cdot 10 - 28 \cdot 18 \cdot 9) \cdot 1.0 = 1,464 \text{ ton}$$

① LWT, Draft in fresh water(T_{fw}), Draft in sea water(T_{sw})

$$\Delta_{LWT} = A_{WP} \cdot T_{fw} \cdot \rho_{fw} \longrightarrow T_{fw} = \frac{\Delta_{LWT}}{A_{WP} \cdot \rho_{fw}}$$

$$\Delta_{LWT} = A_{WP} \cdot T_{sw} \cdot \rho_{sw} \longrightarrow T_{sw} = \frac{\Delta_{LWT}}{A_{WP} \cdot \rho_{sw}}$$

In fresh water, the draft for light ship condition is given by:

$$\Delta_{LWT} = A_{WP} \cdot T_{fw} \cdot \rho_{fw}$$

Thus, the draft is

$$T_{fw} = \frac{1,464}{20 \cdot 30 \cdot 1.0} = 2.44\,m$$

In sea water, the draft for light ship condition is given by :

$$\Delta_{LWT} = A_{WP} \cdot T_{sw} \cdot \rho_{sw}$$

Thus, the draft is

$$T_{sw} = \frac{1,464}{20 \cdot 30 \cdot 1.025} = 2.39\,m$$

[Example] Calculation of Barge Ship's Trim and Heel Angles (6/18)

Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρ_m=1.0ton/m^3

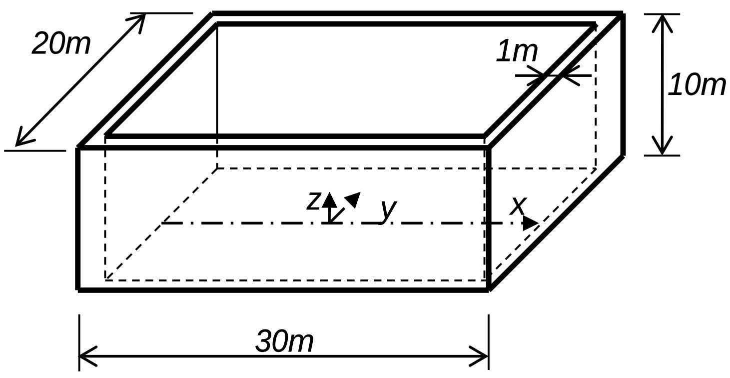
Find:

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.



② When the freight 1 and 2 are loaded in fresh water,
ⓐ Deadweight(DWT) ⓑ TPC ⓒ MTC ⓓ Trim
ⓔ Fore and after drafts ⓕ LCB ⓖ LCG

ⓐ $\Delta = LWT + DWT$

Before loading the freight, the ship's displacement is equal to lightweight(LWT).

$$\Delta_0 = LWT = 1,464\,ton$$

Thus the ship's deadweight(DWT) is

$$DWT = 3 \cdot 100 + 2 \cdot 150 = 600\,ton$$

After loading the freights, the ship's displacement becomes

$$\Delta = LWT + DWT = 2,064\,ton$$

[Example] Calculation of Barge Ship's Trim and Heel Angles (7/18)

Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρ_m=1.0ton/m^3

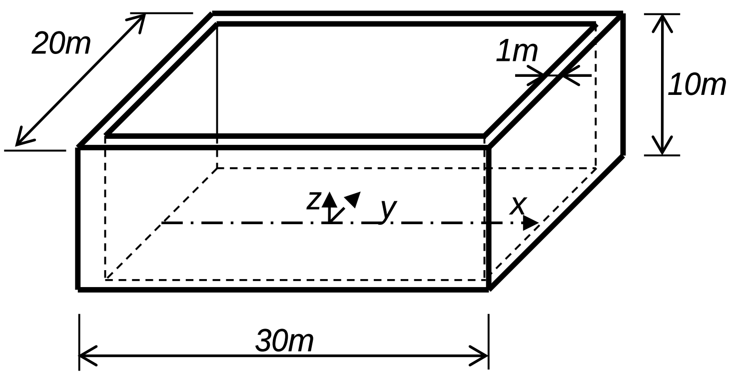
Find:

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.



② When the freight 1 and 2 are loaded in fresh water,
ⓐ Deadweight(DWT) ⓑ TPC ⓒ MTC ⓓ Trim
ⓔ Fore and after drafts ⓕ LCB ⓖ LCG

ⓑ TPC is calculated as follows:

$$TPC = \frac{A_{WP} \cdot \rho_{fw}}{100} = \frac{20 \cdot 30 \cdot 1.0}{100} = 6\, ton/cm$$

ⓒ MTC is calculated as follows:

$$\delta T = \frac{DWT}{TPC} = \frac{600}{6} = 100\, cm = 1\, m$$

After loading the freights, the ship's displacement in fresh water is

$$T = T_{fw} + \delta T = 2.44 + 1 = 3.44\, m$$

$$MTC = \frac{\Delta \cdot GM_L}{L_{BP} \cdot 100}$$

$$GM_L = KB + BM_L - KG$$

[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: ρ_m=1.0ton/m^3

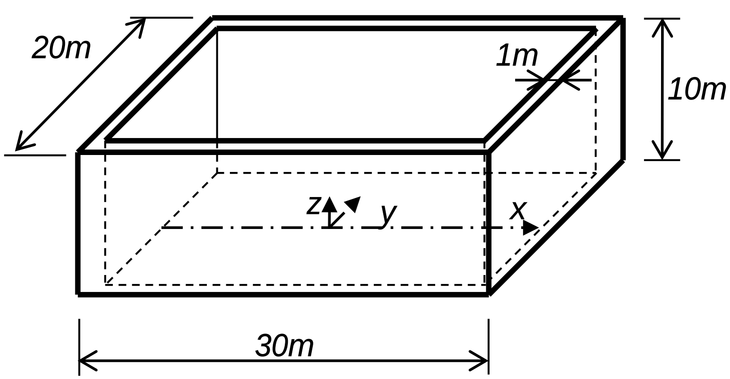
Find:

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.



② When the freight 1 and 2 are loaded in fresh water,
ⓐ Deadweight(DWT) ⓑ TPC ⓒ MTC ⓓ Trim
ⓔ Fore and after drafts ⓕ LCB ⓖ LCG

ⓒ MTC: $MTC = \dfrac{\Delta \cdot GM_L}{L_{BP} \cdot 100}$, $GM_L = KB + BM_L - KG$

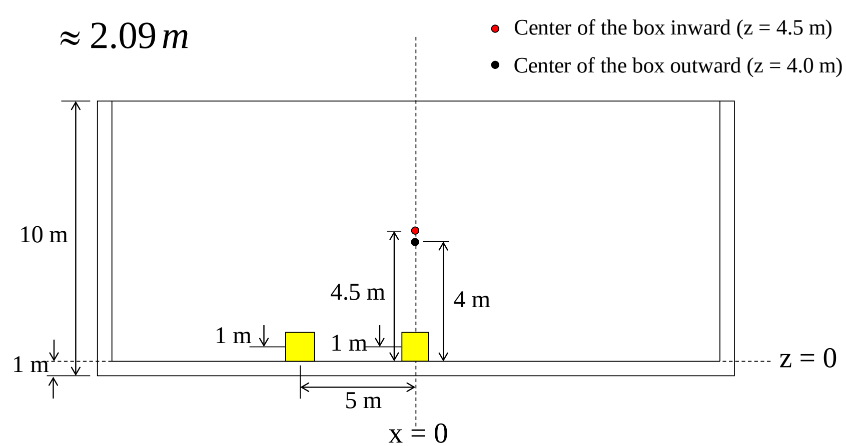
After loading the freight, the changed center of buoyancy becomes:

$$KB = \frac{T}{2} = \frac{3.44}{2} = 1.72m$$

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

$$KG = \frac{30\cdot 20\cdot 10\cdot 4 - 28\cdot 18\cdot 9\cdot 4.5 + 100\cdot 3\cdot 1 + 150\cdot 2\cdot 1}{2,064}$$

$$\approx 2.09m$$



[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: ρ_m=1.0ton/m^3

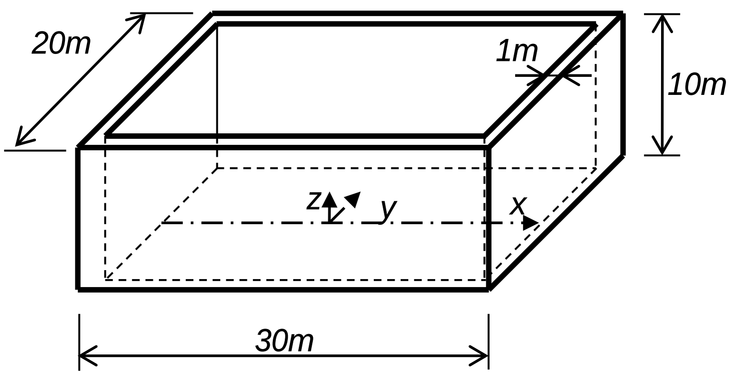
Find:

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.



② When the freight 1 and 2 are loaded in fresh water,
ⓐ Deadweight(DWT) ⓑ TPC ⓒ MTC ⓓ Trim
ⓔ Fore and after drafts ⓕ LCB ⓖ LCG

ⓒ MTC: $MTC = \dfrac{\Delta \cdot GM_L}{L_{BP} \cdot 100}$ $, GM_L = KB + BM_L - KG$

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

$$KB = \frac{T}{2} = \frac{3.44}{2} = 1.72m$$

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

$$KG = \frac{30\cdot 20\cdot 10\cdot 4 - 28\cdot 18\cdot 9\cdot 4.5 + 100\cdot 3\cdot 1 + 150\cdot 2\cdot 1}{2,064}$$

$$\approx 2.09\,m$$

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

$$BM_L = \frac{I_T}{\nabla} = \frac{45,000}{2,064/1.0} \approx 21.8\,m$$

$$GM_L = KB + BM_L - KG$$
$$= 1.72 + 21.8 - 2.09 = 21.43\,m$$

[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: ρ_m=1.0ton/m^3

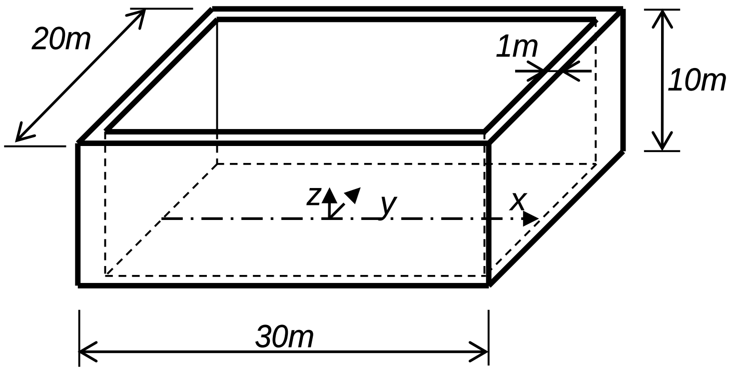
Find:

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.



② When the freight 1 and 2 are loaded in fresh water,
ⓐ Deadweight(DWT) ⓑ TPC ⓒ MTC ⓓ Trim
ⓔ Fore and after drafts ⓕ LCB ⓖ LCG

ⓒ MTC: $MTC = \dfrac{\Delta \cdot GM_L}{L_{BP} \cdot 100}$, $GM_L = KB + BM_L - KG$

$$KB = 1.72m$$

$$KG \approx 2.09m$$

$$BM_L = 21.8m$$

$$GM_L = KB + BM_L - KG$$
$$= 1.72 + 21.8 - 2.09 = 21.43m$$

Therefore, MTC(moment to trim 1 cm) is

$$MTC = \frac{\Delta \cdot GM_L}{100} = \frac{2,064 \cdot 21.43}{100}$$
$$\approx 442.32\ ton \cdot m / cm$$

SYstem Design Laboratory

[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: ρ_m=1.0ton/m^3

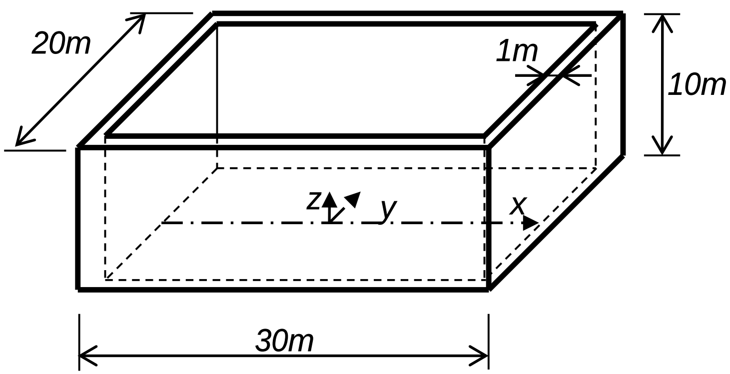
Find:

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.



② When the freight 1 and 2 are loaded in fresh water, ⓐ Deadweight(DWT) ⓑ TPC ⓒ MTC ⓓ Trim ⓔ Fore and after drafts ⓕ LCB ⓖ LCG

ⓓ Loading of the freight 2 leads to

$$Trim\ Moment = -5 \cdot (150 \cdot 2) = -1,500\ ton \cdot m$$

$$Trim = \frac{Trim\ Moment}{MTC} = -3.39\ cm = -0.0339\ m$$

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

$$\text{Draft at fore part}=T - \frac{1}{2} \cdot 0.0339 \approx 3.42\ m$$

$$\text{Draft at after part}=T + \frac{1}{2} \cdot 0.0339 \approx 3.46\ m$$

Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρ_m=1.0ton/m^3

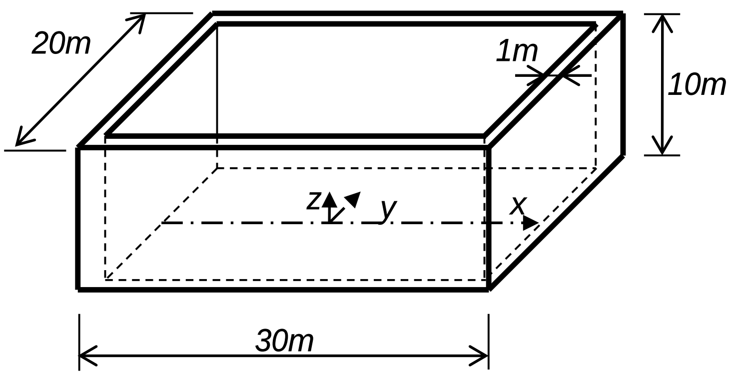
Find:

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.

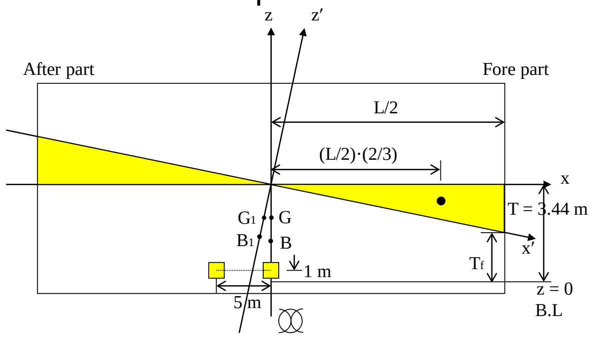
③ Freight 2 is unloaded from ②, calculate LCB, LCG.

④ Freight 1 moves 5m along the positive y direction. Calculate the heel angle.



② When the freight 1 and 2 are loaded in fresh water, ⓐ Deadweight(DWT) ⓑ TPC ⓒ MTC ⓓ Trim ⓔ Fore and after drafts ⓕ LCB ⓖ LCG

ⓕ Let us calculate the ship's LCB.



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

$$-\frac{1}{2}\cdot\frac{L}{2}\cdot(T-T_f)\cdot(\frac{L}{2}\cdot\frac{2}{3})\cdot B$$

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

$$-\frac{1}{2}\cdot\frac{L}{2}\cdot(T_a-T)\cdot(\frac{L}{2}\cdot\frac{2}{3})\cdot B$$
$$=-\frac{1}{2}\cdot\frac{L}{2}\cdot(T-T_f)\cdot(\frac{L}{2}\cdot\frac{2}{3})\cdot B$$

[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: ρ_m=1.0ton/m^3

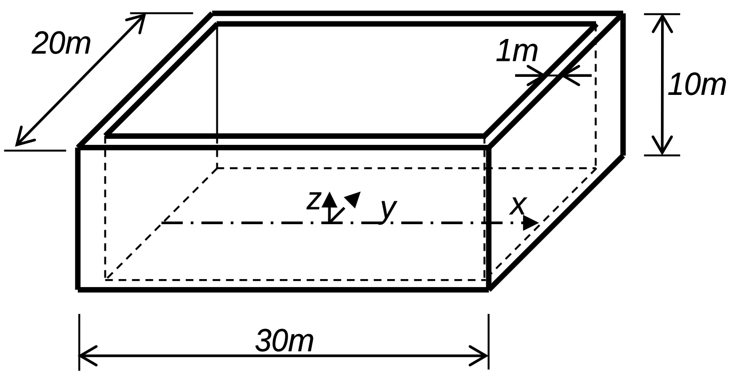
Find:

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.

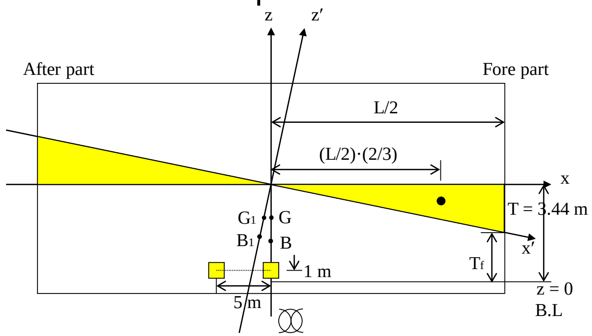
③ Freight 2 is unloaded from ②, calculate LCB, LCG.

④ Freight 1 moves 5m along the positive y direction. Calculate the heel angle.



② When the freight 1 and 2 are loaded in fresh water,
ⓐ Deadweight(DWT) ⓑ TPC ⓒ MTC ⓓ Trim
ⓔ Fore and after drafts ⓕ LCB ⓖ LCG

ⓕ Let us calculate the ship's LCB.



$$-\frac{1}{2}\cdot\frac{L}{2}\cdot(T-T_f)\cdot(\frac{L}{2}\cdot\frac{2}{3})\cdot B,\quad -\frac{1}{2}\cdot\frac{L}{2}\cdot(T-T_f)\cdot(\frac{L}{2}\cdot\frac{2}{3})\cdot B$$

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

$$M_L = -2\cdot\left(\frac{1}{2}\cdot\frac{L}{2}\cdot(T-T_f)\right)\cdot(\frac{L}{2}\cdot\frac{2}{3})$$

$$= -3,750\ ton\cdot m$$

$$LCB = \frac{M_L}{\nabla} = \frac{-3,750}{2,064/1.0} = -1.82\ m$$

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

[Example] Calculation of Barge Ship's Trim and Heel Angles (14/18)

Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρ_m=1.0ton/m^3

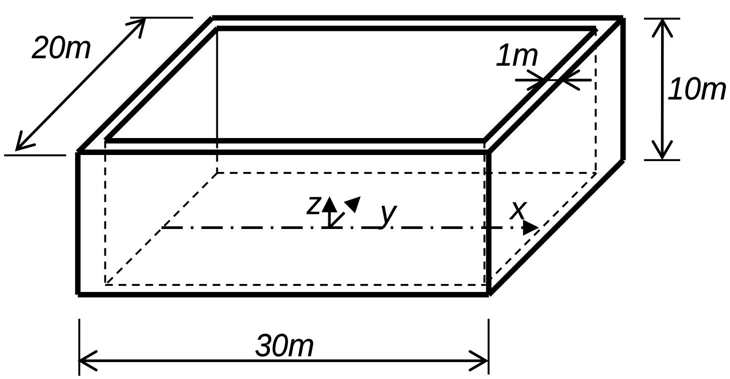
Find:

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.



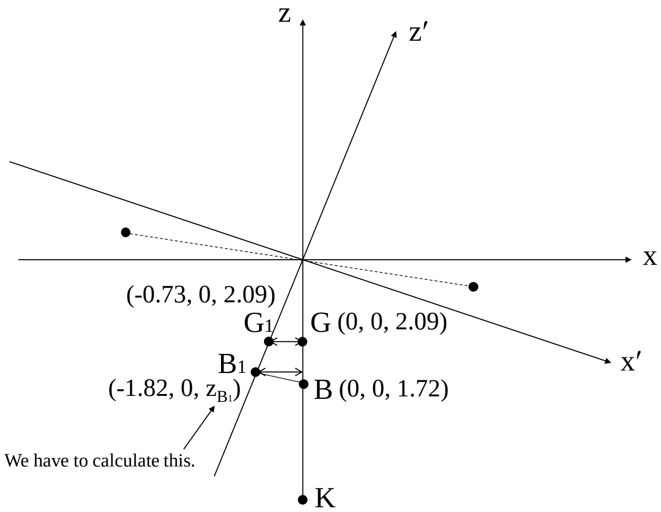
② When the freight 1 and 2 are loaded in fresh water,
ⓐ Deadweight(DWT) ⓑ TPC ⓒ MTC ⓓ Trim
ⓔ Fore and after drafts ⓕ LCB ⓖ LCG

ⓖ LCG is obtained as follows:

$$LCG = \frac{w}{W} l_L = \frac{(150 \cdot 2)}{2,064} \cdot (-5) = -0.73\ m$$

Consequently, trim moment due to loading freights is expressed as follows:

$$\text{Trim moment} = 2,064 \cdot 0.73 = 5 \cdot (150 \cdot 2)$$



[Example] Calculation of Barge Ship's Trim and Heel Angles (15/18)

Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρ_m=1.0ton/m^3

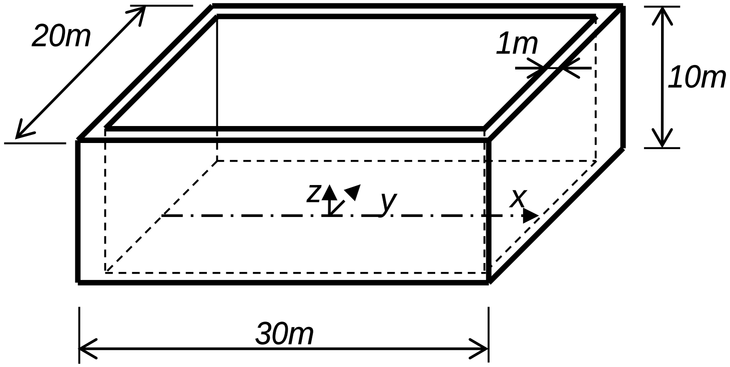
Find:

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.



③ Freight 2 is unloaded from ②, calculate LCB, LCG.

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 Δ is 1,764ton, draft is 1,764/(30·20)=2.94m.

Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρ_m=1.0ton/m^3

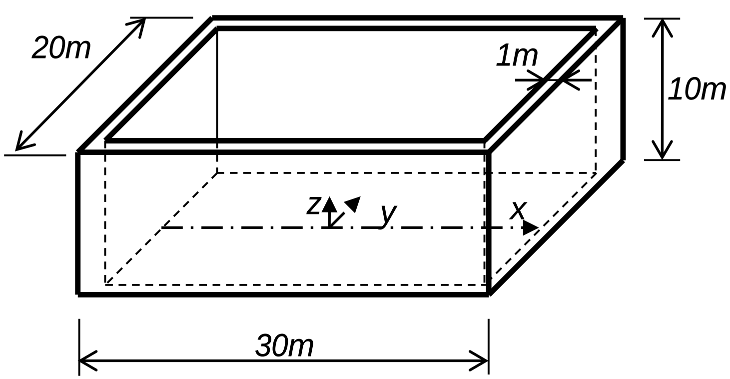
Find:

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.



④ Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

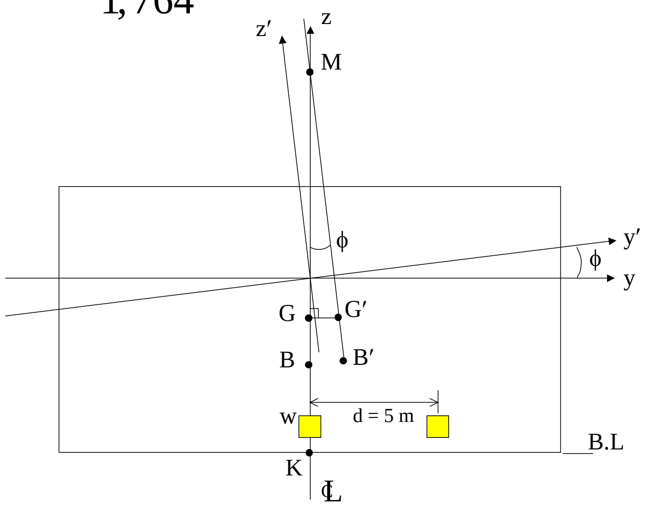
$$\text{Heeling moment} = w \cdot d \cdot \cos\phi$$

$$\text{Restoring moment} = \Delta \cdot GZ \approx \Delta \cdot GM \cdot \sin\phi$$

The freight 1 moves 5m along the positive y direction from centerline, total center of gravity G moves perpendicularly to G'.

Thus from $\text{Heeling arm}=\dfrac{w \cdot d}{\Delta}\cos\phi$

$$GG'=\frac{w \cdot d}{\Delta}=\frac{(100 \cdot 3) \cdot 5}{1,764} \approx 0.85\ m$$



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

Given:
L: 30m, B: 20m, D: 10m, Shell plate thickness: 1m
Density of the shell plate: ρ_m=1.0ton/m^3

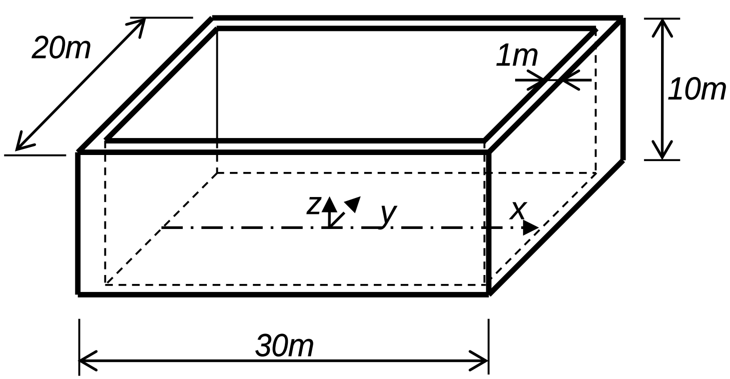
Find:

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.



④ 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,

$$KB = \frac{T}{2} = \frac{2.94}{2} = 1.47\ m$$

$$BM = \frac{I_T}{\nabla} = \frac{LB^3/12}{\nabla} \approx 11.34\ m$$

$$KG = \frac{30 \cdot 20 \cdot 10 \cdot 4 - 28 \cdot 18 \cdot 9 \cdot 4.5 + 100 \cdot 3 \cdot 1}{1,764}$$
$$= 2.20\ m$$

$$GM = KB + BM - KG = 1.47 + 11.34 - 2.20$$
$$= 10.61\ m$$

[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: ρ_m=1.0ton/m^3

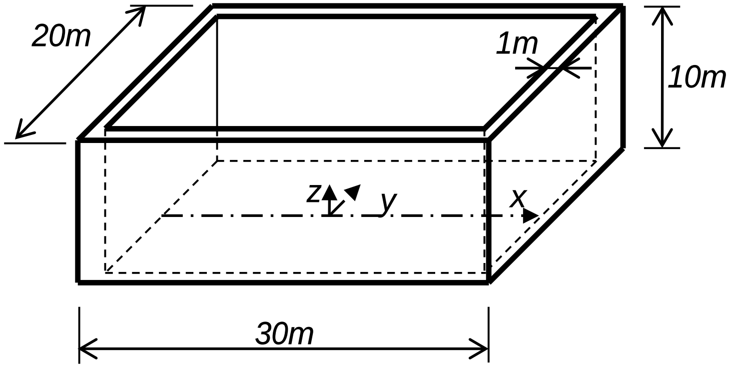
Find:

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.



④ Freight 1 moves 5m along the positive y direction. Calculate the heel angle.

Heel angle is calculated as

$$\text{Righting arm} = \text{Heeling arm}$$

$$GM \cdot \sin\phi = \frac{w \cdot d}{\Delta} \cos\phi$$

$$\tan\phi = \frac{w \cdot d}{\Delta} \frac{1}{GM} = \frac{GG'}{GM}$$

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

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

A bulk carrier of which the length between perpendiculars(L_{BP}) 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.

DWT 150,000 *ton* Bulk Carrier, *Lbp* = 264 *m*

HYDROSTATIC TABLE

DRAFT (EXT.) (M)	DISPL EXT. (MT)	TPC (MT/CM)	MTC (MT*M/CM)	L.C.B (M)	L.C.F (M)	KMT (M)	Cb	WETSUR (M^2)
15.200	150450	105.4	1906.1	9.464	2.107	18.717	0.8128	17013
15.220	150667	105.5	1907.1	9.454	2.081	18.714	0.8129	17023
15.240	150883	105.5	1908.1	9.443	2.055	18.712	0.8130	17019
15.260	151100	105.5	1909.0	9.432	2.029	18.709	0.8131	17032
15.280	151316	105.5	1910.0	9.422	2.004	18.706	0.8132	17062
15.300	151532	105.5	1911.0	9.411	1.978	18.704	0.8133	17078
15.320	151749	105.6	1911.9	9.400	1.953	18.701	0.8134	17065
15.340	151965	105.6	1912.9	9.389	1.928	18.699	0.8135	17074
15.360	152182	105.6	1913.9	9.379	1.903	18.696	0.8136	17093
15.380	152399	105.6	1914.8	9.368	1.878	18.694	0.8137	17128
15.400	152615	105.6	1915.8	9.357	1.854	18.691	0.8138	17123
15.420	152832	105.6	1916.7	9.347	1.829	18.689	0.8139	17121
15.440	153049	105.7	1917.7	9.336	1.805	18.686	0.8140	17132
15.460	153265	105.7	1918.6	9.325	1.781	18.684	0.8141	17153
15.480	153482	105.7	1919.6	9.314	1.757	18.682	0.8142	17180
15.500	153699	105.7	1920.5	9.304	1.733	18.679	0.8143	17190
15.520	153916	105.7	1921.5	9.293	1.709	18.677	0.8144	17217
15.540	154133	105.8	1922.4	9.282	1.685	18.675	0.8145	17234
15.560	154350	105.8	1923.3	9.271	1.662	18.673	0.8146	17210
15.580	154567	105.8	1924.3	9.261	1.638	18.671	0.8147	17192
16.600	165679	106.7	1968.5	8.709	0.589	18.598	0.8196	17711
16.620	165898	106.7	1969.3	8.698	0.570	18.597	0.8197	17722
16.640	166116	106.7	1970.1	8.687	0.552	18.597	0.8198	17733
16.660	166335	106.7	1970.9	8.676	0.534	18.596	0.8199	17744
16.680	166554	106.7	1971.6	8.665	0.516	18.595	0.8200	17756
16.700	166773	106.7	1972.4	8.655	0.498	18.595	0.8201	17767
16.720	166991	106.7	1973.2	8.644	0.480	18.594	0.8202	17777
16.740	167210	106.8	1974.0	8.633	0.462	18.594	0.8203	17788
16.760	167429	106.8	1974.7	8.622	0.444	18.593	0.8204	17799
16.780	167648	106.8	1975.5	8.611	0.426	18.592	0.8205	17810
16.800	167867	106.8	1976.2	8.601	0.408	18.592	0.8206	17821
16.820	168086	106.8	1977.0	8.590	0.390	18.591	0.8207	17831
16.840	168305	106.8	1977.7	8.579	0.372	18.591	0.8208	17841
16.860	168524	106.8	1978.4	8.568	0.354	18.590	0.8209	17851
16.880	168743	106.9	1979.1	8.558	0.336	18.590	0.8209	17861
16.900	**168962**	**106.9**	**1980.1**	**8.547**	**0.324**	**18.590**	**0.8210**	**17871**
16.920	169181	106.9	1980.9	8.536	0.308	18.590	0.8211	17881
16.940	169400	106.9	1981.7	8.525	0.292	18.589	0.8212	17891
16.960	169619	106.9	1982.6	8.514	0.276	18.589	0.8213	17901
16.980	169839	106.9	1983.4	8.504	0.261	18.589	0.8214	17911

NOTE : POSITIVE SIGN(+) OF L.C.B & L.C.F MEANS FORWARD DIRECTION OF MIDSHIP.
DISPLACEMENT(EXT) IS BASED ON SEA WATER S.G OF 1.025.

[Example] Practical Calculation of a Ship's Fore and Aft Drafts (2/9)

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

Find:

Fore and after drafts

DWT 150,000 *ton* Bulk Carrier, *Lbp* = 264 *m*

HYDROSTATIC TABLE

DRAFT (EXT.) (M)	DISPL EXT. (MT)	TPC (MT/CM)	MTC (MT*M/CM)	L.C.B (M)	L.C.F (M)	KMT (M)	Cb	WETSUR (M^2)
15.200	150450	105.4	1906.1	9.464	2.107	18.717	0.8128	17013
15.220	150667	105.5	1907.1	9.454	2.081	18.714	0.8129	17023
15.240	150883	105.5	1908.1	9.443	2.055	18.712	0.8130	17019
15.260	151100	105.5	1909.0	9.432	2.029	18.709	0.8131	17032
15.280	151316	105.5	1910.0	9.422	2.004	18.706	0.8132	17062
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15.380	152399	105.6	1914.8	9.368	1.878	18.694	0.8137	17128
15.400	152615	105.6	1915.8	9.357	1.854	18.691	0.8138	17123
15.420	152832	105.6	1916.7	9.347	1.829	18.689	0.8139	17121
15.440	153049	105.7	1917.7	9.336	1.805	18.686	0.8140	17132
15.460	153265	105.7	1918.6	9.325	1.781	18.684	0.8141	17153
16.800	167867	106.8	1976.2	8.601	0.408	18.592	0.8206	17821
16.820	168086	106.8	1977.0	8.590	0.390	18.591	0.8207	17831
16.840	168305	106.8	1977.7	8.579	0.372	18.591	0.8208	17841
16.860	168524	106.8	1978.4	8.568	0.354	18.590	0.8209	17851
16.880	168743	106.9	1979.1	8.558	0.336	18.590	0.8209	17861
16.900	**168962**	**106.9**	**1980.1**	**8.547**	**0.324**	**18.590**	**0.8210**	**17871**
16.920	169181	106.9	1980.9	8.536	0.308	18.590	0.8211	17881
16.940	169400	106.9	1981.7	8.525	0.292	18.589	0.8212	17891
16.960	169619	106.9	1982.6	8.514	0.276	18.589	0.8213	17901
16.980	169839	106.9	1983.4	8.504	0.261	18.589	0.8214	17911

NOTE : POSITIVE SIGN(+) OF L.C.B & L.C.F MEANS FORWARD DIRECTION OF MIDSHIP.
DISPLACEMENT(EXT) IS BASED ON SEA WATER S.G OF 1.025.

$$\mathbf{F} = \mathbf{A}\mathbf{x}$$

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.

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

Unload the freight
➡ Change in force(moment) is given.

Find:

Fore and after drafts

Problem to calculate the change of the position and orientation

[Example] Practical Calculation of a Ship's Fore and Aft Drafts (3/9)

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

Find:

Fore and after drafts

DWT 150,000 *ton* Bulk Carrier, *Lbp* = 264 *m*

HYDROSTATIC TABLE

DRAFT (EXT.) (M)	DISPL EXT. (MT)	TPC (MT/CM)	MTC (MT*M/CM)	L.C.B (M)	L.C.F (M)	KMT (M)	Cb	WETSUR (M^2)
15.200	150450	105.4	1906.1	9.464	2.107	18.717	0.8128	17013
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15.240	150883	105.5	1908.1	9.443	2.055	18.712	0.8130	17019
15.260	151100	105.5	1909.0	9.432	2.029	18.709	0.8131	17032
15.280	151316	105.5	1910.0	9.422	2.004	18.706	0.8132	17062
15.300	151532	105.5	1911.0	9.411	1.978	18.704	0.8133	17078
15.320	151749	105.6	1911.9	9.400	1.953	18.701	0.8134	17065
15.340	151965	105.6	1912.9	9.389	1.928	18.699	0.8135	17074
15.360	152182	105.6	1913.9	9.379	1.903	18.696	0.8136	17093
15.380	152399	105.6	1914.8	9.368	1.878	18.694	0.8137	17128
15.400	152615	105.6	1915.8	9.357	1.854	18.691	0.8138	17123
15.420	152832	105.6	1916.7	9.347	1.829	18.689	0.8139	17121
15.440	153049	105.7	1917.7	9.336	1.805	18.686	0.8140	17132
15.460	153265	105.7	1918.6	9.325	1.781	18.684	0.8141	17153
16.800	167867	106.8	1976.2	8.601	0.408	18.592	0.8206	17821
16.820	168086	106.8	1977.0	8.590	0.390	18.591	0.8207	17831
16.840	168305	106.8	1977.7	8.579	0.372	18.591	0.8208	17841
16.860	168524	106.8	1978.4	8.568	0.354	18.590	0.8209	17851
16.880	168743	106.9	1979.1	8.558	0.336	18.590	0.8209	17861
16.900	**168962**	**106.9**	**1980.1**	**8.547**	**0.324**	**18.590**	**0.8210**	**17871**
16.920	169181	106.9	1980.9	8.536	0.308	18.590	0.8211	17881
16.940	169400	106.9	1981.7	8.525	0.292	18.589	0.8212	17891
16.960	169619	106.9	1982.6	8.514	0.276	18.589	0.8213	17901
16.980	169839	106.9	1983.4	8.504	0.261	18.589	0.8214	17911

NOTE : POSITIVE SIGN(+) OF L.C.B & L.C.F MEANS FORWARD DIRECTION OF MIDSHIP.
DISPLACEMENT(EXT) IS BASED ON SEA WATER S.G OF 1.025.

Calculation of the approximate solution by linearizing the problem

1. Calculation of trim

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

①-1) Trim Moment: (LCG-LCB)·Δ

At the initial state, the ship is on an even keel.

Thus, LGG = LCB.

After unloading, LCG becomes

$$LCG = \frac{W \cdot x_W - w \cdot x_w}{W'},$$

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

①-2) $MTC = \dfrac{\Delta \cdot \overline{GM}_L}{100 \cdot L_{BP}}$, LCF

2. Calculation of the changed draft

$$T_{Aft} = d - \frac{\frac{L}{2} + LCF}{L} \times \text{trim} \qquad T_{Foreward} = d + \frac{\frac{L}{2} - LCF}{L} \times \text{trim}$$

[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_{AFT}: 16.9m, T_{FORE}: 16.9m,

No.1 Cargo Hold: 16,032ton unloaded

(Cargo hold position in longitudinal direction: 107.827m)

Find:

Fore and after drafts

DWT 150,000 *ton* Bulk Carrier, *Lbp* = 264 *m*

HYDROSTATIC TABLE

DRAFT (EXT.) (M)	DISPL EXT. (MT)	TPC (MT/CM)	MTC (MT*M/CM)	L.C.B (M)	L.C.F (M)	KMT (M)	Cb	WETSUR (M^2)
15.200	150450	105.4	1906.1	9.464	2.107	18.717	0.8128	17013
15.220	150667	105.5	1907.1	9.454	2.081	18.714	0.8129	17023
15.240	150883	105.5	1908.1	9.443	2.055	18.712	0.8130	17019
15.260	151100	105.5	1909.0	9.432	2.029	18.709	0.8131	17032
15.280	151316	105.5	1910.0	9.422	2.004	18.706	0.8132	17062
15.300	151532	105.5	1911.0	9.411	1.978	18.704	0.8133	17078
15.320	151749	105.6	1911.9	9.400	1.953	18.701	0.8134	17065
15.340	151965	105.6	1912.9	9.389	1.928	18.699	0.8135	17074
15.360	152182	105.6	1913.9	9.379	1.903	18.696	0.8136	17093
15.380	152399	105.6	1914.8	9.368	1.878	18.694	0.8137	17128
15.400	152615	105.6	1915.8	9.357	1.854	18.691	0.8138	17123
15.420	152832	105.6	1916.7	9.347	1.829	18.689	0.8139	17121
15.440	153049	105.7	1917.7	9.336	1.805	18.686	0.8140	17132
15.460	153265	105.7	1918.6	9.325	1.781	18.684	0.8141	17153
16.800	167867	106.8	1976.2	8.601	0.408	18.592	0.8206	17821
16.820	168086	106.8	1977.0	8.590	0.390	18.591	0.8207	17831
16.840	168305	106.8	1977.7	8.579	0.372	18.591	0.8208	17841
16.860	168524	106.8	1978.4	8.568	0.354	18.590	0.8209	17851
16.880	168743	106.9	1979.1	8.558	0.336	18.590	0.8209	17861
16.900	**168962**	**106.9**	**1980.1**	**8.547**	**0.324**	**18.590**	**0.8210**	**17871**
16.920	169181	106.9	1980.9	8.536	0.308	18.590	0.8211	17881
16.940	169400	106.9	1981.7	8.525	0.292	18.589	0.8212	17891
16.960	169619	106.9	1982.6	8.514	0.276	18.589	0.8213	17901
16.980	169839	106.9	1983.4	8.504	0.261	18.589	0.8214	17911

NOTE : POSITIVE SIGN(+) OF L.C.B & L.C.F MEANS FORWARD DIRECTION OF MIDSHIP.
DISPLACEMENT(EXT) IS BASED ON SEA WATER S.G OF 1.025.

1. Calculation of trim

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

①-1) Trim Moment: (LCG-LCB) · Δ

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=16.9m is listed in the hydrostatic table.

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

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

[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_{AFT}: 16.9m, T_{FORE}: 16.9m,
No.1 Cargo Hold: 16,032ton unloaded
(Cargo hold position in longitudinal direction: 107.827m)

Find:

Fore and after drafts

DWT 150,000 *ton* Bulk Carrier, *Lbp* = 264 *m*

HYDROSTATIC TABLE

DRAFT (EXT.) (M)	DISPL EXT. (MT)	TPC (MT/CM)	MTC (MT*M/CM)	L.C.B (M)	L.C.F (M)	KMT (M)	Cb	WETSUR (M^2)
15.200	150450	105.4	1906.1	9.464	2.107	18.717	0.8128	17013
15.220	150667	105.5	1907.1	9.454	2.081	18.714	0.8129	17023
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15.300	151532	105.5	1911.0	9.411	1.978	18.704	0.8133	17078
15.320	151749	105.6	1911.9	9.400	1.953	18.701	0.8134	17065
15.340	151965	105.6	1912.9	9.389	1.928	18.699	0.8135	17074
15.360	152182	105.6	1913.9	9.379	1.903	18.696	0.8136	17093
15.380	152399	105.6	1914.8	9.368	1.878	18.694	0.8137	17128
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15.440	153049	105.7	1917.7	9.336	1.805	18.686	0.8140	17132
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16.880	168743	106.9	1979.1	8.558	0.336	18.590	0.8209	17861
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16.980	169839	106.9	1983.4	8.504	0.261	18.589	0.8214	17911

NOTE : POSITIVE SIGN(+) OF L.C.B & L.C.F MEANS FORWARD DIRECTION OF MIDSHIP.
DISPLACEMENT(EXT) IS BASED ON SEA WATER S.G OF 1.025.

1. Calculation of trim

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

①-1) Trim Moment: (LCG-LCB) · Δ

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

i) Full loading condition

Ship's total weight at full loading condition: $\Delta = 168,962\ ton$

Moment in longitudinal direction $= \Delta \times LCG = 168,962 \times (+8.547)$
$= 1,444,118\ ton \cdot m$

ii) Unloading of freight

Weight of the unloaded freight: $w = -16,032\ ton$
$LCG(l) = +107.827\ m$

Moment in longitudinal direction $= w \times l = -16,032 \times (+107.827)$
$= -1,728,770\ ton \cdot m$

[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_{AFT}: 16.9m, T_{FORE}: 16.9m,
No.1 Cargo Hold: 16,032ton unloaded
(Cargo hold position in longitudinal direction: 107.827m)

Find:

Fore and after drafts

DWT 150,000 *ton* Bulk Carrier, *Lbp* = 264 *m*

HYDROSTATIC TABLE

DRAFT (EXT.) (M)	DISPL EXT. (MT)	TPC (MT/CM)	MTC (MT*M/CM)	L.C.B (M)	L.C.F (M)	KMT (M)	Cb	WETSUR (M^2)
15.200	150450	105.4	1906.1	9.464	2.107	18.717	0.8128	17013
15.220	150667	105.5	1907.1	9.454	2.081	18.714	0.8129	17023
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15.440	153049	105.7	1917.7	9.336	1.805	18.686	0.8140	17132
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16.800	167867	106.8	1976.2	8.601	0.408	18.592	0.8206	17821
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16.840	168305	106.8	1977.7	8.579	0.372	18.591	0.8208	17841
16.860	168524	106.8	1978.4	8.568	0.354	18.590	0.8209	17851
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NOTE : POSITIVE SIGN(+) OF L.C.B & L.C.F MEANS FORWARD DIRECTION OF MIDSHIP.
DISPLACEMENT(EXT) IS BASED ON SEA WATER S.G OF 1.025.

1. Calculation of trim

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

①-1) Trim Moment: (LCG-LCB) · Δ

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

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

$$= 1,444,118 - 1,728,770 = -284,652 \ ton \cdot m$$

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

Weight = Weight at full loading condition
– Weight of the unloaded freight

$$= 168,962 - 16,032 = 152,929 \ ton$$

Longitudinal center of gravity = **LCG**

$$= \frac{-284,652}{152,929} = -1.861 m$$

[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_{AFT}: 16.9m, T_{FORE}: 16.9m,
No.1 Cargo Hold: 16,032ton unloaded
(Cargo hold position in longitudinal direction: 107.827m)

Find:

Fore and after drafts

DWT 150,000 *ton* Bulk Carrier, *Lbp* = 264 *m*

HYDROSTATIC TABLE

DRAFT (EXT.) (M)	DISPL EXT. (MT)	TPC (MT/CM)	MTC (MT*M/CM)	L.C.B (M)	L.C.F (M)	KMT (M)	Cb	WETSUR (M^2)
15.200	150450	105.4	1906.1	9.464	2.107	18.717	0.8128	17013
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15.300	151532	105.5	1911.0	9.411	1.978	18.704	0.8133	17078
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15.340	151965	105.6	1912.9	9.389	1.928	18.699	0.8135	17074
15.360	152182	105.6	1913.9	9.379	1.903	18.696	0.8136	17093
15.380	152399	105.6	1914.8	9.368	1.878	18.694	0.8137	17128
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16.800	167867	106.8	1976.2	8.601	0.408	18.592	0.8206	17821
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16.980	169839	106.9	1983.4	8.504	0.261	18.589	0.8214	17911

NOTE : POSITIVE SIGN(+) OF L.C.B & L.C.F MEANS FORWARD DIRECTION OF MIDSHIP.
DISPLACEMENT(EXT) IS BASED ON SEA WATER S.G OF 1.025.

1. Calculation of trim

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

①-1) Trim Moment: (LCG-LCB) · Δ

①-2) $MTC = \dfrac{\Delta \cdot \overline{GM_L}}{100 \cdot L_{BP}}$, LCF

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

$$Displacement\,(\Delta) = 152{,}929\ ton$$

$$Draft(d) = \frac{15.440 - 15.420}{153{,}049 - 152{,}832} \times (152{,}929 - 152{,}832) + 15.420$$
$$= 15.429\ m$$

$$LCB = \frac{9.336 - 9.347}{153{,}049 - 152{,}832} \times (152{,}929 - 152{,}832) + 9.347$$
$$= +9.342\ m\,(\text{Forward from midship})$$

$$MTC = \frac{1{,}917.7 - 1{,}916.7}{153{,}049 - 152{,}832} \times (152{,}929 - 152{,}832) + 1{,}916.7$$
$$= 1{,}917.147\ ton \cdot m / cm$$

$$LCF = \frac{1.805 - 1.829}{153{,}049 - 152{,}832} \times (152{,}929 - 152{,}832) + 1.829$$
$$= +1.818\ m\,(\text{Forward from midship})$$

[Example] Practical Calculation of a Ship's Fore and Aft Drafts (8/9)

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

Find:

Fore and after drafts

DWT 150,000 *ton* Bulk Carrier, *Lbp* = 264 *m*

HYDROSTATIC TABLE

DRAFT (EXT.) (M)	DISPL EXT. (MT)	TPC (MT/CM)	MTC (MT*M/CM)	L.C.B (M)	L.C.F (M)	KMT (M)	Cb	WETSUR (M^2)
15.200	150450	105.4	1906.1	9.464	2.107	18.717	0.8128	17013
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NOTE : POSITIVE SIGN(+) OF L.C.B & L.C.F MEANS FORWARD DIRECTION OF MIDSHIP.
DISPLACEMENT(EXT) IS BASED ON SEA WATER S.G OF 1.025.

1. Calculation of trim

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

①-1) Trim Moment: (LCG-LCB) · Δ

①-2) $MTC = \dfrac{\Delta \cdot \overline{GM}_L}{100 \cdot L_{BP}}$, LCF

$$\text{Distance between LCB and LCG} = 9.342 - (-1.861) = 11.203\ m$$

$$Trim\ Moment = 152{,}929 \times 11.203 = 1{,}713{,}276\ ton \cdot m$$

$$Trim = \frac{Trim\ Moment}{100 \cdot MTC} = \frac{1{,}713{,}276}{100 \cdot 1{,}917.147} = 8.937\ m$$

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

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

Find:

Fore and after drafts

DWT 150,000 *ton* Bulk Carrier, *Lbp* = 264 *m*

HYDROSTATIC TABLE

DRAFT (EXT.) (M)	DISPL EXT. (MT)	TPC (MT/CM)	MTC (MT*M/CM)	L.C.B (M)	L.C.F (M)	KMT (M)	Cb	WETSUR (M^2)
15.200	150450	105.4	1906.1	9.464	2.107	18.717	0.8128	17013
15.220	150667	105.5	1907.1	9.454	2.081	18.714	0.8129	17023
15.240	150883	105.5	1908.1	9.443	2.055	18.712	0.8130	17019
15.260	151100	105.5	1909.0	9.432	2.029	18.709	0.8131	17032
15.280	151316	105.5	1910.0	9.422	2.004	18.706	0.8132	17062
15.300	151532	105.5	1911.0	9.411	1.978	18.704	0.8133	17078
15.320	151749	105.6	1911.9	9.400	1.953	18.701	0.8134	17065
15.340	151965	105.6	1912.9	9.389	1.928	18.699	0.8135	17074
15.360	152182	105.6	1913.9	9.379	1.903	18.696	0.8136	17093
15.380	152399	105.6	1914.8	9.368	1.878	18.694	0.8137	17128
15.400	152615	105.6	1915.8	9.357	1.854	18.691	0.8138	17123
15.420	152832	105.6	1916.7	9.347	1.829	18.689	0.8139	17121
15.440	153049	105.7	1917.7	9.336	1.805	18.686	0.8140	17132
15.460	153265	105.7	1918.6	9.325	1.781	18.684	0.8141	17153
16.800	167867	106.8	1976.2	8.601	0.408	18.592	0.8206	17821
16.820	168086	106.8	1977.0	8.590	0.390	18.591	0.8207	17831
16.840	168305	106.8	1977.7	8.579	0.372	18.591	0.8208	17841
16.860	168524	106.8	1978.4	8.568	0.354	18.590	0.8209	17851
16.880	168743	106.9	1979.1	8.558	0.336	18.590	0.8209	17861
16.900	**168962**	**106.9**	**1980.1**	**8.547**	**0.324**	**18.590**	**0.8210**	**17871**
16.920	169181	106.9	1980.9	8.536	0.308	18.590	0.8211	17881
16.940	169400	106.9	1981.7	8.525	0.292	18.589	0.8212	17891
16.960	169619	106.9	1982.6	8.514	0.276	18.589	0.8213	17901
16.980	169839	106.9	1983.4	8.504	0.261	18.589	0.8214	17911

NOTE : POSITIVE SIGN(+) OF L.C.B & L.C.F MEANS FORWARD DIRECTION OF MIDSHIP.
DISPLACEMENT(EXT) IS BASED ON SEA WATER S.G OF 1.025.

2. Calculation of the changed draft

Change in trim: $\delta t = 8.937\ m$

Fore draft: $$da = d - \frac{\frac{L}{2} + LCF}{L} \times \delta t$$

$$= 15.429 - \frac{\frac{264}{2} + 1.818}{264} \times (-8.937)$$

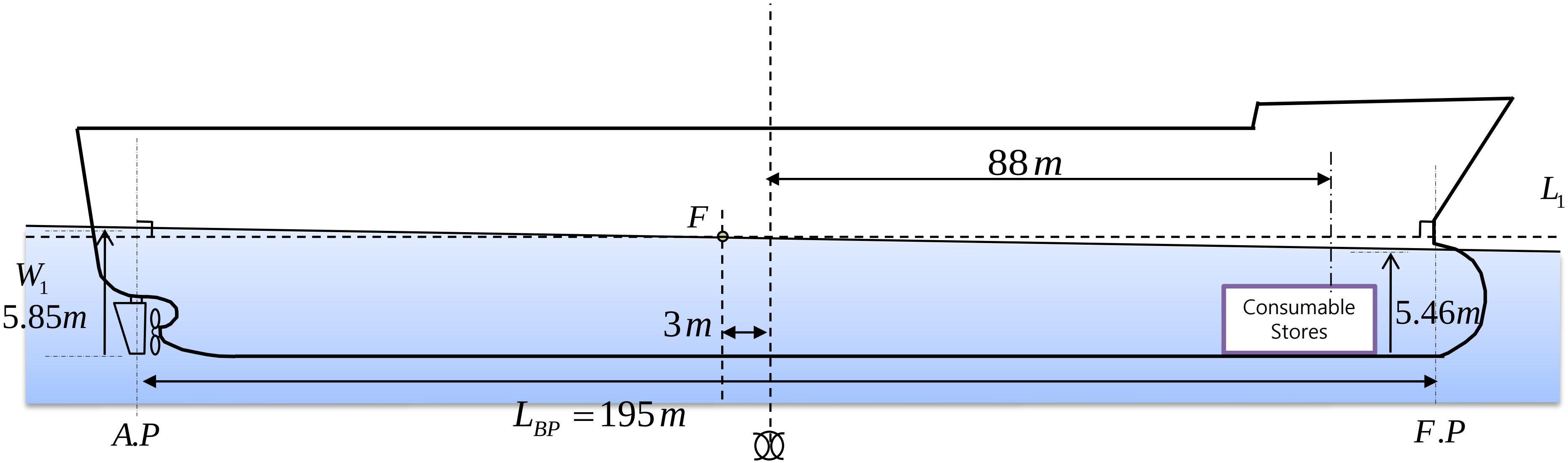
$$= 19.959\ m$$

After draft: $$df = d + \frac{\frac{L}{2} - LCF}{L} \times \delta t$$

$$= 15.429 + \frac{\frac{264}{2} - 1.818}{264} \times (-8.937)$$

$$= 11.022\ m$$

[Example] Calculation of Draft Change Due to Fuel Consumption (1/4)



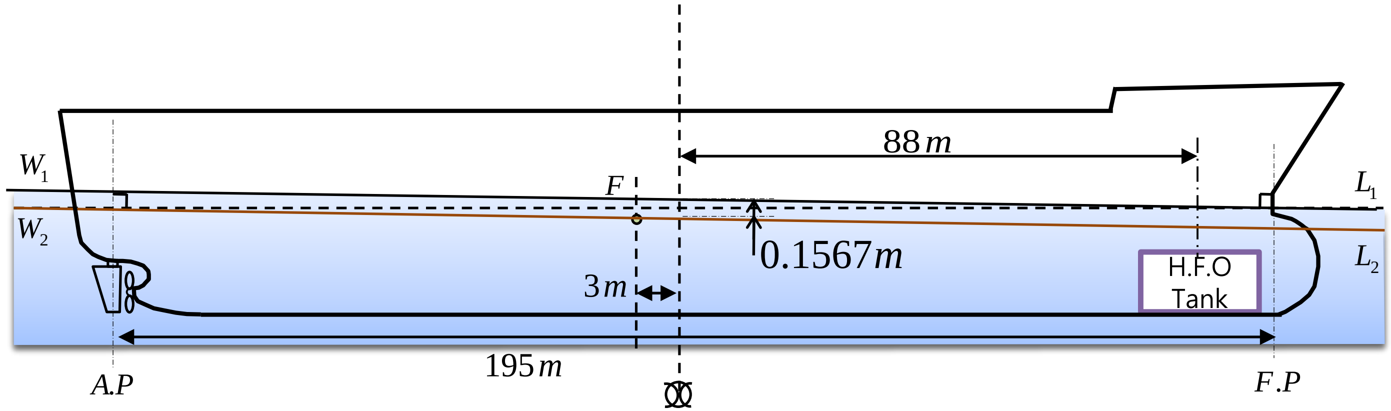
During a voyage, a cargo ship uses up 320ton of consumable stores (H.F.O: Heavy Fuel Oil), located 88m forward of the midships.

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

At the mean draft between forward and after perpendicular, the hydrostatic data show the ship to have LCF after of midship = 3m, Breadth = 10.47m, moment of inertia of the water plane area about transverse axis through point F = 6,469,478m^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=1.0ton/m^3).

[Example] Calculation of Draft Change Due to Fuel Consumption (2/4)



① Calculation of parallel rise (draft change)

$$A_{WP} = C_{WP} \cdot L \cdot B = 0.8 \cdot 195 \cdot 10.47 = 1,633.3[m^2]$$

- Tones per 1 cm immersion (TPC)

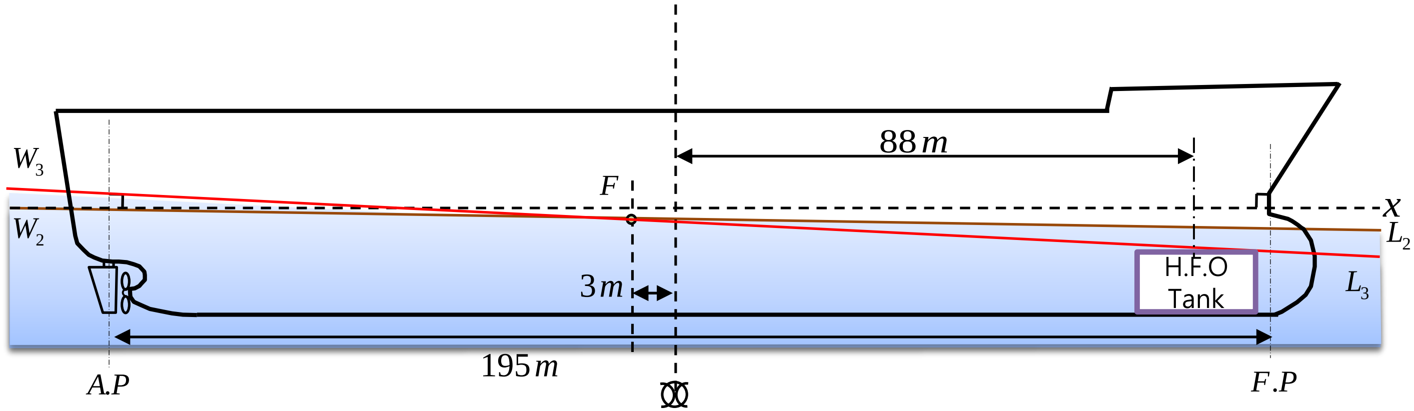
$$: TPC = \rho \cdot A_{WP} \cdot \frac{1}{100} = 1[ton/m^3] \cdot 1,633.3[m^2] \cdot \frac{1}{100[cm/m]}$$

$$= 20.4165[ton/cm]$$

- Parallel rise

$$: \delta d = \frac{weight}{TPC} = \frac{320[ton]}{20.4165[ton/cm]} = 15.6736[cm] = 0.1567[m]$$

[Example] Calculation of Draft Change Due to Fuel Consumption (3/4)



② Calculation of trim

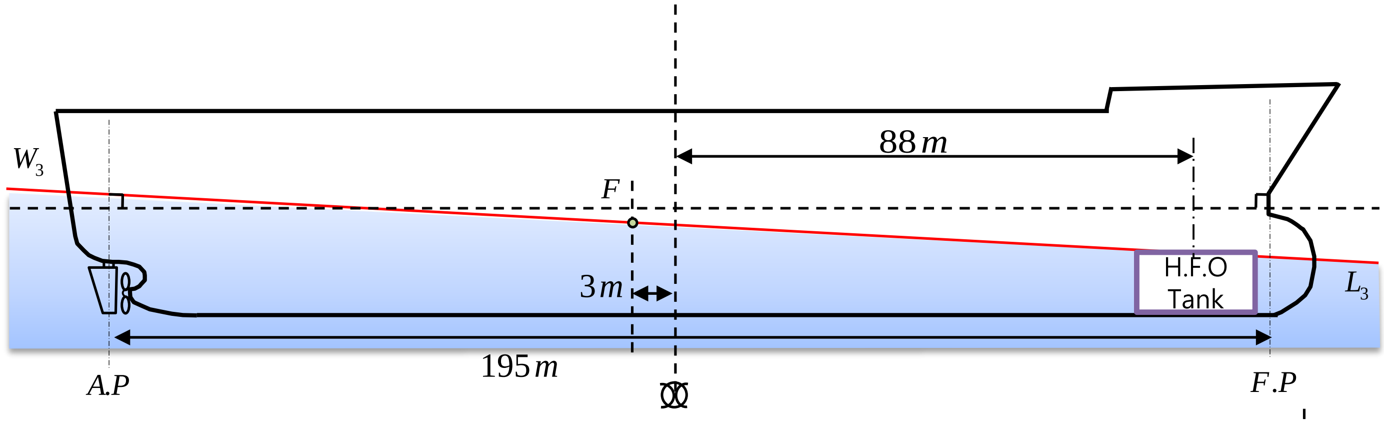
- Trim moment : $\tau_{trim} = 320[ton]\cdot 88[m] = 28{,}160[ton\cdot m]$
- Moment to trim 1 cm (MTC)

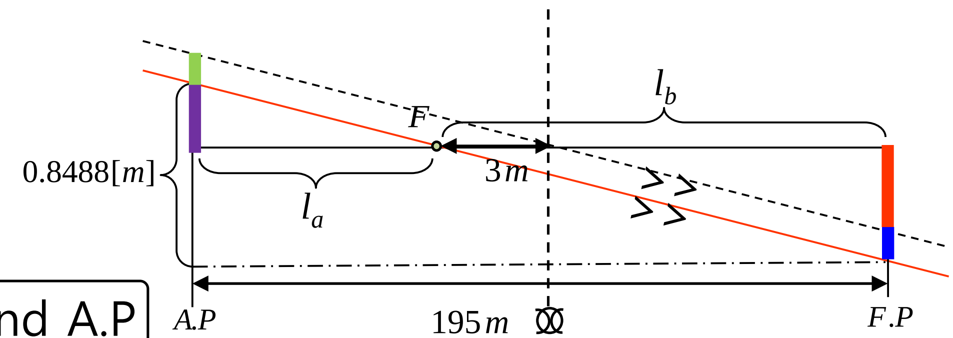
$$: MTC = \frac{\rho \cdot I_L}{100 \cdot L_{BP}} = \frac{1[ton/m^3]}{100[cm/m]\cdot 195[m]} \cdot 6{,}469{,}478[m^4] = 331.7949[ton\cdot m/cm]$$

- Trim

$$: Trim = \frac{\tau_{trim}}{MTC} = \frac{28{,}160[ton\cdot m]}{331.7949[ton\cdot m/cm]} = 84.8785[cm] = 0.8488[m]$$

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





(195 : 0.8488 = l_a : ?)

(195 : 0.8488 = l_b : ?)

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

- Draft change at F.P due to trim $= -\dfrac{195/2+3}{195} \times 0.8488 = -0.4375[m]$
- Draft change at A.P due to trim $= \dfrac{195/2-3}{195} \times 0.8488 = 0.4113[m]$
- Changed Draft at F.P : draft – parallel rise - draft change due to trim
  $= 5.46[m] - 0.1567[m] - 0.4375[m] \quad = 4.8658[m]$
- Changed Draft at A.P : draft – parallel rise + draft change due to trim
  $= 5.85[m] - 0.1567[m] + 0.4113[m] \quad = 6.1046[m]$