- Ship Stability -

Part.1-III Stability Criteria

2009

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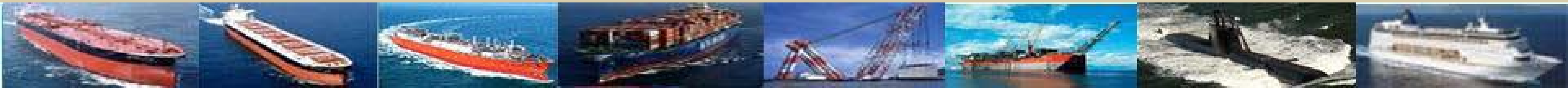


Overview of "Ship Stability"

F_B: Buoyancy force
ϕ : Angle of Heel, θ : Angle of Trim
(x_G, y_G, z_G) : Center of gravity in waterplane fixed frame
(x_B, y_B, z_B) : Center of buoyancy in waterplane fixed frame

Fundamental of Ship Stability

Force & Moment on a Floating Body

Newton's 2nd Law
Euler Equation

Hydrostatic Values

- Properties which is related to hull form of the ship

y'_G , y'_B in body fixed frame

Rotational Transformation!

y_G , y_B in waterplane fixed frame

Righting Moment

Transverse Righting Moment : $F_B \times GZ$

Longitudinal Righting Moment : $F_B \times GZ_L$

GZ Calculation

<Method ①>

$$GZ = (-y_G + y_B)$$

$$GZ_L = (-x_G + x_B)$$

<Method ②>

$$GZ = GM \sin\phi \quad , GM = KB + BM - KG$$

$$GZ_L = GM_L \sin\theta \quad , GM_L = KB + BM_L - KG$$

Pressure Integration Technique

- **Calculation Method to find GZ with respect to IMO regulation**

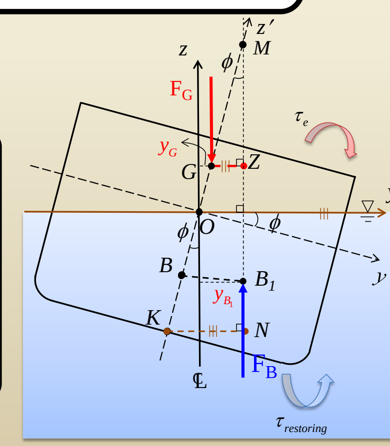
Stability Criteria

Intact Stability

- IMO Requirement (GZ)
- Grain Stability
- Floodable Length

Damage Stability

- MARPOL regulation



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Naval Architecture & Ocean Engineering

- Ship Stability -

Ch.9 Intact Stability

September, 2009

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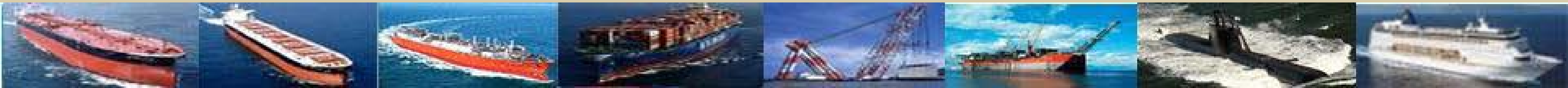


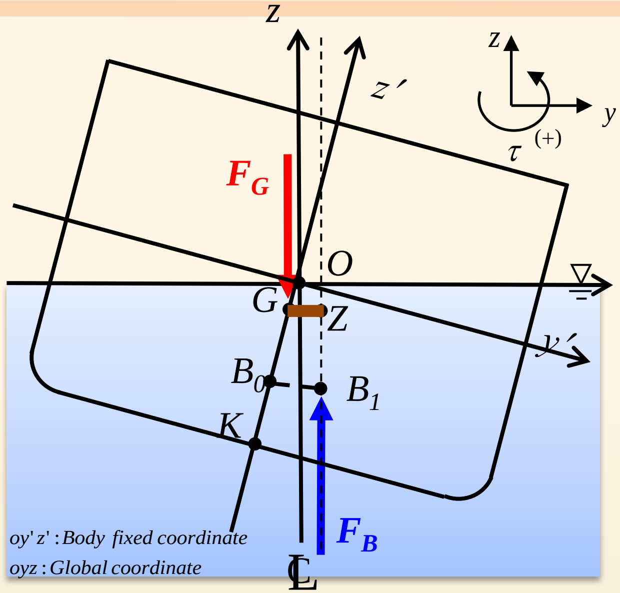
Sec.1 Stability Curve and Stability Criteria

Sec.2 Grain Stability

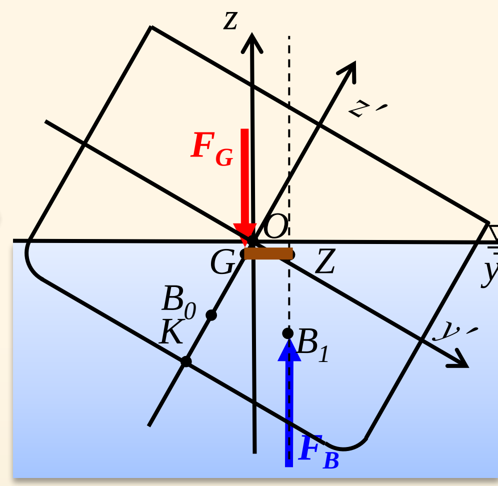
Sec.3 Floodable Length

Sec.4 3,700 TEU Container Ship : Example of Stability Calculation

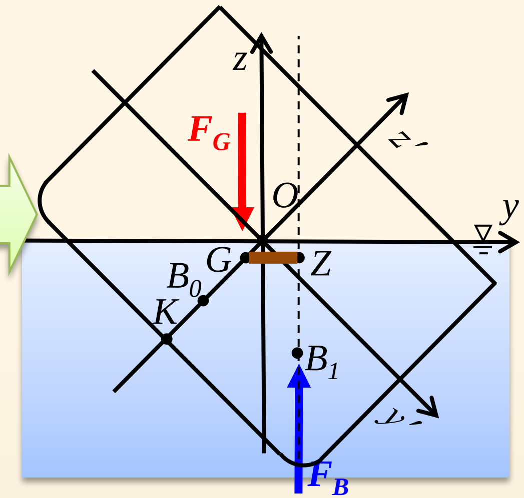
Statical Stability Curve



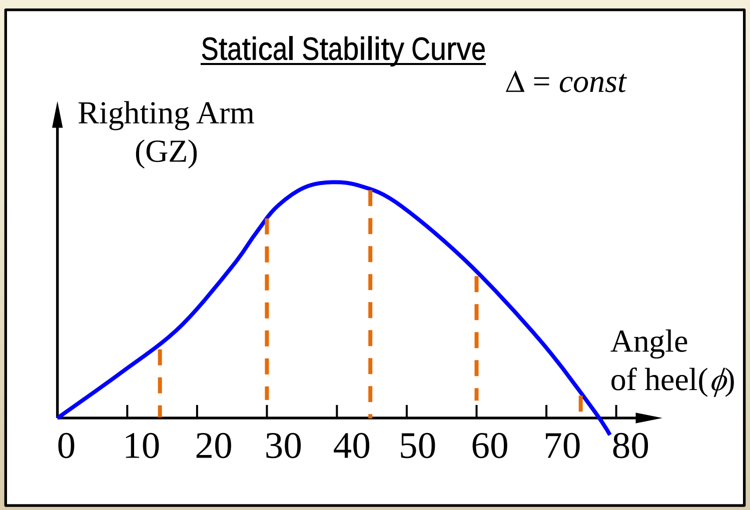
< Righting arm in 15˚ heel>

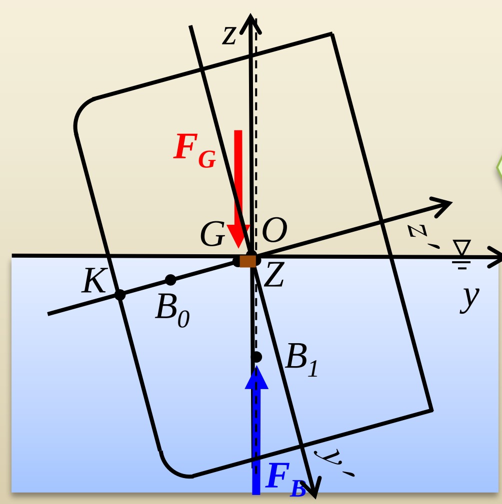


< Righting arm in 30˚ heel>

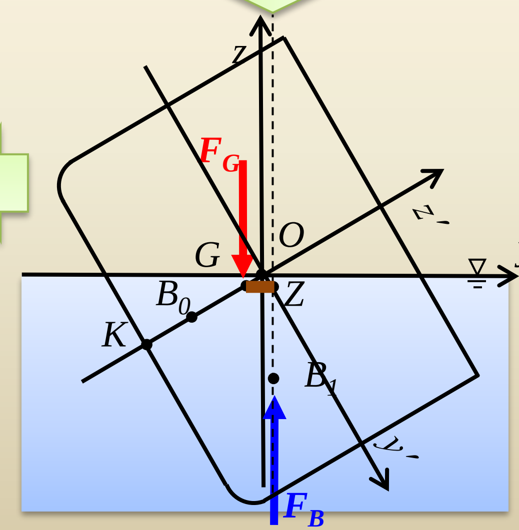


< Righting arm in 45˚ heel>





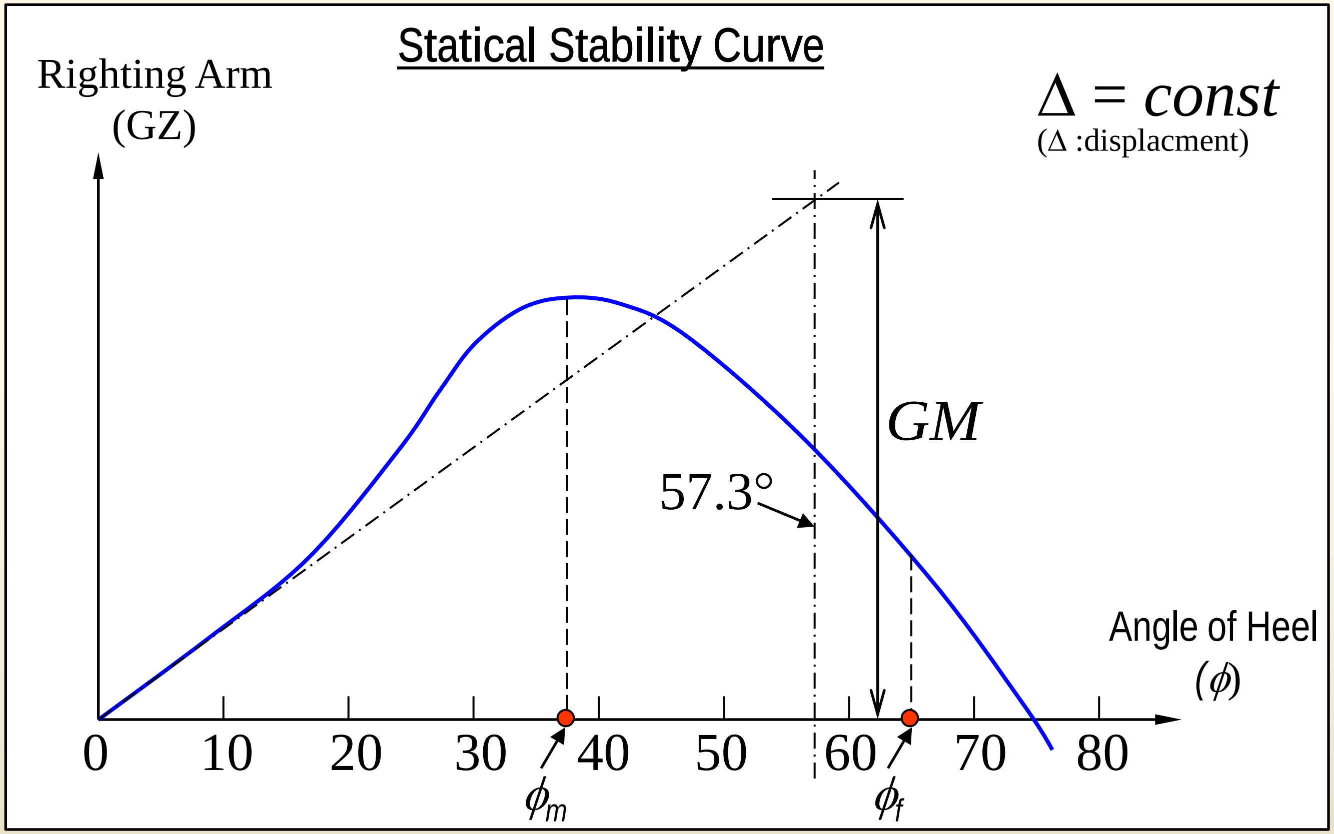
< Righting arm in 75˚ heel>



< Righting arm in 60˚ heel>

Statical Stability Curve

$$\tau_{restoring} = F_B \cdot GZ$$



ϕ_m : Angle of maximum righting arm

ϕ_f : Angle of downflodding

✓ GM in statical stability curve

If we assume ϕ is small

$$GZ \approx GM \sin|\phi|$$

Slop of curve at ϕ =0

$$\lim_{\phi \to 0} \frac{GZ}{\phi} = \lim_{\phi \to 0} \frac{GM \sin\phi}{\phi}$$

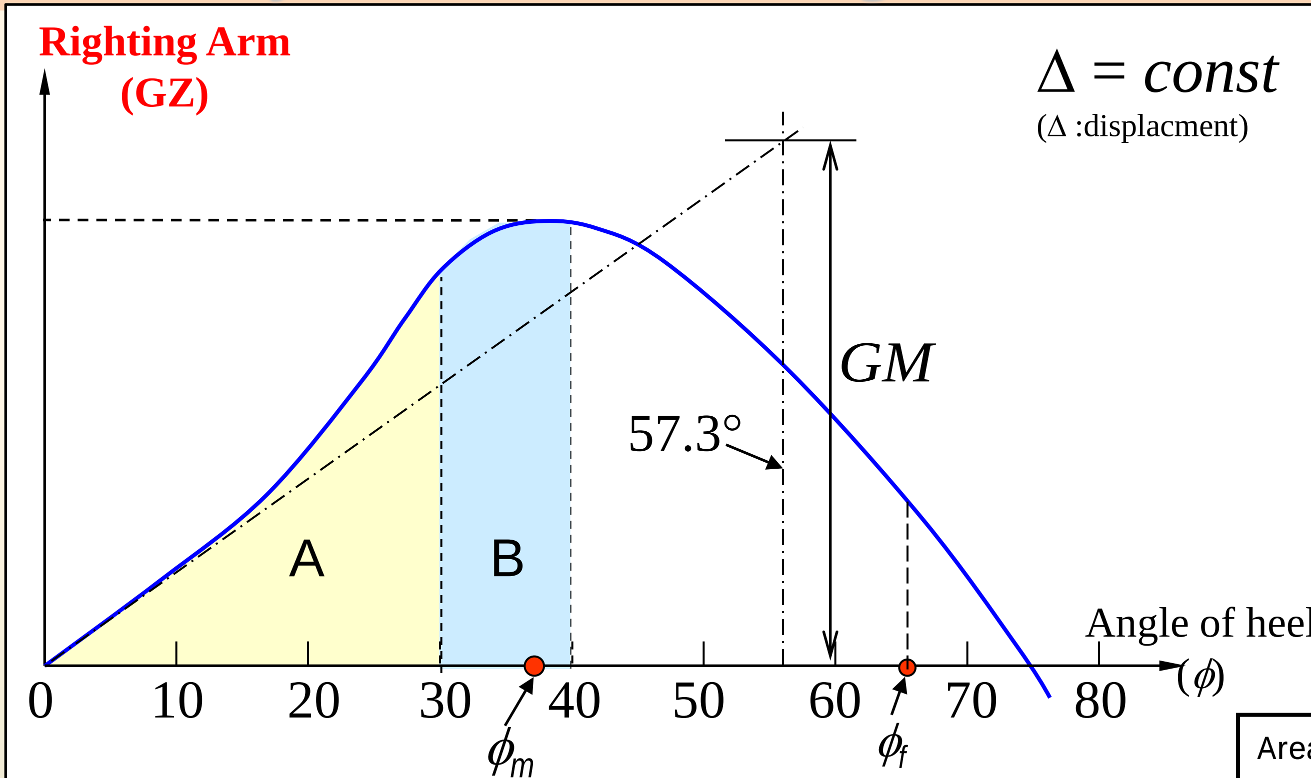
$$= \frac{GM}{1(rad)} \quad , \left(\lim_{\phi \to 0} \frac{\sin\phi}{\phi} = 1 \right)$$

$$= \frac{GM}{57.3^\circ}$$

As GM is the slop of the righting arm curve at the upright floating position(ϕ =0), this value can be read at an angle of heel equal to 1 rad(=57.3°)

: Stability Criteria – IMO Regulations for Intact Stability

(IMO Res.A-749(18) chapt.3.1)



Area A : Heel Angle from 0° ~ 30°

Area B : Heel Angle from 30° ~ min(40°, ϕ_f)

※ ϕ_f : An angle of heel at which openings in the hull

ϕ_m : Angle of maximum righting arm

IMO Regulations for Intact Stability

(a) Area A ≥ 0.055 m-rad

(b) Area A + B ≥ 0.09 m-rad

(c) Area B ≥ 0.030 m-rad

(d) GZ ≥ 0.20 m at an angle of heel equal to or greater than 30°

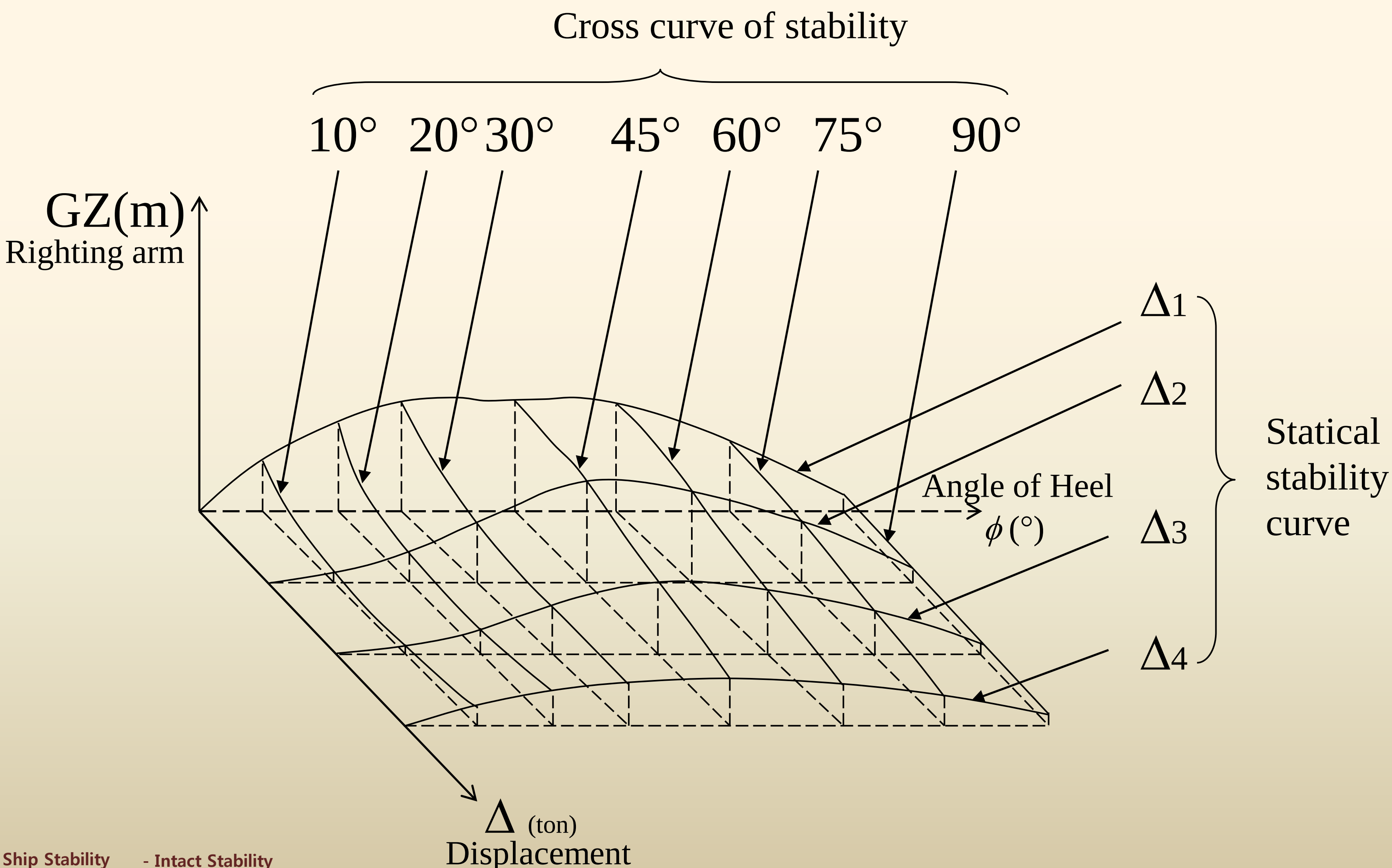
(e) GZ_{max} should occur at an angle of heel equal to or greater than 25°

(f) The initial metacentric height GM_o should not be less than 0.15 m.

※ After receiving approval of calculation of IMO regulation from Owner and Classification Society, ship construction can proceed.

Statical Stability Curve by using Cross Curve of Stability

- 3 dimensional expression of cross curve of stability

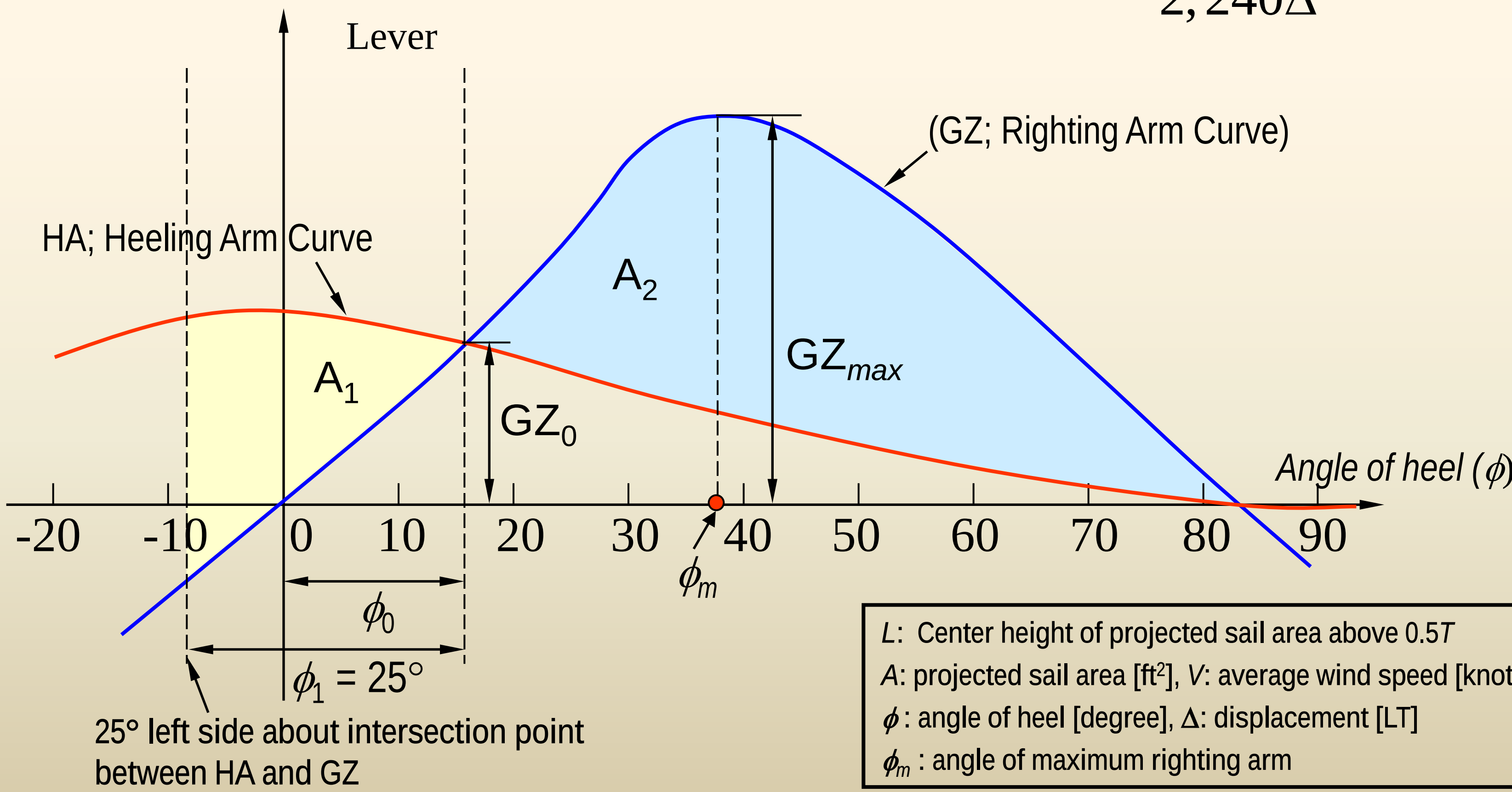


Stability Criteria for Intact Stability -
- Stability Criteria of Battleship*

- Regulation

$GZ_0 \leq 0.6 \cdot GZ_{max}$, $A_2 \geq 1.4 \cdot A_1$

$$HA = \frac{0.004V^2 \cdot A \cdot L \cos^2 \phi}{2,240\Delta}$$



L: Center height of projected sail area above $0.5T$
A: projected sail area [ft^2], V: average wind speed [knots]
ϕ: angle of heel [degree], Δ: displacement [LT]
ϕ_m: angle of maximum righting arm

* Brown, A.J., Deybach, F., "Towards A Rational Intact Stability Criteria For Naval Ships", Naval Engineers Journal, pp.65-77, 1998.

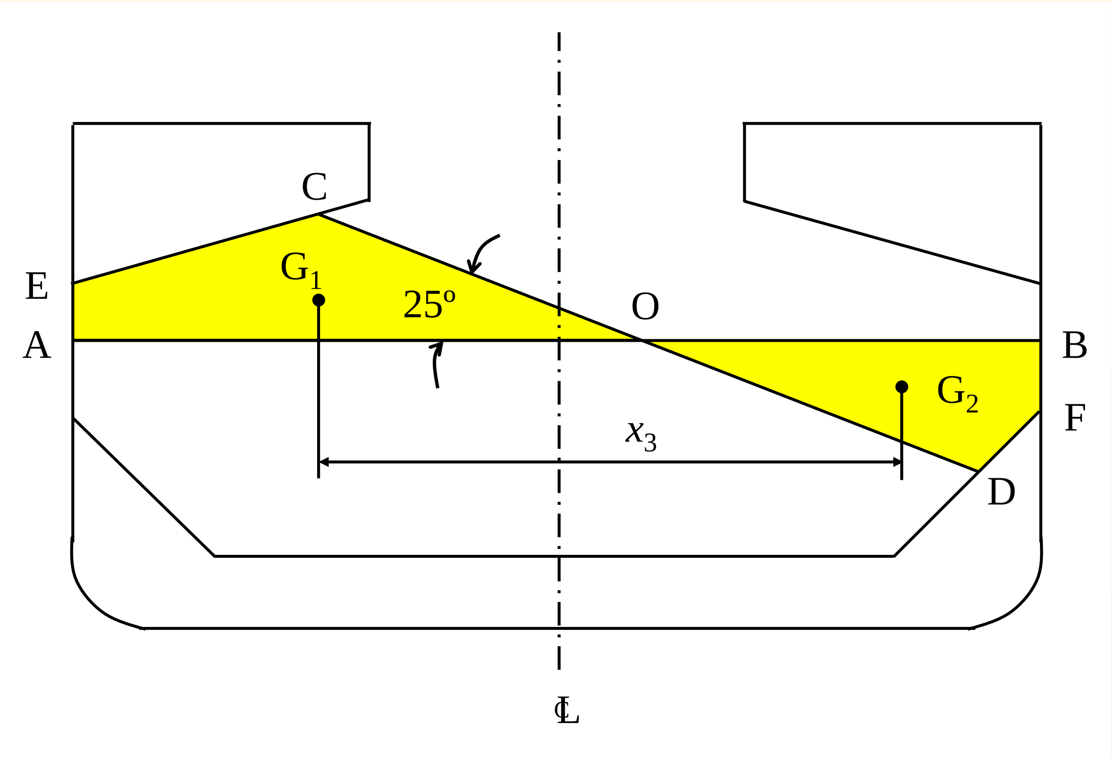
Sec.1 Stability Curve and Stability Criteria

Sec.2 Grain Stability

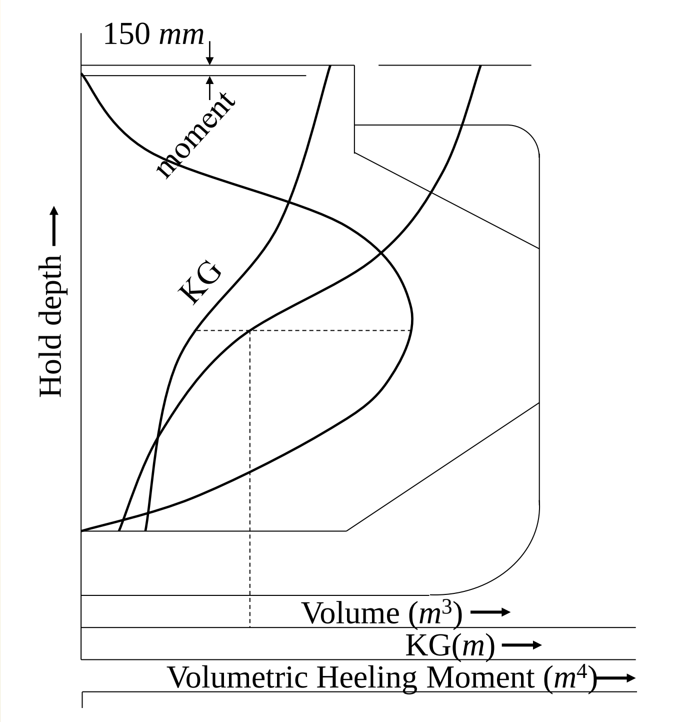
Sec.3 Floodable Length

Sec.4 3,700 TEU Container Ship : Example of Stability Calculation

Grain Stability
- Moment due to Grain shift



Heeling moment in cargo hold



Volumetric heeling moment in cargo hold

✓ Surface of the grain are shifted with respect to heel
- -Fully filled compartment : Assumption of α=15° to the horizontal
- -Partially filled compartment : Assumption of of α=25° to the horizontal

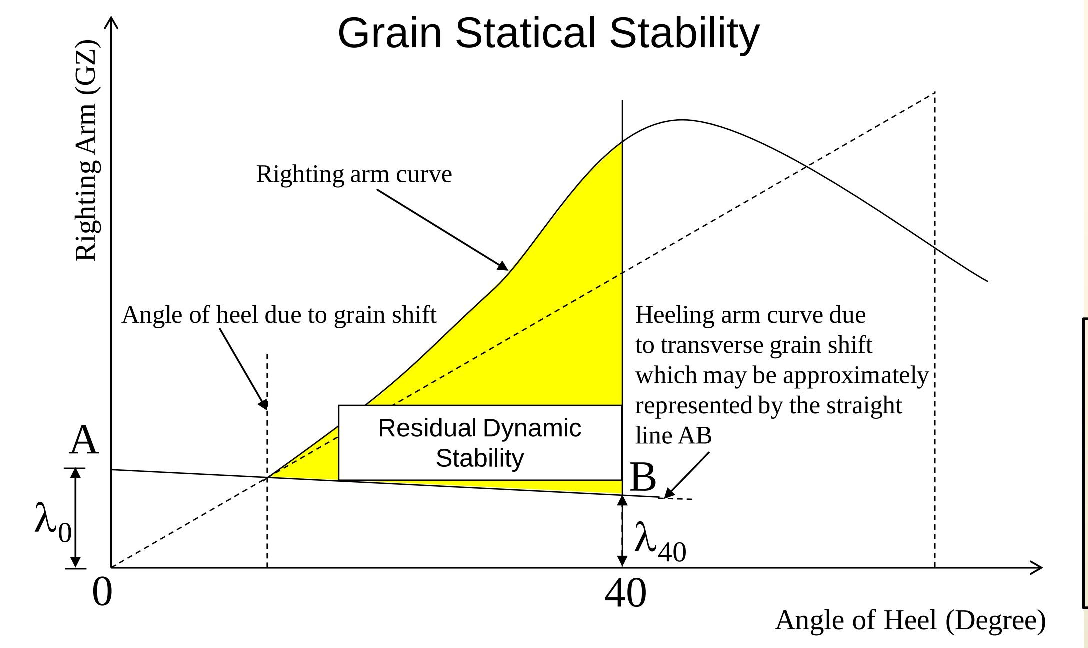
Calculate heeling moment due to grain shift with above assumption

*Barrass, C.B., Ship stability for maters and mates, 6th ed., Elsevier, 2006, Ch.30, pp.268

Grain Stability

(SOLAS 1974 A264)

✓ The intact stability characteristics of any ship carrying bulk grain must be shown to meet, throughout the voyage, the following criteria relating to the moments due to grain shift.



$$\lambda_0 = \frac{\text{Assumed volumetic heeling moment due to transverse shift}(m^4)}{\text{Stowage factor}(m^3/t)\times \text{displacement}(t)}$$

$$\lambda_{40} = 0.80\lambda_0$$

A-B is straight line

(a) The angle of heel due to the shift of grain shall not be greater than 12°.

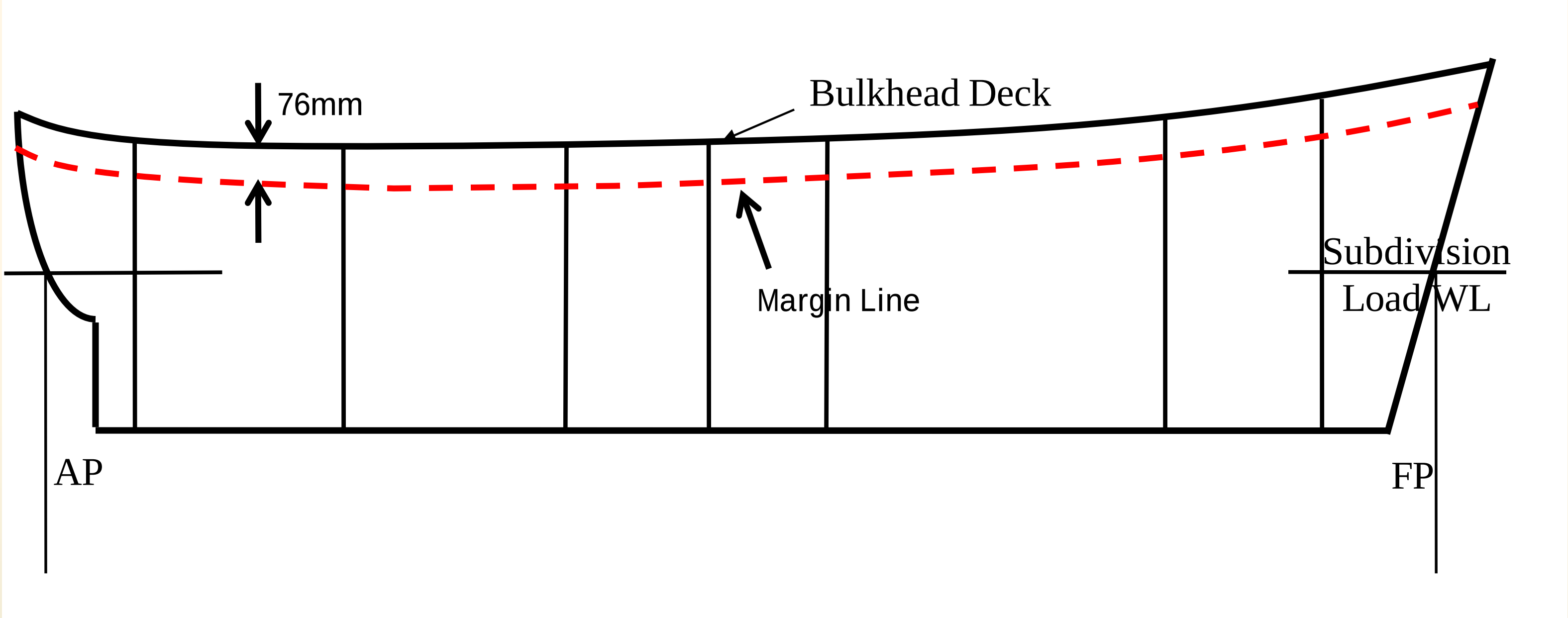
(b) The Net or residual area(Yellow color area) between the heeling arm curve and the righting arm curve up to the angle of heel of maximum difference between the ordinates of the two curve, or 40° or the angle of flooding, whichever is the least, shall in all conditions of loading be not less than 0.075 meter-radians.

(c) Initial metacentric height, after correction for free surface effects of liquids in tanks, shall not be less than 0.30 m.

※ θ_f : an angle of heel at which openings in the hull

*Barrass, C.B., Ship stability for maters and mates, 6th ed., Elsevier, 2006, Ch.30, pp.266

Floodable Length(1)
- Margin Line, Permeability



☑ **Margin Line**

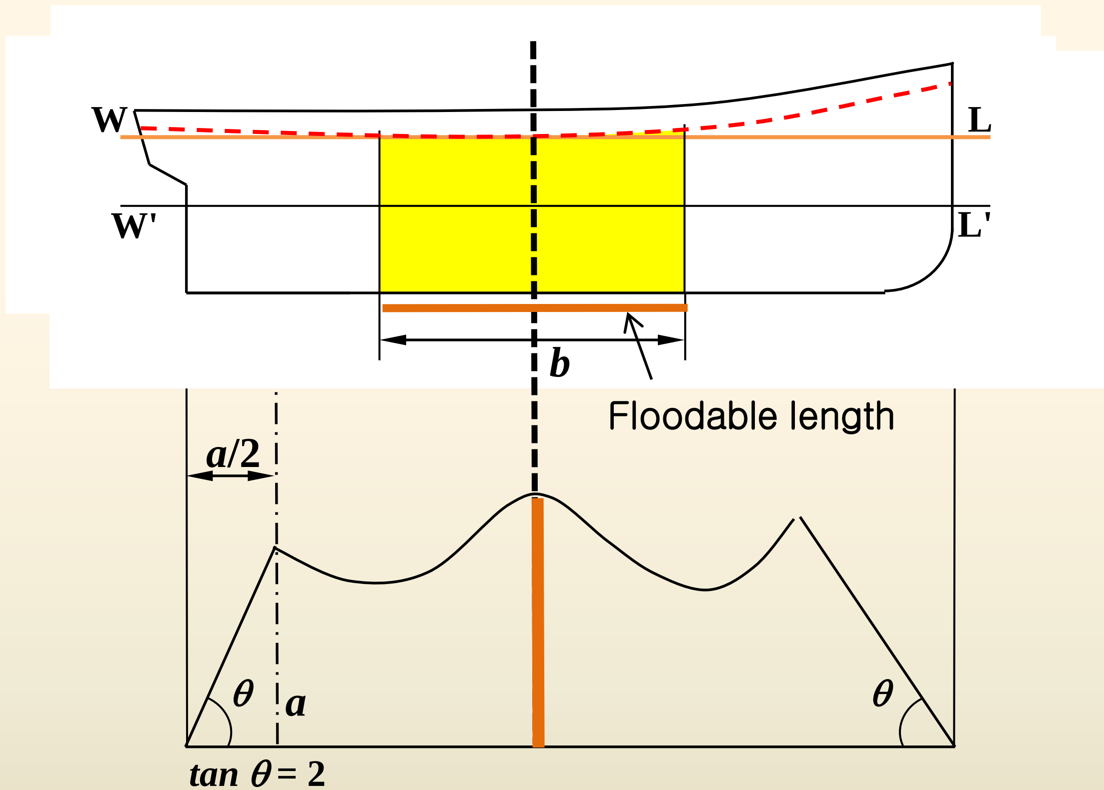
- Line drawn parallel to and 76mm below the bulkhead deck at side.

☑ **Permeability**

- Amount of water that can enter a compartment after the compartment has been bilged.
- Denoted as 'μ' and given as a percentage
- If the compartment was initially empty, then 'μ' would be 100%.

*Barrass, C.B., Ship stability for maters and mates, 6th ed., Elsevier, 2006, Ch.27, pp.243

Floodable Length(2)
- Floodable Length

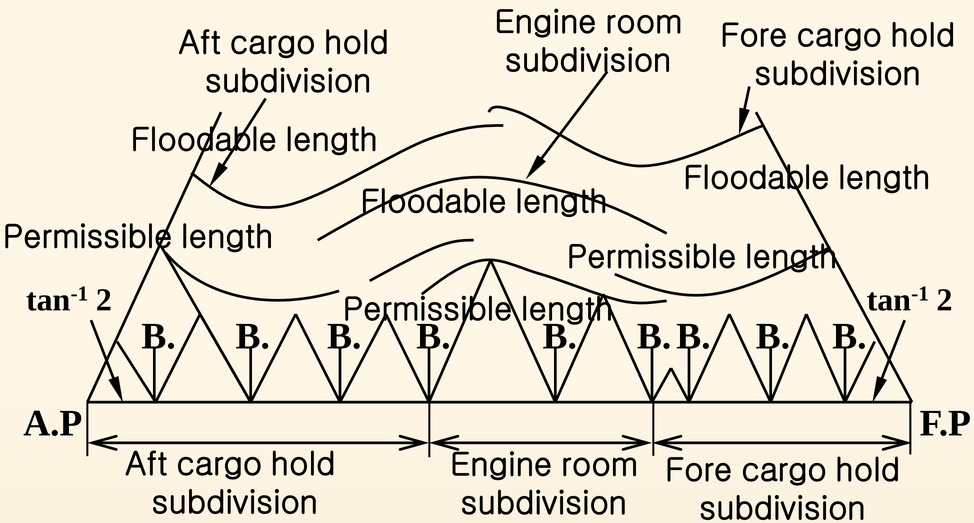


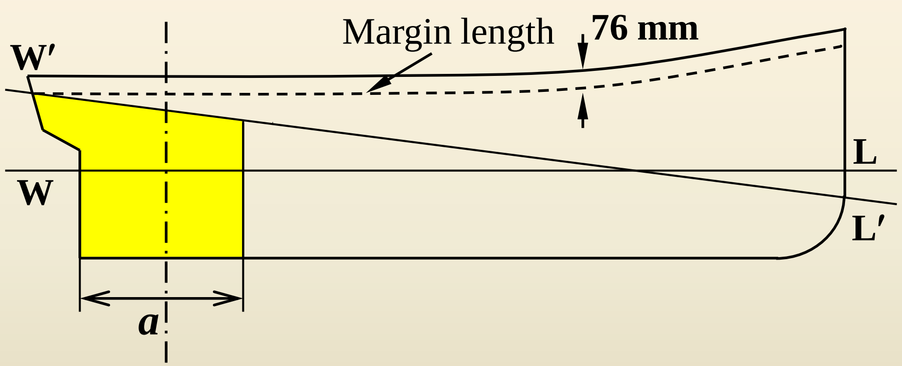
☑ **Floodable Length (FL)**

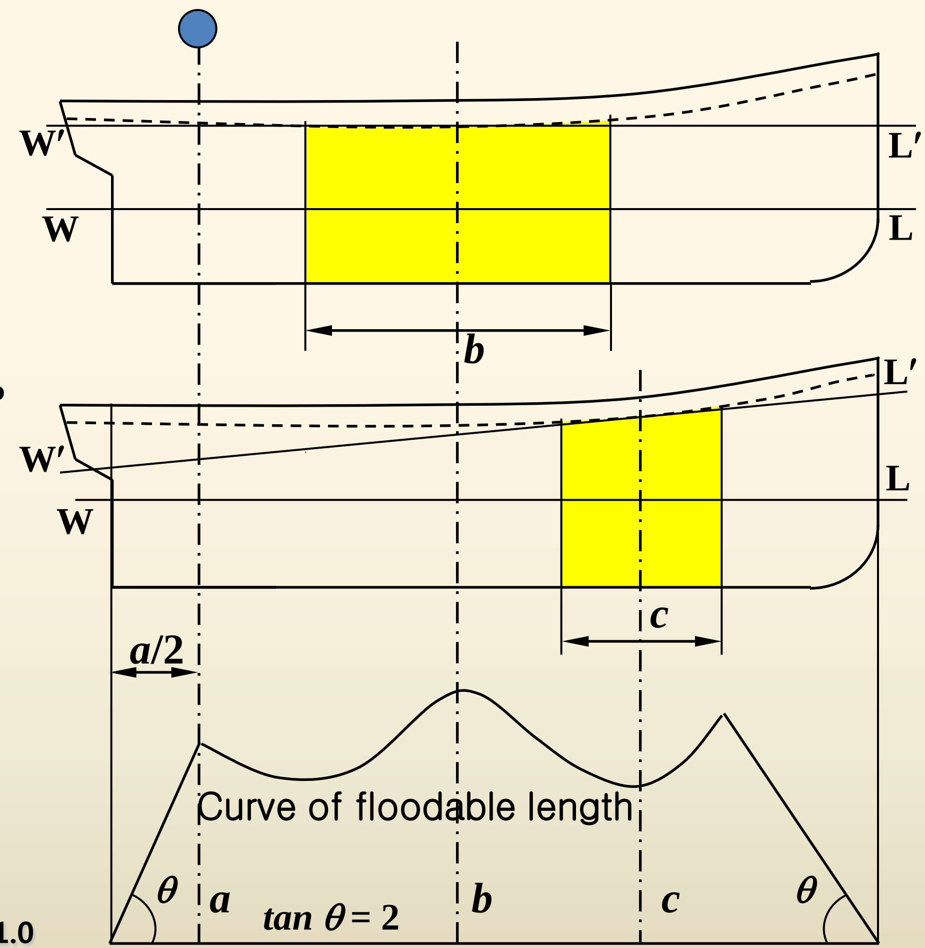
- **Maximum allowable length of a compartment at any point along the length (with that point as centre), that can be flooded without submerging the margin line.**
- **Vessel to be always upright, with no heel.**

*Barrass, C.B., Ship stability for maters and mates, 6th ed., Elsevier, 2006, Ch.27, pp.244

Floodable Length(3)
- Factor of Subdivision, Permissible Length







- **Factor of Subdivision (F_S)**
  - Factor of subdivision. It can range in value from 0.5 to 1.0
  - The 1.0 value signifies that very few passenger are being carried on board. The 0.5 value signifies that a very large number of passengers are being carried on the ship.
  - Formula for factor of subdivision exist in SOLAS 1974
- **Permissible Length(PL)**
  - Lower curve, obtained after the floodable length curve ordinates have been modified for contents within the compartments being considered
  - FL ordinates x F_S = PL ordinates

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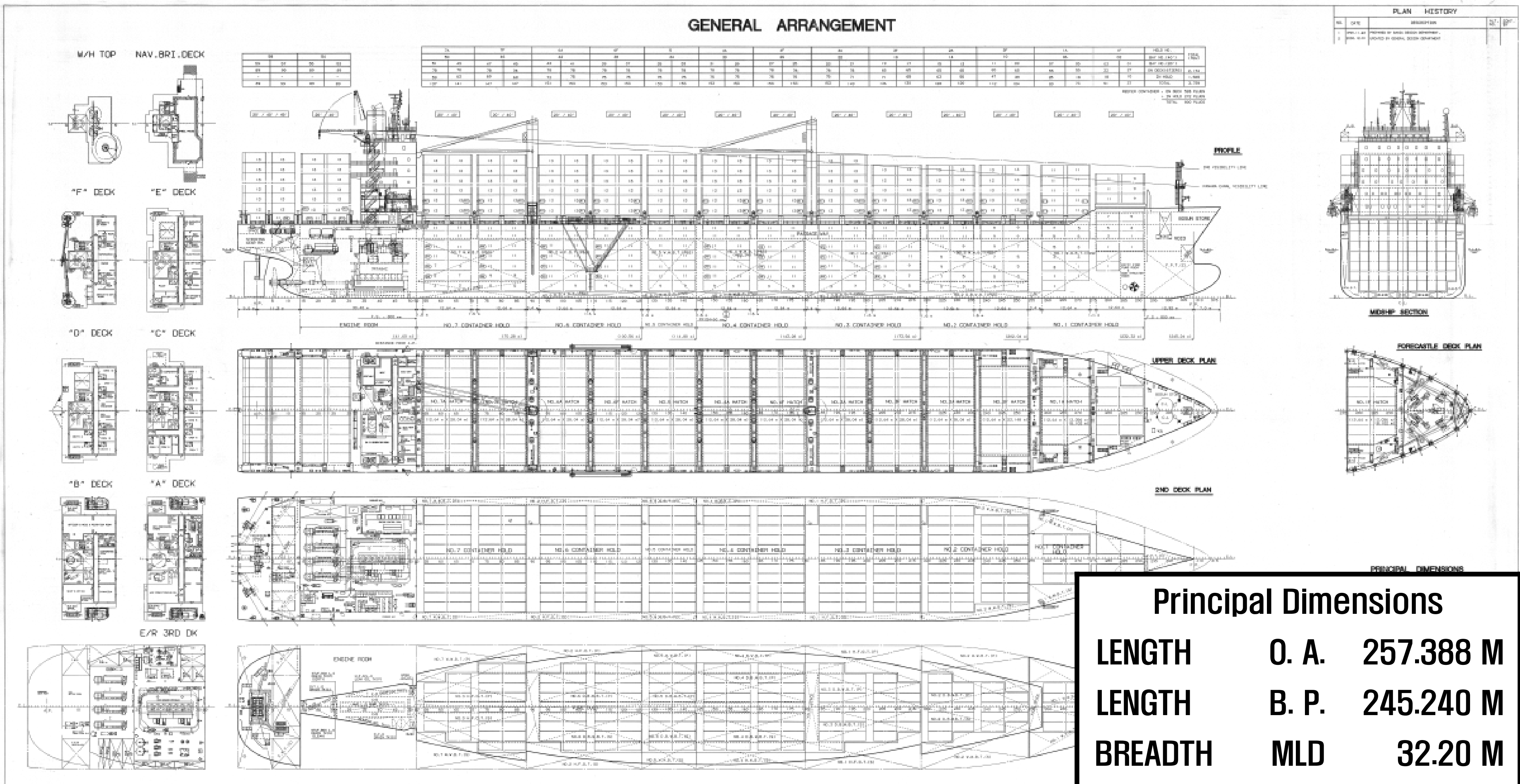
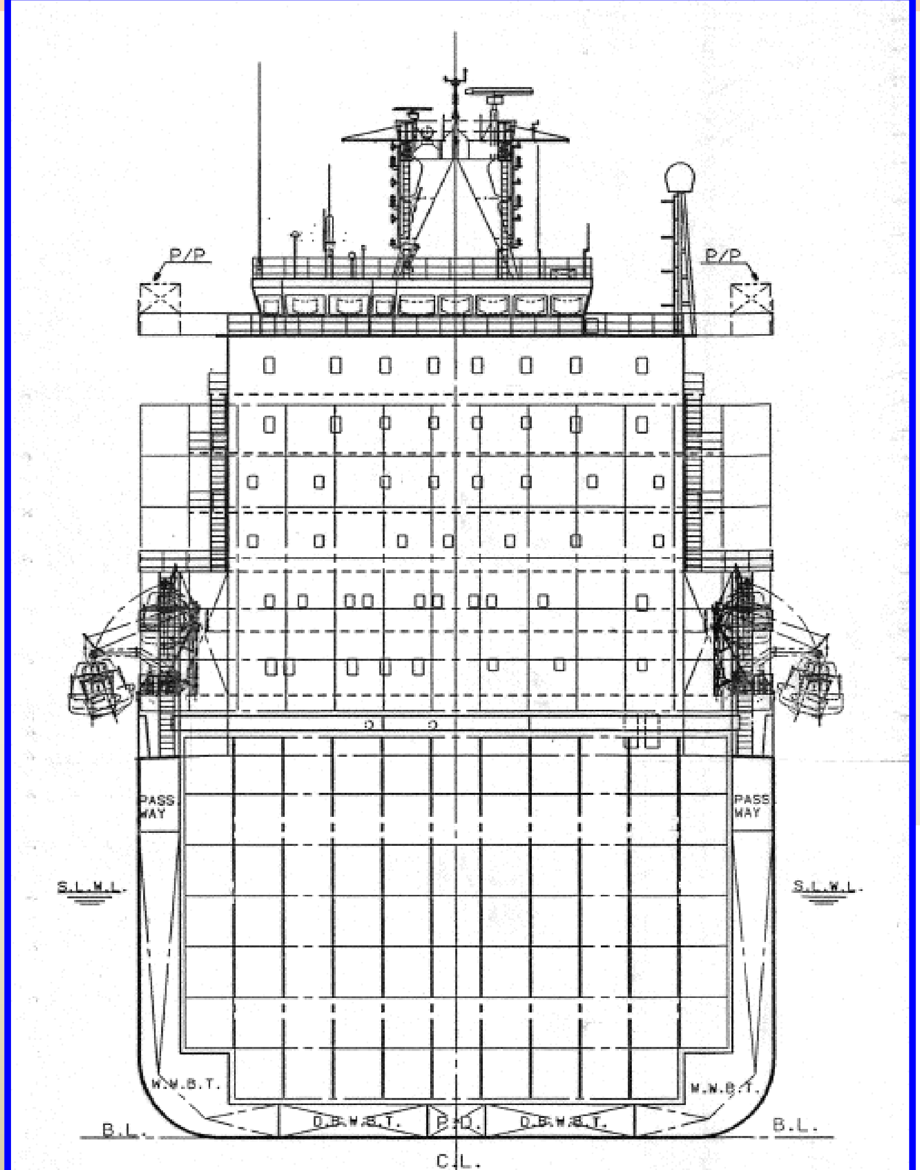
3,700 TEU Container Ship : Example of Stability Calculation
-General Arrangement(G/A)



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
	SCANT.	12.50 M

3,700 TEU Container Ship : Example of Stability Calculation
- General Arrangement(G/A)

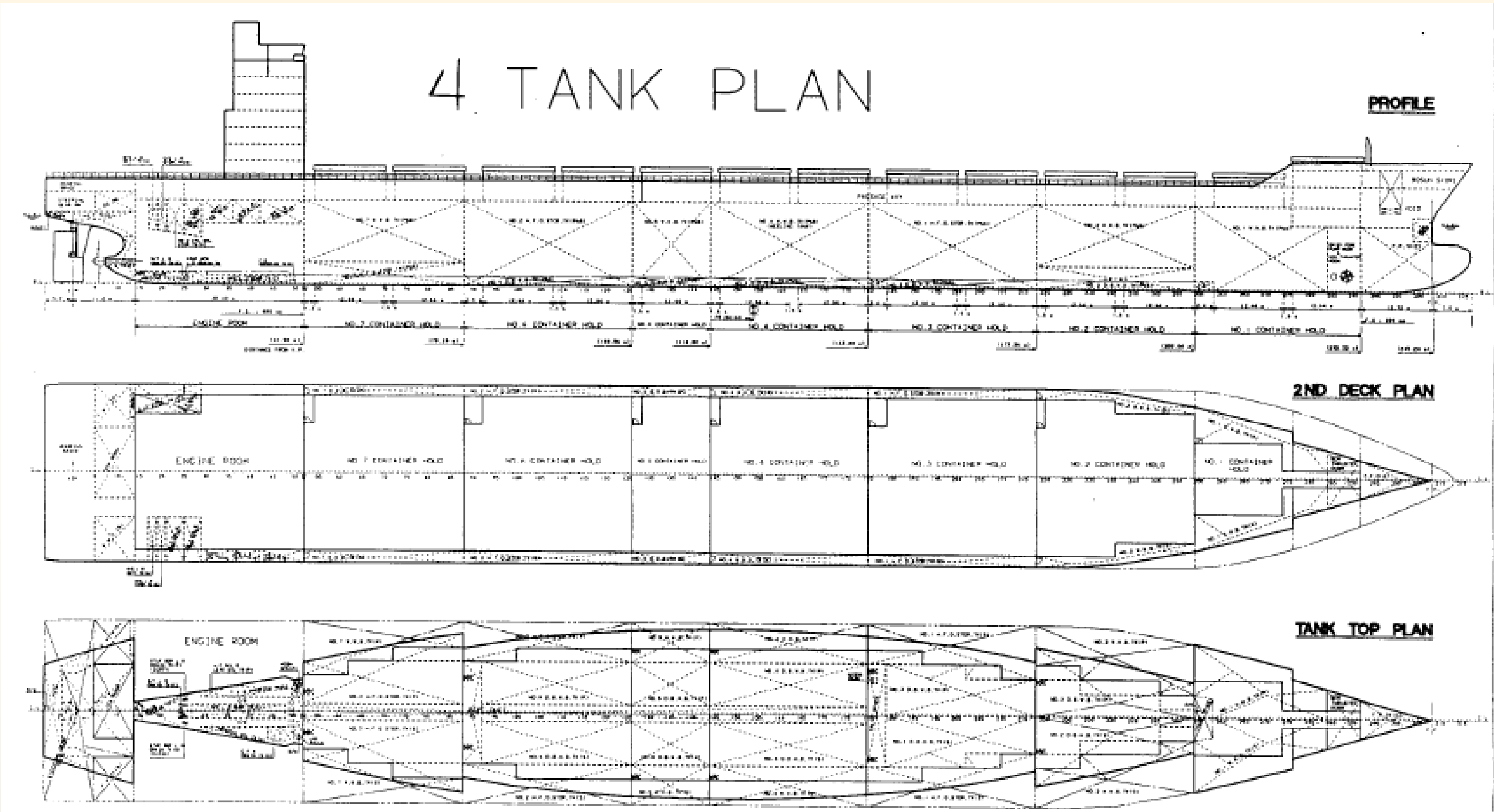


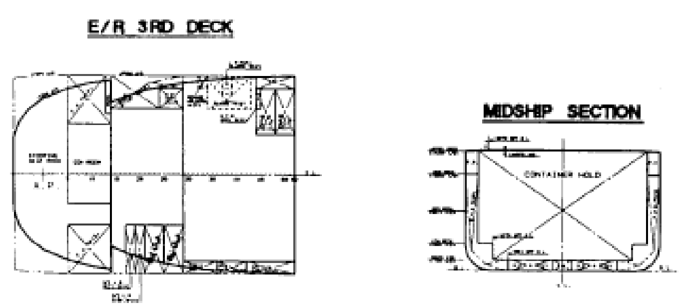
MIDSHIP SECTION

- **Principal Dimensions**

• LOA	257.368 M
• LBP	245.240 M
• BREDTH MOULDED	32.20 M
• DEPTH MOULDED	19.30 M
• DESIGNED DRAUGHT MOULED	10.10 M
• SCANTLING DRAUGHT MOULED	12.50 M

3,700 TEU Container Ship : Example of Stability Calculation
-Tank Plan





- **Principal Dimensions**
  - LOA 257.368 M
  - LBP 245.240 M
  - BREDTH MOULDED 32.20 M
  - DEPTH MOULDED 19.30 M
  - DESIGNED DRAUGHT MOULED 10.10 M
  - SCANTLING DRAUGHT MOULED 12.50 M

3,700 TEU Container Ship : Example of Stability Calculation
-Tank Summary Table

Name	Specific Gravity	Filling Ratio
Heavy Fuel Oil	0.990	98%

ex) $1214.6 \times 0.99 = 1202.4$

$1118.6 \times 0.99 = 1107.4$

HEAVY FUEL OIL TANKS

(S.G.= .990)

COMPARTMENT	LOCATION (FR.NO.)	CAPACITIES VOLUME 100%FULL (M**3)	VOLUME 98%FULL (M**3)	WEIGHT 98%FULL (TONNES)	100% FULL L.C.G FROM A.P (M)	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)

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
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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			

3,700 TEU Container Ship : Example of Stability Calculation
-Tank Summary Table

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

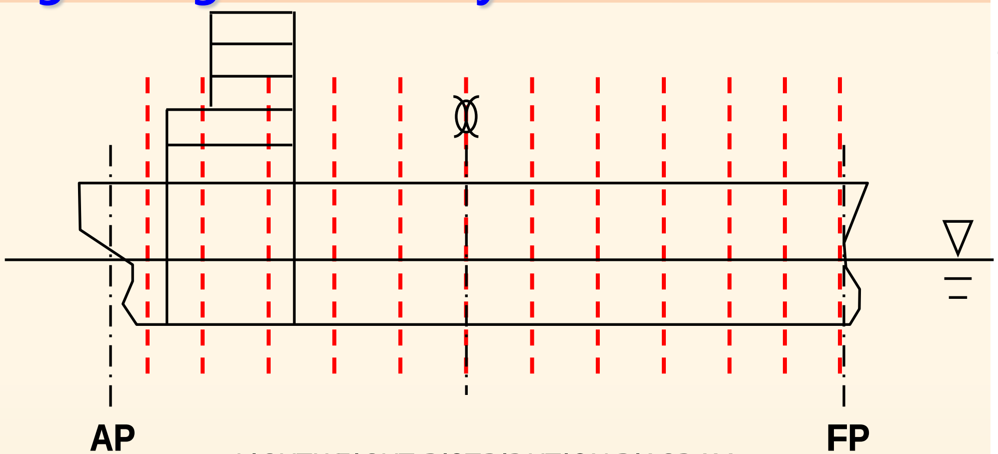
LCG_j	: Longitudinal center of lightweight
W_j	: Distributed lightweight in longitudinal direction

LCG_{DWT} is variable based on Loading Condition.

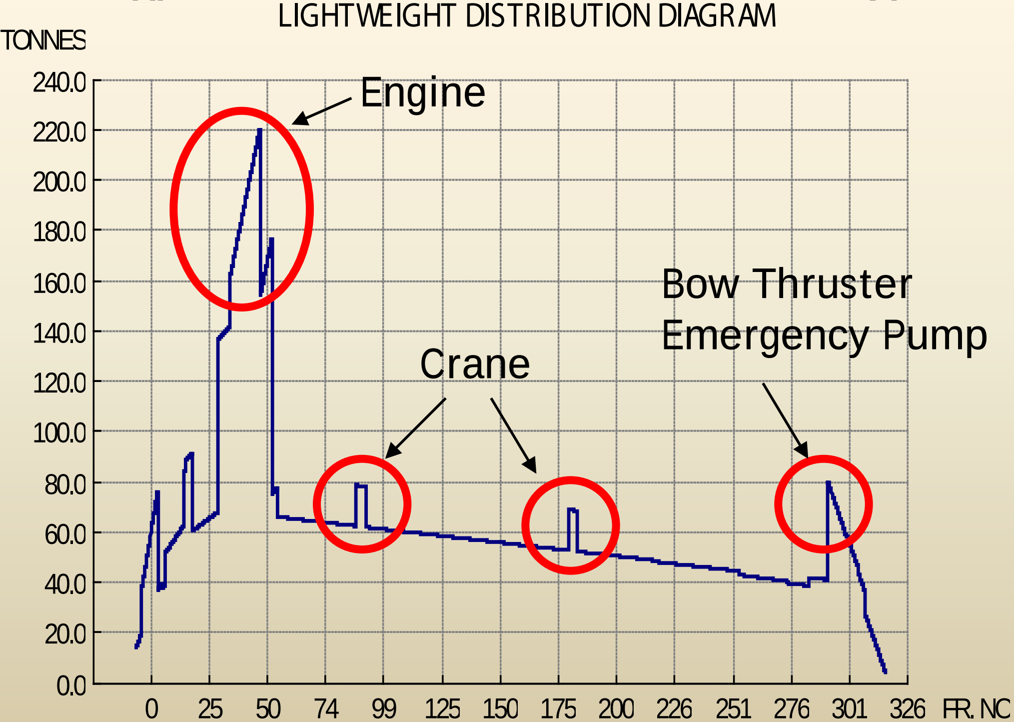
LCG_{LWT} : Location of LCG_{LWT} is fixed.

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

Example of Stability Calculation of 3,700 TEU Container ship -Lightweight Summary



LIGHTWEIGHT DISTRIBUTION DIAGRAM



LIGHT WEIGHT SUMMARY

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

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

LIGHT SHIP TOTAL = 15998.10 **103.228** 551446.5

3,700 TEU Container Ship : Example of Stability Calculation
-Hydrostatic Table

- ☑ Draft Mld : Draft from baseline , moudled (m)
- ☑ Disp.Mld : Displacement moulded (m^3)
- ☑ Disp.Ext : Displacement extreme (tonnes) S.G. = 1.025 (S.G.: Specific gravity)
- ☑ VCB : Vertical center of buoyancy above base line (m)
- ☑ *LCB* : Longi. center of buoyancy from midship (Sign : - Aft / + Forward)
- ☑ *LCF* : Longi. center of floatation from midship (Sign : - Aft / + Forward)
- ☑ KM_T : Trans. metarcenter height above base line (m)
- ☑ KM_L : Longi. metarcenter height above base line (m)
- ☑ *MTC* : Moment to change trim one centimeter (Tonnes-m)
- ☑ *TPC* : Increase in Disp.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

Hydrostatics Table

Constant c

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

$\times\ 1.025 \times c$

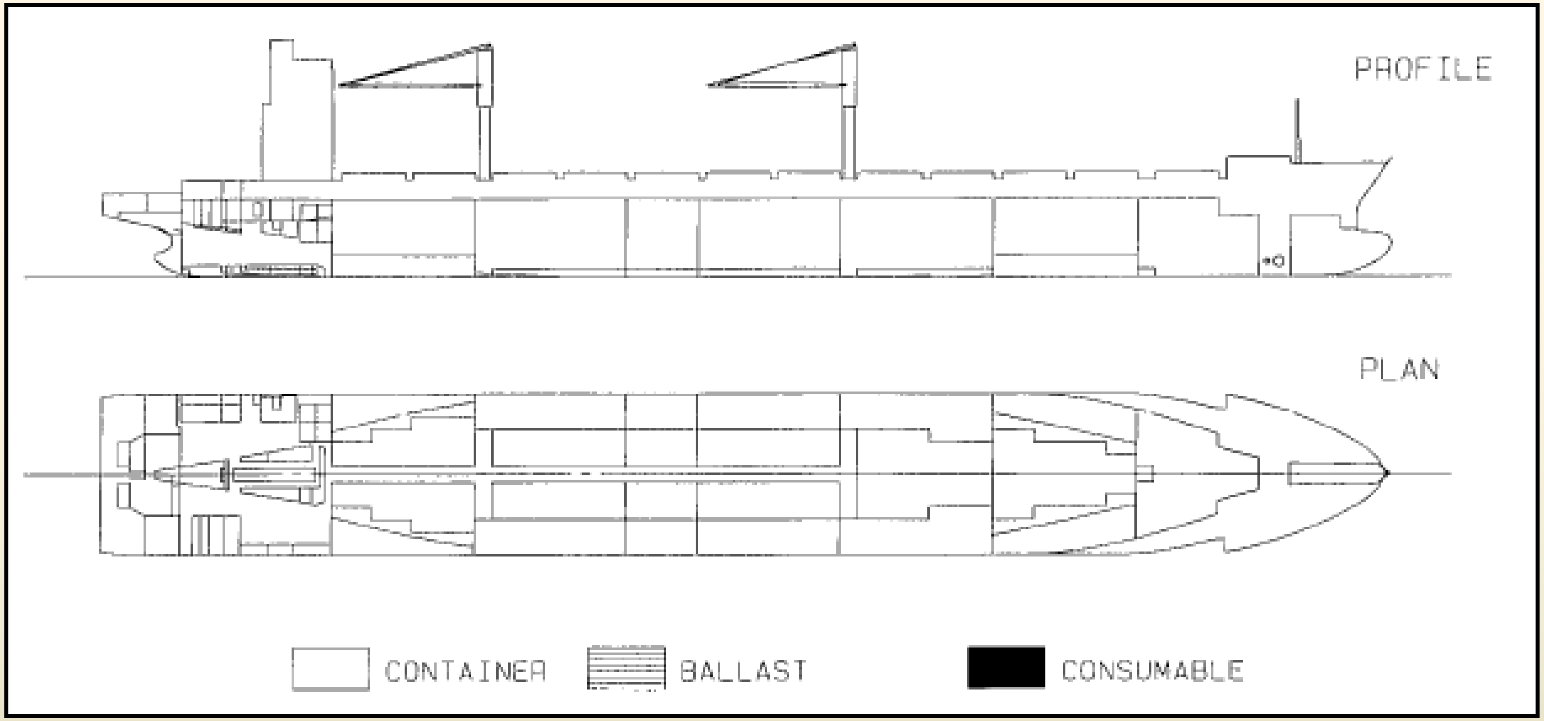
DRAFT (M)	DISP MLD(M3)	DISP EXT(T)	VCB (M)	LCB (M)	LCF (M)	KMT (M)	KML (M)	MTC (T-M)	TPC (TON)	WSA (M2)	C B	C W	C P	C M
3.75	14919.7	15400.8	2.025	118.394	119.002	21.691	838.95	525.6	49.7	5602.1	.5072	.6127	.5421	.9356
3.80	15160.8	15648.4	2.051	118.403	119.048	21.524	830.42	528.6	49.9	5631.7	.5086	.6145	.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
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	-3,13		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

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

3,700 TEU Container Ship : Example of Stability Calculation
-Loading Condition : Lightship Condition (1)

- Lightship condition : Condition that loaded nothing



3,700 TEU Container Ship : Example of Stability Calculation
-Loading Condition : Lightship Condition (2)

■ Calculation of *MTC*

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	① 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

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, $VCB(=KB) = 2.087[m], KM_L = 818.38[m]$

$$\left(BM_L = KM_L - KB = 818.38 - 2.087 = 816.293\right)$$

$$MTC = \frac{\Delta \times GM_L}{100 \times LBP} \approx \frac{\Delta \times BM_L}{100 \times LBP} = \frac{15998.1 \times 816.293}{100 \times 245.24} = 532.5[T\text{-}m]$$

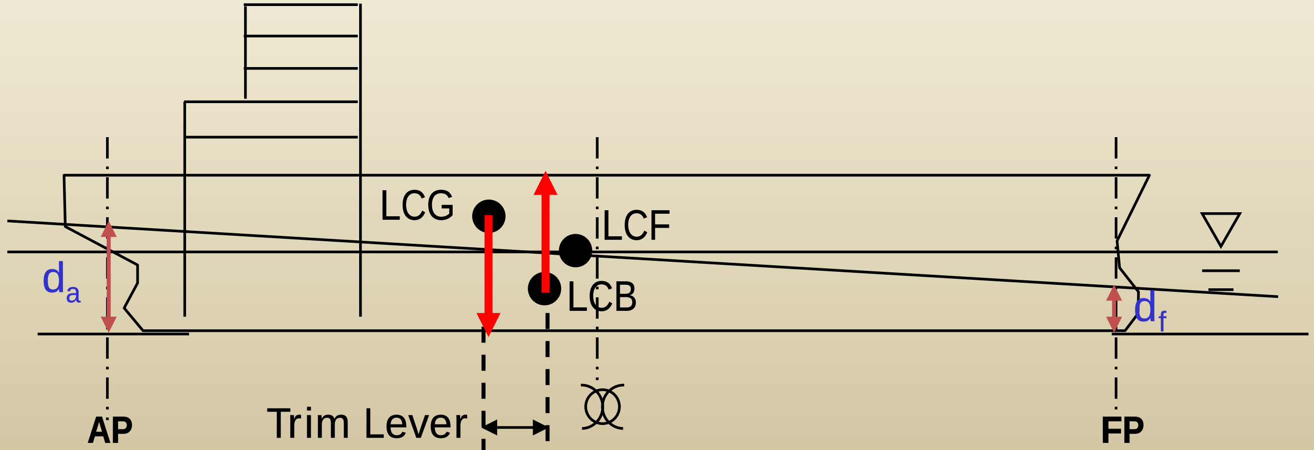
3,700 TEU Container Ship : Example of Stability Calculation
-Loading Condition : Lightship Condition (3)

■ 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

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

③ $Trim[m] = \dfrac{\Delta \times Trim\ Lever}{MTC \times 100} = \dfrac{15998.1 \times 15.188}{532.8 \times 100} = 4.560[m]$



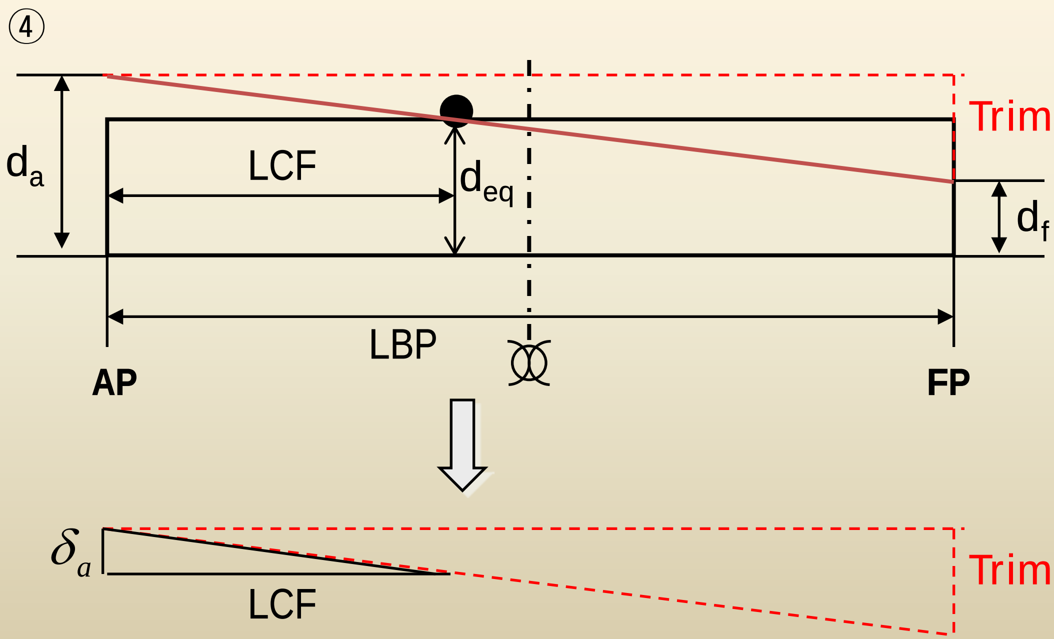
3,700 TEU Container Ship : Example of Stability Calculation
-Loading Condition : Lightship Condition (4)

■ Calculation of *Trim forward, Trim aft*

④

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



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

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

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

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

$$= 6.086[m]$$

$$d_f = d_a - Trim$$

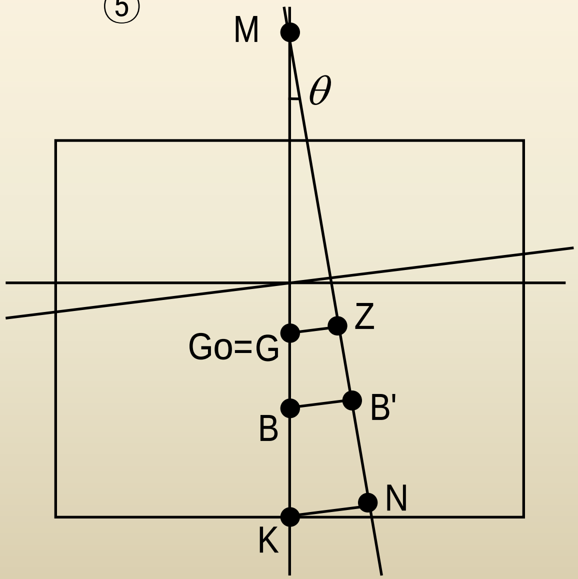
$$= 6.086 - 4.560 = 1.526[m]$$

3,700 TEU Container Ship : Example of Stability Calculation
-Loading Condition : Lightship Condition (5)

■ Calculation of *GM, KG*

					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 hydrostatics table (KM_T = 21.296 [m])

KG : Calculation from distribution of LWT and DWT (KG = 13.2 [m])

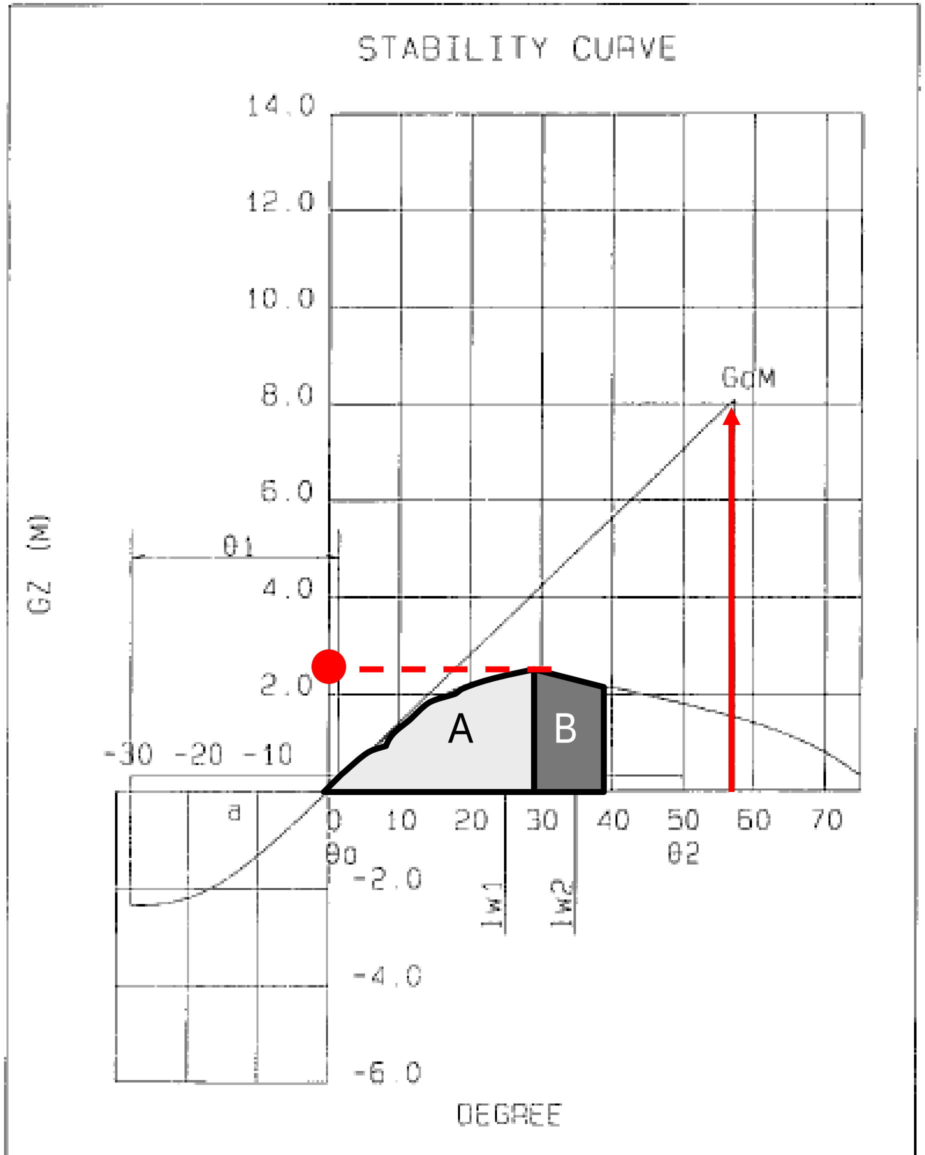
$GM = KM_T - KG$ (GM = 21.296 – 13.2 = 8.096 [m])

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

∴ $KGo = KG = 13.2$

3,700 TEU Container Ship : Example of Stability Calculation
-Loading Condition : Lightship Condition (6)

■ Stability check



IMO A-749(18) CHAP.3.1 CRITERION

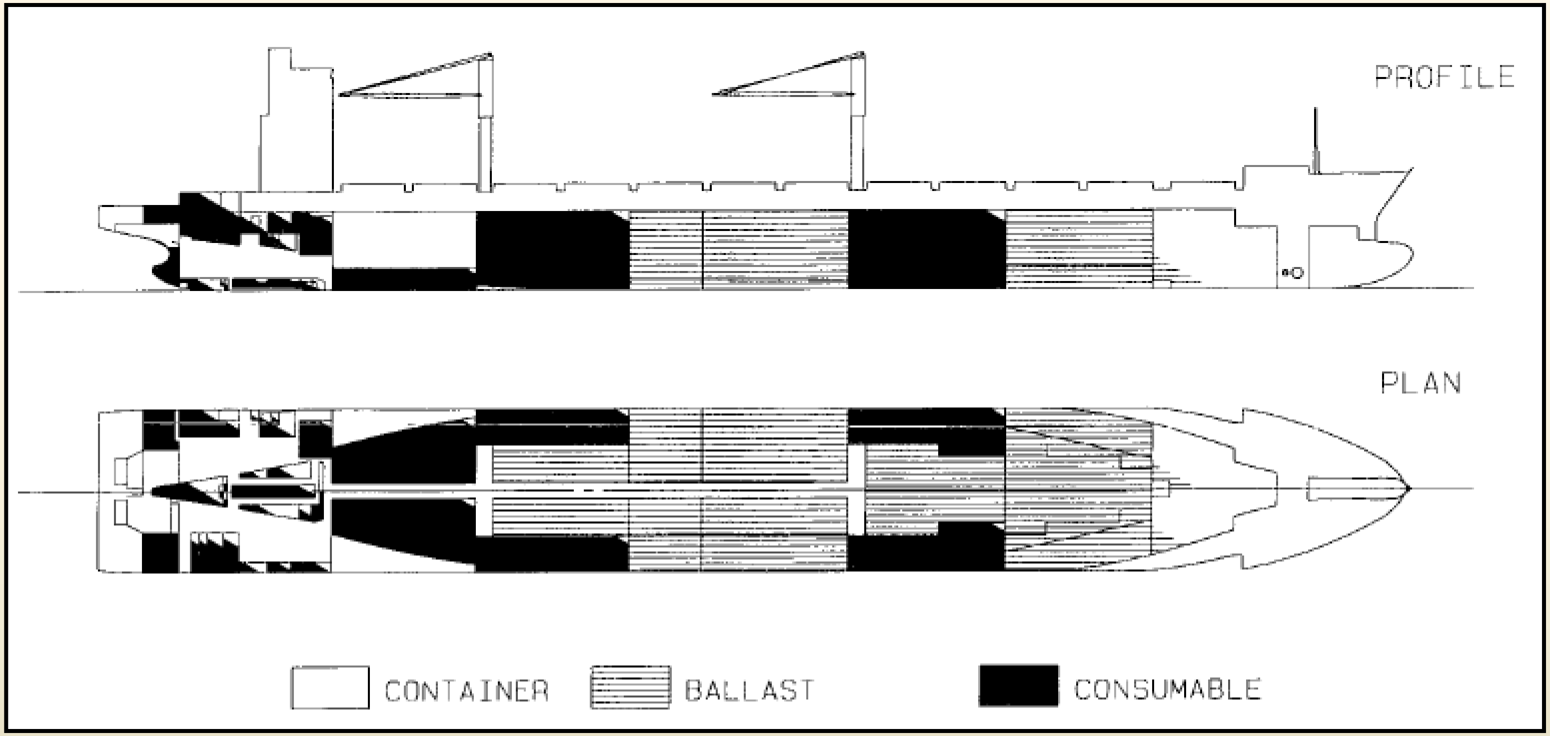
	ACTUAL	REQ.	
MIN. GoM	8.096	0.150	M
AREA 0-30	.849	0.055	M-RAD
AREA 0-40(θf)	1.236	0.090	M-RAD
AREA 30-40(θf)	.387	0.030	M-RAD
MAX. GZ	2.352	0.200	M
MAX. GZ OCCURS AT	27.2	25.00	DEG.
FLOODING ANGLE IS	90.0		DEG.

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.

3,700 TEU Container Ship : Example of Stability Calculation
-Loading Condition : Ballast Departure Condition (1)

- Ballast Departure condition : Condition that loaded ballast water and consumable cargo



3,700 TEU Container Ship : Example of Stability Calculation
-Loading Condition : Ballast Departure Condition (2)

■ 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)	=	5.957 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	①	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

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, $VCB(=KB)=3.826[m], KM_L=495.55[m]$

$$\left(BM_L = KM_L - KB = 495.55 - 3.826 = 491.724\right)$$

$$MTC = \frac{\Delta \times GM_L}{100 \times LBP} \approx \frac{\Delta \times BM_L}{100 \times LBP} = \frac{32980.1 \times 491.724}{100 \times 245.24} = 661.3[T-m]$$

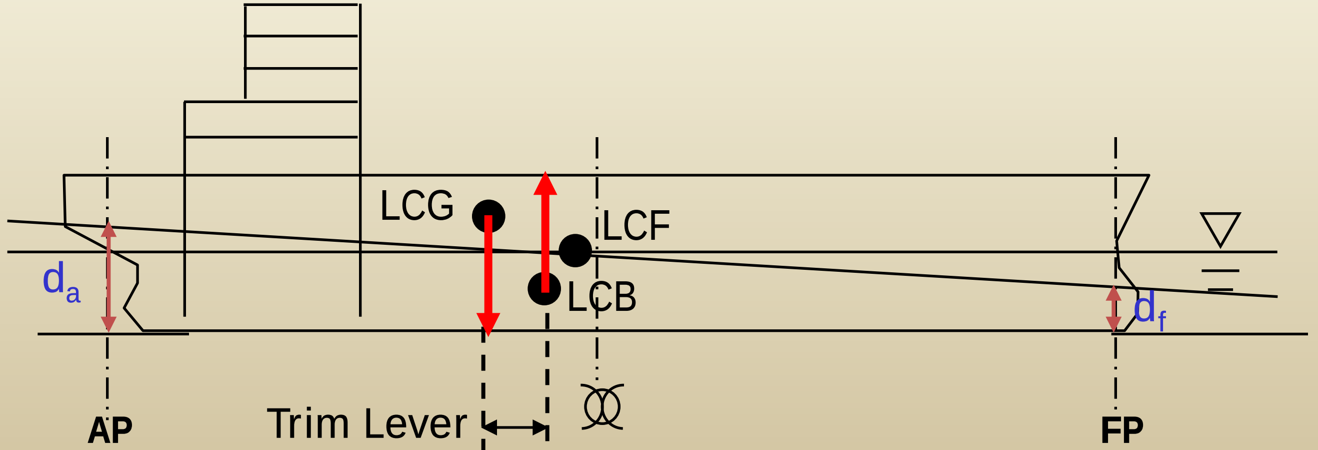
3,700 TEU Container Ship : Example of Stability Calculation
-Loading Condition : Ballast Departure Condition (3)

■ 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)	=	5.967 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

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

③ $$Trim[m] = \frac{\Delta \times Trim\ Lever}{MTC \times 100} = \frac{32980.1 \times 5.794}{661.3 \times 100} = 2.890[m]$$

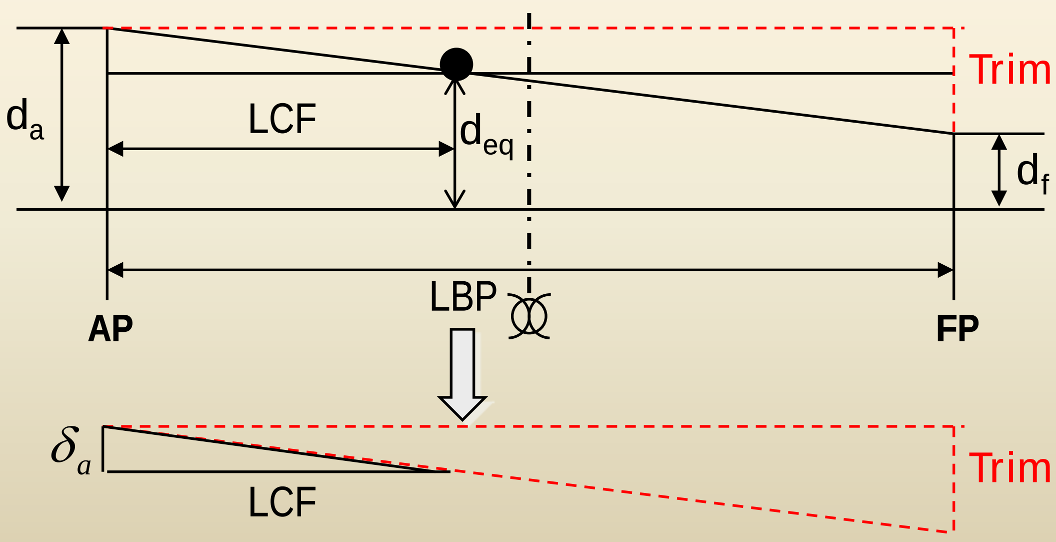


■ Calculation of *Trim forward, Trim aft*

④

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

④



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

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

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

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

$$= 8.443[m]$$

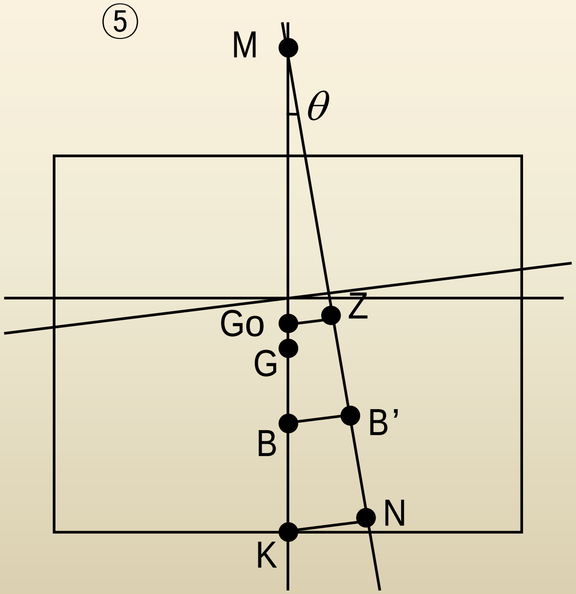
$$d_f = d_a - Trim$$

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

■ Calculation of *GM, KG*

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])

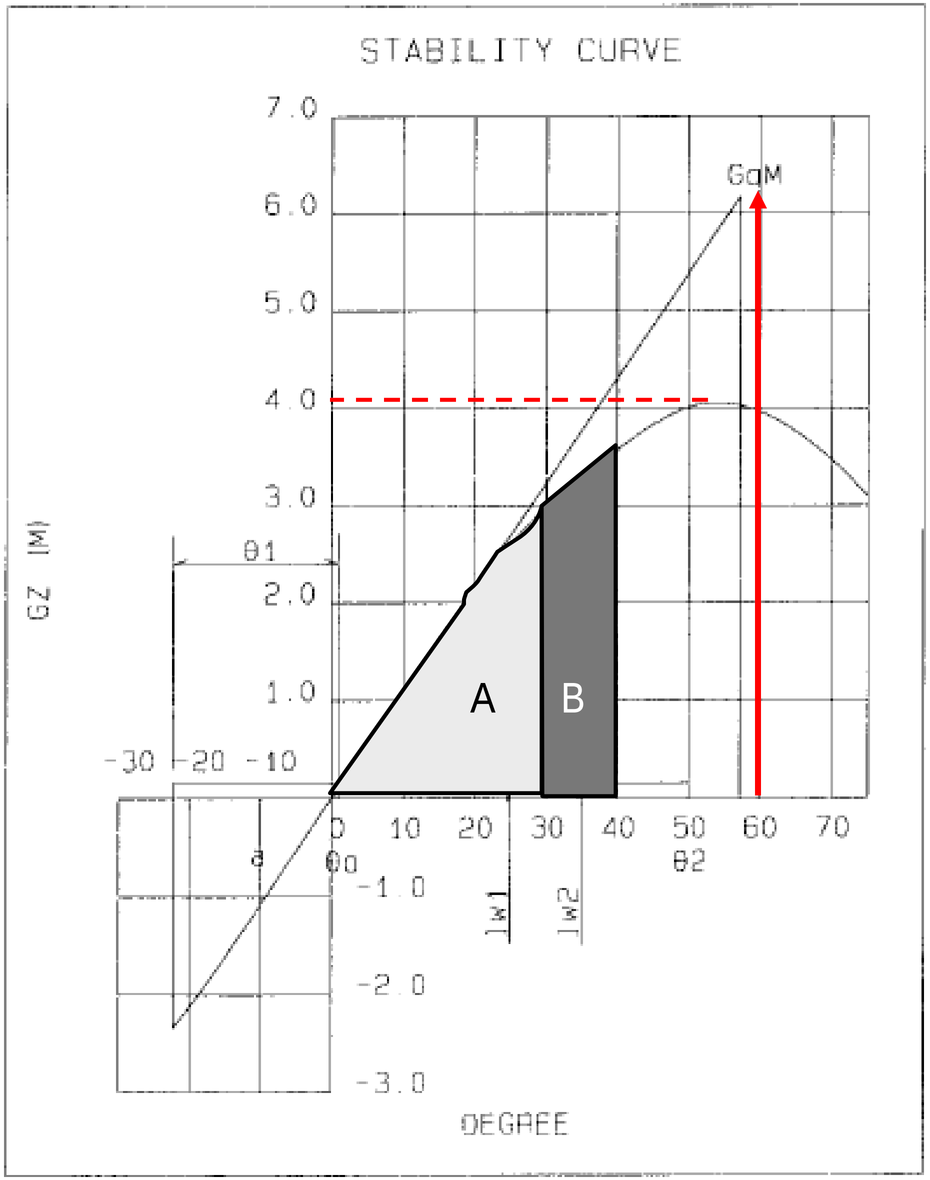
$GM = KM_T - KG$ (GM = 15.728 – 9.584 = 6.144 [m])

GGo = 0.177

$\therefore\ KGo = KG + GGo$ = 5.967 [m]

3,700 TEU Container Ship : Example of Stability Calculation
-Loading Condition : Ballast Departure Condition (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.

Naval Architecture & Ocean Engineering

- Ship Stability -

Ch.10 Damage Stability

September, 2009

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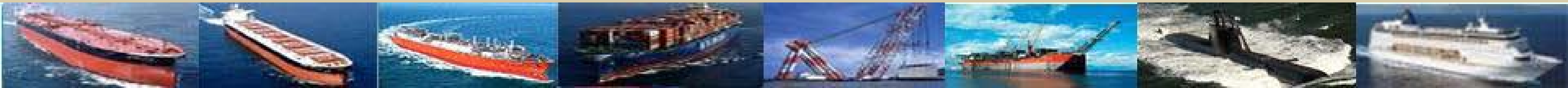
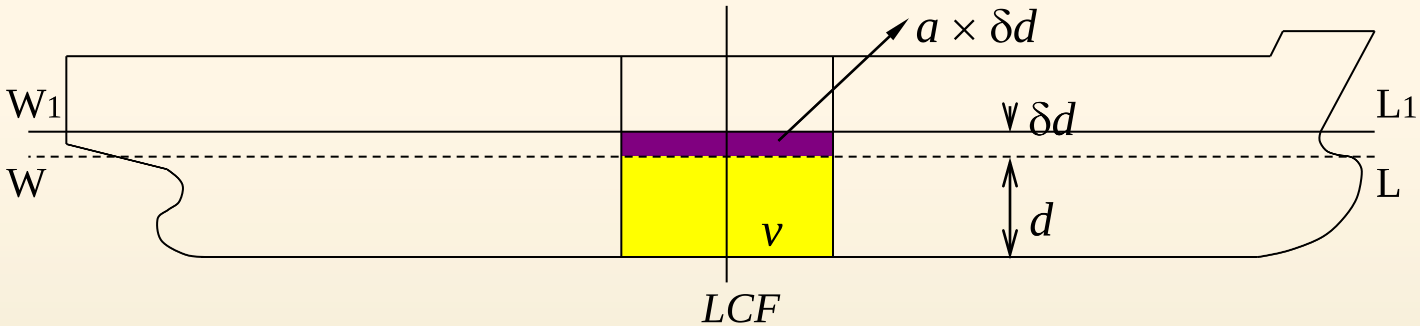


Calculation Method 1.
: Added Weight Method*

"The water that enters damaged compartment is considered as an added weight with no loss of buoyancy."



Weight of seawater due to damaged compartment $$w = (v + a \cdot \delta d) \cdot 1.025$$

Increased weight due to immersion $$b = A_{WP} \cdot \delta d \cdot 1.025$$

w = b

$$(v + a \cdot \delta d) \cdot 1.025 = A_{WP} \cdot \delta d \cdot 1.025$$

Draft change due to damaged compartment

$$\delta d = \frac{v}{A_{WP} - a}$$

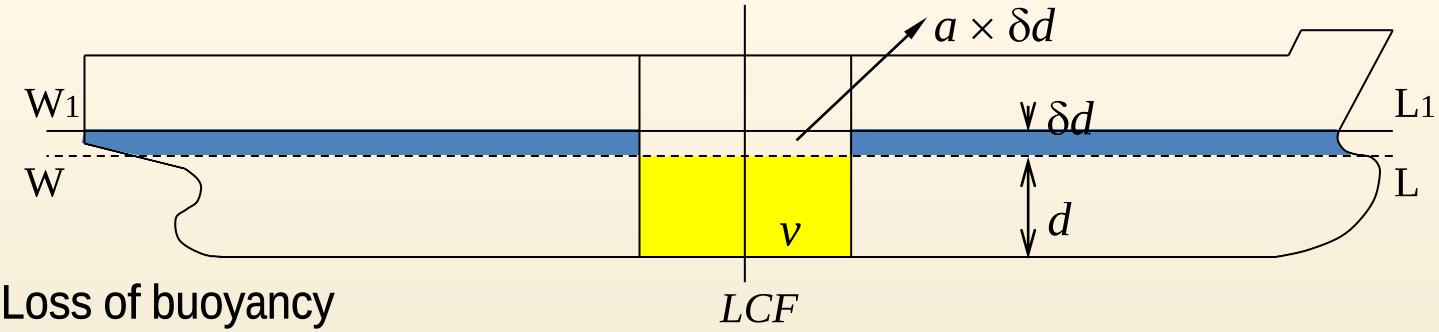
A_{WP} : Waterplane area of the ship (Including waterplane area of the damaged compartment)
a : Waterplane area of the damaged compartment
d : Draft before the compartment is not damaged
δd : Draft change due to damaged compartment
v : Volume of damaged compartment below waterplane

➡ Assume that weight of the ship and center of the gravity of the ship change, and waterplane area of the ship does not change.

*Dage, J.L., Gemert, L.V, Stability and trim for the ship's officer, 4th ed., D. Van Norstrand company, 1952, Ch.7, p.88

Calculation Method 2.
: Lost Buoyancy Method*

The water that enters damaged compartment is considered as still part of the sea, and the buoyancy of the flooded space is lost.
And the loss of buoyancy is recovered by immersion.



Loss of buoyancy

(Seawater flowed into damaged compartment is considered as part of the sea)

$$v = (A_{WP} - a) \cdot \delta d$$

$$\delta d = \frac{v}{A_{WP} - a}$$

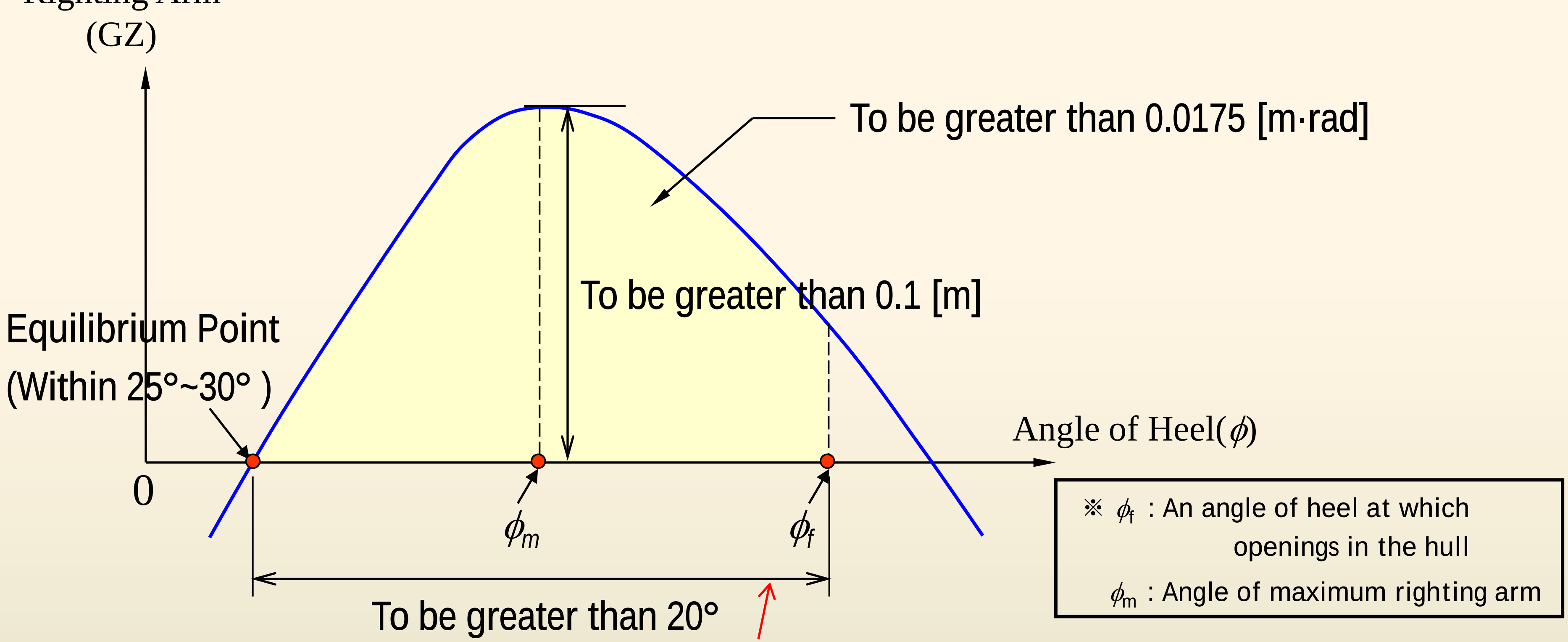
A_{WP} : Waterplane area of the ship
(Including waterplane area of the damaged compartment)
a : Waterplane area of the damaged compartment
d : Draft before the compartment is not damaged
δd : Draft change due to damaged compartment
v : Volume of damaged compartment below waterplane

➡ Assume that weight and displacement of the ship and center of the gravity of the ship does not change, and waterplane area of the ship changes.

*Dage, J.L., Gemert, L.V, Stability and trim for the ship's officer, 4th ed., D. Van Norstrand company, 1952, Ch.7, p.88

Damage Stability
- MARPOL Regulation for Damage Stability

MARPOL 1973/78/84 Annex I/25



a) The final waterline shall be below the lower edge of any opening through which progressive flooding may take place.

b) The angle of heel due to unsymmetrical flooding shall not exceed 25 degrees, provided that this angle may be increased up to 30 degrees if no deck edge immersion occurs.

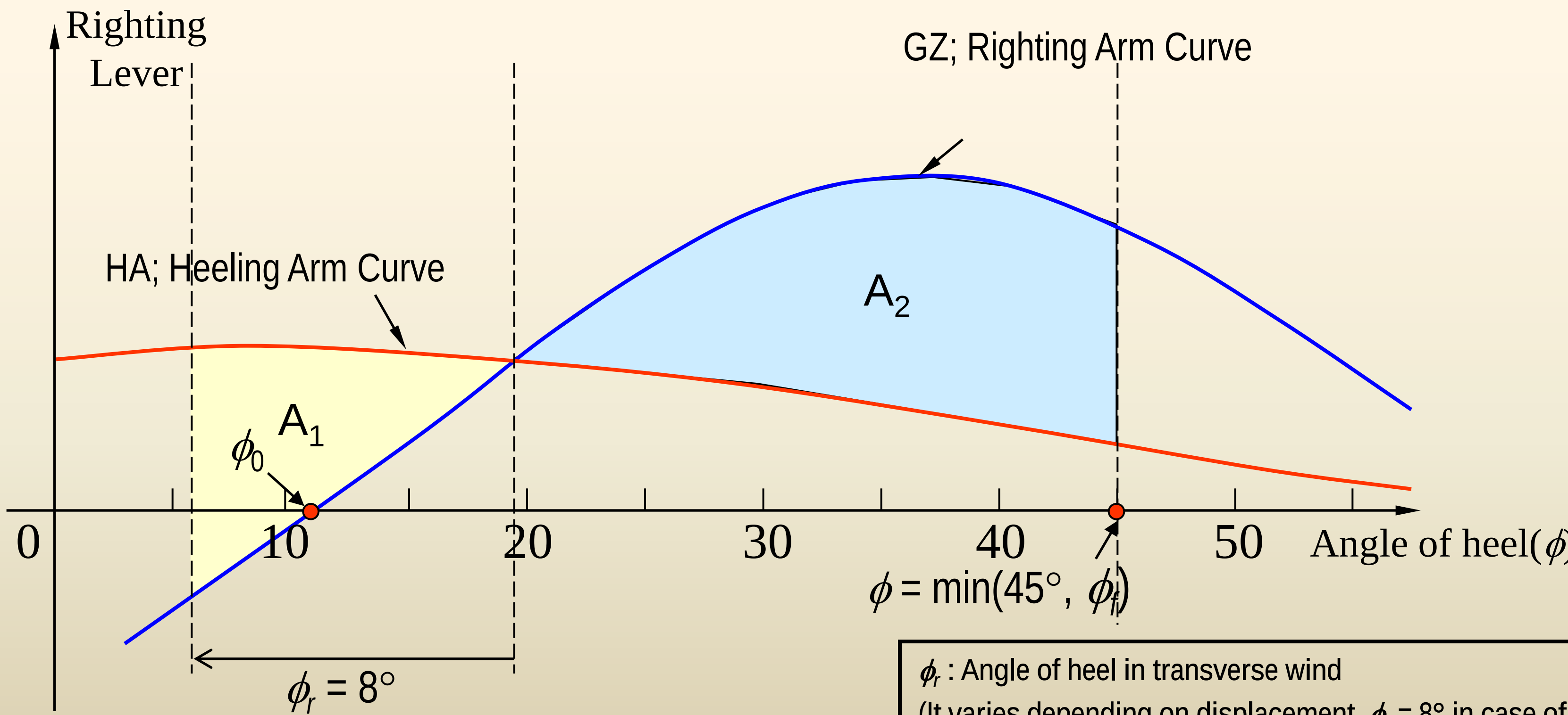
c) Righting lever curve has at least a range of 20 degrees beyond the position of equilibrium in association with a maximum residual righting lever of at least 0.1 meter within the 20 degrees range

d) The area under the curve within this range shall not be less than 0.0175 meter-radians

Damage Stability
- Damage Stability Criteria in Battleship*

Regulation

ϕ_0(Initial Angle of Heel) $\leq 15°$, $A_2 \geq 1.4 \cdot A_1$



ϕ_r : Angle of heel in transverse wind

(It varies depending on displacement, $\phi_r = 8°$ in case of battleship with displacement of 9,000 ton)

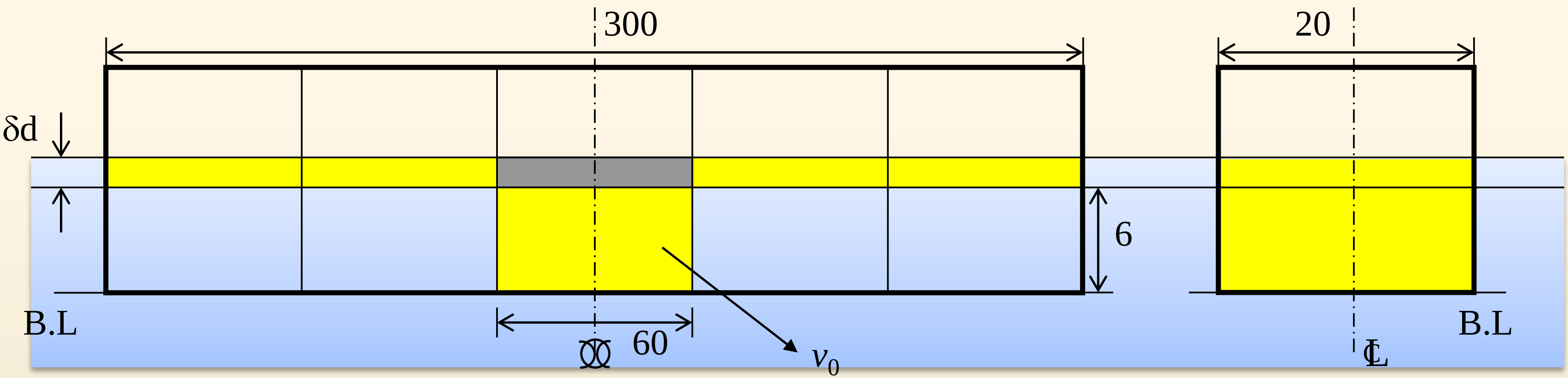
ϕ_f : An angle of heel at which openings in the hull

* Surko, S.W., "An Assessment of Current Warship Damaged Stability Criteria, Naval Engineers Journal, 1994.

Examples

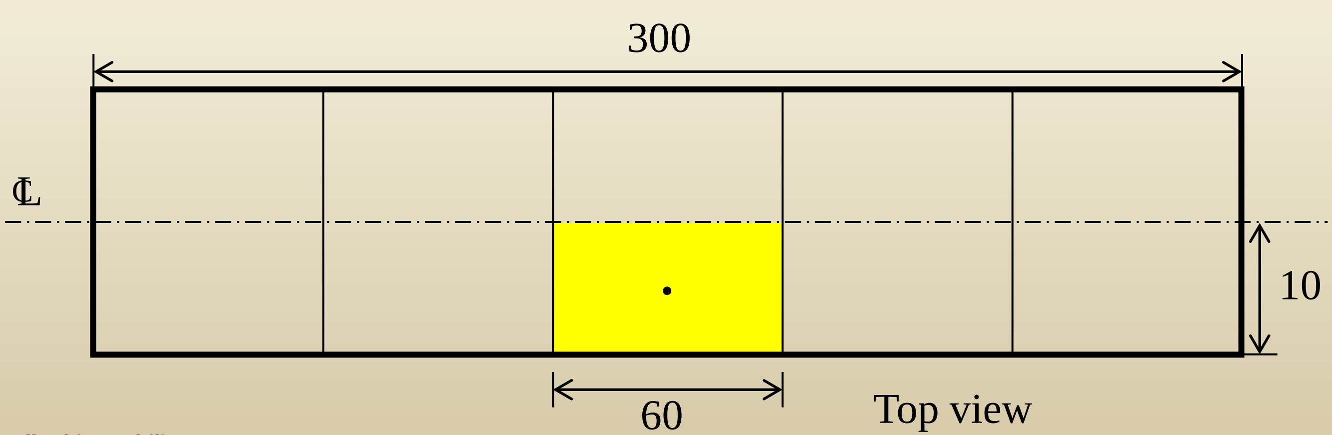
Problem> Calculation of Position of Ship with damaged subdivision

Question) The compartment of a ship (L=300m, B=20m, GM=3m, d=6m) is damaged as shown on following picture. Calculate position of a ship by the added weight method and by the lost buoyancy method.



Side view

Section view

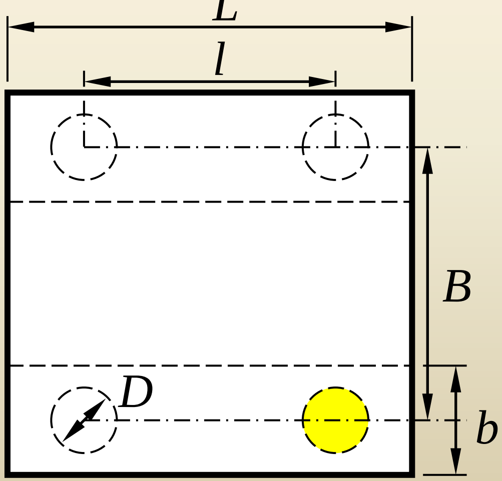


Top view

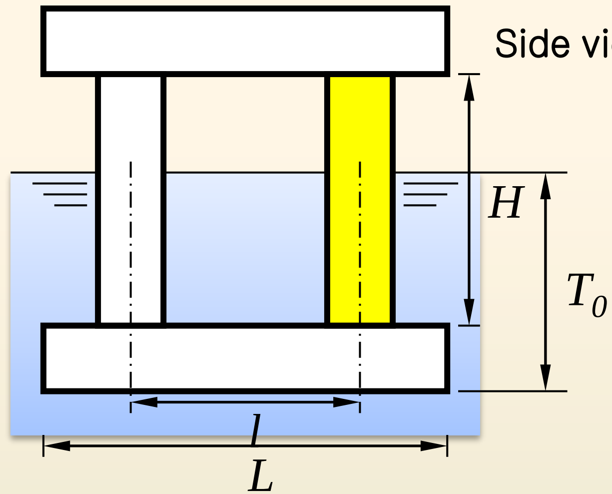
Problem> Calculation of Heel Angle of Semi-Submersible Rig with damaged subdivision

Question) Semi-submergible drilling rig is in sea water as shown in the picture. Assuming that one of the 4 columns is damaged, calculate an angle of heel by the added weight method and by the lost buoyancy method. (KG=11.0m)

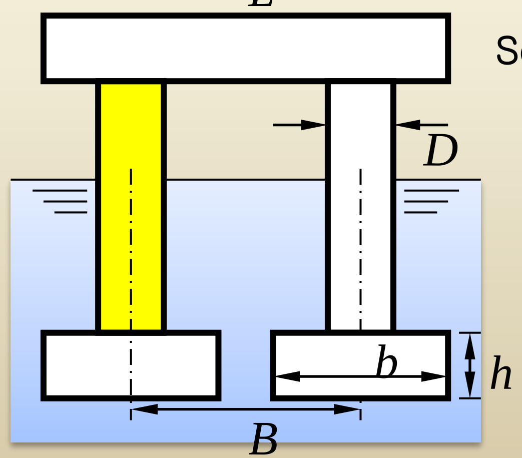
Top view



Side view

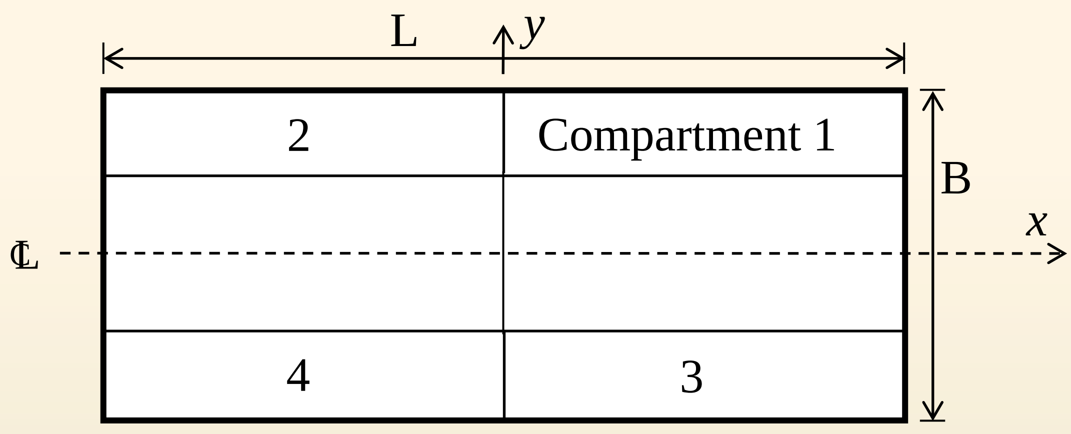


Section view

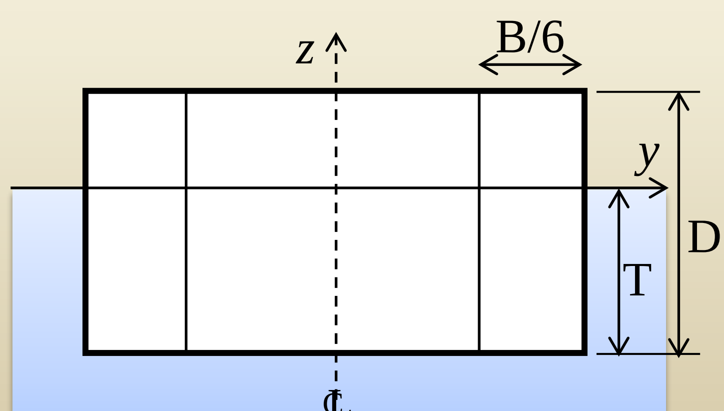


Problem> Calculation of draft of barge with damaged subdivision

Question) When No.1 and No.2 compartments of the barge are damaged and bilged, explain detail procedure of finding final draft with figures.



Plan view



Section view

Problem> Calculation of draft of ship with damaged subdivision

Question) There is a ship of L=100m , A_w= 2,000 m^2 , I_{LM}(at Midship) = 1,567,000 m^4, *LCF*= -3m), T= 8*m*, KG= 7*m*, KB= 5*m*. Each sectional area is given by the following table.

Station	A.P	1/2	1	2	3	4	5	6	7	8	9	$9_{1/2}$	F.P
Area(m^2)	0	50	110	140	160	180	180	180	150	120	80	30	0

When compartments from A.P to No.3 station is bilged, calculate draft forward and aft.

(Area of bilged compartment a=320m^2, i_L(at centroid)=4,100 m^4 , *lcf*=-28 m, Bilged compartment Kb=6.5m)