Ship Stability

Ch. 8 Curves of Stability and Stability Criteria

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Ch. 8 Curves of Stability and Stability Criteria

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2. Stability Criteria for Intact State
3. Stability Criteria for Damage State
4. Example of Stability Evaluation

Introduction

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

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

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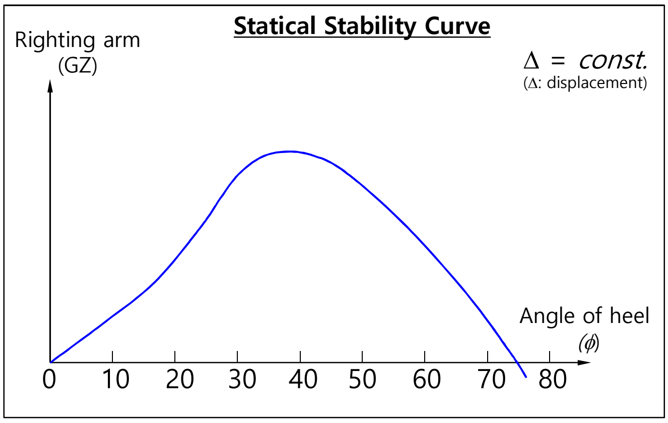
Today's main subject!

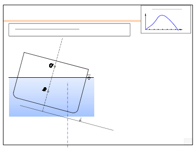
1. Statical Stability Curve

Definition and Purpose of the Statical Stability Curve

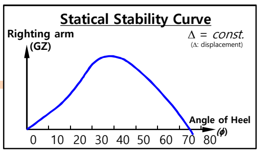


The statical stability curve is a plot of or against for a given loading condition.

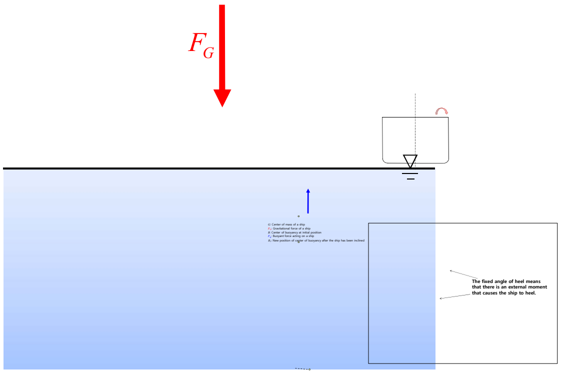
So far as the intact ship is concerned, the statical stability curve provides useful data for judging for the given loading condition.



Definition and Purpose of the Statical Stability Curve - Calculation Method of "GZ" (1/2)



1. At a certain angle of heel, calculate the static equilibrium position of the ship.



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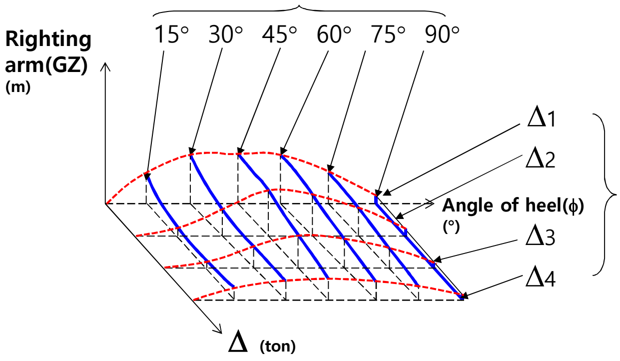
2. By using the center of mass (G) and new position of the center of buoyancy (B_1), calculate the righting arm "GZ".

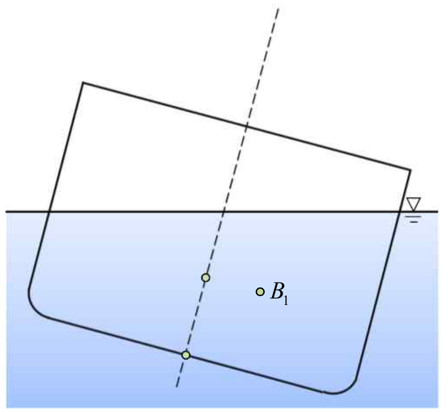
Definition and Purpose of Cross Curves of Stability



The cross curve of stability is a plot of righting arm against **displacement for a given angle of heel**.

A statical stability curve for a certain value of displacement (loading condition) can be obtained from the cross curves of stability.

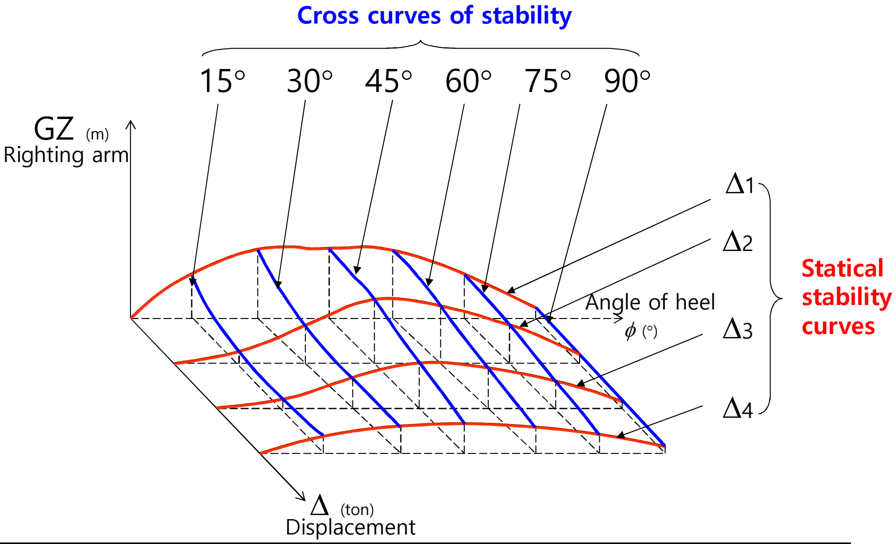
Method for Obtaining Cross Curves of Stability



G: Center of mass of a ship
B: Center of buoyancy at initial position
B_1: New position of center of buoyancy after the ship has been inclined

Obtaining Statical Stability Curves from Cross Curves of Stability

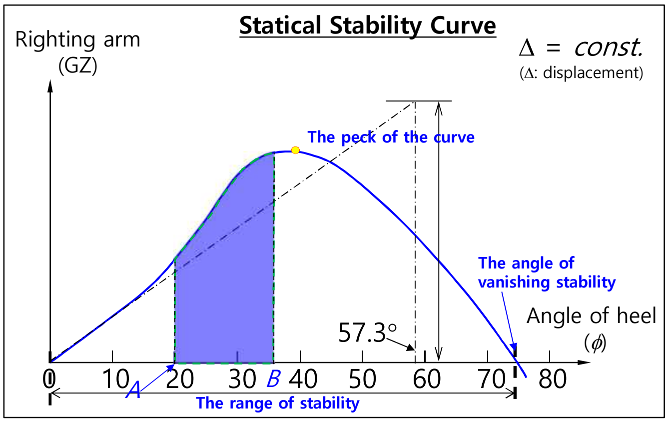
- **Three-dimensional cross curves of stability**

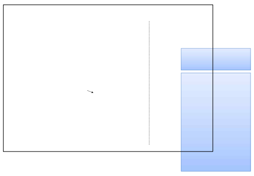


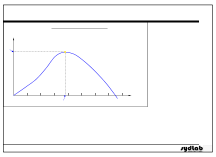
Significance of the Statical Stability Curve (1/5)

The statical stability curve has a number of features that are significant in the analysis of the ship's stability.

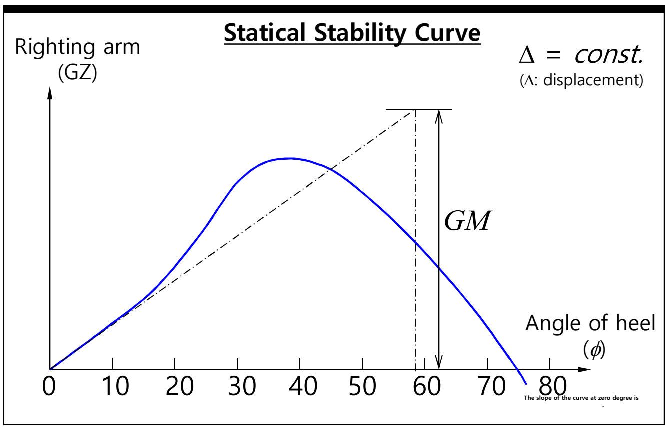
- The slope of the curve at zero degree, the peak of the curve, the range of stability, the angle of vanishing stability, and the area under the curve



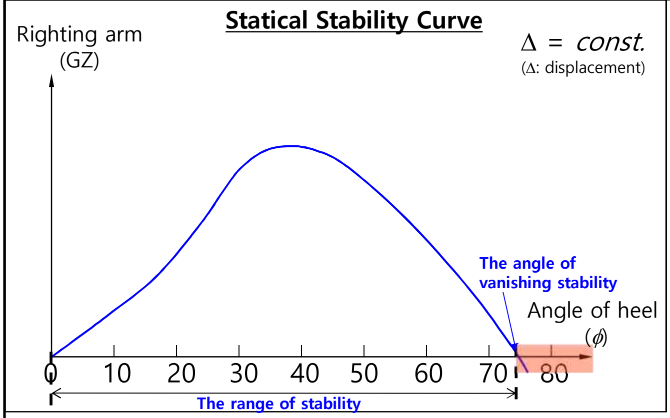




Significance of the Statical Stability Curve (2/5)
(1) The Slope of the Curve at Zero Degrees



Significance of the Statical Stability Curve (4/5)
(3) The Range of Stability and the Angle of Vanishing Stability

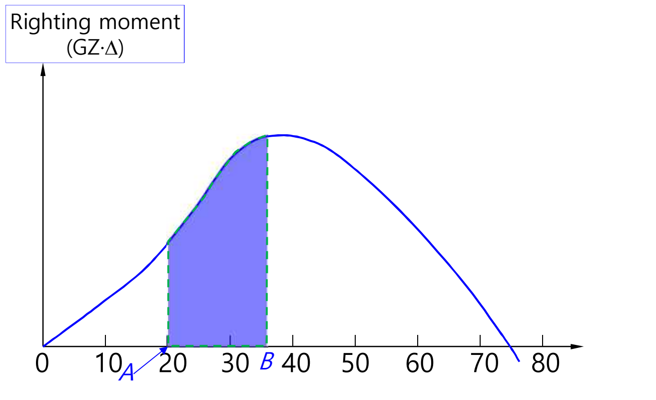


The range of stability is the range over which the ship has positive righting arms.

The angle of vanishing stability is the angle of heel at which the righting arm returns to zero.

If the ship heels beyond this angle, the moment caused by gravitational force and buoyant force will act to capsize, rather than to right, the ship.

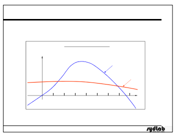
Significance of the Statical Stability Curve (5/5)
(4) The Area under the Curve



The statical stability curve can be the plot of righting moment against angle of heel for a given condition by the product of the displacement and the righting arm.

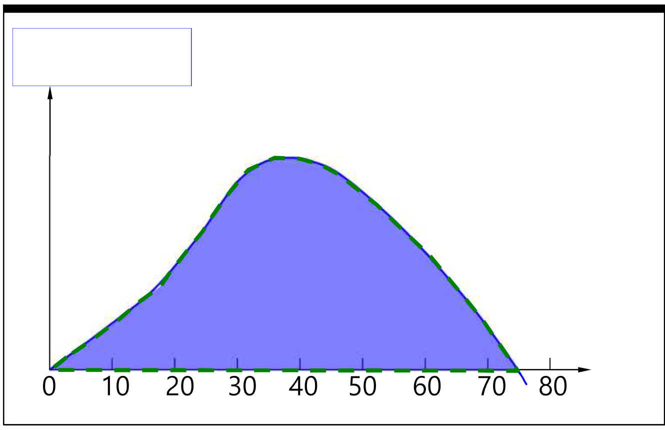
The area under the curve, such as between angle A and angle B, represents the from angle A to angle B.

When M is the moment at any angle of heel (ϕ),
the work required to rotate the ship against this moment (M) through an angle ($d\phi$) = $M\,d\phi$
The work (W) required to rotate from angle A to angle B: $W = \int_A^B M\,d\phi$, (ϕ in radinas)



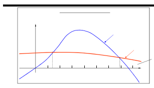
Significance of the Statical Stability Curve (5/5)
(4) The Area under the Curve – Total Area

$W = \int_A^B M \, d\phi, \quad (\phi \text{ in radinas})$



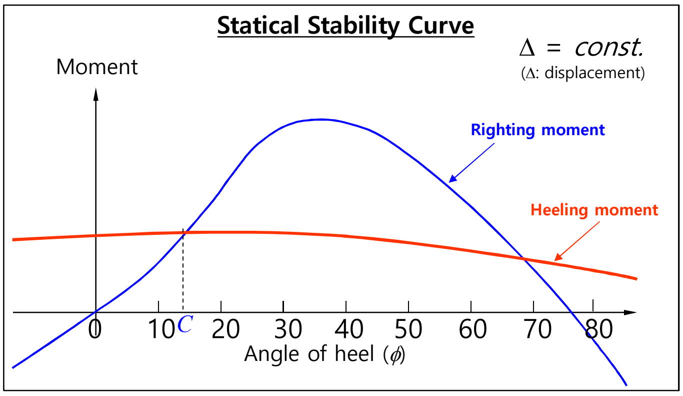
The total area between the statical stability curve (at zero degree to the angle of vanishing stability) and the horizontal axis represents from the upright position.

This is often referred to as .



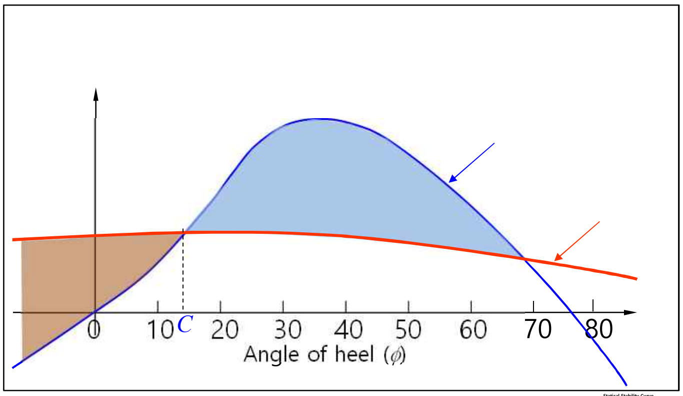
Representation of Heeling Moments on the Statical Stability Curve

- Significance between the Statical Stability Curve and Heeling Moments Curve (1/3)



At angle C and D, the heeling moment is equal to the righting moment and the forces are in equilibrium.

Representation of Heeling Moments on the Statical Stability Curve
- Significance between the Statical Stability Curve and Heeling Moments Curve (3/3)



Statical Stability Curve

Moment

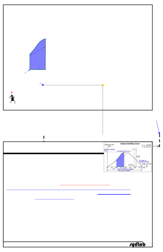
$\Delta = const.$ (Δ: displacement)

Righting moment

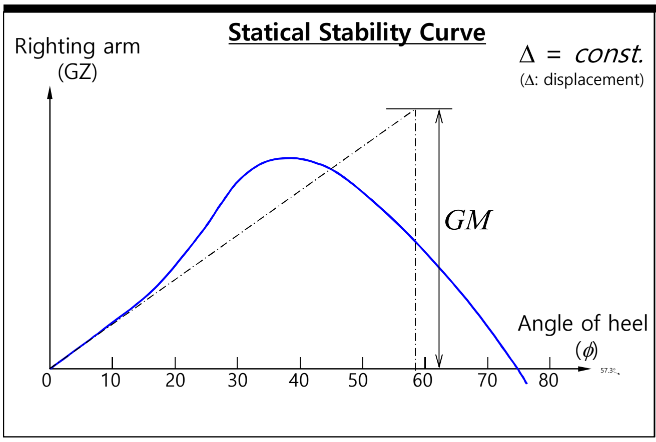
Heeling moment

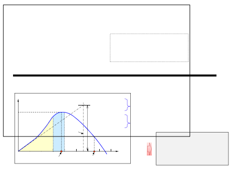
Energy imparted to the ship as kinetic energy

Assumption) The ship was heeled to the left to angle E, has come to rest, and is about to be hilled in the opposite direction.

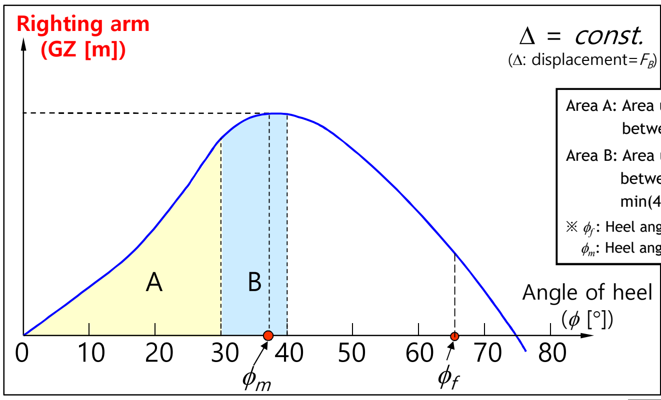


[Review] Statical Stability Curve





Stability Criteria
- IMO Regulations for Intact Stability



$$\tau_r = GZ \cdot F_B$$

Area A: Area under the righting arm curve between the heel angle of 0° and 30°

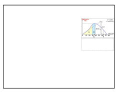
Area B: Area under the righting arm curve between the heel angle of 30° and min(40°, ϕ_f)

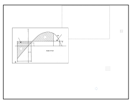
※ ϕ_f: Heel angle at which openings in the hull submerge
ϕ_m: Heel angle of maximum righting arm

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°.

※ After receiving the approval for the intact and damage stability of IMO regulation from owner and classification society, ship construction can be proceed.





Merchant Ship Stability Criteria
- IMO Regulations for Intact Stability

☑ **Special Criteria for Certain Types of Ships**

- **Containerships greater than 100 m**

These requirements apply to containerships greater than 100 m. They may also be applied to other cargo ships with considerable flare or large water plane areas. The administration may apply the following criteria instead of those in paragraphs of previous slide.

IMO Regulations for containerships greater than 100 m

(a) Area A ≥ 0.009/C (m-rad)

(b) Area A + B ≥ 0.016/C (m-rad)

(c) Area B ≥ 0.006/C (m-rad)

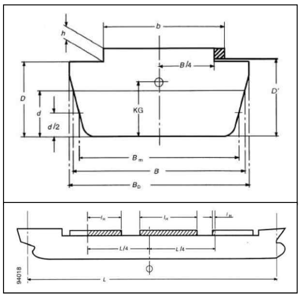
(d) GZ ≥ 0.033/C (m) at an angle of heel equal to or greater than 30°

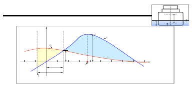
(e) GZ_{max} ≥ 0.042/C (m)

(f) The total area under the righting arm curve (GZ curve) up to the angle of flooding ϕ_f should not be less than 0.029/C (m-rad)

In the above criteria **the form factor C** should be calculated using the formula and figure on the right-hand side.

$$C = \frac{dD'}{B^2_m}\sqrt{\frac{d}{KG}}\left(\frac{C_B}{C_W}\right)\sqrt[2]{\frac{100}{L}}$$

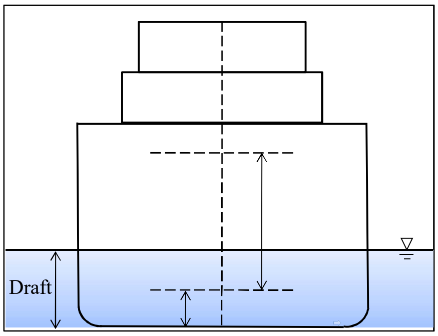




War Ship Stability Criteria
- U.S. Navy Criteria (1/2)

☑ **General U.S. Navy criteria are intended to ensure the adequacy of stability of all types and sizes of naval ships, as evidenced by sufficient righting energy to withstand various types of upsetting of heeling moments.**

(Example) Beam Winds Combined with Rolling



When winds of high velocity exist, beam winds and rolling are considered simultaneously.

If the water were still, the ship would require only sufficient righting moment to overcome the heeling moment produced by the action of the wind on the ship's "sail area".

However, when the probability of wave action is taken into account, an additional allowance of dynamic stability is required to absorb the energy imparted to the ship by the rolling motion.

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 (degree)

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

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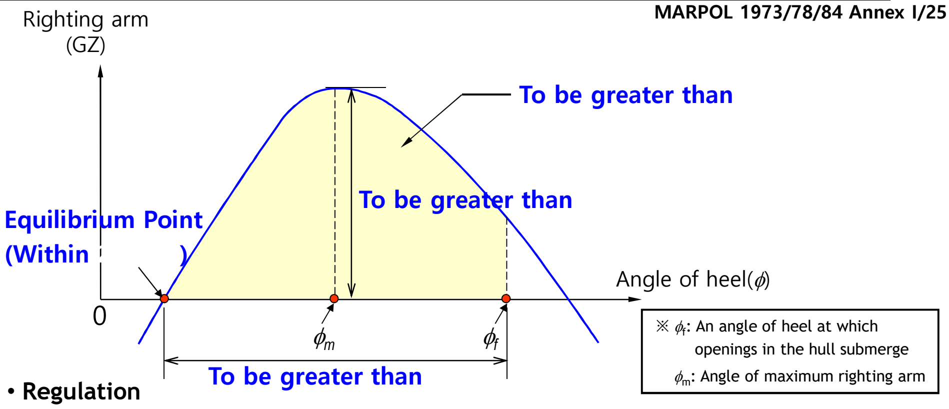
3. Stability Criteria for Damage State

MARPOL Regulation for Damage Stability - Deterministic Damage Stability

MARPOL 1973/78/84 Annex I/25



- **Regulation**

(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.

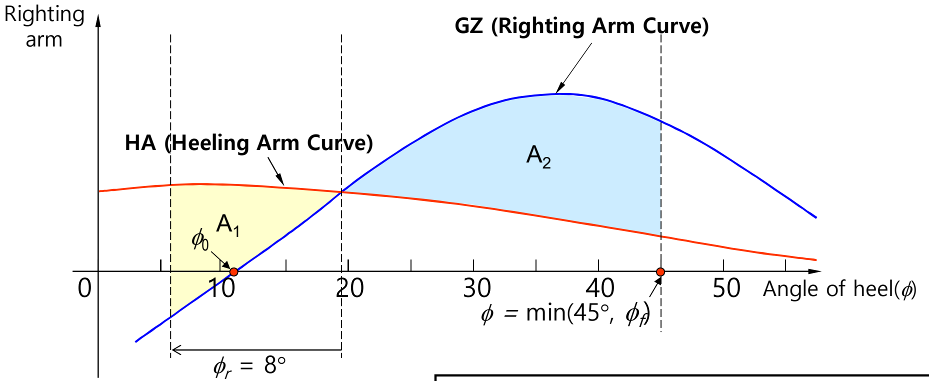
(c) The statical stability curve has at least a range of 20 degrees beyond the position of equilibrium in association with a maximum residual righting arm of at least 0.1 meter within the 20 degrees range

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

Damage Stability Criteria in Battleship*

- **Regulation**

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



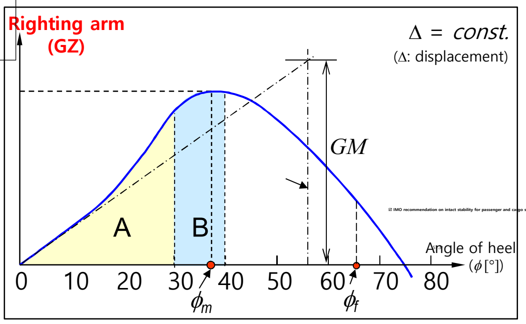
ϕ_r: Angle of heel in transverse wind
(It varies depending on displacement, ϕ_r = 8° in case of battleship with displacement of 9,000 ton.)
ϕ_f: Angle of heel at which openings in the hull submerge

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

4. Example of Stability Evaluation for 7,000 TEU Container Carrier at Homo. Scantling Arrival Condition (14mt)

Merchant Ship Stability Criteria - IMO Regulations for Intact Stability

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



※ After receiving approval of calculation of IMO regulation from owner and classification society, ship construction can proceed.

IMO Regulations for Intact Stability

(a) Area A ≥ 0.055 (m·rad)

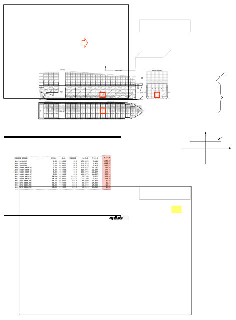
(b) Area A + B ≥ 0.09 (m·rad)

(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 preferably exceeding 30° but not less than 25°.

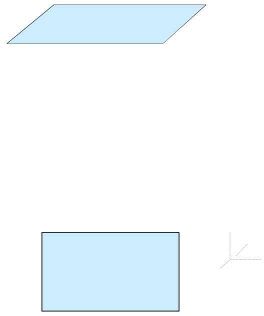
(f) The initial metacentric height GM_o should not be less than 0.15 (m).



Effect of Free Surfaces of Liquids in Tanks
- 7,000 TEU Container Carrier at Homo. Scantling Arrival Condition

$$GG_0 = \frac{\sum \rho_F \cdot i_T}{\rho_{SW} \nabla}$$

: Free surface moment



i_T: Moment of inertia of liquid plane area in tank about longitudinal axis

: Free surface moment

Effect of Free Surfaces of Liquids in Tanks

- 7,000 TEU Container Carrier at Homo. Scantling Arrival Condition

Calculating free surface moment of other tank at homo. scantling arrival condition (14mt)

WEIGHT ITEMS	FILL. (%)	S.G	WEIGHT (MT)	L.C.G (M)	V.C.G (M)	F.S.M (MT-M)
NO2 DB WBT(P)	100.00	1.0250	560.1	228.280	2.640	0.0
NO2 DB WBT(S)	100.00	1.0250	560.1	228.280	2.640	0.0
NO3 DB WBT(P)	100.00	1.0250	940.7	200.357	2.015	0.0
NO3 DB WBT(S)	100.00	1.0250	940.7	200.357	2.015	0.0
NO3 WWBT(P)	100.00	1.0250	1070.1	201.907	11.873	0.0
NO3 WWBT(S)	100.00	1.0250	1070.1	201.907	11.873	0.0
NO4 DB WBT(P)	100.00	1.0250	1266.8	173.078	1.923	0.0
NO4 DB WBT(S)	100.00	1.0250	1266.8	173.078	1.923	0.0
NO5 DB WBT(P)	100.00	1.0250	1145.4	143.534	1.690	0.0
NO5 DB WBT(S)	100.00	1.0250	1145.4	143.534	1.690	0.0
NO5 WWBT(P)	100.00	1.0250	977.8	143.500	12.369	24.3
NO5 WWBT(S)	100.00	1.0250	977.8	143.500	12.369	24.3
NO6 DB WBT(P)	100.00	1.0250	1143.6	114.585	1.690	0.0
NO6 DB WBT(S)	100.00	1.0250	1143.6	114.585	1.690	0.0
NO7 DB WBT(P)	100.00	1.0250	1031.2	85.978	1.778	0.0
NO7 DB WBT(S)	100.00	1.0250	1031.2	85.978	1.778	0.0
TOTAL WATER BALLAST			16271.3	156.848	4.463	48.7
FRESH WATER			41.6	45.600	12.757	20.7
HEAVY FUEL OIL			800.0	71.121	12.188	7109.2
DIESEL OIL			40.0	66.300	11.175	60.5
LUBRICATING OIL			47.4	66.318	7.861	14.1
DEADWEIGHT CONSTANT			900.0	73.100	24.200	0.0
TOTAL DEADWEIGHT			92328	143.449	18.408	7253.3
LIGHT SHIP			27710	122.656	16.000	
TOTAL DISPLACEMENT			120038	138.649	17.852	7253.3

$$GG_0 = \frac{\sum \rho_F \cdot i_T}{\rho_{SW} \nabla} = \frac{7,253.3}{120,038} = 0.06(m)$$

Merchant Ship Stability Criteria
- IMO Regulations for Intact Stability

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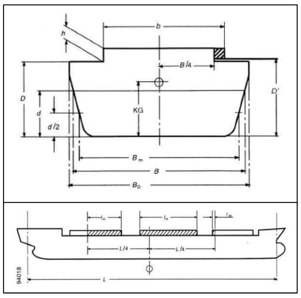
(d) GZ ≥ 0.033/C (m) at an angle of heel equal to or greater than 30°

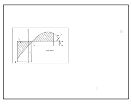
(e) GZ_{max} ≥ 0.042/C (m)

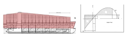
(f) The total area under the righting lever curve (GZ curve) up to the angle of flooding ϕ_f should not be less than 0.029/C (m-rad)

In the above criteria **the form factor C** should be calculated using the formula and figure on the right-hand side.

$$C = \frac{dD'}{B_m^2}\sqrt{\frac{d}{KG}}\left(\frac{C_B}{C_W}\right)^2\sqrt{\frac{100}{L}}$$







Design Criteria Applicable to All Ships
- IMO Regulations for Severe Wind and Rolling Criteria (Weather Criteria)

☑ Scope

The weather criteria should govern the minimum requirements for passenger or cargo ships of 24 m in length and over.

ϕ_0: Angle of heel under action of steady wind
ϕ_1: Angle of roll to windward due to wave action
ϕ_2: Angle of down flooding (ϕ_f) or 50°, whichever is less
where,
ϕ_f : Angle of heel at which openings in the hull submerge
ϕ_c: Angle of the second intersection between wind heeling arm and GZ(righting arm) curves

IMO Regulations for Severe Wind and Rolling Criteria (Weather Criteria)

The ship is subjects to a steady wind pressure acting perpendicular to the ship's center line which results in a steady wind heeling arm (lw_1).

$$lw_1 = \frac{P \cdot A \cdot Z}{1000 \cdot g \cdot \nabla} \ (m)$$

The ship is subjected to a gust wind pressure which results in a gust wind heeling arm (lw_2).

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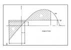


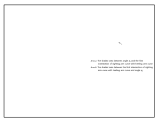
IMO Regulations for Severe Wind and Rolling Criteria (Weather Criteria) - 7,000 TEU Container Carrier at Homo. Scantling Arrival Condition

(b) Under these circumstances, *area b* should be equal to or greater than *area a*.

First, we have to know the value of a gust wind heeling arm (lw_2).

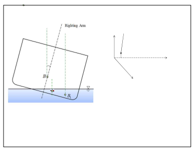
$$lw_2 = 1.5 \cdot lw_1$$
$$= 1.5 \cdot 0.1 = 0.15(m)$$

Second, we have to know the angle of roll (ϕ_1).



Third, ϕ_2 is angle of down flooding (ϕ_f) or 50°, whichever is less. We assume that ϕ_2 for this container carrier is .

Forth, the area a is (m-rad) and the area b is (m-rad).



[Appendix] Statical Stability Curve

Method for Obtaining Cross Curves of Stability

- Calculating for a Number of Waterline at Various Drafts and Angles of Heel (1/4)

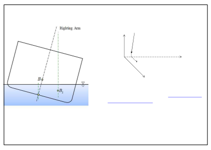
B: Center of buoyancy at initial position

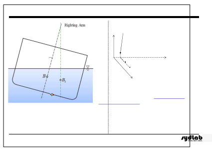
B_1: New position of center of buoyancy corresponding displacement

Righting arm(KN) is calculated for a number of waterlines at various drafts and angles of heel.

✓**Assumption: There is a complete watertight envelope consisting of bottom, side shell and weather deck*.**

*Weather deck: Any deck exposed to the outside

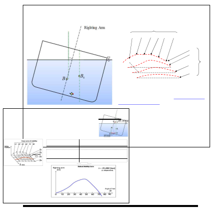




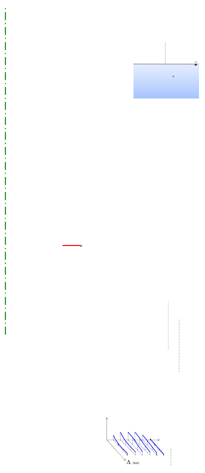
Righting Arm

Righting arm(KN) is calculated for a number of waterlines at various drafts

*Weather deck: Any deck exposed to the outside



Righting Arm



Calculation of Static Equilibrium Position of a Ship

Given: $\mathbf{r}^{(0)} = \left[z^{(0)} \quad \phi^{(0)} \quad \theta^{(0)} \right]^T,$

$$F\left(\mathbf{r}^{(0)}\right), M_T\left(\mathbf{r}^{(0)}\right), M_L\left(\mathbf{r}^{(0)}\right)$$

✓ Governing equation of hydrostatic equilibrium

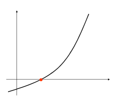
Given

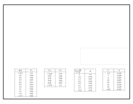
Iteration

Assumption

53

◆ Check





[Appendix] IMO Regulations for Severe Wind and Rolling Criteria (Weather Criteria)

The Angle of Roll (ϕ_1)
Rolling Period (T)

IMO Regulations for Severe Wind and Rolling Criteria (Weather Criteria) - The Angle of Roll (ϕ_1)

The Angle of Roll (ϕ_1) should be calculated as follows:

$$\phi_1 = 109 \cdot k \cdot x_1 \cdot x_2 \cdot \sqrt{r \cdot s} \quad \text{(degrees)}$$

s: factor as shown in table 4

where:
- x_1: factor as shown in Table 1
- x_2: factor as shown in Table 2
- k: factor as follows:
  - k = 1.0 for round-bilged ship having no bilge or bar keels
  - k = 0.7 for a ship having sharp bilges
  - k = as shown in table 3 for a ship having bilge keels, a bar keel of both

with OG = distance between the center of mass and the waterline (m)
('+' if center of mass is above the waterline, '-' if it is below)

IMO Regulations for Severe Wind and Rolling Criteria (Weather Criteria)
- The Angle of Roll (ϕ_1)
- 7,000 TEU Container Carrier at Homo. Scantling Arrival Condition

The Angle of Roll (ϕ_1):

$$\phi_1 = 109 \cdot k \cdot x_1 \cdot x_2 \cdot \sqrt{r \cdot s} \quad \text{(degrees)}$$

L: Waterline Length of the ship (m)
B: Moulded breadth of the ship (m)
d: Mean moulded draft of the ship (m)
C_B: Block coefficient
A_K: Total overall area of bilge keels, or area of the lateral projection of the bar keel, or sum of these areas (m²)

1) K = as shown in table 3 for a **ship having bilge keels**, a bar keel of both

The symbols in the above formula for the rolling period are defined as follows:

where,

B: Moulded breadth of the ship (m)
d: Mean moulded draft of the ship (m)
C_B: Block coefficient
A_K: Total overall area of bilge keels, or area of the lateral projection of the bar keel, or sum of these areas (m²)
GM: Metacentric height corrected for free surface effect (m)

L: Waterline Length of the ship (m)