Naval Architecture & Ocean Engineering

Ship Stability

2009 Fall

Prof. Kyu-Yeul Lee

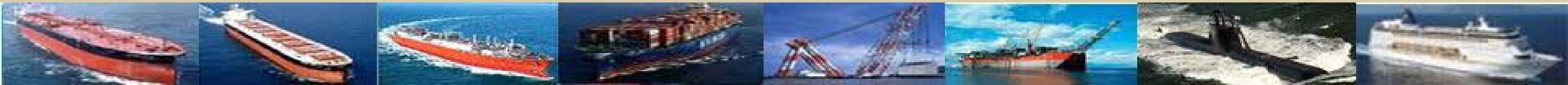
Department of Naval Architecture and Ocean Engineering,
Seoul National University

Reference

- Kyu-Yeul Lee, **선박안정론**, Seoul National University, 2003.9

Seoul National Univ.

@SDAL Advanced Ship Design Automation Lab. http://asdal.snu.ac.kr



- Contents -

Part.1-I Fundamentals of Ship Stability

Ch.1 Overview of Ship Stability
Ch.2 Physics for Ship Stability
Ch.3 Hydrostatic Pressure, Force and Moment on a Floating Body
Ch.4 Concept of Righting Moment
Ch.5 Hydrostatic Values

Part.1-II Righting Moment

Ch.6 Transverse Righting Moment
Ch.7 Longitudinal Righting Moment
Ch.8 Heeling Moment caused by Fluid in Tanks

Part.1-III Stability Criteria

Ch.9 Intact Stability
Ch.10 Damage Stability

Part.1-IV Pressure Integration Technique

Ch.11 Calculation of Static Equilibrium Position
Ch.12 Governing Equation of Force and Moment with Immersion, Heel and Trim
Ch.13 Partial Derivatives of Force and Moments with Immersion, Heel and Trim

- Ship Stability -

Part.1-I Fundamentals of Ship Stability

2009 Fall

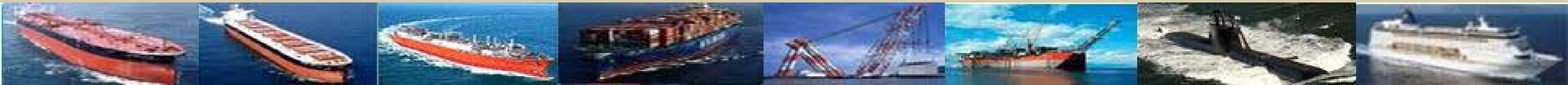
Prof. Kyu-Yeul Lee

Department of Naval Architecture and Ocean Engineering,
Seoul National University

Naval Architecture & Ocean Engineering

Seoul National Univ.

@SDAL
Advanced Ship Design Automation Lab.
http://asdal.snu.ac.kr



Naval Architecture & Ocean Engineering

- Ship Stability -

Ch.1 Overview of Ship Stability

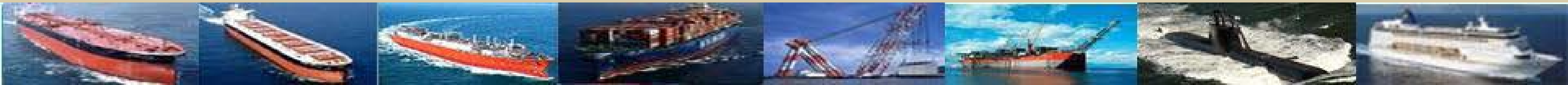
2009 Fall

Prof. Kyu-Yeul Lee

Department of Naval Architecture and Ocean Engineering,
Seoul National University

Seoul National Univ.

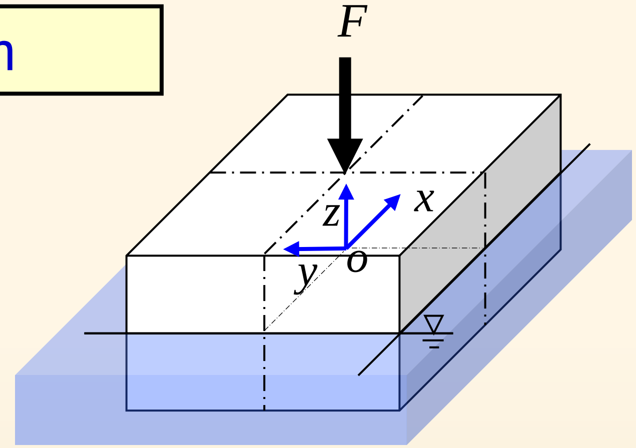
@SDAL
Advanced Ship Design Automation Lab.
http://asdal.snu.ac.kr

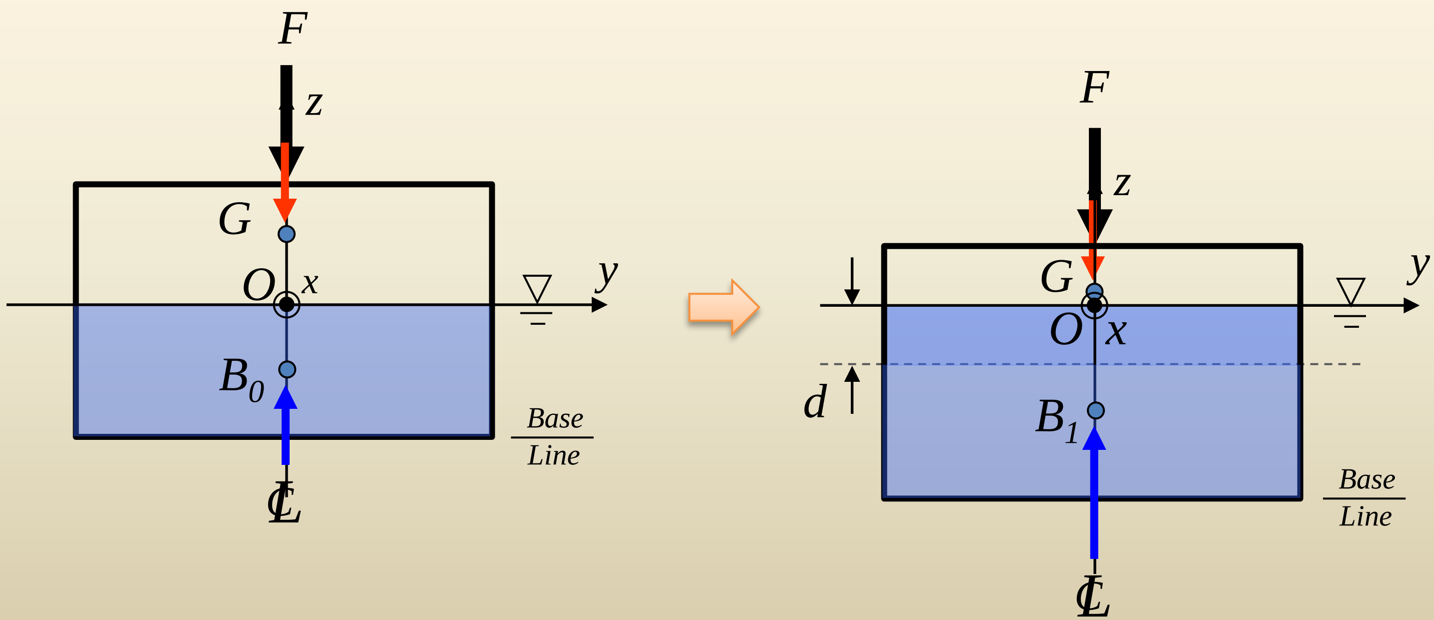


Change of Position of Ship – 1. Immersion

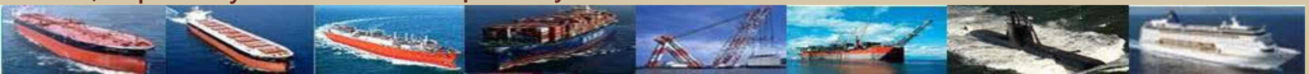
Change of Position of Ship – 1. Immersion

Immersion due to external force

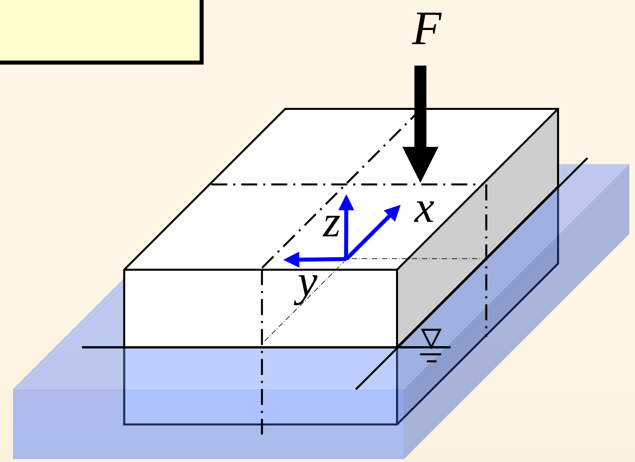




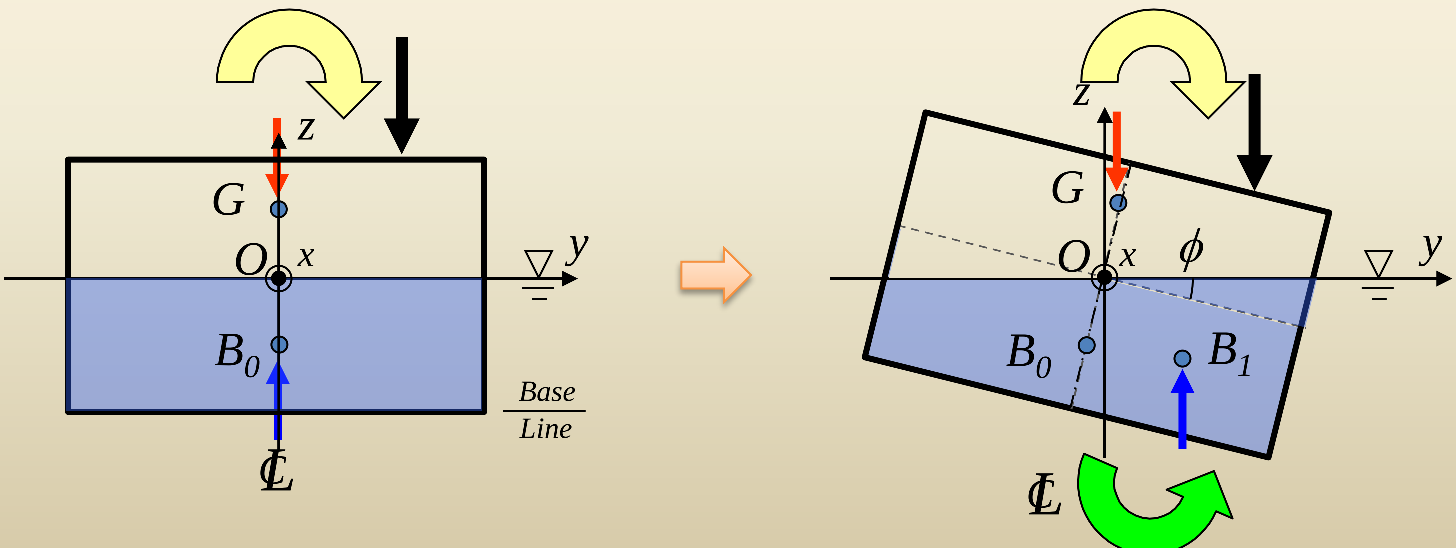
G : Center of gravity
B : Center of buoyancy
F : Force
d : Immersion



Change of Position of Ship – 2. Heel



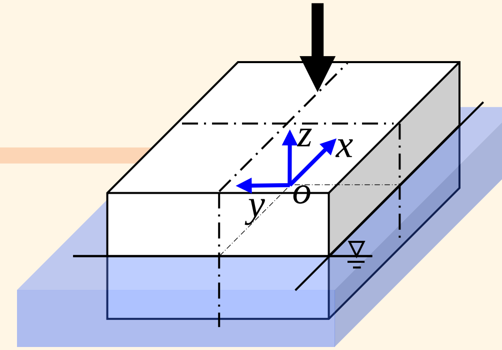
Heel due to external moment

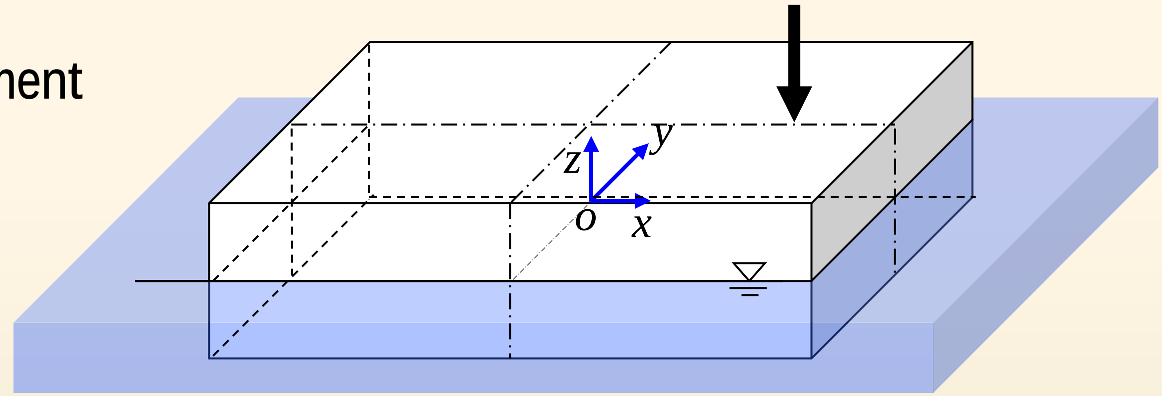


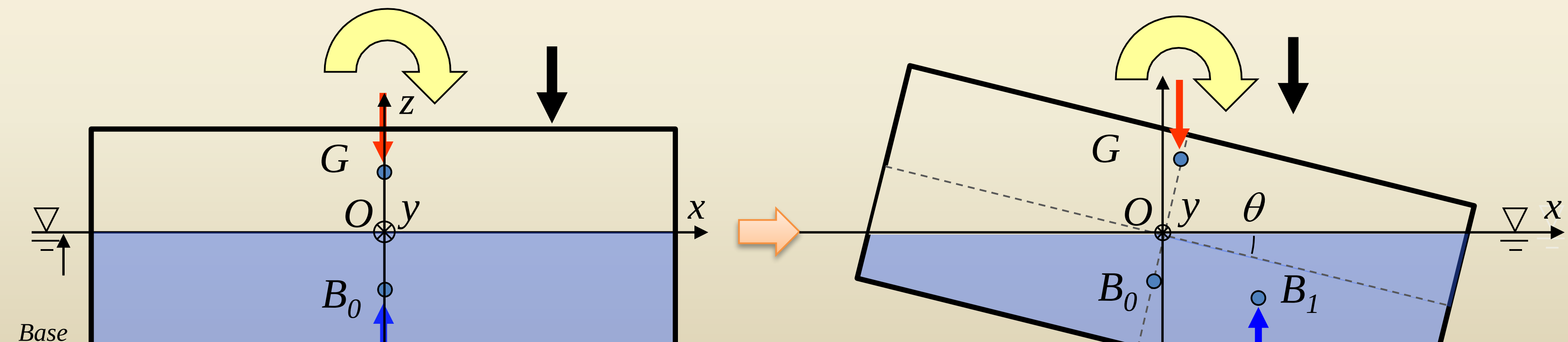
G : Center of gravity
B : Center of buoyancy
F : Force
ϕ : Heel Angle

Change of Position of Ship – 3. Trim

Trim due to external moment

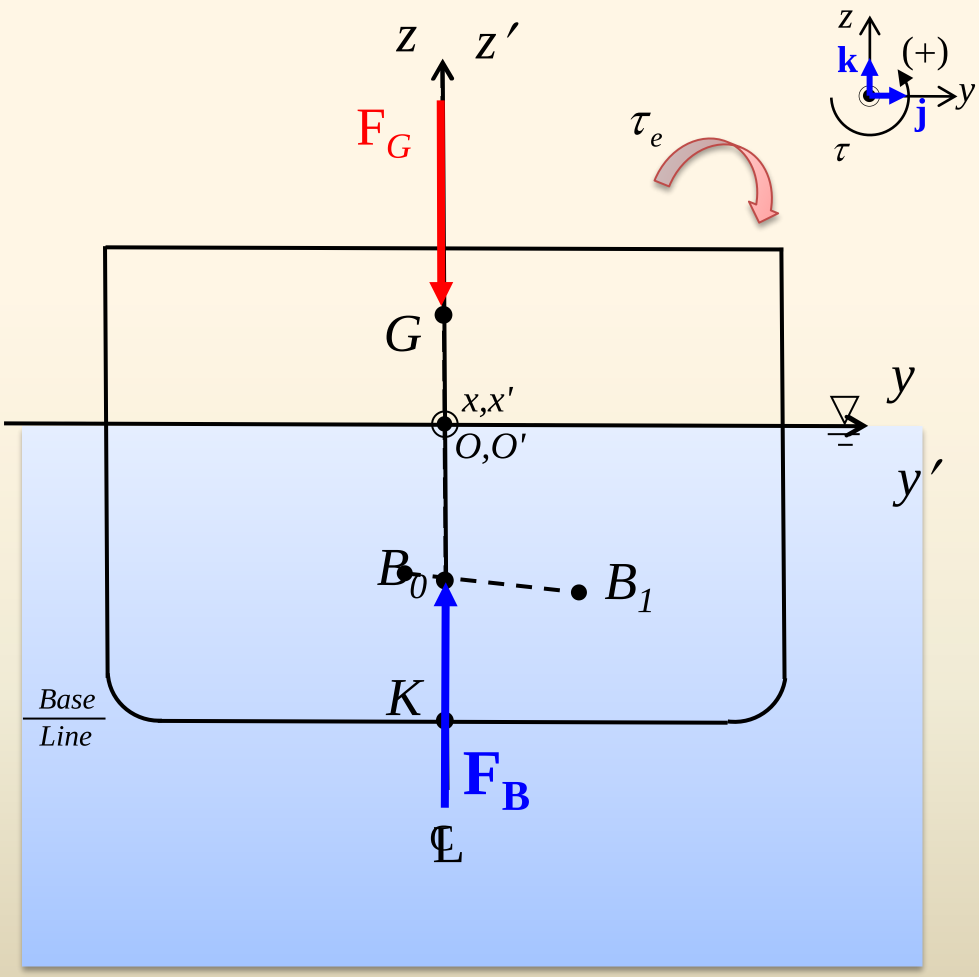






G : Center of gravity
B : Center of buoyancy
F : Force
θ : Trim Angle

Introduction to Ship Stability
: Transverse Righting Moment of Ship (1)

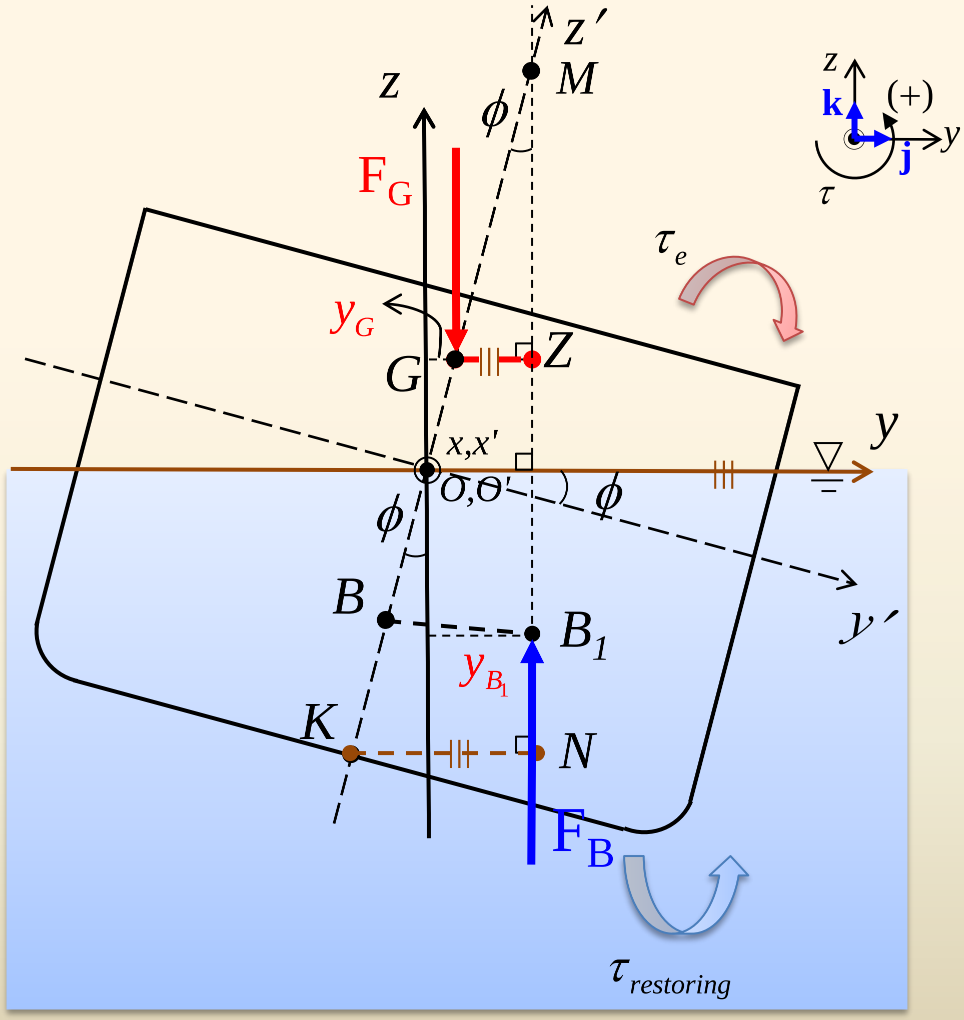


- **Righting Moment :** Moment to return the ship to the upright floating position (Moment of statical stability)

O'x'y'z' : Body fixed frame

Oxyz : Waterplane fixed frame

Introduction to Ship Stability
: Transverse Righting Moment of Ship (2)



O'x'y'z' : Body fixed frame

Oxyz : Waterplane fixed frame

- **Righting Moment :** Moment to return the ship to the upright floating position (Moment of statical stability)

- **Transverse Righting moment**

$$\tau_{restoring} = (-y_G + y_{B_1}) \cdot F_B \, \mathbf{i} \;\; = \underbrace{GZ}_{\text{Righting arm}} \cdot F_B \, \mathbf{i}$$

- **Righting Arm** (GZ)

① From direct calculation

$$GZ = -y_G + y_{B_1}$$

We should know y_G, y_{B1} in waterplane fixed frame

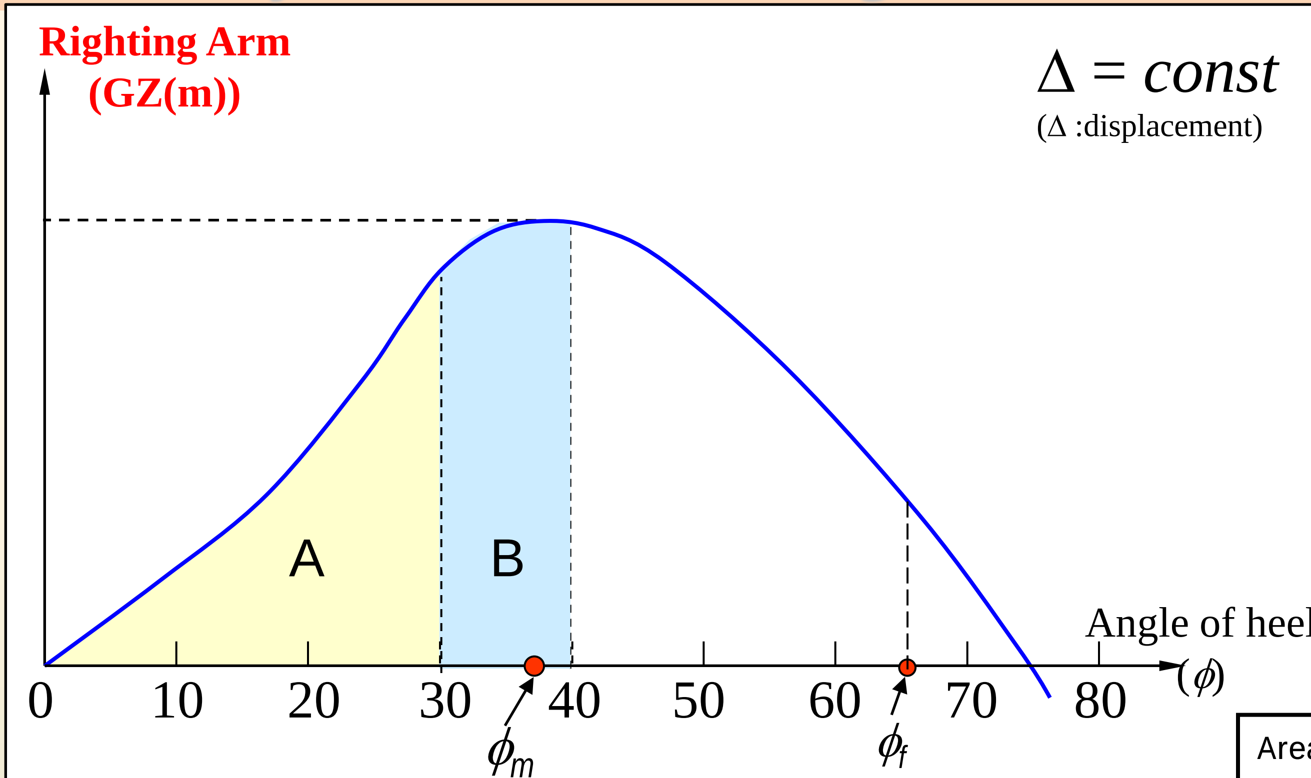
② From geometrical figure with assumption that M does not change within small angle of heel (about 10°)

$$GZ = GM \cdot \sin\phi$$

GM is related to below equation by geometrical figure

$$GM = KB + BM - KG$$

(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.

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>

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

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

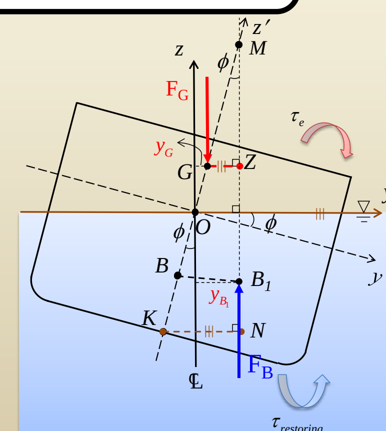
Pressure Integration Technique

- 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



-Pressure and Force acting on Fluid Particle
-6 D.O.F Equations of Ship Motions
: Relations among Undergraduate Lectures

r : displacement of particle with respect to time

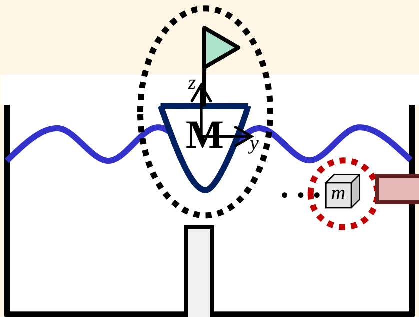
$\mathbf{V} = \frac{d\mathbf{r}}{dt}, \mathbf{a} = \frac{d^2\mathbf{r}}{dt^2}$

$\mathbf{F}_{F.K}$: Froude- krylov force
$\mathbf{F}_D$: Diffraction force
$\mathbf{F}_R$: Radiation force

1) RTT : Reynold Transport Theorem
2) SWBM : Still Water Bending Moment
3) VWBM : Vertical Wave Bendidng Moment

✓ Assumption
① Newtonian fluid*
② Stokes Assumption**
③ invicid fluid
④ Irrotational flow
⑤ Incompressible flow

Ship Hydrodynamics, Dynamics (2nd-year undergraduate)



$\mathbf{r} = [\xi_1, \xi_2, \xi_3, \xi_4, \xi_5, \xi_6]^T$

ξ_1 : surge , ξ_4 : roll
ξ_2 : sway , ξ_5 : pitch
ξ_3 : heave , ξ_6 : yaw

✓Equations of motions of Fluid Particles

Lagrangian & Eulerian Description

Shear stress

Curl & Rotation

Newton's 2nd Law

$m\ddot{\mathbf{r}} = \sum \mathbf{F} = (\text{Body force} + \text{Surface force})$

→ Cauchy equation → ①② Navier-Stokes equation → ③ Euler equation → ④⑤ Bernoulli equation

Mass Conservation Law ④⑤ → Laplace equation

$(\mathbf{V} = \nabla\Phi)$

$\nabla^2\Phi = 0$

$\rho\frac{\partial\Phi}{\partial t} + P + \frac{1}{2}\rho|\nabla\Phi|^2 + \rho g z = 0$

Microscopic/ Macroscopic Derivation(RTT[1])

Enigneering Math. (2nd-year undergraduate)

✓6 D.O.F equations of motion

Behavior of ship and its control (3rd -year undergraduate) Dynamics (2nd -year undergraduate)

① Coordinate system (Waterplane Fixed & Body-fixed frame)

② Newton's 2nd Law

$$\mathbf{M}\ddot{\mathbf{r}} = \sum \mathbf{F} = (Body\ \ Force) + (Surface\ \ Force)$$

$$= \mathbf{F}_{gravity}(\mathbf{r}) + \mathbf{F}_{Fluid}(\mathbf{r}, \dot{\mathbf{r}}, \ddot{\mathbf{r}})$$

$$= \mathbf{F}_{gravity} + \mathbf{F}_{Buoyancy}(\mathbf{r}) + \mathbf{F}_{F.K}(\mathbf{r}) + \mathbf{F}_D(\mathbf{r})$$

$$\mathbf{F}_{R,Damping}(\mathbf{r}, \dot{\mathbf{r}}) + \mathbf{F}_{R,Mass}(\mathbf{r}, \ddot{\mathbf{r}})$$

Planning procedure of naval architecture and ocean engineering (2nd-year undergraduate)

...ms → Non-linear equation

→ Difficulty of getting analytic solution

Numerical Method → Computer aided ship design (3rd-year undergraduate)

Velocity potential Φ

$\Phi = \Phi_I$ (Incident wave potential)
$+\Phi_D$ (Diffraction potential)
$+\Phi_R$ (Radiation potential)

✓Calculation of Fluid Force

Ocean environment Information system (3rd -year undergraduate)

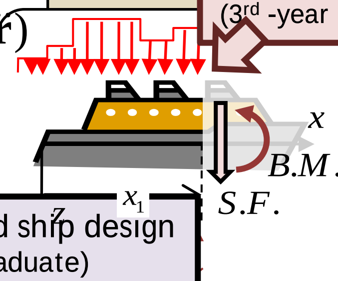
$$P = -\rho g z - \rho\frac{\partial\Phi}{\partial t}$$

$\left(-\frac{1}{2}\rho|\nabla\Phi|^2 = 0\right)$

$$\mathbf{F}_{Fluid}(\mathbf{r}, \dot{\mathbf{r}}, \ddot{\mathbf{r}}) = \iint_{S_B} P\mathbf{n}dS = \mathbf{F}_{Buoyancy}(\mathbf{r}) + \mathbf{F}_{F.K}(\mathbf{r}) + \mathbf{F}_D(\mathbf{r}) + \mathbf{F}_R(\mathbf{r}, \dot{\mathbf{r}}, \ddot{\mathbf{r}})$$

Ship Structural Design system (3rd -year undergraduate)

Fundamental of maritime Structural statics (2nd -year undergraduate)



$m(x)a_z$, $f_{Gravity}$

(a_z : Acceleration of z direction by heave& pitch motion)

$f_{F.K.}$, f_D , $-a_{33}a_z$, $-b_{33}v_z$, f_{Static}

... & bending moment(B.M.)

Shear force($S.F.$)

🡇 Integral

Bending moment($B.M.$)