Offshore Hydromechanics Module 1

Dr. ir. Pepijn de Jong

2. Hydrostatics and Stability part 2

Introduction

E-Assessment

- Not compulsory
- Grade counted as follows: exam 80%, bonus assignments 20%

- E-Assessment:
  - Formative Exercises (set of around 5, 4 tries, minimum 2/3 score)
  - Bonus Assignment

- 4 Sets for topic

Introduction

Overview

	Tutorial				Lecture				Online Assignments	
Week	date	time	location	topic	date	time	location	topic	deadline	topic
2					11-Sep	8:45-10:30	3mE-CZ B	Intro, Hydrostatics, Stability		
3					18-Sep	8:45-10:30	DW-Room 2	Hydrostatics, Stability		
4	23-Sep	8:45-10:30	TN-TZ4.25	Hydrostatics, Stability	25-Sep	8:45-10:30	3mE-CZ B	Potential Flows	27-Sep	Hydrostatics, Stability
5					02-Oct	8:45-10:30	3mE-CZ B	Potential Flows		
6	07-Oct	8:45-10:30	TN-TZ4.25	Potential Flows	09-Oct	8:45-10:30	3mE-CZ B	Real Flows	11-Oct	Potential Flows
7	14-Oct	8:45-10:30	TN-TZ4.25	Real Flows	16-Oct	8:45-10:30	3mE-CZ B	Real Flows, Waves	18-Oct	Real Flows
8					23-Oct	8:45-10:30	3mE-CZ B	Waves	25-Oct	Waves
Exam	30-Oct	9:00-12:00	TN-TZ4.25	Exam						

Introduction

Topics of Module 1

• Problems of interest	Chapter 1
• Hydrostatics	Chapter 2
• **Floating stability**	**Chapter 2**
• Constant potential flows	Chapter 3
• Constant real flows	Chapter 4
• Waves	Chapter 5

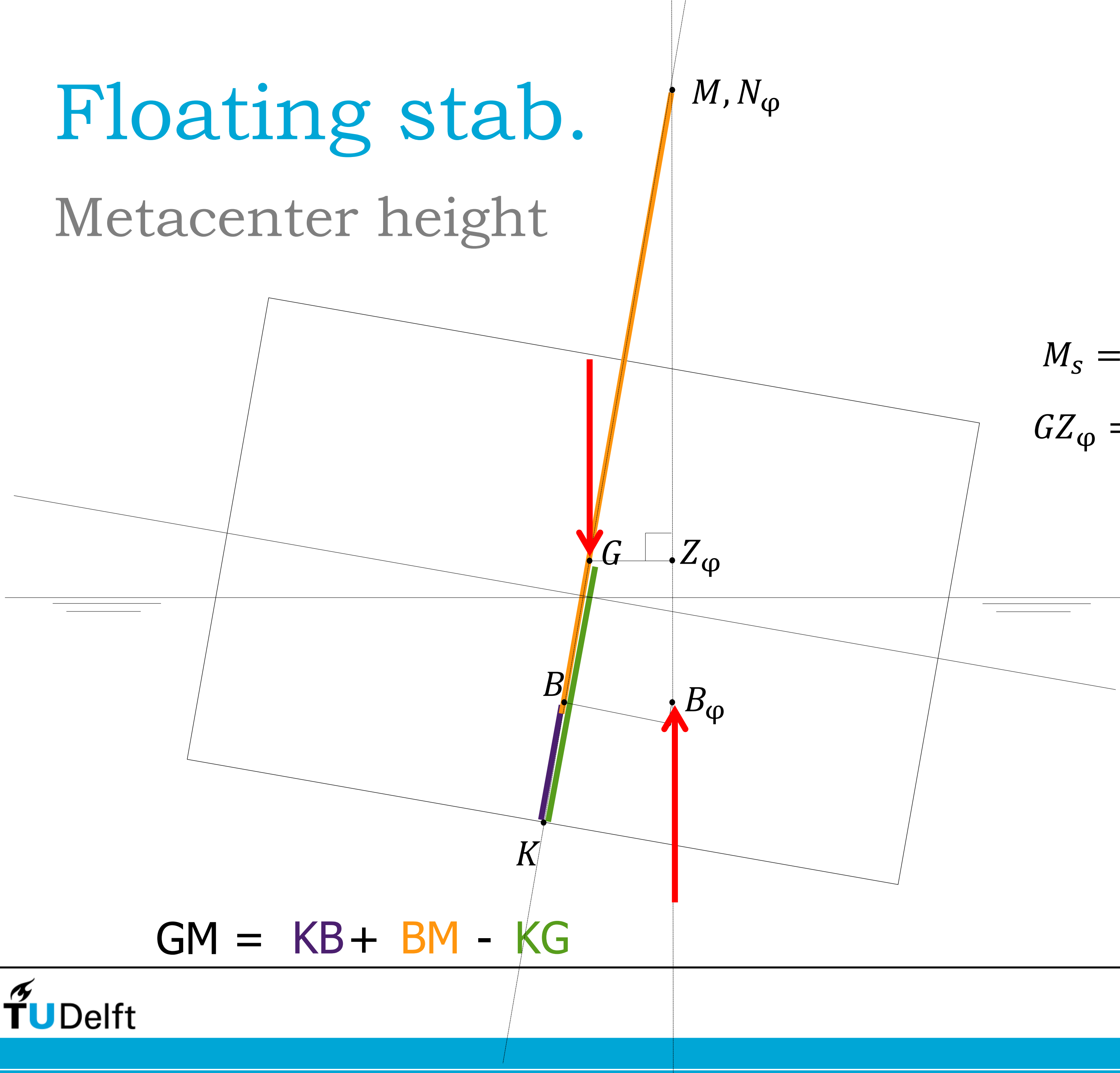
Learning Objectives

Chapter 2

- To carry out and analyse hydrostatic and floating stability computations at a superior knowledge level, including the effect of shifting loads and fluids in partially filled tanks

Floating stab.

Metacenter height



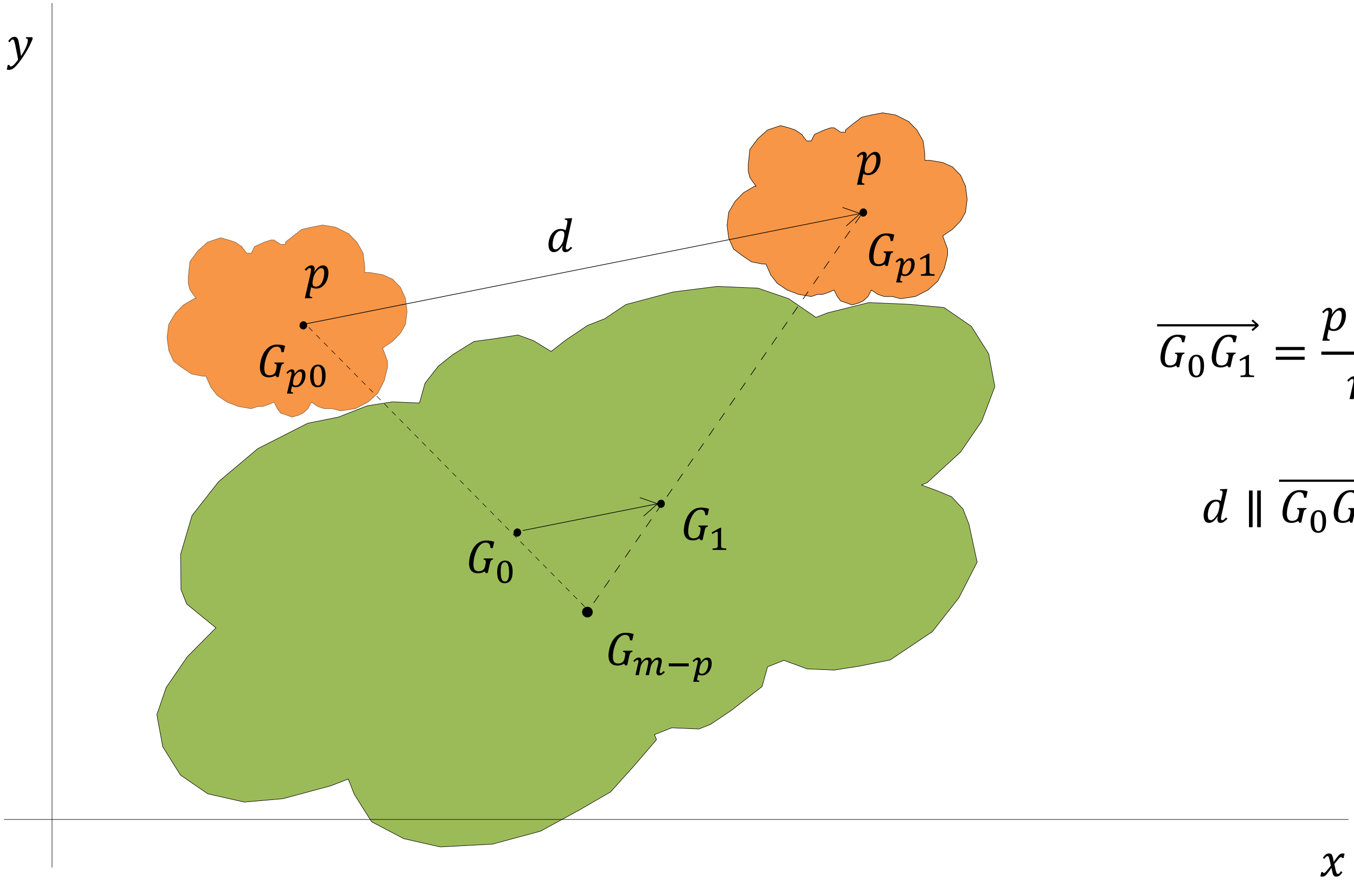
$$M_s = GZ_\varphi \rho g \nabla$$

$$GZ_\varphi = GN_\varphi \sin\varphi$$

GM = KB + BM - KG

Floating stability

Shift of mass or volume center

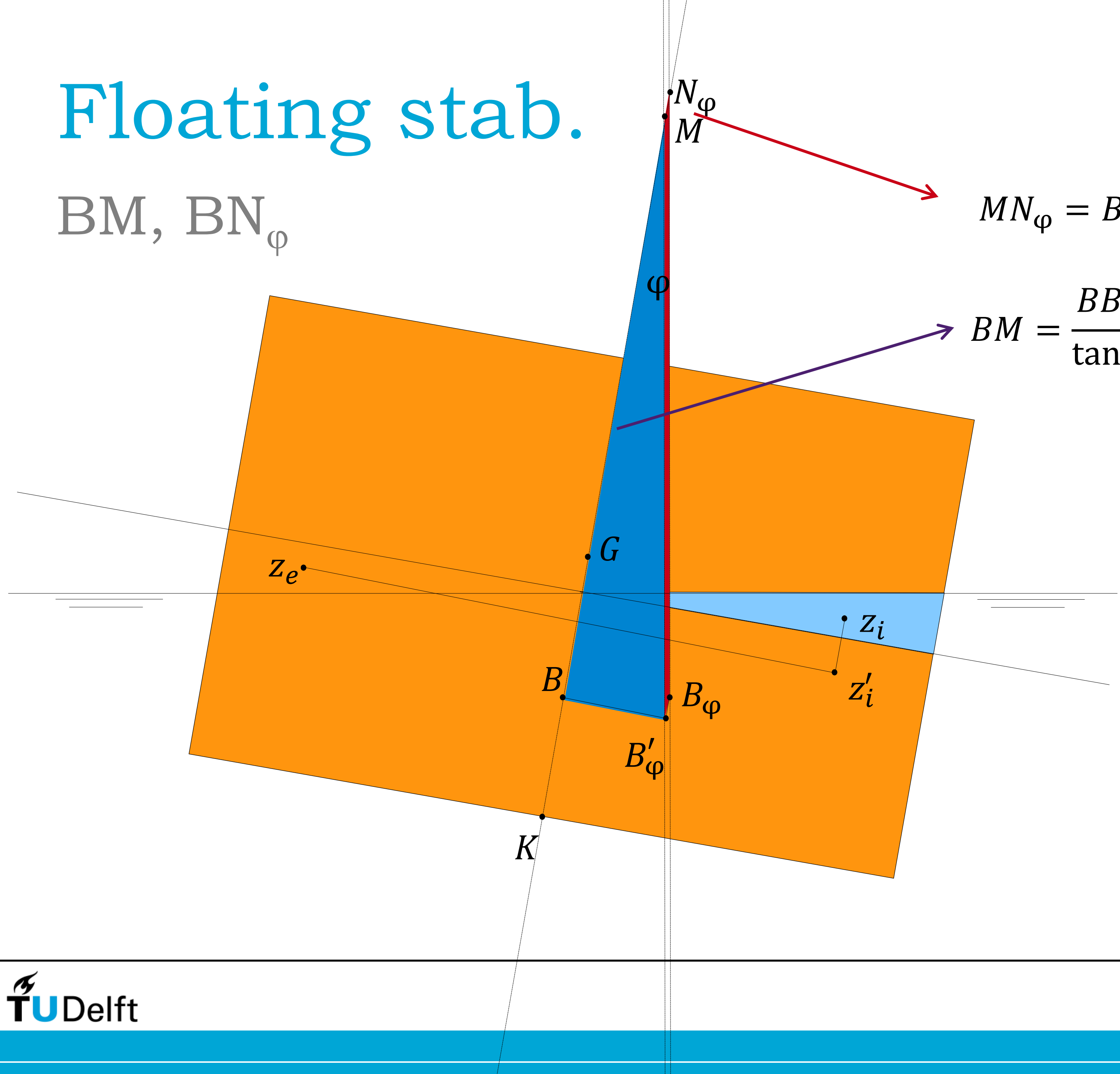


$$\overrightarrow{G_0G_1} = \frac{p \cdot d}{m}$$

$$d \parallel \overrightarrow{G_0G_1}$$

Floating stab.

BM, BN_φ



$$MN_\varphi = B'_\varphi B_\varphi$$

$$BM = \frac{BB'_\varphi}{\tan\varphi}$$

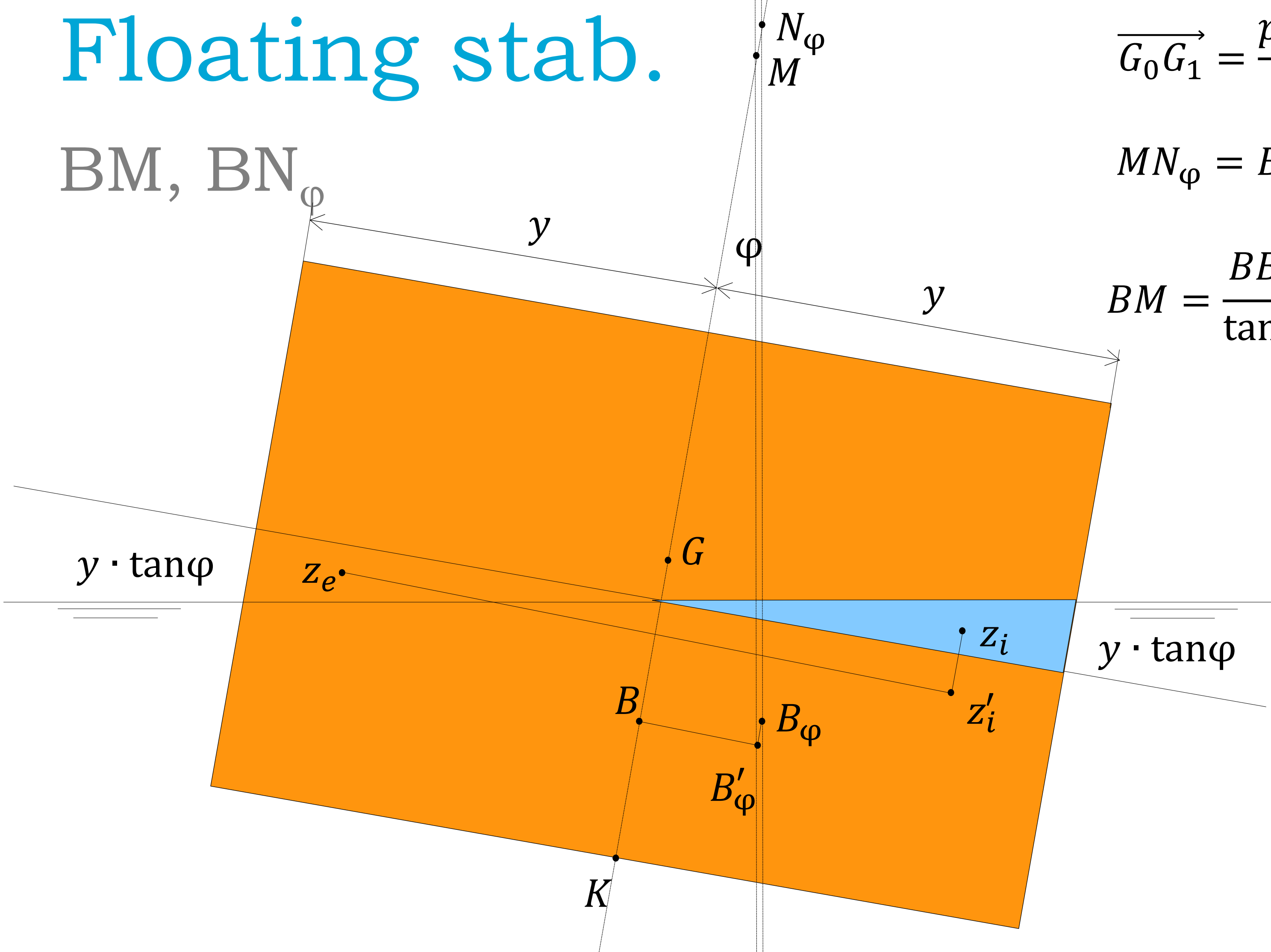
Floating stab.

BM, BN$_\varphi$

$$\overrightarrow{G_0G_1} = \frac{p \cdot d}{m}$$

$$MN_\varphi = B'_\varphi B_\varphi$$

$$BM = \frac{BB'_\varphi}{\tan\varphi}$$



Floating stability

BM, BN$_\varphi$

$$\overrightarrow{G_0G_1} = \frac{p \cdot d}{m}$$

$$BB'_\varphi = \frac{\int_L \ {}^1/_2 \cdot y \cdot y \tan\varphi \cdot {}^4/_3 y \cdot dx}{\nabla}$$

$$B'_\varphi B_\varphi = \frac{\int_L \ {}^1/_2 \cdot y \cdot y \tan\varphi \cdot {}^2/_3 y \cdot \tan\varphi \cdot dx}{\nabla}$$

I_t

$$BB'_\varphi = \frac{2\int_0^L 1/3\, y^3 dx}{\nabla} \tan\varphi$$

$$B'_\varphi B_\varphi = \frac{1}{2}\frac{2\int_0^L 1/3\, y^3 dx}{\nabla} \tan^2\varphi$$

$$BM = \frac{BB'_\varphi}{\tan\varphi} = \frac{I_t}{\nabla}$$

$$MN_\varphi = \frac{1}{2}\tan^2\varphi \frac{I_t}{\nabla}$$

Floating stability

Metacenter height

- For small heeling angles (<5 to 10 degrees): Initial stability

$$GM = KB + BM - KG = KB + \frac{I_t}{\nabla} - KG$$

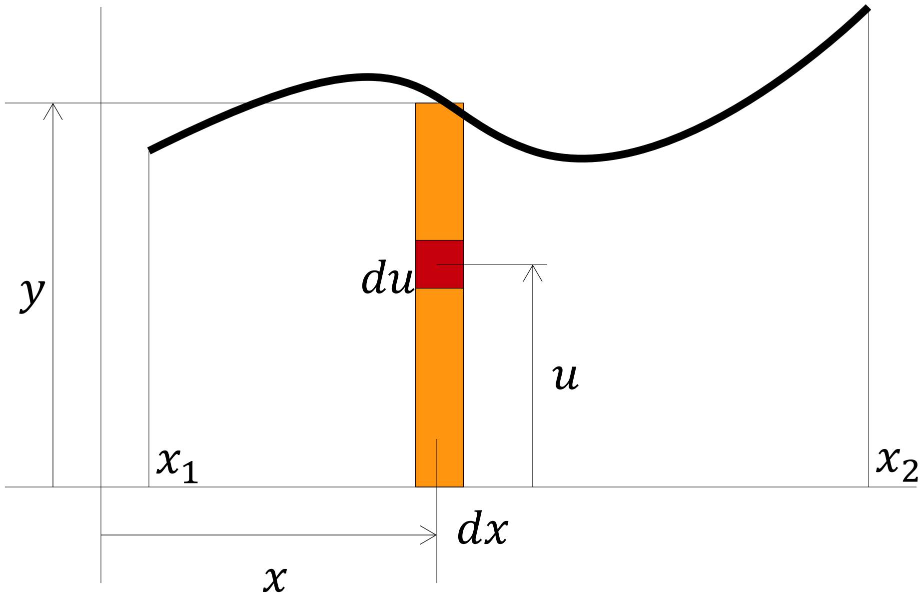
- For slightly larger heeling angles (5 to 15 degrees): Scribanti

$$GM = KB + BN_{\varphi} - KG = KB + \frac{I_t}{\nabla}(1 + 1/2\tan^2\varphi) - KG$$

- Exact?
- For large heeling angles (> 10 to 15 degrees)
- Need of more accurate description: GZ curve

Floating stability

Second moment of area: moment of inertia of area

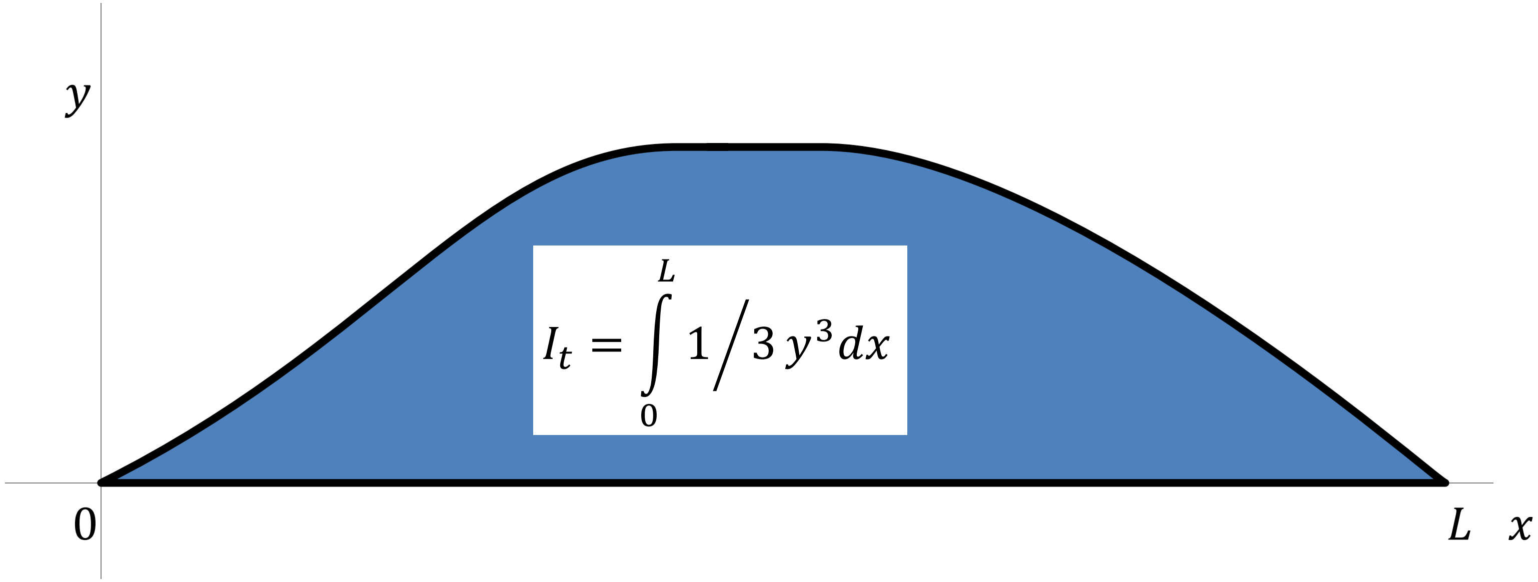


$$dI_{xx} = \int_0^y u^2\, du dx = 1/3\, y^3 dx$$

$$I_{xx} = \int_{x_1}^{x_2} {}^1\!/_3\, y^3 dx$$

Floating stability

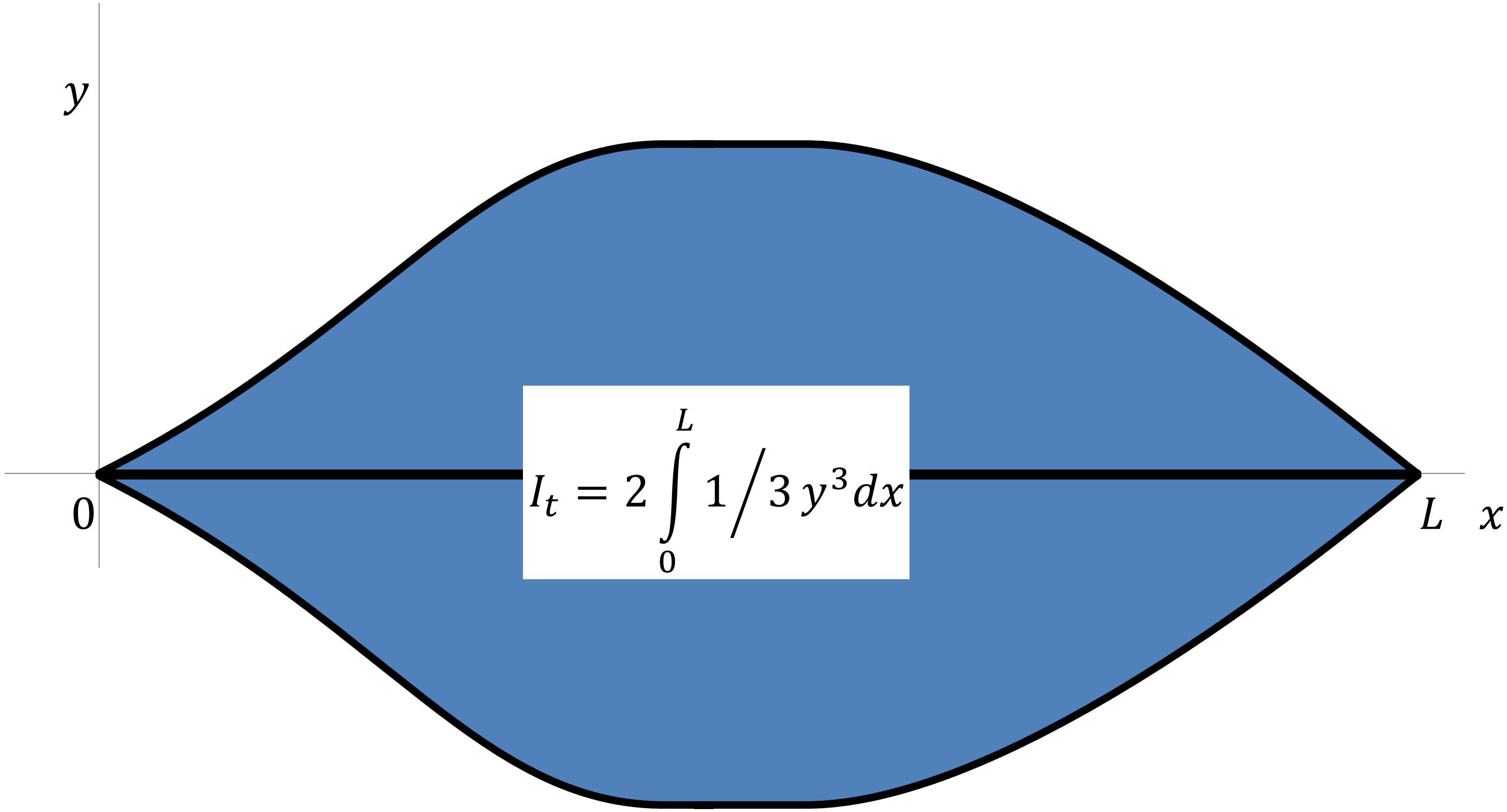
Moment of inertia of water plane area



$$I_t = \int_0^L 1/3\, y^3 dx$$

Floating stability

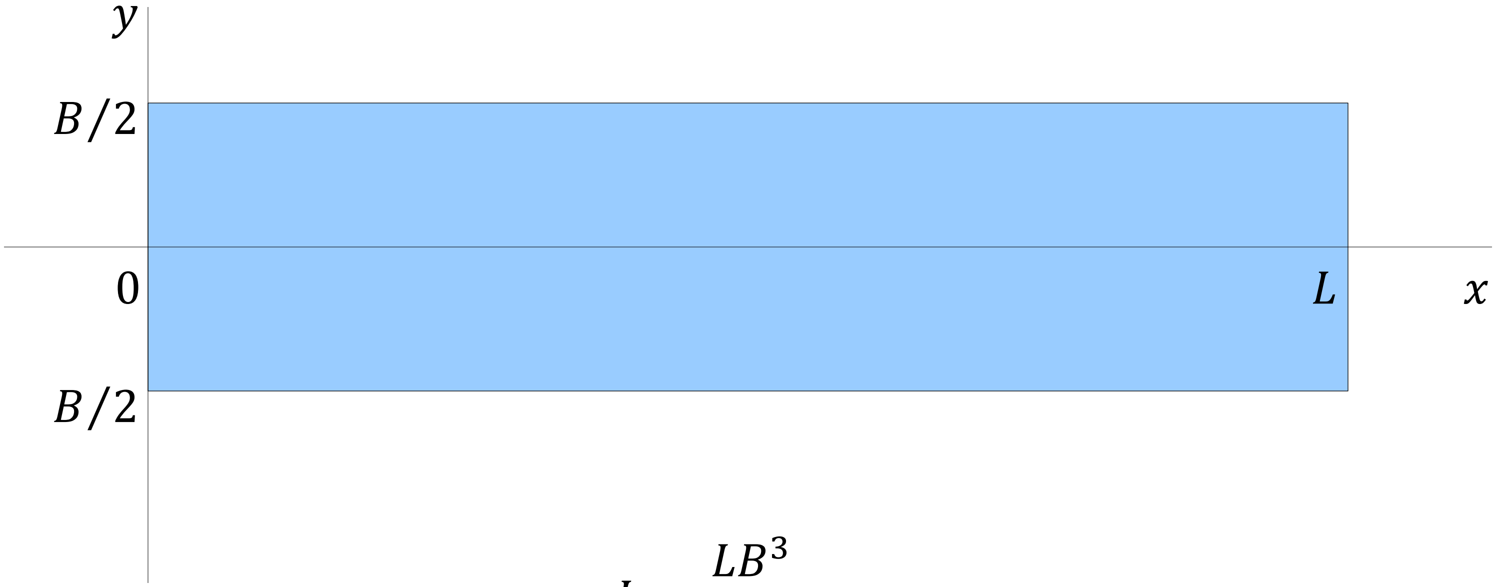
Moment of inertia of water plane area



$$I_t = 2\int_0^L \frac{1}{3} y^3 \, dx$$

Floating stability

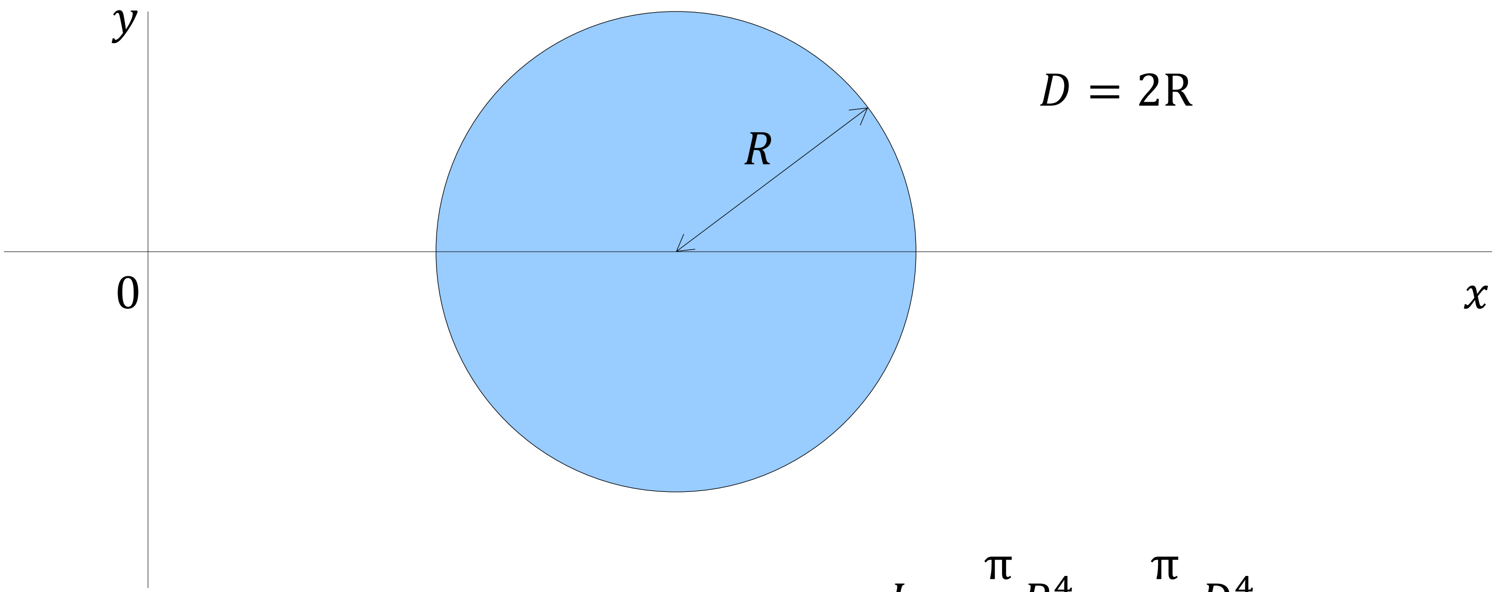
Moment of inertia of water plane area



$$I_t = \frac{LB^3}{12}$$

Floating stability

Moment of inertia of water plane area

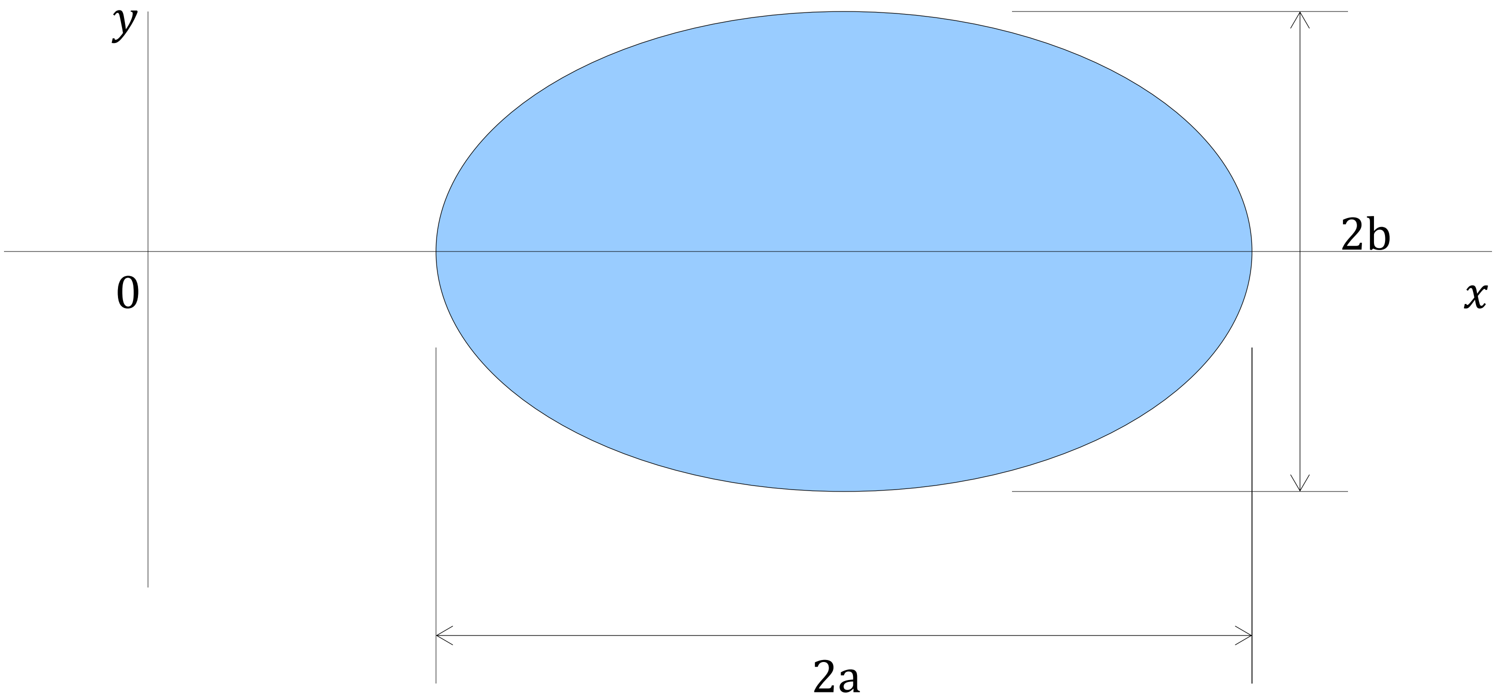


$D = 2\mathrm{R}$

$$I_t = \frac{\pi}{4} R^4 = \frac{\pi}{64} D^4$$

Floating stability

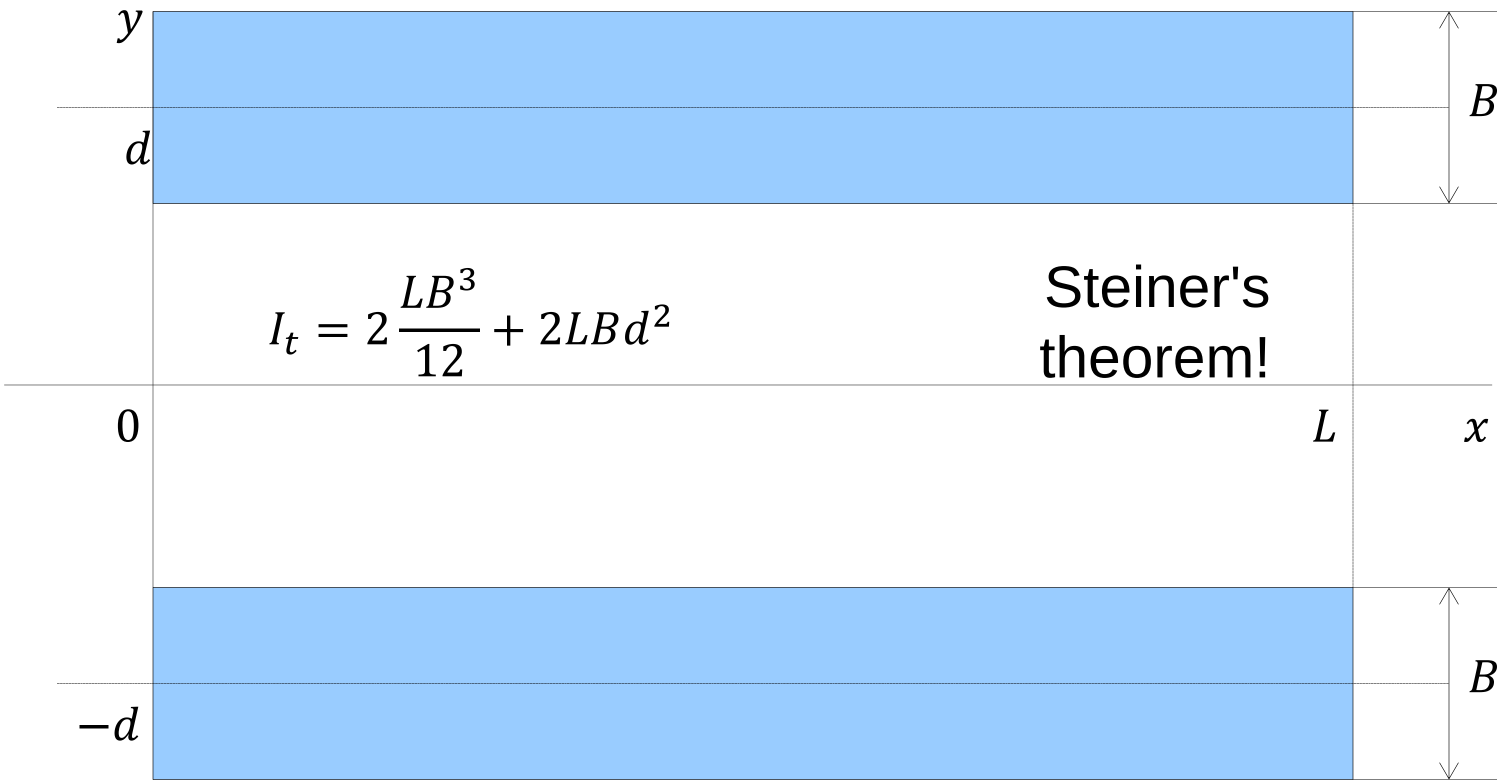
Moment of inertia of water plane area



$$I_t = \frac{\pi}{6} a b^3$$

Floating stability

Moment of inertia of waterplane area

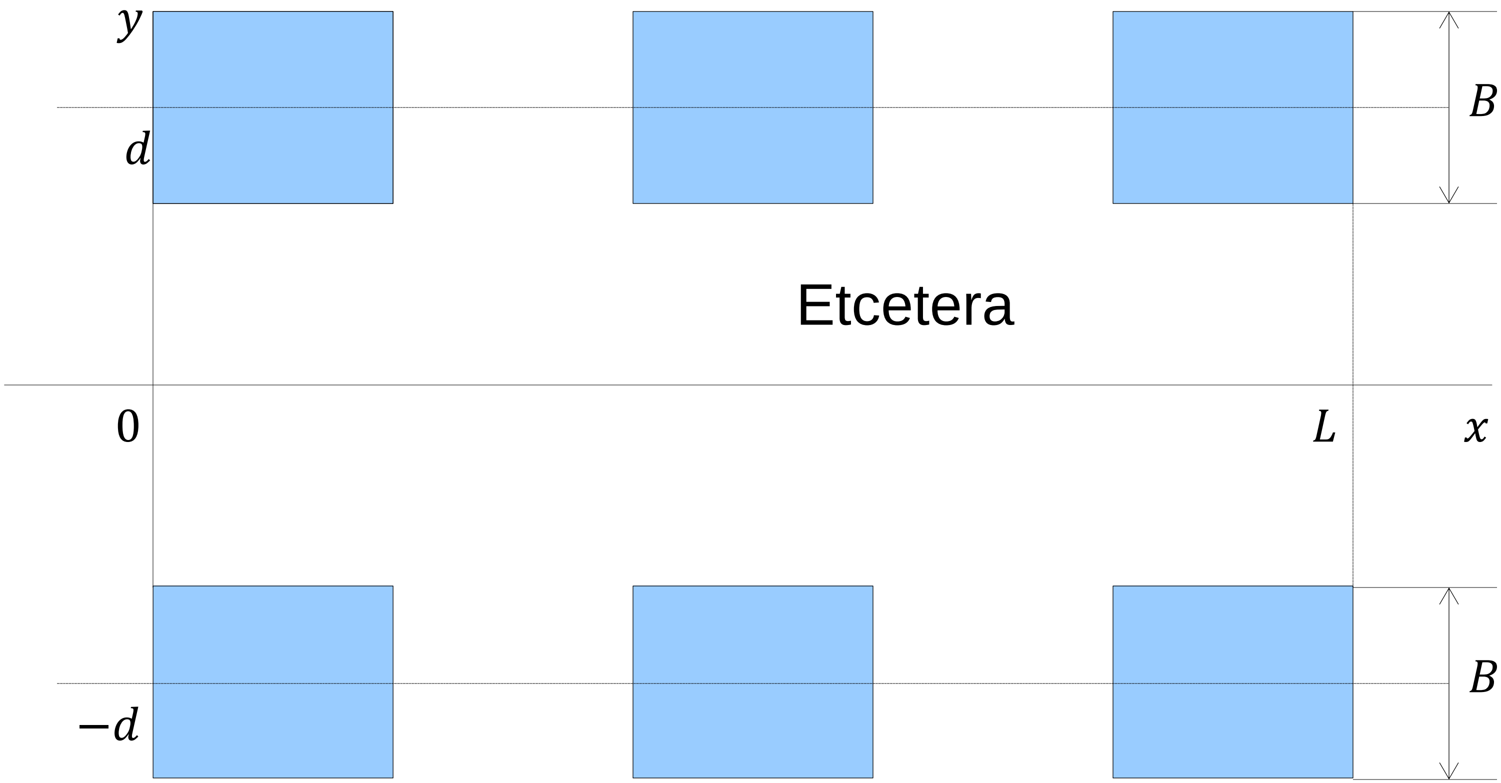


$$I_t = 2\frac{LB^3}{12} + 2LBd^2$$

Steiner's theorem!

Floating stability

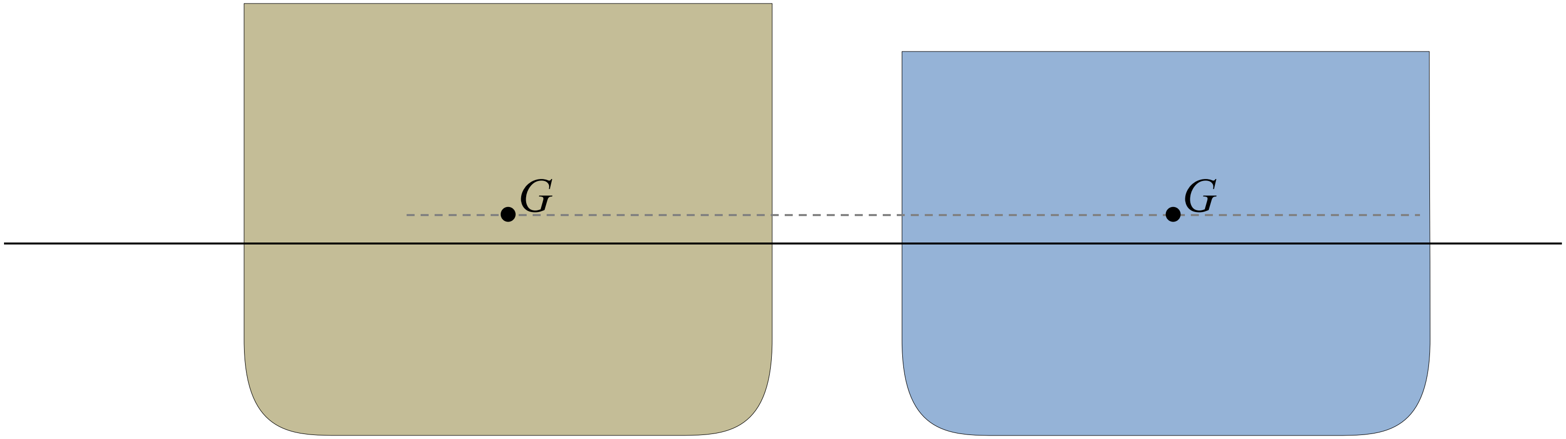
Moment of inertia of water plane area



Floating stability

GM

Equally safe?



Floating stability

Metacenter height

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$$GM = KB + BM - KG = KB + \frac{I_t}{\nabla} - KG$$

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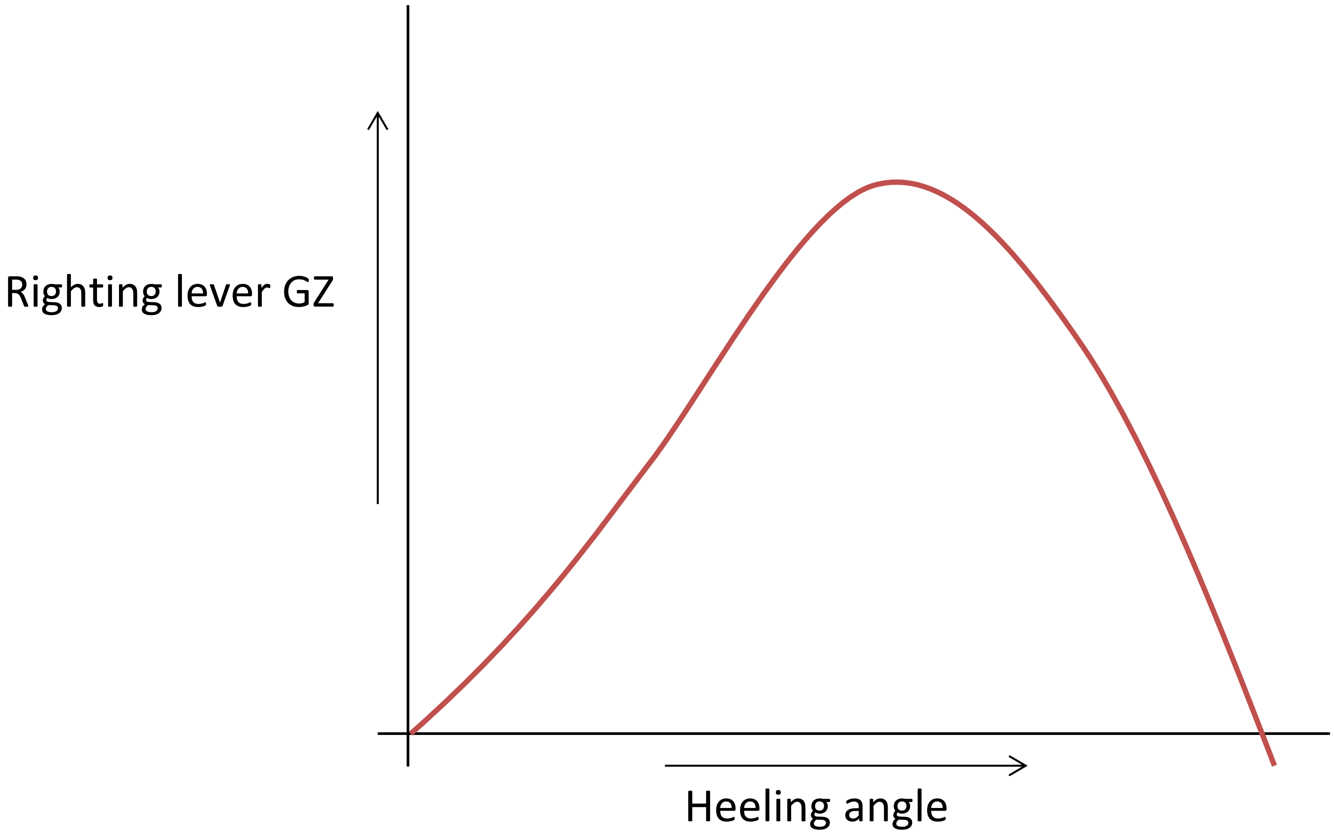
- For large heeling angles (> 10 to 15 degrees)

- Need of more accurate description: GZ curve

Floating stability

GZ-curve



$$M_s = GZ_{\varphi} \rho g \nabla$$

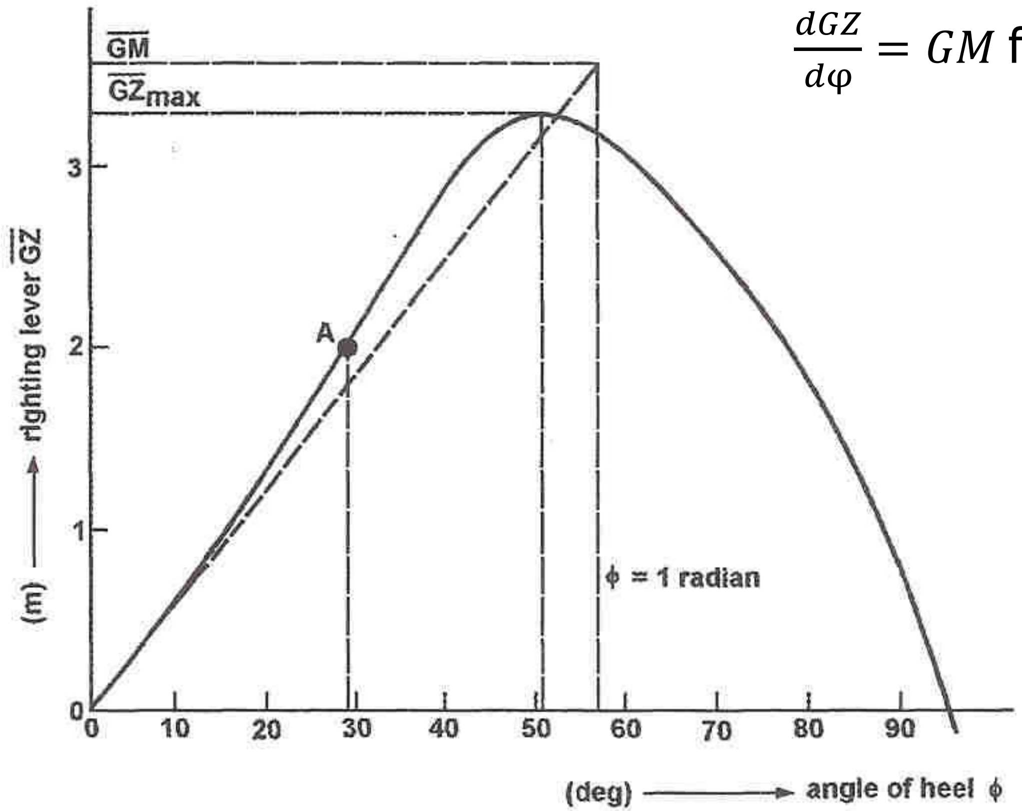
Floating stability

GZ-curve

$GZ = GM\sin\varphi$ for small φ [rad]

$GZ = GM\varphi$ for very small φ [rad]

$\frac{dGZ}{d\varphi} = GM$ for very small φ [rad]

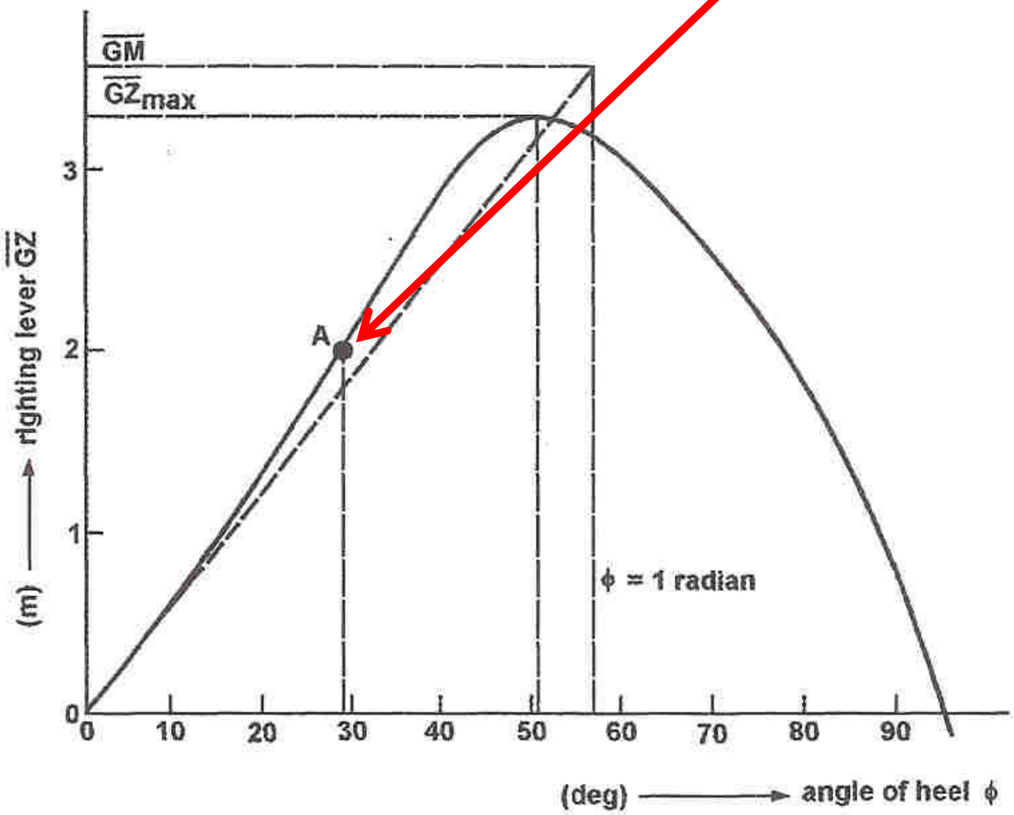


$M_s = GZ_\varphi \rho g \nabla$

Floating stability

GZ-curve

Deck immersed

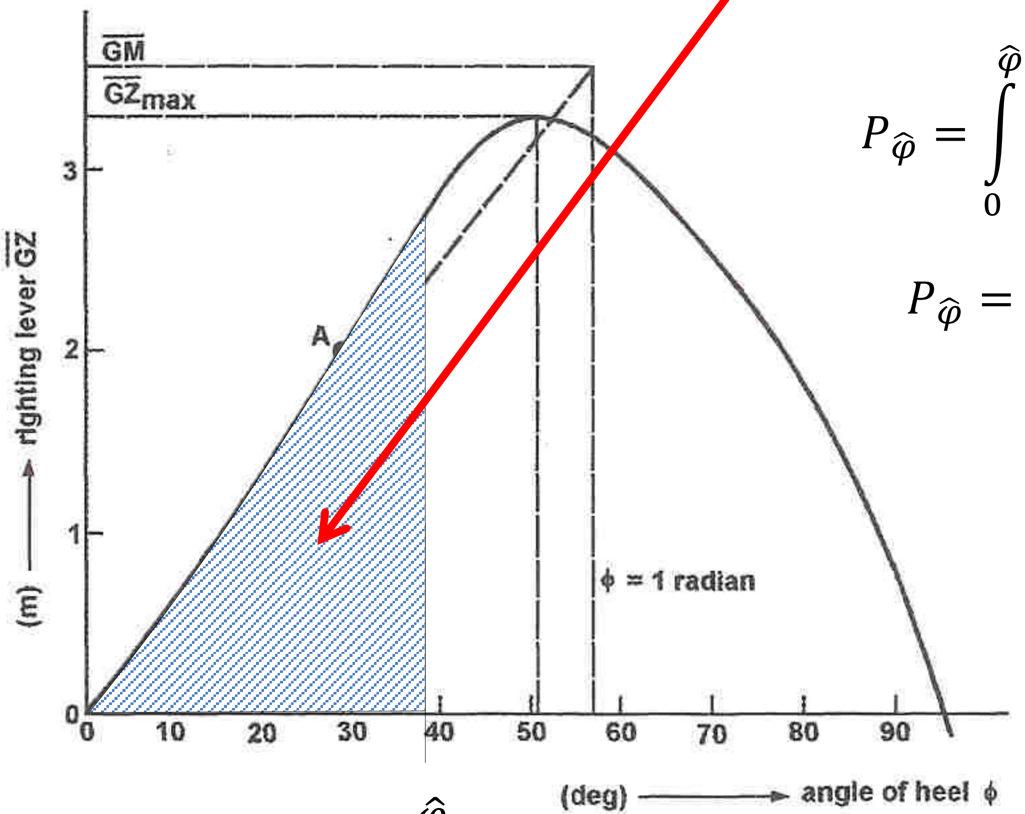


$$M_s = GZ_{\varphi}\rho g \nabla$$

Floating stability

GZ-curve

Area under curve: work done



$\hat{\varphi}$

$$P_{\hat{\varphi}} = \int_0^{\hat{\varphi}} M_{stab} \cdot d\varphi$$

$$P_{\hat{\varphi}} = \rho g \nabla \cdot \int_0^{\hat{\varphi}} GZ \cdot d\varphi$$

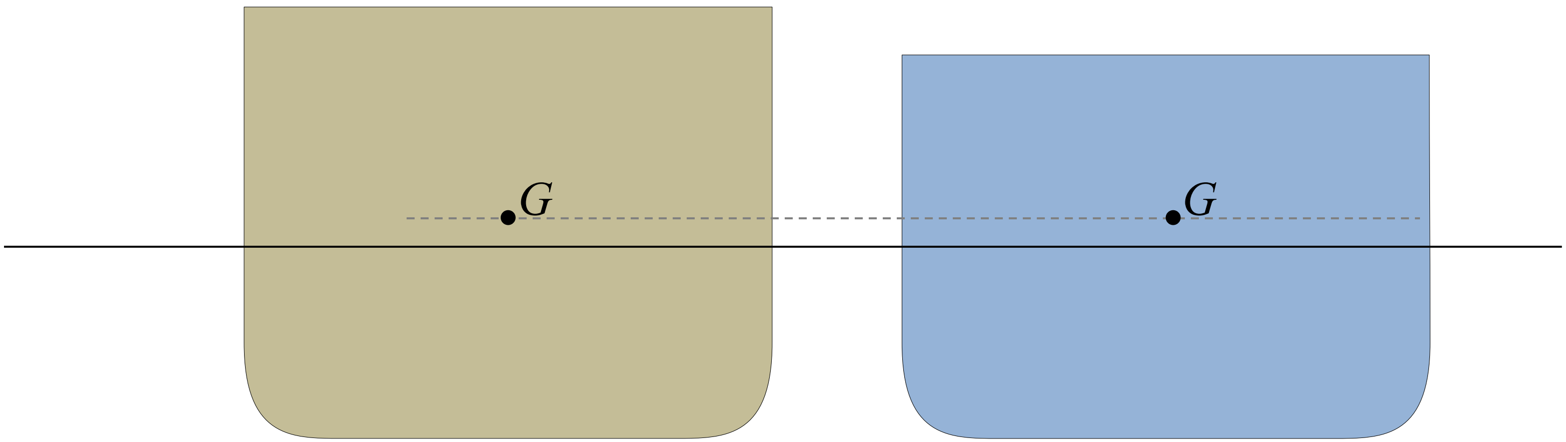
$$M_s = GZ_{\varphi} \rho g \nabla$$

TU Delft

Floating stability

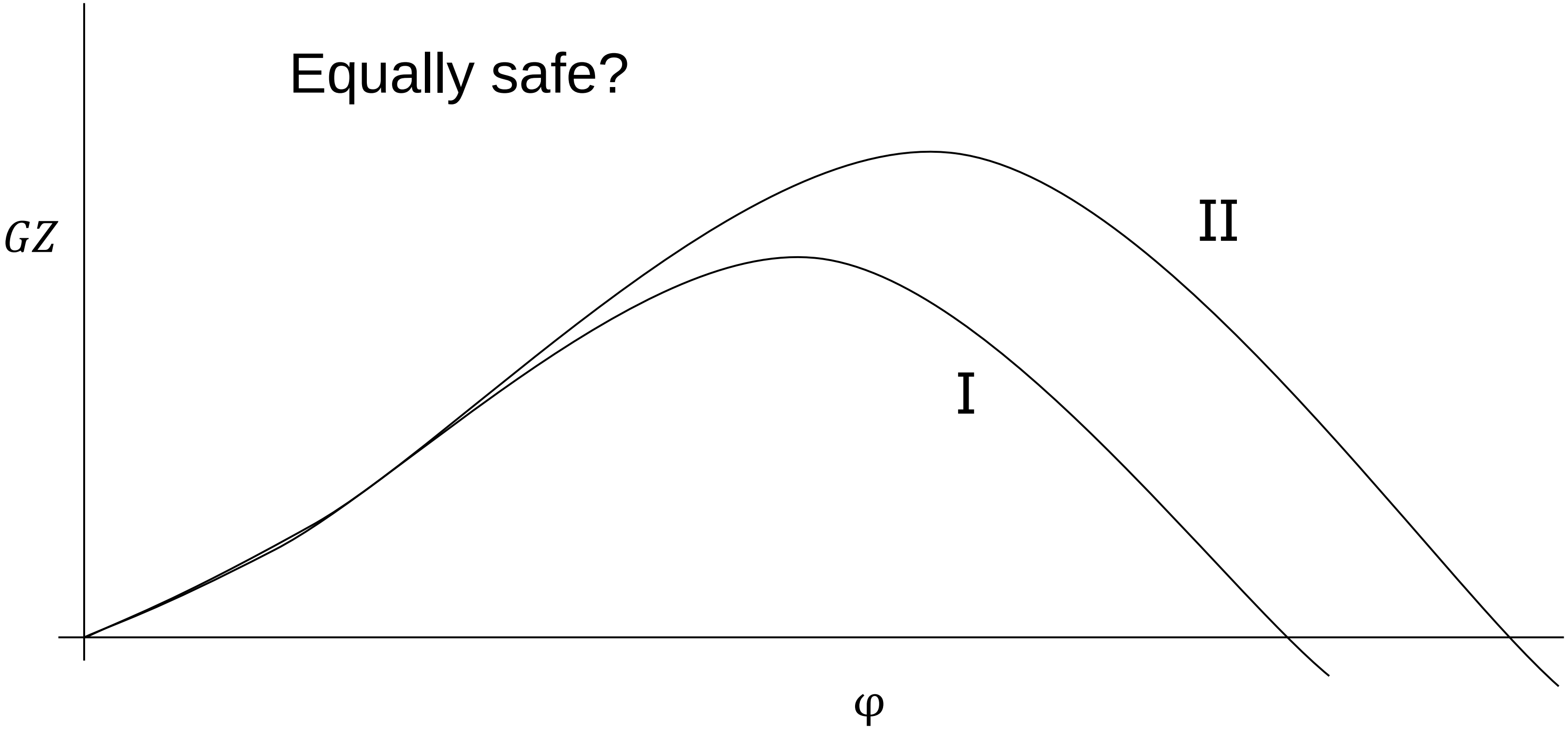
GZ-curve

Equally safe?



Floating stability

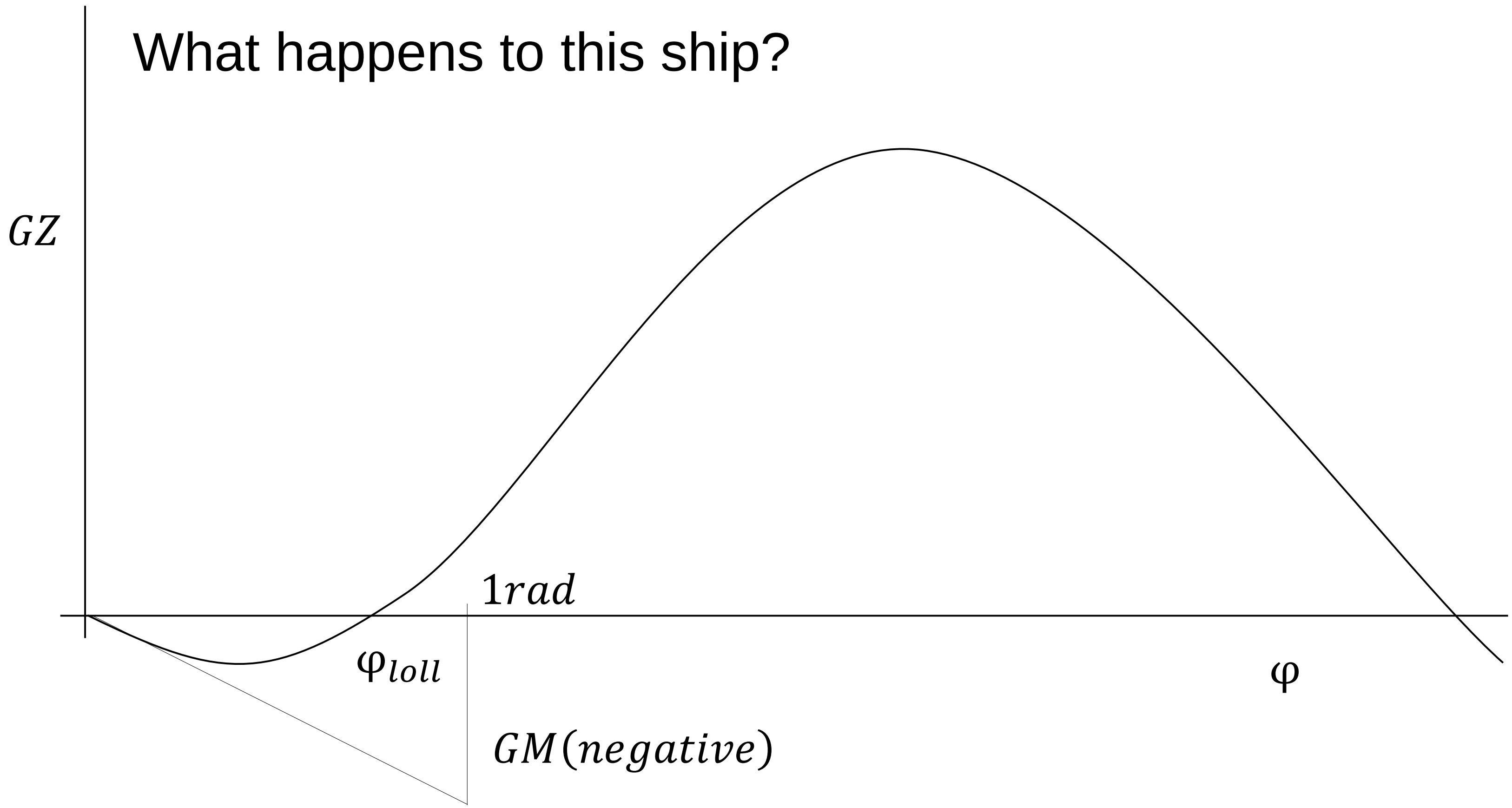
GZ-curve



Floating stability

GZ-curve

What happens to this ship?



Floating stability

Questions

- How do submerged bodies remain stable?
- How to increase stability?
- Why shape semi-submersibles?


[1]


[2]

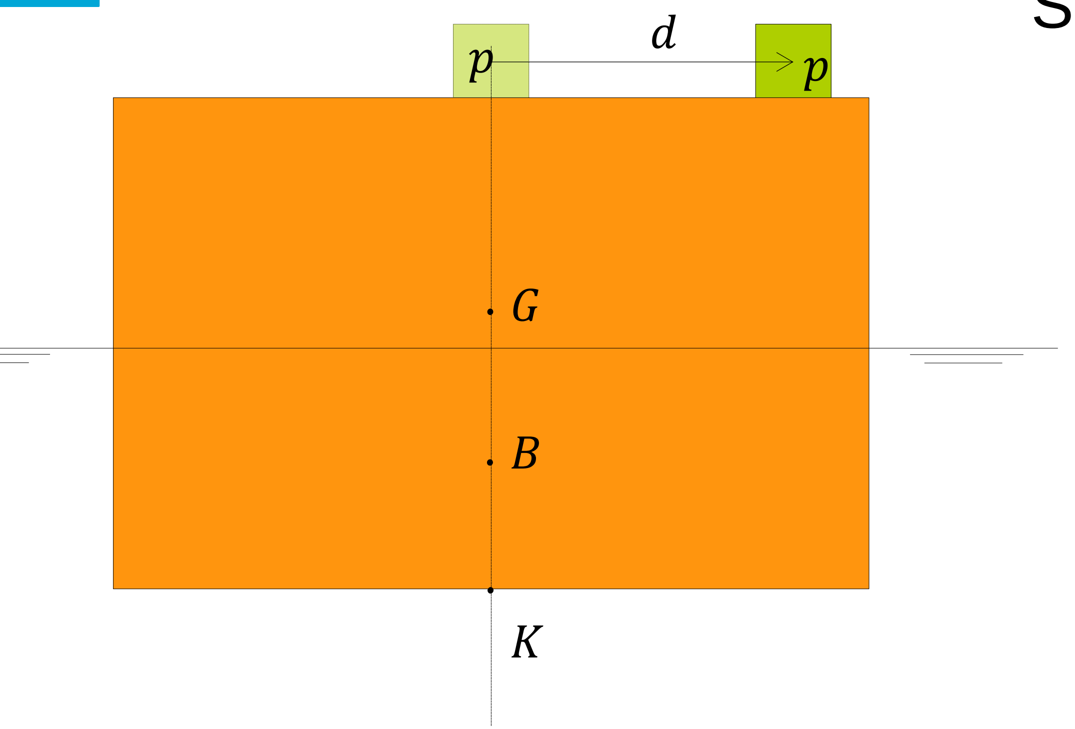
Floating stability

Applications

- Eccentric Loading
- Free surfaces in tanks
- Stability of submerged bodies

Floating stability

Case 1: shift mass on board



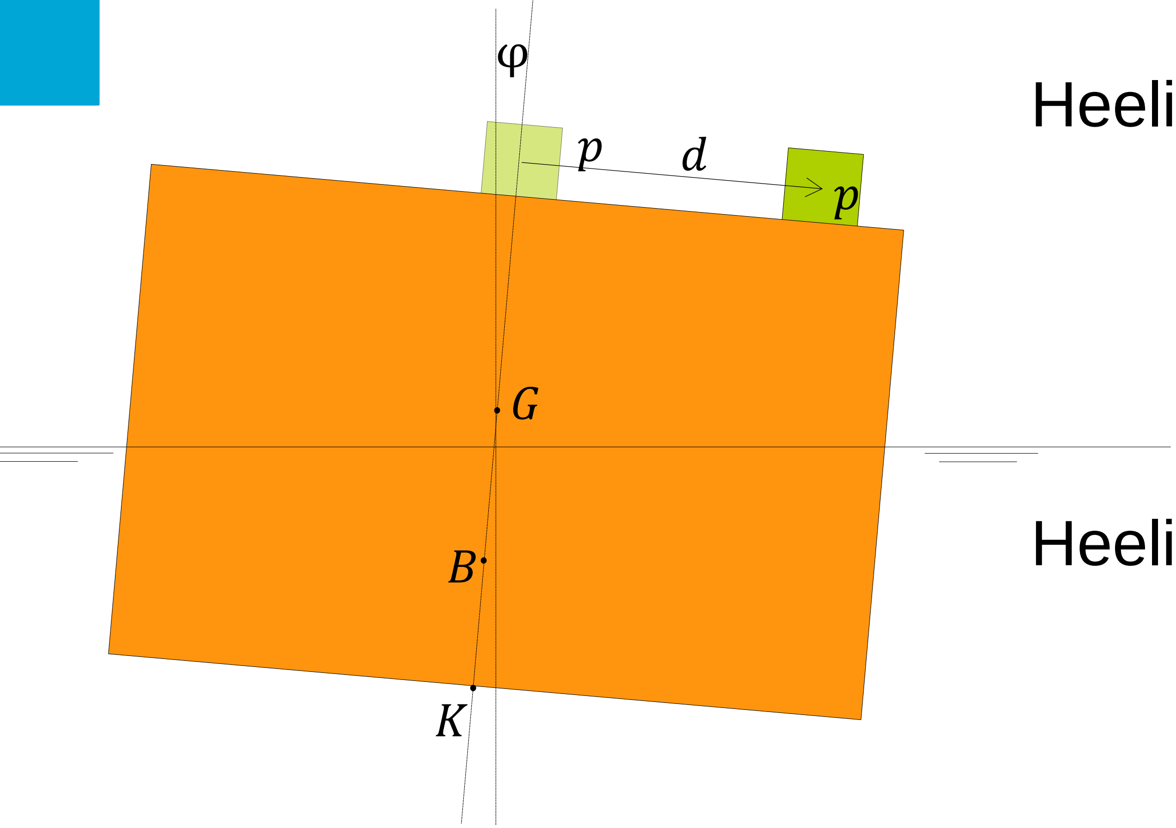
Stability Moment:

$$M_{stab} = \rho g \nabla GM \sin\varphi$$

$$GM = KB + BM - KG$$

Floating stability

Case 1: shift mass on board



Heeling Moment:

$$M_{heel} = pgd\cos\varphi$$

Heeling angle:

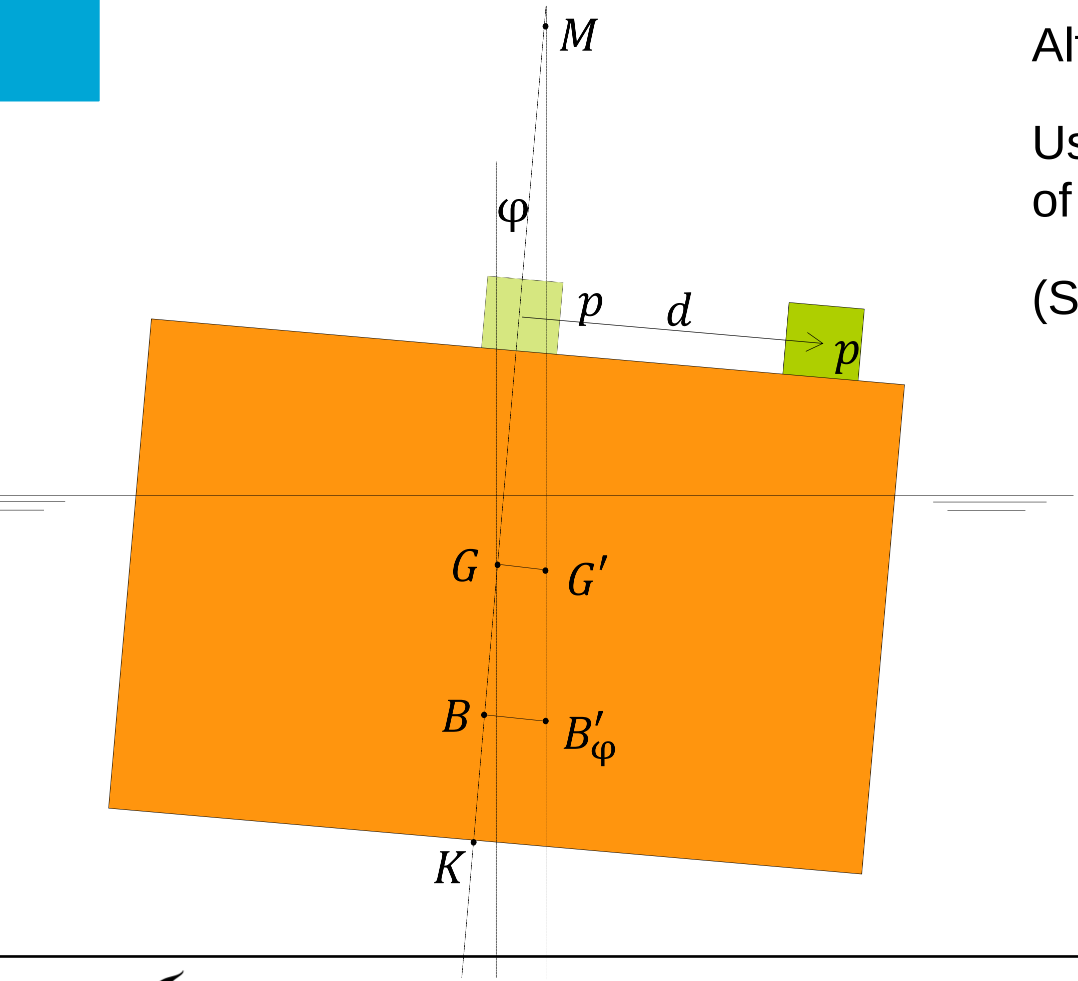
$$M_{stab} = M_{heel}$$

$$\rho g \nabla GM \sin\varphi = pgd\cos\varphi$$

$$\tan\varphi = \frac{pd}{\rho \nabla GM}$$

Floating stability

Case 1: shift mass on board



Alternative approach:

Use horizontal shift of G to G' instead of Mheel = Mstab

(Same result)

$$GG' = \frac{pd}{\rho \nabla}$$

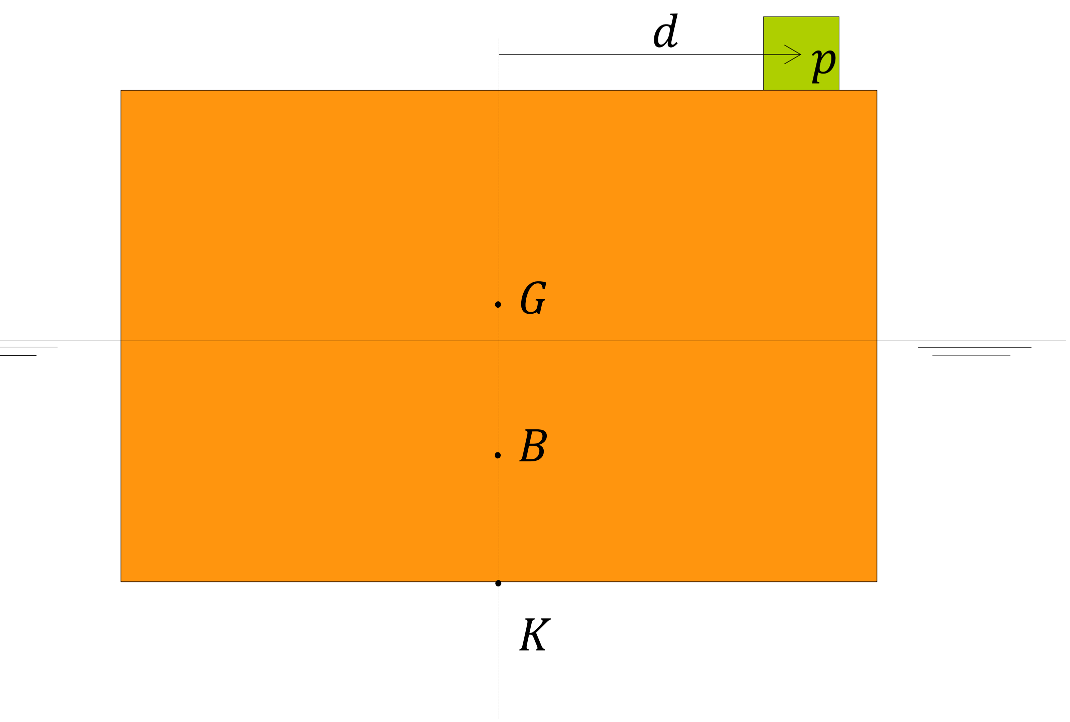
$$GM = \frac{GG'}{\tan\varphi}$$

$$GM = \frac{pd}{\rho \nabla \tan\varphi}$$

$$\tan\varphi = \frac{pd}{\rho \nabla GM}$$

Floating stability

Case 2: add eccentric mass on ship



Steps:

First assume no eccentricity:

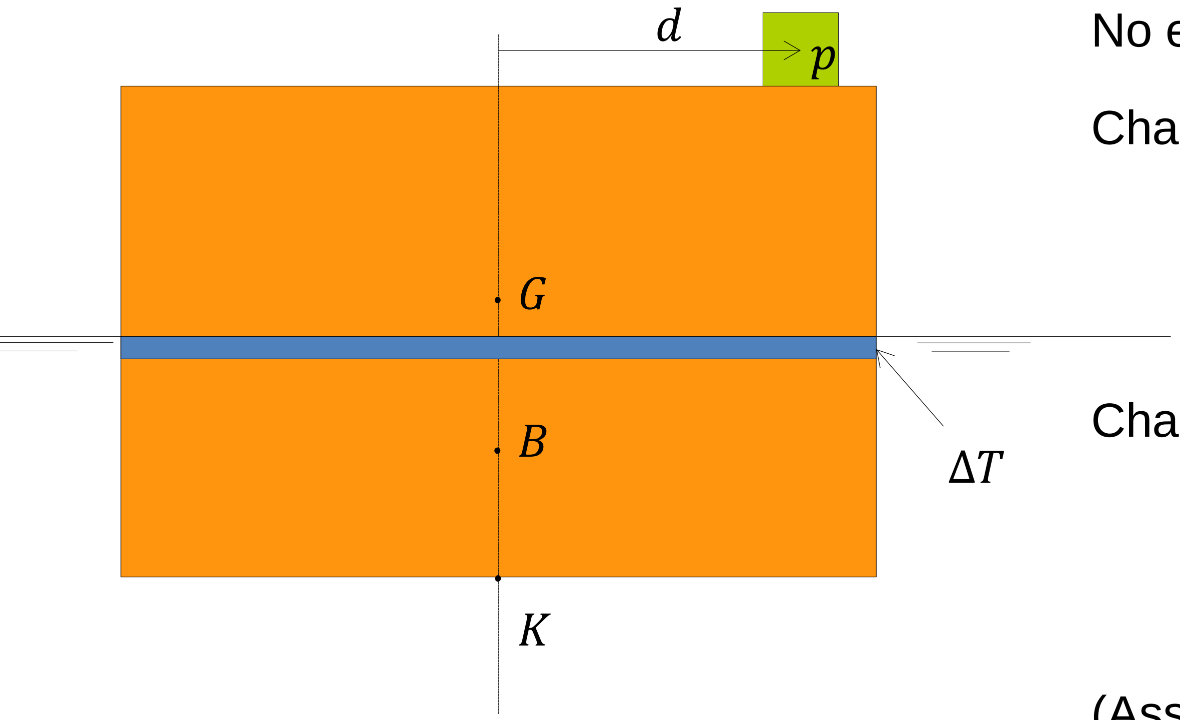
- Determine change in volume
- Determine change in KB
- Determine change in KG
- Determine change in It and BM

Second shift mass to right position:

- Determine heeling moment
- Determine stability moment

Floating stability

Case 2: add ecc. mass on ship



No eccentricity:

Change in volume:

$$\nabla_{new} = \nabla_{old} + \Delta\nabla$$

$$pg = \rho g \Delta\nabla$$

Change in draft:

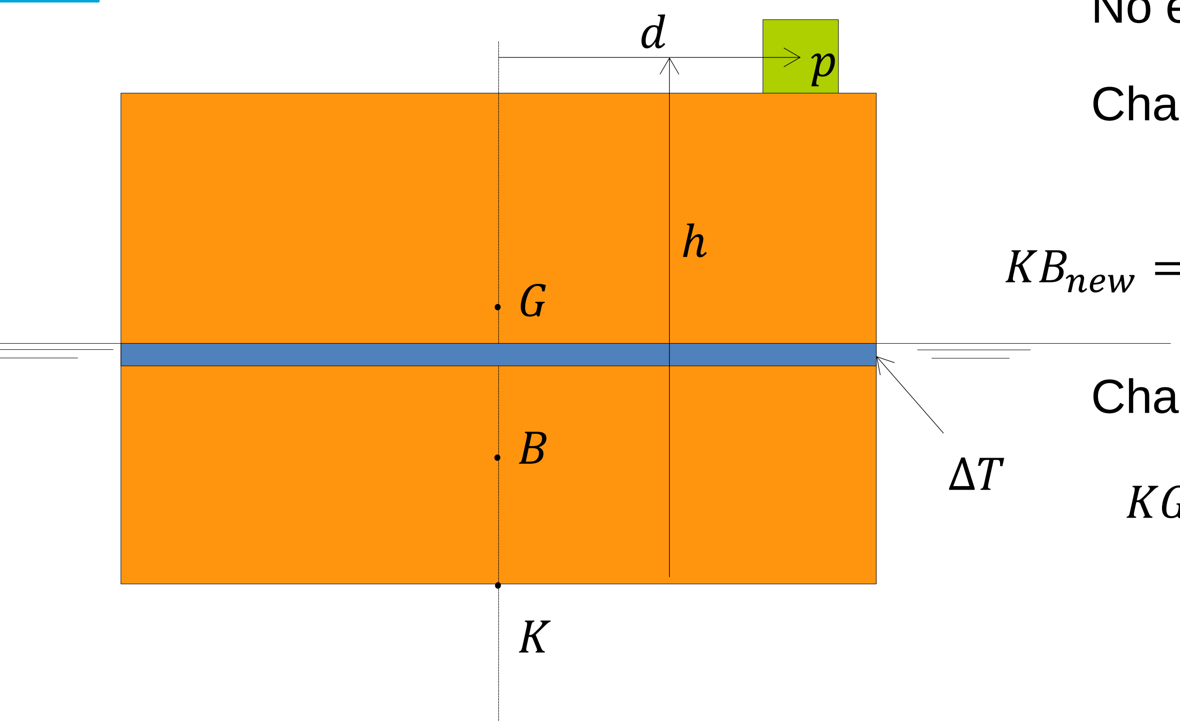
$$\Delta T = \Delta\nabla / A_{wl}$$

$$T_{new} = T_{old} + \Delta T$$

(Assuming water plane area constant)

Floating stability

Case 2: add ecc. mass on ship



No eccentricity:

Change in KB:

$$KB_{new} = \frac{KB_{old}\nabla_{old} + (T_{old} + \Delta T/2)\Delta T A_{wl}}{\nabla_{new}}$$

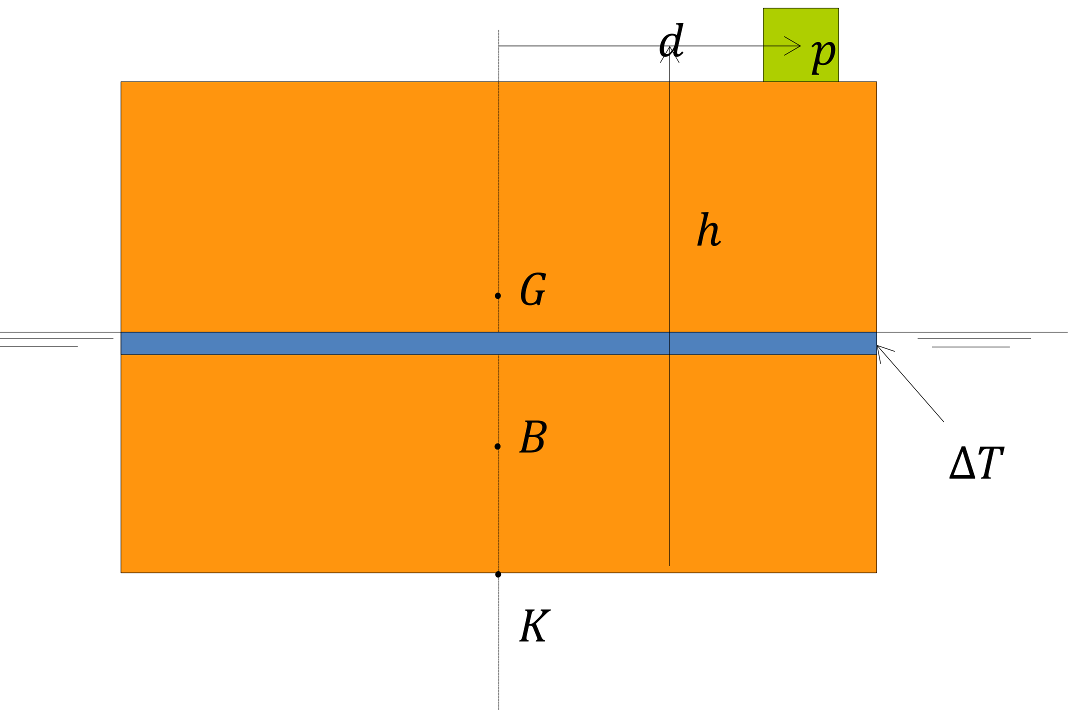
Change in KG:

$$KG_{new}(m + p) = KG_{old}m + ph$$

$$KG_{new} = \frac{KG_{old}m + ph}{m + p}$$

Floating stability

Case 2: add ecc. mass on ship



No eccentricity:

Change in It:

- Depends on change in water plane area

Can be neglected if:

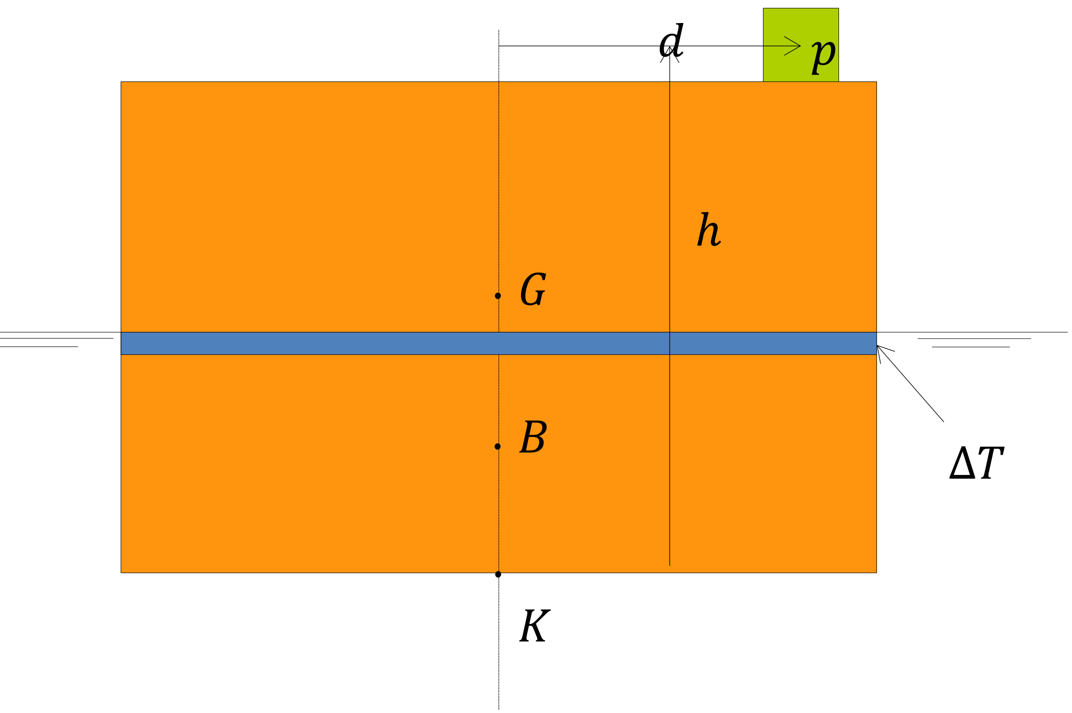
- p small wrt mass ship
- Wall sided ship

Change in BM:

$$BM_{new} = \frac{It}{\nabla_{new}}$$

Floating stability

Case 2: add ecc. mass on ship



Now GM is know for the new situation:

$$GM_{new} = KB_{new} + BM_{new} - KG_{new}$$

Second step:

Shift mass to its right position

Calculate heeling moment and resulting heeling angle

$$M_{stab} = M_{heel}$$

$$\rho g \nabla_{new} GM_{new} \sin\varphi = pgd\cos\varphi$$

Floating stability

Inclining Experiment

- KB and BM can be reliably obtained with calculations
- KG however not
- To determine KG, GM for an existing ship:
  - Shift a known weight over a known transverse distance
  - Measure the heeling angle
- Now it is possible to reverse procedure to obtain GM and so KG

$$M_{stab} = M_{heel}$$

$$\rho g \nabla GM \sin\varphi = pgd\cos\varphi$$

$$GM = \frac{p \cdot d}{\rho \nabla \tan\varphi}$$

$$KG = KB + BM - GM$$

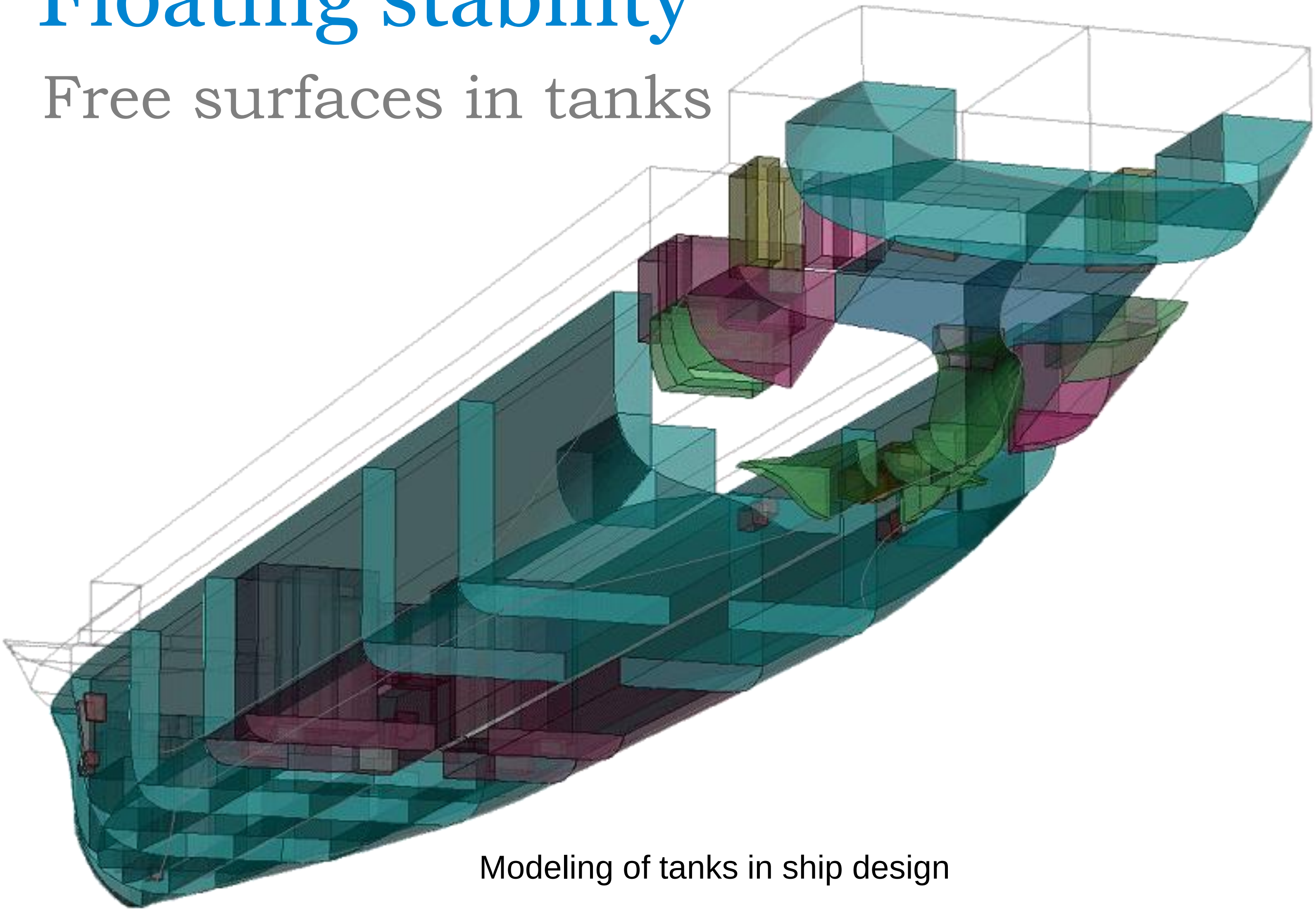
Floating stability

Inclining Experiment

- However:
    - Often weight is **added** to ship
    - This changes the volume, KB and BM as well
    - So you need to correct for this
    - Not difficult, but quite some work

Floating stability

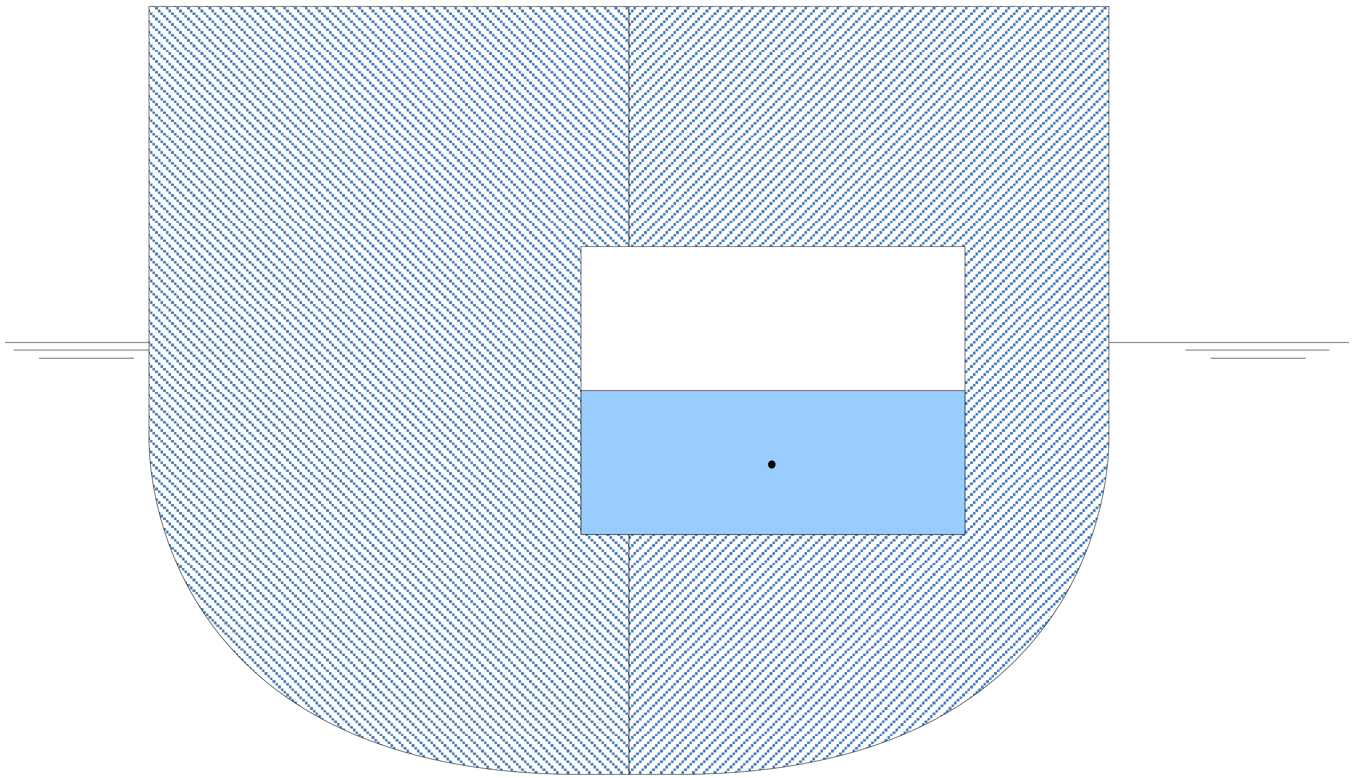
Free surfaces in tanks



Modeling of tanks in ship design

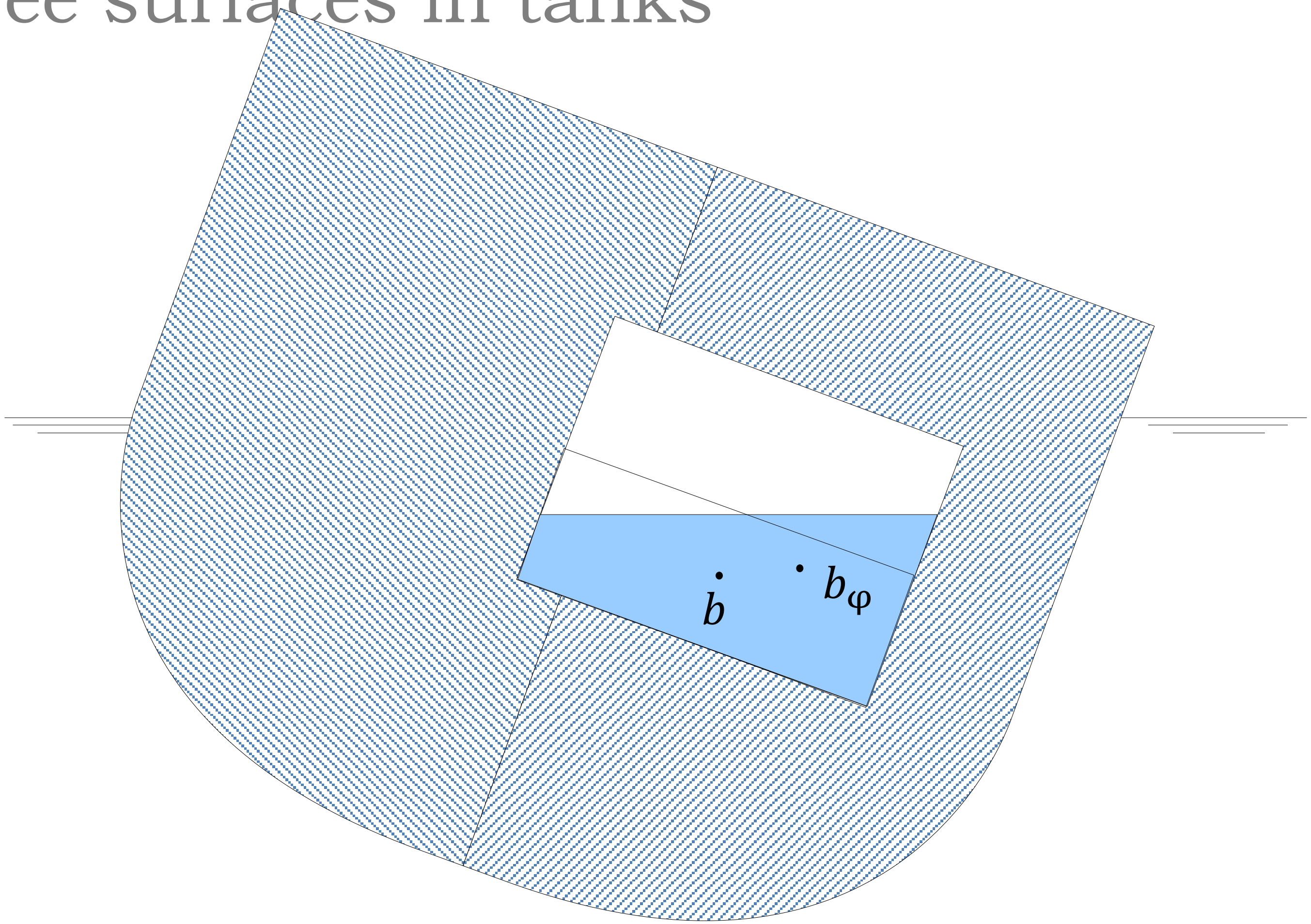
Floating stability

Free surfaces in tanks



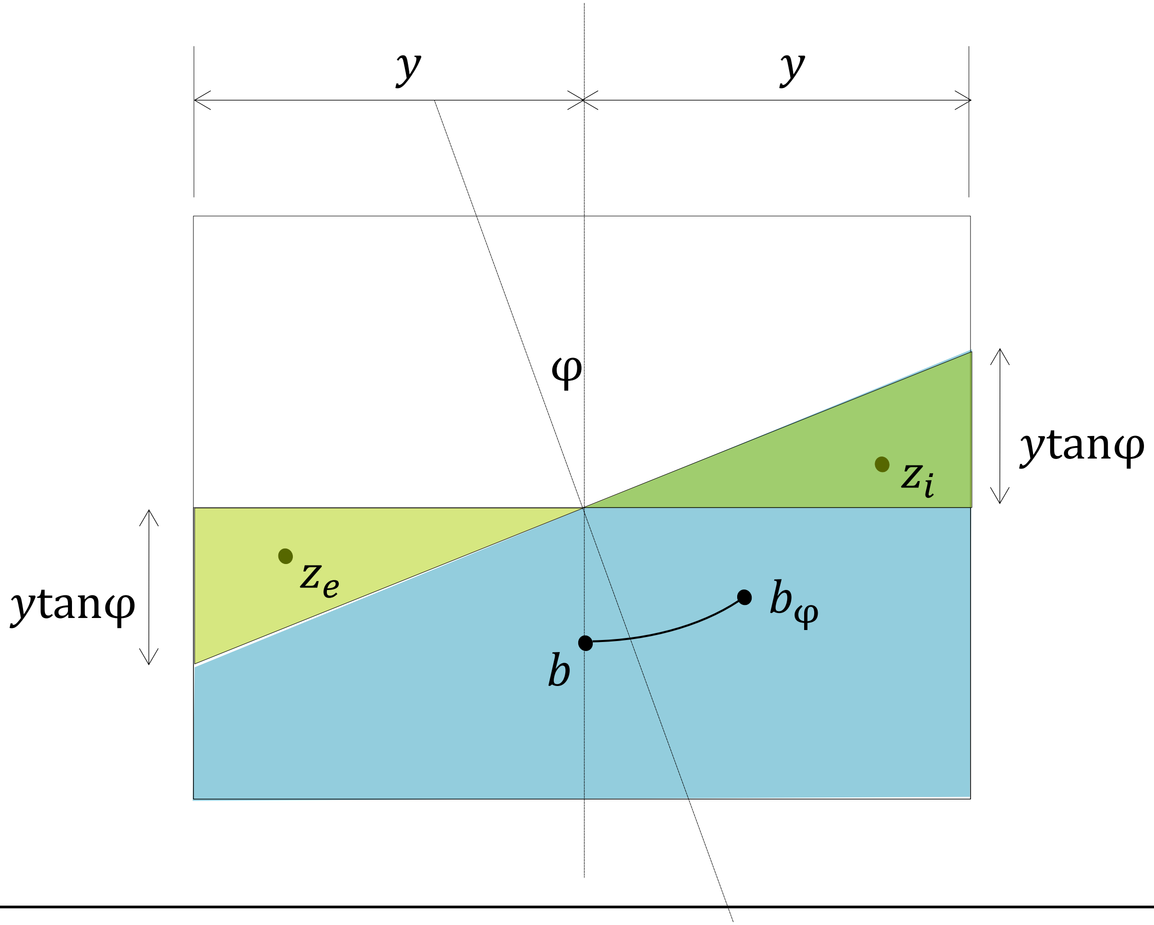
Floating stability

Free surfaces in tanks



Floating stability

Free surfaces in tanks

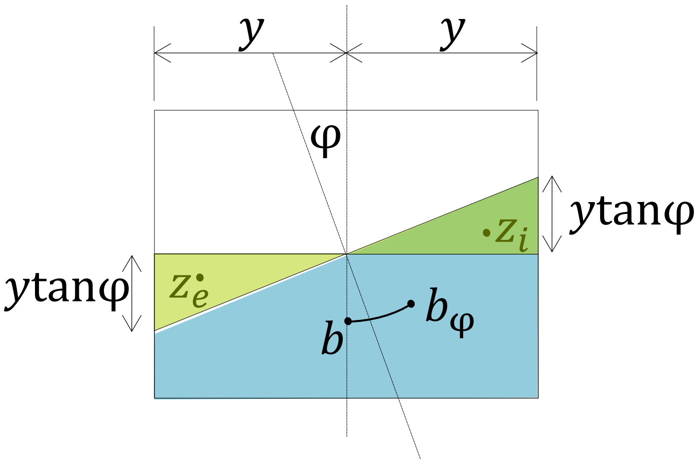


Floating stability

Free surfaces in tanks

Shift of center of gravity of tank

$$bb_{\varphi horizontal} = \frac{\int_0^{L_{tank}} \frac{1}{2} \cdot y \cdot y\tan\varphi \cdot \frac{4}{3} y dx}{v} = \frac{i}{v}\tan\varphi$$



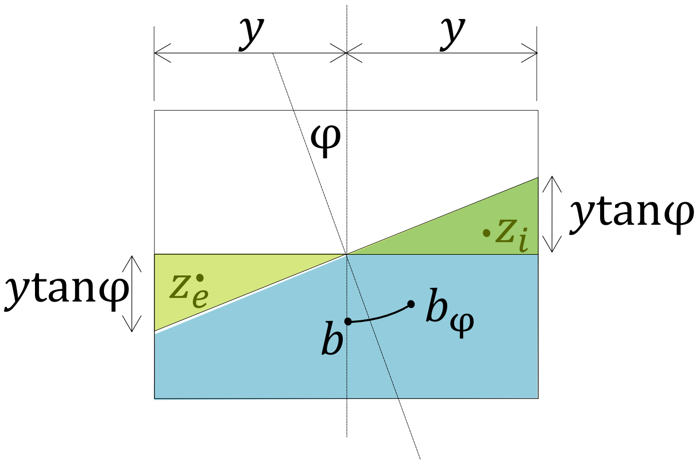
Floating stability

Free surfaces in tanks

Shift of center of gravity of tank

$$bb_{\varphi horizontal} = \frac{\int_0^{L_{tank}} \frac{1}{2} \cdot y \cdot y\tan\varphi \cdot \frac{4}{3} y dx}{v} = \frac{i}{v}\tan\varphi$$

$$bb_{\varphi vertical} = \frac{\int_0^{L_{tank}} \frac{1}{2} \cdot y \cdot y\tan\varphi \cdot \frac{2}{3} y\tan\varphi dx}{v} = \frac{i}{v}\frac{1}{2}\tan^2\varphi$$



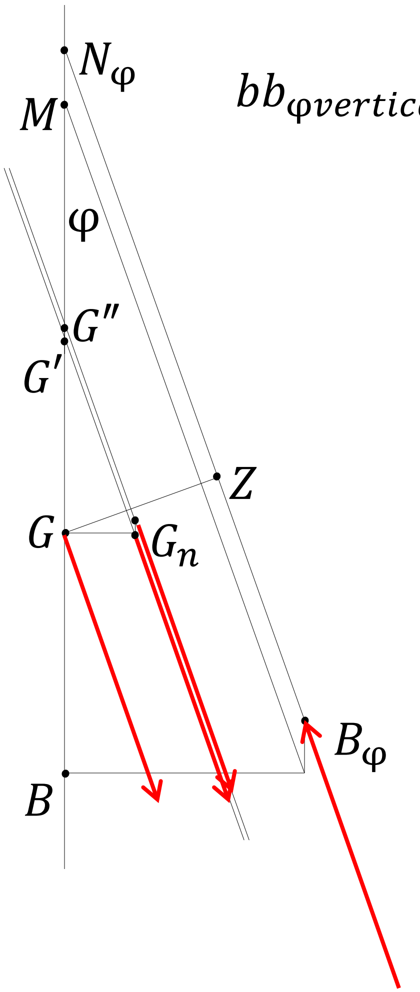
Floating stability

Free surfaces in tanks

$$bb_{\varphi horizontal} = \frac{i}{v} \tan\varphi$$

$$bb_{\varphi vertical} = \frac{i}{v}\frac{1}{2} \tan^2\varphi$$

Shift of center of gravity due to liquid in tank:



1. Sideways
2. And up

Floating stability

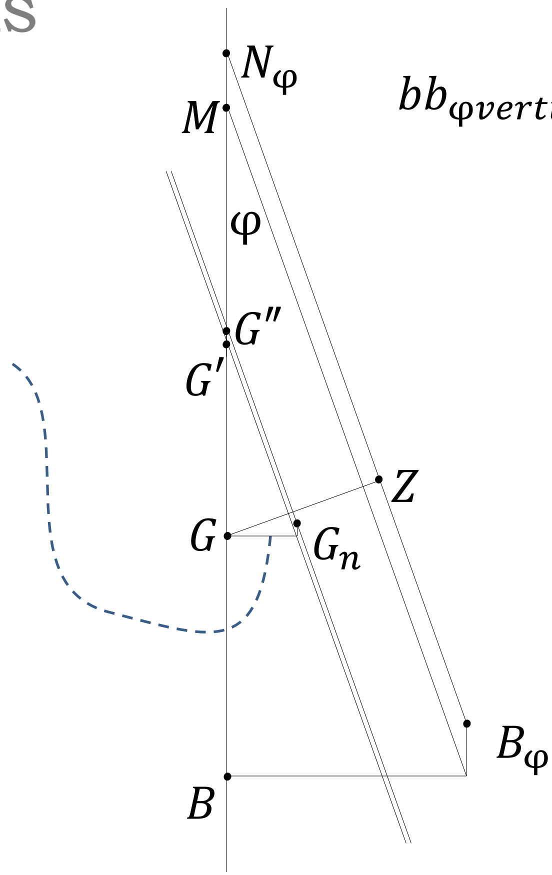
Free surfaces in tanks

$$bb_{\varphi horizontal} = \frac{i}{v}\tan\varphi$$

$$bb_{\varphi vertical} = \frac{i}{v}\frac{1}{2}\tan^2\varphi$$

Shift of center of gravity

$$G'G\tan\varphi = \frac{bb_{\varphi horizontal} \cdot v\rho'}{\nabla\rho} = \frac{\rho'}{\rho}\frac{i}{\nabla}\tan\varphi$$



Floating stability

Free surfaces in tanks

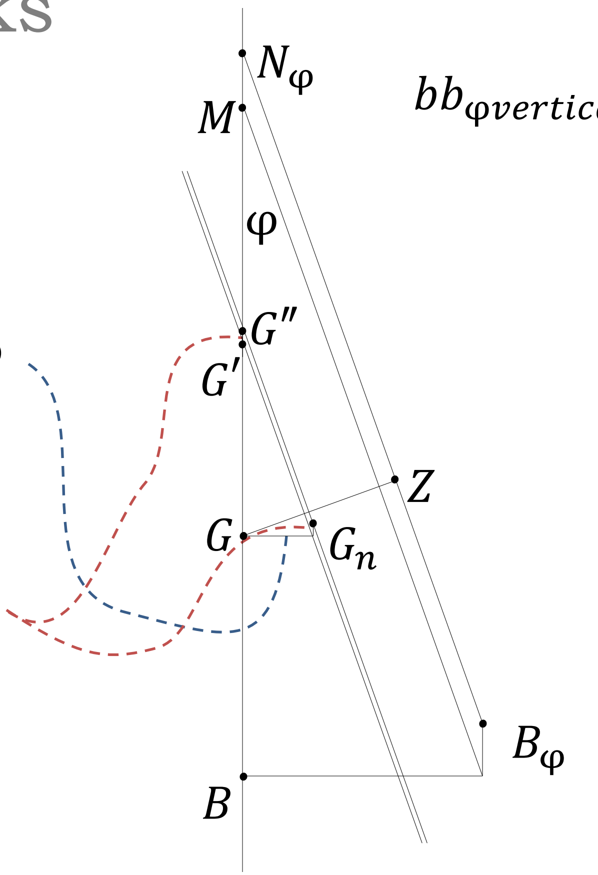
$$bb_{\varphi horizontal} = \frac{i}{v}\tan\varphi$$

$$bb_{\varphi vertical} = \frac{i}{v}\frac{1}{2}\tan^2\varphi$$

Shift of center of gravity

$$G'G\tan\varphi = \frac{bb_{\varphi horizontal} \cdot v\rho'}{\nabla\rho} = \frac{\rho'}{\rho}\frac{i}{\nabla}\tan\varphi$$

$$G'G'' = \frac{bb_{\varphi vertical} \cdot v\rho'}{\nabla\rho} = \frac{\rho'}{\rho}\frac{i}{\nabla}\frac{1}{2}\tan^2\varphi$$



Floating stability

Free surfaces in tanks

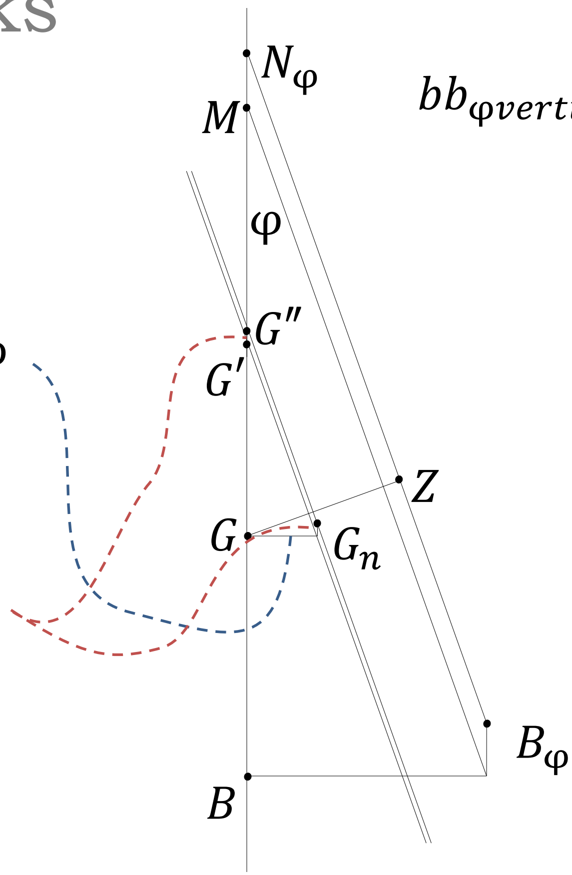
$$bb_{\varphi horizontal} = \frac{i}{v}\tan\varphi$$

$$bb_{\varphi vertical} = \frac{i}{v}\frac{1}{2}\tan^2\varphi$$

Shift of center of gravity

$$G'G\tan\varphi = \frac{bb_{\varphi horizontal} \cdot v\rho'}{\nabla\rho} = \frac{\rho'}{\rho}\frac{i}{\nabla}\tan\varphi$$

$$G'G'' = \frac{bb_{\varphi vertical} \cdot v\rho'}{\nabla\rho} = \frac{\rho'}{\rho}\frac{i}{\nabla}\frac{1}{2}\tan^2\varphi$$



Apparent reduction of GM:

$$GG'' = \frac{\rho'}{\rho}\frac{i}{\nabla}\left(1 + \frac{1}{2}\tan^2\varphi\right)$$

Floating stability

Free surfaces in tanks

Apparent reduction of GM due to 1 tank:

$$GG'' = \frac{\rho'}{\rho}\frac{i}{\nabla}\left(1 + \frac{1}{2}\tan^2\varphi\right)$$

Apparent reduction of GM for all tanks:

$$GG'' = \frac{\sum(\rho' i)}{\rho\nabla}\left(1 + \frac{1}{2}\tan^2\varphi\right)$$

Small heeling angles:

$$GG'' = \frac{\sum(\rho' i)}{\rho\nabla}$$

$\frac{\rho'}{\rho}$ influence density of fluid in the tank

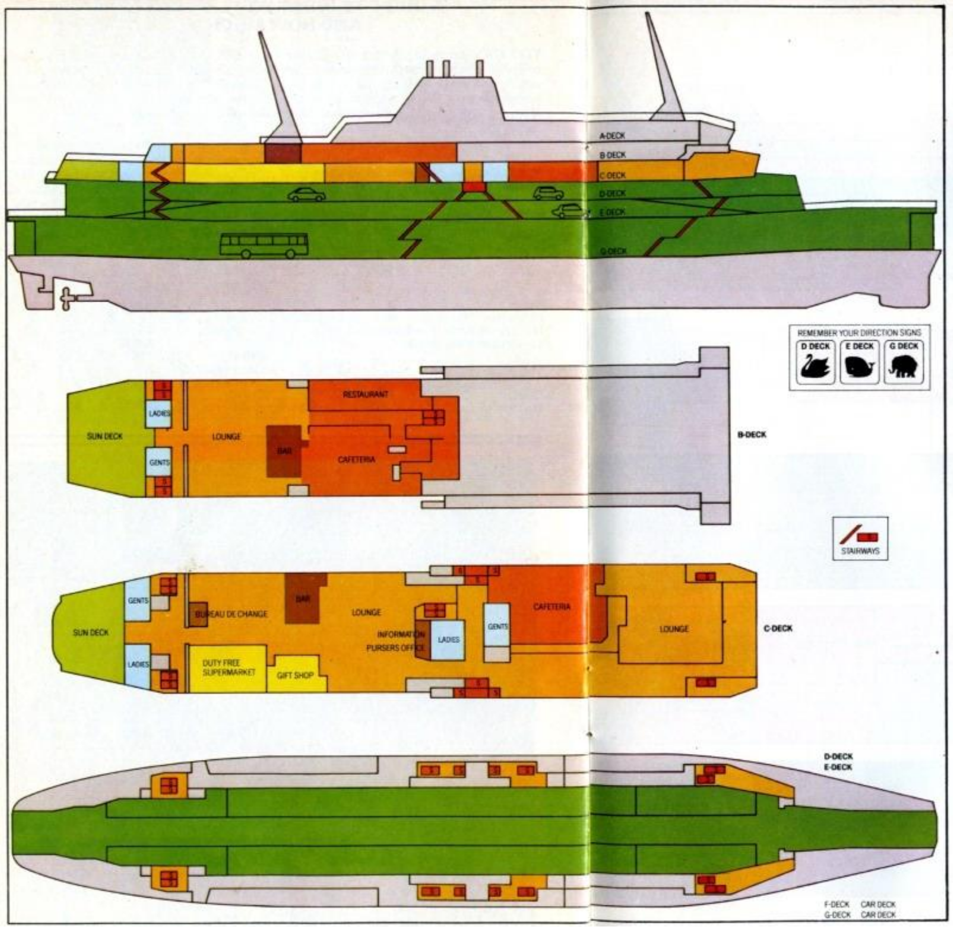
Floating stability

Free surfaces in ships


[3]

Floating stability

Free surfaces in ships



BLUE RIBAND CLASS

THERE are three ships in Townsend Thoresen's Blue Riband class operating the 75-minute crossing from Dover to Calais.

Spirit, Herald and Pride of Free Enterprise were purpose built for the route and have revolutionised cross-Channel travel with their two complete drive-through car decks.

Passenger services include a waiter-service restaurant, two cafeterias, duty-free supermarket and gift shop, bureau de change, automated "Fun Fayre", comfortable lounges with bars, and a conveniently situated information office.

Each ship can carry 1300 passengers and 350 cars.

The purser is the ship's hotel services manager. If in difficulty please ask for him so he can help immediately.

[4]

Sources images

[1] Pacific Ocean, (Jun 4, 1998) The attack submarine USS Columbus (SSN 762) home ported at Naval Station Pearl Harbor, Hawaii, conducts an emergency surface training exercise, 35 miles off the coast of Oahu, HI., source: U.S. Navy photo by Photographer's Mate 2nd Class David C. Duncan/Commons Wikimedia
[2] Source: A.B.S. Model (S) Pte Ltd
[3] Bikes as far as the eye could see along the Car Deck, source: http://www.gl1800.org.uk/touring/mosel-tour-2009-tour-report-part-1-the-outbound-journey/
[4] Herald of Free Enterprise from Townsend-Thoresen in better times, source: unknown