# Offshore Hydromechanics Module 1

Dr. ir. Pepijn de Jong

## 1. Intro, Hydrostatics and Stability

# Introduction

## OE4630d1 Offshore Hydromechanics Module 1

- dr.ir. Pepijn de Jong
  Assistant Prof. at Ship Hydromechanics & Structures, 3mE

- Book: Offshore Hydromechanics by Journée and Massie
  - At Marysa Dunant (secretary), or download at www.shipmotions.nl

# Introduction

## OE4630d1 Offshore Hydromechanics Module 1

- Communication via Blackboard

- Exam (date&place may be subject of change!)
  - Formula sheet comes with exam, however...
  - Closed book
  - Don't forget to subscribe!

# 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

## Assignments

- Online on Blackboard
  - Automatic
  - Feedback included

- 4 series with deadlines:
  - Hydrostatics & Stability
  - Potential Flow
  - Real Flows
  - Waves

- First series and details follow later this week

- Regular exercises and old exams on Blackboard

# 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 |

# Contents

## Lecture 1

| | |
|---|---|
| • Introduction Module 1 | done |
| • Problems of interest (Chapter 1) | next up |
| • Hydrostatics (Chapter 2) | |
| • Floating stability (Chapter 2) | |

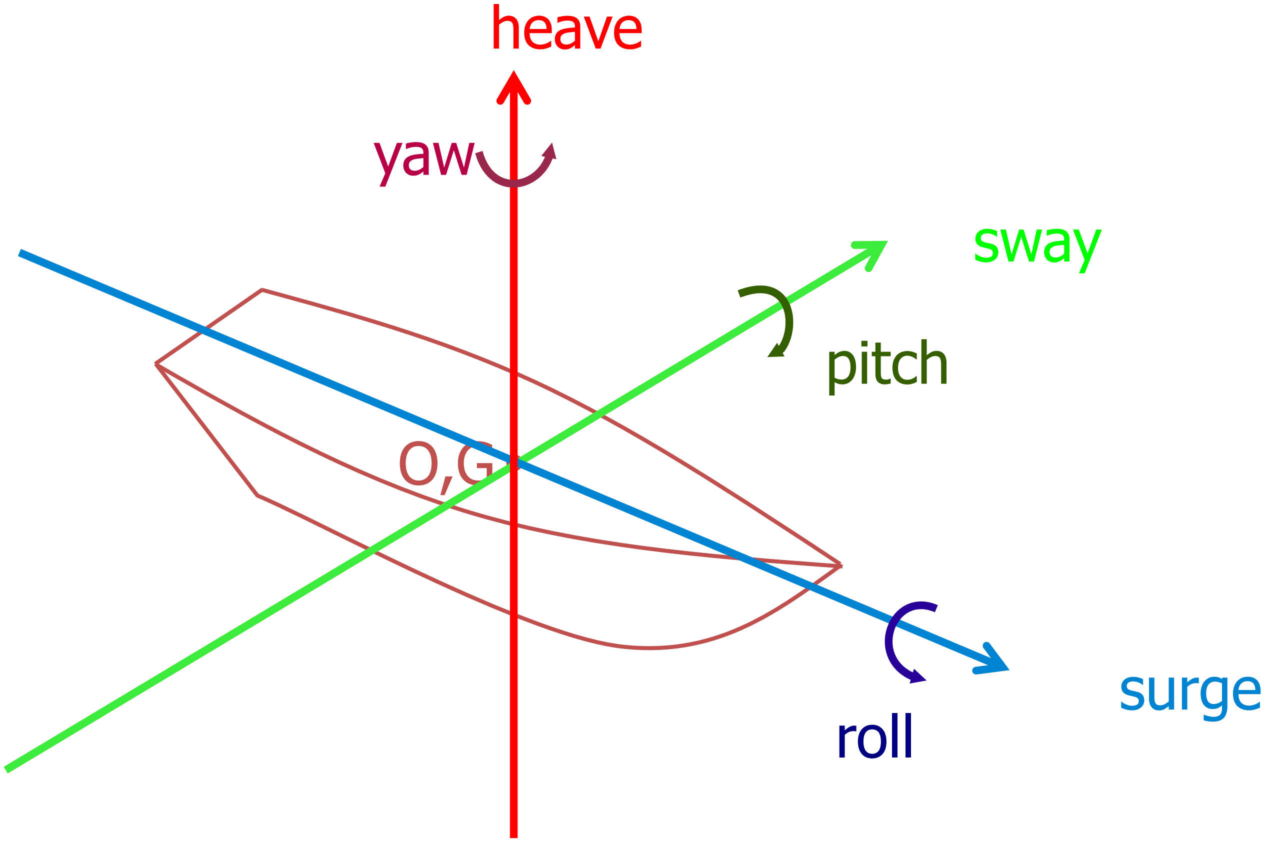
# Learning Objectives

## Chapter 1

- Describe the field of application for hydromechanics in the offshore industry
- Know the definition of ship motions

# Chapter 1

## Coordinate system and ship motions



# Contents

## Lecture 1

| | |
|---|---|
| • Introduction Module 1 | done |
| • Problems of interest (Chapter 1) | done |
| • Hydrostatics (Chapter 2) | next up |
| • Floating stability (Chapter 2) | |

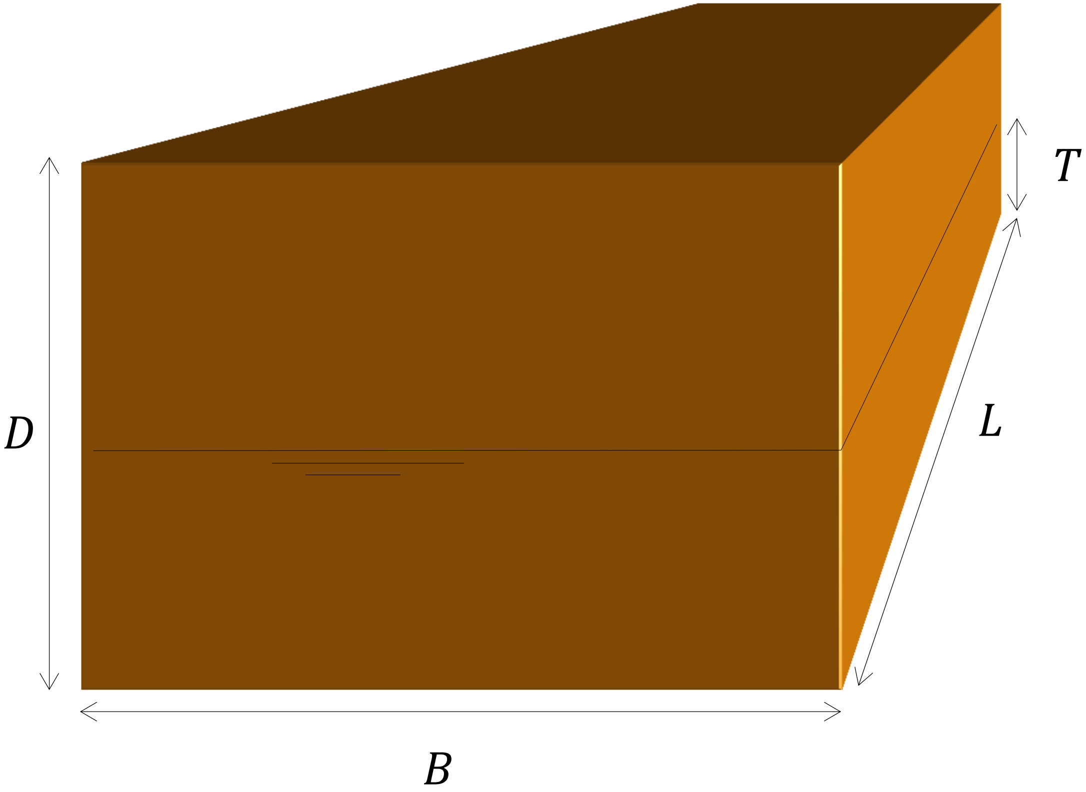
# Learning Objectives

## 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

# Hydrostatics

## Naming Conventions Ship Dimensions



L Length

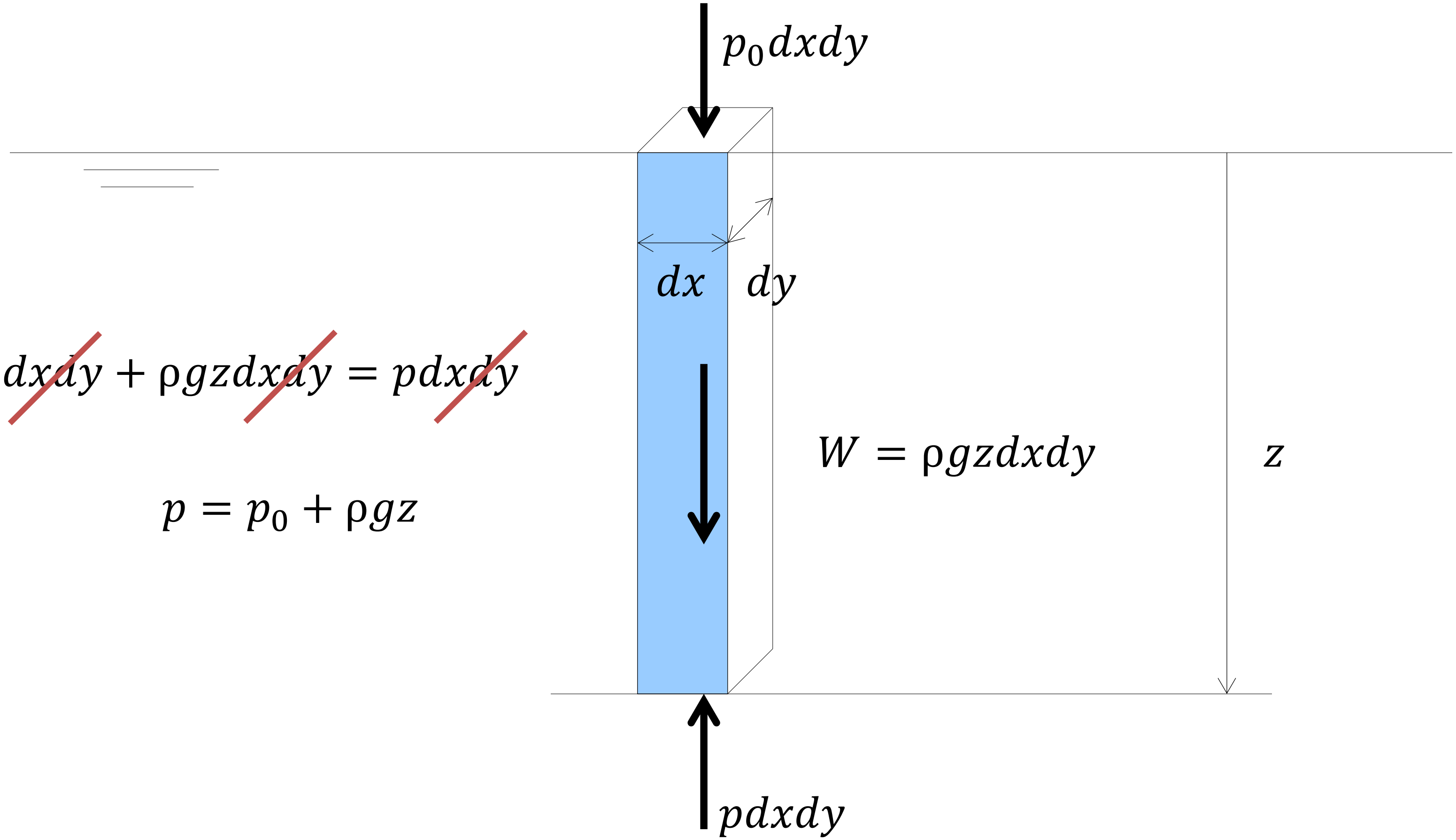
B Beam/width

D Depth

T Draft

# Hydrostatics

## Hydrostatic pressure

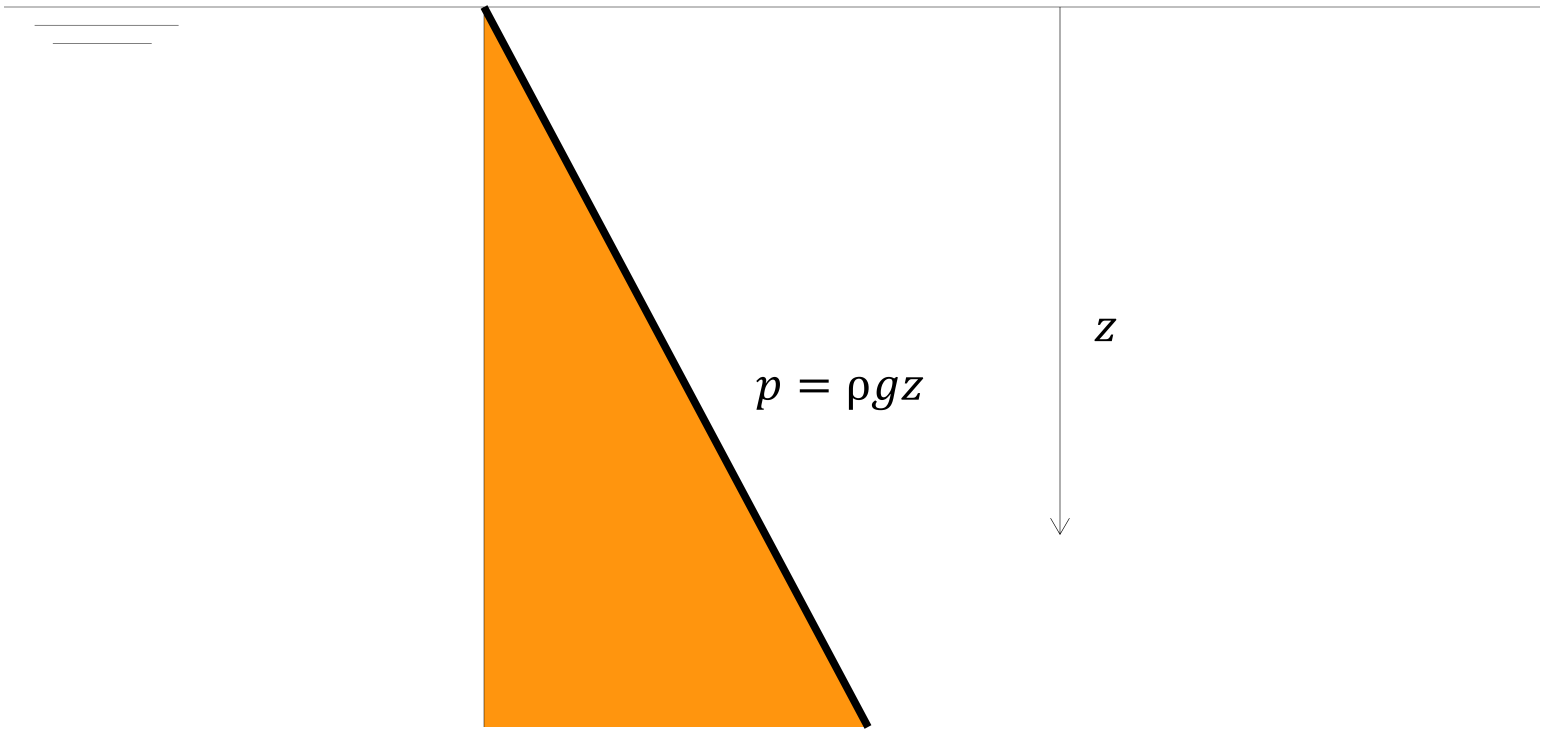


$$p_0dx\cancel{dy} + \rho gzdx\cancel{dy} = pdx\cancel{dy}$$

$$p = p_0 + \rho gz$$

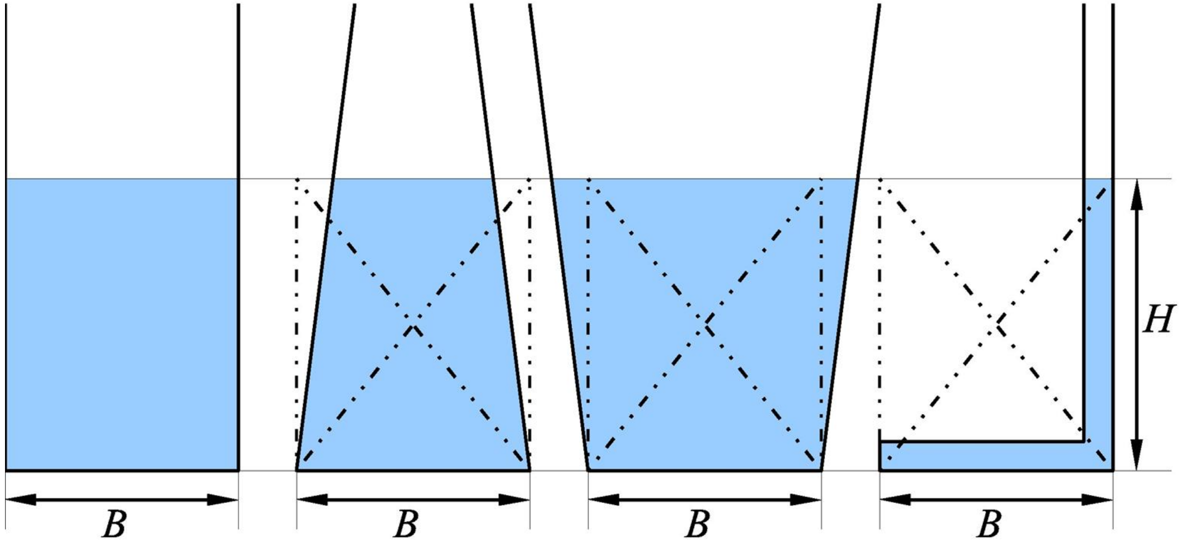
# Hydrostatics

## Hydrostatic pressure



# Hydrostatics

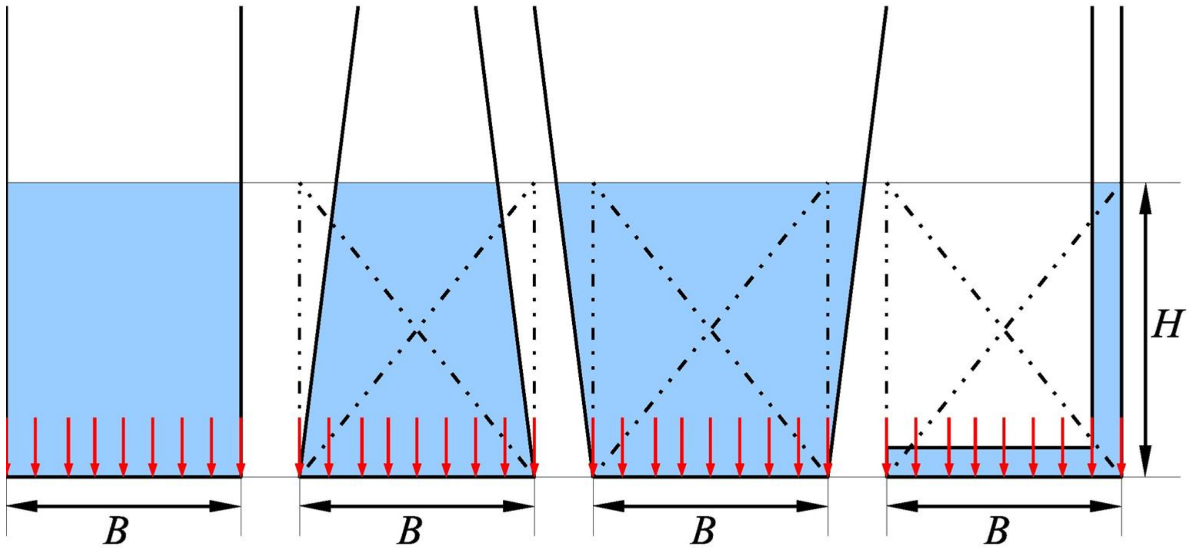
## Hydrostatic pressure



Which one has the largest pressure on its bottom?

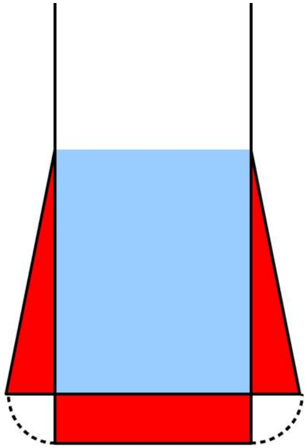
# Hydrostatics

## Hydrostatic paradox



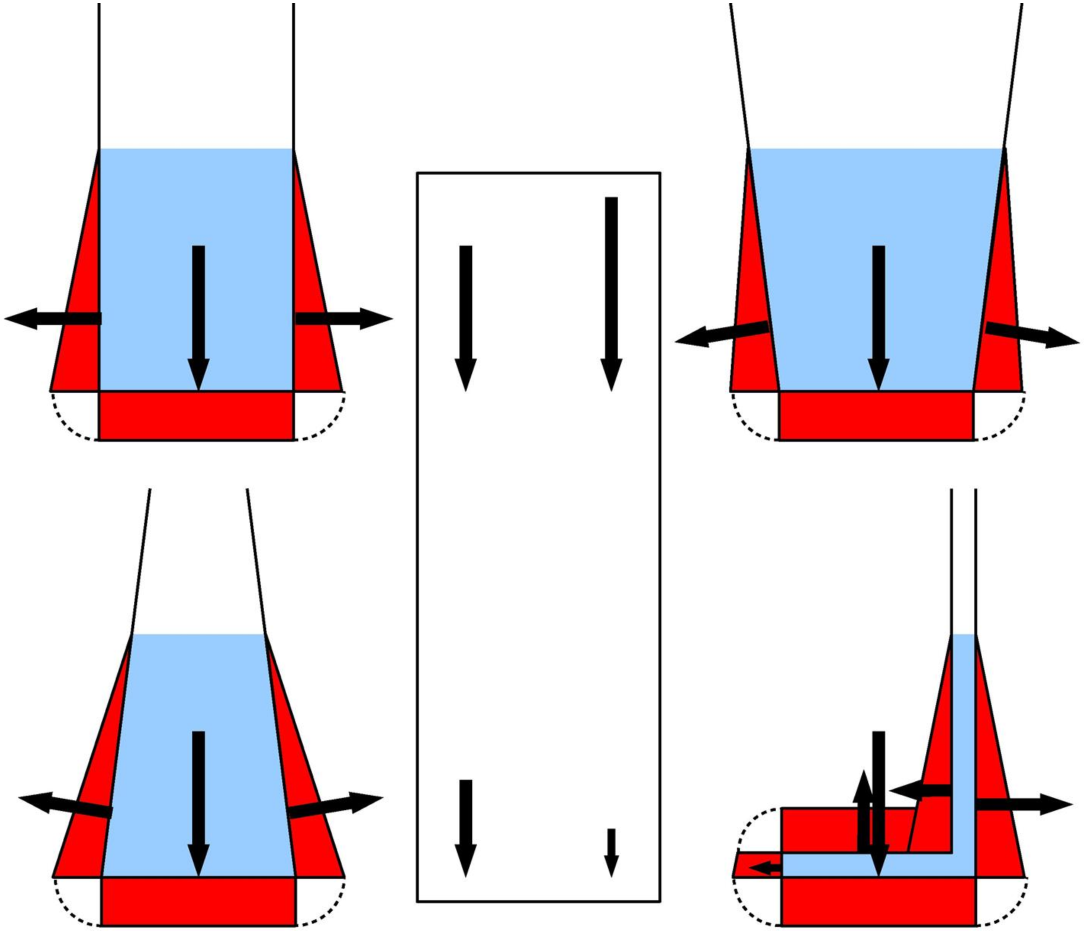
# Hydrostatics

## Hydrostatic paradox



# Hydrostatics

## Hydrostatic paradox



# Hydrostatics

## Archimedes Law and Buoyancy

- The weight of an floating body is equal to the weight of the fluid it displaces

- Displacement of a floating body:

  The amount of fluid the body displaces often expressed in terms of mass or volume:

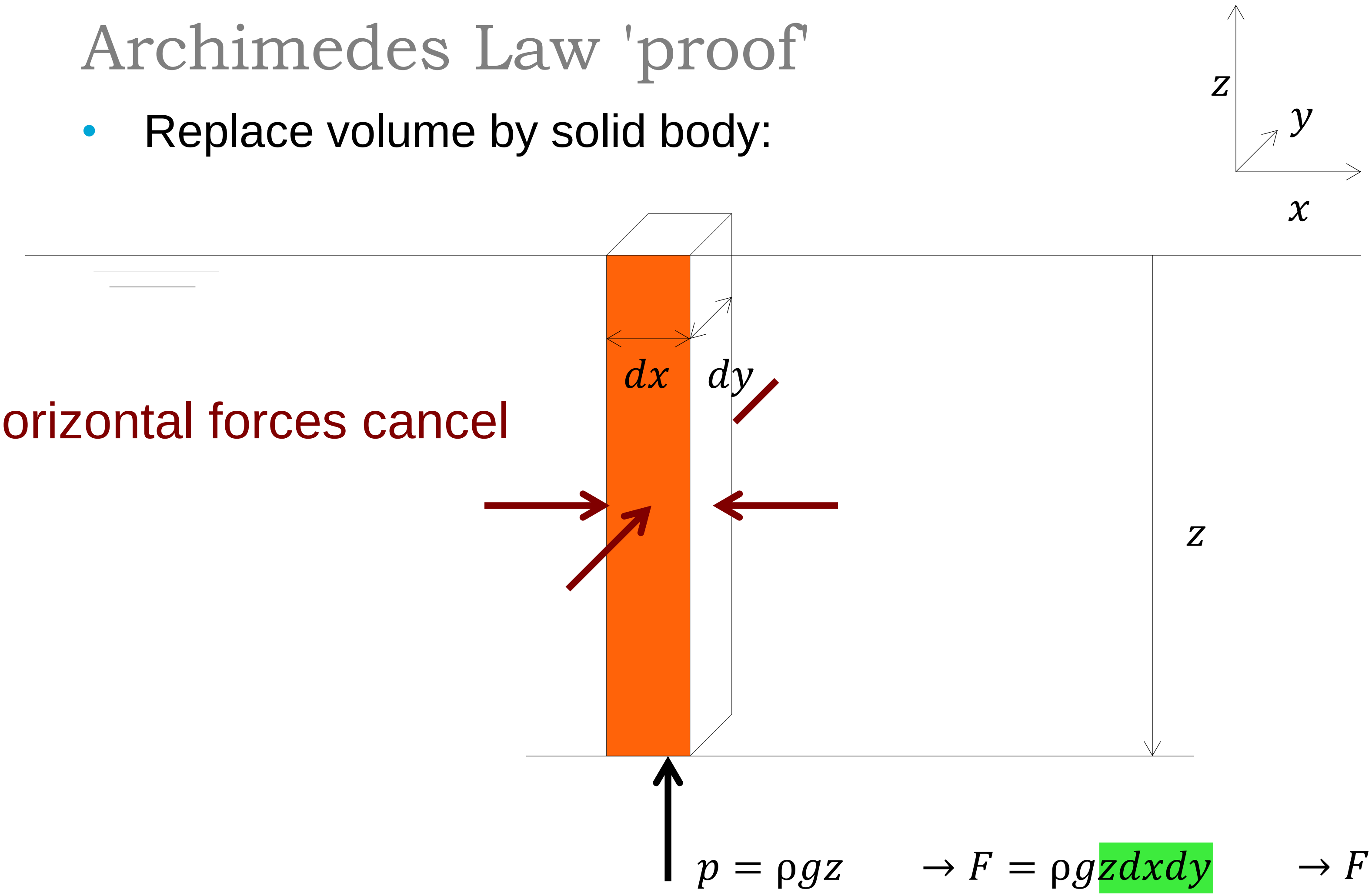
$$\Delta = \rho g \nabla$$

| | | | |
|---|---|---|---|
| $\Delta$ | Weight of displacement | [N] | |
| $g$ | Gravity accel. | [m/s$^2$] | 9.81 |
| $\rho$ | Density | [kg/m$^3$] | 1025 |
| $\nabla$ | Volume of displacement | [m$^3$] | |

# Hydrostatics

## Archimedes Law 'proof'

- Replace volume by solid body:



Horizontal forces cancel

$p = \rho g z \quad \rightarrow F = \rho g z dx dy \quad \rightarrow F = \rho g \nabla$

# Hydrostatics

## Archimedes Law and Buoyancy

- The weight of an floating body is equal to the weight of the fluid it displaces

- Displacement of a floating body:

  The amount of fluid the body displaces often expressed in terms of mass or volume:

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| | | | |
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| $\Delta$ | Weight of displacement | [N] | |
| g | Gravity accel. | [m/s$^2$] | 9.81 |
| $\rho$ | Density | [kg/m$^3$] | 1025 |
| $\nabla$ | Volume of displacement | [m$^3$] | |

# Hydrostatics

## Archimedes Law and Buoyancy

- Two ways of looking at buoyancy:

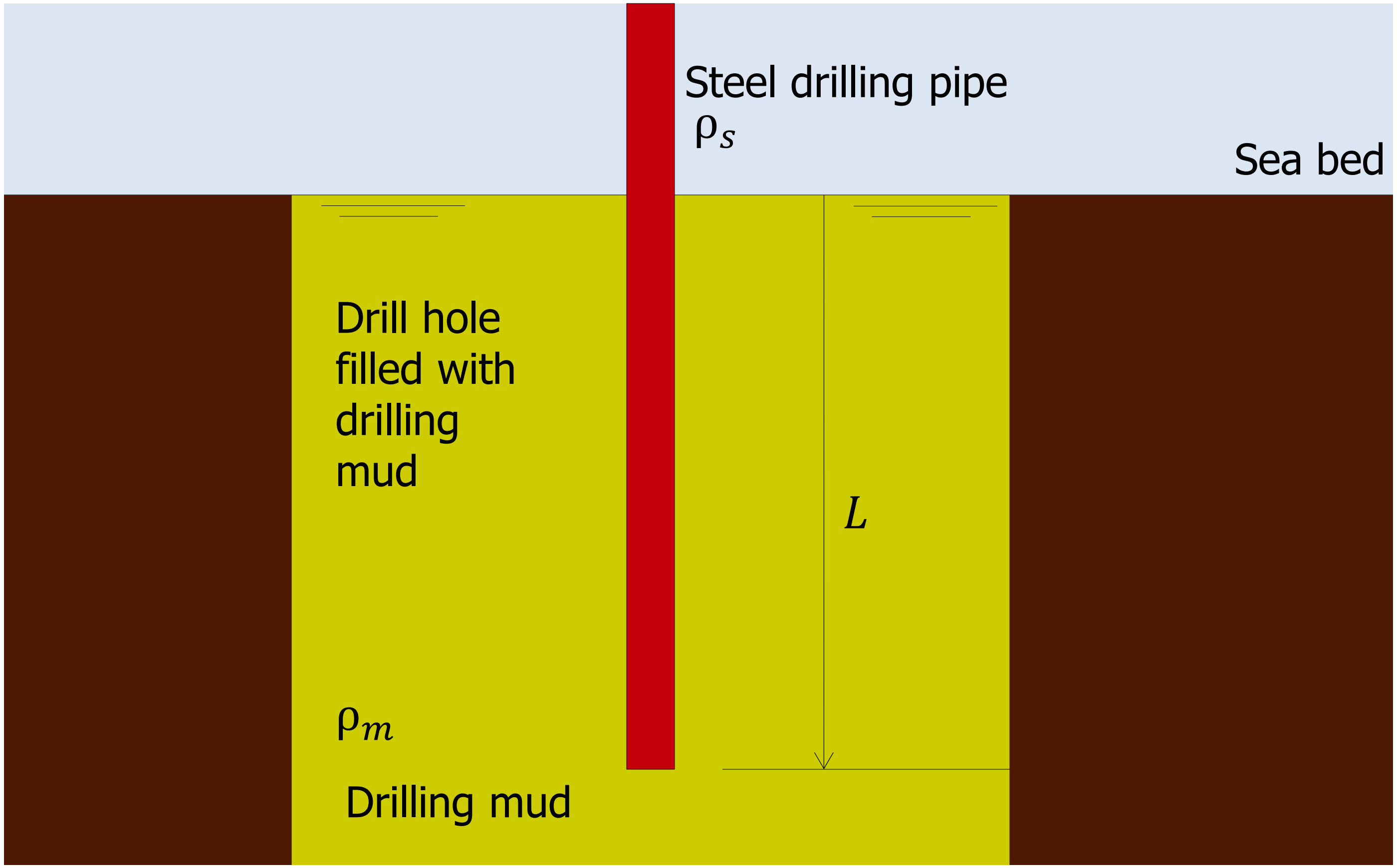
  1. As distributed force $\Delta = \rho g \nabla$

  2. The result of external (hydrostatic) pressure on the interfaces

- Illustration: drill string suspended in a well with mud

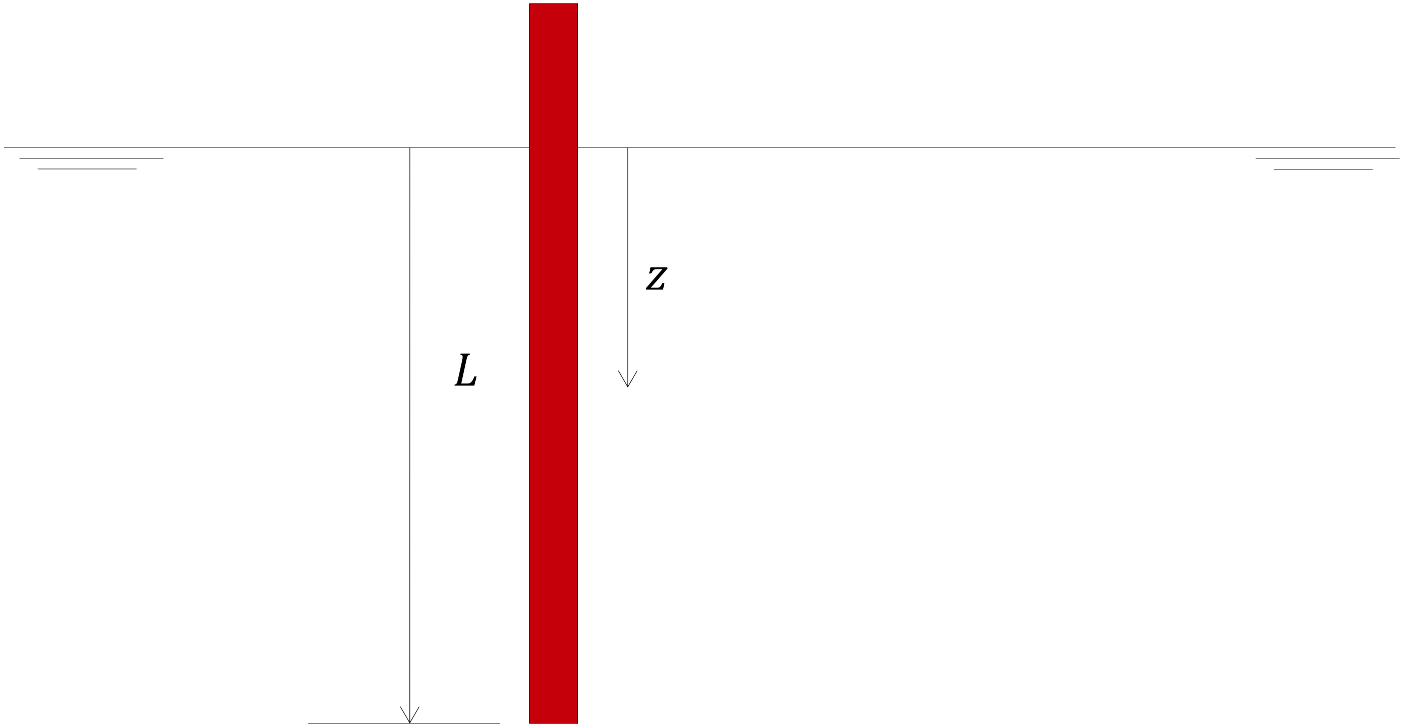
# Hydrostatics

## Example: drill string in mud



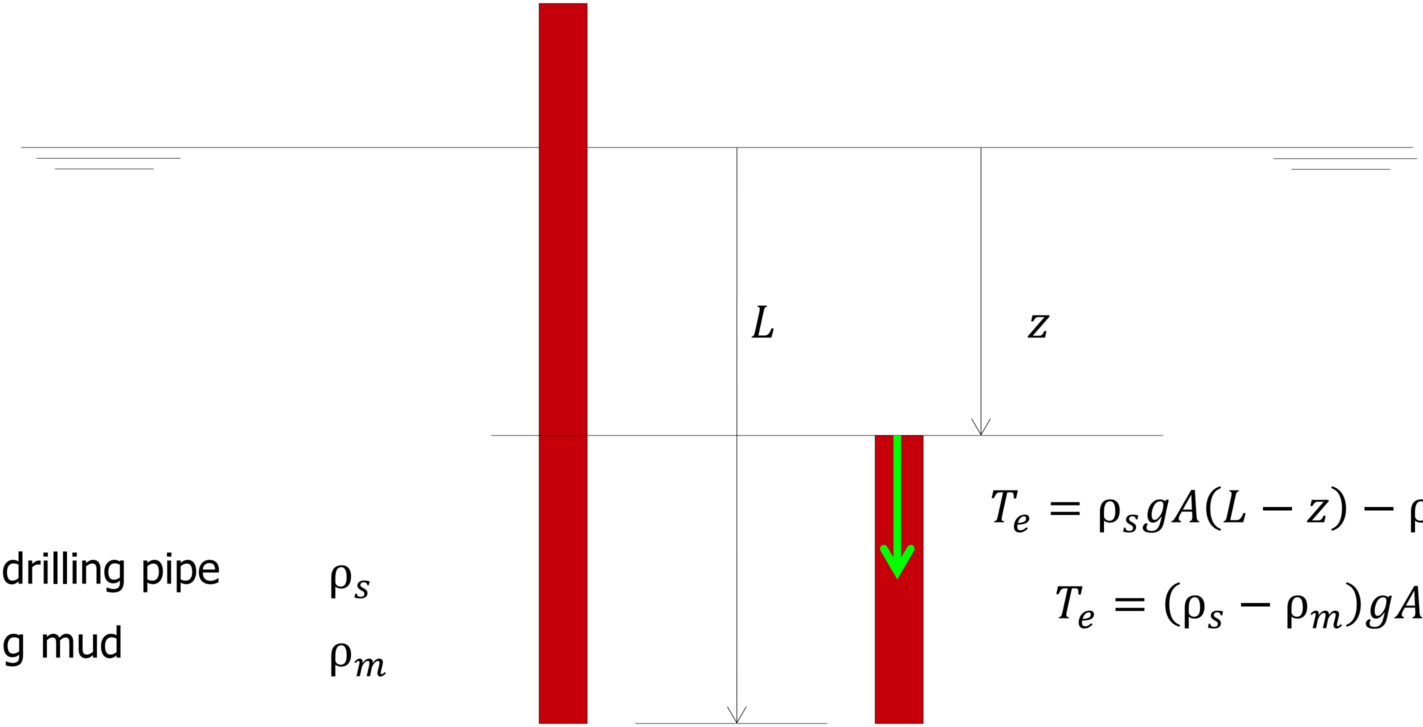
# Hydrostatics

## 2 Consider buoyancy result of pressures



# Hydrostatics

## 1 Consider distributed buoyant force



$$T_e = \rho_s g A(L-z) - \rho_m g A(L-z)$$

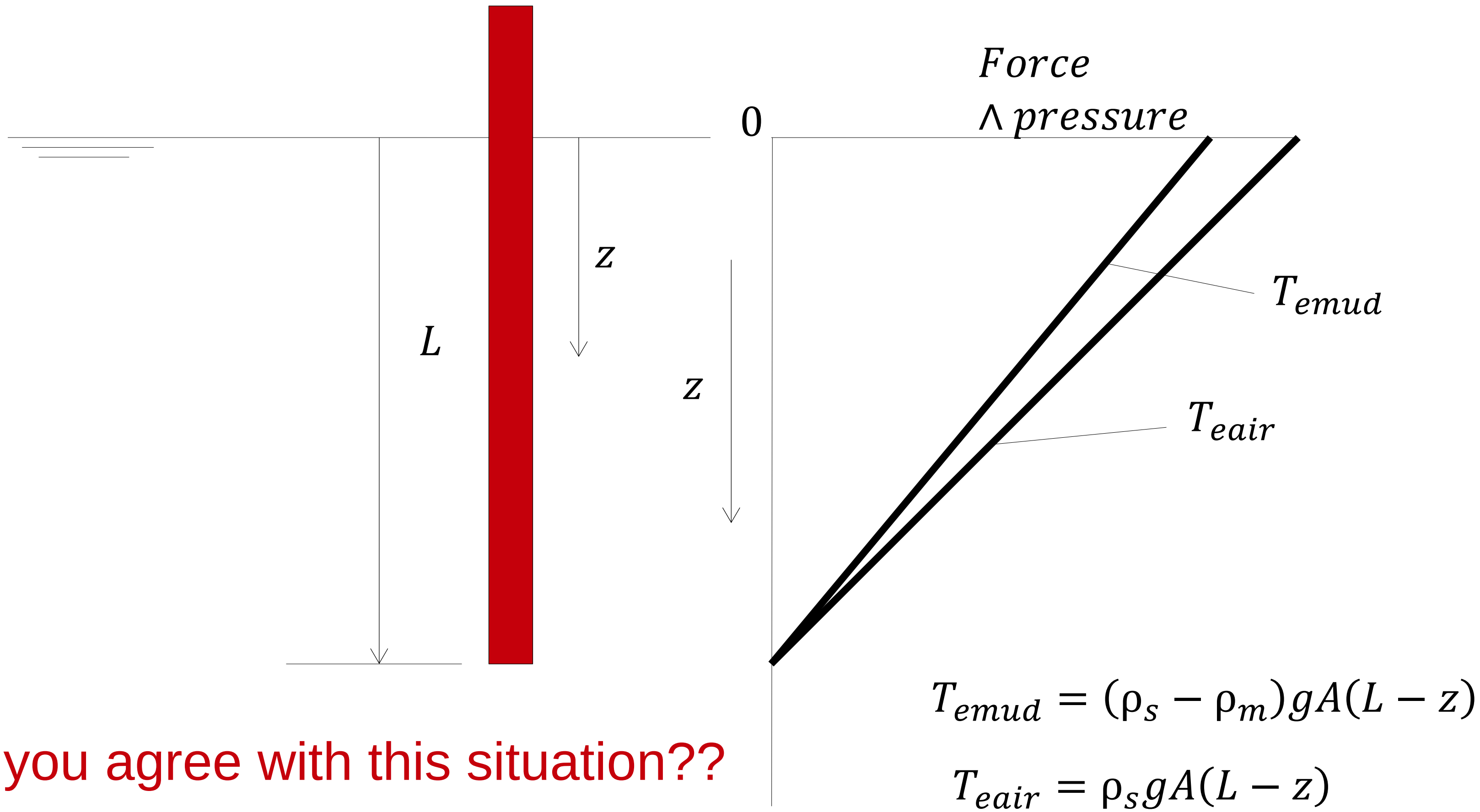
$$T_e = (\rho_s - \rho_m) g A(L-z)$$

Steel drilling pipe $\rho_s$

Drilling mud $\rho_m$

# Hydrostatics

## 1 Consider distributed buoyant force



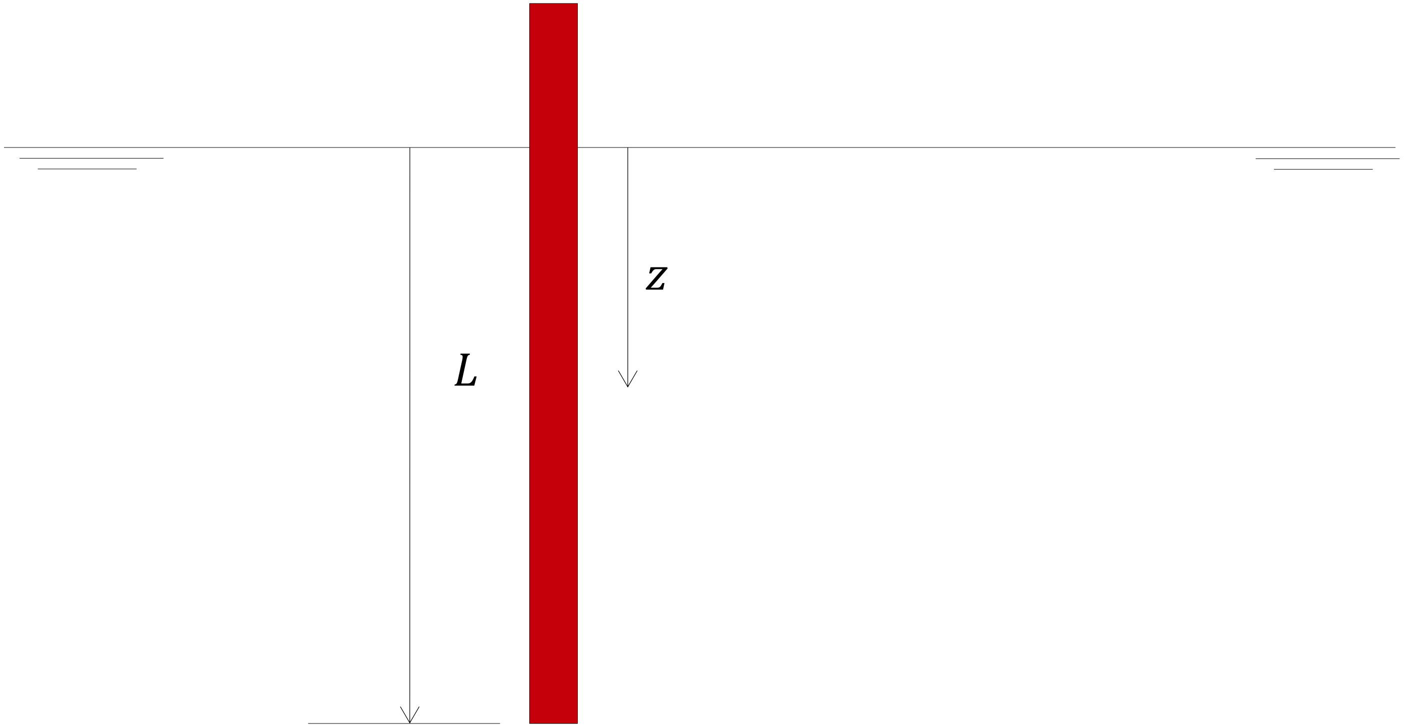
$$T_{emud} = (\rho_s - \rho_m)gA(L - z)$$

$$T_{eair} = \rho_s gA(L - z)$$

Do you agree with this situation??

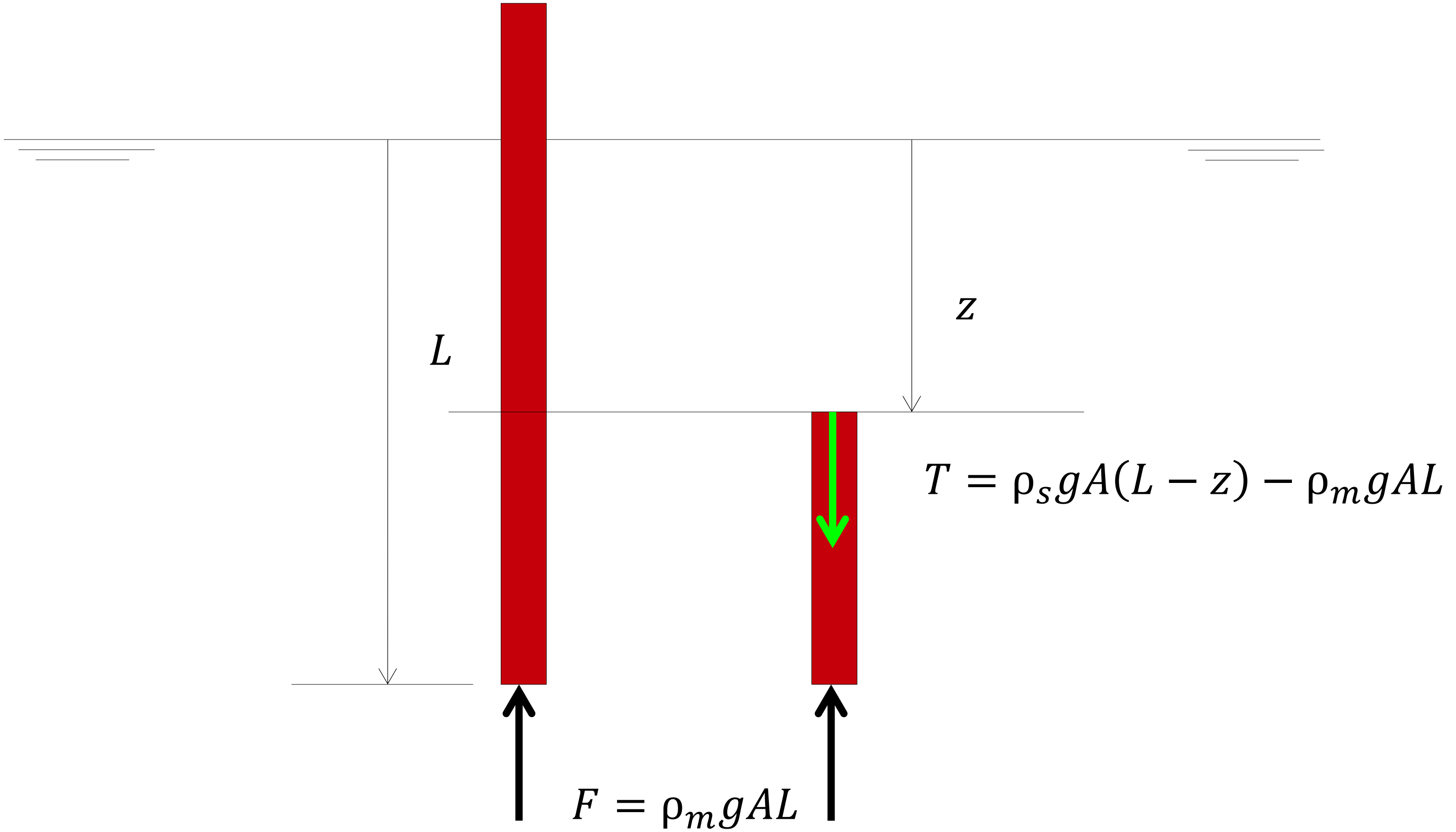
# Hydrostatics

## 2 Consider buoyancy result of pressures



# Hydrostatics

## 2 Consider buoyancy result of pressures



$T = \rho_s g A(L - z) - \rho_m g A L$

$F = \rho_m g A L$

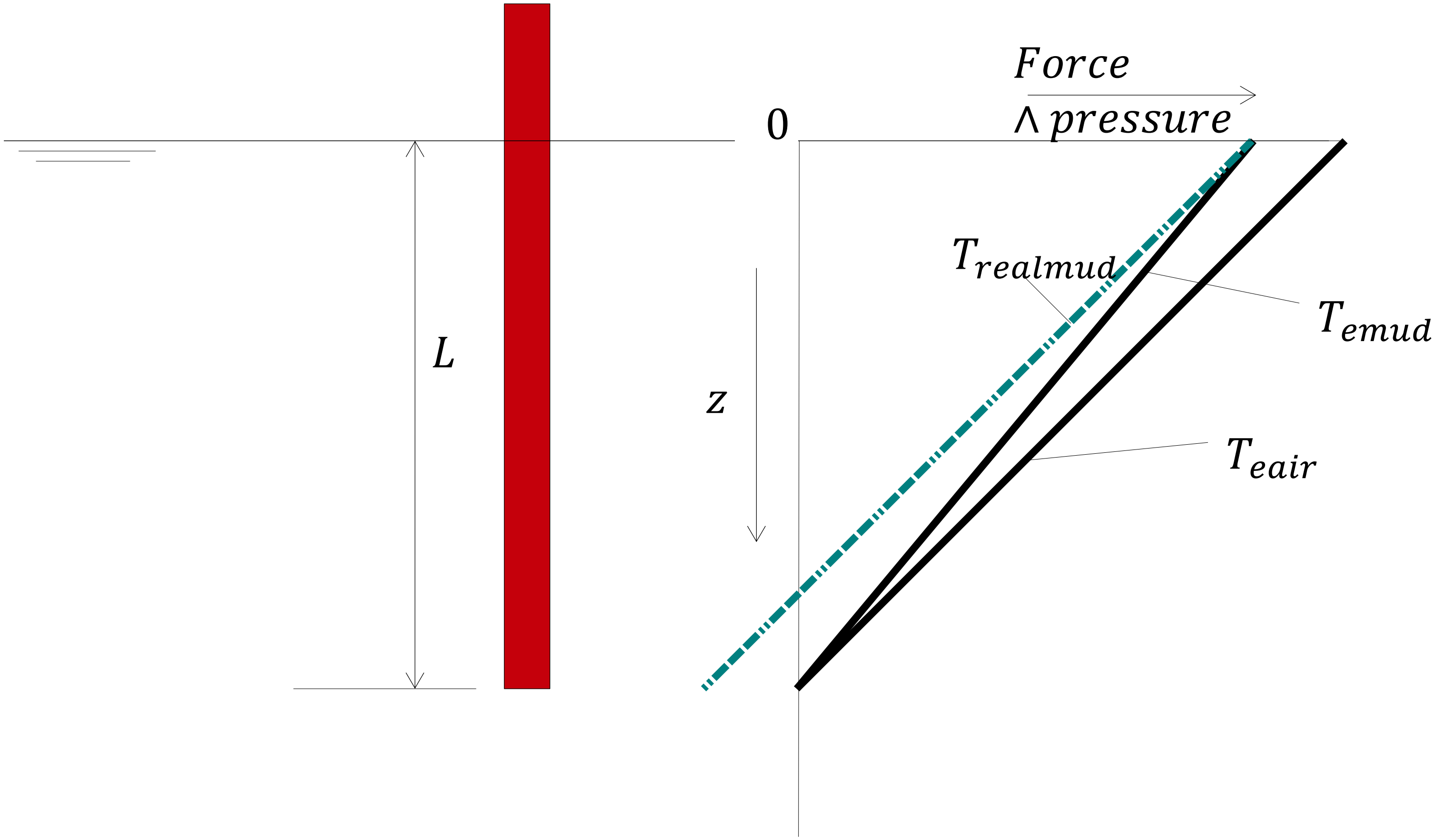
# Hydrostatics

## Comparison

$$T_{realmud} = \rho_s g A(L-z) - \rho_m g A L$$

$$T_{emud} = (\rho_s - \rho_m) g A(L-z)$$

$$T_{eair} = \rho_s g A(L-z)$$



# Contents

## Lecture 1

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| Introduction Module 1 | done |
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| Hydrostatics (Chapter 2) | done |
| Floating stability (Chapter 2) | next up |

# Floating stability

## Definition

- All properties that floating structures exhibit when perturbed from their equilibrium state

- A ‘stable’ ship quickly restores its equilibrium when perturbation is removed

- Often we wish for:
    - A stable working platform, i.e. a platform that does not move too much in waves
    - Is this the same property?

- Do we always desire maximum stability?

# Floating stability

## Example


[1]

# Floating stability

## Example

[2]

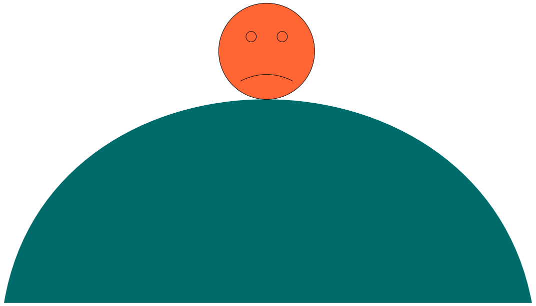
# Floating stability

## Example

[3]

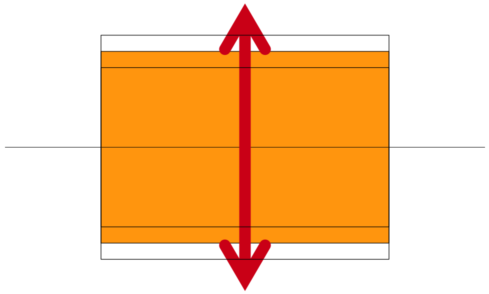
# Floating stability

## Equilibrium states

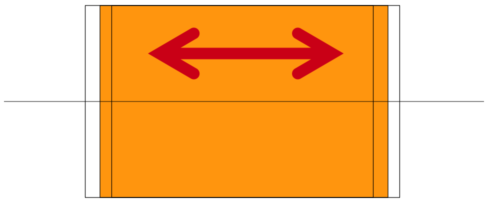


# Floating stability

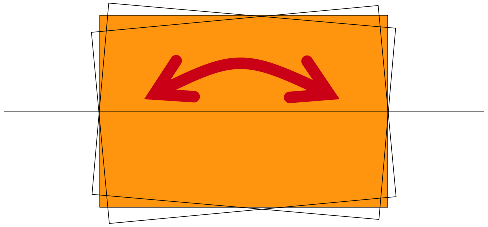
## Equilibrium for floating structures



vertical



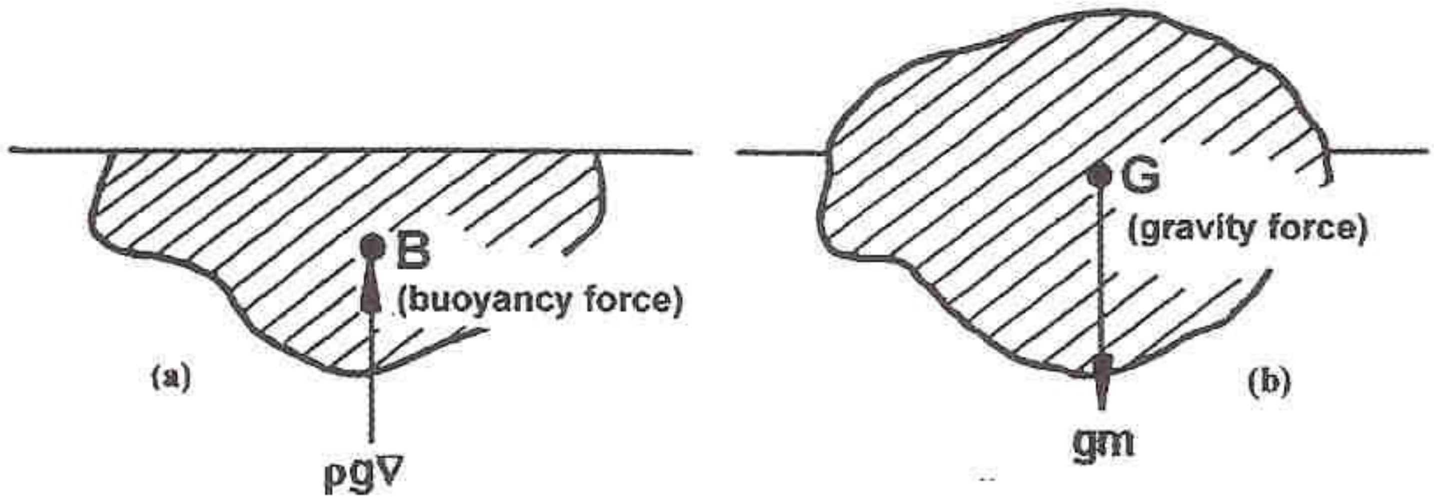
horizontal



rotational

# Floating stability

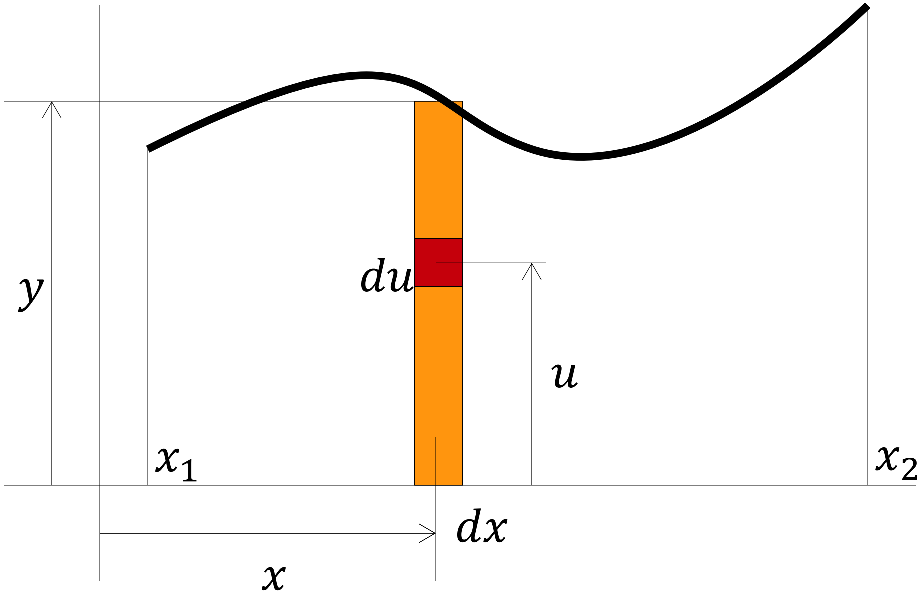
## Center of buoyancy and center of gravity



| | |
|---|---|
| B | point about which first moment of submerged volume = 0 |
| G | point about which first moment of mass or weight = 0 |

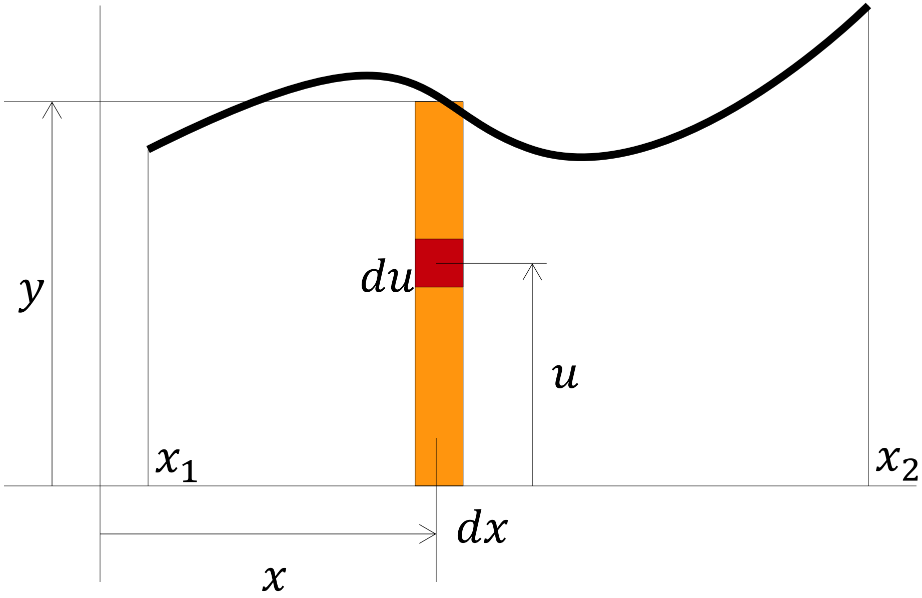
# Floating stability

## First moment of area/volume/mass/…



# Floating stability

## First moment of area/volume/mass/…



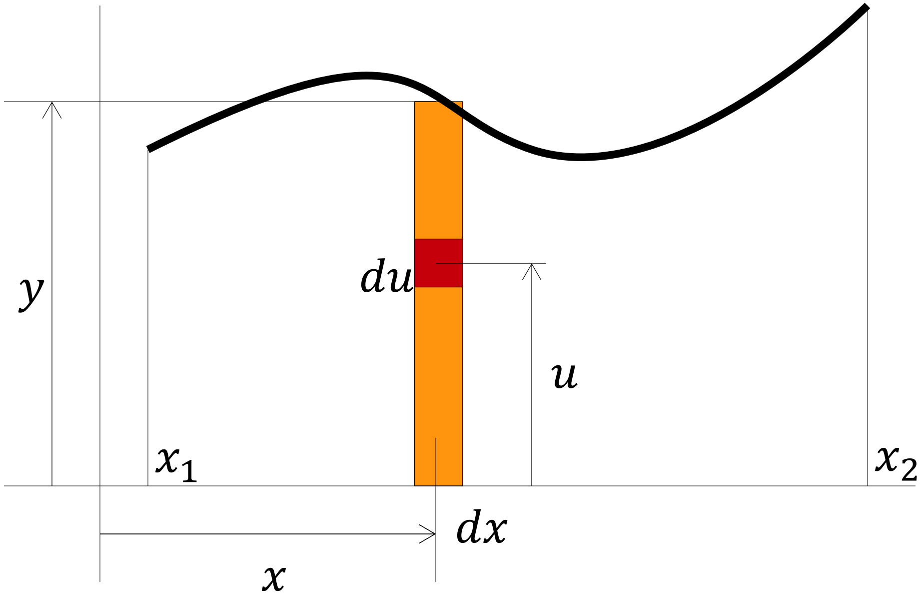
Area:

$$dA = y dx$$

$$A = \int_{x_1}^{x_2} y\, dx$$

# Floating stability

## First moment of area/volume/mass/…



Static moment:

$$ds_x = ududx$$

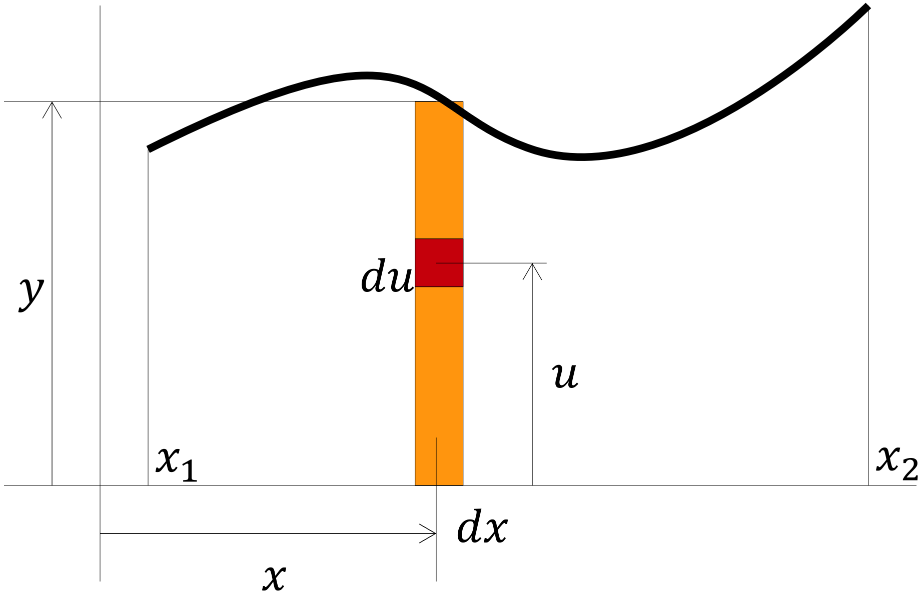
$$dS_x = \int_o^y u\,dudx = 1/2\,y^2dx$$

$$S_x = \int_{x_1}^{x_2} 1\big/2\,y^2dx$$

# Floating stability

## First moment of area/volume/mass/…

Static moment:

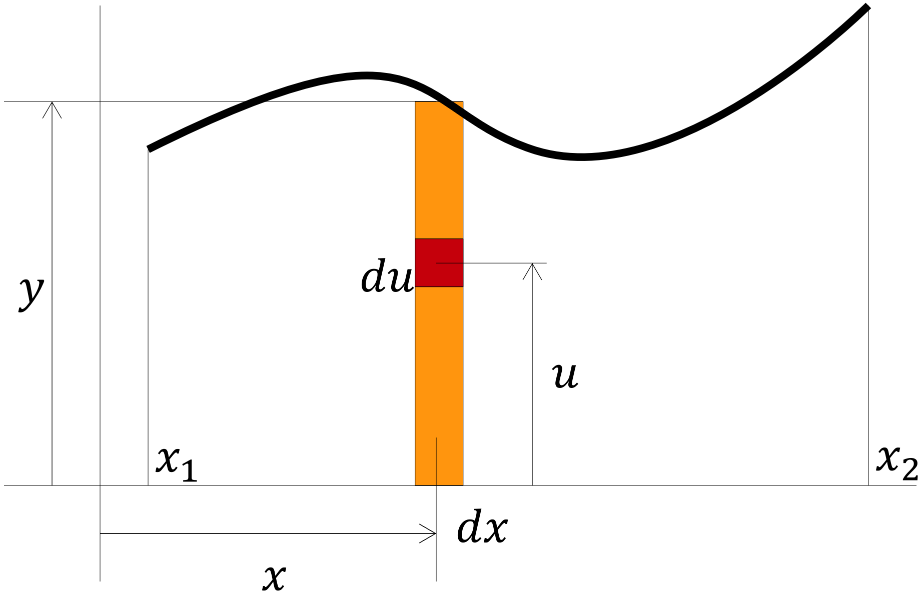


$$dS_y = xydx$$

$$S_y = \int_{x_1}^{x_2} x\,ydx$$

# Floating stability

## First moment of area/volume/mass/…



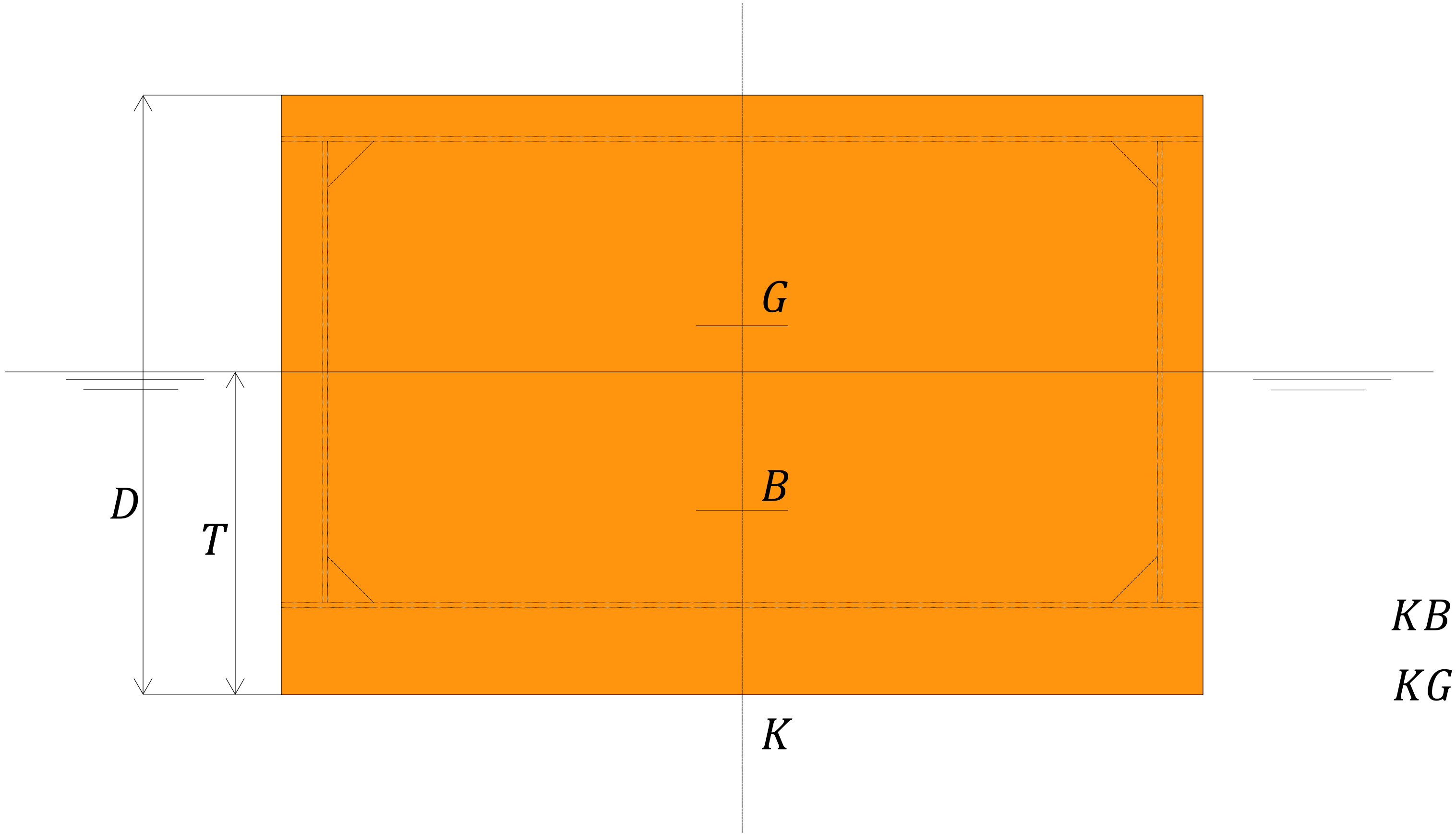
Center of area

$$y_A = \frac{S_x}{A}$$

$$x_A = \frac{S_y}{A}$$

# Floating stability

## Center of buoyancy and center of gravity

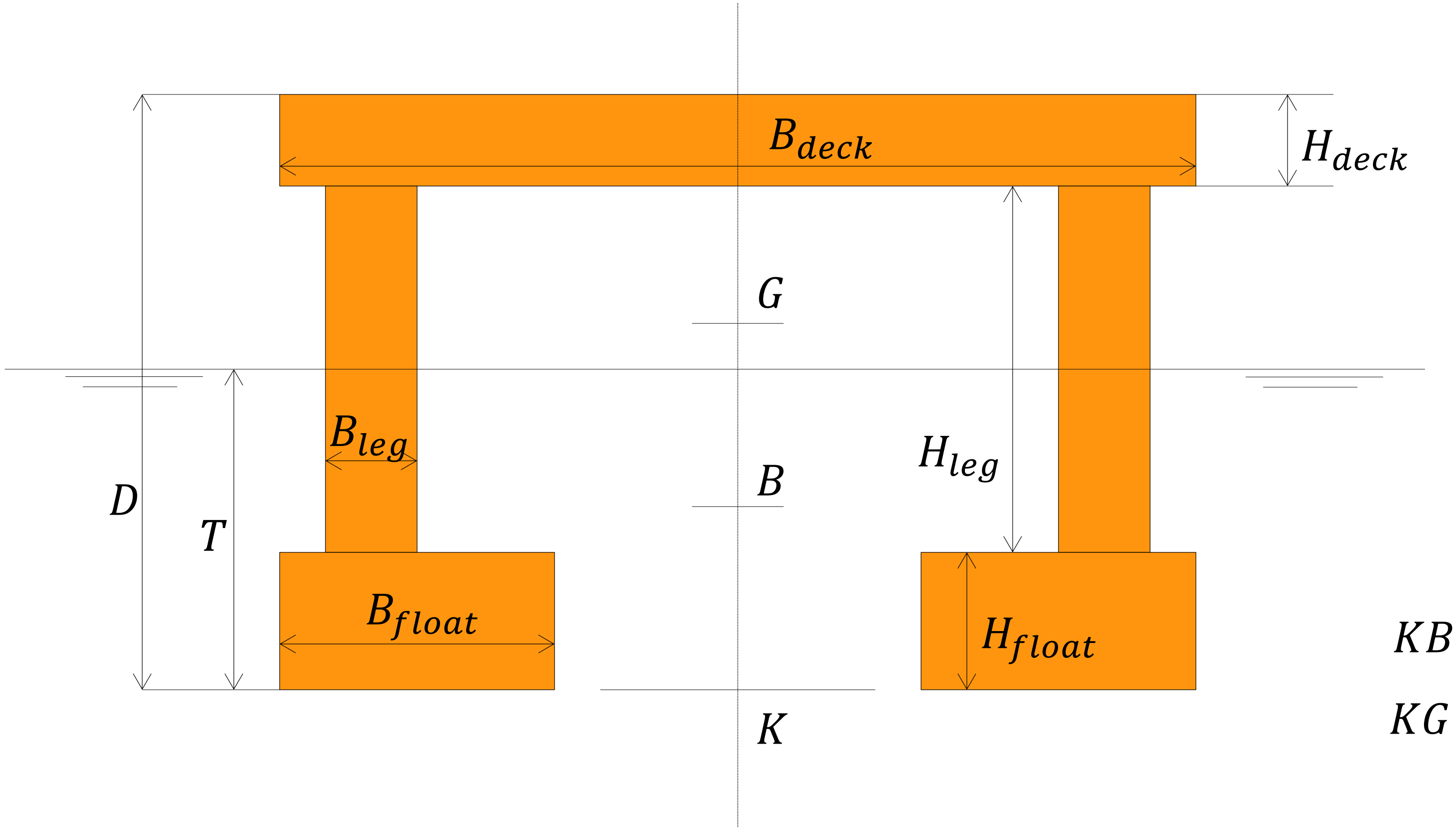


$KB = ?$

$KG = ?$

# Floating stability

## Center of buoyancy and center of gravity



Length:

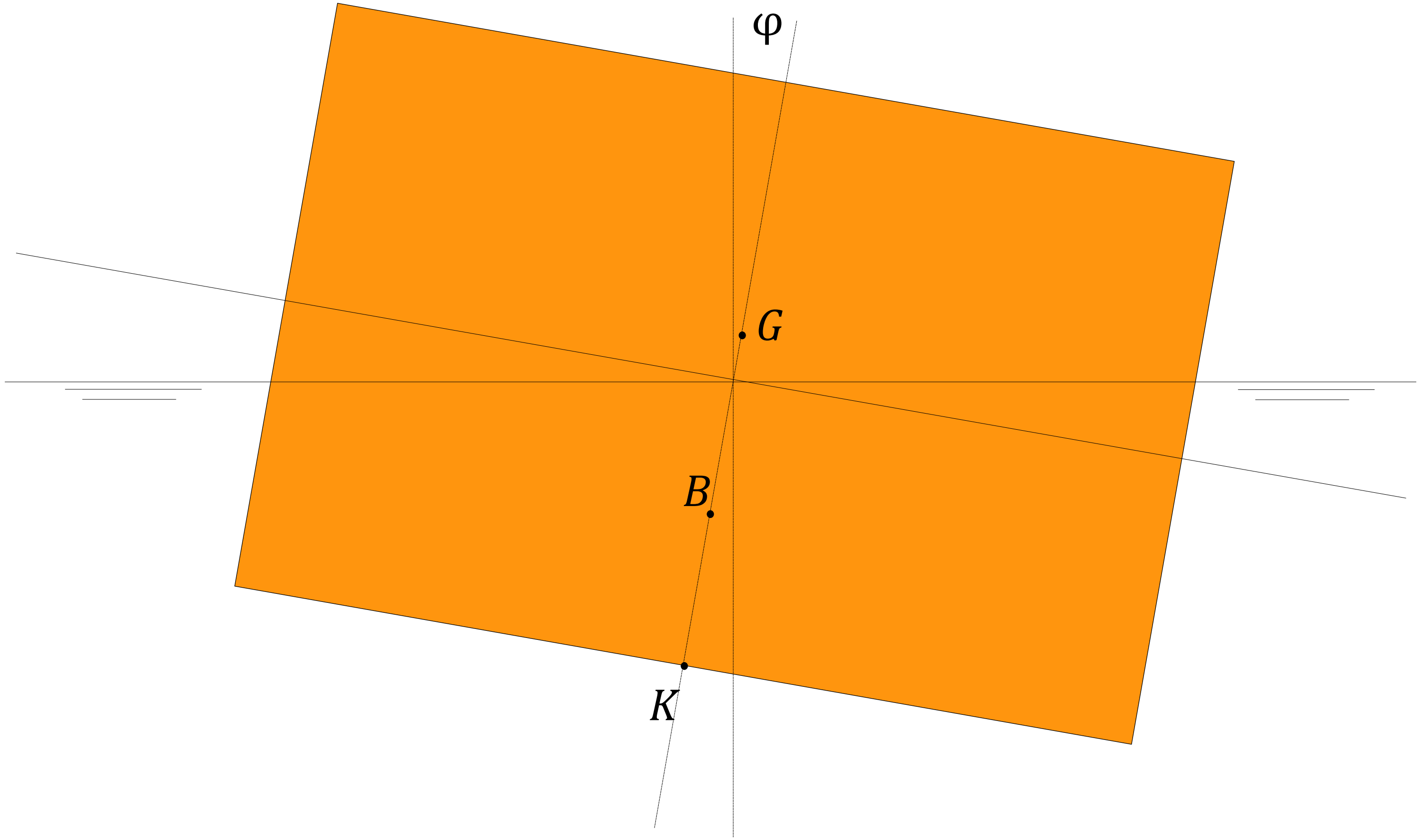
$L$

$KB$ =?

$KG$ =?

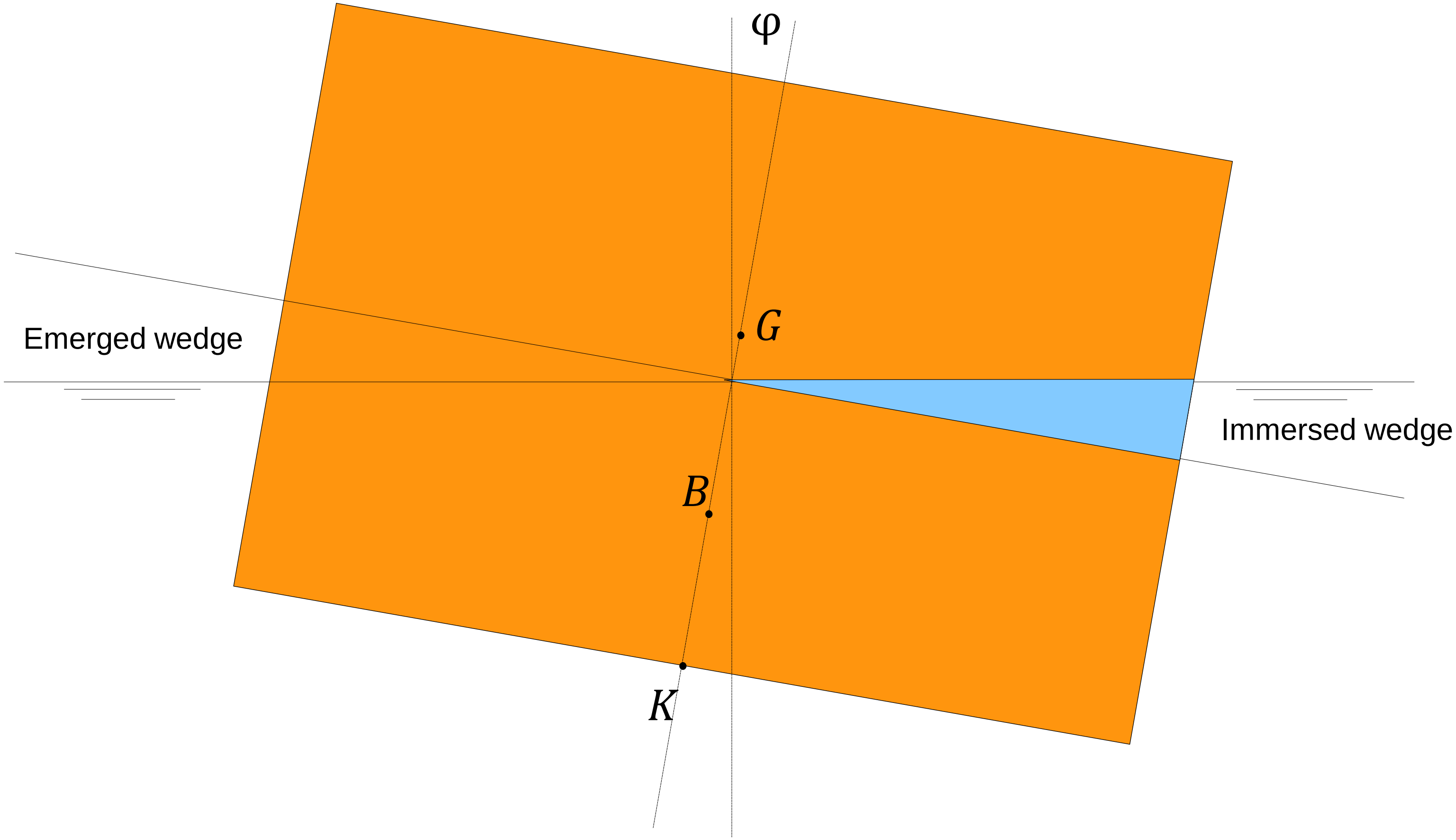
# Floating stability

## Stability moment



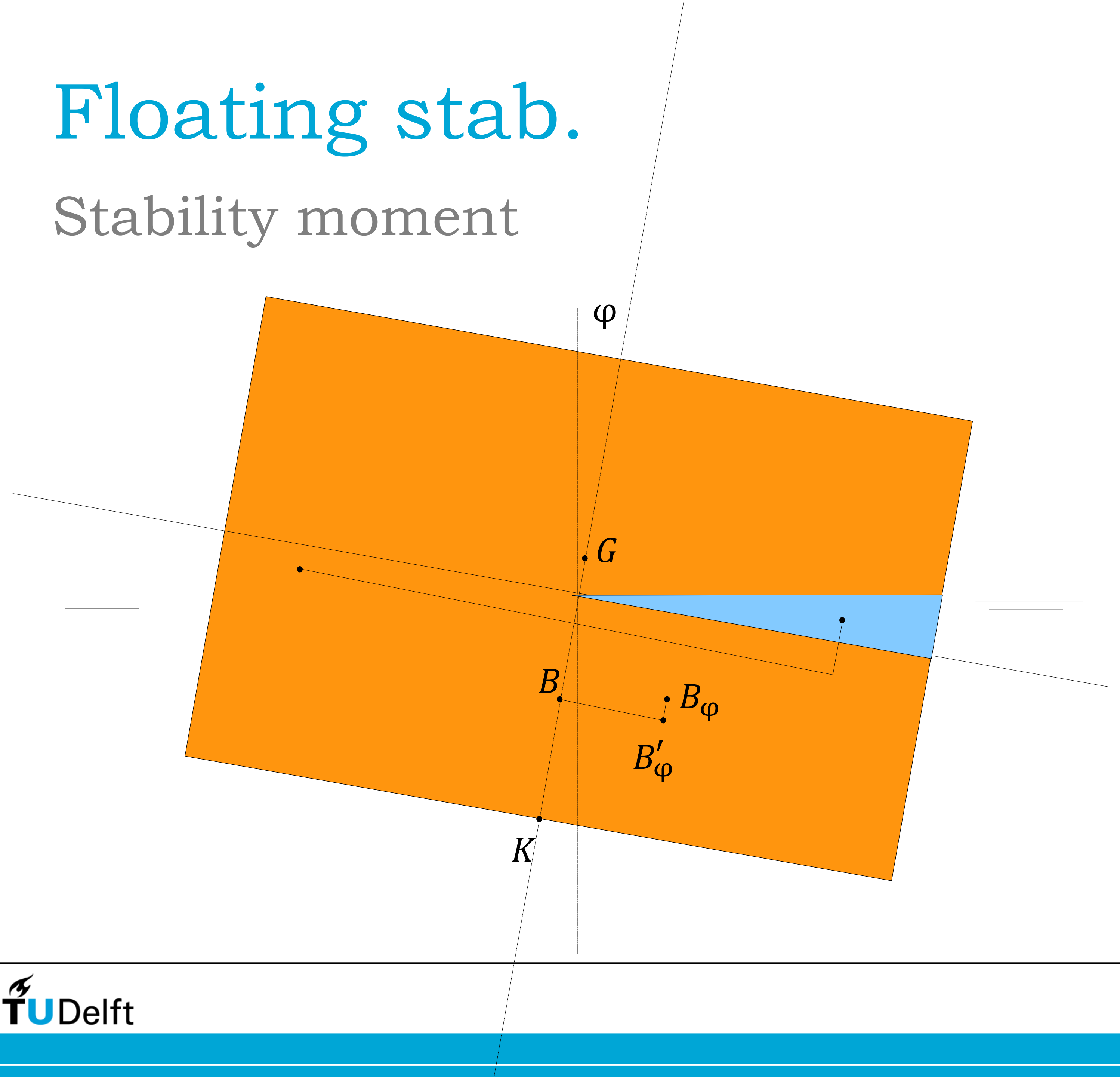
# Floating stability

## Stability moment

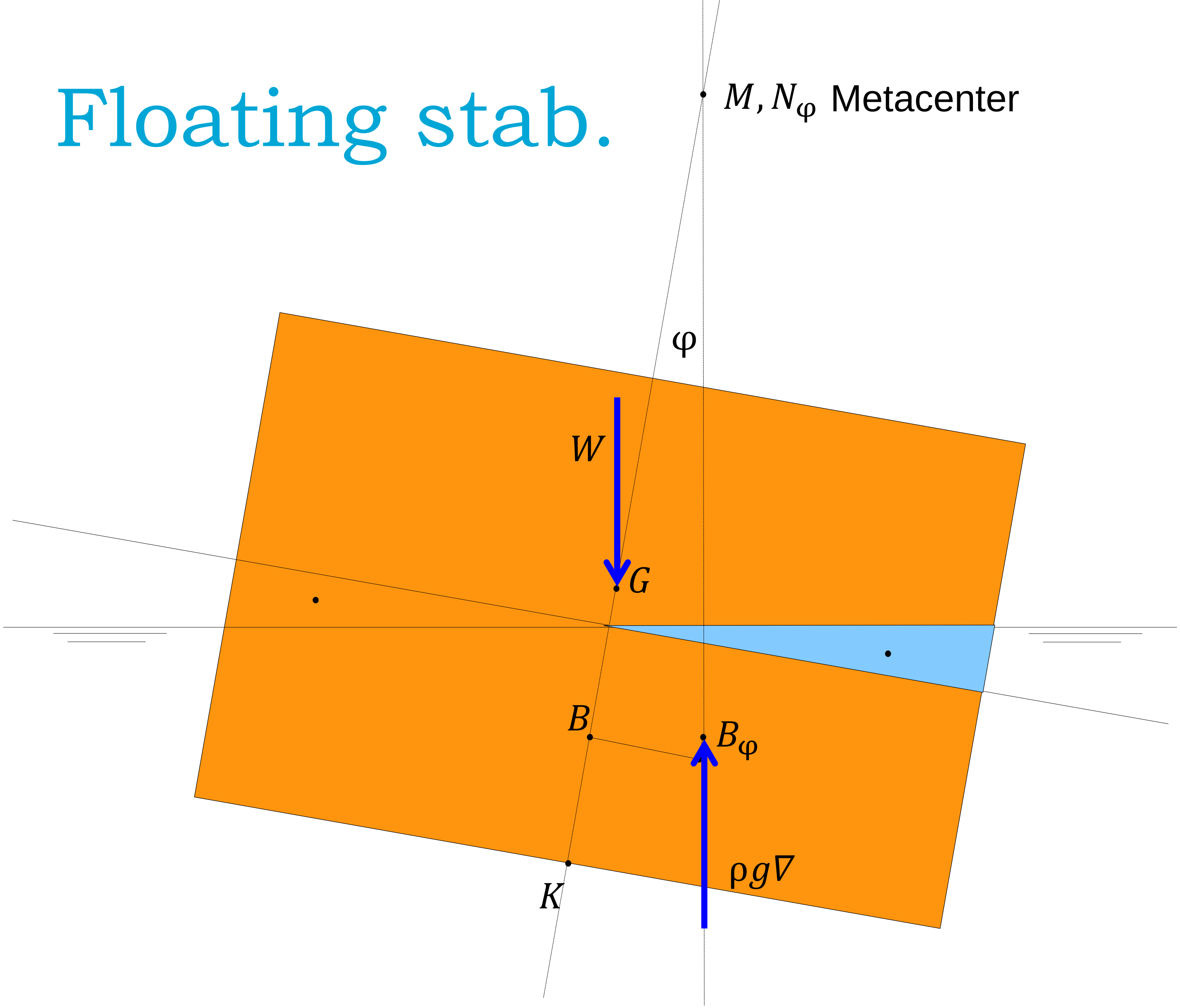


# Floating stab.

## Stability moment

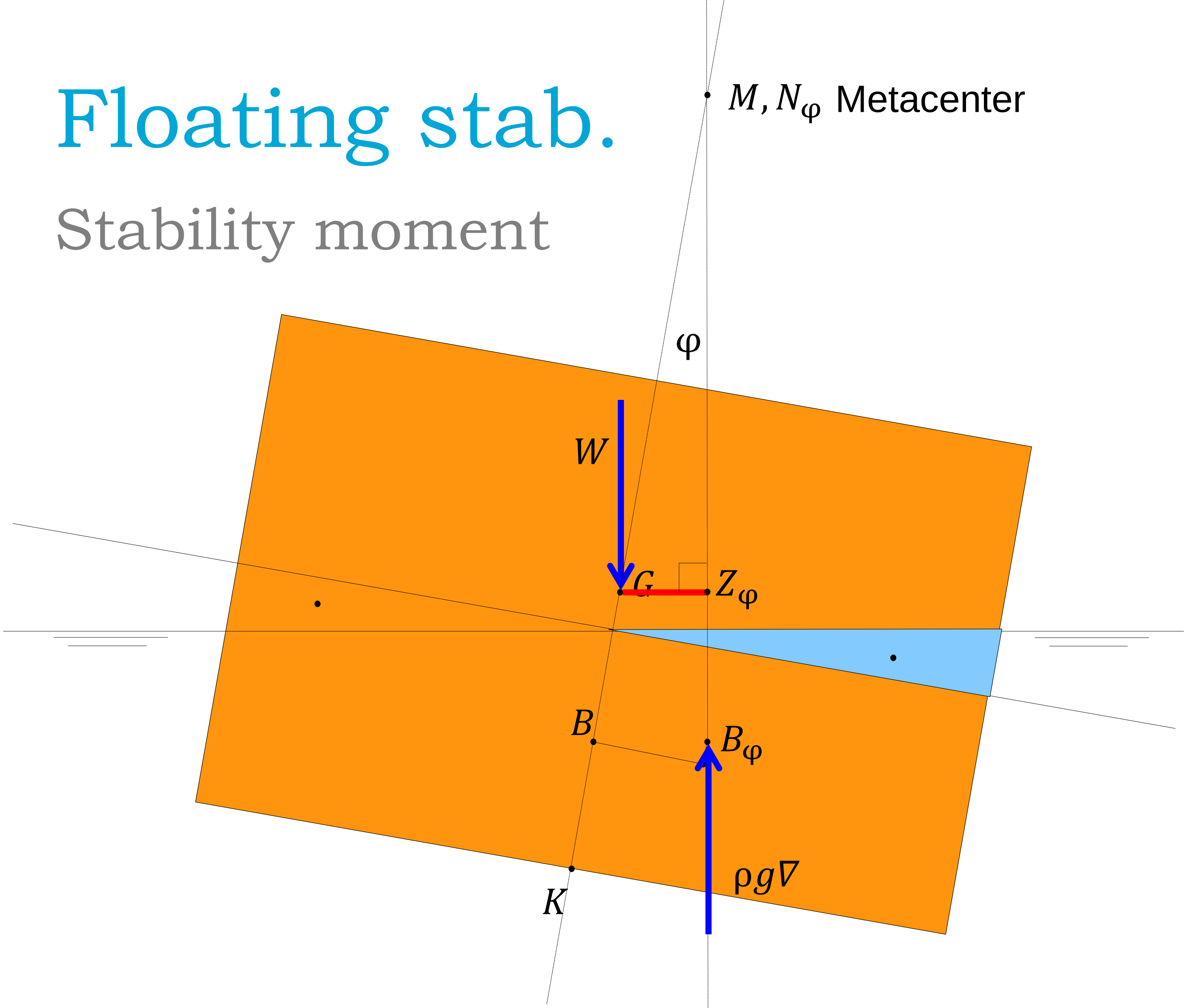


# Floating stab.



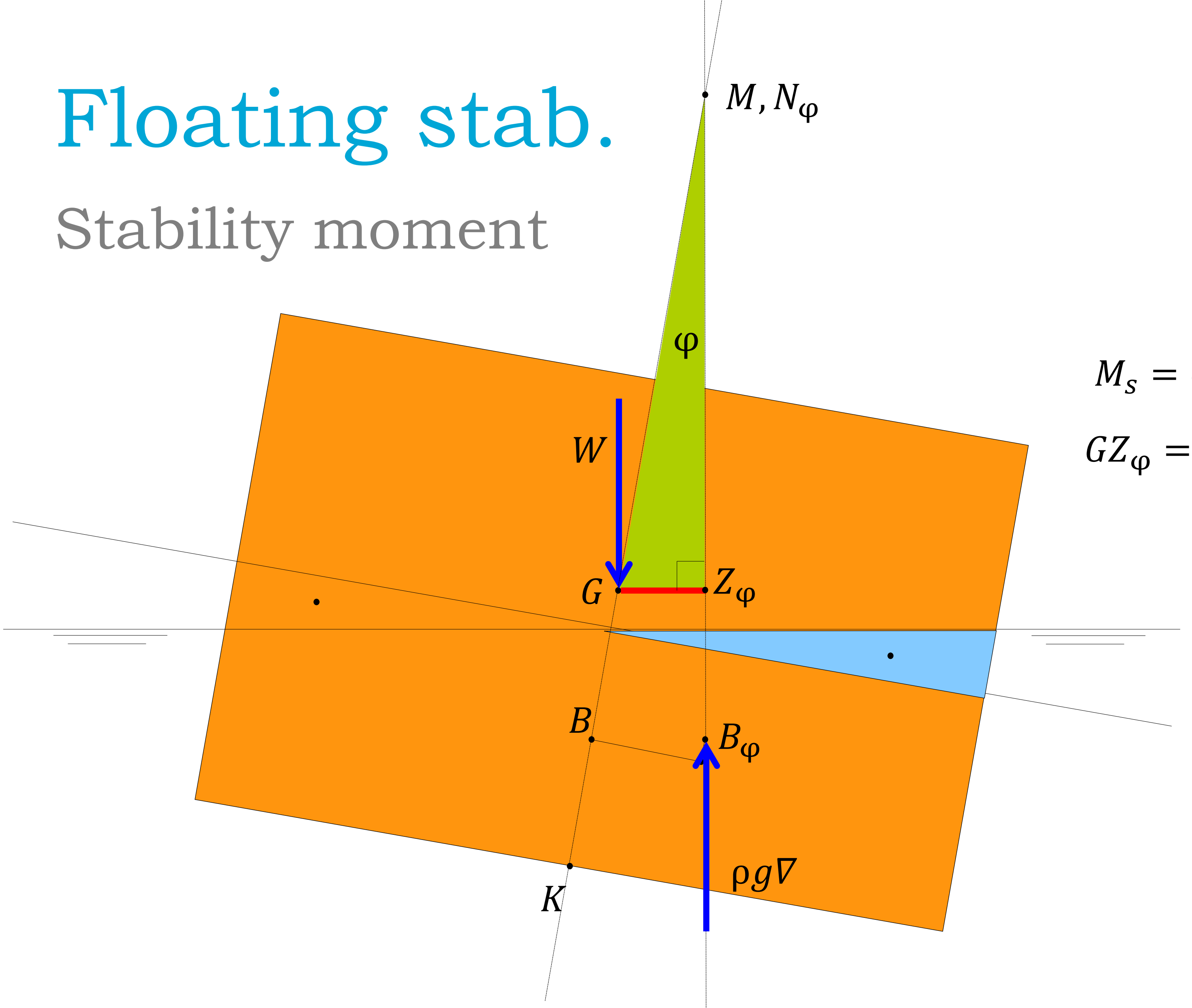
# Floating stab.

## Stability moment



# Floating stab.

## Stability moment

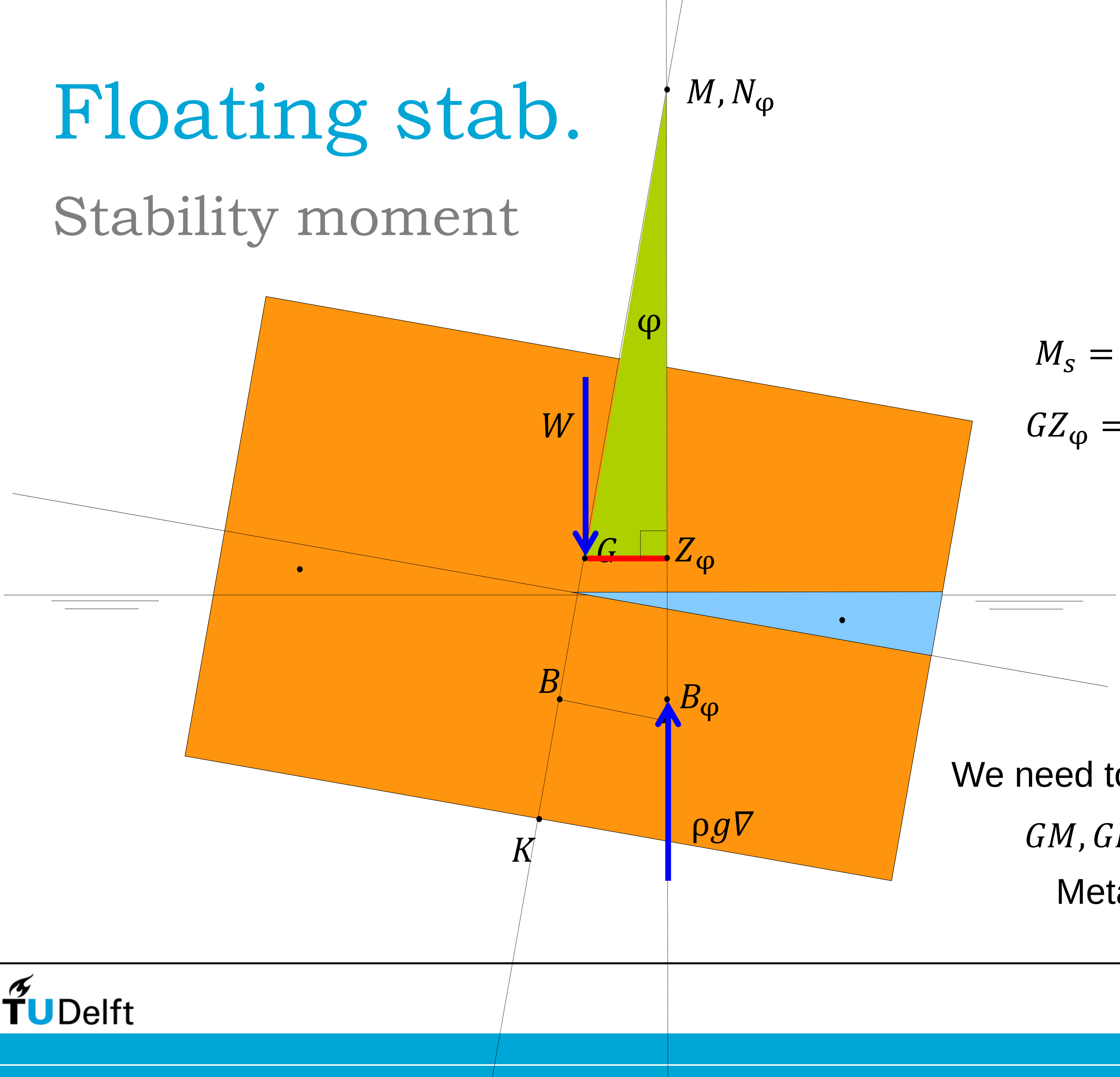


$$M_s = GZ_\varphi \rho g \nabla$$

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

# Floating stab.

## Stability moment



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

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

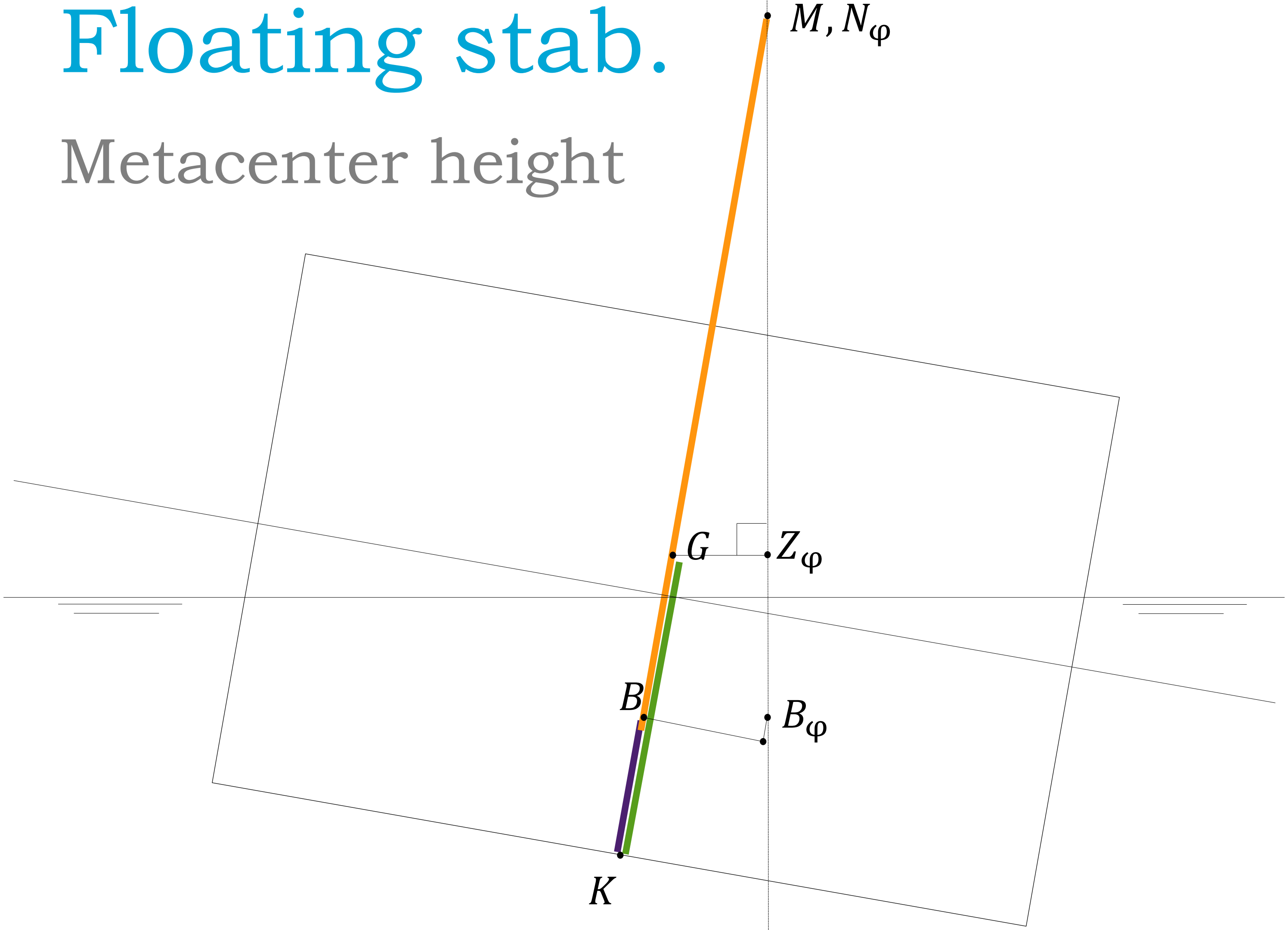
We need to find:

$GM, GN_\varphi$

Metacenter height

# Floating stab.

## Metacenter height



GM = KB + BM - KG

# Floating stability

## Metacenter height

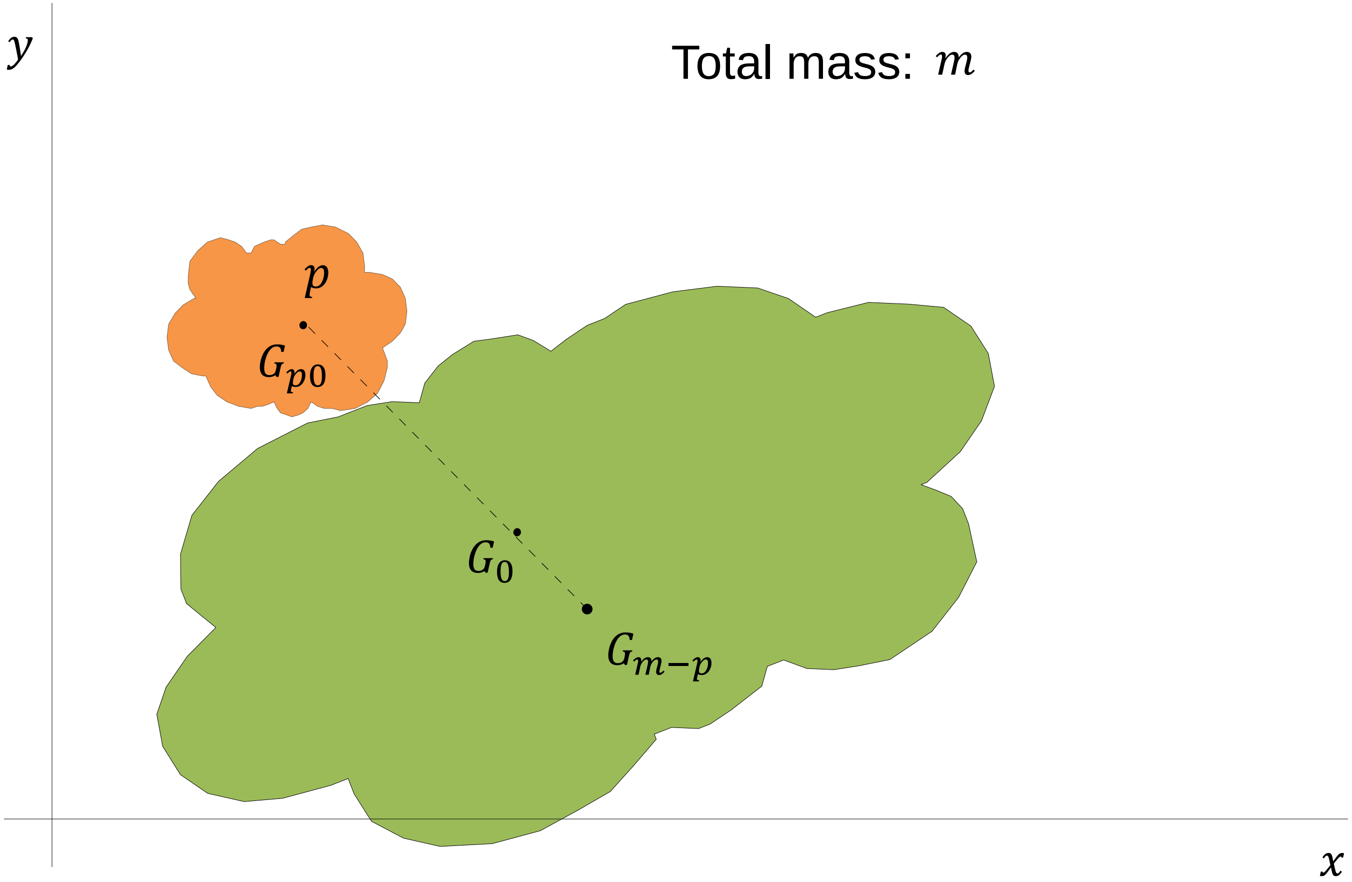
- KB en KG straightforward

$$GM = KB + BM - KG$$

- BM more complicated:
  - Determined by shift of B sideways and up
- Three 'methods':
  - Initial stability: wall sided ship and **sideways** shift of B
  - Scribanti: wall sided ship and B shifts **sideways** and **up**
  - 'Real ship': determine GZ curve for actual shape

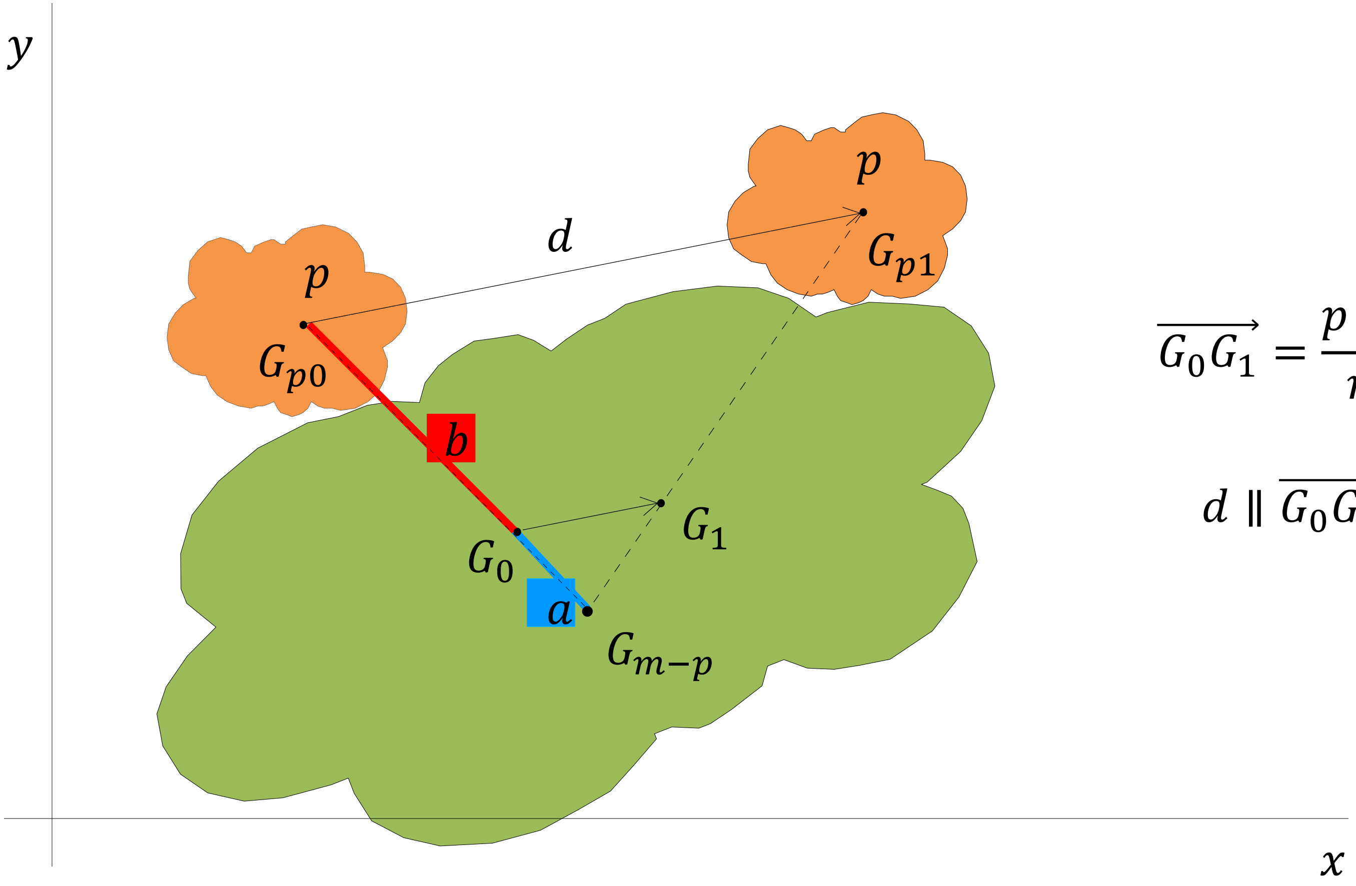
# Floating stability

## Shift of mass or volume center



# Floating stability

## Shift of mass or volume center

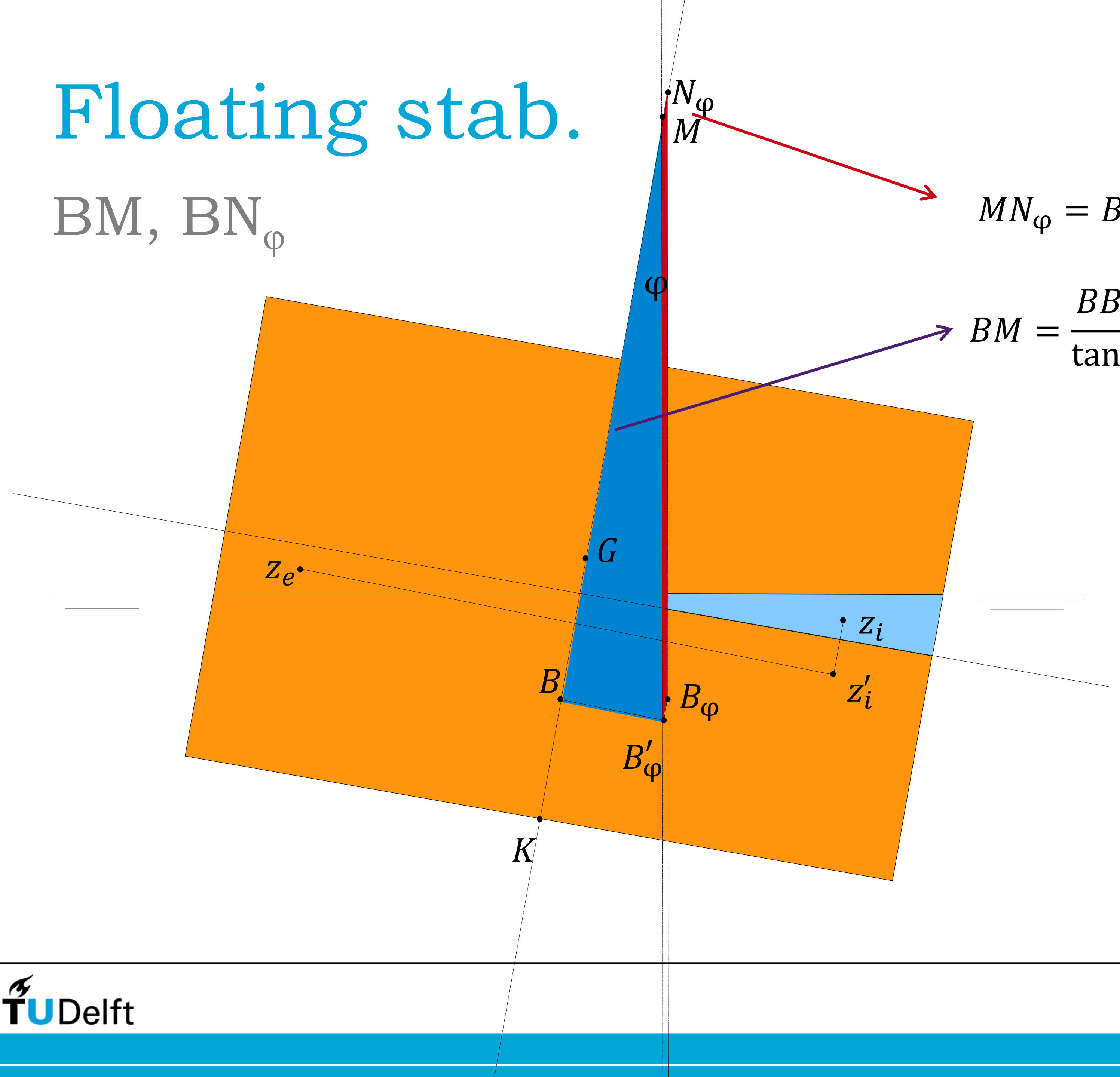


$$\overrightarrow{G_0G_1} = \frac{p \cdot d}{m}$$

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

# Floating stab.

## BM, $BN_\varphi$

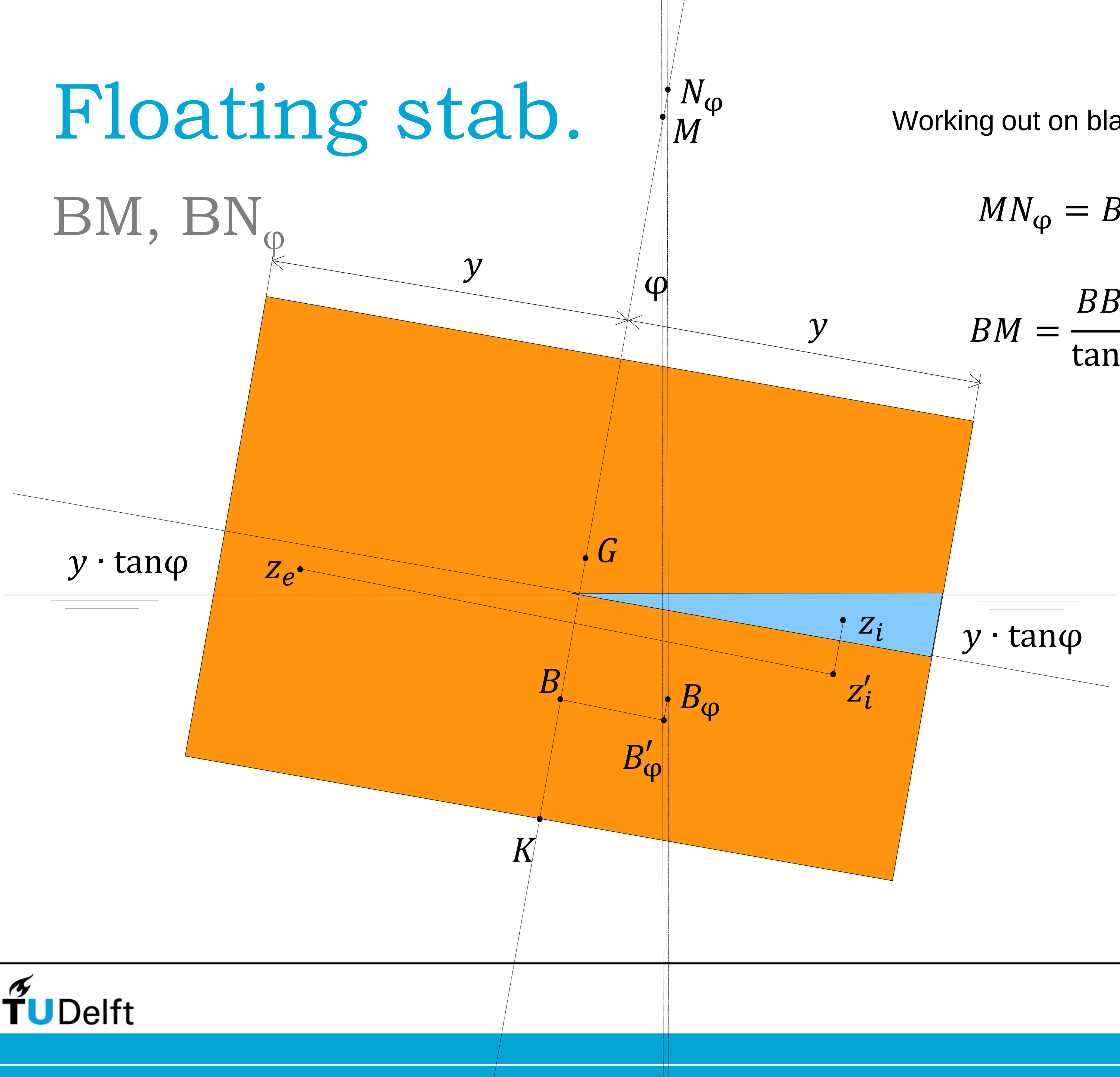


$$MN_\varphi = B_\varphi' B_\varphi$$

$$BM = \frac{BB_\varphi'}{\tan\varphi}$$

# Floating stab.

## BM, $BN_\varphi$



Working out on blackboard...

$$MN_\varphi = B_\varphi' B_\varphi$$

$$BM = \frac{BB_\varphi'}{\tan\varphi}$$

# Floating stability

## BM, BN$_\varphi$

$I_t$

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

$$BM = \frac{BB'_\varphi}{\tan\varphi} = \frac{I_t}{\nabla} \qquad MN_\varphi = \frac{1}{2}\tan^2\varphi\frac{I_t}{\nabla}$$

# 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

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

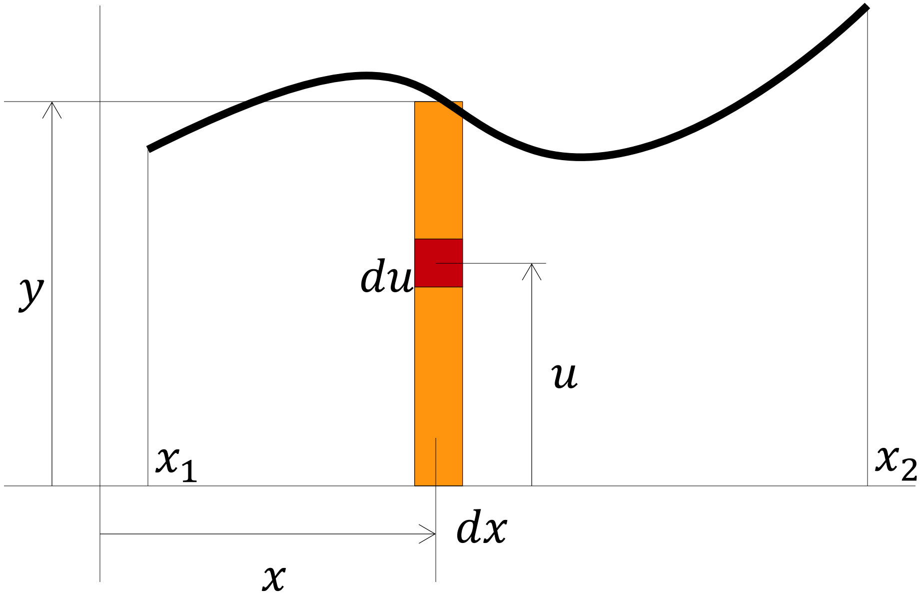
- Exact?

- 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

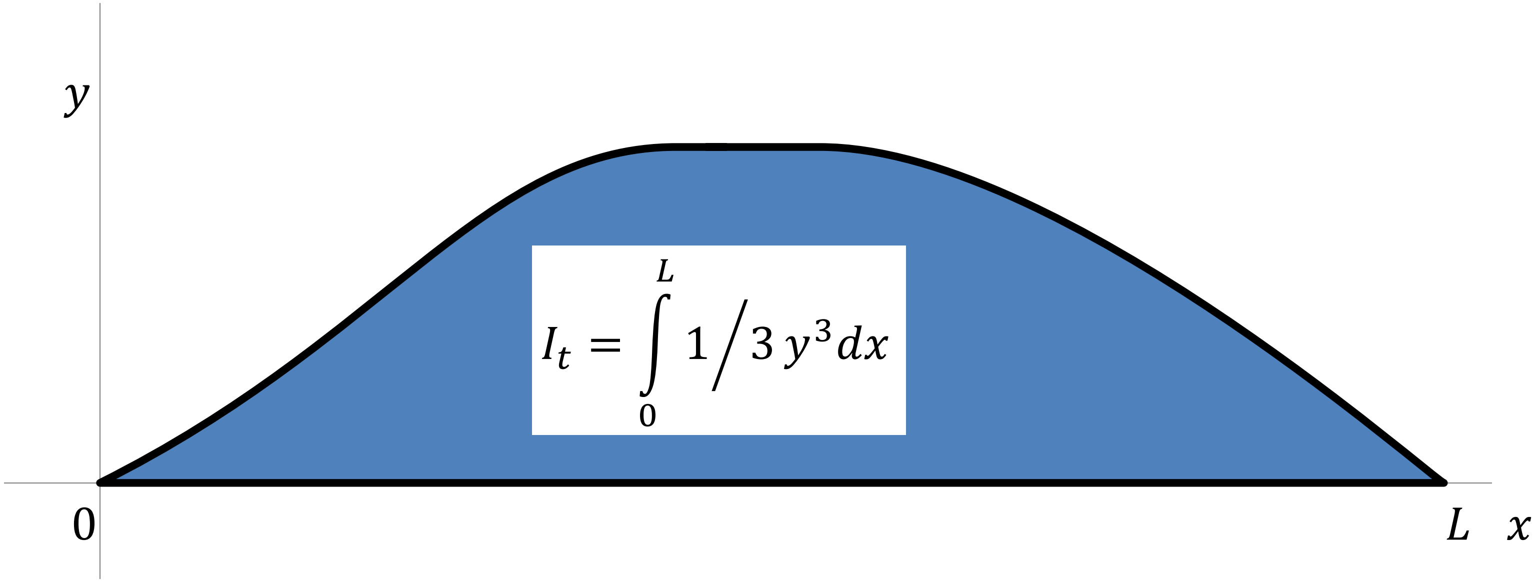


$$dI_{xx} = \int_0^y u^2\, du dx = 1/3\, y^3 dx$$

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

# Floating stability

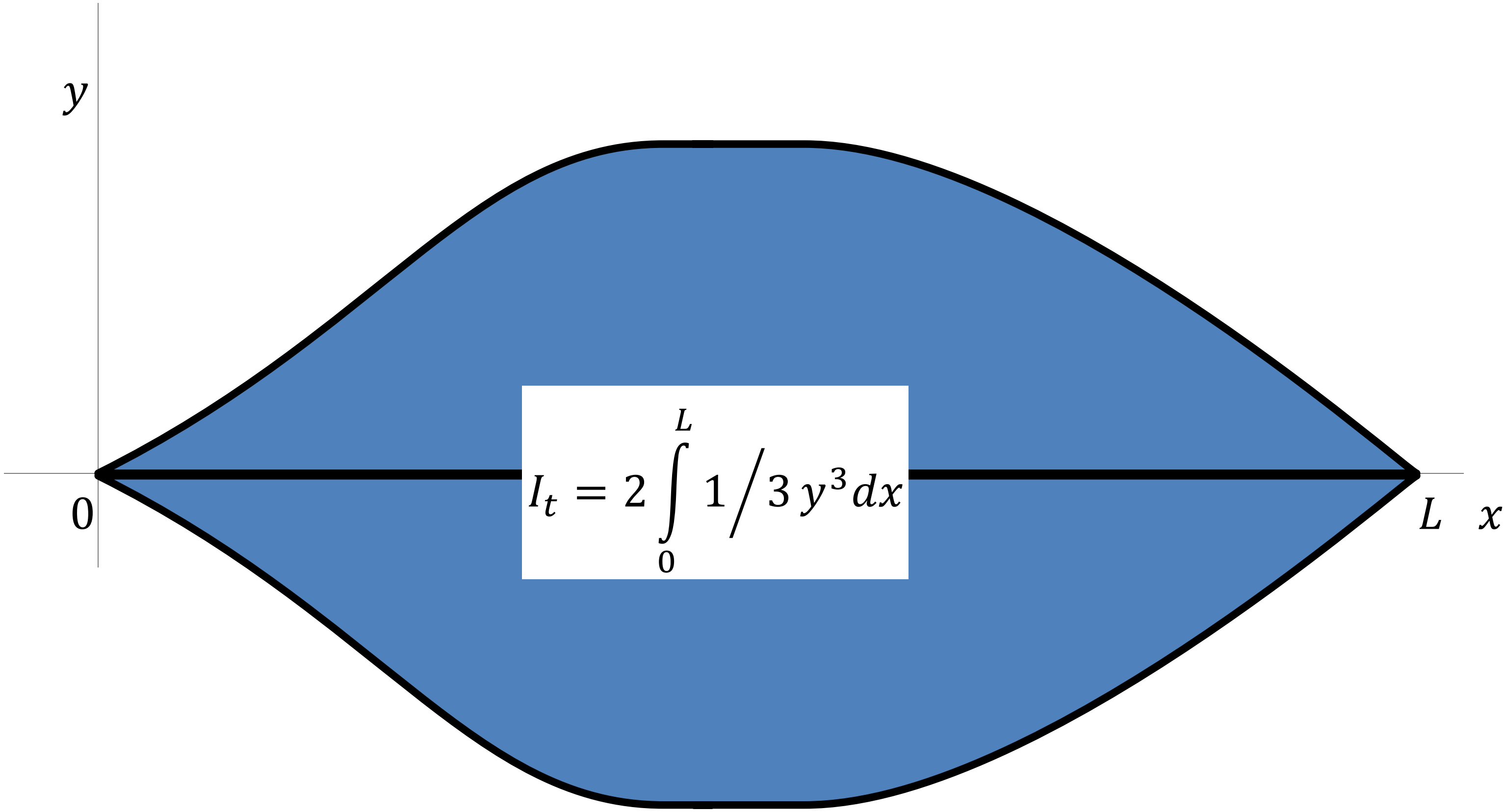
## Moment of inertia of water plane area



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

# Floating stability

## Moment of inertia of water plane area



$$I_t = 2\int_0^L {}^1\!/_3\, y^3 dx$$

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

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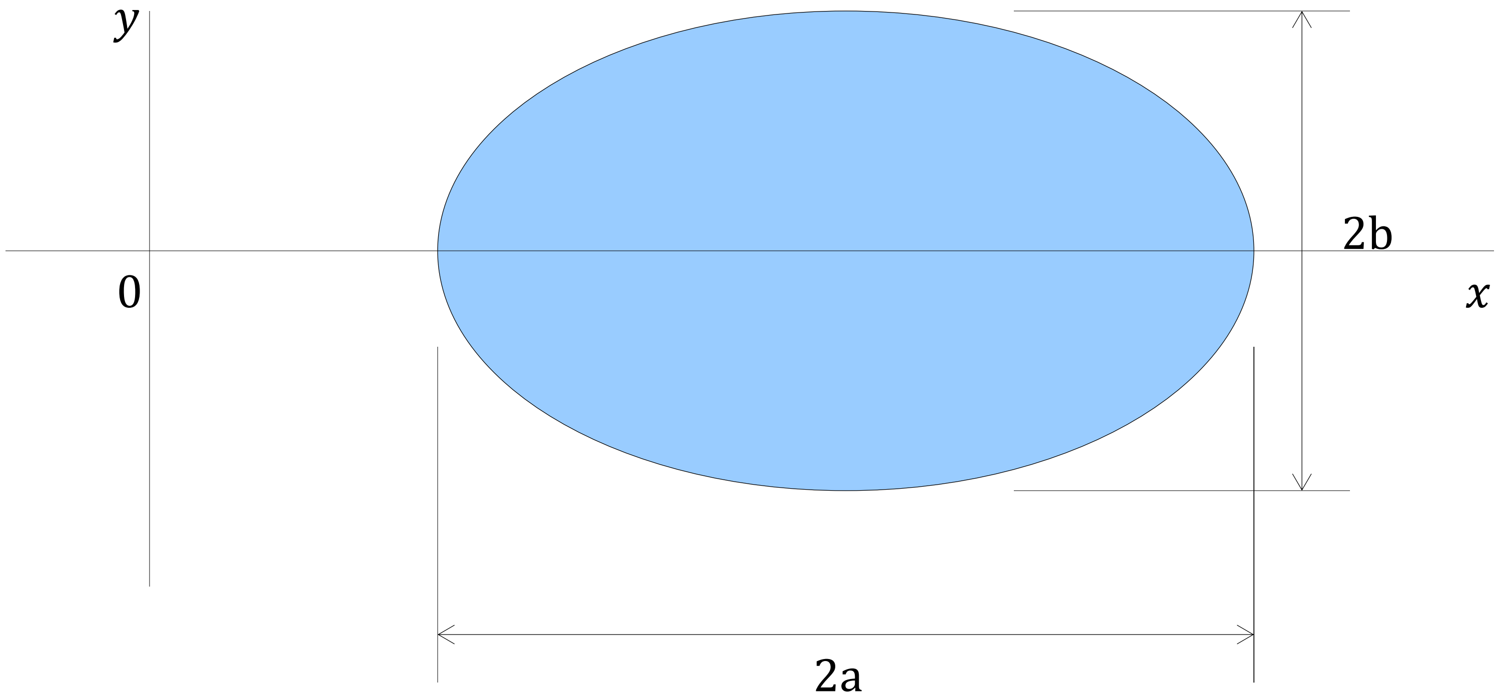

$$I_t = \frac{\pi}{6} ab^3$$

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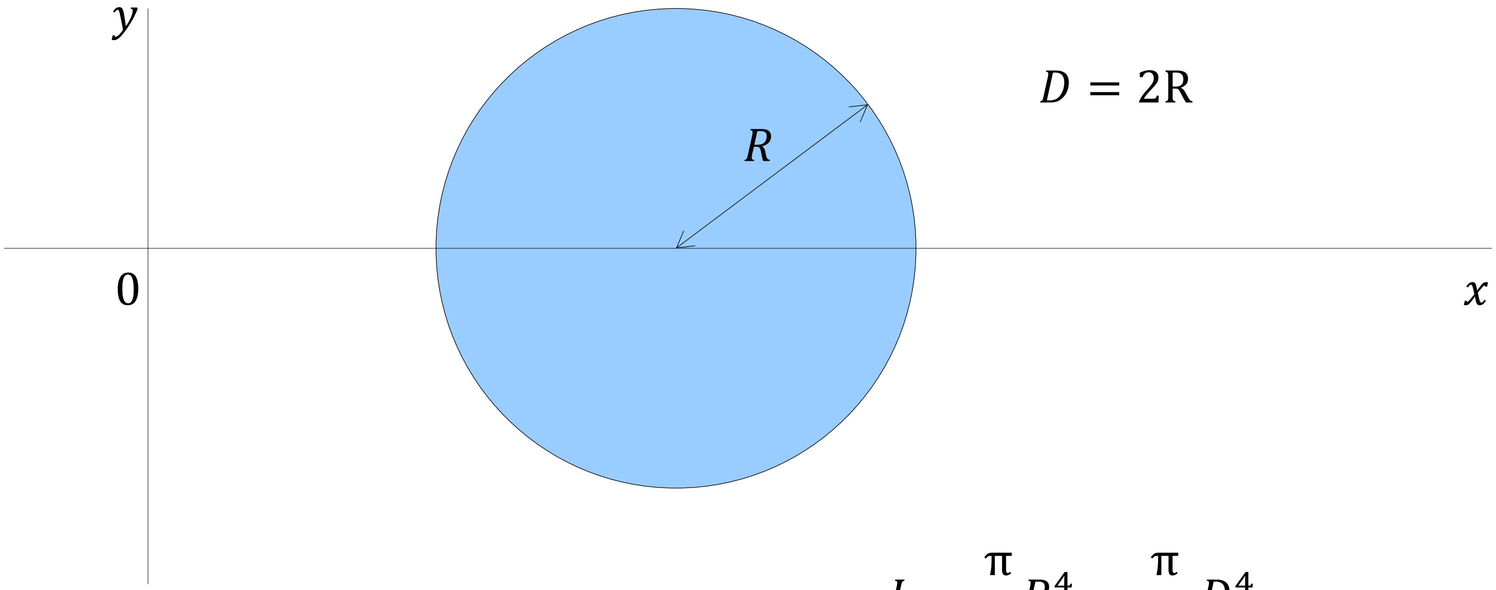

$D = 2\mathrm{R}$

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

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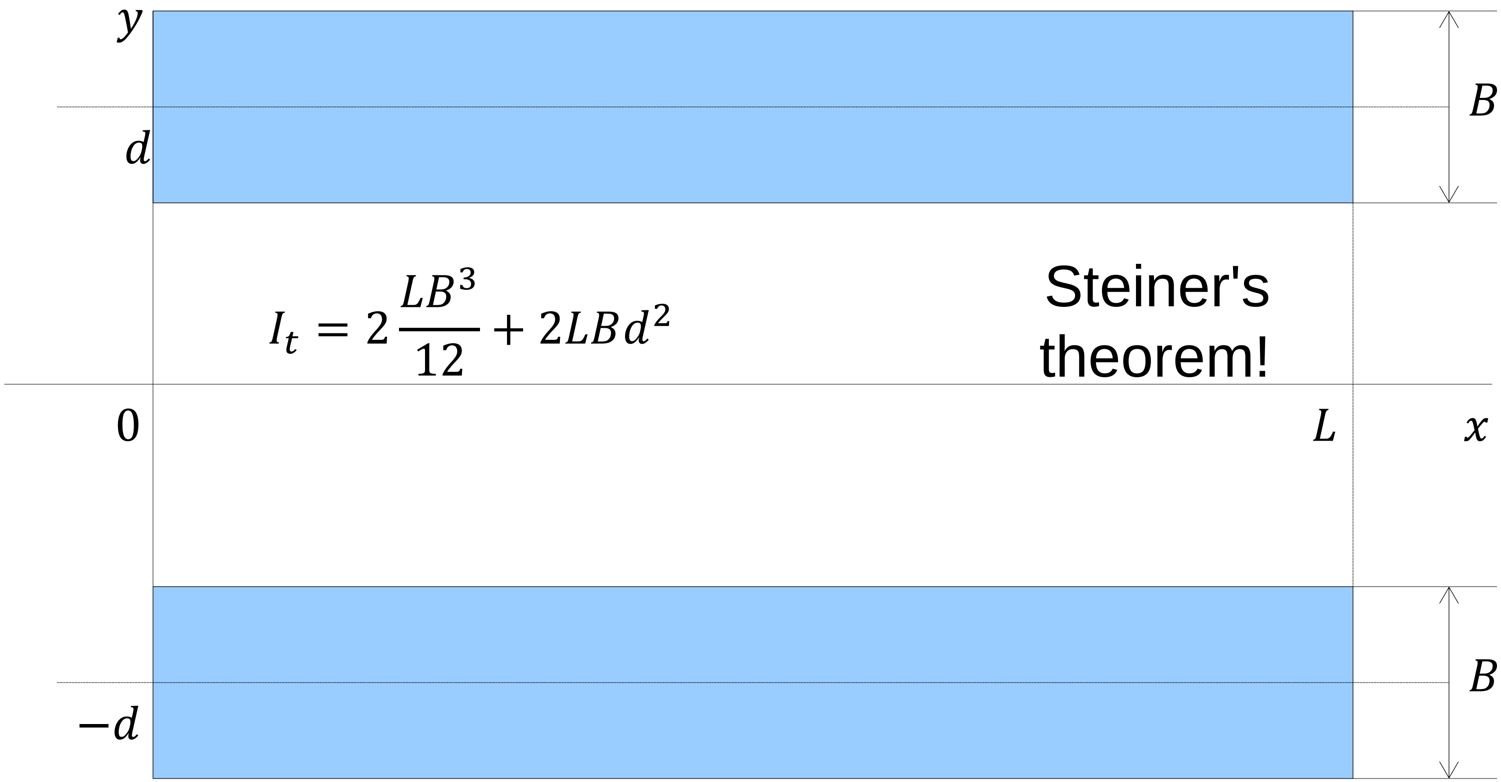

$$I_t = 2\frac{LB^3}{12} + 2LBd^2$$

Steiner's theorem!

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## Questions

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

[4]

[5]

# Sources images

[1] Topside is skidded onto the HYSY229 launch barge, source: Dockwise Ltd.
[2] Topside, source: DTK offshore
[3] The WindFloat prototype operating 5km offshore in Portugal at a water depth of 50m, picture credit: Principle Power
[4] 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
[5] Source:  A.B.S. Model (S) Pte Ltd