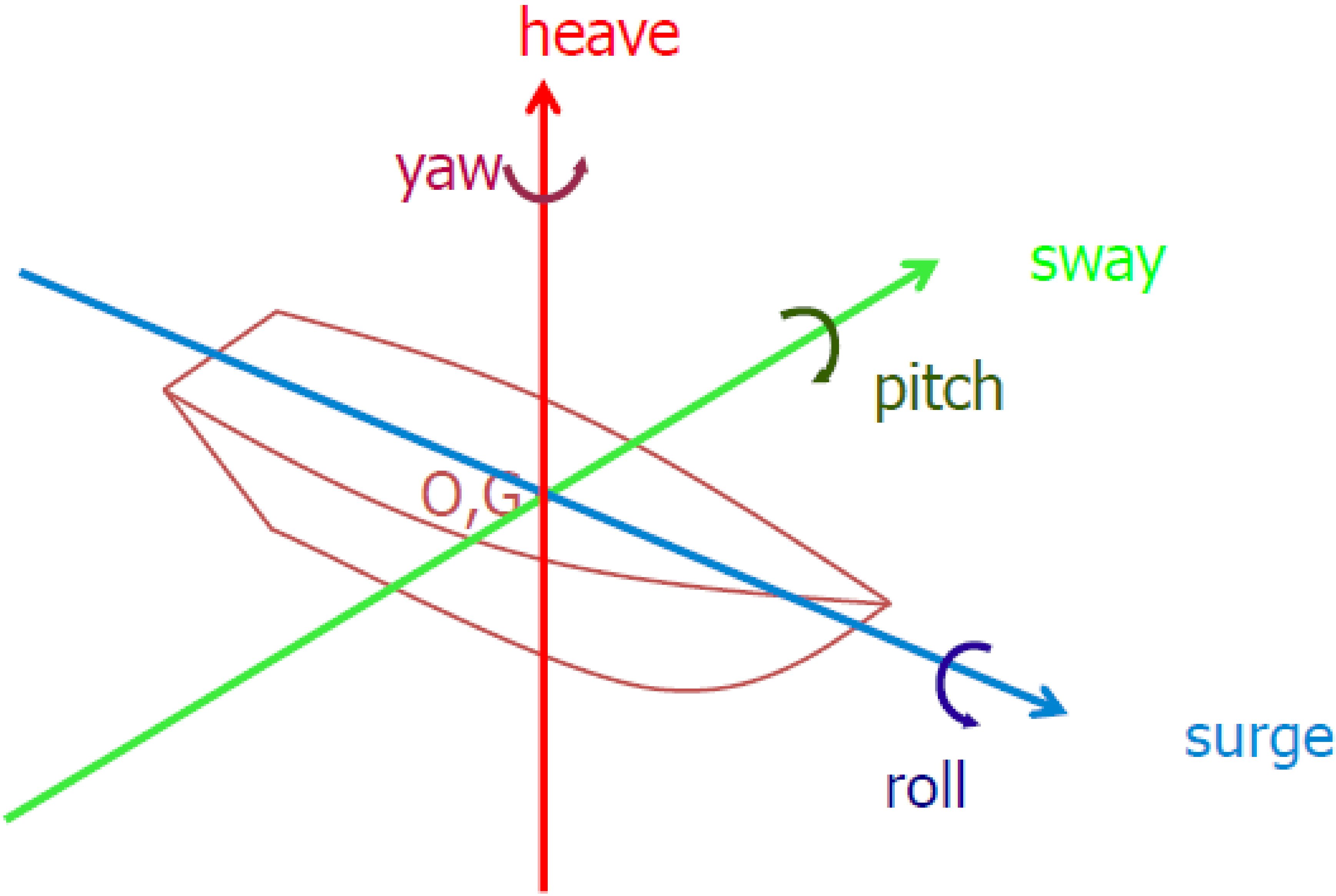
Co-funded by the Erasmus+ Programme of the European Union

MARE

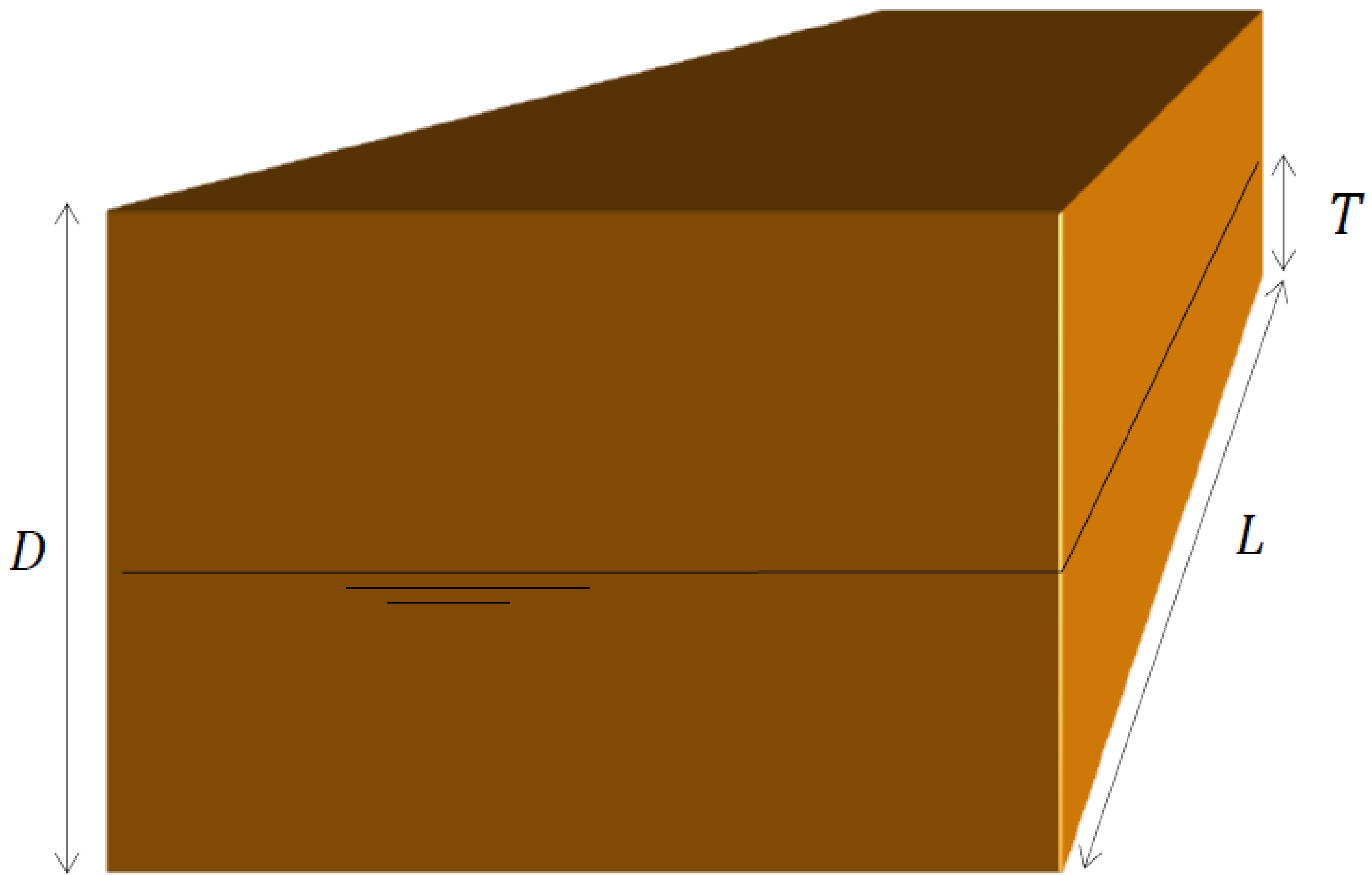
Fundamental of Stability of Floating Bodies

Coordinate system and ship motions



Hydrostatics

Naming Conventions Ship Dimensions



L Length

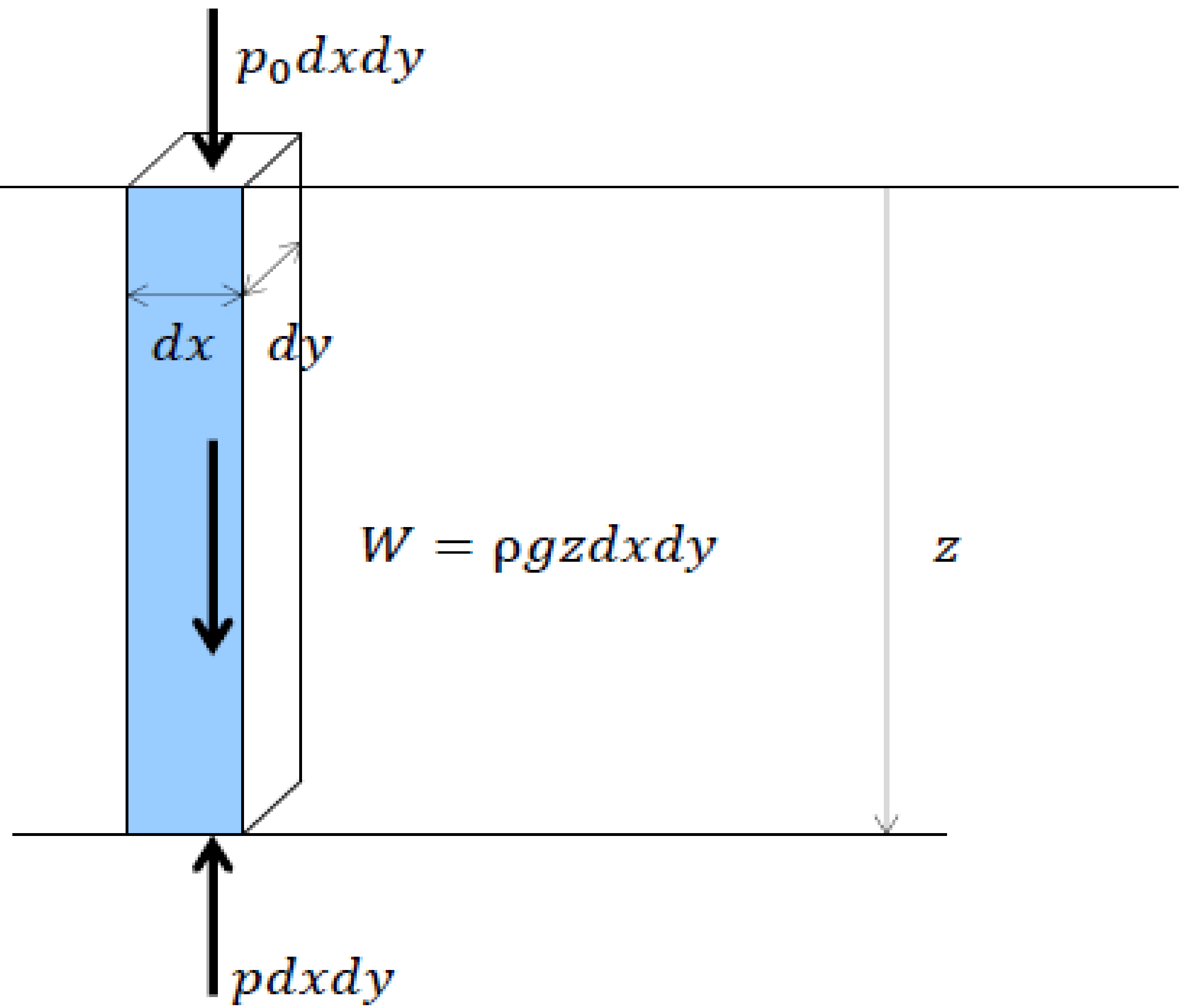
B Beam/width

D Depth

T Draft

Hydrostatics

Hydrostatic pressure

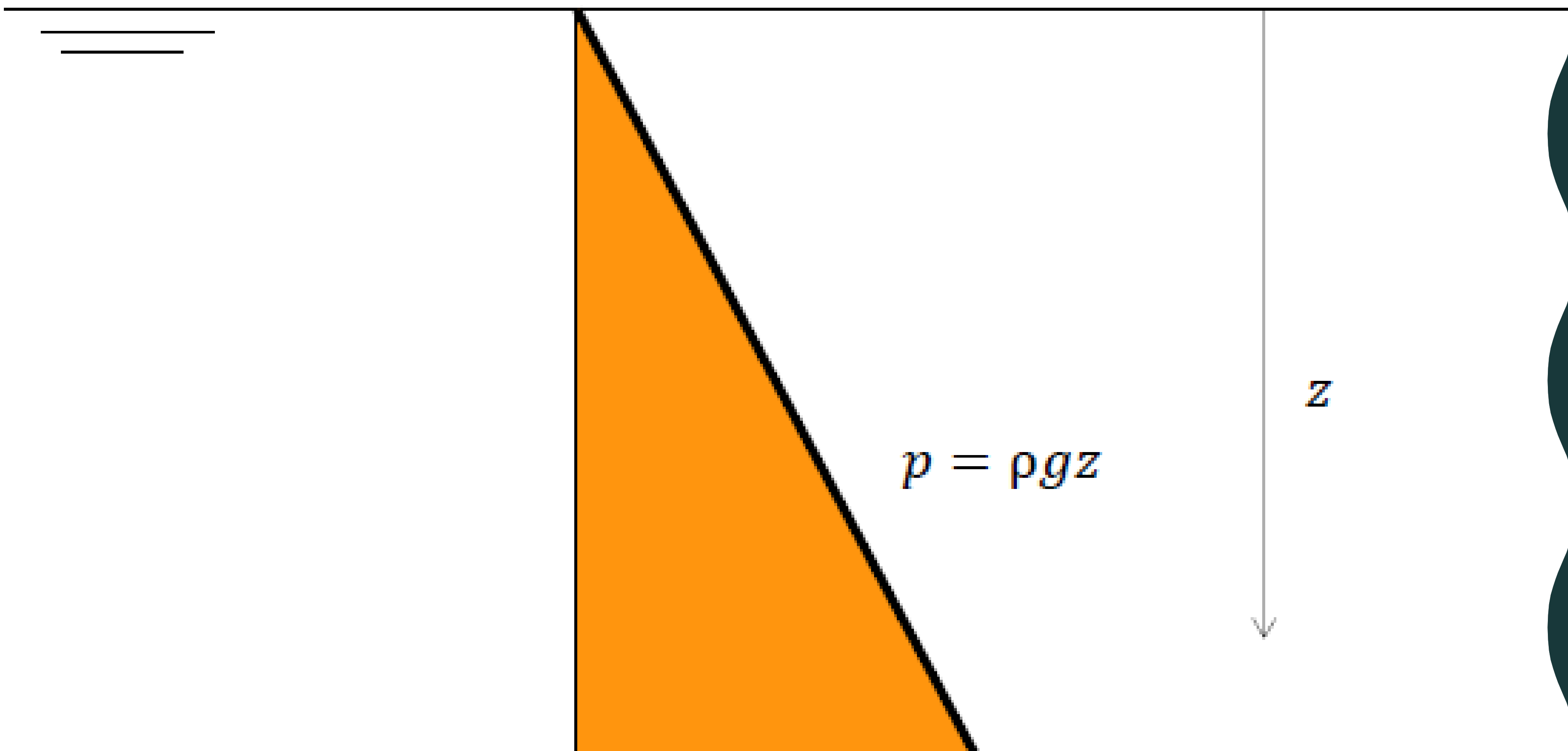


$$p_0 dx\cancel{dy} + \rho g z dx\cancel{dy} = p dx\cancel{dy}$$

$$p = p_0 + \rho g z$$

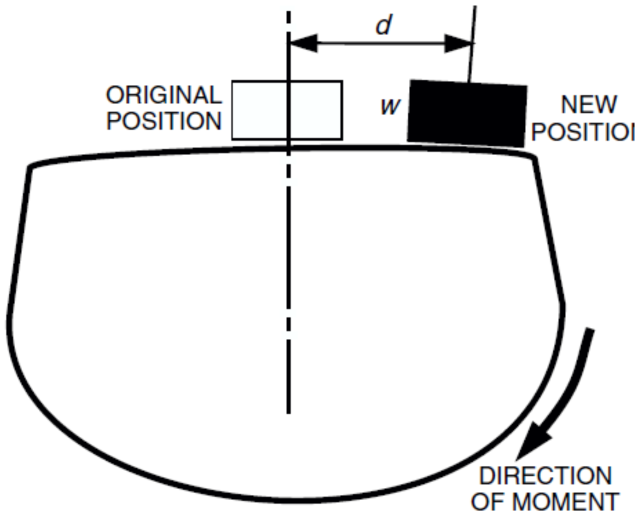
Hydrostatics

Hydrostatic pressure

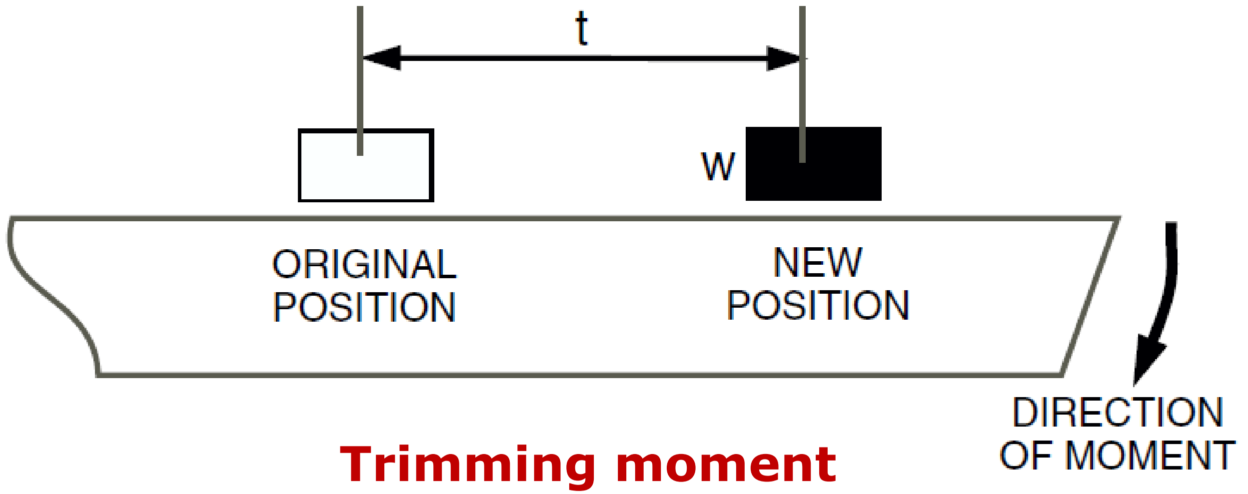


Stability of Floating Structures

- Stability of floating structures is a fundamental design problem that requires understanding of the basic physics that control the stability of the floaters.
  - Stability is the game of these physics terms: volume, density, weight, center of gravity, force, and moments.



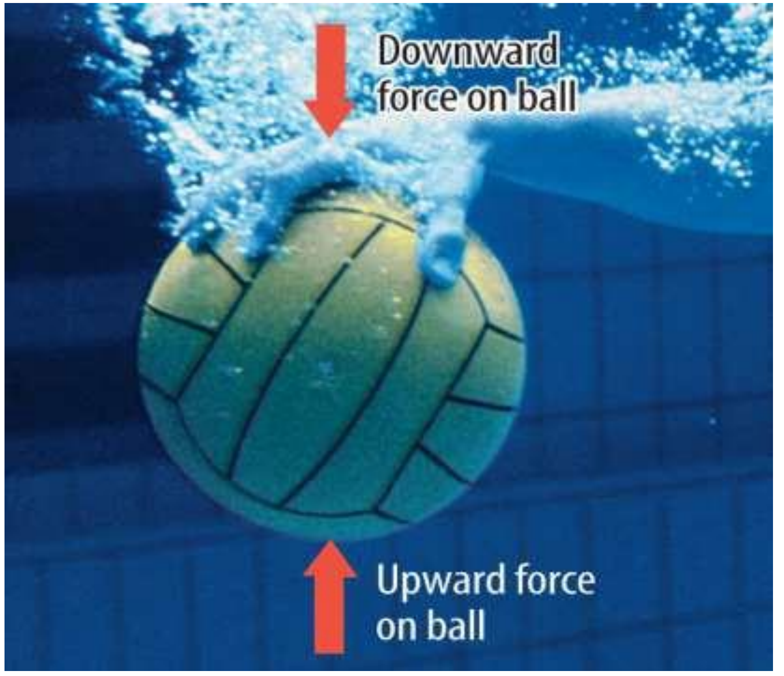
Inclining moment produced by moving a Weight outboard



Trimming moment

What Is Buoyancy Force

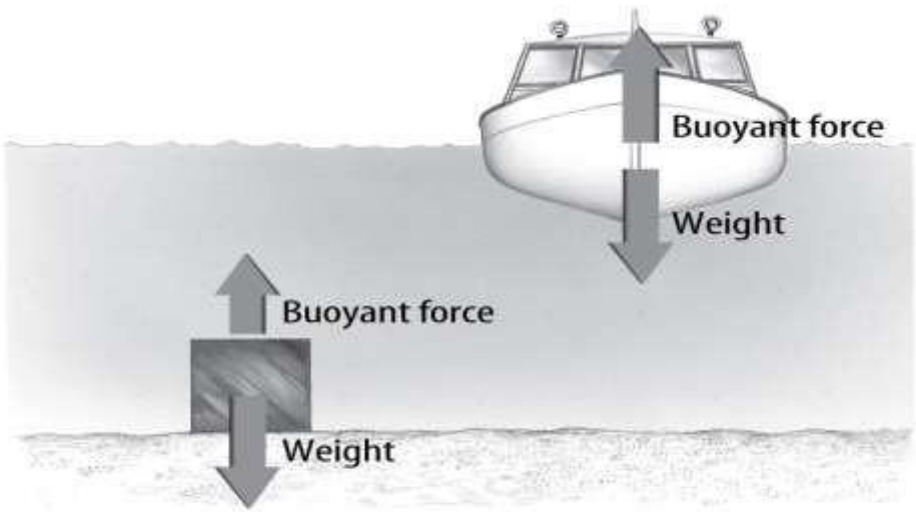
- When a body is immersed in fluid, an upward force is exerted by the fluid on the body.
- This upward force is equal to the weight of the fluid displaced by the body and is called the force of buoyancy.



What causes buoyant force?

Buoyant force is the  force on an object exerted by the surrounding fluid.

- When an object pushes water, the water pushes back with as much force as it can.
- If the water can push back as hard, the object
  - floats (boat). If not, it sinks (steel).



Forces Acting on Buoyancy

- The **buoyant force** is caused by the difference between the pressure at the top of the object (**gravitational force**), which pushes it downward, and the pressure at the bottom (**buoyant force**), which pushes it upward
- Since the pressure at the bottom is always greater than at the top, every object submerged in a fluid feels an upward buoyant force.
    - **Buoyancy= "the floating force"**
    - Water is "heavier" than the object…so the object floats
    - Low density-more likely to float
    - Buoyant force is measured in **Newtons (N)**

How do you Calculate B_F?

Buoyant Force= Weight of displaced fluid

OR

$$B_F = W_{air} - W_{water}$$

Buoyant Force = Weight of object in air - Weight of object in water

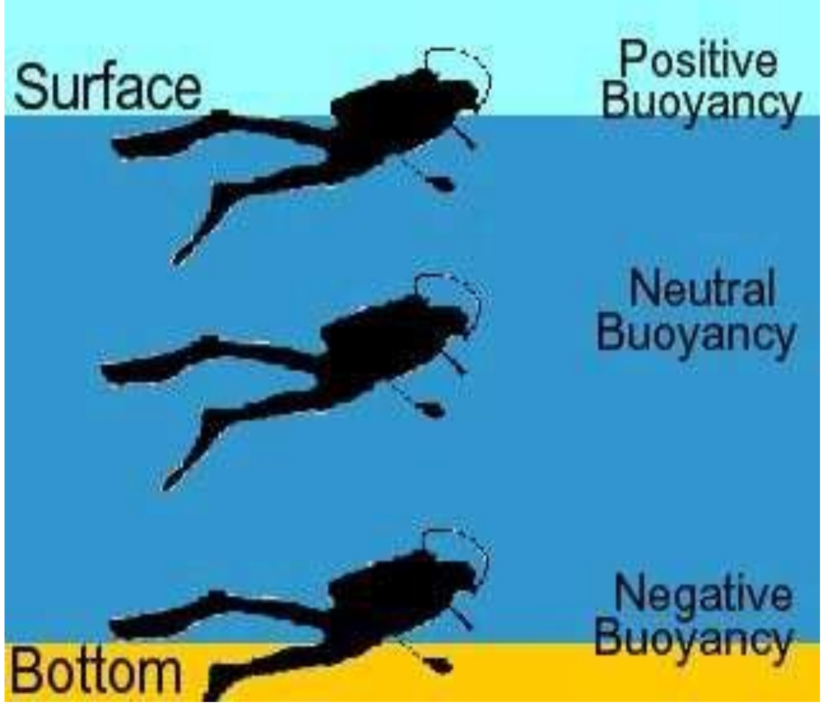
Condition of equilibrium of a floating and sub-merged bodies

Positive buoyancy:

- Buoyant force is greater than weight so the object floats.

Neutral buoyancy:

- Buoyant force is equal to weight so the object is suspended in the fluid.



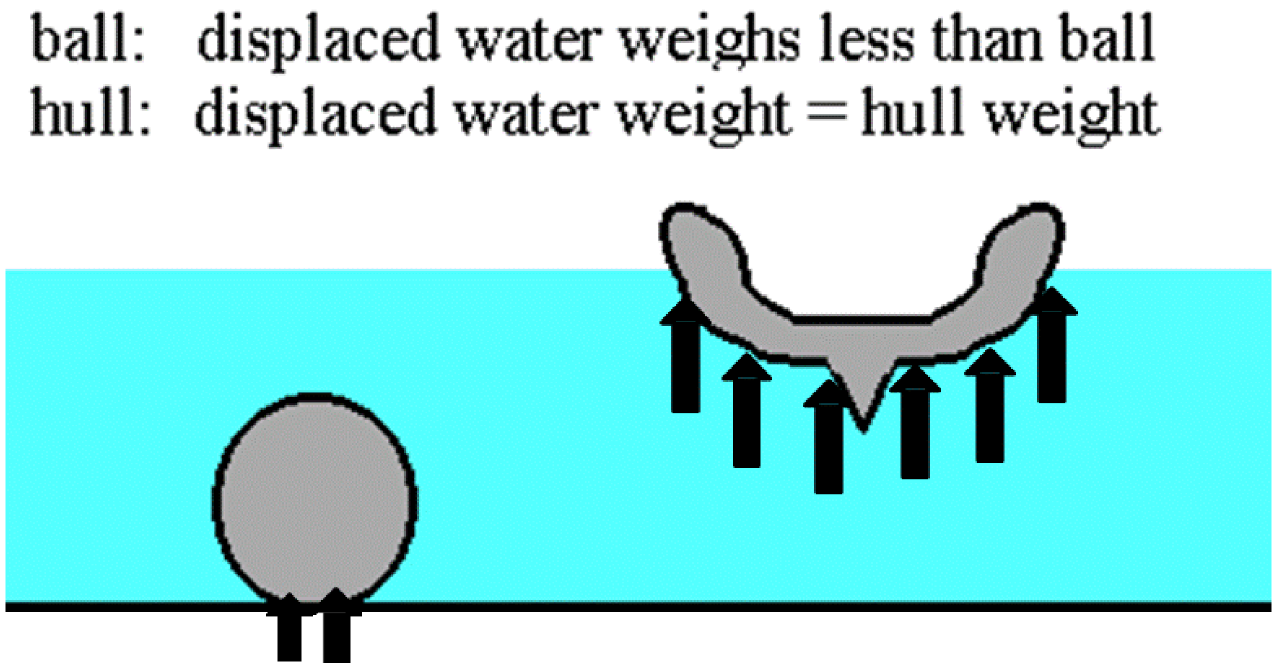
Negative buoyancy:

- Buoyant force is less than weight so the object sinks.

Why do things float?

1. Things float if they are less dense than the fluid they are in.
2. Things float if they weigh less than the buoyant force pushing up on them.
3. Things float if they are shaped so their weight is spread out.

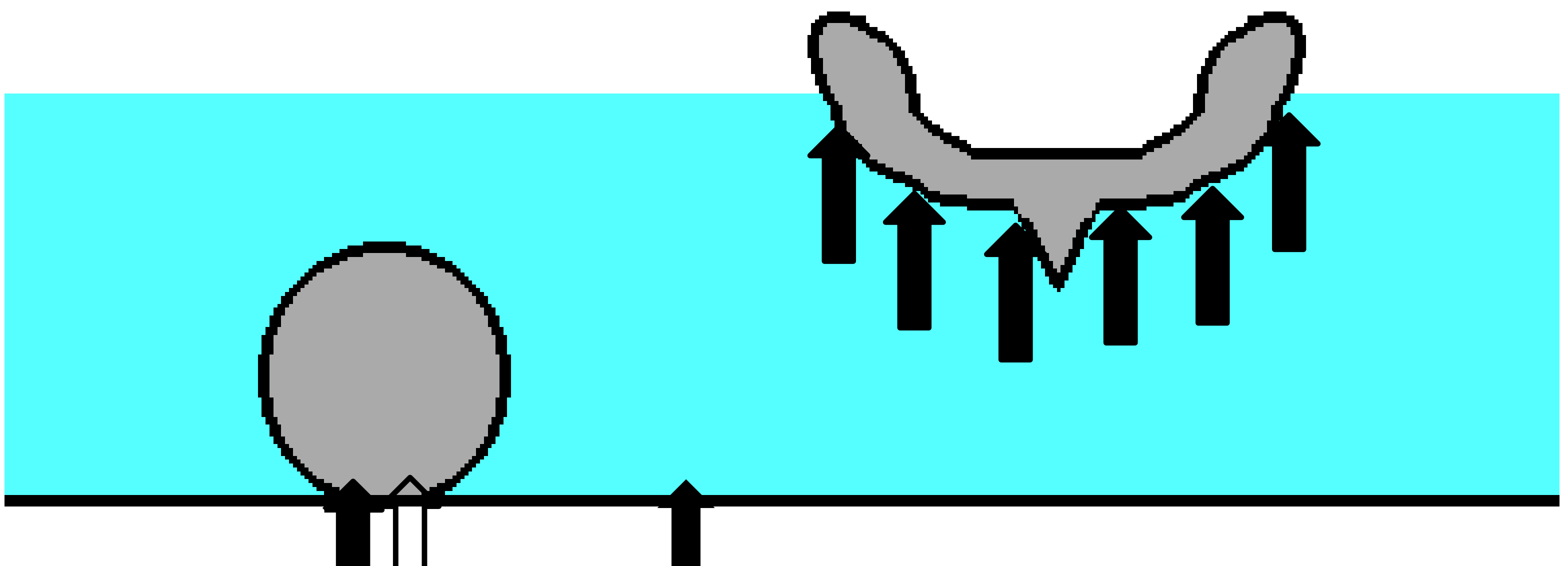
How can you get 50 kg of solid steel to float?



Shape

- How can you get 50 kg of solid steel to float?

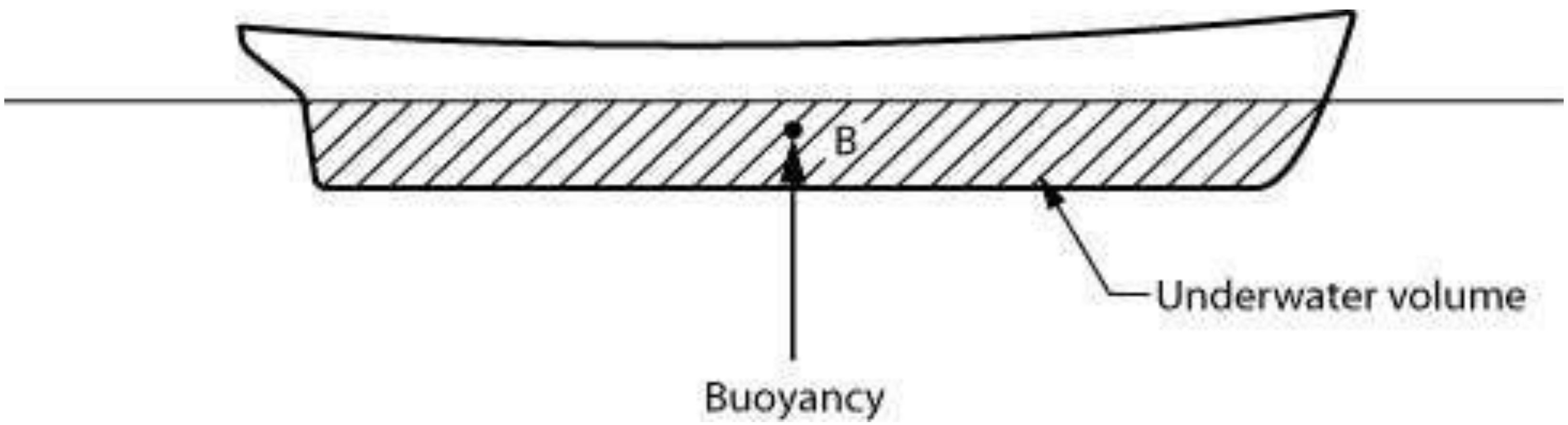
ball: displaced water weighs less than ball
hull: displaced water weight = hull weight



Centre of Buoyancy

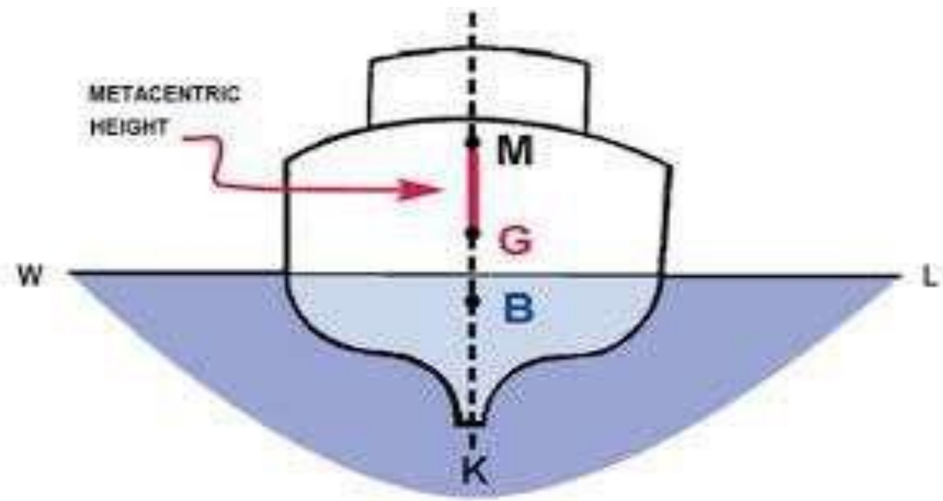
Definition:-

- The point through which the force of buoyancy is supposed to act is known as Centre of Buoyancy.



META-CENTRE

- It is defined as the point about which a body starts oscillating when the body is tilted by a small angle.
- It is the point at which the line of action of the force of buoyancy will meet the normal axis of the body when the body is given small angular displacement.



Meta-centric Height

- It is the distance between the meta-centre of floating body and centre of gravity.
- We can find this height by two methods:-

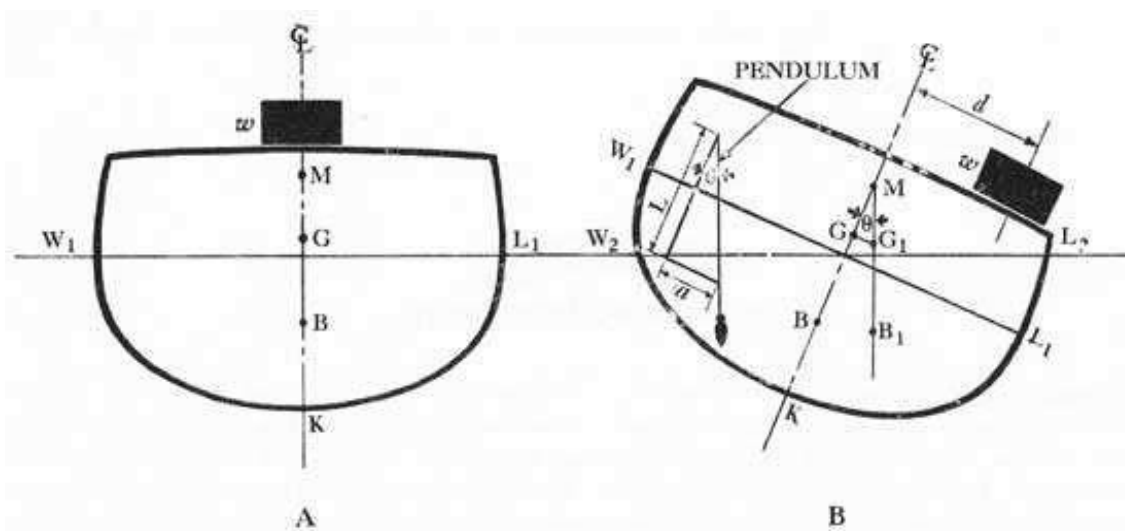
1. Analytical Method

$$GM = \frac{I}{\forall} - BG$$

Here,

I=Moment of Inertia m^4

$\forall$ =Volume of sub-merged body



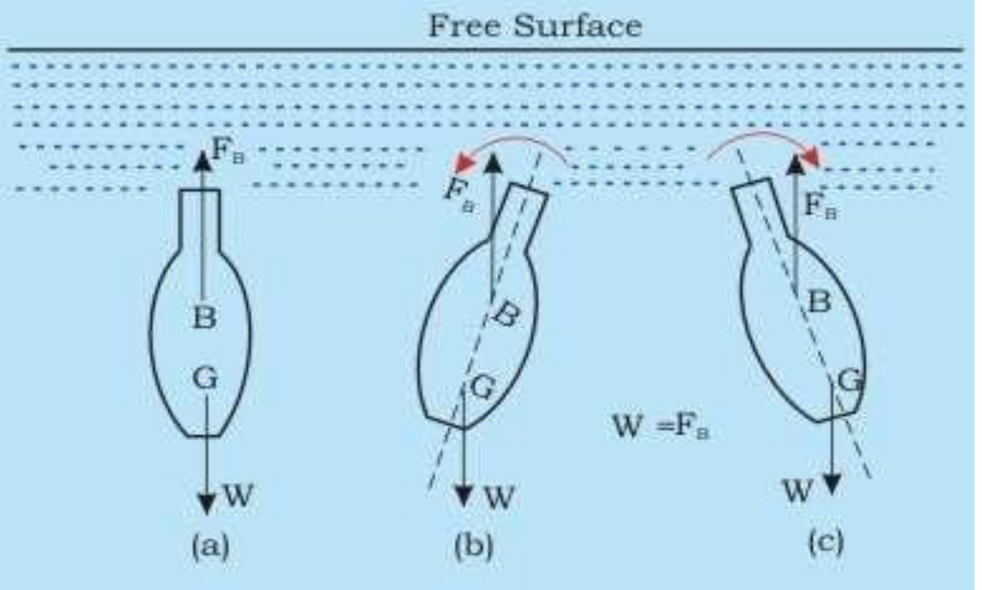
Condition of equilibrium of a floating and sub-merged bodies

Stability of Sub-merged Body:-

a. Stable Equilibrium:-When W=F_b and point B is above G .

b. Unstable Equilibrium:- When W=F_b but B is below G.

c. Neutral Equilibrium:-When W= F_b and B & G are the same point.

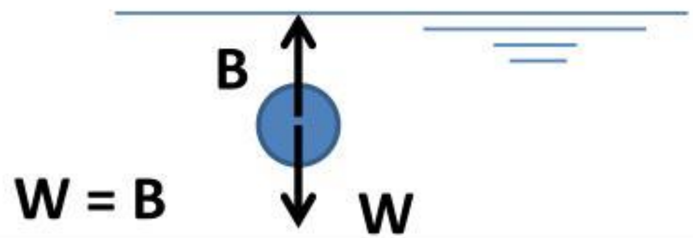


Engineering Principle #1: Neutral Buoyancy & Stability

- **Weight (W) – Measure of the gravitational force on an object (not submerged)**

- **Buoyancy (B) - Upward force exerted by a liquid on an immersed or floating object.**

- **Neutrally Buoyant - An object that will neither sink nor float. W = B**

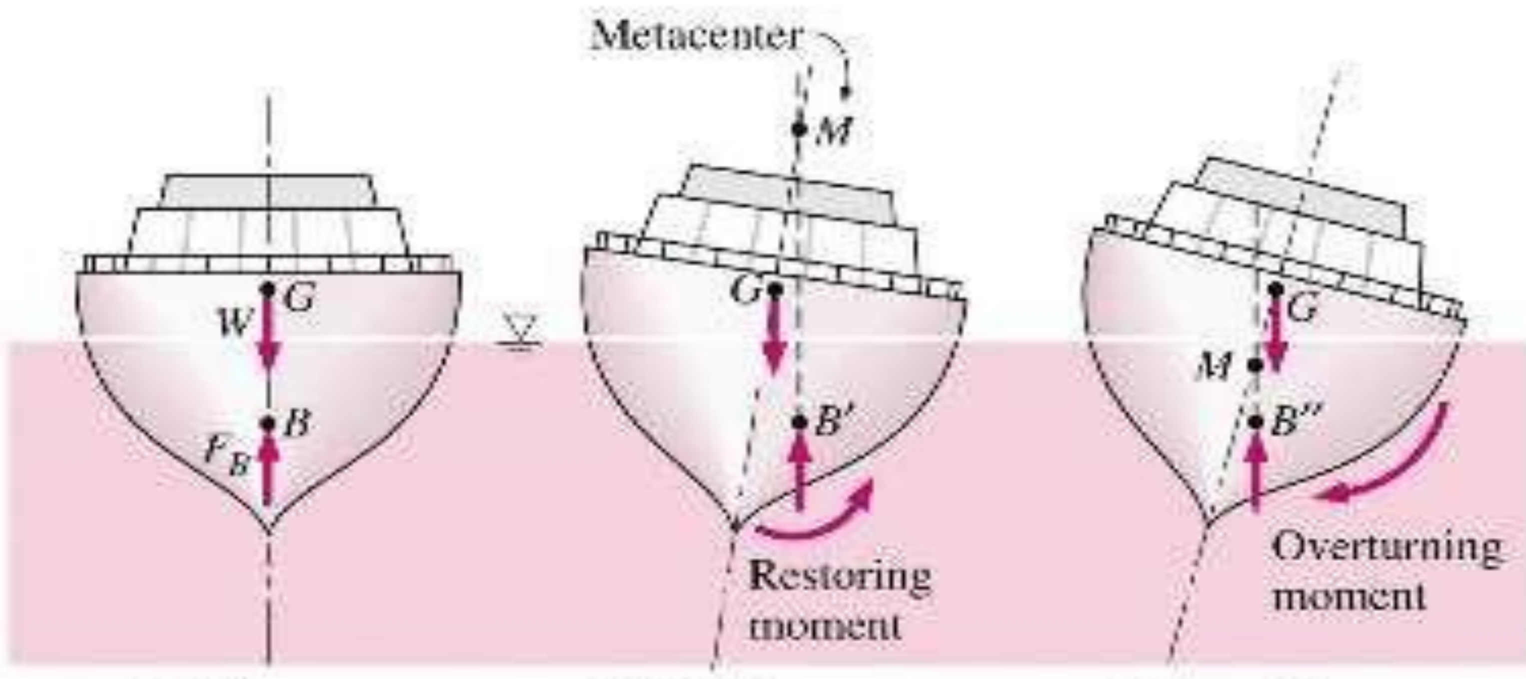


- **Center of Buoyancy (CB) – Center of gravity of the displaced fluid.**
- **Center of Gravity (CG) – Point where the weight of the entire body can be considered to act.**

Design Goal: Nearly Neutrally Buoyant with CB above CG.

Stability of Floating Body

a. Stable Equilibrium:-If the point M is above G.
b. Unstable Equilibrium:-If the point M is Below G.
c. Neutral Equilibrium:-If the point M is at the G.

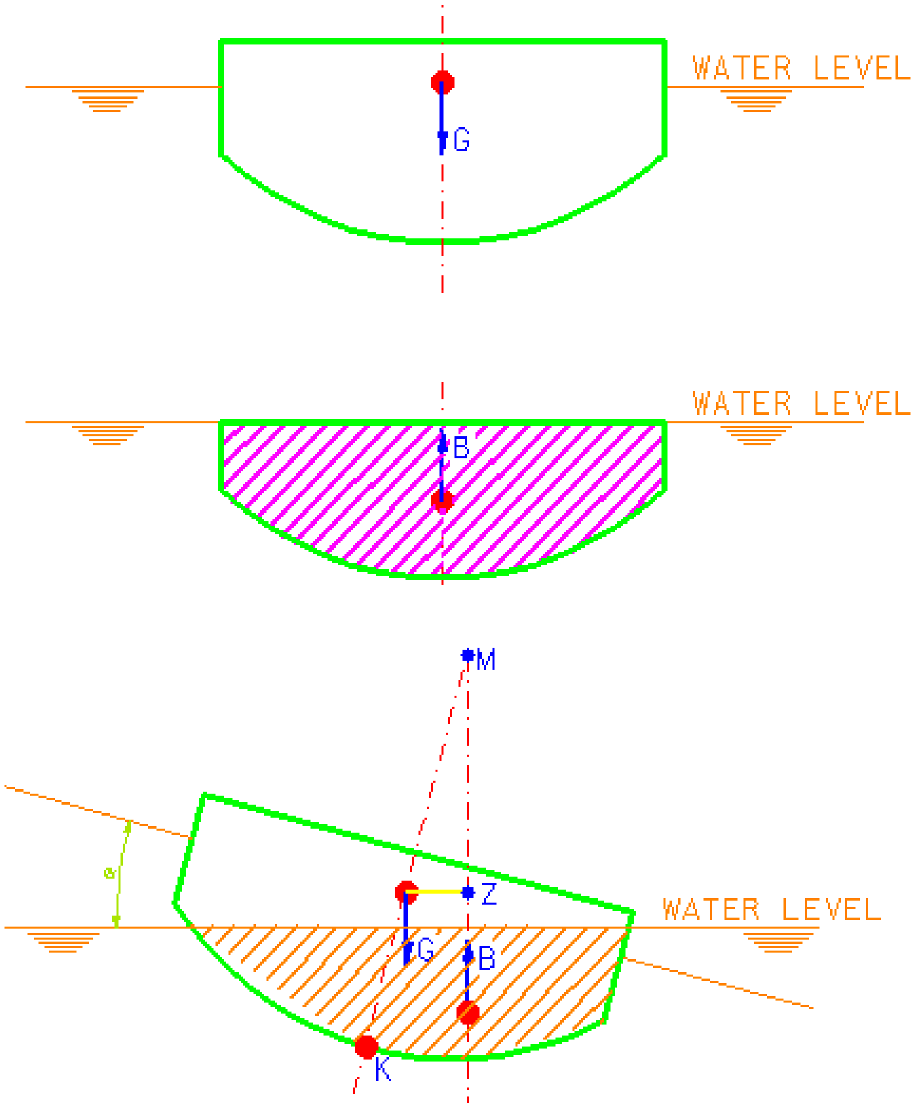


(a) Stable (b) Stable (c) Unstable

Naval Architecture

HYDROSTATICS AND STABILITY:

- Stability is resistance to capsizing
- Centre of Buoyancy is located at centre of mass of the displaced water.
- Under no external forces, the centre of
- gravity and centre of buoyancy are in same vertical plane.
- Upward force of water equals to the weight of floating vessel and this weight is equal to weight of displaced water
- Under wind load vessel heels, and thus CoB moves to provide righting (stabilizing) moment.
- Vertical line through new centre of buoyancy will intersect CoG at point M called as Metacentre



Rules of Floaters Design

First Rule of Floaters: Buoyancy must equal weight *plus any external vertical forces*.

Weight includes:

1. Hull Steel Weight
2. Hull Outfitting
3. Topsides Payload (fixed and variable)
4. Topsides Structure
5. Ballast in Hull (fixed and variable)

External Vertical Forces Include

1. Component of Mooring Load
2. Component of Riser Load
3. Suspended weights (e.g. from crane)

DW Floaters Design Criteria

Hydrostatics and Stability

Floating stability

Definition

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

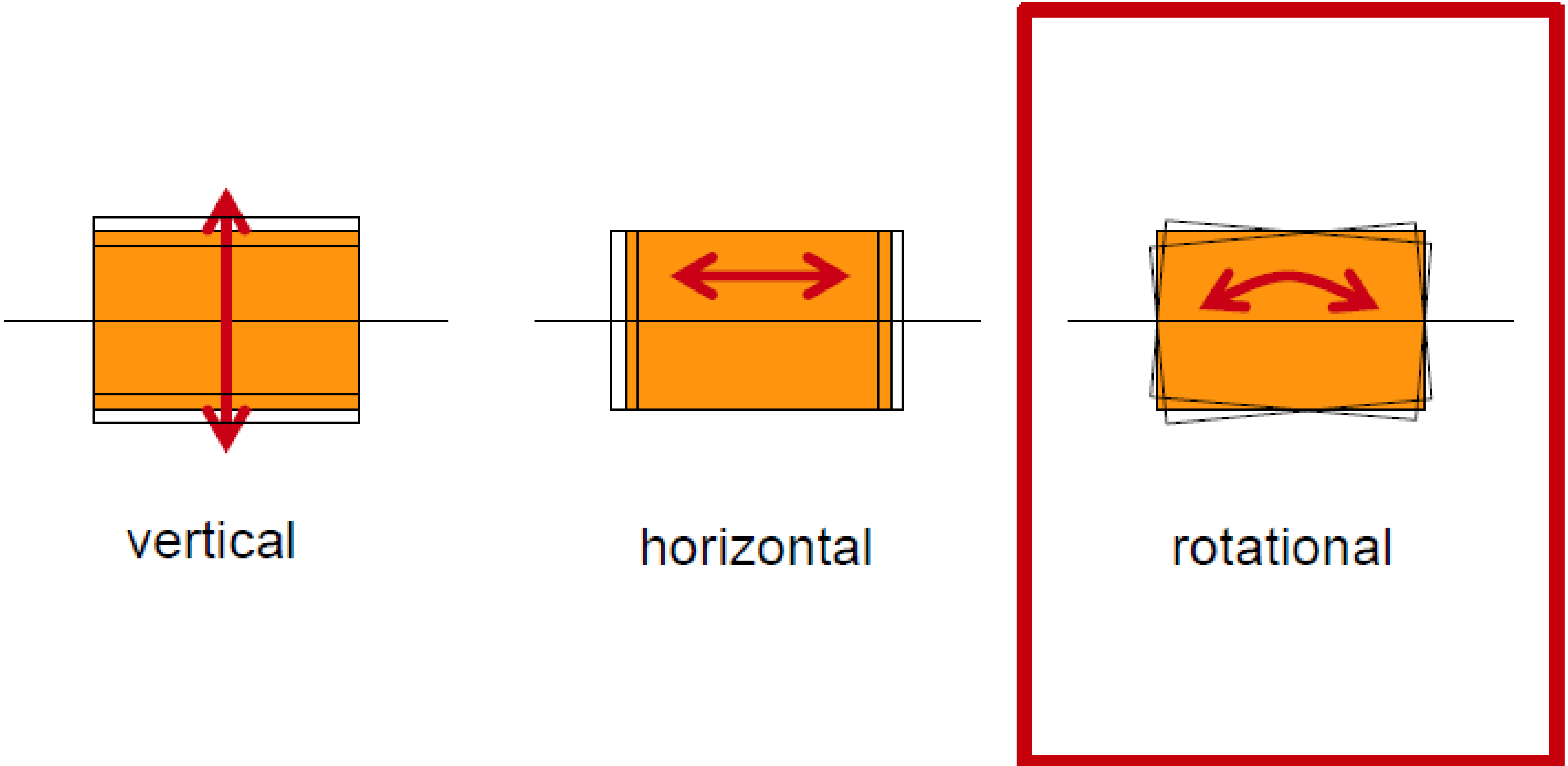
- A ‘stable’ ship quickly restores its equilibrium when perturbation is removed

- 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?

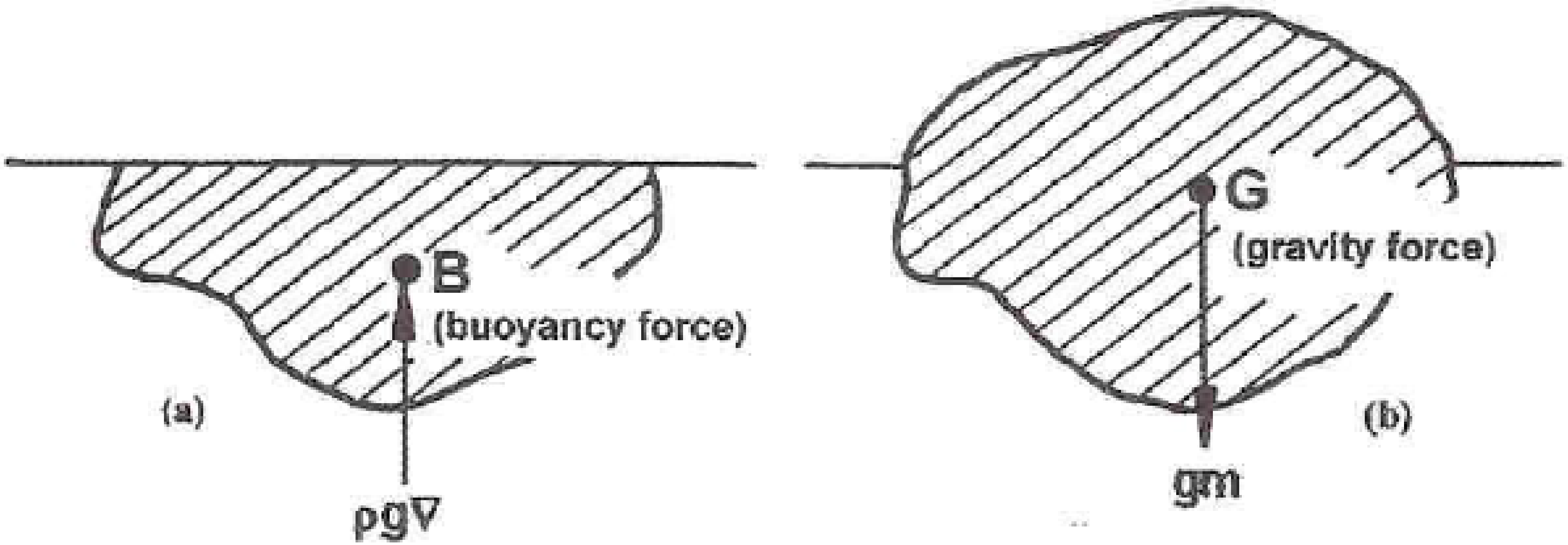
Floating stability

Equilibrium for floating structures



Floating stability

Center of buoyancy and center of gravity

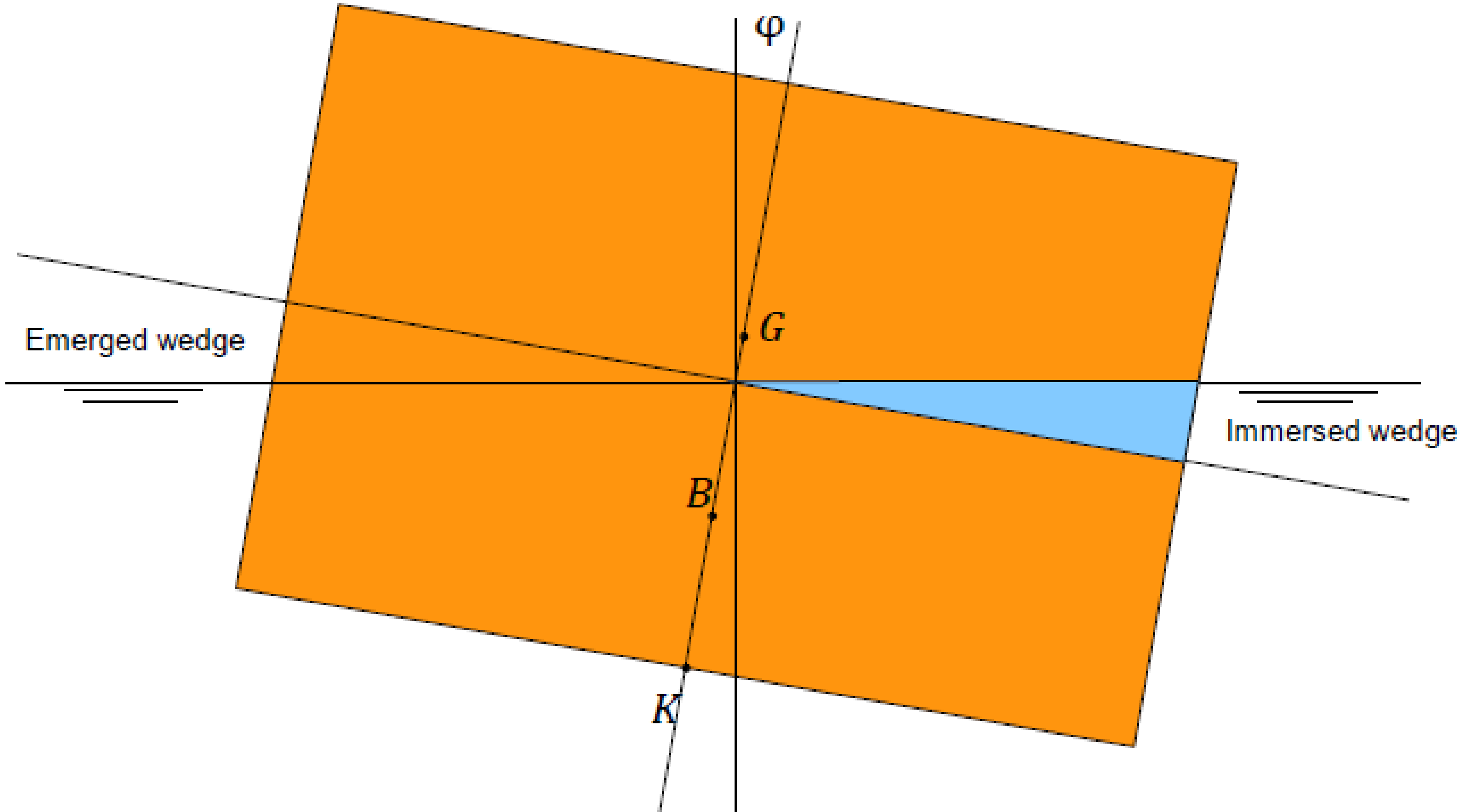


B point about which first moment of submerged volume = 0

G point about which first moment of mass or weight = 0

Floating stability

Stability moment



DW Concept

Weight Efficiency Metric

$$\text{Structural Weight Efficiency} = \frac{\text{Total Topsides Payload}}{\text{Total Hull Plus Deck Weight}}$$

Total Topsides Payload = Weight of all deck equipment and facilities including quarters, drilling systems, etc. Also includes TTR loads, SCR loads and secondary deck steel. Topsides equipment or facilities carried in the hull, and hull ballast earmarked for future expansion are also included.

Total Hull Plus Deck Weight = Structural steel weight of hull, hull marine systems, hull appurtenances and outfitting. Also includes deck primary structural steel weight.

Hull Form / Location	Design Maturity	Ratio Range
CTLPs in GoM	As-Built	0.6 – 0.8
ETLPs in GoM	As-Built	1.1 – 1.2
ETLPs in W Africa	As-Built	1.3 – 1.4
ETLPs in Brazil	Conceptual	1.2 – 1.3

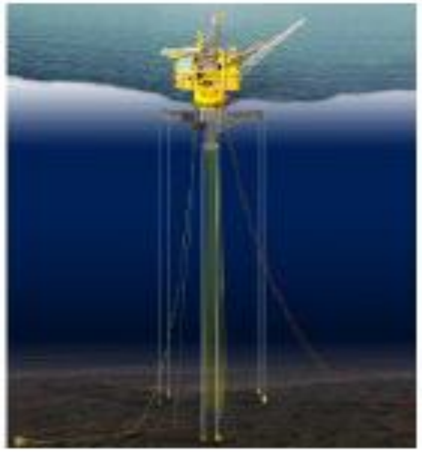
DW Concept

Evaluation of floating platforms (hulls)

- Deck area for support and arrangement of topsides
- Wave-induced motions and effect of current and wind for:
  - heave (affecting riser, production process
  - horizontal drift-off and surge/sway
  - roll (of ship shape floaters)
- Implication on riser types and support of risers
- Structural challenges- complex details, large plate thicknesses, fatigue problems etc
- Safety wrt accidental events, structural robustness
- Fabrication issues – modular fabrications
- Installation

Rules of Floaters Design

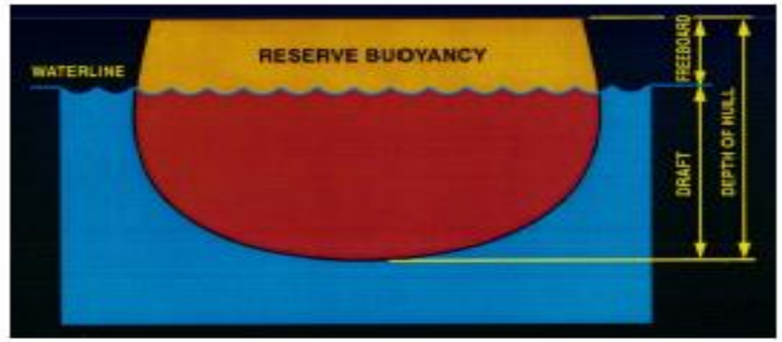
2^{nd} Rule of Floaters: The weight shall be positioned such that the hull will not tip over!



Typhoon TLP after Hurricane Rita

Rules of Floaters Design

3rd Rule of Floaters: There should be enough Reserve Buoyancy to maintain balance and stability even with tanks flooded!



Thunderhorse Semi after Hurricane Dennis – Reserve Buoyancy in Deck saved it from sinking!

P-36 After Explosion in Column – Not Enough Reserve Buoyancy

Rules of Floaters Design

4th Rule of Floaters: The Platform Should Stably Support the Deck Above the Highest Wave Crest






Intro to hydrostatics and stability

Nomenclature

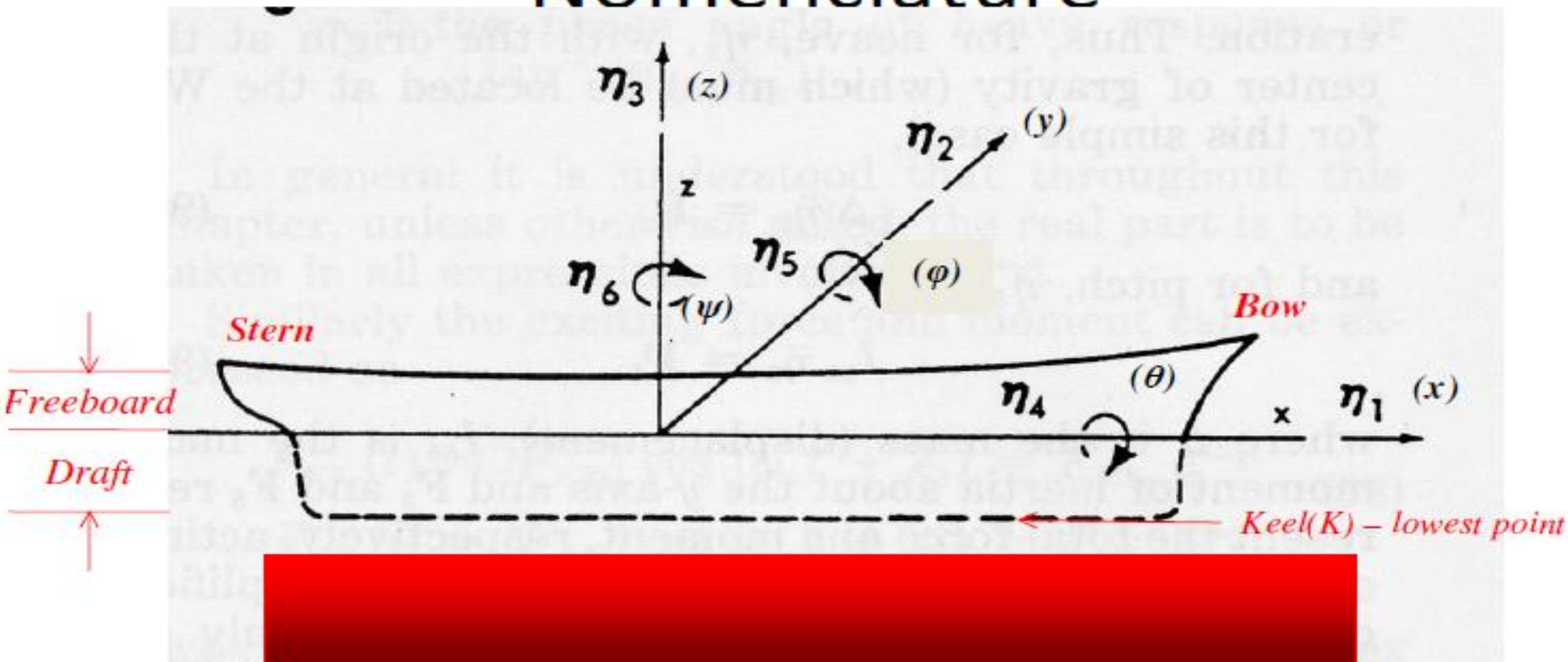


Fig. 37 Sign convention for translatory and angular displacements

Heel= static roll

Trim = static pitch

Intro to hydrostatics and stability

More Nomenclature

- Depth (of vessel): vertical height from keel to top deck
- Breadth (of vessel): Width
- Scantlings: Dimensions of structural components

Intro to hydrostatics and stability

Archimedes Principle

- The buoyancy of an object is equal to the weight of displaced fluid

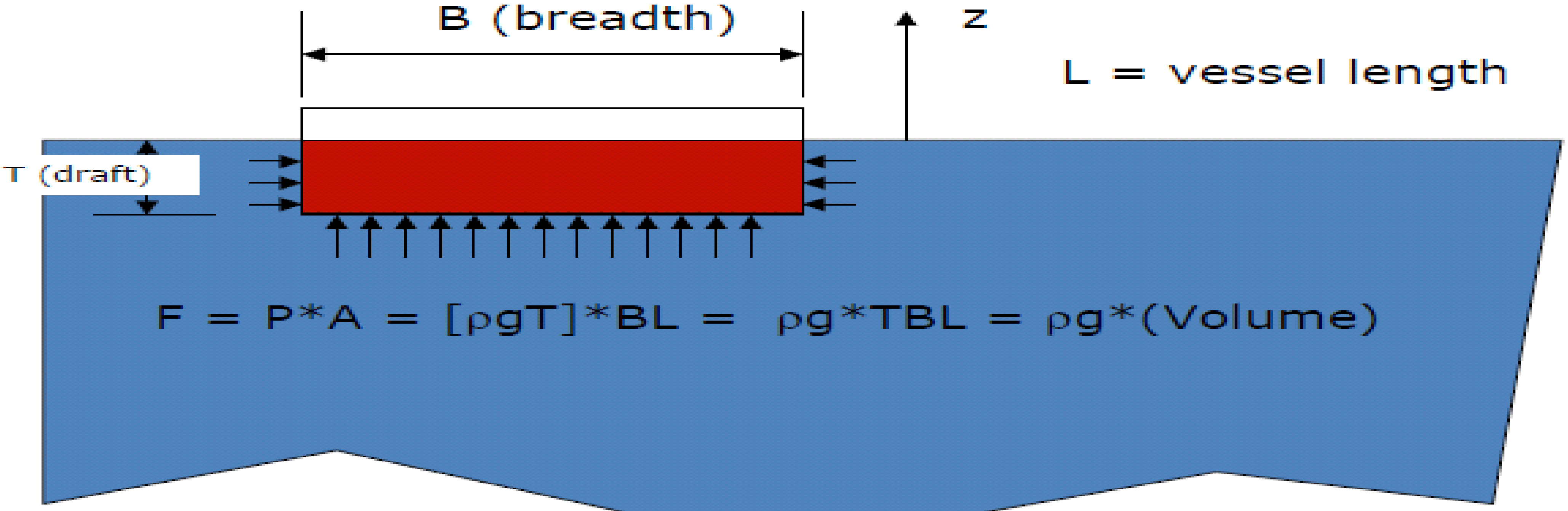
Intro to hydrostatics and stability

Buoyancy Force Example

Rectangular Barge

Static Pressure $P = \rho g z$

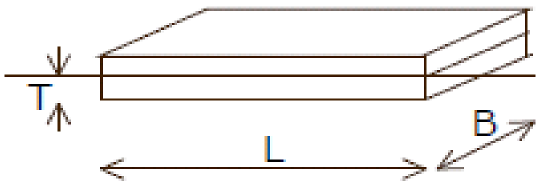
Force = Pressure x Area



Tip: All fluid forces of importance for offshore structures are pressure forces!

Intro to hydrostatics and stability

Displacement

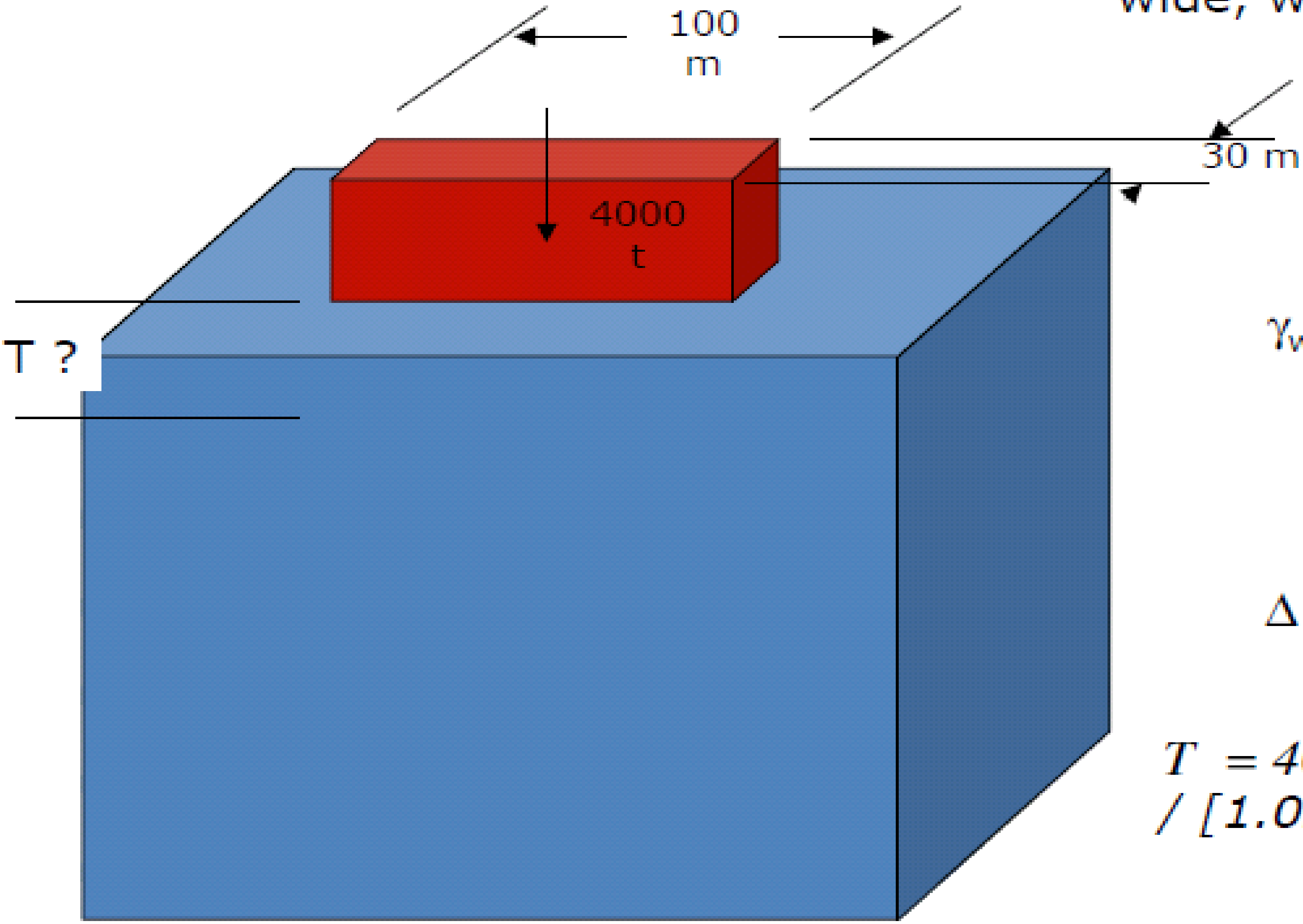


$$\nabla = LBT \qquad \Delta = \gamma_W LBT$$

$$\nabla = LBTC_B \qquad \Delta = \gamma_W LBTC_B$$

L = *Length*
B = *Beam (width)*
T = *Draft*
C_B = Block coefficient
∇= Volumetric Displacement
Δ= Displacement (Buoyancy Force)
γ_W = Density of fluid = ρg

Intro to hydrostatics and stability



Example 1: Compute draft (T) for prismatic barge, 100 m long, 30 m wide, weight 4000 t

γ_W =1.025 t/m^3

Seawater

$$\Delta = \gamma_W LBT = 4000\ t$$

T = 4000 t / [γ_WLB] = 4000 t / [1.025 t/m^3 * 100 m * 30 m] =

1.3 m Draft

Example 3.2

A cuboid shaped wooden block (L x B x D) 1.45m x 0.5m x 0.25m floats in water. If the block weighs 0.154 tonnes, find its draught if it floats in freshwater density 1.00 tonne/m^3.

Solution:

The weight of the block of 0.154 tonnes must be supported by displaced water i.e. the block must displace 0.154 tonnes of water:

In fresh water,

Volume of displaced water $\nabla = L \times B \times T$

Weight of displaced water $\Delta = \nabla \times \rho_{FW}$

$$\Delta = 1.45 \times 0.5 \times T \times \rho_{FW}$$

This must equal 0.154 tonne

$$1.45 \times 0.5 \times T \times \rho_{fw} = 0.154 \text{ tonnes}$$

$$T = \underline{0.212 \text{ m}}$$

CASE 2: If we know its draught, we can know its volume displacement, we can find its weight

If we know the draught of the cuboid, we can find its volume displacement and hence the weight of the object;

Say if we know its draught T, volume displacement = L x B x T
Weight = Buoyancy = Volume Displacement x ρ_{water}
Weight = L x B x T x ρ_{water}

Example 3.3

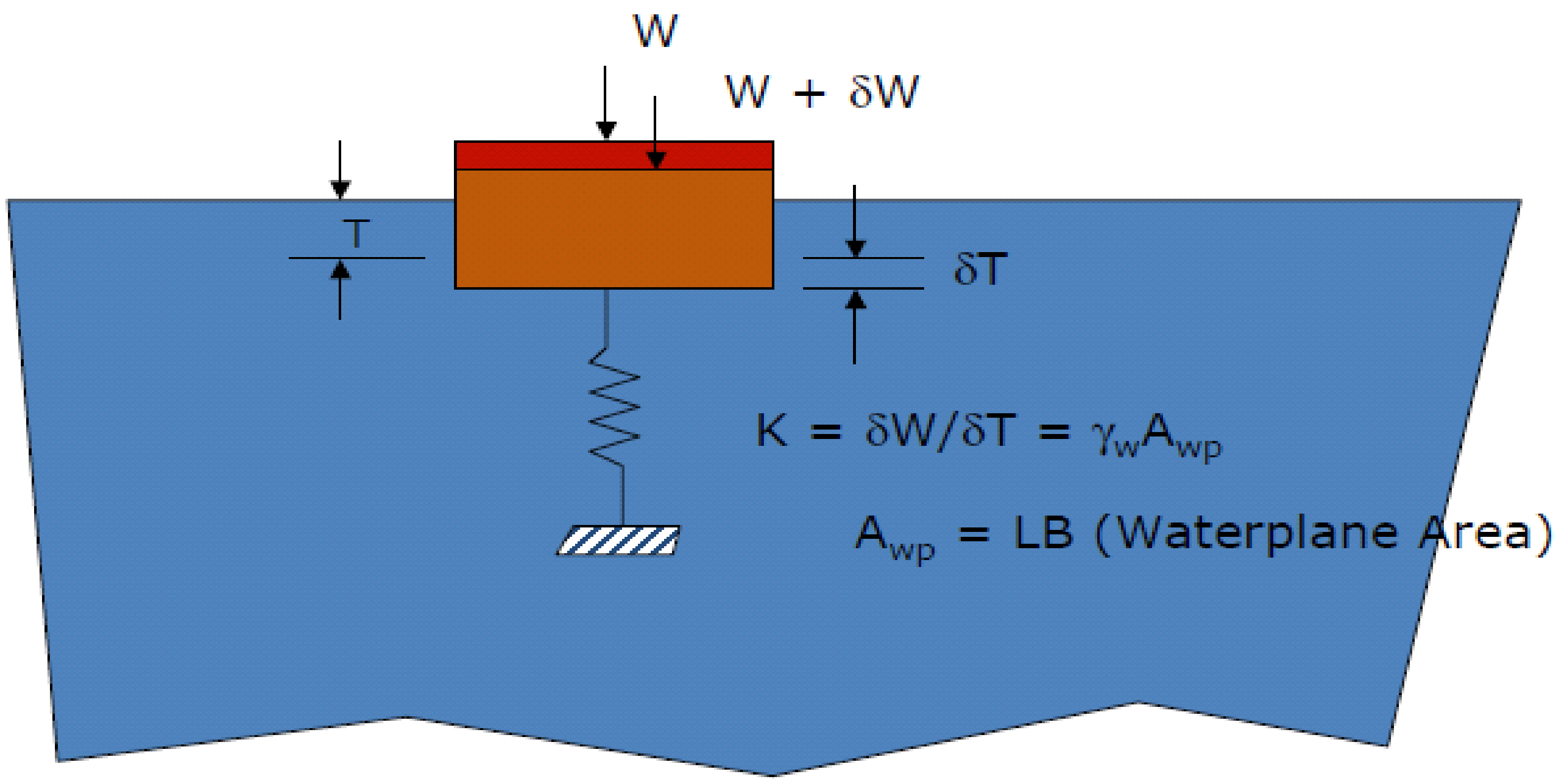
A box barge length 100m breadth 20m floats at a draught of 5m in sea water 1.025 tonne/m^3. Find its weight.

Solution

While floating in sea water density 1.025 tonne/m^3:
Volume Displacement = ∇ = L x B x T
Weight of barge = Weight displacement, Δ
W = Δ = $\nabla \times \rho_{salt\ water}$
= 100 x 20 x 5 x 1.025
= **10250 tonnes**

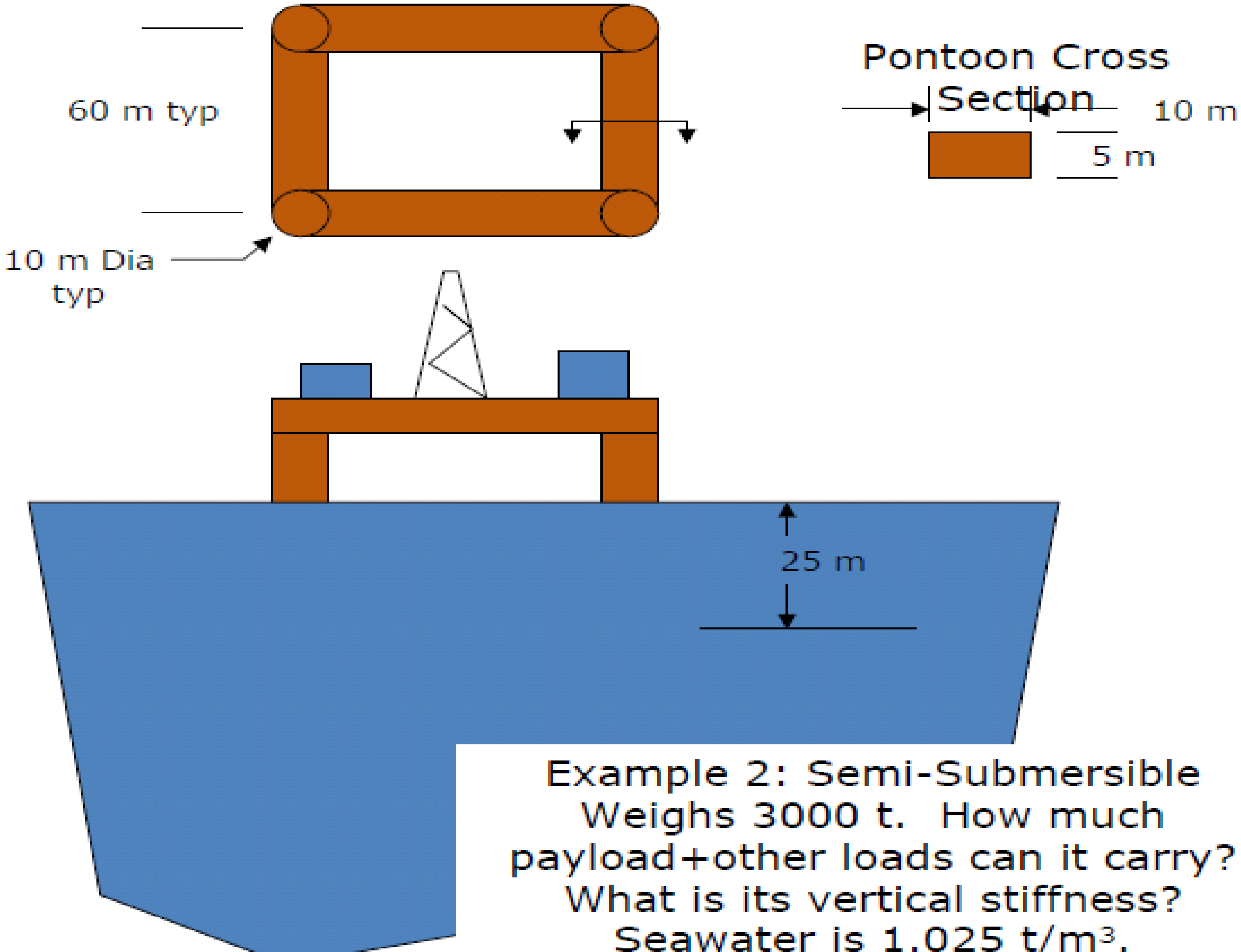
Intro to hydrostatics and stability

Hydrostatic Stiffness



Think of the water as a spring!

Intro to hydrostatics and stability

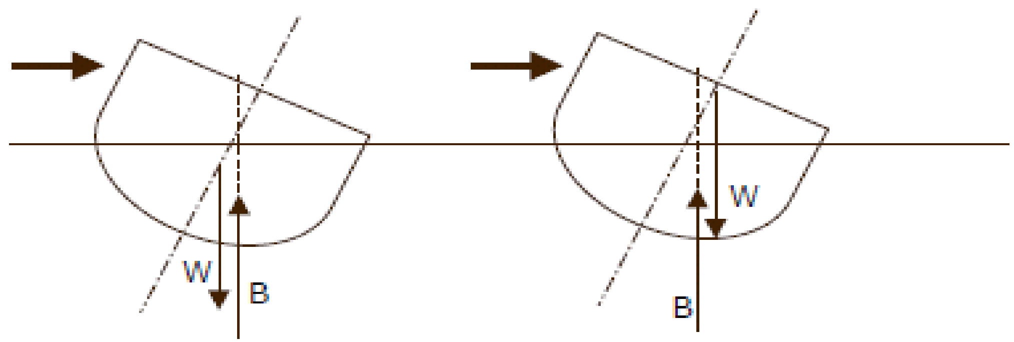


Example 2: Semi-Submersible Weighs 3000 t. How much payload+other loads can it carry? What is its vertical stiffness? Seawater is 1.025 t/m³.

Intro to hydrostatics and stability

Transverse Stability

Stability = Tendency to return to a previous condition when perturbed!



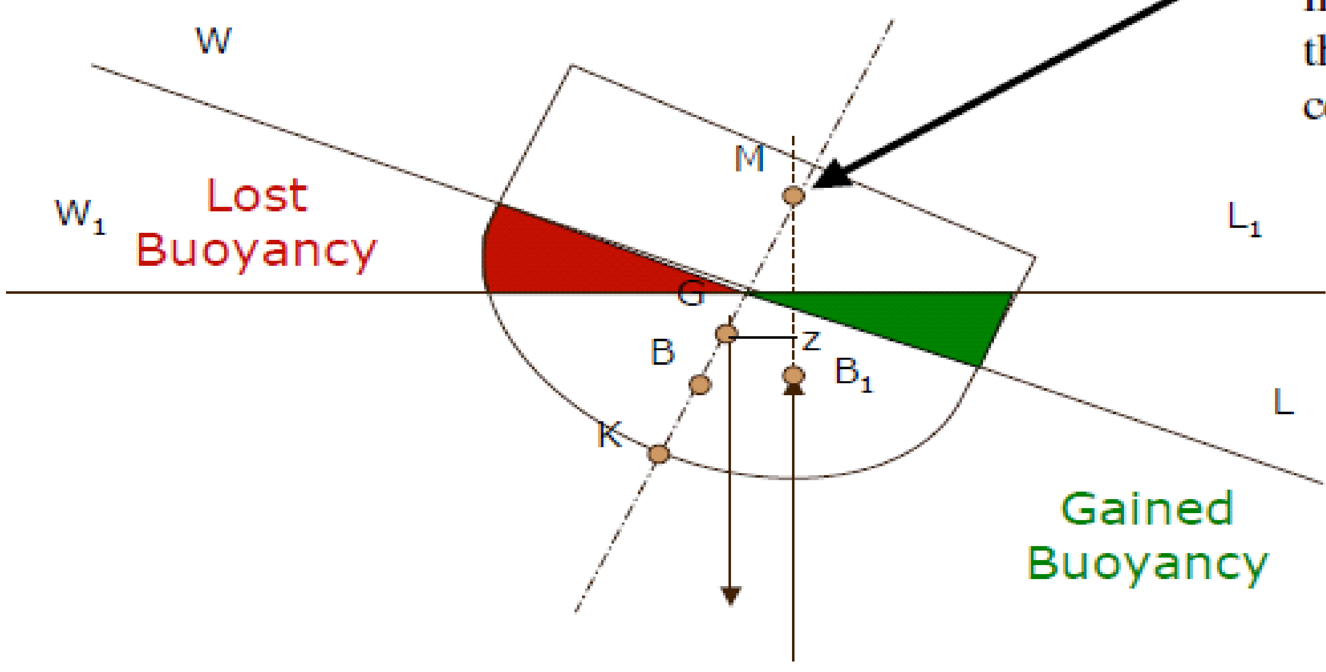
Case 1: Positively stable

Case 2: Negatively stable or unstable

Intro to hydrostatics and stability

Metacenter

When a vessel rolls or pitches… the center of buoyancy shifts. This is what makes the vessel with the center of gravity above the center of buoyancy stable (or not).



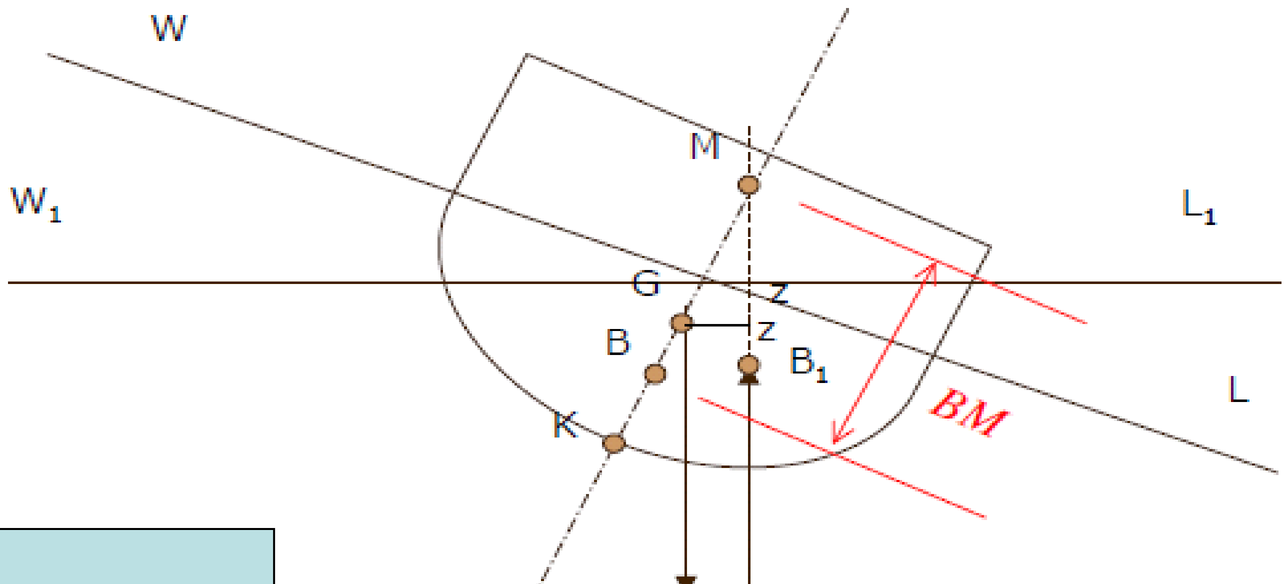
The metacenter is the point of intersection between the action of the buoyant force and the centerline of the vessel.

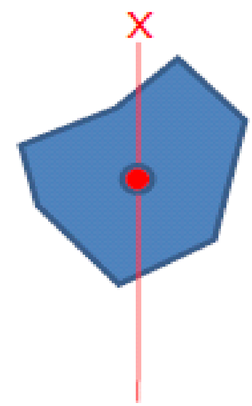
Intro to hydrostatics and stability

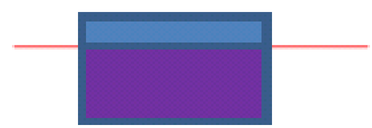
Center of Buoyancy to Metacenter (BM)

"BM" is a function of the waterplane inertia (moment of square of the distance from the axis). The following relationship can be shown from analytical geometry:

$$BM = \frac{I_{xx}}{\nabla}$$

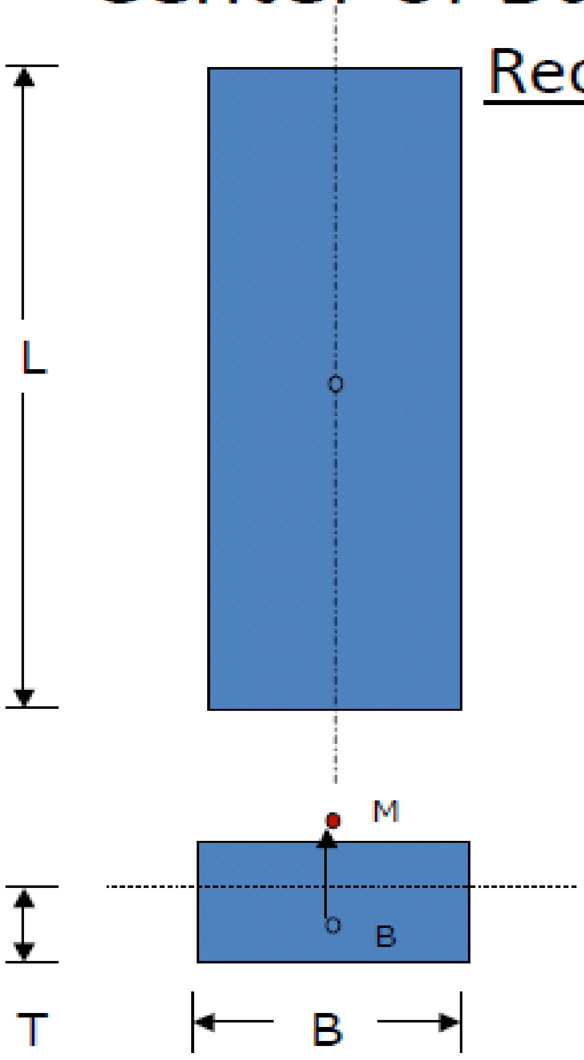






Intro to hydrostatics and stability

Center of Buoyancy to Metacenter Example



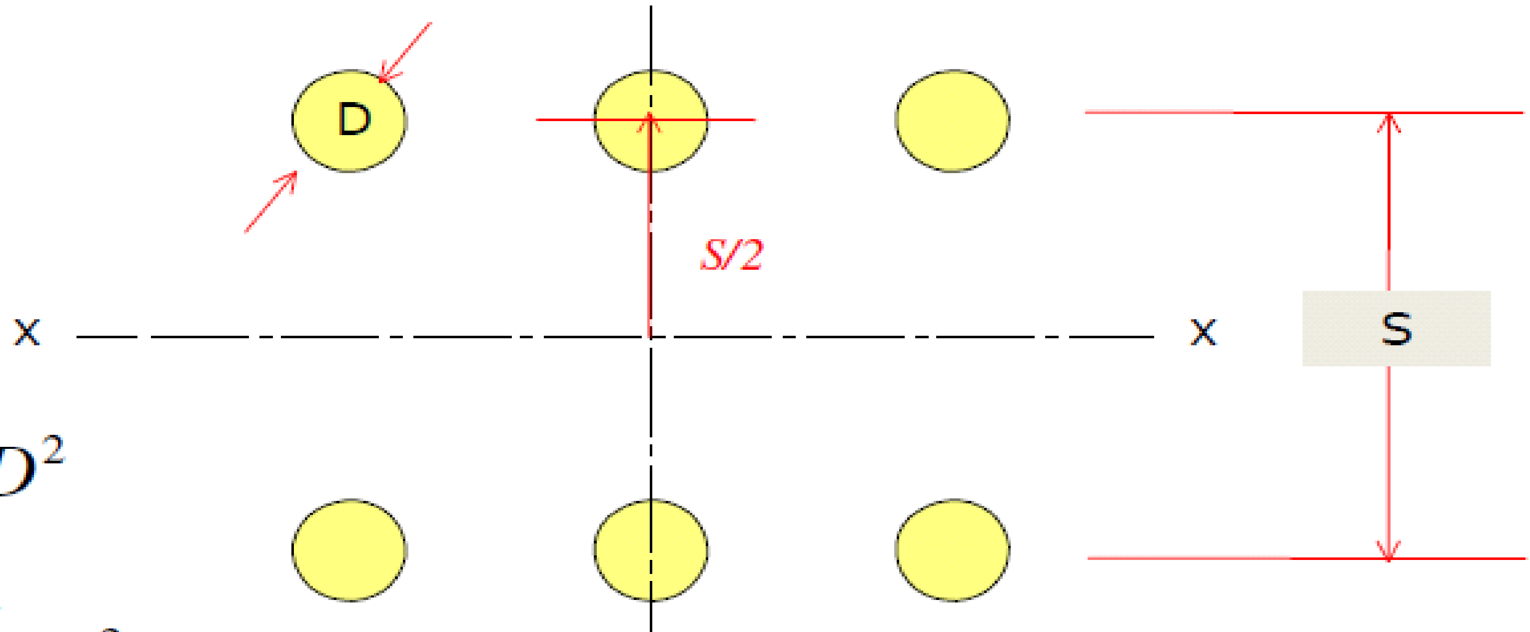
Rectangular Barge (Transverse)

$$BM = \frac{I_{xx}}{\nabla} = \frac{LB^3/12}{LBT} = \frac{B^2}{12T}$$

Quiz: work out the longitudinal BM

Intro to hydrostatics and stability

BM Example: Semi Submersible (transverse)



$$A_c = \frac{\pi}{4} D^2$$

$$I_{xxc} = \frac{\pi}{64} D^2$$

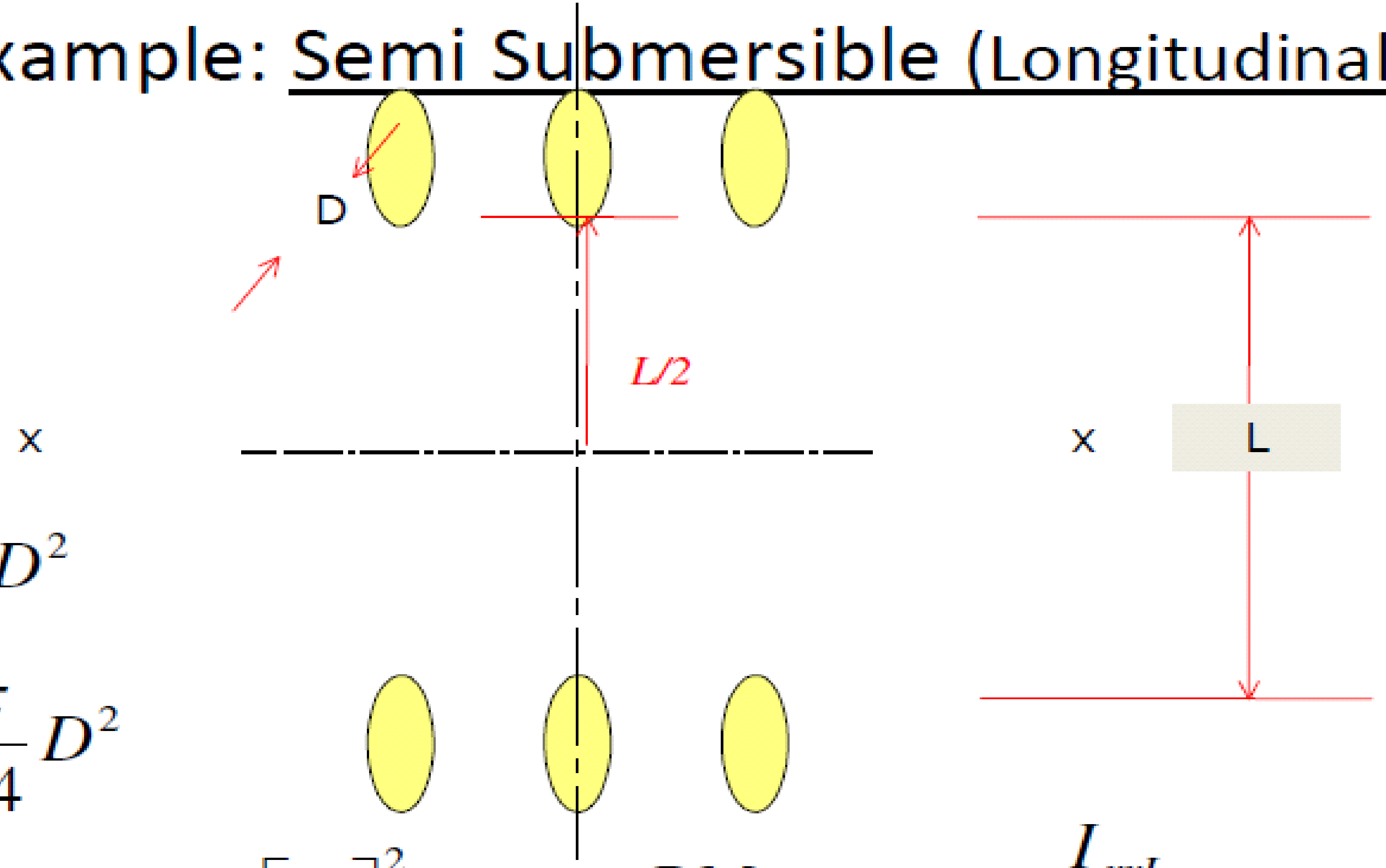
Use parallel axis theorem

$$I_{xxT} = 6I_{xxc} + 6A_c \left[\frac{S}{2} \right]^2$$

$$BM_{transverse} = \frac{I_{xxT}}{\nabla}$$

Intro to hydrostatics and stability

BM Example: Semi Submersible (Longitudinal)



$$A_c = \frac{\pi}{4} D^2$$

$$I_{xxc} = \frac{\pi}{64} D^2$$

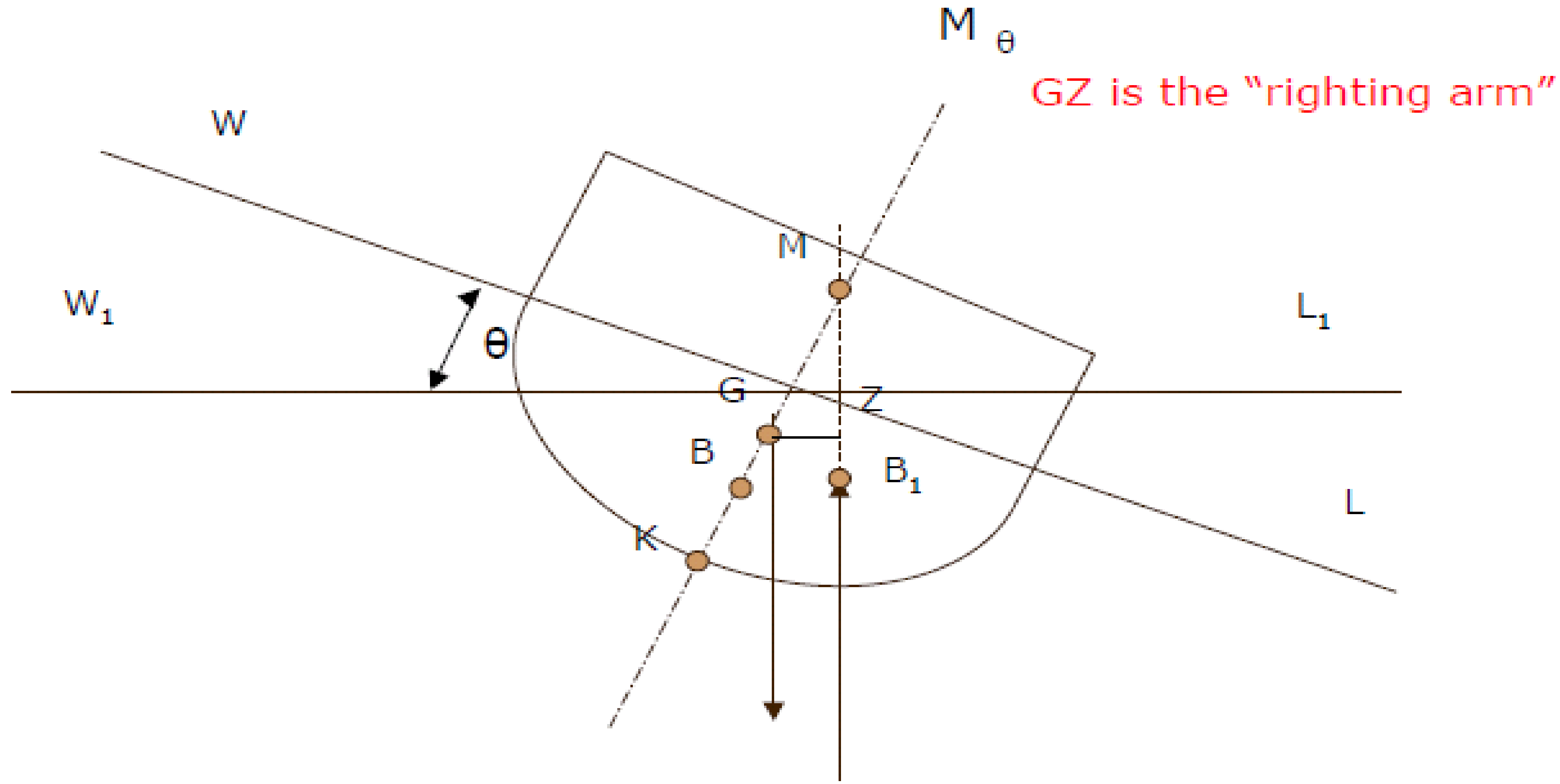
$$I_{xxL} = 6I_{xxc} + 4A_c\left[\frac{L}{2}\right]^2$$

$$BM_{longitudinal} = \frac{I_{xxL}}{\nabla}$$

Stability and Rotational Stiffness

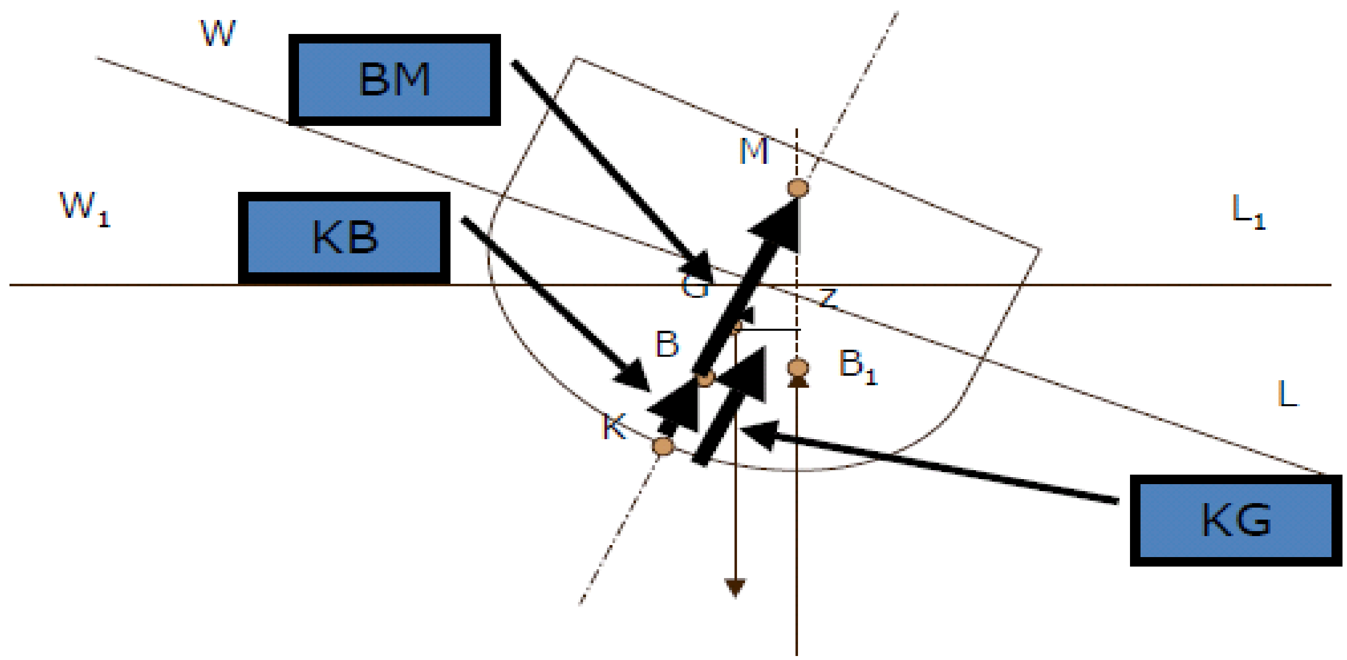
Metacentric Height (GM)

Restoring Moment, $M_\theta = GZ*\Delta \sim GM*\Delta*\sin(\theta)$ (small angles)



Stability and Rotational Stiffness

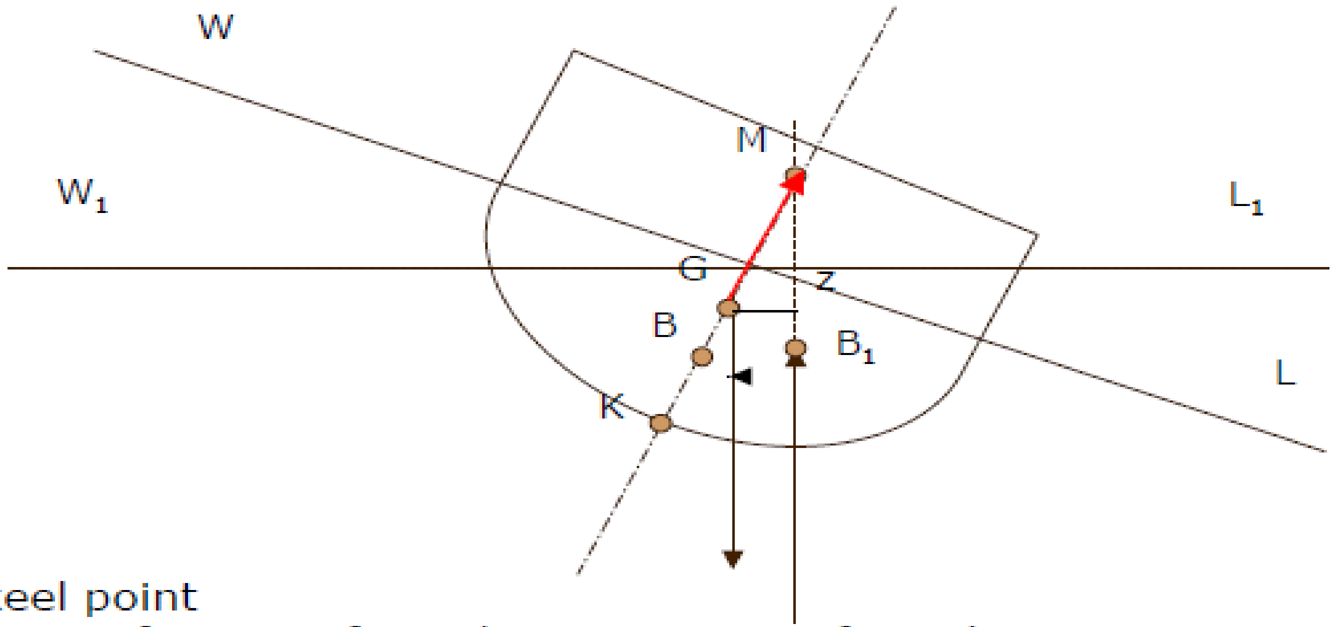
Metacentric Height (GM) and BM



$$GM = KB + BM - KG = BM - BG$$

Stability and Rotational Stiffness

A vessel is Stable if GM is Positive, It is Unstable if GM is Negative!!



K – keel point
G – point of action of weight, i.e. *center of gravity*
B – point of action of buoyancy, i.e. *center of buoyancy*; The position of B shifts with the amount of heel (B to B1)
M – Point of intersection of line of buoyancy and centerline, i.e. *Metacenter*
GM – Distance between G and M, i.e. *metacentric height.*
KB - Distance from Keel Point to B
KG- Distance from Keel Point to G

Stability and Rotational Stiffness

GM and the Center of Gravity

$$GM = KB + BM - KG = BM - BG$$

- BM is a function of vessel geometry (waterplane area and displacement) only, regardless to center of gravity. It is fixed by the design!
- The vertical center of gravity is the most important operational variable that determines stability.
- Rules require that the maximum VCG be specified in the vessel operating manual for each loading condition.

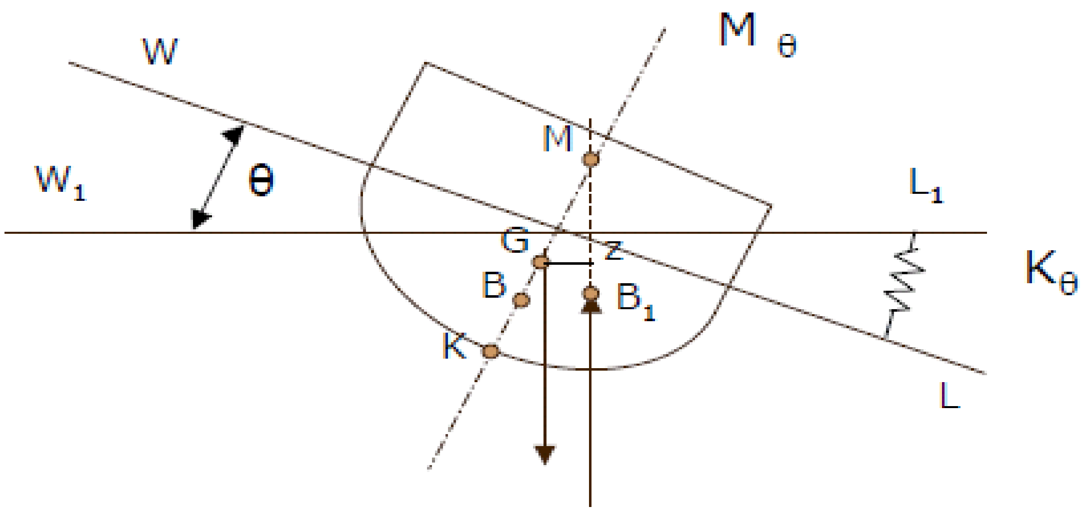
Stability and Rotational Stiffness

Metacentric Height (GM) and Hydrostatic Stiffness

Hydrostatic Stiffness

$$K_\theta = \partial M_\theta / \partial \theta = \sim GM*B = GM*\Delta$$

Buoyancy (B) and Displacement (Δ) the Same (values in force units, e.g. N)



Stability and Rotational Stiffness

Typical Minimum GM Values

- Passenger and Cargo Ships
  - Initial GM>0.15 m by law
  - Typically 0.5 – 3 m
- Semi-Submersibles GM > 3 m typical
- Spars GM > 6 m typical

Stability and Rotational Stiffness

Partially Filled Tanks Reduce GM

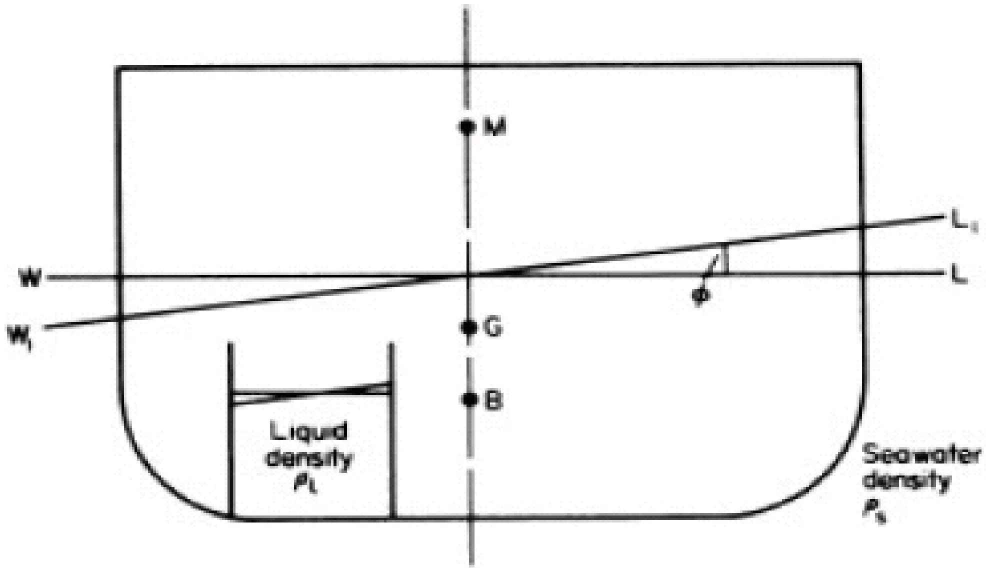
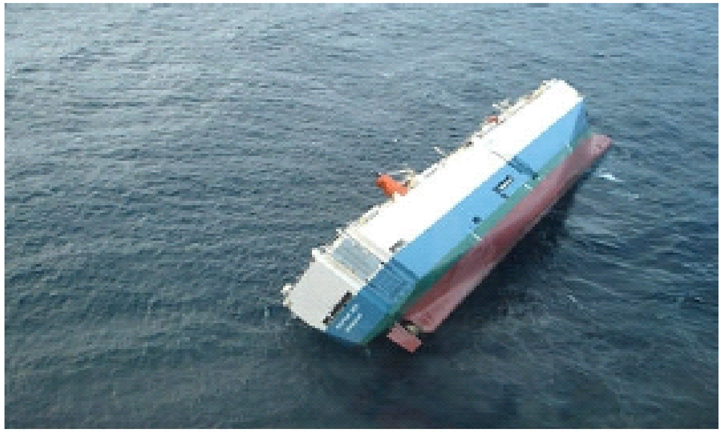


Fig. 4.5 Liquid free surface

Tanks with free surface cause center of gravity to shift in same direction as the center of buoyancy shifts, reducing stability!

$$GM = GM_{initial} - \sum \frac{\rho_L}{\rho_w} \frac{i_{xx}}{\nabla}$$

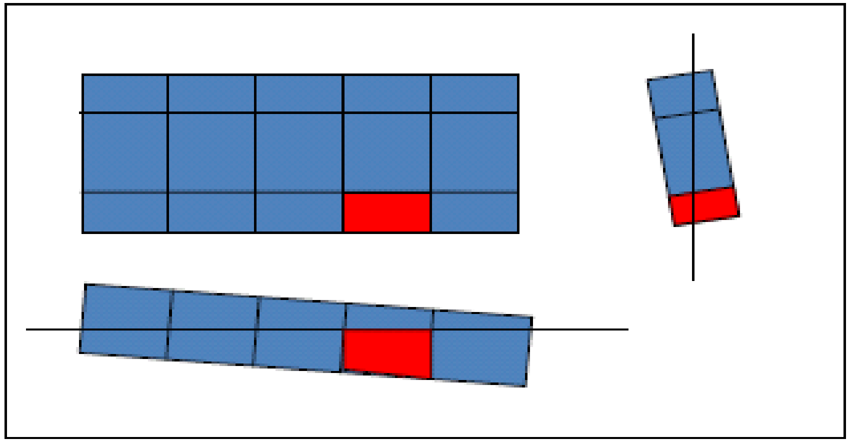


i_{xx} is waterplane moment of inertia of the individual compartment. This is why large tanks are undesirable.

Stability and Rotational Stiffness

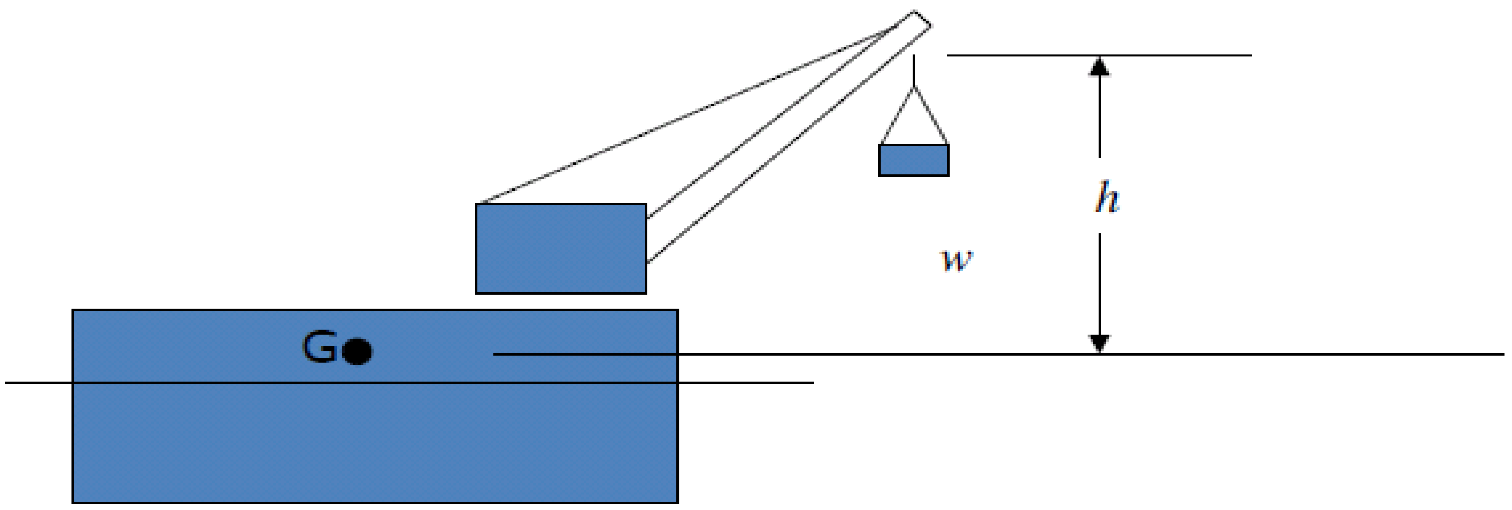
Damaged Stability

- Flooding causes loss of freeboard (sinking), heeling or trimming (mean angle), and reduction in GM.
- Treat a flooded space as either lost buoyancy or added weight to compute new equilibrium.



Stability and Rotational Stiffness

Crane Operations Reduce GM



$$GM\,(\text{new}) = GM - \frac{wh}{\rho\nabla}$$

Stability Satisfying Rules

Stability Requirements

- Rules are set by Classification Societies, Coast Guard and SOLAS (Intl Treaty on "Safety of Life at Sea")
- Coast Guard and SOLAS require minimum GM, e.g. GM>0.15m for Passenger Vessels.
- Class Rules base their requirement on a more complicated wind heeling moment method.

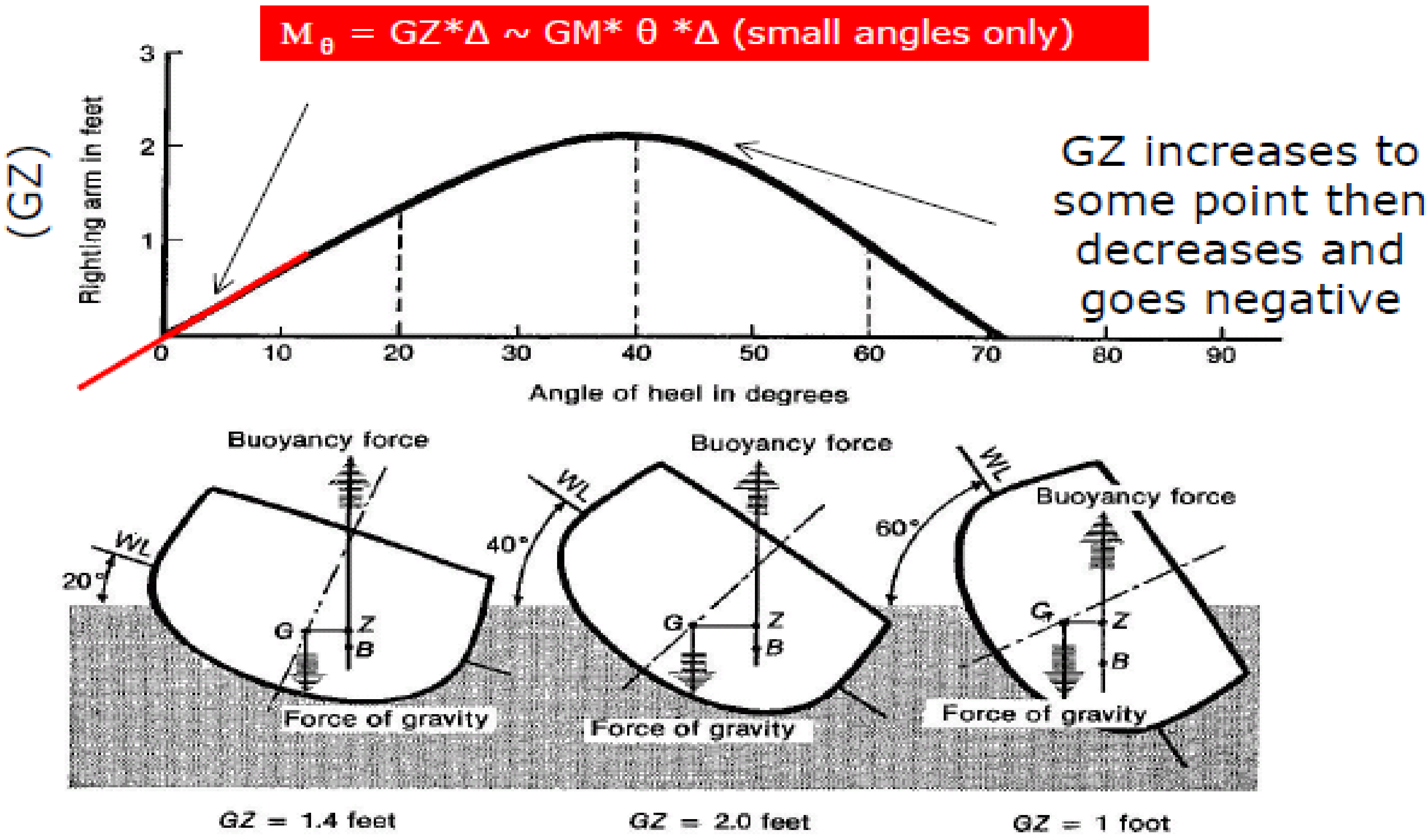
Stability Satisfying Rules

Stability Requirements

- Floating Offshore Platforms normally are designed to Rules for Mobile Offshore Drilling Units (MODU Rules) by ABS, DNV, Lloyds or BV.
- The Rules require calculation of a <u>large angle restoring moment</u> and comparable <u>wind heeling moment</u>.

Stability Satisfying Rules

Large Angle Restoring Moment Curve



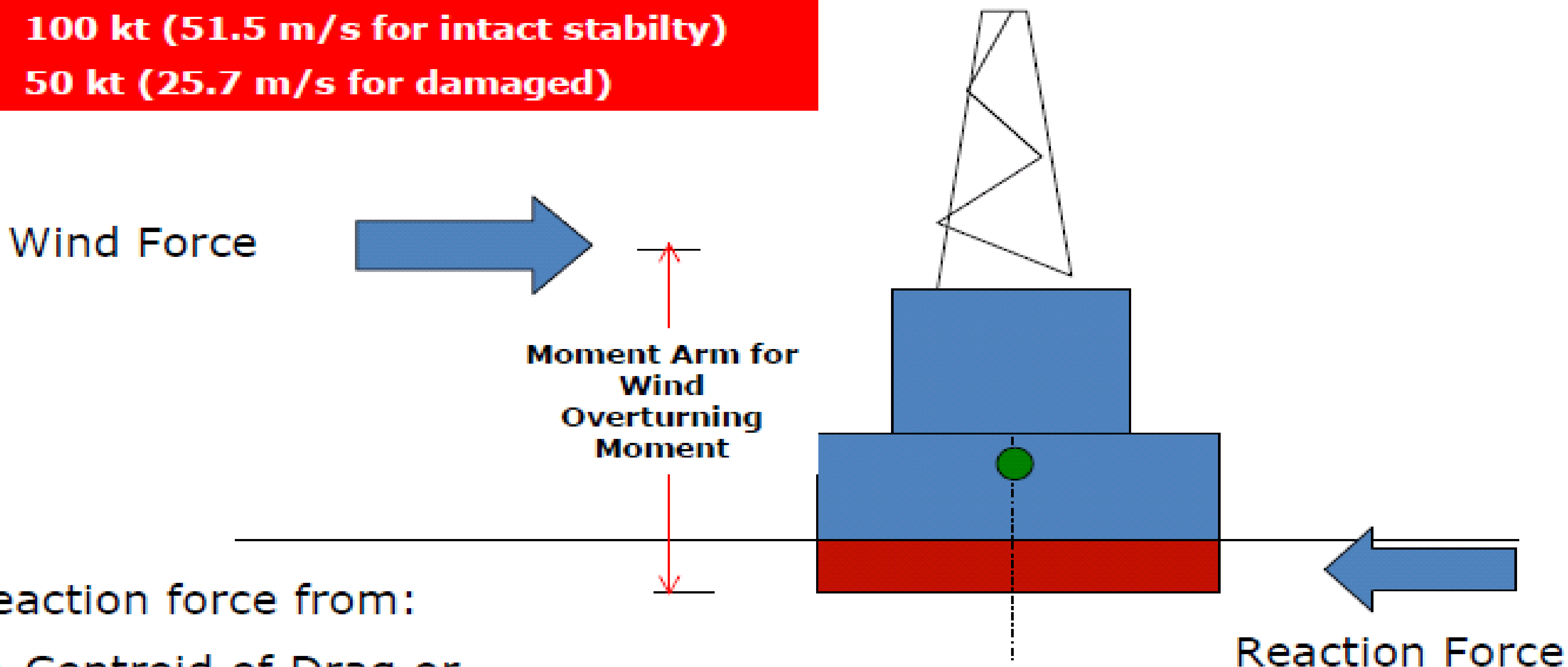
Equilibrium Conditions

Overturning Moment

Wind Speed to use per RULES

a) 100 kt (51.5 m/s for intact stabilty)

b) 50 kt (25.7 m/s for damaged)



Reaction force from:

a) Centroid of Drag or

b) Moorings

Equilibrium Conditions

Wind Tunnel Testing

Offshore on site

Photos from
Force
Technology
(www.force.dk)

An inclined semi-submersible in the wind tunnel and in full scale

Equilibrium Conditions

MODU Intact Stability Rules

1. Must have a positive GM for all conditions
2. Survive overturning moment from 100 kt wind (51.5 m/sec)
3. Inclining test is required for first unit of series
4. Righting moment curves and overturning moment curves are required for all operating drafts

Equilibrium Conditions

Watertight & Weathertight Integrity

Weathertight

Weathertight means that in any sea condition associated with the mode of operation, water will not penetrate into the unit.

Watertight

Watertight means the capability of preventing the passage of water through the structure in any direction under a head of water for which the surrounding structure is designed.

Equilibrium Conditions

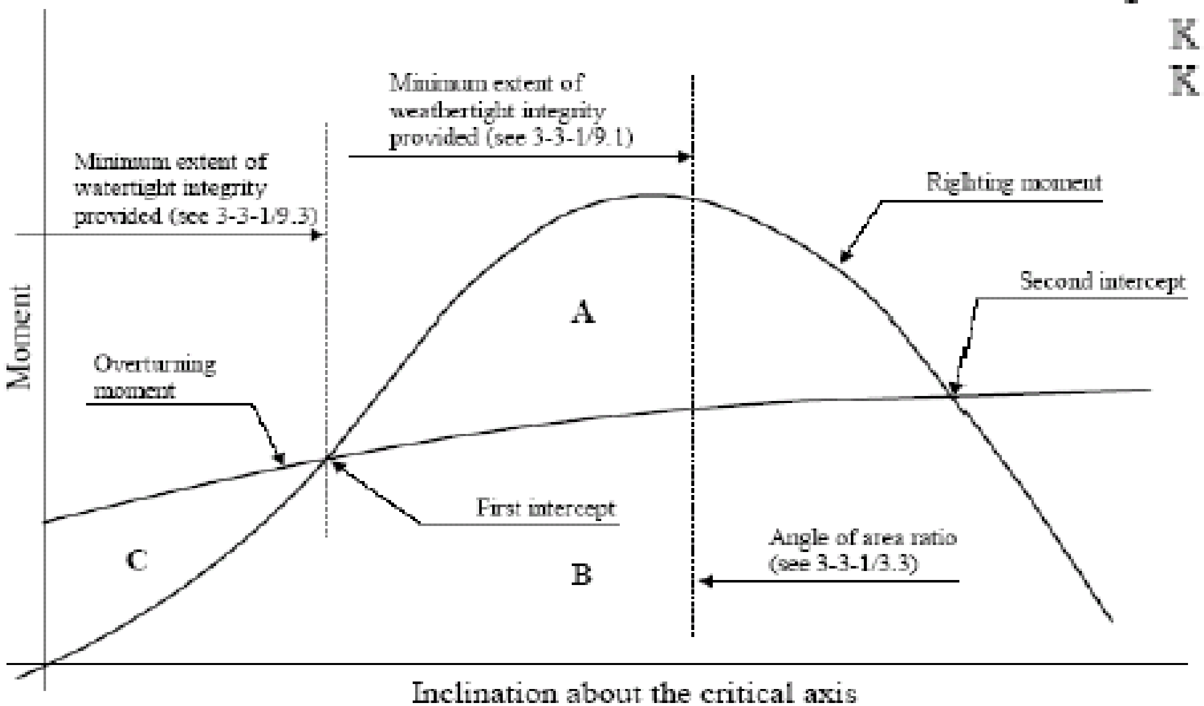
Intact Stability Criteria

FIGURE 1
Intact Stability Curve *(2005)*

Area[A+B] ≥ K Area[B+C]

K = 1.3 for column-stabilized units

K = 1.4 for all other units



Intact Stability in 100 kt Wind (51.5 m/sec)

Equilibrium Conditions

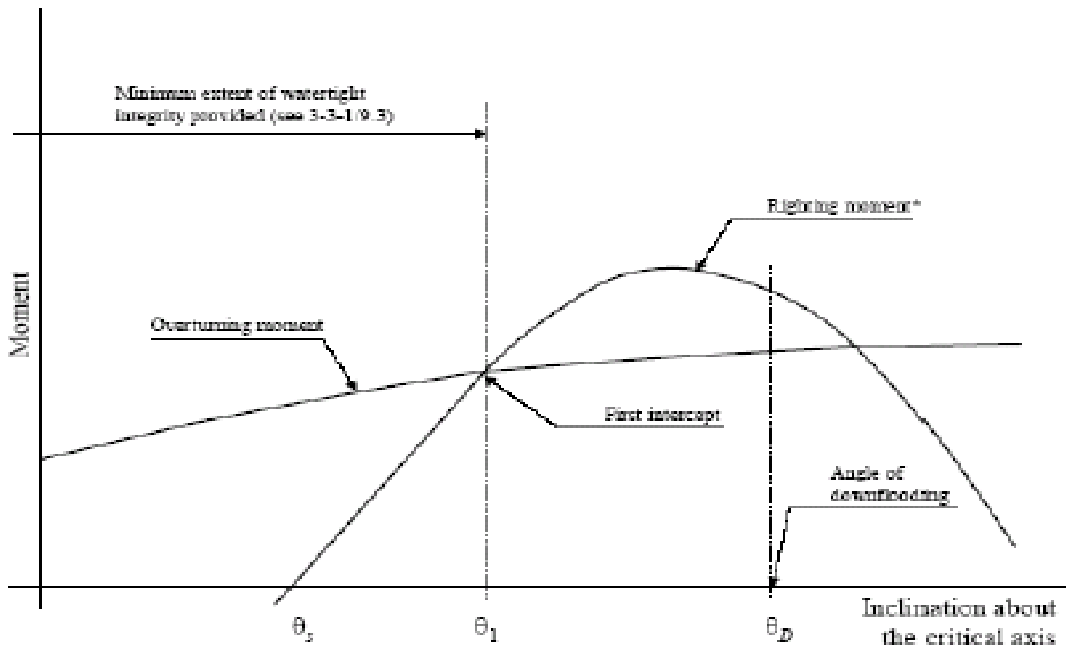
MODU Damaged Stability Rules:
Extent of Flooding Assumed

- <u>Compartments +5/-3 m from waterline</u>
  - 3 m high vertical opening, penetrate 1.5 m
  - Two compartments flooded if horizontal flat in this area
  - Vertical bulkhead not penetrated unless spacing is less than 1/8th circumference
- <u>Tanks below the waterline</u>
  - Containing ballast pumps
  - Containing machinery with sea water cooling
  - Adjacent to the sea

Equilibrium Conditions

Basic Damaged Stability Criteria

FIGURE 2
Damage Stability Curve *(2005)*



* Righting moment ≥ Overturning moment

$\theta_D \geq \theta_1$

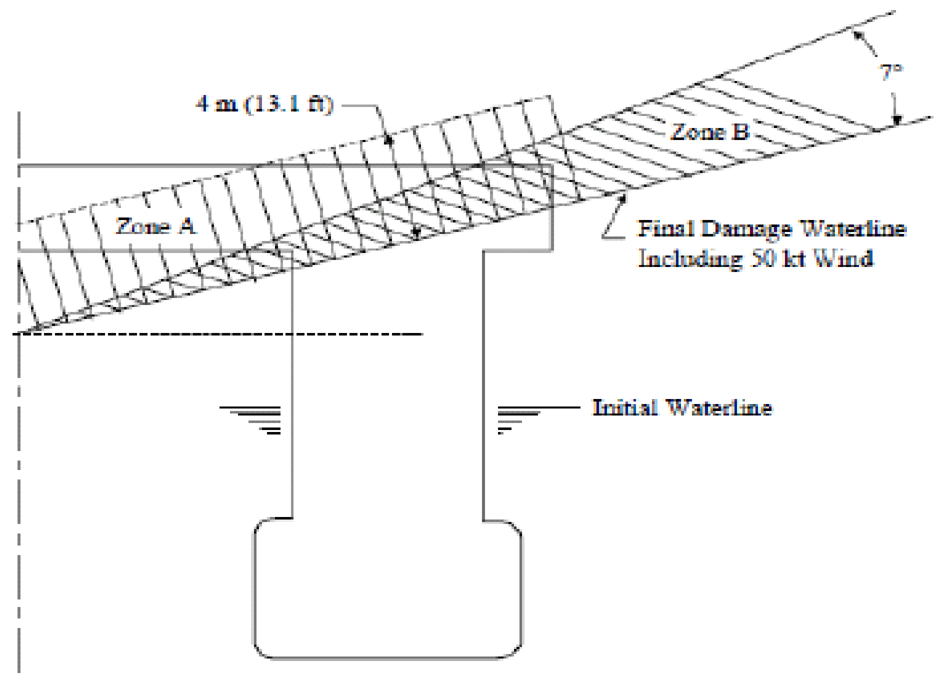
Damage stability in 50 kt Wind (25.6 m/sec)

1. Minimum extent of watertight integrity > 1st Intercept (equilibrium)
2. Downflood angle > 1st Intercept

Equilibrium Conditions

Weathertight Integrity Requirements

FIGURE 5
Minimum Weathertight Integrity Requirements for Column-Stabilized Units



Zone A - Minimum 4 m (13.1 ft) zone of weathertight integrity
Zone B - Minimum 7° range of weathertight integrity

Equilibrium Conditions

General ABS Stability Rules

(Based on Current Guide for Floating Production Installations)

	Semi-Submersible (Column Stabilized)	TLP	Spar	FPSO (Ship Type)
Guide for FPI	1. Positive GM in All Conditions 2. MODU Rules 3. Alternate Stability Criteria Accepted	1. MODU Rules while free floating (e.g. installation) 2. Adequate Tendon Tension under damaged conditions	1. CG below CB 2. 90° range of positive stability 3. Downflooding angle >= 30° 4. MODU Rules relaxed 5. Limits set on maximum tilt from Global Responses	1. MODU Rules 2. 1966 Load Line Convention 3. MARPOL 73/78
MODU Rules	1. Intact, 2. Damaged 3. Residual Stability (for column stabilized units_) 4. Alternative: Dynamic Response Based Criteria			

Other Design Considerations

Global Response of Floating Structures

Fixed vs. Floating Structures: Reaction to Dynamic Loads

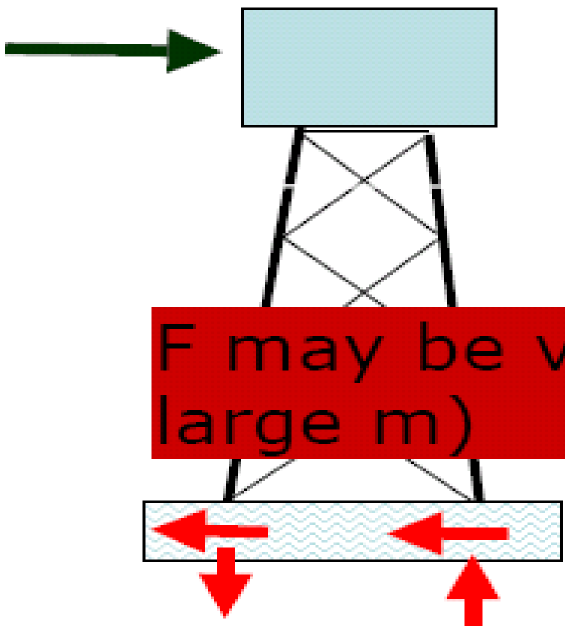
"Fixed" Structures: Static Equilibrium $\sum \vec{F} = 0$

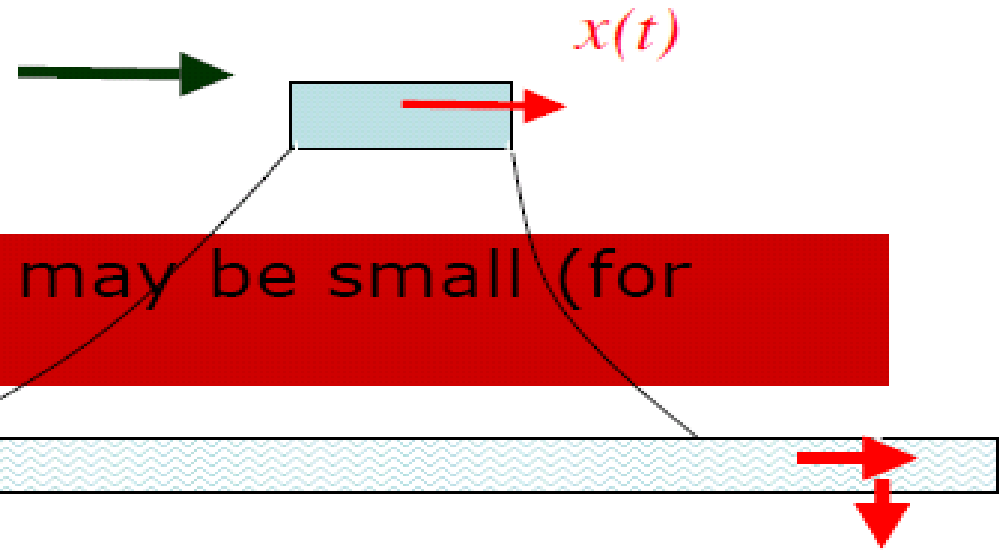
Compliant Structures: Dynamic Equilibrium

$$\sum \vec{F} = m\ddot{x} + Kx$$

External Force, $F(t)=F_0+F\,sin(\omega t)$

External Force, $F(t)=F_0+F\,sin(\omega t)$





F may be very large, Kx may be small (for large m)

Reactions

Reactions

Reactions

"FIXED" Structure = - Fohn"Compliant" Structure = -Kx

Foundation Loads

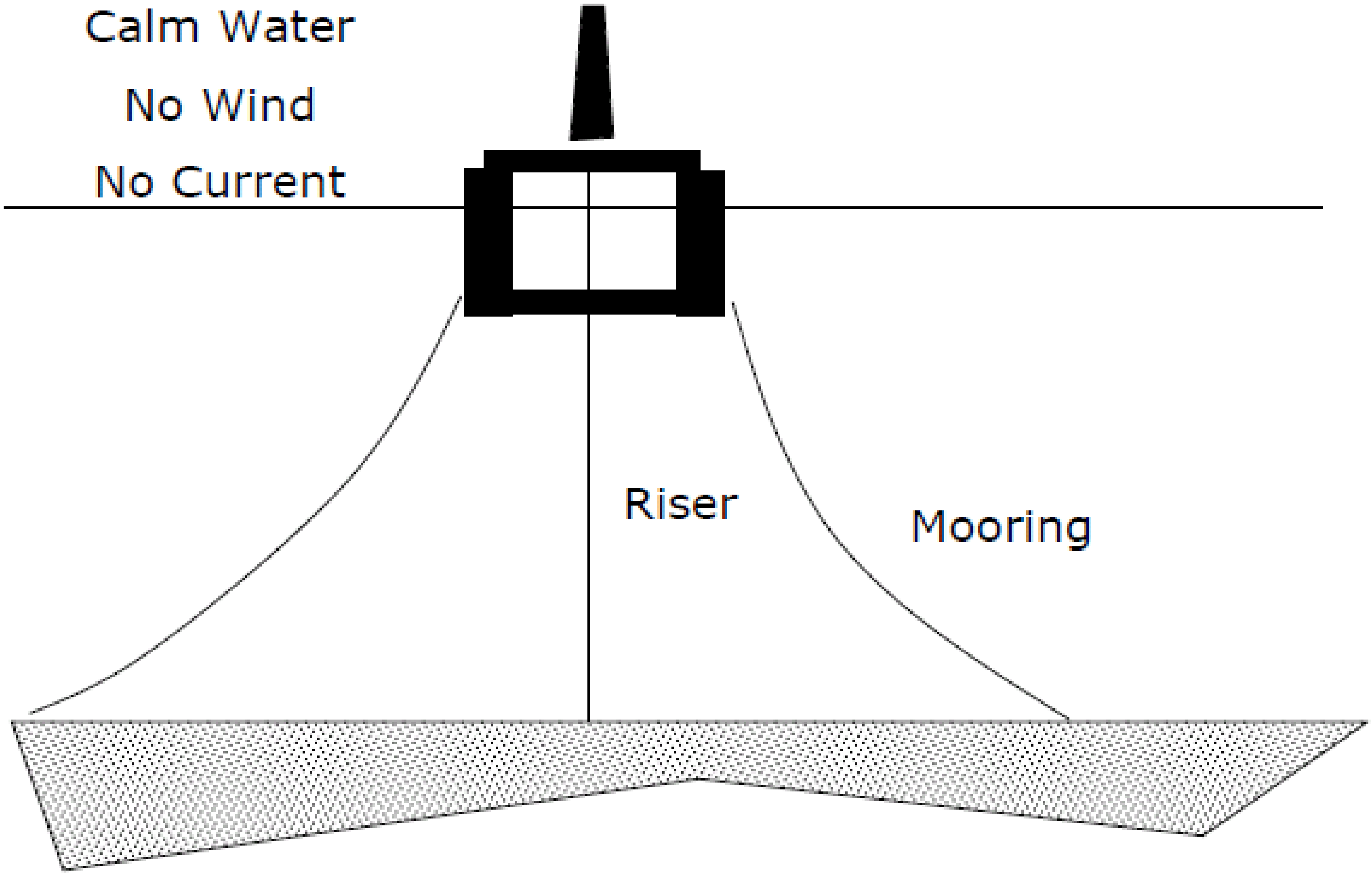
Anchor force for floating structure $Kx = \sum \vec{F} - m\ddot{x}$

K = Stiffness of mooring system

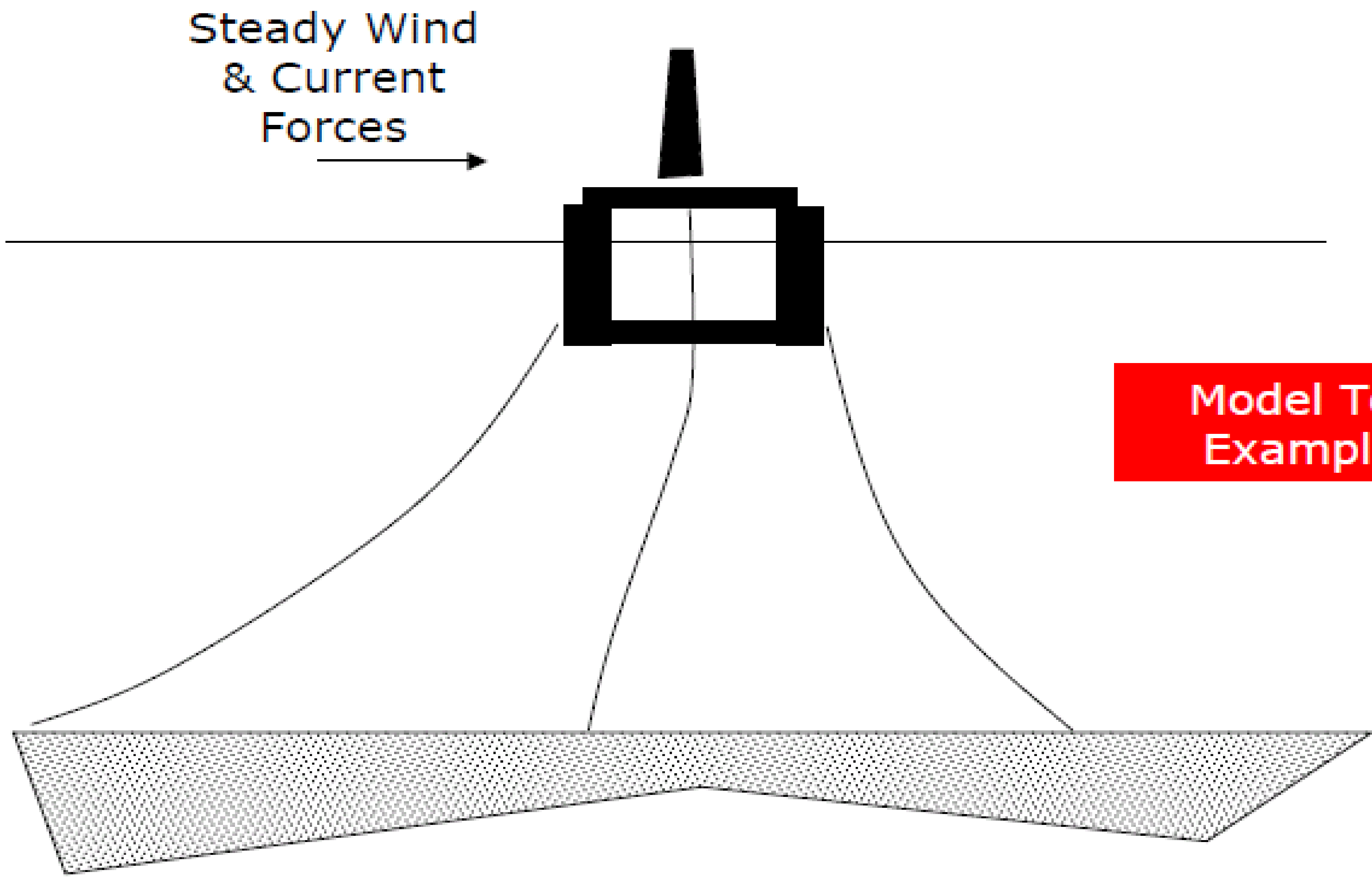
Force Components

- Waves
  - Mean (drift)
  - Wave Frequency
  - Slowly varying wave drift
- Wind
  - Mean
  - Varying (gusts)
- Current

Global Motions



Steady ("mean") Offset from Wind and Current



Model Test Examples

Why are we concerned about Global Responses?

- Maximum offsets
  - Top tensioned riser bending loads at sea floor
  - Steel Catenary Riser bending loads at sea floor
  - Maximum mooring line tension
  - TLP Setdown
  - TLP Flex joint angles for the tensons
  - Riser stroke

- Maximum angles and lateral accelerations
  - Riser bending or flex joint design at the connection to the platform
  - Lateral forces on the topsides and platform (e.g. truss spar truss loads, global loads)

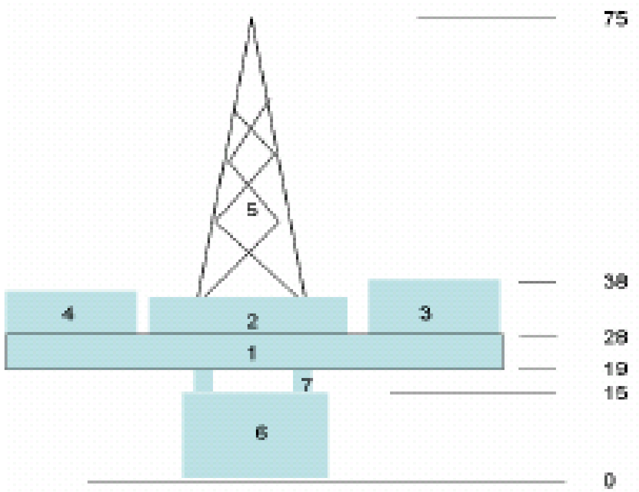
- Maximum heave
  - Riser stroke
  - Mooring line dynamics
  - Riser dynamic loadings: SCR extreme bending moments at touchdown

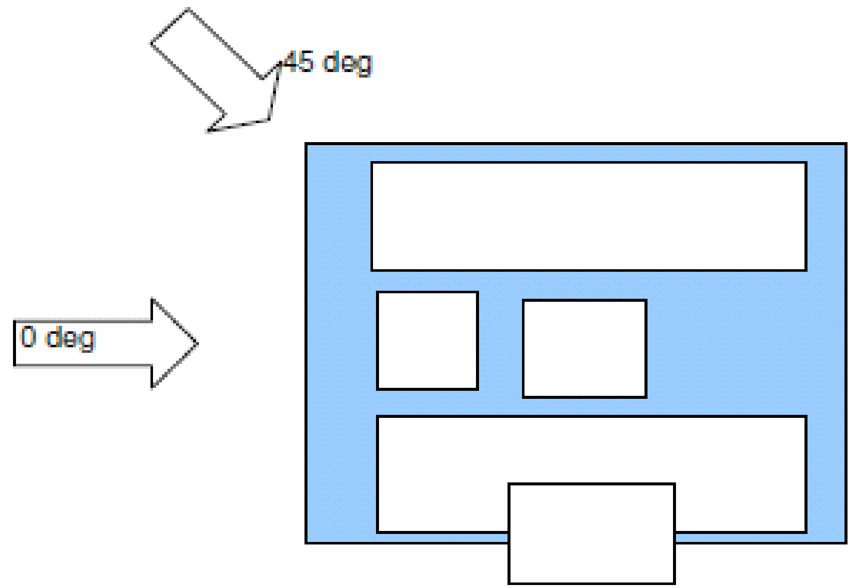
- Cyclic loads: riser and mooring fatigue

Sources of Motion

- Mean
  - Wind (average part)
  - Current
  - Wave Drift
- Slowly Varying (at resonance)
  - Non-linear wave forces
  - Wind gusts
  - Current (Vortex Induced Motions)
- Wave Frequency
  - 1st Order Wave Forces

Wind Load Example





Block	Desc	z center	Ch (ABS)	Length	Height	Area	Area Corre	Adj Area	Cs	CsChArea	Force/Ur**2
1	Lower Decks	23.5	1.1	100.0	9.0	900	1.0	900	1.00	990	605
2	Rig	31.5	1.2	30.0	7.0	210	1.0	210	1.00	252	154
3	Quarters	33.0	1.2	20.0	10.0	200	1.0	200	1.00	240	147
4	Process	32.0	1.2	20.0	8.0	160	1.0	160	1.00	192	117
5	Derrick	46.0	1.3	15.0	40.0	600	0.6	360	1.25	585	357
6	Hull	7.5	1.0	21.9	15.0	329	1.0	329	1.00	329	201
7	Deck Supports	17.0	1.1	21.9	4.0	88	0.6	53	1.00	58	35

Force at 0 deg — Total Force/Ur^2 1617 $N/(m/s)^2$

Equivalent Area = Force/($.5\rho_w Ur^2$) 2646 m^2

Centroid of Force 28.6

Rev 14/10/06

Force at 45 deg ~ 1.2* Force at 0 deg — Total Force/Ur^2 1940 $N/(m/s)^2$

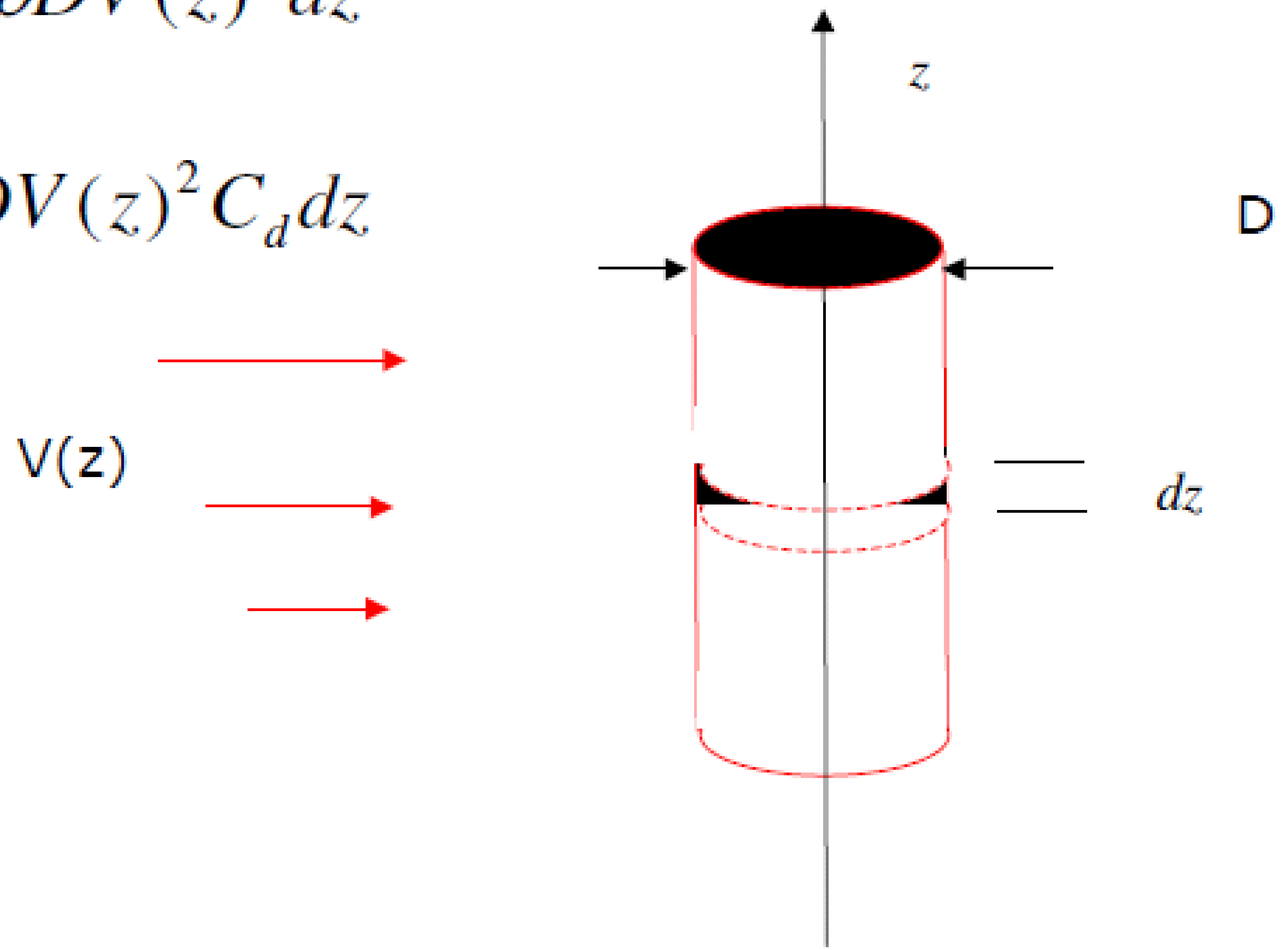
Equivalent Area = Force/($.5\rho_w Ur^2$) 3175 m^2

Force Coefficient 0.198 $t/(m/s)^2$

Current Force – Drag

$$dF_c = \frac{1}{2} C_d \rho D V(z)^2 dz$$

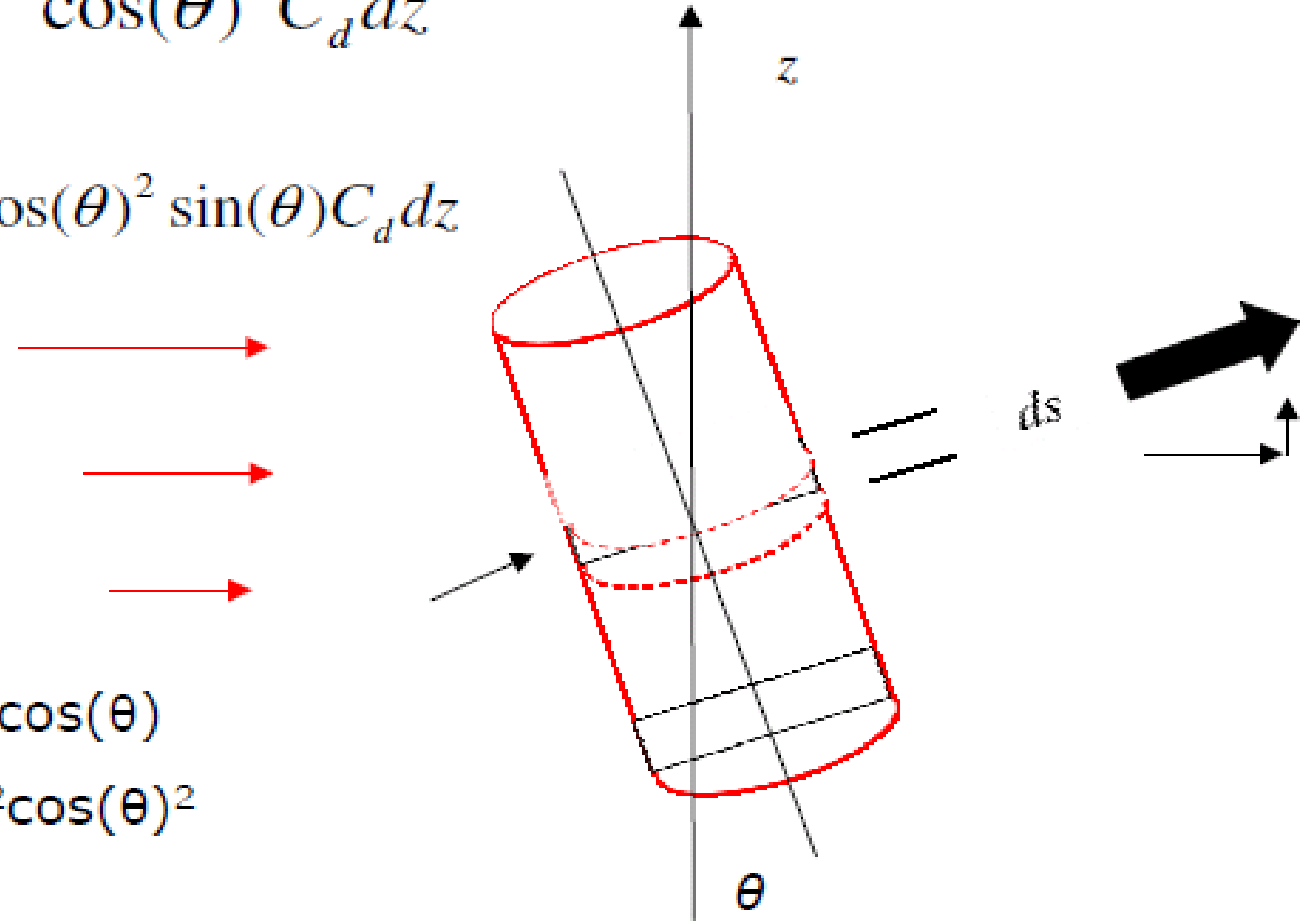
$$F_c = \int \frac{1}{2} \rho D V(z)^2 C_d dz$$



Current Force – Inclined Cylinder

$$F_{cx} = \int \frac{1}{2} \rho D V(z)^2 \cos(\theta)^3 C_d dz$$

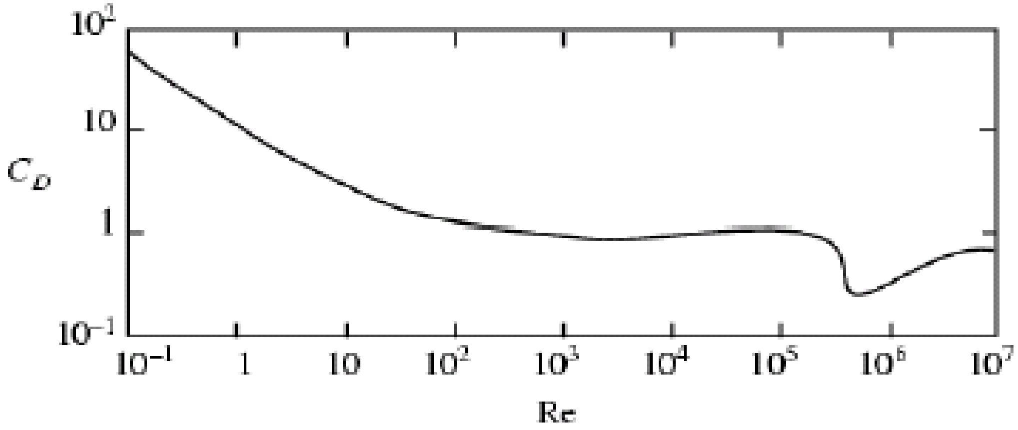
$$F_{cz} = \int \frac{1}{2} \rho D V(z)^2 \cos(\theta)^2 \sin(\theta) C_d dz$$

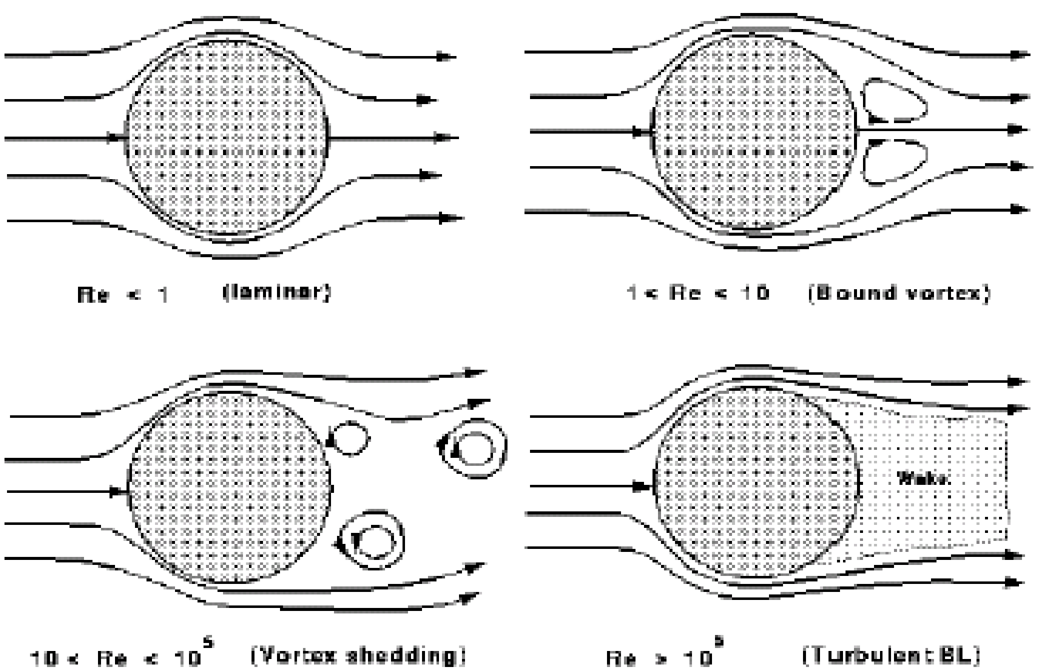


$V_n = V_x \cos(\theta)$

$V_n^2 = V_x^2 \cos(\theta)^2$

Steady Drag Coefficient
(smooth cylinder)





$$Re = \frac{UD}{\upsilon}$$

$$U = velocity(m/s)$$

$$D = Diameter(m)$$

$$\upsilon = Kinematic\_Viscosity(10^{-6}\,m^2/s)$$

Example:

U = 1 m/s
D = 10 m
Re = 10^7
C_D = 0.8

Drag Coefficient – Shapes with Flat Surfaces (API RP 2SK)

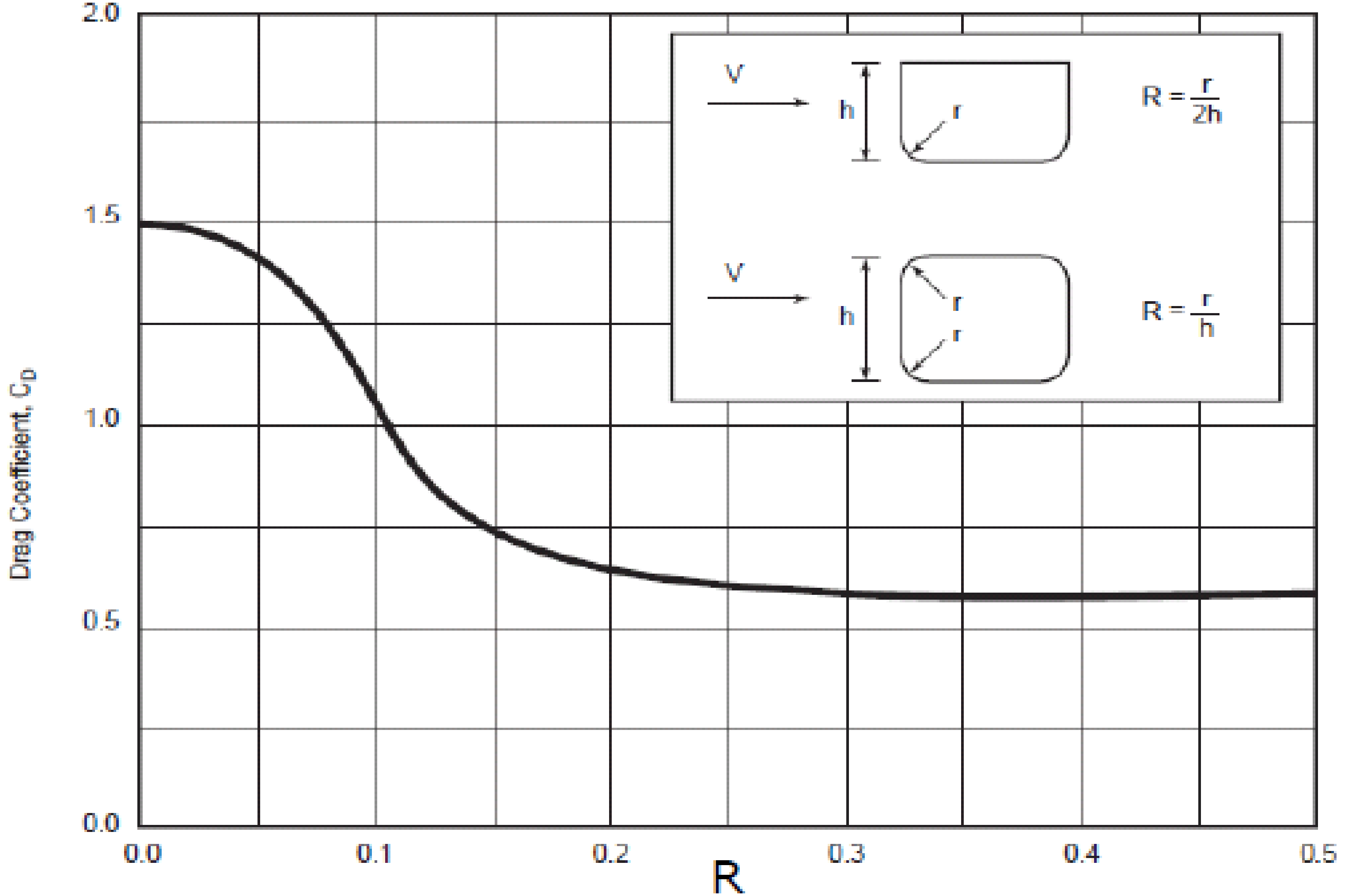
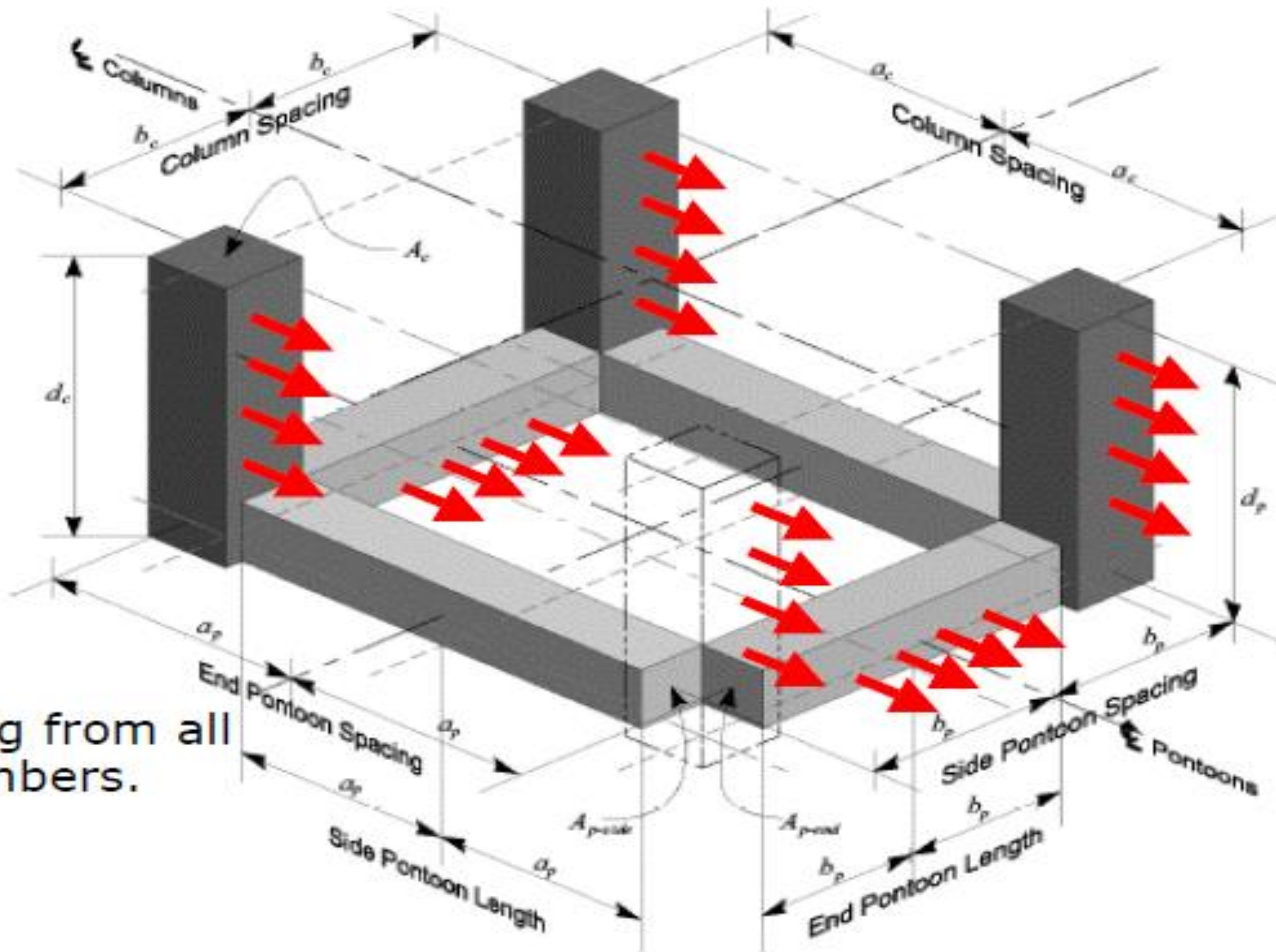


Figure C.1—Semisubmersible Current Drag Coefficient for Members Having Flat Surfaces

Assumes $Re > 10^6$, height = width

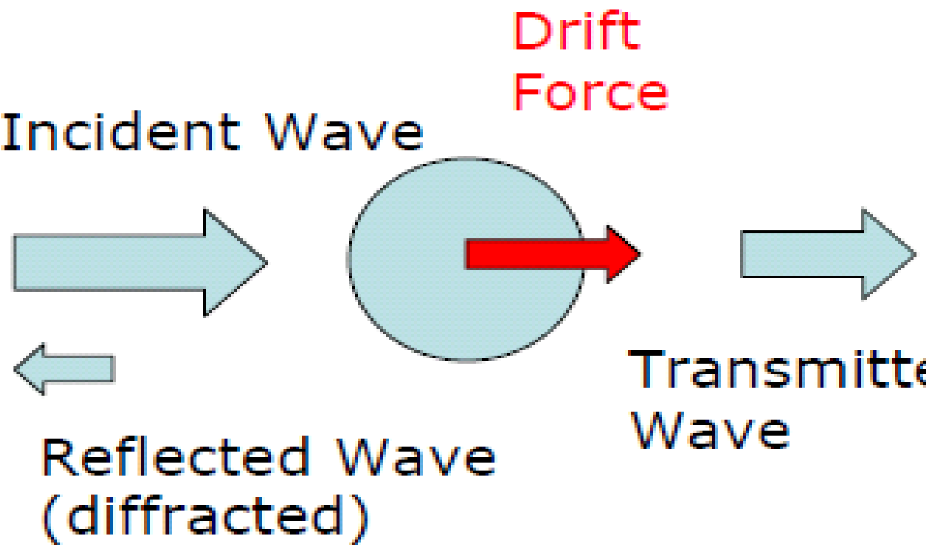


Add drag from all members.

Figure 7.41 Initial Design Underwater Model – Closed Array Pontoon, 4 Columns

Wave Drift

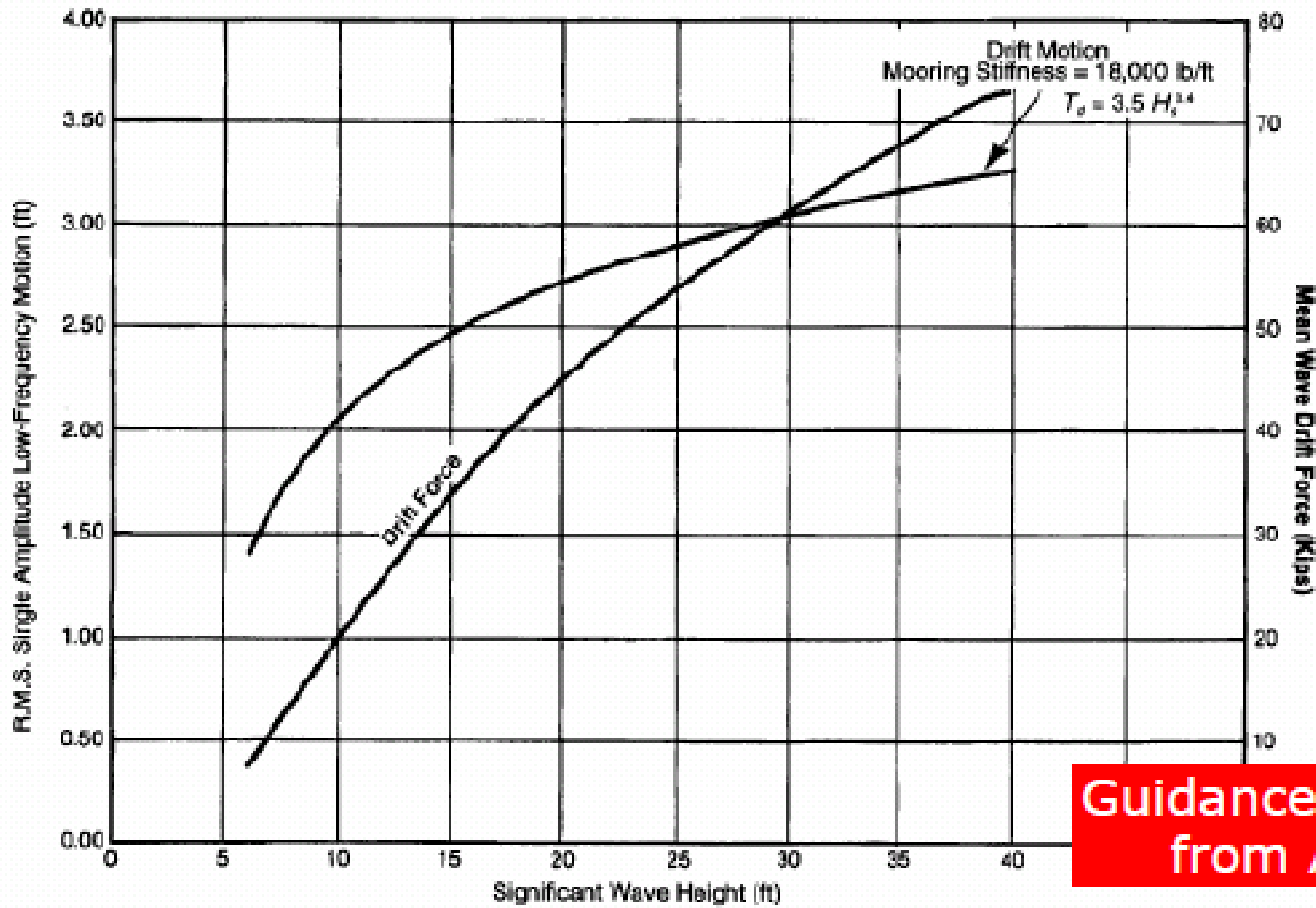
- Drift Force preserves conservation of momentum
- Magnitude is proportional to wave height squared.
- Magnitude is two orders of magnitude less than linear wave load!



The importance of wave drift is not the steady loads, but the slowly varying wave drift due to grouping which can excite large resonant responses at long periods for moored platforms in deep water!

Wave Drift

Several causes of wave drift: variations in wetted area (non-linear), diffraction (reflected energy), viscous drag (third order)



Guidance on drift forces from API RP-2SK

Figure A-15—Wave Drift Force and Motion for Semisubmersibles—Bow Seas

Wave Drift Particularly Important for Ship Shaped Bodies

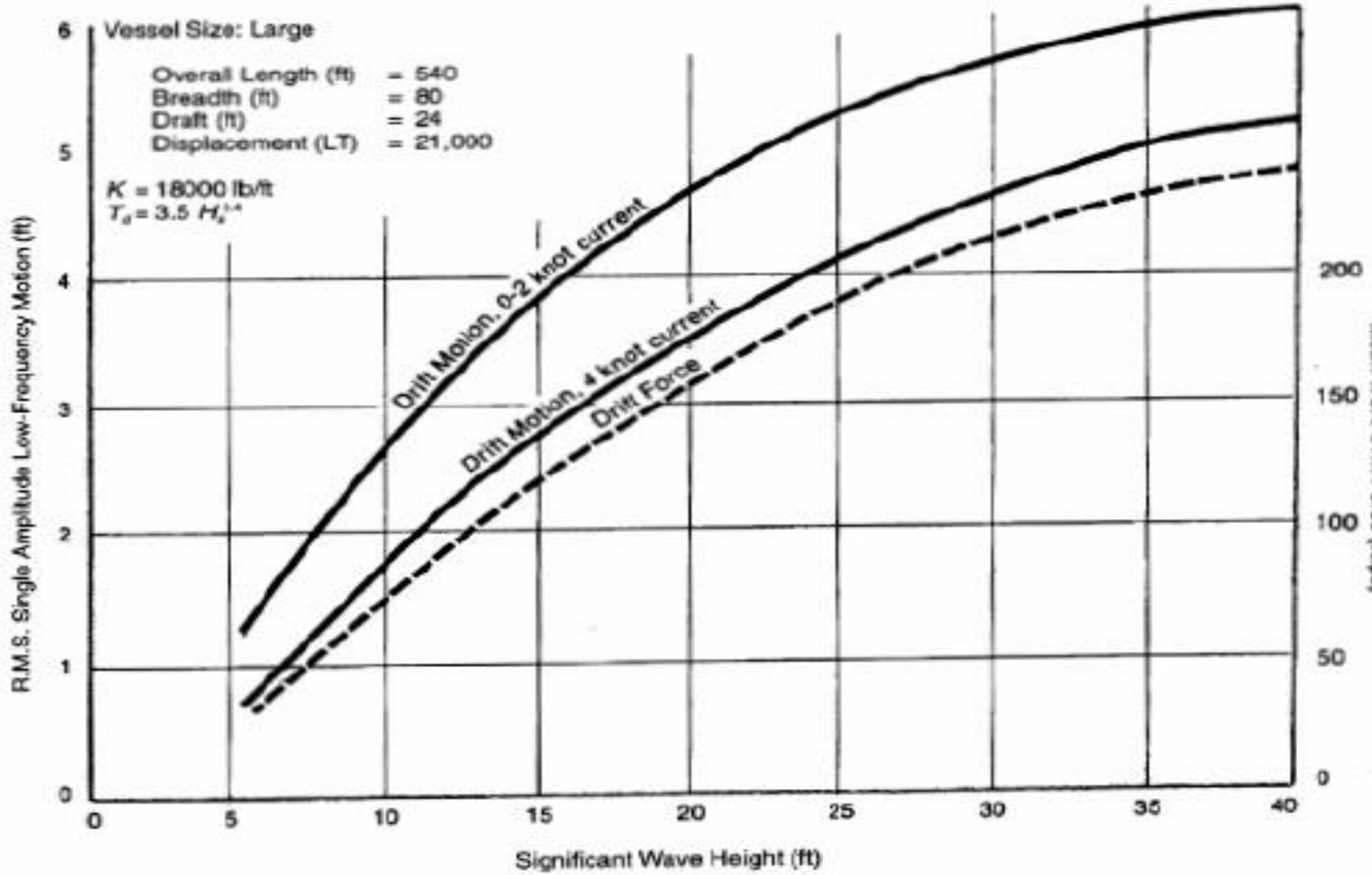


Figure A-14—Wave Drift Force and Motion for Drillships Beam Seas

Wave Motions

- Regular vs. Irregular Seas
  - Motion equations are solved for regular waves
  - Motions are a function of frequency
  - Real seas have many frequencies
  - Combine the motions by superposition

Structural Design

Load Conditions and Structural Design Criteria

STRUCTURAL DESIGN

- **Loads:**
- Offshore structure shall be designed for following types of loads:
  - Permanent (dead) loads.
  - Operating (live) loads.
  - Environmental loads
    - Wind load
    - Wave load
    - Earthquake load
  - Construction - installation loads.
  - Accidental loads.
- The design of offshore structures is dominated by environmental loads, especially wave load

STRUCTURAL DESIGN

Permanent Loads:

Weight of the structure in air, including the weight of ballast.

- Weights of equipment, and associated structures permanently mounted on the platform.
- Hydrostatic forces on the members below the waterline. These forces include buoyancy and hydrostatic pressures.

STRUCTURAL DESIGN

- **Operating (Live) Loads:**
  - Operating loads include the weight of all non-permanent equipment or material, as well as forces generated during operation of equipment.
    - The weight of drilling, production facilities, living quarters, furniture, life support systems, heliport, consumable supplies, liquids, etc.
    - Forces generated during operations, e.g. drilling, vessel mooring, helicopter landing, crane operations.
    - Following Live load values are recommended in BS6235:

    Crew quarters and passage ways: 3.2 KN/m^2

    Working areas: 8,5 KN/m^2

STRUCTURAL DESIGN

- **Wind Loads:**
  - Wind load act on portion of platform above the water level as well as on any equipment, housing, derrick, etc.
  - For combination with wave loads, codes recommend the most unfavorable of the following two loadings:
    - 1 minute sustained wind speeds combined with extreme waves.
    - 3 second gusts.
  - When, the ratio of height to the least horizontal dimension of structure is greater than 5, then API-RP2A requires the dynamic effects of the wind to be taken into account and the flow induced cyclic wind loads due to vortex shedding must be investigated.

STRUCTURAL DESIGN

Wave load:

- The wave loading of an offshore structure is usually the most important of all environmental loadings.
- The forces on the structure are caused by the motion of the water due to the waves
- Determination of wave forces requires the solution of ,

a) Sea state using an idealization of the wave surface profile and the wave kinematics by wave theory.

b) Computation of the wave forces on individual members and on the total structure, from the fluid motion.

Design wave concept is used, where a regular wave of given height and period is defined and the forces due to this wave are calculated using a high-order wave theory. Usually the maximum wave with a return period of 100 years, is chosen. No dynamic behavior of the structure is considered. This static analysis is appropriate when the dominant wave periods are well above the period of the structure. This is the case of extreme storm waves acting on shallow water structures.

STRUCTURAL DESIGN

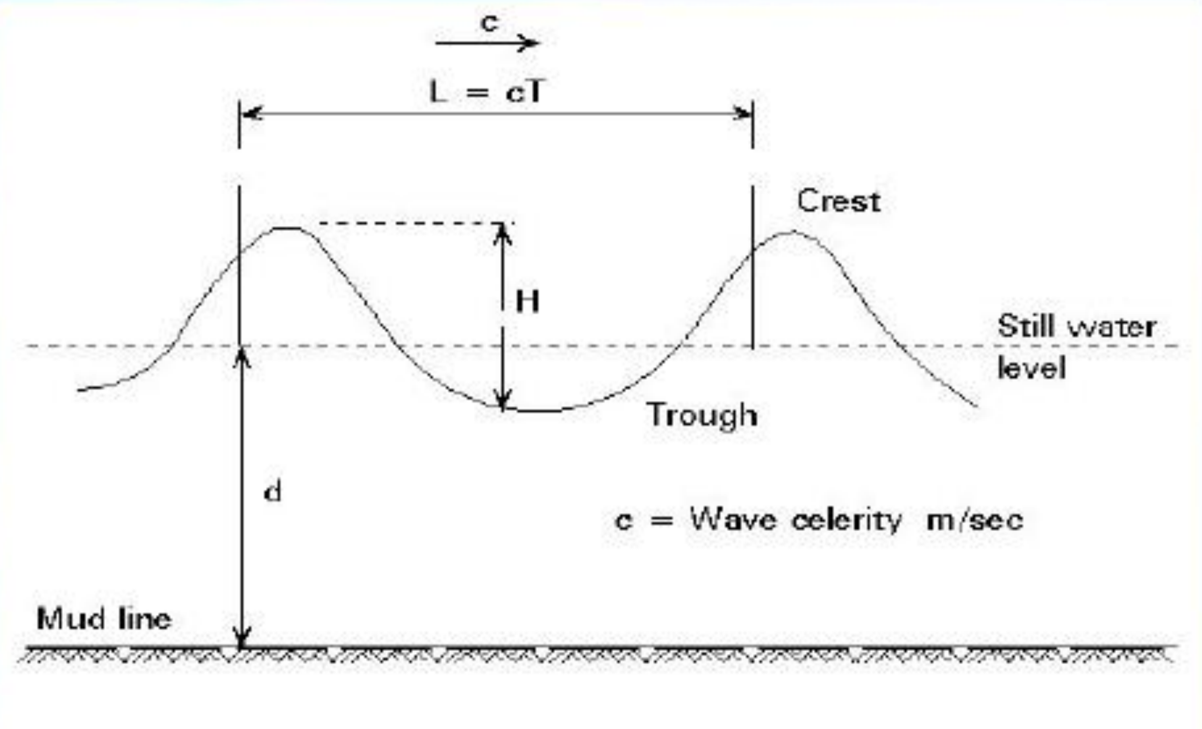


Figure 1 Wave symbols

Wave Load: ***(Contd.)***

- **Wave theories**

Wave theories describe the kinematics of waves of water. They serve to calculate the particle velocities and accelerations and the dynamic pressure as functions of the surface elevation of the waves. The waves are assumed to be long-crested, i.e. they can be described by a two-dimensional flow field, and are characterized by the parameters: wave height (H), period (T) and water depth (d).

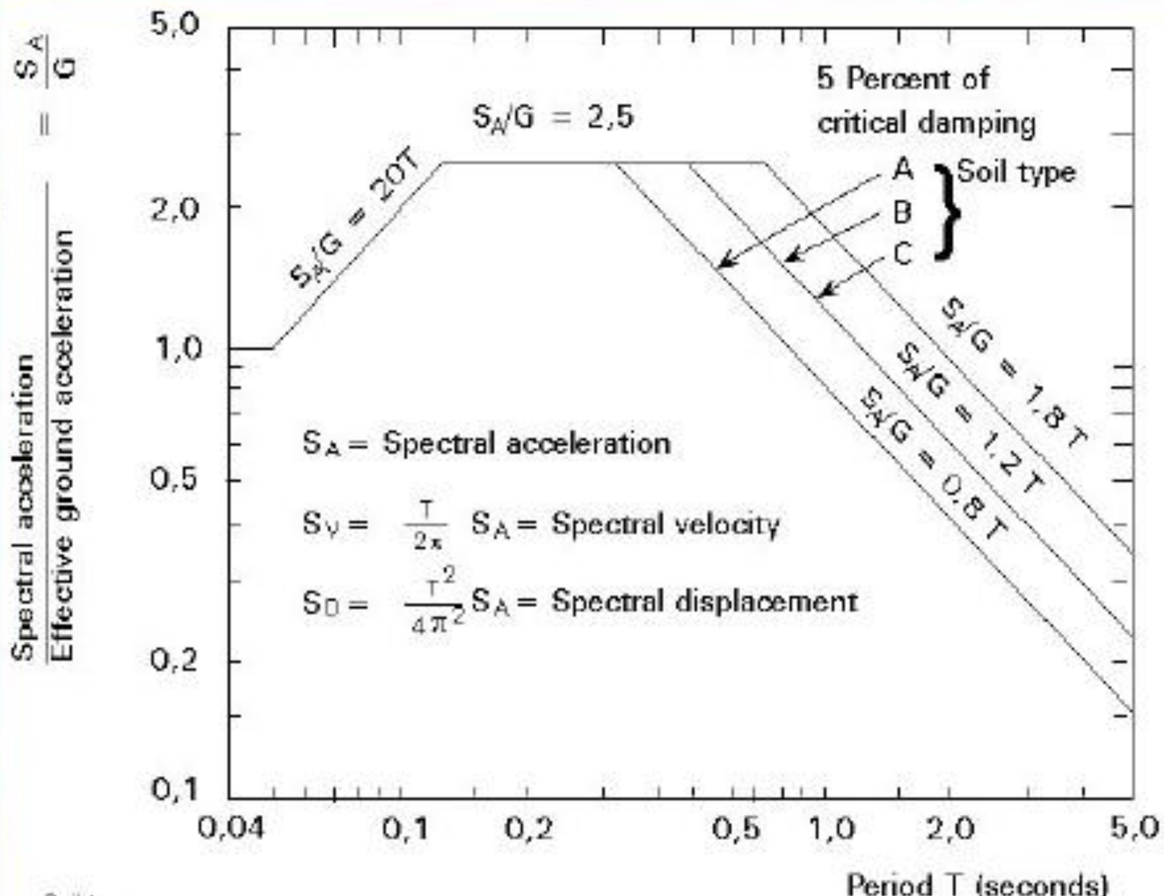
STRUCTURAL DESIGN

Wave theories: *(Contd.)*

- **Wave forces on structural members**

- Structures exposed to waves experience forces much higher than wind loadings. The forces result from the dynamic pressure and the water particle motions. Two different cases can be distinguished:
- Large volume bodies, termed hydrodynamic compact structures, influence the wave field by diffraction and reflection. The forces on these bodies have to be determined by calculations based on diffraction theory.
- Slender, hydro-dynamically transparent structures have no significant influence on the wave field. The forces can be calculated in a straight-forward manner with Morison's equation. The steel jackets of offshore structures can usually be regarded as hydro-dynamically transparent
- As a rule, Morison's equation may be applied when $D/L < 0.2$, where D is the member diameter and L is the wave length.
- Morison's equation expresses the wave force as the sum of,
  - An inertia force proportional to the particle acceleration
  - A non-linear drag force proportional to the square of the particle velocity.

STRUCTURAL DESIGN



Soil type

A Rock - crystalline conglomerate or shale - like material generally having shear wave velocities in excess of 3000 ft/sec (914 M/sec)

B Shallow strong alluvium - competent sands, silts and stiff clays with shear strengths in excess of about 1500 psf (72kPa) Limited. to depths of less than about 200 ft (61M) and overlying rock-like materials

C Deep strong alluvium-competent sands, silts and stiff clays with thicknesses in excess of about 200 feet (61M) and overlying rock-like materials

Figure 9 Design response spectra recommended in API RP2A

Earthquake load:

- Offshore structures are designed for two levels of earthquake intensity.
  - Strength level :Earthquake, defined as having a "reasonable likelihood of not being exceeded during the platform's life" (mean recurrence interval ~ 200 - 500 years), the structure is designed to respond elastically.
  - Ductility level : Earthquake, defined as close to the "maximum credible earthquake" at the site, the structure is designed for inelastic response and to have adequate reserve strength to avoid collapse.

STRUCTURAL DESIGN

Ice and Snow Loads:

Ice is a primary problem for marine structures in the arctic and sub-arctic zones. Ice formation and expansion can generate large pressures that give rise to horizontal as well as vertical forces. In addition, large blocks of ice driven by current, winds and waves with speeds up to 0,5 to 1,0 m/s, may hit the structure and produce impact loads.

Temperature Load:

Temperature gradients produce thermal stresses. To cater such stresses, extreme values of sea and air temperatures which are likely to occur during the life of the structure shall be estimated. In addition to the environmental sources , accidental release of cryogenic material can result in temperature increase, which must be taken into account as accidental loads. The temperature of the oil and gas produced must also be considered.

Marine Growth:

Marine growth is accumulated on submerged members. Its main effect is to increase the wave forces on the members by increasing exposed areas and drag coefficient due to higher surface roughness. It is accounted for in design through appropriate increases in the diameters and masses of the submerged members.

STRUCTURAL DESIGN

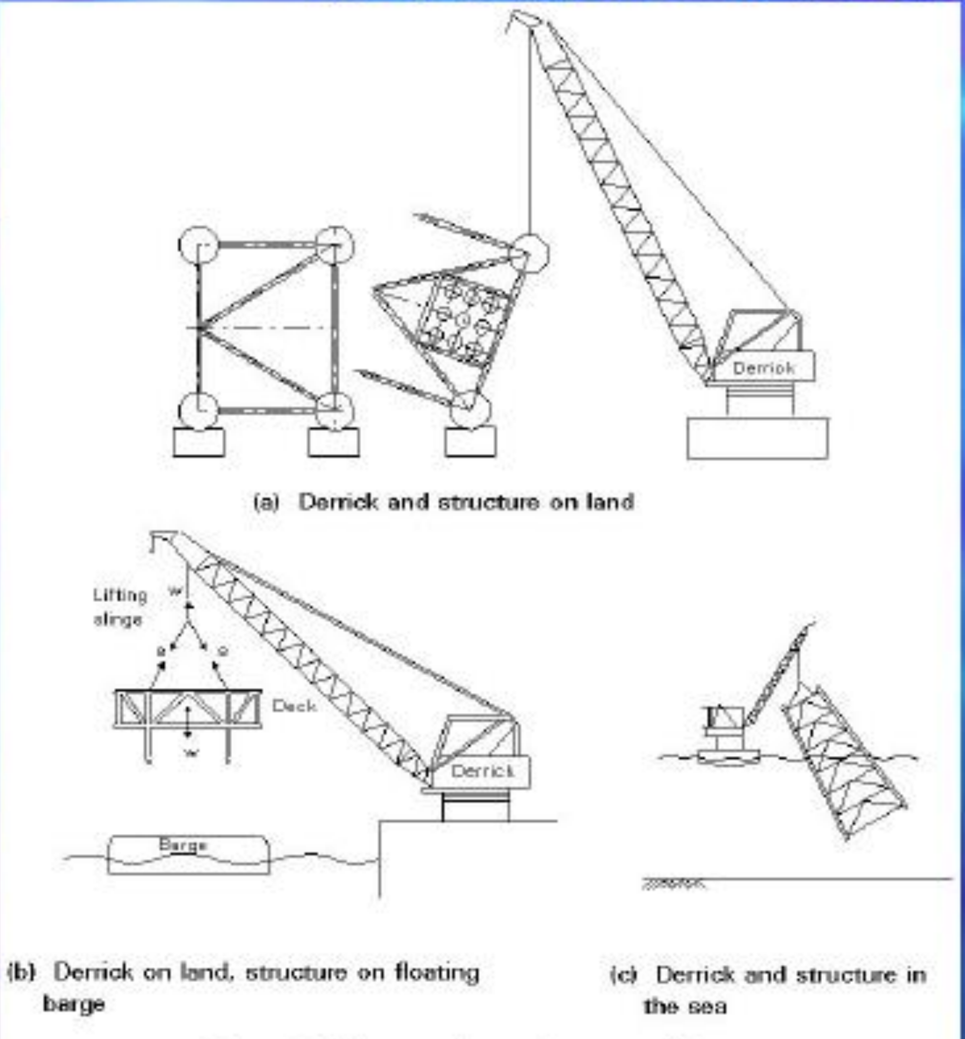


Figure 1 Lifts under various conditions

Installation Load :

These are temporary loads and arise during fabrication and installation of the platform or its components. During fabrication, erection lifts of various structural components generate lifting forces, while in the installation phase forces are generated during platform load out, transportation to the site, launching and upending, as well as during lifts related to installation.

All members and connections of a lifted component must be designed for the forces resulting from static equilibrium of the lifted weight and the sling tensions.

Load out forces are generated when the jacket is loaded from the fabrication yard onto the barge. Depends on friction co-efficient

STRUCTURAL DESIGN

Accidental Load :

- According to the DNV rules , accidental loads are loads, which may occur as a result of accident or exceptional circumstances.
- Examples of accidental loads are, collision with vessels, fire or explosion, dropped objects, and unintended flooding of buoyancy tanks.
- Special measures are normally taken to reduce the risk from accidental loads.

STRUCTURAL DESIGN

Load Combinations :

- The load combinations depend upon the design method used, i.e. whether limit state or allowable stress design is employed.
- The load combinations recommended for use with allowable stress procedures are:
  - Normal operations

    Dead loads plus ***operating*** environmental loads plus ***maximum*** live loads.
    Dead loads plus ***operating*** environmental loads plus ***minimum*** live loads.

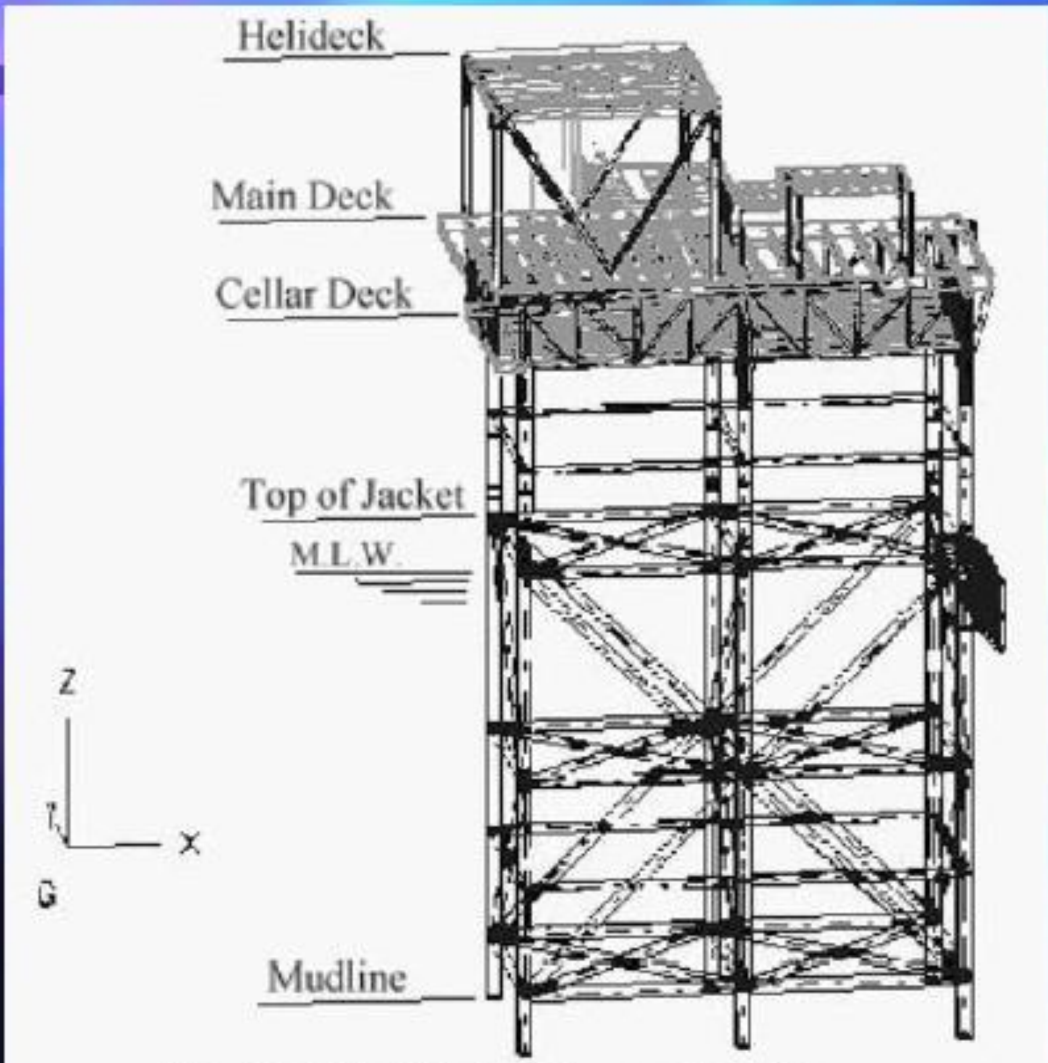
  - Extreme operations

    Dead loads plus ***extreme*** environmental loads plus ***maximum*** live loads.

    Dead loads plus ***extreme*** environmental loads plus ***minimum*** live loads

- Environmental loads,should be combined in a manner consistent with their joint probability of occurrence.
- Earthquake loads, are to be imposed as a separate environmental load, i.e., not to be combined with waves, wind, etc.

STRUCTURAL ANALYSIS

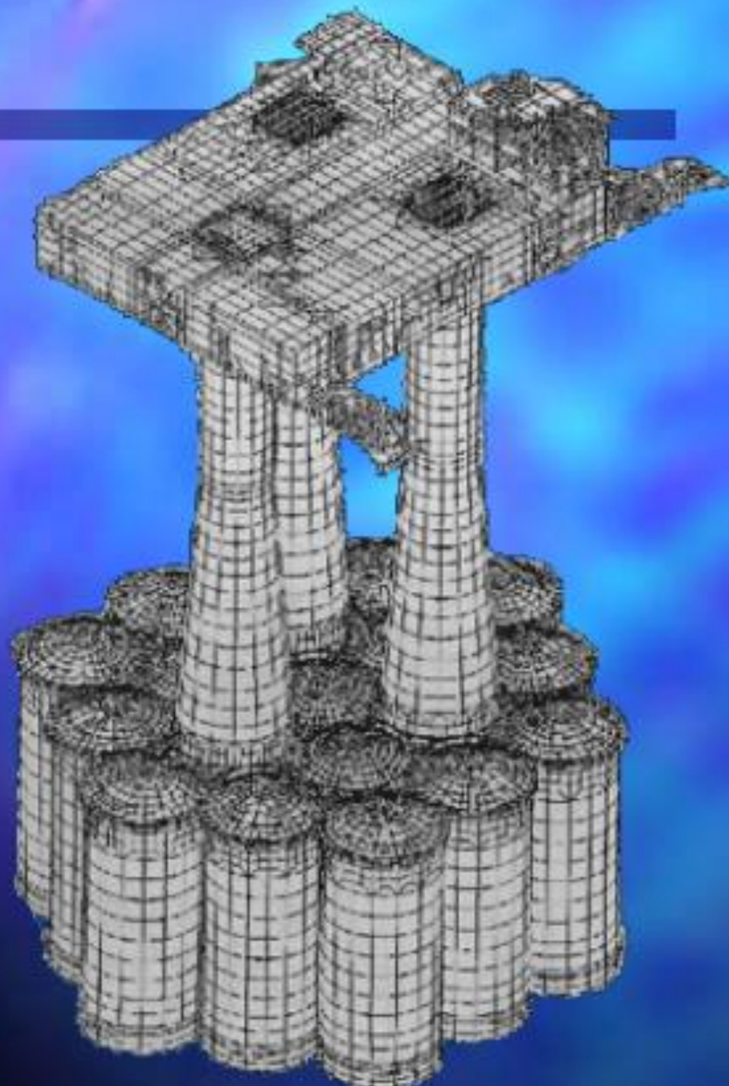


StruCad Model of offshore oil platform.

ANALYSIS MODEL:

- The analytical models used in offshore engineering are similar to other types of on shore steel structures
- The same model is used throughout the analysis except supports locations.
- Stick models are used extensively for tubular structures (jackets, bridges, flare booms) and lattice trusses (modules, decks).
- Each member is normally rigidly fixed at its ends to other elements in the model.
- In addition to its geometrical and material properties, each member is characterized by hydrodynamic coefficients, e.g. relating to drag, inertia, and marine growth, to allow wave forces to be automatically generated.

STRUCTURAL ANALYSIS:



- Integrated decks and hulls of floating platforms involving large bulkheads are described by plate elements.
- Deck shall be able to resist crane's maximum overturning moments coupled with corresponding maximum thrust loads for at least 8 positions of the crane boom around a full 360° path.
- The structural analysis will be a static linear analysis of the structure above the seabed combined with a static non-linear analysis of the soil with the piles.
- Transportation and installation of the structure may require additional analyses
- Detailed fatigue analysis should be performed to assess cumulative fatigue damage
- The offshore platform designs normally use pipe or wide flange beams for all primary structural members.

Acceptance Criteria:

- The verification of an element consists of comparing its characteristic resistance(s) to a design force or stress. It includes:
- a strength check, where the characteristic resistance is related to the yield strength of the element,
- a stability check for elements in compression related to the buckling limit of the element.
- An element is checked at typical sections (at least both ends and mid span) against resistance and buckling.
- Tubular joints are checked against punching. These checks may indicate the need for local reinforcement of the chord using larger thickness or internal ring-stiffeners.
- Elements should also be verified against fatigue, corrosion, temperature or durability wherever relevant.

STRUCTURAL DESIGN

- **Design Conditions:**

  Operation

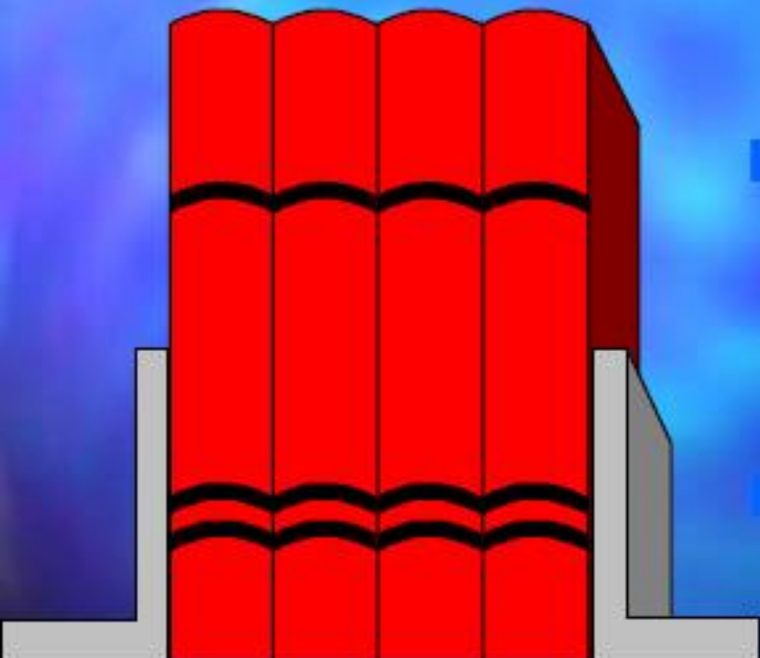
  Survival

  Transit.

- The design criteria for strength should relate to both intact and damaged conditions.

- Damaged conditions to be considered may be like 1 bracing or connection made ineffective, primary girder in deck made ineffective, heeled condition due to loss of buoyancy etc.

CODES



- **Offshore Standards (OS):**

  Provides technical requirements and acceptance criteria for general application by the offshore industry eg.DNV-OS-C101

- **Recommended Practices(RP):**

  Provides proven technology and sound engineering practice as well as guidance for the higher level publications eg. API-RP-WSD

- **BS 6235: Code of practice for fixed offshore structures.**
  - British Standards Institution 1982.
  - Mainly for the British offshore sector.


THANK YOU!
QUESTIONS?