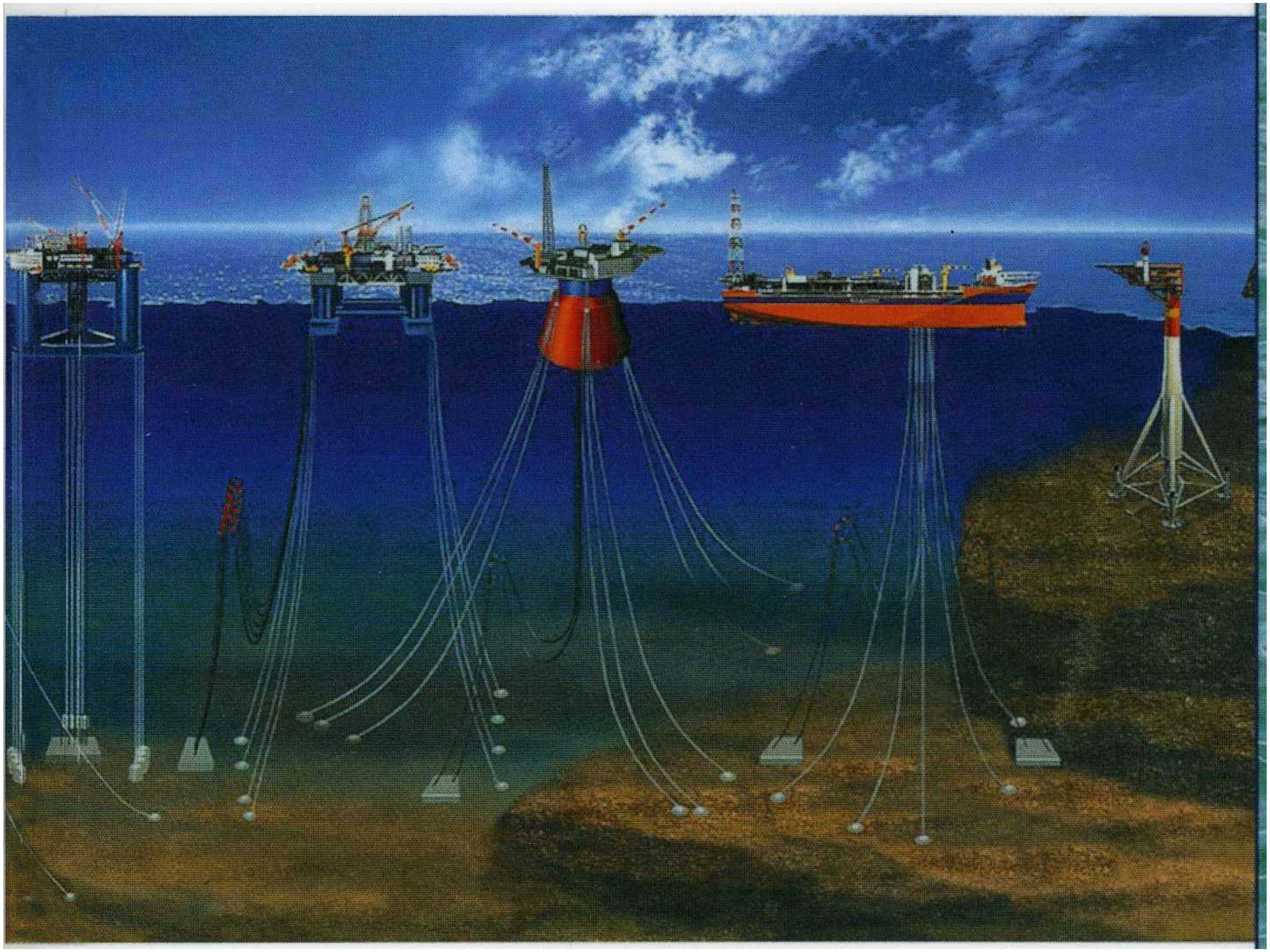
2.019 Design of Ocean Systems

Lecture 2

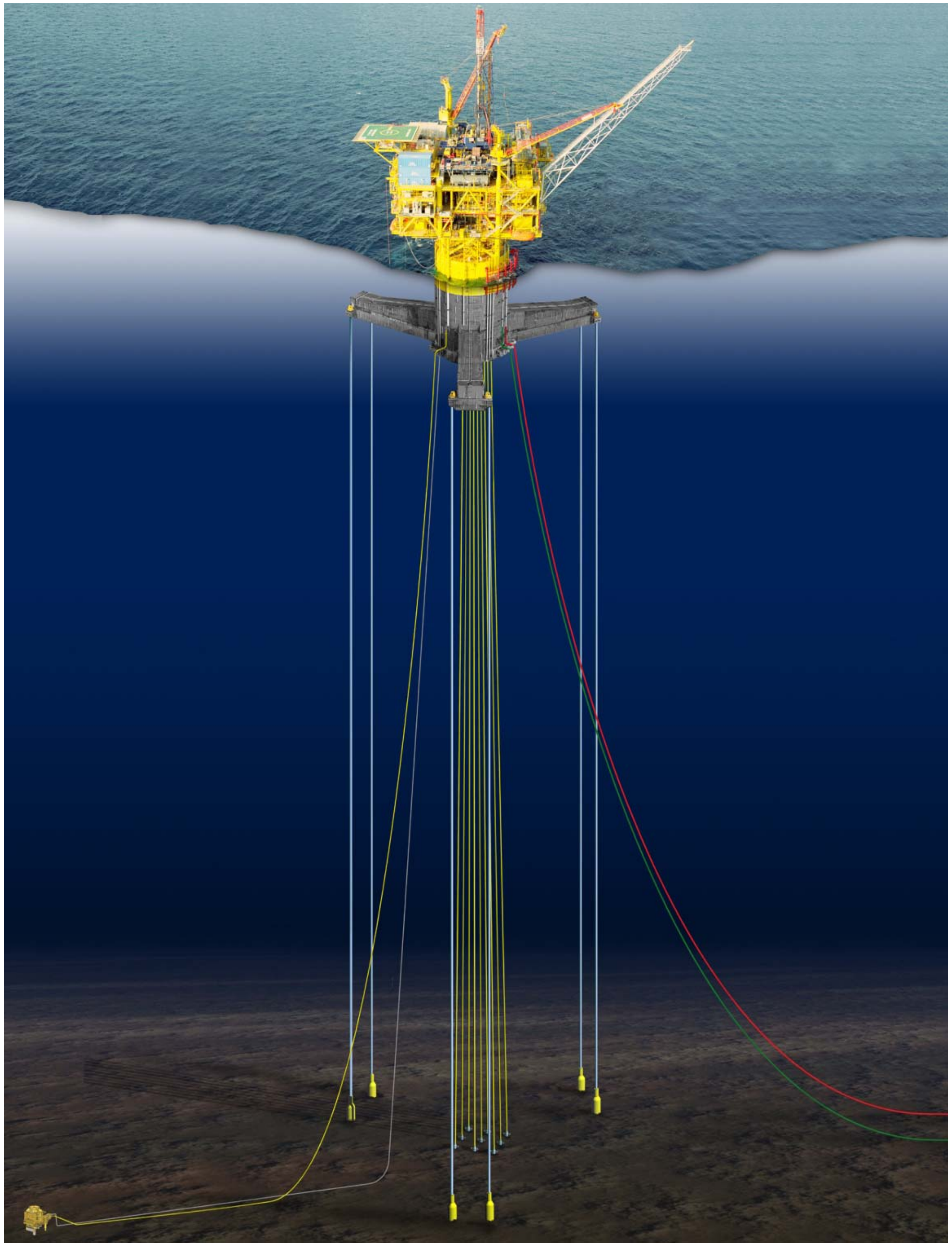
February 11, 2011

Typical Offshore Structures



Platforms:
- Fixed platform
- FPSO
- SPAR
- Semi-Submersible
- TLP (Tension Leg Platform)

Key Components:
- Platform on surface (with production facility, gas/oil storage)
- Risers
- Mooring
- Subsea system
- Pipelines or transport tankers



Tension-Leg Platform (TLP)

Semi-Submersible Platform

Gravity-Based Platform

FPSO (Floating, Production, Storage, Offloading)

- Movable
- Versatile for use in smaller reservoirs
- Relatively cheap in cost

- Topside
- Hull
- Mooring/riser system

Design of FPSO vs. Tankers/Ships

Tankers/ships:

- Storage
- Stability
- Speed
- Motion (seakeeping)
- Cost

FPSO:

- Storage
- Stability
- No Speed requirement
- Motion (seakeeping)
  - Limited riser top-end displacement
  - Production
  - Offloading
  - Equipment installation
- Freeboard
  - Green water
  - Bow impact
- Mooring/risers
  - Drift motion
  - slowly-varying motion
- Reliability

Basic Design Requirements of FPSO

- Requirement for a turret mooring to allow the FPSO to weathervane and minimize environmental loads on the mooring system
- Selection of suitable hull size and form with good motion characteristics
- Freeboard
- Production facilities design to minimize motion downtime
- Hull size to provide adequate buffer storage to minimize shuttle tanker offloading downtime
- Hull structure design (strength and fatigue)
- Human safety

Hull Size and Form

Major requirements:

- Crude oil storage
- Deck space
- Sea-Keeping performance
- Availability of tanker hulls for conversion

Typically,

- Weight of lightship (i.e. steel): 13-16% of displacement
- Weight of topside: 7-8% of displacement
- Cargo deadweight (i.e. oil storage): ~ 75% of displacement
- Weight of risers/moorings: depending on type and number of riser/mooring lines

In general,

- Hull steel weight: Length/depth ratio of hull and hull size
- Deck space: Length X breadth
- Mooring loads: Breadth/length
- Stability: Breadth/depth
- Sea-keeping (primarily pitch): Length
- Green water on deck: Freeboard
- Bottom slamming forward: Ballast capacity
- Bow wave impact: Bow fineness

Structure Configuration

Double sides /bottom:

- Minimize risk of oil spilling due to collision
- Single or double bottoms are OK for FPSO
- 2m width of wing tank for trading tankers

Bulkhead spacing:

- Minimize free surface effects due to partial-filled tanks
- Limits on maximum tank size to keep oil spillage below a certain volume in the event of tank rupture
- Structure support of production/utility system
- More tanks to allow safe inspection and maintenance while not interrupting operation

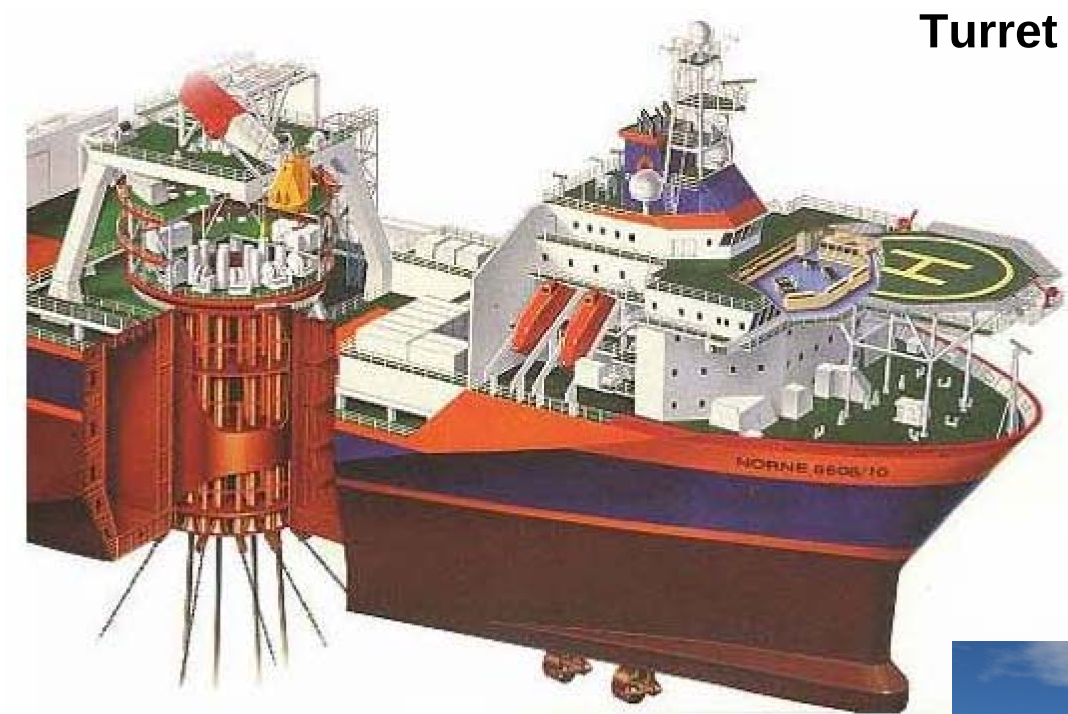
Typically, the cargo tank region is subdivided by a centre-line bulked and four or more transverse bulkheads.

Ballast System

The capacity and location of ballast tanks should be designed to ensure that with crude oil storage tanks empty or part-fill, the FPSO draft and trim meets requirements on:

- stability
- maximum trim for production equipment operation
- minimum draft forward to prevent bottom slamming.

Turret Mooring/Riser System



Internal Turret:
- Smaller riser head displacement due to pitch motion
- Easy for maintenance
- Large deck space
- Longer ship length

External Turret:
- No effect on ship hull length and deck area
- Inconvenient for maintenance
- Larger riser head displacement due to pitch motion

Estimate of Heave and Pitch Natural Periods

For a barge, length L, width B, draft T

Heave:

$$T_{nh} = 2\pi\sqrt{\frac{m+m_a}{K}} = 2\pi\sqrt{\frac{C_B T}{C_w g}(1+0.4B/T)}$$

$C_B = \nabla/(LBT)$: block coefficient; $C_w = S/(LB)$: waterplane coefficient

Pitch:

$$T_{np} = 2\pi\sqrt{\frac{m(R^2+R_a^2)}{\rho g \nabla H}} \approx 2\pi\sqrt{\frac{\frac{12T}{L^2}R^2+\frac{B}{4}}{g}}$$

H: metacentric height in longitudinal direction
R: radius of gyration
R_a: radius of gyration of pitch added mass

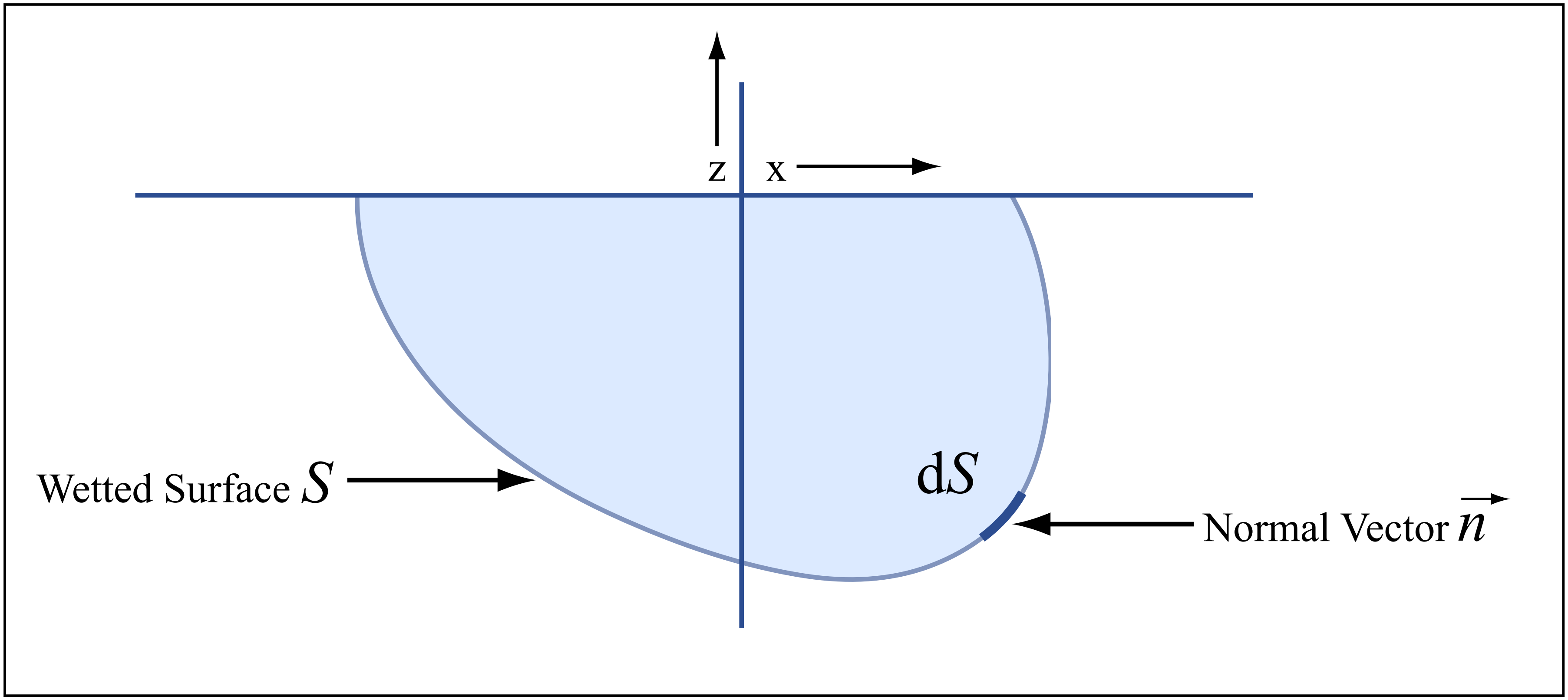
Stability Requirements

Intact stability
Damage stability

Hull Structure and Deflection

Shear requirement
Sagging/hogging moment requirements
Deflection requirement

Hydrostatic Pressure and Forces



Hydrostatic Pressure: $p = p_a - \rho g z$

Force: $\vec{F} = -\int\int_S \rho g z \vec{n} \mathrm{d}S$

Moment: $\vec{M} = -\int\int_S \rho g z (\vec{x} \times \vec{n}) \mathrm{d}S$

$$
\begin{aligned}
F_z &= \rho g \int\int\int \mathrm{d}Volume \\
&= \rho g \times \text{submerged volume} \\
F_x &= 0 \\
F_y &= 0 \\
M_x &= \rho g \int\int\int_V y \mathrm{d}Volume \\
M_y &= \rho g \int\int\int_V x \mathrm{d}Volume \\
M_z &= 0
\end{aligned}
$$

Hydrostatic Stability — Fully Submerged Body

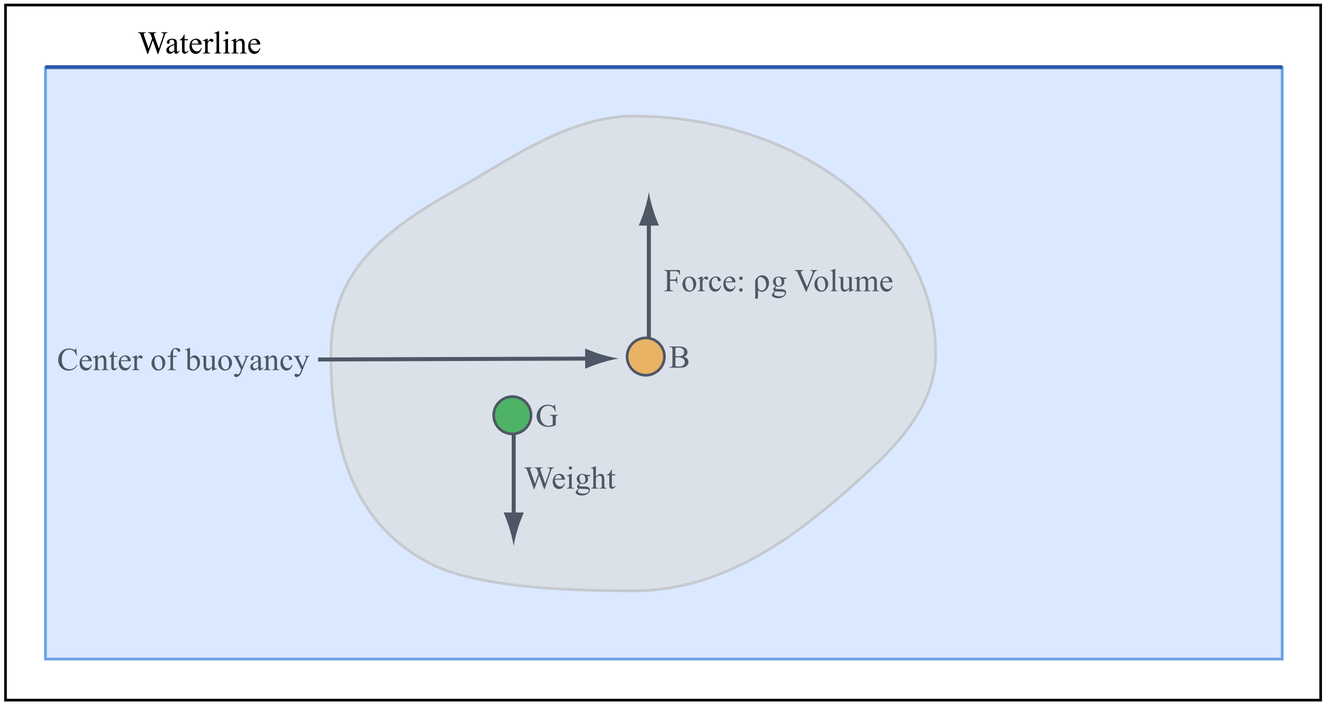


Image by MIT OpenCourseWare.

Moment Equilibrium: G and B are in a vertical line
Restoring moment $M_r = -\rho g \nabla \times GB \sin\theta$ under a rotation θ

Stable: G is under B (i.e. $GB > 0$)
Unstable: G is above B (i.e. $GB < 0$)

Hydrostatic Restoring Moment — Surface Piercing Body

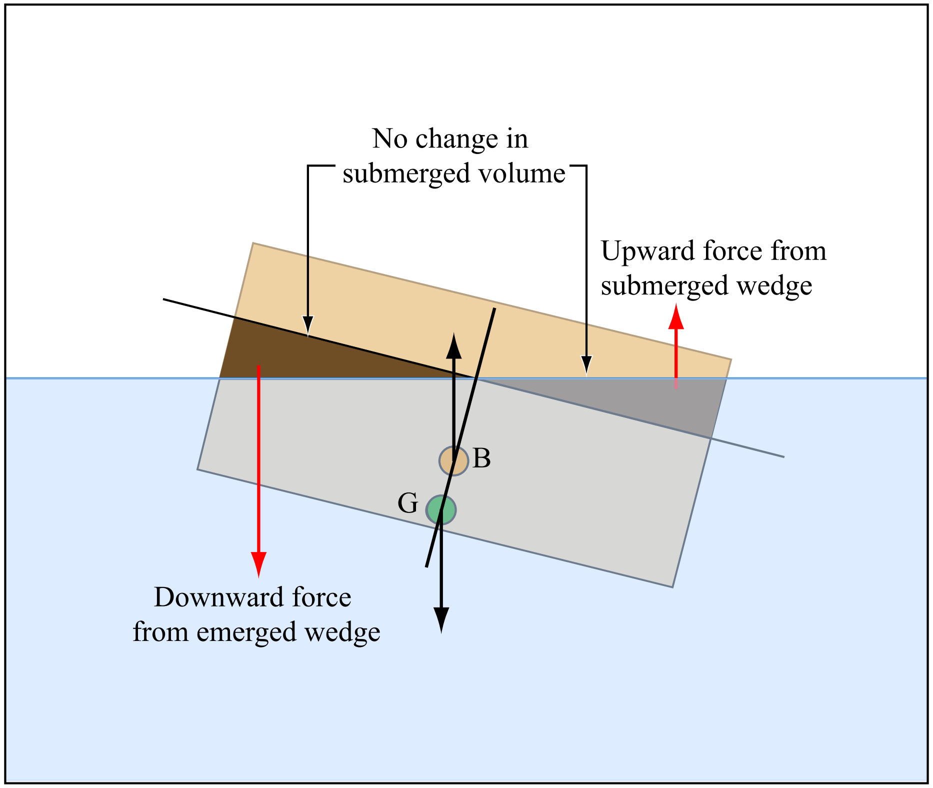


Image by MIT OpenCourseWare.

For equal displacement volume, the waterline contribution to restoring moments:

$$M_{rx} = -\rho g I_t \theta_x \qquad (heel)$$

$$M_{ry} = -\rho g I_l \theta_y \qquad (trim)$$

Moments of inertia of waterplane area:

$$I_t = \int\int_{A_w} y^2 \mathrm{d}A\ , \qquad I_l = \int\int_{A_w} x^2 \mathrm{d}A$$

Center of flotation (COF):

$$\int\int_{A_w} x\mathrm{d}A = 0\ , \qquad \int\int_{A_w} y\mathrm{d}A = 0$$

Total restoring moments:

$$\begin{aligned} M_{rx} &= (-\rho g I_t - GB\rho g \nabla)\theta_x \\ &= -\rho g \nabla (\frac{I_t}{\nabla} + GB)\theta_x \\ &= -\rho g \nabla \times GM \times \theta_x \end{aligned}$$

Metacentric height for transverse rotation:

$$GM = \frac{I_t}{\nabla} + GB$$

- Stable if GM > 0
- Compared to the submerged bodies, the presence of free surface increases the restoring moment.

Righting Arm

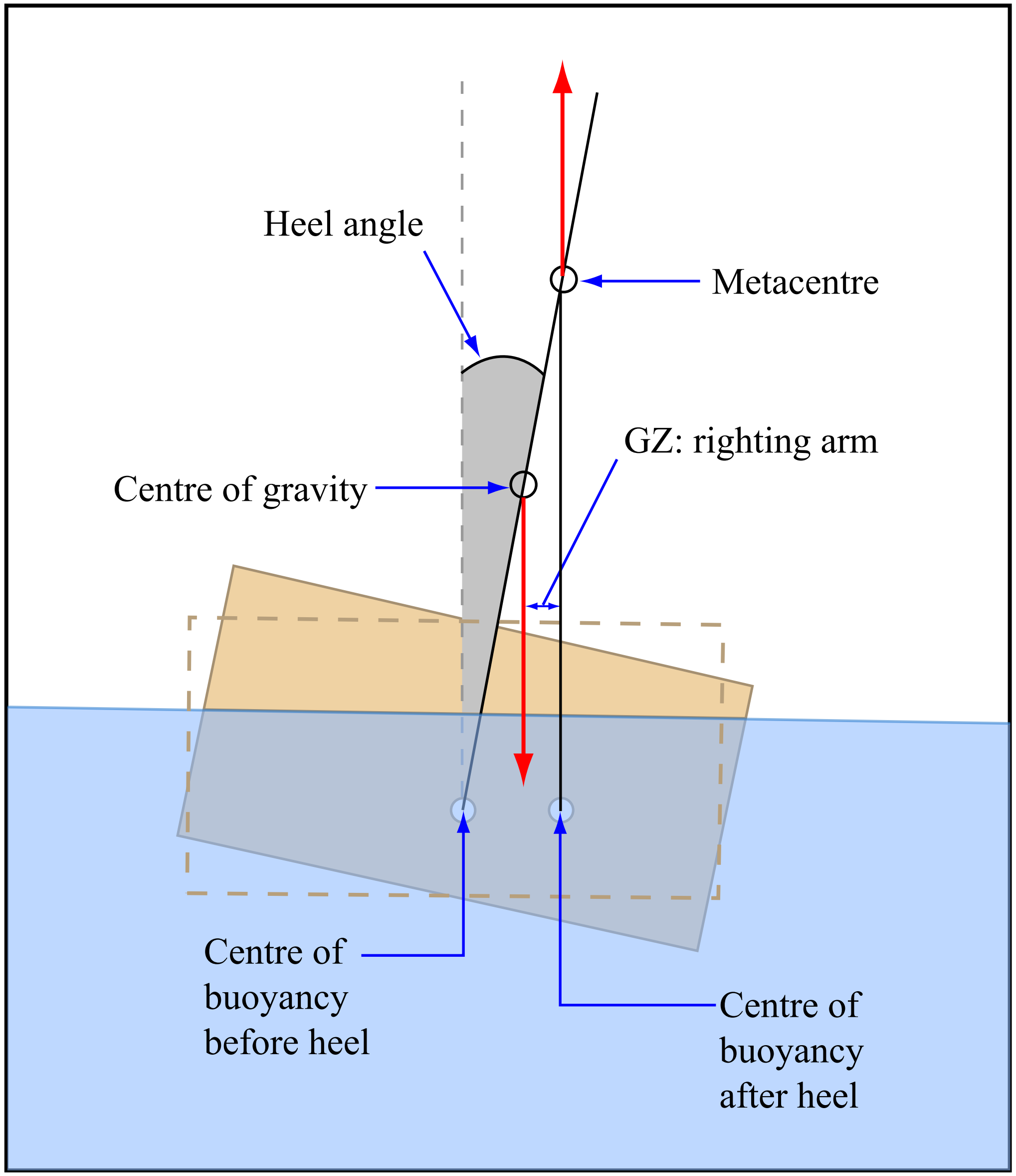


Image by MIT OpenCourseWare.

Righting arm GZ:

$$GZ = -\frac{\text{righting moment}}{\text{displacement}} = GM \times \sin\theta_x \approx GM\theta_x$$

GZ Curve

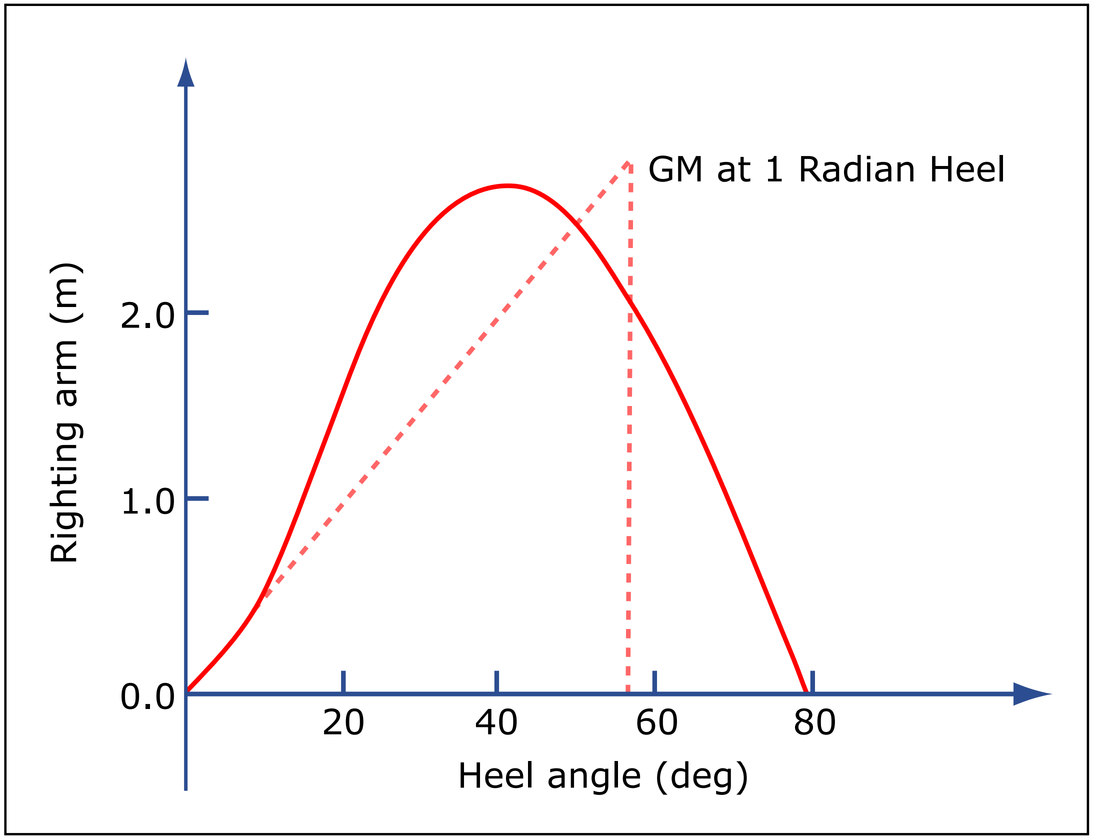


Image by MIT OpenCourseWare.

A floating structure is STABLE for heel and trim respectively when:

$$GM_t > 0(\text{heel})$$

$$GM_l > 0(\text{trim})$$

Wind Overturning Moment

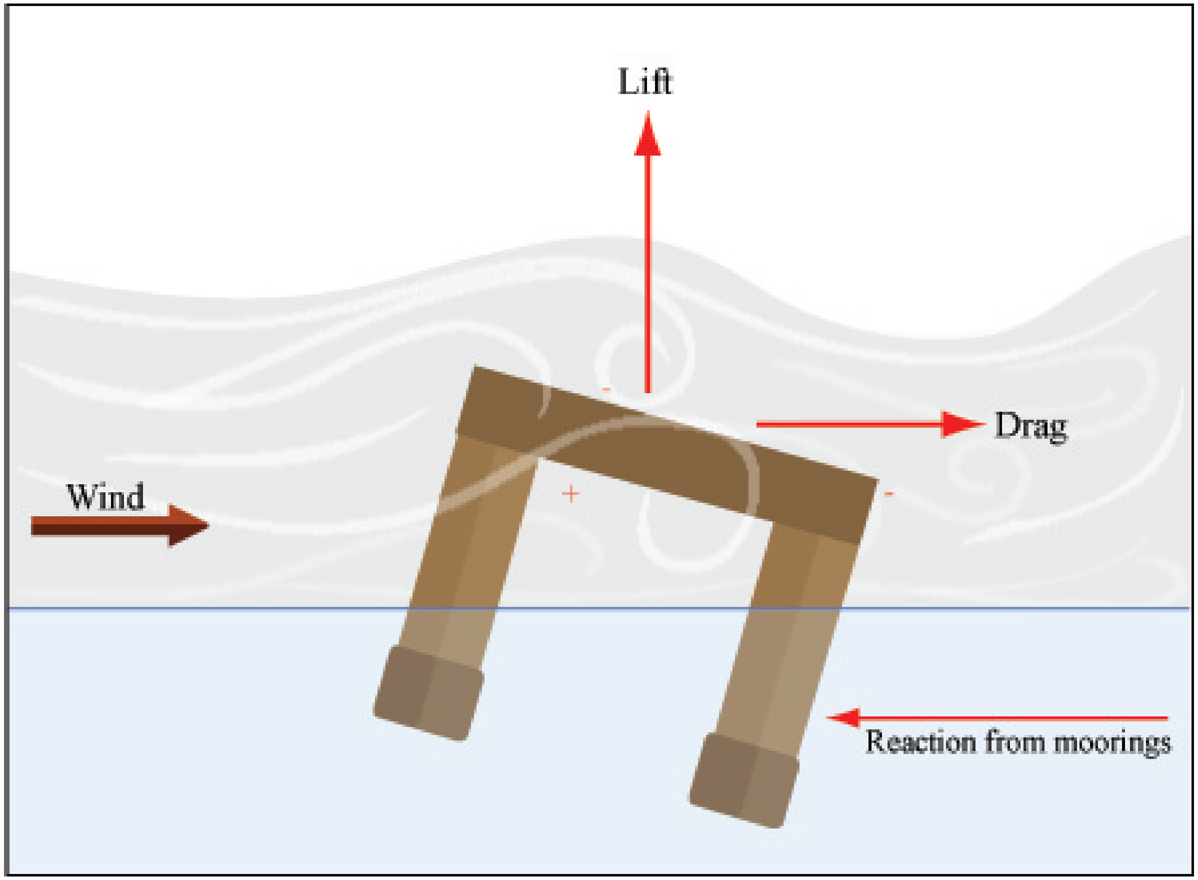
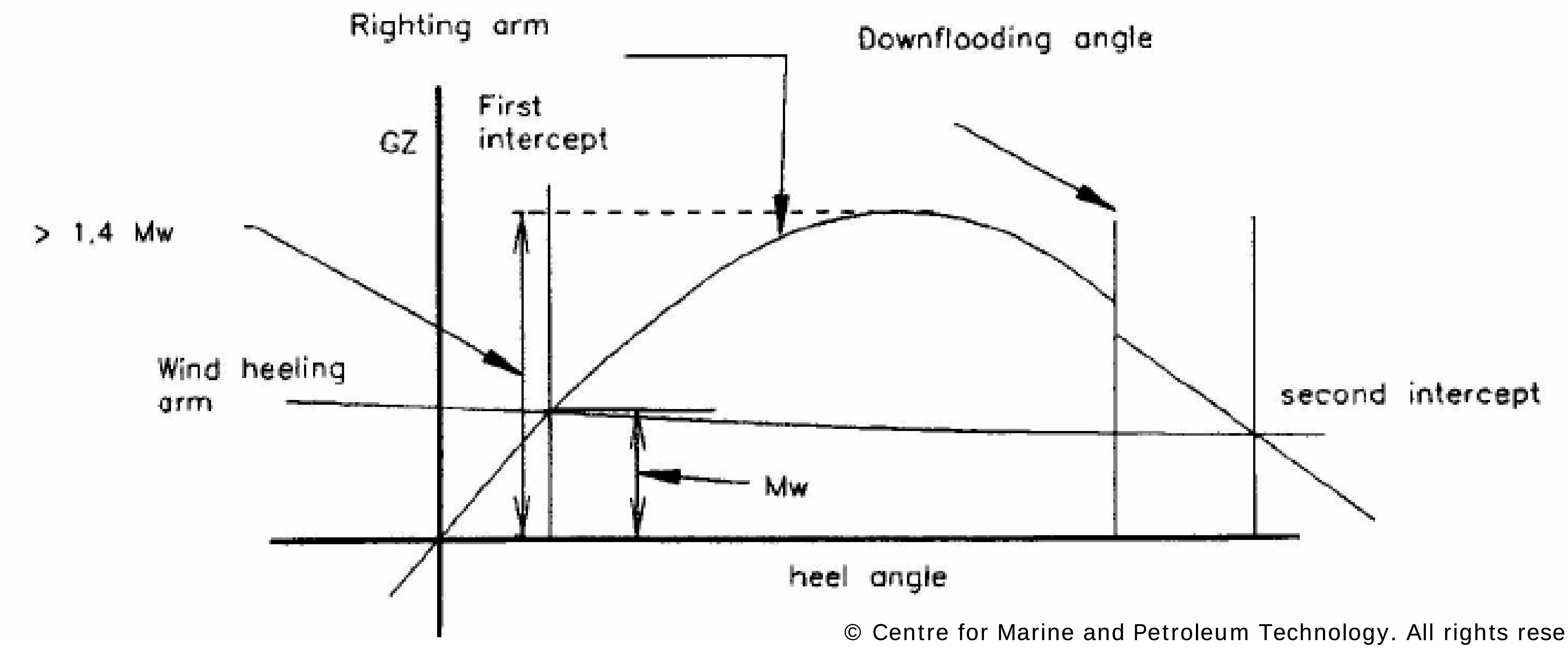


Image by MIT OpenCourseWare.

$$F_{wind} = \frac{1}{2}\rho_{air} C_s C_H V_{10}^2 A \qquad M_{wind} = \sum F_{wind} \times h$$

C_s: shape coefficient, C^s=1.0 for large flat surface
C_H: height coefficient, C_H=1.0 for FPSO
V_{10}: wind velocity at 10m above sea surface
A: Project area of the exposed surfaces in the vertical or the heeled condition
h: vertical distance between center of wind force and center of resistance (by mooring lines, etc)

Evaluation of Large Angle Hydrostatic Stability



Wind heeling arm = (wind moment) / displacement

Safety Criterion: $M_{max} \geq M_w$

M_{max}: maximum righting arm
M_w: wind moment

Dynamic Stability Criterion:

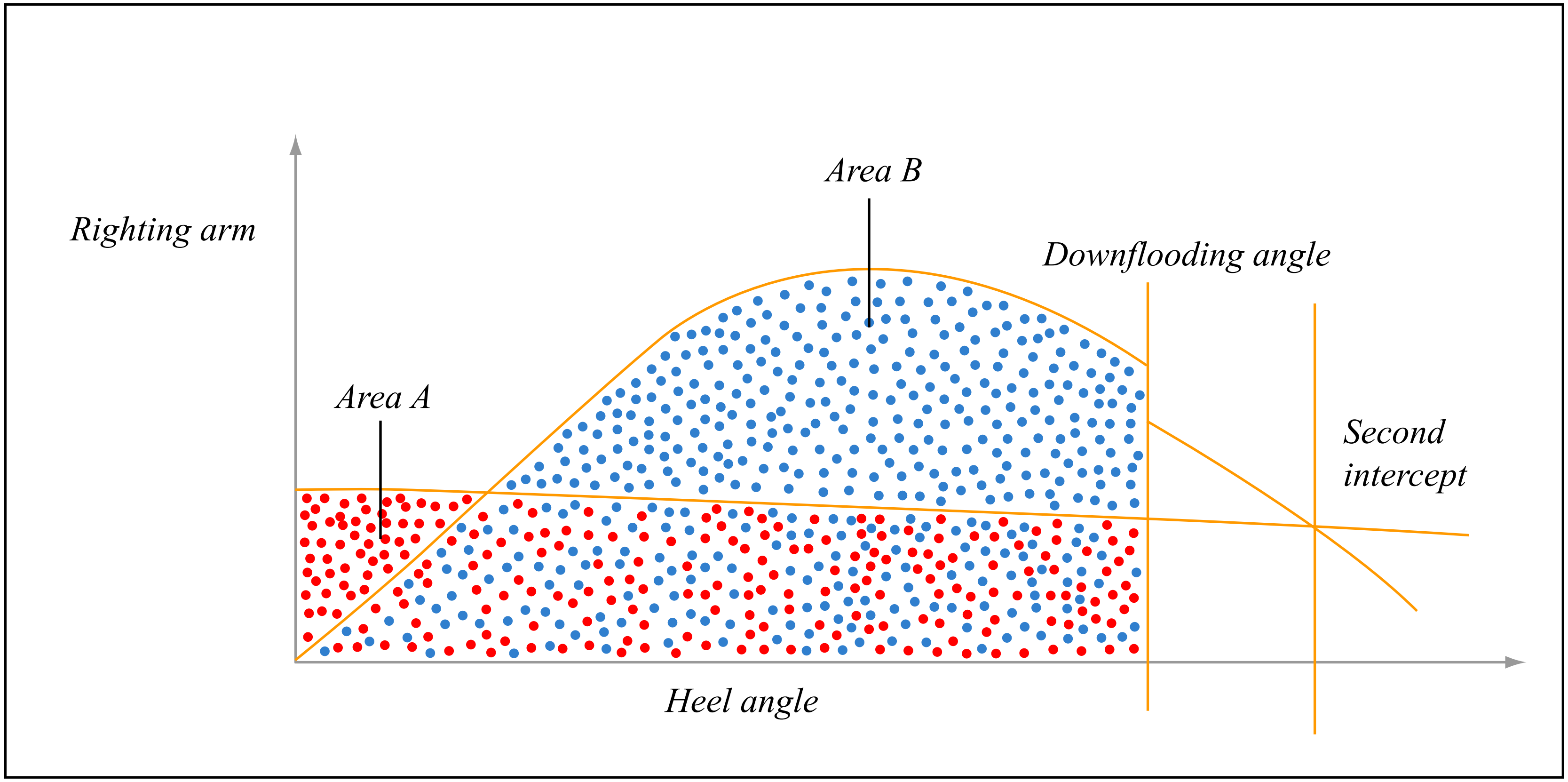


Image by MIT OpenCourseWare.

$$E_{\text{righting}-\text{moment}} \geq 1.3(\text{or}1.4)E_{\text{wind}}$$

$$E_{\text{right}-\text{moment}} = \text{Area} \quad \text{B}$$

Hydrostatic Stability Analysis of Ships and FPSOs

Intact stability analysis:

- Compute GZ curves for various loading conditions
- Compute heeling moments by wind, etc
- Compare righting lever, GZ, to heeling lever

Damaged stability analysis:

- Both wind loading and a degree of flooding are assumed
- Flooding due to waterline damage and/or flooding due to burst ballast
- Evaluate the stability as in intact stability analysis
- *Typical rule requirements: 50 knot wind and side or bottom damage*

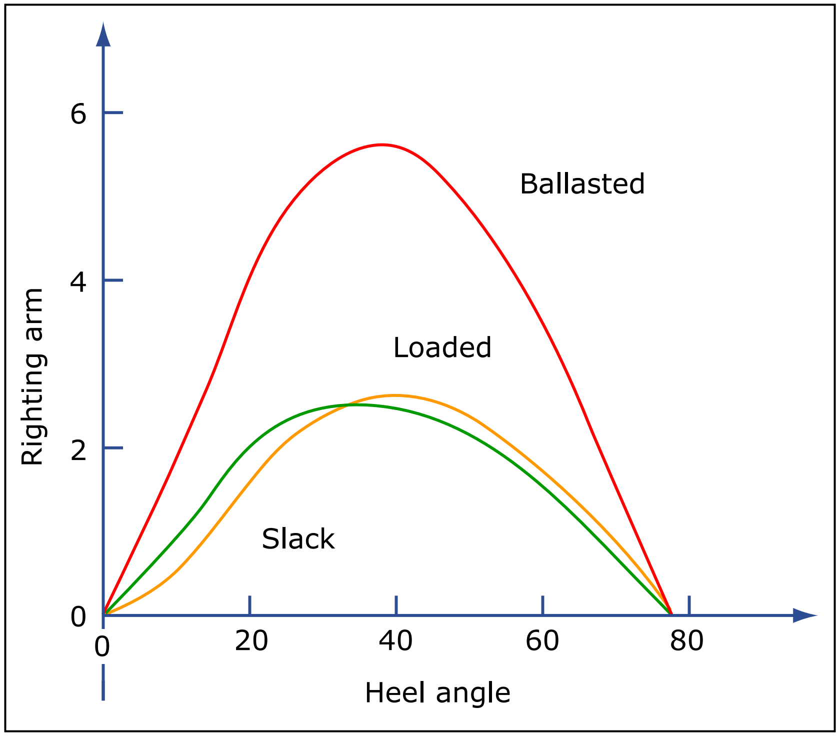


Image by MIT OpenCourseWare.

GZ curve for a FPSO

ABS MODU (Mobile Offshore Drilling Unit) Stability Regulations

Intact Stability:

- Design wind speed: 100 knots
- The angle of inclination should be no greater than 25 degree
- Dynamic stability criterion:

$$E_{\text{righting}-\text{moment}} \geq 1.3(\text{or}1.4)E_{\text{wind}}$$

Damage Stability:

- Design wind speed: 50 knots
- The angle of inclination should be no greater than 25 degree
- Horizontal penetration should be at least 1.5m
- Longitudinal damage extent should be (1/3) $L^{2/3}$ or 14.5m, whichever is less
- Damaged compartments are completely filled
- Downflooding angle must be larger than the first intersection of the righting moment and heeling moment

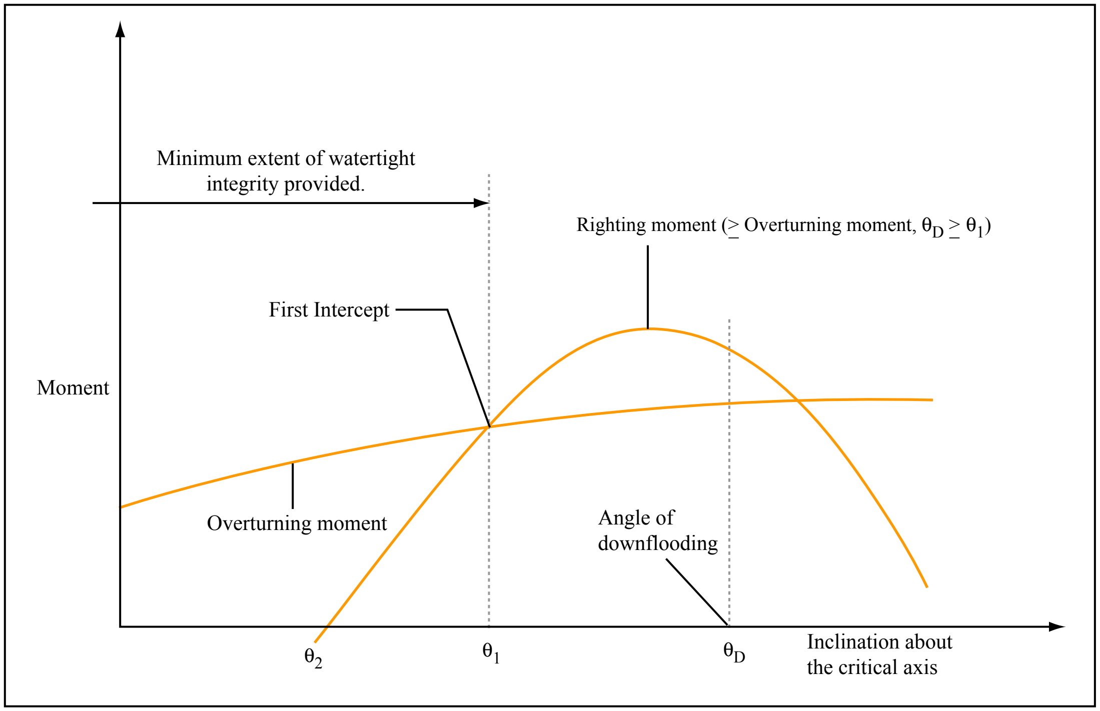


Image by MIT OpenCourseWare.