Fixed and Floating Offshore Systems

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UNIVERSITY *of* NICOSIA

Overview

- Fixed platforms:
  - Jacket (steel) installations
  - Monopods
  - Compliant towers
  - Guyed towers
- Gravity based platforms
- Tension leg platforms (TLPs)
- Jack-up rigs
- Semi-submersibles
- Spar platforms

Overview (2)

- Floating, production, storage & offloading (FPSOs)
- Drillships
- Floating LNG (FLNG)
- Floating Storage and Regas Unit (FSRU)
- Offshore mooring systems
- Subsea systems

Salvaging the San Juan sub?

- Diesel-electric sub lost Nov. 16, 2017
- Crew: 44 including first female sailor
- Discovered by Ocean Infinity at 3,000 ft
- It is feasible to recover the vessel? Vessel was never salvaged
- Probably yes, at a cost of $100m
- Video: Argentina submarine
- Kursk: https://bit.ly/2QocwT9
- Dutch Mammoet-Smit





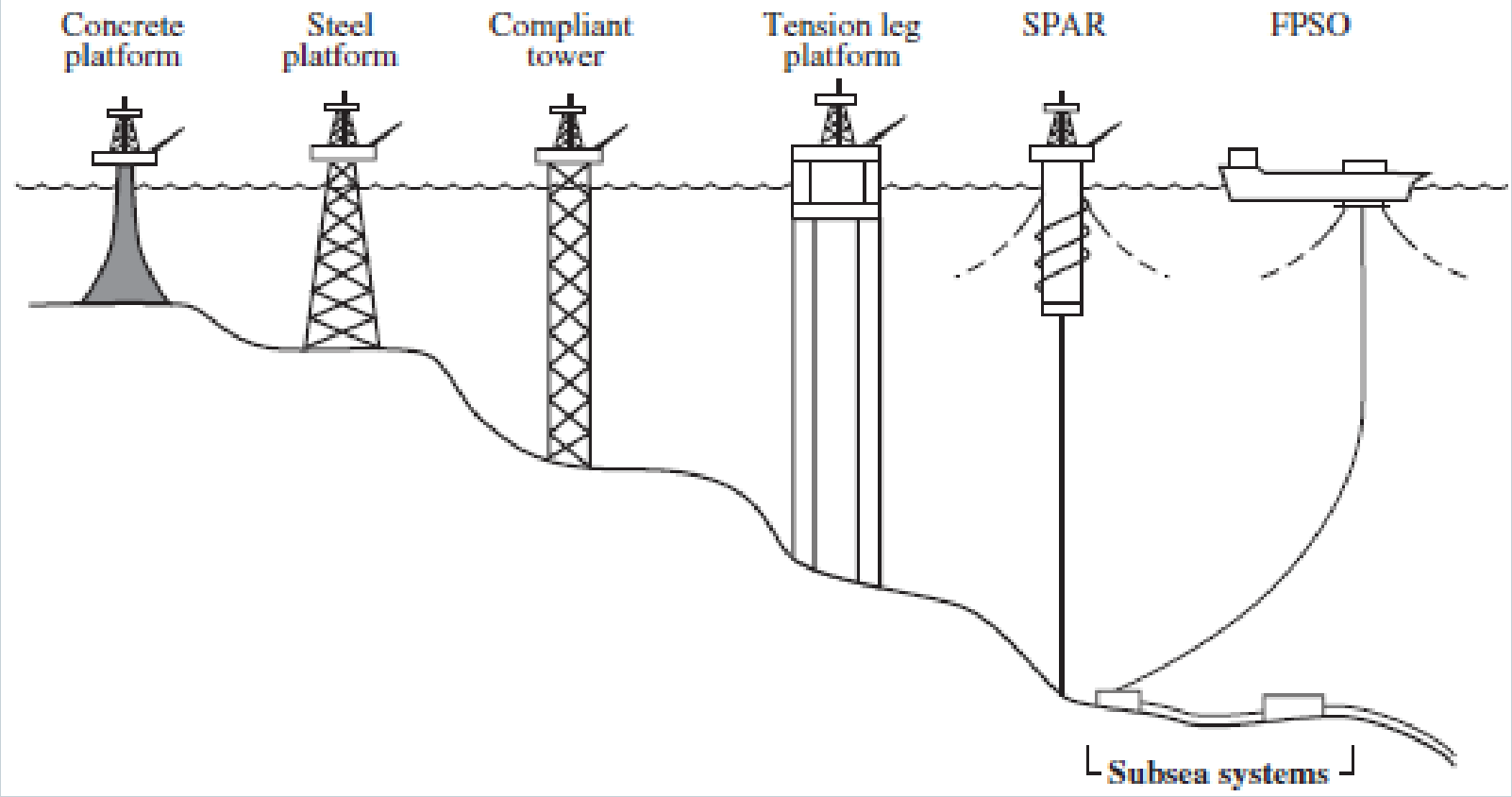
Offshore O&G seascape

- Offshore O&G exploration covers ~7,100 fields in >120 countries
- 2025: Offshore O&G platform (fixed, gravity & floating) count: 12,000
- Subsea components amount to ~8,200
- About 30,000 offshore pipelines siphon O&G to shore

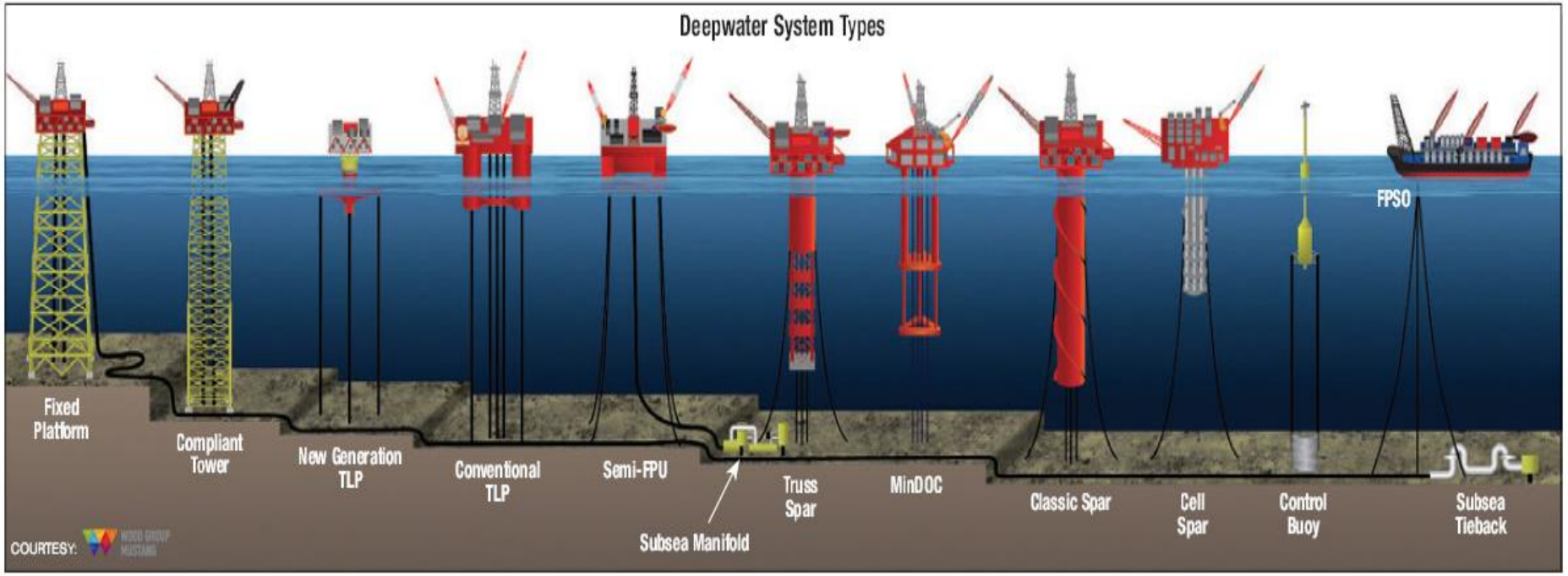


Offshore fields development options

- Fixed foundations, moored & tethered & subsea installations



Offshore O&G systems

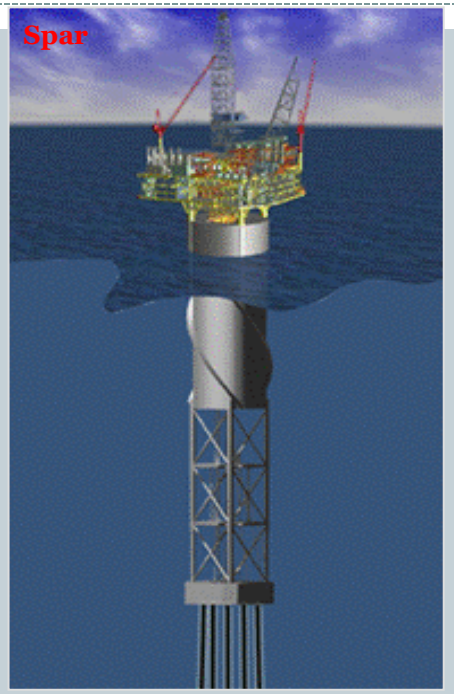


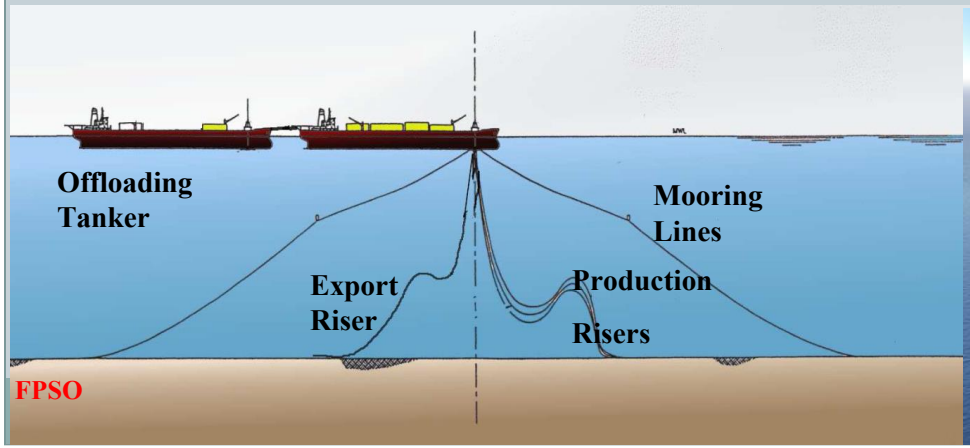
Floating Systems Overview

Courtesy: Shell





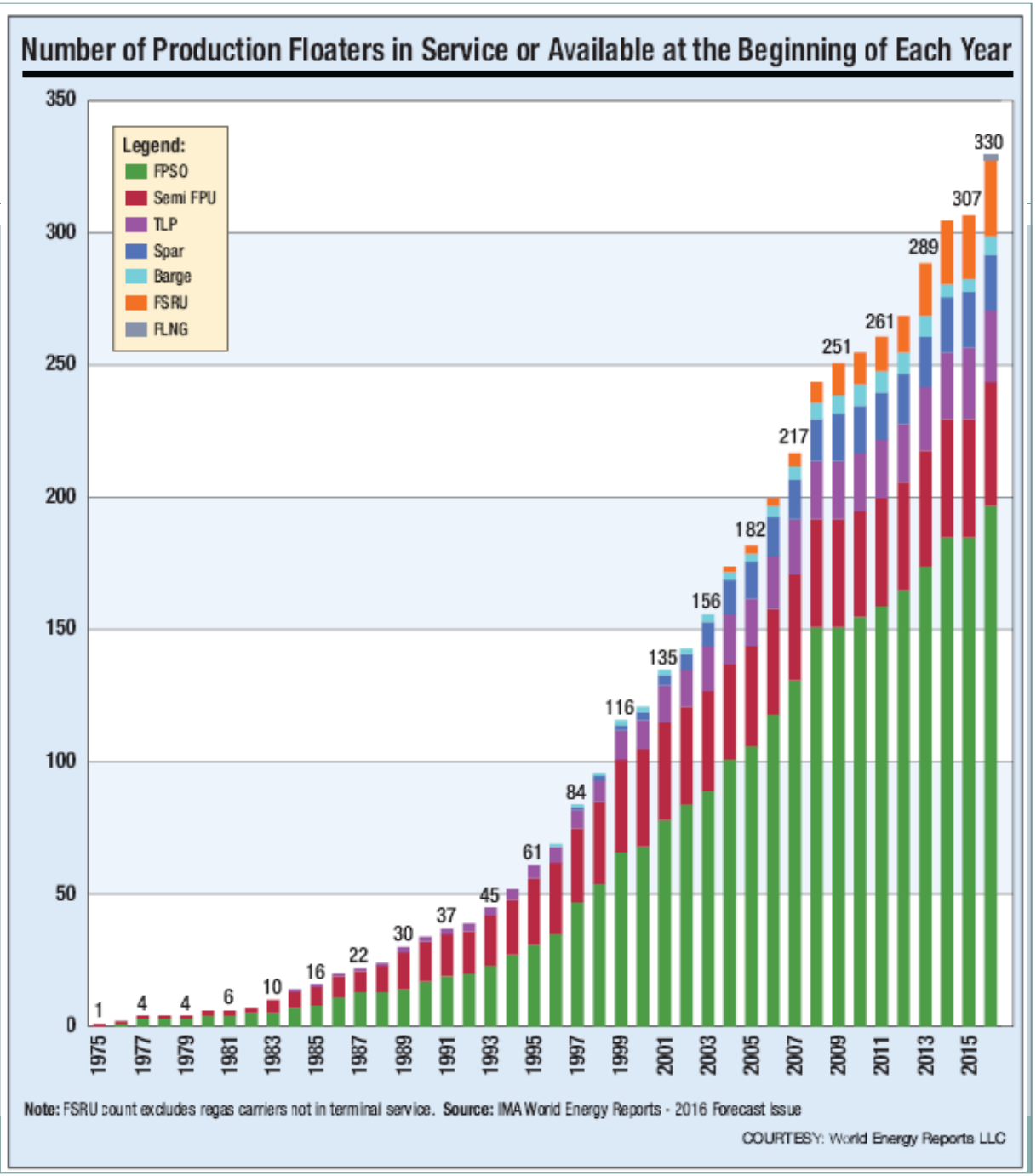


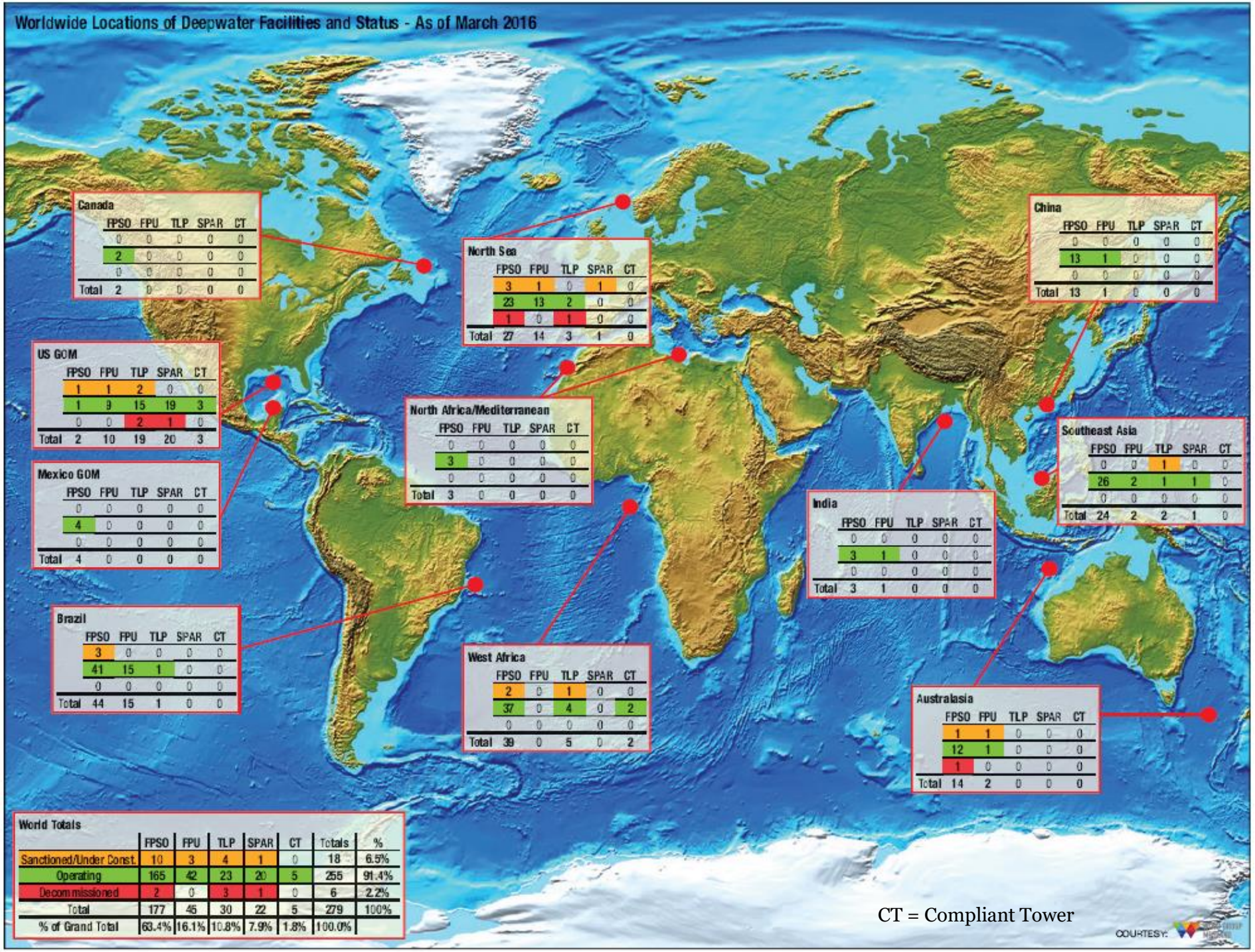




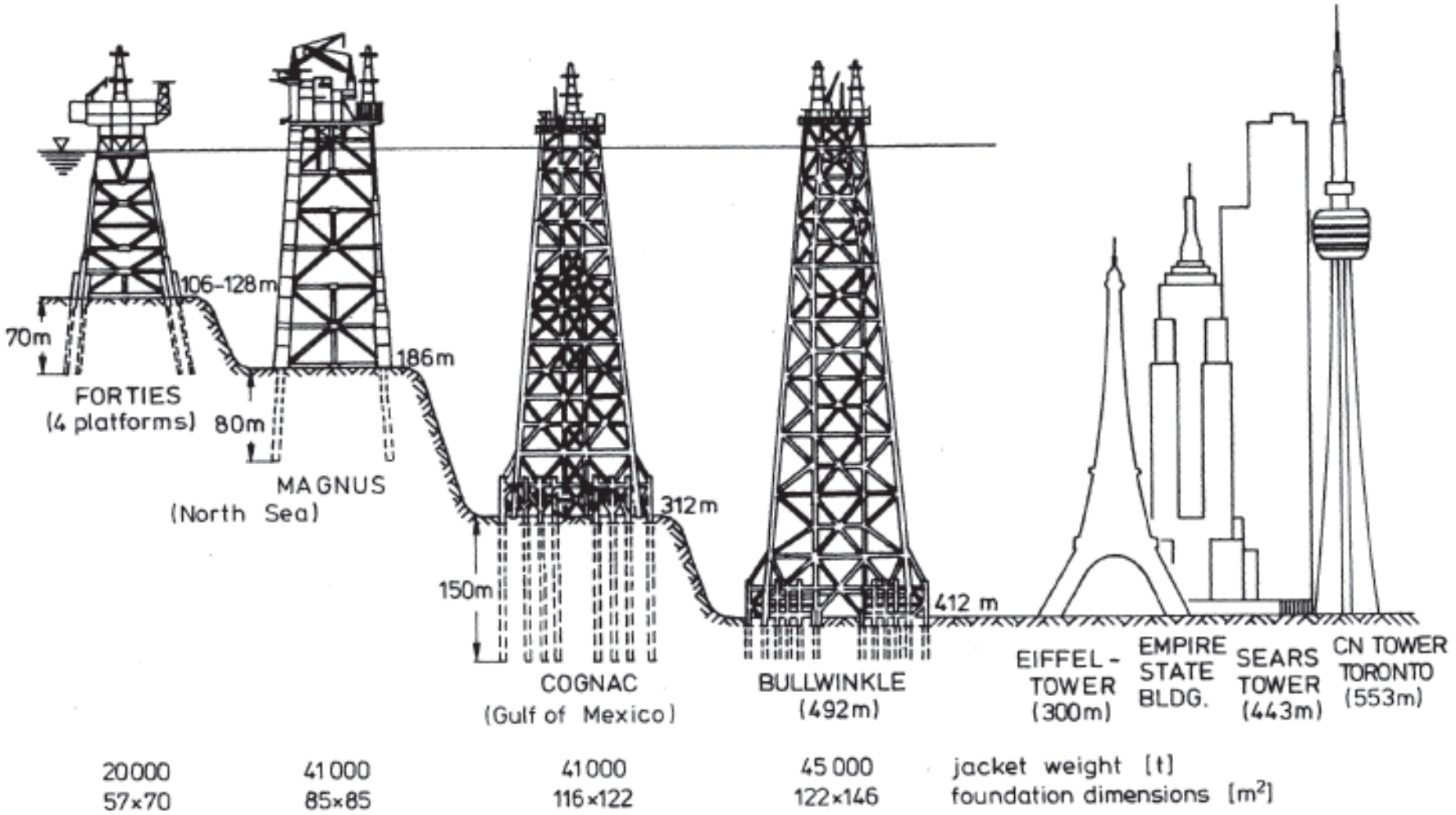
Production systems

- FPSOs account for most of *floating* offshore oil production systems
- 2025: about 270 FPSOs currently in operation



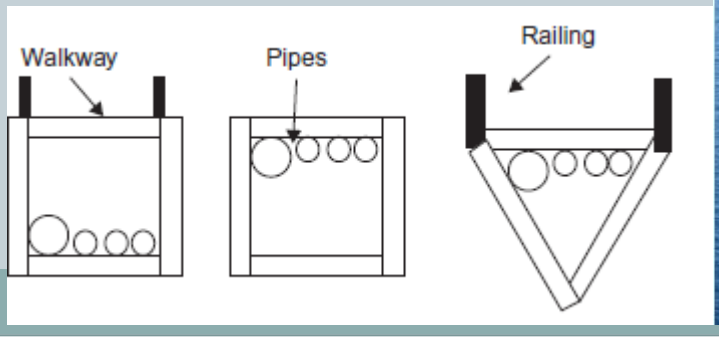

Worldwide Locations of Deepwater Facilities and Status - As of March 2016
Canada
FPSO FPU TLP SPAR CT
0 0 0 0 0
2 0 0 0 0
0 0 0 0 0
Total 2 0 0 0 0
North Sea
FPSO FPU TLP SPAR CT
3 1 0 1 0
23 13 2 0 0
1 0 1 0 0
Total 27 14 3 1 0
China
FPSO FPU TLP SPAR CT
0 0 0 0 0
13 1 0 0 0
0 0 0 0 0
Total 13 1 0 0 0
US GOM
FPSO FPU TLP SPAR CT
1 1 2 0 0
1 9 15 19 3
0 0 2 1 0
Total 2 10 19 20 3
North Africa/Mediterranean
FPSO FPU TLP SPAR CT
0 0 0 0 0
3 0 0 0 0
0 0 0 0 0
Total 3 0 0 0 0
Southeast Asia
FPSO FPU TLP SPAR CT
0 0 1 0 0
26 2 1 1 0
0 0 0 0 0
Total 24 2 2 1 0
Mexico GOM
FPSO FPU TLP SPAR CT
0 0 0 0 0
4 0 0 0 0
0 0 0 0 0
Total 4 0 0 0 0
India
FPSO FPU TLP SPAR CT
0 0 0 0 0
3 1 0 0 0
0 0 0 0 0
Total 3 1 0 0 0
Brazil
FPSO FPU TLP SPAR CT
3 0 0 0 0
41 15 1 0 0
0 0 0 0 0
Total 44 15 1 0 0
West Africa
FPSO FPU TLP SPAR CT
2 0 1 0 0
37 0 4 0 2
0 0 0 0 0
Total 39 0 5 0 2
Australasia
FPSO FPU TLP SPAR CT
1 1 0 0 0
12 1 0 0 0
1 0 0 0 0
Total 14 2 0 0 0
World Totals
FPSO FPU TLP SPAR CT Totals %
Sanctioned/Under Const. 10 3 4 1 0 18 6.5%
Operating 165 42 23 20 5 255 91.4%
Decommissioned 2 0 3 1 0 6 2.2%
Total 177 45 30 22 5 279 100%
% of Grand Total 63.4% 16.1% 10.8% 7.9% 1.8% 100.0%
CT = Compliant Tower
COURTESY:

Fixed platforms



Types of fixed offshore platforms

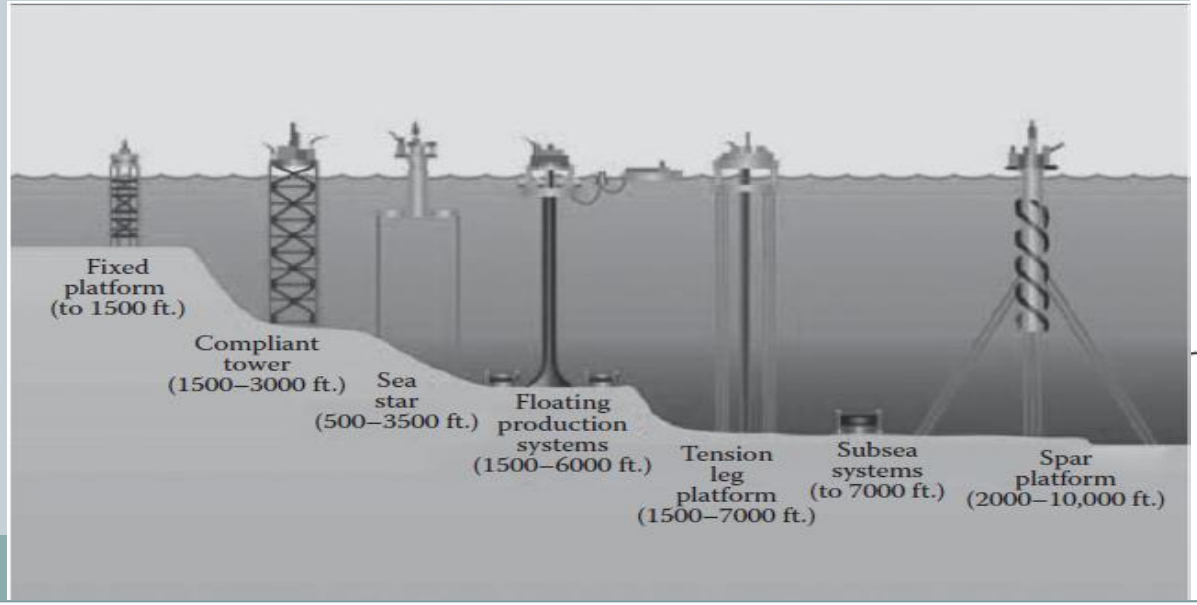
- Drilling/well-protector platforms
- Self-contained platforms (template and tower)
- Production platforms (control rooms, compressors, storage tanks, fluids' treatment, …)
- Auxiliary platforms (pumping/compressor stations, oil storage, quarters platforms or production platforms,
- Quarters platforms
- Flare jacket and flare tower platforms
- Bridges
- Helipads

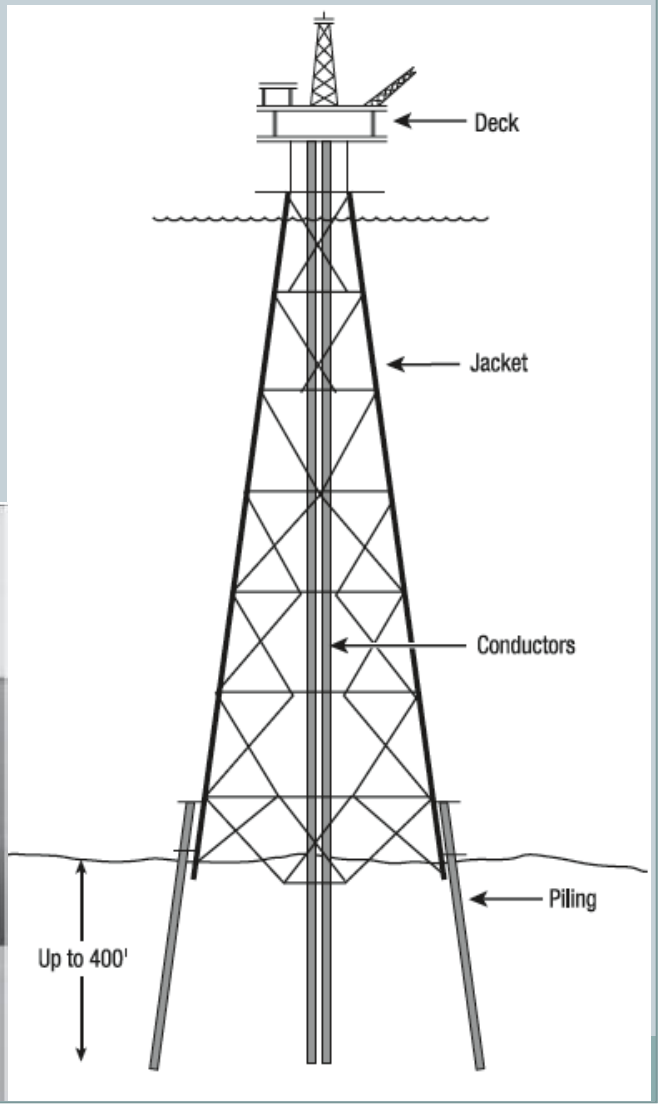




Jacket platforms

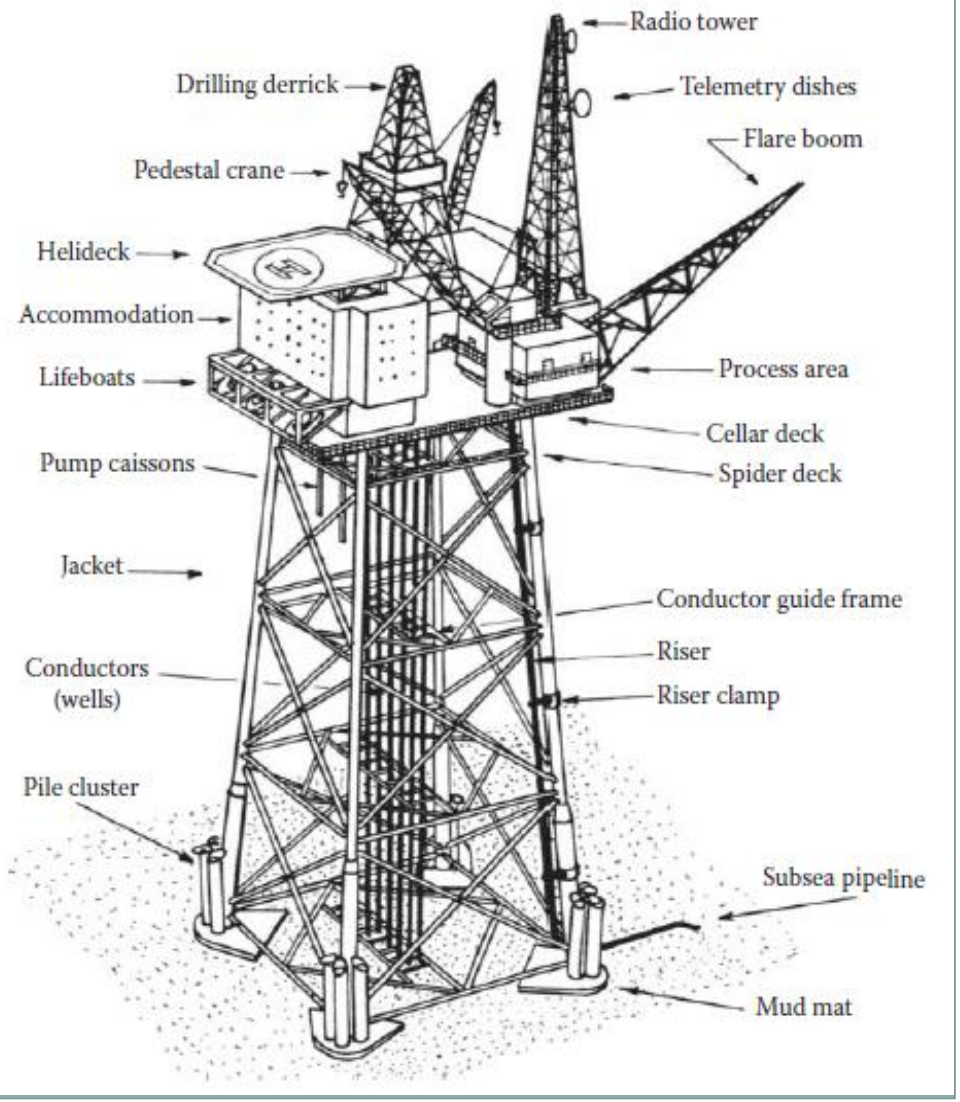
- *Pilings*: steel tubular members secure platform to seabed
- Cylindrical members:
  - Pose less resistance to ocean waves & currents
  - Reduce mass of steel & weight of rig
  - Lower materials cost
- Waves should not wet the topside deck





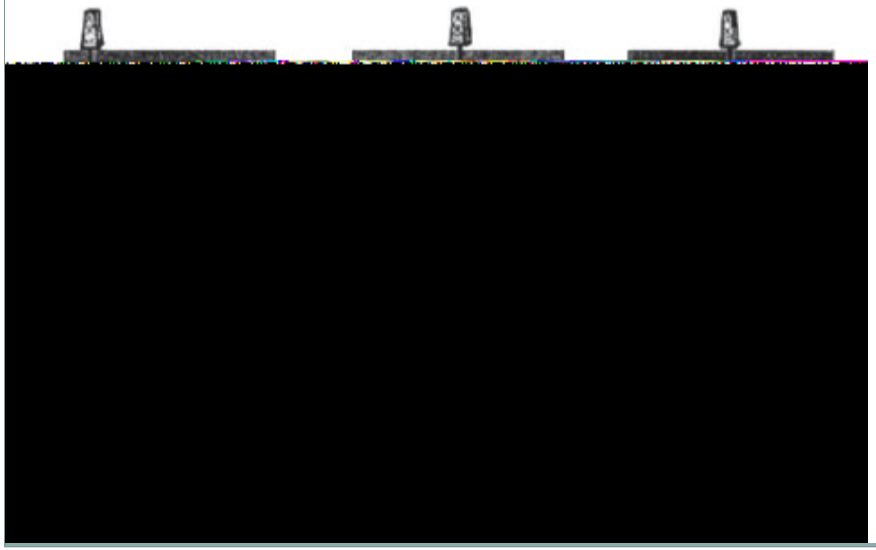
Framed offshore structure

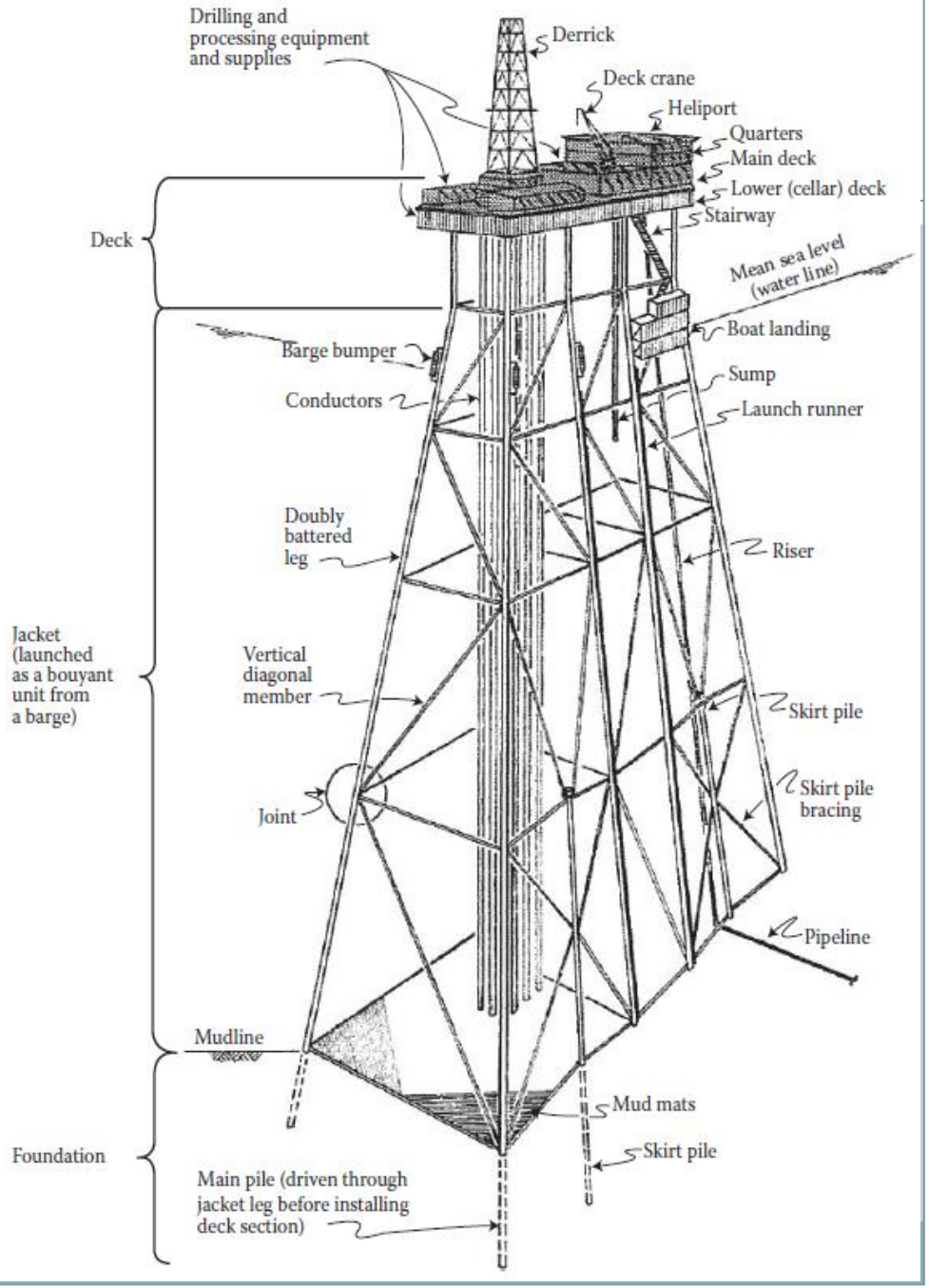
- Limited to water depth of 1,500ft (~460m)
- Bullwinkle base: 400×480ft
- Pilings: 7ft × 2” × 400ft deep
- 300ft of water: 3,000t of steel + 1,000t pilings, legs: 54”
- 1,500ft of water: 50,000t of steel + 15,000t pilings, legs, *d*: 90”, pilings, *d*: 75”



- Deck
- Jacket
- Foundation

Deviated wells spudded from offshore platforms

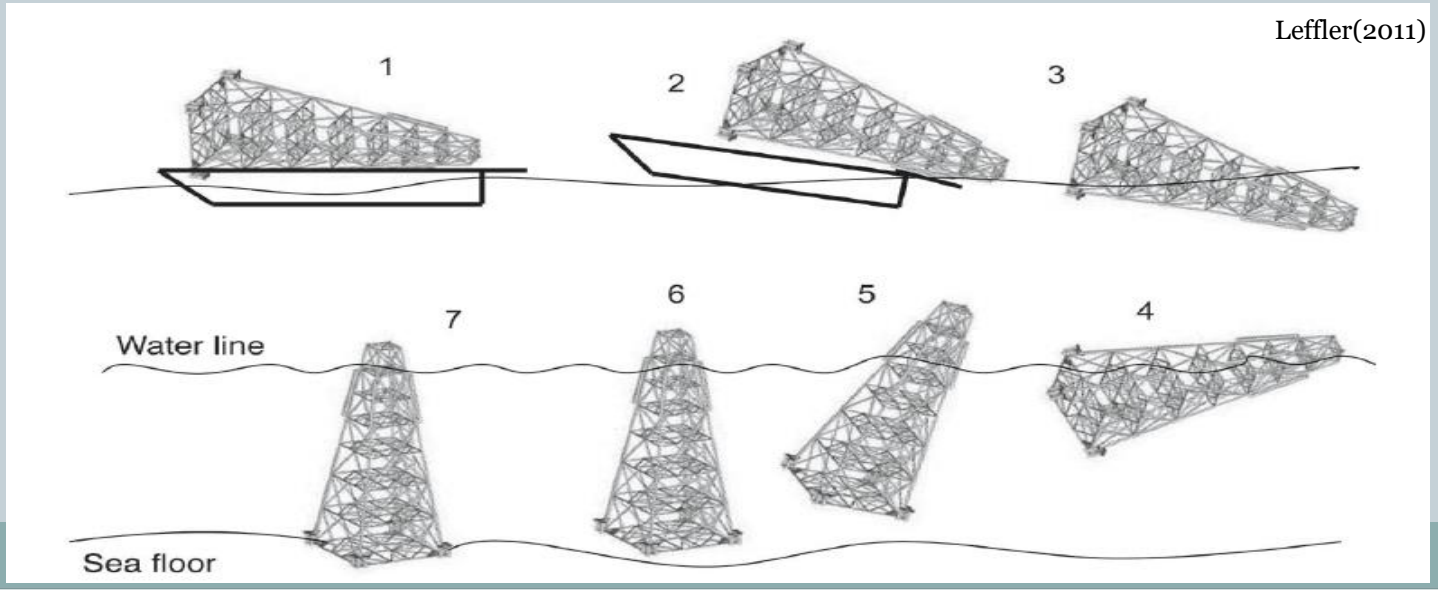




Installing a jacket platform

- Hydraulic jacks or winches move to barge
- Base structure needs to float
- Flooding lower structure to seabed
- Tugs facilitate positioning of jacket base
- ROV ensures seabed siting is right
- Pilings secure platform to seabed



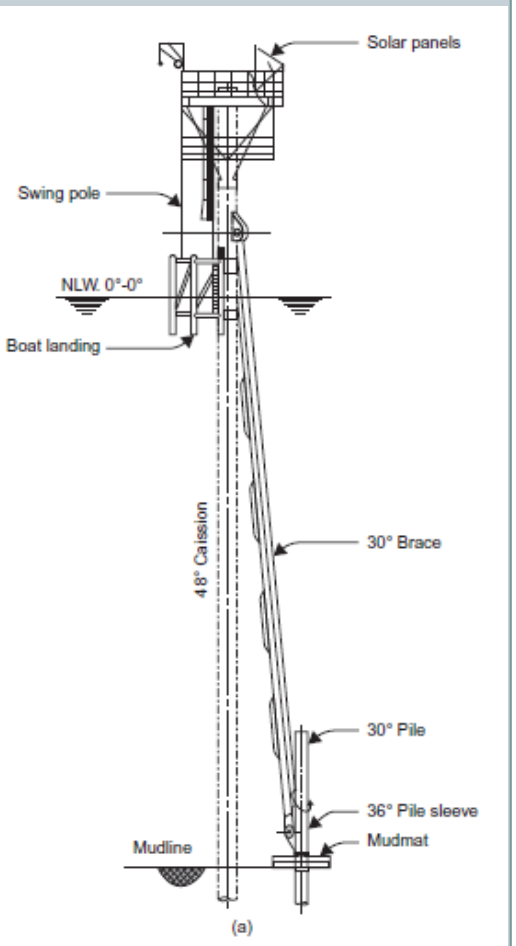


Leffler(2011)

Mono/tri-pods

- Used for single wells
- Low-cost solution
- Uses conductor pipes
- Alternative to wet tree



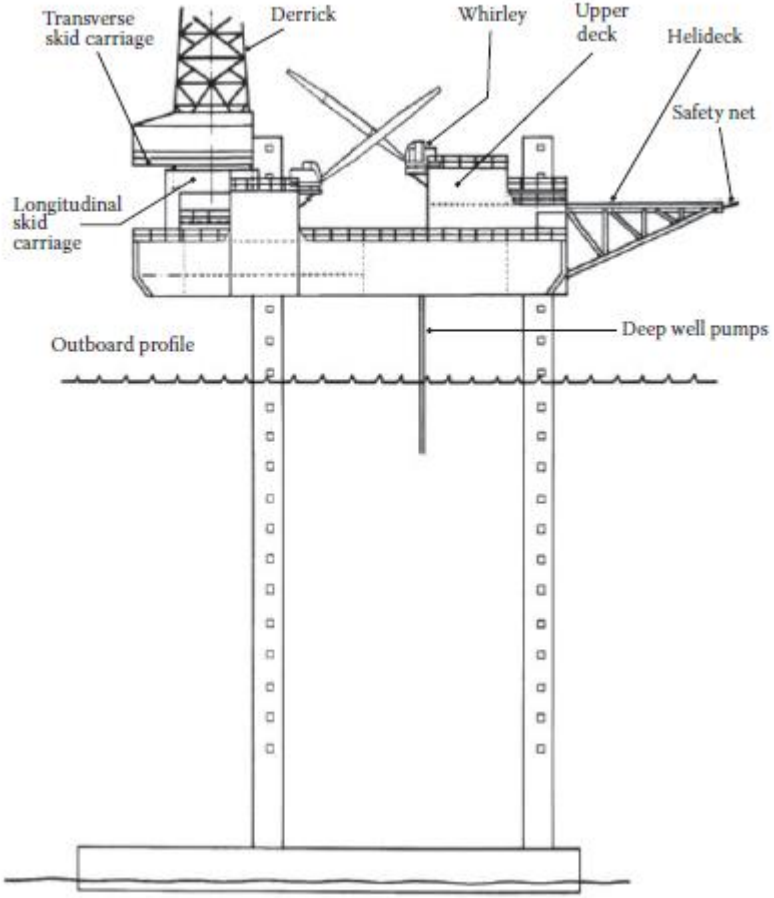


Jack-up rigs

- Mobile platform that rests on seabed
- Make up ~60% of MODUs
- MODUs are divided into:
  - Jack-ups with cylindrical legs
  - Jack-ups with truss legs

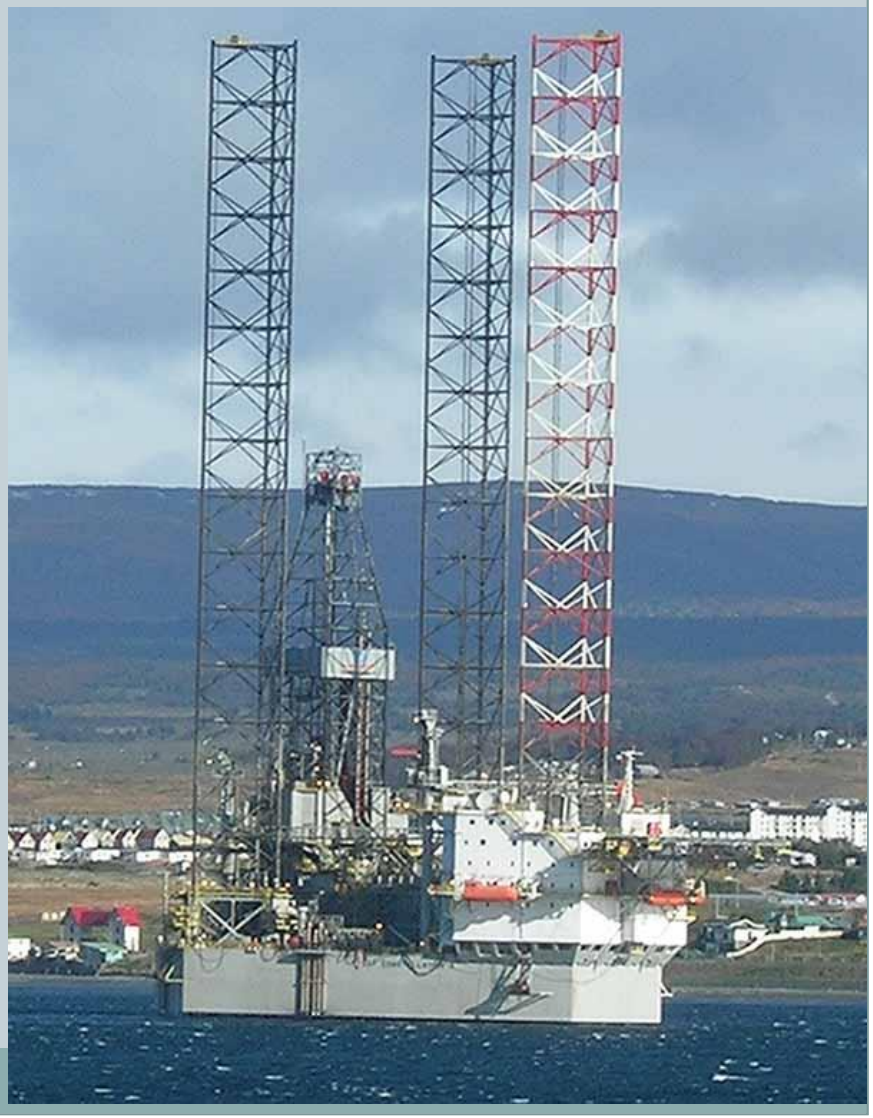


Mat supported jack-up



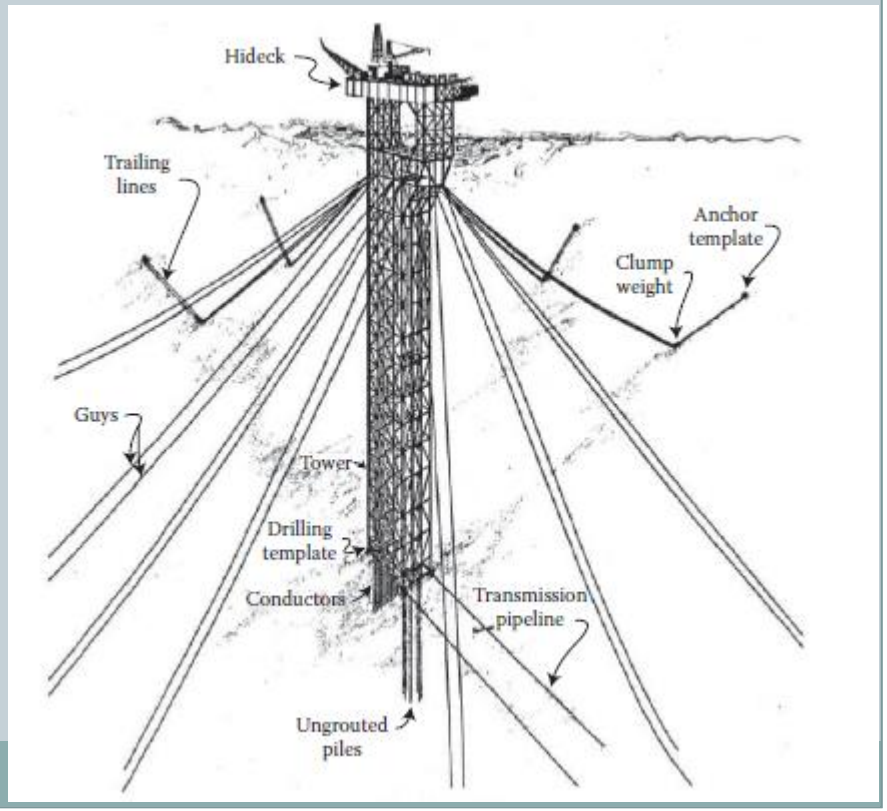
Jack-ups

- Legs can enter seabed
- Working depth: 150m-190m
- Generally, not self-propelled
- 2025: 380 jack-ups in operation
- Leg no vary: 3, 4, 6, 8
- Legs powered by hydraulics or electric motors
- Merits:
  - Good stability due to fixed legs
  - Relatively economical
  - Suitable for different seafloor soils
- Drawbacks:
  - Hard to tow; sensitive to waves
  - Working depth: 0-200m
  - Large legs pose vibration issues



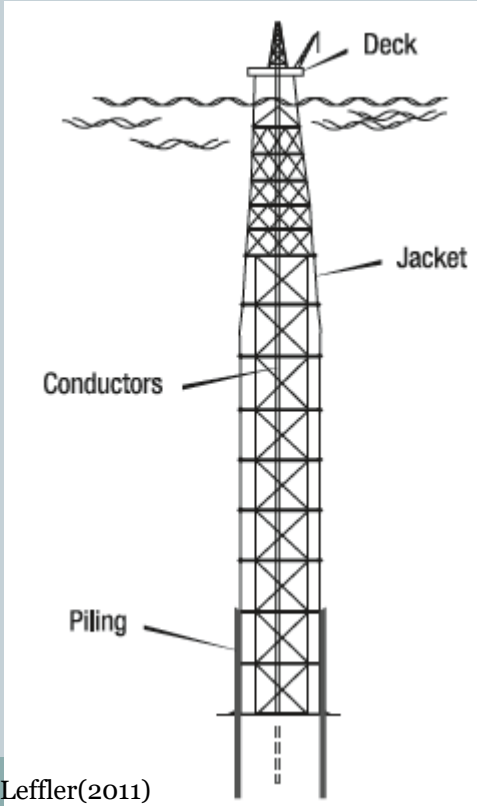
Guyed towers

- Fixed platforms in water depth of ~300m
- Clump weights on guy lines allow tower to sway or "comply" with waves
- Made of tubular steel elements
- Dry wellheads installed on platform
- Anchored to seabed with lines
- Guy: a rope, cord, or cable used to steady, guide, or secure something.



Compliant towers

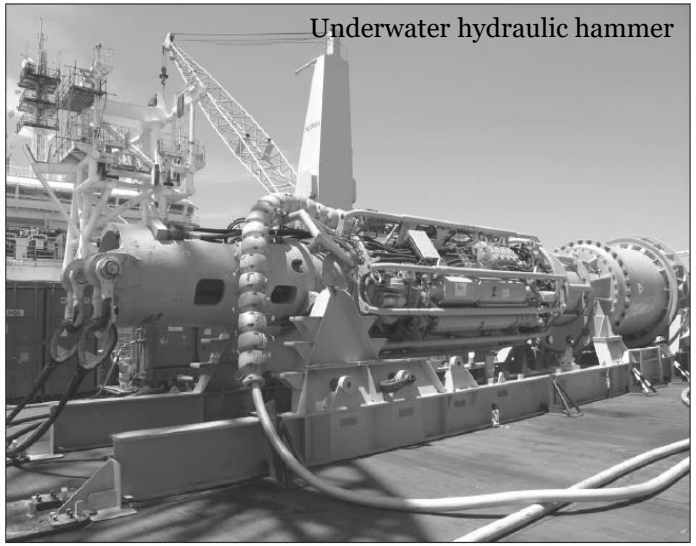
- Water depth range: 1,000-3,000ft
- Behave like reed; waves pass thru before structure responds
- Slender base (140ft × 100ft)
- Sway in currents & waves: 10–15ft
- Require less steel than jacket rigs
- Considerable mass & buoyancy at upper zone
- 1,700ft: 30,000t of steel; 7,000t pilings



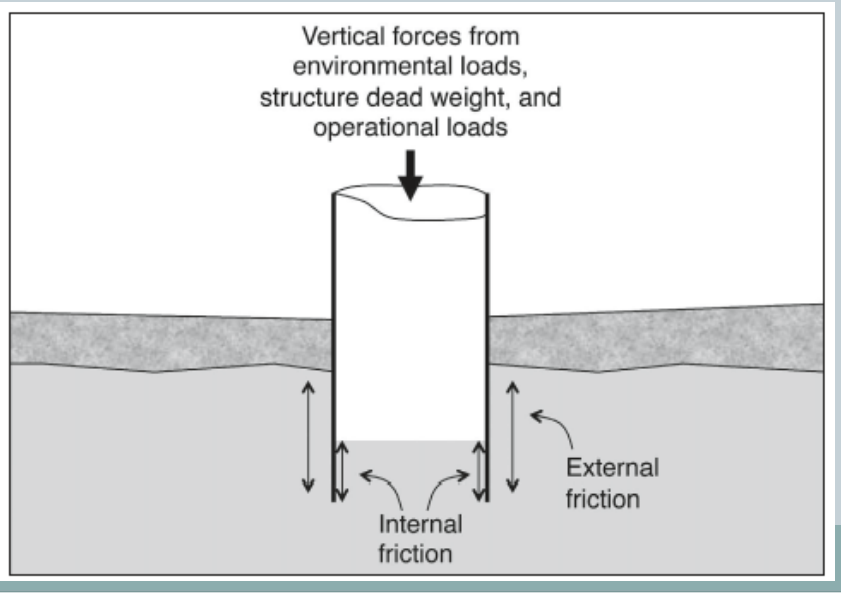
Leffler(2011)

Pilings

- Steel pilings secure fixed structure to seabed
- Depth of pilings extend up to 450ft (150m)
- Wall thickness btw 0.1 to 2.5” (63.5mm)
- Pilings driven only during favourable weathe



Underwater hydraulic hammer

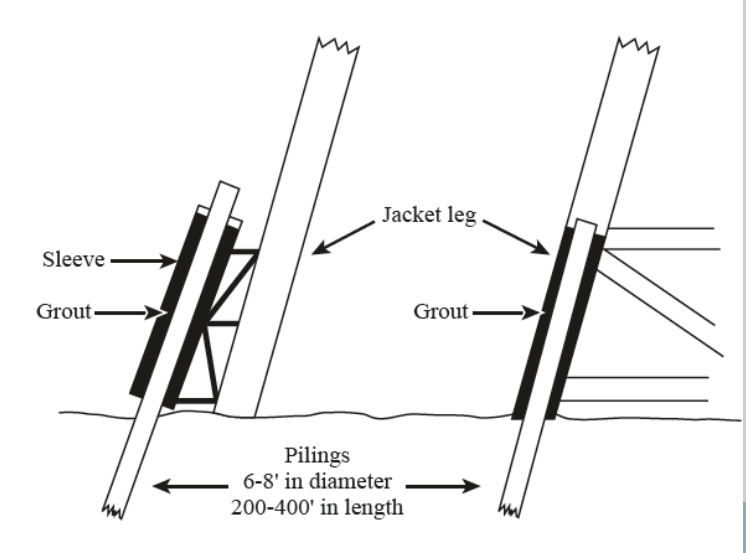




96-inch diameter (2.44m) steel piling

Pilings (2)

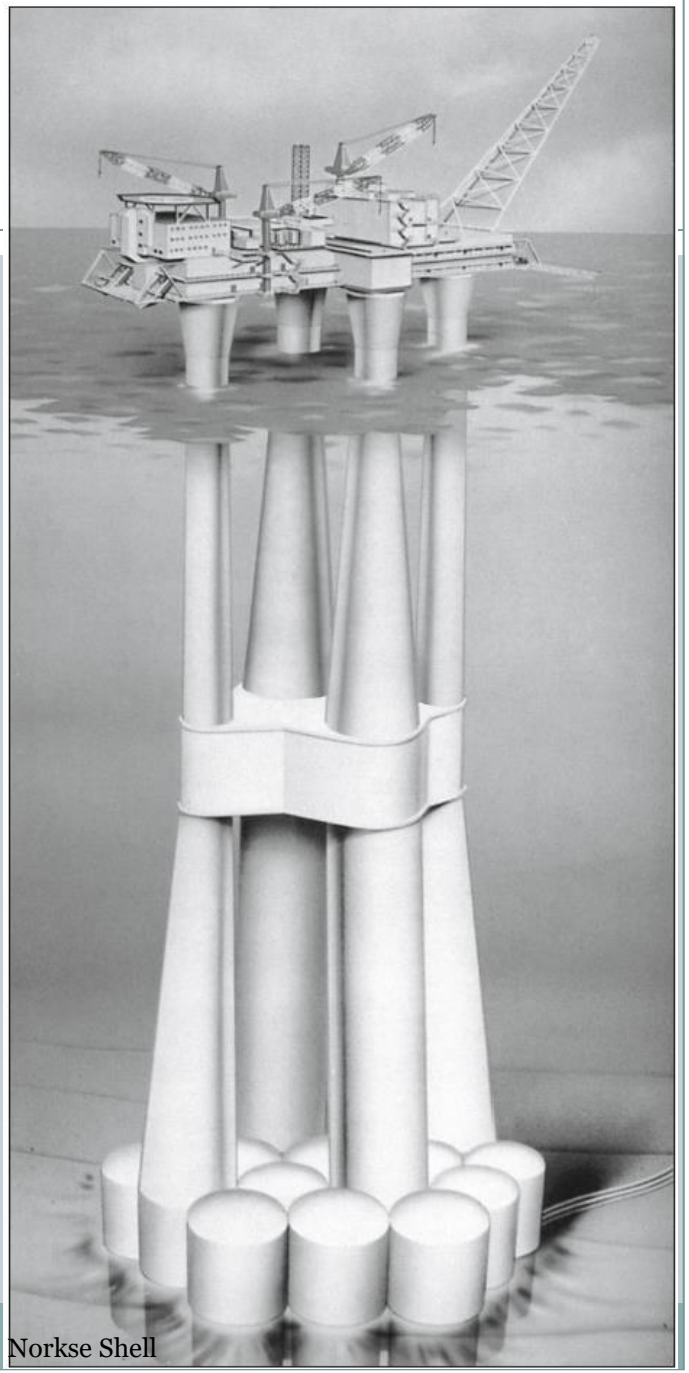
- Suction could initially be applied
- In swallow-water, jacket is welded to pilings
- In deepwater, grout secures jacket to pilings





Gravity based platforms

- Emerged in 1970s; made of reinforced or pre-stressed concrete
- 2025: 50 offshore concrete gravity platforms used in oil & gas industry of which 12 used by offshore wind farms
- Require hard seabed e.g., clay
- Secured on site by their sheer weight
- Cumbersome to transport & position
- Require no anchoring
- Difficult to decommission

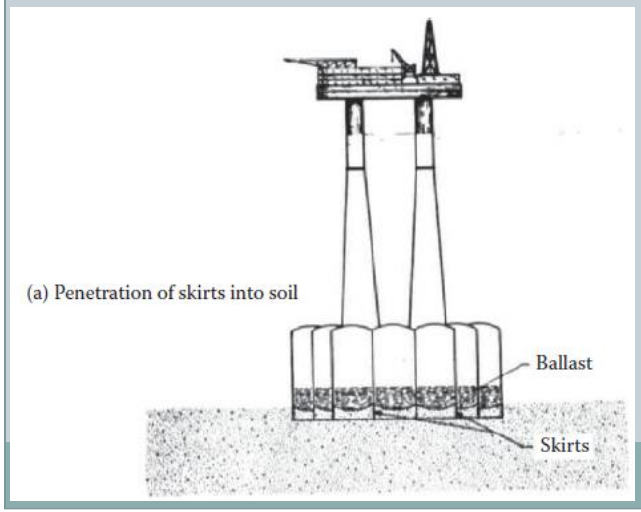


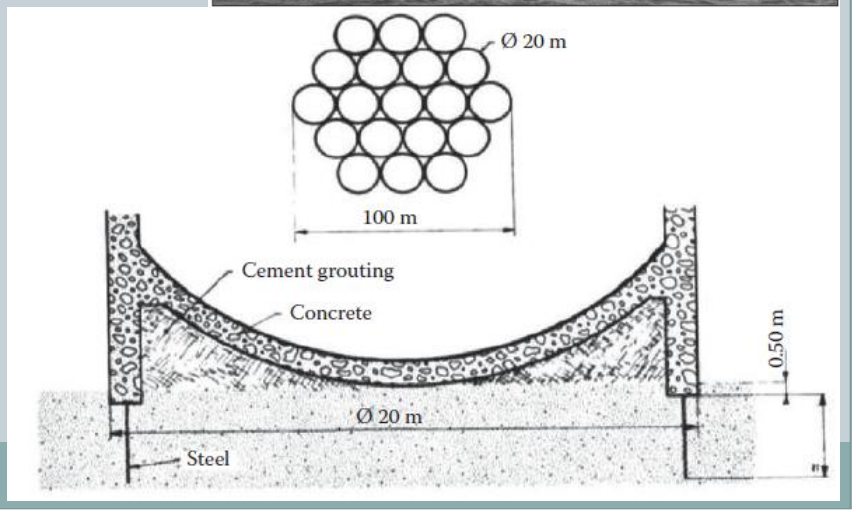
Norkse Shell

Gravity based platforms (2)

- Steel skirts secure platform to seabed
- Production & injection lines embedded in concrete legs





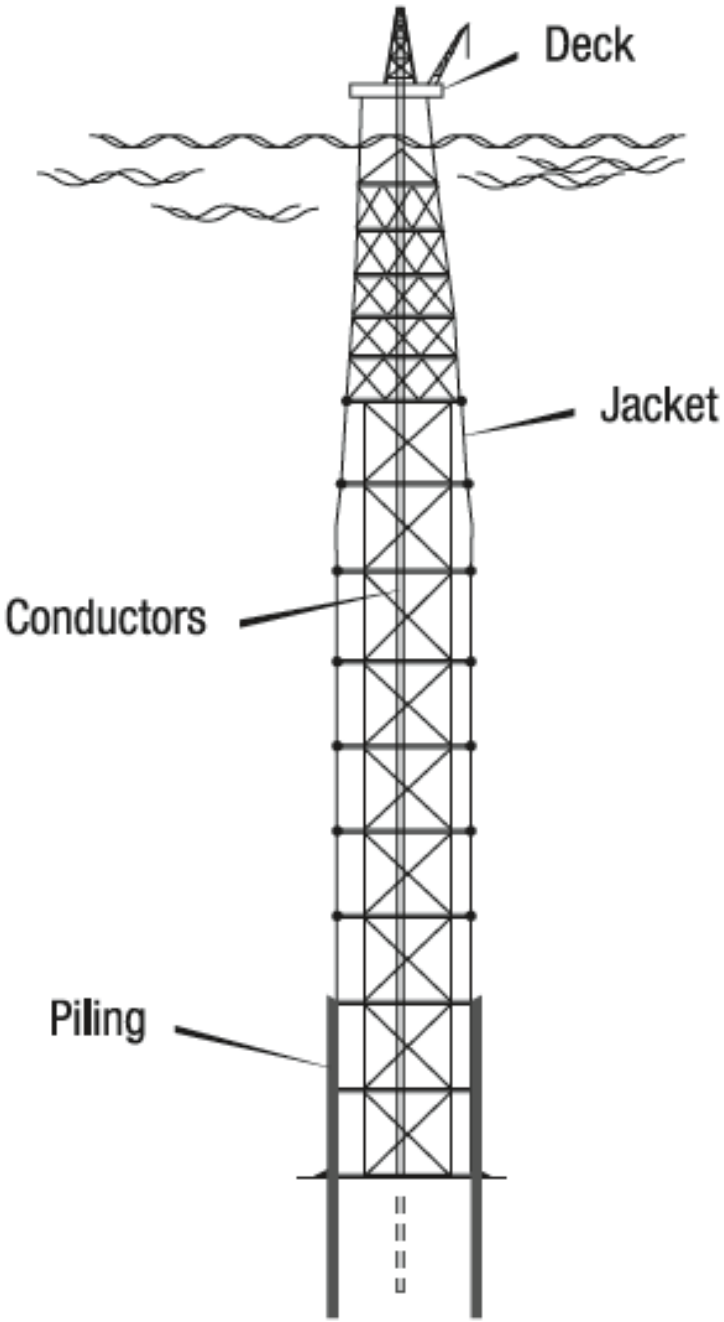


Video

- Troll; 20”

Compliant towers

- Can sway 10–15ft off centre in extreme cases
- Since most of “mass” on upper sections, structure is “invisible” to waves
- At d>500m jacket platforms become impractical
- Why?
  - Due to stiff response of the structure



Black Sea marine expedition



Black Sea shipwrecks





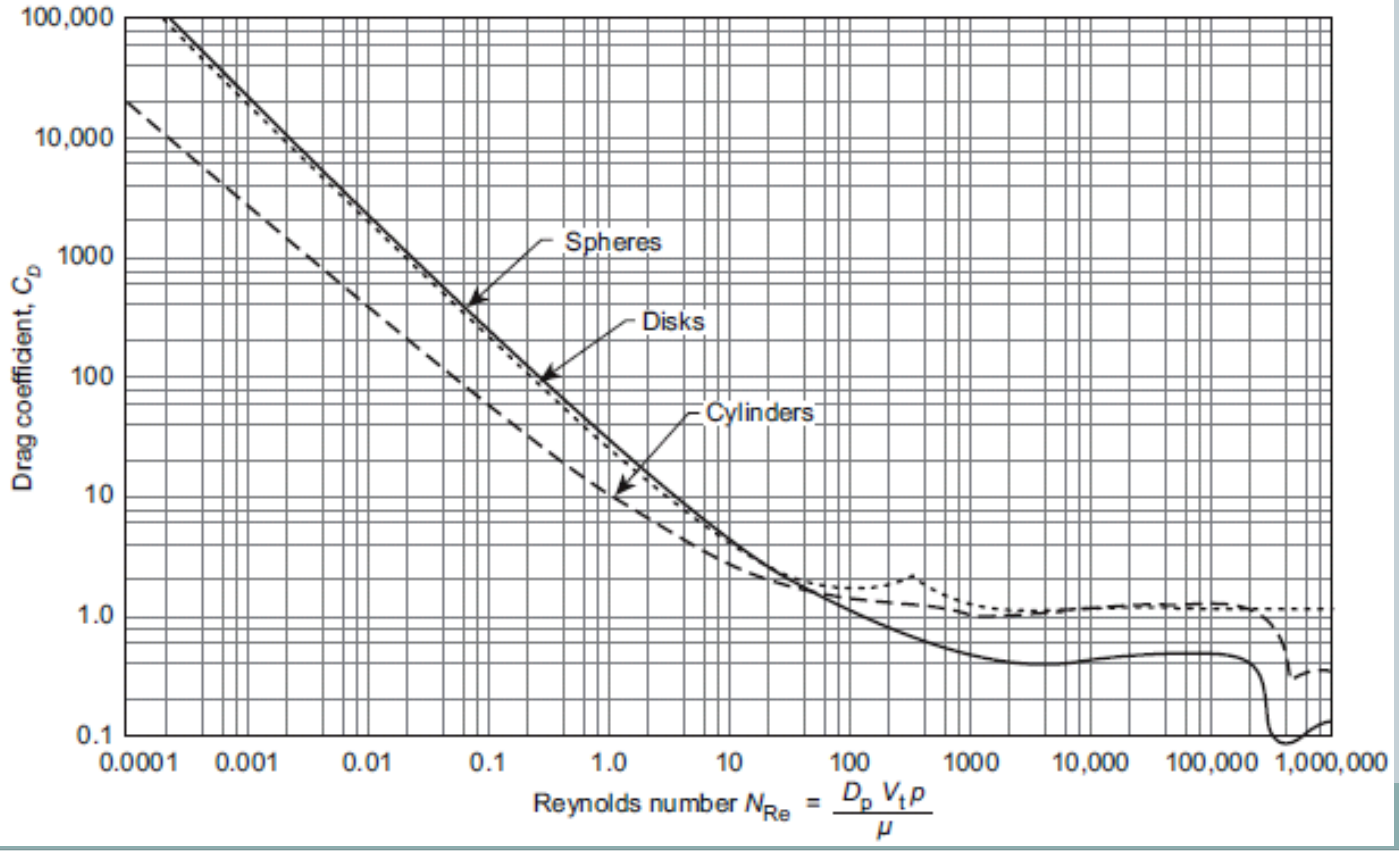
Theory

- Theory #3

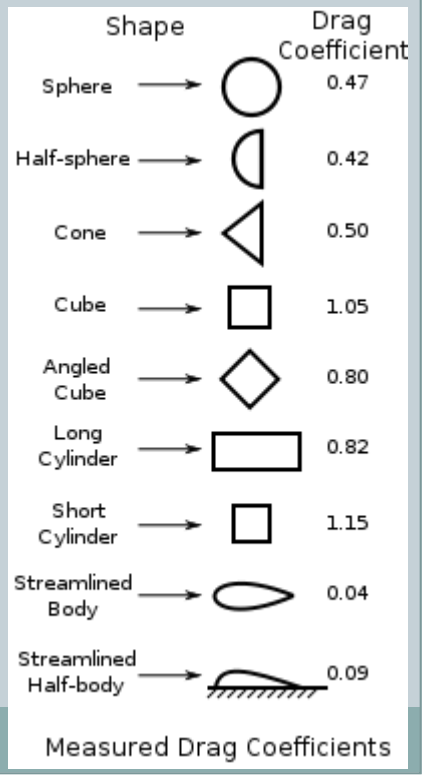
Drag coefficient

- Drag coefficient (C_D) quantifies drag or resistance of an object in a fluid
- C_D emanates from *skin friction* & *form (pressure) drag*

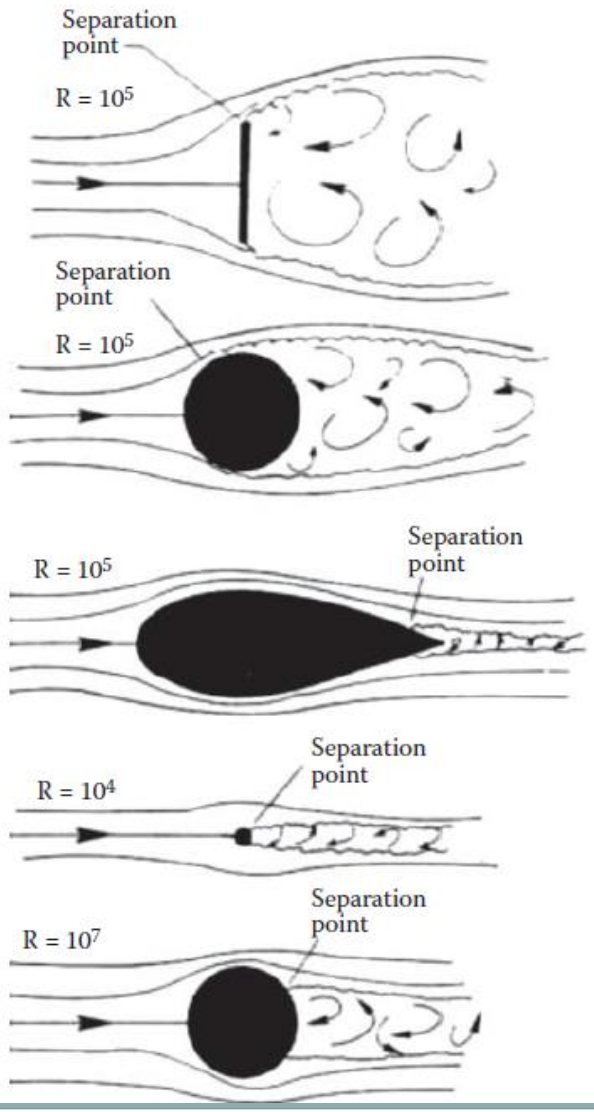
Fig. 1 C_D vs Re#



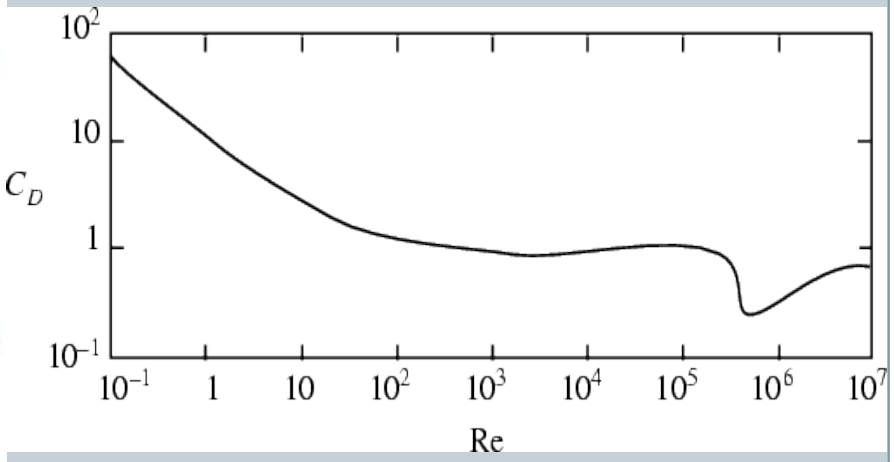
C_D for Re=10^4



C_D of various shapes @ various Re#



Drag coefficient of an infinite circular cylinder of diameter *d*



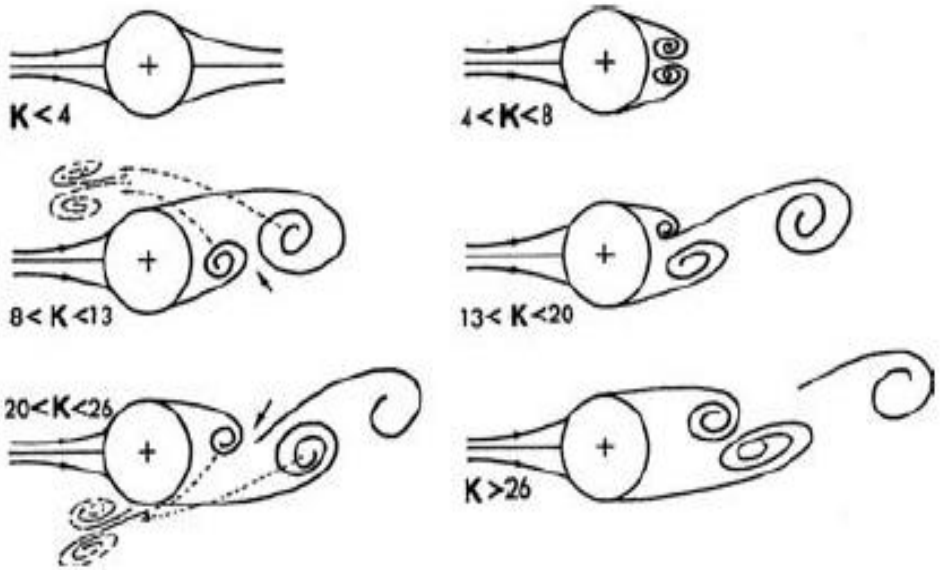
Keulegan–Carpenter number

- The *Keulegan-Carpenter* number (period number) quantifies the relative importance of drag forces over inertia forces for bluff objects in oscillatory fluid flows

$$K_C = \frac{VT}{L}$$

- T = wave period; Low K_C: inertia dominates; high K_C turbulence dominates

Evolution of vortices wrt K_C



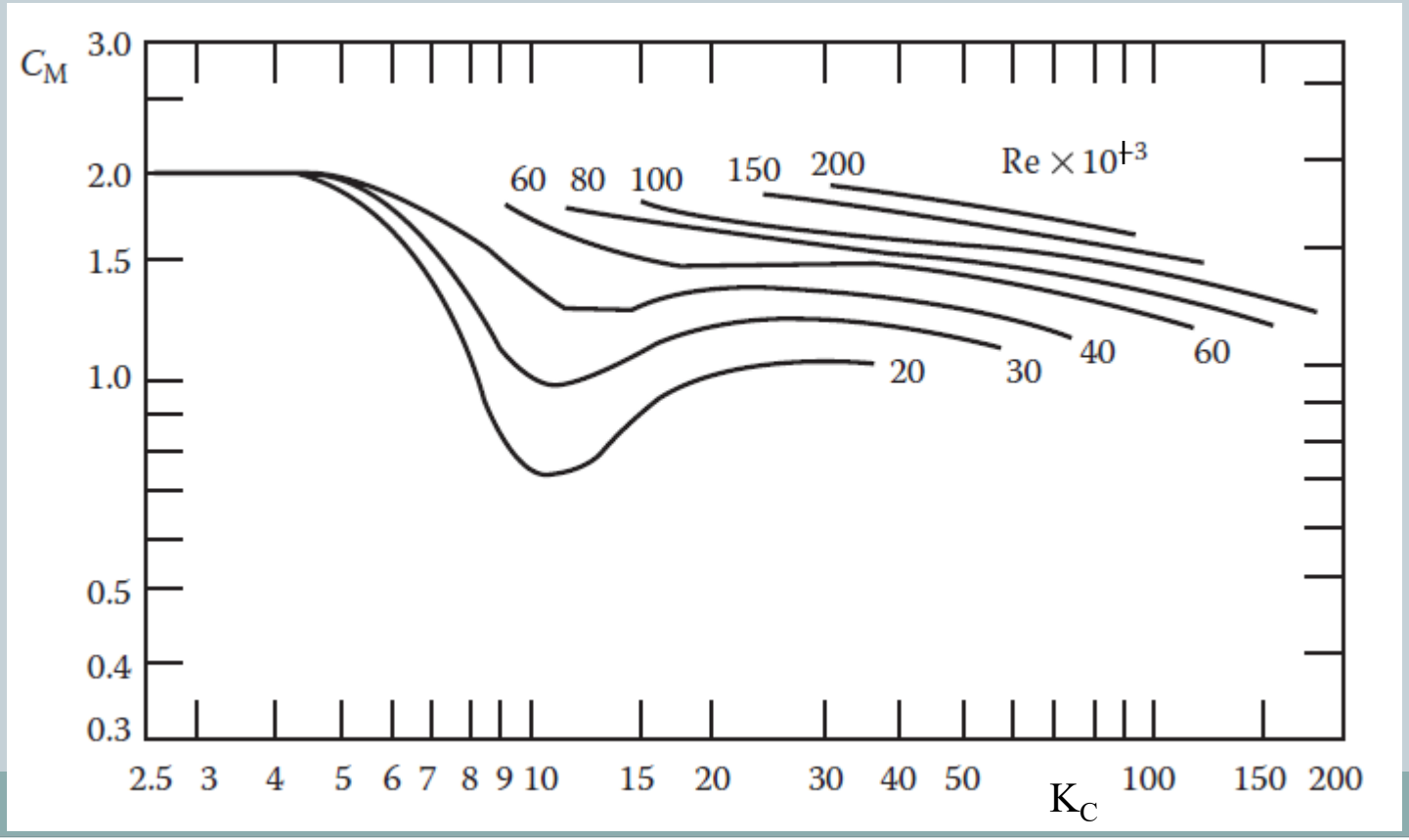


Oseberg platform in NS

C_M vs K_C# & Re#

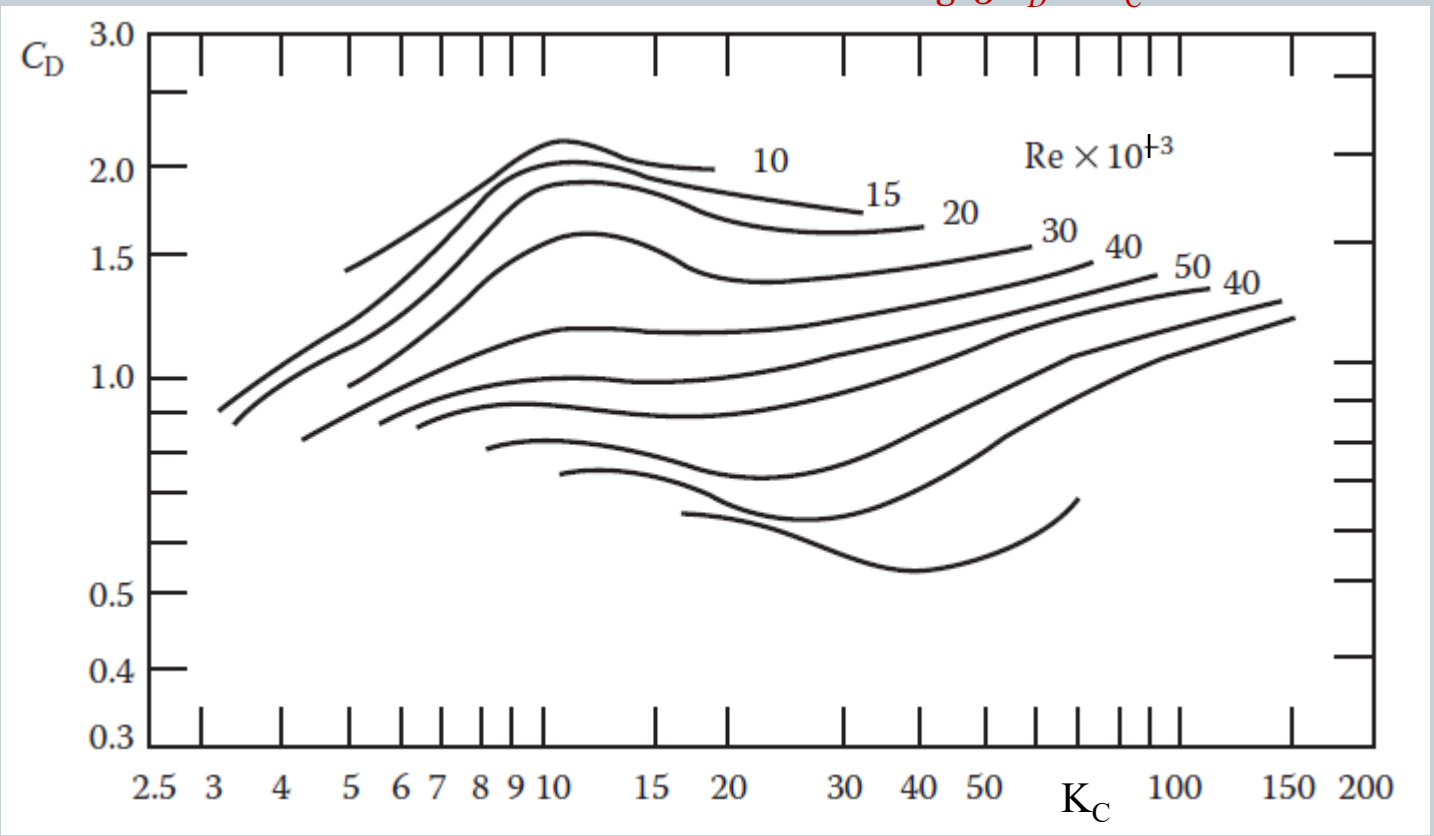
- Inertia effects dominate, if K_c<10.0
- Inertia & drag forces significant, if 10.0<K_C<20.0
- Drag forces dominate, if K_C>20.0

Fig. 2 C_M vs K_C at various Re#



C_D vs K_c# at various Re#

Fig. 3 C_D vs K_C at various Re#s



Values of ξ

- Recall:

$$\frac{F_{D_{max}}}{F_{I_{max}}} = \xi\left(\frac{H}{D}\right)$$

$$\xi = \left(\frac{1}{4\pi}\right)\left(\frac{C_D}{C_M}\right)\left[\frac{(2k(\mathrm{H}/2+\mathrm{d})+\sinh(2\,\mathrm{k}(\mathrm{H}/2+d))}{\sinh(kd)(\sinh\mathrm{k}(H/2+d))}\right]$$

Fig. 4 Values of ξ vs H/λ

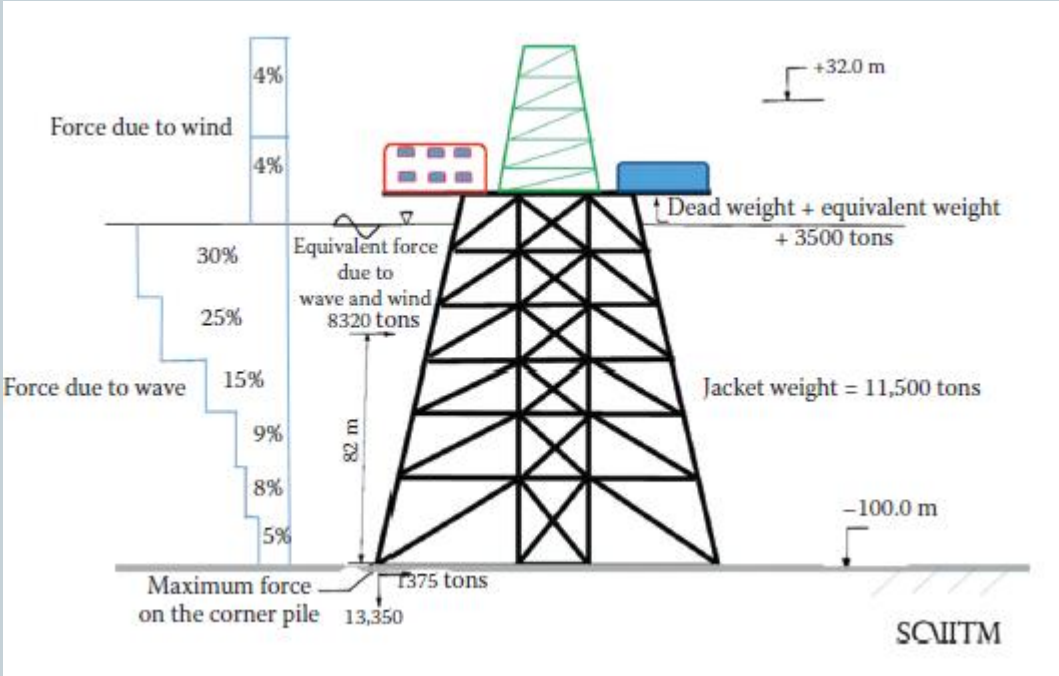
	H/λ = 0.03		H/λ = 0.07	
d/λ	$(2k)(d + H/2)$	ξ (H/D)	$(2k)(d + H/2)$	ξ (H/D)
0.03	0.565	0.847	0.817	0.866
0.07	1.068	0.367	1.320	0.378
0.15	2.074	0.178	2.325	0.187
0.30	3.958	0.105	4.210	0.115
0.50	6.472	0.090	6.723	0.101
1.00	12.755	0.0875	13.066	0.102
∞	∞	0.0875	∞	0.098

Exercise

- Example#8

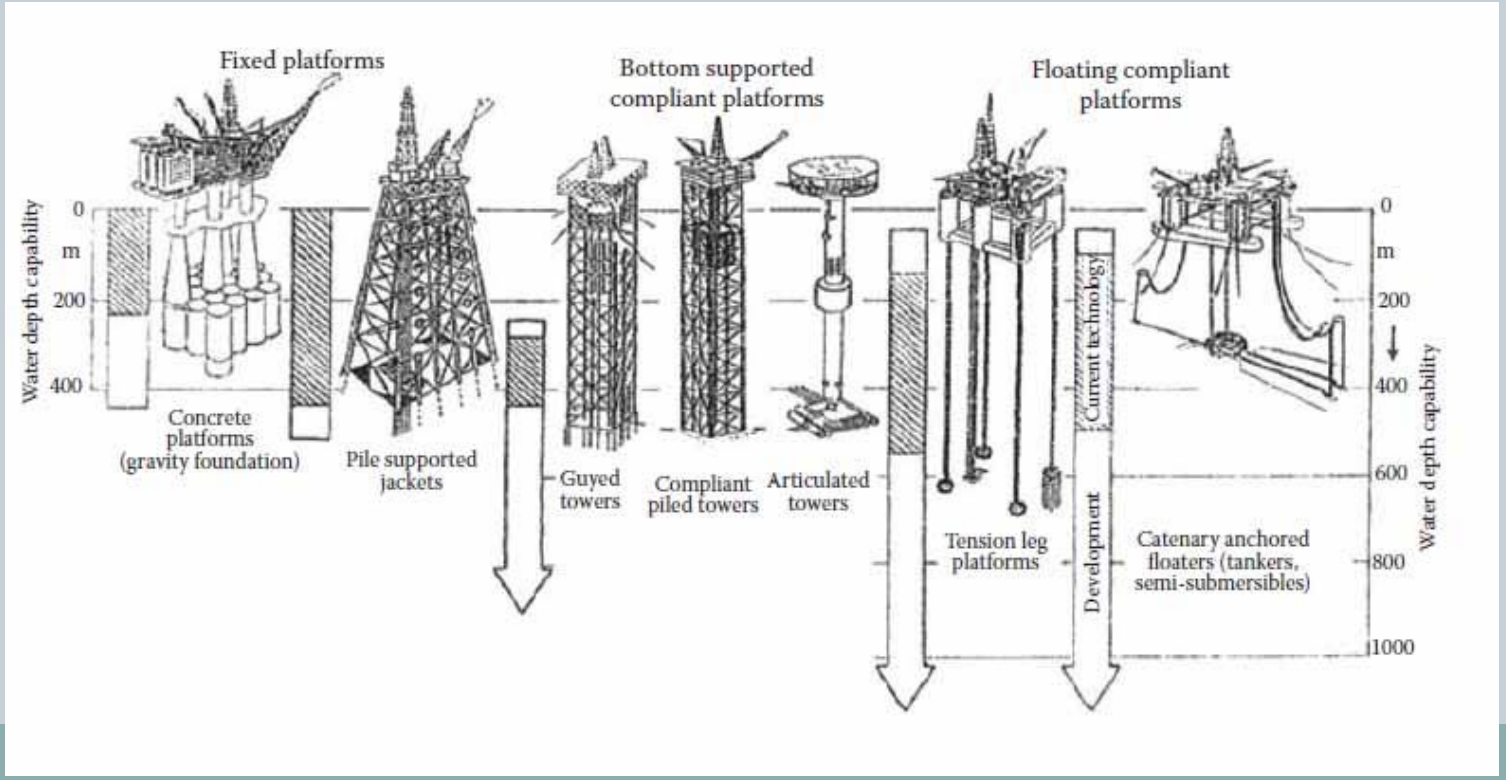
Waves & wind loads

- Wave induced forces outweigh wind related forces

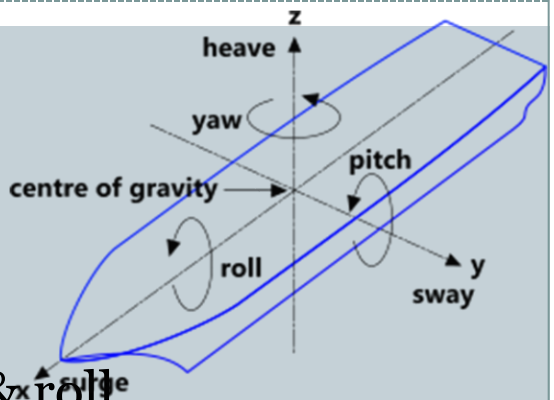


Floating production systems (FPS)

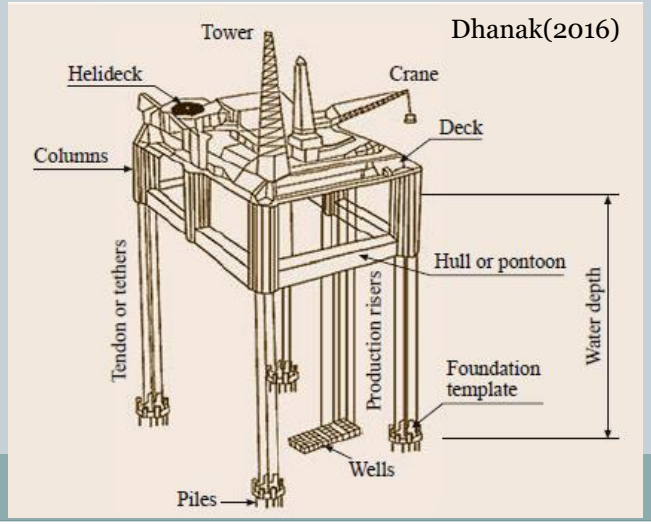
- FPSs (eg, floating vessels) present economic & technically viable option
- System can be reused; lower risk of risky assets
- Quick disconnect during contingencies e.g., hurricane, earthquake, …

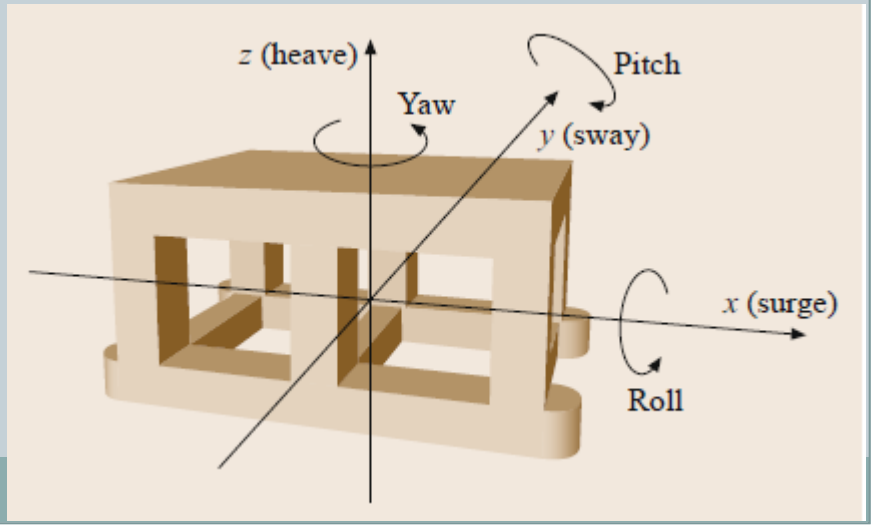


Tension leg platforms (TLPs)



- 1984: First TPL was deployed
- 2025: 21 to 26 TLPs currently in operation or under construction
- Vertical tendons hold the platform in place
- Tension in tubular tethers minimizes heave, pitch & roll
- Tendons permit sway, surge & yaw degrees of freedom
- TLPs water depth limit up to 1,500m

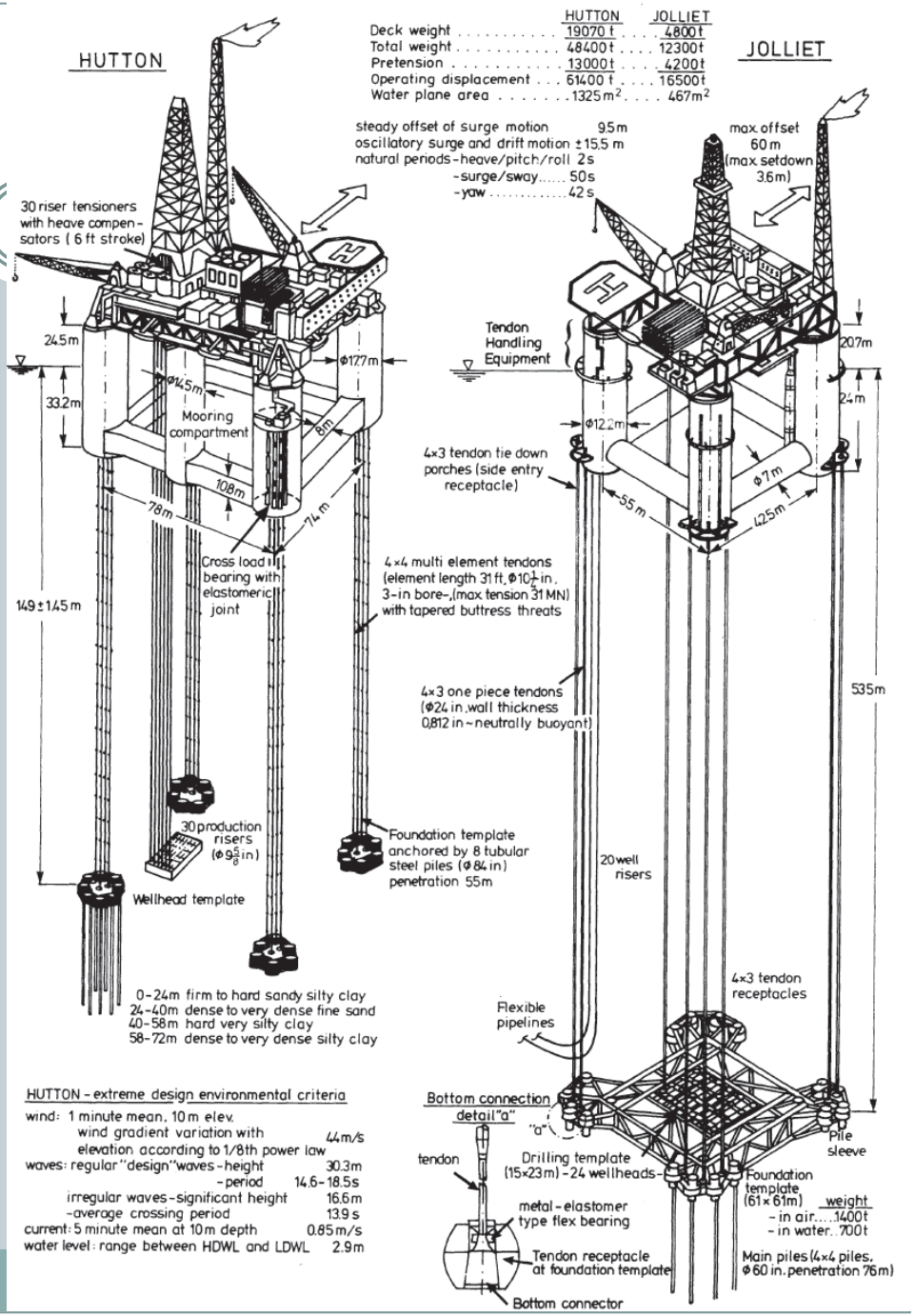




TLPs

- Tendons resemble drilling collars (26cm (d) × 9.5m (L), bore: 7.5cm, t = 9.25mm)
- Mooring compartment adjusts wire tension
- Steel piles penetrate 55m subsea
- Feature mainly dry trees
- Due to tension, TLPs are designed heavier & stronger





TLPs

- Advantages of TLPs include:
  - (i) Mobility and reusability;
  - (ii) Stability (minimal vertical motions);
  - (iii) Low-cost increases as a function of increasing water depth;
  - (iv) Deepwater capabilities;
  - (v) Low maintenance costs.

- Drawbacks of TLPs comprise:
  - (i) High initial (capital) costs;
  - (ii) High subsea costs;
  - (iii) Fatigue (resonance) of tension legs;
  - (iv) Difficult maintenance of subsea systems;
  - (v) Little or no oil storage.

Auger TLP



Heidrun TLP



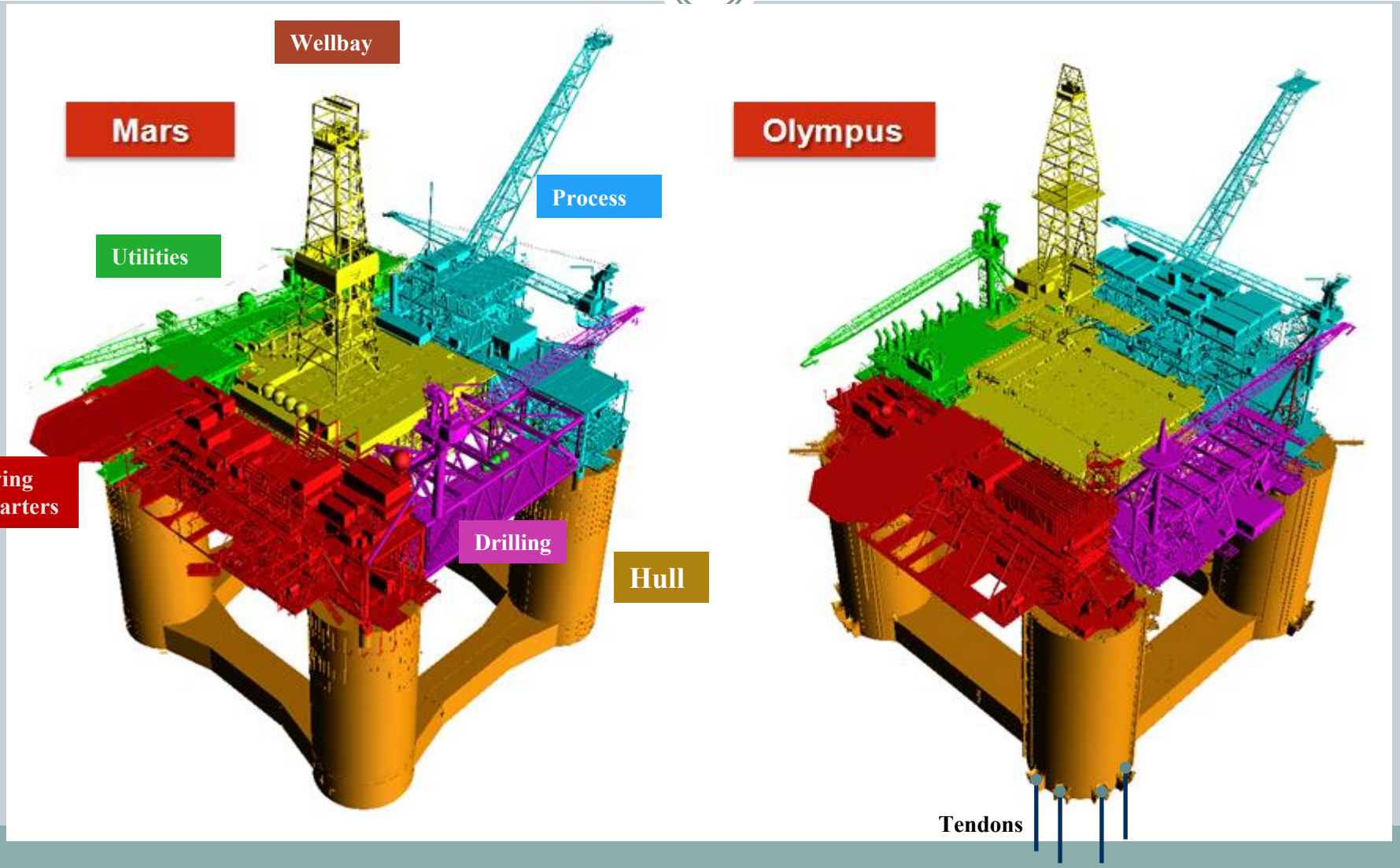
Olympus TLP

- Water depth: ~3,100ft (945m)
- Displacement: 120,000t; 406ft,~125m tall; column spacing: 250ft, 76m
- Production capacity: 100,000 boe/d
- Tendons offer vertical (heave) restraint
- Direct Vertical Access (DVA) capability for drilling & production
- Stiff responses in heave, roll & pitch
- Compliant responses in surge and sway
- Limited to WD<1,500m due to tendon resonance (fatigue)

- Olympus TLP video [4m]

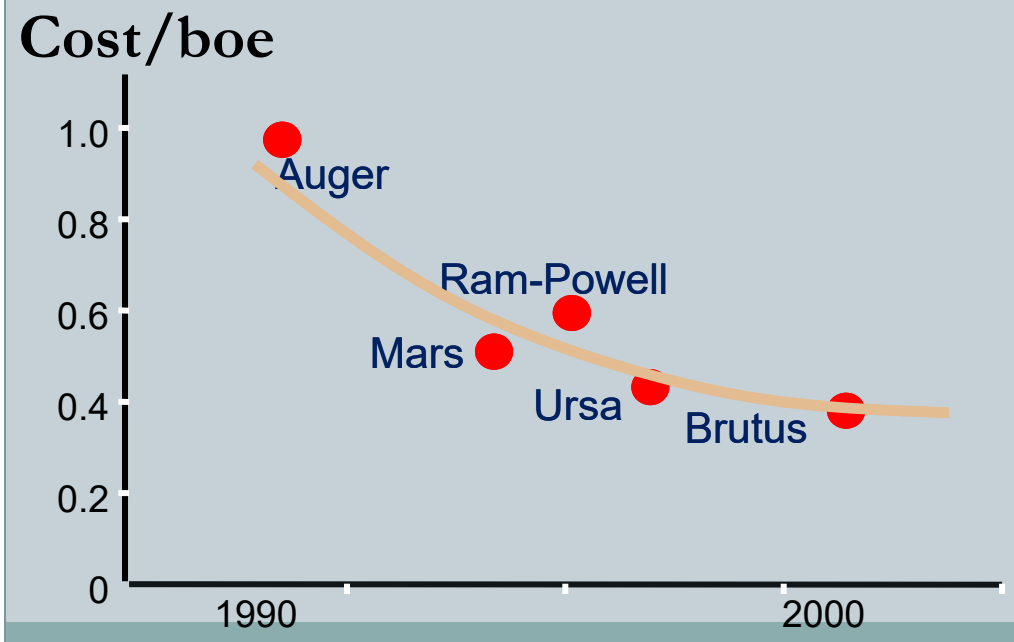


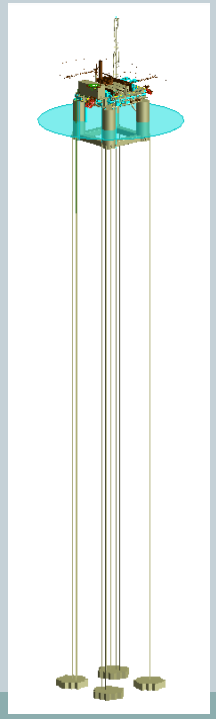
Olympus & Mars TLPs (courtesy Shell)



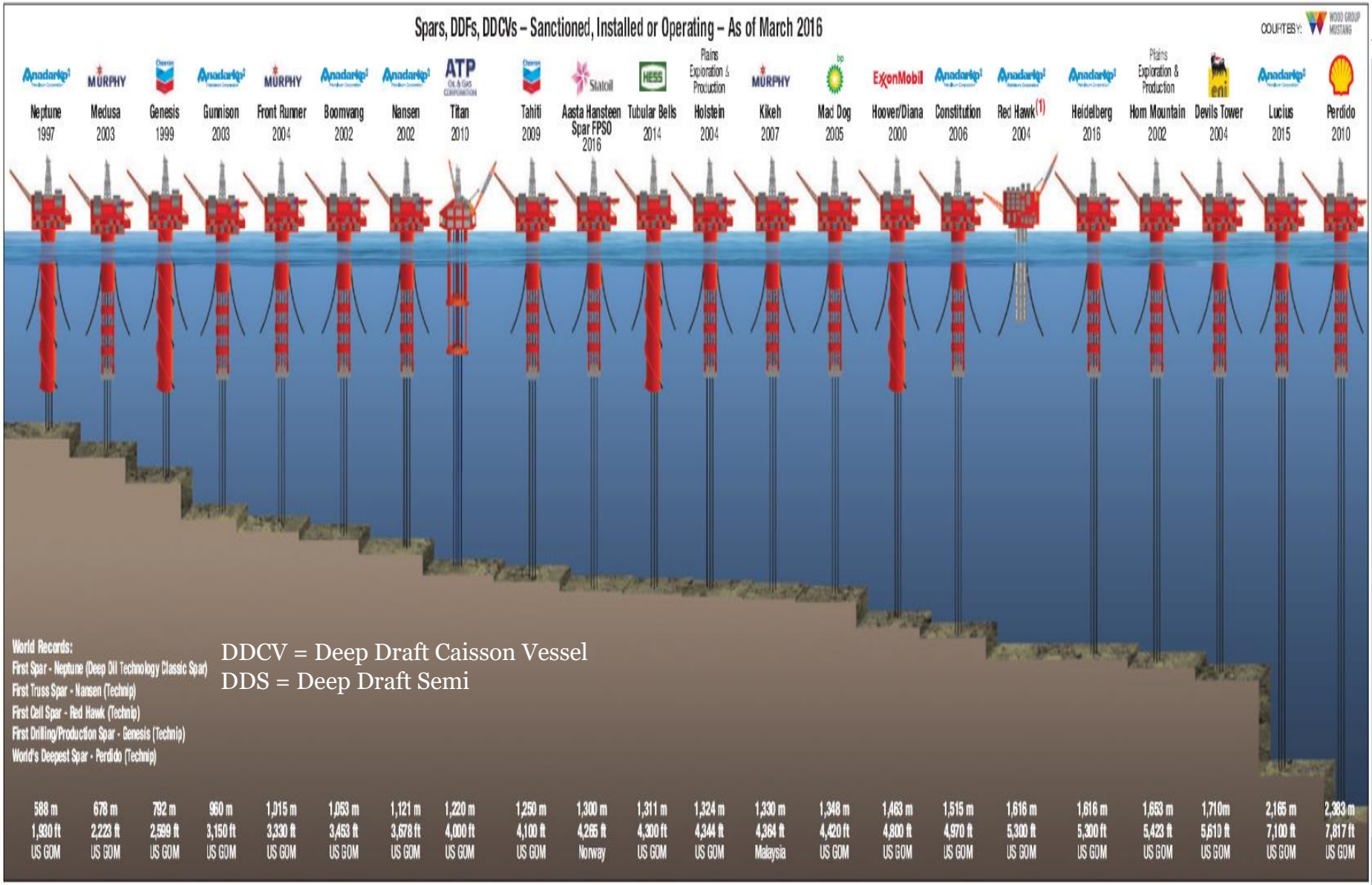
TLPs learning curve for Shell

- Innovations: simplification of hull systems & reduction in hull entry
  - Pre-install tendons
- Learning Curve – lower costs
  - Standardisation & repeatability
  - System improvements (well productivity)



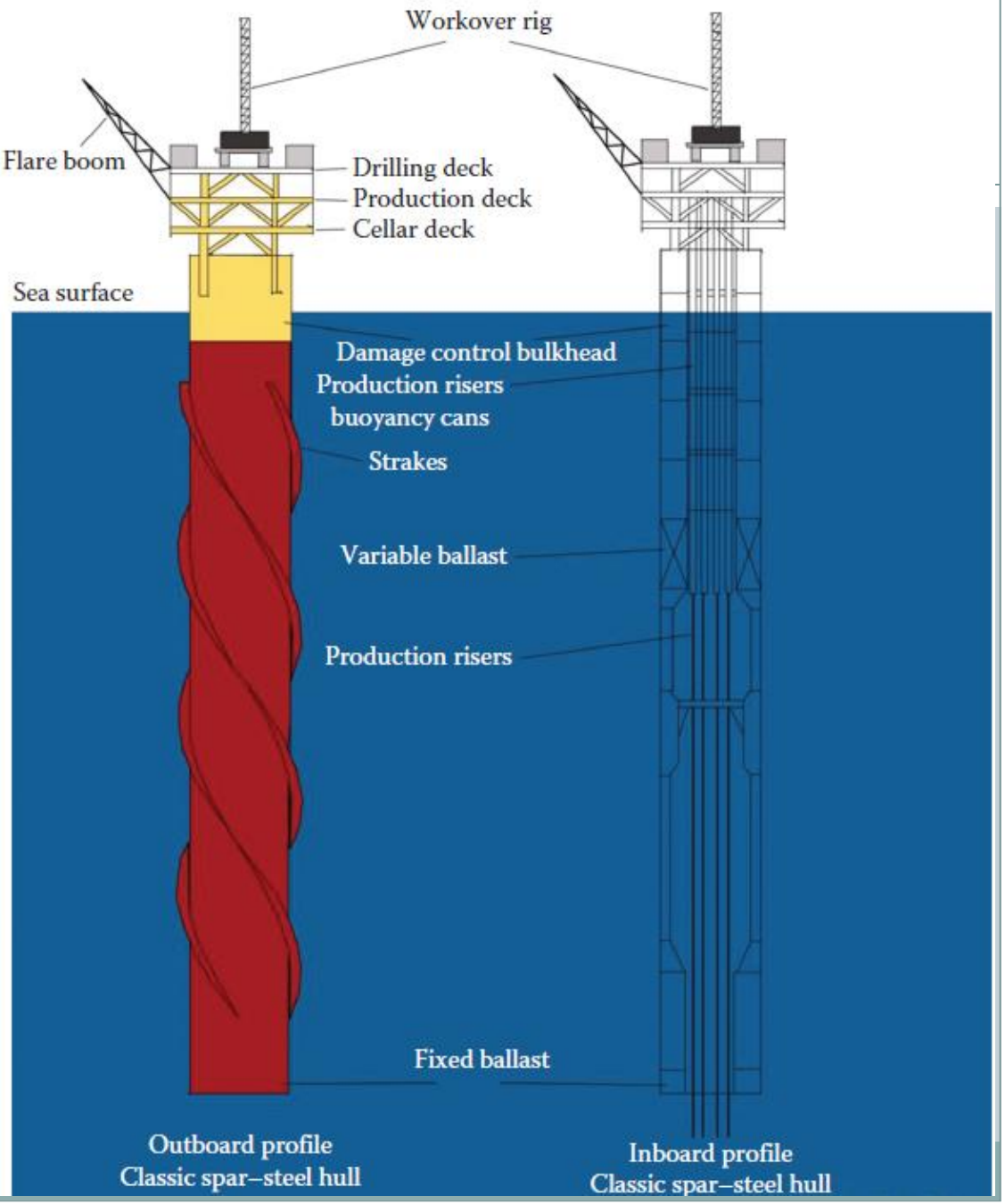


Spars


Spars, DDFs, DDCVs – Sanctioned, Installed or Operating – As of March 2016
COURTESY: WOOD GROUP MUSTANG
Neptune 1997 | 588 m | 1,930 ft | US GOM
Medusa 2003 | 678 m | 2,223 ft | US GOM
Genesis 1999 | 792 m | 2,599 ft | US GOM
Gunnison 2003 | 960 m | 3,150 ft | US GOM
Front Runner 2004 | 1,015 m | 3,330 ft | US GOM
Boomvang 2002 | 1,053 m | 3,453 ft | US GOM
Nansen 2002 | 1,121 m | 3,678 ft | US GOM
Titan 2010 | 1,220 m | 4,000 ft | US GOM
Tahiti 2009 | 1,250 m | 4,100 ft | US GOM
Aasta Hansteen Spar FPSO 2016 | 1,300 m | 4,265 ft | Norway
Tubular Bells 2014 | 1,311 m | 4,300 ft | US GOM
Holstein 2004 | 1,324 m | 4,344 ft | US GOM
Kikeh 2007 | 1,330 m | 4,364 ft | Malaysia
Mad Dog 2005 | 1,348 m | 4,420 ft | US GOM
Hoover/Diana 2000 | 1,463 m | 4,800 ft | US GOM
Constitution 2006 | 1,515 m | 4,970 ft | US GOM
Red Hawk(1) 2004 | 1,616 m | 5,300 ft | US GOM
Heidelberg 2016 | 1,616 m | 5,300 ft | US GOM
Horn Mountain 2002 | 1,653 m | 5,423 ft | US GOM
Devils Tower 2004 | 1,710m | 5,610 ft | US GOM
Lucius 2015 | 2,165 m | 7,100 ft | US GOM
Perdido 2010 | 2,383 m | 7,817 ft | US GOM
World Records:
First Spar - Neptune (Deep Oil Technology Classic Spar)
First Truss Spar - Nansen (Technip)
First Cell Spar - Red Hawk (Technip)
First Drilling/Production Spar - Genesis (Technip)
World's Deepest Spar - Perdido (Technip)
DDCV = Deep Draft Caisson Vessel
DDS = Deep Draft Semi

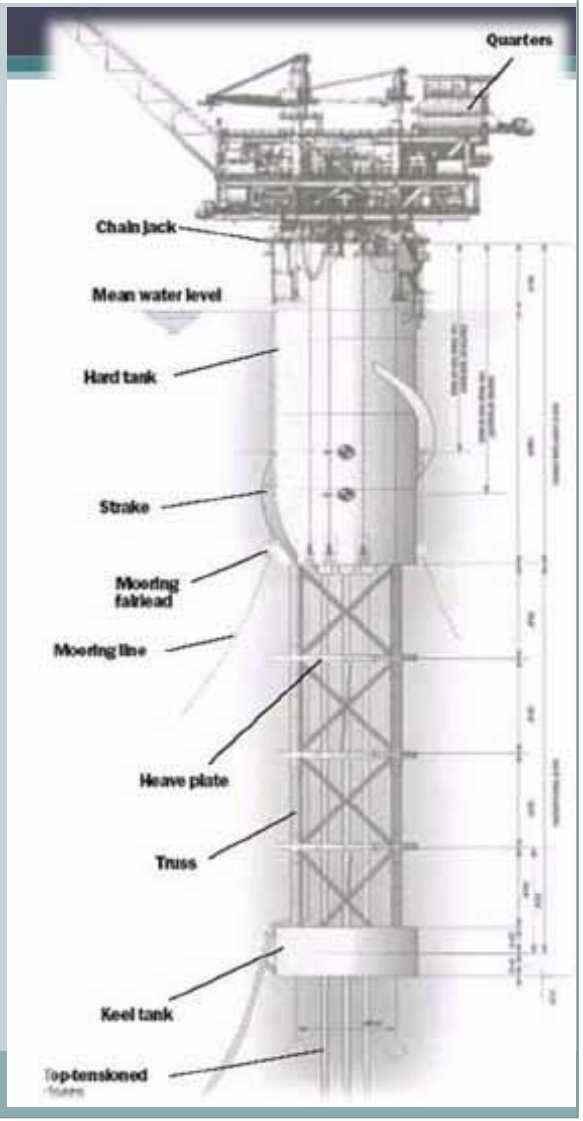
Spars

- Merits:
  - (i) Made of deep-draft hollow caisson
  - (ii) Deep-draft yields low heave & pitch motions
  - (iii) Water depth range: 500-3,000m
  - (iv) Full drilling & production capabilities
  - (v) Dry trees & surface BOP
  - (vi) Steel catenary risers
  - (vii) Cost insensitive to water depth
  - (viii) Relocatable structure
  - (ix) Potential of drilling & processing
  - (x) +ve GM, COG below COB

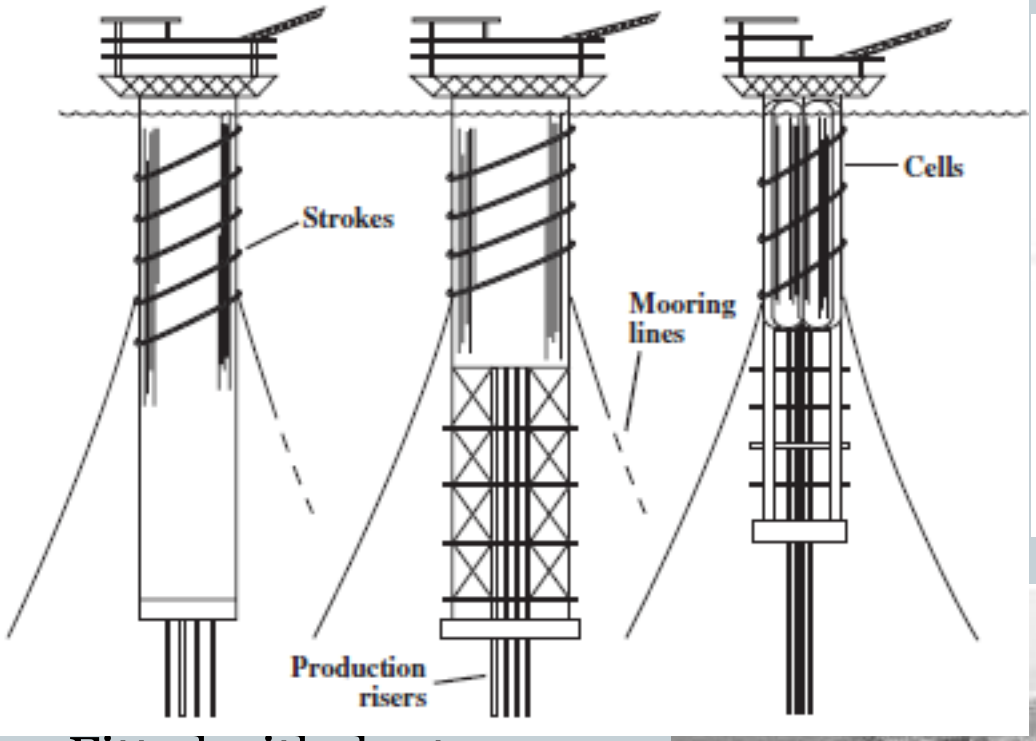


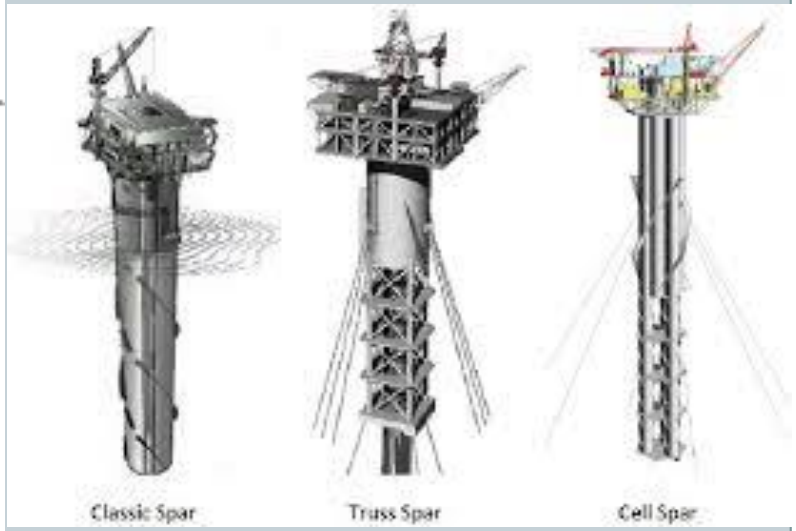
Spars

- 1976: Brent spar installed at North Sea
- 2025: 17 Spars in operation: 3 classic cylindrical hull designs, 13 truss designs & 1 cell type
- Disadvantages of spars comprise:
  - Open-sea mounting topside to hull;
  - Little storage capacity; tied to pipeline or FSO;
  - Relatively difficulty to transport (mostly built in Finland)
  - Need to damp vortex induced vibrations (VIVs)
- Truss spar is the evolution of the classic spar
- Truss spar consists of:
  - Hard tank provides most of the buoyancy
  - Truss section supports the keel tank to hard tank
  - Keel tank contains fixed ballast & connects export p/lines & flow lines



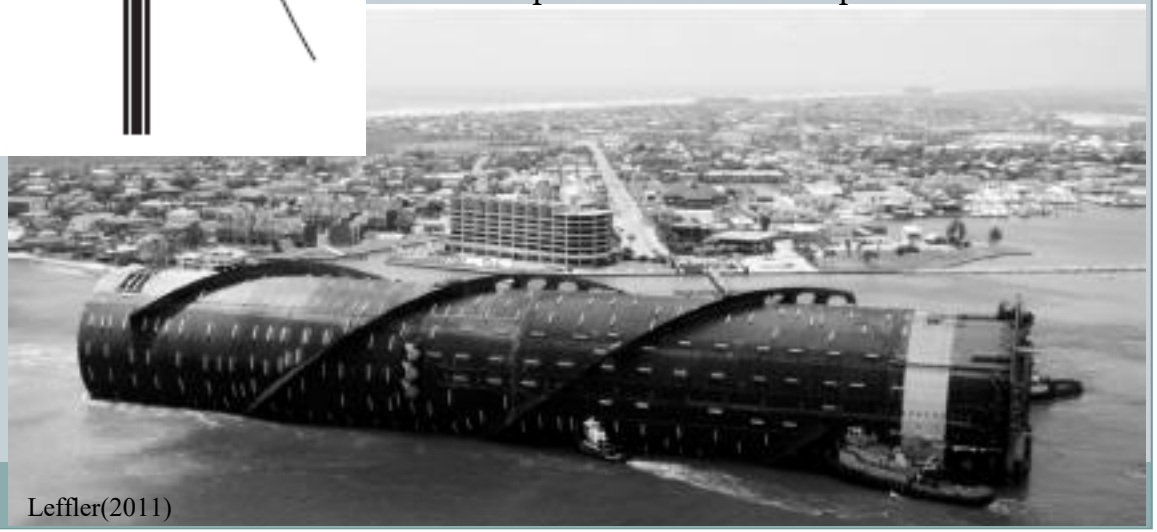
Evolution of spars





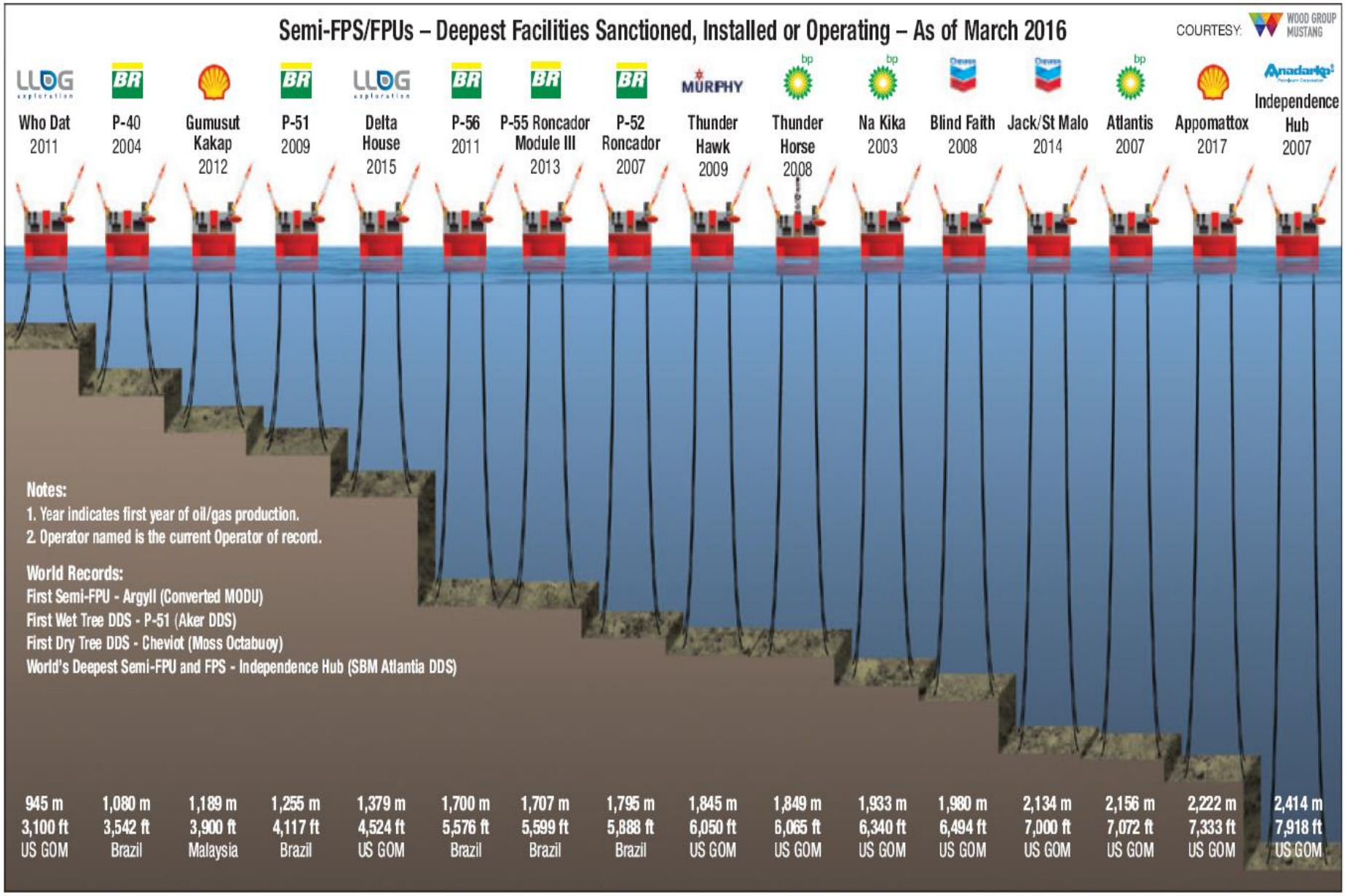
Transportation of Genesis spar hull

- Fitted with dry trees



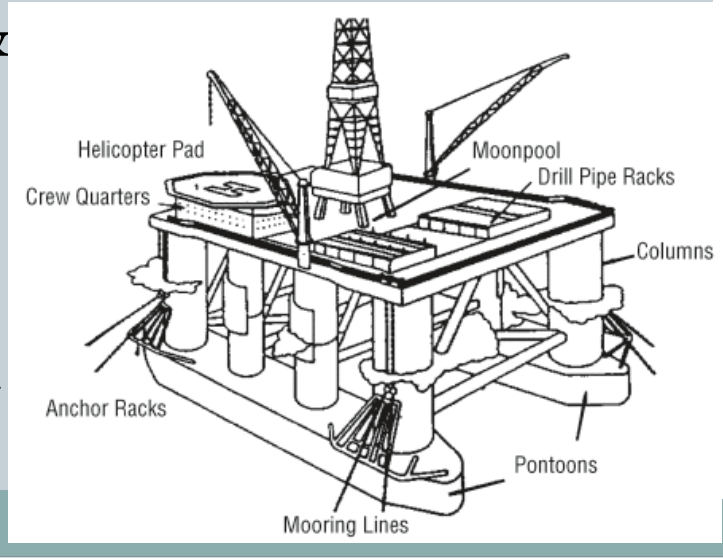
Leffler(2011)

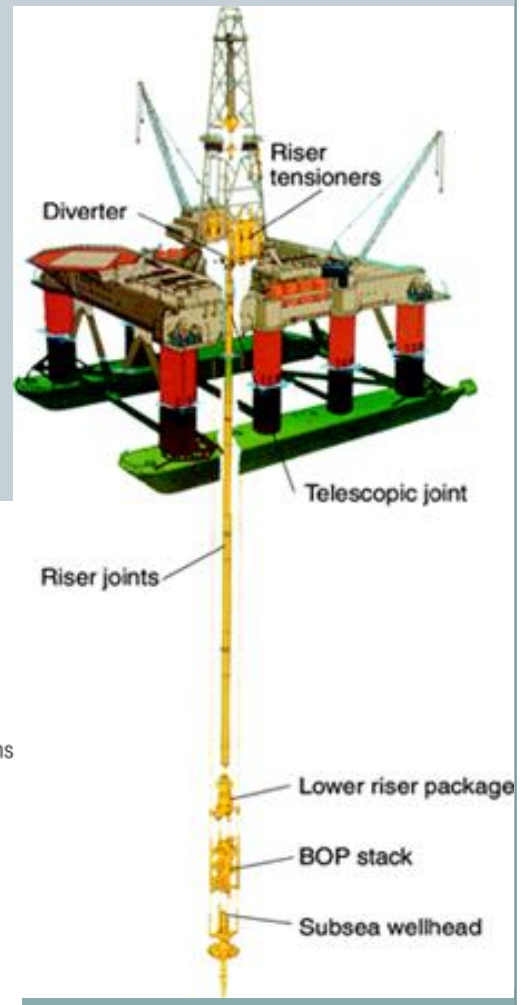
Semi-submersibles



Semi-submersible platforms

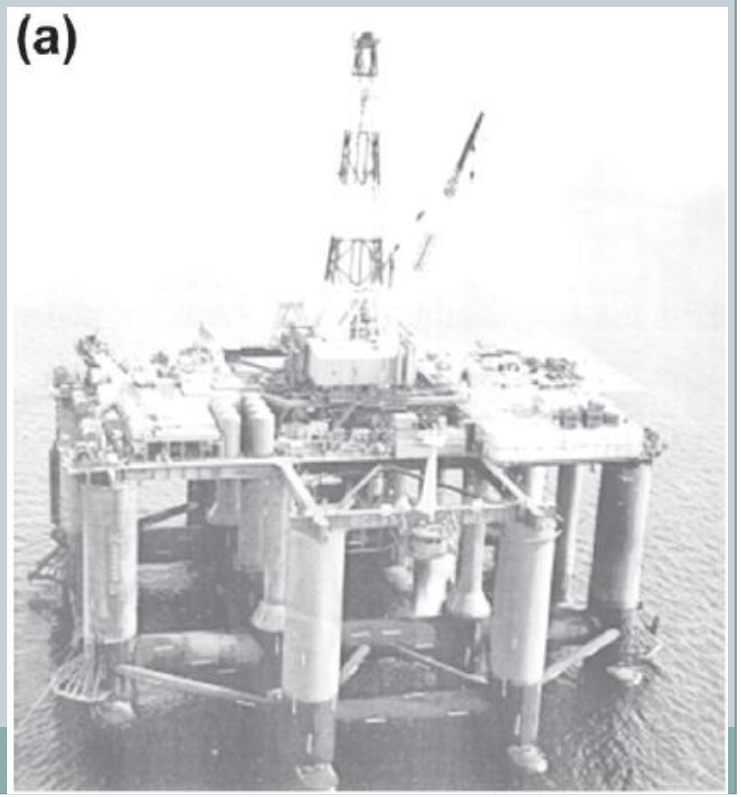
- Capable of drilling & production operations
- Increased draft provides stability
- Lack of propulsion system (longer transit times)
- Require temporary anchoring systems (8 to 12) or dynamic positioning (DP) system
- Towed by tug-boats or dry transport
- Lower rates than drillships ($400k/d)
- Heave compensators & marine risers protect drill bit
- Operational envelope: >300 semi-subs operate in water depth 500m<D_{H2O}<4,000m





Floating production systems (FPS)

- Either self-propelled or towed to location
- Draft increased by flooding buoyancy tanks
- Kept in position by DPS or mooring system
- Structure built of 4, 6, 8 or more columns
- Merits:
  - Good stability even in rough seas
  - Good mobility at small draft (T)
  - Large deck area
- Shortcomings:
  - Low propulsion speed <8kn
  - Expensive to built >$100m
  - Sensitive to load



Blind Faith

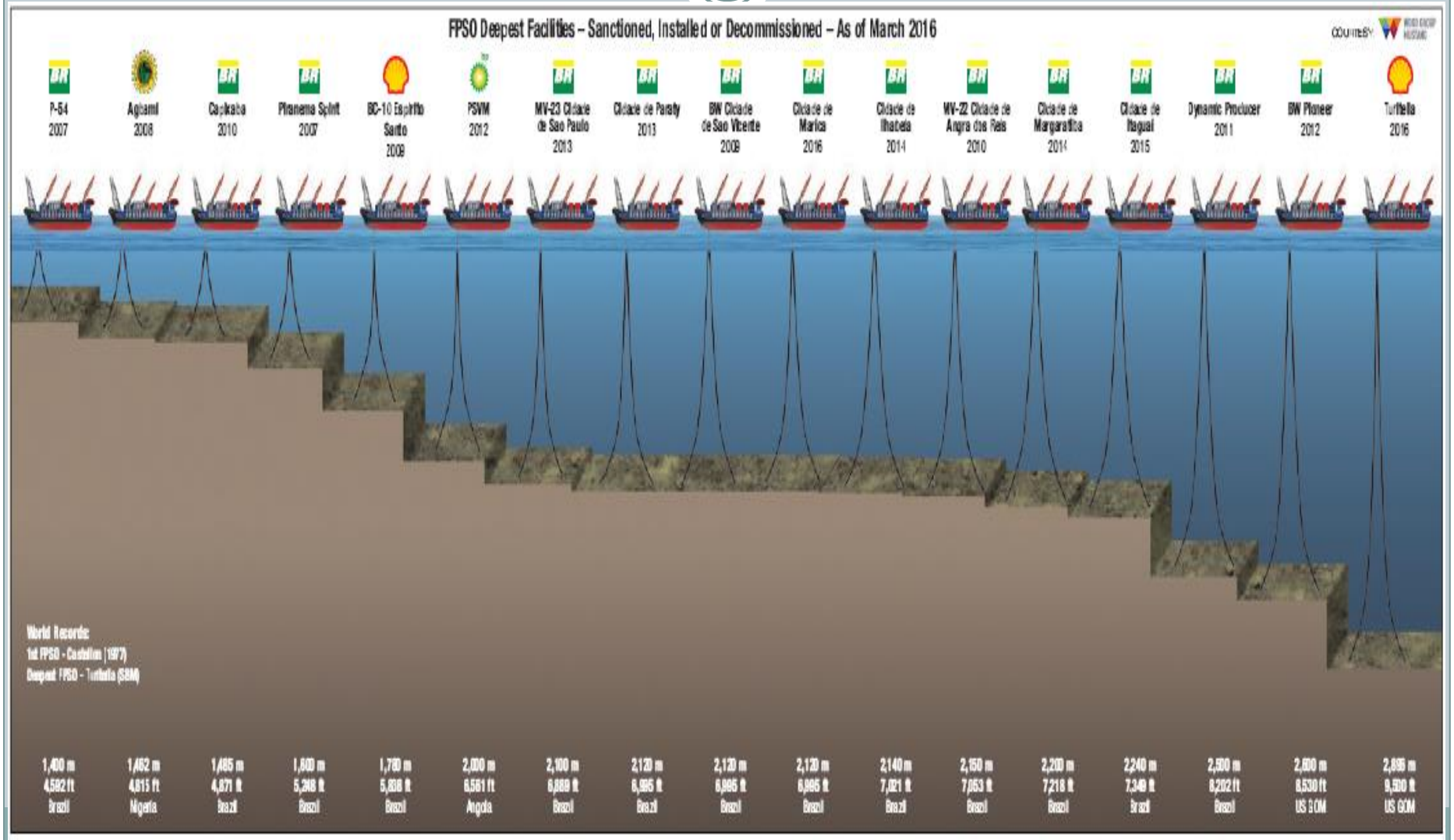
- Year: 2008
- WD: 6,500ft
- Δ=40,000t
- Chevron & Kerr-McGee
- $900m
- 65,000 bpd



Ichtys LNG central processing platform

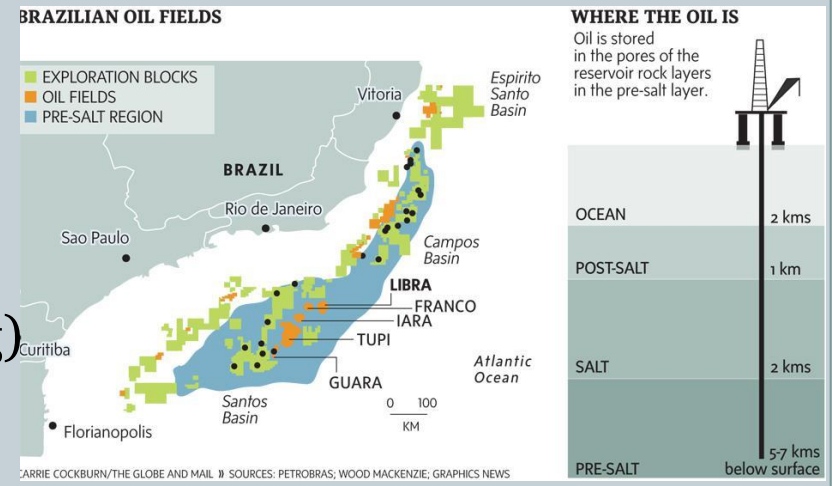
- Video (Icthys) -- YouTube
- Specs:
  - 8.4 mtpa LNG
  - 1.6 mtpa LPG
  - 100,000 bpd of condensates

FPSOs


FPSO Deepest Facilities – Sanctioned, Installed or Decommissioned – As of March 2016
P-54 2007
Agbami 2008
Capixaba 2010
Piranema Spirit 2007
BC-10 Espirito Santo 2009
PSVM 2012
MV-23 Cidade de Sao Paulo 2013
Cidade de Paraty 2013
BW Cidade de Sao Vicente 2009
Cidade de Marica 2016
Cidade de Ilhabela 2014
MV-22 Cidade de Angra dos Reis 2010
Cidade de Mangaratiba 2014
Cidade de Itaguai 2015
Dynamic Producer 2011
BW Pioneer 2012
Turritella 2016
World Records:
1,400 m 4,592 ft Brazil
1,462 m 4,815 ft Nigeria
1,485 m 4,871 ft Brazil
1,800 m 5,248 ft Brazil
1,780 m 5,838 ft Brazil
2,000 m 6,561 ft Angola
2,100 m 6,889 ft Brazil
2,120 m 6,955 ft Brazil
2,120 m 6,955 ft Brazil
2,120 m 6,955 ft Brazil
2,140 m 7,021 ft Brazil
2,150 m 7,053 ft Brazil
2,200 m 7,218 ft Brazil
2,240 m 7,349 ft Brazil
2,500 m 8,202 ft Brazil
2,600 m 8,530 ft US GOM
2,895 m 9,500 ft US GOM

Brazil's pre-salt discoveries

- About 30 platforms (FPSOs) operated by Petrobras
- Production: 41,000bblpd (2010) to 2.3mbblpd (2022)
- Proven reserves: 11.5bn bbloe
- Itapu tapped by P-71 FPSO
- 11 more FPSOs by 2027
- Break-even price: $35/bbl
- CO_2 footprint: 18kg/bbl (1/2 global avg)
- Equatorial Margin next frontier



P-71 FPSO: Production: 150,000 bblpd & 1.6 MMbbl of storage.



Source: Revista USP

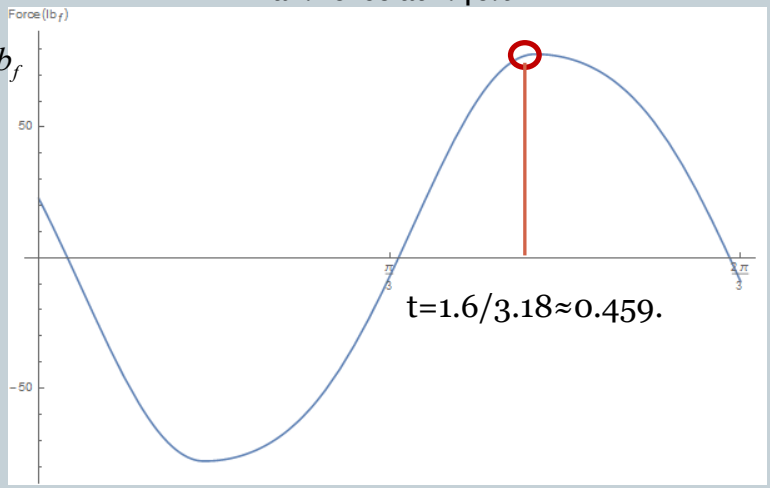


Exercise

- Example#9

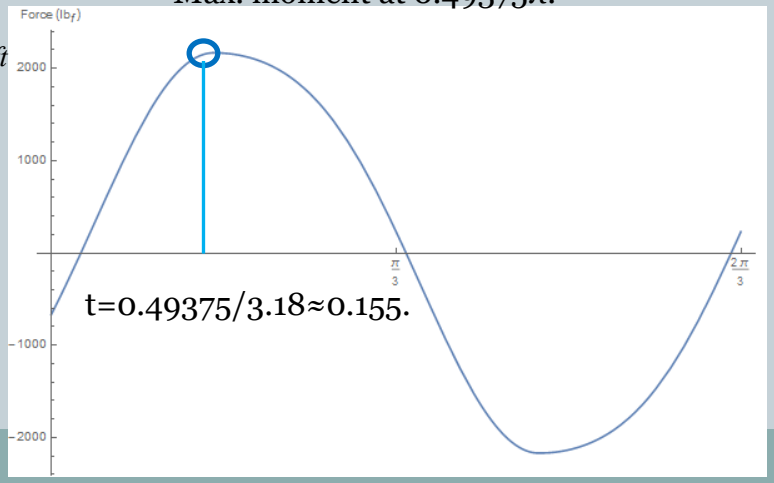
$F_{T_x} = 77.9 lb_f$

Max. force at 1.46π



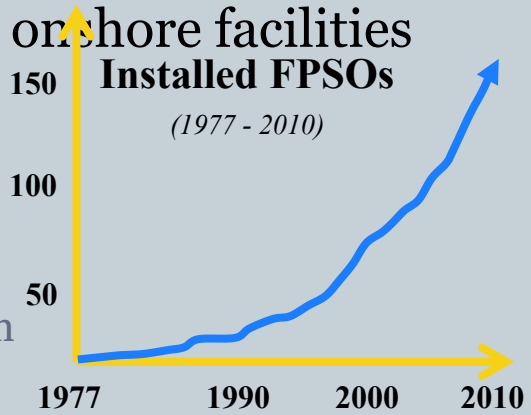
$M_{T_{max}} = 2{,}168.3 lb_f - ft$

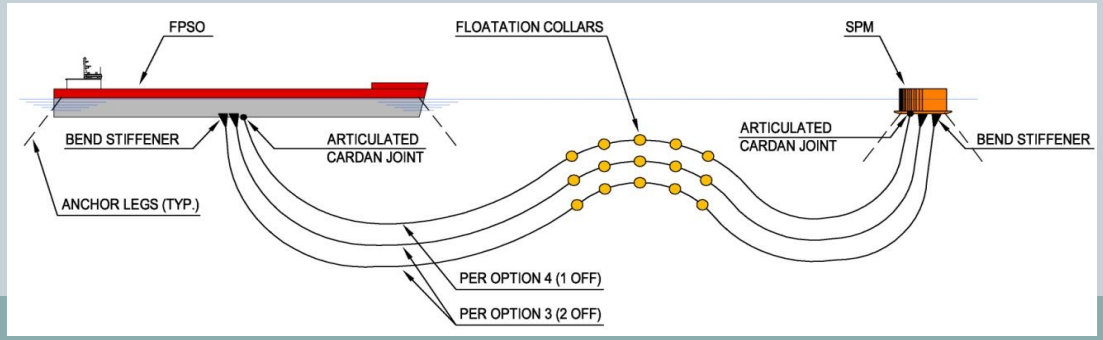
Max. moment at 0.49375π.



FPSOs

- Storage & offloading alleviates need for pipelines & onshore facilities
- Weathervaning (turret-moored) in other areas
- Newbuild or conversion. World count: 270 FPSOs
- Storage needs:
  - (i) parcel size, (ii) duration of offloading, (iii) oil remaining in tanks (iv) tank inspection in service
- Parcel size: amount of oil offloaded to tanker (1 mbbl for WA)
- Offloading duration: ~24 hrs
- Storage required = parcel size + 4 days of production



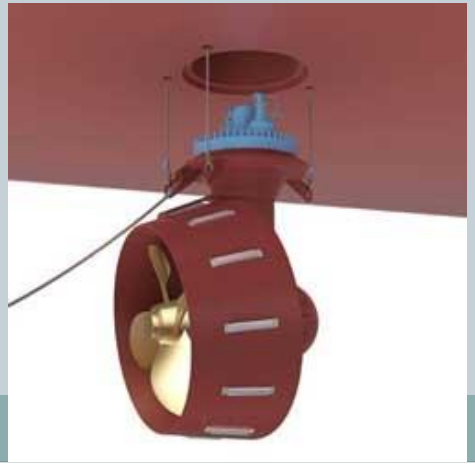


Bonga FPSO



Drillships

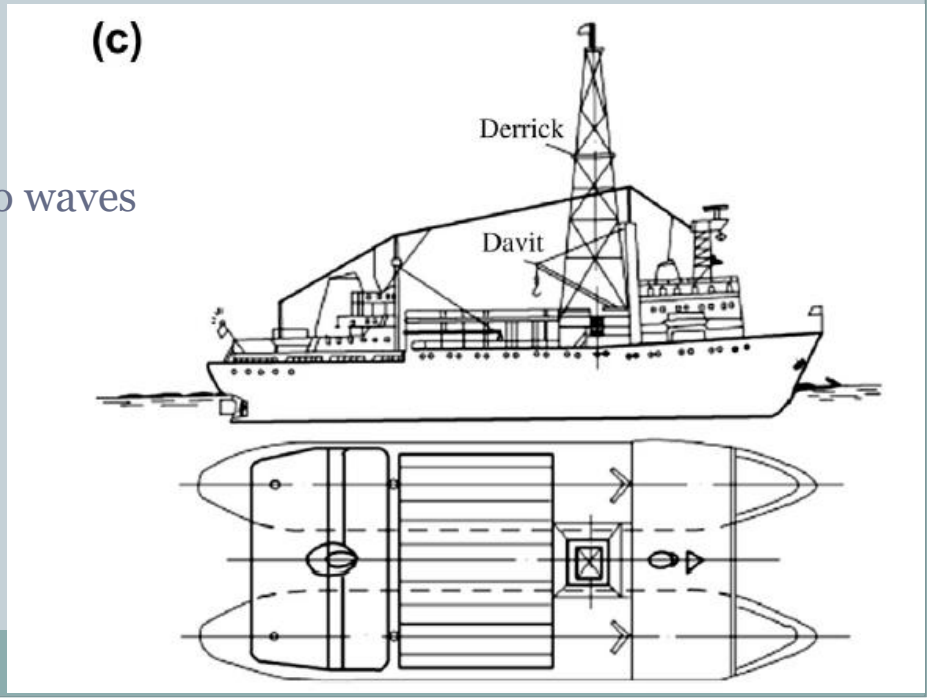
- Swift transit & manoeuvring characteristics
- Less idle time but more expensive to operate
- Used only for drilling operations
- Retained in place by dynamic positioning (DP) via thrusters
- Energy intensive operations (w/o anchoring)
- Operational water depth = 12,000ft (3,660m)
- Dual handling capabilities; centre-line moon-pool
- World fleet ~80 ships | Cost = ~$600m/each





Drillships

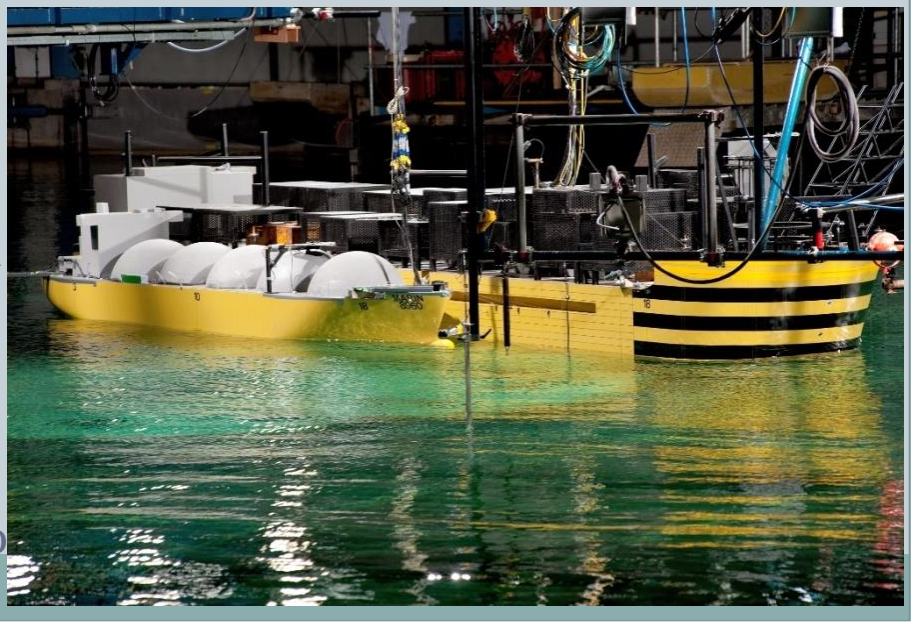
- 2025: 140 active drillships & semisubs in operation
- Merits:
  - Good mobility
  - High self-propulsion speed: 8–14 knots
  - Large load & storage capabilities
  - Water depth value ~6,000m
- Weaknesses:
  - Shallow draft make drillships sensitive to waves
  - Expensive
  - Asymmetric hull



Floating LNG

- 2025: 5 FLNG in operation: Cameroon, Argentina, Australia, Malaysia, Mazambique
- Obviate need for submarine export pipeline(s)
- Innovation: onboard liquefaction; working life: 30–40 yrs
- 3.5–5.5 mtpa (2–3tcf)
- Issues:
  - LNG sloshing
  - Topsides: equipment miniaturization & access for maintenance
  - Hull: no dry-docking
  - Mooring systems: must not interfere with production & offloading
  - Safety considerations
  - Offloading: sea motions during transfer operations
  - Metocean design conditions: 100-year; 10

Courtesy: Royal Dutch Shell



Prelude FLNG project

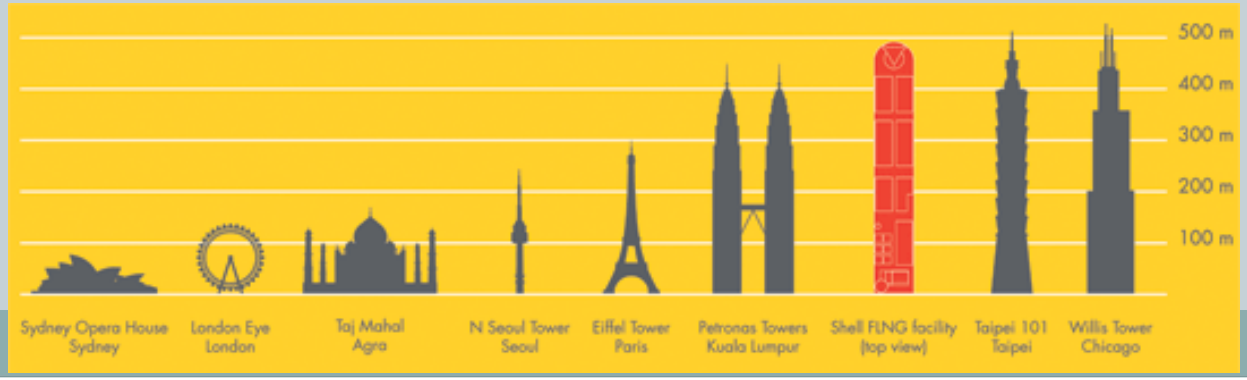
- Entered operation in 12/2018; offshore NW Australia
- Capacity: 5.3mtpa (3.6mpta *LNG*, 1.3mtpa *condensates*, 0.4mtpa *LPG*)
- Construction commenced in Oct., 2012
- FLNG Prelude 1st in the world
- Cost: $14bn
- 600,000 t | Length: 488m
- Hull floated on Dec. 3rd, 2013
- Built by SHI, S. Korea



Prelude FLNG in numbers

- **>600** engineers worked on the facility's design options
- **93m** by **30m** the turret secured to the seabed by mooring lines
- **50 tonnes/hr** cold H_2O to be drawn from the ocean to help cool the NG
- **20-25 years** is the time the Prelude FLNG facility will stay at the location to develop gas fields
- **>200 km** is the distance from the Prelude field to the nearest land
- **175 Olympic-sized swimming pools** could hold the same amount of liquid as the facility's storage tanks
- **6 of the largest aircraft carriers** would displace the same amount of water as the facility

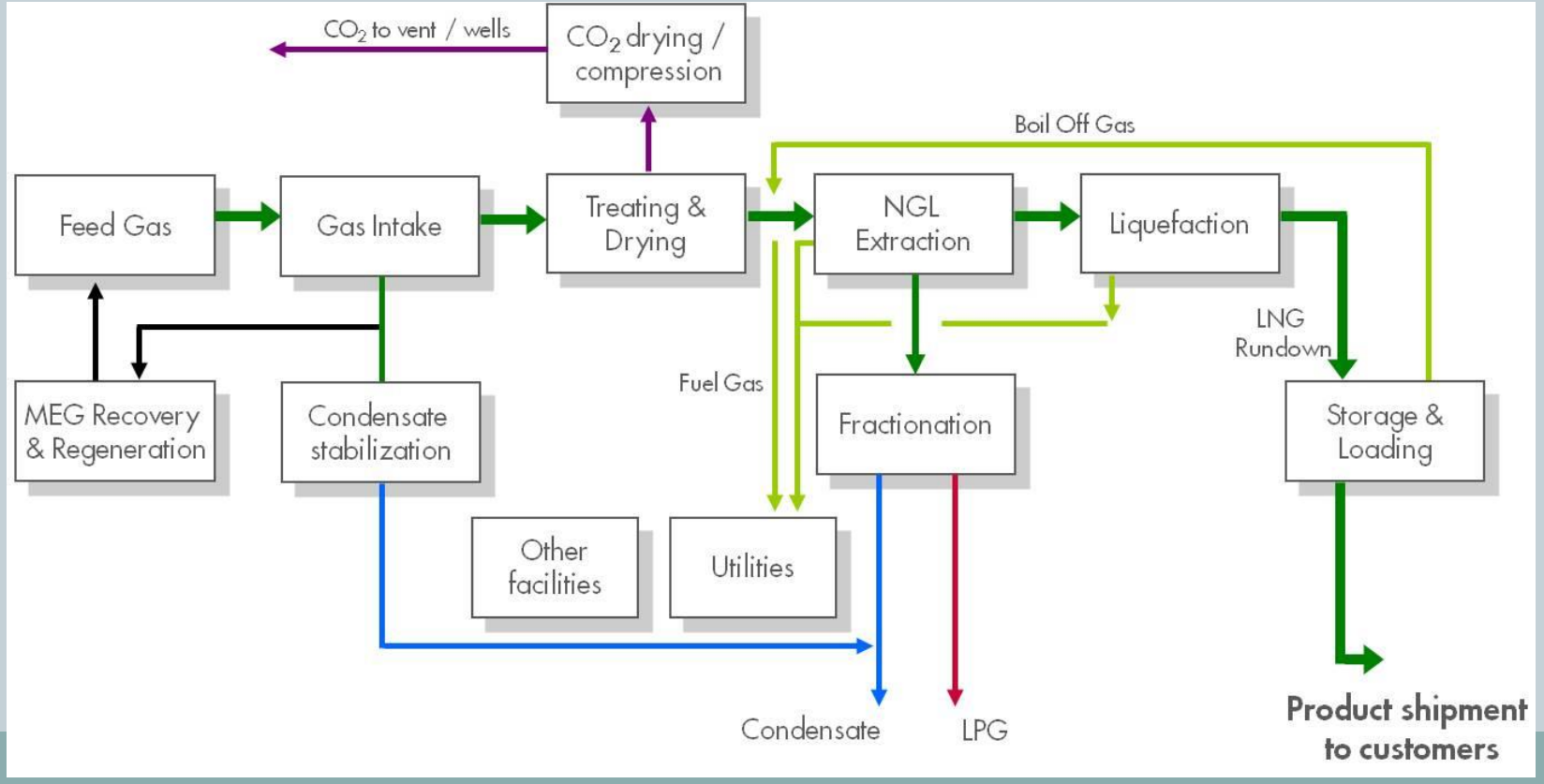
Courtesy: Royal Dutch Shell



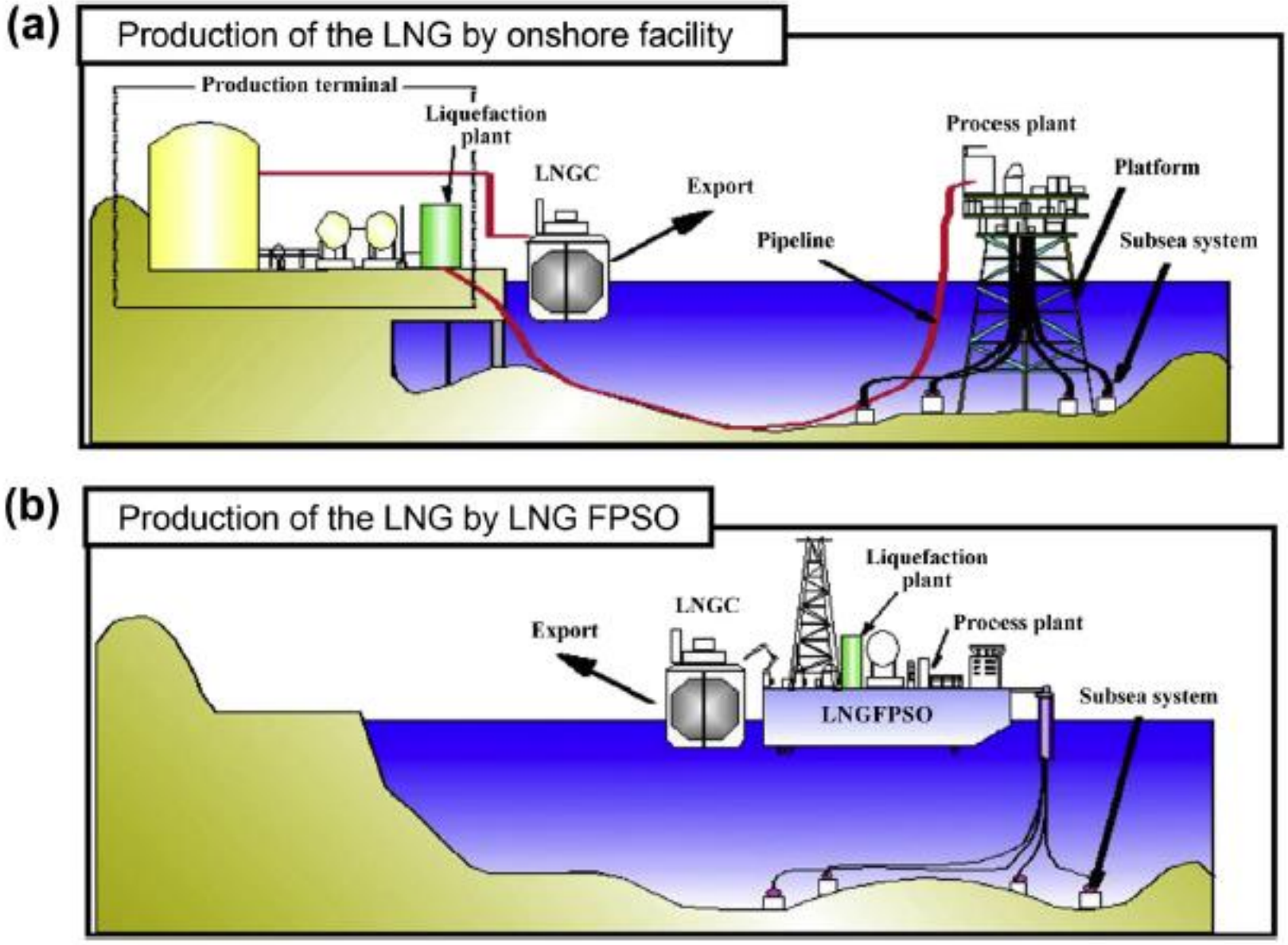
Floating NG liquefaction

- Fluids:
  - CH_4, C_2H_6, C_3H_8, C_4H_{10}
  - Condensates, CO_2, H_2O, etc.

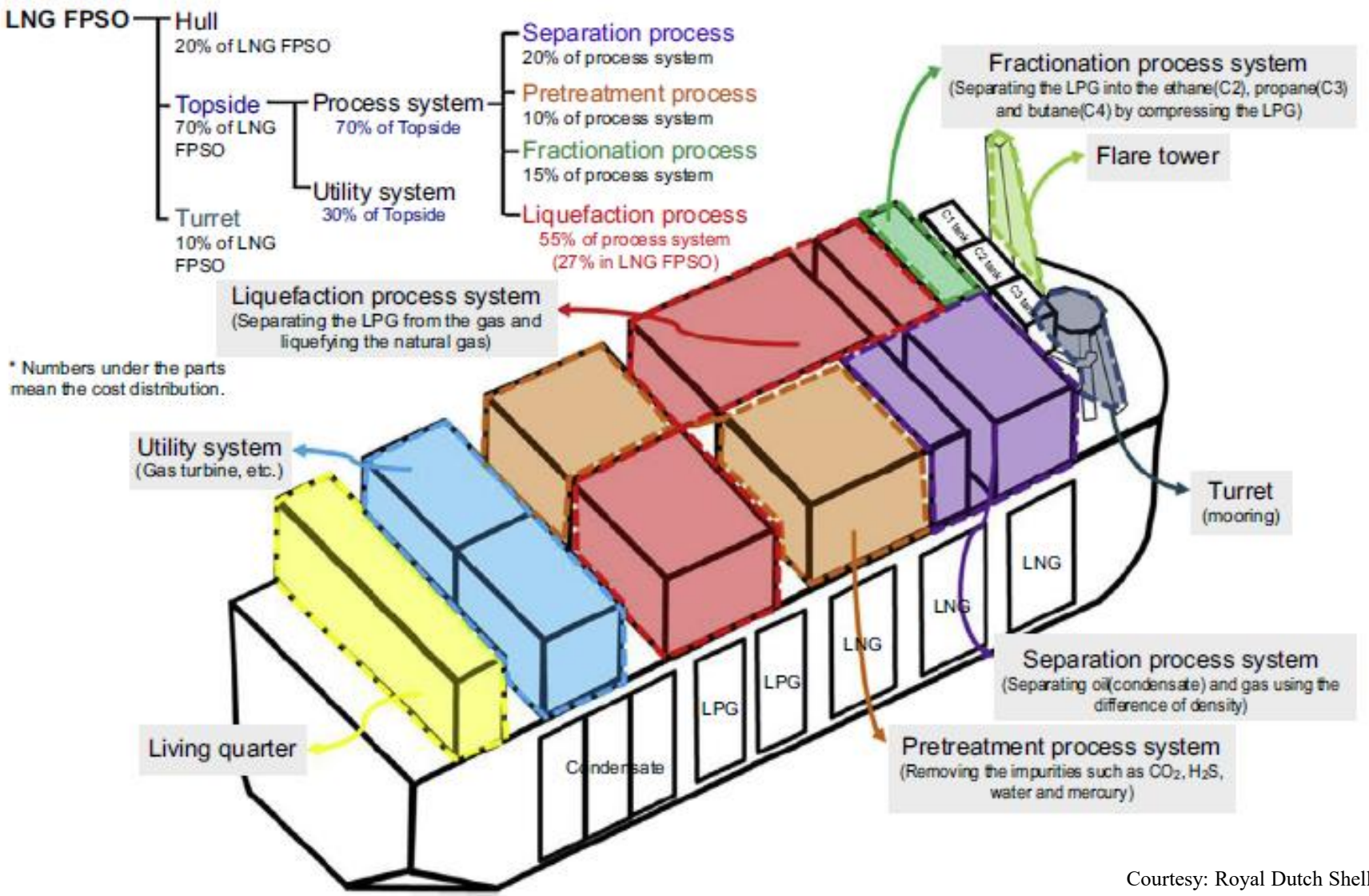
Courtesy: Royal Dutch Shell



Onshore vs offshore LNG



FLNG layout



Courtesy: Royal Dutch Shell

Prelude FLNG project (2)



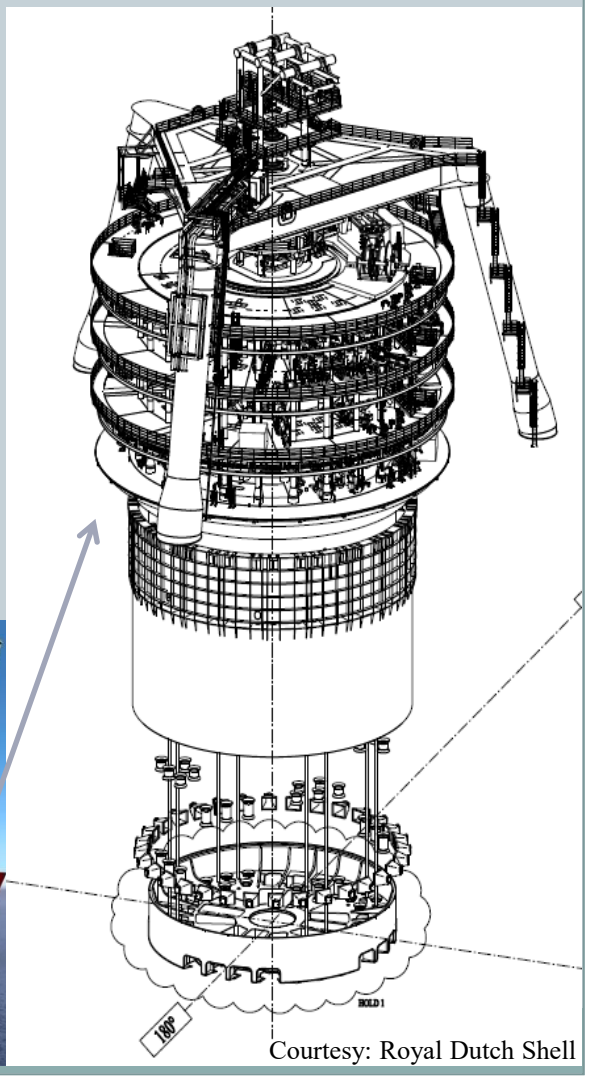
Courtesy: Royal Dutch Shell

Prelude FLNG turret & mooring system

- Turret allows ship to weathervane
- Turret height: 100m, diameter: 26m
- Mass: 11,000 tons
- Mooring provides station keeping 4×4 (16 lines)
- Swivel stack to enable transfer of fluids (gas)







Courtesy: Royal Dutch Shell

Offshore mooring systems

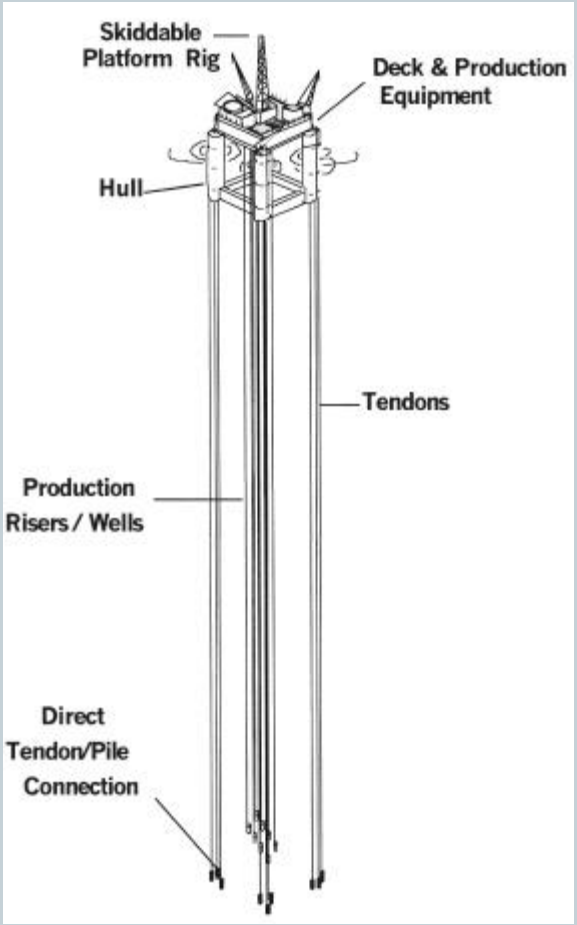
Offshore mooring systems

- Objectives: secure floating structure in position with min. forces on it
- Two types of mooring systems:
  - Temporary mooring: semi-subs, work vessels, dredgers, pipe-laying vessels, …
  - Permanent mooring: TLPs, F(D)PSOs, Spars, FPS, FSRUs, semi-subs, SPMs, …
- Classification also based upon:
  - Spread, multi-point mooring (MPM)
  - Single point mooring (SPM)
- Flexibility & tension can be attained by:
  - Line sags due to its mass (weight) (e.g., chain line)
  - Action of buoyancy on floater and line
  - Material flexibility: nylon, propylene, wire lines, …
- Traditionally, steel wire rope in the middle & chains at seabed (touchdown) and at surface

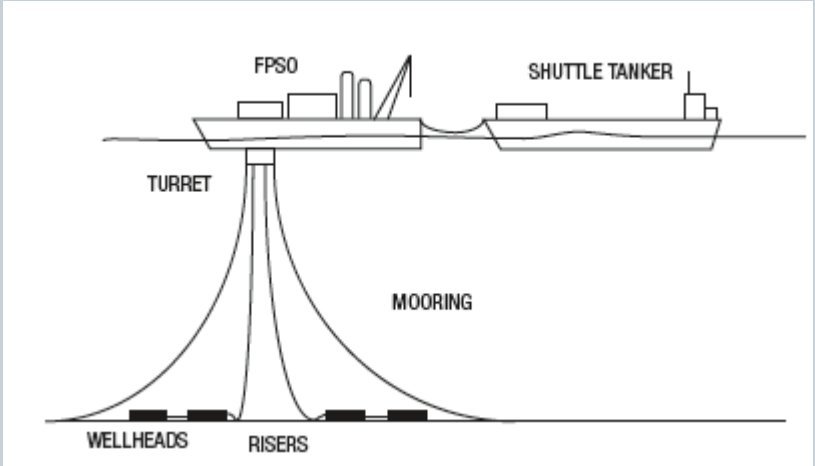


Line arrangements

Single point tendons

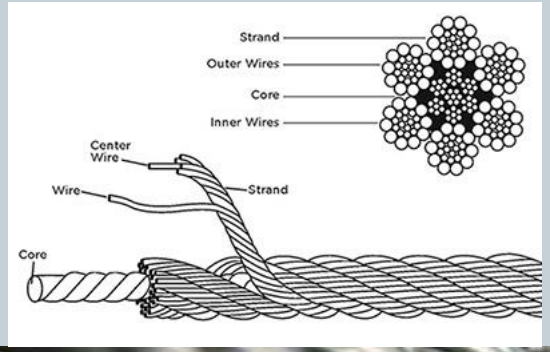


Spread mooring

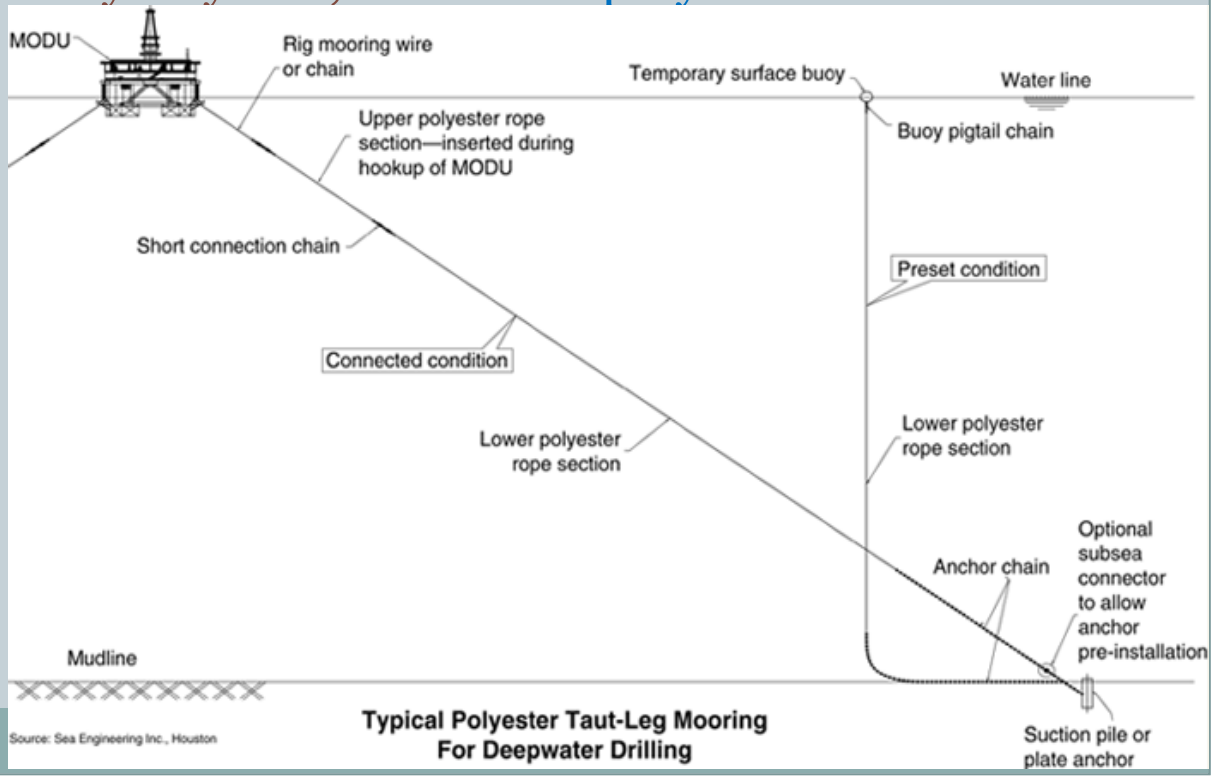


Taut-leg mooring

- D<100m: chain; 100m>D>300m: wire rope; D>2000m: chain, synthetic & wire rope or 2000m>D>3000m: steel wire + chain
- Synthetic lines: lighter & more elastic to wire/chain; neutral buoyancy
- But synthetic lines do not [yet] posses the stiffness of metallic ones
- Synthetic lines include: Polyethylene, aramid or polyester



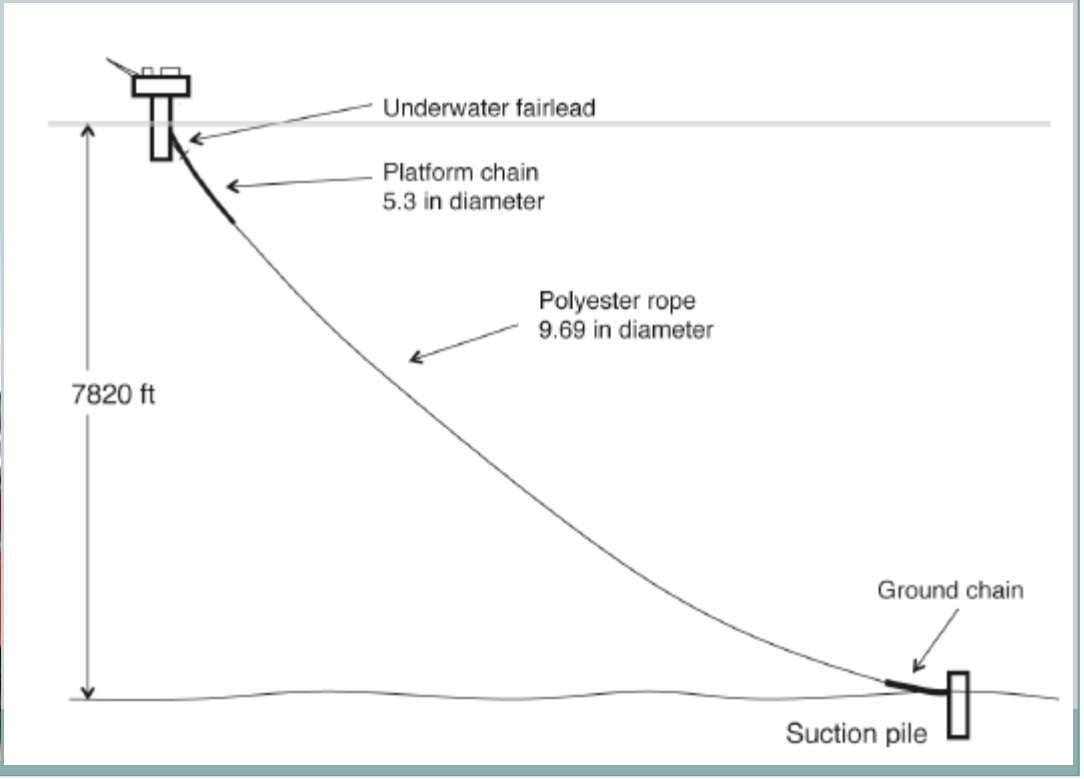




Perdido spar mooring lines

- Line length: 3.2km
- Thickness: 245mm
- Total of 9 mooring lines
- Water depth: 2,450m
- Operation date: 2008



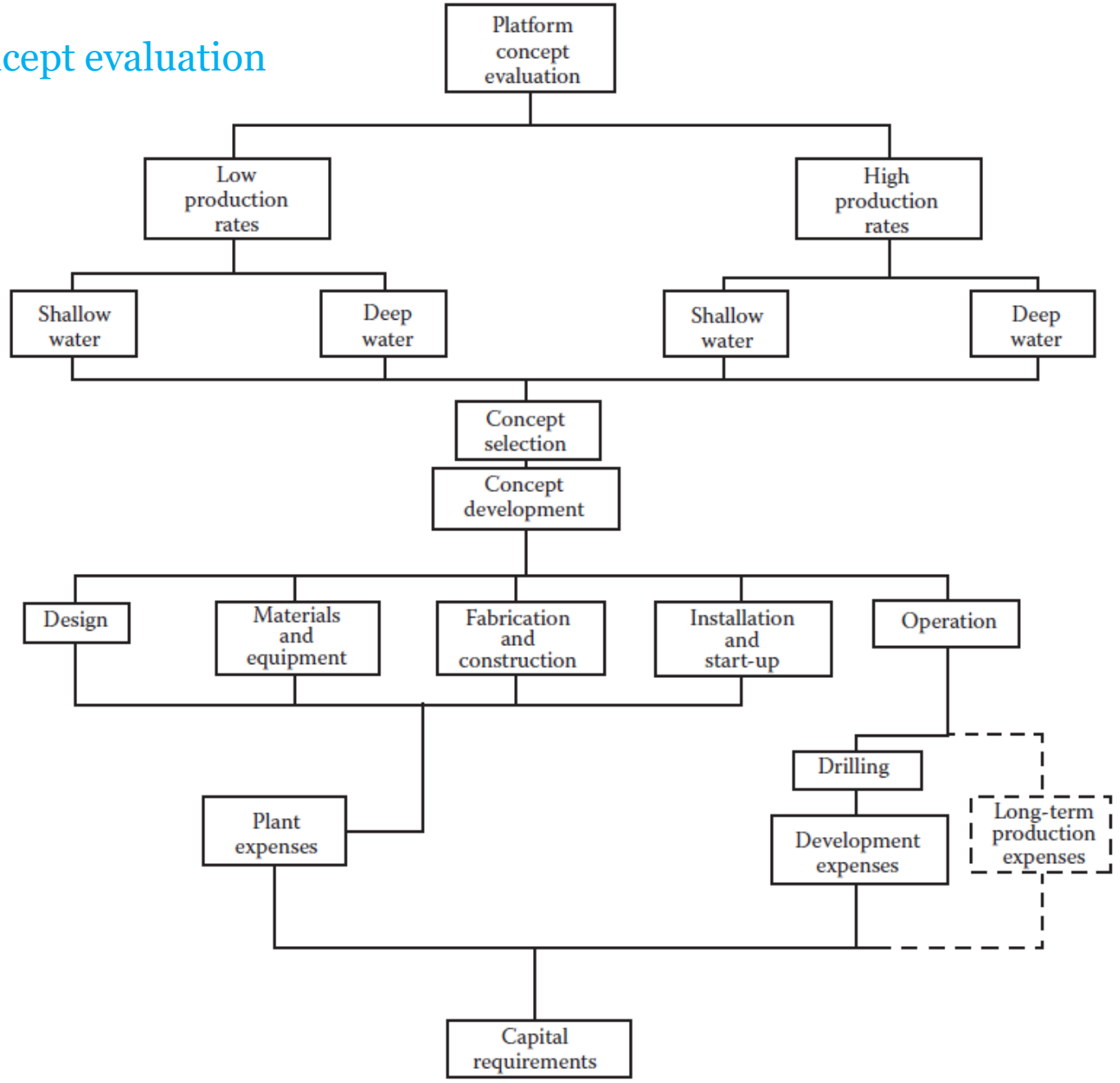


Polyethylene rope *vs* steel wire

- Video



Platform concept evaluation



Theory

- Theory #4: Design of offshore structures

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- Dr. Mike Efthymiou, Shell Netherlands



Thanks for your attention!