Fixed and Floating Offshore Systems

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Overview

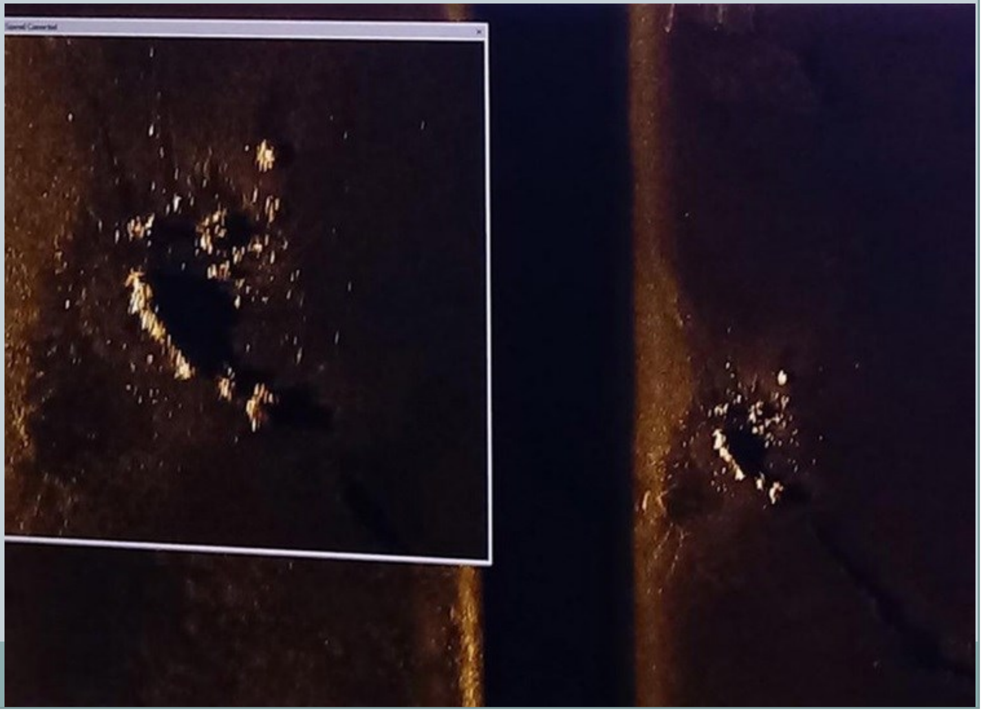
- Fixed platforms:
  - Jacket (steel) installations
  - Monopods
  - Compliant towers
  - Guyed towers
- Gravity based platforms
- Tension leg platforms (TLPs)
- Jack-up rigs
- Semi-submersibles
- Spar platforms

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?
- Probably yes at a cost of $100m
- Video: Argentina submarine
- Kursk: https://bit.ly/2QocwT9
- Dutch Mammoet-Smit

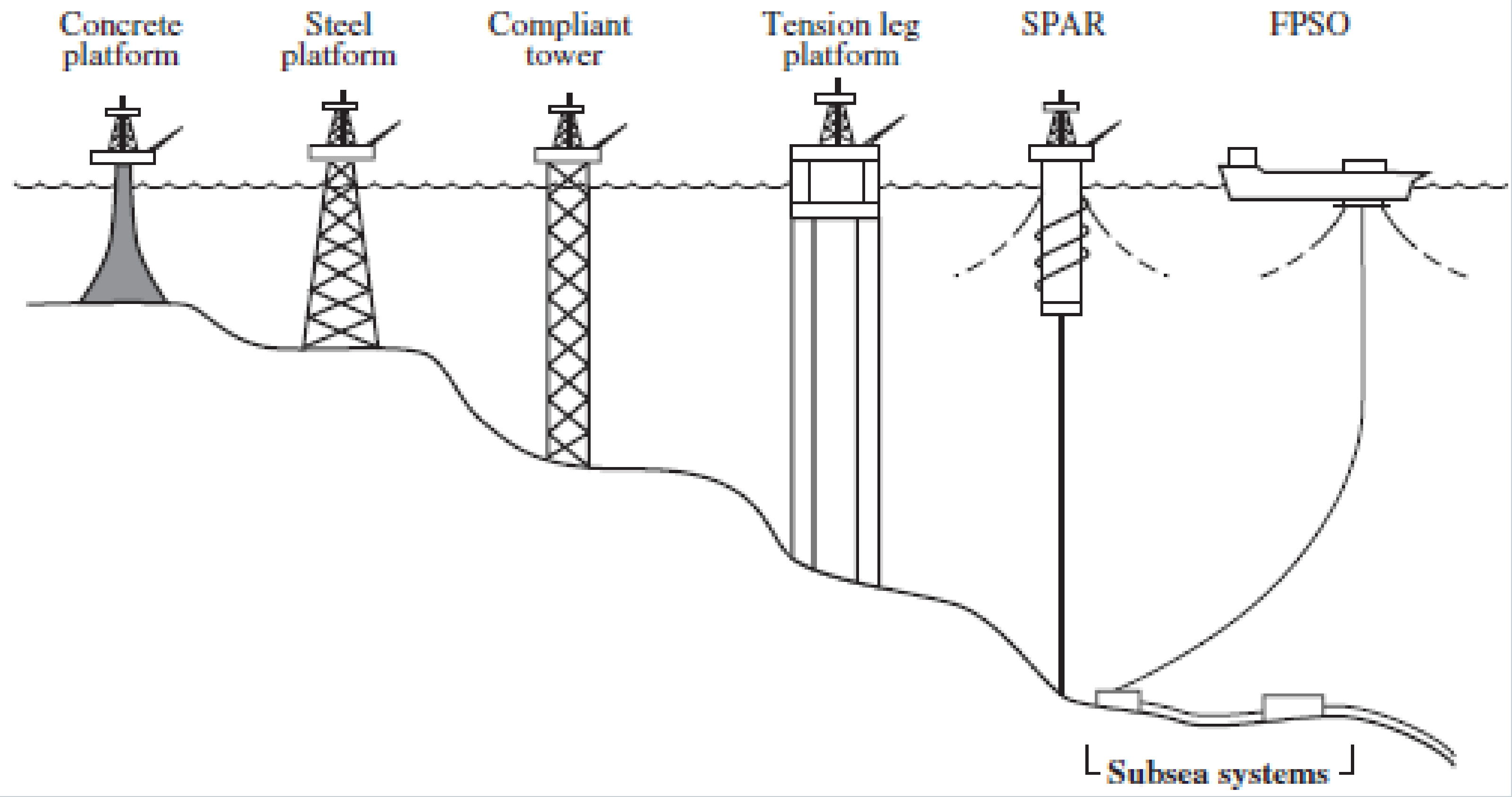


Offshore O&G seascape

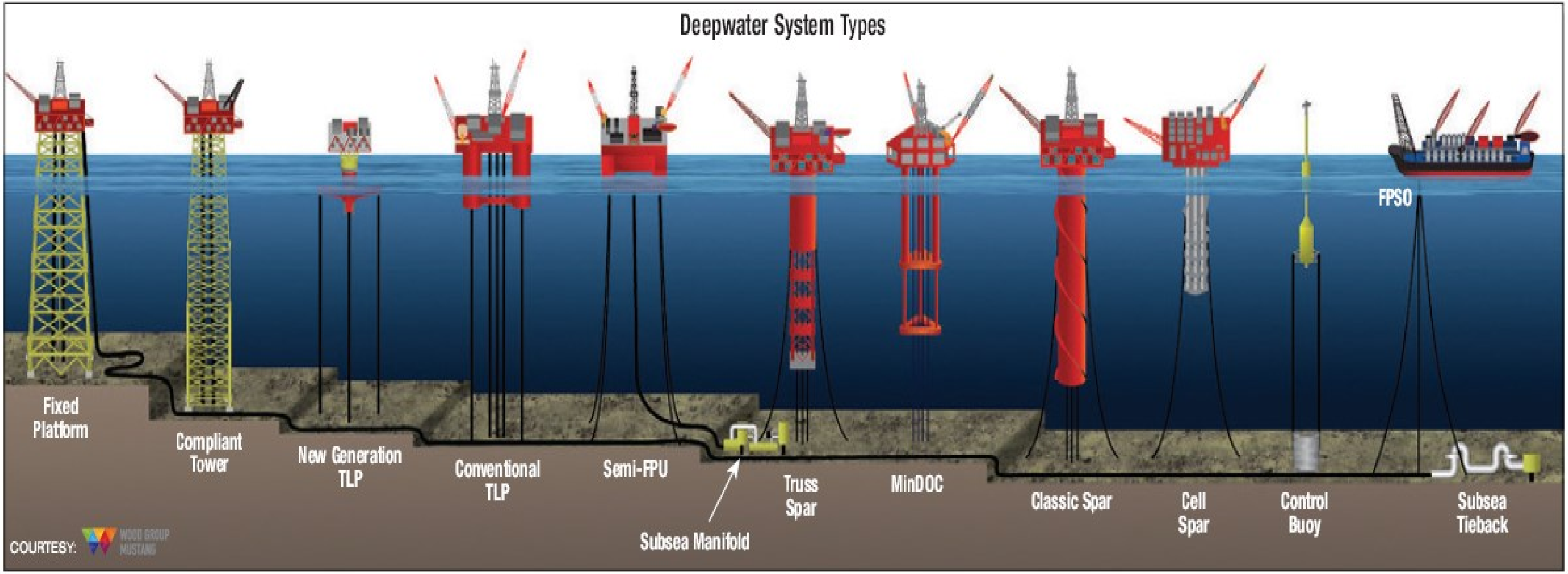
- Offshore O&G exploration covers ~7,100 fields in >120 countries
- Offshore platform (fixed, gravity & floating) count: 14,500
- Subsea components amount to ~8,200
- About 30,000 offshore pipelines siphon O&G to shore

Offshore fields development options

- Fixed foundations, moored & tethered & subsea installation

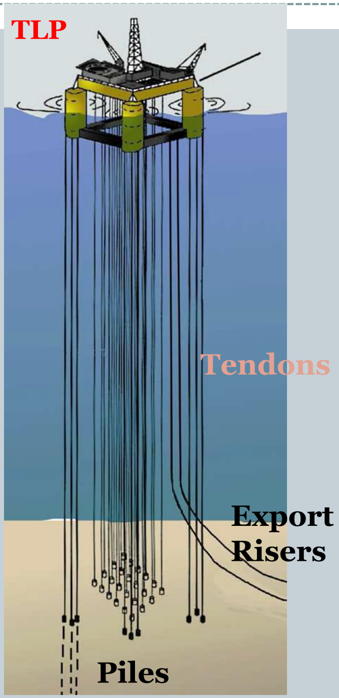


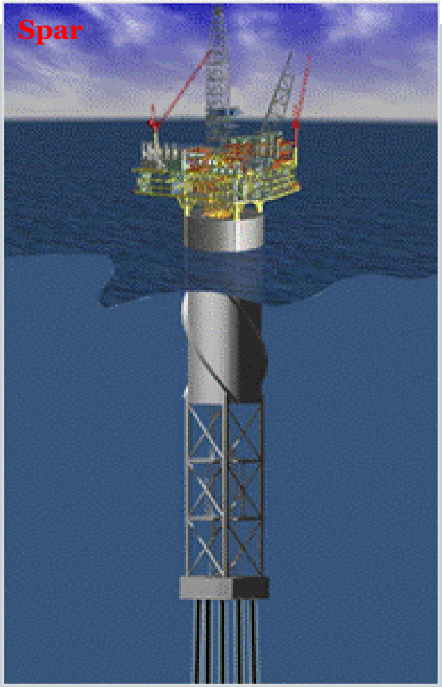
Offshore O&G systems

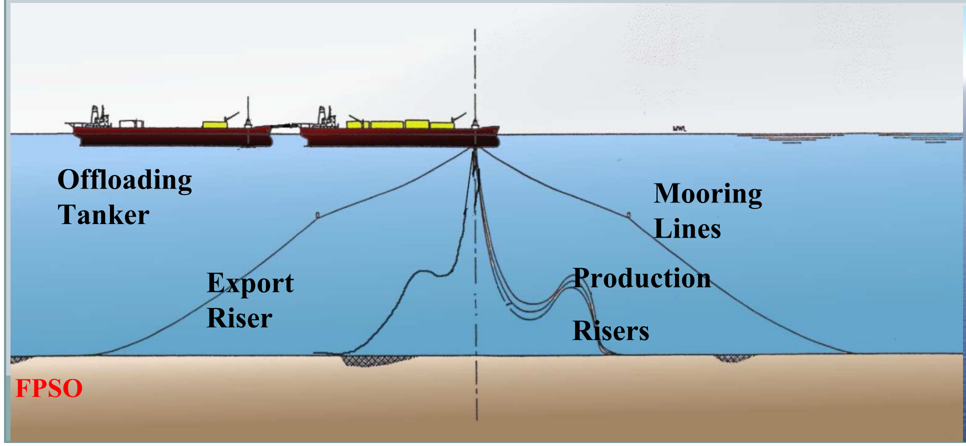


Floatings Systems Overview

Courtesy: Shell

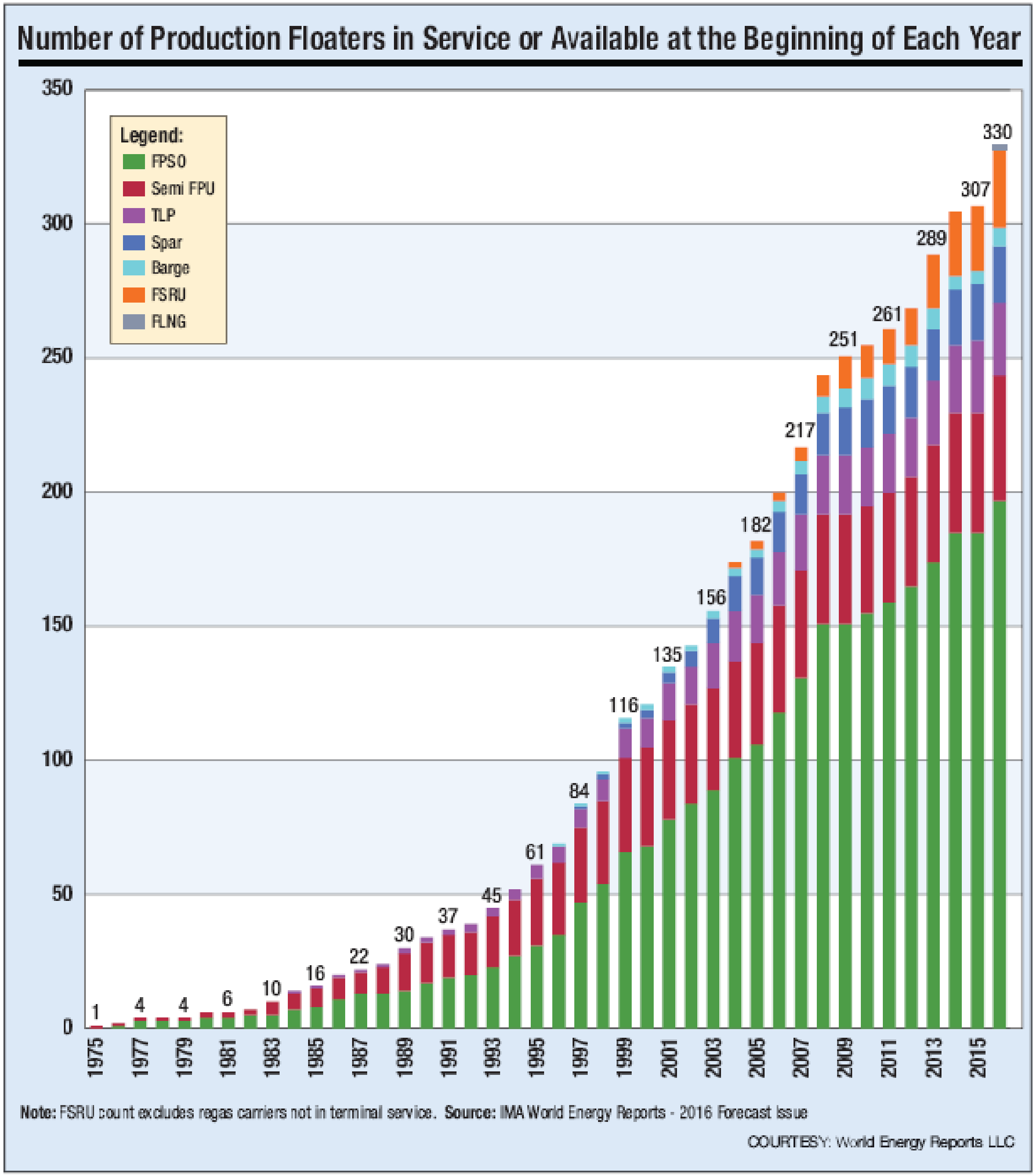




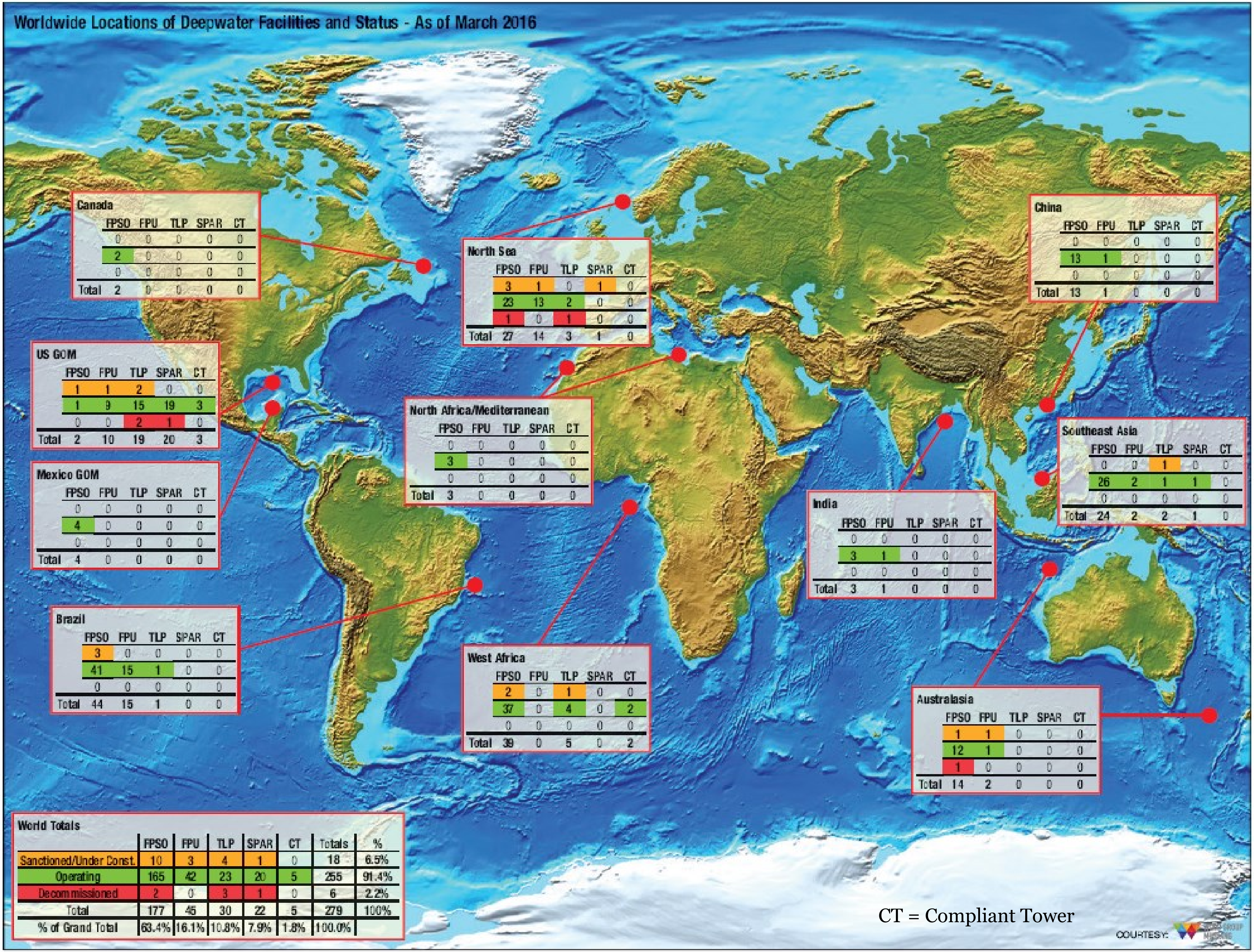


Production systems

- FPSOs account for most of *floating* offshore oil production systems



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

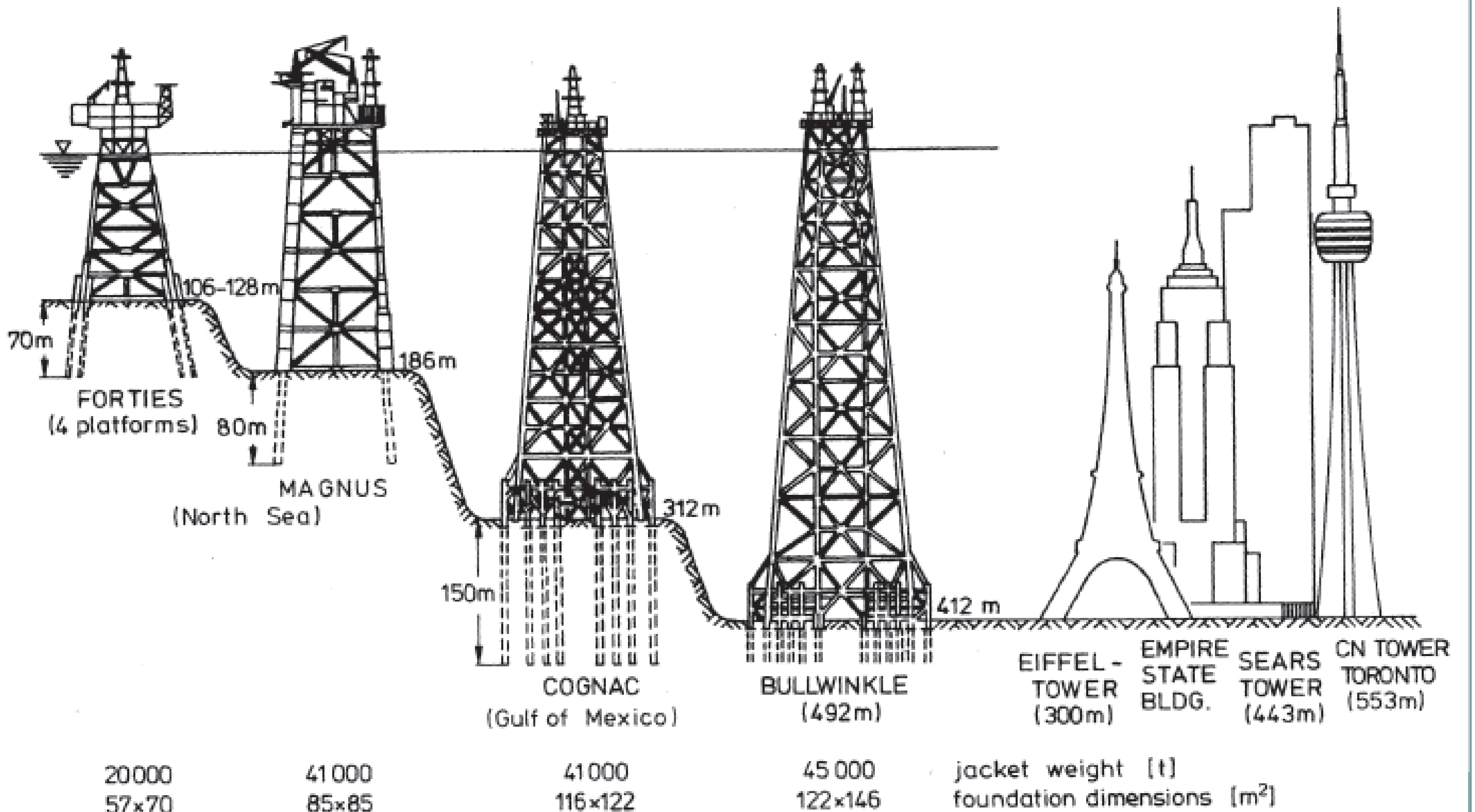
World Totals

	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

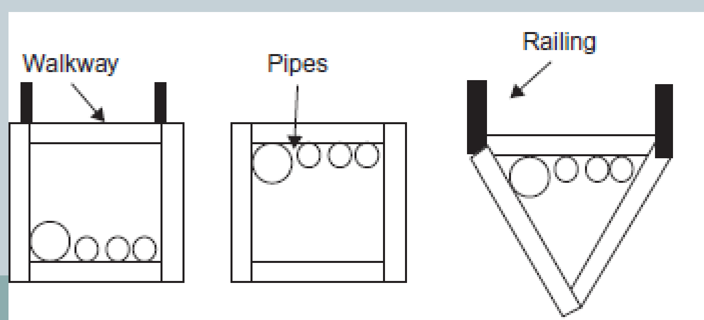
COURTESY:

Fixed platforms



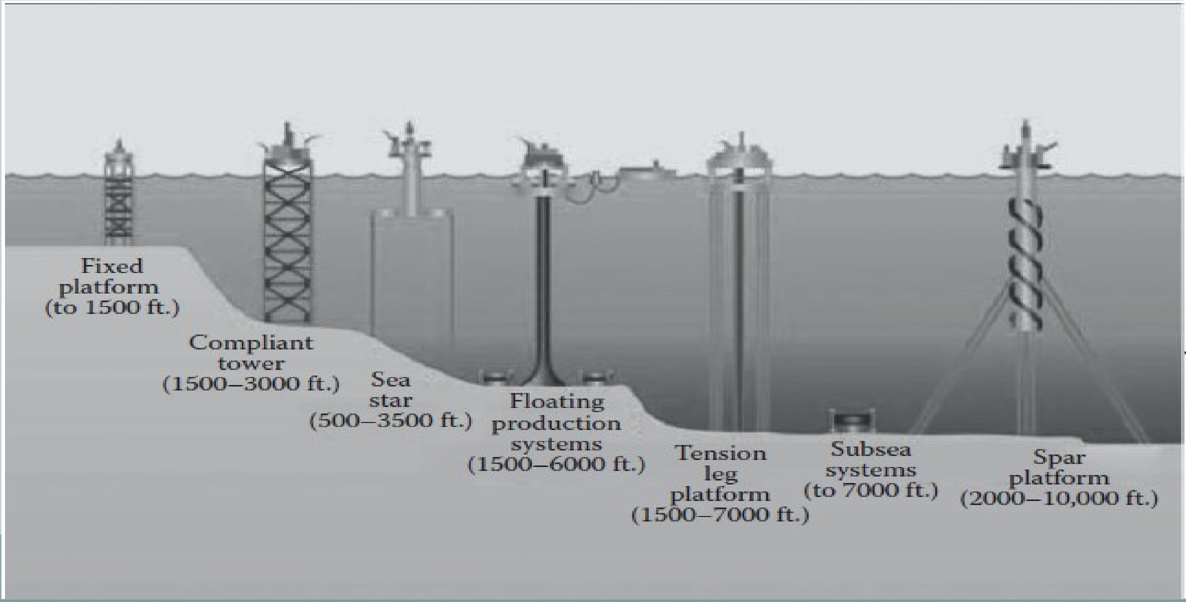
Types of fixed offshore platforms

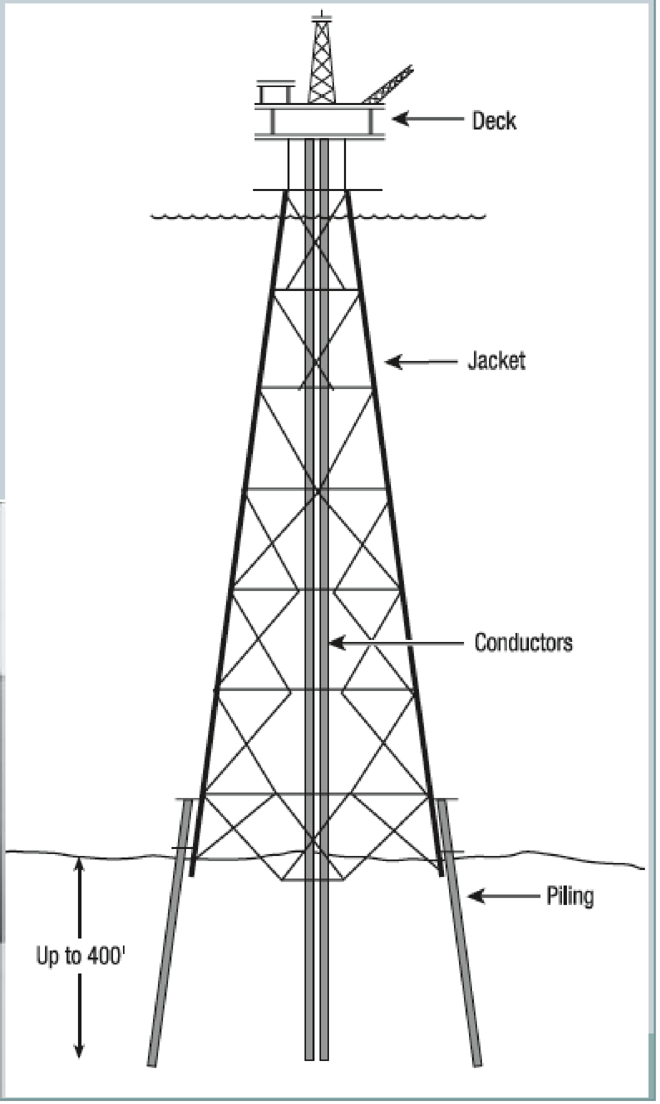
- Drilling/well-protector platforms
- Self-contained platforms (template and tower)
- Production platforms (control rooms, compressors, storage tanks, treating, …)
- Auxiliary platforms (pumping/compressor stations, oil storage, quarters platforms or production platforms,
- Quarters platforms
- Flare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



Jacket platforms

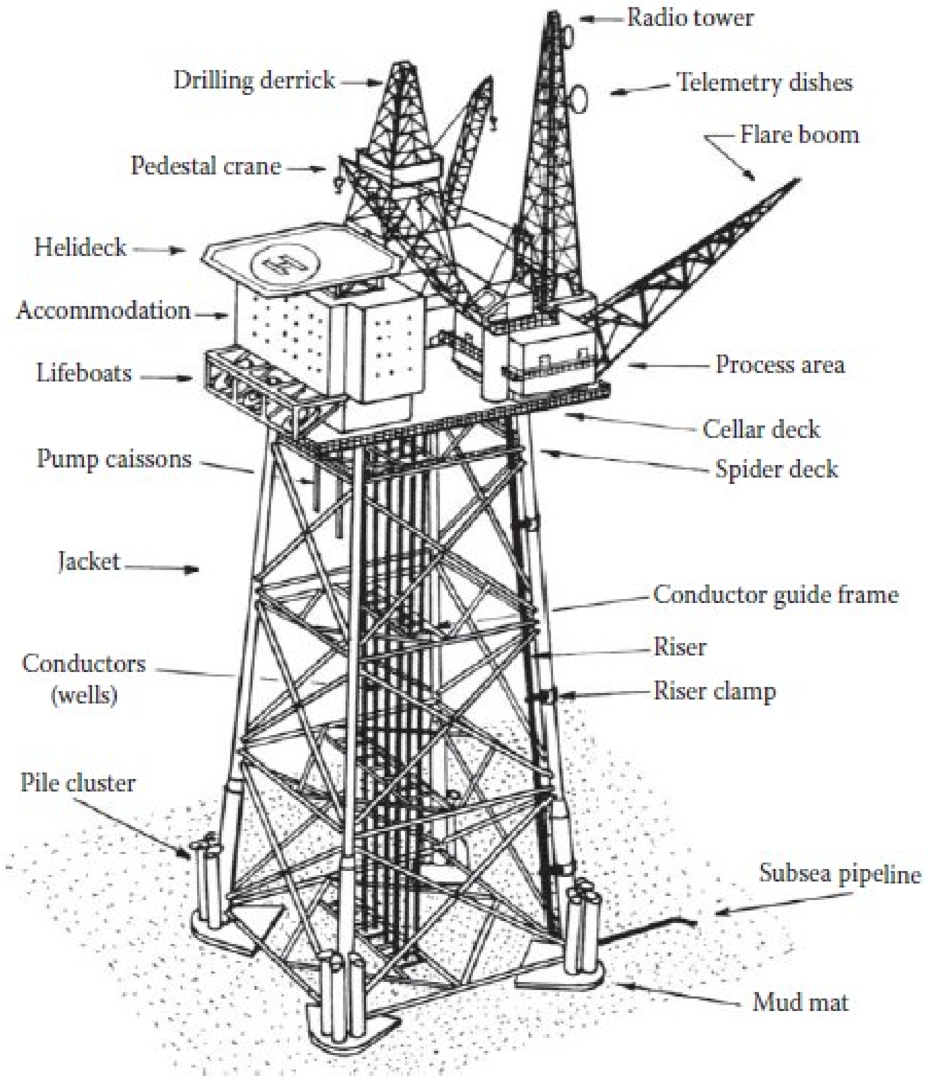
- *Pilings*: steel tubular members secure platform to seabed
- Cylindrical members:
  - Pose less resistance to ocean waves & currents
  - Reduce mass of steel & weight of rig
  - Lower material cost
- Waves should not wet the deck





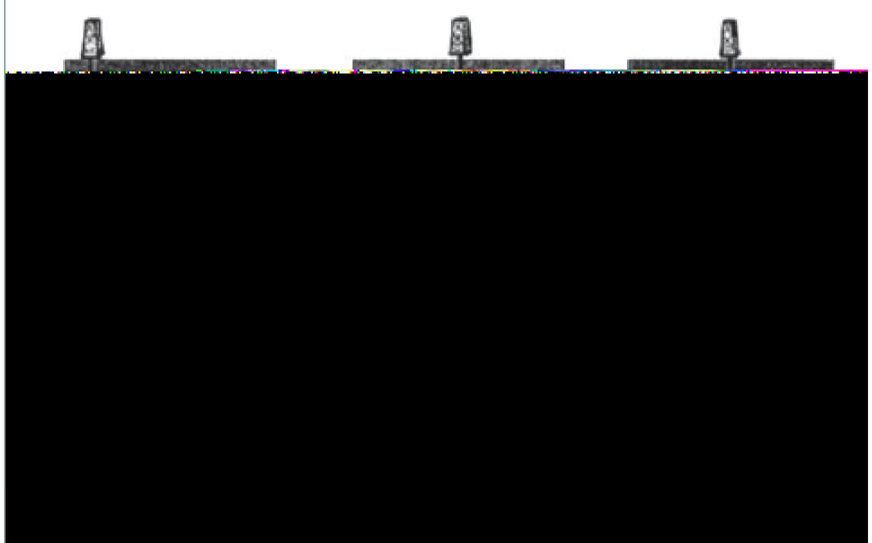
Framed offshore structure

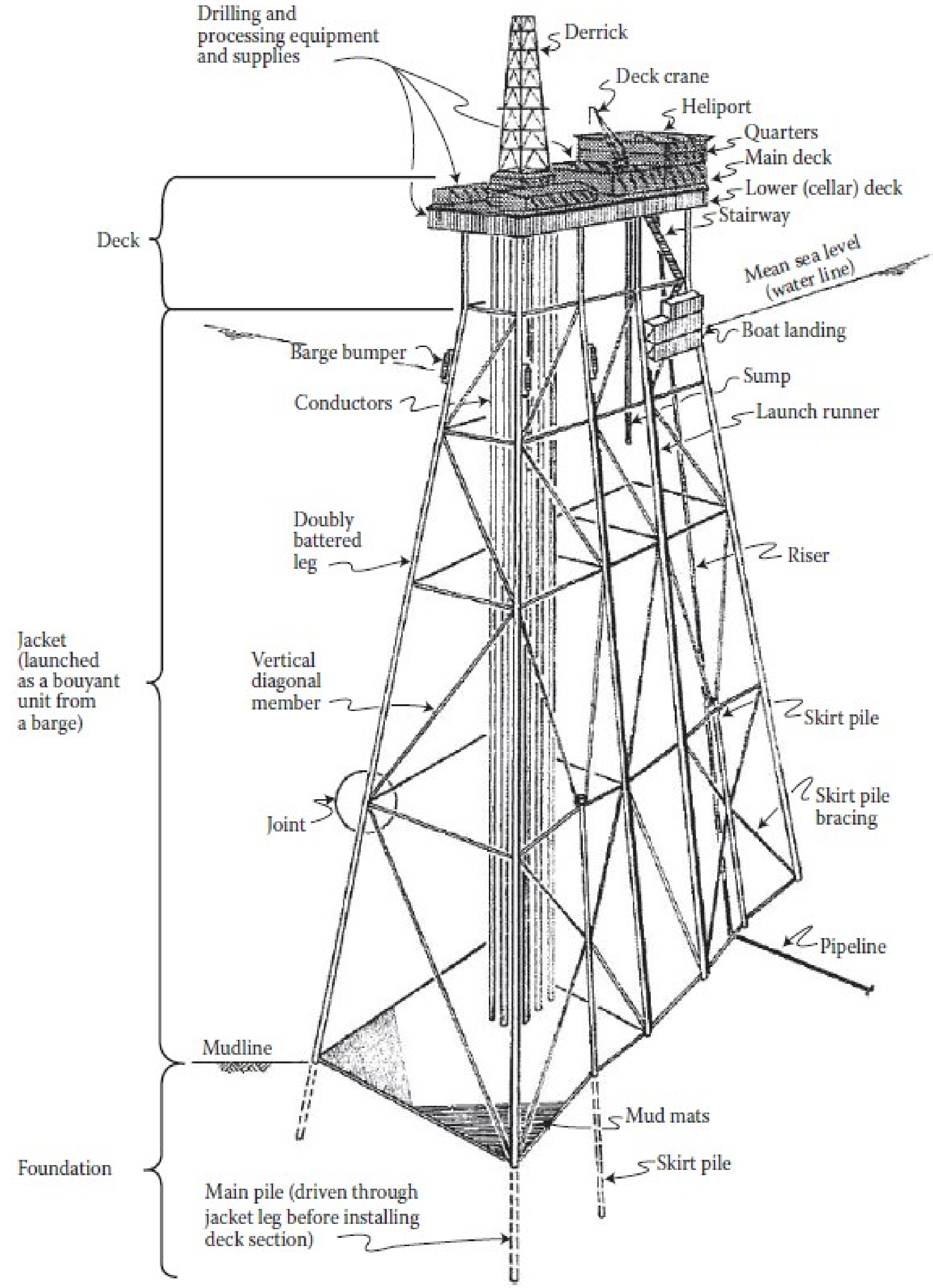
- Limited to water depth of 1,500ft
- Bullwinkle base: 400×480ft
- Pilings: 7ft × 2" × 400ft deep
- 300ft of water: 3000t of steel + 1000t pilings, legs: 54"
- 1,500ft of water: 50,000t of steel + 15,000t pilings, legs, *d*: 90", pilings, *d*: 75"



- Deck
- Jacket
- Foundation

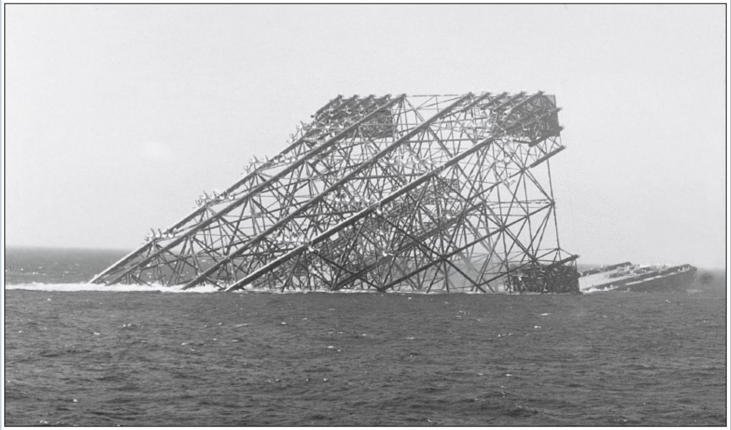
Deviated wells spudded from offshore platforms



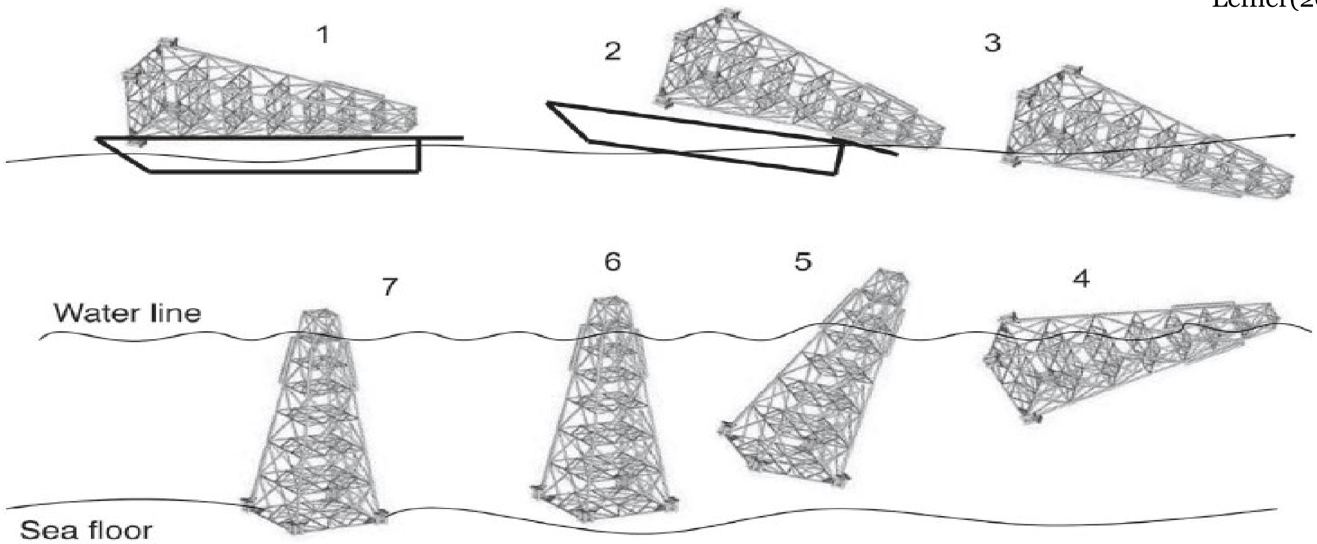


Installing a jacket platform

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

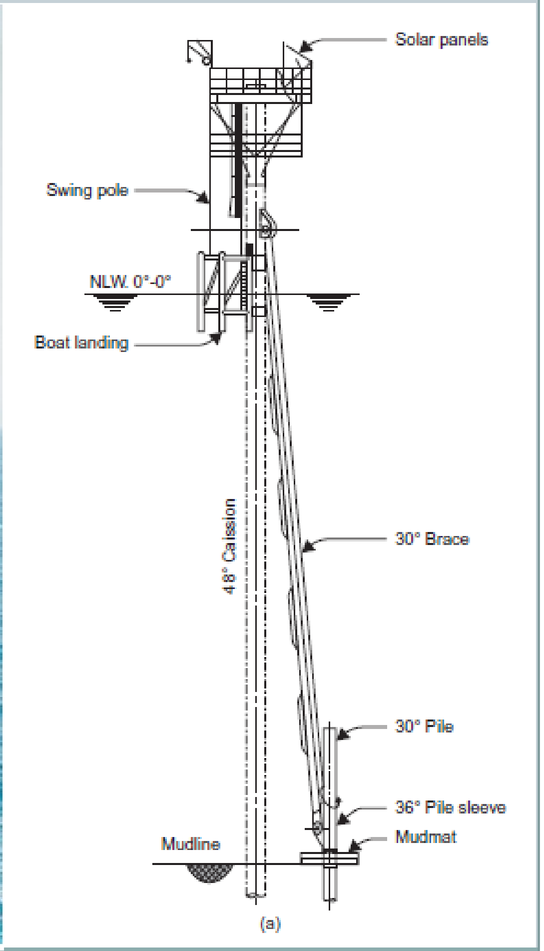


Leffler(2011)



Mono/tri-pods

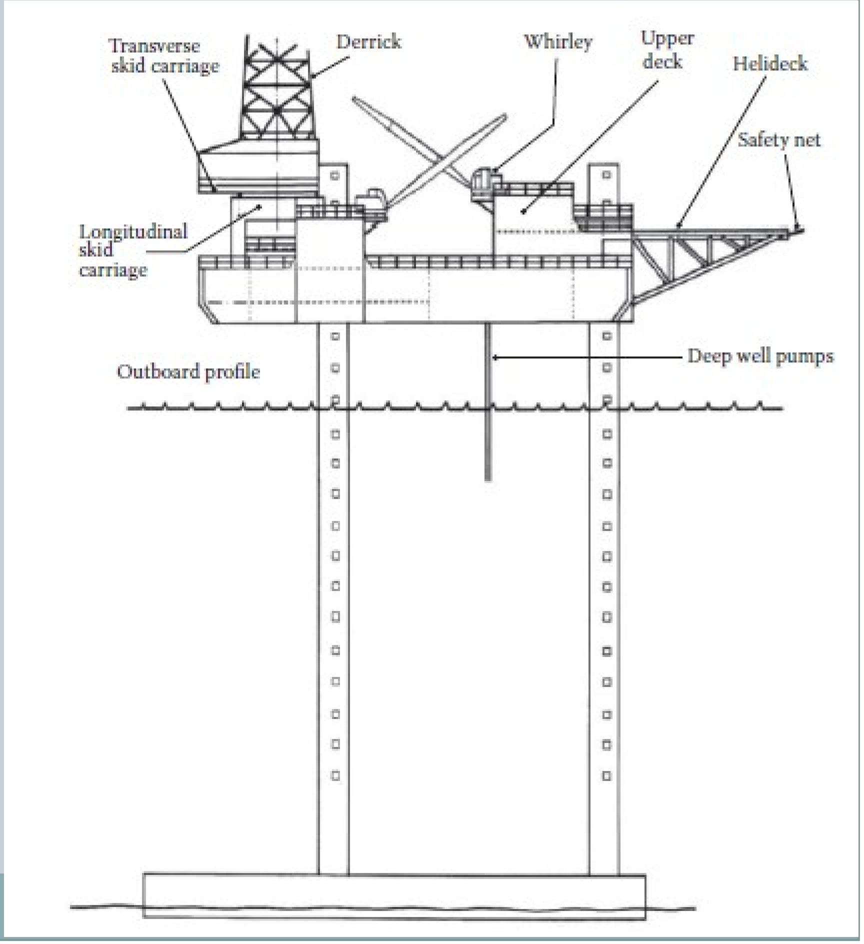
- Used for single wells
- Low cost solution
- Uses a conductor
- Alternative to wet tree



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

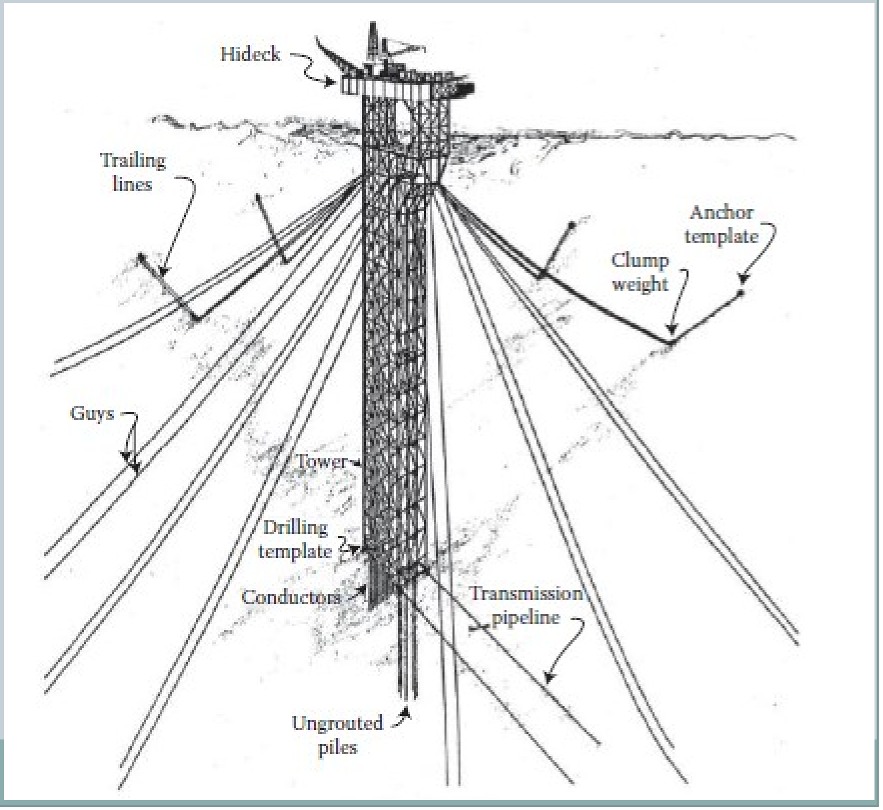


Jack-ups

- Legs can enter seabed
- Working depth: 150m-190m
- Generally not self-propelled
- No. of jack-ups: 540 (2013)
- Leg no vary: 3, 4, 6, 8
- Legs powered by hydraulics or motors
- Merits:
  - Good stability due to fixed legs
  - Relatively economical
  - Suitable for different seafloor soils
- Drawbacks:
  - Hard to tow; sensitive to waves
  - Working depth: 0-100m
  - Large legs pose vibration issues

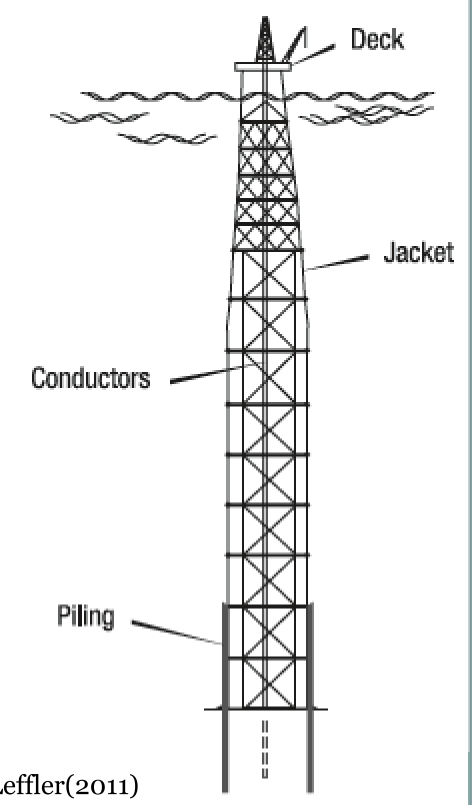
Guyed towers

- 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



Compliant towers

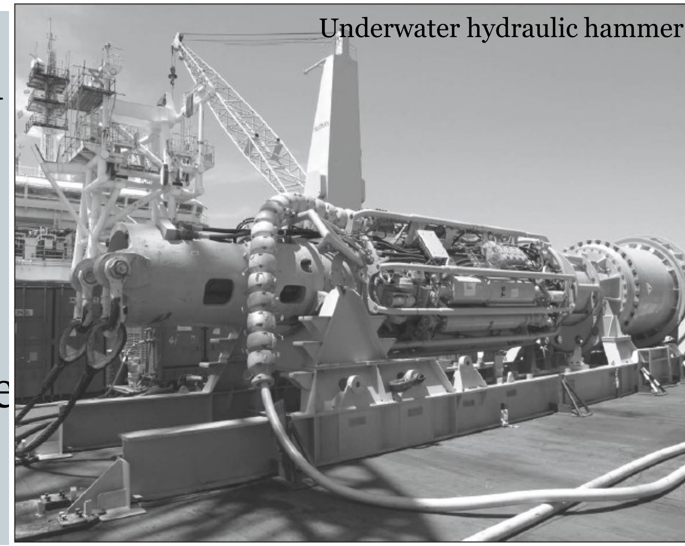
- Water depth range: 1,000-3,000ft
- Behaves like reed; waves pass thru before structure respond
- Slender base (140ft × 100ft)
- Sway in currents & waves: 10-15ft
- Require less steel than jacket rigs
- Considerable mass & buoyancy at upper zone
- 1,700ft: 30,000t of steel; 7,000t pilings



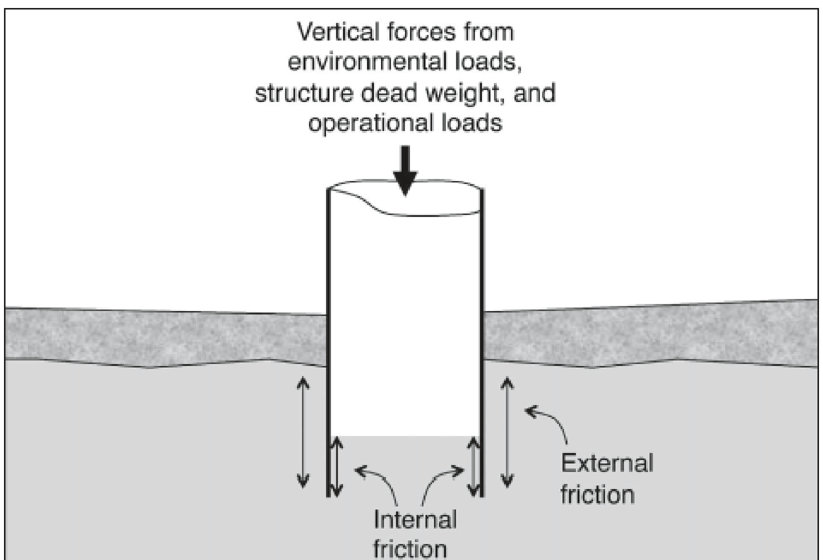
Leffler(2011)

Pilings

- Steel pilings secure fixed structure to seabed
- Depth of pilings extend up to 400ft (130m)
- Pilings driven only during favourable weathe



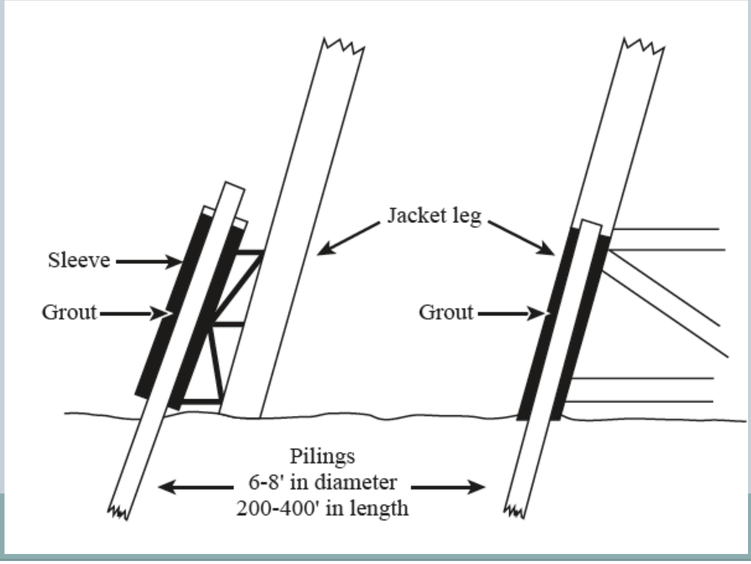
Underwater hydraulic hammer

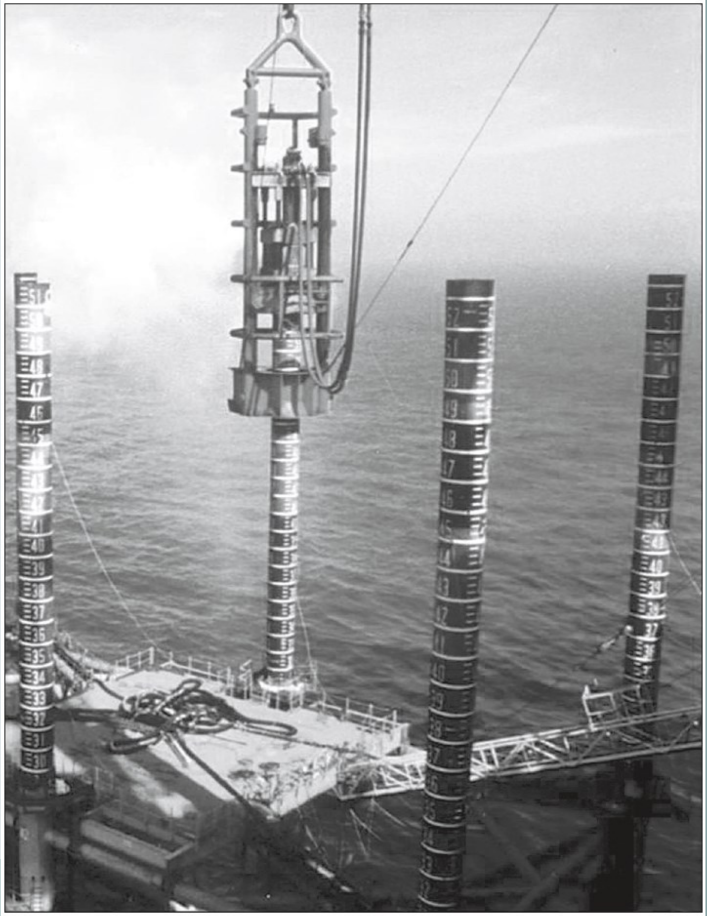


96 inch diameter (2.44m) steel piling

Pilings (2)

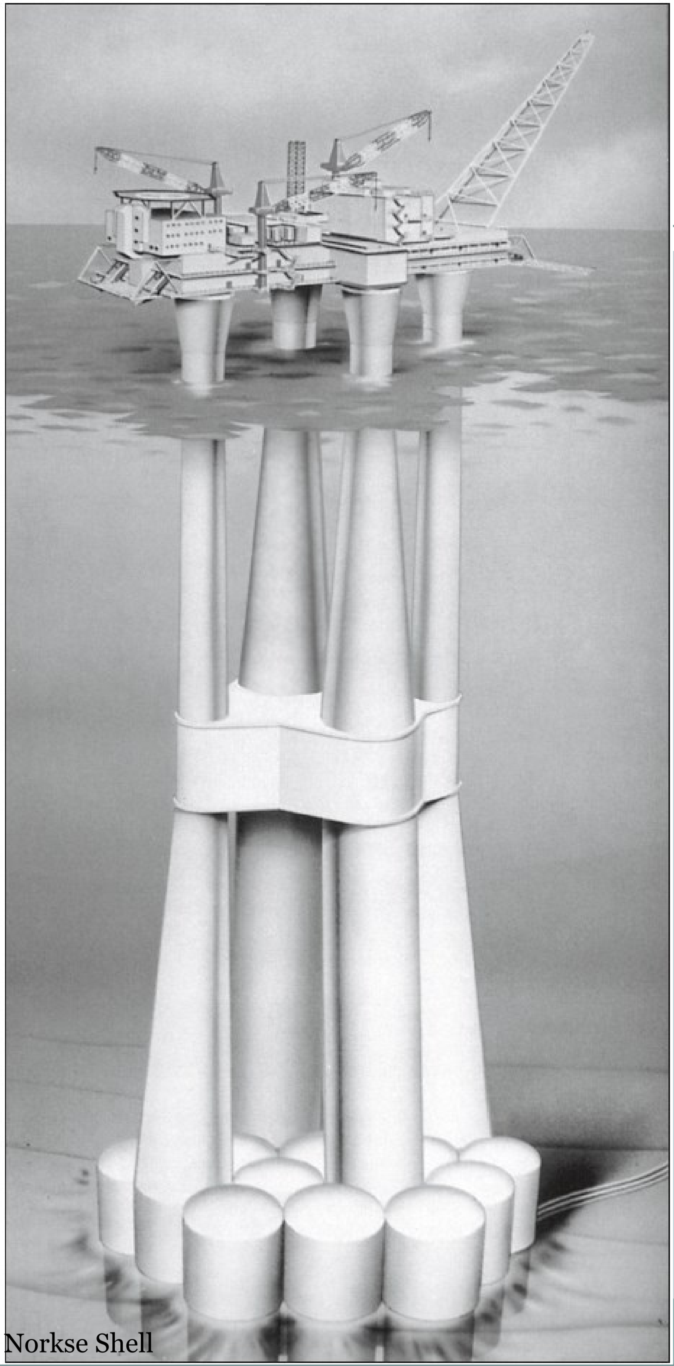
- Suction could initially be applied
- In swallow-water jacket is welded to pilings
- In deepwater grout secures jacket to pilings





Gravity based platforms

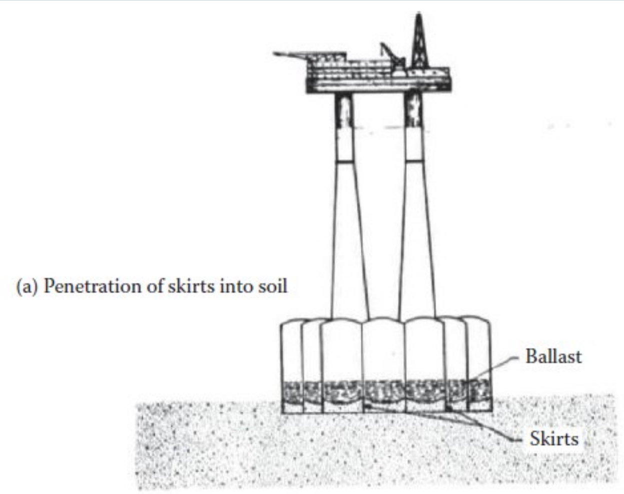
- Emerged in 1970s; made of reinforced or pre-stressed concrete
- Require hard seabed eg, clay
- Secured on site by their sheer weight
- Cumbersome to transport & position
- Require no anchoring

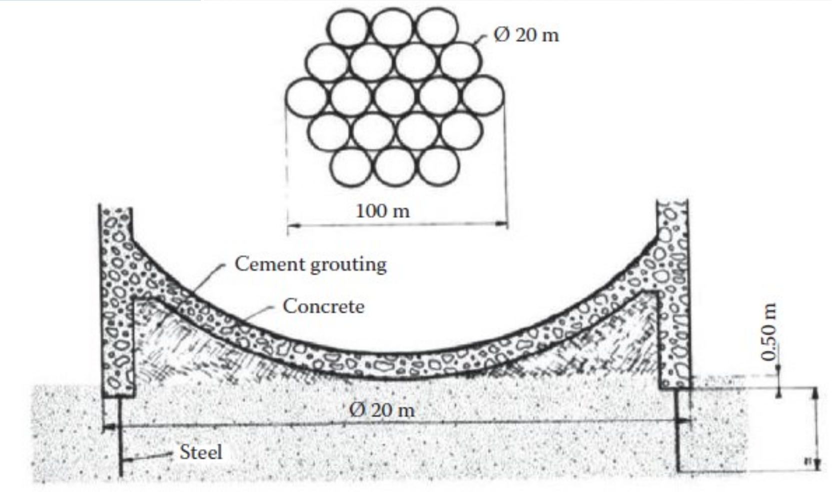


Norkse Shell

Gravity based platforms (2)

- Steel skirts secure platform to seabed
- Flowlines embedded in concrete legs



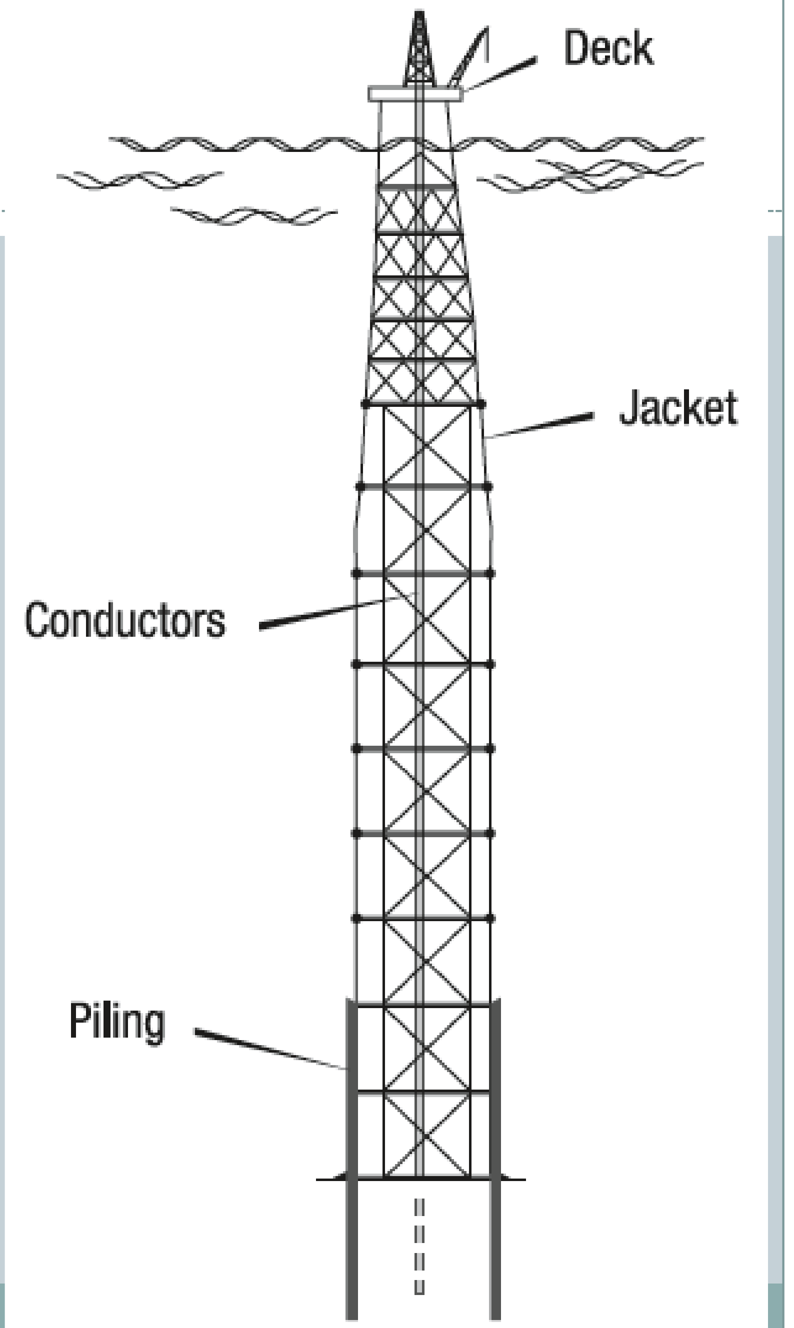


Video

- Troll; 20”

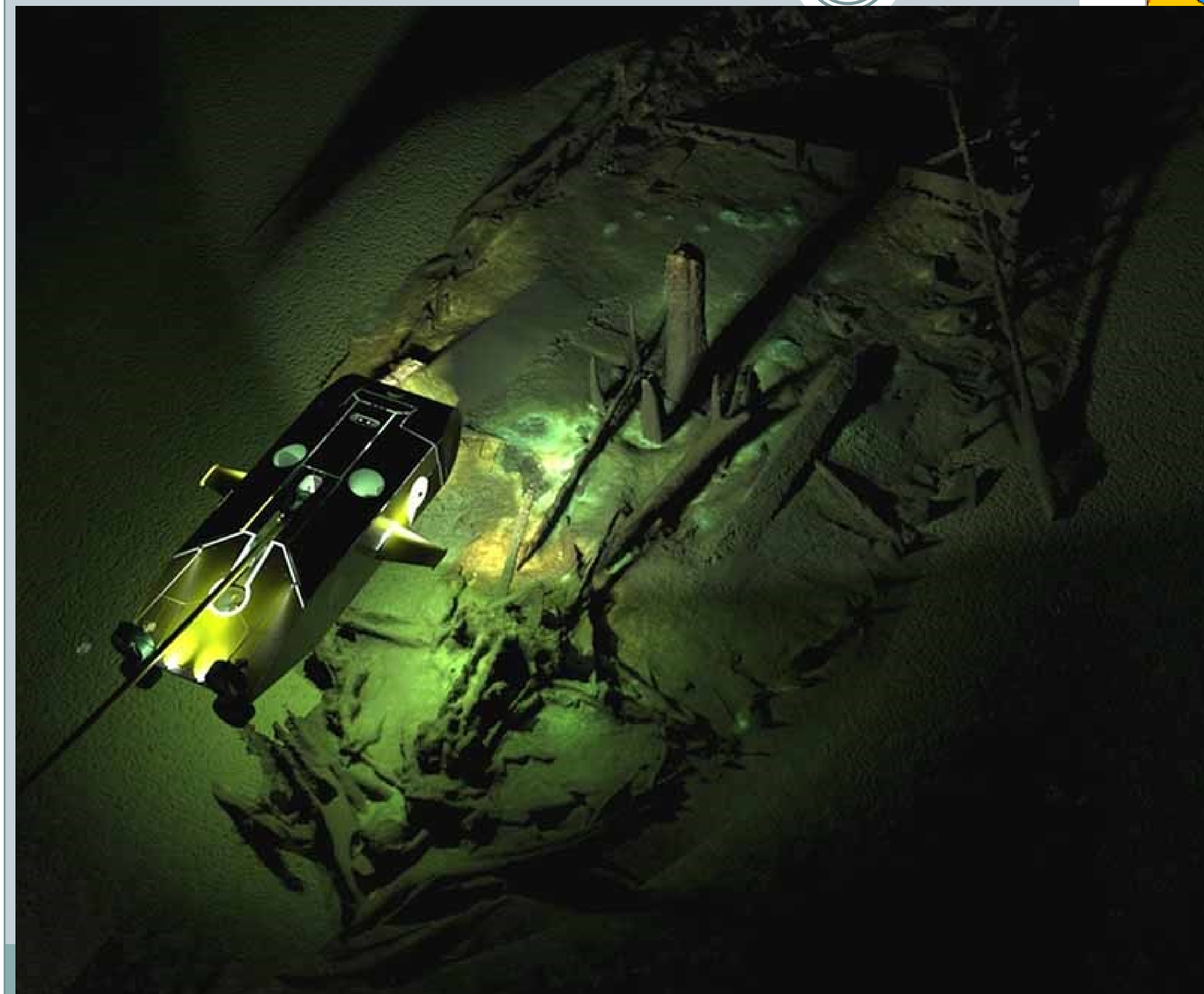
Compliant towers

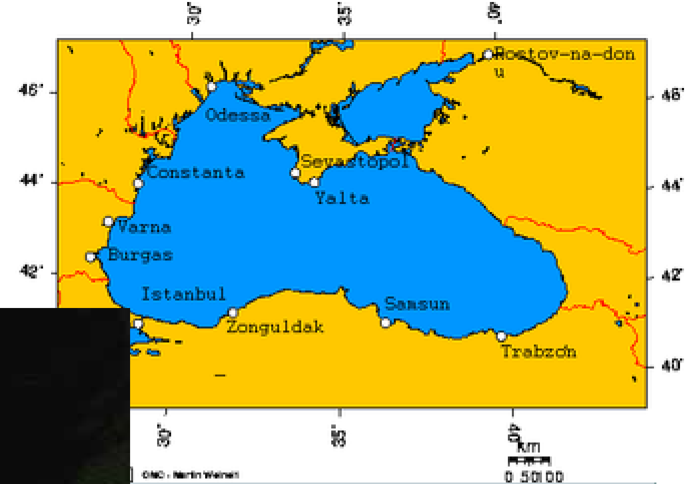
- Can sway 10-15ft off centre in extreme cases
- Since most of "mass" on upper sections, structure is "invisible" to waves
- At d>500m jacket platforms become impractical
- Why?
  - Due to stiff response of the structure



Black Sea marine expedition

Black Sea shipwrecks





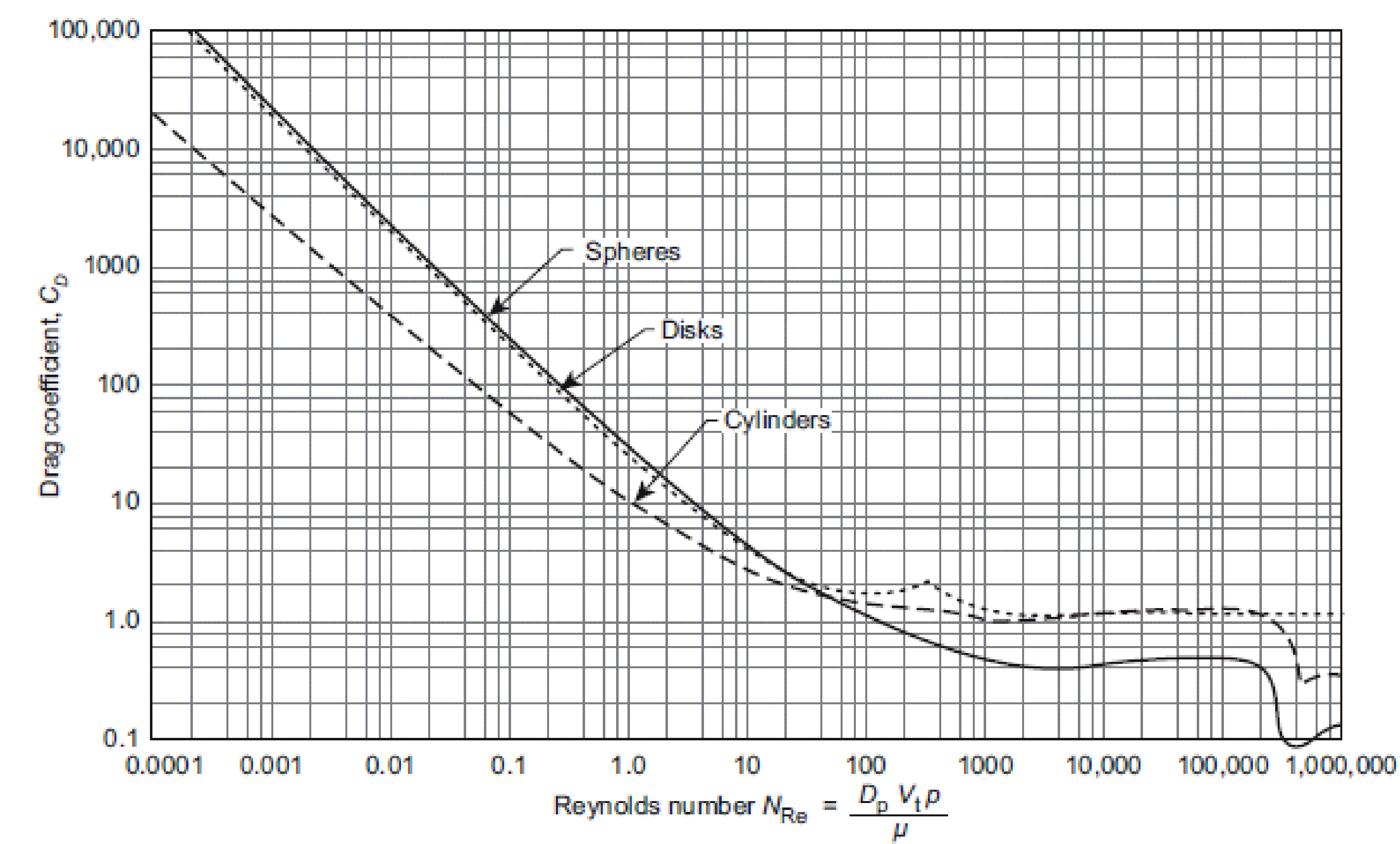
Theory

- Theory #3

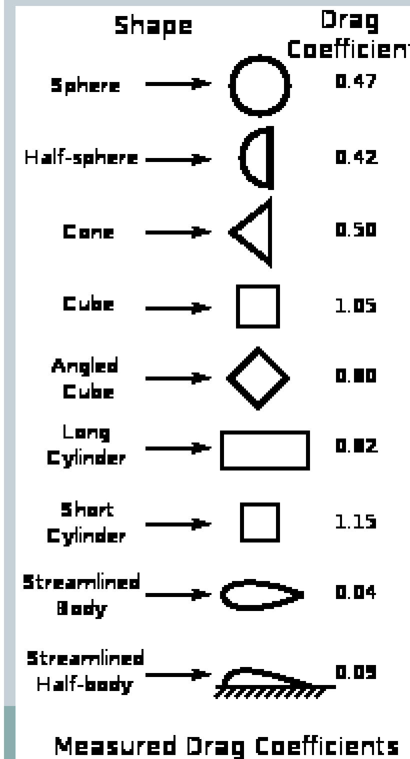
Drag coefficient

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

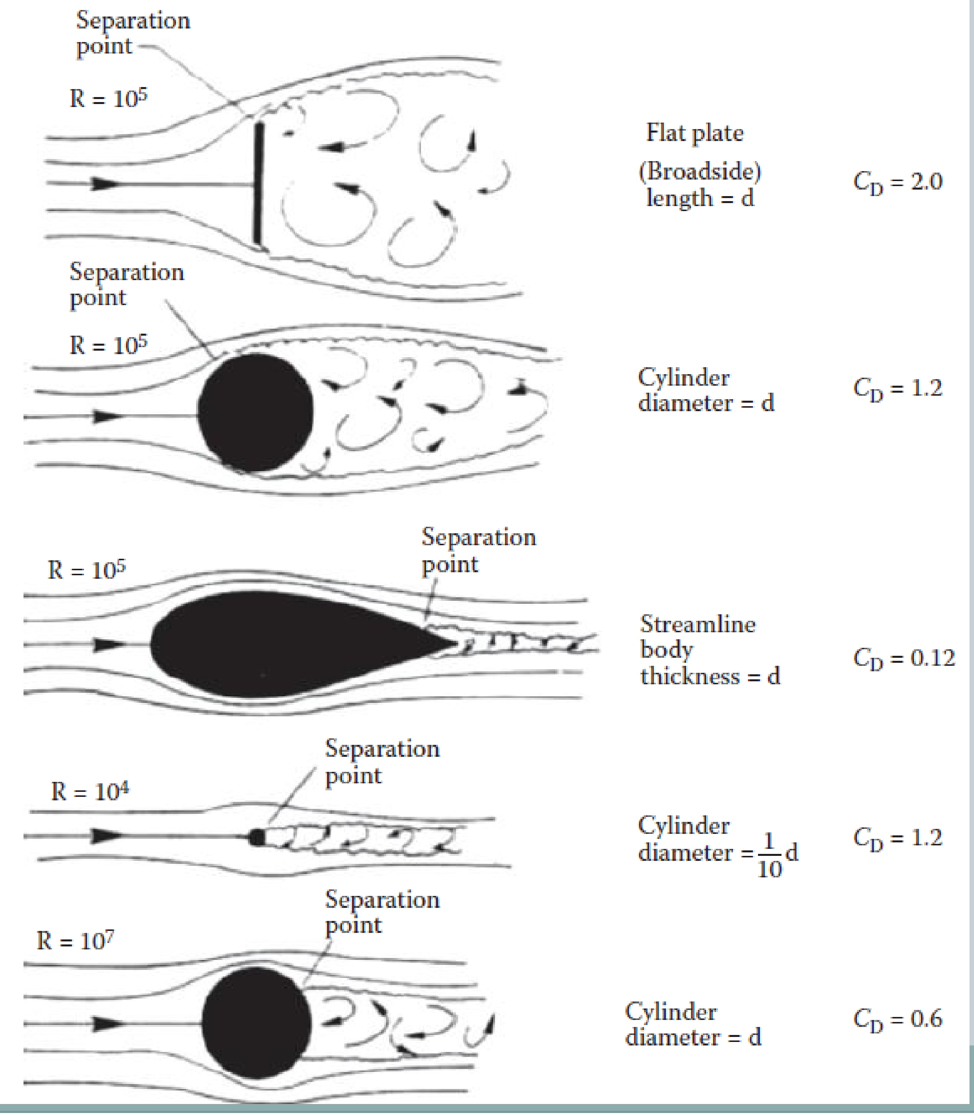
Fig. 1 C_D vs Re#



C_D for Re=10^4



C_D of various shapes @ various Re#

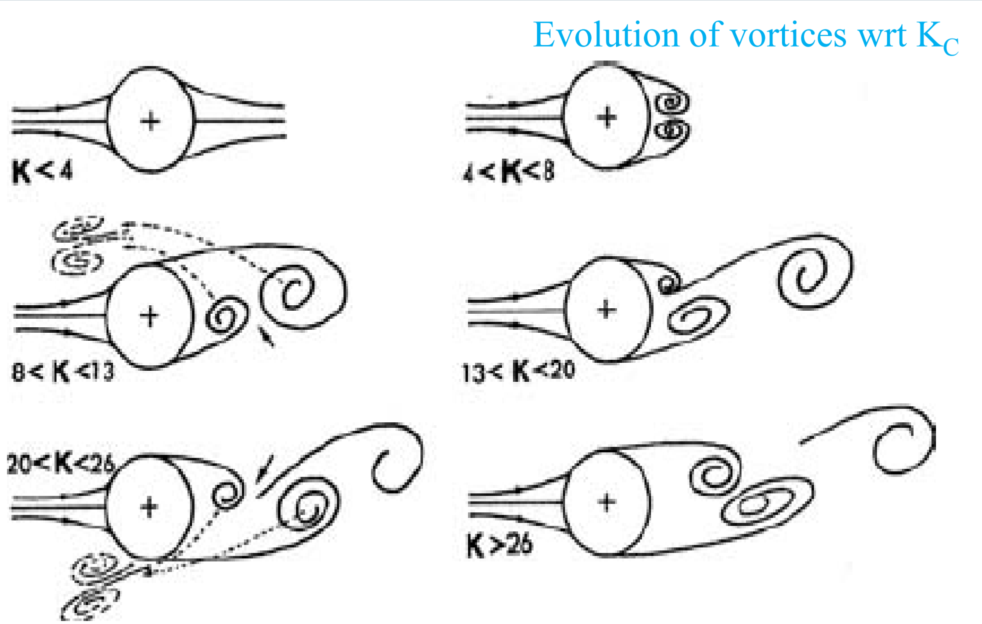


Keulegan–Carpenter number

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

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

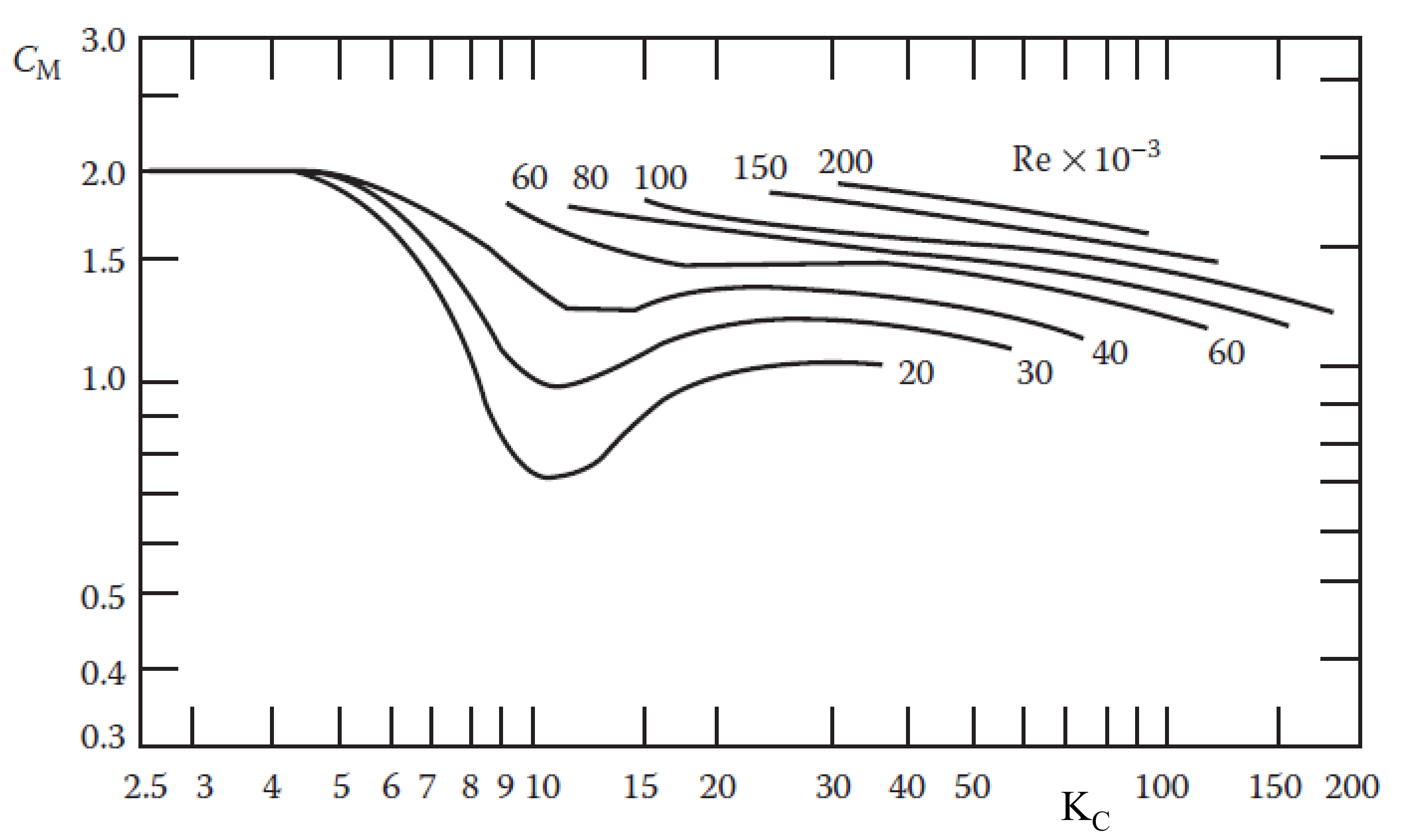
- Low K_C: inertia dominates; high K_C turbulence dominates



C_M vs K_C# & Re#

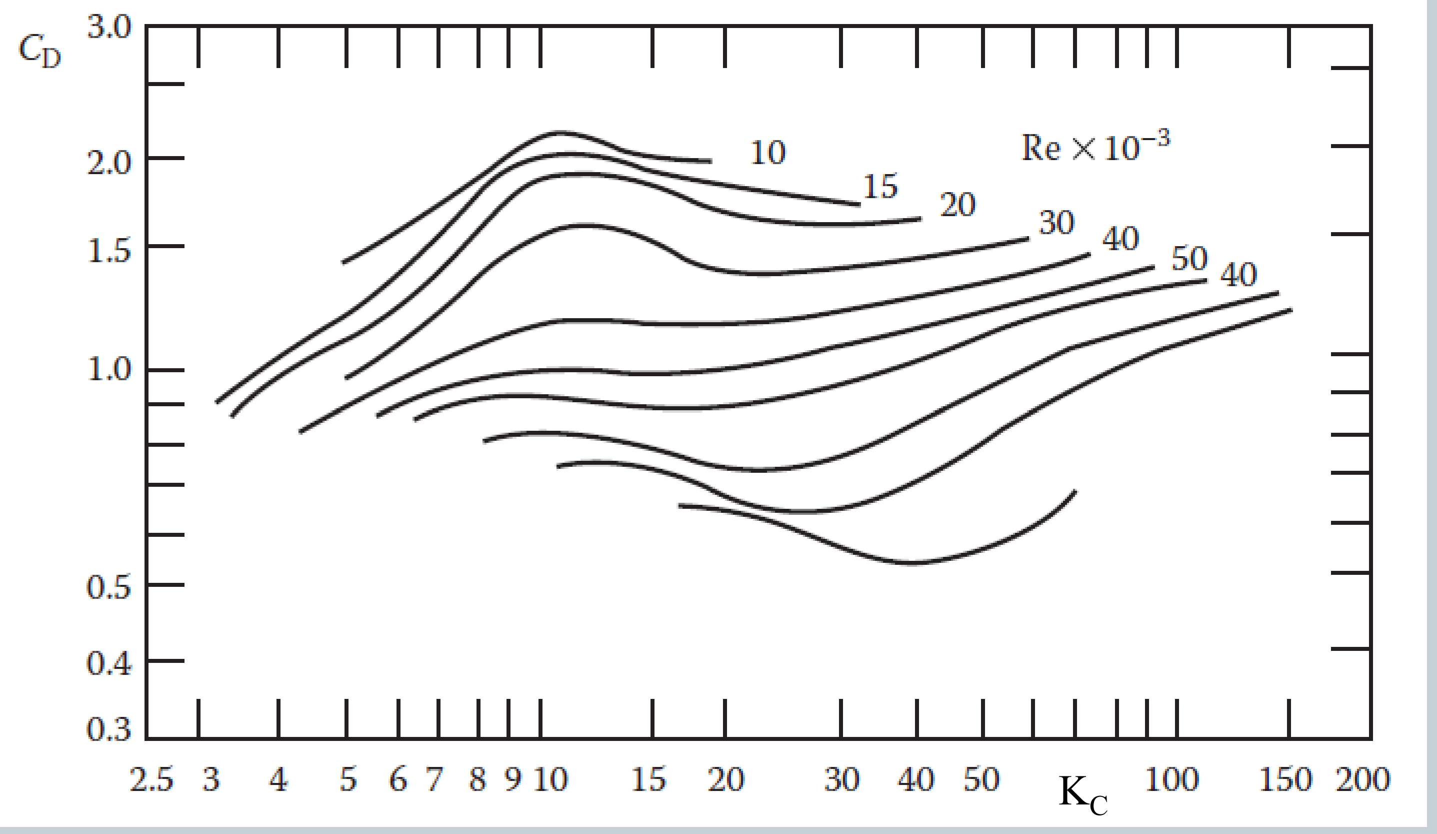
- Inertia effects dominate if K_c<10.0
- Inertia & drag forces significant if 10.0<K_C<20.0
- Drag forces dominate of K_C>20.0

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:

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

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

Fig. 4 Values of ξ vs H/λ

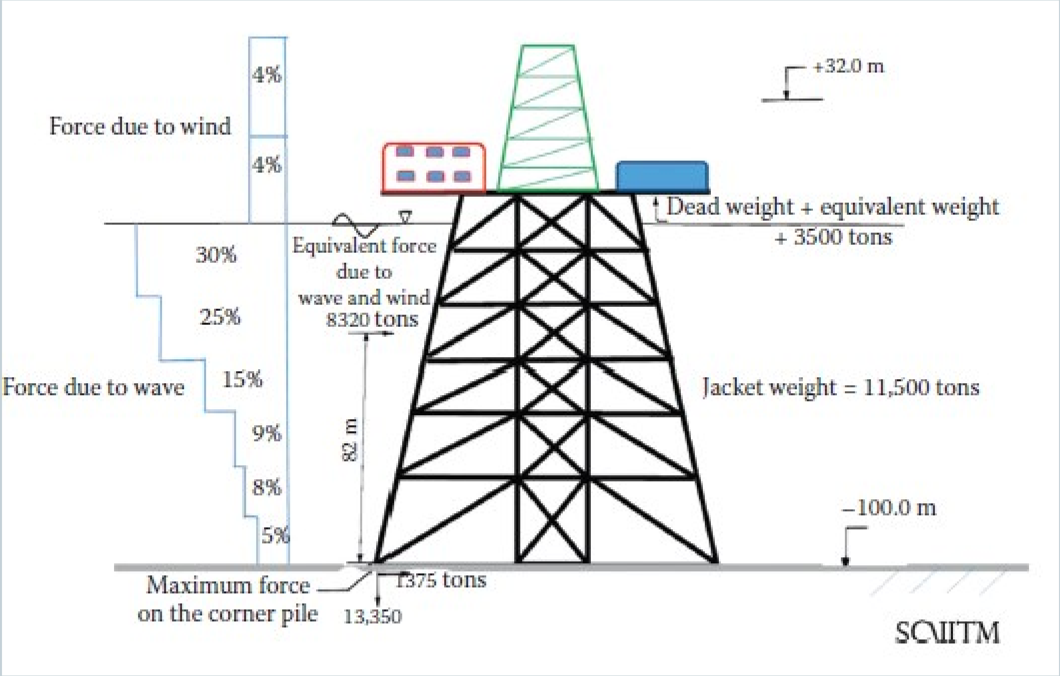
	H/λ = 0.03		H/λ = 0.07	
d/λ	$(2k)(d + H/2)$	ξ (H/D)	$(2k)(d + H/2)$	ξ (H/D)
0.03	0.565	0.847	0.817	0.866
0.07	1.068	0.367	1.320	0.378
0.15	2.074	0.178	2.325	0.187
0.30	3.958	0.105	4.210	0.115
0.50	6.472	0.090	6.723	0.101
1.00	12.755	0.0875	13.066	0.102
∞	∞	0.0875	∞	0.098

Exercise

- Example#8
- Example#9

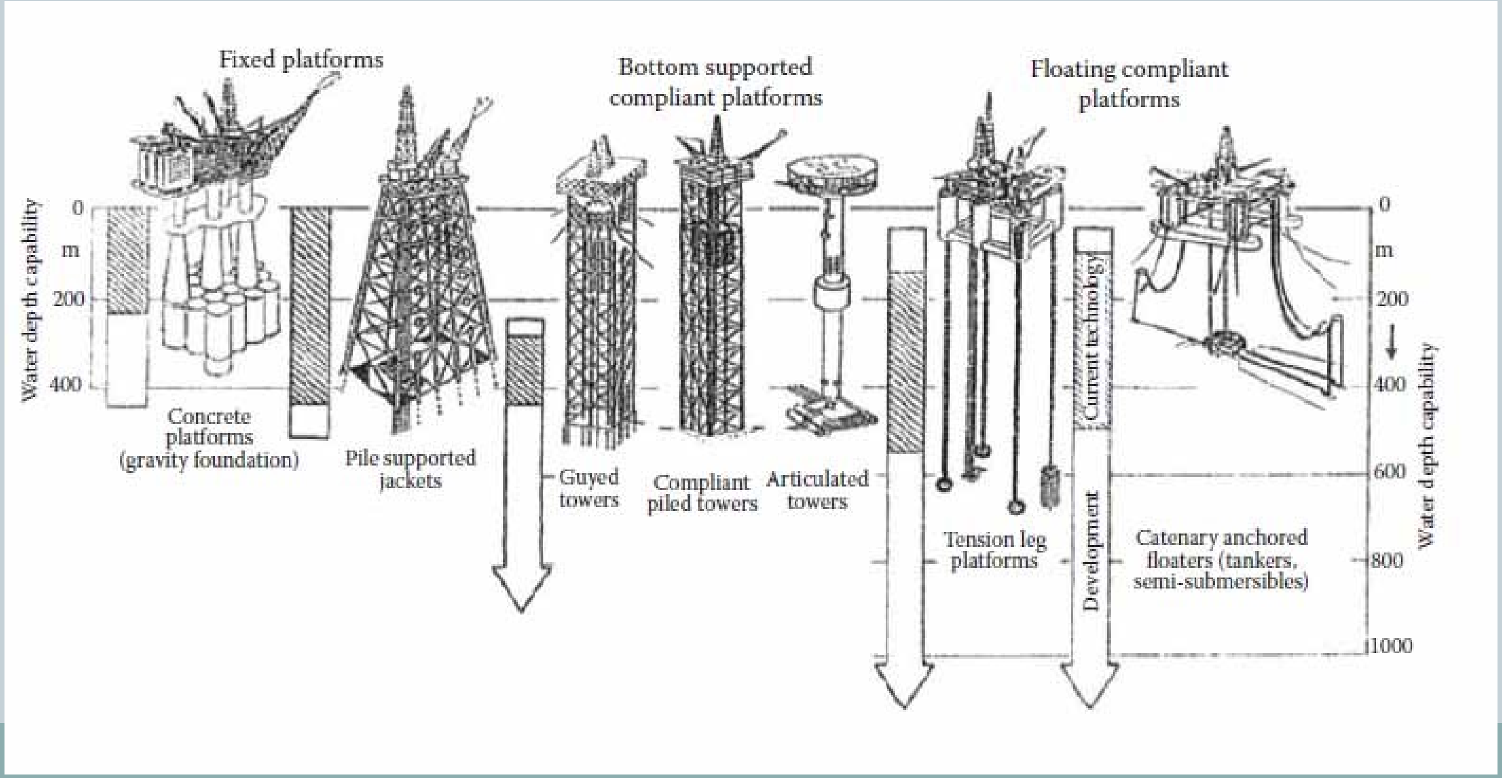
Waves & wind loads

- Wave induced forces outweigh wind related forces



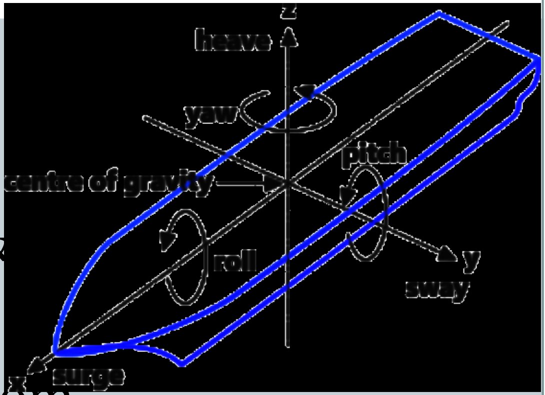
Floating production systems (FPS)

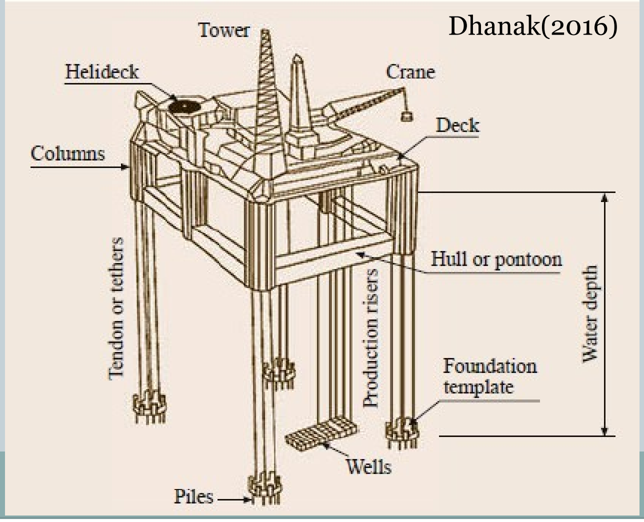
- FPSs (eg floating vessels) present economic & technically viable option
- System can be recycled; lower risk of risky assets
- Quick disconnect during contingencies eg, hurricane, earthquake, …

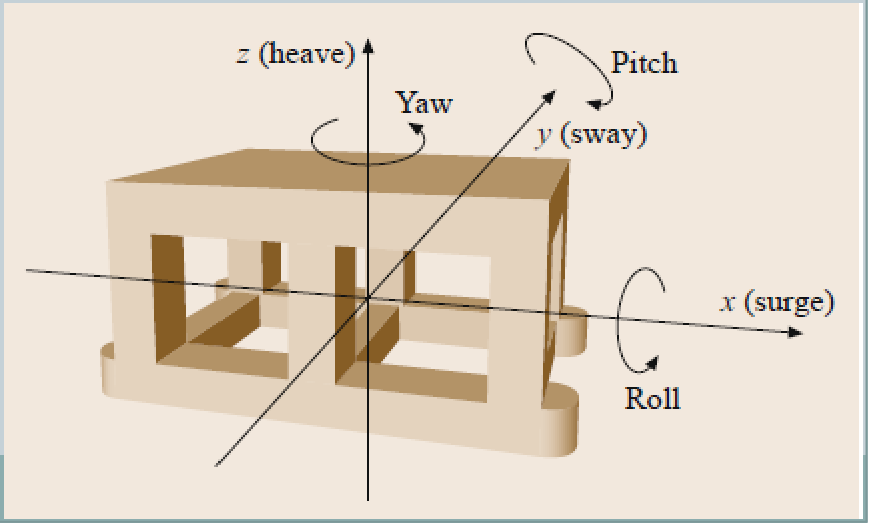


Tension leg platforms (TLPs)

- Vertical tendons hold the platform in place
- Tension in tubular tethers minimizes heave, pitch &
- Tendons permit sway, surge & yaw degrees of freedom
- TLPs water depth limit up to 1,500m

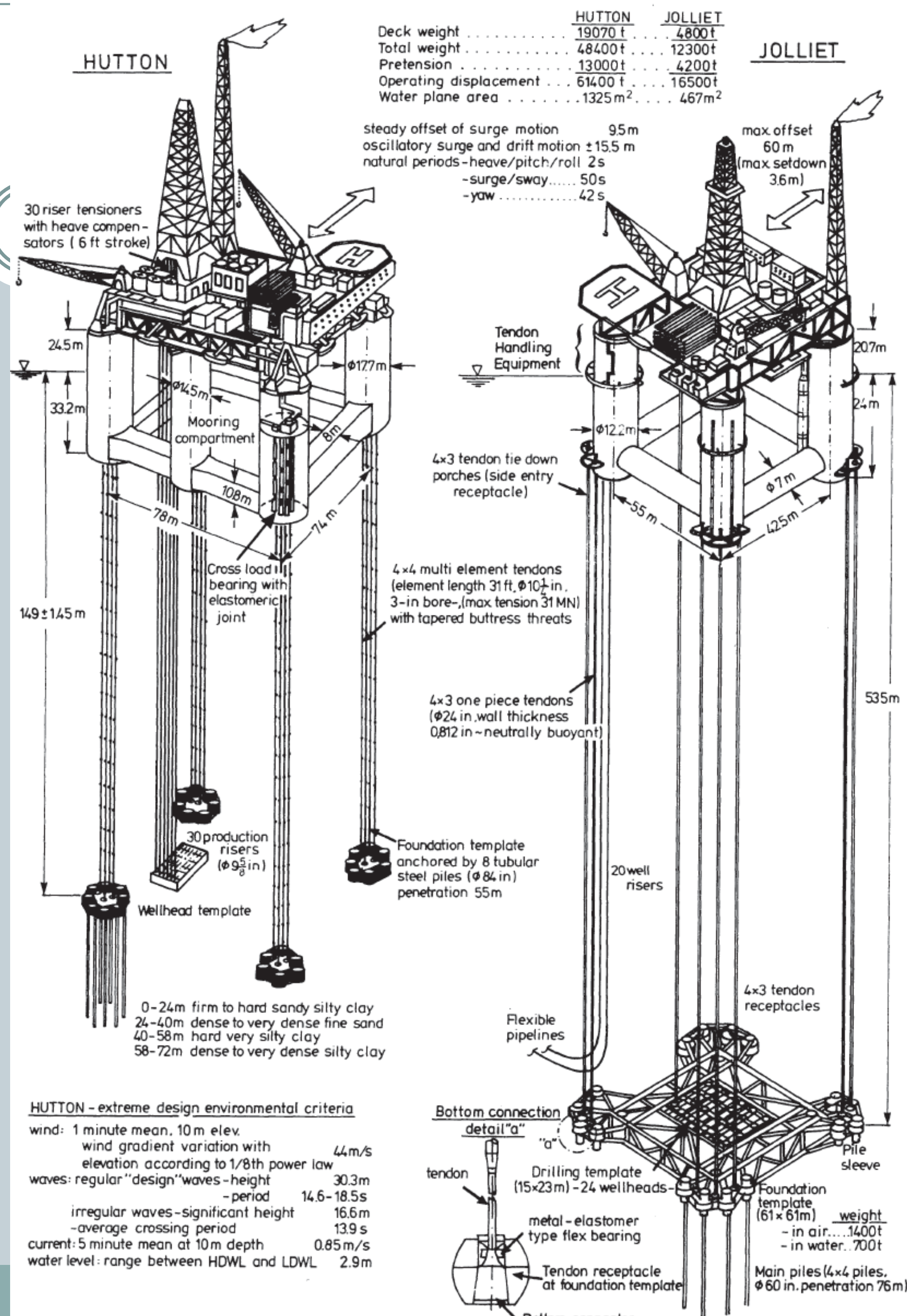






TLPs

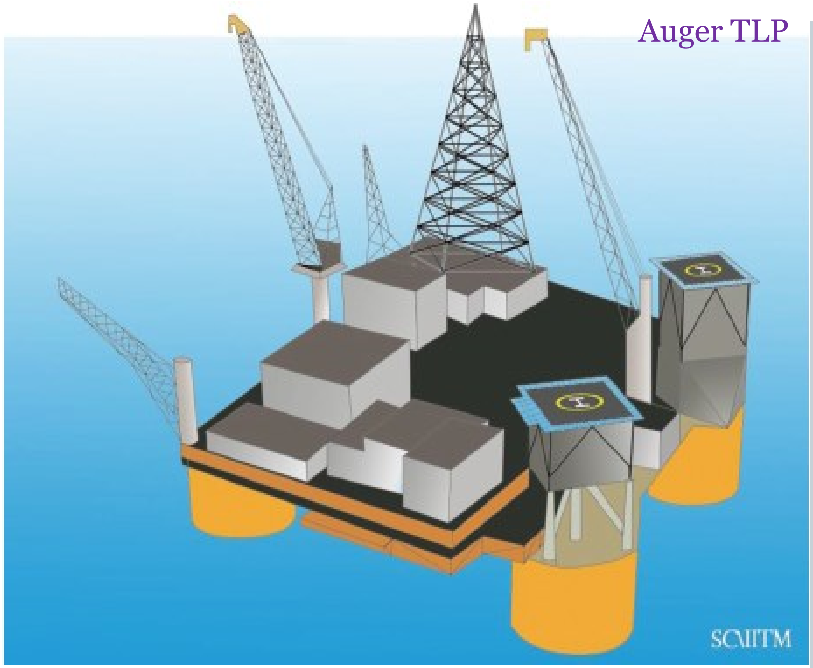
- Tendons resemble drilling collars (26cm (d) × 9.5m (L), bore: 7.5cm, t = 9.25cm)
- Mooring compartment adjusts wire tension
- Steel piles penetrate 55m subsea
- Feature dry trees
- Due to tension TLPs are designed heavier & stronger



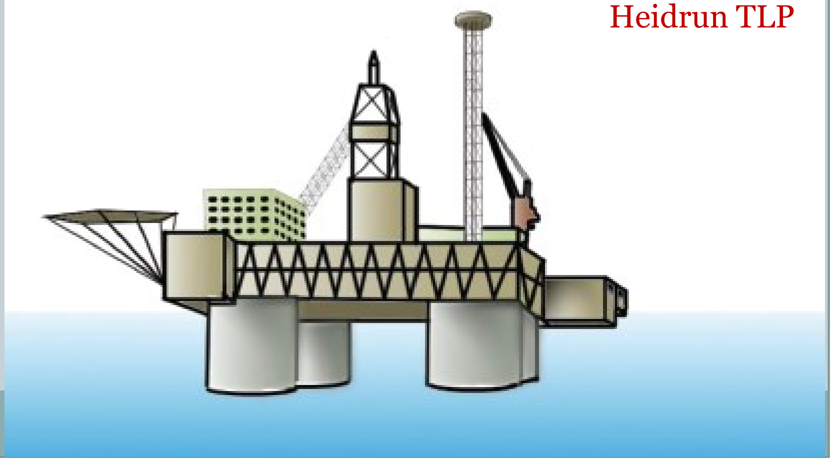
TLPs

- Advantages of TLPs include:
  - (i) Mobility and reusability;
  - (ii) Stability (min. minimal vertical motions)
  - (iii) Low cost increase as a function of increasi
  - (iv) Deepwater capability;
  - (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 storage.



Auger TLP



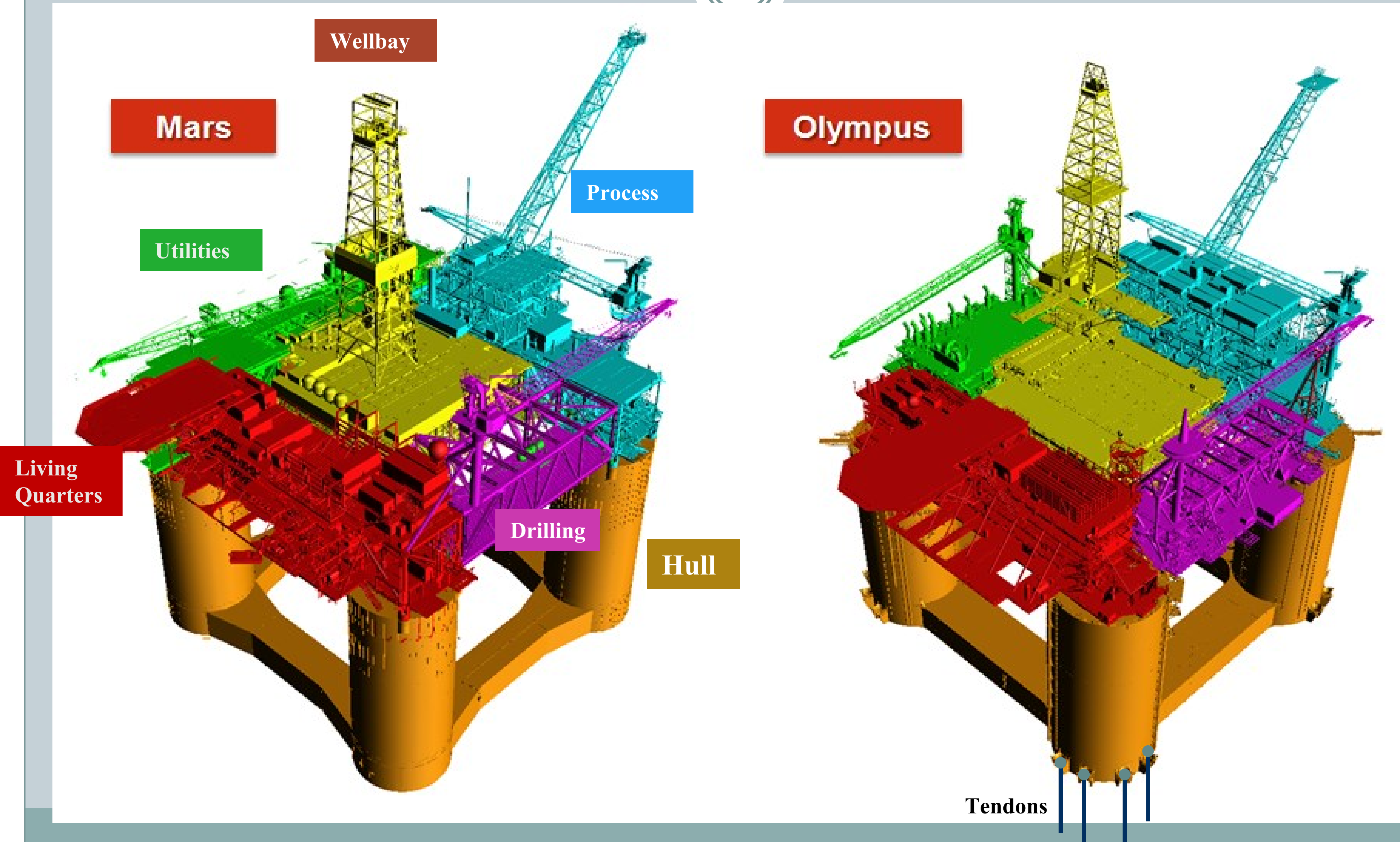
Heidrun TLP

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 restraint
- Direct Vertical Access (DVA) capability for drilling & production
- Stiff responses in heave, roll & pitch
- Compliant responses in surge and sway
- Limited to WD<1500m due to tendon resonance (fatigue)

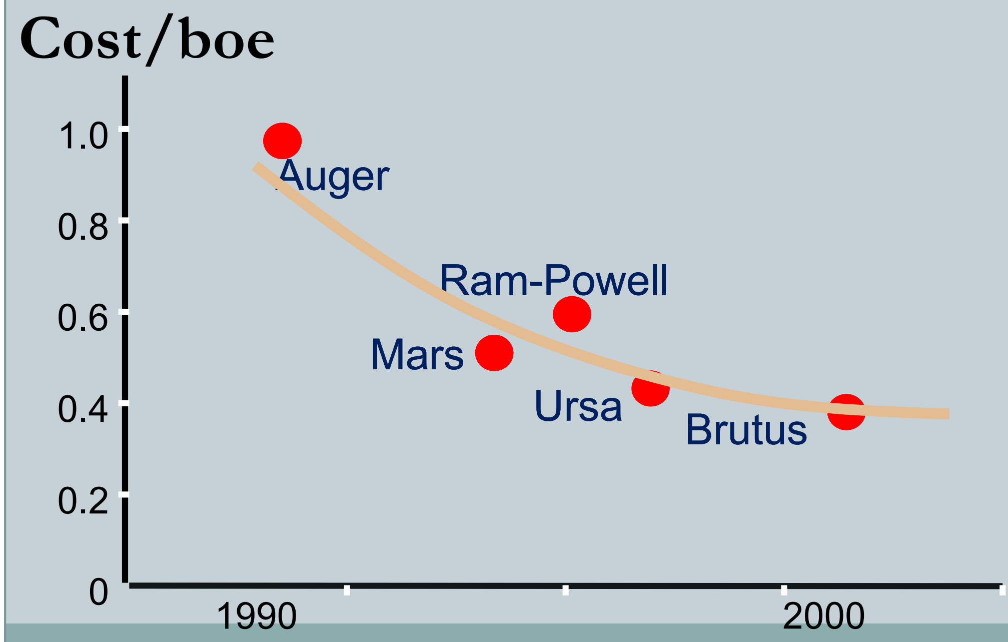
- Olympus TLP video [4m]

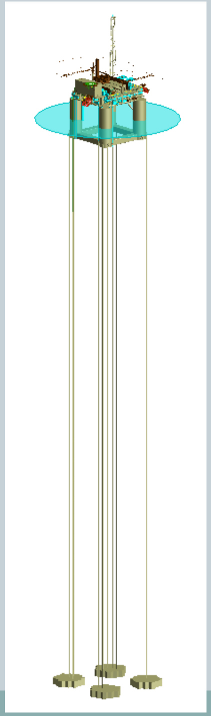
Olympus & Mars TLPs (courtesy Shell)



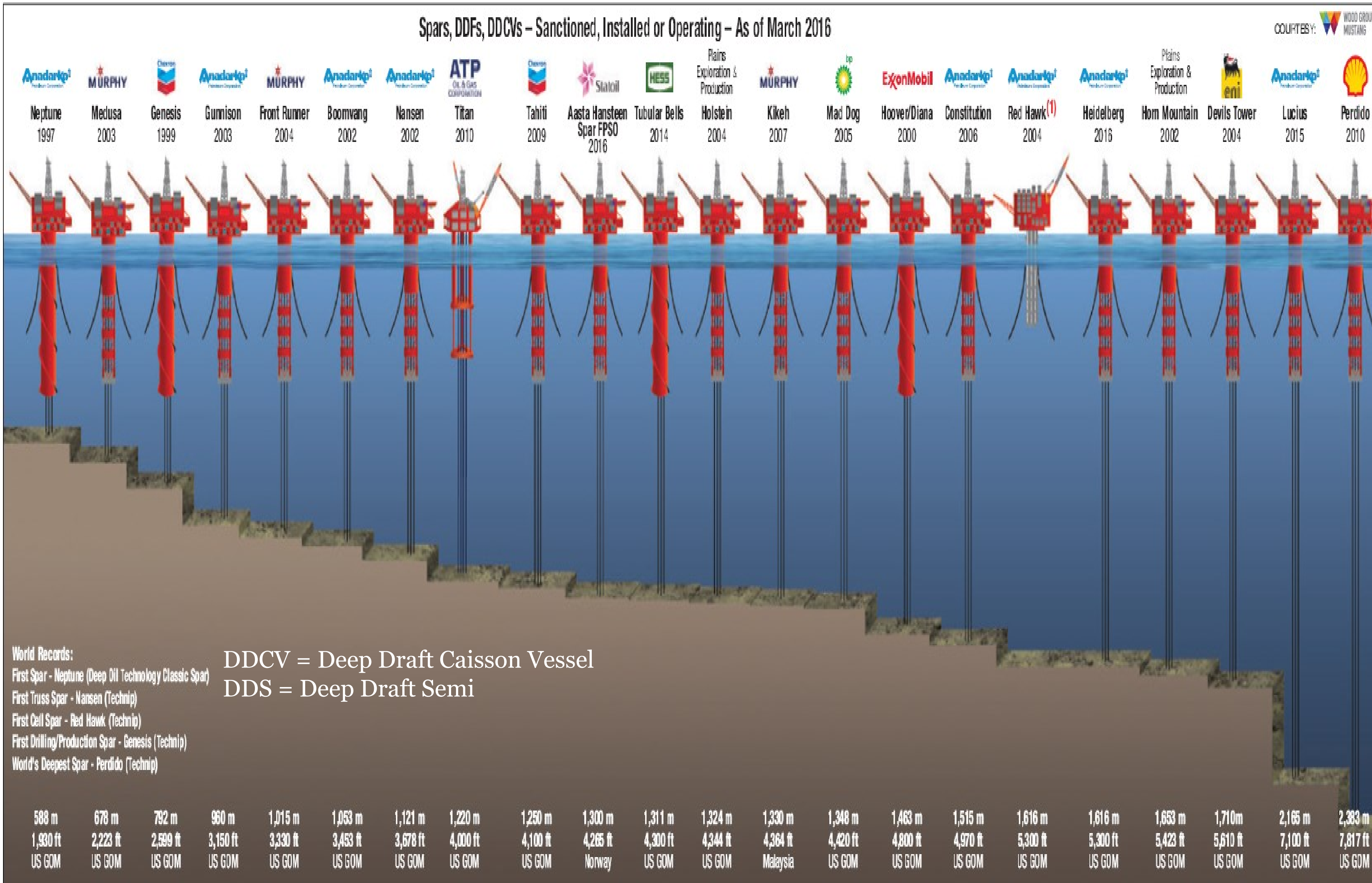
TLPs learning curve for Shell

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





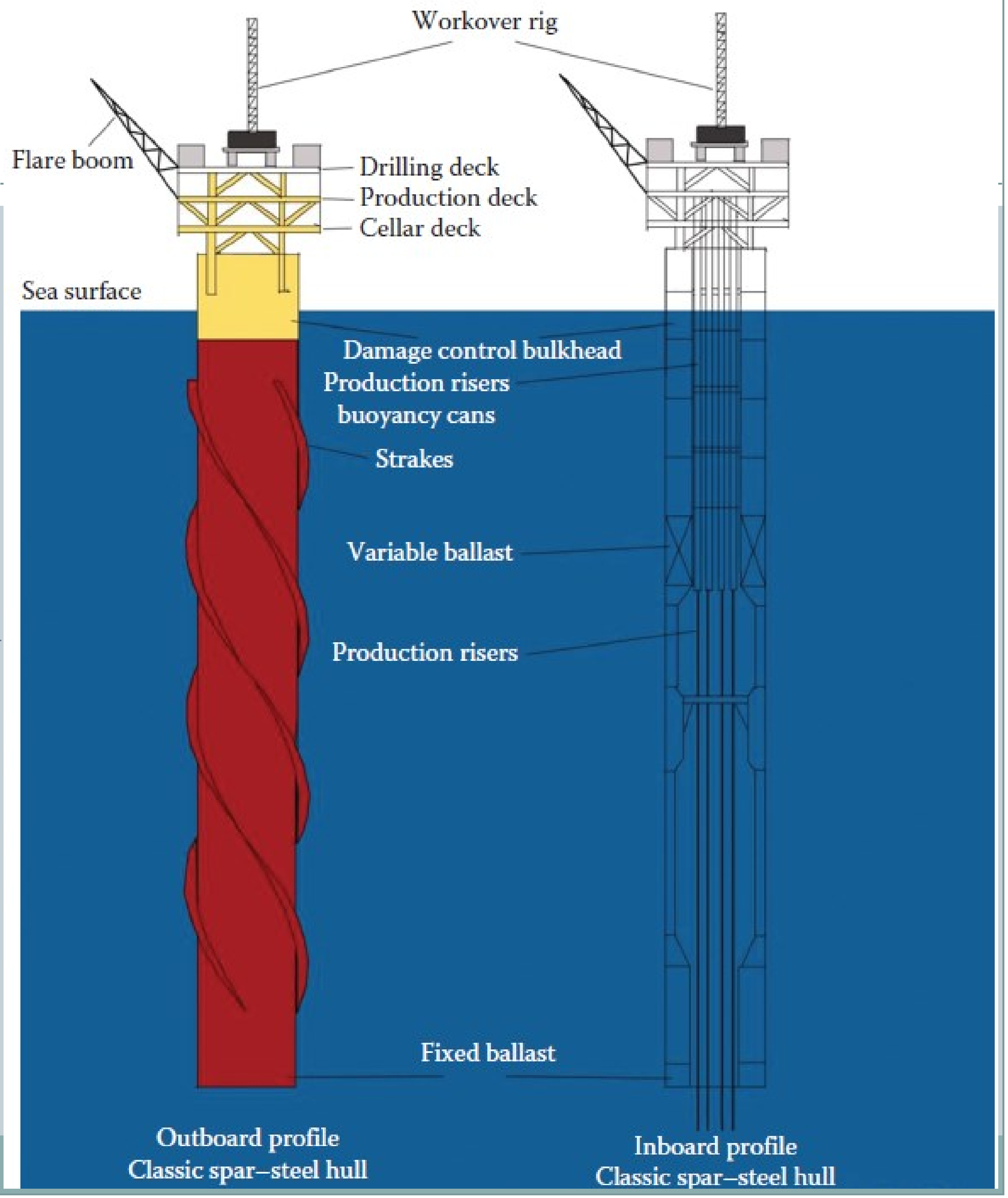
Spars



DDCV = Deep Draft Caisson Vessel
DDS = Deep Draft Semi

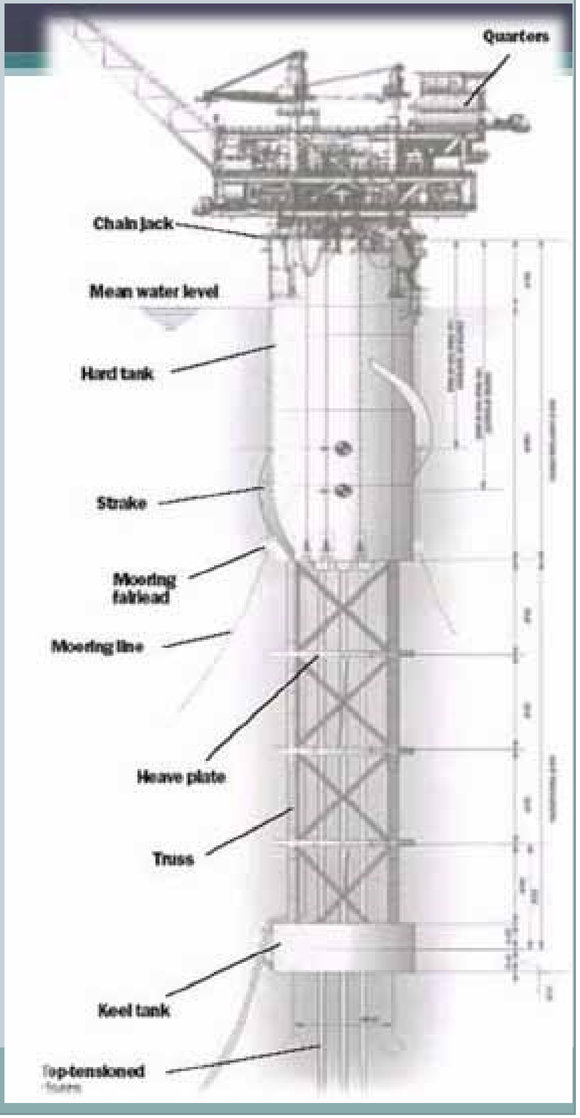
Spars

- 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

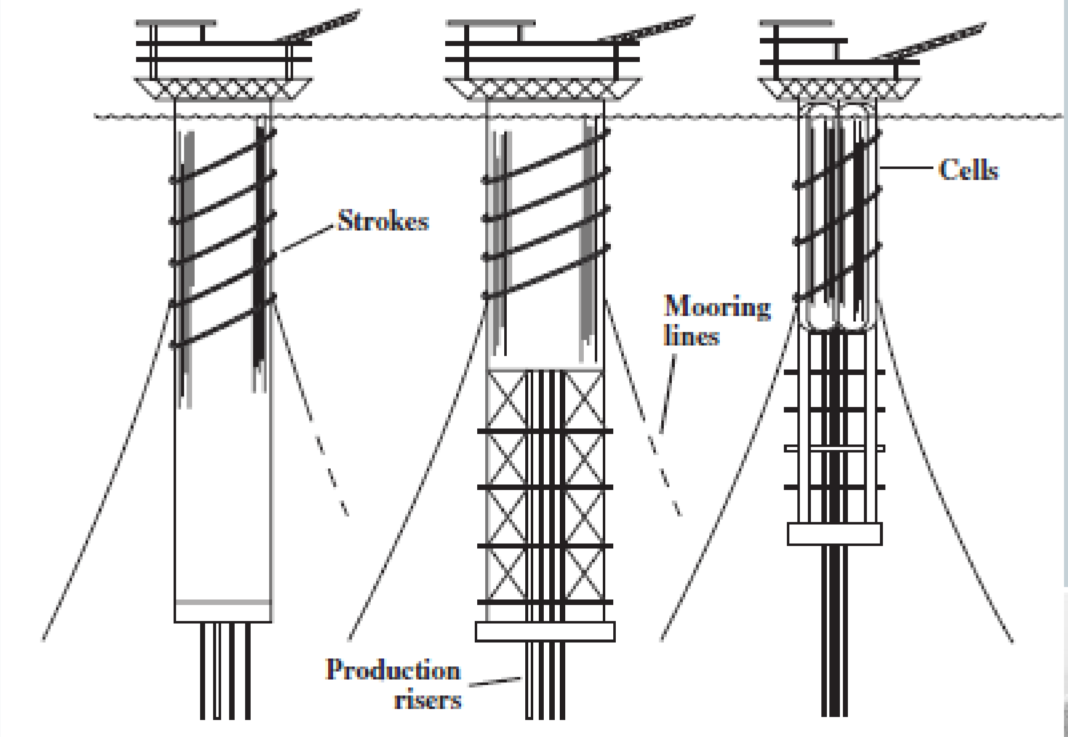


Spars

- 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 keep tank to hard tank
  - Keel tank contains fixed ballast & connects export p/lines & flow lines



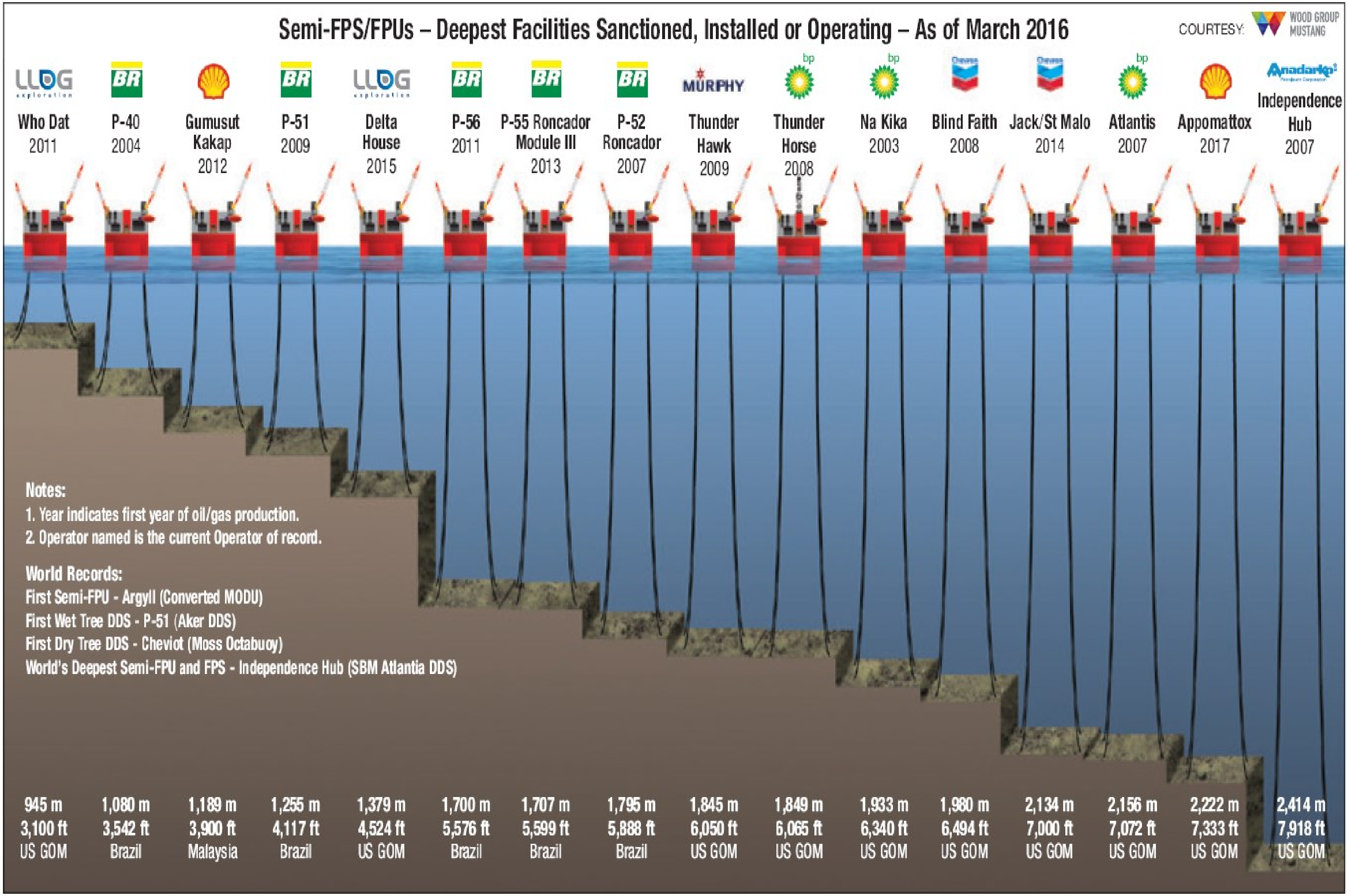
Evolution of spars



Transportation of Genesis spar hull

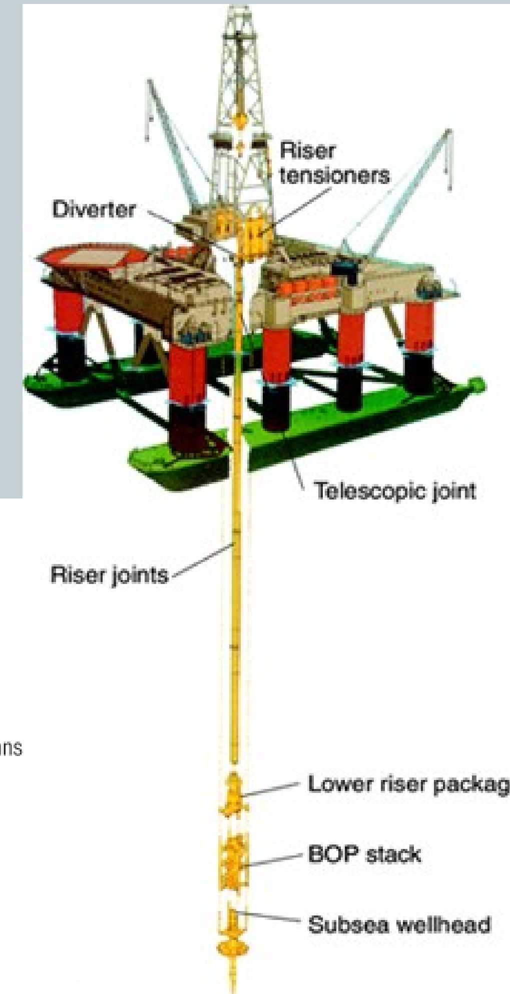
Leffler(2011)

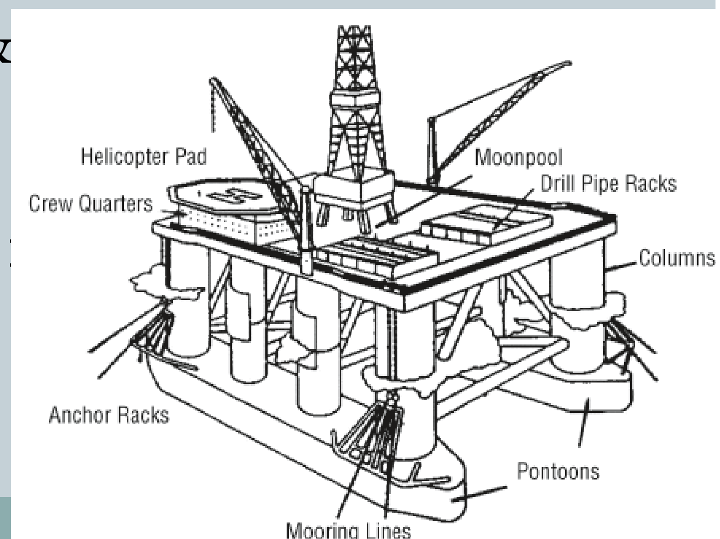
Semi-submersibles



Semi-submersible platforms

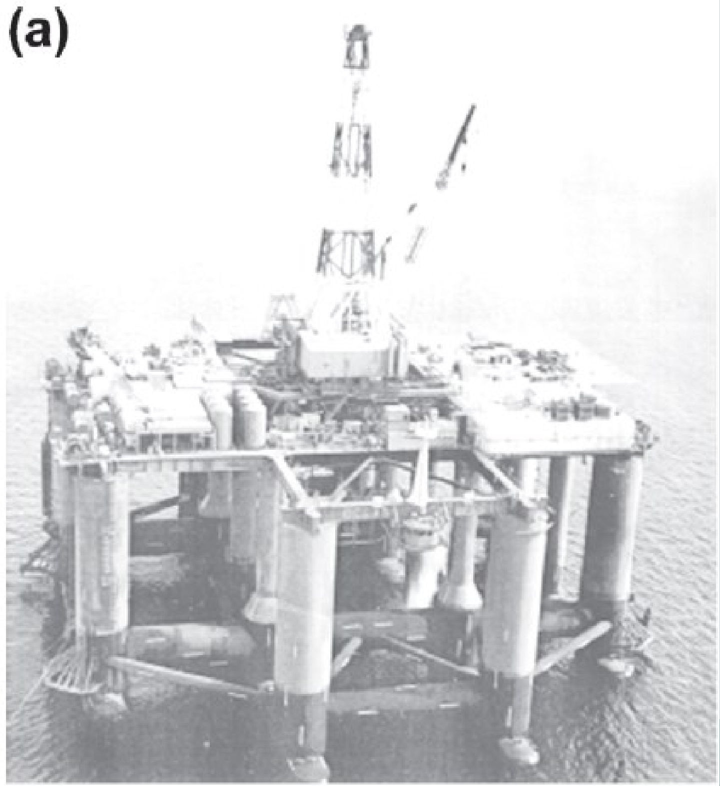
- Capable of drilling & production operations
- Increased draft provides stability
- Lack propulsion system (longer transit times)
- Require temporary anchoring systems (8 to 12) or dynamic positioning (DP) system
- Towed by tug-boats or dry transport
- Lower rates than drillships ($4k/d)
- Heave compensators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





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 incl. in rough seas
  - Good mobility at small T
  - Large deck area
- Shortcomings:
  - Low propulsion speed <8kn
  - Expensive to built >$100m
  - Sensitive to load



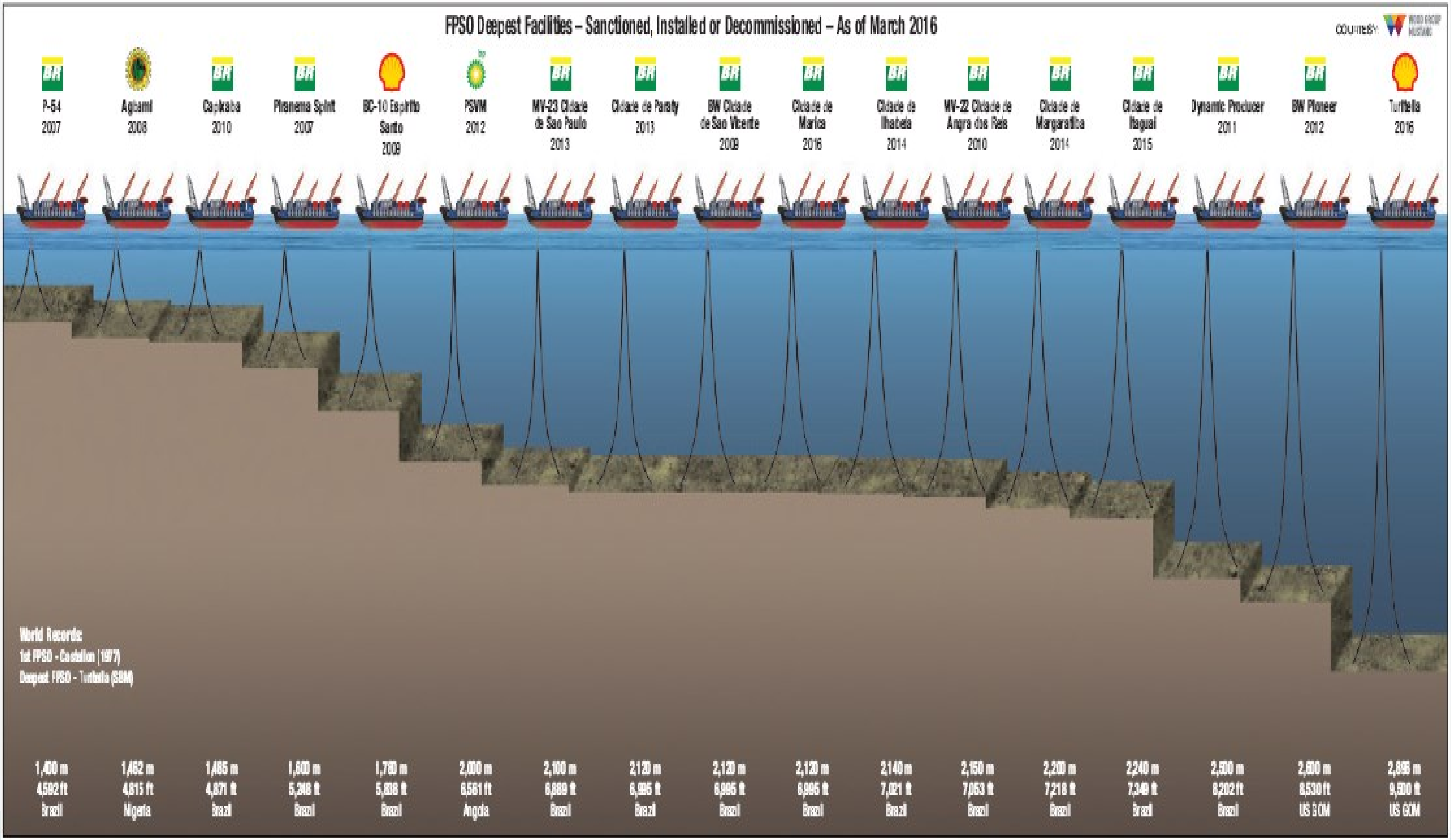
Blind Faith

- Year: 2008
- WD: 6500ft
- Δ=40,000t
- Chevron & Kerr-McGee
- $900m
- 65,000 bpd

Ichtys LNG central processing platform

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

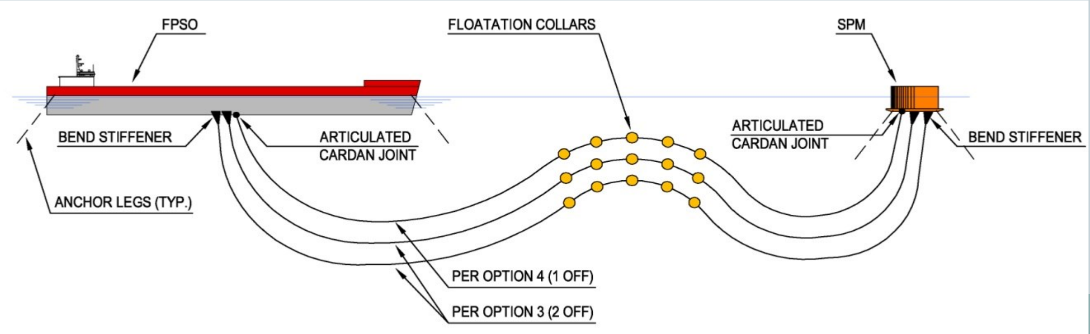
FPSOs


FPSO Deepest Facilities – Sanctioned, Installed or Decommissioned – As of March 2016
COURTESY
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:
1st FPSO - Castellon (1977)
Deepest FPSO - Turritella (SBM)
1,400 m 4,592 ft Brazil
1,462 m 4,815 ft Nigeria
1,485 m 4,871 ft Brazil
1,600 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 6,995 ft Brazil
2,120 m 6,995 ft Brazil
2,120 m 6,995 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

FPSOs

- Storage & offloading alleviates need for pipelines & onshore facilities
- Weathervaning (turret-moored) in other areas
- Newbuild or conversion
- Storage needs:
  - (i) parcel size, (ii) duration of offloading, (iii) oil remaining in tanks (iv) tank inspection in service

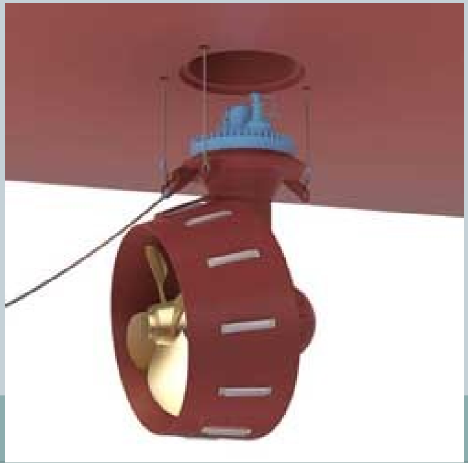
- Parcel size: amount of oil offloaded to tanker (1 mbbl for WA)
- Offloading duration: ~24 hrs
- Storage required = parcel size + 4 days of production



Bonga FPSO

Drillships

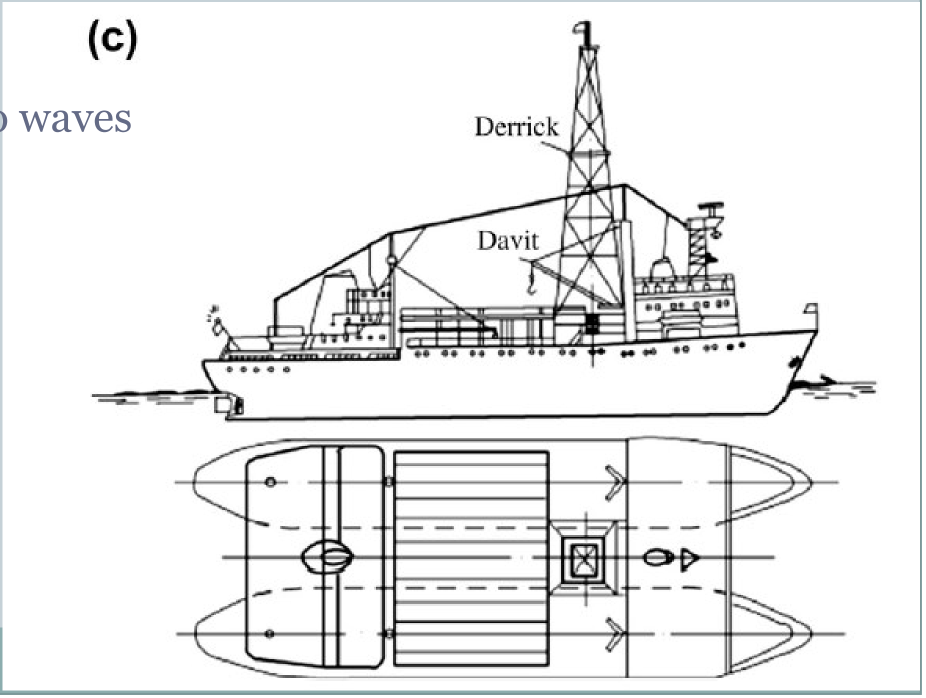
- Swift transit & manoeuvring characteristics
- Less idle time but more expensive to operate
- Used only for drilling ops
- Retained in place by dynamic positioning (DP) via thrusters
- Energy intensive operations (w/o anchoring)
- Operational water depth = 2,500m
- Dual handling capabilities; centre-line moon-pool
- World fleet ~80 ships | Cost = ~$600m



Drillships

- 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



Floating LNG

- Obviate need for submarine transmission pipeline(s)
- Innovation: onboard liquefaction
- 3.5-5.5 mtpa (2-3tcf)
- Working life: 30-40 yrs
- 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; 10,000 year load

Courtesy: Royal Dutch Shell

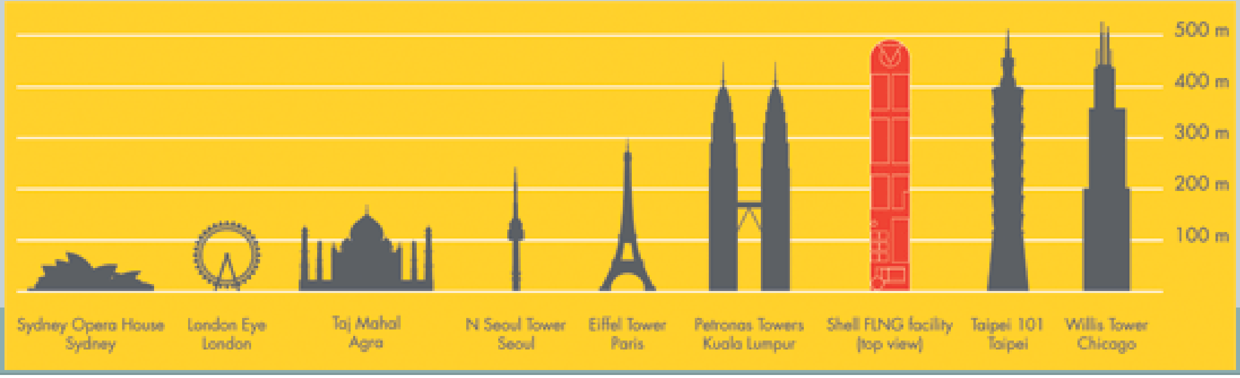
Prelude FLNG project

- Expected to commence operation in 2017; 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
- Delivery date: 2017
- Cost: $14 bn
- 600,000 t | Length: 488m
- Hull floated on Dec. 3rd, 2013
- Build 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

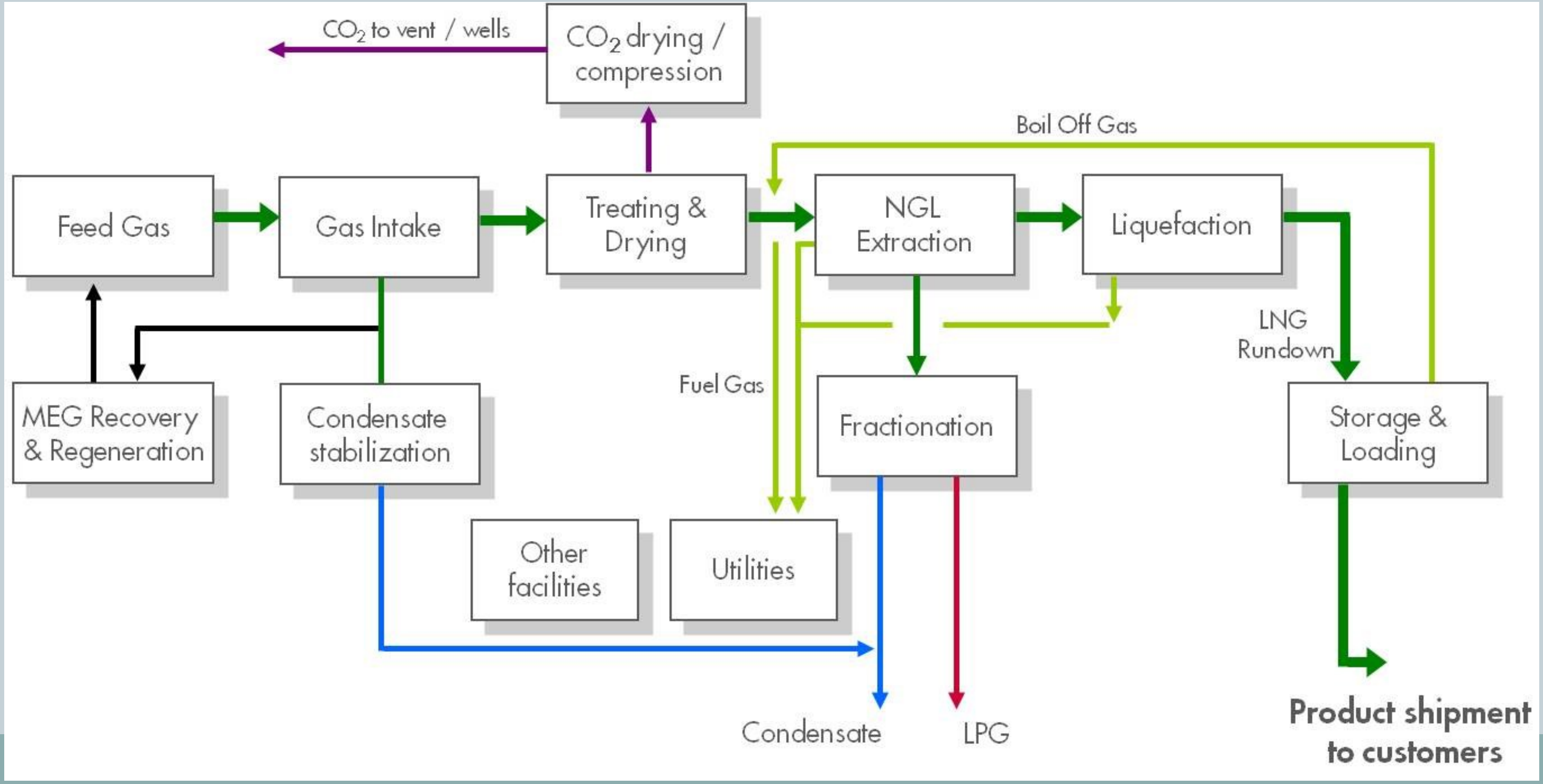
Courtesy: Royal Dutch Shell



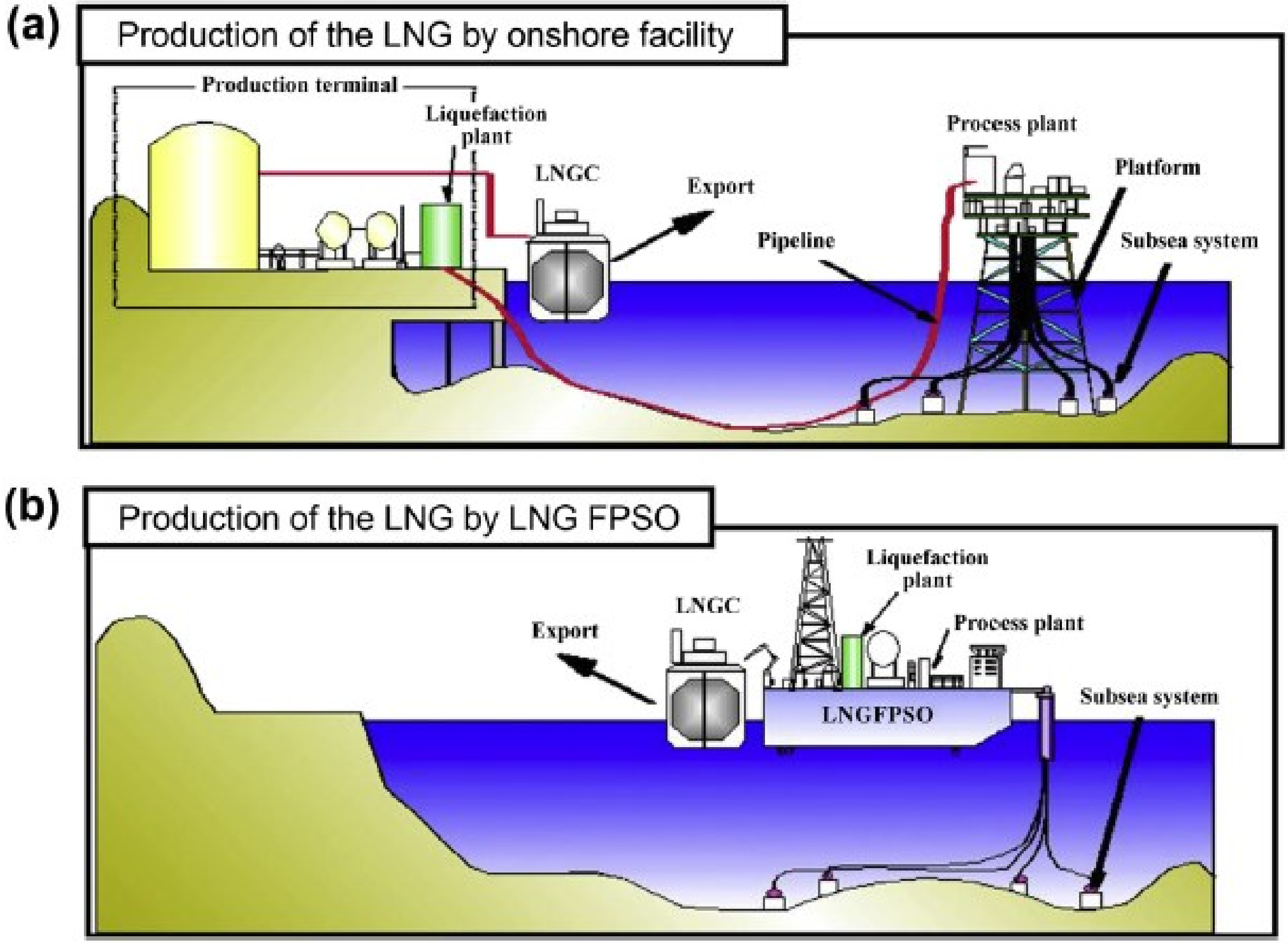
Floating NG liquefaction

- 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

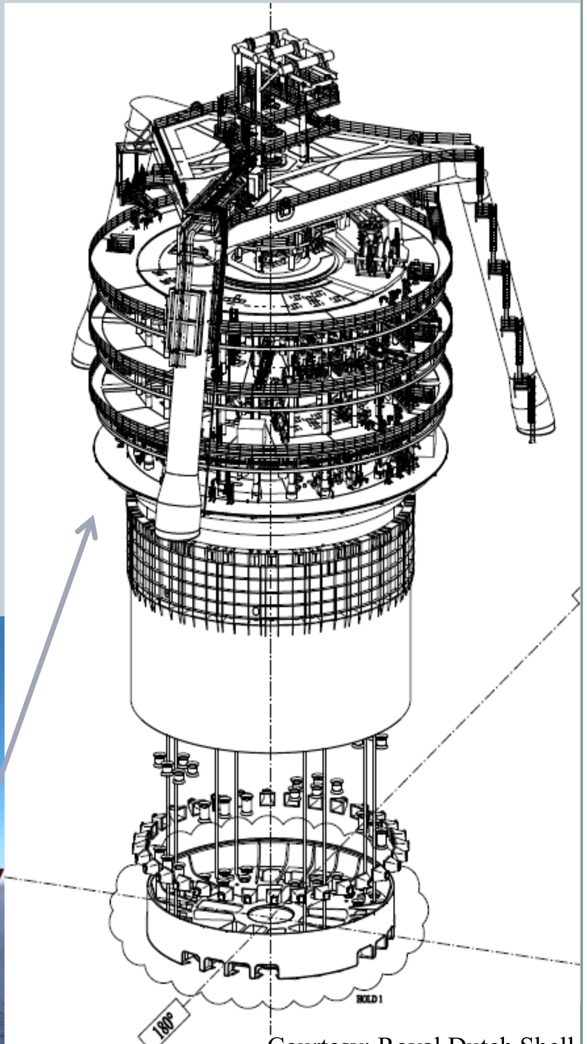


Prelude FLNG project (2)

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

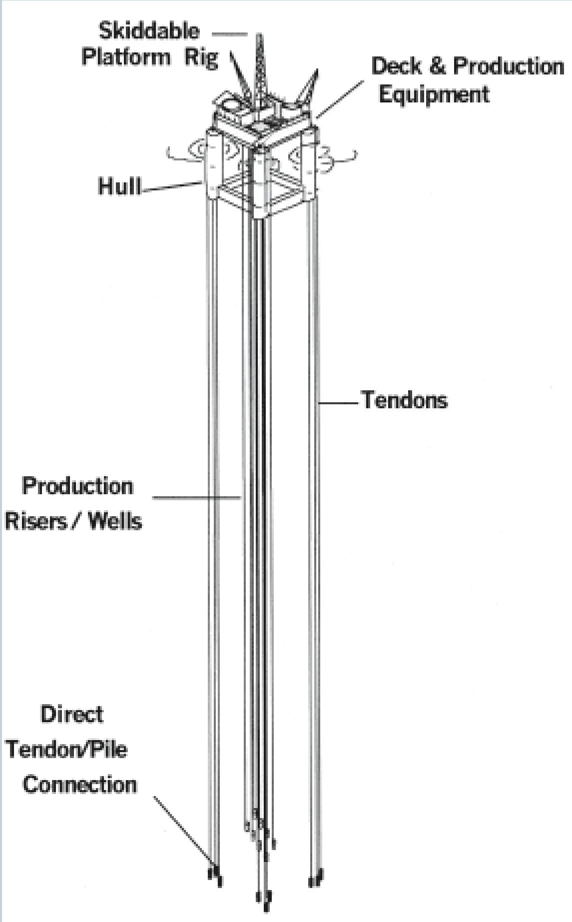
Offshore mooring systems

Offshore mooring systems

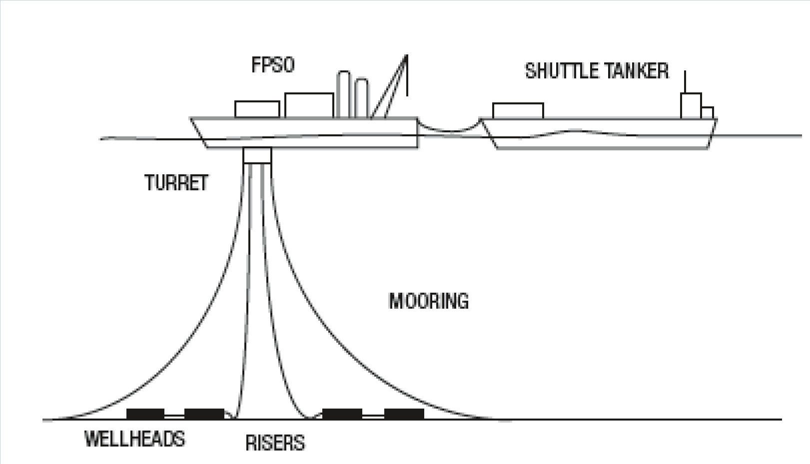
- Objectives: secure floating structure in position with minimal forces
- Two types of mooring systems:
  - Temporary mooring: semi-subs, work vessels, dredgers, pipe-laying vessels, ...
  - Permanent mooring: TLPs, F(D)PSOs, Spars, FPS, ...
- Classification also based upon:
  - Spread, multi-point mooring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

Line arrangements

Single point tendons

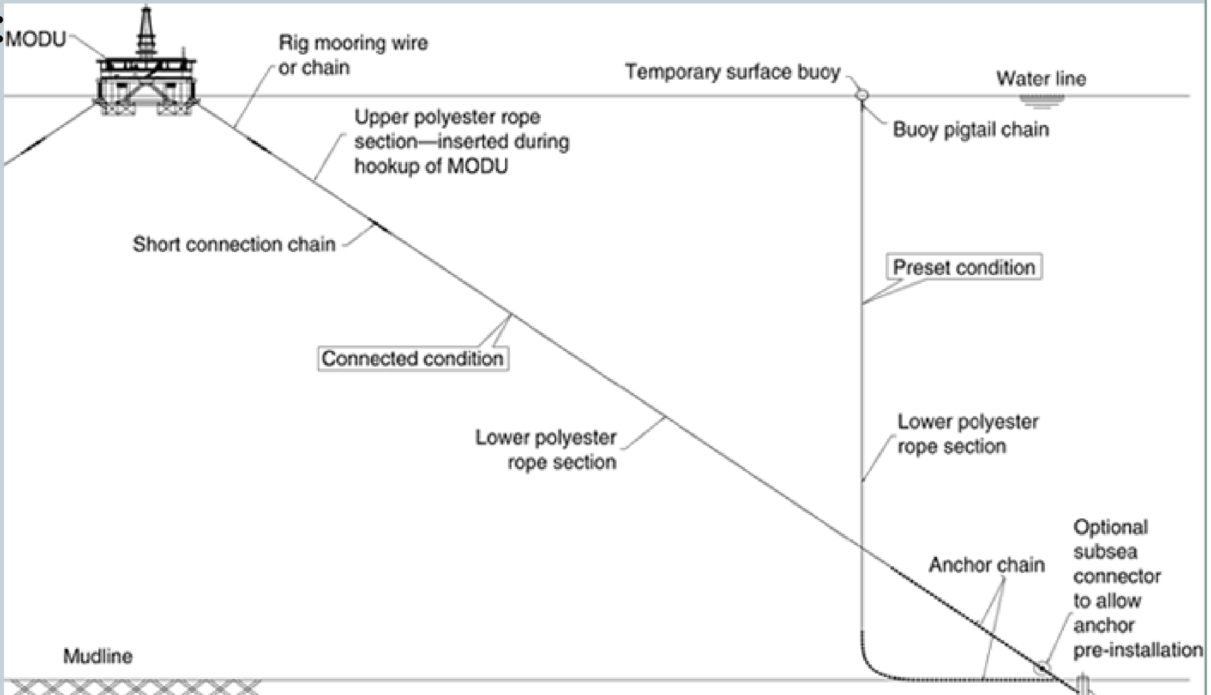


Spread mooring



Taut-leg mooring

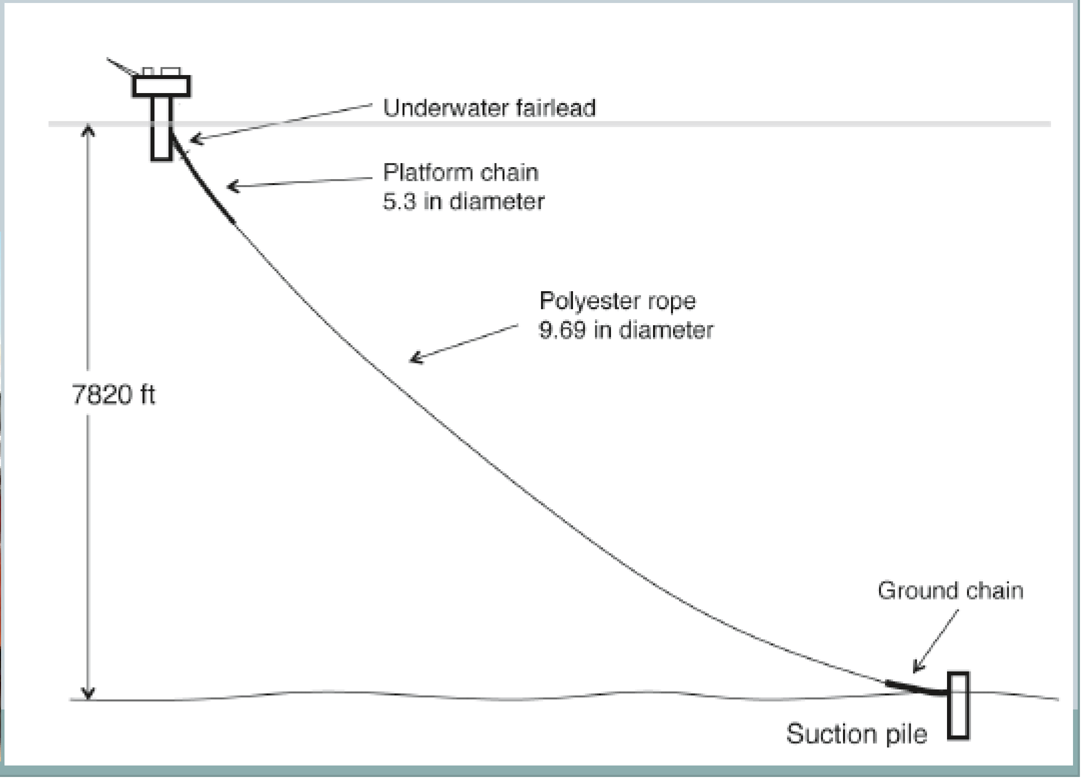
- D<100m: chain; 100m>D>300m: wire rope; 2000m>D>3000m: wire + chain; D>2000m: chain, synthetic & wire rope
- Synthetic lines: lighter & more elastic to wire/chain; neutral buoyancy
- But synthetic lines do not [yet] posses the stiffness of metallic ones
- Synthetic lines include:
  - Polyethylene
 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



Typical Polyester Taut-Leg Mooring For Deepwater Drilling

Perdido spar mooring lines

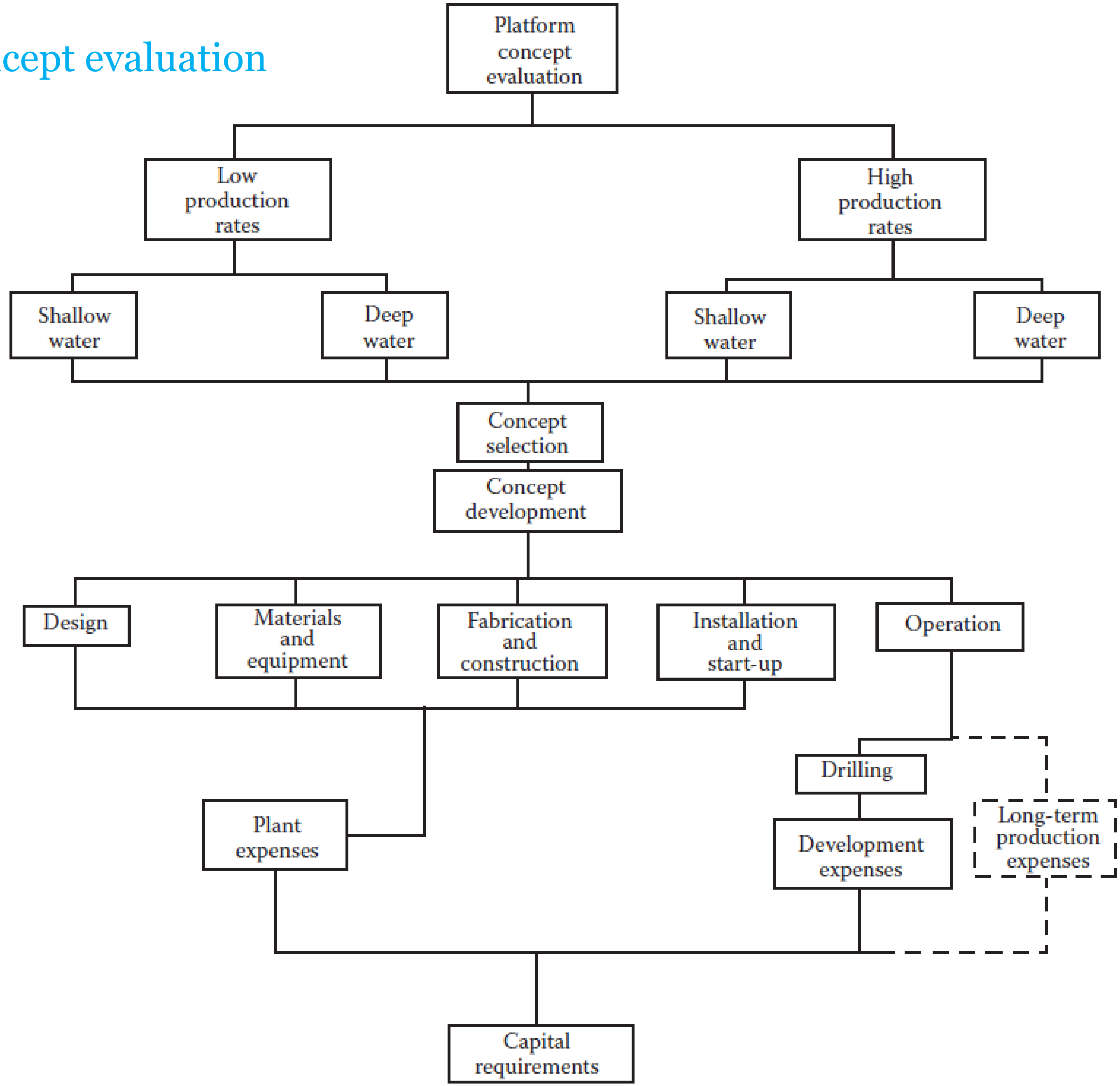
- Line length: 3.2km
- Thickness: 245mm
- Total of 9 mooring lines
- Water depth: 2,450m
- Operation date: 2008



Polyethylene rope *vs* steel wire

- Video

Platform concept evaluation

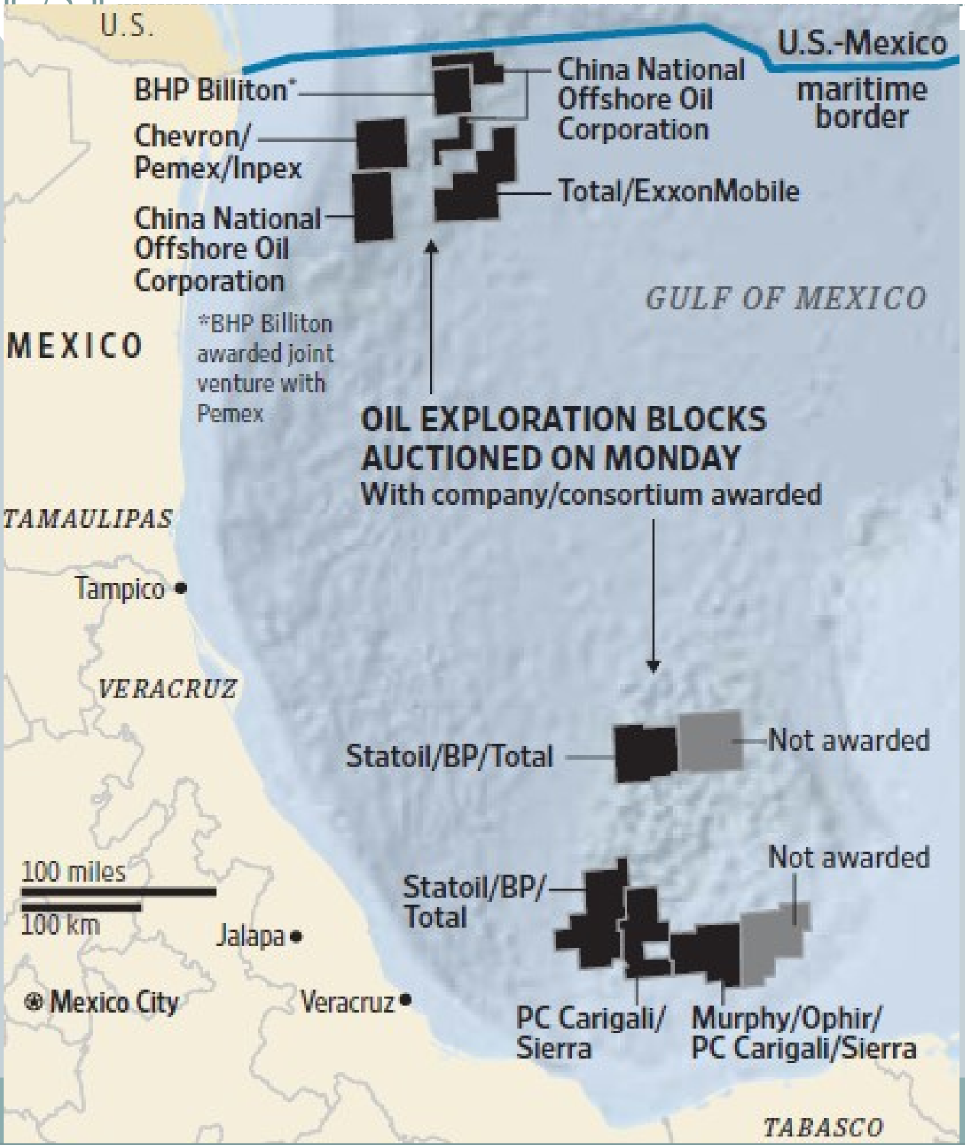


Theory

- Theory #4: Design of offshore structures
- Posted online

Mexico offshore licensing round

- Awarded 8 out of 10 blocks
- BHP Billiton outbid BP
- Investments: ~$40bn
- New entrants: CNOOC



Acknowledgments

- Dr. Mike Efthymiou, Shell Netherlands

Thanks for your attention!