Deep Water Mooring Systems

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SOFEC Inc.

- Engineering and Construction Company based in Houston, Texas
- Founded in 1972
- Acquired by MODEC, Inc. in December 2006
- Core Technologies
  - Marine Import/Export Terminals
  - Specialty Mooring Systems
- Approximately 200 Employees in Houston
  - ***Project Execution:*** Project Management, QAQC, Fabrication, Procurement, Project Engineering Management, Most Engineering Disciplines
  - ***Product Development and Mooring Technology:*** Product Development and R&D, Hydrodynamics, Mooring Technology
  - ***Business / Project Acquisition:*** Financial and Commercial, Sales & Marketing.
- SOFEC's Reputation in the Industry
  - Dedicated Workforce, Highly Qualified and Experienced
  - Quality, High Performing Turret Mooring Systems, with Minimal Maintenance

SOFEC Major Products and Projects Summary

External Turret: 27

Internal Disconnecectable Turret: 5

Internal Permanent Turret: 4

Spread Moored: 16

Tower Yoke: 5

CALM/SALM: 60

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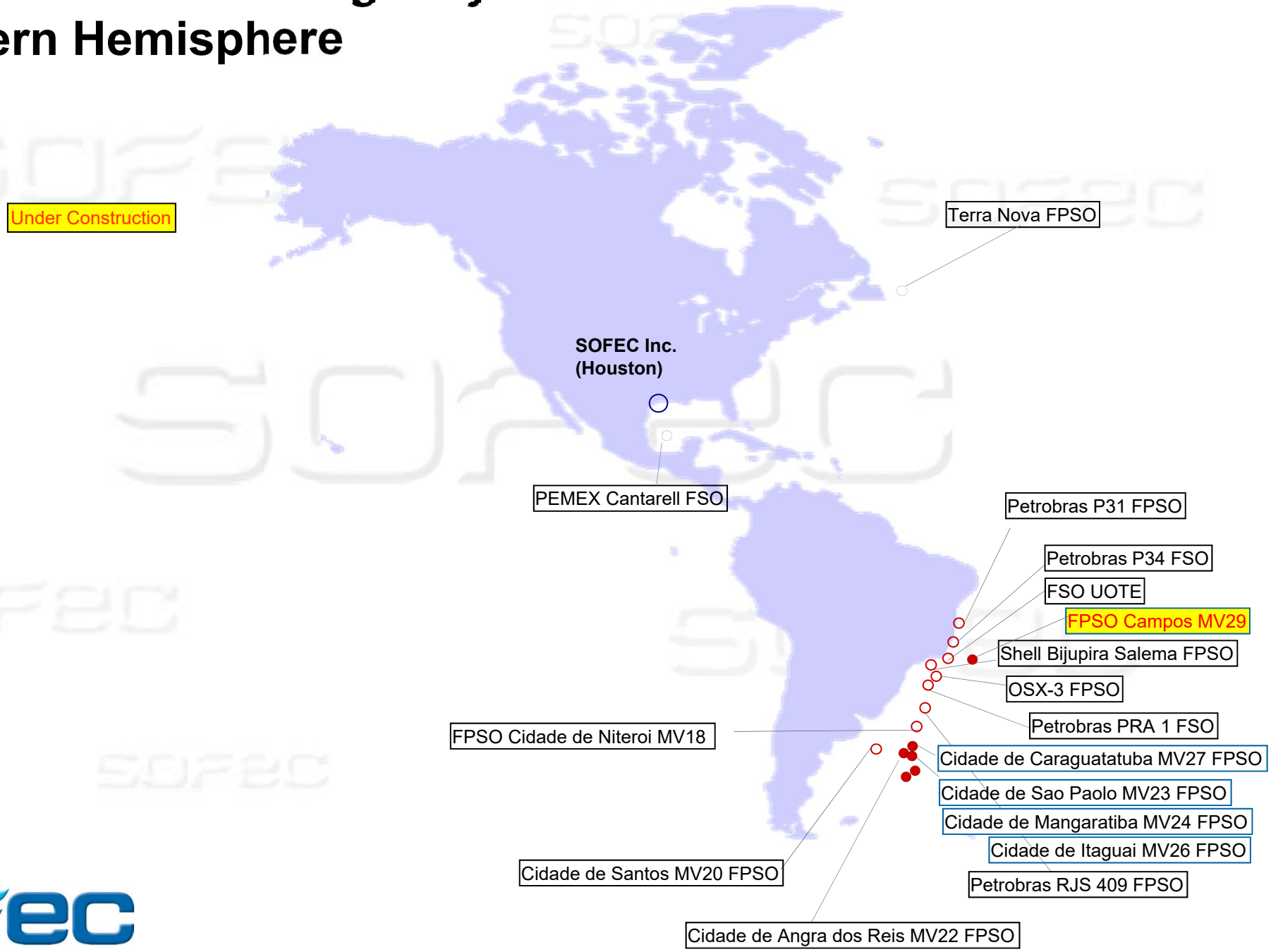
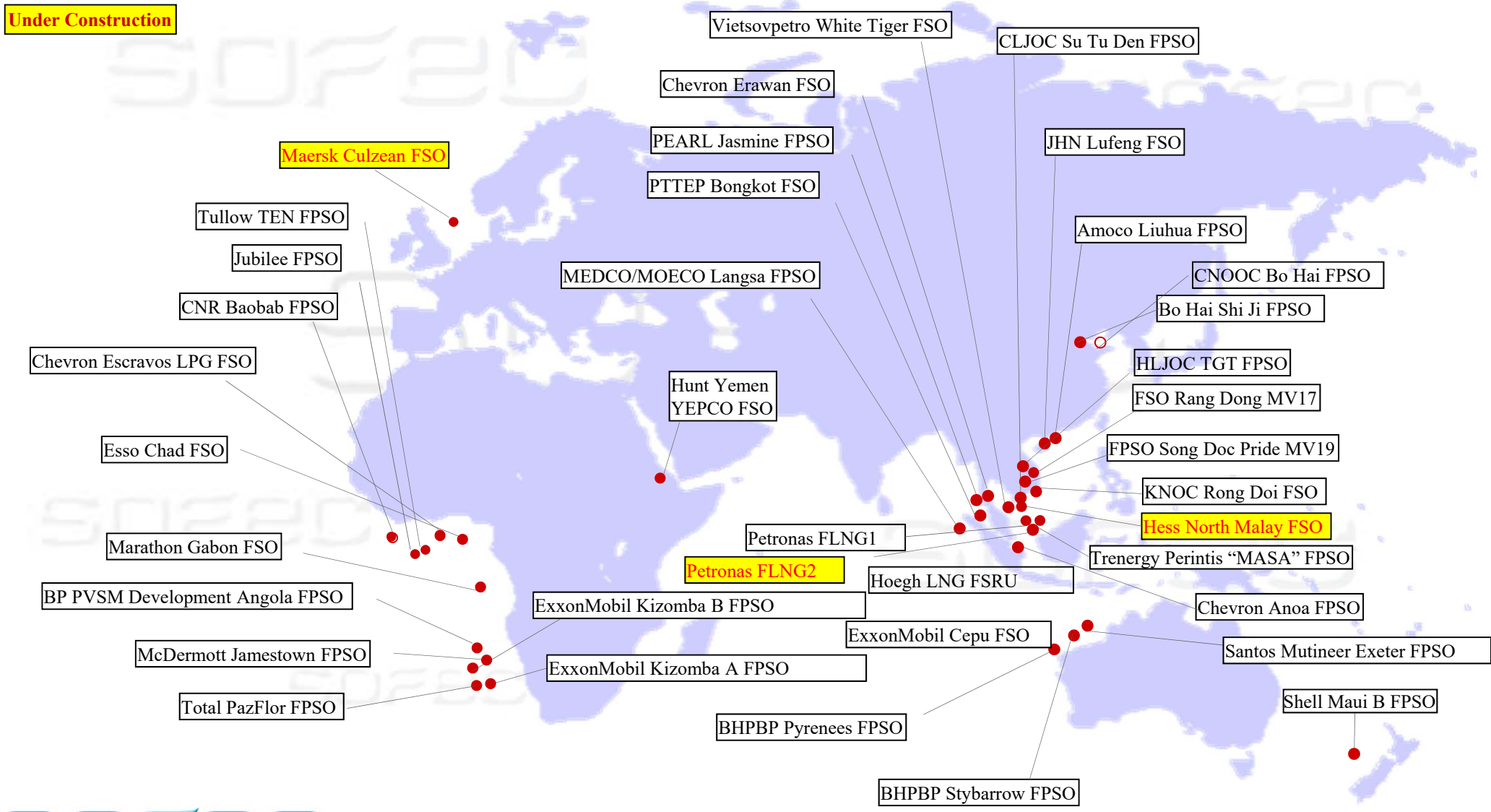
SOFEC FPSO Mooring Project Locations
Western Hemisphere



SOFEC FPSO Mooring Project Locations
Eastern Hemisphere



Mooring Systems for Floating Production Units

External Turret: Tandem Offloading

Internal Turret: Tandem Offloading

Spread: Tandem Bow or Stern Offloading

Tower Yoke: Tandem Offloading

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SOFEC Turret Mooring Systems: 41 to date

- SOFEC's Turret Mooring Design and Operational Experience from 1988 - 2017
  - 4 Permanent Internal Turret Mooring Systems
  - 5 Internal Disconnectable Turret Mooring Systems
  - 27 External Turret Mooring Systems (industry trend for turret types)
  - 5 Tower Yoke Systems
- Overall 260 years of operational life
  - Longest duration: 24 years on site (Safer FSO, Yemen, 1988)

Most Common Mooring Systems for Floating Production Units
Turret Vs. Spread Moor

Comparative Summary

	Turret-Moored	Spread-Moored
Vessel Orientation	360 degree weathervaning	Fixed orientation, can impact flare
Environment	Mild to extreme, directional to spread	Mild to moderate, uni- to fairly directional
Field Layout	Fairly adaptable, partial to distributed flowline arrangements	Prefers flowline arrangement to approach beam-on
Riser Number & Arrangement	Requires commitment, moderate expansion capability	Can be designed for flexibility, additional tie-ins
Riser Systems	Location of turret (bow) requires robust riser design	Adapts to various riser systems, combinations of various types
Stationkeeping Performance	Number of anchor legs, offsets minimized	Larger number of anchor legs, offsets variable
Vessel Motions	Weathervaning capability reduces motions	Dependent on relative vessel/ environment directionality
Vessel Arrangement	Turret provides "compact" load and fluid transfer system	Components spread on deck, requires extensive interfaces
Offloading Performance	FPSO typically aligned with mean environment	Dependent on vessel/ environment orientation

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Most Common Mooring Systems for Floating Production Units
Internal Vs External Turret

External Cantilevered Turret Systems: most popular

⇒ Applications in mild to moderate environments:
West Africa, Brazil, Southeast Asia, Middle East, South Pacific

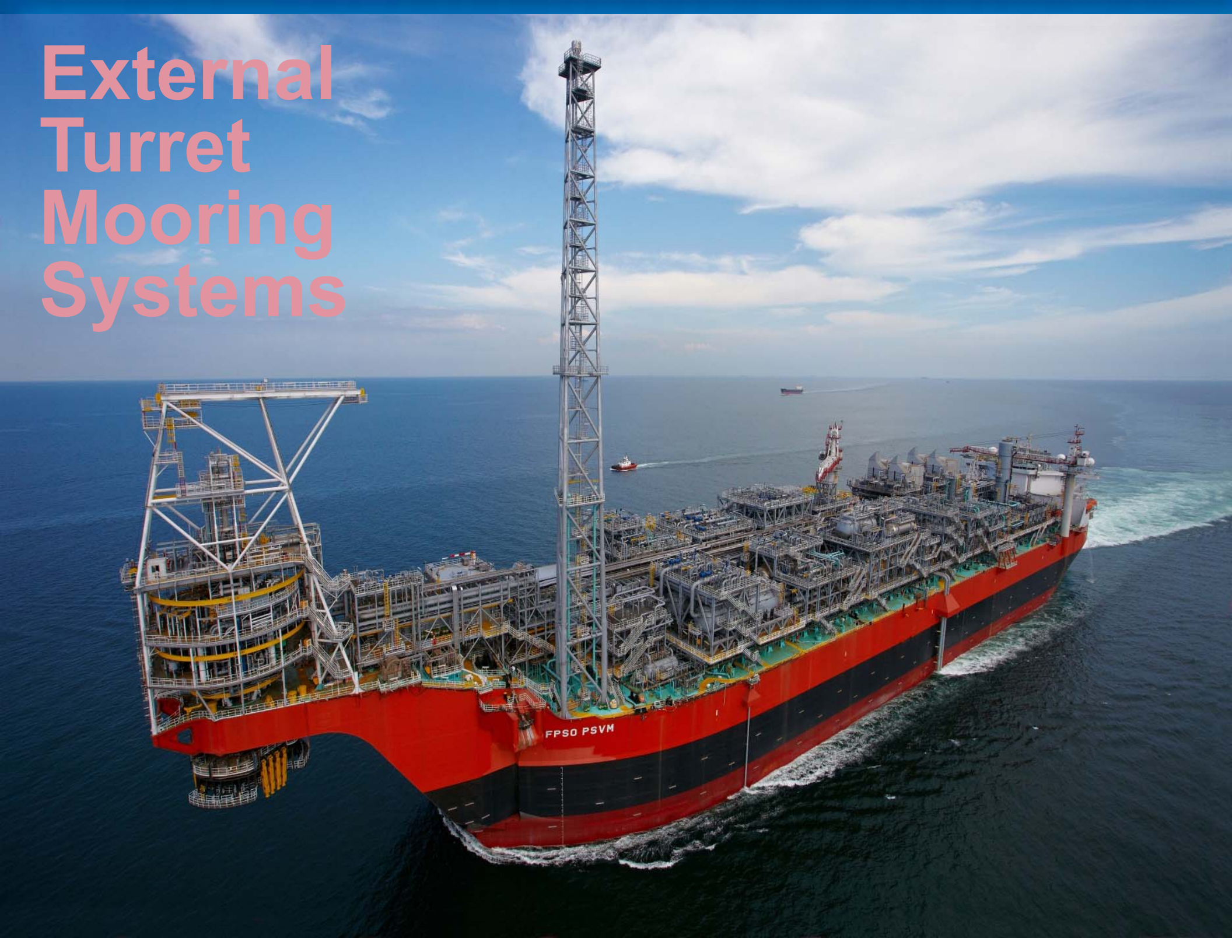
⇒ Permanent systems (generally)

⇒ Smaller number of risers

⇒ Shallow to deep water depth applications

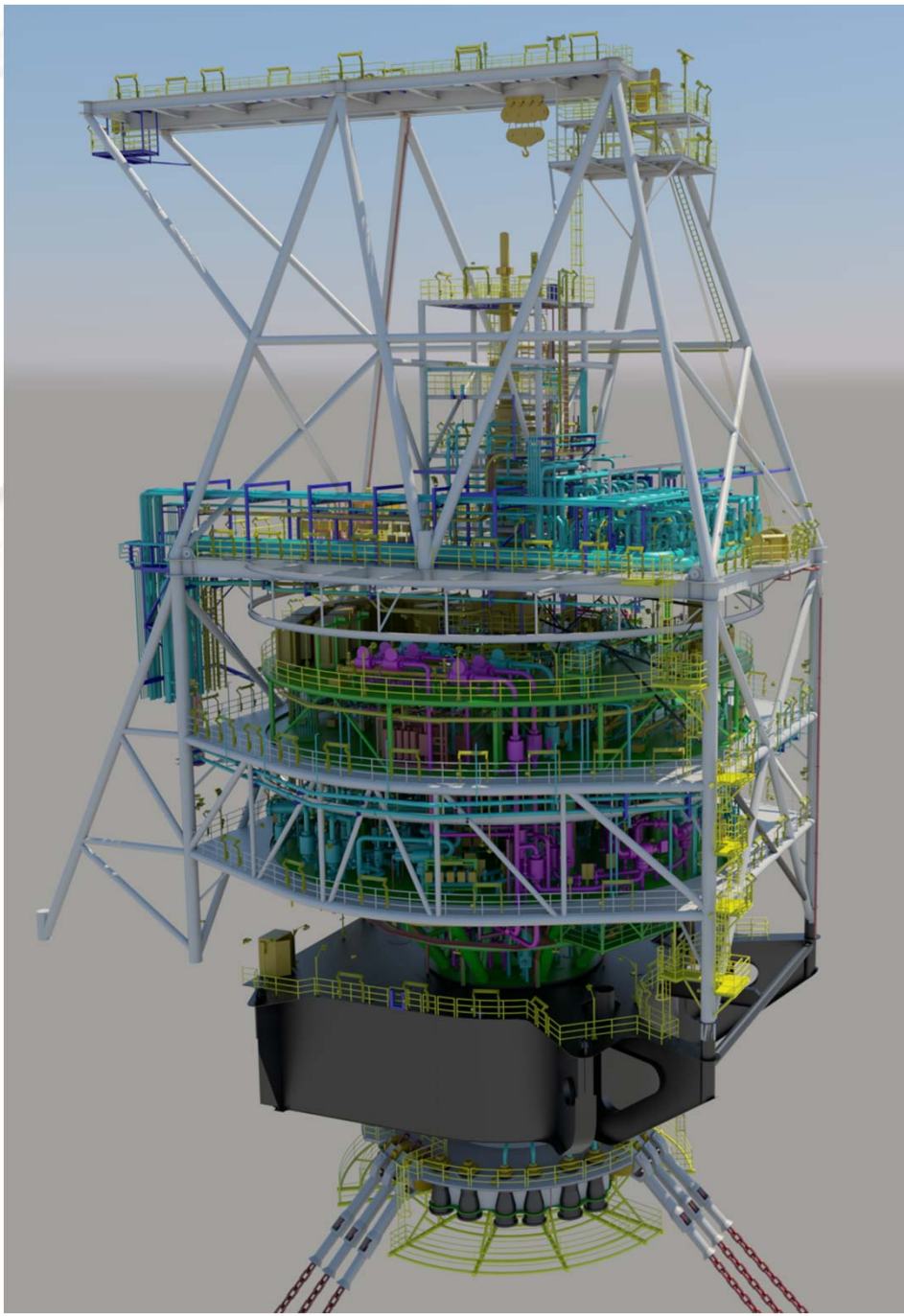
Generally less costly than internal turrets, but not ideal for large, deep water fields in the Gulf of Mexico

External Turret Mooring Systems



Tullow Ten External Turret Mooring [4200 MT]

- Offshore Ghana
- ~1450 m water depth
- VLCC FPSO
- 3 X 3 Anchor Leg System
- 17 Risers & 7 Umbilicals
- DNV Class
- Fabricated @ Keppel Fels



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External Turret Mooring Systems

Yepco Red Sea, Yemen

Amoseas Anoa, Indonesia

Shell Todd Maui B, New Zealand

Chevron Escravos, Nigeria

PEMEX Cantarell, Mexico

Petronas (MASA), Malaysia

Nexen Buffalo, Australia

Vietsovpetro 01, Vietnam

Shell Bijupira-Salema, Brazil

PTTEP Bongkot, Gulf of Thailand

CLJOC Su Tu Den, Vietnam

CNR Baobab Ivoirien Côte D'Ivorie,

PEARL Jasmine Thailand

KNOC Rong Doi Vietnam

Petrobras PRA-1 Brazil

JVPC Rang Dong Vietnam

BP PSVM Angola

Tullow Jubilee Ghana

HLJOC TGT FPSO Vietnam

FSO Erawan Thailand

OSX3 FPSO

UOTE FSO

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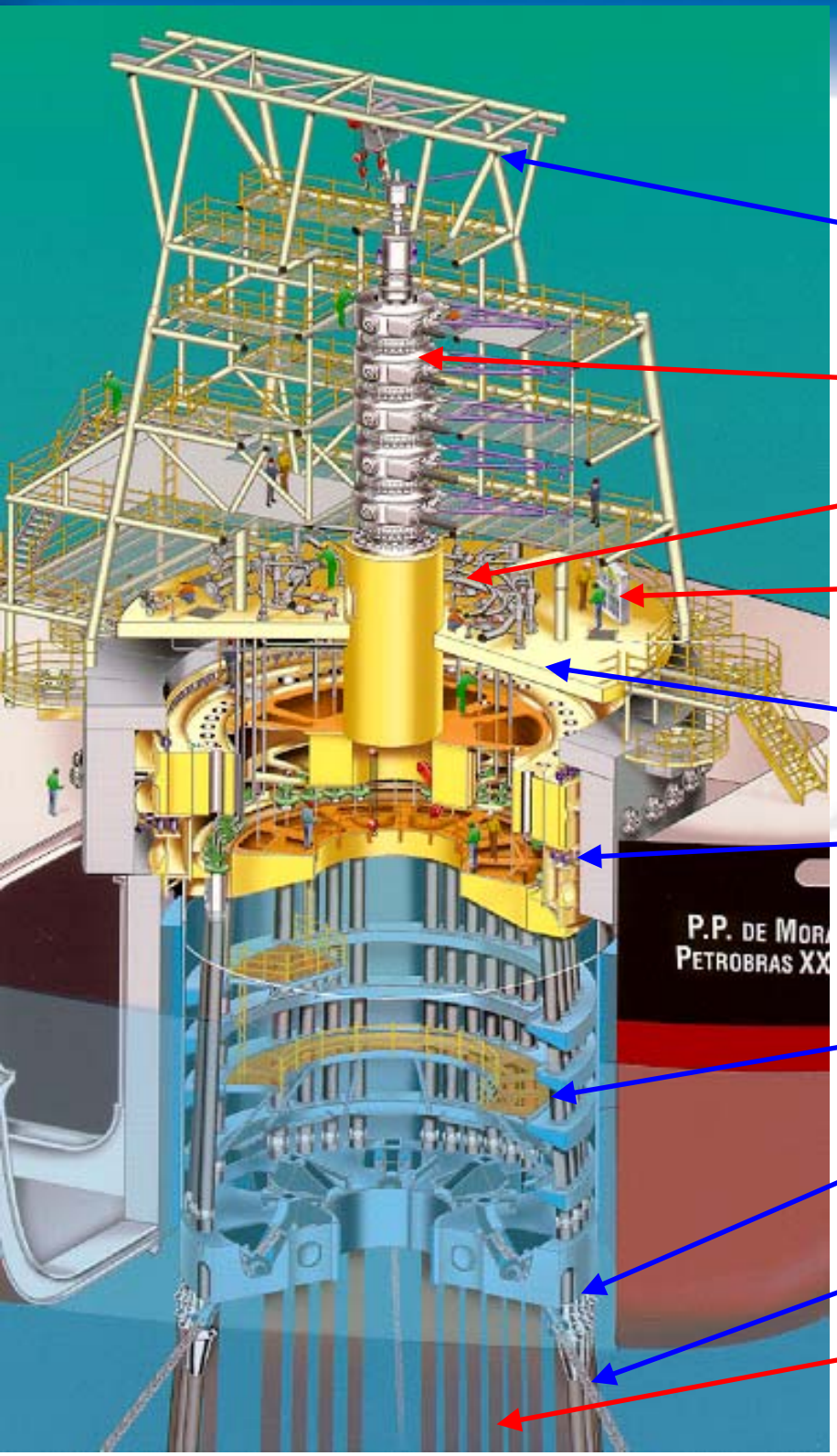
Internal Turret Mooring Systems



Swivel Access Structure

Swivel Stack (Production/Controls)

Manifolds + Pig Launching/Receiving

E-House + Subsea Controls + HPUs

Fluid-Transfer

Anchor Leg + Riser Pull-In Equipment

Wheel & Rail Bearing System

Turret Shaft

Chain Supports

Anchor Legs

Risers & Umbilicals

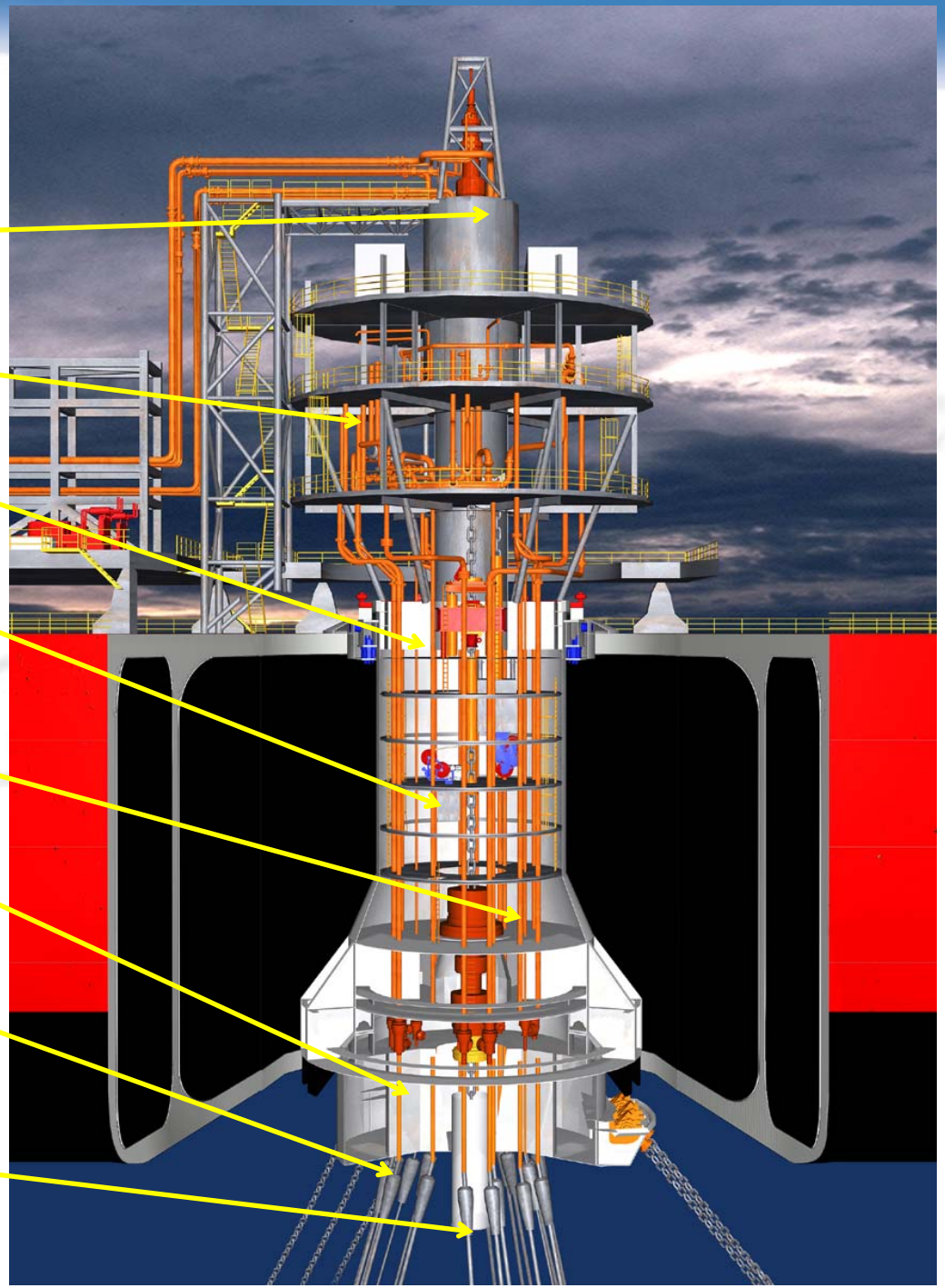
Load-Transfer

Petro-Canada Terra Nova FPSO (Eastern Canada)

- Awarded 1/98
- Installed 10/01
- 95m water depth
- New-build vessel
- 193,000 MT displacement
- 950,000 bbls storage
- 19 risers & umbilicals

- Disconnect for Icebergs / Pack-Ice Only
- Stay Connected in 100-year storm
- Controlled Disconnect: 4

Terra Nova Turret



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SOFEC Disconnectable FPSOs

Santos Mutineer-Exeter, NW Australia (2005)
10 risers & umbilicals, 160m water depth

BHPB Pyrenees (2009)
12 Risers & 3 Umbilicals, 200m water depth

BHPB Stybarrow, NW Australia (2007)
12 risers & umbilicals, 850m water depth

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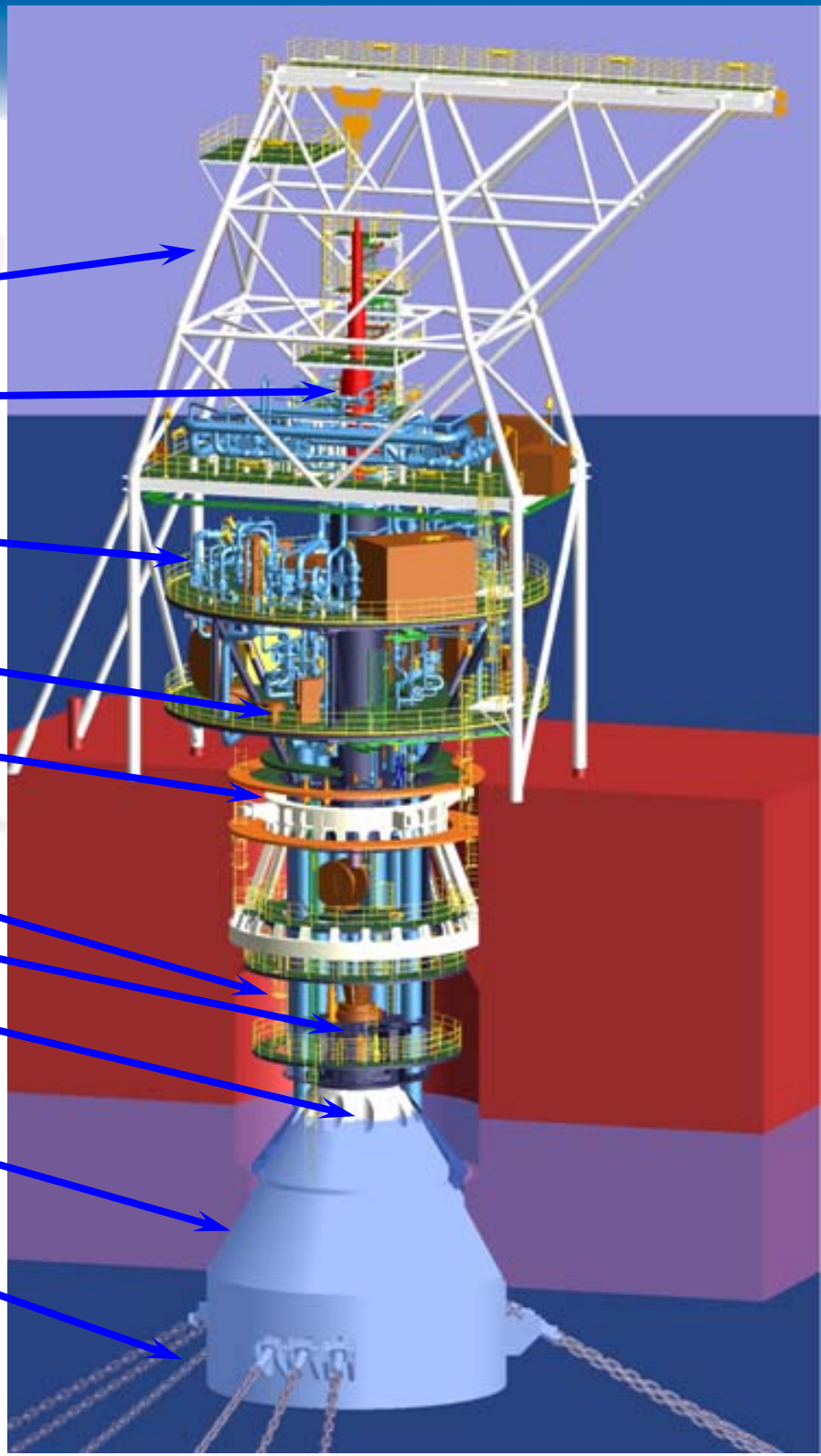
Stybarrow Turret Mooring (Turret fabricated at MMHE)

- Swivel Access Structure
- Swivel Stack
- Manifold Piping
- Riser Deck
- Main Bearing
- Turret Shaft
- Connector
- Risers & Umbilicals
- Spider Buoy
- Anchor Legs



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Tower Yoke Mooring Systems

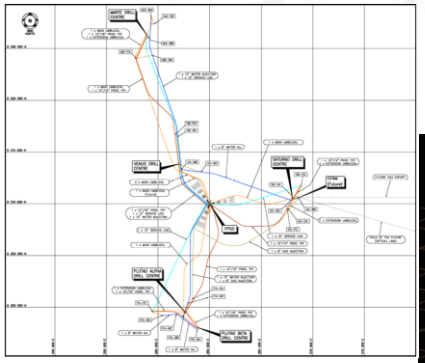
Water Depth = 24m
Mild Environment
240 mmscfd @ 153 barg
SBS Offloading

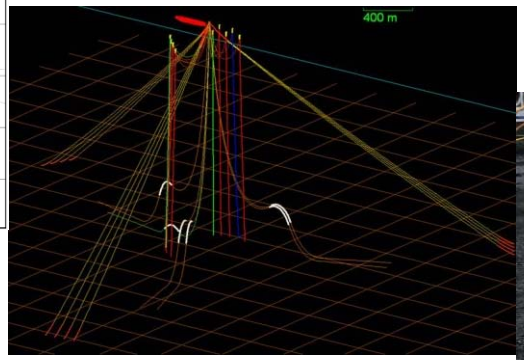
Spread Mooring Systems

As an Ocean Engineer in the Oil & Gas offshore industry…

- Involved in All Mooring-Related Project Phases
  - Conceptual design and preliminary analysis (FEED)
  - Detailed design and class approvals, schedule, budget, project sanctioning (reality sets in)
  - Model Testing (the moment of “truth” for the Ocean Engineer)
  - Specifications and Construction (what it really costs)
  - Offshore installation (it looked good on paper!)

Mooring System Project Life-Cycle – from concept to installation





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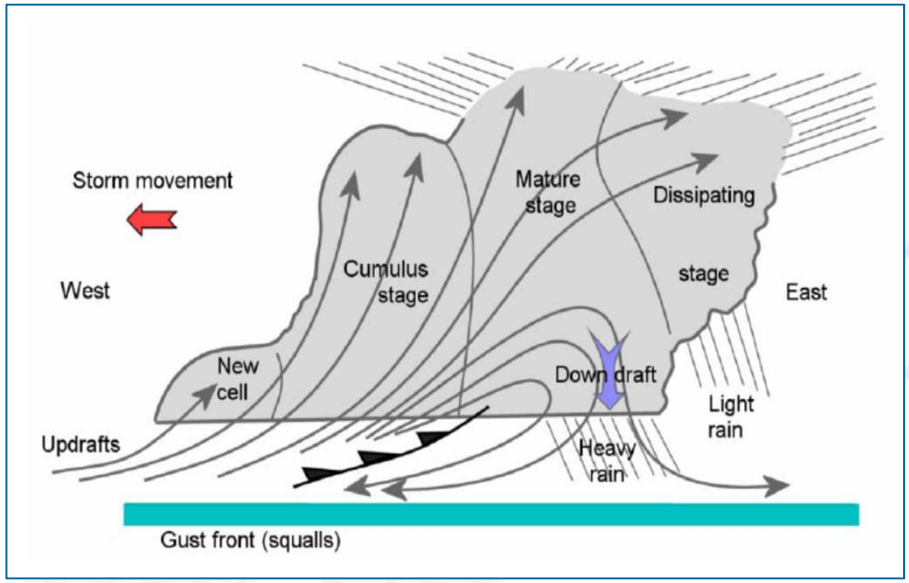
West Africa Environmental Design Criteria

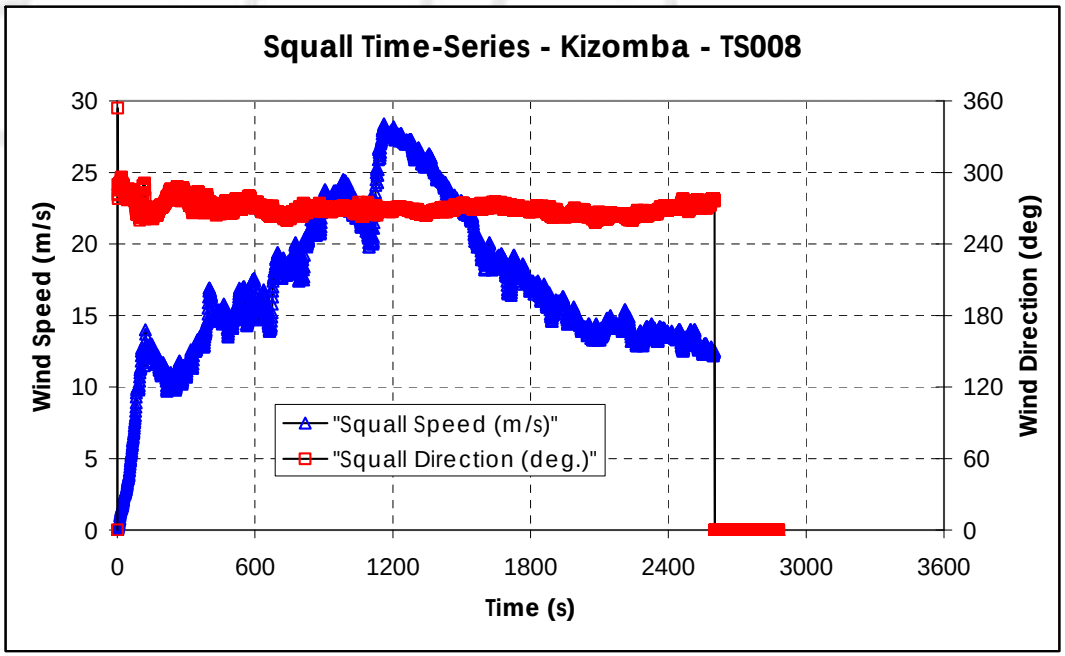
⇒2.0+ m/s (3.9kts) Congo River Outflow

West Africa Environmental Design Criteria

Environmental Design Criteria

⇒Squall-dominated mooring loads and offsets → time-domain analysis
100-yr squall wind 28 m/s (55kts)

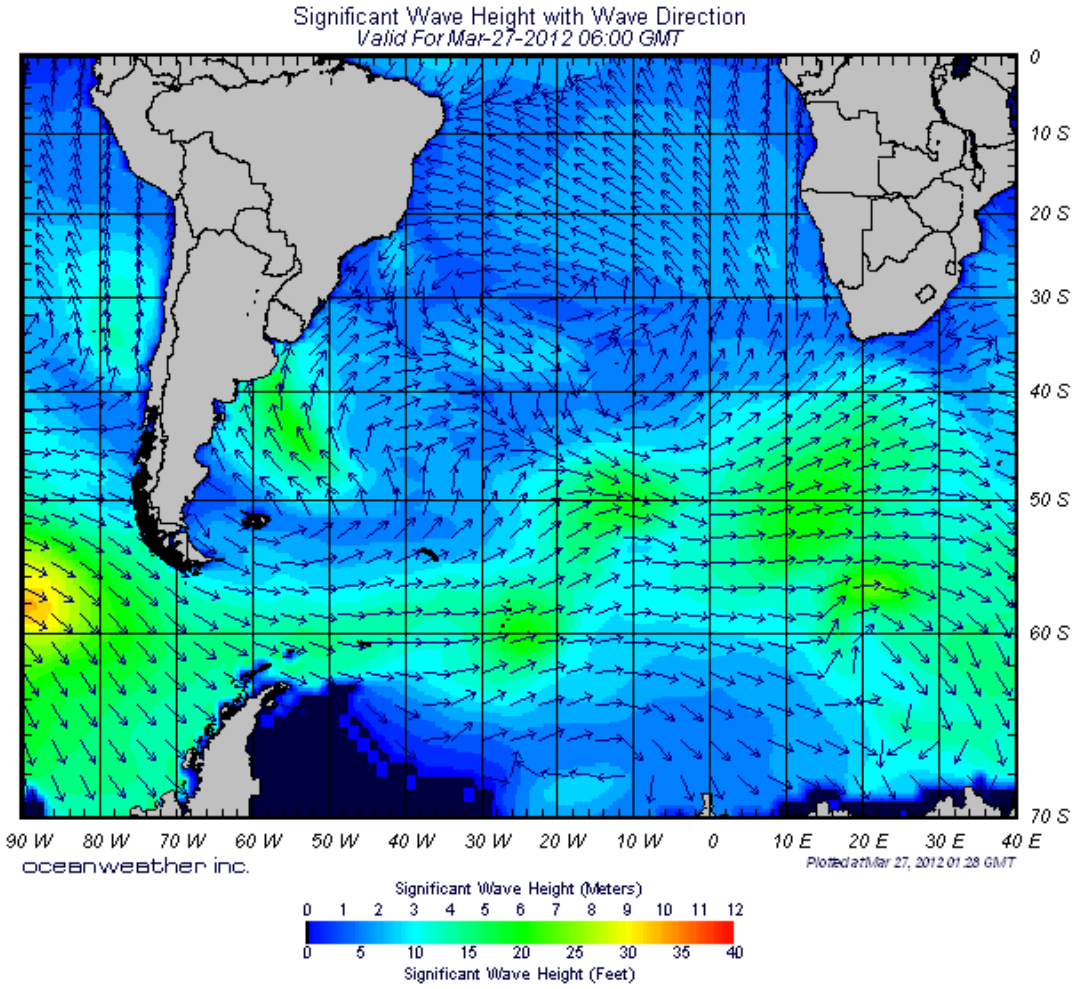




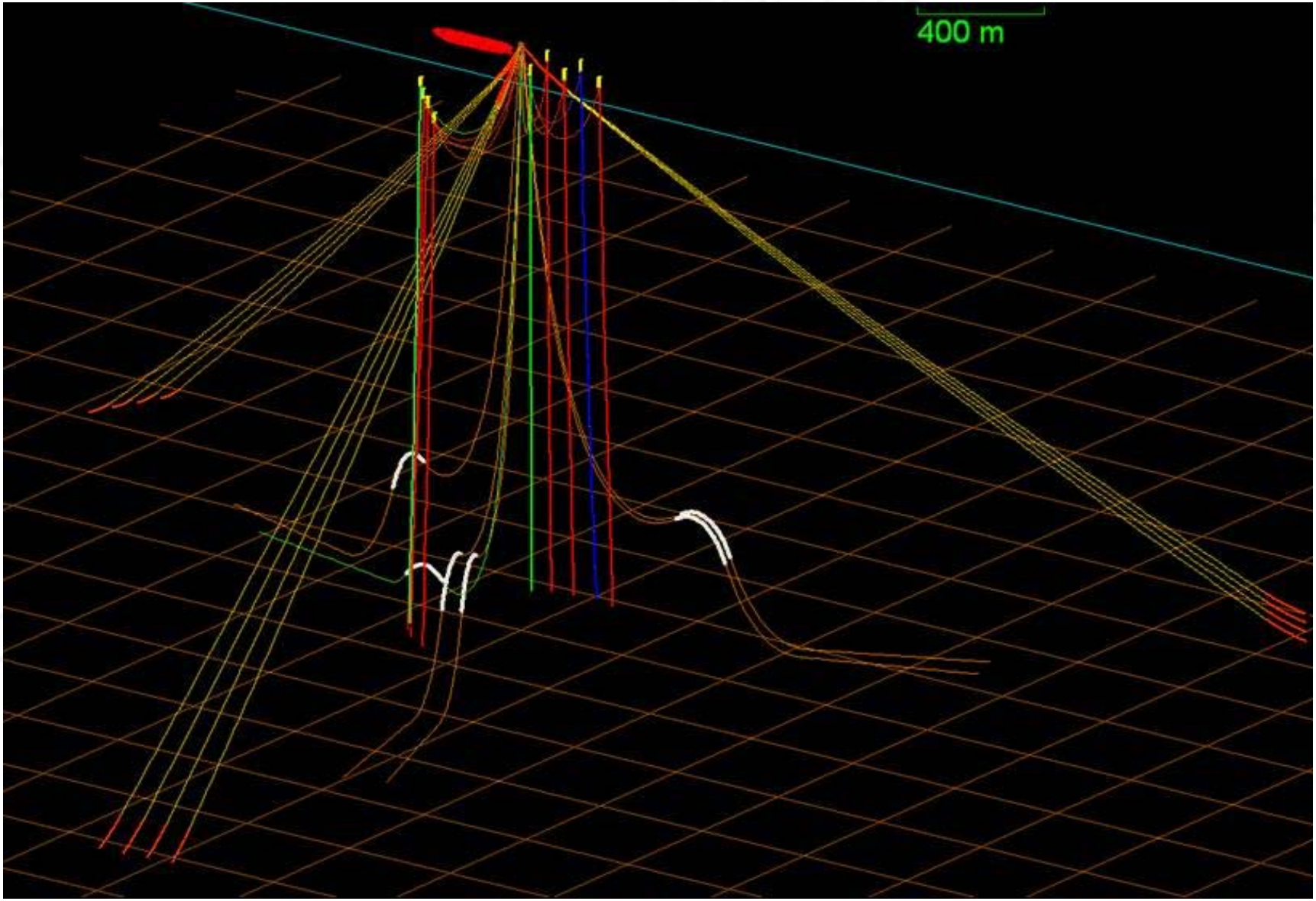
West Africa Environmental Design Criteria

Environmental Design Criteria

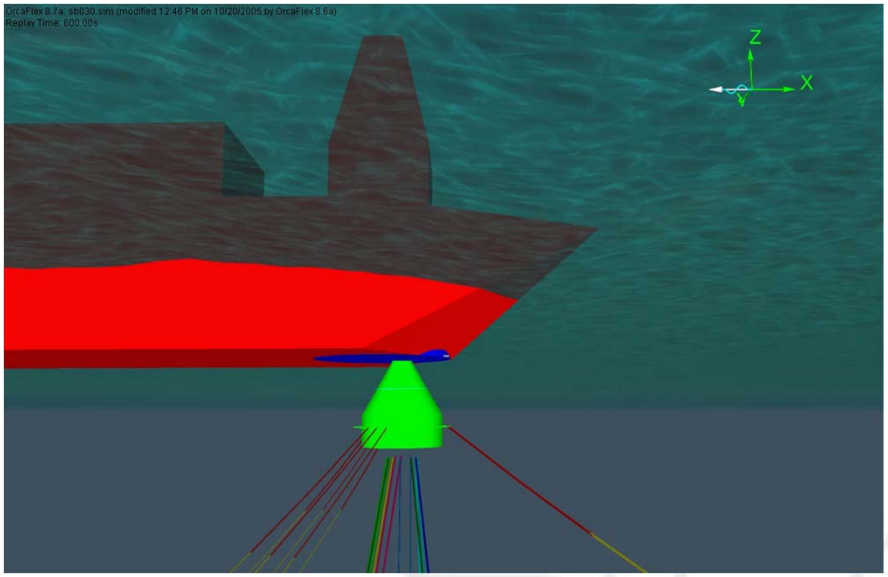
⇒Swell-dominated bearing inertia loads → frequency-domain analysis
100-yr Swell Hs = 4.5m

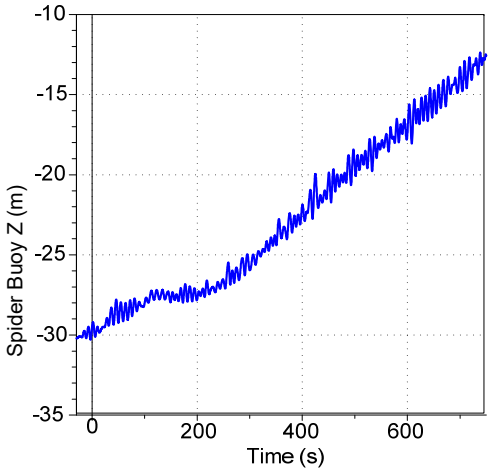


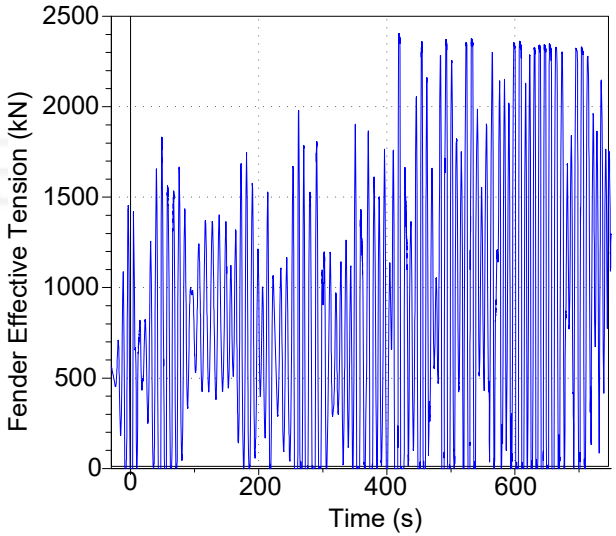
Numerical Modelling of Risers and Mooring



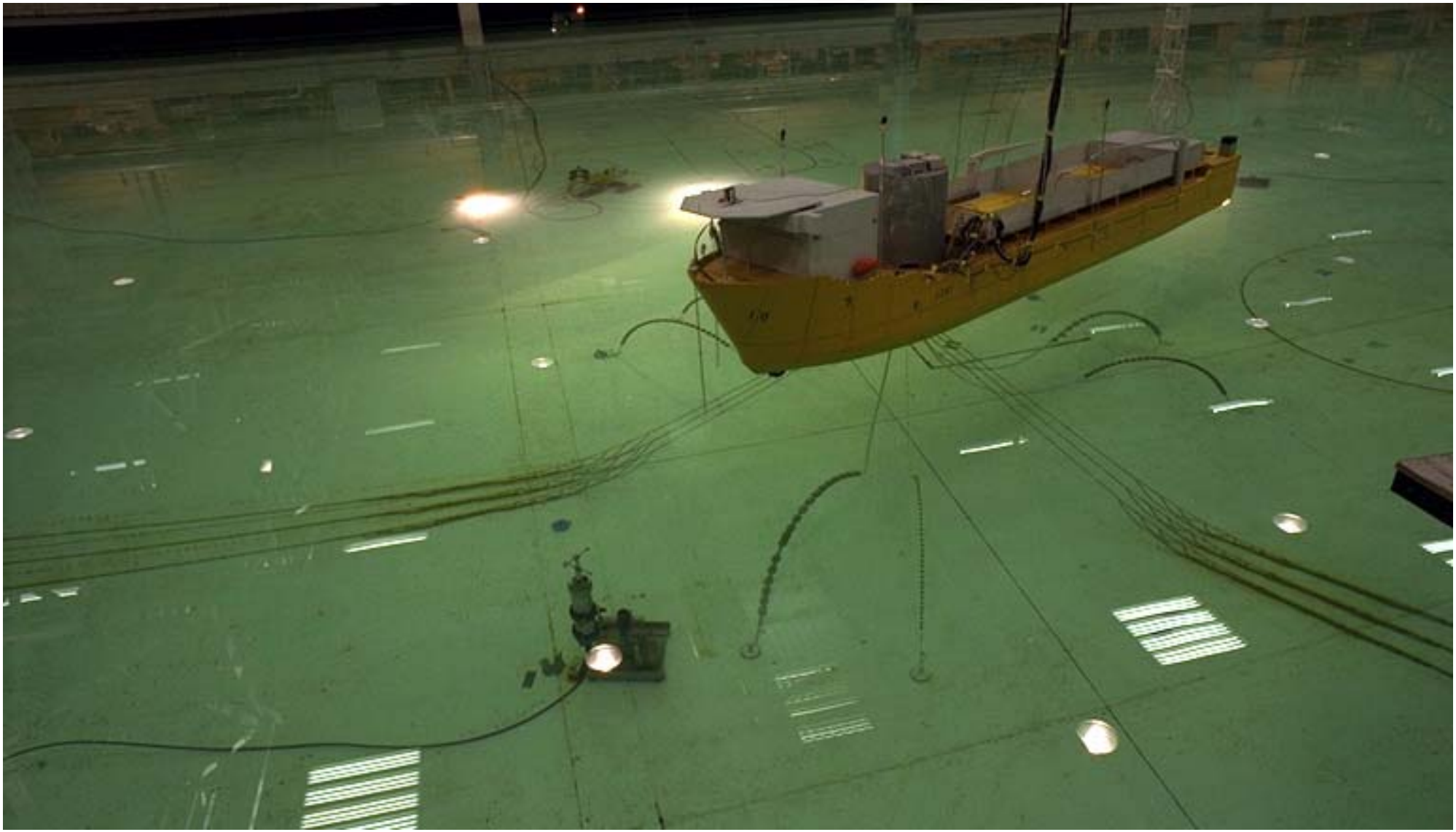
Simulation of Buoy Pull-in Operation





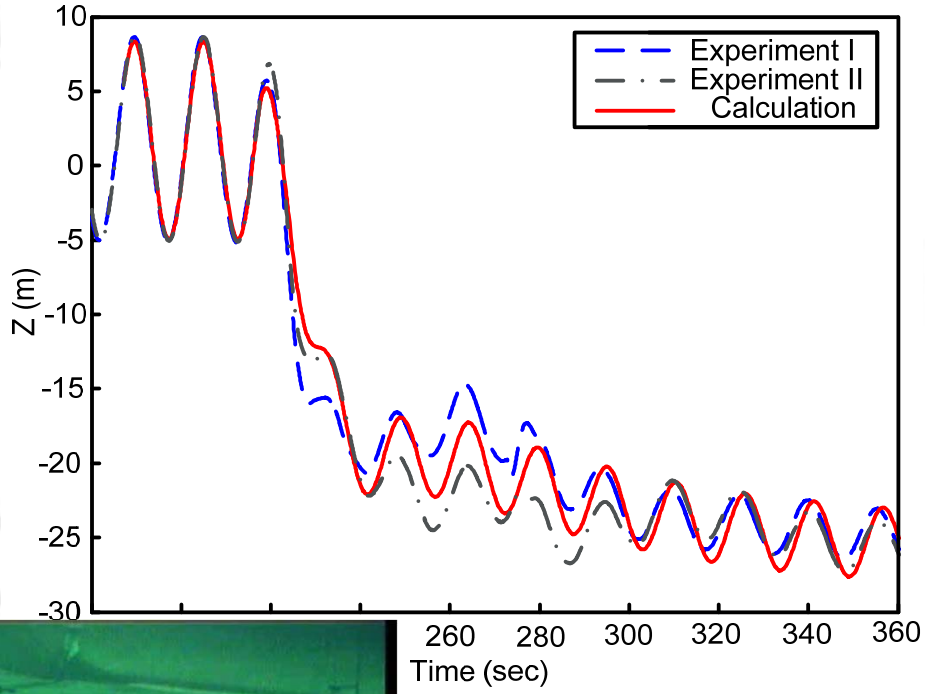


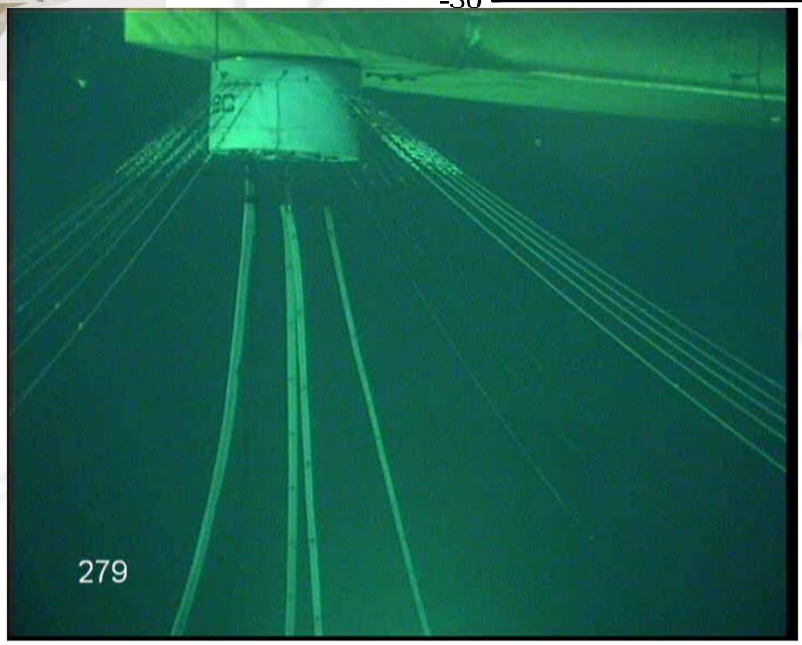
Model Test :: Extreme Events



Performance in Pack-Ice

Disconnect Tests





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Disconnect under 5,000 MT load

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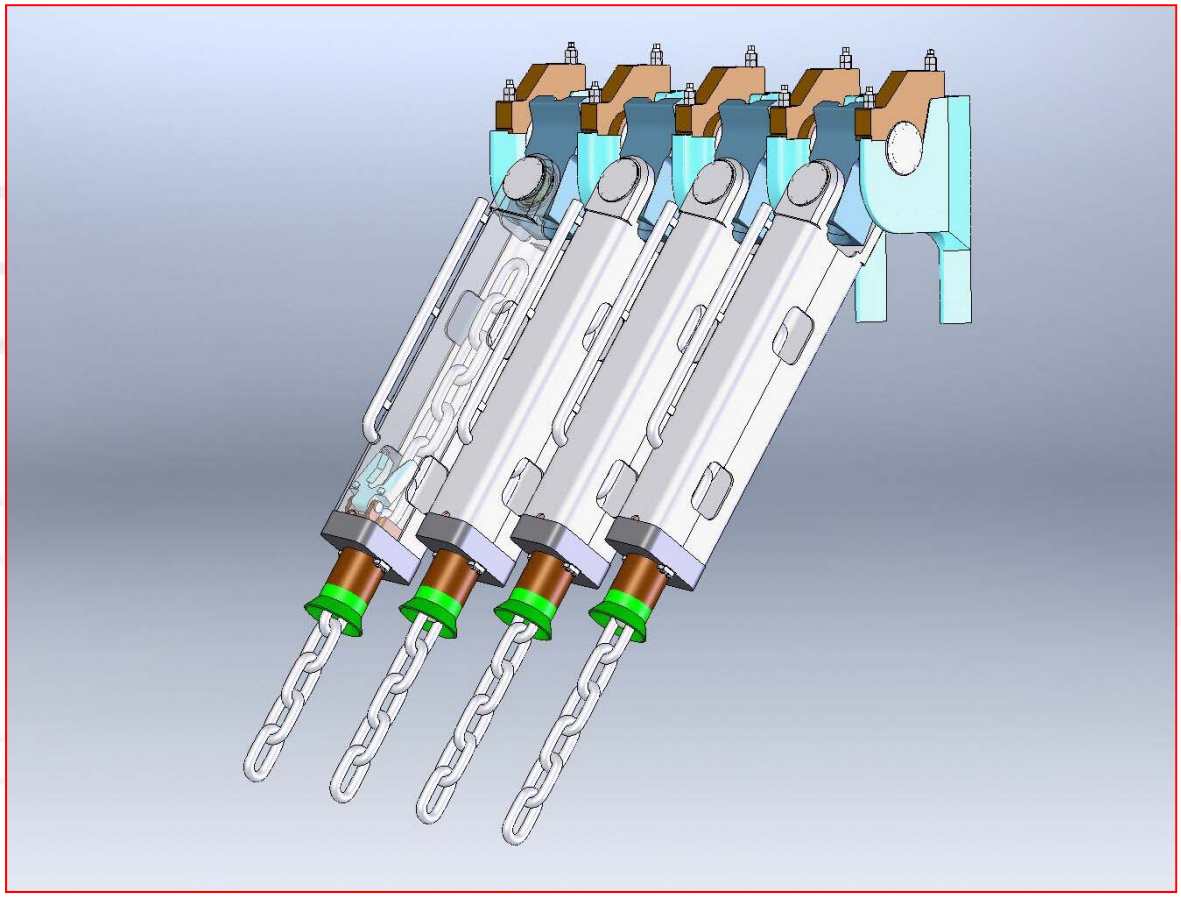
Support the Design of Mechanical Components

Environmental Design Criteria

⇒Fatigue-dominated chain sizing

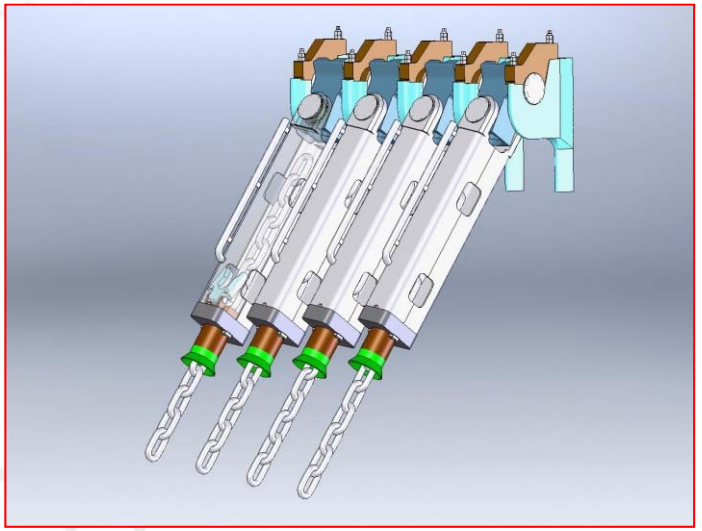
⇒Out-of-Plane bending (OPB) fatigue → Dual Axis Chain Supports

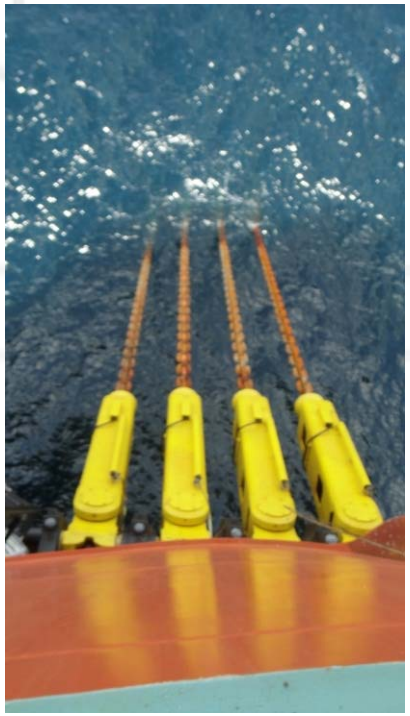


Support the Design of Mechanical Components

Mooring Components

⇒Dual axis chain supports, 5.4m long.
Reduces OPB on top chain.





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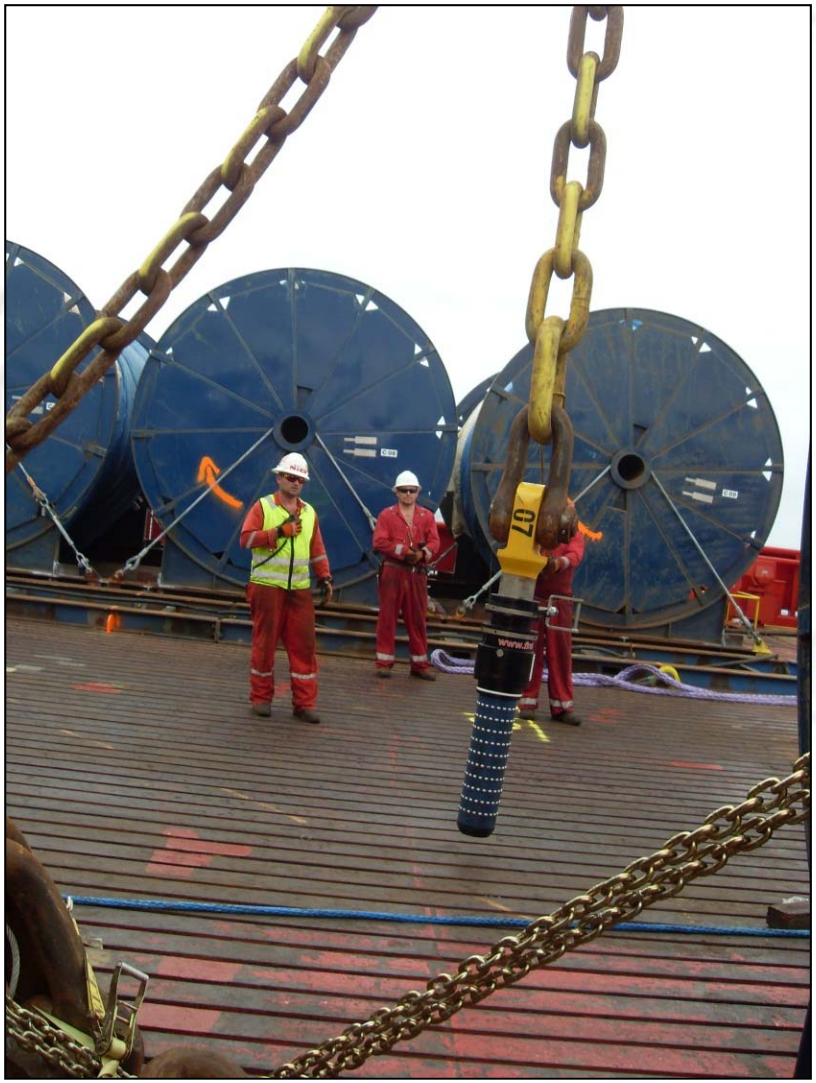
Support the Design of Mechanical Components

Mooring Components

⇒Over-boarding of male Ballgrab and bottom chain



Mooring Components

Ball Grab Subsea Connector and Suction Pile

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Offshore Support

Mooring Leg Hookup