Deep Water Turret-Moored FPSO for West Africa

Marty Krafft, Ph.D.
Lead Research Engineer
R&D / Hydrodynamics Dept.

March 30, 2012

FSO/FPSO MOORING SYSTEMS – 46 Completed; 3 Under Design/Construction

Internal Turret
Permanent & Disconnectable

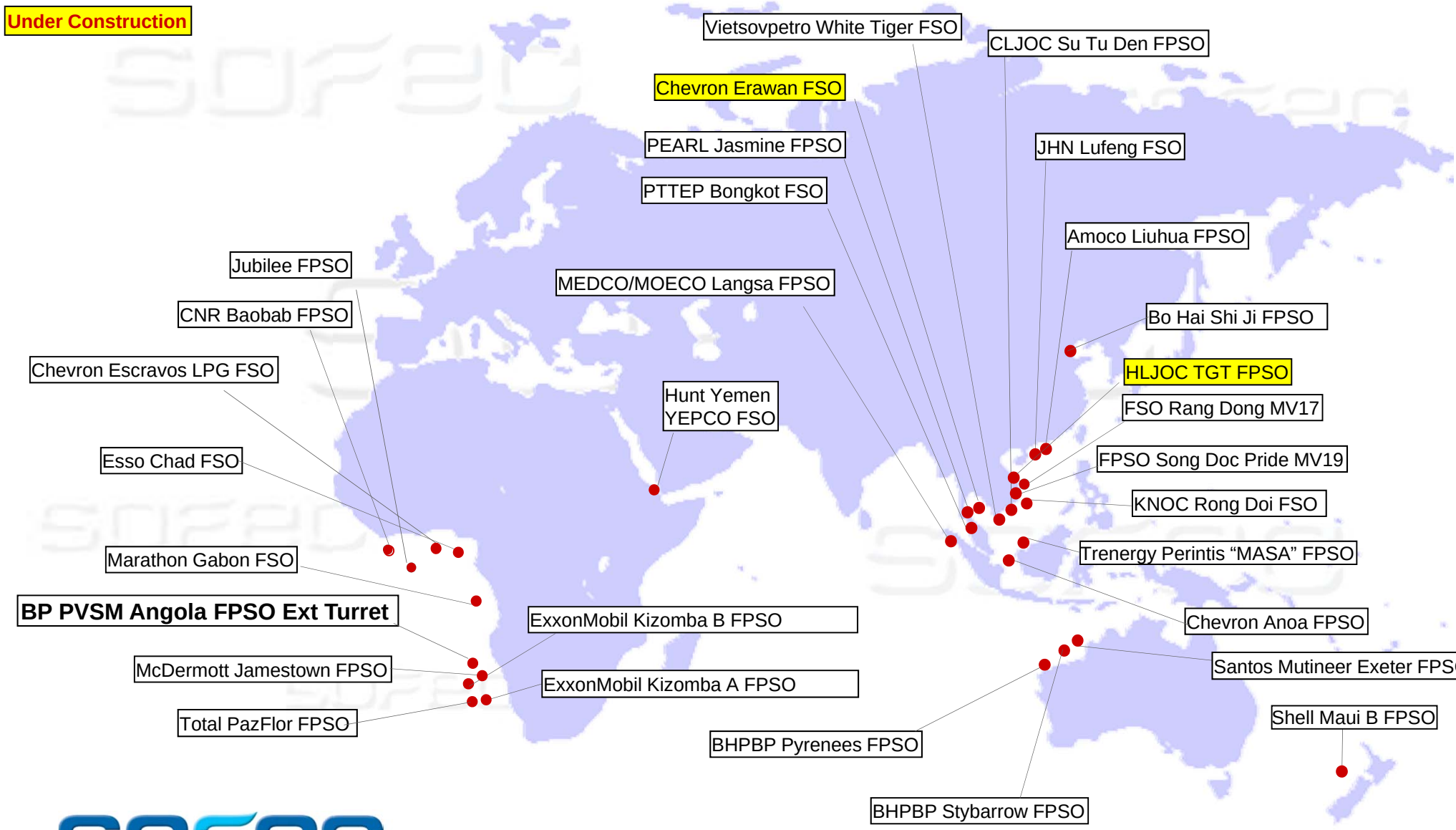
External Turret

Spread Mooring

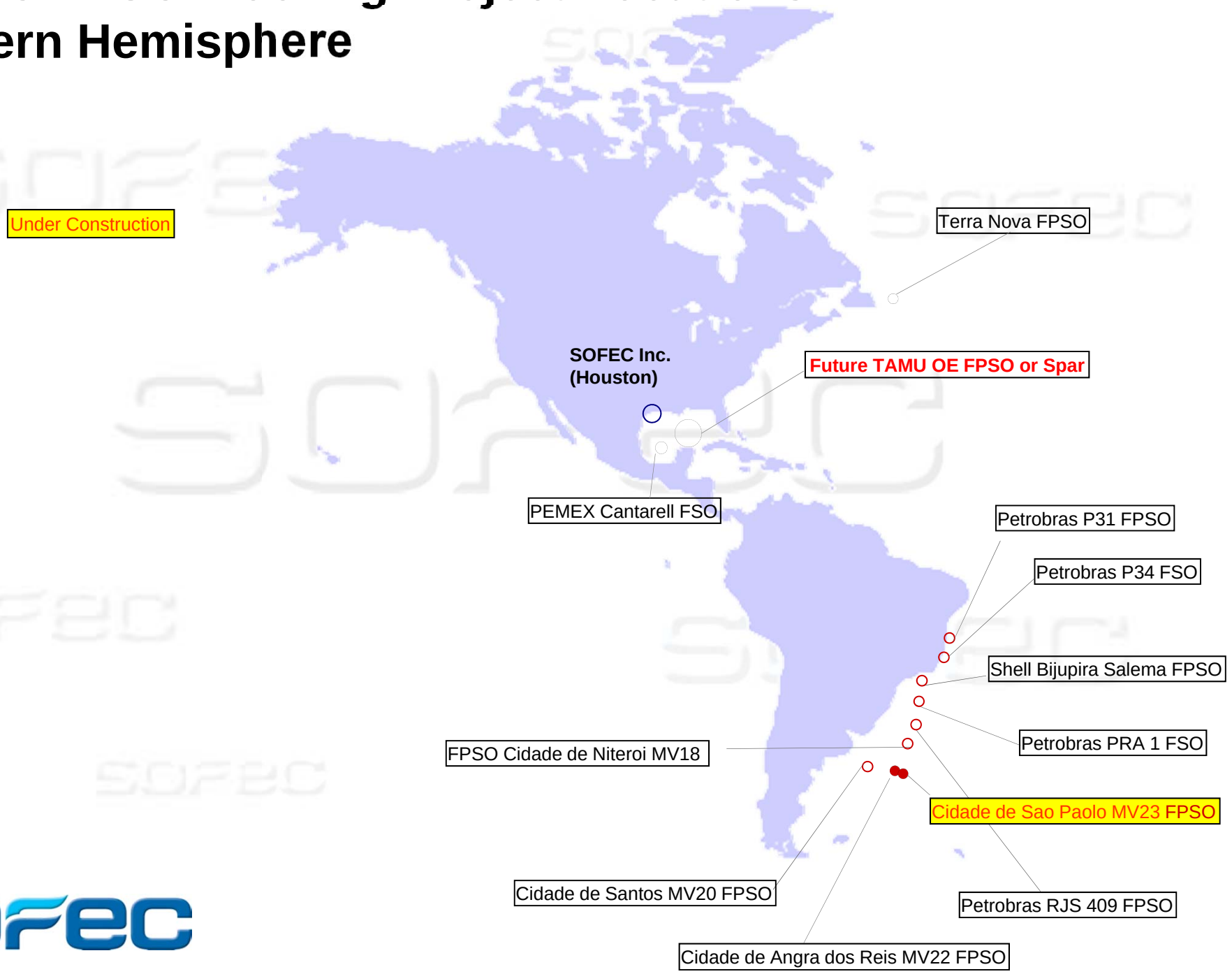
Tower Yoke (Shallow Water)

SOFEC

SOFEC FPSO Mooring Project Locations
Eastern Hemisphere



SOFEC FPSO Mooring Project Locations
Western Hemisphere



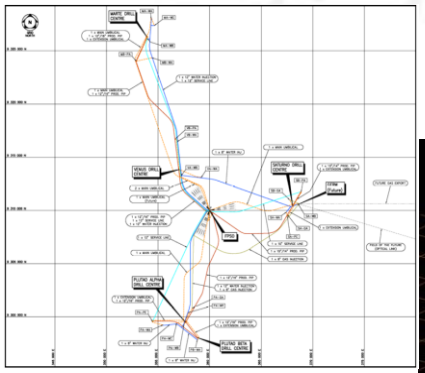
I really like my job!…

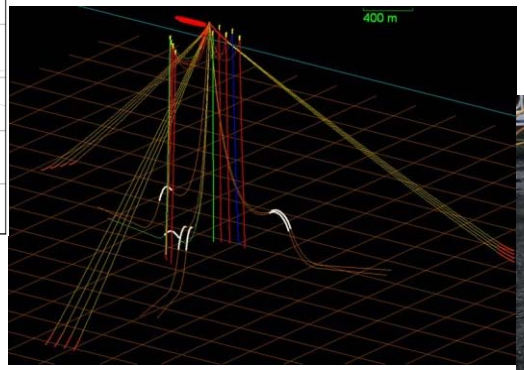
- 22 (+ 3) years on the job as mooring and riser designer

  (I count the last 3 years of OE grad school at A&M doing what you students have been doing all year – applied design and analysis)
- 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!)

I Really like my job!…

- Mooring System Project Life-Cycle – from concept to installation





SOFEC Turret Mooring Systems: 33 to date

- SOFEC's Turret Mooring Design and Operational Experience from 1988 - 2012
  - 3 Permanent Internal Turret Mooring Systems
  - 5 Internal Disconnectable Turret Mooring Systems
  - 25 External Turret Mooring Systems (industry trend for turret types)
- Overall 260 years of operational life
  - Longest duration: 24 years on site (Safer FSO, Yemen, 1988)
  - Shortest duration: 24 days (BP PSVM FPSO, Angola, March 6 2012)

FPSOs: Turret Vs Spread Moor

46 FSO/FPSOs Completed; 3 Under Construction

External Turret: Tandem and Side-By-Side

Internal Turret: Tandem

Spread: Tandem Bow or Stern

External Turret: Tandem

SOFEC

FPSOs: Turret Vs Spread Moor

Comparative Summary of Turret Moored and Spread Moored FPSO Systems

	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

SOFEC

FPSOs: Turret Vs Spread Moor

Offloading Systems

Offloading Operability, Offloading Operability, Offloading Operability

(How do we get the ~~money~~ oil to shore as efficiently as possible?)

- Tandem Offloading

  - From bow or stern on Spread Moor
  - From stern only on Turret Moor

- Side-by-Side

  - Turret or Spread, but increased risk of vessel collision often kills this option
  - Reduced environment compared to tandem

- Remote (Satellite) Offloading from Buoy

  - Offers best uptime for large, high production, deep water fields.
  - Lowest risk of collision

SOFEC

FPSOs: Turret Vs Spread Moor

Production Rate Vs Offloading System

- < 50k BPD + 1M Barrel Offload Parcel Every 20 days
  - Spread Moor + Tandem Offload (bow and stern)
  - Tandem offloading from spread moored vessel possible especially in West Africa and Brazil
- 50k – 80k BPD
  - Gray Area.
- 80k – 150k+ BPD (BP PSVM FPSO External Turret, 157kBPD)
  - Turret with tandem offloading is usually the best solution.
- 175k – 300k+ BPD
  - Turret or Spread Moor each with Remote, Deep Water Offloading Buoy
- All Ultra-Large Fields in WA use Spread Moor + Remote DW CALM Buoy

Internal Vs. External Turret Systems

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

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

Chevron Erawan Thailand

SOFEC

BP Angola PSVM FPSO External Turret

Characteristics

- ⇒MODEC Int. LLC 300,000DWT VLCC Conversion: one of the world's largest FPSO's
- ⇒Approx. conversion cost of $1.5B compared to $2.0+B new-build
- ⇒1.8Mbbls storage ($216,000,000)
- ⇒157,000 barrels of oil per day ($18,800,000/day) and 245 million cubic feet gas per day
- ⇒8.1 million man-hours for construction
- ⇒20,000+ tonnes of topsides equipment
- ⇒One of the biggest external turrets ever constructed: 3,000+ tonnes
- ⇒2,030m (6,660ft) water depth, 3 x 4 grouped, taut poly anchor legs
- ⇒15 Single Leg Hybrid Risers (SLHR) and Lazy Wave umbilicals
- ⇒Tandem Offloading

SOFEC

BP Angola PSVM FPSO External Turret

Mooring System Design Criteria

⇒Maximum intact/damaged offset = 5% / 6% of water depth

⇒1-line missing = “intact”, 2-lines missing = “damaged” → (redundancy: 3 x 4 mooring system required instead of 3 x 3)

⇒No contact with SLHR risers or Lazy-Wave umbilicals

⇒Wire rope or polyester rope allowed (no poly rope on seabed)

⇒Rope segment replaceable → subsea connector

⇒Extremely soft soil → low aspect ratio suction pile

⇒20-yr design life

⇒Coupled Mooring+Riser Analysis

BP Angola PSVM FPSO External Turret

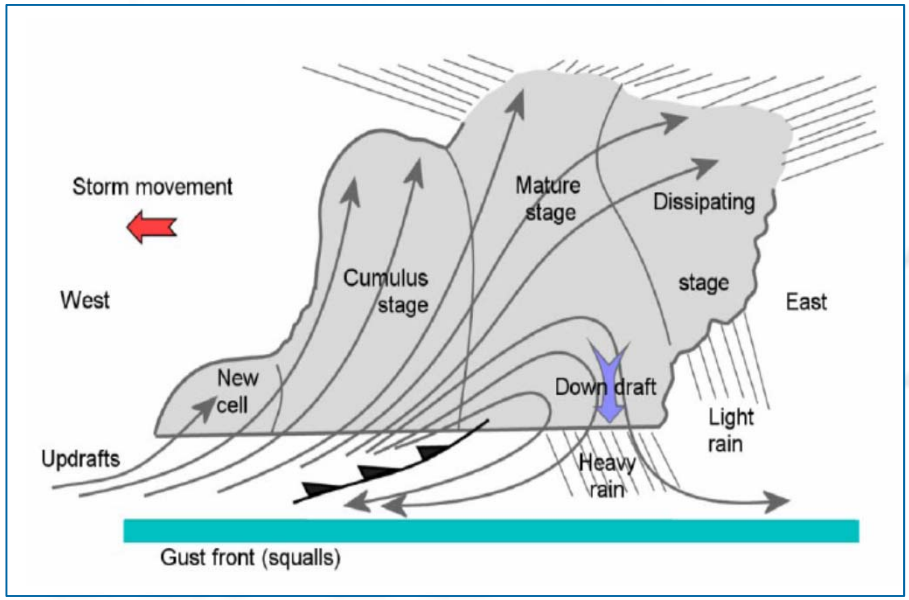
Environmental Design Criteria

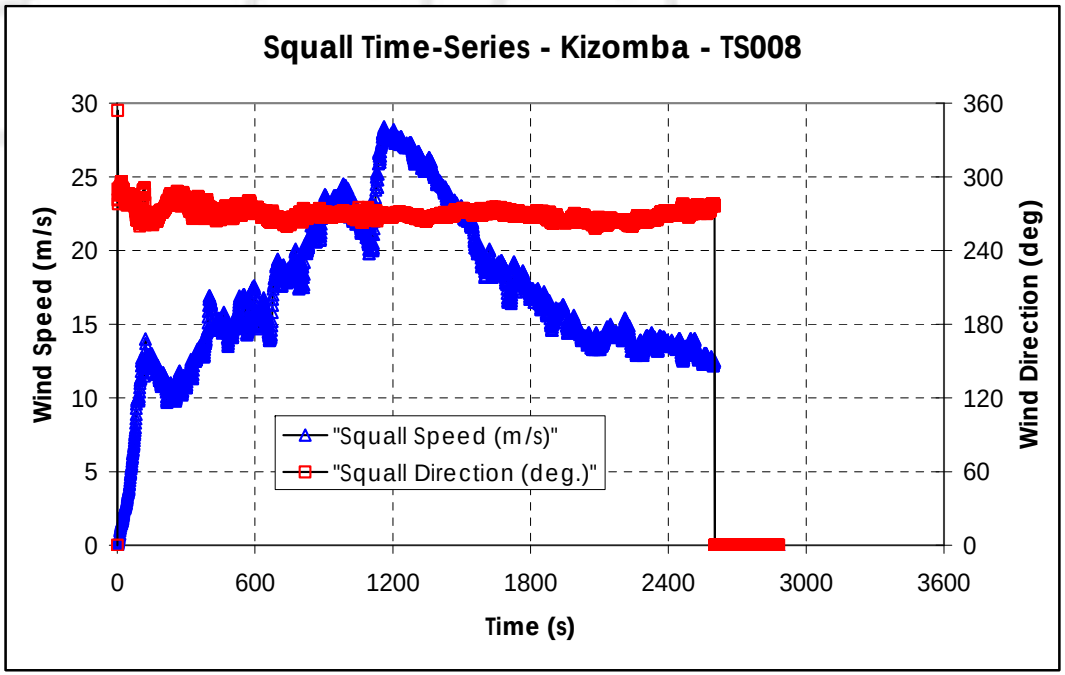
⇒2.0+ m/s (3.9kts) Congo River Outflow

BP Angola PSVM FPSO External Turret

Environmental Design Criteria

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

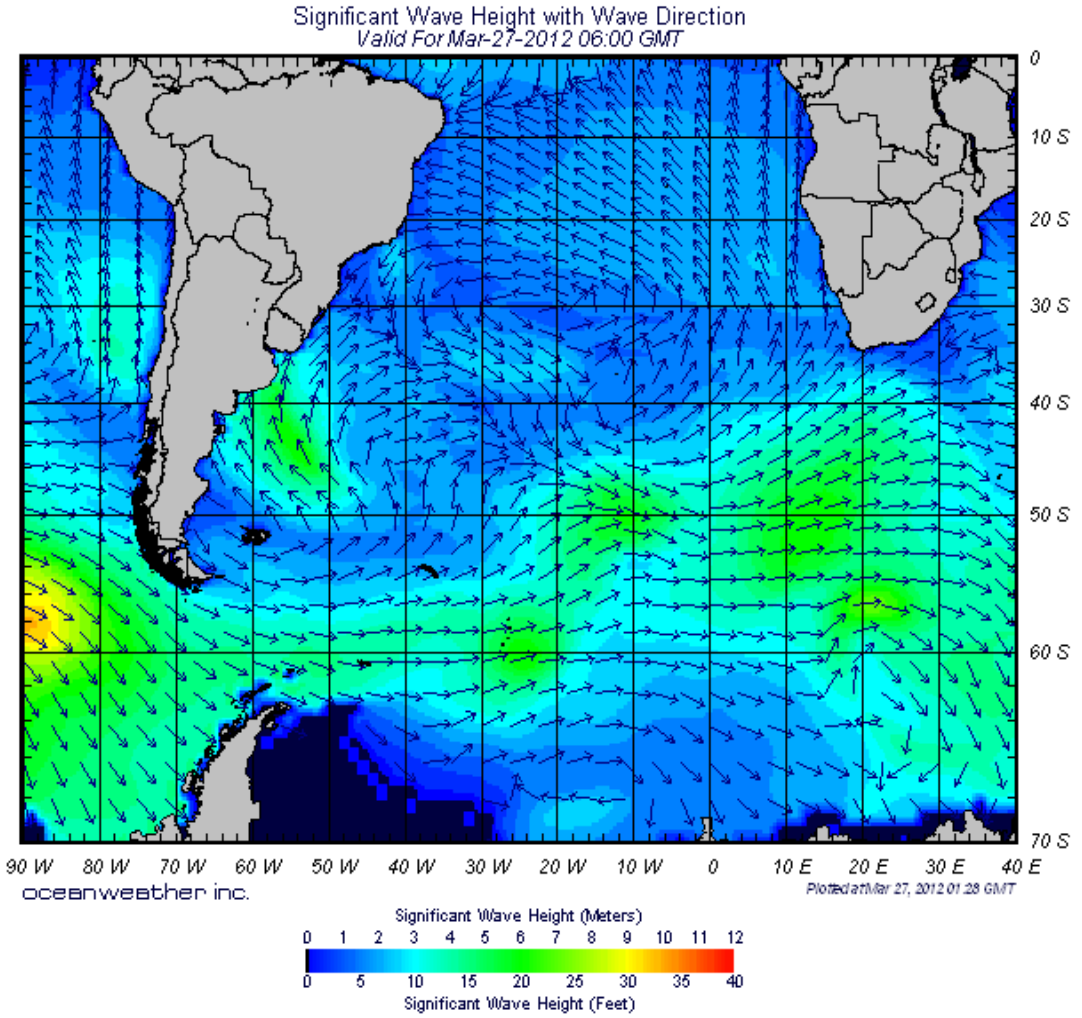




BP Angola PSVM FPSO External Turret

Environmental Design Criteria

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

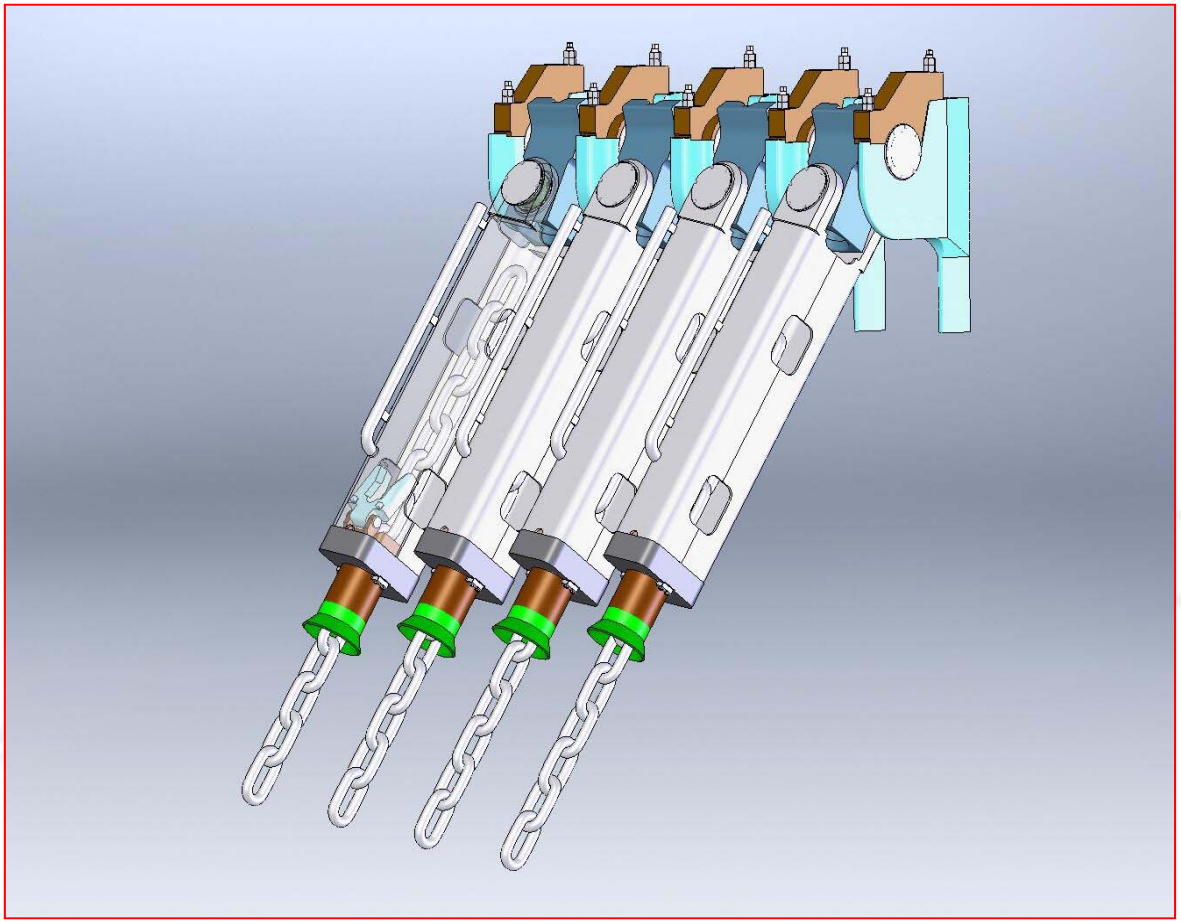


BP Angola PSVM FPSO External Turret

Environmental Design Criteria

⇒Fatigue-dominated chain sizing

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



BP Angola PSVM FPSO External Turret

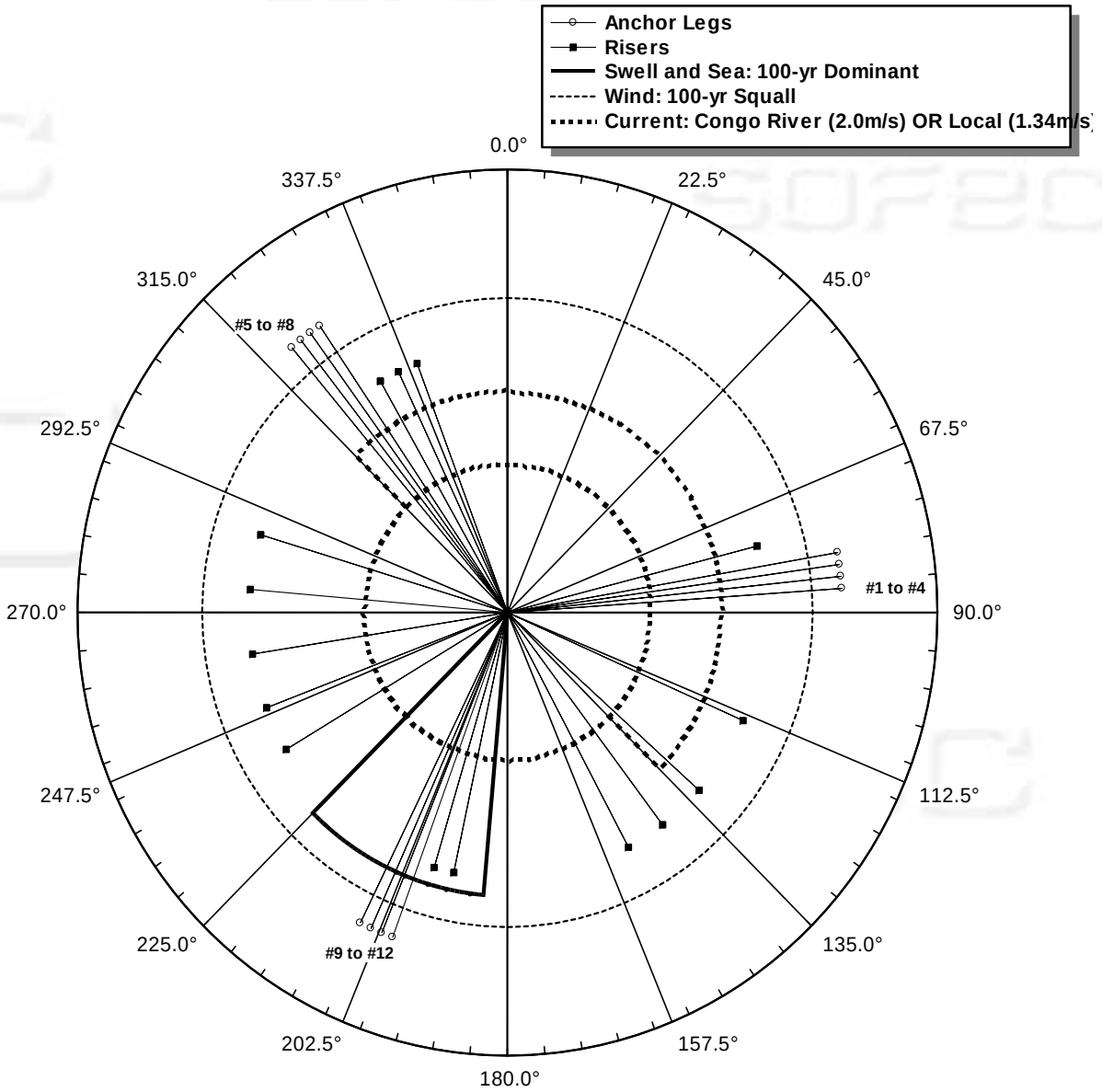
Mooring Components

- ⇒3 x 4 taut polyester mooring system
- ⇒7.3m single piece, 3 row roller bearing
- ⇒Dual axis chain supports
- ⇒98mm studless top chain, 130 meters (large diameter for OPB)
- ⇒414 tonne MBL polyester rope, 3,000 meters
  (twice the distance between Rec Center and OE building)
- ⇒76mm studless bottom chain
- ⇒500 tonnes First Subsea Ballgrab connector
- ⇒4m x 17m suction pile, 66 tonnes

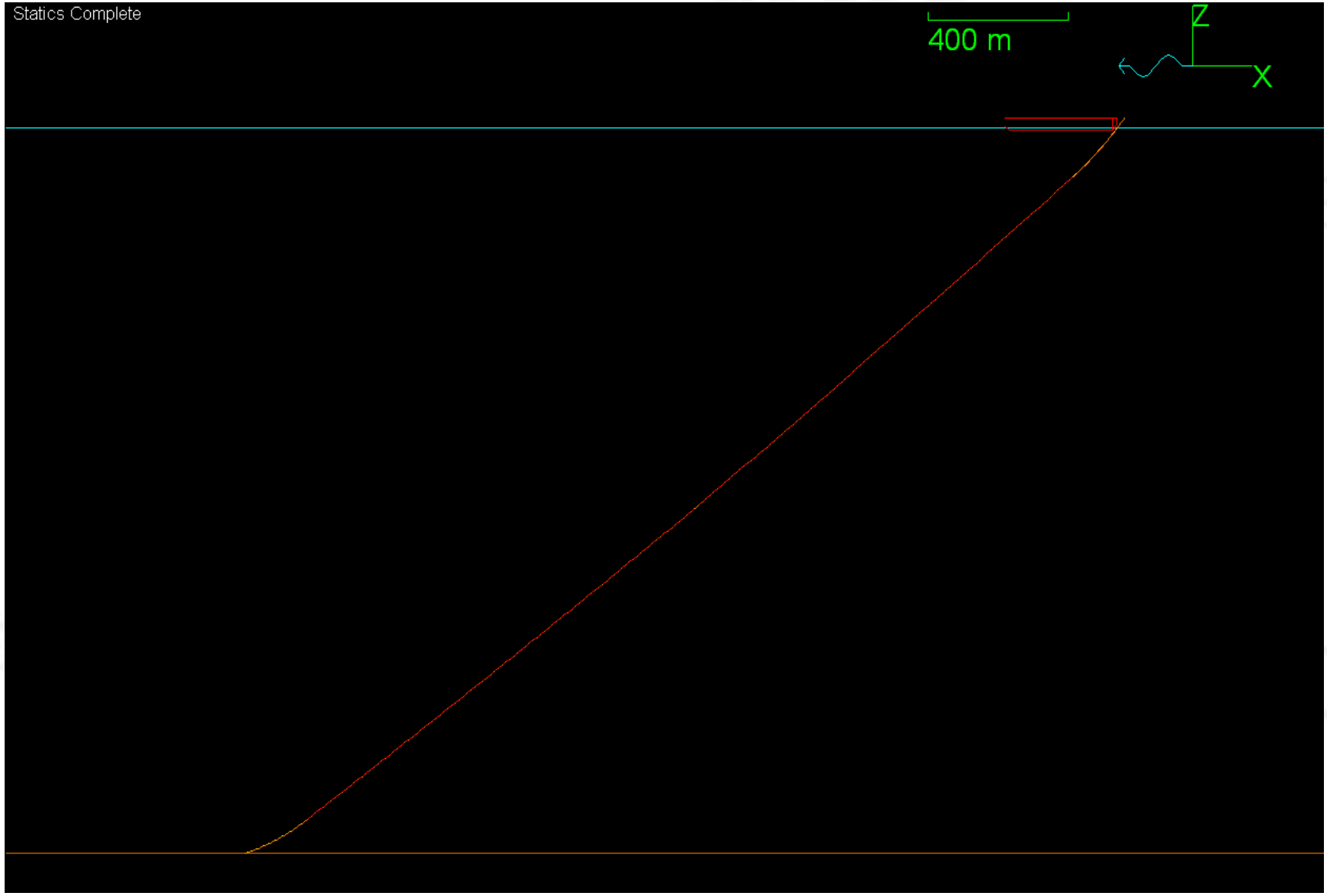
BP Angola PSVM FPSO External Turret

Mooring Components

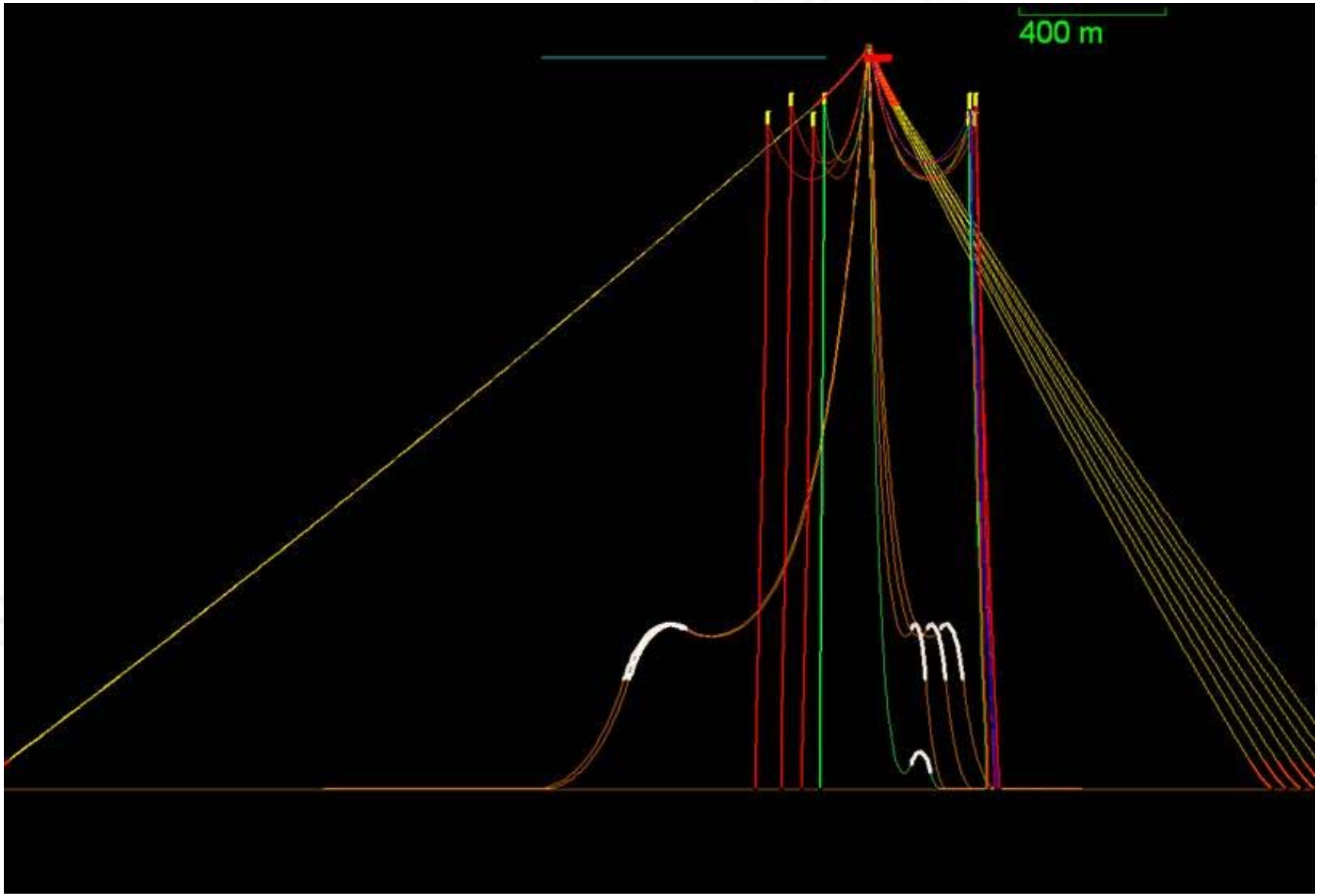
⇒3 x 4 taut polyester mooring system



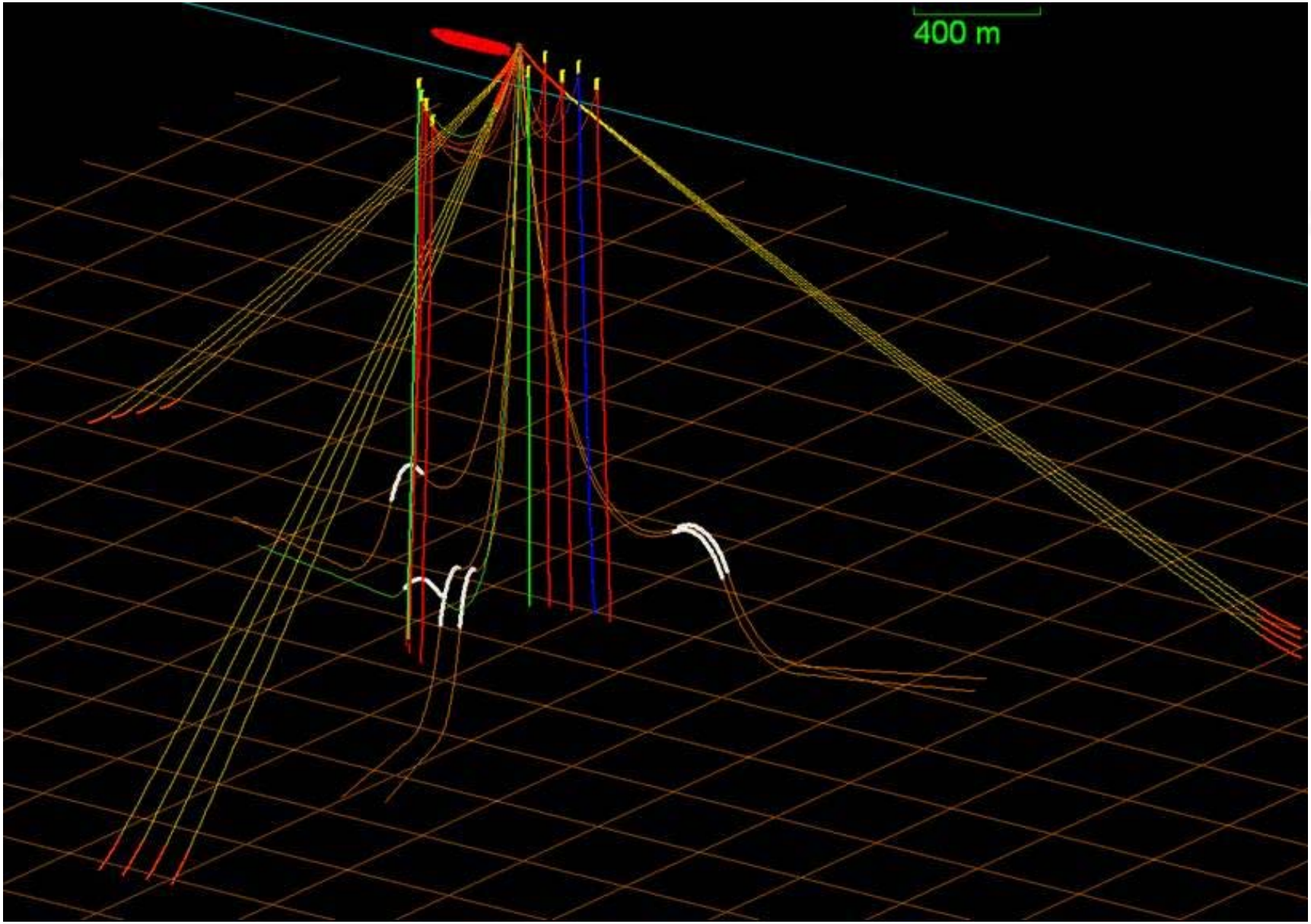
BP Angola PSVM FPSO: 2,030m depth



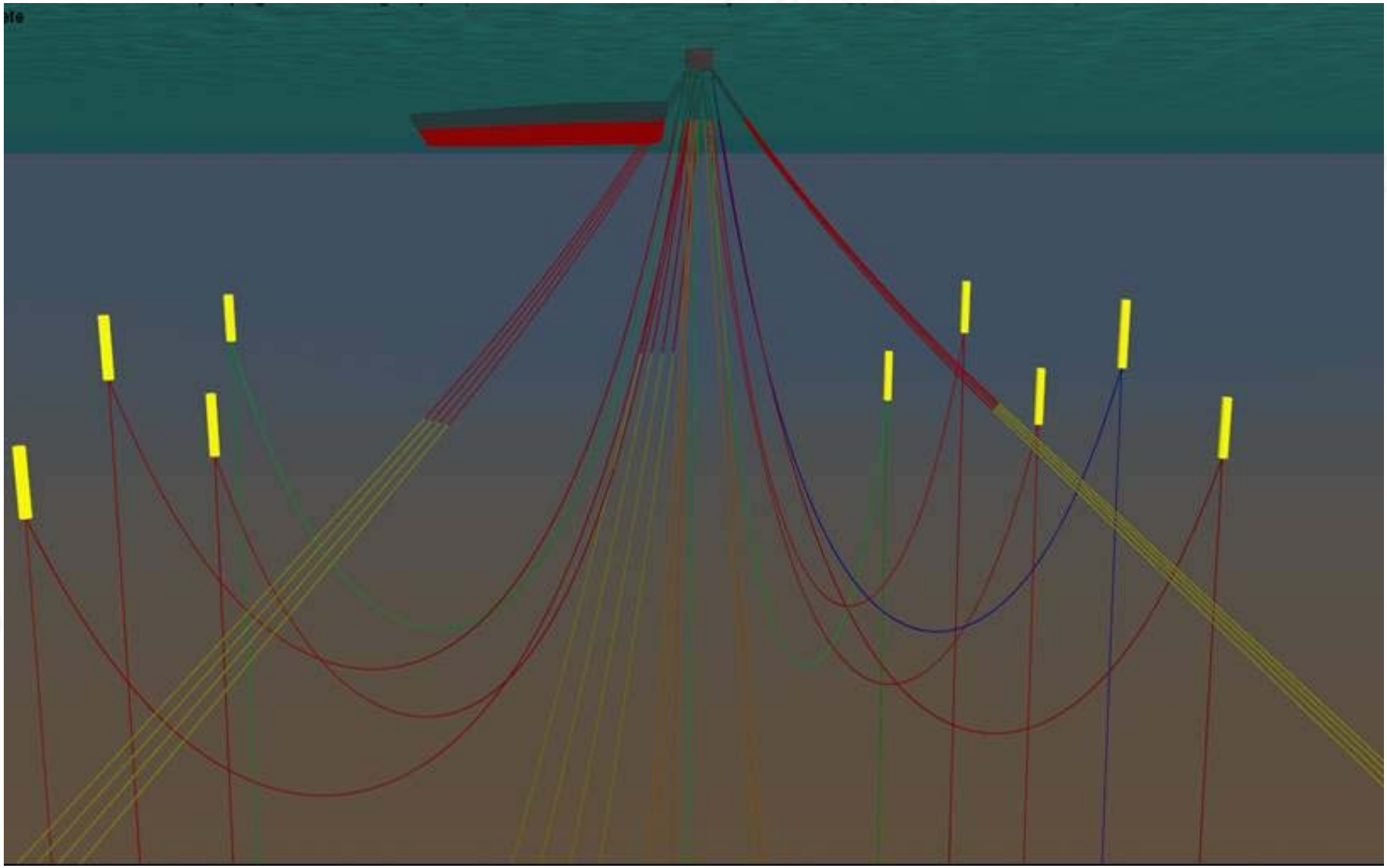
BP Angola PSVM FPSO: 2,030m depth



BP Angola PSVM FPSO : 2,030m depth



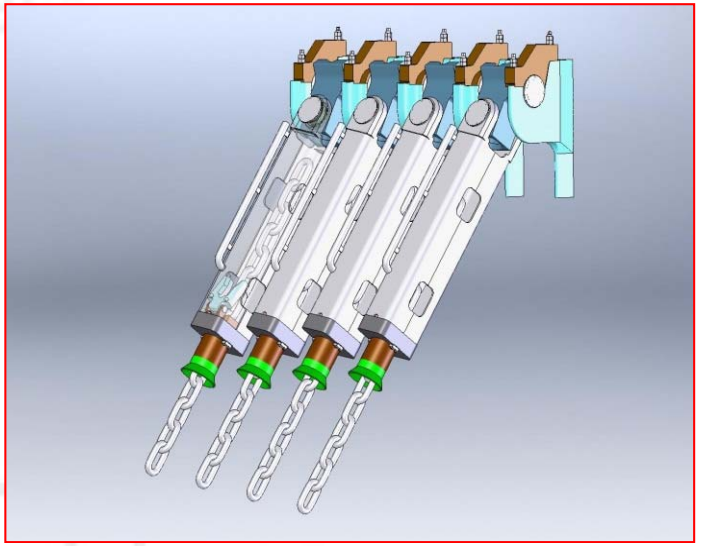
BP Angola PSVM FPSO : 2,030m depth

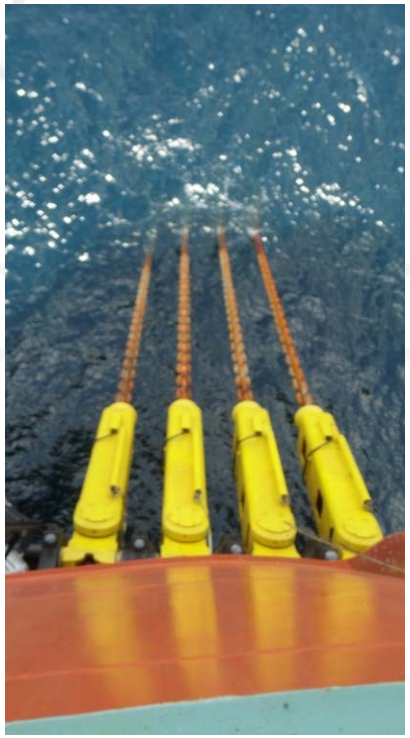


BP Angola PSVM FPSO External Turret

Mooring Components

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

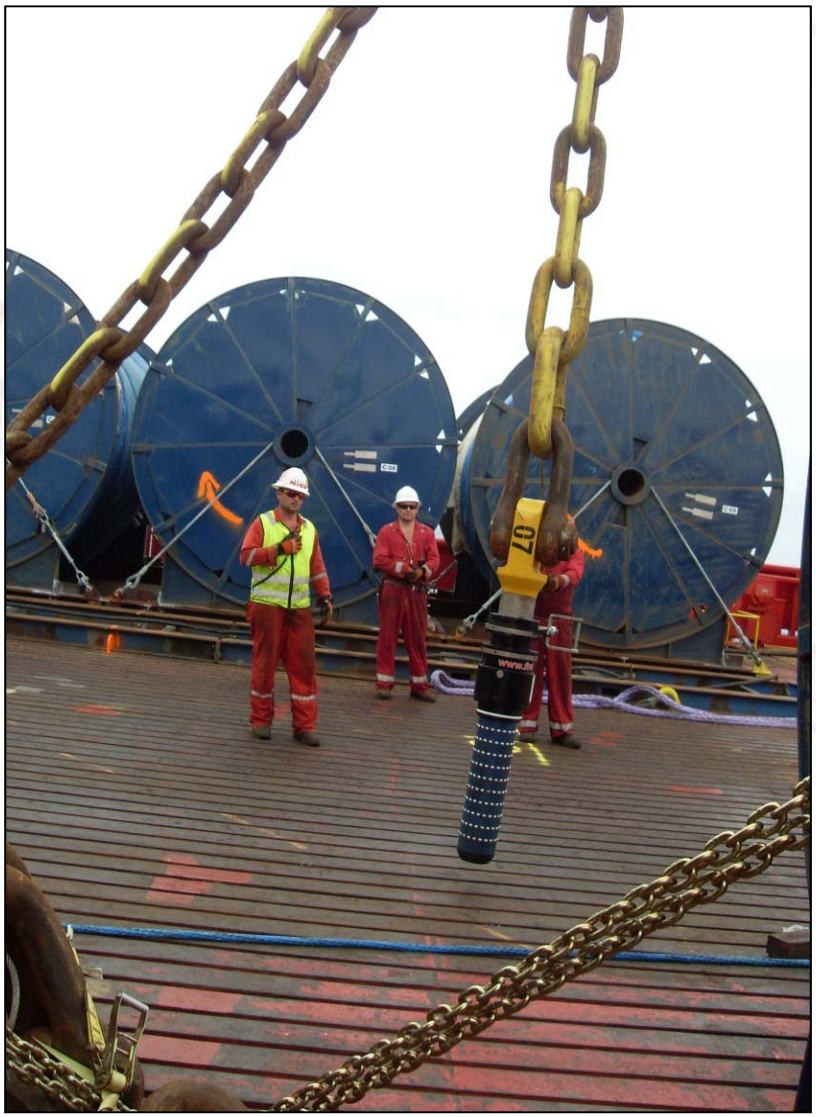




BP Angola PSVM FPSO External Turret

Mooring Components

⇒Over-boarding of male Ballgrab and bottom chain



BP Angola PSVM FPSO External Turret

Mooring Components

⇒Over-boarding of bottom chain and poly rope
(links painted to ensure no twist during deployment)

BP Angola PSVM FPSO External Turret

Mooring Components

⇒Ball Grab Subsea Connector and Suction Pile

BP Angola PSVM FPSO External Turret

Mooring Components

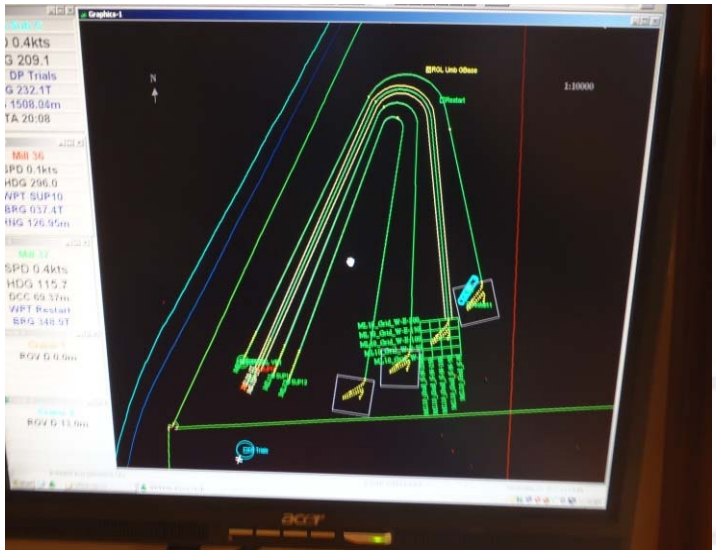
⇒Polyester Rope

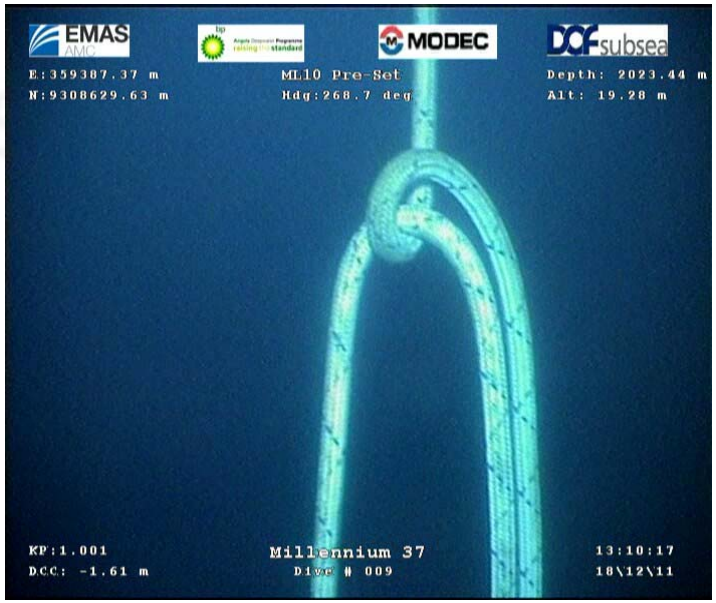
- Not originally intended to touch the seabed (soil ingress concerns)
- Sand/Soil filter capable of blocking 5 micron particles (typical bacteria size is on the order of 10 micron)
- Project delay issues resulted in pre-deployment and temporary abandonment of poly on seabed.
- However, pre-stretching of polyester made this very light rope (2kg/m wet) stiff in bending and difficult to lay on the seabed without kinking (first, pre-streched leg took 24 hours to lay down cleanly). Pre-stretch procedure was eliminated for remaining legs, and subsequent poly laydown went very quickly.

SOFEC

BP Angola PSVM FPSO External Turret

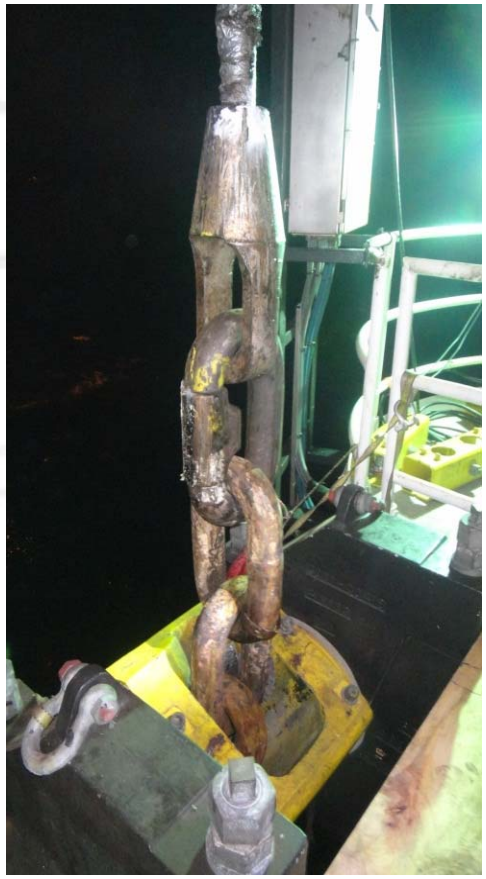
Polyester Rope Laydown: difficulty with pre-stretched rope





BP Angola PSVM FPSO External Turret

Mooring Leg Hookup: EMAS *Boa Deep C* Handing Off Leg to FPSO



BP Angola PSVM FPSO External Turret

Mooring Leg Hookup

⇒riggers are amazing at fixing problems!

BP Angola PSVM FPSO External Turret

Mooring Leg Hookup

⇒First leg hooked up!

BP Angola PSVM FPSO External Turret

Mooring Leg Tensioning

⇒Extra top chain length is provided so that initial installation loads are low: initial hookup to first link with long wire rope.

⇒Final tensioning performed with a short, higher strength synthetic pull-in rope.

⇒Chain support angles are measured simultaneously with turret position.

⇒Measured angles and turret position are used to calibrate numerical model (OrcaFlex). Length of polyester rope in model adjusted to match measured angles (exact length of rope is not known ahead of time as the rope experiences varying constructional stretch and creep during installation and handling).

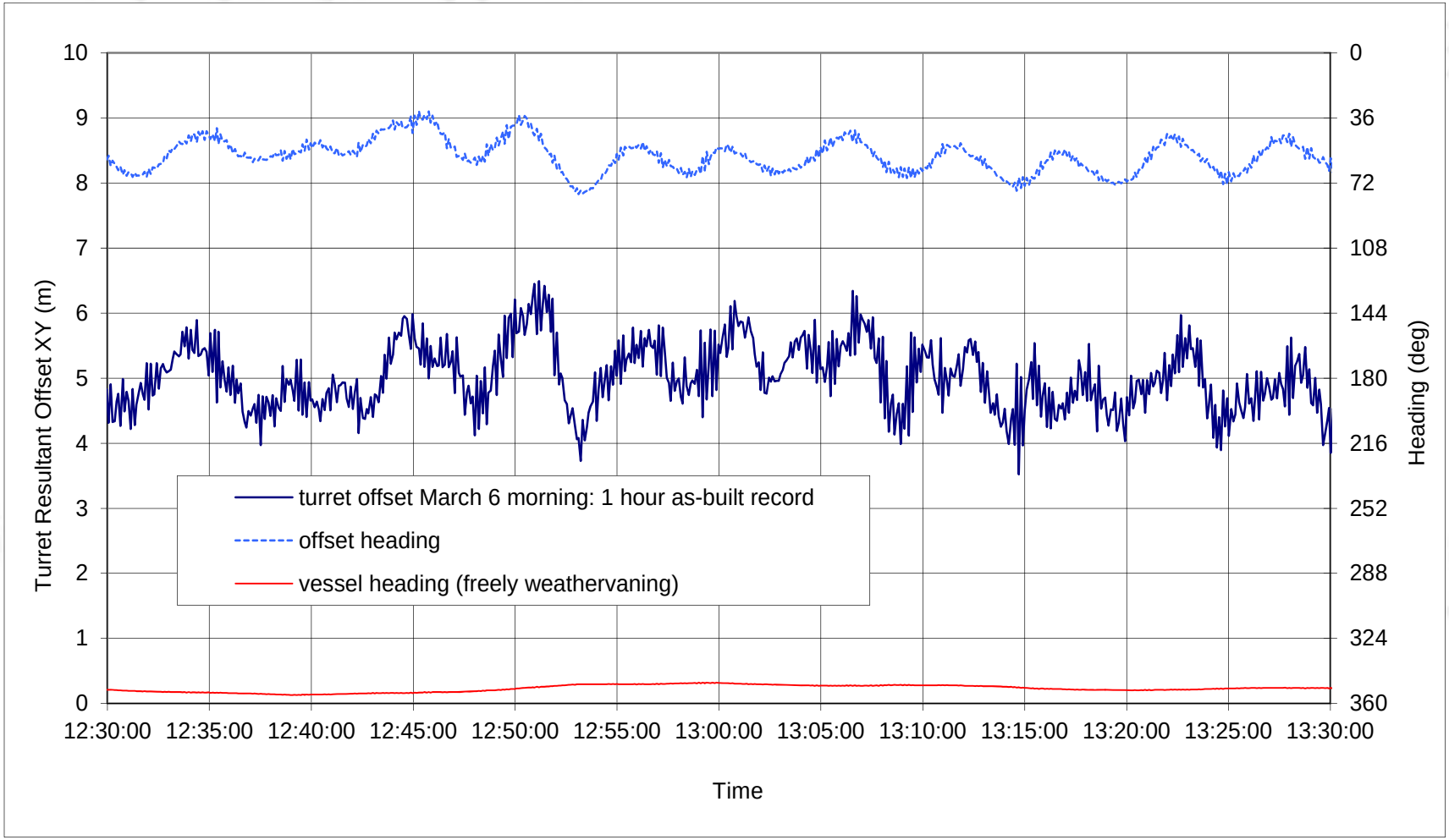
⇒Tensioning operations conducted in 3 stages, with model continually being re-calibrated for poly constructional stretch and creep.

SOFEC

BP Angola PSVM FPSO External Turret

Mooring Tensioning

⇒DGPS time history of turret position during top angle measurements



BP Angola PSVM FPSO External Turret

Mooring Tensioning

⇒Measured angles Vs. turret position:

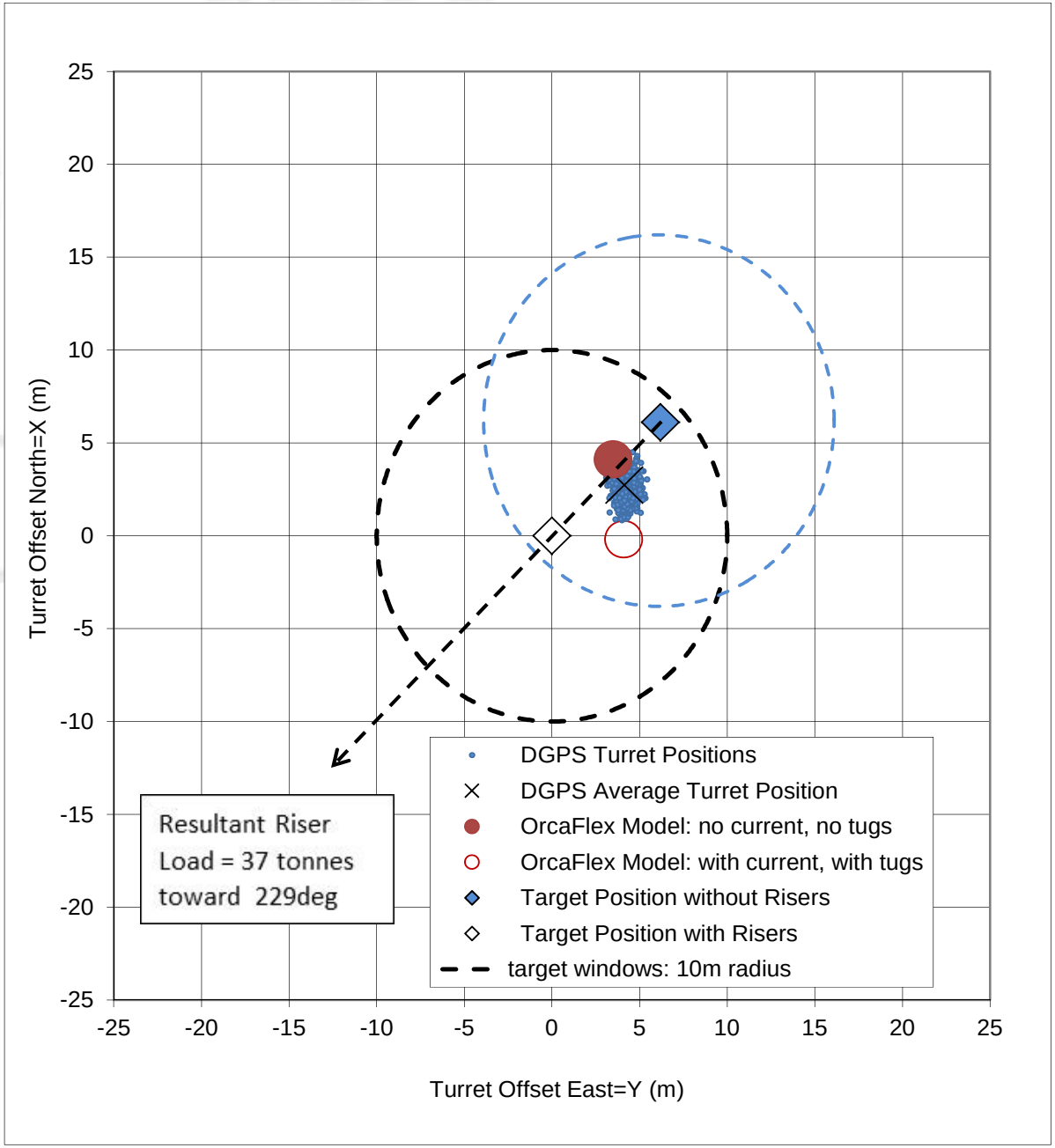
Leg No.	Time	Turret Position		Top Angle	
		North	East	measured	target
1	12:28:00	3.3	4.0	57.7	58.1
2	12:30:00	2.6	3.9	59.0	58.1
3	12:33:00	2.9	4.3	59.2	58.1
4	12:35:00	3.7	3.9	59.7	58.1
5	12:37:30	2.3	3.8	59.5	60.0
6	12:39:30	2.9	3.8	59.2	60.0
7	12:41:30	2.7	3.9	59.0	60.0
8	12:44:30	4.3	3.6	61.0	60.0
9	12:47:15	2.8	4.1	59.6	60.3
10	12:50:00	4.3	3.7	59.1	60.3
11	12:51:30	3.2	4.8	60.3	60.3
12	12:54:45	2.5	4.4	59.6	60.3
average		**3.1**	**4.0**		
target		**6.1**	**6.2**		

BP Angola PSVM FPSO External Turret

Mooring Tensioning

⇒As-Built Turret Position
(within 0.2% of water depth)

Turret Position	North (x)	East (y)	XY
OF Model: no env	**4.1**	**3.5**	**5.4**
OF Model: with env	**-0.2**	**4.1**	**4.1**
target position no risers	**6.1**	**6.2**	**8.7**
measured position no risers	**2.7**	**4.1**	**5.0**
target position with risers	**0.0**	**0.0**	**0.0**



BP PVSM External Turret Loaded out from MMHE 3 Nov 2010

BP Angola PSVM FPSO External Turret

BP Angola PSVM FPSO External Turret – waiting on risers - *thanks*