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 Disconneectable Turret: 5
- Internal Permanent Turret: 4
- Spread Moored: 16
- Tower Yoke: 5
- CALM/SALM: 60
SOFEC FPSO Mooring Project Locations
Western Hemisphere

- PEMEX Cantarell FSO
- Shell Bijupira Salema FPSO
- Petrobras RJS 409 FPSO
- Petrobras PRA 1 FSO
- Petrobras P34 FSO
- FSO UOTE
- FPSO Campos MV29
- FPSO Cidade de Niteroi MV18
- Terra Nova FPSO
- Petrobras P31 FPSO
- OSX-3 FPSO
- Petrobras PRA 1 FSO
- Cidade de Caraguatatuba MV27 FPSO
- Cidade de Sao Paolo MV23 FPSO
- Cidade de Mangaratiba MV24 FPSO
- Cidade de Itaguai MV26 FPSO
- Petrobras RJS 409 FPSO
- Cidade de Santos MV20 FPSO
- Cidade de Angra dos Reis MV22 FPSO
Mooring Systems for Floating Production Units

External Turret: Tandem Offloading

Internal Turret: Tandem Offloading

Spread: Tandem Bow or Stern Offloading

Tower Yoke: Tandem Offloading
SOFECSOFEC Turret Mooring Systems: 41 to date

• SOFECSOFEC’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

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

Turret Shaft

Chain Supports

Anchor Legs

Risers & Umbilicals

Swivel Access Structure

Swivel Stack (Production/Controls)

Manifolds + Pig Launching/Receiving

E-House + Subsea Controls + HPUs

Anchor Leg + Riser Pull-In Equipment

Wheel & Rail Bearing System

Turret Shaft

Chain Supports

Anchor Legs

Risers & Umbilicals

Fluid-Transfer

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 h
SOFEC Disconnectable FPSOs

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

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

BHPB Pyrenees (2009)
12 Risers & 3 Umbilicals, 200m water depth
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
Water Depth = 24m
Mild Environment
240 mmscfd @ 153 barg
SBS Offloading
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
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

Spider Buoy Z (m)

Time (s)

Fender Effective Tension (kN)

SOFEC
Model Test :: Extreme Events
Performance in Pack-Ice
Disconnect Tests

[Graph showing data comparison over time]

[Image of a submerged object with identification number 8453]

[Image of an underwater scene with the number 279]
Disconnect under 5,000 MT load
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.
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
Offshore Support

Mooring Leg Hookup