“Notice: The materials presented do not constitute an offer to sell the equipment or perform the services described herein”
Dynamic Risers for Deepwater Floating Production Systems

Typical Floating Production Platforms

- Spar
- TLP
- Semi
- Tanker

Hub Class Spar (courtesy Shell DDSI)
Small Water-Plane Area Hull

FPSO Tanker
Large Water-Plane Area Hull
Dynamic Risers for Deepwater Floating Production Systems

- FPSO Turret Systems: Elegant Solution, Highly Functional

External Turret

Shell Todd Maui B, New Zealand

Internal Turret

Amoco Liuhua, S. China Sea
Dynamic Risers for Deepwater Floating Production Systems

- FPSO Turret Systems: Elegant Solution, Highly Functional

  Provides Station Keeping
  - primary method for station keeping (thruster assist can be added)
  - restricts offsets to maintain riser system integrity

  Allows 360 degree weathervaning capability
  - reduces loads on mooring system
  - reduces motions for riser system and process (roll)
  - passive system can be unmanned during hurricanes

  Platform for mooring and riser systems pull-in equipment
  - Self contained pull-in systems require no additional support vessels after anchor leg/riser handoff to FPSO
Comparison of Floating Production Platform Motions

Comparison of Maximum Total Horizontal Offset

Offset as % of Water Depth (Depth=1,800m=6,000ft)

Horizontal Offset (%depth)

- FPSO: Inverted Catenary Mooring
- FPSO: Taut Polyester Mooring
- Semi: Catenary Risers
- TLP
- Spar: 18 SCR's, 16 Vertical Risers

Non-FPSO Motions courtesy Shell and Deepstar
Comparison of Floating Production Platform Motions

Comparison of Maximum Total *Heave, Pitch, Vert. Accel.*

- Maximum Total Heave
- Maximum Total Pitch
- Maximum Vertical Acceleration

Non-FPSO Motions courtesy of Shell and Deepstar

FPSO: 150kDWT 1MBBL
FPSO: 280kDWT 2MBBL
Semi: Catenary Risers
TLP: 16 Vertical, 18 SCR's
Spar: 16 Vertical, 18 SCR's

Non-FPSO Motions courtesy of Shell and Deepstar
Comparison of Floating Production Platform Motions

- Semi, Spar and TLP motions are “De-Tuned” from Waves (small water-plane area hull forms compared to FPSO)
  - Wave Periods: 4 to 20 seconds (95% energy)
  - Semi Natural Periods: 20 to 50 seconds (heave & pitch)
  - Spar Natural Periods: 30 to 150 seconds (heave & pitch)
  - Therefore dynamics are generally less severe than for FPSO

- Heave & Pitch Natural Periods for tanker: 8 to 12 seconds

- Tanker-Based FPSO will require a more “compliant” or “de-coupled” riser configuration compared to simple catenary or top tensioned vertical risers
Comparison of Floating Production Platform Motions

- FPSO Motion Reduction & Motion-Tolerant Riser Systems
  - Hull Form Optimization: ⇒ minimize wave motions
  - Utilize Oversized Hull: ⇒ reduce wave motions
  - Thruster-Assisted Mooring: ⇒ smaller wave/vessel heading
  (may require manned reduces motions & offsets,
  platform for Hurricane) ⇒ turret closer to midships reduces wave motions
  - Taut Polyester Mooring: ⇒ reduce vessel offsets
  - Compliant Riser Configurations: ⇒ e.g., Steel Lazy Wave
  - Decoupled Riser Configurations: ⇒ e.g., TLR, FTB, Hybrid Tower
Mooring and Riser System Design

Shallow water design
- Vessel offsets = 30% to 40% of water depth: riser design challenge
- Riser loads nearly insignificant for turret design
- Anchor leg / riser interference is key design issue

Deep water design
- Offsets = 10% to 20% of water depth: helps simplify riser design
- Riser loads significant for turret design and total restoring force
- Surge-drift damping contribution from anchor legs and risers is large
- Current loads on anchor legs and risers can be large
- VIV induced motions/loads on risers must be considered for fatigue

\[ \therefore \text{Coupled analysis and simultaneous optimization of mooring & risers is critical for deepwater} \]
Deepwater Riser Systems
Flexible vs. Steel Pipe

General Comparison of Flexible and Steel Pipe:

**FLEXIBLE PIPE (non-bonded composite)**
- Smaller allowable bend radius
- More fatigue resistant
- Simple top connections
- Tolerates larger relative motions
- I.D. limited (practically) to 16 in.

**STEEL PIPE**
- Approximately half the cost of flexible pipe
- Larger available diameters
- More collapse resistant
- Top connection less tolerant of large motions: use flex-joint or short section of flexible riser
- Lower wet weight than flexible pipe
Deepwater Riser Systems Design Codes

Riser Design Codes:
- API RP 2RD (Steel Risers for FPS and TLPs)
- API RP 1111 (Steel Pipelines)
- DNV OS-F201 (Offshore Standard for Metallic Risers)
- API 17B and API 17J (Flexibles)

Design Codes Specify:
- Wall Thickness Criteria
- Global Dynamic Analysis Requirements
- Detailed Structural Analysis (Components/Connections)
- Materials (Welds, Coatings, Corrosion, Wear, Marine growth, etc.)
Steel Pipe Wall Thickness Design Criteria:

- Internal Pressure
- Extreme Axial Loads
- Collapse Due to External Pressure
- Buckling Due to Combined Bending and External Pressure
- Buckle Propagation
Global Analysis:

- Extreme/Survival Analysis
  Check for Extreme Loads & Stresses, MBR, Compression, Interference, Top angle variations

- Fatigue Analysis
  Wave Induced
  Slow Drift Induced (less important for risers connected to a turret moored FPSO)
  Vortex Induced Vibrations (VIV) Induced
  Transport/Installation induced

- Installation Analysis
Each Geometric Riser Configuration has Unique Performance, Cost and Applicability

Final configuration depends on:

- Water Depth & Severity of Environment
- Vessel Offset
- Turret Location/Motions
- Impact on Turret Design (Loading)
- Number of Risers, Plan Layout
- Soils and Seabed Topography
- Flow Assurance Requirements (insulation, pipe-in-pipe, etc.)
Deepwater Riser Systems Configurations

Free Hanging Catenary Riser

Advantages:
- Cost effective solution
- Standard technology/installation

Weaknesses:
- High loads on turret
- Large fatigue at top and TDP
- Not usually feasible on turret except in mild environment
Objective: De-couple motion at TDP from the FPSO motions
Deepwater Riser Systems
De-Coupled Hybrid Systems

De-couple motions using self-standing hybrid risers or buoy

Multibore Hybrid Tower
Single Leg Hybrid
TLR

Connection to the FPSO via flexibles
Deepwater Offloading Systems: Steel Suspended-Wave Flowlines

Used to offload an FPS to a CALM or FPSO

Direct Connect

De-coupled Solution
Qualitative Comparison of Deepwater Riser Systems

<table>
<thead>
<tr>
<th>Category</th>
<th>Configuration Example</th>
<th>Offset Sensitivity</th>
<th>Turret/Buoy Impact</th>
<th>Fatigue Resistance</th>
<th>CAPEX</th>
<th>Installability</th>
<th>Main Design Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Connect</td>
<td>Free Hanging SCR</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Easy</td>
<td>Fatigue, Survival, Top Load</td>
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<tr>
<td>Compliant</td>
<td>Lazy Wave</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Moderate</td>
<td>Fatigue, Top Load</td>
</tr>
<tr>
<td>Hybrid</td>
<td>Tension Leg Riser</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Variable *</td>
<td>Complex</td>
<td>Installation</td>
</tr>
<tr>
<td>Suspended Offloading</td>
<td>Surface Buoy</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Moderate</td>
<td>Transport, Installation, Fatigue</td>
</tr>
<tr>
<td>Flowlines</td>
<td>FTB</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Medium/High</td>
<td>Moderate</td>
<td>Transport, Installation</td>
</tr>
</tbody>
</table>

* Variable cost means lower (higher) cost per riser as number of risers increases (decreases)
Dynamic Risers for Deepwater Floating Production Systems

TLR
Riser System

Steel Lines De-Coupled from FPSO Motions
Deepwater Riser Systems
TLR or Hybrid configurations

Steel Lines
De-Coupled from FPSO Motions

TDP isolated

Drastically Reduces Turret Loads
TLR Riser System:

- FPSO motions de-coupled using a submerged steel buoy supporting SCRs and flexible jumpers to the turret
- Can accommodate a large number of risers
- De-coupling effective ⇒ buoy motions are small
- SCR’s not affected by the 100-year hurricane or fatigue environments
- Proven technology, with standard fabrication/installation procedures
- Recent DeepStar study concluded that TLR system is feasible in 3,000m depth and less costly than Steel Lazy Wave or Hybrid Riser Towers:

### COST COMPARISON:

<table>
<thead>
<tr>
<th></th>
<th>*TLR</th>
<th>Lazy Wave</th>
<th>Hybrid Tower</th>
</tr>
</thead>
<tbody>
<tr>
<td>(based on large, multi-riser field development)</td>
<td>100%</td>
<td>120%</td>
<td>145%</td>
</tr>
</tbody>
</table>

* TLR cost benefits may be reduced for fewer number of risers.
Deepwater Riser Systems
TLR System

TLR
Riser
System

Steel Lines
De-Coupled
from
FPSO
Motions
Deepwater Riser Systems
TLR System

Steel Lines
De-Coupled from FPSO Motions
Deepwater Riser Systems: Steel Suspended-Wave Flowlines

Flowline Termination Buoy (FTB) Riser System

Steel Lines De-Coupled from FPSO

FTB is more robust & fatigue resistant compared to “direct-connect” riser systems
Deepwater Riser Systems: Steel Suspended-Wave Flowlines

SPM to FTB Riser System

Steel Lines De-Coupled from FPSO

SPM can be CALM or FPSO
Deepwater Riser Systems: Steel Suspended-Wave Flowlines

SPM to FTB Riser System

Steel Lines De-Coupled from FPSO

Fluid Swivels Above Water
Deepwater Riser Systems: Steel Suspended-Wave Flowlines

SPM to FTB Riser System

Steel Lines De-Coupled from FPSO

Product Swivels Above Water
Deepwater Riser Systems: Suspended-Wave Flowlines SPM to FTB
FPDSO → FPSO with Drilling and Workover Capability

Specialized turret allows simultaneous drilling, production & storage.

*Non-conventional vessel, conventional components.*
Deepwater Exploration and Production: Tomorrow’s Technology

- FPDSO
  - Top tensioned drilling risers
  - Tower hybrid production risers
  - Drag Chain product transfer system
  - Turret located near midship
  - Thruster-assist heading control
FPDSO

- Drilling radius = 100 meters
- Product riser radius = 200 meters
- Grouped mooring system (3x3)
Deepwater Exploration and Production: Tomorrow’s Technology

- FPDSO

Drag Chain product transfer system allows 270 degree vessel rotation (no fluid swivels required)
Deepwater Exploration and Production: Tomorrow’s Technology

- **FPDSO**

  - Compact drag chain system allows deployment of BOP stack and subsea templates without disassembly of drag chain system

  Net result is balance between production and drilling equipment requirements.

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