Qualification of Flexible Fiber-Reinforced Pipe for 10,000-Foot Water Depths
# Enabling Ultra-Deepwater Risers

<table>
<thead>
<tr>
<th>Application</th>
<th>Engineering Design/Build</th>
<th>Comment</th>
<th>Logistics</th>
<th>Comment</th>
<th>Installation</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPSO</td>
<td>三星🌟🌟🌟</td>
<td>Reduced turret engineering, cost, and buoyancy</td>
<td></td>
<td></td>
<td>三星🌟🌟🌟</td>
<td>Lower cost installation vessel, no need for high top tension or VLS system, reduced buoyancy req.</td>
</tr>
<tr>
<td>Fixed Structure J-Tube</td>
<td>一星启🌟</td>
<td>Lower weight reduces size of crane for j-tube pulls</td>
<td>三星🌟🌟🌟</td>
<td>Lower weight reduces the size of required crane</td>
<td>三星🌟🌟🌟</td>
<td>Lower cost installation vessel, no need for high top tension or VLS system</td>
</tr>
<tr>
<td>Sour Service</td>
<td>三星🌟🌟🌟</td>
<td>Corrosion resistant material while maintaining strength</td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow Assurance</td>
<td>一星启🌟</td>
<td>U-value can be up to 50% versus conventional</td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultra Deepwater Enabling</td>
<td>三星🌟🌟🌟</td>
<td>One continuous catenary is possible</td>
<td>NA</td>
<td></td>
<td>三星🌟🌟🌟</td>
<td>Lower cost installation vessel, reduced buoyancy req.</td>
</tr>
</tbody>
</table>
Task: a project was set up by Research Partnership to Secure Energy for America (RPSEA) to develop an ultra-deepwater riser to the following specification.

- 7-inch ID
- 10,000 psi
- 3000m WD
- Sour service
- 120 celsius

This would push flexible riser technology well beyond today's limitations and enable ultra-deepwater solutions.

Project scope of work involved a three stage process:

- Phase 1 – Engineering study
- Phase 2 – Prototype manufacturing and qualification testing
- Phase 3 – Field deployment supply
Phase 1 – Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Diameter</td>
<td>177.8 mm (7 inch)</td>
</tr>
<tr>
<td>Design Temperature</td>
<td>120 °C</td>
</tr>
<tr>
<td>Design Pressure</td>
<td>68.9 Mpa (10,000 psig)</td>
</tr>
<tr>
<td>Outer Diameter</td>
<td>359.0 mm (14.1 inch)</td>
</tr>
<tr>
<td>Weight Empty in Air</td>
<td>172.0 kg/m</td>
</tr>
<tr>
<td>Weight Empty in Seawater</td>
<td>68.2 kg/m</td>
</tr>
<tr>
<td>Storage Bend Radius</td>
<td>2.7 m</td>
</tr>
<tr>
<td>Operating Bend Radius</td>
<td>4.0 m</td>
</tr>
<tr>
<td>Burst/Design Ratio</td>
<td>2.0</td>
</tr>
<tr>
<td>Collapse/Design Ratio</td>
<td>1.9</td>
</tr>
<tr>
<td>Failure Tension</td>
<td>20,498 kN</td>
</tr>
</tbody>
</table>

Pipe Design
- End Fitting Design
- Riser System Design
- Analyses to demonstrate compliance with API 17J/17B/DNV OS-C501
- FMECA
- Manufacturing Plan
- Qualification Plan in compliance with DNV RP-A203
- Field Development Plan
- Integrity Management Plan
- Phase 2 Proposal
Fully Unbonded Layer Construction

- Minimum bending radius (MBR) of conventional unbonded flexible pipe
- Resistant to composite layer failure due to delamination, dis-bondment and void formation due to bending fatigue load
Dual Annulus

**Outer Annulus**
- Flooded outer annulus
- Less severity in ageing conditions as composite material is exposed to seawater only but not permeated gases
- Low failure risk under cyclic bending and rapid pipe bore depressurization as permeated gas is not absorbed into composite material

**Inner Annulus**
- Permeated gas flow to surface via inner annulus flow path
- Inner annulus monitoring allows early detection of internal fluid leakage before major loss of fluid containment to environment
Intermediate Anti-Collapse Sheath

Membrane

- R0 + R1 provide collapse resistance
- Membrane seal prevents the ingress of seawater in the inner annulus which allows the metallic pressure armor to provide additional collapse resistance over the primary collapse resistance of the conventional carcass layer
Hybrid Pressure Armor

• Proven technology for primary fluid and pressure containment

• Composite hoop layer as a backup pressure armor for increased pressure capacity (patent pending)
Composite Tensile Armor

- Zero risk of corrosion as composite material does not corrode in seawater
- Stable helical shape of tensile armors provide sufficient axial compression capacity for the pipe
- Low risk of fatigue
## Phase 2 - Qualification

<table>
<thead>
<tr>
<th>Phase</th>
<th>Task</th>
<th>Objective</th>
<th>TRL at Start</th>
<th>TRL at Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A</td>
<td>12 - Material Qualification</td>
<td>Qualify the new technology ✓ Composite pressure armor reinforcement ✓ Composite tensile armor reinforcement ✓ Inner annulus design ✓ End fitting anchoring of composite layers ✓ Hybrid pressure armor design ✓ Anti-wear layer design ✓ Interlock pressure armor design</td>
<td>1-2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>13 - Gap Spanning</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>14 - Wear Test</td>
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<tr>
<td></td>
<td>15 - Permeation Test</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>16 - Phase 2A Prototype and Test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2B</td>
<td>17 - Carcass and Liner Test</td>
<td>Full scale prototype qualification test ✓ Qualify the overall structure FHRP riser with API 17B prototype qualification tests</td>
<td>3</td>
<td>4-5</td>
</tr>
<tr>
<td></td>
<td>18 - Phase 2B Prototype</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>19 - Static Test</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>20 – Bending / Curved Collapse Test</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>Dynamic Fatigue Test*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermal Cycling Test*</td>
<td></td>
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</tr>
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</table>
Phase 2A – New Technology

Composite Material Qualification
• Suitability confirmation of materials used in different layers of pipe

Gap Spanning Test
• Maximum gap simulation in pressure armor and test liner at maximum conditions

Wear Test
• Performance verification of anti-wear tapes and calibrate service life model by confirming friction coefficient

Permeation Test
• Validation of permeation rate and shielding factors presented in the permeation model
Manufacturing at DeepFlex Manitowoc, WI facility

Pipe Layers
- Liner (PA-11)
- Metallic interlock pressure armor (carbon steel)
- Membrane (HDPE)
- Composite hoop layer (carbon reinforced stack)
- 2 tensile layers (carbon reinforced stack)
- Jacket (HDPE)
Phase 2A – Tension Test

To confirm the tensile capacity of the tensile reinforcement layers and the design of the anchoring system in the end fitting

- Predicted tensile failure: 2246 kips
- Tested tensile failure: 2197 kips
To confirm the pressure containment capacity of pipe and end fitting design

- Predicted burst pressure: 21312 psi
- Tested burst pressure: 22496 kips
Phase 3 Preparation
• Review of pipe design based on field-specific data, as well as findings of phase 2

Dynamic Fatigue Test
• Conduct a service simulation test as defined by API 17B

Thermal Cycling Test
• Integrity verification of the liner seal when subject to thermal cycling

<table>
<thead>
<tr>
<th>Technology Assessment</th>
<th>Technology Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application Area</td>
<td>1 - Proven</td>
</tr>
<tr>
<td>1 - Known</td>
<td>1</td>
</tr>
<tr>
<td>2 - Limited Knowledge</td>
<td>2</td>
</tr>
<tr>
<td>3 - New</td>
<td>3</td>
</tr>
</tbody>
</table>

1 = No new technical uncertainties
2 = New technical uncertainties
3 = New technical challenges
4 = Demanding new technical challenges
Phase 3A – Pipe Manufacturing

Pipe Manufacture

- Pipe layer material procurement
- Pipe manufacture
- End fitting procurement
- Verification of the ancillary equipment qualification and bend stiffener procurement
- Pipe sample assembly and factory acceptance tests
Phase 3B – Field Deployment

Field Deployment

- Installation plan update
- Selection of the installation contractor
- Mobilization of the installation vessel
- Transition to the field
Phase 3B – Integrity Management

Integrity Management

- Integrity management plan update
- Contracting the equipment supplier
- Inspection
- Monitoring
DeepFlex have developed an ultra-deepwater riser to 7” ID, 10,000psi, 3000m WD, sour conditions at 120 Celsius

Utilizing composite technology pushes flexible riser technology well beyond todays limitations to enable ultra-deepwater riser solutions

Project Scope of Work involved a three phase process

- **Phase 1 – Engineering Design**
  - Flexible unbonded design
  - Dual annulus
  - Hybrid pressure armor
  - Composite tensile armor

Reducing flexible pipe mass while retaining strength reduces top tension enabling ultra-deepwater risers to be deployed in dynamic conditions
• Phase 2 – Prototype Manufacturing and Qualification Testing
  o Phase 2A 100% complete
  o Phase 2B in progress 100% complete by end 2015

• Phase 3 – Field Deployment Supply
  o Manufacturing to commence Q2 2016 with installation Q4 2016

*Reducing flexible pipe mass while retaining strength reducing top tension and enabling ultra-deepwater risers to be deployed in dynamic conditions*