Offshore Pipeline Technology – Challenges & Solutions

LISTENS...DELIVERS...EVOLVES.

WHOLE LIFE SOLUTIONS FOR PIPELINE AND SUBSEA SYSTEMS

Nick Brown
Presentation Contents

• Review of Key Subsea Pipeline Technology Drivers
  – Frontier oil & gas development drivers
  – Environmental drivers

• Technical Challenges: Continental Shelf-break Crossings
  – Crossing of steep & rugged seabeds
  – Geohazards

• Technical Challenges: HP/HT developments
  – Pipelines protected by Instrumented over-pressure protection systems
  – Management of Lateral buckling

• Technical Challenges: Environment
  – Cryogenic offloading pipelines
  – Pipeline stabilisation innovations
Subsea Pipeline Technology Drivers: Typical Deep Water Subsea Tie-back Development

- Large diameter linepipe at manufacturing limits
- Large diameter pipeline installation limits
- High external over-pressure & thermal loads
- Corrosion resistant materials
- Large bore valves & diverless connections
- Deep water: 1000m common. 3000m under development

Pipelines designed for wellhead conditions

Steep and uneven terrain

Gas export

Onshore processing

Subsea production

Multiple transport
Subsea Pipeline Technology Drivers:
Example Technical Challenges

- High pressure wells: Class 2500 Large Bore equipment
- Linepipe manufacturing technical limits (CRA clad, wall thickness, ovality)
- Hydrate prevention challenges during pre-commissioning
Procurement Challenges: Linepipe

- Bluestream, 24-inch x 31.8mm
- Na kika, 20-inch x 25.4mm
- Na kika, 24-inch x 28.6mm
- Greenstream, 32-inch x 30.2mm
- Ormen Lange, 30-inch x 29.7mm
- Balearics, 20-inch x 18.6mm
- Balearics, 20-inch x 18.6mm
- Greenstream, 32-inch x 30.2mm
- Mardi Gras Cleopatra, 20-inch x 20.6mm

**Graph Details:**
- **Y-axis:** Depth (m)
- **X-axis:** D/t
- **Data Points:**
  - Bluestream, 24-inch x 31.8mm
  - Na kika, 20-inch x 25.4mm
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  - Greenstream, 32-inch x 30.2mm
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Installation Challenges

Deep water pipelay

Deep water excavation

Deep water rock dump
Environmental Challenges

Environmental Sensitivities: Dredging

Exteme Environments: Ice & cyclones
## Australian Subsea Gas Development Examples

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>OPERATOR</th>
<th>MAX WATER DEPTH (M)</th>
<th>PIPELINE LENGTHS (KM)</th>
<th>ENVIRONMENTAL CHALLENGES</th>
<th>SHELF-BREAK CROSSING</th>
<th>HP/HT</th>
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CONTINENTAL SHELF-BREAK PIPELINE CROSSINGS

1. Crossing of steep & rugged seabeds
2. Geohazards
Scarp Crossings A steep slope or long cliff that results from erosion or faulting and separates two relatively level areas of differing elevations.
SCARP CROSSING ROUTE FLY-THROUGH.
Large Freespans at Scarp Crossings: The Challenge

- **Long Span Lengths**
  - 200m + in length
  - May exceed static structural limits for combined loading
  - May be subject to multimode vortex-induced-vibration

- **Steep seabed slopes**
  - May exacerbate liquid slugging
  - Limits ability to transport sand

- **Interaction with thermal loads**
  - Buckling
  - Creep
Novel Solutions: Vertical Strategic Anchor System (VSAS)

- Tension controlled bending
- High installation tension
- Added buoyancy
Geohazards: Catastrophic Events

1000s of cubic Kms of material transported over 100s of kms
Geohazards: The Challenge

• Need to develop robust geological & geotechnical models
  – Seabed evolution & historical events
  – Current seabed characteristics
  – Potential sources of instability (seismicity, shallow gas, soliton currents)

• Need to characterise geohazard events
  – Slope failures
  – Debris flows
  – Turbidity flows

• Need to define pipeline loads & response
  – Flow paths
  – Hydrodynamic & soil shear loads
  – Pipeline response modelling
Debris & Turbidity Flows

Head scarp formation
Geohazards: Event Modelling

Debris Flow Modelling

Lateral

Axial

Oblique

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Geohazards: FEA Solutions

Extreme Slab Event FEA Model with Lateral Buckling

Non-Linear End Axial Spring to model pipe continuity.

2D Flat Seabed surface

Pipe Nodes

Pipe-seabed interaction

Initial imperfection at downslope pipeline section

Apply Slab Event to Pipeline

Effective Axial Force

$\mu W_s \times \frac{1}{2} L_1 (\text{max})$

Initial imperfection at downslope pipeline section

Listens. Delivers. Evolves.
Whole Life Solutions for Pipeline and Subsea Systems
HIGH PRESSURE / HIGH TEMPERATURE RESERVOIRS

1. Application of Instrumented Over-pressure Protection Systems
2. Pipeline Buckling
Instrumented Over-Pressure Protection Systems

- "Conventional Design"
- "Mission Critical"
- "Burst Critical"

Shut-in

Operating

Pressure

Burst
Yield
Burst
Yield
Burst
Yield

IOPPS
HIPPS

"Conventional Design"
Instrumented Over-pressure Protection Systems: The Challenge

- **Project enabling technology**
  - High pressure reservoirs make pipeline design impractical
  - Large diameter linepipe can only be cost effectively manufactured by UOE
  - CRA clad linepipe difficult to manufacture in high wall thicknesses

- **Pipeline Design**
  - Code compliant AS2885.4 (DNV OS F101)
  - Target pressure containment reliability consistent with conventional design
  - ULS & ALS limit states to be addressed
  - Structural Reliability Analysis to quantify impact of over-pressure
  - Need to address all pressure dependent failure modes

- **IOPPS reliability**
  - Need to ensure that probability of over-pressure $<10^{-2}$/yr (ALS)
  - Typical IOPPS reliability results in probability of over-pressure $<10^{-3}$/yr
IOPPS: The Solution

Fortified Zone (design to WHSIP)  De-rated Zone (design to IOPPS set point)

SCM I

SCM II / PPS

2003

M1 Manifold

Tree & Well

Secondary

Primary

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# IOPPS & HIPPS: Track Record

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>OPERATOR</th>
<th>Pipeline Diameter (inch)</th>
<th>WHSIP (barg)</th>
<th>Pipeline Design Pressure (barg)</th>
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<tr>
<td>Kingfisher</td>
<td>Shell</td>
<td>10</td>
<td>690</td>
<td>320</td>
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<tr>
<td>Penguin</td>
<td>Shell</td>
<td>12</td>
<td>400</td>
<td>200</td>
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<tr>
<td>Rhum</td>
<td>BP</td>
<td>16</td>
<td>709</td>
<td>210</td>
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<tr>
<td>Kristin</td>
<td>Statoil</td>
<td>-</td>
<td>740</td>
<td>330</td>
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<td>Tweedsmuir</td>
<td>Talisman</td>
<td>12</td>
<td>410</td>
<td>275</td>
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Lateral Buckling: The Challenge

Pressure & Temperature Induced Buckling

Survey Image of Buckled Pipeline

Figure 7  Axial Force Distribution – Multiple Buckles; Free End
Lateral Buckling: The Solution
(3D FE Modelling – JPK SIMULATOR)

- 3D Seabed
  - Use survey data
- Pipe Lay Process
  - Model pipe lay process from lay barge
- Pipe-Soil Response Model
  - Embedment
  - Passive Resistance
- Cyclic loading
  - Pressure & temperature

Figure 11 Typical Cross Profile at Crown of Lateral Buckle on an Operated Pipeline
Lateral Buckling: The Solution
(Mitigation Methods)

Figure 3: Typical Snake Lay Configuration (exaggerated vertical scale)

Figure 4: Buckle Initiation Using Sleepers (typically 2 to 3 joints of large diameter pipe)

Figure 5: Buckle Initiation Using Distributed Buoyancy

Pitch (Typically 2 to 5 km)
Offset (Typically 1000m)
Lay bend radius
(typically 1500m)
Lateral Buckling

Sleepers (typically 2 joints of large diameter pipe)

Sleepers spacing
(typically 2 to 3km)

Buckle spacing
(typically 2 to 3km)

Distributed buoyancy added to reduce weight
(Typically <100m)
ENVIRONMENTAL CHALLENGES

1. Application of Cryogenic Pipelines
2. North West Shelf Pipeline Stabilisation
Cryogenic Pipelines: The Challenge

- Reducing LNG/LPG terminal costs whilst reducing environmental impact

Insulated pipe jetty of minimum length. Can require substantial dredging for ship access

Subsea insulated cryogenic pipelines offer economic long step-out offloading reducing dredging requirements
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TYPICAL CRYOGENIC PIPE ARRANGEMENT

**Insulation**
Annular spaces contain insulation in gas at reduced pressure. Monitoring of the two annuli pressures and temperatures can confirm that there is no leakage.

**Intermediate pipe**
Carbon steel or stainless steel.

**Inner pipe**
Stainless steel with expansion facility or Invar. Invar has very low thermal expansion coefficient and is currently preferred.

**External Pipe**
Carbon steel pipe provides protection and an outer pressurised annulus.
ITP LNG Pipe Design

38” OD Outer carbon steel pipe

Outer annulus

34” OD Intermediate carbon steel pipe

Inner annulus at reduced pressure

40 mm Izoflex insulation

28” OD, 36% nickel inner pipe

(Design temp -196°C for LNG operation)
Camisea, Peru
World’s first subsea LPG pipeline
- Insulated -43°C
Pipeline Stabilisation: The Challenge

- **Stabilisation**: 30%
- **Management & Engineering**: 10%
- **Materials & Fabrication**: 30%
- **Installation (excluding Stabilisation)**: 30%

Lowered Pipeline

Natural Seabed
The Solution: Innovations in Pipeline Stabilisation

Strategic Pipeline Anchors

- Piled Pipeline-Seabed Anchors (spacing >500m)
- Allow significant lateral displacement
- Tensile restraint to Limit Lateral Movement
- Reacted via collar / clamp arrangement
- Bending Control at Restraints
- Fabricated Bellmouth Arrangement
- Primary (End) and Secondary (Midline) Anchors
The solution: Innovations in Pipeline Stabilisation - Strategic Anchors
Innovations in Pipeline Stabilisation: Gravity Anchors

<table>
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<tr>
<th>Individual Gravity Anchor Characteristics:</th>
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<tbody>
<tr>
<td>Length</td>
<td>5.5 m</td>
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<tr>
<td>Width</td>
<td>3.3 m</td>
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<tr>
<td>Height</td>
<td>2.3 m</td>
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<tr>
<td>Weight</td>
<td>31 tonnes</td>
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Innovations in Pipeline Stabilisation: Gravity Anchors
Conclusions

• Frontier developments lead to significant challenges
  – Location & environment
  – High risk

• Innovation is key to Robust & Cost Effective Design
  – Understand the problem
  – Develop innovative practical solutions
  – Develop the right tools for the job