Comprehensive Site Integrity Assessments and Mitigations for Unbonded Flexible Pipes

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UNBONDED FLEXIBLE PIPE

Unbonded flexible pipes consist of concentric layers of metallic wires and thermoplastics which are specially designed to cater to the characteristics of the transported fluid and specific environment requirements.

Source: Credit to http://fps.nov.com/subsea/flexibles/dynamic-flexible-risers
This inspection approach focuses on 59% of damage mechanisms:
- External sheath
- Overbending
- Birdcaging
- End fitting leak
- Vent system anomalies

The remaining 41% of damage mechanisms remain as integrity uncertainties by inspection. These include:
- Aged & Pull-Out Internal Sheath
- Ancillary Device Failure
- Ovalisation
- Wax blockage
- Corrosion
- Carcass failure
- Others
INSPECTION APPROACH

The inspection approach comprises the following sequence of methods:

1. Ultrasonic Testing (UT)
2. Visual Testing (VT) via ROV
3. Cathodic Protection Survey

- UT results will determine the necessity of executing the other two (2) activities that follow.
- They may not be necessary if UT results indicate that the pipes are free from any sign of damage.
INSPECTION PRINCIPLE

• In a perfect condition, the annulus of flexible pipes will either be dry or flooded with permeated hydrocarbon gases.

• When any submerged portion of the flexible pipe’s outer sheath is damaged, air from the pipe annulus instantly escapes, causing seawater to rush into the pipe’s annulus.

Pipe Inspection should be extended to the sea bed areas should the inspection at riser be disclosed as dry condition.

Inspection focus area by UT (riser portion) for tracing of any sign of seawater inside the flexible pipe annulus.

This area will be filled by sea water when the outer sheath is damaged.
**UT PRINCIPLE**

**Undamaged Outer Sheath**
- Use compressional wave probe.
- Most of the UT energy will return to probe.

**Damaged Outer Sheath**
- Use compressional wave probe.
- Most of the UT energy will travel into annulus due to presence of couplant i.e. sea water.

Note: A single crystal frequency probe (i.e. 1 to 6 MHz) is applicable as a minimum requirement.
Most of the UT energy returns back to probe due to air barrier inside the annulus.

Most of the UT energy will travel inside the annulus and scatter away due to complex geometry of steel wire resulting in no energy returning back to probe.
UT ANALYSIS

Unflooded Annulus

How much UT energy is reflected?

\[ R = \left( \frac{Z_1 - Z_2}{Z_1 + Z_2} \right)^2 \]

R: Coefficient of Reflection
Z: Acoustic Impedance

Let \( Z_1 = 1.76 \) (polyethylene)
\( Z_2 = 0 \) (air)

\[ R = \left( \frac{1.76 - 0}{1.76 + 0} \right)^2 = 1 \]

Ultrasonic energy transmitted into the annulus, \( T \):

\[ T = 1 - R \]
\[ T = 1 - 1 \]
\[ T = 0 \]

As such, no UT energy is transmitted into the annulus.

Flooded Annulus

How much UT energy is transmitted?

\[ R = \left( \frac{Z_1 - Z_2}{Z_1 + Z_2} \right)^2 \]

R: Coefficient of Reflection
Z: Acoustic Impedance

Let \( Z_1 = 1.76 \) (polyethylene)
\( Z_2 = 1.569 \) (water)

\[ R = \left( \frac{1.76 - 1.569}{1.76 + 1.569} \right)^2 = 0.003 \]

Ultrasonic energy transmitted into the annulus, \( T \):

\[ T = 1 - R \]
\[ T = 1 - 0.003 \]
\[ T = 0.997 \]

As such, 99.7% of UT energy is transmitted into the annulus.
UT ANALYSIS

- Almost 100% of UT energy is transmitted into flexible pipe annulus, but no energy returns to probe.
**Scenario 1**

- Annulus is dry by UT finding.
- Utilises ROV for visual inspection and to detect any signs of anomalies such as overbending, birdcaging, end fitting leak and signs of gas diffusion through the external sheath.

In the event of a perfect condition, the next targeted inspection date will be based on the criticality of the visual inspection.
VISUAL TESTING VIA ROV

Scenario 2

- Annulus is filled with sea water.

- Utilise ROV for visual inspection and to detect any signs of anomalies such as overbending, birdcaging, end fitting leak and signs of gas diffusion through the external sheath.

- Pinpoint the location of the outer sheath damage area.

CP survey and metal loss study need to be conducted due to corrosion.
CATHODIC PROTECTION SURVEY

- The damaged area receives CP in between -850 mV to 1200 mV (carbon steel) or maximum of -850 mV (stainless steel).

- The damaged area is receiving enough protection against corrosion by CP.

- CP interval survey shall be established.

- The damaged area receives CP more positive than -850 mV (carbon steel) or more negative than -850 mV (stainless steel).

- Mitigation is required.
CORROSION ASSESSMENT

\[
\text{Metal Loss} = \frac{3.2706 \times \text{molar mass of iron} \times \text{current density}}{\text{density} \times \text{number of electron}}
\]

Total Metal Loss (mm) = a \times \text{total no. of year}

Let;
- Molar mass = 56 g/mol
- Current density* = 0.01mA/cm²
- Density of carbon steel = 7.88 g/cm³
- Number of electron = 2

Then;
- \[
\text{Metal loss} = \frac{3.2706 \times 56 \text{g/mol} \times 0.01 \text{mA/cm²}}{7.88 \text{g/cm³} \times 2}
\]
- Metal loss = 0.116 mm/year

If the last inspection was conducted 20 years ago;
- Total metal loss = 0.0116 mm/yr \times 20 years = 2.32 mm

If armour wire nominal thickness is 3 mm;
- Thus, remaining armour wire thickness = 3 - 2.32 mm = 0.68 mm

*Current density at 22°C: 100mA/m² (in accordance with PTS 37.19.30.30)
CORROSION ASSESSMENT

- Flexible pipe manufacturer will perform stress analysis to determine the remaining permissible utilisation factor (UF) against the current stresses onto the affected flexible pipe section.

- Revised UF will be cross-checked with specified UF value in API 17J.

- If the revised UF is less than specified value, the pipe shall be scheduled for replacement.

- If the value meets API 17J requirement, the current armour wire thickness is acceptable and flexible pipe is fit-for-service. However, corrosion rate shall be suppressed through mitigation.
MITIGATION

If the flexible pipe is found to be unfit-for-service by engineering analysis, mitigation shall be performed by one of the following methods:

- Retrofit Anode
- Clamp
- Encirclement thermoplastic welding sheath
RETROFIT ANODE INSTALLATION

- The retrofit anode can be designed for any severe condition with a specific extended life.
- All the tensile armour wires shall be considered in CP calculation.
- The flexible pipe length coverage by CP is subject to agreement by Owner.

Source: Credit to Deepwater Corrosion Services, Inc.
FLEXIBLE PIPE REPAIR - ABOVE WATER

Supported by DnV RP B401 para 6.3.7
Closed and sealed flooded compartments do not normally need CP.

Any decision for flexible pipe repair shall be approved by Principal which is either by clamping or an encirclement repair sheath.

Repair is permitted in API 17J
FLEXIBLE PIPE REPAIR - UNDERWATER

- It will remain fit-for-purpose as long as CP is protecting the inside metallic wires.
- Encirclement thermoplastic welding is yet to be established.
- Two (2) methods of clamping if the metallic wires are marginally protected by CP i.e. more positive than -850 mV.
  - Clamping without sealing off the damaged area.
  - Clamping with sealing off the damaged area.

Extra precaution
- Sealing off the damaged area will cut off the continuity of sea water electrolyte i.e. quantity of sea water inside the annulus will remain unchanged. As such, the external CP will not protect the tensile armour wires.
- Continuous feeding of corrosive gases inside the annulus for sour or sweet full term (HC) services.
## SUMMARY FOR SUBSEA STATIC FLOW LINE INTEGRITY ASSESSMENT

<table>
<thead>
<tr>
<th>UT</th>
<th>VT</th>
<th>CP</th>
<th>Corrosion rate</th>
<th>Mitigation</th>
<th>Integrity</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>No anomalies</td>
<td>Not required</td>
<td>Not applicable</td>
<td>Not required</td>
<td>As per design life</td>
<td>Acceptable. Plan for next inspection.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flooded</td>
<td>Major damage</td>
<td>Required</td>
<td>Based on two (2) inspection intervals</td>
<td>Not required when CP reading is in between -850 mV and 1200 mV</td>
<td>As per design life</td>
<td>Acceptable. Plan for next inspection.</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Required (CP &lt;-850 mV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Retrofit CP?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Metal loss?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Subject to analysis by flexible pipe’s Principal – remaining utilisation factor</td>
</tr>
</tbody>
</table>

### Additional requirement:
The flexible pipe will be subject to immediate retirement should VT observe major anomalies such as major birdcaging, and others.
## SUMMARY FOR RISER INTEGRITY MANAGEMENT

<table>
<thead>
<tr>
<th>UT</th>
<th>VT</th>
<th>CP</th>
<th>Corrosion rate</th>
<th>Mitigation</th>
<th>Integrity</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>No anomalies</td>
<td>Not required</td>
<td>Not applicable</td>
<td>Not required</td>
<td>As per design life</td>
<td>Acceptable. Plan for next inspection.</td>
</tr>
<tr>
<td>Dry</td>
<td>Anomalies</td>
<td>Not Required</td>
<td>Applicable</td>
<td>Required – encirclement thermoplastic welding sheath</td>
<td>As per design life</td>
<td>Acceptable. Plan for next inspection.</td>
</tr>
</tbody>
</table>

Additional requirements:

- Flexible riser shall be checked visually in frequent and regular intervals.
- The amount of sea water (from splash) should be calculated based on agreed specific period and specific frequency (weight/hour). Once the damaged area is sealed off, the trapped sea water inside the annulus may be considered as “closed compartment” which requires no action.
DISCUSSION

1. The aging of internal pressure sheath (polymer such as PVDF) is not accessible by inspection and as such is purely based on original design and operating conditions.

2. However, Operator may choose, at their discretion, to install plastic coupon monitoring system (at topside portion) to assess the integrity of plastic layers after it is exposed to service environment over a specific time.

Normally required for polyamide materials due to effect of hydrolysis when fluid temperature is close to its limit.

Source: Credit to FORCE TECHNOLOGY
DISCUSSION

3. Any crack on the tensile armour wire is not detectable via this inspection method. However, flexible pipes are designed with large safety factors which allow for some percentage of broken wires.
DISCUSSION

4. Flexible pipes used in water services will face difficulties in identifying the exact location of outer sheath damage (no bubble produced – no permeation of gases). As a result, ROV survey may require longer time to complete underwater survey.
DISCUSSION

5. The evolution of $\text{H}_2$ and permeation of corrosive gases inside the annulus is still a subject of study. Various papers have been presented to international conferences regarding this subject:

- **Offshore Technology Conference:**
  - Comparison of models to predict the annulus conditions of flexible pipe.
  - Operational experience of fatigue performance of a flexible riser with a flooded annulus.

- **Technip-Coflexip product research and development:**
  - High strength metallic materials for flexible pipes – specific environments and corrosion behavior.
CONCLUSION

• With this inspection approach, at least 59% of the damage mechanism for unbonded flexible pipes can be predicted.

• Scheduled inspection is crucial in determining the time factor for calculating corrosion rate.

• Any repair works that is required to be executed on the flexible pipe shall be approved by the Principal.

• A new guideline shall be developed in due time to address flexible pipe safety factors to achieve an appropriate level of reliability.
APPRECIATION

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