UK Industry Seminar
Integrity management of unbonded flexible pipelines and risers

Failure modes and integrity monitoring

Overview & new failure modes

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Today's focus!

- Know the “important” failure modes
- Manage integrity

Safer operation 🧡👍
Operational failure mode overview

- Progressing from inside
  - Carcass fatigue
  - Carcass collapse
  - Errosion
  - Temperature cycling fatigue
  - Ageing
    - Chemicals
    - Temperature
    - Water
  - H$_2$S / CO$_2$ diffusion $\rightarrow$ acid annulus
  - Armour fatigue
  - Vent system malfunction (external sheath breach)

- Progressing from outside
  - Wear from interfacing structures (arch, GT, bend stiffener)
  - Wear of fabric tape
  - Dropped objects
  - Interference with structures
  - Entanglement with other lines
  - External sheath breach
  - Aging
  - Corrosion
  - Hydrogen Induced Stress Cracking (HISC)

Most common
Corrosion related failures →

- **O₂ corrosion**
  - Minor corrosion → SCF
  - Loss of wires

- **CO₂ corrosion**
  - Minor corrosion → SCF
  - Minor loss of material
  - Increased fatigue

- **HISC**
  - Seawater + anodes + high strength steel + high stress
  - Loss of wires

- **Increased fatigue**
  - Wet annulus
  - Higher CO₂ / H₂S partial pressure in annulus
  - Reduced fatigue capacity
Focus area #1:

$O_2$ Corrosion
O$_2$ Corrosion

• Wires normally protected by anodes at pipe ends / vessel
• Exposed to free O$_2$ corrosion armour wires corrode away in 1-2 years
• Areas of concern
  – Failed CP system
  – Splash zone
  – Inside guide tubes & bend stiffeners
  – Voids in end fittings
  – Voids inside annulus
Corrosion inside guide tubes

Free vent GT

Pressurised GT

$O_2$ $O_2$
Splash zone corrosion

- Difficult to observe damaged external sheath near surface
  - ROV inspection not effective close to surface
  - Marine growth may reduce visibility from surface or ROV general visual inspection
What about bend stiffeners?

- Also difficult to see inside...
- High dynamic stresses
- Humid environment
- Lots of $O_2$
- High temperatures
- Anodes not efficient
Observed external sheath failure

- Dynamic riser
- 12 years in operation
- Estimated 98°C average bore temp
- Bend stiffener removed
- Cracking of external sheath
- Oxidation / hydrolysis
Avoiding splash zone corrosion!

- **Free hanging risers**
  - Check annulus vent system
  - Annulus vacuum or low pressure test
  - Annulus gas sampling
  - Inspection by climber from surface
  - Deballasting of vessel
  - Cleaning

- **Risers in guide tube**
  - Video inspection inside GT
  - Pressurised GT
  - Annulus gas release monitoring
Focus area #2:
New HISC failure mode
Hydrogen induced stress cracking

- **Flexible pipe**
  - High strength tensile armour with approx. 55 deg lay angle
  - No pressure armour
  - Carcass
  - Anodes in the vicinity

- **Low energy impact**
  - Breach of the external sheath
  - Seawater in annulus
  - Plastic deformation of armour wires

- **Studied by detailed riser cross section FE model**
Permanent strain after low energy impact

Model includes carcass + pressure sheath + tensile armour wires

Impact from rigid steel cylinder
Hydrogen induced stress cracking

- Small breach of external sheath
- Moderate plastic deformation of steel armour
- Normal operating pressure gives local stress near yield
- HISC
  - Seawater
  - Anodes
  - High strength steel
  - High stress
How to avoid HISC?

- Avoid impacts
- Seal off external sheath failures
- Mitigate by pressure test?
  - Remove residual stress
  - Currently studied in FE-model
- Lower CP potential?
- Shut down line?
Pipe inspection tool (AGR)

- Accurate external inspection
- Identifies deformed armour wires
- Avoid pipe replacement
Focus area #3: Information handling
Integrity management recommendations

Initial information acquisition, inspection, testing and status/risk evaluation

Don’t stop here..

Evaluate information and update risk assessment

Perform system improvements and mitigations

Perform monitoring, inspections and tests

Update program for inspection, testing and monitoring

Information handling
Integrity management recommendations

• Know your system !!
• Assess risk / criticality
• Establish integrity plan
• Perform monitoring / inspection / testing
• Document results and improve program

• Integrity management of flexibles should be fully integrated with other company systems !
Thanks!

Illustrations from
- StatoilHydro
- AGR
- NTNU / Sintef
- Shell
- 4subsea

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