Subsea Pipelines
Anchor Damage Assessment and Repair

An Overview of Methods and Limitations
With A Case Study From the BP CATS Pipeline

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Outline

- Challenges
  - Safety – pressure reductions
  - Assessment Stages
  - Typical Damage
  - Inspection Options/Limitations
  - Assessment Methods/Limitations
  - Repair Options
  - Case Study
Pipeline Damage - Challenges

- Ensure Safety
- Maintain Operation
  - Prevent Failure
  - Shutdown only if required
- Select the Right Repair
  - Contain pressure
  - Support structure
- Repair Quickly
- Repair Permanently

Defect Identification, Measurement and Assessment

Emergency Repair System

Safety!

- Industry Practice - Reduce Pressure
  - Prevent Rupture
  - Prevent time dependent failure
- Will Pipe Collapse?
  - Bending
  - Ovalisation
  - Denting
  - External pressure
- Can Pressure be Reduced?
  - Hydrostatic head
  - Phase change
- Even Basic Pressure Reduction Decision Requires Defect + Risk Assessment

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Defect Assessment - Stages

- Incident Reported
  - Preliminary assessment
- ROV + Sonar Survey
  - Secondary assessment
- Detailed Diver/ROV Survey
  - Main assessment
Preliminary Assessment

- Questions

- Incident Reported
  - Ship reports snagging
  - ILI report indicates dent and
gouge
  - Sonar/ROV survey indicates
damage

- Preliminary Assessment Questions
  - Should the pipeline be shutdown?
  - Is a pressure reduction required?
  - Is it safe for a vessel to approach?
  - Will a repair be needed?
  - What type of repair is likely?

- Preliminary Assessment
  - Data

- Incident details
  - Location,
  - Ship speed,
  - Was anchor abandoned on Pipeline?
  - Did anchor chain break?
  - Leak?

- Ship details
  - Tonnage,
  - Anchor size/weight,
  - Anchor chain weight/breaking strain.

- Pipeline details
  - Diameter,
  - Wall thickness,
  - Material,
  - Coatings,
  - Depth of burial,
  - Operating pressure.
**Preliminary Assessment**

- **Approach**
  - Calculate Damage Resistance
    - Dent Depth vs Impact Energy
    - De-burial vs Ship kinetic energy
    - Bending vs Ship kinetic energy
  - Calculate Available Energy for Damage
    - Anchor + chain weight and velocity
      - Concrete crushing
      - Local denting
    - Ship mass and velocity
      - Pipeline de-burial
      - Global deformation/bending

\[
E := \frac{3}{d^2 \cdot 100 \cdot mp} \frac{1}{\sqrt{OD}}
\]

- **Potential Conclusions**
  - Significant damage not credible (Small ship + Large pipeline)
    - No immediate pressure reduction
    - Proceed with ROV survey
    - Review repair readiness
  - Significant damage possible (Large ship + Large pipeline)
    - Reduce pressure
    - Mobilise emergency repair system (grouted sleeve)
    - Proceed with ROV
  - Significant damage likely (Large ship + Small pipeline)
    - Shutdown or significantly reduce pressure
    - Mobilise emergency repair (mechanical connectors)
    - Proceed with ROV
**ROV + Sonar Survey**

- Initial survey to:
  - Confirm location
  - Provide general visual information

- ROV:
  - Video survey
    - De-burial
    - Displacement
    - Coating state
    - Evidence of denting
    - Evidence of gouging
  - Currents
  - Sediment/silt
  - Basic measurements
  - CP stab – identify bare metal

- Sonar:
  - Displacement
  - Seabed scars

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**Secondary Assessment - Questions**

- Should the pipeline be shutdown?
- Is a pressure reduction required?
- Is it safe for divers?
- Can the anchor be safely removed?
- Can excavation / exposure be carried out?
- Can the coating be removed?
- Will a repair be needed?
- What type of repair is likely?
Secondary Assessment

- ‘Global’ Stress analysis of snagging/displacement to evaluate stress condition
- Span assessment
- Stability
- Identify ‘likely’ local damage type:
  - Plain dent
  - Dent on weld
  - Dent plus gouge
  - Gouge only
- Calculate critical damage sizes
  - Identifies measurements required

Diver Survey

- Excavate
- Remove coating
- Detailed visual inspection
- Geometric inspection
- Magnetic Particle Inspection
- Ultrasonic inspection
Final Assessment
- Questions

- Should the pipeline be shutdown?
- Is a pressure reduction required?
- Will a repair be needed?
- What type of repair?

Final Assessment

- Assess local damage
  - Burst pressure
  - Fatigue life
  - Operational restrictions
- Basis of assessment
  - Industry guidance/experience
  - FEA
  - Include effects of displacement
- Damage behaviour and failure mechanism
  - Repair performance requirements
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Typical (Possible) Damage

- Rupture
- Gouge
- Displacement
- Plain Dent
- Dent Plus Displacement
- Dent on Weld
- Dent and Gouge
- Kinked Dent
Inspection Options and Limitations

- Sonar Survey
- ROV
  - Visual
  - Position
  - CP
- Diver
  - Visual
  - Calliper
  - Straight edge
  - MPI
  - UT
  - Laser scanning

Assessment Options and Limitations

- Gouge – NG18
- Displacement – FEA or Beam Theory (strain limits)
- Plain Dent – Empirical limits, strain assessment, EPRG fatigue model
- Dent Plus Displacement – No proven methods
- Dent on Weld – EPRG fatigue model
- Dent and Gouge – EPRG model
- Kinked Dent – No Proven method

\[
\frac{\sigma_f}{\sigma} = 1 - \frac{d + d_s}{t} = 1 - \frac{d + d_s}{t} \frac{1}{M}
\]

\[
N = \left( \frac{1}{10} \right) 10^{00} \left[ \frac{(\sigma_U - 50)}{2\sigma_A K_s} \right]^{4.292}
\]

\[
\frac{\sigma_f}{\sigma} = \frac{2}{\pi} \cos^{-1} \left[ \exp \left\{ \frac{1.5\pi E}{\sigma_A Ad} \left[ y(1 - 1.8D_s) + y(10.2 R D_s) \right] \right\} \right]
\]
Offshore Pipeline Repair Options

- Grinding
- Clamps / Sleeves
- Section Replacement
  - Connectors
  - Hyperbaric welding
  - Recovery to surface

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Grind repair

Clamps / Sleeves
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Details of the Incident

- Late evening on 25th June 2007 a large crude tanker which had been anchored to the north of the CATS Pipeline for a period of time awaiting entry to Teessport Harbour, began to drag its anchor in deteriorating weather.
- At approx. 2330 the vessel reported that it had “snagged” its anchor on a pipeline to the south east of its original position.
- After around 10 minutes the vessel was able to free itself from the pipeline and move off to the south.
- Harbour Authority reported incident to CATS Terminal staff.
- BP Emergency Response Plans instigated & investigation commenced.
- Incident has been fully investigated by Marine Accident Investigation Branch & the report has recently been published (Report No. 3/2008 at www.maib.gov.uk).
Anchor Damage – Case Study

- 25th June 2007 - A ship was in difficulty in bad weather.
- One of its anchors hit the 36" pipeline and lifted it from under the seabed

- Harbour Authority reported incident to CATS Terminal staff
- BP Emergency Response Plans instigated & investigation commenced

Initial Assessment

- No evidence of rupture
- No evidence of leak
- Potentially severe damage
- Small pressure reduction imposed
- Pressure controlled

- Anchor weight and velocity – approx. 15 mm dent (1.7%)
- Gouging? Displacement? Bending?
ROV Survey

- Initial reports showed concrete damage, bending, gouging, and denting

Secondary Assessment

- Apparently severe damage
  - Dent gouge calculations indicate failure pressure below design for credible combinations.

- Pressure reduction required

- Review repair options
Investigation of Repair options

BP Project Team established & dedicated to the repair.

following repair options reviewed in parallel with inspection activities

- Do nothing or dress defect, assess and leave
- Wet weld, metal build up
- Deploy existing BP clamp / identify alternatives across the globe
- Replace section with subsea connectors
- Replace section with hyperbaric welds
- Lift pipe and re-lay section with lay barge and tie-in
- Re-lay new section with lay barge and tie-in

Detailed Inspection / Work Program

1. Pipeline depressurisation (in controlled stages from 113 barg to 54 barg) to enable safe diver access
2. Diverless excavation of pipeline and further ROV inspection
3. Final excavation of pipe spool (approx. 20m)
4. Concrete & Coal Tar Coating removal (approx. 14m)
5. Detailed Diver Inspection
   - Close visual inspection
   - Out of Straightness survey
   - Ovality Survey
   - Taut Wire
   - Magnetic Particle Inspection (welds & defect areas)
   - Ultrasonic Inspection (welds & defect areas) – automated and manual
Inspection Results

• 1.5m vertical displacement
• 4.5m horizontal displacement
• Damage over a 4m length in middle of spool

• 2 Dents within a larger deformed area
• 31mm and 25mm max. depth (3.4%D)
• 2 Protrusions of max. 15mm
• Weld deformed
• No weld defects / cracking
• No gouging

Final Defect Assessment

- Defects were assessed using the Pipeline Defect Assessment Manual (PDAM)
- Limitations:
  - No method for combined dent and external load.
  - Limited test data for large diameter offshore pipelines.
- FEA of displacement.
- FEA of dented area
- EPRG dent fatigue
Results of Defect Assessment

- Analysis Findings:
  - No reduction in static strength of pipeline
  - Fatigue life of pipeline reduced by dents on weld

- Repair Decision:
  - Existing sleeve would not fit (too short and pipe bent)
  - Structural, cement grouted sleeve repair selected to provide reinforcement of dented area

How long did it take?

- Incident occurred - 25 June
- Initial survey complete – 30 June
- Pipeline shutdown – 1 July
- Pipe depressurised and safe to dive – 18 July
- Detailed inspection complete – 28 July
- Go ahead for sleeve fabrication – 29 July
- Sleeve Fabrication / Fit-Up Trials complete - 17 August
- Diving Support Vessel on location - 18 August
- Pipeline recommissioning commenced - 24 August
- Delivery of on-spec gas - 1 Sept
- Rock dump complete – 2 Oct
Critical Success Factors

- Cross-industry support to release vessels during peak summer period – both from operators and contractors
- Fantastic support & dedication from key contractors with whom BP already had long term relationships – Technip, Acergy, RBG, JP Kenny, Penspen/APA, Jee, Foundocean, Subsea 7 and others
- Rapid mobilization of dedicated project team from BP & contractors
- Existing relations with BP global experts simplified assurance processes
- Clear accountabilities within Project Team – Pipeline Integrity, Subsea Activities, Terminal Ops, Sleeve Fabrication, JV and Reputation Management
- Strong engagement with regulators from Day 1

HIGH QUALITY, PERMANENT PIPELINE REPAIR SAFELY IMPLEMENTED IN LESS THAN 3 MONTHS

Summary

- There are stages to damage assessment
- Uncertainties at each stage
- Data changes
- Need to use all available data
- Specialist skills/experience needed
- Contingency plans/repairs may not be appropriate
- Proven methods for assessment may not be available
- Caution is needed
Repair Management

- Pipeline operator
- Vessel operator
- Diving contractor
- ROV operator
- NDT contractor
- Defect specialists
- Welding
- Re-commissioning
- Subsea designer
- Verification agency/consultant
- Equipment suppliers
  - Pipe handling
  - Concrete removal
  - Pipe cutting
  - Clamp or connectors
  - Welding habitat
  - Isolation tools
  - De-watering pigs
- Regulator

REPAIR: Caution.

Some wise words on repair*:

- ‘Do no harm!’
  - A bad repair can make matters worse.
  - Repairs need careful engineering, at least as much as a new construction.
  - Do not act in haste.
- A repair is often not a good time to try something new.
  - There is less experience with a new procedure, compared to tried and tested designs. Surprises may occur with uncertainty and incompletely planned engineering