Flexible Pipe Integrity; post-Sureflex & introducing the draft EI life extension guidance

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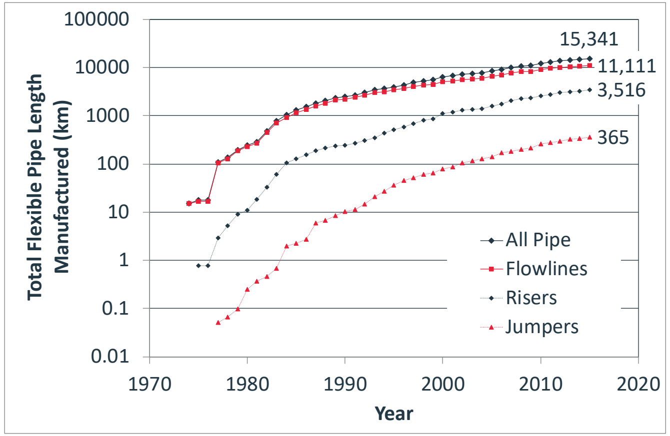
Sureflex JIP (published 2017)

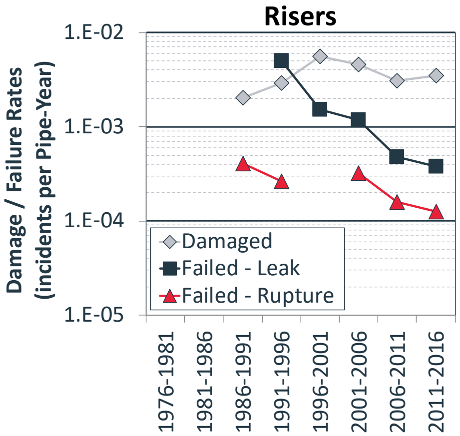
Population statistics

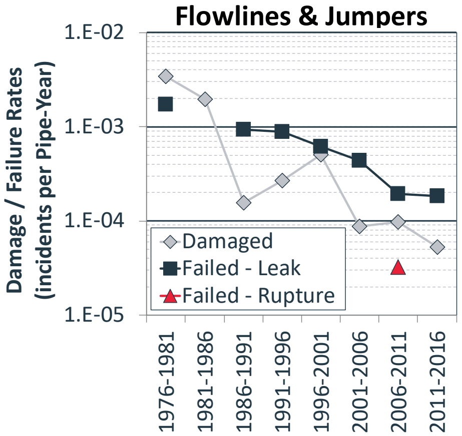
- 1970s to date
- ~16,000km inventory



Damage & Failure

- ~600 industry events categorised
- Incident rate trending





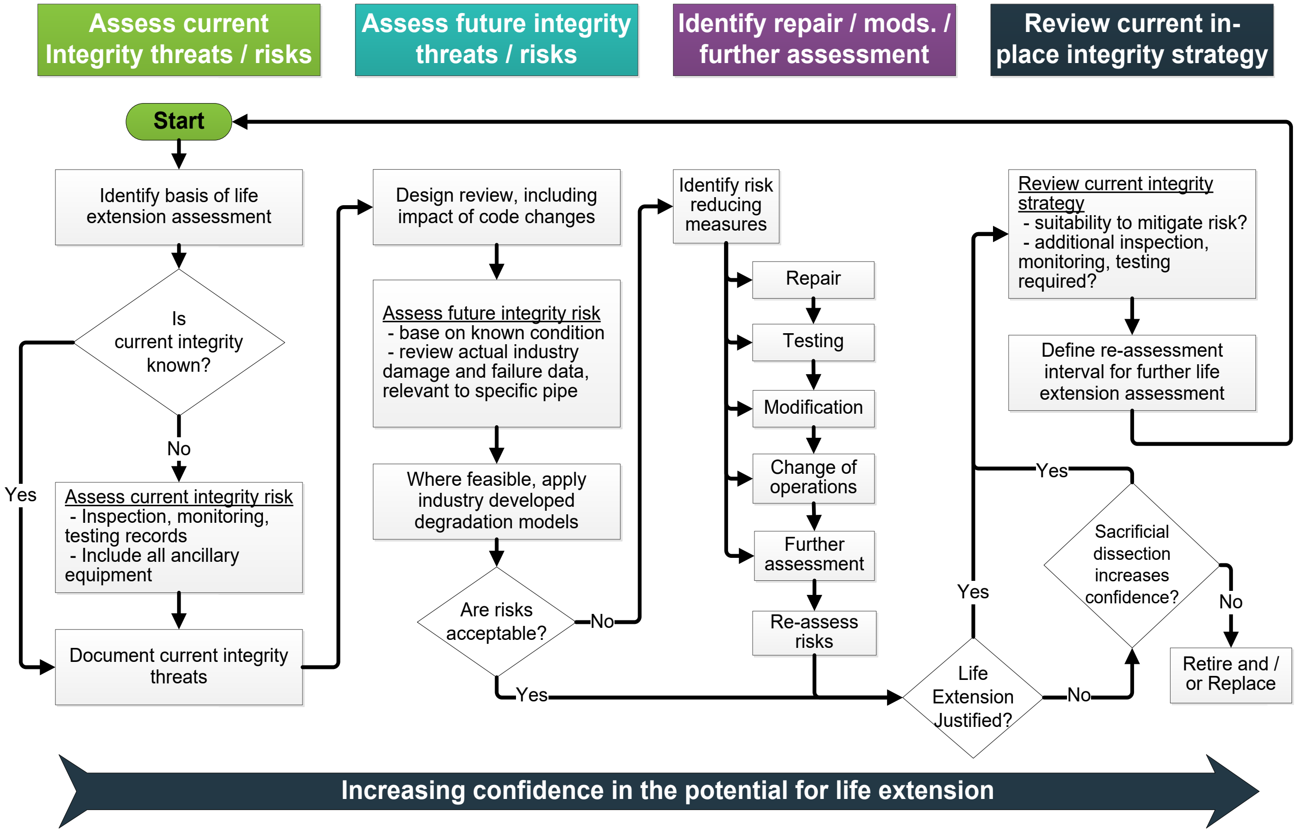
Sureflex JIP (published 2017)

- Inspection & Monitoring Technology
  - ~40 methods peer reviewed / categorised and guidance presented via dedicated workshops
- Integrity Management Good Practice & Lessons Learned
- Flexible Pipe Technology Developments
  - Manufacturer & other JIPs / Forums
- Operator Information Exchange Workshop Sessions
  - Detailed, but desensitised, lessons & challenges shared

Post Sureflex

- Since Sureflex, more high profile events
  - Further corrosion failures
  - Riser replacement based on fatigue experience in combination with inspection / monitoring findings
  - Further ancillary equipment degradation / failure
  - Further end fitting leaks
- Have corrosion / fatigue failure statistics reached equilibrium?
  - Probably not…
  - Need to continue collating and sharing good practice, and guidance on mitigation of in-service threats

EI Draft Guidance – Life Extension of Unbonded Pipe



EI Draft Guidance – Life Extension of Unbonded Pipe

- Historical tendency to focus on riser fatigue analysis
  - Important to address in life extension, but…
  - Represents single damage / failure mechanism with very limited in-service experience

- In comparison, significant range of damage/failure mechanisms
  - Pipe cross section
  - Ancillary equipment / interfaces

- Guidance addresses flexible pipe systems
  - i.e. include all mechanisms, ancillary equipment & interfaces

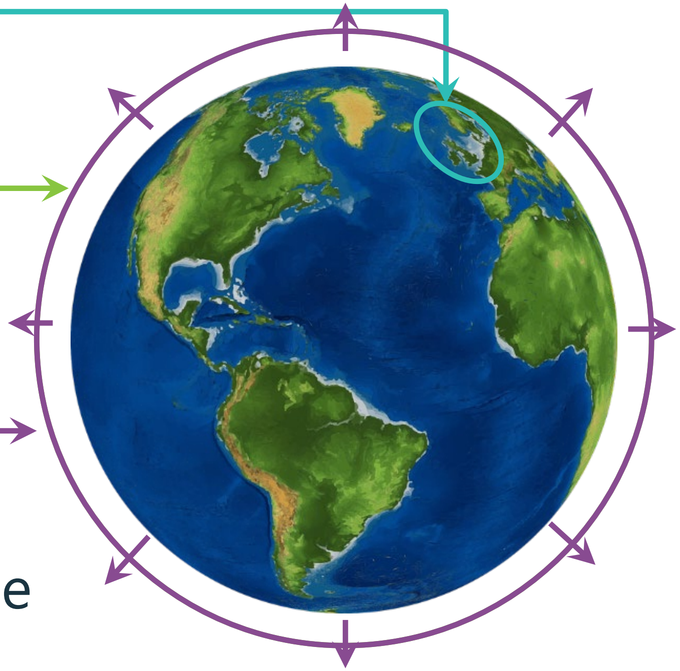
EI Draft Guidance – Life Extension of Unbonded Pipe

- Semi-qualitative risk-based approach
- Questions to consider
  - Distinguishing features of the damage / failure experience compared to the flexible pipe being assessed
    - similar design / operating conditions, test / inspection history?
  - What was the timeline to damage / failure?
  - Are there mitigating factors for the assessed pipe?

- What datasets / experience do we direct these questions to?

EI Draft Guidance – Life Extension of Unbonded Pipe

- 3 datasets of failure mechanism *experience*
  1. "Our" world
     - Within our local operated assets
  2. Wider world
     - Across the global industry e.g. Sureflex
  3. Outside our world experience
     - Potential mechanism with limited or no reported industry experience



EI Draft Guidance – refresh of industry experience

Grouped Damage / Failure Cause	Time Dependent	Time Independent	Riser or Flowline&Jumper	Damage / Failure Status: Degradation / Damage / Perceived Degradation, without Failure	Damage / Failure Status: Failed - Leak	Damage / Failure Status: Failed - Rupture	Sub-Total No.	Sub-Total %	Total No.	Total %
Sheath Damage / Annulus Flooded	✓	✓	Riser	189			**189**	**34.0%**	**215**	**38.7%**
			Flowline&Jumper	26			**26**	**4.7%**		
Internal Pressure Sheath, Ageing	✓		Riser	11	5		**16**	**2.9%**	**31**	**5.6%**
			Flowline&Jumper	3	12		**15**	**2.7%**		
Carcass Failure, Multilayer PVDF Collapse		✓	Riser	32	4		**36**	**6.5%**	**36**	**6.5%**
			Flowline&Jumper				**0**	**0.0%**		
Internal Pressure Sheath, End Fitting Pull-out	✓		Riser	13	16		**29**	**5.2%**	**33**	**5.9%**
			Flowline&Jumper	1	3		**4**	**0.7%**		
Vent System Anomalies / Blockage	✓	✓	Riser	27			**27**	**4.9%**	**28**	**5.0%**
			Flowline&Jumper	1			**1**	**0.2%**		
Ancillary Equipment	✓	✓	Riser	59	5		**64**	**11.5%**	**64**	**11.5%**
			Flowline&Jumper				**0**	**0.0%**		
Tensile Armours - Birdcaging	✓	✓	Riser	4	7		**11**	**2.0%**	**18**	**3.2%**
			Flowline&Jumper		7		**7**	**1.3%**		
Corrosion of Armours	✓		Riser	7		4	**11**	**2.0%**	**27**	**4.9%**
			Flowline&Jumper	3	13		**16**	**2.9%**		
Overbend / Pressure Armour Unlock		✓	Riser	2	5		**7**	**1.3%**	**15**	**2.7%**
			Flowline&Jumper	2	6		**8**	**1.4%**		
End Fitting Leak / Failure	✓		Riser	1	6		**7**	**1.3%**	**17**	**3.1%**
			Flowline&Jumper		9	1	**10**	**1.8%**		
Internal Pressure Sheath, Fatigue / Fracture / Microleaks	✓		Riser	3	5		**8**	**1.4%**	**13**	**2.3%**
			Flowline&Jumper	1	4		**5**	**0.9%**		
Carcass Failure, Tearing / Pullout	✓		Riser	6	2		**8**	**1.4%**	**9**	**1.6%**
			Flowline&Jumper		1		**1**	**0.2%**		
Global pipe defect, Wax Blockage	✓	✓	Riser	9			**9**	**1.6%**	**11**	**2.0%**
			Flowline&Jumper	2			**2**	**0.4%**		
Smooth Bore Liner Collapse		✓	Riser	1	3	3	**7**	**1.3%**	**9**	**1.6%**
			Flowline&Jumper		2		**2**	**0.4%**		
Tensile Armour Wire Breakage	✓		Riser	2	3	1	**6**	**1.1%**	**6**	**1.1%**
			Flowline&Jumper				**0**	**0.0%**		
Other	✓	✓	Riser	5	1	1	**7**	**1.3%**	**24**	**4.3%**
			Flowline&Jumper	14	3		**17**	**3.1%**		
SUM				**424**	**122**	**10**	**556**	**100%**	**556**	**100%**
%				**76.3%**	**21.9%**	**1.8%**				

EI Draft Guidance – per damage / failure mechanism

- Applicability to specific pipe systems
- Description of time dependency
- Mitigations (existing or future), categories;
  - Design, Operations, Inspection, Monitoring, Testing, Analysis, Intervention, Management
- Relative strength of mitigations

EI Draft Guidance – e.g. damage / failure mechanism

Example;

- existing industry experience

<table>
<tr><td>Grouped Damage / Failure Mechanism</td><td colspan="3">Carcass Failure, Multilayer PVDF Collapse</td></tr>
<tr><td>Time Dependent / Independent</td><td colspan="3">Predominantly time independent.</td></tr>
<tr><td>Applicability</td><td colspan="3">Only applicable to flexible pipes with multi-layer PVDF pressure sheathes. Mechanism has only been experienced on 3-layer PVDF products to date, although 2 layer designs may also be susceptible. Collapse risk is <u>reduced</u> (not eliminated) by design modifications that were applied after identification of failures (post-2002).</td></tr>
<tr><td rowspan="2">Risk Factors</td><td colspan="3">Potential Mitigations</td></tr>
<tr><td>Type</td><td>Mitigation</td><td>Strength</td></tr>
<tr><td rowspan="4">Carcass Failure, Multilayer PVDF Collapse</td><td>Design</td><td>Confirm design documentation defines depressurisation limits to mitigate threat.</td><td>Weak (<u>application</u> of limits in operation is main barrier)</td></tr>
<tr><td>Operations</td><td>Close monitoring of bore depressurisation <u>rates</u> and confirmation that limits are adhered to throughout all operating phases.</td><td>Strong (<u>if</u> confidence is high in monitoring of actual breaches of the rate limits)</td></tr>
<tr><td>Inspection / Intervention</td><td>Internal inspection has been applied by some operators to verify the internal condition, although this is normally a major / abnormal intervention. This is a Strong mitigation that the collapse has not occurred <u>at the time of inspection</u> if the full pipe length is inspected.</td><td>Strong (in combination with future monitoring)</td></tr>
<tr><td>Inspection / Intervention</td><td>Some operators have discovered carcass pieces in topsides chokes / valves / process vessels. However, this is only a "passive" and weak mitigation.</td><td>Weak</td></tr>
<tr><td>Other Supporting Notes</td><td colspan="3">The failure mechanism was first identified after 2001. For older pipes, where the more restrictive depressurisation rates (to mitigate damage) may not have been included in the design documentation, the manufacturer should be consulted to confirm recommended limits. In the absence of this, typical linear maximum depressurisation rates for flexible pipe to mitigate this collapse threat is ~100barg/hr.</td></tr>
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EI Draft Guidance – e.g. damage / failure mechanism

Example;

- Limited / no reported industry experience

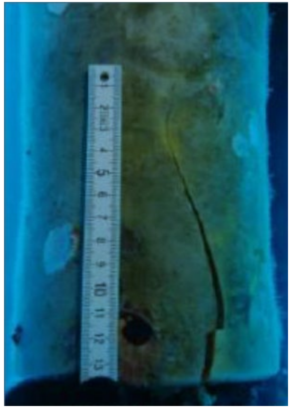
Damage / Failure Cause	API RP17B Defect Ref.	Guidance (e.g. potential risk factors, industry experience)	Indicative Residual Likelihood of Occurrence
Carcass; hole, crevice, pitting, or thinning	1.1	• Erosion not normally a major issue. Although a flexible pipe design MBR is relatively low, it is not common for a pipe to be in this condition through long-term operation. • Carcass / collapse design normally conservatively assumes worst case external hydrostatic pressure **and** no pressure in the bore. In liquid and multiphase oil/gas/water systems, the hydrostatic head in the pipe bore normally partially resists collapse even when the pipe is depressurised. • Applied industry models tend to be conservative based on experience of recovered pipe samples. • Carcass defects may exist (undetected by industry, as failure has not occurred), especially in areas of relatively tight bends / high flows / entrained solids. • In-service inspection utilising internal visual examination may be able to confirm absence of gross defects, although cleaning may be required, and the technology is not known to have been used for this specific application to date. • With combination of factors (aggressive bore contents and flowrates, tight bends, and long-term exposure), it is possible this mechanism will occur in future / long-life operations.	**Unlikely**, if operated within design limits (taking into account extended operation). **Possible**, if operated outside of design limits (taking into account extended operation).

EI Draft Guidance – Life Extension of Unbonded Pipe

- Lastly, updated guidance on inspection & monitoring
  - are initiating defects really identifiable through GVI?

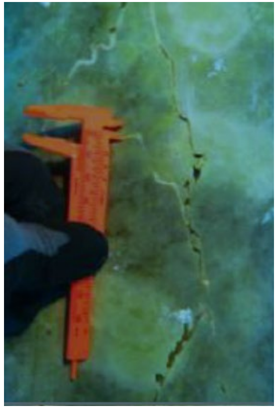
Bend Stiffener Tip Inspection

Stiffener Tip Damage



Cleaning Damage

In-situ



Recovered

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