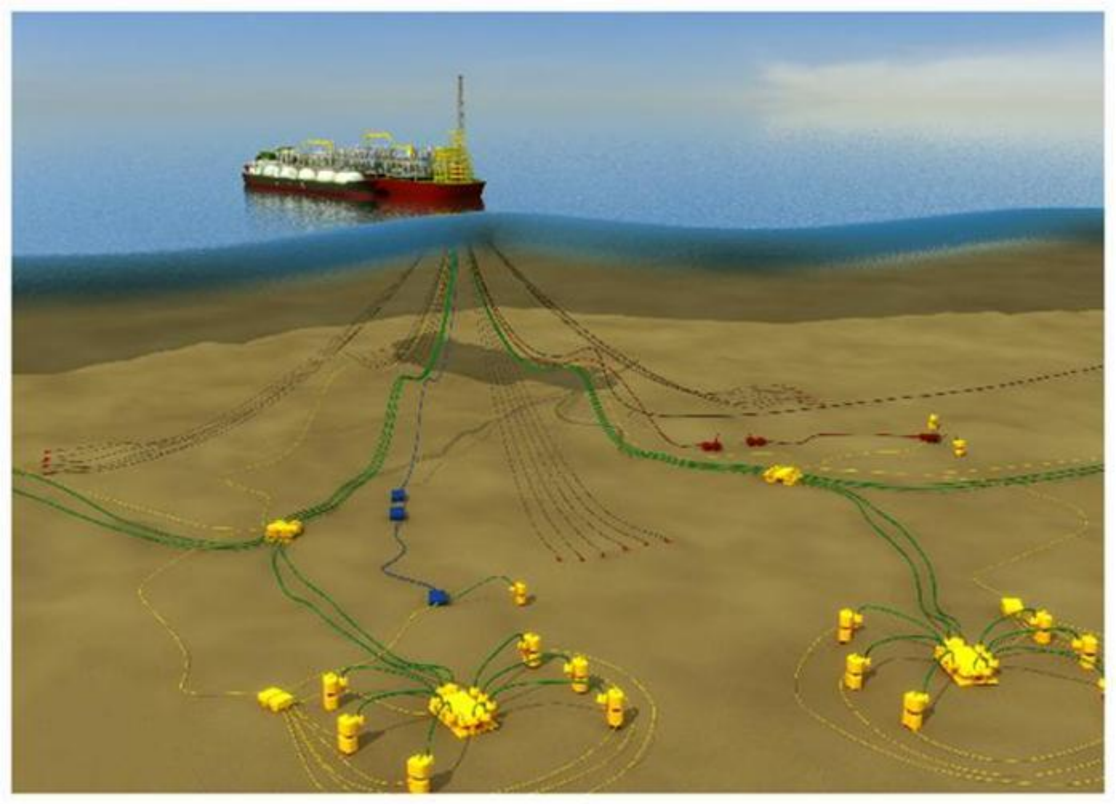
Shell Projects and Technology

16-12-10 KIvI lecture

How to live with Flexible Pipe, happily ever after?

J. M. M. (Hans) Out



KlvI Flexible pipe
content

- Introduction
  - What is flexible pipe?
    - Design specification
    - Polymers
    - End-fitting
- Shell's research efforts
- Design analysis
- Failure mechanisms
- Integrity management
- current issues

Operation *Pluto* (Pipe-Lines Under The Ocean)

In January 1945, 305 tonnes of fuel was pumped to the Allied forces in France per day. This increased tenfold to 3,048 tonnes per day in March, and eventually to 4,000 tons (almost 1,000,000 Imperial gallons) per day.
In total, over 781 000 m³ (equal to a cube with 92 meter long sides) of gasolinehad been pumped to by VE day, providing a critical supply of fuel until a more permanent arrangement was made, although the pipeline remained in operation for some time after.

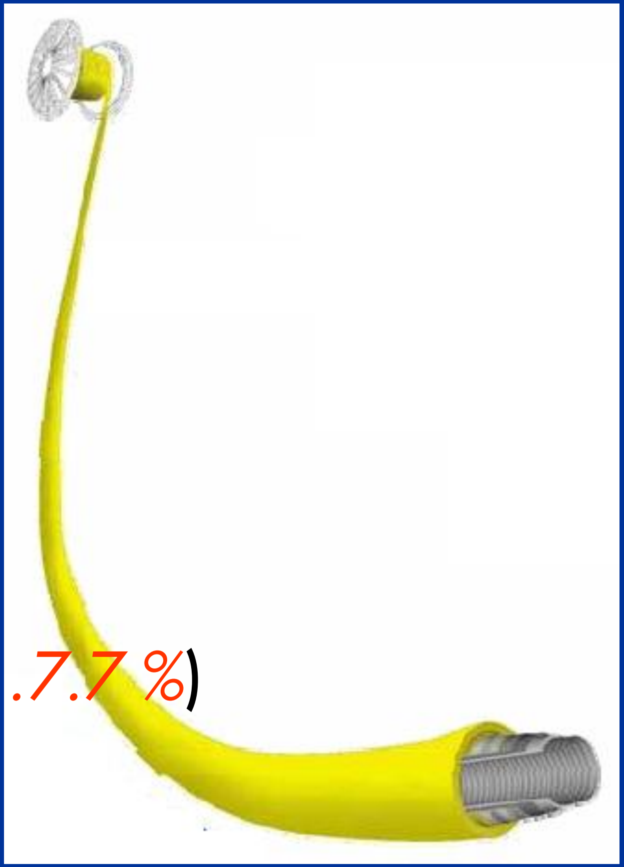
No report of loss of containment or mechanical failure.

Not torque balanced

Flexible pipe

Flexible **means:**

- Capacity to highly bend, to **MBR**
- Low **bending stiffness**



MBR determined by**:**

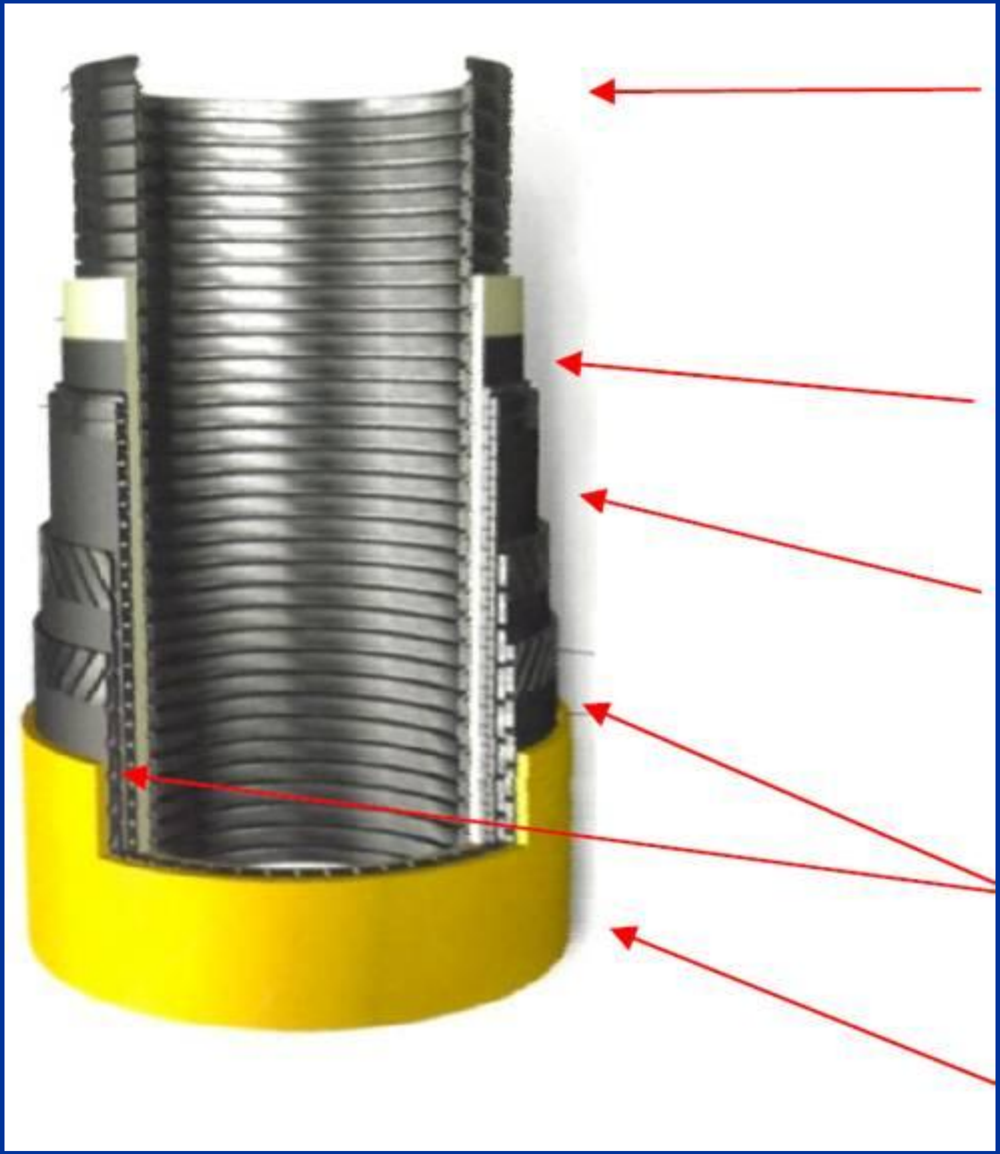
- strain of **polymer sheaths** (*3.5…7.7 %*)
- *not any interlocking*

Bending Stiffness governed by:

- stiffness of **polymer sheaths** *but friction…*

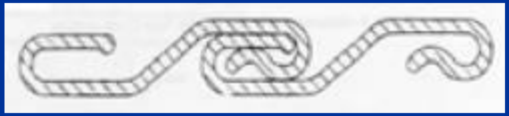
Axial / radial stiffness and strength
governed by **steel reinforcing**

Flexible pipe



smoothbore: topsides use, water injection

Interlocking carcass



internal pressure sheath

Interlocking pressure armour

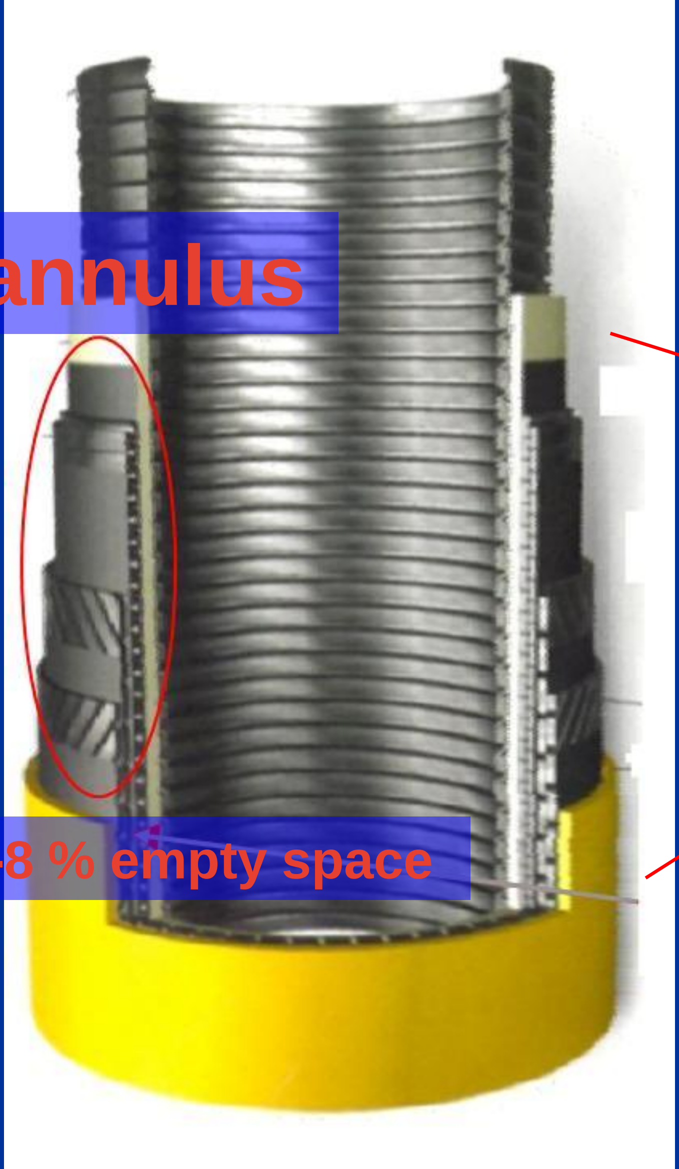
or double C, or T/ clip

(supplementary pressure armour)

tensile armours

external sheath

Flexible pipe



annulus

7-8 % empty space

polymer sheaths pressure tight – but permeable

Flexible riser design parameters

- Internal Diameter
- Internal pressure
- Blow down rate
- Waterdepth (850 m), floater (semi+mooring), environment
  - External pressure
- Fluid composition (CO_2, H_2S…), production chemicals
- Temperature (max, min)
  - Flow assurance, insulation
- Static or dynamic
- Installation method
- Design life
- Sand – max flow velocity

Flexible pipe
Standards

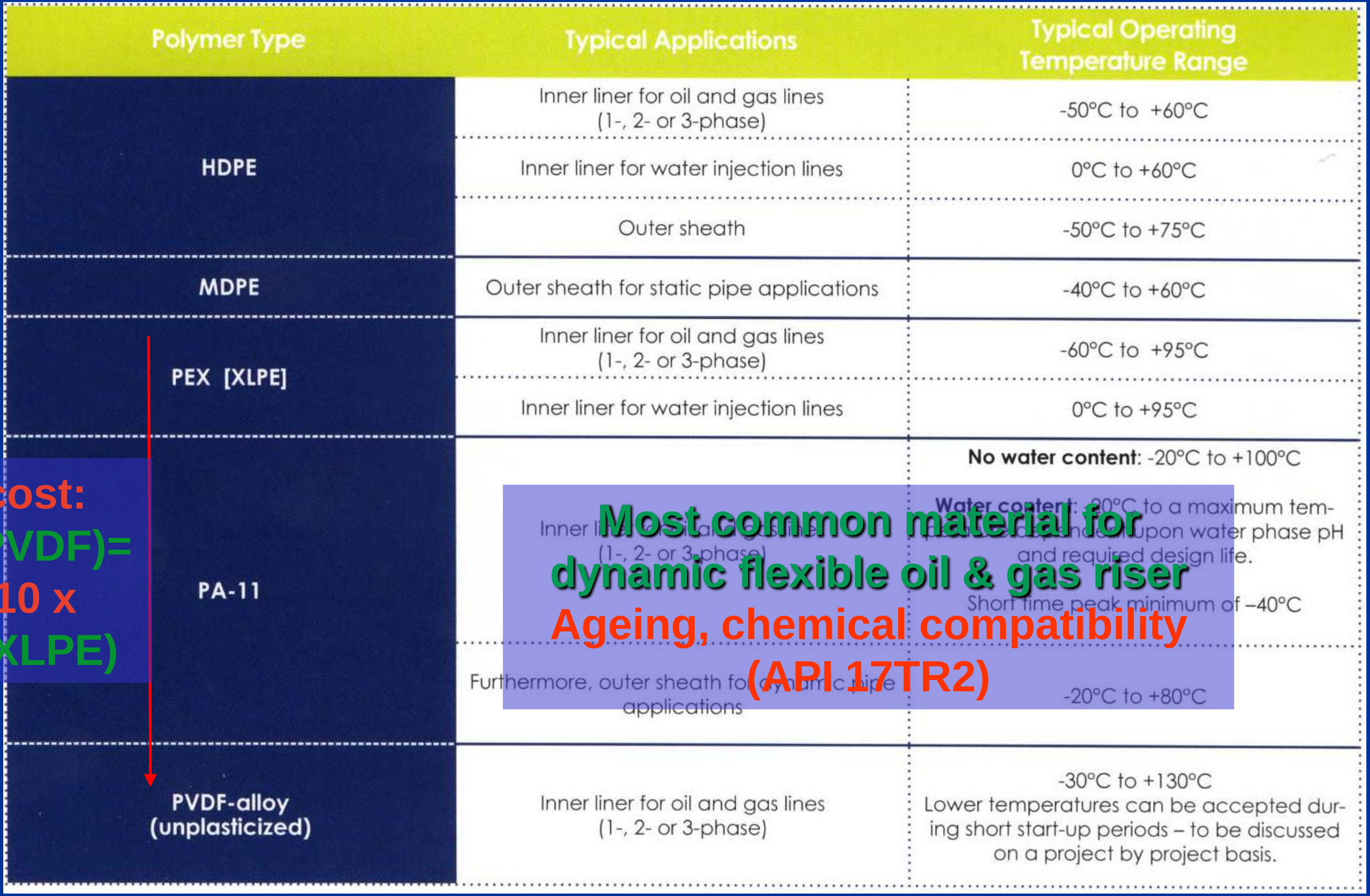
Recommended Practice for Flexible Pipe, ANSI/API Recommended Practice 17B, 4th Ed., July 2008

Specification for Unbonded Flexible Pipe
ANSI/API Spec. 17J 3rd Ed., July 2008

Specification for bonded flexible pipe 17K

API TR 17TR2 The Ageing of PA-11 in Flexible Pipes

Flexible pipe – polymer materials



Polymer Type	Typical Applications	Typical Operating Temperature Range
HDPE	Inner liner for oil and gas lines (1-, 2- or 3-phase)	-50°C to +60°C
	Inner liner for water injection lines	0°C to +60°C
	Outer sheath	-50°C to +75°C
MDPE	Outer sheath for static pipe applications	-40°C to +60°C
PEX [XLPE]	Inner liner for oil and gas lines (1-, 2- or 3-phase)	-60°C to +95°C
	Inner liner for water injection lines	0°C to +95°C
PA-11	Inner liner for oil and gas lines (1-, 2- or 3-phase)	**No water content**: -20°C to +100°C **Water content**: -20°C to a maximum temperature dependent upon water phase pH and required design life. Short time peak minimum of –40°C
	Furthermore, outer sheath for dynamic pipe applications	-20°C to +80°C
PVDF-alloy (unplasticized)	Inner liner for oil and gas lines (1-, 2- or 3-phase)	-30°C to +130°C Lower temperatures can be accepted during short start-up periods – to be discussed on a project by project basis.

cost: $(PVDF)= 10 x $(XLPE)

Most common material for dynamic flexible oil & gas riser

Ageing, chemical compatibility (API 17TR2)

Flexible pipe end-fitting (1)

End-fitting functions:

Assume roles of the stack of flexible pipe components:

- seal
- strength

Vent gasses from the annulus

Most proprietary flexible pipe component

Flexible pipe end-fitting (2)

annulus venting tube (3 x)

KIvI Flexible pipe

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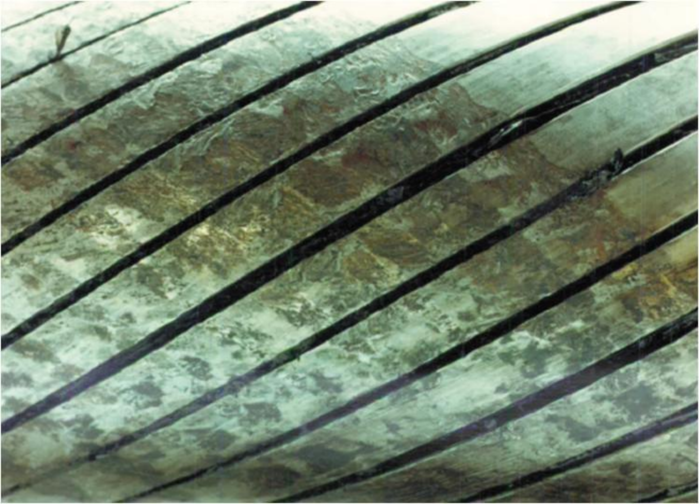
Shell's research efforts
testing

Endurance testing – rotative bending

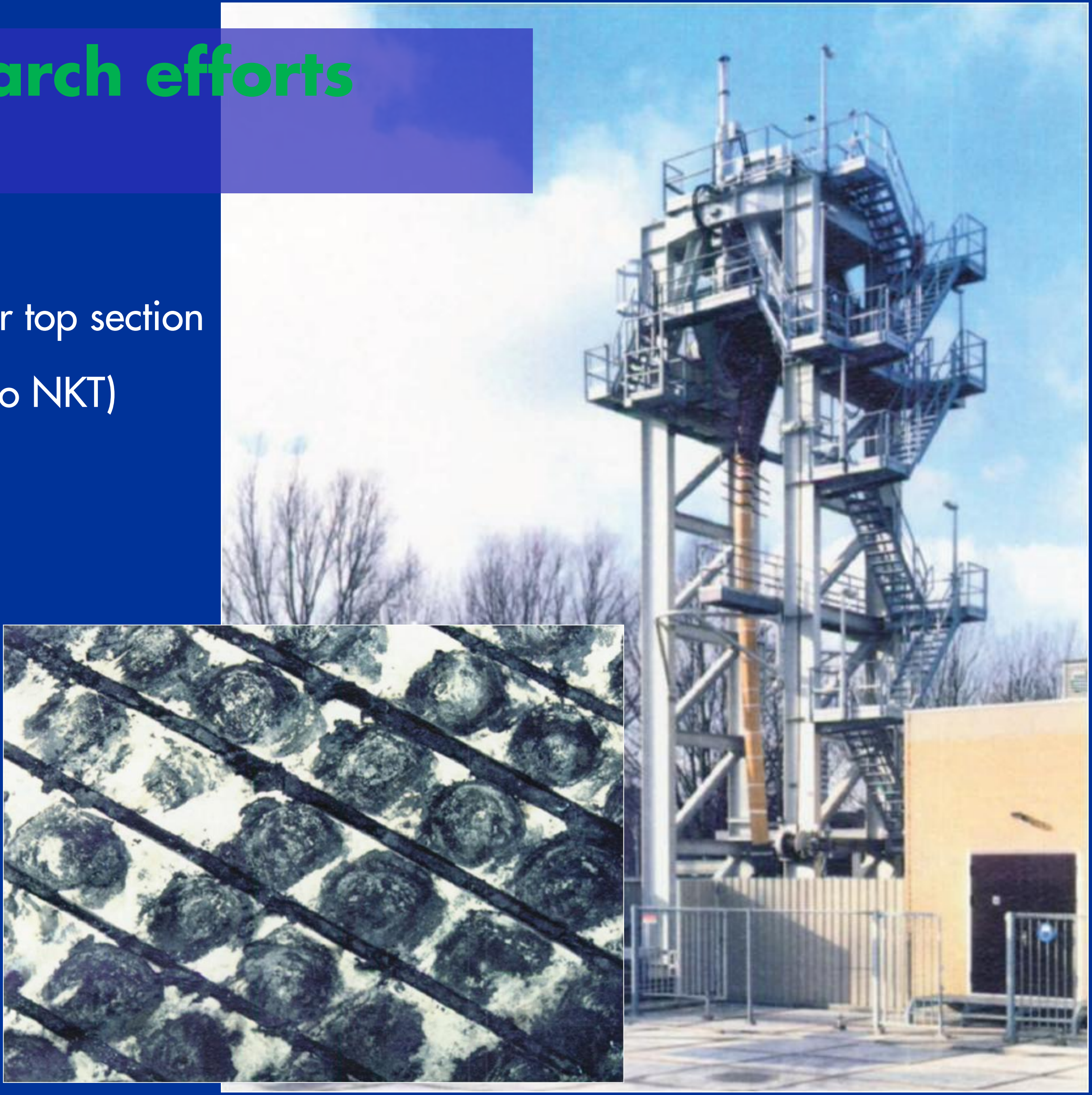
1980 – 2000-ish

Severe

- all circumference
- speed



Shell's research efforts *testing (2)*



Endurance testing – riser top section

1989 – 2000-ish (sold to NKT)

JIPs

Realistic top section

- In plane bending
- Tension
- Bend stiffener

Purpose

- Qualification

Shell's research efforts *analysis*

Service life analysis model based on:

- dynamic analysis, yielding global forces and curvature changes
  - Option of incorporating hysteretic behaviour
  - Mature (programs, contractors)...
- Cross-sectional analysis model (σ, ε, φ, κ from p, N, M_t, M_b)
  - Including bending
- Endurance life dominated by **wear** – *failure mode now obsolete*
- Small scale wear experiments
- Calibration from full scale tests

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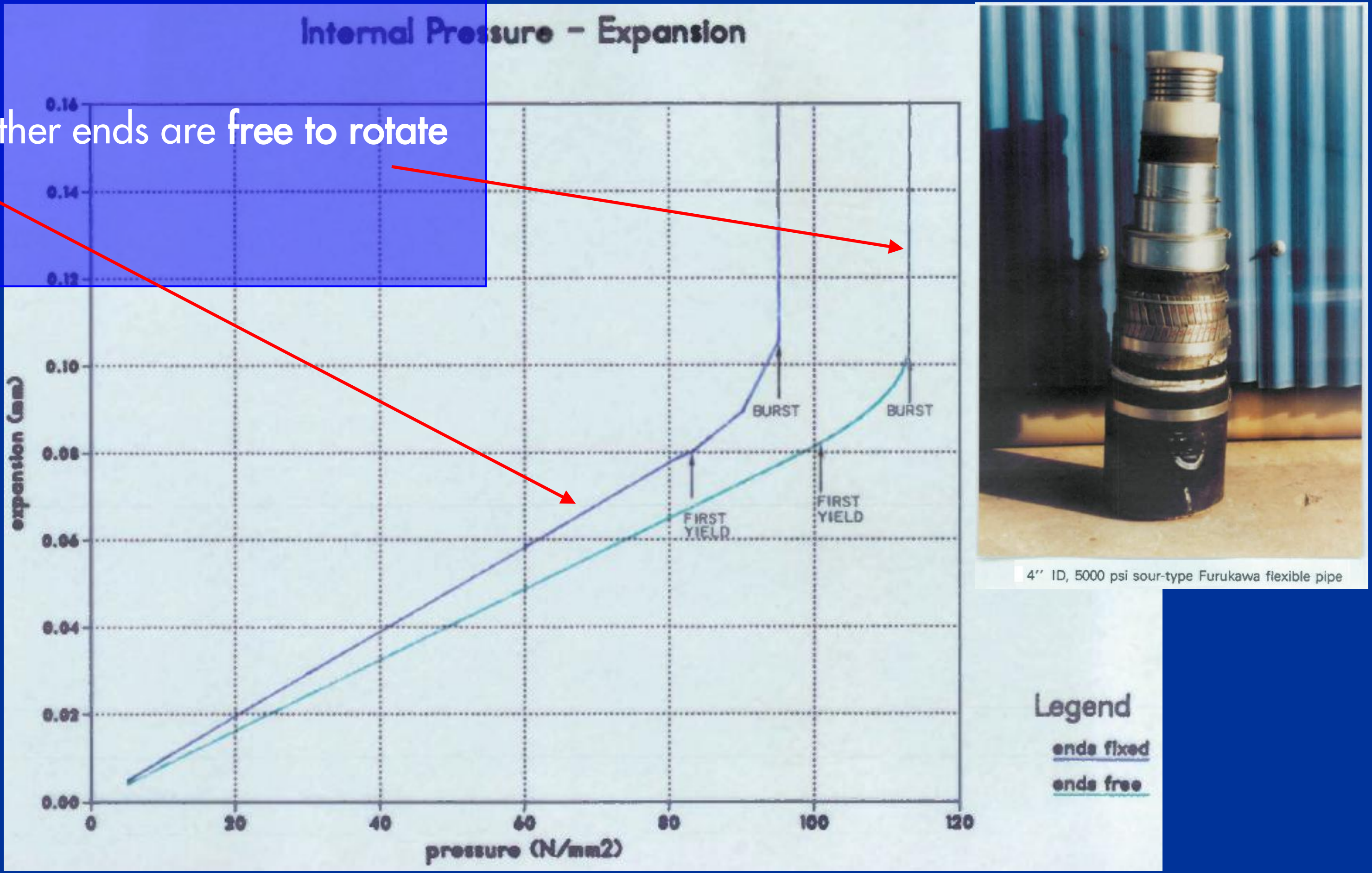
Flexible pipe analysis (2)

Example of torque balance

Burst test:

Influence of whether ends are **free to rotate** or **fixed**



4'' ID, 5000 psi sour-type Furukawa flexible pipe

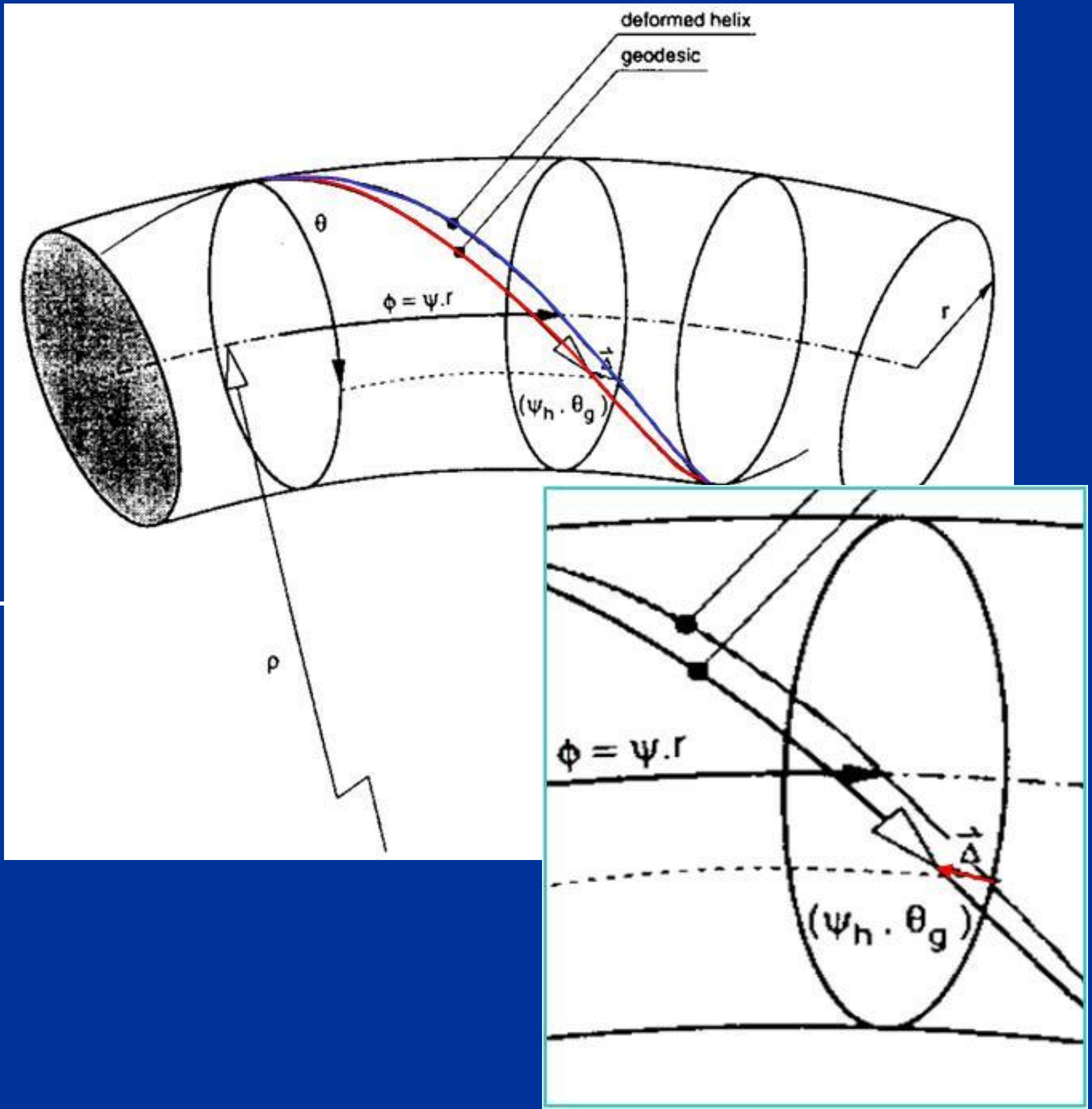
Flexible pipe analysis
Example of bending analysis (1)

Difficult, not possible exactly

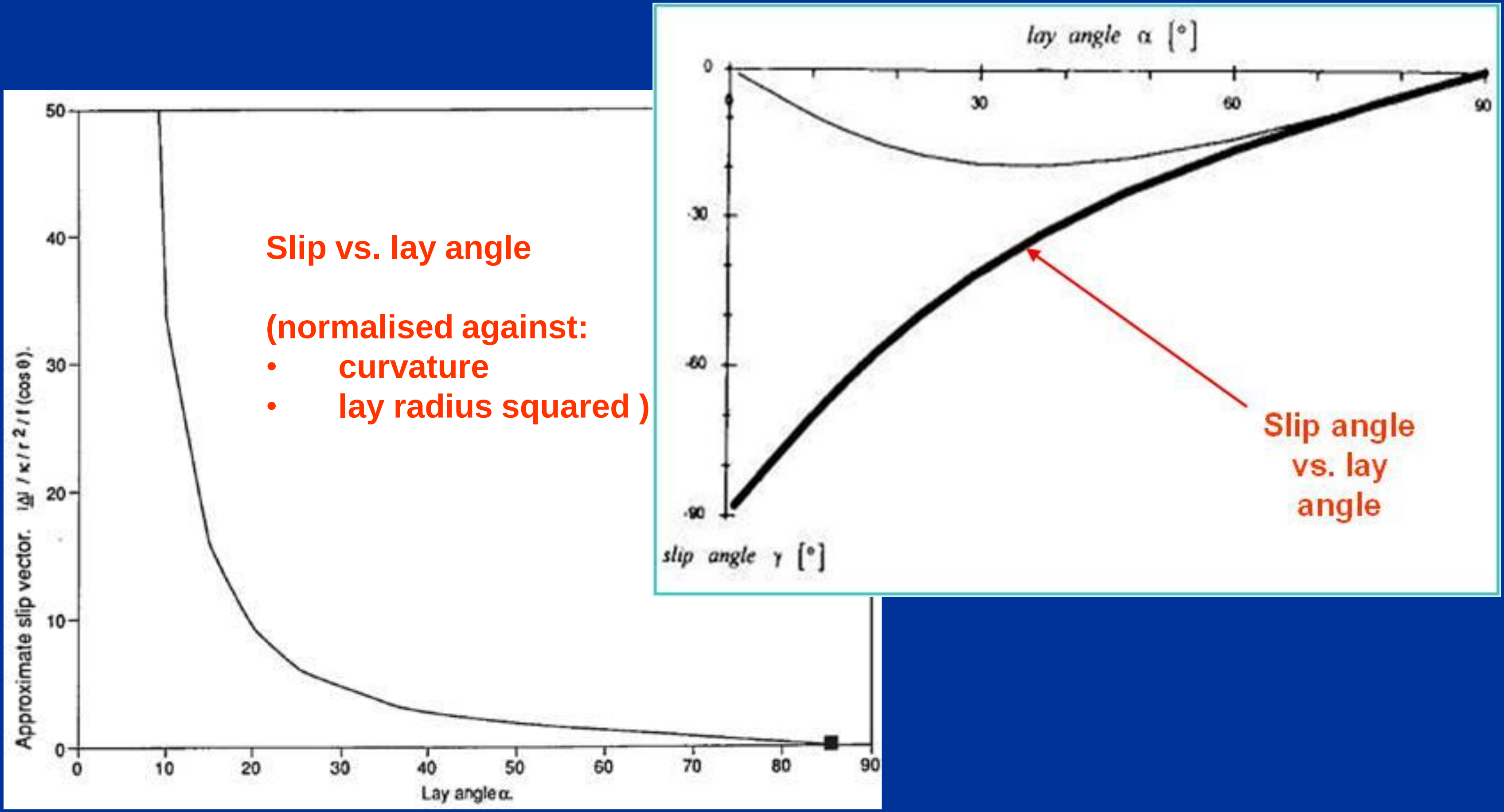
Need:

- Calculation of slip of wires (*essential property*!)
- Curvature changes of wires - fatigue

Friction!



Flexible pipe analysis
Example of bending analysis (2)



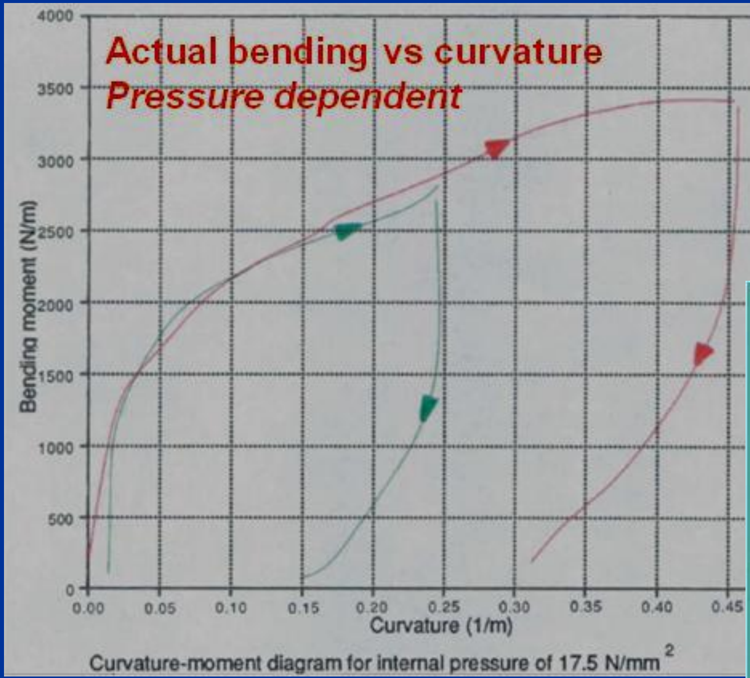
Slip vs. lay angle

(normalised against:
- curvature
- lay radius squared)

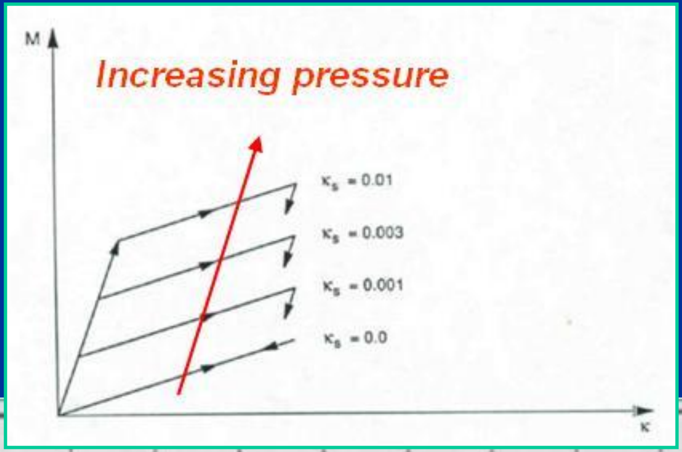
Slip angle vs. lay angle

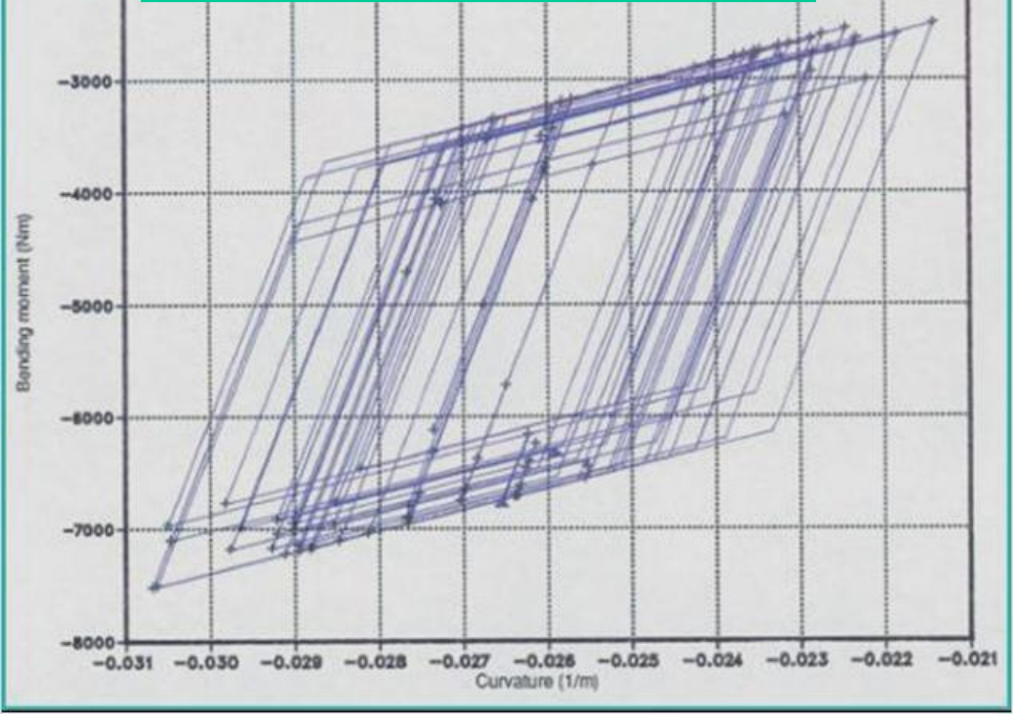
Flexible riser analysis

Fatigue analysis (1)



Curvature-moment diagram for internal pressure of 17.5 N/mm^2





Pipe stiffer than assumed

Damage mostly during slip sections

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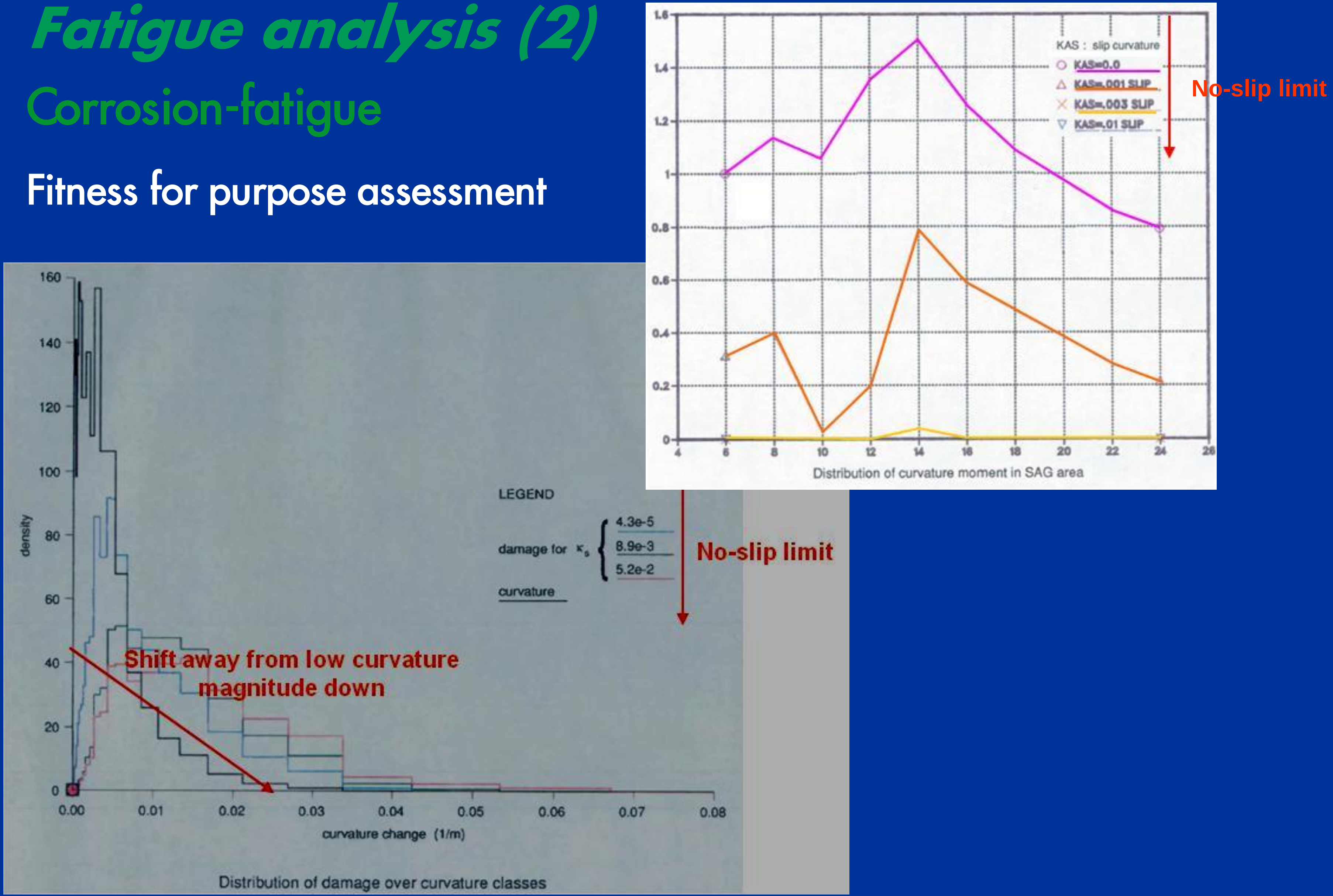
Flexible riser analysis

Fatigue analysis (2)

Corrosion-fatigue

Fitness for purpose assessment



Distribution of curvature moment in SAG area

No-slip limit

Distribution of damage over curvature classes

No-slip limit

Shift away from low curvature
magnitude down

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Shell’s flexible pipe application history

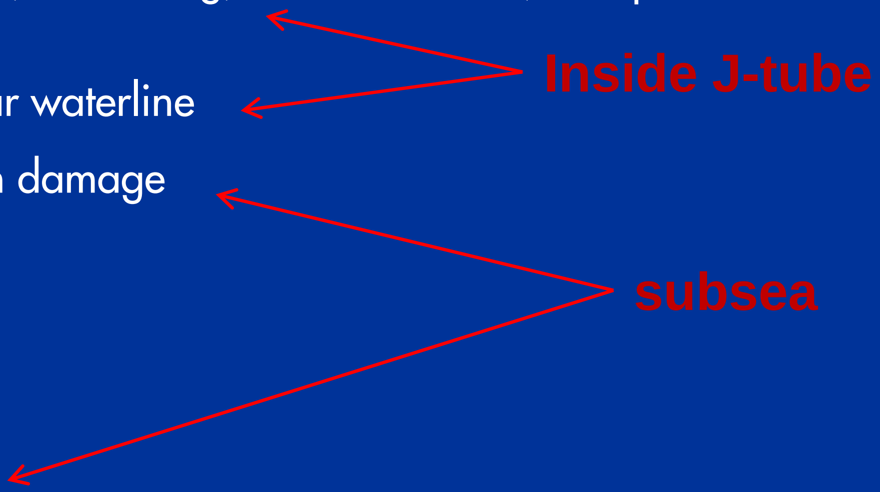
Shell operate over 400 km of flexible pipe
- *riser: static or dynamic*
- *flowline*
- *subsea jumper*
- *topside jumper*

Internal Diameter <2”, 18.7”>

Pressure < 570 bar

Shell Flexible Pipe application history (2)
loss of containment

- '05 – Water injection line failed at pressure test - overbending
- '05 – blocked annulus vent system plus cracked pressure sheath
- '05 – slow leak f/ inside end-fitting
- '95, '00, '05 – high external pressure J-tube, no venting, smoothbore WI, collapse of internal sheath
- '04 – leaking external sheath, corrosion near waterline
- '05 – bird caging caused by external sheath damage
- '99 – PVDF slipping out of end-fitting
- '99 – leak inside end-fitting
- '95 – local bending
- '94 – 3 x PVDF slipping out of end-fitting
- '93 – leak in end-fitting, no annulus venting



Inside J-tube

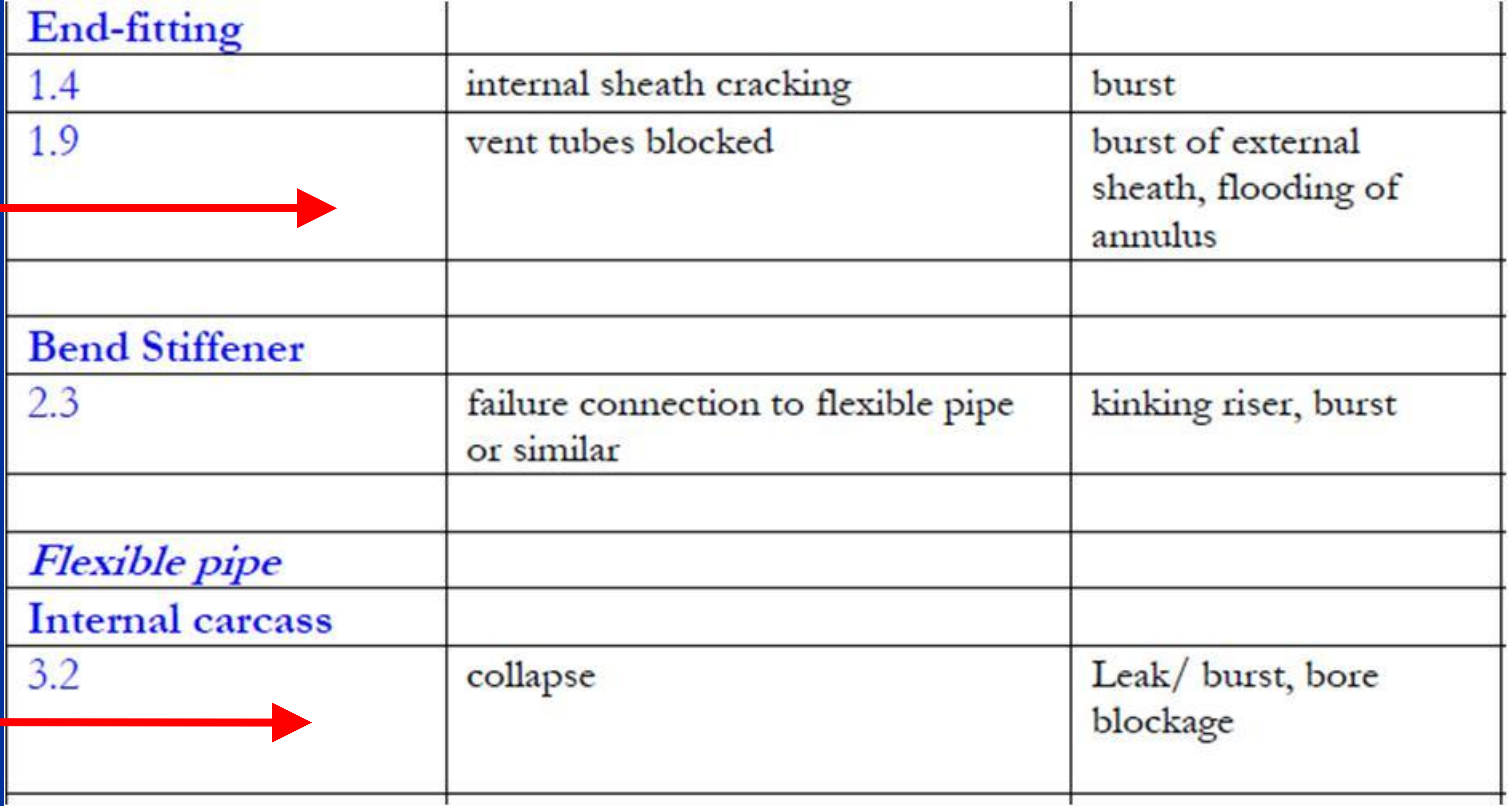
subsea

Shell Flexible application history (2)
No loss of containment

- ’09 – external sheath damage
- ’08 – leaking external sheath, corrosion near waterline, low fatigue lives
- ’07 – operation above material’s temperature spec.
- ’04 – upheaval buckling
- ’04 – sour service susceptibility
- ’04 – carcass/ Coflon sacrificial layer failure
- ‘99 – advanced degradation – operation above material’s temp. spec.
- late 90’s – flooded annulus, corrosion of armouring, preventative change-out; failed two-layer bend stiffeners (6 replaced)
- 90’s – external sheath damage during installation, increasing H2S, low fatigue life → changed out proactively 2008

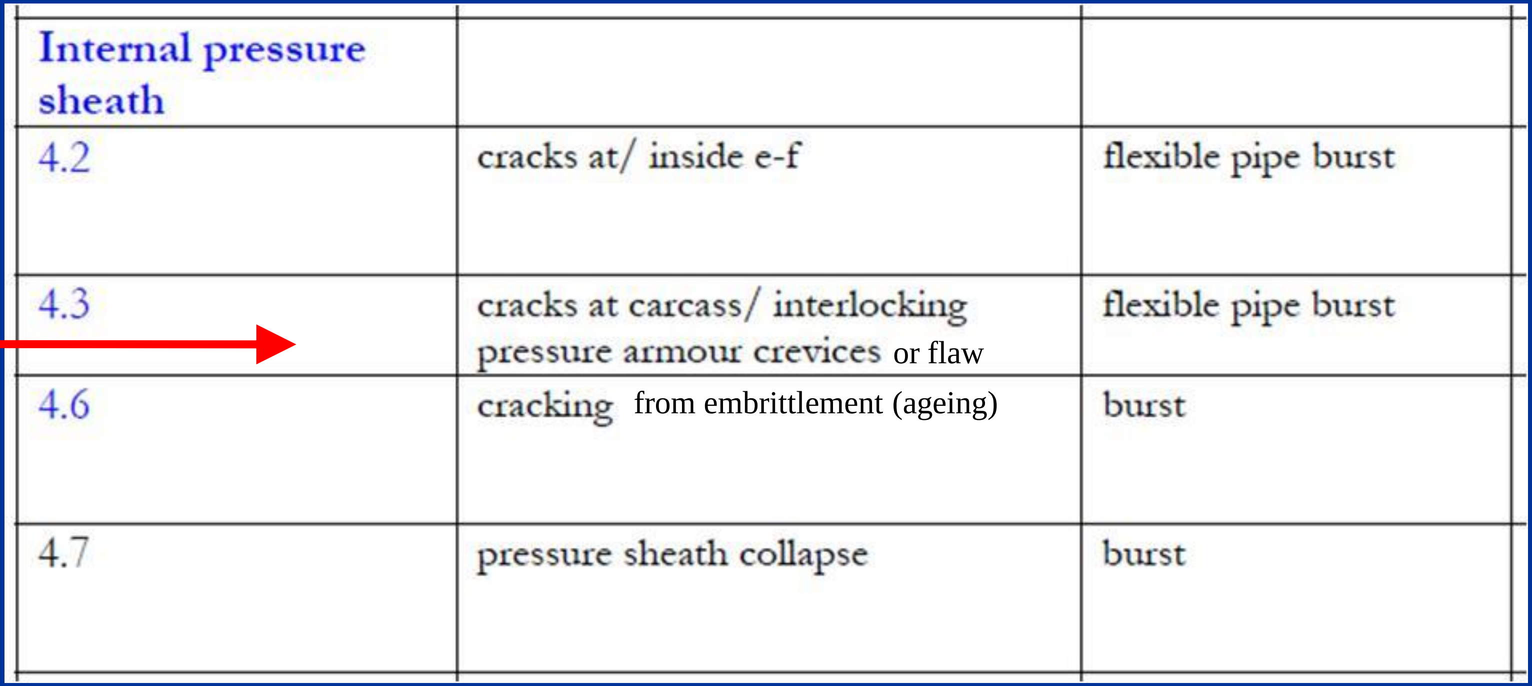
Failure mechanisms

High Risk (1)



End-fitting		
1.4	internal sheath cracking	burst
1.9	vent tubes blocked	burst of external sheath, flooding of annulus
Bend Stiffener		
2.3	failure connection to flexible pipe or similar	kinking riser, burst
Flexible pipe		
Internal carcass		
3.2	collapse	Leak/ burst, bore blockage

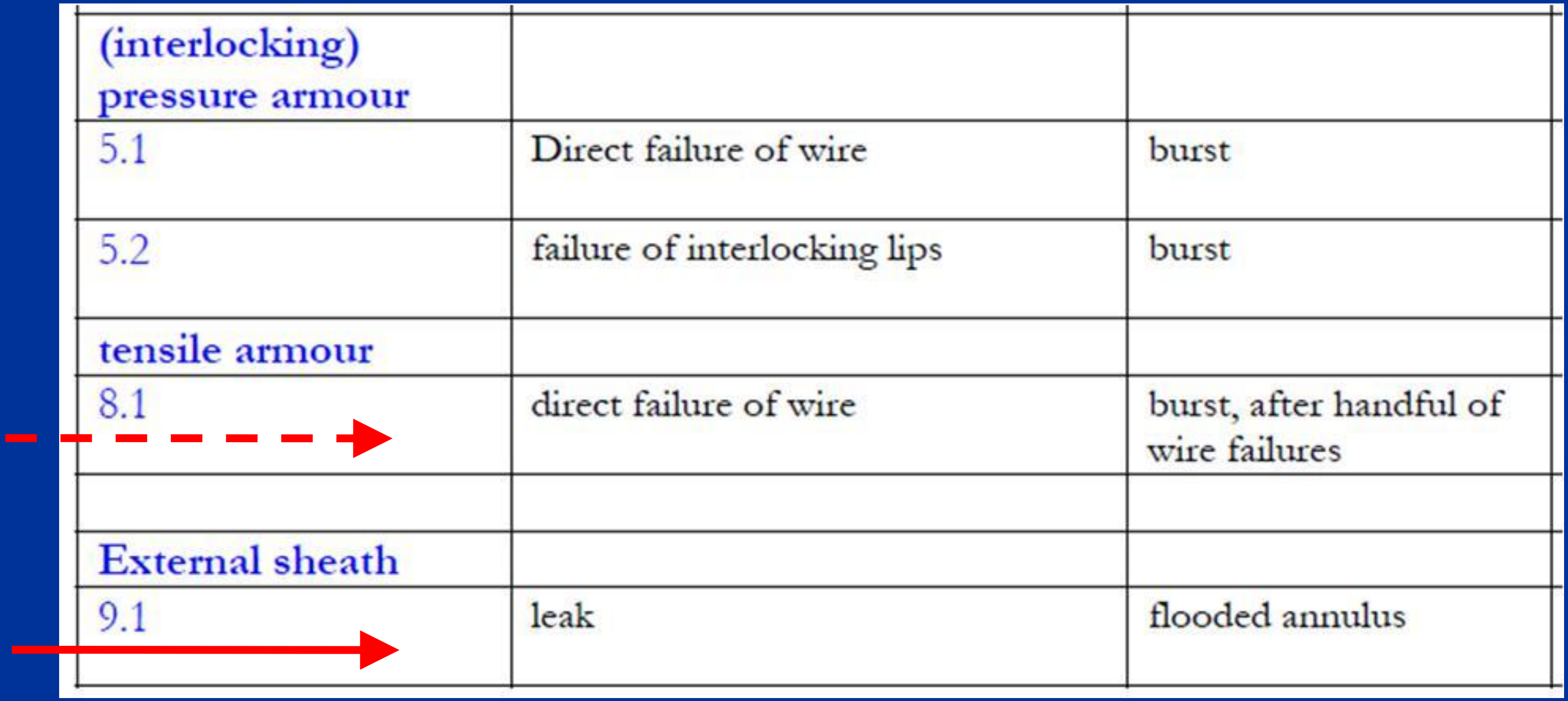
Failure mechanisms
High Risk (2)



Internal pressure sheath		
4.2	cracks at/ inside e-f	flexible pipe burst
4.3	cracks at carcass/ interlocking pressure armour crevices or flaw	flexible pipe burst
4.6	cracking from embrittlement (ageing)	burst
4.7	pressure sheath collapse	burst

Failure mechanisms

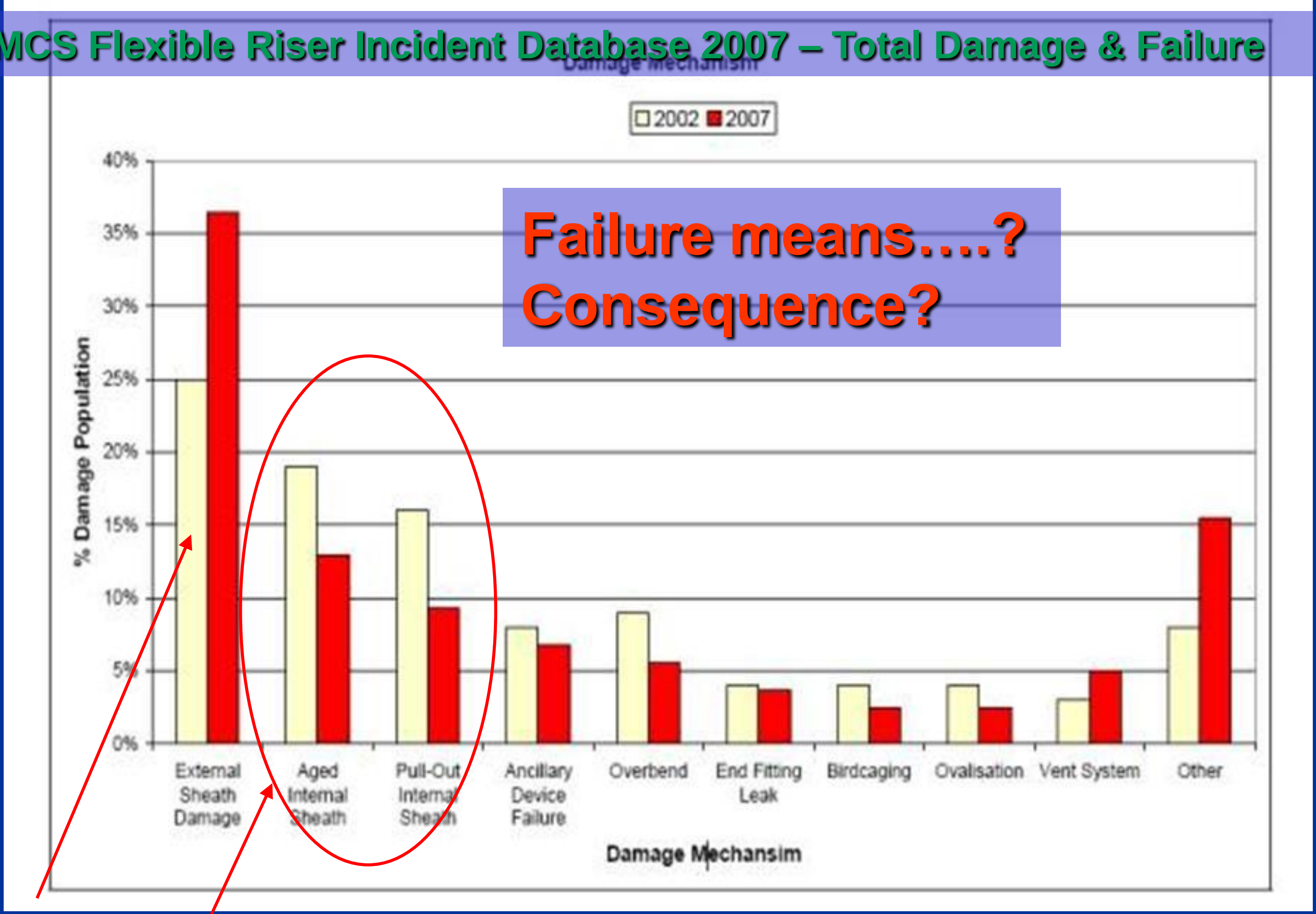
High Risk (3)



(interlocking) pressure armour		
5.1	Direct failure of wire	burst
5.2	failure of interlocking lips	burst
tensile armour		
8.1	direct failure of wire	burst, after handful of wire failures
External sheath		
9.1	leak	flooded annulus

Flexible riser – Failure statistics

Historical failure rate of flexible risers has been high



MCS Flexible Riser Incident Database 2007 – Total Damage & Failure

Failure means….?
Consequence?

25 (35)% attributed to **external sheath damage**

35 (22)% to internal sheath **polymer** issues (PVDF and PA-11) - now better understood / dealt with in current design codes

Failure mechanisms

End-fitting – vent tubes (1)

Annulus venting tubes not functional

- flattened, blocked

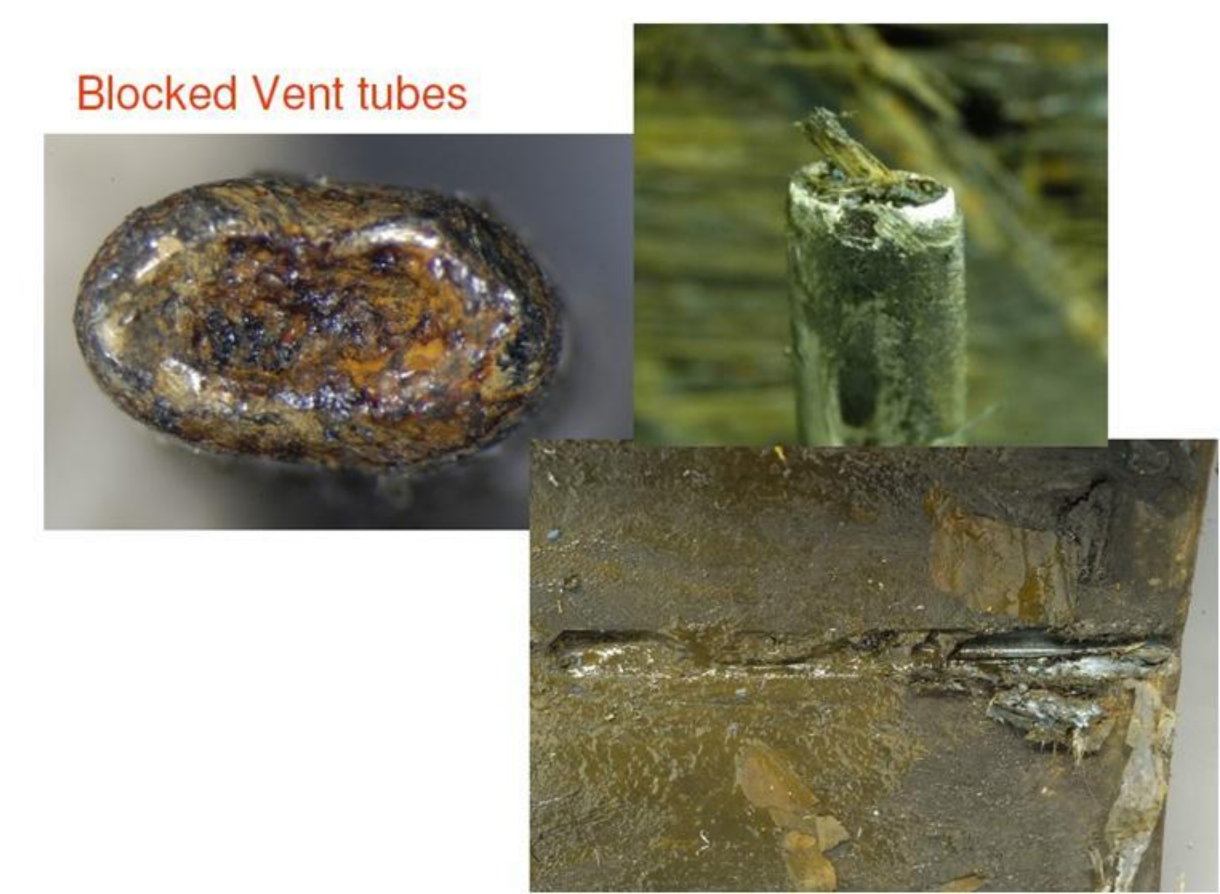
causing puncture of external sheath

Shell:

5 instances that led to dramatic failure

Flexible riser – Failure histories

End-fitting (2)



Blocked Vent tubes

vent tube blocked and flattened

Flexible riser – Failure histories

End-fitting (3)

Leak across main seal… manifesting itself externally like so:

Tear in
external sheath

Flexible riser – Failure histories
End-fitting (4)

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Flexible riser – Failure histories

External sheath

Flexible riser – Failure histories

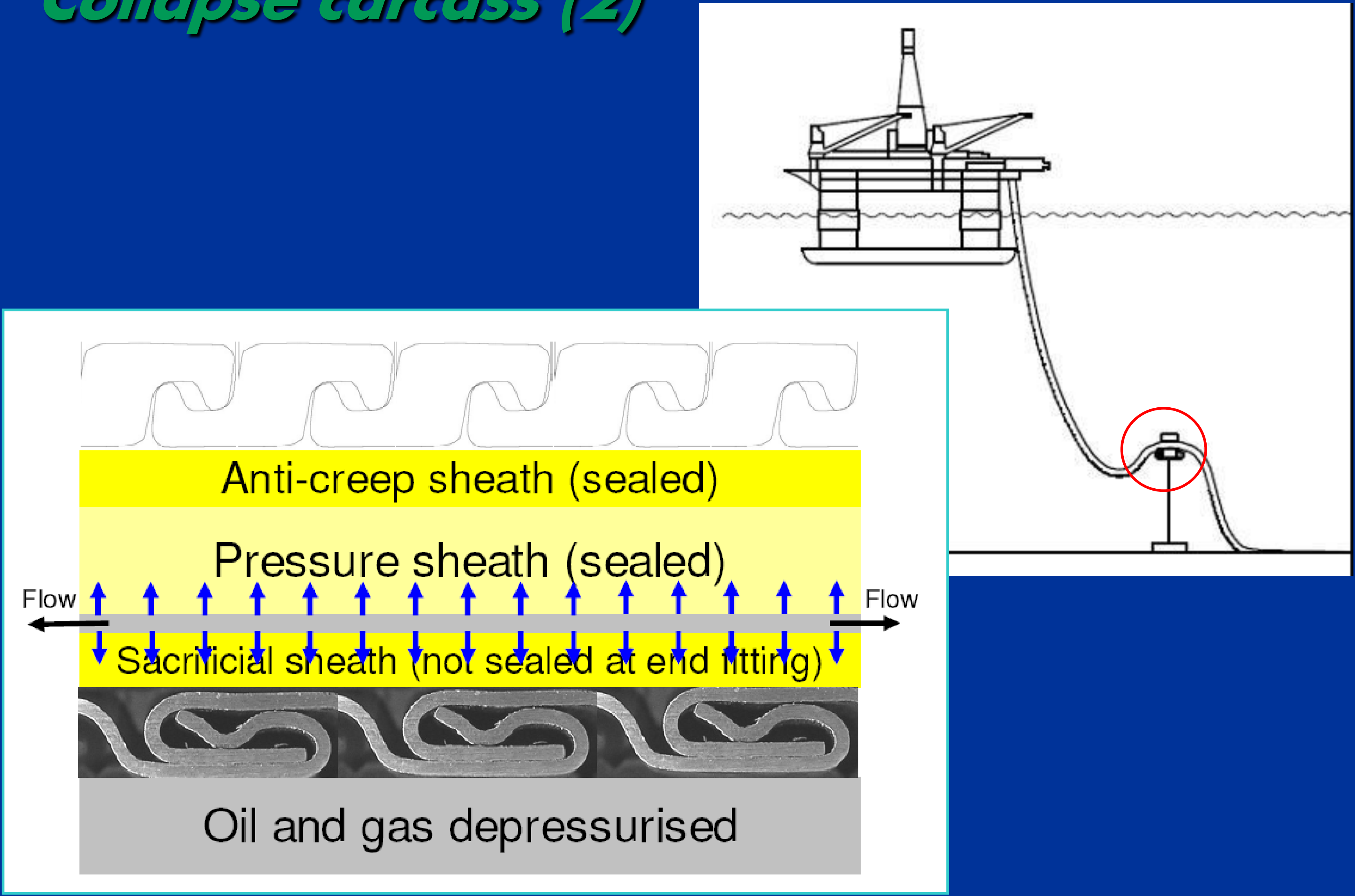
Collapse carcass (1)

Collapse from excessive radial compression

Fatigue/ Collapse from excessive radial compression

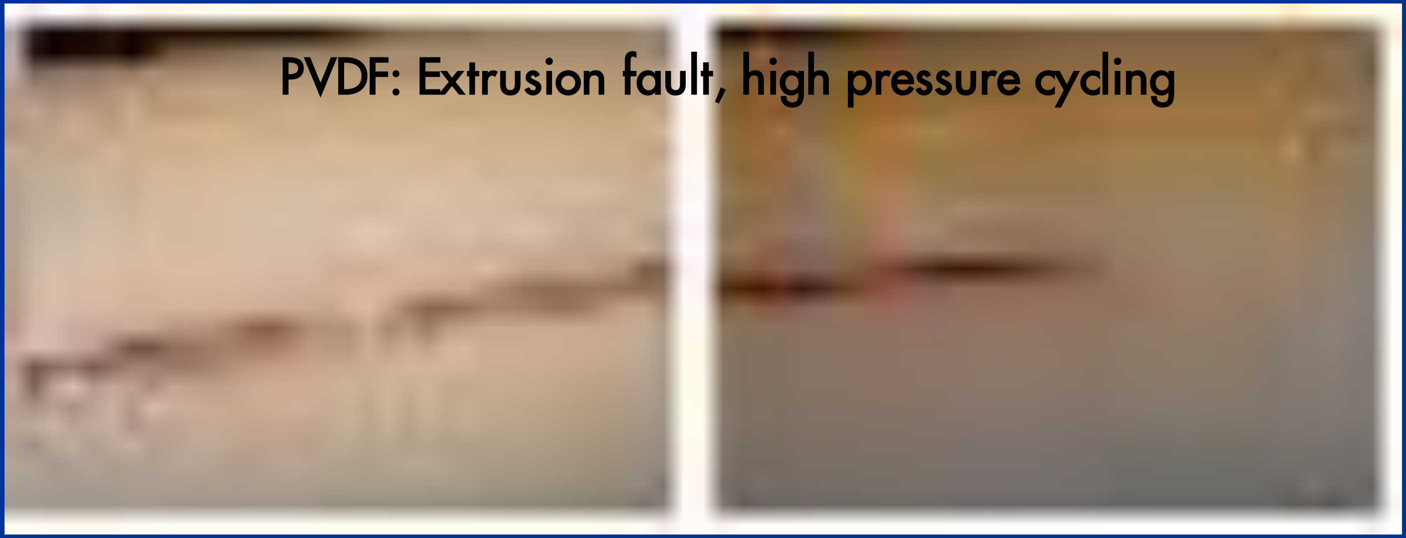
Flexible riser – Failure histories

Collapse carcass (2)



Flexible riser – Failure histories
Internal pressure sheath

- Cracking (PVDF) – failures



PVDF: Extrusion fault, high pressure cycling

- Ageing of pressure sheath (PA11) – loss of ductility, cracking – no failures but expensive proactive replacements

Flexible riser – Failure histories

Tensile armours (1)

Corrosion (free, sweet, sour)

Static riser in J-tube

- annulus venting system blocked
- external sheath breached
- annulus flooded
- free corrosion

Flexible riser – Failure histories

Tensile armours (2)

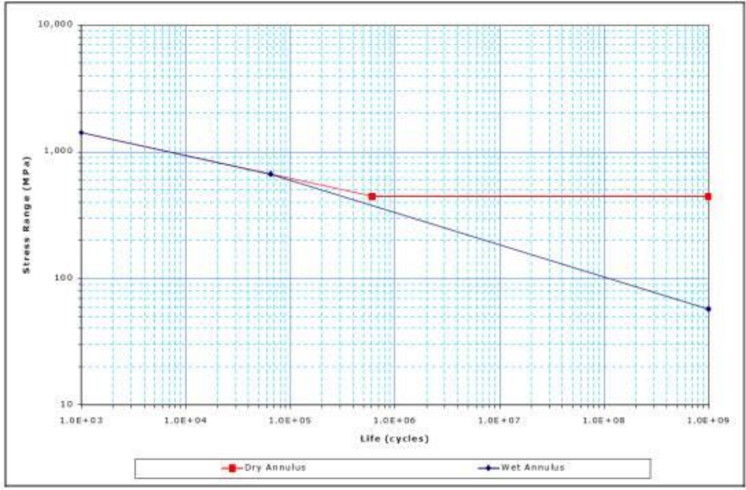
Corrosion-fatigue (water, O_2, CO_2)

No registered failures

For all practical purposes: is it real?

S-N curves

- generated under high Volume to Surface area conditions.
- Annulus presents the opposite → saturation with corrosion product.



Several cases – preventative replacement

KIvI Flexible pipe

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Flexible riser Integrity management (1)

Design

- Material selection to be based on *reasonable* worst case conditions (p, T, fluids)
- Develop S-N curve for corrosion-fatigue for particular application
- Inhibiting the annulus with a specific corrosion inhibitor in the factory

QA/ QC

Rigorous attention to extrusion of pressure sheath and end-fitting construction

Installation

prevent damage (outer sheath, over-bending), or at least detect, then repair

Flexible riser Integrity management (2)

Service

- Integrity of the **external sheath** is one key to degradation in service
  - corrosion-fatigue, metal loss corrosion
- Integrity of the **pressure sheath** the other
  - Material selection vs bore conditions, end-fitting, QAQC
- **Fatigue** will not be any issue in practice, unless the annulus is filled with seawater as a result of a puncture of the external sheath → **corrosion-fatigue**

Flexible riser Integrity management (3)

Task	Reason
GVI of external surface …..	basic integrity (gross damage, sheath)
top angle, bend stiffener …	design verification, LTE
operations parameters (p, T, chemical, sand)	ageing internal sheath (operation within/ outwith spec., chem composition, LTE)
annulus integrity ……….	Corrosion-fatigue, metal loss corrosion
annulus gas flow and composition analysis	external sheath, permeation characteristics, corrosion activity
internal sheath ageing ……	*design verification, LTE*
integrity tensile armour layers	suspected damage (bend restrictor area)

Annulus venting system SCE

Flexible riser Integrity management (4)

Inhibiting the annulus with a corrosion inhibitor in the factory

At Foinaven/ Schiehalion, BP have flushed the annulus with "TROS 528 *RMS 920*"

- Mono-Ethylene Glycol *RMS 126* (75.8 %),
- Methanol *RMS 127* (24%),
- Sodium Hydrogen Carbonate *RMS 351* (0.075%) – baking soda, neutraliser
- Troskil 1 *MS 061* (0.1%) – corrosion inhibitor
- TROS Seadye (0.025%) - dye for detection of a leak subsea.

Environmentally acceptable and compatible with the PVDF/ XLPE pressure sheath

Density as per seawater

Issue at installation: limit hydrostatic pressure

Monitoring flexible riser (1)

Record the annulus pressure build-up

Function of production parameters

  - To be recorded

Analyse trend

  - Leak internal sheath
  - Ageing internal sheath
  - Puncture external sheath

Monitoring flexible riser (2)

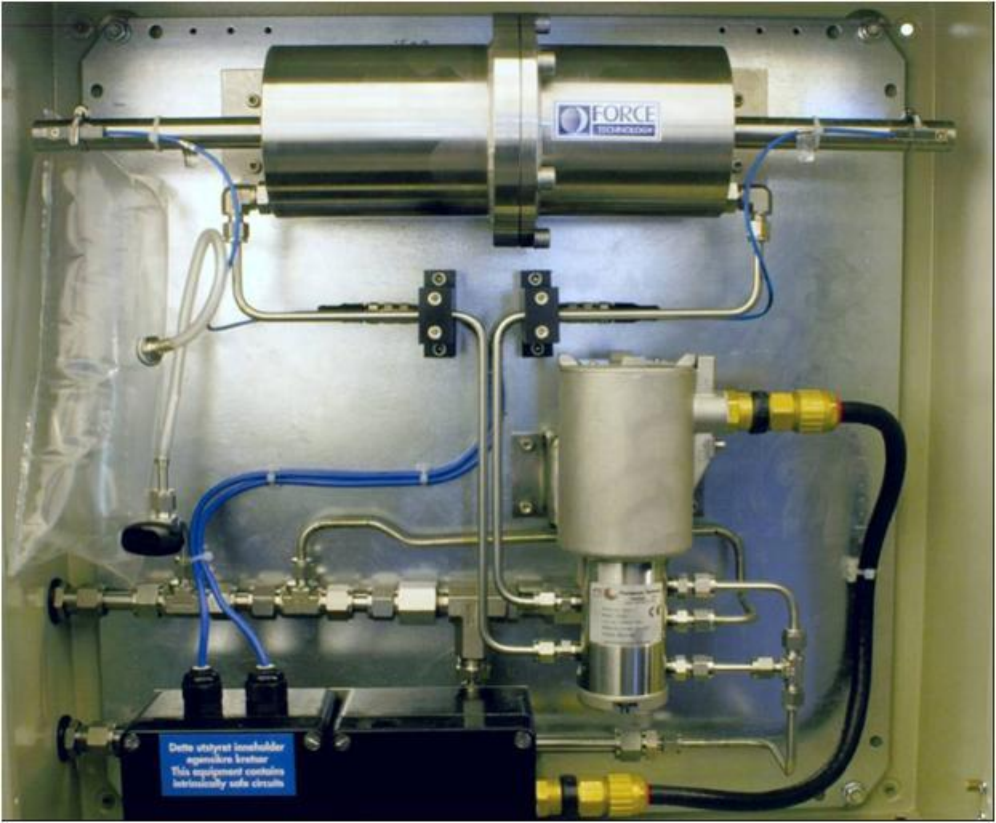
Analysing the annulus gasses

Detect harmful gasses

- CO_2
- H_2S

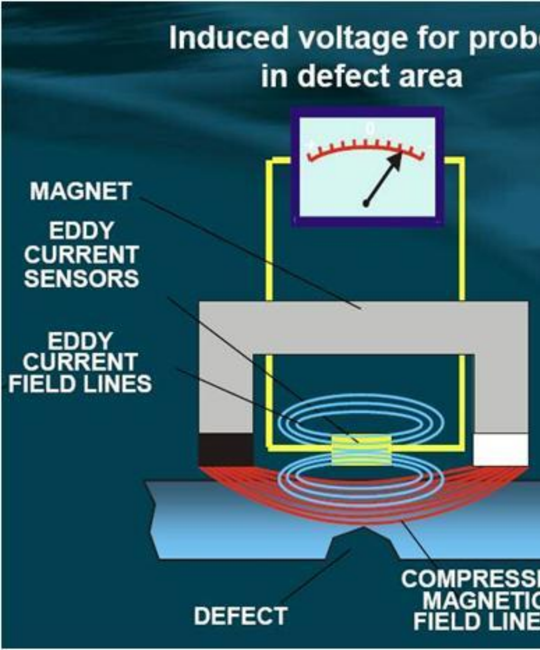
and those that indicate active corrosion:

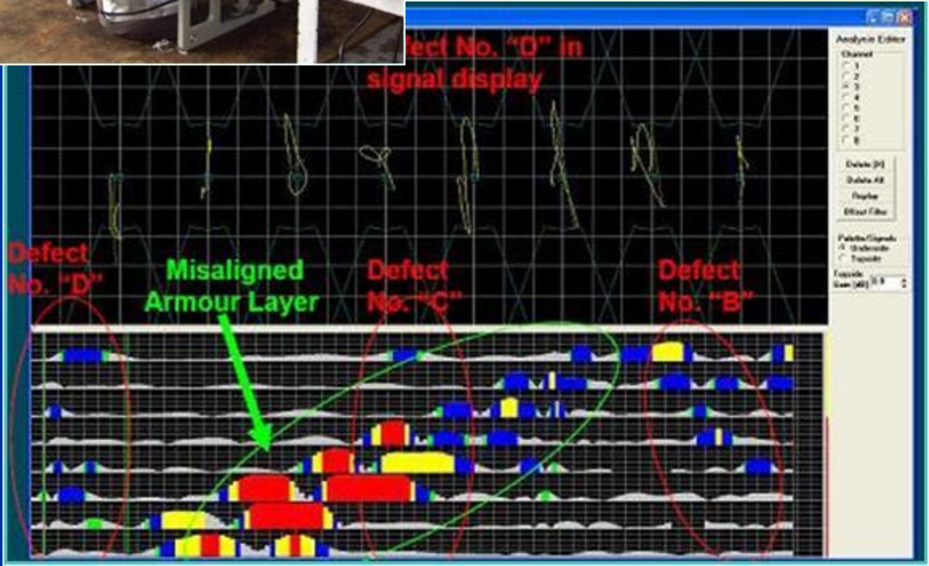
- H_2



Monitoring flexible riser (3)

Detection of defects (metal loss, fractures) in armouring package





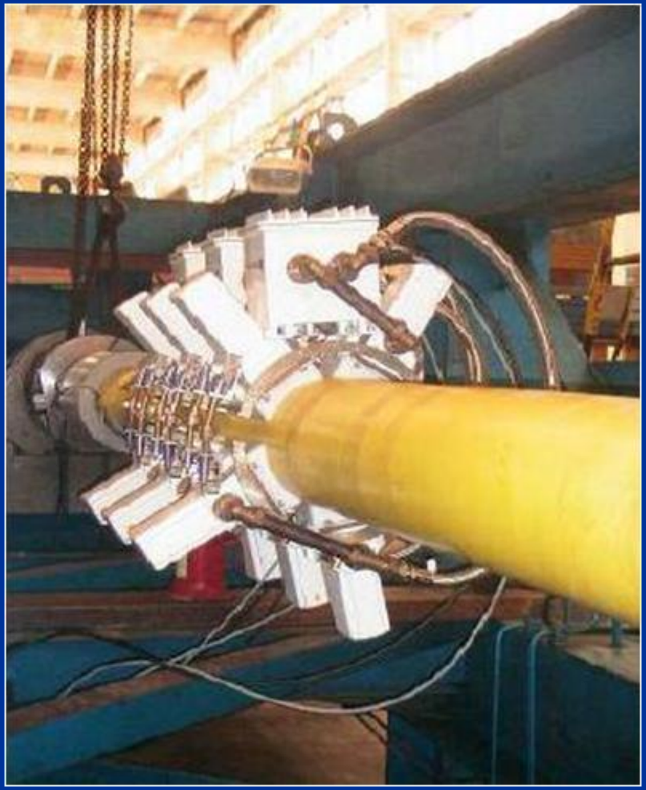
Innospection's SLOFEC

Monitoring flexible riser (4)

Detection of defects (metal loss, fractures) - top section underneath bend restrictor -

2-Tier approach:

- Acoustic Emission to detect fractures occurring
- MAPS-FR to remotely detect fractures (changes in stress will be felt a few pitchlength away) – *stress measurement magnetostriction effect*

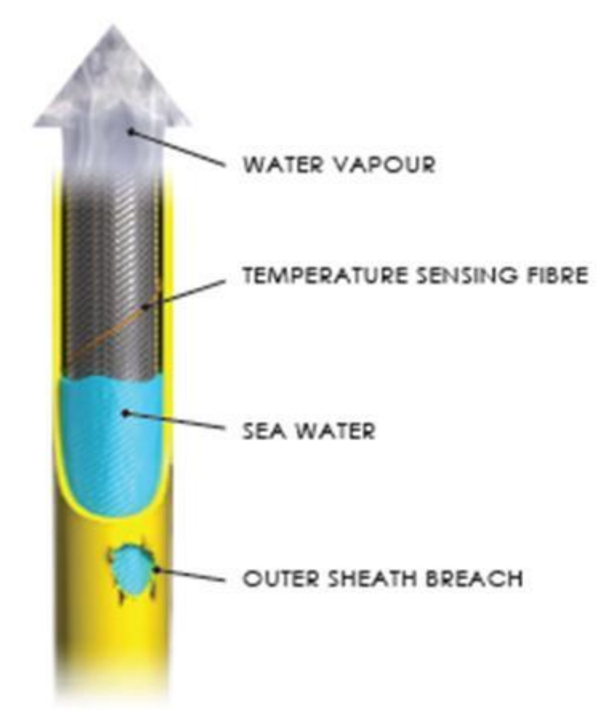


Monitoring flexible riser (5)

Fibre-optics

Monitoring of

- Strain → global deformation
- Temperature → location of any liquid level
- Level of annulus flooding



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Flexible pipe

Current issues

- Erosion
  - Produced gas
- CO_2 injection
  - Supercritical CO_2 - polymers
- Dynamic Interference analysis
- Deep water?
- Jumpers

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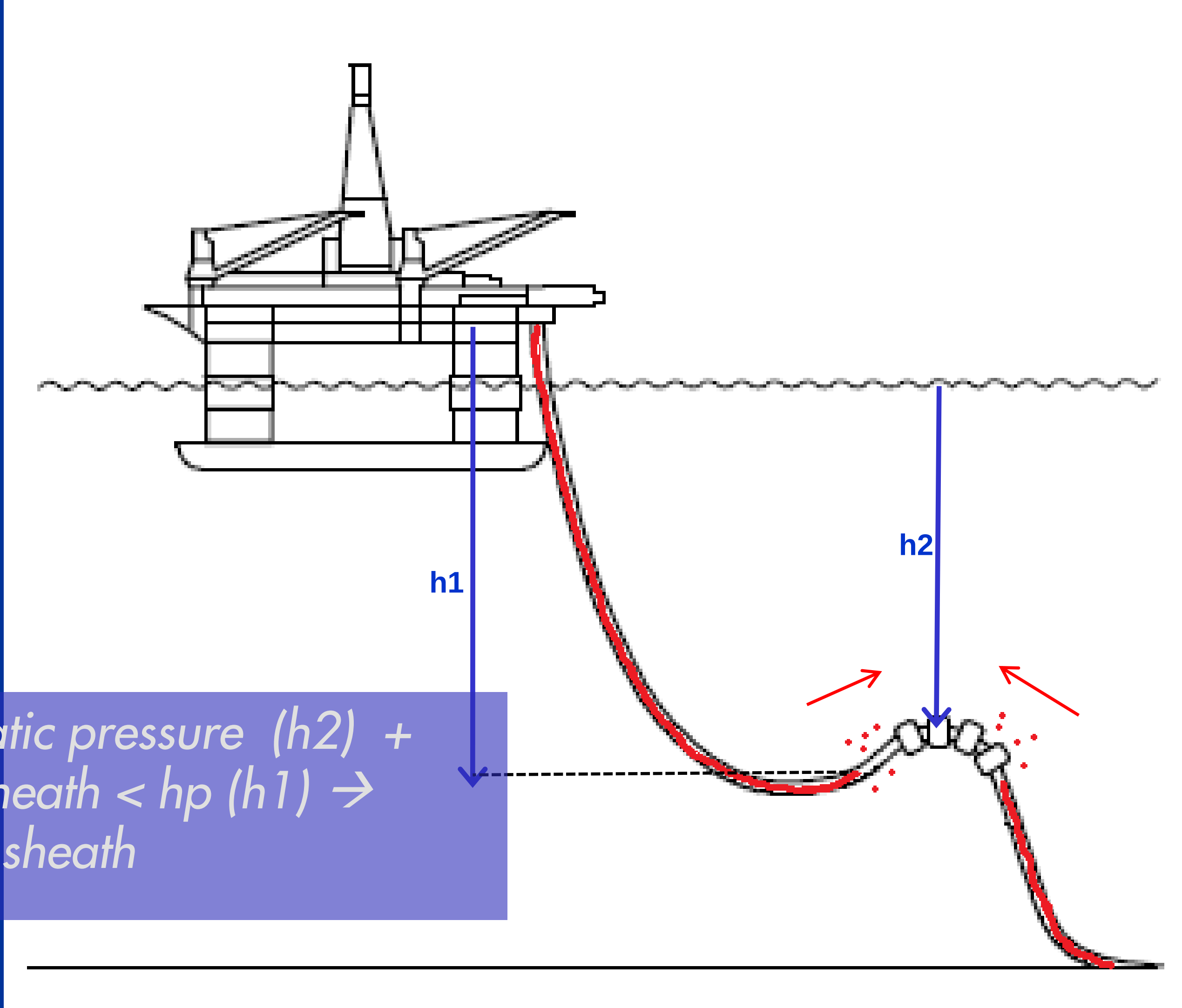
Flexible pipe

Current issues (2)



- *If hydrostatic pressure (h2) + strength sheath < hp (h1) → breach of sheath*

Flexible pipe
Concluding remarks

- Knowledge of flexible pipe reduces risk inherent in system,
  - ✓ Specification (polymers), LTE, fitness for purpose
- Integrity management essential
  - ✓ Starts rigorous with QAQC
  - ✓ Annulus venting system to be designated as SCE
  - ✓ Simple measures suffice during operation
  - ✓ Detailed inspection needed in case of doubt - under development
- Resolve "corrosion fatigue, real or phantom?"