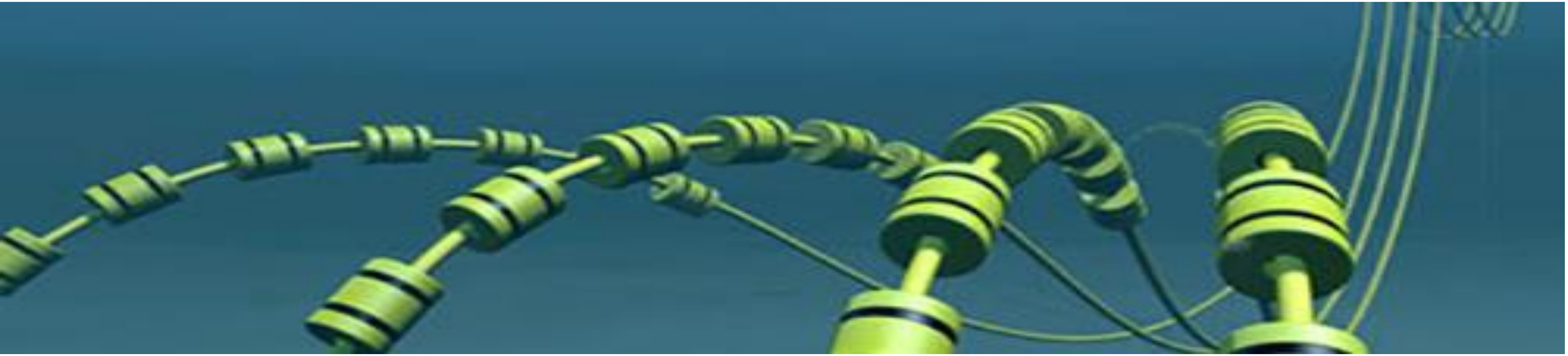

Technology qualification of flexible pipes based on learnings from previous failures

Flexible pipe seminar – Management of Integrity, aging, sharing of experiences and continuous improvement.

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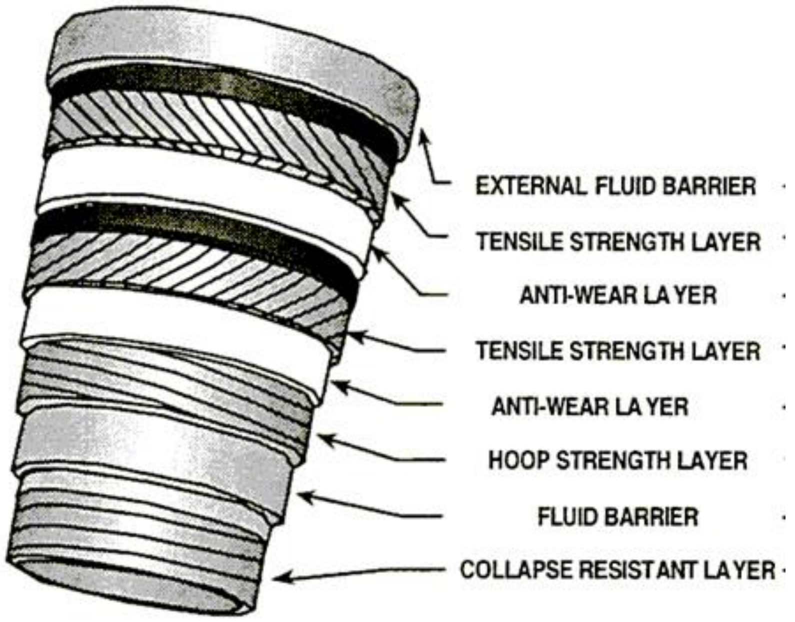
Content

- Historical experiences
- Examples of ongoing technology qualification
- Technology qualification – areas of increased awareness
- Component- versus scenario oriented threat assessment
- Main objective : Discuss how to handle complex failure modes involving ageing and other time dependant degradation mechanisms

Evolution of flexible pipe technology

- High pressure flexible pipe introduced early 70ites
- Today - a key enabler for floating production
  - More than 3000 dynamic risers have been produced
- Continuous technology development push
  - Dynamic application in harsh environment
  - High internal/external pressure
  - High temperature
  - Flow assurance/insulation
  - Gas risers
  - Increased bore diameter
  - Aggressive bore fluids (e.g. sour service)
- Innovation process
  - Operators setting the requirements
  - Manufacturers responding with new technical solutions



Technology Qualification (TQ) – a key element in technology evolution

- Standards/design codes represent accumulated experience for known technology
  - Addresses known failure mechanisms
  - Applies known methods
- Compliance ensures that the technology will have an acceptable margin to failure by following the requirements given in the applicable design codes

- *All technology components presently considered as 'field proven' has once been 'new' technology*

- Technology qualification is a vital driver in the technology evolution
  - Enables to address new technology in a responsible manner and over time make it known
- Continuous process ongoing in the industry.

- Design codes are developed/updated in parallel as the technology is matured

Some ongoing qualification activities

- Deep water challenges
  - Weight saving
  - Aggressive bore fluids

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- 'Hybrid' composite cross-sections
  - Composite tensile and/or pressure armour
  - Stainless steel tensile and/or pressure armour

- Flow assurance
  - Mitigate hydrate/wax formation
  - Continues/intermittent heating requirements
  - Risers/flowlines

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- Active electrical heating
  - Riser: floater to subsea heating
  - Flowlines : subsea to subsea heating

- Flip mitigation
  - 'Smooth' carcass profiles

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- New carcass solutions
  - T-profile, K-carcass etc

Some unexpected incidents in the evolution of flexible pipes

Some serious issues

- PVDF Pressure sheath pull-out from end-fitting
- ‘Singing risers’ caused by vortex induced carcass vibrations of gas risers
- Carcass tear off in 3 layer PVDF pressure barrier risers.

Consequences

- Potential safety threats
- Shut-downs, loss of production
- Riser replacements
- Time consuming root cause investigations

Causes

- Unknown failure mechanisms
- Not addressed in design, manufacturing, operation.

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Dissection and failure investigations – Key elements of RCA fact finding

- Failure event recordings
- Operational history
- Previous experience - similar failures

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- Failure investigations
- Dissections
- Material characterisation
- Metallurgical investigations

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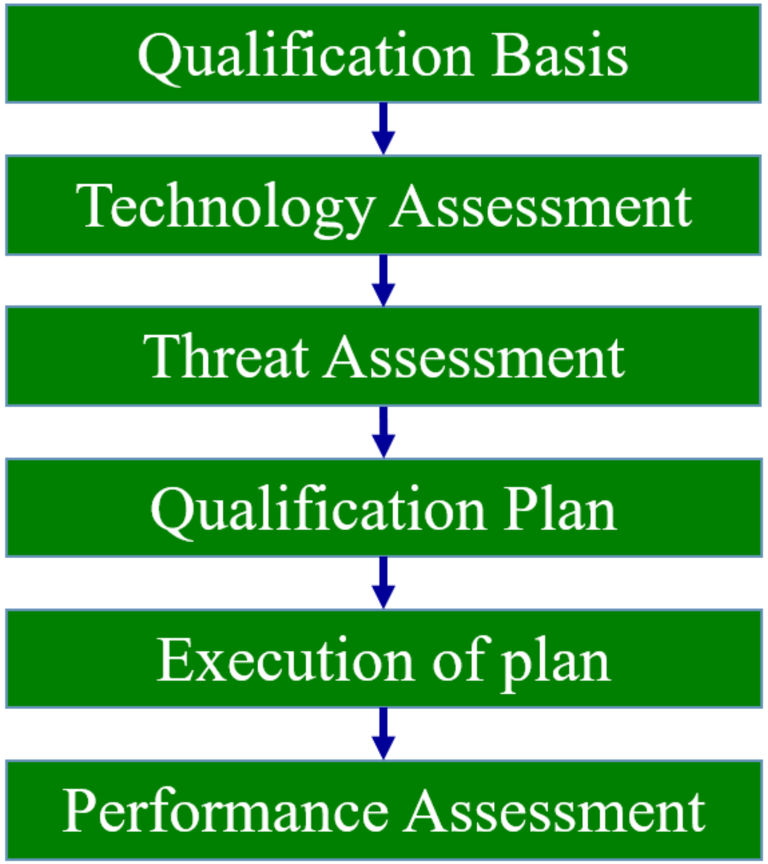
- Basis for root cause investigations (facts)

Why did this happen ?

- **Root cause**
  - Most severe consequences are linked to overlooking a failure mechanism when introducing new technology
  - Some complex mechanical aspects of flexible pipes not accounted for properly
  - Complexity overlooked in design/operation
  - The root cause of failure can be surprisingly simple when the problem is fully understood

- **How can we prevent this from happening again ?**
  - What can be improved in the TQ process to reduce the risk of overlooking failure mechanisms ?
  - How to capture possible complex failure when introducing new technology ?

TQ process – main steps (DNV-RP-A203) and areas of increased awareness

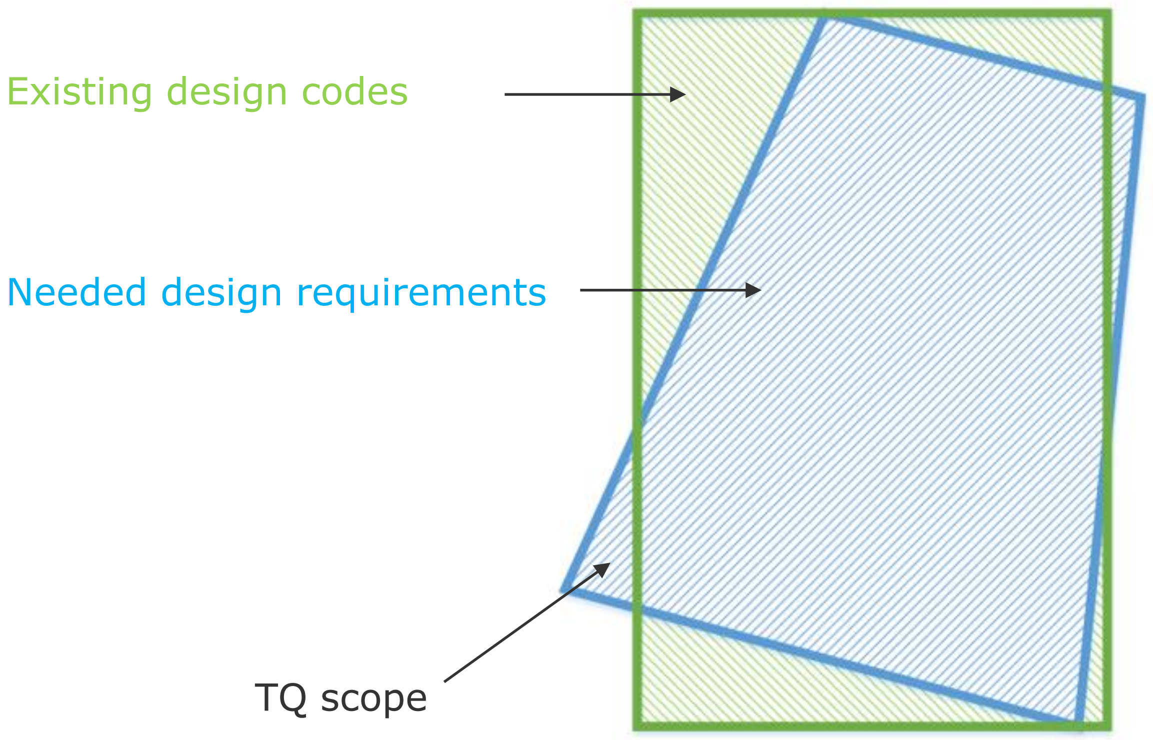


- What is new ?
  - Define technology components requiring qualification
  - *Increased awareness* not to exclude anything

- What can go wrong ?
  - Identify failure modes/mechanism
  - Traditional *component oriented* FMEA
  - *Scenario oriented FMEA* capture complex failure developments

- The qualification plan is incomplete if something is missed
- Might lead to overlooking failure modes /mechanisms

Technology assessment – identification what to consider in the TQ process



- Identification of new technology issues not addressed by existing design practice/standards
- Be very careful not to exclude seemingly ‘harmless’ modifications as new technology
- Small modifications can make a huge difference
- Modifications to improve performance could trigger new failure modes
- ‘Known’ technology elements that may influence ‘new’ technology elements should be included
- Assessment shall be based on documented track records, not subjective statements like ‘this has been used before’ and ‘will not have any influence’

- If in doubt, include in TQ scope.

Traditional FMEA (Failure Mode and Effect Analysis) – component oriented

Typical working process

- Technology is broken down in components
  - E.g. carcass, liner, pressure armour etc
- Function of each component is identified
- Threats are identified as mechanisms leading to loss of function for each component

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- Fundamental process for failure mode identification
- Shall always be carried out as a starting point

Complex failure modes - some challenges

- Capture interaction between components
  - Interfaces and failure mechanism involving several components
- Capture influence of time dependant degradation mechanisms
  - E.g. creep, ageing etc not leading to loss of function itself
- Capture timeline of failure development
  - Manufacturing, installation, operation
  - Combination with time dependant degradation mechanisms

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- Possible, but challenging to handle in traditional FMEA
- Require special attention to capture complex failure mechanisms

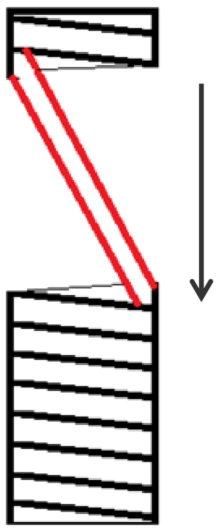
Scenario oriented FMEA

- Targeted scenario oriented FMEA
  - Focus on possible complex failure developments (timeline and interaction)
  - Supplement to component oriented FMEA
  - Build on failure modes identified in component oriented FMEA

- Identify scenarios leading to loss of function
  - Timeline of failure development (sequence of events)
  - Manufacturing, installation, operation
  - Interfaces and failure mechanisms involving several components
  - Capture influence of time dependant degradation mechanisms (creep, ageing, etc)

- Working process
  - Workshop with multidiscipline competence
  - Focus on the process- follow the loads, look for failure mechanisms
  - Reporting format: mind-map, event-tree, spreadsheet etc as appropriate

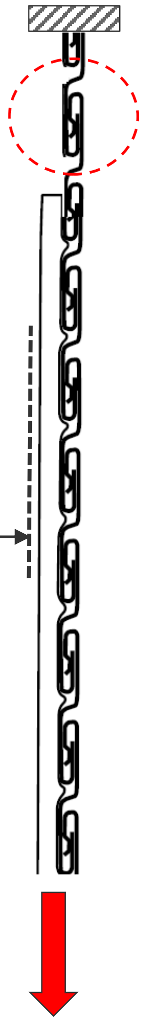
Example : Carcass tear off in 3-layer PDF risers

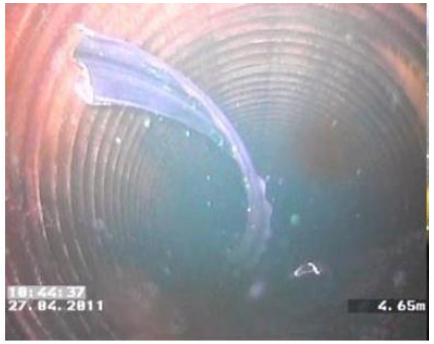


- Concluded root cause: loss of core holding force
  - Volume loss of PVDF layers (loss of plasticizer)
  - Creep of anti-creep layer into pressure amour
- Axial overload of carcass due to:
  - Thermal contraction of sacrificial sheath
    - Increased thermal load due to aged sacrificial sheath
  - Self weight of riser core
  - Pressure bulk compacting of sacrificial sheath
- Carcass spin-out follows initial overload
  - starts at the radially unsupported end of carcass inside topside end-fitting (weakest point)

'Ageing' mechanisms

- Critical load case: Pressure test of cold riser





Ref : Several papers 2013-2017 by Equinor,4Subsea and DNVGL

Carcass tear off - publications

- ’Carcass failures in multilayer PVDF risers’ Farnes, K.-A., Kristensen,C, Kristoffersen, S., Muren, J., Sødahl, N.. OMAE 2013
- ‘Carcass Axial capacity in Flexible risers’. Skeie, G., Skjerve, H., Pettersen, S., Axelsson,G. Engh, B., Vethe, S., Rio Pipeline conference 2013
- ‘Carcass tear out load model for multi-layer pressure sheath risers’. Kristensen, C. Muren, J., Skeie, G., Skjerve, H., Sødahl, N. OMAE 2014
- ‘Test validation of finite element analysis results of carcass axial capacity’ Skeie, G., Skjerve, H., Pettersen, S., Axelsson, G., Engh, B., Vethe, S., and Kristensen, C. E., 2014. OMAE 2014
- ‘Findings from dissection and testing of used flexible risers’. Skjerve, H., Kristensen, C., Muren, J., Søfferud, M., and Engelbreth, K. I., OMAE 2014
- ‘Full-scale Validation of Axial Carcass Loads in Flexible Pipe Structure from cyclic pressure load and temperature.’ Claus E Kristensen, Jan Muren ,Andreas Gjendal, Erik B Hanssen,Bjørn, Melve,Nils Sødahl, Bjørn Engh, Mario Søfferud, OMAE2017-62042
- ‘Time Dependent Carcass-liner Interface load model’ Geir Skeie, Roger Wold, Nils Sødahl, OMAE2017-64439

Knowing the failure mechanisms is everything

- Design – known technology
  - Acceptance criteria covered by design codes
  - Identification of critical failure mechanisms/parameters
    - For in-service follow-up

- Technology qualification – new technology
  - Basis for qualification program
  - Controls to mitigate loss of function- design methodology
  - Finds missing acceptance criteria

- Operational follow-up
  - Inspection/monitoring
  - Criticality ranking - RBI

- Life time extension

Conclusions

- Technology boundaries are continuously expanded to meet operator demands
- Highly competent and dedicated manufacturers
- A thorough TQ process can contribute significantly to reduce the inherent risks involved in the future technology development of flexible pipe technology
- Threat assessment should include component- and scenario oriented FMEA
- TQ should be an integral part of the development process, not an after-thought
- This will also contribute to reduced project risks, very expensive to discover something serious late in the process
- TQ is a small investment compared to possible consequences of overlooking a failure mechanism

But regardless what we do, there will always be a residual risk….

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