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MANAGING AGEING FLEXIBLE PIPE ASSETS

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ABSTRACT

The population of flexible pipes is increasing exponentially and by definition it is ageing. Over the coming years an increasing number of flexible pipes will reach the end of their design life, therefore prudent operators should focus on understanding the integrity status of their flexible pipes. Understanding and effectively managing the integrity of flexible pipes is necessary to prevent, predict, or detect the presence of any loss of integrity.

A detailed understanding of the manufacturing history, operational conditions, any previous repairs and inspection or test history are all required to gain a full insight of the flexible pipe fitness and assess its suitability for continued operation and for any potential life extension beyond the initially intended service life.

This paper presents guidelines for developing and implementing an integrity management strategy, which utilises the correct mix of inspection and assessment tools (degradation of internal pressure sheath, fatigue assessment, corrosion and annulus condition monitoring etc.) and operating procedures that will allow the operator to assess the opportunity for life extension of flexible pipes.

ABBREVIATIONS

The signification of abbreviations and acronyms used throughout the paper are as follows:

API	American Petroleum Institute
CIV	Corrected Inherent Viscosity
CO2	Carbon Dioxide
COR	Consequence of Occurrence Rating
FAT	Factory Acceptance Testing
GVI	General Visual Inspection
H2O	Water
H2S	Hydrogen Sulphide
PA-11	Polyamide 11
pH	Potential Hydrogen
POR	Probability of Occurrence Rating
PVDF	PolyVinyliDene Fluoride
TAN	Total Acid Number
TR	Technical Report
UKOOA	United Kingdom Offshore Operators Association

1. INTRODUCTION

Ensuring the safety and reliability of subsea facilities is crucial to the success of subsea developments; to do this, understanding and managing the risks to personnel safety, environment and overall costs is essential.

Once a flexible pipe has reached the end of its initial service life, degradation of component characteristics can cause its failure. In order to perform a full assessment of the possible life extension of an ageing asset system, a full understanding is required regarding the main degradation mechanisms of ageing flexible pipes. This is primarily achieved by evaluating if the pipe has been operated within its design limits. Focus should be on assessing the service history and identifying the material compatibility. Failure of a flexible pipe can be either time dependent (e.g. damage progress slowly with time) or instantaneous.

This paper presents MCS in house flexible pipe failure modes database, covering worldwide operating flexible pipes, including Brazil, Australasia, Gulf of Mexico and the West of Africa. Furthermore, a comparison of failure modes responsible for damage to flexible pipes observed in 2002 ([Ref. 1 and 2]) and 2007 (MCS database, [Ref 3]) is presented.

Given the advances in understanding of the complex flexible pipe inter-layer behaviour, this paper demonstrates that through proper asset management, ageing flexible pipe service life can often be extended beyond the original design value. Similarly, operation of flexible pipes that had previously been considered damaged and requiring early replacement can be justified on the basis of a detailed integrity assessment.

A list of design and operational history data, presented below, is the ideal required information in order to allow a reliable integrity assessment of the flexible risers and flowlines:

- Manufacturing and Installation reports;
- Design Premise and design reports;
- Flexible service history:
  - Temperature;
  - Pressure;
  - Fluid composition and pH;
  - H2S and CO2 levels in fluid;
  - Fluid water cut
  - Chemical injection history;
  - Sand monitoring data
  - Dynamic response (vessel motions, riser motions)
  - Gas system water content
- GVI history/ anomaly history
- Annulus vacuum testing history
- Polymer coupon history, when available

Knowledge of the flexible pipe failure modes, as well as awareness of the available inspection and testing techniques is necessary to achieve a robust understanding of threats to the system. The overall flexible pipe risk potential may reduce once the validation of uncertain operational factors is complete, hence reducing the conservatism of design assumptions. The predicted service life, and therefore the level of risk, is highly dependent on the operating conditions. It is good to emphasise that most of the aged flexible pipe designs do not account for the state of the art approach and tools which are now available in the industry.

In order to evaluate if the pipe has operated within its design envelope, a check list of key integrity concerns which must be assessed is presented below:

- Temperature and Pressure during operation;
- Pressure sheath degradation calculations – PA-11 polymer ageing assessment or PVDF crack propagation;
- Annulus condition;
- Bore condition;
- Metallic degradation of the inner layer (corrosion and erosion);
- Extreme vessel motions and offsets – review of dynamic response;
- GVI review;
- Ancillary equipment integrity status review;
- Fatigue – perform a full re-lifeing assessment

A good Integrity Management Strategy should allow the operator to re-assess the remaining life of a flexible pipe after years of service, and therefore to assess the possibility of extending its service.

The main failure modes on aged flexible pipes that will be discussed in this paper are Polymer degradation, Fatigue, Corrosion, Wearing (I-Tube interface) and production parameters.

2. RISK ASSESSMENT

In order to understand the risks associated with an ageing flexible pipe system, a complete and detailed analysis requires data on manufacturing conditions, operating conditions, previous repairs and/or inspections [Ref. 4]. This information will for example inform the operator of any operation conditions outside the design limits experienced by the system, or of unexpected variations revealing any emerging anomalies.

The potential risks of failure of a system can be evaluated based on factors that affect the Probability of Occurrence Rating (POR) and Consequence of Occurrence Rating (COR) of a failure mode. COR is mainly influenced by hazard to personnel safety, environment (release of products/ leaks) and operability of a system. It is unlikely that the COR would be affected by the time factor. Therefore, risk can only be controlled by reduction of POR. The effectiveness of inspection tools depends on accuracy and sensitivity of the technique chosen. In order to decrease the likelihood of failures, the following recommendations should be followed:

- Increase of available integrity information via increasing measures;
- Decrease of time interval in between inspections.

Different levels of mitigation can be implemented. Once the risk levels are calculated and a full understanding of system complexity is achieved, an integrity management strategy must be defined as a combination of:

- Inspection measures,
- Monitoring measures,
- Testing and analysis measures,
- Integrity management procedures.

2.1. Flexible Pipe Statistics

During 2002, a guidance note was published by UKOOA entitled: “Monitoring Methods & Integrity Assurance for Unbonded Flexible Pipe” [Ref. 2]. This guidance note significantly drew on information collated in 2001, specifically on the failure mechanisms and the use of flexible pipe. MCS have independently maintained a database based on information collected up to 2007 [Ref 3]. It should be noted that the original published data was based on flexible pipe systems located in the North Sea.

The update has been expanded to include a number of flexible pipe assets operating worldwide including Brazil, Australasia, Gulf of Mexico and the West of Africa. It is important to stress that the population of flexible pipes used for this paper, does not include the complete worldwide flexible pipe inventory. However, it is the authors' belief that the information presented is a reasonable indicator of the current status of flexible pipe in the oil and gas industry.

Figure 1 presents the main Failures Modes responsible for damage to flexible pipes in 2002 and 2007.

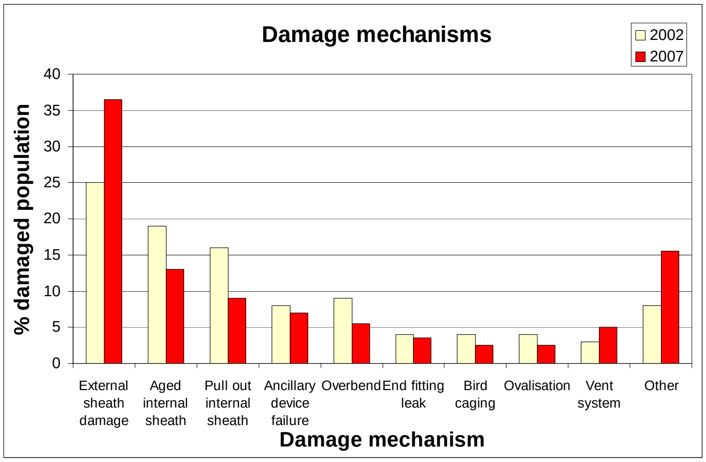

Figure 1: Chart showing the most significant causes of damage to flexible pipes in 2002 and 2007.

It also shows the evolution of failure modes that occurred over the last 5 years. The first noticeable change that appears, concerns external sheath damage. This can be explained by the development of Integrity Management Strategies, planning visual inspection, vacuum testing and other measures which allow the detection of this type of failure. Depending on the location of the external sheath damage, failures associated with corrosion fatigue and free corrosion are likely to occur (e.g. I-tube wearing causing free corrosion due to constant oxygen replenishment).

The second evolution is the reduction in failures due to Aged Internal Pressure Sheath. This is due to a better understanding of polymer behaviour, and the release of recommended practice documents, such as API 17 TR2 [Ref. 5] and most recently the PA-11 degradation JIP [Ref. 6].

Figure 2 shows the length of time before damage occurs to flexible pipe. This figure illustrates the early stage failures and random failures of the flexible pipe population life.

The curve can be divided in 3 parts:

- Early stage failure: This type of failure concerns newly manufactured or newly installed flexible pipes. It can be attributed to poor design or manufacturing problems like poor welding etc. These failures should not be present in systems leaving the factory as these faults should show in Factory Acceptance Tests (FAT). In addition the installation phase is a critical stage on the overall integrity of flexible pipe as it can be responsible for different failure as external sheath damage, compression and etc.
- Random failures can occur during the entire life of a flexible pipe due to collapse, bird caging, corrosion, extreme environmental events, etc. therefore spare equipment should be available should repairs need to be carried out.
- Once a flexible pipe has reached the end of its intended service life, degradation of component characteristics can cause its failure. Degradation of a flexible pipe can appear as internal pressure sheath degradation, fatigue, corrosion, erosion, etc. The ageing does not appear in this figure because very few flexible pipes in operation have yet reached their specified design life.

The number of failures should increase as the flexible pipe population moves towards the end of their predicted lives, unless the end of field life occurs earlier.

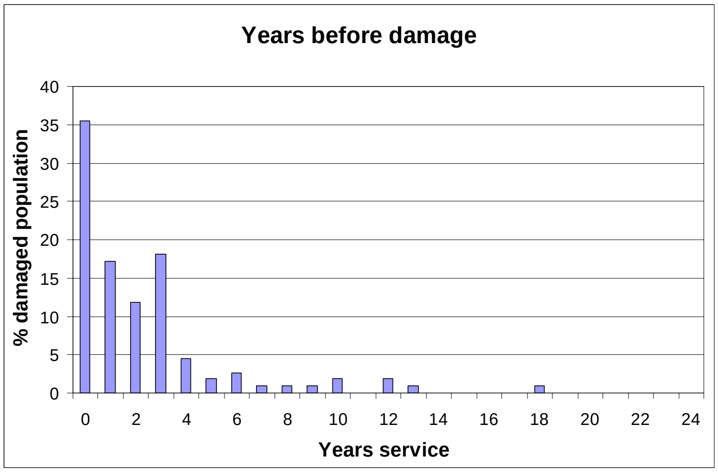

Figure 2: Chart showing the number of years before damage occurs within the flexible pipe population.

It is worth mentioning that this should be used when defining the inspection requirements as part of the integrity management strategy e.g. short inspection interval at start and end of life and decrease inspection requirements in "middle of field life".

3. AGEING POLYMER DEGRADATION MECHANISMS

3.1. Data Required

The data required for the assessment of internal pressure sheath degradation consist in:

- Internal pressure sheath material
- Temperature history
- Pressure history
- Production history (water cut, pH, treatment chemicals, inhibitors)

3.2. Discussion

The internal pressure sheath of flexible pipes is typically made of PA-11 (nylon) or PVDF, depending of operational conditions (temperature, pressure, chemical injection philosophy, etc.). The internal pressure sheath is responsible for the fluid retaining capability of the flexible pipe and therefore represents one of the most important pipe layers. All polymers can and will suffer from one form of degradation (ageing) when exposed to pressure, temperature and hydrocarbons. It is ultimately the rate of degradation that determines the service life of polymer components.

High temperatures experienced by a flexible pipe can lead to the degradation of the internal pressure sheath. Ageing processes are characterised by change in properties, such as reduction in strength or ductility, and embrittlement or softening. Examples of physical ageing are swelling or blistering. In addition, the physical properties of the polymer can be significantly altered by migration of the plasticizer. The change of material properties and reduction in resistance to deformation can lead to formation of cracks in the pressure sheath. Besides, aggressive chemicals injected in the flexible pipe can lead to embrittlement of the polymer, and may increase the bending stiffness of the pipe.

3.2.1. PA-11

For PA-11, the primary ageing concern is the effect of water at elevated temperature. The hydrolysis reaction breaks down the polyamide links within the polymer leading to embrittlement of the material. The rate of PA-11 ageing is highly dependant on a number of operational factors including the water content of the fluid, temperature, acidity, oil composition and presence of injected chemicals (such as methanol).

Hydrate inhibiting chemicals may affect the ageing of PA-11. Liquid methanol diffuses quickly through PA-11 and very effectively extracts plasticizer and swells the material. As a hydrate prevention and remediation measure, methanol is typically introduced either by continuous injection or batch treatments. In continuous injection, the temperature is typically high, but the concentration is low. In batch treatment, the average exposure temperature may be lower than the production temperature, but the methanol is high in concentration. For continuous injection, at low concentrations, field experience suggests that methanol is not a problem. For batch treatment, an estimation of cumulative time and temperature must be made.

The “Batch Methanol Treatment” case gives a conservative indication of the effect of the batched methanol on a PA-11 pressure sheath, by considering cumulative exposure time and temperature for methanol batch treatments. The approach presented by API 17TR2 [Ref. 5] is known to be a conservative one, but corresponds to the current best known practice in the industry. A sensitivity analysis based on API 17TR2 in relation to the ageing mechanism of PA-11 has been performed varying the water cut (dry or wet service), temperature and pH (Fig 4).

There are continued industry initiatives on PA-11 [Ref. 6

Results from the SESAM PA11 joint industry project [Ref. 6] indicate that ageing in a fixed concentration of organic acids will degrade the PA-11 to an equilibrium plateau defined by the concentration and the exposure temperature. As long as this is above the acceptance value for the Corrected Inherent Viscosity (CIV) there is a good case for continued use of the pipe.

In contrast the API 17TR2 ageing degradation model for the water induced hydrolysis does not account for an equilibrium molecular weight plateau.

This means that pipes operating at temperatures higher than 70°C will be expected to reach the defined acceptance criteria within less than 10 years. At 80°C the API model suggests a service life of 3-4 years.

However, new knowledge suggests that PA-11 can maintain adequate performance properties for much longer at higher temperatures provided the TAN is sufficiently low and that the use of Methanol batch treatment is limited. Furthermore the 17TR2 model indicates a much stronger effect from lowering the CO2 driven pH than recent testing indicates.

The service life model in API 17TR2 has been developed by Technip. They recognise that there will be an equilibrium molecular weight but that this will be at a level where the Corrected Inherent Viscosity (CIV) = 0.90 to 1.0 which is well below the acceptance criteria CIV= 1.2. However, work performed [Ref. 6] shows a much higher equilibrium value.

This model is proprietary and has not yet been subject to the rigorous independent industry scrutiny of the 17TR2 model. In addition, it should be pointed out that the use of a new service life model requires a thorough assessment of the exposure conditions to which it is applied. In particular, if organic acids are present in the production environment (or other acids in treatment chemicals) comparison to ongoing laboratory tests must be made and it may be necessary to carry out dedicated laboratory ageing tests.

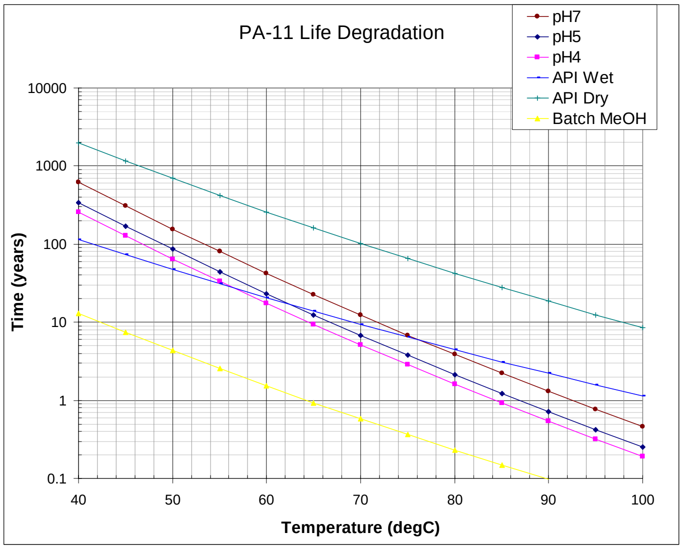

Figure 4: PA-11 degradation curves – API 17 TR2.

3.2.2. 3.2 PVDF

PVDF is highly notch sensitive material and can be susceptible to failure due to thermal cycles. PVDF crack propagation is dependent on the stress ranges generated by drops in temperature during operation (shut down and start ups). Large differences in fluid temperature induce high ranges of axial stress, which can cause circumferential cracks in the material to propagate at a high rate. The crack growth rate is dependent both on temperature and the applied stress. Repeated thermal cycling leads to crack extension and eventually could causes through-thickness failure of the PVDF pressure sheath. Fatigue performance improves significantly for lower operating temperatures; however the likelihood of failure is governed more by the initial crack size than the thermal stress.

Polymer fatigue due to thermal cycles is characterised by circumference cracking in the pressure sheath. A schematic of the phenomenon is shown in Figure 5.

A fracture mechanics assessment can be applied to evaluate the crack propagation phenomenon. It is based on summation of accumulated crack growth over each measured thermal cycle as described in [Ref. 7]. It is assumed that the Paris Law is applicable for PVDF for the thermal cycle range of interest;

$$da/dN = C\Delta Km \qquad (1)$$

where: *da/dN* is the rate of growth of a crack of length a per cycle N
C is a material constant
m is a material constant
ΔK is the stress intensity range for a given cycle – a function of the applied stress, the geometry and crack size.

The procedure for lifetime calculation is outlined below:

1. Calculate thermal drop ΔTi
2. Calculate thermal stress $\Delta\sigma$i due to temperature drop
3. Calculate stress intensity ΔKi, based on thermal stress and current crack size *ai*
4. Calculate crack growth during load cycle Δa using Paris Law
5. Add to current crack growth ai+1=ai+Δa and repeat steps (1)-(5) for the next thermal cycle until a full thickness crack is achieved.

An initial crack size must be assumed in order to undertake a fracture mechanics assessment.

The number of cycles required to reach the failure criterion depends on the size of the initial crack present in the material. Manufacture of the internal pressure sheath (extrusion of the material, manual handling, and potential scratches) can induce roughness on the surface, creating an initial stress concentration point. In order to avoid thermal cycle fatigue, it is important that good quality control is maintained during manufacture. If significant surface flaws are present in the PVDF pressure layer, failure due to thermal cycle fatigue is a credible failure mode and would be expected to occur. Information on these types of irregularities helps define a range of size for the initial crack.

In order to perform an accurate fatigue crack propagation analysis, information is required on the material properties such as elastic modulus and thermal expansion coefficient for the range of temperature experienced by the line along its life.

To mitigate crack propagation in the internal pressure sheath, sacrificial layers may be introduced to avoid notches at the carcass and pressure armour boundaries.

A conservative method for calculating the stress intensity range can be utilised by assuming a constant depth circumferential crack. Under this assumption the stress intensity range is given by:

$$\Delta K = 1.12\sqrt{(\pi a)}\Delta\sigma \qquad (2)$$

where ΔK is the stress intensity range,
$\Delta\sigma$ is the thermal stress range, and
a is the crack depth

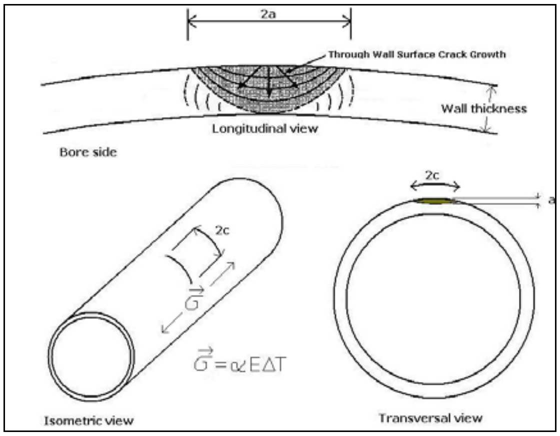

Figure 5: Circumferential Cracking due to Thermal Cycle Fatigue.

4. FATIGUE

4.1. Data Required

The data required to assess the expected fatigue life of a system consist in:

- Maximum continuous operating pressure
- Pressure and tensile armour layer material
- Armour wire shape (i.e. Z, T or C shaped)
- Dynamic in-place loading
- Annulus environment (dry/flooded, CO2 content, H2S content, pH)
- Vessel and flexible pipe response.

4.2. Discussion

The fatigue performance of tensile armour wires is dependent on a wide range of service life factors that include material, environment, global and local pipe cross-section response.

Nowadays, most of the fatigue analysis approaches used take into account the annulus condition (dry/flooded). However this has not been the case for a majority of the flexible pipes currently in service. Examples have shown that fatigue life of a flexible pipe with a flooded annulus can reduce from 20 to just 2 years. A flooded annulus promotes corrosion and corrosion fatigue for dynamic systems. In addition, the presence of CO_2 and H_2S creates a corrosive environment promoting stress corrosion cracking, hydrogen induced cracking and pitting. Therefore considering a critical case with flooded annulus can significantly change the results of a fatigue analysis.

A Joint Industry Project (JIP), RealLife [Ref. 8] has presented guidelines on Fatigue Analysis Methodology, which addresses:

1. Global fatigue analysis of the riser system
2. Transportation from the global to local analyses
3. Local stress analysis of the tensile armour wires
4. Estimation of fatigue life from the wire stresses.

The RealLife JIP objective was to develop a methodology for assessing the fatigue life of flexible pipes more accurately, in particular by improving and refining the approach of key issues which are usually over simplified at design stage. Figure 6 presents an overall fatigue analysis process, which involves different stages.

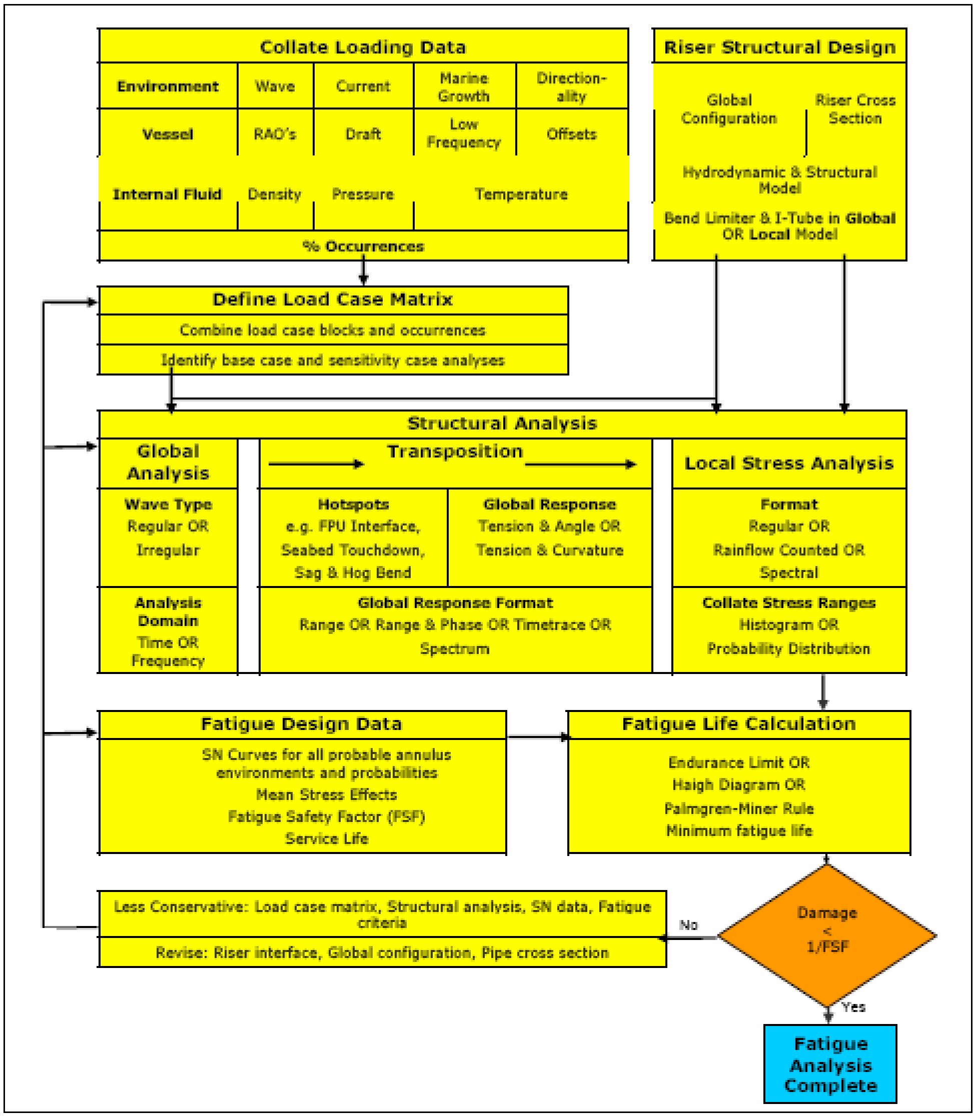

Figure 6: Flowchart of overall Fatigue analyses methodology.

The use of irregular waves and directionality for environmental conditions, the account for structural damping, non linear moment-curvature response, and variation of armour wire stresses around the pipe circumference will reduce the conservatism from a fatigue analysis [Ref. 9].

Keeping track of the annulus condition is essential in assessing accurately the remaining fatigue life of a flexible pipe. Different S-N curves correspond to different annulus environments, with an annulus full of sea water being the most critical. Therefore the remaining fatigue life will not be the same if the annulus has been flooded since installation or after a certain time of operation and remains flooded, or if the annulus has been flooded and subsequently flushed with a corrosion inhibitor fluid.

5. CORROSION

5.1. Data Required

The data required to assess the susceptibility to corrosion of a flexible pipe consist in:

- Pressure and tensile armour material
- Armour wire shape
- Carcass material
- Configuration design.
- Operating pressure
- Operating temperature
- Product fluid composition ((water cut, pH, treatment chemicals, inhibitors)
- Annulus environment.

5.2. Discussion

The tensile and pressure armours are located within the pipe annulus, between the internal and external sheaths. Since the armours are designed to operate in a seawater-free environment, it is typically assumed that they are not exposed to seawater corrosion. However, experience indicates that external sheath damage, and subsequent seawater ingress into the annulus is relatively common, especially for ageing systems. Therefore, there is a potential for significant corrosion of the metallic armour wires over this time. External sheath damage can be caused during installation, or operation (as presented in section 2.1, it represents roughly 36% of anomalies observed in flexible pipes). During operation, external sheath damage can be caused due to dropped objects, wearing of the external sheath with other components (as presented in section 6) or also due to pressure build up in the annulus as a consequence of gas permeation. (The pressure in the annulus will increase until it reaches the point of external sheath failure.) The risk of pressure build-up is in particular possible if no annulus venting system is present on the pipe end-fittings, or if the system is blocked, with corrosion by instance. If the damage is located at the splash zone, where the sea water is constantly re-oxygenated, there is a higher risk of free corrosion of the steel armour wires. Corrosion is time dependent.

Tensile armour wires are the most likely to suffer from corrosion. Unlike pressure armour wires the gaps separating them is relatively large. Pressure armour wires are tightly arranged and flush against the internal pressure sheath. These conditions significantly reduce the possibility of water ingress to the sides of the armour wires and the potential for corrosion. Furthermore, as sea water must pass the tensile armour layers to reach the pressure armour it is likely that some oxygen in the water will have been absorbed (by corroding the tensile armour). As such the corrosion is likely to be less than that experienced by the tensile armour wires.

A study has been carried out by Wellstream [Ref. 10] for the corrosion testing of reinforcement wires in simulated annulus environments of flexible risers. The results vary significantly in these tests as a function of the different environments.

It is very hard to predict the corrosion that could have taken place on a flexible pipe annulus due to the lack of knowledge of past operating data and not knowing whether the armour wires are operating in a wet or dry condition. Based on MCS in house knowledge, typical rate of corrosion of steel in seawater is 0.1 – 0.15mm per year which is in reasonable agreement with the Wellstream report. Although in some scenarios, this assessment was proven to be conservative..

Local analysis can be performed based on operating loads and annulus environment to determine what the minimum thickness of the armour wires is before failure. Therefore, a better understanding of the retaining load bearing capacity with the reduced remaining thickness of the tensile armours can be achieved.

Corrosion rates are difficult to calculate for damaged flexible pipe, where damage has not been mitigated. The environment and size of damage to the riser can differ greatly. The permeation of gas species from the bore into the annulus can significantly alter the corrosion environment in the annulus, with CO_2 and H_2S being the chief driving forces behind corrosion.

Pressure / strength tests during the service life could also demonstrate armour wire integrity. The objective is to verify the stress utilisation of the flexible pipe is within the API 17J specifications [Ref. 11], meaning the stress utilisation at design pressure must be less than 0.85, as per Figure 7.

The required test pressure can be determined using the following methodology:

- Determine the wire thickness necessary to have a 0.85 utilisation after X years of operation.
- Work back the current required wire thickness from the corrosion rates to meet this criterion after X years.
- Calculate pressure to reach Ultimate Tensile Stress.
- Determine test pressure.

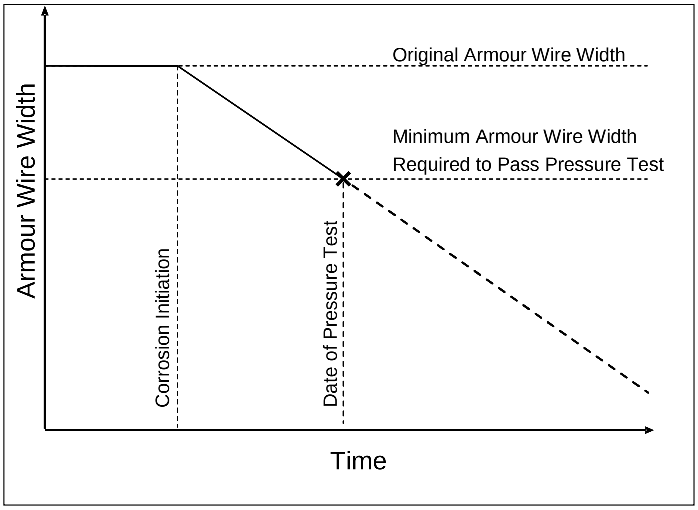

Figure 7: Wire minimum thickness to pass pressure test.

Furthermore, evidence of cathodic protection in place to protect the armour layers from corrosion in the event of seawater ingress into the annulus should be assessed.

6. WEAR

6.1. Data Required

The parameters that determine whether wearing in the I-tube is a primary failure driver are as follows:

- I-Tube geometry;
- Internal surface finish;
- Riser outer sheath material;
- Bend stiffener and bend stiffener connector internal geometry;
- Bend stiffener and bend stiffener connector surface finish.
- Contact pressure

6.2. Discussion

Wear of a riser at the I/J-tube interface is a concern due to the cyclic dynamic behaviour of flexible pipes. Curvature in the I/J-tube can generate high contact forces between the riser and the I-tube, causing abrasion of the outer sheath, and eventually exposing the steel armour layers. Wear of the outer sheath can be worsened by the presence of sharp edges in the I/J-Tube, poor quality surface finish, and small design clearance between the flexible riser and the I/J-Tube.

External sheath abrasion can also be caused by the bend stiffener internal insert. Metallic interferences between the bend stiffener edge and the tensile armour are possible failure modes.

The use of a centralizer will reduce the movement of the pipe relative to the I/J-Tube, and therefore the risk of wear of the outer sheath.

Axial movement (stretching and contraction) of risers inside curved I-Tubes can also cause abrasion of the outer sheath.

Annulus vacuum testing is the primary physical means in which to identify the integrity of the annulus section of the flexible. The presence of a breach in the outer sheath above the sea level would make it impossible to maintain the vacuum during the test. If a breach in the outer sheath is present below the sea level, the test will reveal that there is only a limited free volume in the annulus, the rest being filled with sea water.

I/J-tubes inside inspection via boroscope should also be recommended in order to:

- Evaluate the integrity of the flexible pipe external sheath at this interface.
- Inspect the internal surfaces of the J-tubes

Inspection access provisions shall be provided for riser guide tube inspection at the riser deck access platform while the riser is engaged using boroscope type camera techniques.

7. PRODUCTION HISTORY

Chemical analysis of the bore fluid shall be used to verify levels of sour gases, water and other substances assumed present in the annulus for pipe design.

Produced fluid sampling should be undertaken for the following fluids:

- H2S presence %volume (& partial pressure)
- CO2 %volume (& partial pressure)
- H2O (water cut)
- pH
- gas / oil ratio
- service fluid concentrations (treatment chemicals, inhibitors etc.)
- sand content

This set of data provides useful information for the steel armour design verification and may also be useful for the degradation assessment of the pressure sheath, in terms of the fluids to which it is exposed, and to the steel carcass, in terms of the fluids and potential erosion to which it is exposed.

Monitored produced fluid measurements shall be compared to pre-defined anomaly limits, which shall be less than or equal to, those which were assumed for the design of the pipe and defined in the flexible pipe design premise. Where levels exceed these limits, expert technical advice should be sought on the implications of measurements.

Records of all produced fluid analysis results should be held for the design life of the production system, or flexible pipe if longer. Gas diffusion/permeation calculations should be performed in order to ascertain the partial pressures of the gases in the annulus.

8. CONCLUSION

The industry understanding of flexible pipe failure modes has greatly improved over the last 10 years. Both methodology and tools have been developed to perform reliable integrity assessment of the pipes which can be used to re-evaluate the pipe operating limits and often allow extending its service life.

This is based in particular on reducing the design conservatism by using actual operating data. While it is understood that operating data might not have been collected from day one of the system operation, it is never too late for an Operator to perform a review of its system and develop a cost-effective strategy that will support its understanding of the asset integrity status.

The end of design life of a flexible pipe is a critical phase to manage, especially due to lack of reliable information to allow a degradation assessment.

A risk assessment must be performed to quantify the risks associated with a flexible pipe, as well define the monitoring or test measures required to mitigate those risks.

There are clear advantages of performing a risk assessment from the design stage that facilitates the installation of the required monitoring equipment, and also allows better interfaces with the system. Numerical models should also be used during design to assess the effect of phenomena occurring along the life of the pipe such as corrosion, polymer degradation, fatigue, gas permeation and erosion, based on consistent prediction of the operation profile.

Once the strategy and the equipment are in place, it is necessary to manage the amount of information generated. Parameters such as pressure and temperature are recorded continuously over the years of operation. The data requires to be reviewed in order to be of use, which can be time consuming. Integrity Management tools should be made available to centralize and control the data from all items of equipment, with the option of setting up alarms when anomaly values are exceeded.

Whenever modifications (asset structure, operation conditions…), replacements or repairs are made to the system along its life, the Integrity Management Strategy should be updated to account for the changes.

Provided the integrity management strategy is followed by the operator, this insures optimum management of the system integrity.

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