SEAFLEX

PSA - NORWAY
Flexible Pipes

Failure modes, inspection, testing and monitoring

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1 INTRODUCTION

1.1 Background

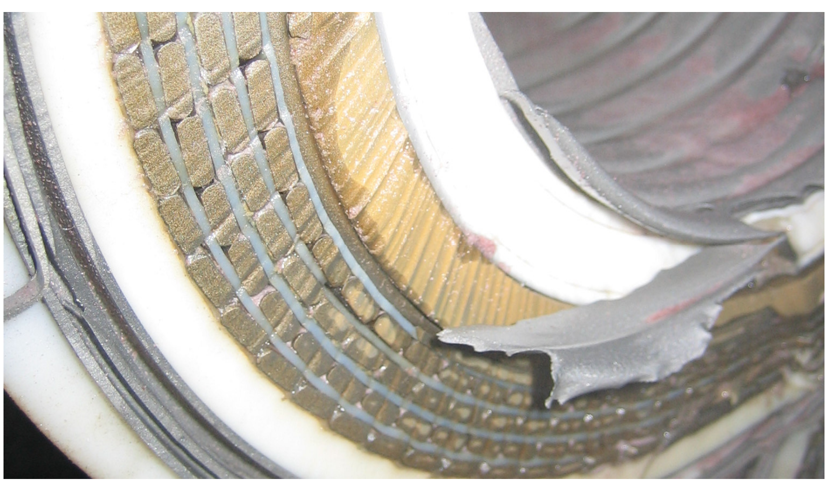
PSA (Petroleum Safety Authority) - Norway has requested SeaFlex to prepare a report on failure modes for flexible pipes and the current best practice for inspection, testing and monitoring of these pipes in context of an integrity management program.

The flexible pipe technology is continuously developing to cope with new challenges in pressure, temperature and water depth, while experiences from often less demanding long term operations are gathered. To enable safe operation of both new and exising flexible pipe systems in this framework, a systematic approach for experience sharing will be of importance. Both the industry in general, fabricators and the operators will benefit from such experience sharing.

The overall objective of this report is to a give brief introduction to the flexible pipe failure modes and integrity management activities. The report is based on world wide experience; hence all information in this report may not be fully applicable for Norwegian offshore sector. As the major part of flexible pipes in operation in Norwegian offshore sector are un-bonded pipes this will be the main focus in this report, but a small summary on bonded pipes is included to broaden the report.

1.2 Historical review

In the Norwegian offshore sector, the use of flexible pipes in oil and gas production was initiated in the late 80's, although the first flexible flowline was installed in the south North Sea already in the early 70's. The first applications were as static subsea tie in jumpers, dynamic jumpers between fixed and floating platforms and static risers. A few risers were used in dynamic application for test production. In the early 90's several project developments in deeper water with floating facilities and flexible riser systems were kicked off. Today a large amount of the oil and gas production and export in the Norwegian offshore sector is successfully conveyed through flexible pipes.



Flexible risers have been one of the key elements in making commercial development of several offshore oil and gas fields.

Figure 1 shows a photo of an advanced un-bonded flexible riser construction, with external fire protection layers and 4 tensile armour layers.

Figure 1-1: Un-bonded flexible pipe (cut by water jet)

In the early years both bonded and un-bonded flexible pipe designs were used. Later, an increased number of un-bonded flexible pipe suppliers, increased competition and technology development have turned the industry more into the use of un-bonded flexible pipes.

Looking back, it is evident that the design and material "know-how" was limited, and that the flexible pipe technology was stretched causing failures ahead of the expected service life for several pipe applications. The suppliers, engineering companies and end users have worked closely together the last decades establishing improved standards for design and qualification test methodology as well as improved models and tools for material degradation prediction, global dynamic analysis and local cross-sectional analysis.

With the previous experience as basis for new designs and deliveries, one should expect less early stage failures due to the fact that experiences are gathered in a wider and wider area of application. The failures we are experiencing today are likely caused by the introduction of more demanding operating conditions.

With respect to flexible riser fatigue, it should be noted that for the Norwegian offshore sector with close to 200 flexible risers, the average riser has been in service for only about 50% of its intended service life (typical design service life is 20 or 25 years).

The overall current status of flexible pipes in the Norwegian offshore sector is that this technology has given cost-effective solutions for a large number of field developments. This is evident through the still growing use of flexible pipes in the North Sea. Figure 2 shows an estimate of the accumulated number of dynamic flexible risers, umbilicals and cables in the Norwegian waters from 90's to 2005. Furthermore, there are several hundred kilometres of static flexible flow lines in the Norwegian sector of the North Sea.

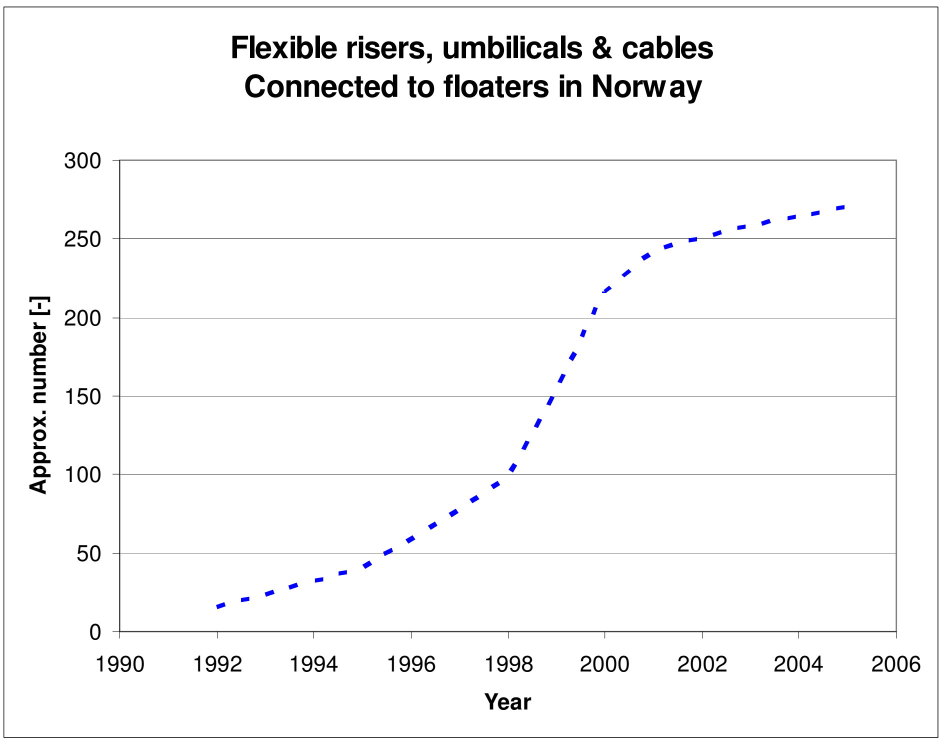


Figure 1-2: Accumulated numbers of dynamic flexible risers, umbilicals and cables in the Norwegian sector

The trend for the future in Norwegian offshore sector is still an increase in the total number of flexible pipes in operation, but not with the same rapid growth as seen from 1996 – 2000. The number of tie-ins, reconfigurations and new developments is expected to outnumber the decommissioned risers, at least in the coming 5 years.

The failure rate measured in failures per year in service has been higher for flexible risers than for rigid risers. From 1995 to 2007, 25 major and 18 minor incidents were reported to PSA. Prior to 1995 there were also failures, but not included in this statistics..

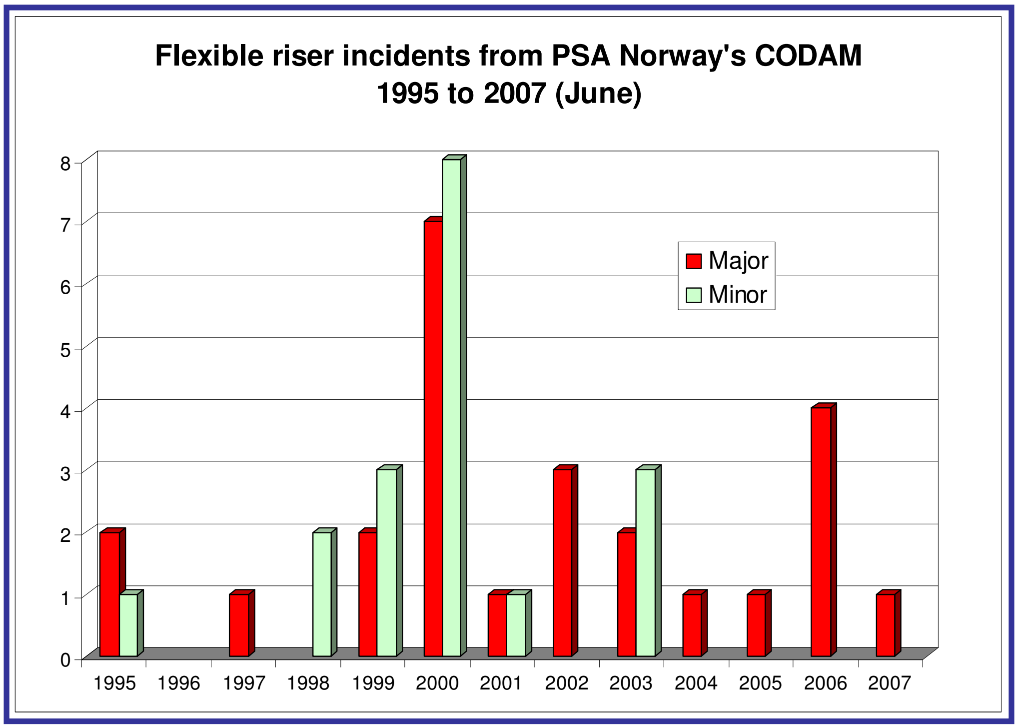


Figure 1-3: PSA Norway Riser failure data

By combining the data in figures 1-2 and 1-3 one may calculate an estimate for the failure rate pr riser in operation for each year. In the figure below, the number of flexible risers has been taken as 0.75 times the estimated total number of flexible risers, umbilicals and cables. Only major incidents from PSA (CODAM database) are included in the figure below.

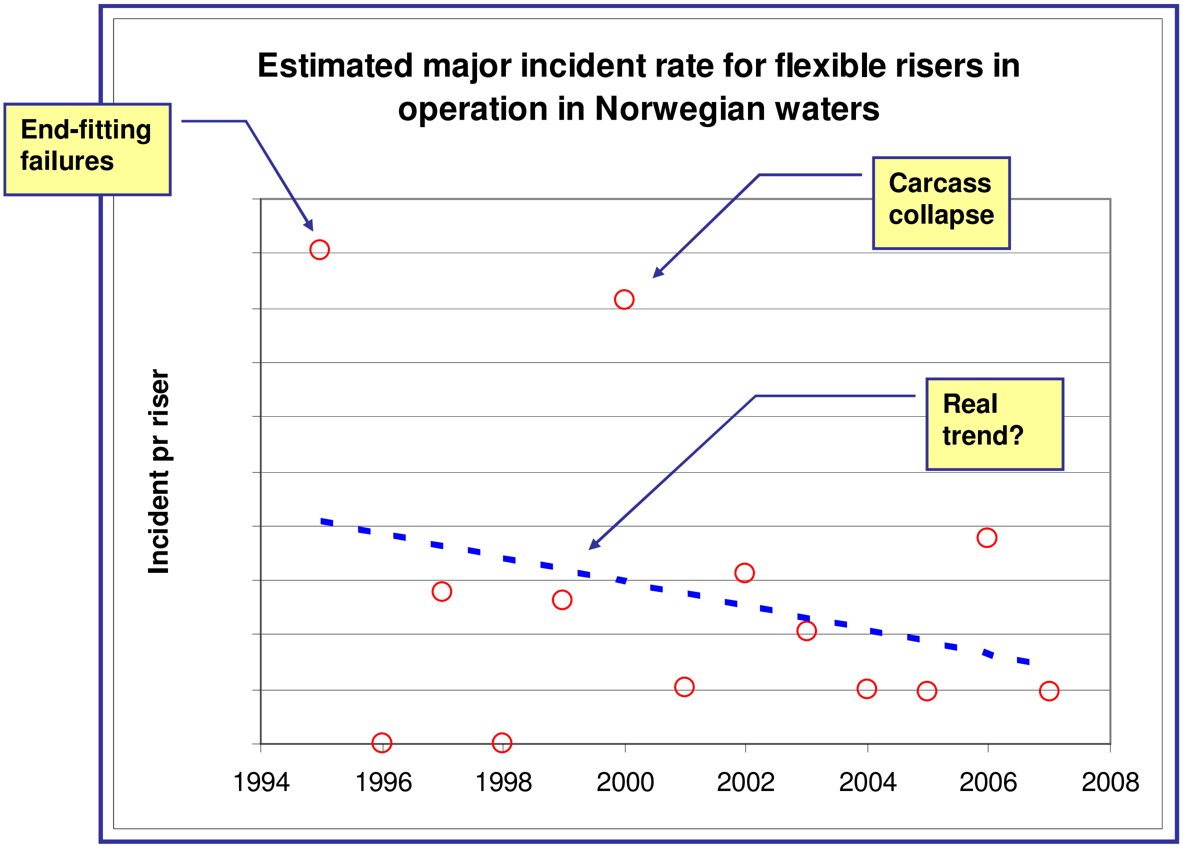


Figure 1-4: Estimated incident rate for flexible risers in Norway

As can be seen from figure 1-4, the trend in reported major riser incidents pr riser in operation is decreasing. If we look into the data for 1995 and 2000 we can identify the dominating failure modes. For 1995 we find that this is related to end fitting failures, while for 2000 it is related to carcass collapse. Both these failure modes are overcome by improved design and revised operational procedures.

As an experiment we may consider an alternative trend where the years 1995 and 2000 both are removed. We will then get a trend picture with a small increase in the major incident rate, in stead of the decreasing trend seen on the previous figure.

Due to limited data it is difficult to predict the trend of incident rate, but a general perception is that the incident rate of older equipment is higher than for newer equipment. This may also be valid for flexible risers as a significant number of failure modes are related to exposure time (fatigue, ageing, wear).

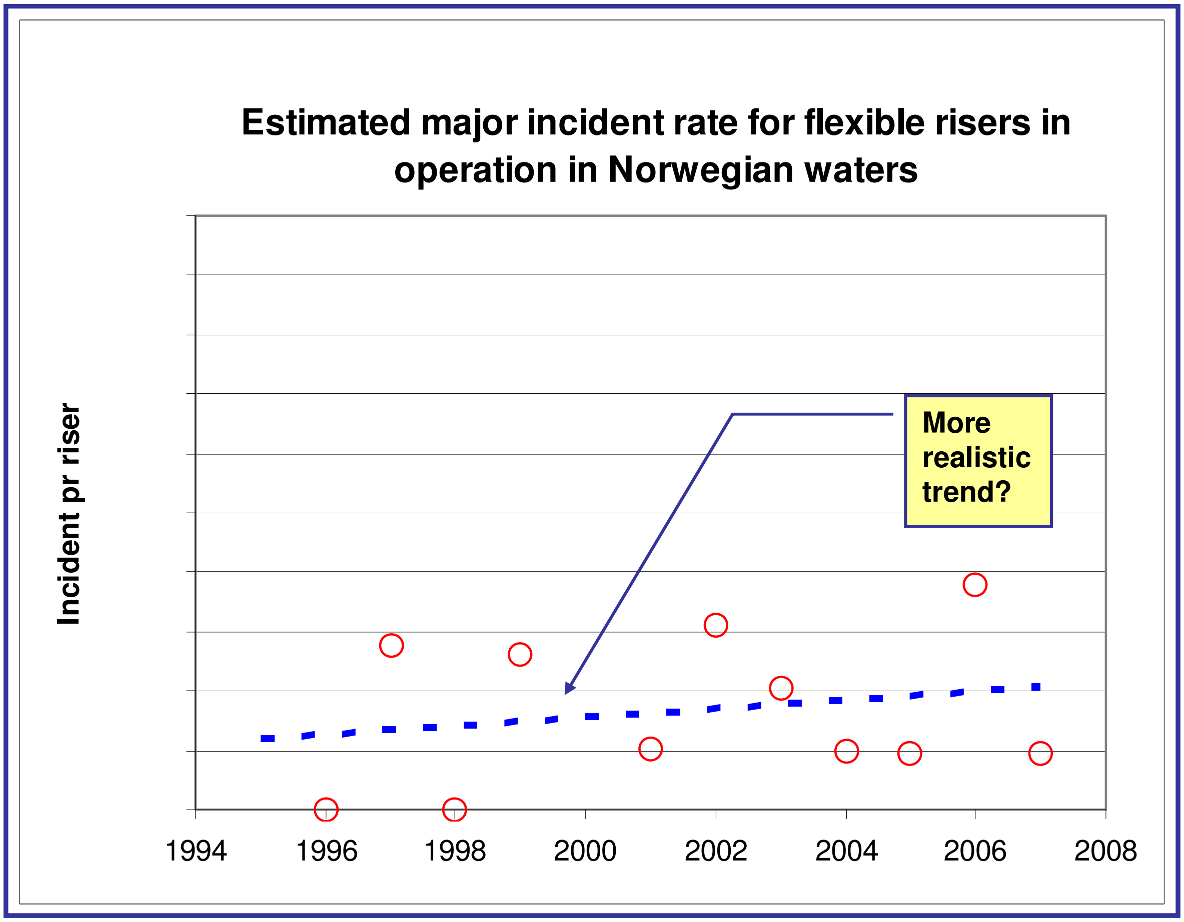


Figure 1-5: Alternative trend with incidents from 1995 and 2000 removed

2 PRACTICES

2.1 Standards

The governing standards for design, fabrication, installation and operation of flexible pipes are the API 17J and 17B specifications, ref /1/ and /2/. These specifications are now in the process of being re-issued as ISO standards, ref /3/ and /4/. The API specification and recommended practices are widely used and form a solid basis for all design, fabrication and operation of flexible pipes.

Several companies have developed company practices and policies for operation of flexible pipe systems. By experience, these practices and the implementation of these may vary significantly from one operator to the other and even between platforms run by the same operator.

For integrity management of risers, DNV is in the process of completing a recommended practice document that is likely to be widely used by the industry, ref /5/. Other previous initiatives to align the industry in a common practice for riser integrity management have only been partly successful.

There is a controversy in the fact that the international standards for flexible pipes are well established, developed over several years, widely used, and still there is a range of riser failures experienced world wide.

Note that extensive updates to the above mentioned standards are under development in order to incorporate learning's from the last decade. One should also bear in mind that API 17J have allowed higher utilization for each new revision.

2.2 Design

There are today three suppliers of un-bonded flexible pipes of larger internal diameters for oil and gas applications, Technip, Wellstream International and NKT-Flexibles. Common to all suppliers are a strong centralised design team responsible for cross section development, qualification testing and development of methods and tools to be used by the in-house engineering teams supporting each pipe delivery.

When developing a new pipe design the pipe supplier will base this on experiences gained over several years, detailed analysis and assessments, along with both small scale and full scale testing. Development of tools and design methods goes hand in hand with testing. A few very successful joint industry projects have been executed, but the majority of development work is still proprietary, and a part of the ongoing competition between the suppliers.

The common practice is that the pipe supplier will have a full EPC (Engineering, Procurement and Construction) responsibility for the pipe delivery, including both detailed cross section design and global configuration design of the pipe systems. Buoyancy modules, bend stiffeners, clamps and other ancillaries are often also included in the delivery. The operators refer in contracts to the international standards, in addition to company specific requirements on functions and interfaces as well as national regulatory requirements and standards.

If the application of the pipe is outside previous experiences or feedback from operations of similar pipes recommends changes, a new qualification program is executed. The qualification requirements are reasonable well defined in API 17J, ref /2/, but still experience shows that introduction of new materials and solutions should be even more carefully evaluated and tested before brought to the market.

By experience, the weakest part of the design loop for flexible pipes is the lack of systematic feedback from installation, operation, recovery, re-use or damage investigations. Some operators use the suppliers to nearly all evaluations after procurement of the pipes, while other operators seldom contact the supplier before the next development project. One reason for these large differences in practice may come from different company policies on industry competition.

2.3 Fabrication

Fabrication of all un-bonded flexible pipes is done in a few highly specialised sites. The sites have specialised equipment and machinery for both polymer extrusion and winding of the different metallic layers. Dedicated areas are also needed for the manual work related to end fitting mounting, various test facilities, storage and handling.

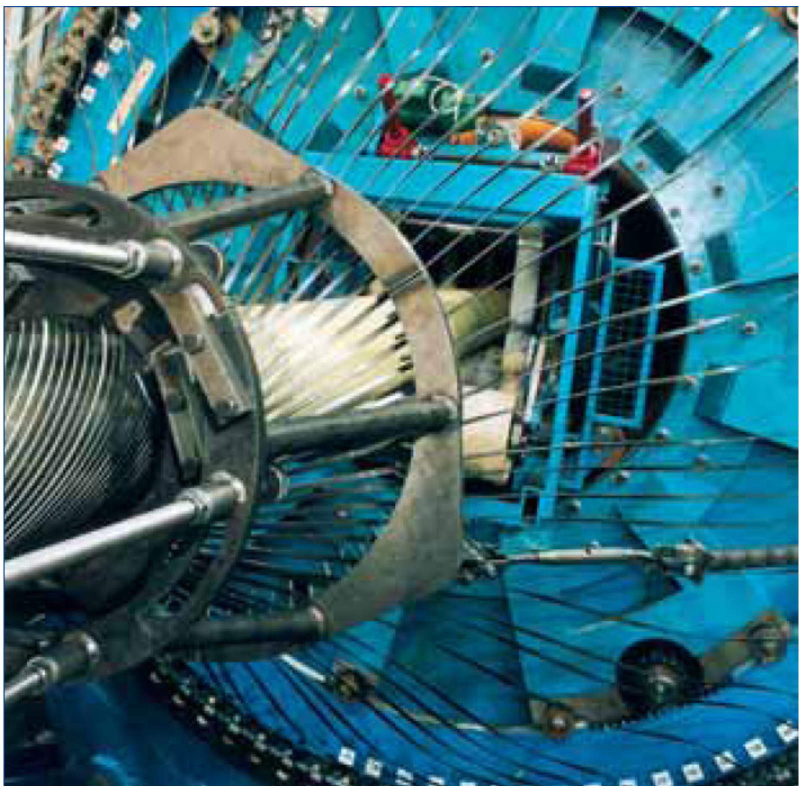


Figure 2-1: Tensil armour winding machine (Wellstream)

The API specification, ref /2/, sets up stringent requirements to the fabrication of all flexible pipe layers, the quality control, and the documentation. All flexible pipe manufacturers have established routines and practices fulfilling the API requirements. At the end of the fabrication process all pipes are subject to a comprehensive set of tests (FAT). These tests have been designed to reveal a wide range of possible fabrication defects. Failures related to dynamics or ageing are not covered by the FAT, but should be covered by design and qualification tests and systematic feedback from operations.

In a life time perspective it is evident that a continuous focus on QA / QC and documentation in the fabrication process will create a good basis for further integrity management activities, life extension projects and possible investigations of failures and incidents experienced in operation. The continuous QA/QC focus is even more important when the activity level is high.

2.4 Transport / Installation

The transportation and installation of flexible pipes are often performed by the installation contractor as a part of a broader EPCI contract. Alternatively the flexible pipes are procured from the fabricator and delivered to the installation contractor as Company supplied items. The transportation and installation procedures will generally not be influenced significantly by the contractual split of responsibilities.

Due to the heavy reels with flexible pipes, the installation vessel often makes several trips to a shore base to load pipe reels on larger projects. The reels will often be lifted by separate heavy lift cranes, if not loaded on the fabrication sites.

The pipe installation operation is controlled through a tensioner unit over a lay tower or over a chute on the vessel side, aft or through a moon-pool. The installation will also include handling of end fittings, bend- stiffeners and restrictors, clamps and buoyancy modules. The correct and efficient handling and installation of ancillary equipment will need special attention to reduce risk and to optimise schedule.

Pipe installation, handling and related installation equipment have improved significantly over the last 15 years. This has lead to reduced risk for installation incidents and delays.

2.5 Operation

The practise for operation of flexible pipes varies enormously between geographical regions, operators, and between the different field development solutions. Even between two floaters operated by the same company we have experienced significant variations in routines, practices and tools for follow up of flexible pipes in operation.

If we limit the view to the Norwegian offshore sector we still see variations between operators and vessels, but in general we can say that there is overall good focus on the integrity of flexible pipes.

Often the focus on integrity issues are related to experienced incidents or difficulties, even though some operators are more proactive and set up good flexible pipe integrity management routines based on assessment of risk rather than experienced problems.

The knowledge related to failure modes and integrity management for flexible pipes have developed continuously over the last 15 years. If the operator shall maintain an acceptable risk level of the flexible pipes, seen in relation to the total experience gained by the industry, it is required to facilitate an active experience transfer both within the operator organisation and with fellow operators. As the experience is gathered the flexible pipe integrity management programs have to be updated.

In a historical perspective we have seen large development since the first flexible pipes in operation, that once a year was inspected by a busy ROV to the current best practice where the flexible pipe operational data is continuously monitored.

3 FAILURE MODE REVIEW (UN-BONDED PIPES)

3.1 General

The number of potential failure modes for a multilayer structure such as a flexible pipe is high. However, the number of different failure modes experienced in operation is more limited. API 17B RP, ref. /1/, lists and describes all of the most probable failure modes and defects for a flexible pipe. The use of this reference is highly recommended to get a complete overview.

Pipe Global Failure Mode to Design Against	Potential Failure Mechanisms	SA or DA[1]	Design Solution/Variables [Ref. API Spec 17J Design Criteria]
Collapse	1. Collapse of carcass and/or pressure armor due to excessive tension.	SA, DA	1. Increase thickness of carcass strip, pressure armor or internal pressure sheath (smooth bore collapse).
	2. Collapse of carcass and/or pressure armors due to excess external pressure.	SA, DA	2. Modify configuration or installation design to reduce loads.
	3. Collapse of carcass and/or pressure armor due to installation loads or ovalisation due to installation loads.	SA, DA	3. Add intermediate leak-proof sheath (smooth bore pipes).
	4. Collapse of internal pressure sheath in smooth bore pipe.	SA, DA	4. Increase the area moment of inertia of carcass or pressure armor.
Burst	1. Rupture of pressure armors because of excess internal pressure.	SA, DA	1. Modify design, e.g., change lay angle, wire shape, etc.
	2. Rupture of tensile armors due to excess internal pressure.	SA, DA	2. Increase wire thickness or select higher strength material if feasible.
			3. Add additional pressure or tensile armor layers.
Tensile failure	1. Rupture of tensile armors due to excess tension.	SA, DA	1. Increase wire thickness or select higher strength material if feasible.
	2. Collapse of carcass and/or pressure armors and/or internal pressure sheath due to excess tension.	SA, DA	2. Modify configuration designs to reduce loads.
	3. Snagging by fishing trawl board or anchor, causing overbending or tensile failure.	SA, DA	3. Add two more armor layers.
			4. Bury pipe.
Compressive failure	1. Birdcaging of tensile armor wires.	SA, DA	1. Avoid riser configurations that cause excessive pipe compression.
	2. Compression leading to upheaval buckling and excess bending (see also Upheaval Buckling failure mode).	SA, DA	2. Provide additional support/restraint for tensile armors, such as tape and/or additional or thicker outer sheath.
Overbending	1. Collapse of carcass and/or pressure armor or internal pressure sheath.	SA, DA	1. Modify configuration designs to reduce loads.
	2. Rupture of internal pressure sheath.	SA, DA	
	3. Unlocking of interlocked pressure or tensile armor layer.	SA, DA	
	4. Crack in outer sheath.	SA, DA	
Torsional failure	1. Failure of tensile armor wires.	SA, DA	1. Modify system design to reduce torsional loads.
	2. Collapse of carcass and/or internal pressure sheath.	SA, DA	2. Modify cross-section design (e.g. change lay angle of wires, add extra layer outside armor wires, etc.) to increase torsional capacity.
	3. Birdcaging of tensile armor wires.	SA, DA	
Fatigue failure	1. Tensile armor wire fatigue.	DA	1. Increase wire thickness or select alternative material, so that fatigue stresses are compatible with service life requirements.
	2. Pressure armor wire fatigue.	DA	2. Modify design to reduce fatigue loads.
Erosion	1. Of internal carcass.	SA, DA	1. Material selection.
			2. Increase thickness of carcass.
			3. Reduce sand content.
			4. Increase MBR.
Corrosion	1. Of internal carcass.	SA, DA	1. Material selection.
	2. Of pressure or tensile armor exposed to seawater, if applicable.	SA, DA	2. Cathodic protection system design.
	3. Of pressure or tensile armor exposed to diffused product.	SA, DA	3. Increase layer thickness.
			4. Add coatings or lubricants.

Notes:
1. SA = static application, DA = dynamic application.
2. Burst, tensile, overbending and torsional failure are not considered in isolation for final design of the flexible pipe.
3. Refer to Tables 29 through 31 for defects important in end fitting designs.

Table 3-1. Failure modes for un-bonded flexible pipes, ref /1/

A good source for data covering flexible riser failures and incidents experienced in the North Sea is the UKOOA guidance note on monitoring methods and integrity assurance for un-bonded flexible pipe from 2002, ref. /6/. The report is based on collected data from a relatively large number of field developments covering both the UK sector and the Norwegian sector of the North Sea. Even though the report does not cover all of the installed flexible risers in the North Sea, it gives a good overview of the different failure modes and incidents experienced.

The figure below summarises the main data covering failure modes seen in operation from the UKOOA work.

It should be noted that a number of the failures are caused by operation outside design limits and that some of the failure modes in the data set have been resolved by the industry

In addition to the data covering the operational phase, the study reported 26 incidents during installation and commissioning with the following main incidents:

- External sheath damage 58%
- Flooded annulus 19%

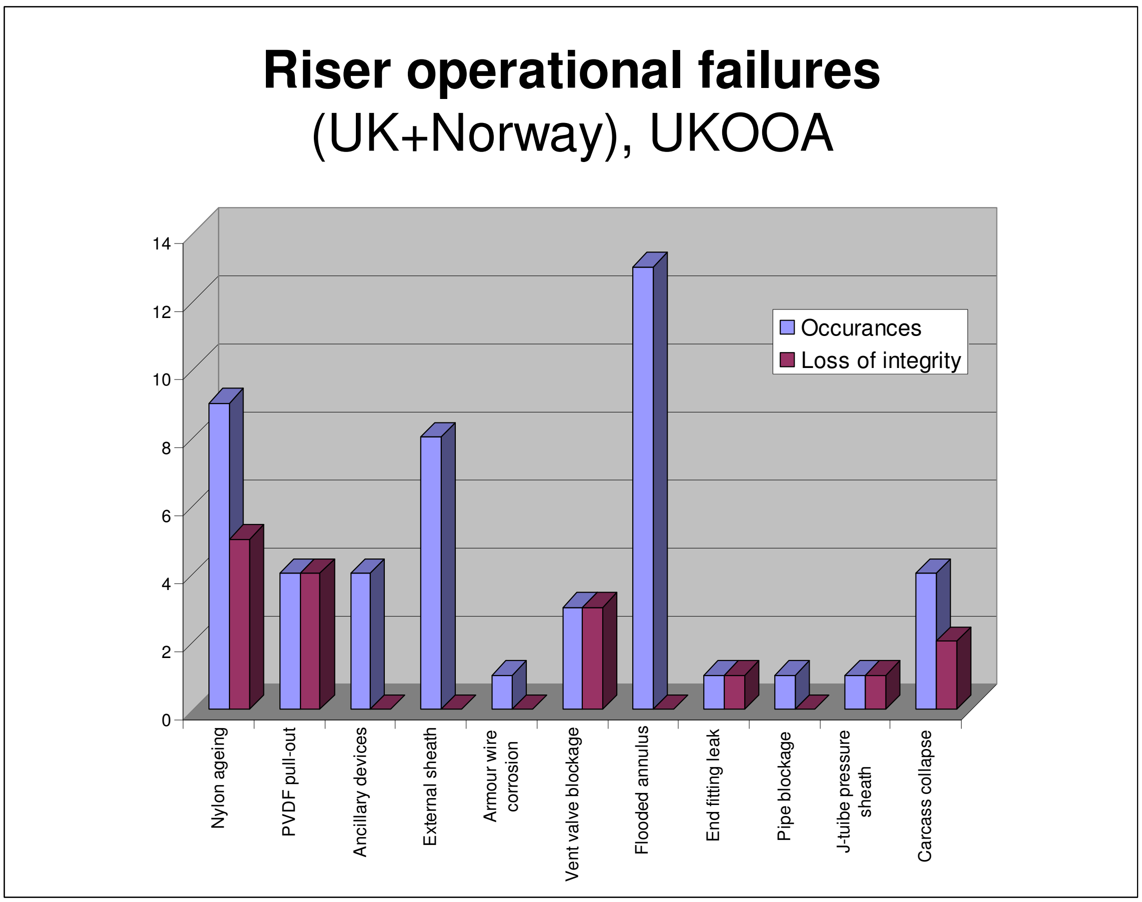


Figure 3-1: UKOOA statistics on flexible pipe failures

3.2 Design & Manufacturing

Some early problems were related to the steel armor interaction at the end fitting interface that for pipes in dynamic applications could lead to fatigue failure of the armor layers followed by pressure barrier failure and leaks. Changes in the termination procedures have resolved this problem (these early failures are not covered in fig 3-1.)

The ageing properties and temperature limitations of PA-11 led to the introduction of plasticized Poly Vinyl Di Fluoride, PVDF, plastic as pressure barrier material for high temperature service. The plasticizer was needed for the extrusion process. Multilayer designs, with sacrificial layers, were used for dynamic service due to the stress concentration sensitivity of the PVDF material.

Early PVDF risers contributed with a major share of flexible riser failures in the Norwegian sector of the North Sea. The first structural failures of PVDF risers were pull-out of the pressure barrier from the end fitting sealing. In order to maintain the anchoring of the PVDF layer when the plasticizer was extracted during service, extensive research and development work were initiated resulting in revised termination procedures, improved designs and new PVDF materials with significantly less plasticizer. Pull out of revised PVDF termination designs has not been reported, but cracking due to thermal cycling has been reported from testing.

Recent structural failures of PVDF risers are caused by pressure build up between the multiple, PVDF layers followed by collapse of the pipe bore during de-pressurisation resulting in leaks for risers in gas injection service as well as for a few production risers with high GOR.

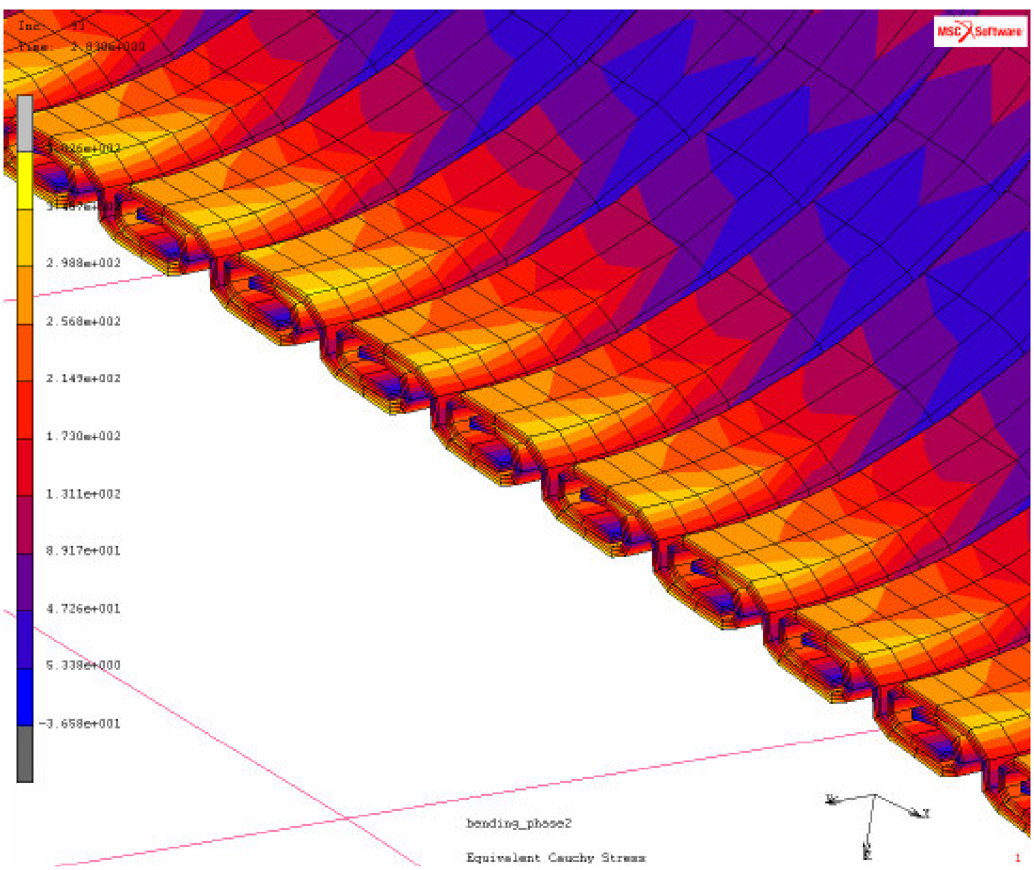


Figure 3-2: Example – Detailed engineering study of carcass stress

Smooth bore (no carcass) flexible pipe designs with an extruded anti collapse layer between the pressure armor and inner tension armor layers, have experienced several failures due to pressure build up between the pressure barrier and the anti collapse layer. The pressure build up may be caused by diffusion from the bore or small leaks in the end fitting sealing or pressure barrier. This is more of a design weakness, and the pros and cons of a smooth bore pipe versus a rough bore pipe have to be evaluated on a case to case basis.

As design procedures, analysis tools and methods have improved, the failures directly related to design are reduced, but as known parameters are optimised the relative importance of the unknown will increase. This paradox should make the designers of flexible pipe keep a general awareness.

There is a small risk for failures related to incomplete or inaccurate design basis, or errors in the design work itself. Errors in the design work are in the majority of cases revealed through checks performed by the operator or a 3rd party engaged for design verification. Experience transfer is a key contributor to an error free design track record.

One failure mode that appears still to be linked to design issues is blockage of annulus vent systems. Some end fitting designs could be improved to enable long term unrestricted flow in the vent system.

It is vital for continuous improvements in design tools, methods and processes that all in-service experienced anomalies or failures related to design and manufacturing of flexible pipes are reported back to the manufacturer.

Another issue is indirect failures on interfacing equipment, as e.g. hub failures due to loads from flexible pipes. This should be kept in mind during design, installation, commissioning and operation.

Polymer Material	General Compatibility Characteristics
HDPE	Good ageing behaviour and resistance to acids, seawater and oil. Weak resistance to amines and sensitive to oxidation. Susceptible to environmental stress cracking (environments include alcohols and liquid hydrocarbons).
XLPE	Good ageing behaviour and resistance to seawater, weak acids (dependent on concentrations and dosage frequency) and production fluid with high water cuts. Weak resistance to amines and strong acids (dependent on concentrations and dosage frequency) and sensitive to oxidation. Less susceptible to environmental stress cracking than HDPE (environments include alcohols and liquid hydrocar-bons).
PA-11	Good ageing behaviour and resistance to crude oil. Good resistance to environmental stress cracking. Limited resistance to acids at high temperatures (recommend pH > 4.5 or TAN < 4.0). Limited resistance to bromides. Weak resistance to high temperatures when any liquid water is present.
PVDF	High resistance to ageing and environmental stress cracking. Compatible with most produced or injected well fluids at high temperatures including alcohols, acids, chloride solvents, aliphatic and aromatic hydrocarbons and crude oil. Weak resistance to strong amines, concentrated sulfuric and nitric acids and sodium hydroxide (recommend pH < 8.5)

Figure 3-3: Example on design recommendations by API, ref /1/

3.3 Transportation

The flexible pipes are, with few exemptions were carousels are applied, transported on large reels from the fabrication facilities to the installation site or a mobilisation base near the installation site. The reels are lifted by large onshore or floating cranes.

Failures during lift and sea transportation are not commented further in this document.

The failures experienced during transportation are related to packing, preservation and seafastening. For long term transportation and storage careful preservation and packing may be needed to protect the flexible pipe and end fittings against sunlight exposure and corrosion of seal surfaces.

Figure 3-4: Flexible pipe transportation / installation reel (NKT)

If the pipes are water filled and the transport is taking place in artic areas, one should carefully evaluate the effect of ice formation in the riser bore. This may be of a special concern if pipes are pressure tested or pigged shortly after transport.

On a few occasions flexible pipes have caught fire during cutting of seafastening. This have had major consequences for the operators field development, as replacing several risers may be very time consuming, even without the need for engineering.

The external sheath of the flexible pipes is vulnerable to dropped objects and small impacts from cargo lifted by cranes during hectic mobilisation work. Damaged external sheath may directly lead to pipe failure if the external sheath damage is located in an unfavourable position, and not repaired prior to installation.

3.4 Installation / recovery

During installation or recovery (for re-use) operation several failure modes may be trigged by unintended minor incidents, errors in procedures, equipment anomalies or lack of precise adherence to procedures. After some initial failures during installation operations, major improvements are now implemented resulting in less installation failures.

Figure 3-5: Flexible pipe installation (Technip)

The most common failure during installation is through thickness damages to the external sheath. Early experiences shows external sheath failures of up to 10% of installed risers. If these damages are small and located close to the pipe ends, there may not be an integrity problem for the pipe. However, each case has to be investigated separately to evaluate the consequence of the damage, possibility and need for repair etc. If the external sheath damage is in the splash zone where the cathodic protection system have limited or no effect, and the access to oxygen is good, major corrosion damages can appear quickly and pipe integrity will be in danger.

Another failure mode experienced during installation operations is over-bending and unlocking of the pressure armour. This may eventually lead to pipe failure when the pipe is exposed to high pressure, as during a pressure test, or during long term operation with high temperature and lower pressure. The unlocking may also progress and damage large sections of the pipe leading to loss of integrity even without high pressure or temperature.

Over bending combined with high hydrostatic pressure (deep water) and compression have lead to failures of the tensile armour wires by overstressing or wire buckling. This failure mode, which is only applicable for deepwater, is referred to as lateral buckling.

Failures may also be experienced when installing ancillary equipment such as clamps, bend limiters or buoyancy modules. Often the external sheath is endangered if the procedures are not carefully adhered to. During clamp attachment the pipe may be squeezed too much if creep effects are not fully taken into account during procedure development or the procedure is not strictly followed.

Damaging interference with neighbouring risers has been experienced during installation and recovery of flexible pipes. The consequences have been damages to the external sheath, loss of subsea anchor position / integrity and loss of buoyancy modules. Careful planning, training and execution are required to prevent such failures, especially during replacement operations on floaters with several risers and mooring lines.

Failures have been experienced with pipe clamps where the highly pre-stressed and anode protected bolts have cracked due to hydrogen embrittlement

As explained above, installation damages are in the range from small external sheath scratches to structural damages requiring shore repairs or scrapping of the pipe.

Minor external sheath damages discovered prior to submerging the damage location into the sea, including limited through sheath thickness damages, can normally be repaired by flexible pipe technicians onboard the installation vessel.

The main problem is related to undetected installation and handling damages causing later failure or seawater flooded pipe annulus possibly resulting in reduced service life.

The recommended preventive efforts to avoid installation related damages include well designed handling and installation equipment, protection of sharp edges and snagging points in the handling route and detailed laying procedures supported by analyses and offshore personnel familiarization. Any deviation to installation procedures should be properly addressed, processed and accepted prior to implementation. The pipe external sheath must be closely visually inspected just prior to deployment into the sea. Any anomalies should be reported, processed and repaired according to the manufacturer's damage assessment and repair guidelines prior to deployment

3.5 Operation

3.5.1 Fatigue

All the materials used in the flexible riser cross section may be subject to mechanical fatigue. Normally, this is in focus only for steel components, but when investigating progression of damages within the flexible pipe cross section one should have in mind the effect of temperature cycle induced fatigue in PVDF. Fatigue in polymers is normally not regarded as a fundamental failure mode for un-bonded flexible pipes, see section 3.1.

The carcass is made by cold forming thin steel ribbons into an interlocked flexible structure. Normally this structure will only see limited stress cycles and be more exposed to erosion or corrosion in case of sand or undesired chemicals in the well stream. Carcass fatigue has been experienced due to inaccuracies in the fabrication or load conditions changing the carcass performance. Recent experiences indicate that the carcass may see significant stress levels when the flexible riser is interacting with arch structures. Normally a fatigue crack in the carcass should not lead to loss of integrity for the flexible pipe, but this has been experienced. A complex interaction with the other cross section layers is needed for the damage to progress into a pipe failure, but the experience so far is that a failed carcass over time may progress further into a pipe failure.

Fatigue in tensile and pressure armour has been experienced in accelerated prototype testing and is currently no significant contributor to pipe failures in operation. Based on analysis performed in the design, fatigue failures are unlikely as the oldest flexible risers in operation in Norwegian waters are just above 10 years.

However, as the design analysis of most risers installed have assumed dry annulus environment there may be some risers that will experience less fatigue life than previously expected. Experience shows that nearly all production risers will fill up the riser annulus with condensed water. Differences will be seen due to different pressure barrier materials, well fluid, temperature etc.

3.5.2 Corrosion

If the external sheath is damaged, the armour wires in the pipe will be exposed to seawater. The wires will corrode if not efficiently protected by anodes in the vicinity. For flexible pipes with damages in the external sheath, some O_2 corrosion is observed, even when the pipe ends are connected to anodes. This is believed to be related to a possible problem of protecting shielded steel a certain distance away from the damage where the steel is not directly exposed to seawater.

Technip have studied the effect of corrosion protection (-850mV) of shielded steel in a test, ref /11/. The test concludes that steel wires in the vicinity of a damage external sheet area should be sufficiently protected against O_2 corrosion. The partial pressure of O_2 seems to fall quicker than the potential from the CP system along the pipe annulus away from the damage area. However, based on observed corrosion on other flexible pipes, it is reason to believe that the good effect of CP system further along the annulus (away from the external sheath damage) is very dependant upon high CP potential.

For external sheath damages in the waterline area where the effect of anodes is limited, several examples on significant O_2 corrosion have been observed, some with dramatic pipe failures.

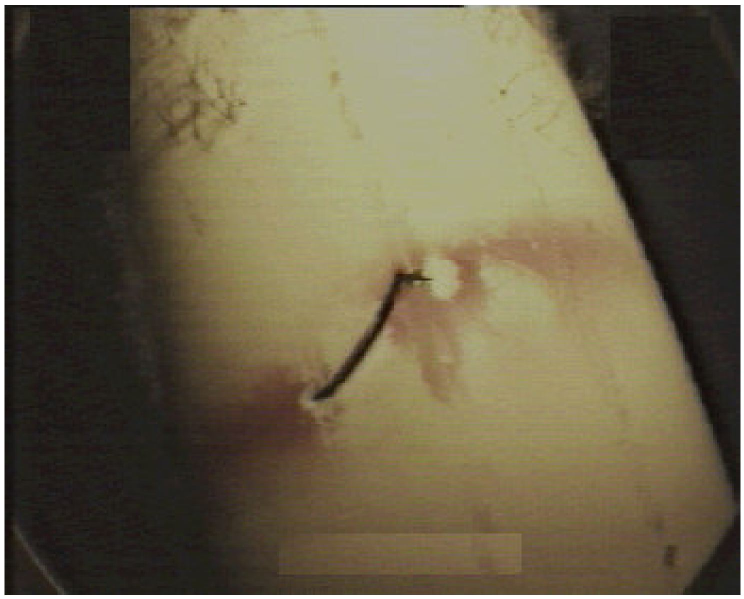


Figure 3-6: Armour wire corrosion due to external sheath damage (Statoil)

CO_2 will diffuse from the pipe bore to the annulus if bore content include CO_2. The partial pressure of CO_2 in the annulus will vary along the riser. The NORSOK standard M506, ref /10/ presents methodology and a calculation sheet for CO_2 corrosion. This NORSOK standard is limited to partial pressure of CO_2 above 0.1bar. The corrosion rate for CO_2 partial pressure above 0.1 is higher than 0.1mm/year for any temperature between 10 and 60 degC and pH between 3.5 and 6.5. This indicates that CO_2 corrosion may be a problem for flexible pipes with water filled annulus, however experience from dissections of damaged flexible pipes has concluded with very limited CO_2 corrosion compared to estimates based on NORSOK 506 for the tension armours of flexible risers and flowlines. CO_2 corrosion may be a long term problem for dynamically exposed risers due to reduced fatigue capacity in annulus environments with moderate to high CO_2 partial pressure.

3.5.3 Collapse

There are two different collapse scenarios that have been experienced by flexible pipes, collapse of internal pressure liner in smooth bore pipes, and carcass and pressure liner collapse in rough bore pipes.

Pressure liner collapse in smooth bore pipes is often seen on water injection pipes when vacuum is reached in the bore due to dynamic flow effects during shut down. There may be several ways to prevent this, but these compensating measures will often lead to operational restrictions. Both adjusted valve closing sequences, vacuum breakers and vacuum in the flexible pipe annulus may be viable options. The pressure sheath will eventually crack after a number of repeated collapses.

Carcass collapse in flexible pipes with multi layer PVDF pressure sheath has been experienced several times. The collapse is caused by an external pressure exceeding the capacity of the carcass. If the carcass has an initial damage or ovalization the collapse capacity may be dramatically reduced.

The actual collapse capacity will be influenced by several factors: Geometry at the damage area, differential pressure, and 3D stiffness / load effects caused by the vicinity of the end fitting or clamps.

Preventive measures may be operational limits, restrictions in pressure relief gradients or design changes on the carcass.

Operation of a pipe with a fully or partially collapsed carcass may be possible for a short time, but movement of the pressure sheath will after some time lead to failure, if pressure or temperature is cycled. In addition, the lack of internal support may lead to failures in other layers; all dependants upon the cross section design.

Recent experiences have shown that carcass collapse due to pressure build up between pressure sheath layers may be more likely when the pipe is exposed to loads from interfacing structures that lead to initial ovalization of the carcass. Such interfacing structures may be curved sections, bend stiffeners, clamps, guide tubes or arches.

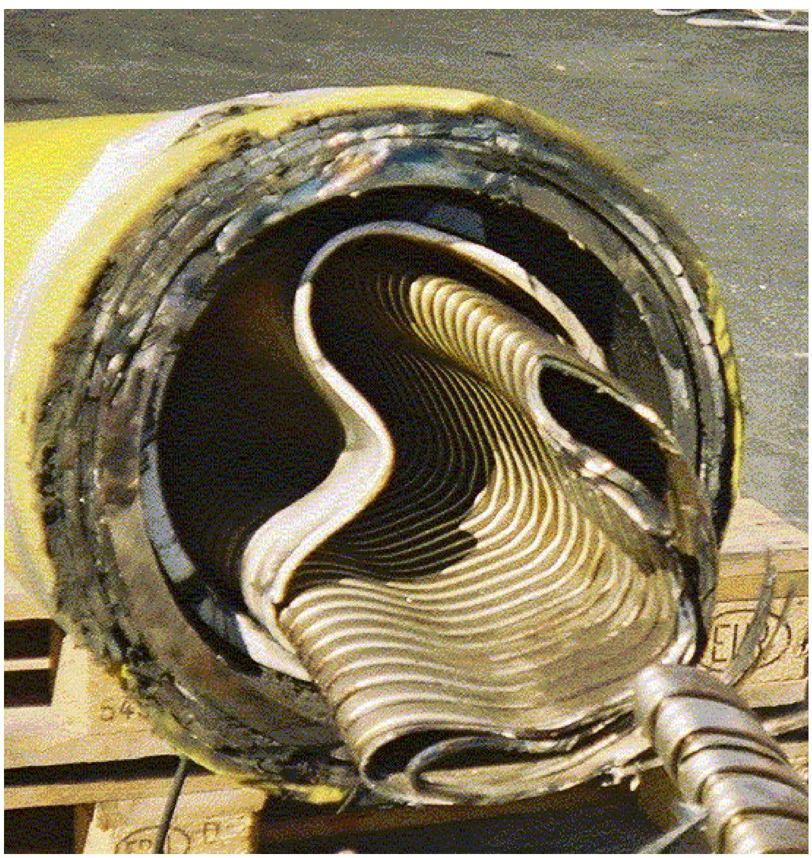


Figure 3-7: Collapsed carcass (Hydro)

3.5.4 Hydrogen embrittlement

Hydrogen embrittlement is known to cause failure of highly loaded high strength steel components protected by nearby anodes. Failures have been experienced in subsea equipment and ancillary equipment for flexible risers. No confirmed hydrogen embrittlement failures of flexible pipe armour wires are known, although some unexpected wire failures have been seen.

Hydrogen embrittlement of high strength armour wires could be disregarded as a primary failure mode, but connected to other initial failures, e.g. effects that give local stress concentration such failures may be seen.

Even if the material do not get brittle seawater, CP and high strength steel may give hydrogen production and a significantly reduced fatigue life, for dynamic applications.

3.5.5 Impacts

Local impacts from dropped objects, fishing equipment or equipment used during nearby marine operations may give a range of serious damages to the flexible pipe. Most commonly experienced failure mode from impacts is damages to the external sheath and subsequent local armour wire corrosion.

More severe impacts may lead to damages to tensile armour wires, unlocking of pressure armour layers or carcass ovalization, potentially leading to a total pipe failure.

A general recommendation: If outer sheath damages expose the armour to seawater and CP, the exposure time should be limited.

3.5.6 Pigging

Smooth bore flexible pipes are often used in water injection systems. This design is significantly more sensitive to pigging damages. Pressure sheath damage due to pigging has occurred resulting in system shut down and riser replacement.

Carcass damages may result from pigging with erroneous pigs in flexible pipes. The carcass damage may develop into a carcass failure in dynamically loaded pipes.

3.5.7 Ageing

The early operational temperature limitations were not conservative and problems were experienced with ageing of the PA 11 plastic material (nylon) when used as pressure barrier. Operation outside humidity and related temperature limits has occurred causing reduced service life and riser replacement. The ageing causes embrittlement and cracking of the pressure barrier.

In order to establish safe operational limits for PA-11 pressure barriers, research and development work were initiated, resulting in revised ageing curves. The API 17TR2, ref /12/ gives reasonable correlation between predicted and actual ageing of PA-11. Test coupons machined from actual flexible riser structures installed in gas injection and oil production lines and retrieved for testing have partly verified good correlation between actual degradation and the API 17TR2 predictions when the curve for pH 4 is applied.

Recent research shows that the ageing of PA-11 is more complicated than assumed in API TR 17TR2, even though adherence to the recommendations in API TR 17TR2 seems to be giving a significant reduction of ageing damages. More research is needed to establish more refined, less conservative and practical recommendations.

Ageing of the external sheath due to UV-exposure may be a long term problem even if this is not reported to be a significant problem today. Ageing of anti wear tape used between the armor layers may be a problem for pipes operating with high temperature, especially if the annulus is filled by condensed water diffused from the pipe bore, or filled by breaches in the external sheath.

Failures due to ageing of other polymer materials used in the flexible pipes are rarely seen compared to the PA-11 / Nylon failures. Adherence to the recommendations in API 17J/B is important if ageing problems should be avoided.

Failure due to material hydrolysis of bend stiffeners made of polyurethane has been experienced. Changes in type of polyurethane material used and increased knowledge of temperature limitations appear to have solved this problem.

3.5.8 Erosion

Sand in the production flow may lead to erosion of the carcass. Erosion is normally not a problem as long as operational limits to sand amount and flow velocities are adhered to.

Another related issue is internal pipe damages due to hydrates. Hydrates created in the flexible pipe or in interfacing pipes systems flowing into the flexible pipes may lead to severe damages to the carcass and subsequent pipe leak.

3.5.9 Buckling / over bending / wire disordering

Flexible pipes may buckle in case of compression loads over a certain limit. For static seabed lines protected by trenching and / or rock dumping special considerations must be made to avoid buckling. In the extreme event, buckling loads may lead to pipe over bending and wire disordering (bird caging). For static flowlines this failure mode has been experienced.

The different buckling modes seen in flexible pipes:

Lateral buckling due to over stress: For a deep water pipe with an intact external sheath, the high frictional forces efficiently restrain the wires from moving until the critical curvature is reached. If exposed to axial compression combined with bending, the “locked or fixed” tensile armor wires could be exposed to compressive stresses above yield and hence fail by overstress.

Lateral buckling due to elastic instability: For a pipe with damaged external sheath exposed to axial compression combined with bending, the radial movement will be restrained by the high strength tapes, but lateral movement could occur with little resistance. Hence, in this case, lateral buckling due to elastic instability could occur. Excessive lateral wire movements could also lead to overstressing if reached before elastic instability occurs.

New test methodology has been developed to test pipe designs and calibrate analytical tools for lateral buckling.

Radial buckling: If the pipe is exposed to true wall compression, the helically laid tension armor wires will try to move in the radial direction possibly leading to wire buckling and significant disorganization of the wires. This effect has also been known to happen during manufacturing. Radial buckling is often referred to as “bird caging”. However, for a pipe with intact external sheath, any radial movement of the wires will be efficiently restrained by the hydrostatic pressure acting on the external sheath. In case of a damaged external sheath, high strength tape layers applied outside the outer tensile armor layer will restrain the radial movement of the wires. Hence, for a properly designed flexible riser with or without intact external sheath, bird caging should not be an issue.

3.5.10 Wear

Flexible pipes in dynamic applications may be subject to wear between the steel armour layers. As these layers have been designed and tested to sustain normal wear loads, shortcomings in the design or changes in interface loads have to be present before wear develops into a failure.

Recent experiences with highly dynamic flexible risers installed in guide tubes, over subsea arches or through bending stiffeners have shown clear indications of excessive wear. Only on a few occasions have this wear lead to rapid degradation of pipe integrity. Geometry, surface roughness, and material selection seem to be important factors.

3.5.11 Vibrations in Gas Pipes

High frequency vibrations have been observed in gas export and gas injection systems. The vibrations are believed to originate from the carcass where a vortex shedding process takes place as the gas flows over the carcass cavities. The phenomenon is currently not fully understood, however parameters including carcass geometry, gas velocity, gas pressure and gas composition affect the vortex shedding process and thereby the vibrations. The presence of acoustic amplifiers in the connecting steel piping is also believed to play an important role.

In one existing system, fatigue failure of topside piping has occurred and topside piping modifications were required in order to continue safe operation. In another system the subsea riser base was retrieved, modified and reinstalled due to components being identified as critical with regard to fatigue loading based on measured vibrations. Some systems experiencing vibrations continue to operate after stress checks by strain gauges have verified that the vibrations do not introduce unacceptable stress levels. It should also be noted that besides fatigue related problems, noise and increased flow resistance resulting from these vibrations have also been identified as a problem for some installations.

New projects planning gas export and/or injection through flexible risers address the potential vibration problem by implementing requirements on the flexible pipe and/or that interfacing piping systems shall not be fatigue sensitive with respect to potential vibrations. Acoustic dampeners or silencers are also being considered.

3.5.12 Annulus environment

Figure 3-8: Burst external sheath due to blocked vent system.

The flexible pipe annulus is empty at delivery, with exception of small amounts of lubrication used during the manufacturing process. Empty or dry annulus was the basis for fatigue and service life analysis of flexible risers for many years. However, in service experience in recent years has shown that in many cases this is not the case. Experience shows that many production risers fill up gradually with diffused and condensed liquid after some time. The filling time varies significantly with temperature, water cut and pressure barrier material and thickness.

The annulus of flexible pipes can be partly or fully flooded due to a range of other events. Below are listed the most typical effects that all have been experienced in the North Sea:

- Leaking or missing annulus vent plugs in end fittings
- Installation damages of external sheaths
- Burst external sheath due to blocked annuli vent system, see Figure 3-8
- Flooding from other topside systems connected to the annuli vent systems

Several operators are using annulus testing actively as part of their in-service integrity management programs combined with periodic inspections of annuli vent system status to track and document the long term status of the pipes. Several projects are initiated on development of armouring wire SN-curves representative to the observed annulus environments, along with development of more accurate diffusion models for flexible pipes. This will enable periodic reassessment of residual service life for critical risers based on true annulus environment, representative SN-curves and recorded operational conditions.

4 FAILURE MODE SUMMARY (BONDED PIPES)

4.1 General

The potential failure modes for a bonded flexible pipe are not very different from the failure modes for un-bonded pipes. API 17B RP, ref. /1/, lists and describes all of the most probable failure modes and defects. The use of this reference is highly recommended to get a complete overview.

Pipe Global Failure Mode to Design Against	Potential Failure Mechanisms	SA or DA[1]	Design Solution/Variables [Ref. API Spec 17K Design Criteria]
Collapse	1. Collapse of carcass due to excessive tension.	SA, DA	1. Increase thickness of carcass strip, or pipe body (smooth bore collapse).
	2. Collapse of carcass due to excess external pressure.	SA, DA	2. Modify configuration or installation design to reduce loads.
	3. Collapse of carcass and due to installation loads or ovalisation due to installation loads.	SA, DA	3. Increase the area moment of inertia of carcass.
	4. Collapse of pipe in smooth bore pipe.		
Burst	1. Rupture of reinforcing armors due to excess internal pressure.	SA, DA	1. Modify design, e.g. change lay angle, cable type, etc.
			2. Increase cable thickness or select higher strength material if feasible.
			3. Add additional reinforcing armor layers.
Tensile Failure	1. Rupture of reinforcing armors due to excess tension.	SA, DA	1. Increase cable thickness or select higher strength material if feasible.
	2. Collapse of carcass and/pipe body sheath due to excess tension.	SA, DA	2. Modify configuration designs to reduce loads.
	3. Snagging by fishing trawl board or anchor, causing overbending or tensile failure.	SA, DA	3. Add two more armor layers.
			4. Bury pipe.
Compressive Failure	1. Compression leading to upheaval buckling and excess bending (*refer to Upheaval Buckling failure mode also*).	SA, DA	1. Avoid riser configurations which cause excessive pipe compression.
Overbending	1. Collapse of carcass or pipe body.	SA, DA	1. Modify configuration designs to reduce loads.
	2. Rupture of liner	SA, DA	
	3. Crack/tear in outer sheath.	SA, DA	
Torsional failure	1. Failure of tensile armor wires.	SA, DA	1. Modify system design to reduce torsional loads.
	2. Collapse of carcass and/or liner.	SA, DA	2. Modify cross-section design (e.g. change lay angle of wires, add extra layer outside armor wires, etc.) to increase torsional capacity.
	3. Birdcaging of tensile armor wires.	SA, DA	
Fatigue failure	1. Tensile armor wire fatigue.	DA	1. Increase wire thickness or select alternative material, so that fatigue stresses are compatible with service life requirements.
	2. Pressure armor wire fatigue.	DA	2. Modify design to reduce fatigue loads.
Erosion	1. Of internal carcass. or liner	SA, DA	1. Material selection.
			2. Increase thickness of carcass.
			3. Reduce sand content.
			4. Increase MBR.
Corrosion	1. Of internal carcass.	SA, DA	1. Material selection.
	2. Of pressure or tensile armor exposed to seawater, if applicable.	SA, DA	2. Cathodic protection system design.
	3. Of pressure or tensile armor exposed to diffused product.	SA, DA	3. Increase layer thickness.
			4. Add coatings or lubricants.

Notes:
1. SA = Static Application, DA = Dynamic Application
2. Burst, tensile, overbending and torsional failure are not considered in isolation for final design of the flexible pipe.
3. See Tables 29 through 31 for defects important in end fitting design.

Table 3-2. Failure modes for bonded flexible pipes, ref /1/

5 FLEXIBLE PIPE INTEGRITY MANAGEMENT

5.1 Introduction

Every field development should develop a field specific Integrity Management Strategy based on a risk assessment in accordance with a recognized guideline. Reference is given to /1/, /5/, /6/ and /7/ for details on flexible pipe monitoring methods and integrity management.

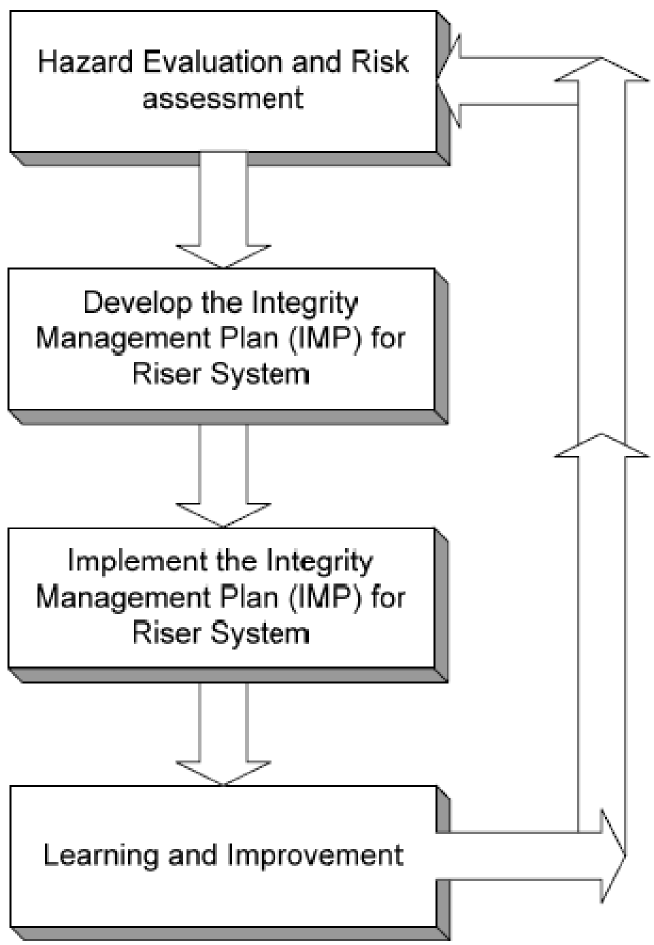


Figure 5-1: Key steps in developing riser integrity management, ref /5/

Experiences with implementation of riser integrity management programmes, on several floating production units shows improved performance, less failures and improved quality in decision processes related to operation of the riser system. The whole process related to riser integrity management will reduce the related risk significantly.

The operational activities in the riser integrity management program may be differentiated in 3 categories, inspection, testing and monitoring. The results from these activities should be seen in context with the original design documentation, new assessments and relevant experiences from similar applications.

The operator should focus on awareness of operating design limitations of flexible pipes in service during training of process technicians and operator personnel.

Finally, it should be pointed out that the hand-over of a project from the development phase to the operational phase is very important. Likewise, feedback and experiences from the operational phase should be transferred back to benefit new developments.

The major challenges for the integrity management program are:

- To establish a broad program covering the whole flexible pipe system and related interfacing equipment and systems
- Continuous follow up and documentation of all planned and un-planned activities related to the flexible pipe system and the integrity management program
- Efficient collection and long term storage of relevant process data, and data from inspection, testing and monitoring, and efficient retrieval of such data for each riser, flowline or component
- Efficient and precise assessment and analysis of information from a variety of sources, and regular update of the status of the flexible pipe system
- Experience transfer internally and externally and subsequent, optimising of the integrity management program to reflect areas of increased or reduced importance, or new areas that need focus

In general, it is experienced that a comprehensive integrity management program will identify degradation processes early and give opportunities for early action and prevention of accidents. One should anyway be aware of the fact that new failure modes for flexible pipes are discovered and a general awareness is required to prevent accidents.

5.2 Inspection

The most common inspection method in use for flexible pipes is general visual inspection by ROV. With some additional planning and prioritizing one could focus the ROV inspections on critical components and areas. Inspection methods currently in use for flexible pipes in operation offshore are:

- Subsea ROV general and close visual inspection
- Deck level manual general and close visual inspection
- Climber close visual inspection (above water)
- Internal remote camera inspection

Risk based evaluations will enable focused inspection programmes targeting specific areas with inspection activities that will contribute significantly to reduced risk.

The figure below shows an example from a guide made for the ROV pilots performing close visual inspection on a flexible riser system in the North Sea. The guide is linked to the online riser integrity management plan and the yearly inspection program. The guide has contributed to increased value of the ROV time spent for inspection.

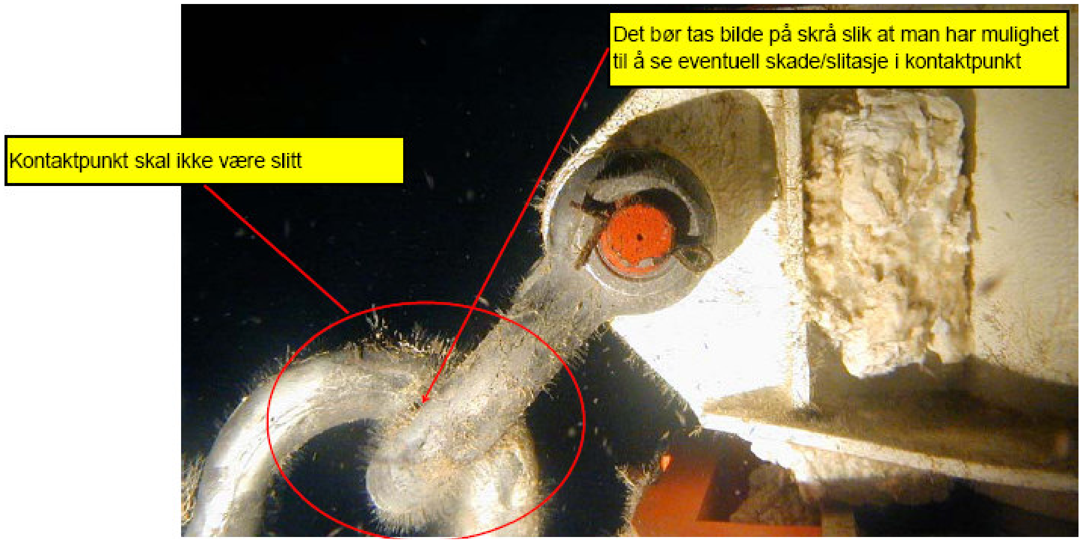


Figure 5-2: Guidance for close visual inspection (Hydro)

5.3 Testing

The relatively large number of cases with flooded annuli has resulted in extensive use of annulus testing. Normal practice today is to perform an annulus test shortly after installation to establish reference values. This annulus test will also uncover any major through thickness damages to the external sheath and any problems with vent ports and valves. There after, periodic annulus free volume testing is performed in order to determine status and to track long-term trends.

Testing methods currently in use for flexible pipes in operation offshore are:

- Pipe pressure testing after installation, modifications, repair etc.
- Annulus vent function testing in order to detect blocked or malfunctioning vent valves, vent ports or problems with the vent system pipe work
- Annulus vacuum or pressure testing to identify intact external sheath and estimate liquid content
- Annulus gas sampling and analysis to identify annulus environment and possible corrosion processes
- Age testing of polymer coupons exposed to production and/or injection flow
- Bore fluid composition test to reveal content of CO_2 and H_2S etc.

5.4 Monitoring

Monitoring of pressure, temperature and flow is performed as part of the process and well control system. The same instruments may be used actively for monitoring in a flexible riser integrity management context. Monitoring methods currently in use for flexible pipes in operation offshore are:

- Pipe bore pressure monitoring, pressure drop between subsea and topside sensors and pressure gradients / cycles
- Pipe bore temperature monitoring, temperature gradients / cycles
- Annulus vent flow pressure and flow monitoring
- Environmental load monitoring and / or floater motion and offset monitoring
- Bore flow rate, especially in relation to pressure drops

5.5 Practical experiences

After implementation of Riser Integrity Management programs on more than 10 floating production facilities in North Sea and West Africa some practical experiences may be highlighted:

- Simple and robust instrument solutions should be aimed for, preferably using instruments needed for day to day operation of process system as these will be maintained regularly.
- Be aware of the fact that many risers' fatigue life is documented for a low operational pressure. New fatigue evaluations will be needed if pressure is increased to e.g. design pressure.
- Visual inspection of sea surface in direction of subsea lines may be very important. This might seem trivial, but has led to the detection of subsea riser leaks on several occasions.
- Do not underestimate the importance of frequent visual above sea-level inspection of riser departure angle, individual spacing and configuration in general (if applicable). Compare with reference photographs taken shortly after installation.
- Monitor subsea and topside differential pressures, including alarm limit settings, in order to detect bore collapse, hydrate formation or other anomalies.
- Target the ROV inspections to critical areas on critical risers, in addition to the general visual inspections recording marine growth and external sheath damages.
- Performance of regular annulus vent system checks, annulus free volume tests and annulus gas sampling will together with temperature and pressure monitoring give a very good status on riser condition and may often enable actions to prevent pipe failure.

5.6 Emerging inspection technologies

Development is ongoing aiming at efficient internal inspection techniques as well as external radiographic techniques. Both efforts aim at giving quality information on the condition of the steel and polymer layers in the pipe.

Successful pilot inspections have been performed with eddy current internal inspection probes, but currently these probes are limited to inspecting the inner magnetic metallic layer. Hence, the system may not be used for armour inspections in pipes with magnetic, or semi magnetic, steel in the carcass, e.g. SS304. Further improvement is necessary to enable this technique to be widely used for condition monitoring.

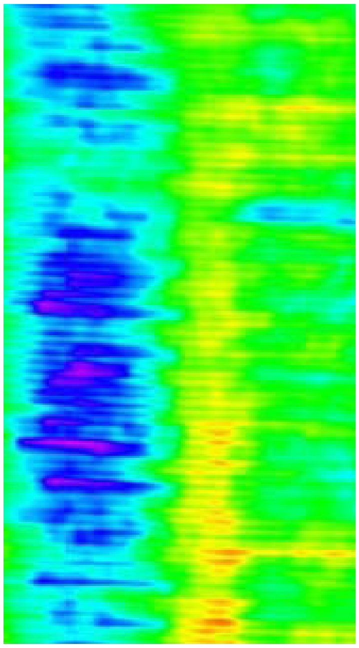


Figure 5-3: Pipe defect identified by eddy current (Force)

Work has been going on for a few years on radiographic tools for inspection of topside end fittings on flexible risers. Successful demonstration of the technology is performed but no commercial service is available. This is related to the current lack of industry demand.

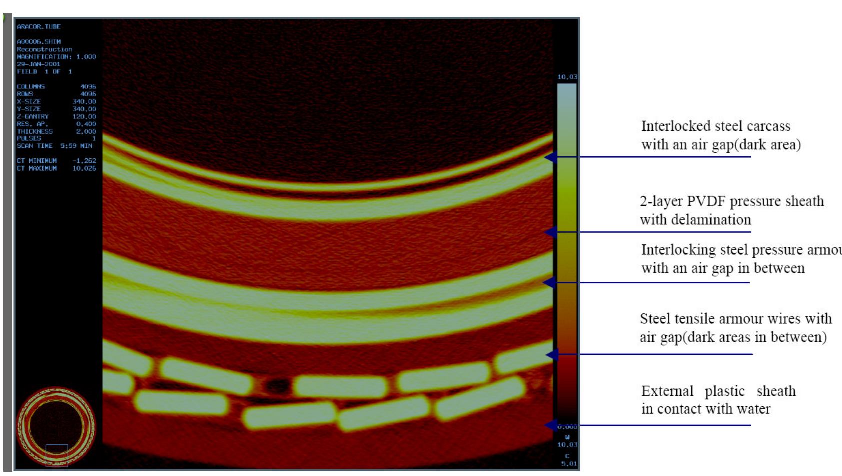


Figure 5-4: X-ray computer tomography image of flexble riser (Tom-X)

6 REPAIR AND LIFE EXTENSION

6.1 Proven repair methods

There are only a limited numbers of proven repair methods for flexible pipes. The methods that have been successfully used over the last years are:

- Dry repair of external sheath damages by plastic welding and replacement sheath sections
- Dry repair of external sheath damages by stainless steel clamps
- Wet installation of a variety of external sheath repair clamps by ROV or divers
- Wet installation of a rigid steel clamp to strengthen pipe and seal of the external sheath by divers
- Wet installation/casting of plastic clamp to seal off external sheath damages
- Disconnection, retrieval and dry re-termination of end fittings
- Re-establishing of annulus vent by drilling new vent access in the end fitting, epoxy filling ports or through the external sheath

Every repair job will need a special assessment and possible analysis to evaluate the repair and the integrity of the pipe. Often the pipe operational life is reduced and preparations for a pipe replacement have to be initiated.

The left picture below shows a relatively small through thickness damage to a flexible riser discovered by a routine ROV inspection. This damage was located in a section of the pipe with small dynamic movements, and after a thorough damage assessment including re-analyses of service life, it was concluded that the pipe had sufficient residual service life provided that the damaged area was sealed off preventing circulation of seawater. The two pictures to the right show testing of the ROV installable soft clamp and the as installed clamp, respectively.

Figure 6-1: External sheath through thickness scratch sealed off by ROV installed soft clamp.

6.2 Service life extension

Several pipes that have suffered some kind of minor damage, unexpected change in annulus condition or planned major change in operating conditions will have a reduced operational life if the original design life analysis should be the basis.

Operators therefore frequently requests pipe suppliers or riser consultancy companies to perform service life extension studies. The analysis methods and requirements for documentation of a possible extended service life are established with basis in API 17J/B, ref /1/ and /2/. In Norway one should also refer to the NPD document "Information Duty Regulations", section 5 and 6, where specific requirements are listed for an application for service life extension.

One major challenge is to determine the technical status for the pipe and the possible extreme or long term loadings that the flexible pipe has seen. Therefore comprehensive studies of all information from production non-conformances to as-installed reports, and production pressure and temperature records have to be performed. For operational periods with missing information a common assumption is that the pipe has been operated at design pressure and temperature. This may be very conservative, but may be the only safe assumption in case of lacking data.

As delivery time and cost of flexible pipes are high there may be significant value in a used riser that can be documented to be safe for some years of additional operation.

Based on experience from several service life extension projects the following recommendations are highlighted:

- Keep track off all documentation for every specific riser through out the full life span, including: design, fabrication, installation, inspection and operation.
- Keep a log of the usage of the flexible pipe, re-termination, repairs, movement and changes etc. If the pipe is moved to another location keep all documentation from previous sites
- Keep all time traces of temperature and pressure relevant for each specific flexible pipe
- Keep a log of bore composition and changes over time
- Keep a log of chemical usage in the flexible pipe, synchronized in time such that temperature may be estimated together with use of e.g. methanol

If all this information is present the day the operator will evaluate a possible service life extension, the probability of a successful assessment is significantly increased.

7 EXPERIENCE TRANSFER

7.1 Standards

Nearly all work related to flexible pipes are today based on the two API documents 17J and 17B, ref /1/ and /2/ (and possibly the equivalent ISO documents in the future). The importance of these documents is reflected in discussions with the pipe suppliers that explain that virtually all contracts of today refer to these API documents.

Most operators have over the last years made company specific specifications. The experience colleted in these documents should be transferred into updated revisions of the international standards.

The maintenance of existing standards and recommended practices will be the best way to get the industry experience transferred to all involved stake holders in flexible pipe business, but update and revision of such documents are time consuming. A broader range of forums should be used for experience gathering and transfer.

7.2 Seminars

The different company policies on shearing information may pose real challenges for experience transfer. Suppliers of flexible pipes are working in a very competitive environment and need to focus on technology development and competitive advantages. On another level this is also valid for the operators that are competing on cost effective developments and operational solutions.

One viable way of experience sharing seems to be through seminars and conferences that focus on technology developments and new solutions. For more safety critical experiences there may be a need for the authorities to play a more significant role in gathering and sharing information.

8 REFERENCES

/1/ API RP 17B, Recommended Practice for Flexible Pipe , Edition: 3, 01-Mar-2002

/2/ API 17J, Specification for Un-bonded Flexible Pipe, Edition: 2, 01-Jul-2000 (add. 2002)

/3/ ISO 13628-2, Design and operation of subsea production systems -- Part 2: Un-bonded flexible pipe systems for subsea and marine applications, Edition: 2, 2006-07-12

/4/ ISO 13628-11, Design and operation of subsea production systems -- Part 11: Flexible pipe systems for subsea and marine applications, Edition: 1, Not published yet

/5/ DNV-RP-F206, Recommended practice for Riser Integrety Management, Draft, Not published yet

/6/ UKOOA Guidance Note on Monitoring Methods and Integrity Assurance for Un-bonded Flexible Pipe. Doc No. 2-1-4-221/GN01 October 2002

/7/ Bondevik J. O. SeaFlex as, Lunde S. Norsk Hydro ASA, Haakonsen R. SeaFlex Riser Technology Inc. Annulus testing for condition assessment and monitoring of flexible pipes. OMAE 2004-51431, Vancouver, Canada

/8/ Bondevik J. O. SeaFlex as, Haakonsen R. SeaFlex Riser Technology Inc. Deep water operation of flexible pipes, lessons learnt from the North Sea, DOT 2004

/9/ Patric O'Brien MCS, Flexible pipe integrity and design – Current Issues, SUT, October 2005

/10/ NORSOK M-506 rev2, june 2005, "CO2 corroison rate calculation model"

/11/ Technip paper, "Cathodic protection beneath thick external coating on flexible pipeline"

/12/ API TR 17TR2, The Ageing of PA-11 in Flexible Pipes, June 2003

/13/ PSA "Information Duty Regulations" – 3. september 2001