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HEALTH & SAFETY LABORATORY

Reinforcing wire corrosion in flexible pipe.

ES/MM/09/07

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EXECUTIVE SUMMARY

Objectives

Following a number of recent in-service incidents with flexible pipe a literature survey of relevant published documents was commissioned to assess the amount of literature available in the public domain regarding the corrosion of reinforcing armour wires in the annuli, ie. between the internal and outer sheaths, of flexible pipes. Three conditions were to be examined, undamaged, damaged and, damaged and repaired.

Main Findings

There is a limited amount of specific information on corrosion found in flexible risers and their subsequent repair. Incidents that have been widely reported in the press, were initially to inform that an incident had occurred and to report the loss of life and/or loss of production. This was generally followed a few weeks/ months later by reports that production from the platform had begun and would increase back to full production over the next few weeks. If any information reached the public domain about the incident, its cause, how it was repaired/ rectified etc it tends to be made public after 3-4 years or more following the incident. However it would appear that for many incidents, their cause and their rectification are kept 'in-house' and tend not to be made available for others to access and to help the general safety of the industry.

Damage to the outer sheath was regarded as one of the main reasons for water to enter the annular space and cause corrosion of the armour wires. Water can also enter the annular space as water vapour from the bore, permeating through the inner polymer liner due the pressure in the bore. The water vapour can condense out and if present mix with the CO_2 and/or H_2S which can also enter the annular space by permeation through the inner polymer layer, to give an acidic solution in close contact with the armour wires.

None of the documented repairs to the flexible risers dealt with a failure due to the presence of CO_2 and H_2S in the annular space. Some failures were originally thought to have been due to gases in the annular space but all were subsequently observed to have been due to damage or a manufacturing fault in the outer polymer layer.

The incidents discussed in this paper all showed some corrosion on the armour wires when examined. The environment was seawater that had entered the annular space through a breach in the external polymer sheath due to damage or a manufacturing fault. One of the flexible pipes was repaired by the damage section being cut out; the cut ends were then reterminated and joined together. The damaged area of outer polymer sheath was removed and repaired by welding on a patch of polymer material. A third riser showed some slight corrosion product on the surface of the armour wires but the riser had a failed carcass, failure of the pressure sheath, failure of the zeta armour and the anti-creep sheath, before the outer sheath failed in the guide tube. The two other pipes discussed had both had seawater in the annular space. Both were repaired by having a density balanced solution, containing corrosion inhibitor, flushed through the annulus to remove the seawater. This solution was left in position when the risers were returned to service and the solution was fed from a top tank and the level monitored. Fatigue tests were also undertaken to increase the confidence in achieving the service life.

1 INTRODUCTION

Following a number of recent in-service incidents involving unbonded flexible pipe, the HSE commissioned a literature survey of relevant published documents to be carried out by Health and Safety Laboratory (HSL). One of the purposes was to see if further research work should be undertaken.

A literature survey of information about the corrosion of reinforcing armour wires between the internal and outer sheaths of flexible pipes was obtained. It was intended that three conditions were covered.

Undamaged -no ingress of seawater but the annulus atmosphere contains hydrocarbon and trace gases due to permeation through the internal sheath. Additionally moisture may be present, and accumulating over time, due to vapour permeating through the internal sheath and then condensing.

Damaged – a breach in the outer sheath such that seawater had entered and partially filled the annulus. Seawater may be refreshed local to the breach by tidal or other action.

Damaged and repaired – a breach in the outer sheath that allowed in seawater but which has been repaired such that there is no refreshment of seawater. In some cases the annulus had been deliberately filled with corrosion inhibiting fluid.

Both ‘flexible riser’ and ‘flexible pipe’ appear to be used interchangeably within the same paper and both refer to the same item.

2 FLEXIBLE RISERS - CORROSION

In common with comments made in many of the papers provided by the search I have to make a comment that there was not a great deal of information regarding failures and repairs available in published documents. Eight papers were reviewed in the later stages of this work as they only came into the public domain recently, these generally related to detecting problems or designing kinetic models to determine the effects of the confined volume in the annular space.

2.1 CONSTRUCTION OF FLEXIBLE RISERS

Flexible pipes are built up as a composite structure comprising metallic and polymer layers. There are three manufacturers of flexible risers and all follow the same general layout described below. The following gives a list of the primary layers in the order in which they occur in the flexible pipe starting at the outer layer:

Outer polymer sheath	– used to protect against penetration of seawater, corrosion, abrasion, and mechanical damage and to keep the tensile armours in position after forming.
Tensile armour layer	– a structural layer with a lay angle between 20 and 55 degrees, which consist of helically wound flat metallic wires and are typically counter would in pairs, generally carbon steel. They totally or partially sustain tensile loads and internal pressure.
Pressure armour layer	- also referred to as hoop layer, or zeta layer (from one manufacturer), consists of a number of structural layers with a lay angle close to 90 degrees that increases the resistance of the flexible pipe to internal and external pressure and mechanical crushing loads. This layer typically consists of an interlocked metallic construction, C-shaped metallic wires and/or metallic strips made of carbon steel.
Internal pressure sheath	- a polymer layer that is a sealing layer that is extruded over the carcass, it is exposed to the fluid in the bore,.
Carcass	- an interlocked metallic construction used as the innermost layer to prevent collapse of the internal pressure sheath due to pipe decompression, external pressure, tensile armour pressure or mechanical crushing loads, also provides protection against pigging tools. Generally stainless steel.

There can be non-metallic anti wear tapes present between some or all of these layers they are generally permeable to gases and liquids and are there purely to prevent wear and tear between the different structural layers.

2.2 ANNULAR SPACE

The annular space is that space between the internal pressure sheath and the outer polymer sheath; it contains the steel wires of the pressure and tensile armour layers. Corrosive gases such as CO_2, and H_2S can permeate from the bore through the polymer internal sheath to the annular space due to the high pressures of the product in the bore. Also water vapour can pass through the internal polymer sheath and if conditions are right it can condense on the wires and combine with the CO_2 and/or H_2S to give an acidic environment. If the outer polymer sheath is breached then seawater can enter the annular space directly.

2.3 OCCURRENCE OF CORROSION

In a study prepared for United Kingdom Offshore Operators Association UKOOA[1] 2001 it is stated that damage to flexible pipes can occur during the installation phase where the external polymer sheath can be accidentally torn. If not detected and repaired it can lead to the annulus being flooded by seawater. Seawater may also penetrate the annular space if the external sheath is damaged during service. The study showed this to be the most frequent incident in the North Sea. Seawater in the annulus can have serious consequences for flexible pipes as corrosion fatigue of the tensile armour wires in a wet annulus environment can reduce the life expectancy of the riser from 20 years to 2 years.

Most of the information received dealt with failure resulting from a breach in the outer sheath of the flexible pipe from a variety of causes.

In a report prepared for Petroleum Safety Authority (PSA) -Norway by Seaflex [2] it is stated that if the external sheath were damaged then the armour wires would be exposed to seawater. The armour wires will corrode if not efficiently protected by anodes in the vicinity. Some oxygen corrosion is observed in flexible pipes with damage of the external sheath, 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. This reference made a general recommendation that the exposure time should be limited if damage to the outer sheath exposes the armour to seawater.

2.4 FATIGUE AND CORROSION FATIGUE

A report prepared by Marintek[3] has a section that deals with fatigue and corrosion fatigue of the tensile armour. The pipe annulus in flexible pipes is filled with air in the as-fabricated state. The fatigue strength criteria for the pipe have been determined on the basis of fatigue tests in air, ie with the annulus pipe environment being benign. However, it is known that service conditions can cause the annulus space to become corrosive, for several reasons:-

Sea water flooding of the annulus - due to leakage from damage to the outer sheath during installation, operation or malfunctioning vent valves. Seawater in the annulus could be depleted in oxygen or saturated with air depending on the nature and distance from the leak, and there are concerns about effectiveness of the cathodic protection at some distance from the pipe ends. The seawater may also combine with H_2S and/ or CO_2 permeating from the bore.

Permeation from the product - H_2S and/ or CO_2 permeating from the bore combined with water condensing and accumulating in the annulus.

Repaired pipes – risers may be repaired, flushed with inhibitor and re-installed following seawater ingress. It is thought that there could be an effect on the residual fatigue life due to the effect of residual seawater and H_2S and/ or CO_2 permeating from the well flow.

The possible corrosion resulting from the above can have a serious effect on the fatigue strength of the wires in the annulus as the annular space is no longer in the as fabricated state and the fatigue strength criteria will have changed.

There are advances being made in the corrosion fatigue resistance of the wires in flexible pipelines when in wet annulus conditions. One recent paper was presented at the Offshore Technology Conference in 2008 [4], and concluded that ‘life of field design of flexible risers can be achieved with onerous corrosion-fatigue conditions if proper rigour is applied in the fatigue design'.

2.5 CORROSION IN THE SPLASH ZONE

The report for the Petroleum Safety Authority (PSA) -Norway by Seaflex (2) also contained a short paragraph on corrosion in the splash zone, as follows: For external sheath damage at the splash zone area where the cathodic protection system can have limited or no effect, and there is access to oxygen, major corrosion damage can occur rapidly and endanger the pipe integrity. The reference suggests that several examples of significant oxygen corrosion have been observed some with dramatic pipe failures, but gave no further information on the failures.

There was also a short comment in a paper by Lozev, Smith and Grimmett(5) written in 2005 regarding the splash zone in which it says that the constant wetting and drying of this zone combined with defects in the coating are usual contributors to corrosion.

2.6 LATEST DEVELOPMENTS

Some of the most recent papers in the public domain have attempted to provide models for corrosion of the armour wires in the annular space. Work has been carried out to determine kinetic models for CO_2 corrosion in a confined aqueous environment (6). The system modelled consisted of a steel surface covered by a thin, deaerated, condensed water film exposed to a pure CO_2 atmosphere. There were no details on the size of the test or whether they were fully sealed. This work agreed with other work that corrosion rates remain much lower than those predicted by bulk corrosion models under the same carbon dioxide partial pressure. This work is leading onto further work to determine models for the behaviour of H_2S corrosion in the annular space and is yet to be published.

Work has also been undertaken on the fatigue design of flexible risers with a non-dry annulus detailed in Offshore Technology Conference in 2008 (4), the paper only refers to a non-dry annulus, how it has become 'non-dry' is not discussed. The paper has shown that it is possible to achieve fatigue designs for wet annulus conditions using the approach described in the paper.

Finally a paper by Clements (7) reports on work undertaken to review the applicable data in the public domain and data held by Wellstream and to develop a formula to predict the long-term corrosion rate in confined flexible pipe annulus. The conclusions of this paper were that the long-term corrosion rate for a flexible pipe annulus was initially 0.015mm/year and this rapidly decreased over the first few months of exposure to 0.15μmm/year. The initial corrosion rate was high and then decreased over time due to an increase in pH and iron ion saturation combined with the build up of corrosion products on the exposed surfaces. The final corrosion rates are significantly affected by confinement levels (ratio of the volume to surface area of the electrolyte to specimen). At temperatures up to 50^{0}C there is no real effect of temperature on the corrosion rate, the overriding factor is the confinement.

2.7 INFORMATION IN THE PUBLIC DOMAIN

Incidents have been widely reported in the press and industry journals initially to inform that an incident had occurred and there had been loss of life and/or loss of production. This is generally followed a few weeks/ months later by reports that production from the platform had begun and would increase back to full production over the next few weeks. If any information reaches the public domain about the incident, its cause, how it was repaired/ rectified etc it tends to be made public after 3-4 years or more following the incident. However it would appear that many incidents, their cause and their rectification are kept ‘in-house’ and tend not to be made available for others to access and to help the general safety of the industry.

3 REPORTED INCIDENTS

I have found four papers in published literature relating to corrosion that was observed after the failure of flexible risers in specific fields. The papers give details of how the problem was discovered, how it was resolved and some indication of the length of useful life of the riser following repair. There is a fifth failure that shows corrosion of the wires under the outer sheath on a photograph but there is no mention of the corrosion in the limited text on the slides. There is another failure about which there is no information at present, which occurred at the Nkossa field in 2007.

3.1 GALLEY FIELD

A paper(8) presented at Offshore Mechanics and Arctic Engineering OMAE2007 detailed the in-service repair of a damaged flexible riser. The damage to the flexible riser was identified in 2003 as recorded in the Integrity Management System. Further investigations revealed significant structural damage to the riser. The failure was originally found as a stream of gas bubbles emanating from the inverted bell-mouth. The level of gas release was consistent with gas permeation from the bore rather than direct leakage. However gas bubbles were visible external to the pipe and this indicated damage to the external sheath allowing permeated annular gases to escape from the riser. A residual life study of the riser was carried out knowing that the annulus of the riser was flooded. Fatigue analysis of these pipes historically considers the wire stress vs no. of cycles in air as the armour wires are isolated from seawater by the outer sheath. A seawater flooded annulus can therefore have a significant impact on the fatigue life due to corrosion fatigue. The damage to the outer sheath had been caused by foreign objects rubbing along it and with some items becoming embedded in the sheath. Removal of part of the sheath revealed significant damage to the armour wires and heavy corrosion in the vicinity of the main sheath breach, however, the internal armour had suffered limited corrosion and circumferentially round from the damage the corrosion was markedly reduced. Following rigorous assessments and structural tests of the damaged sections integrity it was decided to reinstate the riser while further concerns regarding fatigue failure of the failed section were addressed. The damage was sealed temporarily with waterproof tape to prevent further seawater ingress, until a more permanent repair could be made. At the end of 2005, thirty metres of the riser was lifted onto the deck of the rig, following detailed analysis to confirm the riser configuration, and the damaged section was removed and the upper section of the riser laid down to allow retermination. The lower riser section was lifted a further 10m and the end reterminated. The two reterminated ends were then joined together to make a mid-line connection before the riser was returned to service in early 2006.

3.2 KRISTIN FIELD

A paper(9) presented at a seminar in December 2007 detailed damage to flexible risers in the above field. The leakage was discovered by the annulus vent monitoring system opening to release gas. It was thought that this was due to leakage of hydrocarbon from the bore through the pressure sheath into the annulus. However testing revealed that the leak was due to damage of the external sheath.

In total five risers showed damage to the outer polymer sheath, damage to four risers was detected in December 2006 and the fifth in May 2007. The presentation indicated that the damage was due to wear of the outer sheath rather than fracture. The consequences of the damage were that tensile armour wires were exposed to corrosion fatigue from aerated seawater and wear between the layers. One of the photographs in the presentation showed corrosion damage to the tensile armour layer. The first riser was repaired in August 2007 and the last at the end of September 2007. However the first riser to be repaired was repaired for a second time at the beginning of October 2007.

The flexible risers were repaired by removal of the damaged outer wrap and repair by welding in a replacement section of the polymer outer, or by applying heat shrink-wrap. From the presentation it was not clear if the damaged wires had been treated or removed prior to the repairs to the outer polymer layer.

The conclusion was that the damage had been caused by wear rather than by fracture. Wear protection collars have been installed on all of the risers. At the time of the presentation in December 2007 work was still ongoing to clarify the causes of the damage. The main areas being considered were wear of the outer sheath against the inner surface of the riser guide tube (RGT), RGT geometry and the riser configuration.

3.3 BANFF RISERS

The presentation on this particular problem was presented at a conference in 2002[(10)]. A problem occurred in the Banff production system when a high-pressure water injector riser developed a bore to annulus leak and treated seawater flooded the annulus areas of all of the production risers. The entry of seawater into the riser annulus is recognised to place the steel reinforcing wires at risk of corrosion with a resulting detrimental effect on their fatigue life. The hoop (pressure) wires in the riser take the hoop stresses resulting from the internal bore pressure and the tensile armour takes all the tensile loading. Seawater in the annulus can lead to loss corrosion (pitting) of the reinforcing wires and consequential reduction in the fatigue life and tensile load bearing capacity. In the worst case the seawater flooded riser had a predicted life of less than 6 months (against a design life of >25 years) without any remedial treatment.

A technology team was set up to develop a treatment regime and this has resulted in the development of a seawater displacement treatment system applicable to damaged/flooded risers. The annular space was flushed with an inhibitor that had a density balanced with seawater. The inhibitor contained a Mono Ethylene Glycol/Methanol mix (75:25), corrosion inhibitor, pH buffer and a biocide. The Banff flexible risers had been subjected to seawater ingress in the pipe annulus, this may have been present for up to two years while the risers had been in service. The paper stated that when in service, the produced gases such as carbon dioxide and hydrogen sulphide permeated into the annulus area, this was an inherent feature of the design of flexible risers. The gas is usually bled off continuously via the annulus gas venting system from the top end fitting to limit any pressure build up and risk of bursting the polymer sheath.

One of the risers was sacrificed for full inspection purposes. The other risers were returned to shore and were subjected to a refurbishment programme where the top end fitting was removed and a full inspection of the wires for pitting and the removal of the seawater from the annulus. Localised corrosion was observed on the tensile armour wires of one of the production risers. To check for further corrosion, particularly at the ‘hog’ bend, five windows were cut in the outer sheath and the condition of the outer tensile wires were assessed, this revealed only minor superficial localised corrosion. The outer sheath was removed from the sacrificed riser and the whole riser inspected for localised corrosion damage. Only very minor damage was found on this riser. Following these examinations the technical specialists decided that the annulus should be filled with Tros 528 (corrosion inhibited fluid) to protect the wires from further degradation and the Tros level in the annulus should be monitored so that any sheath breach would be identified quickly and appropriate action taken.

The paper concluded that:

Localised mild corrosion was observed on the risers after two years service in a seawater annulus environment.

The use of Tros 528 fluid considerably reduces the effect of the corrosive annulus environment and extends the operational life of the risers.

Remedial treatment of all damaged risers will provide a conservative estimate of service life for the production risers, based on the new corrosion fatigue data.

A corrosion fatigue test programme continues to further confirm fatigue life estimates and provide a firmer statement of the effect of remedial treatment on the risers on the ultimate fatigue life. Riser integrity will be further evaluated for the possibility of hydrogen sulphide entering the production fluids and further corrosion fatigue tests will be undertaken to increase the confidence of achieving extended service lives.

An ongoing riser monitoring programme in place to assess the integrity of the risers – the design of segregated gas venting systems to avoid multiple flooded risers and annulus monitoring to detect flooding and implement suitable repairs.

Retention of riser operational pressure data is important for future justification of riser service lives

Ongoing integrity of the risers assured to the satisfaction of the regulatory authorities.

3.4 FOINAVEN

A paper presented to the 2002 Offshore Technology Conference entitled 'Managing the integrity of flexible pipe field systems: Industry guidelines and their applications'. By JW Picksley, K Kavanagh, S Garnham and D Turner. OTC 14064 [(11)] included a discussion of damage to and the subsequent repair of several Foinaven risers. Significant damage had occurred to the external sheath of several risers during installation. Seawater had therefore ingressed into the riser annuli. Fatigue failure became the main riser integrity issue as fatigue loads had already been identified as a high risk failure mode. The solution was to flush the annuli with a glycol/methanol/corrosion inhibitor mixture that had a similar density to seawater to prevent corrosion of the armour and pressure wires in the annulus. A top up tank was connected and monitored for inhibitor usage. By displacing the seawater it was possible to improve the fatigue S-N curves developed through exhaustive testing. The damaged areas on the outside of the risers were repaired to prevent further ingress of seawater into the annulus and to install a clamp with a venting arrangement at the hog bend to allow accumulated gases to be vented and prevent bursting of the external sheath. An Integrity Management Strategy was developed following the repair to risers with four main areas considered: 1. Inspection; 2. Monitoring; 3. Testing and analysis and 4. Management.

I have included the failure here as it is recognised, in many of the papers that I have reviewed, that seawater ingress through a damaged outer sheath into the annular space can result in corrosion of the tensile and armour wires. Although corrosion is not specifically mentioned in the paper the act of flushing the annulus with a solution which included a corrosion inhibitor showed that the intention appeared to be to help prevent corrosion taking place.

3.5 VARG 10" RISER

A presentation was given in 2005 that detailed a failure of a 10" production riser on the Petrojarl Varg [(12)]. The riser failed in November 2004 after 8 years in service. There were several areas of damage on the riser. The main damage was at the MWA (Mid water arch) and there was also damage near the topside end, which consisted of a blown external sheath. There were two other areas of damage that were described as recovery damage. The damage was attributed to a manufacturing defect. A photograph in the presentation showed the wires under the external sheath and these all appeared to have some corrosion product on them, although no reference was made to it on the slides and it was not included in the conclusions. Examination of the failed riser showed cracking of the zeta pressure sheath (pressure armour layer), and fatigue cracking in the carcass. At the MWA fatigue cracking was indicated in the carcass, sacrificial sheath, pressure sheath and the anti-creep sheath. A more detailed failure scenario, reproducing the list given in the presentation, indicated that:

1. Concentrated dynamics at MWA and high stresses in the carcass gives fatigue crack growth and lead to carcass failure.

2. The inner sacrificial PVDF sheath failed in fatigue along with the crack in the carcass.

3. The carcass and sacrificial sheath pull back, leaving a 40-50mm gap.

4. The damaged carcass cuts marks in the PVDF pressure sheath.

5. Fatigue cracks start in the pressure sheath from the cut marks from the carcass.

6. The fatigue cracks grow due to temperature cycling and dynamics (which were confirmed in the Lab).

7. The failed inner sections give reduced bending stiffness and support for the pressure armour.

8. The zeta armour extends locally due to self-weight and no support from surrounding layers during shutdown.

9. Pipe expands with pressure and temperature and locks the zeta armour and fails in repeated overload due to bending, pressure and tension.

10. The failed zeta and back-up spiral unwind and chokes the outer PVDF anti-creep sheet.

11. The anti-creep sheath fails in overload due to pressure, tension and dynamics (leak to pipe annulus starting)

12. The external sheath at MWA buoy failed (main damage area) due to increasing annulus fluid flow and restrictions under MWA-clamp.

13. External sheath in guide tube fails due to high annulus gas flow, restrictions in vent system and low external pressure.

3.6 NKOSSA

Nkossa failure, occurred in May 2007 – there are no details about this failure other than reports in the press and industry journals that an incident occurred that caused loss of life and production and further reports 3 weeks later stating that production had restarted and would be approaching pre-incident levels in the following weeks. There have been no further reports on what had failed and the reason for the failure that have been uncovered during the searches carried out on my behalf.

4 PREVENTING CORROSION

A paper presented to Offshore Mechanics and Arctic Engineering OMAE 2007[13] on the prevention and monitoring of fatigue corrosion of flexible risers' steel reinforcements, concluded that water flooding of the annulus (by seawater ingress or condensed water vapour) is to be avoided in order to ensure a long life. The paper gives an over view of the annulus environment, and new innovations developed and tested concerning the prevention of annular space flooding by seawater ingress or diffused water. It details designs for integrating monitoring sensors into the pipe structure and corrosion fatigue mitigation methods. In the section on fatigue-corrosion it was suggested that the best solution to not having the steel layers subjected to fatigue-corrosion is to prevent water flooding. This section indicated ways in which water flooding of the annulus can be prevented. Finally it covered the monitoring and integrity assessment of the risers not only of features in general but also to record actual operating conditions which can give an early indication of damage. It suggests that the best method is to directly measure the presence of water inside the annulus itself.

The main strategy to prevent corrosion in the annular space, or limiting the effect, is to carry out inspections to look for potential damage of the outer polymer layer, which is one of the main causes of seawater ingress into the annular space. In-service inspections are preferred as they do not disrupt production, and this tends to mean that the inspections are carried out externally, are generally visual and are carried out by remotely operated vehicle or by divers for the underwater parts. This requires experienced divers to report the status of the riser[14].

Papers given at the recent HSE seminar "Integrity management of unbonded flexible pipelines" 27 November 2008 and available on the HSE website indicate that monitoring for sheath damage can be carried out using annulus vacuum testing or low pressure testing, damage can be detected using fluorescent dye and laser leak detection and repair clamps have been developed for known breaches. Fatigue of the armour layers appears to be coming more of a concern from sheath damage leading to annulus flooding and the increasing H_2S levels being encountered. The key issues are maintaining the annulus condition, monitoring process conditions and protection of the annulus by flushing with inhibiting fluid. Examination of the flexible riser using a ROV (remote operated vehicle) deployable ultrasonic based system can determine water in the annulus, determine outer armour wire thickness, scan for snapped or disorganised wires and it can also find a hole in the outer sheath.

Non-destructive examination methods are also used to inspect the metallic parts of the flexible riser. Some forms of eddy current testing have been used but these can only identify problems in the outer armour wire layers, it cannot be used to check the wires deeper in the structure.

Radiography is the only proven method that can be used to inspect the numerous layers but there are problems with regular use due to the required exposure time and the safety requirements of using a radioactive source. It can also only be used above water.

5 GENERAL DISCUSSION

Incidents have been widely reported in the press initially to inform that an incident had occurred and there had been loss of life and/or loss of production. This is generally followed a few weeks/ months later by reports that production from the platform had begun and would increase back to full production over the next few weeks. If any information reaches the public domain about the incident, its cause, how it was repaired/ rectified etc it tends to be made public after 3-4 years or more following the incident. However it would appear that many incidents, their cause and their rectification are kept ‘in-house’ and tend not to be made available for others to access and to help the general safety of the industry.

There is a small amount of general information in the public domain that deals with repairs to the flexible riser, the corrosion processes in the annular space and their effect on the fatigue and corrosion fatigue properties of the metallic components. A recent paper quoted initial corrosion rates for corrosion in the annular space and rates that would apply within a short period of time, and, there appears to be an increasing number of monitoring methods that can indicate what gases have permeated through the inner liner, their pressure, whether there is any water in the annular space and whether this is water condensate or seawater from an outer sheath breach.

The general outcome is that corrosion can occur on wires exposed to seawater and permeated gases from the bore product such as CO_2 and H_2S. Damage to the outer sheath was regarded as one of the main reasons for seawater to enter the annular space, and to cause corrosion of the armour wires.

There appears to be a general acknowledgement that the annular space will become contaminated with something whether it is seawater from a breach in the outer polymer layer, or gases and water vapour that are able to permeate through the internal polymer liner due to the pressure from the bore. All of these can cause corrosion although many of the papers I have reviewed consider that the corrosion rate can be relatively low to start with and can decrease rapidly as a protective layer of product forms on the surface of the wires and reduces the corrosion rate further. Although the refreshment of the seawater to the affected area might not have been considered. However, some of the wires shown in presentations given on the repair of the risers have shown loss corrosion (pitting) on some of the armour wires, with a corresponding expected reduction in static strength and the fatigue life of the armour wires and therefore of the riser.

There are some descriptions of methods of repairing the risers and putting them back into service, however some papers that have been reviews of the information at that time indicated that many risers were not repaired but were shutdown initially and then removed from service. The repair of risers appears to have arisen as a few months disruption to production and a repair were preferable to replacing the whole riser. Methods have been developed that allow the damaged area, usually of the outer polymer layer, to be removed. The wires exposed were examined and decisions made whether to put them back into service, or whether to remove a whole section of damaged pipe and reconnect the cut ends of the riser. Methods have also been developed to repair the outer polymer sheath. Where there has been seawater flooding some risers have been put back into service with the annular space filled with a liquid that contained a corrosion inhibitor and other liquids that had a density balanced to seawater as a means of preventing further corrosion of the armour wires.

Methods of protecting the outer sheath of the riser have also been developed such as wear protection collars that are fitted around the riser to prevent damage.

None of the documented repairs to the risers dealt with a failure due to the presence of CO_2 and H_2S in the annular space. Some failures were originally thought to have been due to gases in the annular space but all were subsequently observed to have been due to damage or a manufacturing fault in the outer polymer layer.

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