FLEXIBLE RISER LIFE EXTENSION WITH FLEXIQ

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Abstract

This paper presents a novel approach to flexible riser life extension through FlexIQ which combines inspection data with a fully simulation-based irregular wave approach to provide life extension assessments.

FlexIQ combines the two proprietary technologies: MEC-FIT™ inspection technique from Innospection and FLEXAS numerical solver from INTECSEA which allows high-resolution stochastic fatigue life to be captured based on realistic conditions. Reducing uncertainty in the design calculations enables operators to continue operating their assets safely and with improved confidence.

FlexIQ has established a step change for industry technology and has been recently successfully deployed on two offloading risers in West Africa with a total inspection length of 2.5km.
Field experience on how FlexIQ has been used to re-evaluate the design life and determine the suitability for life extension of the risers will be presented.

The analysis predicted safe and reliable operation of the assets well beyond the original design life, provided the asset management recommendations made within the study are adhered to.
FADFAE Engineering Services Ltd. with their headquarters in Lagos Nigeria facilitated the application of this technology to their West Africa clients.

Introduction

Extending the operating life of existing subsea assets is dependent on understanding the current condition and predicting the future operating condition to enable the risk of ongoing operations to be established. This has become routine for rigid steel pipelines due to the development of inspection methods, in particular In-Line Inspection (ILI) tools, and the corresponding integrity assessment methods, which have been developed in parallel over many years. New inspection equipment was developed with respect to what defects are potentially dangerous. Failure analysis and fracture mechanics is used to establish reasonable probability of detection (PODs) and minimum allowable defect sizes. Conversely assessment methods are more and more tailored to the data that they are based on. Defect grouping algorithms are developed such that an ILI report can be the basis of the assessment. Also a measurement error of an inspection instrument is considered, when probabilistically calibrated factors are given in assessment codes like in DNV RP-F101 [1], [2]

For flexible pipe, the layer construction introduces further complexity. Understanding the condition of each layer via inspection and predicting the future degradation is highly dependent on not only the condition of each layer, but also the interaction between layers.

For dynamic flexible risers the tensile armour wires are cited to be the critical layer. Inspection from the external or internal surface requires penetration through additional layers. With the existing technologies available for flexible riser monitoring and inspection available so far it was either not possible addressing the layer(s) of interest or verifying larger sections of flexible pipe in reasonable time.

Condition assessment has traditionally been based on basic fatigue analysis leading to lifetime predictions. However due to the complexity of the structure the limitation of computational techniques have simplified this analysis.

FlexIQ combines two technologies that have been developed that now have a proven track record that enable these challenges to be overcome:

Novel technology based on MEC-FIT^{TM} (Magnetic Eddy Current Flexible riser Inspection Technology) facilitates dynamic inspection of flexible pipe tensile armour wires through the outer sheath with the aim of detecting and accurately sizing anomalies and defects such as wire disorganization, pitting and general corrosion and cracking in up to three metallic layers. The inspection results are used as input to an advanced assessment with FLEXAS.

FLEXAS (FLEXible Advanced Simulation) is a numerical solver which allows high-resolution stochastic fatigue life calculations [3] to be executed that can define the effect of defects on the fatigue response of the wires. Realistic remaining life of the tensile armour wires than can therefore be calculated and embedded into a risk based approach to life extension.

The following will describe a case study where the two approaches, FLEXAS and MEC-FIT™, have been combined in one single offering.

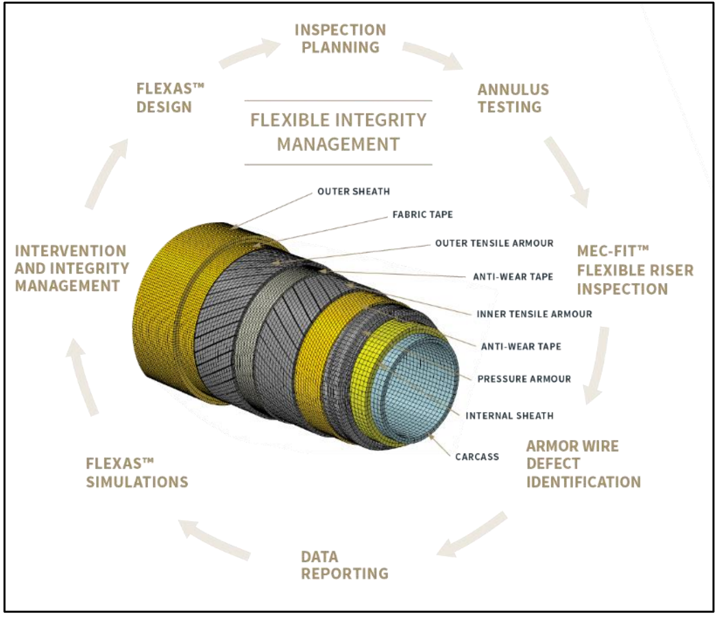


Figure 1: FlexIQ – The continuous cycle of integrity assertion.

Together with Annulus Testing and Risk-based integrity management a complete integrity circuit is set up. This concept of continuous integrity assessment is shown in Figure 1. This service is offered as FlexIQ.

Case Study

The section describes the case study of a set of offloading risers located in West Africa. The risers were installed in a continuous wave configuration and linking a Floating System Production and Offloading (FPSO) facility to an Single Point Mooring (SPM) Buoy which was used as an offloading point for tankers (approximately every 4 days). The deepest section of the riser (sag bend) was in -352m below mean sea level (MSL).

The following explains how the FlexIQ assessment process has been implemented in the field. The key execution steps are as follows:

- Offshore Cleaning of risers
- MEC-FIT ™ inspection
- Advanced Analysis Using FLEXAS Solver
- Embedding Inspection and Analysis into a Risk Based Integrity Assessment

Each of these are discussed in the following sections.

Marine Growth Cleaning and MEC-FIT^{TM} Inspection Operation

Two risers were to be inspected. Each riser had two sections to be 100% scanned using the MEC-Hug inspection tool:

- FPSO side – from buoyancy module to below the bend stiffener on both the middle and lower riser.
- SPM side - from buoyancy module to below the bend stiffener on both the middle and lower riser.

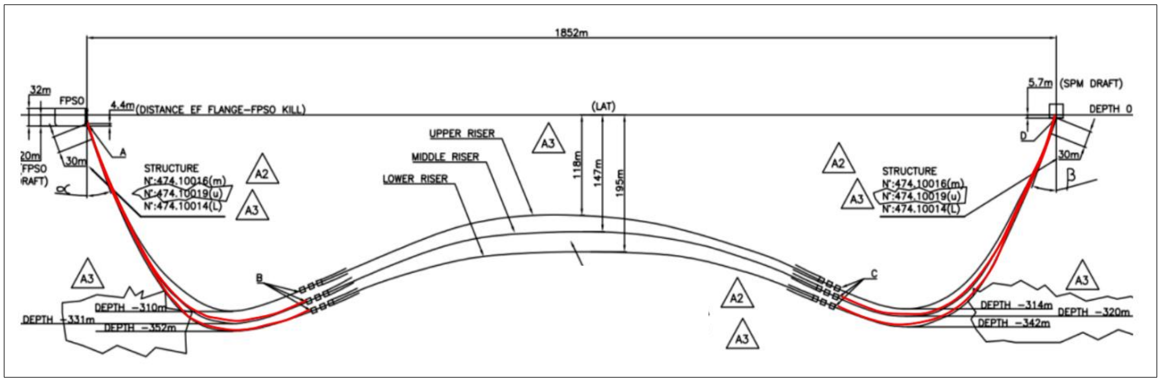


Figure 2: Profile showing the offloading risers and the riser sections to be inspected (marked red)

The riser specification can be found in Table 1 below:

Table 1 Riser Specification

Specification	Middle Riser	Lower Riser
Riser ID	18.75”	18.75”
Riser OD	586mm	586mm
Total Length	2240m	2240m
Buoyancy Section Length	1080m	1026m
Length Inspected	2 x 580m	2 x 607m
Inner Tensile Lay Angle	54.8 degrees	54.8 degrees
Outer Tensile Lay Angle	55 degrees	55 degrees
Tensile Wire Thickness	3.6mm	3.6mm

The risers are designed for low pressure applications and the design is classed as Product Family II as per API 17B.

The pressure armour layer is not present in this design, therefore both - pressure and axial containment is provided by the tensile wires typically laid at a higher angle ~55 °. Therefore in this case even more emphasis can be placed upon tensile wire inspection assessment.

The risers were installed in 2004 with a 20 year design life. The only previous integrity assessment performed was two field hydro tests. No annulus testing had been performed owing to the fact the risers were hung-off subsea and no vent pipework had been installed. No vent valves had been installed. The vent ports were plugged.

It was essential that all heavy marine growth should be removed from the risers prior to inspection. Marine growth removal ensures the following:

- The wheels of the inspection tool can move both axially and circumferentially without slippage ensuring quality scanning data is retrieved.
- The encoder moves smoothly over the riser ensuring the correct scan track distance is maintained/recorded.
- There are no barnacles protruding which could damage the sensors.
- All of the above relate to maintaining quality data collation

Figure 3: Marine growth removal utilizing the “cheese wire” tool

The preferred method of cleaning was by using the “cheese wire” a common form of cleaning flexible risers in the UKCS. It consists of nylon coated wire suspended across two arms which are attached to a cleaning frame. This tool is attached to the front of the ROV.

Once subsea, the ROV carefully approaches the riser and moves in an upward and downward motion along the riser. The riser section circumference can typically be cleaned in in 3 or 4 x passes (OD dependant).

This method typically works better on the vertical sections where marine growth is at its heaviest, especially between MSL to -80m where ambient sunlight can still penetrate the sea. Beyond this depth the marine growth tends to be lighter, where the inspection tool can cope with lighter marine growth. But ideally as much marine growth as practicable should be removed.

Whilst the cleaning process was in operation Innospection used the opportunity to visually inspect the outer sheath of the risers. Following marine growth removal, Innospection were able to confirm their team did not witness any major mechanical damage/anomalies in the form of deep scratches, gouges, abrasions, dropped object impact, breaches or any deformation to the outer sheath. This proved very advantageous to the client who previously had only performed ROV fly-by inspection whilst the risers were still covered in marine growth.

The cleaning operation was completed within three days working day and night shifts.
Then the inspection operation commenced. The inspection tool was connected to the Work Class ROV on board the DSV, which provided the following to the inspection tool:

- Hydraulic connection/supply.
- Electrical connection/supply.
- Comms via a fiber connection to relay the inspection data back to technicians on board the DSV.

Once a full integration was complete and comms were established a full pre-dive test was performed to ensure full tool functionality:

- Rotation of all drive wheels in the same direction.
- Simultaneous tipping of the drive wheel and encoder wheel.
- Opening and closing the arms.
- Switching on and off the magnets.
- Ensuring the failsafe was working i.e. the arms would open and the magnets would dis-engage.
- Calibration/reference test was performed on a rigid test piece, ensuring pre-determined defects were detected.[4]

The tool was placed upon the cleaning frame which doubles as a deployment pad. Additional rigging was attached to the tool to ensure it remained in situ during the dive. The primary manipulator arm was located onto the ‘fish tail’ handle on the inspection tool, whilst the secondary manipulator arm was located onto the additional rigging. The ROV along with the tool was positioned overboard by the LARS and the dive commenced to the first inspection point at the buoyancy module. The ROV dived to the first location, the arms of the tools were opened and the tool was placed in position. Magnets were engaged and the arms were closed. The ROV released its connection points and retreated to a safe distance. The ROV and tool remained attached purely by the umbilical which houses electrical, hydraulic and fiber connections. The tool performed several test movements and positioned itself adjacent to the buoyancy module.

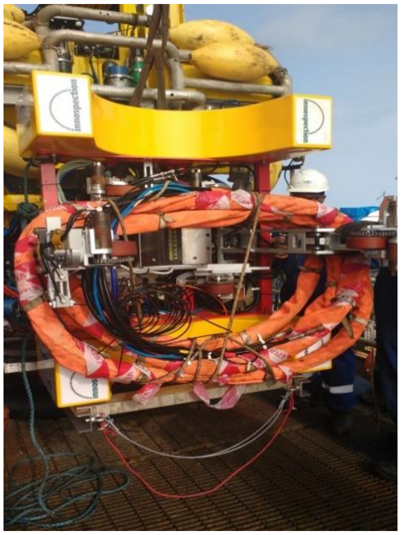


Figure 4: MEC-Hug inspection tool and Work Class ROV before dive

Once the technicians were satisfied, the tool commenced its automated scanning of the first section. Scanning was done circumferentially. After each full 360 degree revolution the tool was moved on in axial direction to scan the adjacent track in another 360 degree revolution with the sense of circumferential movement being reversed, and so forth. The lift-off of the sensors to the inspected object was set to 5 mm. The scanning speed for all tracks was relatively constant and in the order of 0.12 m/s. An average pipe length of 14.2m was inspected per hour of scanning.

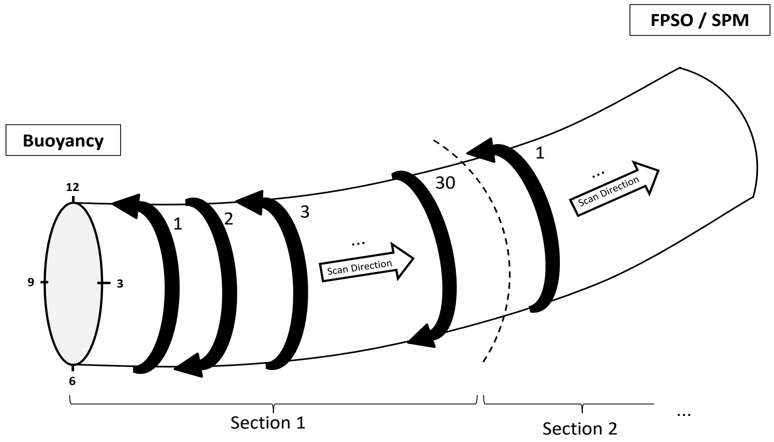


Figure 5: Order of scanning

The longest duration of continual scanning was 26hrs.

Whilst the field work progressed inspection data were transferred to the Innospection Technical Service Centre where they were analysed in detail with the aim to detect and accurately size defects and anomalies such as

- cracks, pitting corrosion and general corrosion in single wire and multiple wires
- wire misalignment and wire gaps

in up to three metallic layers. Any major indications (critical or non-critical) are displayed within the report. The image shows evidence of larger tensile wire gapping within the inner layer.

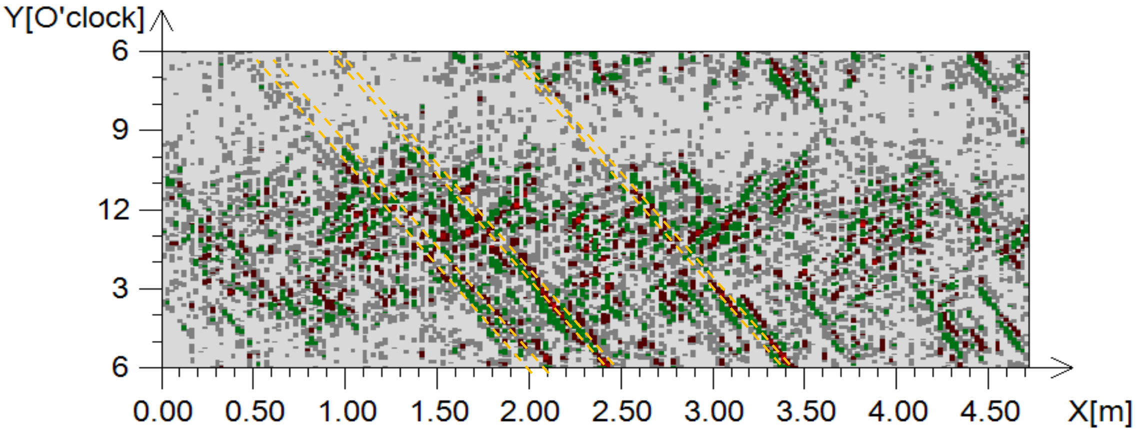


Figure 6: Larger tensile wire gapping in inner layer (marked yellow)

The image below shows evidence of a reoccurring pattern at the pitch length of the outer tensile layer that corresponds to the helical step of the wiring.

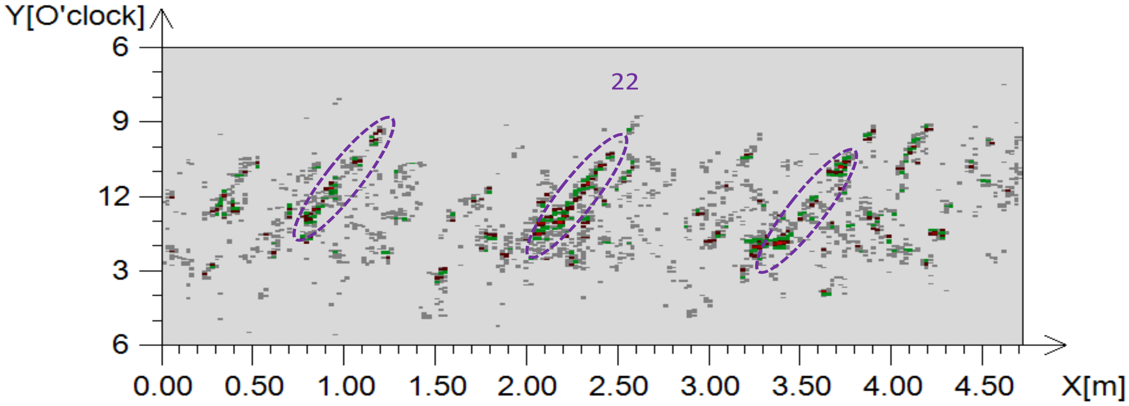


Figure 7: Reoccurring pattern at pitch length

The inspection report formed input to the next project phase which is described in the following.

Advanced Assessment using the FLEXAS Solver

A major component of the integrity assessment is to estimate accurately the fatigue life.

Accurate flexible riser fatigue life predictions require the capability to compute accurate tensile armour wire stress time-histories. This has been performed using the FLEXAS numerical solver.

FLEXAS offers the only solution framework available in the industry that computes irregular wave wire stresses using dynamic simulation of high-fidelity finite element models using Nonlinear Dynamic Sub-structuring (NDS). This eliminates approximations and uncertainties associated with non-simulation based approaches.

Table 2 below highlights the differences between the Stress Transfer Function (STF) and NDS approach to fatigue modelling [5].

Table 2 Comparison between STF and NDS

Stress Transfer Functions (STF)	Nonlinear Dynamic Substructuring (NDS)
Irregular wave nonlinear local analyses are not executed Static stress vs curvature relationships (“material curves”) extracted from local model within pre-defined tension/pressure envelopes Wire stresses are computed based on interpolating material curves Assumptions include interpolation-based stress, micro-slip, no ratcheting, and no local model dynamics effects	Irregular wave nonlinear local analyses are executed High-fidelity FE local model simulated under dynamic loading Captures nonlinear effects and impact of local model dynamics Local wire damage data (from inspection) can be modeled into 3D wires

The modelling and simulation scope of work has been completed in a two-phase approach consisting of:

- Global Model – system level simulation of the two full risers inclusive of FPSO and SPM
- Local Model – high-fidelity simulation of an isolated section of a riser featuring critical curvatures identified in the global analysis
- Numerical Simulation – using the FLEXAS solver to allow NDS simulation.

Global Modelling

The objective of global analysis is to capture the stochastic external rotation and tension variations that need to be applied to the local model. These loads are applied in the local model to perform fatigue analysis of flexible pipe.

To determine the critical bins, the product of the fatigue bin probability and standard deviation of the curvature is chosen as the performance index. The output is shown in Figure 8.

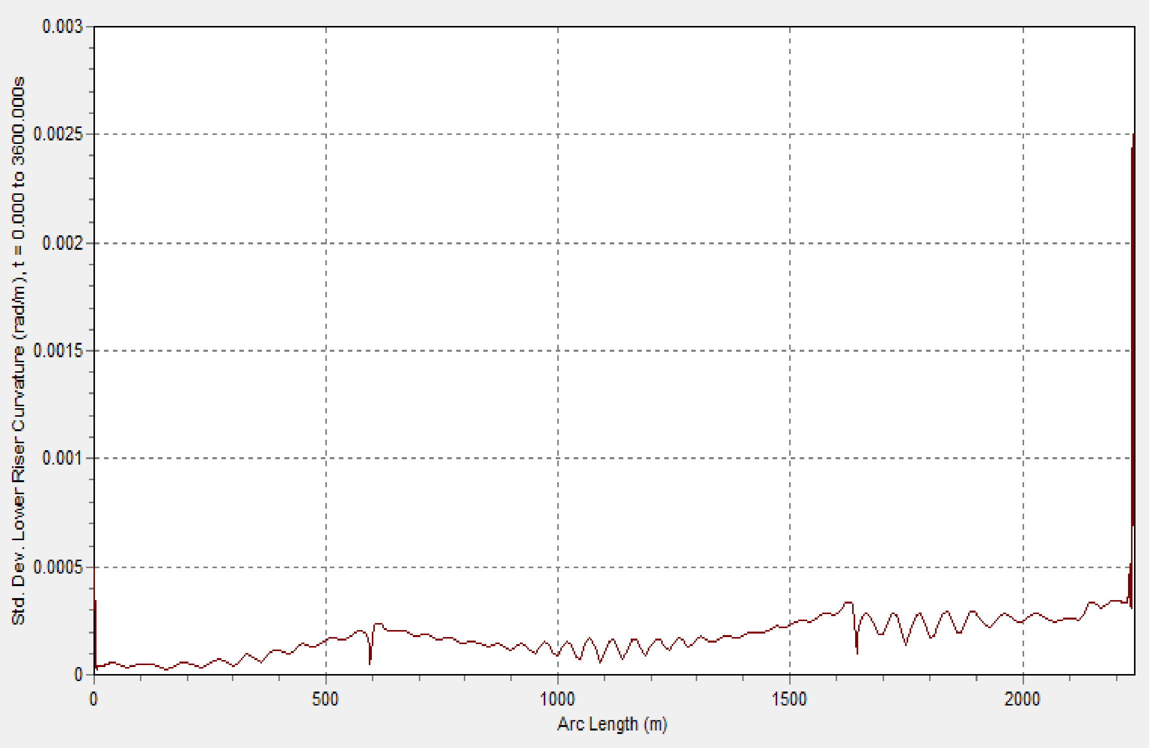


Figure 8: Global Modelling output

As shown in Figure 8 above, the section near the SPM hang-off has the largest standard deviation of curvature and is the most critical section for wave fatigue damage.

Based on this, the lower flexible section (10 pitch length) near the SPM hang-off is selected for further detailed local analysis.

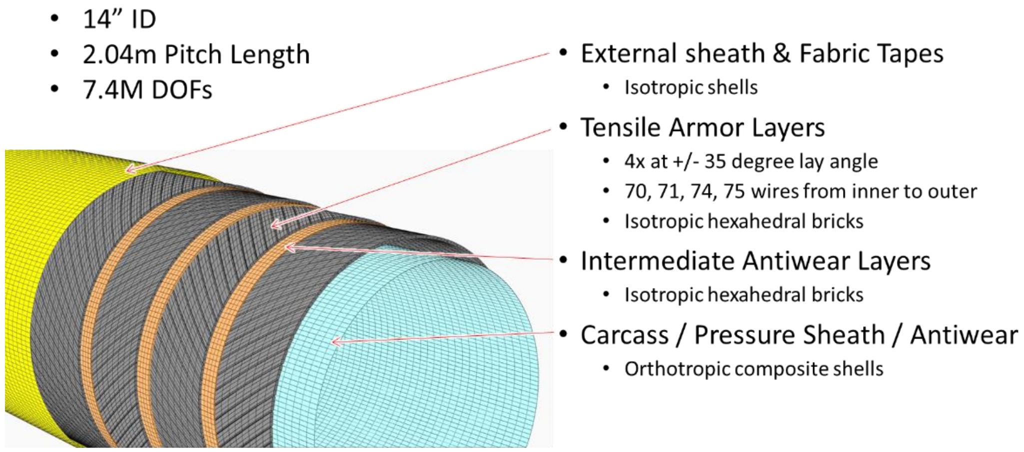
Local Modelling

The model used for this project is a geometric replication of the flexible cross-section, extruded to 1.2 m to form one full pitch-length of the tensile armour wires, as shown in Figure 9.

Stress recovery elements are defined at the mid-span of the pitch-length model.

The internal kinematics of the composite section is captured through individual modelling of all of the tensile armour wires, combined with an equivalent orthotropic shell representing the carcass in order to provide hoop stiffness and radial support.

Following the inspection campaign, the physical findings are incorporated into the local model in terms of both the annulus and tensile armour wire condition.



- 14” ID
- 2.04m Pitch Length
- 7.4M DOFs

- External sheath & Fabric Tapes
  - Isotropic shells
- Tensile Armor Layers
  - 4x at +/- 35 degree lay angle
  - 70, 71, 74, 75 wires from inner to outer
  - Isotropic hexahedral bricks
- Intermediate Antiwear Layers
  - Isotropic hexahedral bricks
- Carcass / Pressure Sheath / Antiwear
  - Orthotropic composite shells

Figure 9 Local Model Configuration

Numerical Simulation – FLEXAS

The FE model is synthesized into a Nonlinear Dynamic Substructure (NDS).

The pitch-length NDS model is replicated 10 times and assembled end to end to form a 12m extended length local model, as shown in the figure.

The contribution of the bend stiffener is incorporated at the top of the model over the first two pitch-lengths. At the top of the model, all 6 degree of freedoms are restrained, while the bottom is held only against lateral displacements.

Execution of the each of the irregular wave cases is performed in FLEXAS in nonlinear dynamic simulations.

Time-history outputs taken from the global analysis are then applied for the full 1-hour duration, with stress time-histories of normal stress in the tensile armour wire lay direction computed at 0.4 second intervals. An example is shown in Figure 10.

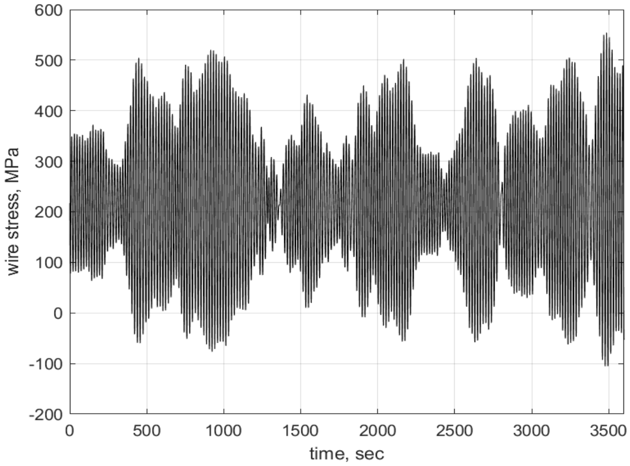


Figure 10 Irregular wave wire stress time-history (wire corner, axial direction)

Fatigue life predictions

The stress time-histories are post-processed into fatigue spectra using the rainflow counting method.

The yearly probability-adjusted fatigue spectra are summed into fatigue damage rates using Miner's Rule, applied using a reference SN curve for the given material specification.

The reference SN curve is degraded assuming to account for ageing of the material, by modifying either the slope or the endurance limit parameters. The output is shown in Figure 11.

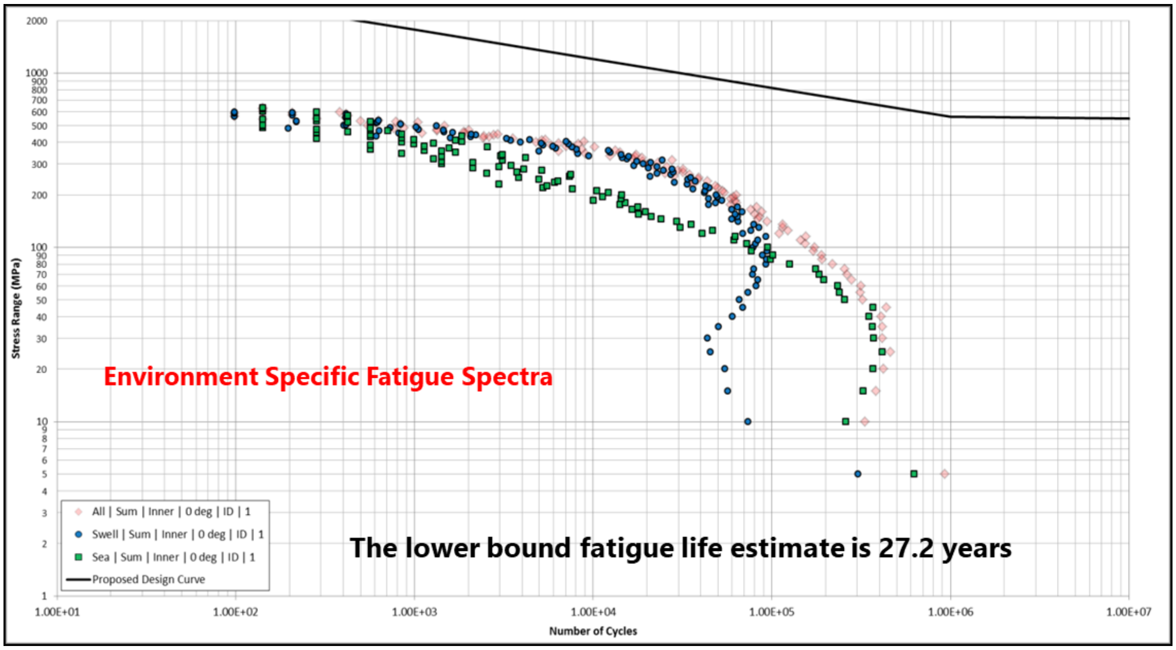


Figure 11 Example S-N Spectra

Embedding Advanced Technology into a Risk Based Integrity Plan

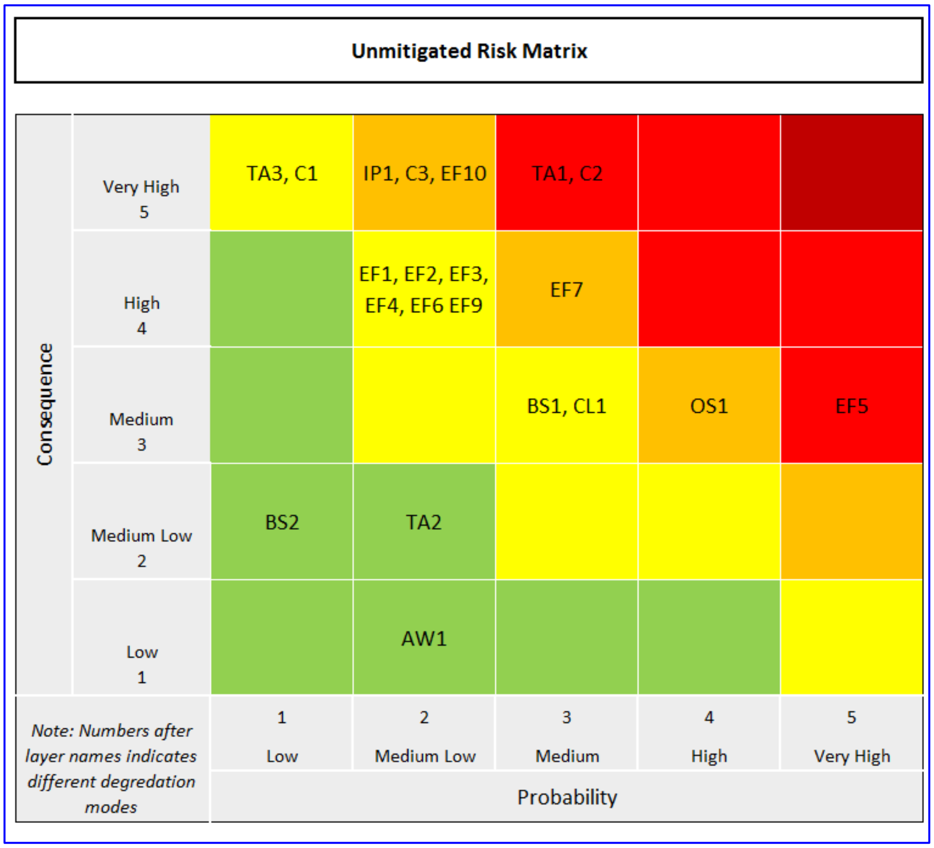
The above inspection and analysis informs on the fatigue response of the tensile armour wires based on the inspection data which provides information on the current condition.

The focus of the risk assessment is to assess qualitatively the risk of failure of each layer of the flexible risers and its ancillary equipment. This ensures the condition of each element (layer) of the flexible is considered in the assessment to ensure a comprehensive integrity plan is developed for ongoing operations.

This Risk Based approach enables the credible degradation threats to be identified and assessed in a logical manner for each layer of the flexible. All the credible degradation mechanism form API 17 N [6] have been considered. It provides an assessment of "non-inspectable" layers (such as carcass, internal plastic sheaths) which are important to the integrity of the flexible and allows the selection of specific mitigation actions (inspection, test, monitoring, additional assessment) to keep the risk level to ALARP (As Low As Reasonable Practicable).

The process is driven through a workshop attended by a team of engineers from operator, inspection company and integrity company. For each credible degradation mechanism, the probability of failure (PoF) and the consequences of failure (CoF) using DNV RP F206 [7] and ISO 17776 [8] are assessed to determine the *unmitigated* risk level defined as

Unmitigated Risk = PoF x CoF



Unmitigated Risk Matrix

Consequence						
	Very High 5	TA3, C1	IP1, C3, EF10	TA1, C2		
	High 4		EF1, EF2, EF3, EF4, EF6 EF9	EF7		
	Medium 3			BS1, CL1	OS1	EF5
	Medium Low 2	BS2	TA2			
	Low 1		AW1			
Note: Numbers after layer names indicates different degredation modes		1 Low	2 Medium Low	3 Medium	4 High	5 Very High
		Probability				

Figure 12 Example Risk Matrix

For mechanisms where the risk is critical (high/medium-high), a bespoke risk reduction plan is discussed and the *mitigated* risk level determined based on implementation of the mitigation plan implemented.

The workshop outcome is captured in a spreadsheet showing the value each mitigation measure has in reducing the risk to an acceptable level.

For this case study the assessment identified the failure mechanisms that carry a high-risk as being to the tensile armour (TA), carcass (C) and end fittings (EF) and enabled the following Short and Long terms measures to be put in place.

Short term plan

- Retrofit plugged vent system and perform a comprehensive annulus testing
- Inspect and perform an integrity assessment of the remaining section of the riser
- Perform water sampling analysis and assess corrosion/cracking susceptibility
- Repair topside piping and perform pressure testing

Long term plan

- Periodic General Visual and Close Visual inspection (GVI and CVI)
- Periodic MEC-FIT^{TM} inspection and FLEXAS analysis
- Periodic Annulus Testing
- Periodic Pressure Testing
- Cathodic Protection System monitoring
- Process condition monitoring and recording
- Period fluid sampling analysis

Implementing a comprehensive risk based integrity plan can form the basis of a life extension study that shall be performed, in accordance with ISO 12747 [9] if the intent is to continue to utilise the riser after the end of the design life (2024).

Conclusion

The case study described in this paper demonstrates that combining methods of advanced inspection and analysis as part of an integrity assessment is a valid solution for increased understanding of flexible riser condition as part of a life extension program.

MEC-FIT^{TM} allows complete scanning of larger flexible riser sections above and below water with the aim of detecting and accurately sizing anomalies and defects such as wire disorganization, pitting and general corrosion and cracking in up to three metallic layers. First time inspection results from flexible pipe can be used as input to advanced analysis as part of an integrity assessment thus helping understanding flexible riser condition as part of a life extension program.

The FLEXAS numerical solver allows high-resolution stochastic fatigue life to be captured based on realistic conditions.

The FlexIQ approach incorporates both solutions and offers a fully integrated service for integrity assessment and life extension to facilitate continued service of flexible riser; where lifetime of an asset does not depend on its age but its condition.

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