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Deepwater Riser and Subsea Integrity Management Strategy

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Abstract

Deepwater oil and gas fields in Asia-Pacific presents many challenges from the development of the reserves during the engineering design stage to ensuring the integrity of the subsea facilities during the operational phase. The deepwater risers and subsea systems are critical components in any field development due to the complex nature of the response to environment and vessel loading.

The deepwater subsea system design methodologies involve assumptions to simplify the complex design process due to lack of understanding and experience. The inherent uncertainties in the environment and operational conditions can impact the safety and reliability of the subsea systems. Operators are recognising the importance of implementing risk based Integrity Management (IM) programs to effectively track the performance of the subsea systems.

The paper highlights the systematic approach to identify the risks involved in the systems and the mitigation and/or monitoring strategy to ensure system integrity. The value of inspection combined with suitable monitoring methods with an emphasis on the ability to quantify the actual performance of the subsea systems and identify anomalies are presented.

Background

Oil and gas fields are increasingly being developed in deeper waters in the Asia Pacific region. Deepwater developments present a more challenging environment for operators. Often, the component designs have evolved from shallower water designs which are constantly pushed to perform at their limits in deeper water. Also, new technologies are implemented to meet the project requirements, raising the concern on the component reliability.

The present industry practice is to utilise factors of safety to overcome any limitations in the current design methodologies which could potentially lead to over-conservatism in the design. In addition, there are inherent uncertainties in the site-specific environmental data for both long-term and extreme loading during the design stage. The component fabrication and installation under tighter project schedule can also cause design non-conformances to go undetected. Surprises do lurk during the operational phase in the form of unanticipated production fluid chemistry increasing corrosion, erosion and/or flow assurance issues, thus requiring changes in the operational practices.

In order to address the above limitations, an integrity management strategy has been developed and implemented by various operators across the globe. A risk-based inspection (RBI) approach is adopted to evaluate the consequence and probability of occurrence of each potential failure mode. The RBI method is used to develop the IM plan which includes the inspection requirements and specifications along with the recommended inspection intervals. An effective IM plan requires more than just normal inspection management which is quite often misunderstood in the industry as IM. An effective IM plan utilises monitoring methods to track the performance of un-inspectable components identified as critical for integrity assurance by the RBI process.

Introduction

The Integrity Management (IM) process is aimed at reducing the risk levels and maximising the operational efficiency for the operators by discovering potential issues at an early stage. The basics of an effective IM program are to have the entire design, fabrication, installation, operation and decommissioning process documented.

To ensure the integrity of deepwater subsea systems, inspection alone is not sufficient as it provides only a snapshot of information in time. Therefore, an IM program should also include monitoring, evaluations of actual environment/operational loading conditions, and regular assessments of loading levels against the design limits.

This paper discusses the IM process for deepwater risers and subsea systems including risers, pipelines, wellheads, manifolds, rigid jumpers, etc. The paper also provides insights on the typical failure modes specific to risers and other subsea systems. The Key Performance Indicators (KPI's), that are typical of risers and subsea systems as an effective measure of the system performance, are highlighted.

The strategy required to set up and implement an IM plan is discussed along with the benefits of a structured IM program such as reduced inspection and maintenance costs, and the ensuring the integrity of the subsea systems.

Integrity Management Approach

The approach adopted for deepwater riser and subsea integrity management is the risk based inspection (RBI) approach as discussed in API-RP-580, [1]. This requires collating design, fabrication and installation documents as well as operational history in to a unifying source called the 'DFI' dossier. It is important to conduct the RBI assessment on the as-installed configuration, and it is vital to include any fallacies that may have occurred during the fabrication and installation phase to avoid any mis-ranking of the risks. The personnel involved in developing the RBI process should be competent in both the system and component levels to identify the potential failure modes, evaluate the risks and propose suitable mitigation methods.

The risk levels are evaluated through a careful assessment of design, fabrication, installation and operational history to determine the probability and consequence of failure on personnel safety, operational downtime and safeguards to the environment. As part of the risk assessment process, the entire system is separated in to different components with their boundaries defined. The primary failure modes including both the internal and external threats specific to each component are identified.

The criticality of each component is evaluated through a combined scoring of consequence and probability of failure, as shown in Figure 1.

The asset specific operational and inspection history can shed some light on the component degradation. Also, the ability to capture the component degradation through inspection or monitoring should reflect on the overall criticality of that component. Therefore, a term called 'confidence grading' is introduced and the overall criticality will be a product of the risk and confidence grading, Figure 2.

In the event of prior inspection records showing acceptable performance levels, the confidence grading can be improved thereby reducing the overall criticality.

The inspection intervals are determined based on the overall criticality and suitable inspection, mitigation or monitoring requirements are identified. In order to quantify the performance, Key Performance Indicators (KPI's) capable of capturing the failure modes are determined and associated design limits are selected through careful engineering appraisal.

The KPI's are continuously tracked. Any anomalies identified during inspection or from monitoring data are recorded and a suitable mitigation/repair strategy is proposed. The emphasis is also placed on the timely close out of repair or mitigation actions.

Integrity Management Strategy

A schematic showing the IM strategy is shown in Figure 3. IM is a continuous process and not a one time activity which is done to satisfy regulatory or verification bodies and subsequently put in a library for reference. The risk levels will alter during the life of an asset due to deterioration, accidents, incidents, change in use, anomalies discovered, etc, and the effect of these must be taken into account to gauge remaining life during operations.

The development of the IM plan is conducted by an expert team comprising key operator personnel and external specialists in areas such as structural dynamics, materials, corrosion, inspection and monitoring. The emphasis should be placed in transferring the knowledge during design, fabrication, installation and operational phases both through personnel involvement and through project documentation to develop the IM plan. Emphasis should also be placed on the competence of the personnel involved such that they understand the functionality of each component and consequence of failure so that the threats are not ignored or un-identified.

Apart from the systematic documentation of KPI's, inspection records, monitoring data, and anomaly records produced during IM process, there should be clarity in the responsibilities in the IM team to ensure that there are no potential gaps in the IM system which can lead to a disastrous consequences.

Failure Mode Assessment

The primary failure mechanisms for deepwater risers and subsea systems can be broadly classified under internal and external threats. The internal threats such as corrosion and erosion are some of the commonly identified failure mechanisms for almost any of the subsea systems that is a conduit for corrosive internal fluids. The internal corrosion can occur due to various mechanisms, such as Sulphide Stress Corrosion Cracking (SSCC) due to sour service, chlorides, and CO2 induced corrosion due to sweet service. There may be other potential corrosion mechanisms which will need to be considered specific to each application such as corrosion due to the presence of water in the production fluid. Similarly, a hydrate plug or wax deposition is another potential threat that could lead to significant downtime in production or export.

The most common external threats are related to impact and external corrosion. The damage from impacts can be mechanical damage caused during fabrication, transportation, or installation. The impacts can also be due to dropped objects during operation. For large field developments, the interference with the neighbouring structures such as risers, moorings, umbilicals, tendons, hull columns, etc., can also lead to impact damage.

The external corrosion threat is largely due to inadequate cathodic protection (CP), poor choice of external coating and/or application of the coating. The cathodic protection largely depends upon electrical continuity, environment and surroundings. It should be noted that the CP design involves assumptions regarding the drainage current available which could potentially be lower due to the lower ambient temperature and deeper water depths.

The severe and long-term environment loading combined with the vessel motions can result in complex dynamic responses such as vortex induced vibrations (VIV), hull vortex induced motions (VIM), etc. The dynamic nature of risers, moorings, rigid jumpers and pipeline free-spans introduce additional threats such as:

- Structural overstress;
- Structural fatigue;
- Structural wear.

The deepwater subsea systems utilise speciality components such as flex joints, tapered joints, keel joints, tensioners, etc., which are susceptible to material degradation. The performance and thus the integrity of the system depend on the ability of the material to last the lifetime of the asset.

In addition to the above mentioned threats, the uncertainty in the environment loading poses a significant threat which cannot be ignored as more and more fields are being developed in un-chartered regions with limited environment record.

Inspection and Monitoring

The IM plan should address methods to capture the failure mechanisms described above. In order to achieve this objective, a strategy of combining inspection with monitoring is used. General visual inspection footage can capture impact damage, marine growth and show any signs of structural damage. Also, upon close visual inspection, the integrity of the coating and any ancillary components such as VIV suppression devices can be identified. However, inspection alone is not sufficient to quantify the riser performance and determine the remaining life of the structure. Also, the implications of the inspection findings on the system and component performance need further analyses. With the availability of monitoring devices, the performance can be quantified and the results can be used to supplement the inspection findings. Apart from the technical merits offered by monitoring systems, a significant commercial advantage can be derived by reducing inspection intervals that can be justified by the presence of monitoring systems.

Monitoring systems can be broadly classified as conditional monitoring and system specific response monitoring. The conditional monitoring provides the most essential parameters that are required to ensure the safe operation and verify the condition of the overall development, while the system specific response monitoring targets the critical areas which are only relevant to the component or system design associated with the operational and prevailing environmental conditions.

Condition Monitoring:

Conditional or essential monitoring should include the following:

- Internal pressure;
- Fluid temperature;
- Flow rate;
- Environment – current and wave;
- Vessel motions – drift and dynamic motions.

Depending on the reservoir chemistry and operational philosophy, sand erosion probes, corrosion coupons and regular fluid sampling may be required to monitor internal corrosion.

Environment Monitoring:

Environmental loading such as current, wave and wind impart loading on the vessel and the resulting vessel motions affects the subsea systems that are connected to the vessel. The current loading is monitored using Acoustic Doppler Current Profilers (ADCP's). Typically ADCP's are used to monitor both surface currents and through-depth currents. Deepwater facilities may require multiple ADCP's, attached to vessel, seabed and mid-water, depending on the extent of coverage required. The wind loading on the vessel superstructure results in the slow drift motion effects. The wind speed and direction can be captured using mechanical propeller type anemometers mounted higher up in the platform away from any vessel appurtenances that can shield or magnify the wind speeds. The wave height and period can be measured using air gap wave radars. The wave radars can be mounted on the platform measuring the vertical gap to the wave surface below.

Vessel Motion Monitoring:
Vessel motions can be monitored using a combination of dynamic and static offset measurement devices. Accelerometers, angular rates sensors or gyroscopes are typically used to obtain the wave induced vessel motions. The slow drift motion can be measured using differential Global Positioning System (DSPS) sensors and inclinometers.

System Specific Monitoring Solutions:
Component or system specific monitoring solutions can be achieved using motion, strain or curvature measurements at/near critical locations identified during risk assessments or through common design knowledge. Such solutions are widely implemented on steel/flexible risers, pipelines free-spans, and speciality components such as bend stiffeners, forged taper joints, flex joints, rigid jumpers, etc.

Corrosion Monitoring:
Internal corrosion is often monitored using fluid sampling methods to determine the fluid composition and level of corrosivity in the fluid. In addition, corrosion coupons are also used.

Cathodic Protection Measurements:
In addition to the visual inspection of the anodes and external coating, periodic CP measurements are obtained using bathy-corrometer style corrosion probes.

KPI Assessment

The Key Performance Indicators (KPI's) are designed to address the failure mechanisms relevant to each subsea component or system. The KPI's provide a quantitative reasoning whether the system is performing within the design limits. Any of the KPI's exceeding the pre-determined alarm levels based on design will trigger a relevant course of action to protect personnel, the environment and the asset.

The KPI's can be assessed either in real time or offline depending on the objectives of the system. An offline system will be sufficient to capture extreme loading and long-term fatigue loading for majority of the subsea structures that experience dynamic and static loading. A real time feedback to ensure the integrity may be required for moored vessel operating in harsh environment conditions risking a mooring line failure.

A few essential KPI's common to majority of the static and dynamic subsea structures are given in the table below.

KPI	**Target Failure Mechanism**
Internal pressure Internal temperature Flow rate	Internal corrosion
Maximum vessel offset	Structural overstress
RMS 6DOF vessel motion	Fatigue
Maximum surface current	Structural overstress Impact Fatigue
Through-depth current	Fatigue
Maximum Wave height	Structural overstress Fatigue

The KPI's specific to each subsea component are discussed below.

Risers

Riser systems can be broadly classified as steel and flexible risers. Rigid steel riser systems include drilling risers, top tensioned risers (TTR's) and steel catenary risers (SCR's). Both shallow water conductors and deepwater risers are subjected to large amounts of cyclic stress from wave loading, wave-induced vessel motions transferred to the riser, and through-depth current loading.

Riser motion and/or strain are typically used to determine the dynamic response. For the steel risers, the fatigue damage accumulation, particularly at welded or threaded connections, can be obtained to enable remaining fatigue life predictions, [2], [3].

Top Tensioned Risers:
The speciality components such as tapered joints located at the vessel and seabed interfaces are both strength and fatigue critical components of a TTR. Similarly, the wellhead and conductor system tend to accumulate fatigue due to motions transferred from the riser. Monitoring approaches to ensure the integrity of these systems have been implemented, [3]. In addition, riser tension and stroke range should be defined as KPI's. Riser annulus pressure is also routinely monitored to detect tubing leaks and for flow assurance.

Steel Catenary Risers:

The critical locations to focus on for the SCR's are the touch-down region, where the riser interacts with the seabed, and the vessel interface through a flex joint or stress joint. The SCR touch-down region is monitored using strain and motion sensors, [4], to monitor the fatigue, trenching and soil interaction loading. The behaviour of elastomeric material in the flexjoints are tracked by monitoring internal fluid composition, temperature, pressure and angular rotations.

Flexible Risers:

Flexible risers and umbilicals are more dynamic compared to their steel counterparts. Similar fatigue loading at the end interfaces and clashing with neighbouring structures are applicable. Polymer coupon sampling can be conducted to determine the ageing of the internal pressure sheath. The coupon should ideally be placed near the wellheads with the highest internal fluid temperatures. Vent rate monitoring is used as a measure to monitor the annulus and to calibrate the fluid permeation models, [5]. In addition, riser accelerations at the vessel hang-off are used to provide an indication of the extreme stresses and fatigue accumulation.

Free-standing Hybrid Risers:

Hybrid riser technologies, such as bundled towers and single-line offset risers (SLOR's), utilise both rigid steel and flexible components, and hence incorporate IM strategies from both steel rigid risers and flexible risers.

Pipelines

Internal fluid sampling and flow rate measurements are commonly adopted approaches to determine any leaks and corrosion potential of the pipeline. Pipelines are also prone to dynamic loading along any free-spans. Free-span mitigation is a preferred approach in comparison to monitoring. However, free-span motion monitoring has been implemented to actively track the dynamic response and the estimate the remaining fatigue life. Similarly, pipeline buckling due to internal temperature fluctuations are addressed through actively monitoring internal temperature and/or pipeline curvature at the most susceptible spots, [6].

It should be noted that historically there are various approaches for pipeline IM. The staggering statistics that majority of the pipelines are un-inspectable calls for a case-specific approach towards ensuring the pipeline integrity.

Subsea Equipment

The IM strategy for subsea manifolds, wellheads, trees, templates and pumps revolves around cathodic protection, internal fluid content sampling and flow rates measurements to address the susceptibility to corrosion and erosion. The internal pressure and temperature are monitored to ensure the component end connections are not over-stressed. The steel rigid jumpers may be susceptible to VIV if there is a possibility of high bottom currents occurring, in which case the monitoring of jumper accelerations would be required.

Moorings

Mooring lines, being critical to vessel station-keeping, affects all the subsea components attached to the vessel. In contrast to the riser design, the primary failure mechanism of mooring lines is through extreme loading caused during severe environmental events. Therefore, mooring line load typically forms a KPI, [7]. Load monitoring is conducted using load-cell or shackle type systems based on LVDT technology for mooring chains, and top angle-catenary shape based tension monitoring is used for wire rope systems.

The critical components in mooring lines are the end terminations shackles, and hence particular attention must be paid to these sections, [8].

Conclusion

An IM program based on the RBI approach is described for risers, conductors, umbilicals, subsea rigid jumpers, wellhead, trees, manifolds, templates, pipelines and moorings. The proposed IM strategy has been implemented by many operators across the globe and had yielded benefits in terms of reduced asset downtime, minimised inspection requirements, and ability to quantifying remainder life of the system. The potential failure mechanisms and mitigation/monitoring methods for the subsea systems are discussed in detail.

The IM program can trigger alarms based on the KPI's with subsequent actions taken to ensure the safety of the personnel, minimal downtime and safeguards to the environment. The IM strategy highlights the need for competent personnel to be involved in the IM program to ensure that all risks associated with the system are captured and addressed to confirm the integrity.

The combined inspection and monitoring strategy paves the way to assess the performance of relatively new technologies and improve the understanding of the same. Similarly, any poor choices of material or components that could lead to failure are identified and form a basis for improvement in the design for future projects.

References

[1] American Petroleum Institute, API Recommended Practice 580, Risk-Based Inspection.

[2] Podskarbi M., Thethi, R., & Howells, H., "Fatigue Monitoring of Deepwater Drilling Risers", Subsea Rio, Rio de Janeiro, Brazil, 8-10th June 2005.

[3] Thethi, R., Howells, H., Natarajan, S., Bridge, C., – "A Fatigue Monitoring Strategy & Implementation on a Deepwater Top Tensioned Riser", OTC, Houston, Texas, USA, 2-5th May 2005.

[4] Karayaka, M., Ruf. W., Natarajan, S., - "SCR Response Characterisation with On-line Monitoring Devices", OMAE 2009, June 2009

[5] UKOOA, "State of the Art Flexible Riser Integrity Issues, Study Report", Doc. No. 2-1-4-181 / SR01, Rev. 4, April 2004.

[6] Corsiglia, F., "Subsea Pipeline & Pipeline Riser Integrity Management", INDOPIPE, Jakarta, Indonesia, 30th May - 1st June 2006.

[7] Hall, A., "Cost Effective Mooring Integrity Management", OTC, Houston, Texas, 2-5th May 2005.

[8] Morandini, C., Legerstee, F., "Consistent Integrity of Mooring Systems", ISOPE, Osaka, Japan, 21-26th June 2009.

Figures

Criticality		Probability of failure			
		Negligible	Low	Medium	High
Consequence	High	Medium	High	Very High	Extreme
	Med	Low	Medium	High	Very High
	Low	Negligible	Low	Medium	High
	Zero	0	0	0	0

Figure 1 – Sample Criticality Matrix

	Confidence Rating				
Criticality	Very Low	Low	Medium	High	Very High
Extreme	Manually assign inspection interval/ determine monitoring				
Very High	a	b	b	c	d
High	b	b	c	d	e
Medium	b	c	d	e	f
Low	c	d	e	f	g
Negligible	d	e	f	g	h

Figure 2 – Sample Inspection/Monitoring Regime Chart

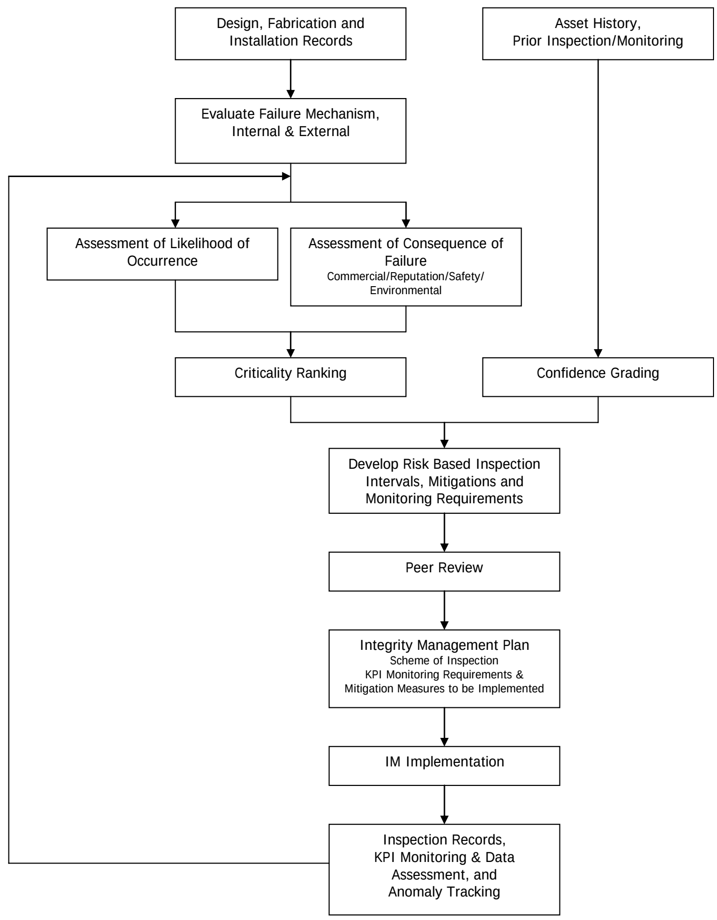

Figure 3 – Risk Based Inspection Methodology