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## **THE ROLE OF OFFSHORE MONITORING IN AN EFFECTIVE DEEPWATER RISER INTEGRITY MANAGEMENT PROGRAM**

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### **ABSTRACT**

As offshore field developments move into deeper water, one of the greatest challenges is in designing riser systems capable of overcoming the added risks of more severe environments, complicated well requirements and uncertainty of operating conditions. The failure of a primary riser component could lead to unacceptable consequences, including environmental damage, lost production and possible injury or loss of human life.

Identification of the risks facing riser systems and management of these risks are essential to ensure that riser systems operate without failure. Operators have recognized the importance of installing instrumentation such as global positioning systems (GPS), vessel motion measurement packages, wind and wave sensors and Acoustic Doppler Current Profiler (ADCP) units to monitor vessel motions and environmental conditions. Additionally, high precision monitoring equipment has been developed for capturing riser response. Measured data from these instruments allow an operator to determine when the limits of acceptable response, predicted by analysis or determined by physical limitations of the riser components, have been exceeded. Regular processing of measured data through automated routines ensures that integrity can be quickly assessed. This is particularly important following extreme events, such as a hurricane or loop current. High and medium alert levels are set for each parameter, based on design analysis and operating data. Measured data is compared with these alert levels, and when an alert level is reached, further response evaluation or inspection of the components in question is recommended.

This paper will describe the role of offshore monitoring in an integrity management program and discuss the development of alert levels based on potential failure modes of the riser systems. The paper will further demonstrate how this process is

key for an effective integrity management program for deepwater riser systems.

### **INTRODUCTION**

Development of deepwater fields requires overcoming numerous design challenges. New technologies are often used in conjunction with proven technologies to meet the demands of harsh operating conditions and larger production capabilities. Conservative design assumptions and high safety factors have been employed to ensure that designs are robust and will last without failure for their required design life. However, at a time when lost production time is so costly, further actions must be taken to avoid component failure.

Riser systems provide one of the most challenging areas of design of deepwater systems. Risers are the conduit between the subsea wellhead and the production platform, and often extend a mile below the surface. Their design requirements include both the high pressure loads of well systems design and the environmental dynamic loading of waves, current and vessel motion. Risers in the Gulf of Mexico are subjected to a strong current environment, which introduces potential for extreme fatigue loading from loop and eddy currents through vortex-induced vibration (VIV). Extreme storm events in the Gulf of Mexico exert loads on risers through vessel offset, tilt and heave.

High margins of safety are applied during the design phase to account for these loads and the uncertainties in environmental parameters. However, in recent years, several large hurricanes have forced operators to question previous 100-yr and 1000-yr storm criteria. Due to the limited experience of riser developments in deepwater fields and the risks involved in component failure, measured data from monitoring systems and instrumentation are being incorporated into risk management programs for deepwater risers to provide

feedback on performance systems and to ensure that the riser systems operate without failure.

## **DEEPWATER RISERS**

Risers on floating production platforms in the Gulf of Mexico include a wide range of technologies. Riser types include vertical top tensioned risers (TTRs), steel catenary risers (SCRs) and flexible pipe risers. Each of these riser types is subjected to different types of loading and associated potential failure modes.

## **INTEGRITY MANAGEMENT**

A risk-based integrity management (IM) program for deepwater risers is based on identification of potential failure modes of riser components and development of a risk mitigation plan that includes recommendations for monitoring, inspection tasks and frequencies, and addressing identified anomalies.

The first step in an effective integrity management plan is to systematically evaluate risks as they apply to various riser components and systems. As possible failure modes are identified, a consequence level is assigned based on the severity of the consequence of failure. A probability is also assigned to each possible mode of failure, and the probability of occurrence and consequence level are combined to form a criticality ranking for each failure mode or identified risk.

The key to bringing the criticality ranking down to an acceptable level for a particular threat is to raise the confidence level. This may involve increasing the understanding of the failure mode, compiling an inspection history that allows an understanding of the current state of the riser system, and often performing further analysis of critical components or systems. Another method of lowering the criticality ranking of a potential risk is by monitoring the riser or the environmental and vessel parameters that affect the riser response, so that riser system health can be determined. As the criticality ranking is lowered, recommended inspection frequencies can be decreased while still assuring that the riser system will last for the required design life.

Another important part of an integrity management plan is to obtain input from key personnel from the project design phase, operations, and specialists during key phases of the plan development. This includes an initial peer review of the risk assessment, and also involves input on setting of alert levels for parameters which may affect riser response. These limits need to be updated and evaluated as changes occur in the system, such as new operating conditions or change of service.

## **MONITORING**

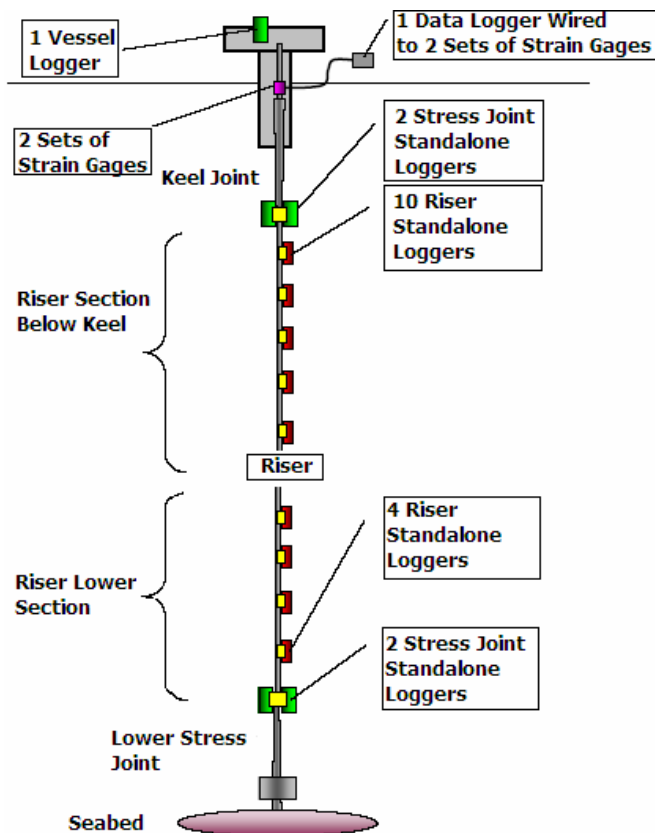
Several types of monitoring data can be used to determine the health of riser systems over the field life. Some examples of these types of instrumentation and data are discussed below.

## **TTR Response Data**

Riser tension and stroke are often measured in conjunction with a standard vessel motion and environment marine monitoring system installed on a vessel. Riser top tension on risers tensioned with buoyancy can systems can be measured using load cells mounted near the top of the riser, often at the upper stem interface with the surface tree. Load cell arrangements involving three or more cells may allow for an additional calculation of the bending moment. Additionally, some risers are instrumented to measure air-can guide lateral loads. On top tensioned risers which are tensioned using a production riser tensioner or drilling riser tensioner, tension measurements are calculated from pressures in the hydraulic cylinders. Typically, four cylinders are each instrumented with pressure gages, and an average of these pressures is used to calculate riser top tension. Riser stroke is commonly measured using a potentiometer which measures relative motion between the riser and platform.

Internally, annulus pressures between the riser casings are measured on production TTR's. Sampling of fluids may also be performed periodically to assess potential for corrosion. Corrosion coupons provide actual corrosion rate data.

In addition to riser data available from vessel-installed systems, instrumentation is often installed on risers to determine fatigue and strength response. Strain gages are not often used on top tensioned risers since installation through the vessel hull elevates the risk of damage of pre-installed instrumentation. However, many options are now available for ROV-installed motion measurement devices. These standalone loggers record data off-line, and are then retrieved so that data can be downloaded. Motion loggers have also been developed as on-line systems capable of transmitting real-time data. High precision accelerometers are used to determine riser motions and frequency of response. From this data, fatigue can be calculated based on modal shape of response and amplitudes. An example configuration of loggers fitted to a spar TTR is shown in Figure 1.



**Figure 1 – Instrumented Top Tensioned Riser on a Spar**

### SCR Response Data

On SCRs, on-line equipment can be used to monitor structural integrity. Fatigue accumulation can be calculated at areas seen as a high risk for failure. These gages, either electrical foil or fiber optic type, can be installed at critical locations along the riser, such as the hang-off location and touchdown point. Mechanical angle measurement devices or inclinometers can be used to measure SCR top angles. Flexjoint temperature and pressure can be monitored on SCRs so that fatigue due to temperature and pressure cycles can be calculated. Flexjoint rotation angles may also be measured.

Another option for measuring riser strain is fiber optic strain measurement mats. These systems are composed of embedded fiber optic strain gages within a composite mat structure which measures changes in curvature along the measured length.

### Vessel Response Data

Standard marine monitoring systems for deepwater platforms include instrumentation to measure vessel response. First order, or high frequency platform motions are measured using a six degree of freedom inertial motion measurement system. This motion measurement system typically consists of accelerometers for calculation of displacements (surge, sway

and heave) and angular rate sensors or gyroscopes to calculate rotations (roll, pitch and yaw). These 6 DOF motion packages, however, are not suitable for measuring second order, or low frequency, vessel motions. Low frequency offsets are recorded by differential GPS units (DGPS) and the measurements are combined to compute actual platform offset.

### Environmental Data

In addition to vessel motion data and riser response data, standard marine monitoring system packages are generally equipped with devices for measurement of environmental parameters which can impart loads on risers either directly, or indirectly through vessel loading.

Currents have a direct and indirect effect on both top tensioned risers and steel catenary risers. Currents may induce fatigue loading through phenomena such as vortex-induced vibration (VIV), and can cause high stresses at the keel and lower stress joint through vessel offset. Current speed and direction are measured through depth using acoustic Doppler current profiler (ADCP) units. The use of multiple ADCP units allows for more coverage in deepwater applications than a single ADCP. An example configuration might include three ADCP units. The first unit, a horizontal ADCP unit, can be mounted between the MWL and the keel of the floating platform and measures surface or near-surface current speed and direction. A second unit, an upper ADCP (UADCP), can be mounted at the platform keel and measures currents over the top portion of the water column. The third unit, or lower ADCP (LADCP) is mounted on the seafloor and records currents in the bottom portion of the water column, from which data is retrieved periodically for analysis. This arrangement allows for complete coverage through the entire water column. In deeper water, a mid-depth ADCP unit can also be installed if required. Different specifications for ADCP units are available depending on the required coverage range. ADCP units with higher sampling frequencies cover a smaller range (typically 200-300m), and work well as horizontal ADCPs. Units with lower sampling frequencies may have a range of over 1,000m, and are better suited to applications involving a longer measurement range and on-line data transmittal, such as an upper ADCP unit.

Wave height and period are measured by air-gap wave radar sensors. These sensors measure the distance between the water surface and the sensor and use the platform motions to derive wave height. Typically, several wave radar units are outfitted on opposing sides of the vessel, so that wave direction can be calculated and vessel effects can be ignored. Use of multiple radars also provides redundancy in the case of malfunction or false readings from one of the sensors.

Wind speed and direction are measured by mechanical propeller type or ultrasonic anemometers. Wind sensors are mounted as high on the platform as possible so that shielding

from the platform does not give inaccurate readings. Like wave radars, multiple wind sensors are often used and the highest reading taken as the actual wind speed.

### AVAILABILITY OF DATA

A successful integrity management plan requires timely data transfer and processing. For some measured data, automatic feeds can be initiated to ensure fast and reliable data retrieval. This is particularly important after a large event, such as a hurricane or loop current.

During hurricane abandonment, marine monitoring systems should be capable of recording continuously with their own power supply. This power supply is typically provided by a hurricane generator or an independent battery powered backup system with sufficient battery life to power the marine monitoring system for 4 to 8 days. Some instrumentation, such as ADCPs, may be shut down during hurricane abandonment, since they are not considered critical to hurricane data processing, and they consume a relatively large amount of power.

### ALERT LEVELS

For measured data parameters that affect riser integrity, alert levels, or key performance indicators (KPIs), are established to determine when these parameters have reached a critical or near-critical level. Alert levels for environmental and vessel response parameters may correspond to extreme environmental cases that result in stresses reaching operating or extreme allowable stresses. 100-yr hurricane winds or 100-yr loop currents can cause maximum vessel offsets, and hence maximum riser stress at the keel or lower stress joint. As a result, KPI limits and the basis for setting the limits may differ for each asset.

Typically, for vessel and environmental KPIs based on riser strength, an Amber limit corresponds to the riser reaching 0.8 of yield. In the event that an Amber limit is exceeded, other KPIs will be examined, further analysis or response evaluation may be conducted, and riser inspection may be initiated if appropriate. A Red limit generally corresponds to an extreme event or case where stresses have approached yield, or when environmental or vessel responses have exceeded those taken into consideration in the design phase. In the case of a Red limit being exceeded, a course of action is immediately decided upon by the integrity management group and asset team. Possible actions may include detailed inspection of the component in question, design of a retrofit mitigation, or even stopping operation.

Upper and lower riser tension KPIs for top tensioned risers may be set based on a calculated expected tension with an additional operating margin or on the physical limits of the tensioning system. A Red limit for riser stroke could correspond to the riser upstop or downstop contacting the deck.

Additionally, an Amber limit may be set when the stroke exceeds maximum stroke levels predicted by analysis.

Internal data may also be used as key performance indicators. Typical measured data may include H<sub>2</sub>S content, O<sub>2</sub> content, H<sub>2</sub>O content, CO<sub>2</sub> content, biological material content and internal temperature and pressure of flowlines and risers. Chemical inhibitor rates or samples of chemical present in the riser or flowline may also be available. These KPIs are used as indicators of potential corrosion. Corrosion coupons may be installed to measure actual corrosion rates and these rates can be compared with KPIs, usually derived from design allowables.

Key performance indicators for a particular riser system will depend on the type and extent of instrumentation installed on the platform and risers. Examples of key performance indicators for riser systems include:

- Maximum roll/pitch for TTR strength and flexjoint rotations on spar
- RMS roll/pitch for fatigue on semi
- RMS surge for SCR fatigue on semi
- Measured near surface current for TTR and SCR strength and fatigue
- Flexjoint temperatures and pressures for flexjoint fatigue due to pressure/temperature cycling
- TTR measured accelerations due to VIV for fatigue
- TTR annulus pressures
- Measured H<sub>2</sub>S content
- SCR measured strains or accelerations for fatigue
- Accelerations at lower stress joint on TTRs for fatigue

Examples of KPI plots are shown in the following figures.

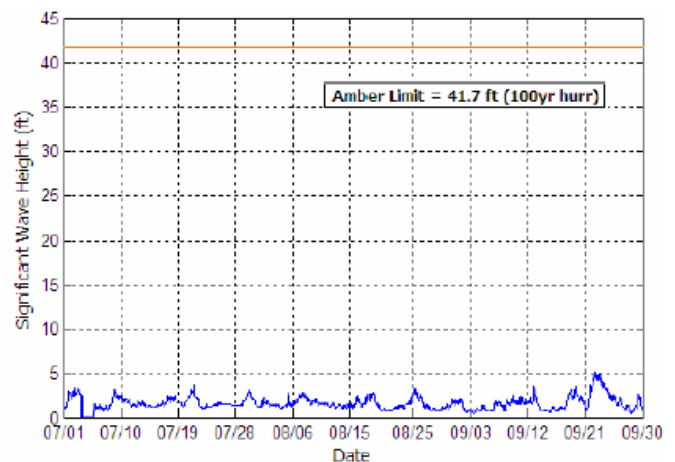
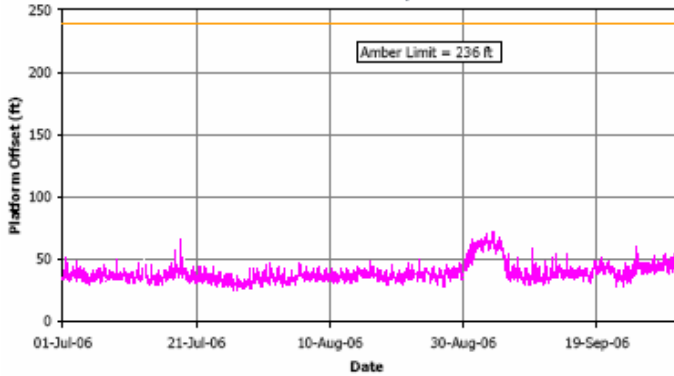
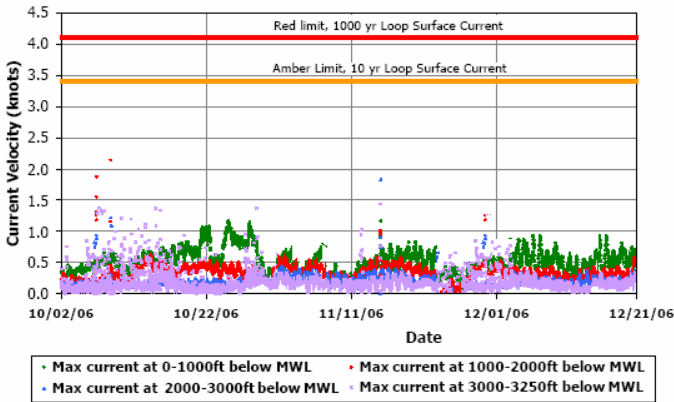


Figure 2 – Example Significant Wave Height KPI



**Figure 3 – Example Platform Offset KPI**



As KPIs are evaluated, gaps may be identified in instrumentation if certain critical parameters are not yet being monitored. For instance, if an ADCP system is not in place, an operator will be unable to determine whether currents seen at the platform location are higher than those assumed in design. Consequently, an accurate prediction of fatigue accumulation will not be possible. In cases like this, an independent environmental or riser monitoring system may be installed to measure key responses not captured by other sensors or systems. Some platforms in the Gulf of Mexico have been equipped with Independent Remote Monitoring Systems (IRMS) after the hurricane season of 2005. The main function of these systems is to operate on a power generator in a case of a severe storm event, when other systems might not be working. However, they can also be used in forensic evidence if other data is not available, regardless of weather conditions.

### ASSESSING RISER HEALTH

KPIs can be divided into short term and long term KPIs. Short term KPIs compare measured data points to alert levels to determine the current performance of the riser. Examples of short term KPIs include comparison of measured surface current with 100-yr loop current values, significant wave height during a hurricane event, or riser top tensions compared to design expected tensions. Short term KPI limits can be utilized to indicate a potential for high stresses in the riser.

Environmental KPIs such as wind and wave, as well as vessel response KPIs such as vessel tilt or static or dynamic offsets can be used as an indication of high bending stress at the keel joint or lower stress joint. Larger than expected operating pressures could cause large-hoop stresses in riser casings. If tension or stroke limits are exceeded, potential exists for failure due to higher than allowable axial stress. Each limit is set according to the criticality and safety margin of the load case in the initial design. When an Amber limit based on a strength case is exceeded, further response evaluation may be triggered. In this case, as-installed models may be run with measured vessel motions to determine whether riser strength is below allowable stress. If stresses are shown by analysis to be higher than yield, an inspection may be required, or in critical cases, a stop of operations.

Long term KPIs require that a certain amount of data be collected before an assessment can be made as to the health of the riser. Long term KPIs include comparisons of currents or vessel response with design probabilities, flexjoint fatigue estimates based on temperature and pressure cycles, or long term fatigue accumulation estimates using measured acceleration or strain. Using these comparison methods, an operator can determine whether the current year of operation has been a “good” or “bad” year for accumulation of fatigue damage in a particular component. An example KPI for fatigue is the percentage of fatigue life consumed over a year.

Assessment of riser health often depends on looking at several KPIs to determine how the system is responding. If high wind speeds are noted and an Amber limit is reached during a large storm or hurricane event, vessel surge and sway data can be examined to determine whether or not the top tensioned risers may have seen a large response. The maximum extreme design case for TTRs is typically a large event, such as a hurricane or loop current, which causes large bending and possibly axial stresses, combined with a shut-in pressure case which generates high hoop stresses. It is important to relate KPIs to other relevant KPIs instead of treating them as isolated indicators.

Daily reports from operations must also be watched so that current operating conditions can be factored into conclusions. These types of reports include operating pressures and vessel position over wells, and also indicate when wells are shut-in or producing. Since the controlling design case for top tensioned risers involves a shut-in pressure combined with a large offset or vessel tilt, so awareness of the current state of operations is key to understanding of data.

### CONCLUSIONS

An effective integrity management plan for deepwater risers requires feedback on the performance of as-installed riser systems through monitoring of riser response and key

parameters affecting response. Comparison of measured response with response predicted by analysis software and model testing allows operators to:

- Account for uncertainty in design margins and operating conditions
- Determine performance of as-built system
- Trigger additional analysis or inspection of critical at-risk components
- Calibrate analysis tools
- Determine relationship between environmental and vessel loading and riser response
- Provide opportunity for expanding system capability from initial purpose (such as tieback capacity)
- Provide lessons learned to other assets and projects to identify possible failure risks
- Improve riser design on future systems

As monitoring options increase, further understanding of the operation of response of riser systems is possible. This understanding will allow for improvements in existing technologies and development of new technologies which operators can rely upon to function reliably and safely in ultra deep water. The cyclical integrity management process ensures that learning from monitoring, inspection and identified anomalies are incorporated into future design and operating practices, ensuring a safe approach to design and operation with the lowest possible risk.

## **NOMENCLATURE**

ACDP	acoustic Doppler current profiler
DGPS	differential global positioning system
IM	integrity management
IMP	integrity management plan
KPI	key performance indicator
RBI	risk based inspection
ROV	remotely operated vehicle
SCR	steel catenary riser
TTR	top tensioned riser
VIV	vortex-induced vibration

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