**Proceedings of the ASME 27th International Conference on Offshore Mechanics and Arctic Engineering**
**OMAE2008**
**June 15-20, 2008, Estoril, Portugal**

**57018**

# PERFORMANCE MONITORING OF DEEPWATER RISERS

**Ricky Thethi / 2H Offshore Inc.**

**Pei An / 2H Offshore Engineering Ltd.**

## ABSTRACT

Deepwater risers are complex dynamic structures subject to extreme events in the Gulf of Mexico such as hurricanes and high currents. The offshore industry in the Gulf of Mexico is aggressively moving into the ultra deep and developing challenging fields with high pressure, high temperature conditions and corrosive production fluids. Floating production vessels such as semi-submersibles and FPSOs are being selected for these developments and these vessels typically have higher motions than Spars and TLPs used to date.

Consequently, the risers become increasingly challenging to engineer and design margins can be significantly reduced. Uncertainties in design basis data, actual response in the field, and component degradation with time can be effectively managed by monitoring the performance of the riser system in service through direct structural monitoring on the riser in conjunction with vessel and environmental monitoring. Such a system forms an integral part of the integrity management program and can allow anomalies to be identified ahead of time to prevent catastrophic riser failure. This paper puts forward the benefits of riser performance monitoring and describes system based architectures for various development scenarios utilizing dry tree vertical top tensioned risers, wet trees with SCRs, and wet trees with free-standing risers.

## NOMENCLATURE

GoM: Gulf of Mexico
FPSO: Floating, Production, Storage, Offloading
FPS: Floating Production System
SCR: Steel Catenary Riser
TTR: Top Tensioned Risers
SLOR: Single Line Offset Riser
TDP: Touch Down Point
TDZ: Touch Down Zone

## INTRODUCTION

The offshore oil and gas industry has pushed aggressively into deeper and deeper water over the last 10 years. This is particularly true in the Gulf of Mexico, where developments are planned and sanctioned in water depths up to 9,000ft before the end of the decade. Compare this to 10 years ago, when developments planned in water depths of 5,000-7,000ft were groundbreaking and deepwater experience was limited to a few large operators and contractors. Today, many more operators are entering the deepwater arena as past deepwater developments prove successful despite the large upfront capital cost.

A key element on any deepwater development is the riser system for the FPS that allows the transport of hydrocarbons from seabed to surface in addition to facilitating the export of processed fluids and injection of produced water and/or gas. Riser system engineering complexity and cost are very much water depth sensitive as top tensioning requirements increase and mechanical loads increase at the seabed and at the vessel interfaces. The industry has adopted large design factors of safety to address the uncertainties with in-service performance and generally refrained from monitoring in the belief the design margins are adequate for the service life intended. Only one oil major [1] has embarked on a wide-scale deepwater riser monitoring campaign over the last 10 years to better understand their systems and manage structural integrity.

It is the belief of the authors that riser structural monitoring will increasing feature in the tender specifications for deepwater riser systems as Operators and Regulators begin to see the value of such systems to manage asset integrity and reduce operational cost and risk. The following sections detail the case for monitoring and describe system architecture suited to 3 common field deep water development scenarios.

## WHY MONITOR?

Aggressive schedules to meet first oil and financial budgets commitments in times of ever increasing construction costs can lead to oversights in the design process as well as fabrication and installation errors. The risks to a dynamic riser system in service to such practices are great as the number of uncertainties that go into the design and build process are significant and include:

- As-built or installation anomalies
- Long-term and extreme environmental data at site
- Vessel motion response
- Under conservative hydrodynamic response predictions
- Material degradation with time
- Change of service or operating conditions

How far can existing design methods be extrapolated to deep water depths without validating through full scale field measurements? There is ample opportunity for the industry to now obtain this information with the significant number of deepwater developments installed in the Gulf of Mexico and in other deepwater areas. Performance data will yield valuable comparisons of actual and predicted response, which could be shown to be over or under conservative [2]. Either way this information is a benefit to the owner and the industry, as it will help manage risk and optimize design methods resulting in reduced costs in the long-term.

Whilst the current design factors of safety are used to safeguard against these anomalies, they can quickly become eroded if anomalies stack up. The ability to check that the riser system is performing as intended during the first years of its life can go a long way in providing assurance that it is fit for its intended service life. In addition, if field or service conditions change, a riser monitoring system can be used to allow more accurate re-calculation of service life.

In addition to its place in an asset integrity management program that is set up to manage risk and reduce production downtime, other tangible benefits of a riser monitoring program include data to justify field life extension and a performance history that Operators and Partners can utilize in future commercial assessments of their asset.

It is noted that a riser monitoring system is relatively inexpensive compared with other capital costs of a field development and compared to the costs involved with riser structural anomalies and production downtime.

## MONITORING SYSTEM DRIVERS

The scope of a riser monitoring system can vary but the most complete strategy would consist of the following:

- Direct measurements on riser at critical locations
- Measurements on riser to determine global response
- Measurement of environmental loads on riser
- Measurement of vessel motions

The above enables a multiple of objectives to be met such as riser response data to provide operational assistance, data to feed into an integrity management program, and data for use to improve future designs.

Operational assistance is particularly important for drilling and completions risers, which are run and retrieved frequently, have operations carried out within them, and rely on the riser response being within specific limits. Typically, riser angles and curvatures are important once connected to the well and VIV fatigue levels become critical when the riser is unlatched and suspended from the vessel in open water.

For integrity management, measurement of riser structural response can provide high value information such as performance data in extreme events to allow fast decision making to restart operations, early warning sign of integrity issues that could lead to downtime, and fatigue damage accumulation to assess possibility of field life extension.

The industry lacks full scale performance data that demonstrate the robustness of existing installations and validate the analysis tools used to design them. Yet the industry is pushing forward with deeper developments whilst relying on these same tools and factors of safety. Feedback of existing and new installations in extreme events and in long-term conditions is essential for the industry to demonstrate fitness for purpose as it pushes the boundaries further on water depth and pressure.

## DRY TREE FPS

The Gulf of Mexico has many deepwater developments with dry trees using TLP and Spar floating production vessels. In recent years, competition in the dry tree floater market has spawned a number of concepts using deep draft semi-submersible vessels with dry tree top tensioned risers.

Top tensioned risers provide the conduit for hydrocarbons from the seabed to the surface. The riser typically consists of a single or dual casing string in which the tubing is run. At the seabed, the riser is connected to the subsea wellhead and has a lower taper joint to manage the high bending loads in this region. The tree is located in the production wellbay of the FPS. Figure 1 depicts a typical arrangement on a Spar.

The riser passes up through the hull and into the wellbay area where it is either supported by an aircan system or a hydro-pneumatic tensioner system. The interfaces between the riser and vessel and particularly complex and vary significantly depending on the vessel type. For instance, on a Spar, due to the deep draft of the hull form, typically 400-500ft, the riser requires a keel joint to manage the high bending loads in this region caused by large vessel lateral offsets and dynamic pitch motions. This is not required on a TLP due to its much shallower draft and decreased lateral excursions as a result of its vertical tendons mooring system.

For semi-submersibles, the use of dry tree top tensioned risers requires a deeper vessel draft to improve dynamic motions and facilitate workover and intervention activities through the dry tree risers. As such, the increased drag area of the hull and larger lateral excursions of the vessel require the presence of a riser keel joint much like a Spar. TLPs support risers using a tensioner system and they can also be considered on a Spar as an alternative to the aircan system. A tensioner system is more appropriate for semis as an aircan system would be subject to high wave and current loading unlike in a Spar, which has a hard tank to shield the most exposed region of the riser system to environmental loading.

Interface loads at the seabed and at the hull riser guide locations need careful design as structural and mechanical loads increase with deepwater and with high pressure systems. A riser monitoring system for a dry tree vertical system must address all the critical areas as well as measure response parameters that can be used as key performance indicators. These include the following:

- Riser top tension
- Riser stroke
- Extreme stress and fatigue at critical joints
- VIV fatigue along riser

Riser top tension measurement is both used as an operational check that the production system is performing as required and as a key input parameter for analysis to calculate the global response of the riser. Tension is measured in various ways depending on the riser stack up configuration and tensioning method. For instance, on a Spar using aircans to support risers, the riser runs up through a central stem within the aircan assembly and is landed at the top of the upper stem where the aircan buoyancy up-thrust is transferred to the riser. At this interface, compression loads cells can be used to monitor tension. In addition, as an indirect way of top tension measurement, pressure transducers can be used in each aircan compartment to locate any compartment leak damage.

Cylinder pressure in hydro-pneumatic tensioner systems can be used as an indirect measurement of riser tension although assumptions on friction loss in the tensioner system must be made to calculate the load applied to the riser. For direct measurement, strain sensors can be used on the upper riser although this will only provide the tension in the outer casing but this data still provides stick slip frictional response data as the riser bears against lateral guides in the hull.

During hurricane or storm abandonment, vertical stroke of the riser relative to the vessel is a measurement that can be used to check that the riser did not over-stroke and potentially overstress due to compression forces at the riser base in the case of excessive up-stroke, or overstress in the upper riser due to high tensions in the case of excessive down-stroke.

Local strain measurement can be utilized at critically loaded areas on the riser. In the past, long-term reliability issues of conventional electrical foil strain gages in deep water precluded strain monitoring at the lower stress joint and keel joint regions. However, there are number of strain monitoring technologies now available for long-term deepwater application. The lower stress joint is a critical area that experiences high bending loads during extreme vessel offsets and dynamic bending loads as a result of vessel first and second order motions, and VIV of the riser and vessel. The interaction of these loads such as VIV and wave loading is not captured by current analysis tools and instead, large design factors of safety are used to provide margin in service. Similarly, with the keel joint, the interaction of various components of dynamic bending loads is not addressed in current analysis methods. In addition, friction at the keel provides additional complexity and uncertainty in current design practice. Other areas may warrant direct strain measurement such as the tension joint or other upper riser joints above the keel that have a centralizer to manage bending loads.

Strakes are typically pre-installed on top tensioned riser joints to mitigate VIV fatigue. As long as the strakes coverage is adequate over the depth of high current experienced at the site and the strakes are kept clean of marine growth, VIV fatigue should be sufficiently suppressed. However, a VIV riser monitoring system can provide assurance if there is any uncertainty in the through depth current profiles at the site location. Uncertainties in how well riser VIV can be predicted with current tools available in the industry, especially for multi mode and high mode response, requires a monitoring system to capture the global VIV response along the riser.

The method of data transmission is a key decision in the design and implementation of a riser monitoring system. Standalone, acoustic and hardwired options are available, each having their advantages and disadvantages. For top tensioned risers, installation of the riser through any riser guides in the hull poses a risk of damage to any large protruding instruments and cables that have been pre-installed on the riser. ROV installed devices have been used as an alternative although such autonomous devices require periodic retrieval using ROV to download data and replace batteries on the vessel [3]. Next generation acoustic data transmission technology and longer lasting batteries should minimize the frequency retrieval requirements such that ROV intervention of the monitoring system can be scheduled with routine visual inspection. A Spar top tension riser monitoring system is illustrated in Figure 1.

A large diameter surface BOP drilling riser may be employed for grass roots drilling from the floating facility. The riser stack up configuration is similar to that of the production riser utilizing a tensioner system, keel joint and lower stress joint. Monitoring requirements will be similar to that of the production riser except that the monitoring system must facilitate easy retrieval and re-running of the drilling riser. Monitoring requirements for drilling operations should focus on curvature measurements at the high bending regions to minimize wear and key seating due to drill string rotation. It can also be used to track fatigue damage from VIV loading.

## WET TREE FPS WITH SCRS

There are several deepwater semi-submersibles based developments in the GoM that use SCRs to connect subsea trees. For ultra deepwater, the semi-submersible offers increase payload capacity, more deck space and quayside topsides integration compared with the Spar. The use of SCRs on such semis is not without its challenges both in design and installation. The larger dynamic motions of a semi compared with a Spar requires rigorous analysis and greater riser construction quality to ensure strength and fatigue requirements are met. Souring of the reservoir as and when water flooding is used in the reservoir is a particular concern with respect to fatigue life. Sour service typically requires an additional factor of 10 to be added to the fatigue life criteria.

Uncertainties also exist in the soil stiffness at the TDP and in the vessel and environmental data used to predict riser fatigue life. Hence for such corrosion-fatigue critical developments, a coherent monitoring strategy is required that combines riser loading response measurements and internal corrosion assessment through analysis of production chemistry, probes and coupons.

The design of a monitoring system to measure the fatigue response of the riser must ensure that the critical fatigue “hot spots” are captured. The regions of high fatigue damage are well known, namely the TDZ and the hang-off areas. However, in the TDZ, the peak fatigue damage location can vary depending on as-installed conditions such as TDP location, trench size and in-service loading conditions. Hence, being able to place a sufficient number of strain sensors with adequate spacing to capture peak fatigue loading become an expensive and fruitless approach. Rather, measurement of global response can be done by monitoring at a number of discrete locations along the riser and the response extrapolated to all other unmonitored regions of the riser using a global finite element analysis.

Measurement of global response can also help monitor some SCR systems in very extreme events that are designed to see some limited amount of compression. Monitoring the riser global response within the first two to three years of service and comparing the response to that predicted in the design in similar environmental and vessel response conditions will determine if the in-service response is within the envelope of design and provide assurance for future long term and extreme loading events.

The hang-off region of an SCR is a critical area that warrants monitoring to ensure fatigue integrity is not compromised. Whether the SCR hang-off arrangement consists of a flexible joint or a tapered stress joint, the vessel dynamic loading and the internal fluid loading conditions require high standards of mechanical and structural integrity. A number of flexible joints leaks on SCR export systems in the GoM have made the industry collaborate to better understand the loading conditions and failure mechanism, and thus improve the fatigue design methodology that can be applied to monitor existing installations and also be used on future designs.

For flexible joints, monitoring should measure internal pressure, temperature, tension and cyclic rotation. This data can be used to track fatigue life usage over the long-term. The consequence of the flexible joint degrading by creep and excessive fatigue of the elastomer components can result in a hydrocarbon leak and increase bending loads into the riser section below it as the rotational stiffness of the flex element increases. Hence, monitoring the fatigue damage at the first weld below the flexible joint using a strain sensor allows the changes in rotational stiffness and fatigue damaged to be tracked. An SCR monitoring system is illustrated in Figure 2.

Monitoring requirements of a drilling riser with subsea BOP and a completion riser run from the FPS are similar to that described earlier for a high pressure drilling riser system. Drill string wear and fatigue loading at high bending regions can be monitored using angle or curvature sensors on flexible joints and tapered stress joints respectively. However, unlike a deep draft FPS where a drilling riser can be left connected to the well in a hurricane event due to the favorable motions of the vessel, the riser must be pulled on a semi-submersible due to the larger vessel heave response and stroke of the riser. In particular, during hurricane season in the GoM, the riser must be pulled on a semi FPS in advance of surface loop currents approaching 2 knots or greater to prevent unacceptable riser lateral deflections. The severe implication being that the riser cannot be retrieved and is left suspended and exposed to high current VIV fatigue damage as an oncoming hurricane approaches.

In addition, a monitoring system can assist the drilling operations [4] as follows:

- Feedback on operational strategies
- Optimize limiting currents for disconnect decisions
- Optimize stack up and tension setting to manage VIV
- Focus joint inspection priorities
- Quick turnaround on assessment of structural integrity following extreme environmental events

## WET TREE FPSO WITH SLORS

It is likely that there will more FPSO developments in the GoM as complex reservoirs require early production systems and remote ultra deepwater areas lack existing pipeline infrastructure to tie in export lines back to shore. Fields in ultra deep water preclude the use of all flexible risers from seabed to surface. Instead, SLORs will be used that comprise of a vertical steel riser self supported by an aircan and connected to the vessel using a flexible jumper. The risers are tied into the FPSO turret to allow the vessel to weather vane and the turret can also be disconnected and lowered below the wave zone in the event of an oncoming hurricane is approaching.

The SLOR has the benefit of being less fatigue sensitive than SCRs as the vertical steel section of the riser is decoupled from the FPSO motions and has its aircan located well below the high current and wave zone region in the upper water column. Hence, monitoring requirements are less focused on fatigue monitoring of the steel riser but rather on flexible jumper integrity, aircan buoyancy and position monitoring of the risers to assess interference between adjacent risers and between risers and mooring lines.

Flexible risers in service have shown to exhibit integrity issues at the vessel connection interface where high axial and bending riser loads are generated. Failure initiators include excessive in-service dynamic loading, installation damage to the outer sheath or gas permeation into the annulus. Armor wires in the flexible can fail, which sets up the progressive failure path. Monitoring for the early detection of armor wire failure can prevent against a serious failure of the flexible. A monitoring device located around the outside of the flexible to detect small high frequency movements and sounds from the flexible can indicate an armor wire has failed. This information is fed into the integrity management system such that the remaining life of the flexible can be estimated and the appropriate decision made on further action such as to repair or replace.

Similar to top tension risers on a dry tree platform, monitoring the riser tension is required to know that each riser has the required level of tension from the aircan and that no aircan compartments have been compromised. The design of upper riser assembly can vary on the SLOR depending on whether the flexible jumper departs from above or below the aircan. Various tension monitoring devices can be used to measure the tension from the aircan. For example, a shackle load cell or a chain tension sensor can be integrated into a chain link section between the riser and aircan. Linear displacement sensors attached on a special instrumentation spool can be integrated into the chain link. A compression load cell can be used where the riser is landed on top of the aircan.

Acoustic data transmission technology can be used for data transmission of the tension data. Longer lasting batteries should minimize the frequency retrieval requirements such that ROV intervention of the monitoring system can be scheduled infrequently.

Interference between riser and mooring lines maybe a concern on a development with a large number of risers. The SLOR lateral displacements are small due to the fixed seabed foundation compared with mooring lines that drape and slide over the seabed. Position monitoring to locate the top of the aircans relative to the vessel provides a check on clearances between risers. In the disconnected mode, the position of the turret can also be monitored to assist with reconnection operations. Acoustic positioning system can be used for this purpose. The system involves a number of seabed positioning beacons and transceivers attached to the top of the air can and turret. A SLOR riser monitoring system is illustrated in Figure 3.

## CONCLUSIONS

Structural monitoring of riser systems should be an essential part of an effective integrity management program to detect anomalies and reduce risk. In addition, the same data can provide operational assistance and be used to validate existing design tools and practices.

The monitoring system architecture should be designed in accordance with the development scenario and the specific requirements of the riser systems to be used. Dry tree vertical risers require top tension measurement and fatigue damage measurement at critical areas such as the lower stress joint and keel joint. SCRs require measurements at the FPS hang-off location to track fatigue loading and provide hang-off tension and angle. Any SCR monitoring system must also provide fatigue measurements in the TDZ. SLORs are less fatigue sensitive and their monitoring requirements involve top tension measurement, riser position as a check for interference with adjacent structures, and flexible jumper integrity at the vessel interface.

There are various methods of achieving these monitoring goals with respect to capturing response at critical locations through either local or global riser system measurements, and the method of data communication back to the FPS. The right solution for a particular riser system requires upfront engineering to ensure the balance between accuracy, reliability, robustness and cost is achieved.

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# ANNEX A

# FIGURES

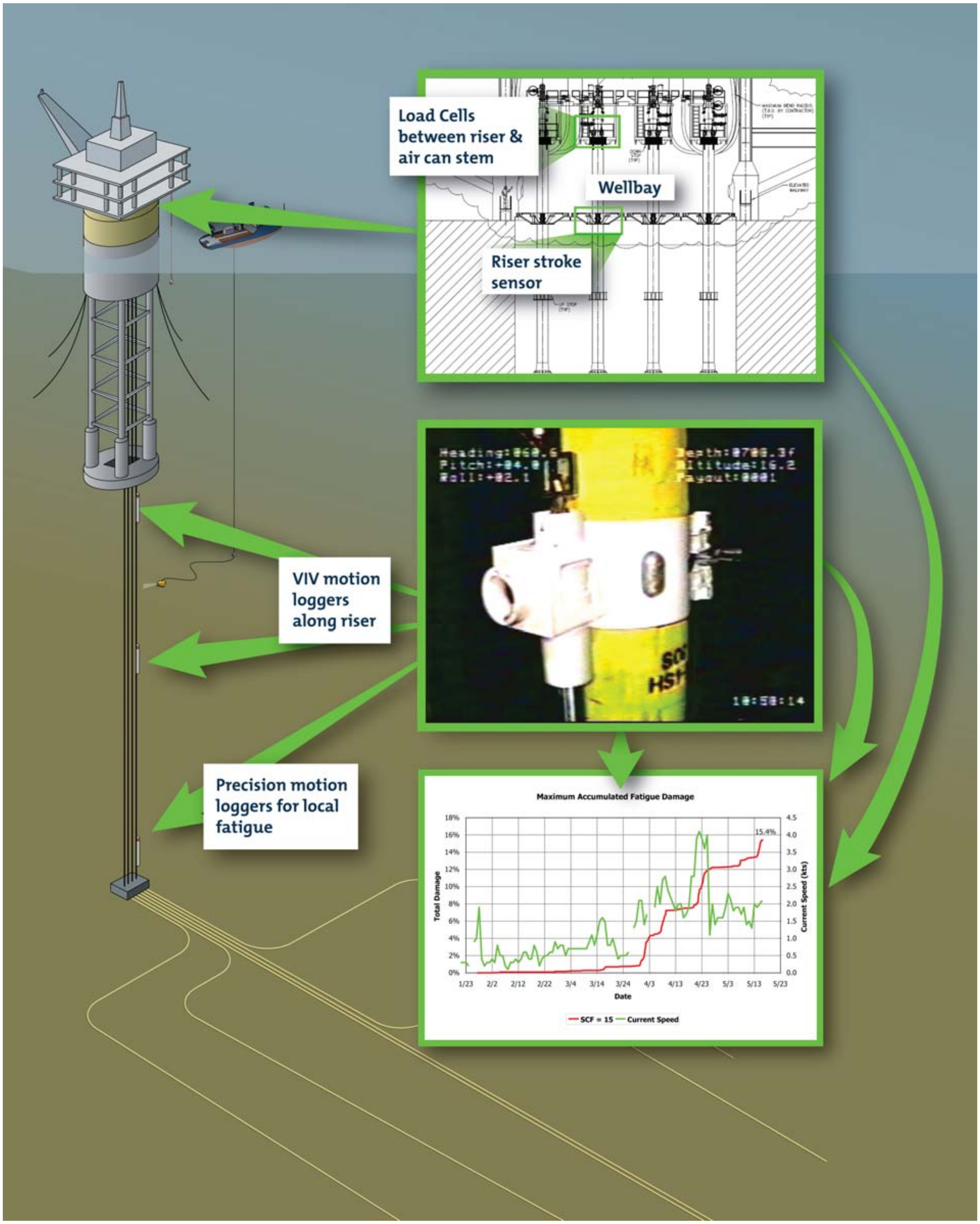


**Figure 1 - Typical Monitoring System for Spar Top Tensioned Riser**

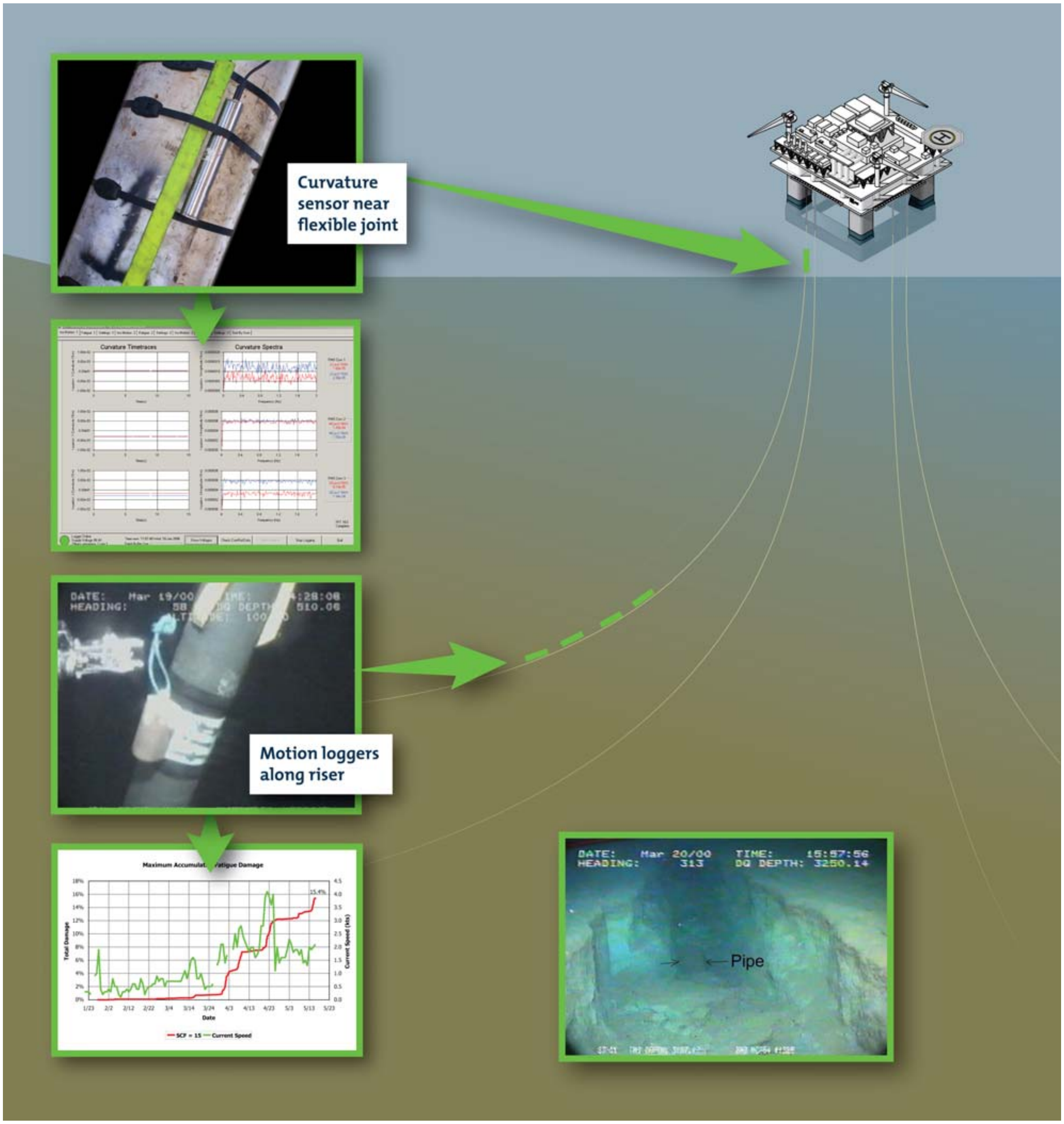


**Figure 2 - Typical Monitoring System for Semi with SCRs**

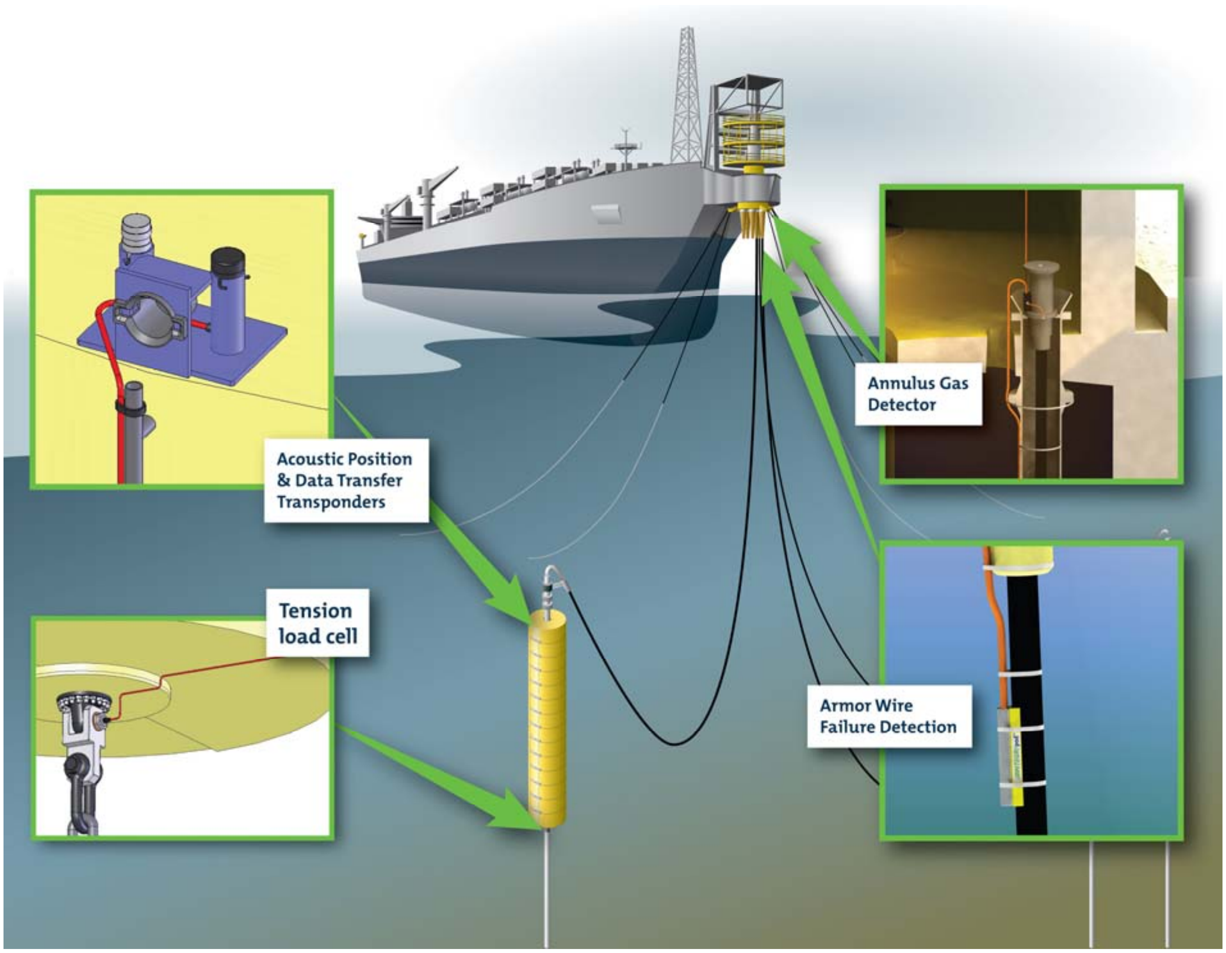


**Figure 3 - Typical Monitoring System for FPSO with SLORs**