Review and Evaluation of Riser Integrity Monitoring Systems and Data Processing Methods

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ABSTRACT

The paper discusses an integrated approach to deepwater riser integrity monitoring. Integrity monitoring is key to asset management and to ensuring functionality and operability throughout the life of the field. Riser response monitoring is one of the main indicators that provides critical performance data during day to day operation and in extreme events. Monitoring also enhances the understanding of complex riser behavior leading to improvement in future design practices.

The paper discusses the various approaches to riser monitoring that suit specific objectives and requirements. A number of existing and planned monitoring programs are reviewed with particular focus on the level of success achieved. Description of riser monitoring techniques, equipment used and methods of installation are also provided. Monitoring instrumentation and applications are discussed from the "fit for purpose" perspective, highlighting how they suit the monitoring objectives, reliability requirements and ease of use.

The second part of the paper discusses the example monitoring projects and added value of the data that riser monitoring provides. The data processing for real-time systems differs significantly from the stand-alone techniques that can be employed on shore post data gathering. The methods are discussed from a twofold perspective. One focus is to provide information that can be used on the offshore facility during day to day activities for enhancing the decision process. Another is to provide information that can be used on the shore in the continuous effort to better understand riser response.

In summary, the paper discusses the relative benefits and problems associated with real-time, stand-alone and acoustic monitoring systems in adding value to the integrity management of deepwater risers.

ASSET MANAGEMENT

Records in deepwater oil and gas exploration are being set every year. Oil is current being produced in water depths up to 7,000ft and drilling activities are ongoing in water depths up to 10,000 ft. This presents significant challenges to equipment used to connect seabed to surface, such as risers and mooring systems. Deepwater risers for drilling, completion and production are subject to particularly harsh loading conditions from internal fluid pressures, the environment, vessel motions and from internal and external corrosion. In many of the deepwater reservoirs, it is common to observe high temperature, high pressure, and corrosive fluids, which when combined with the deepwater environmental loads, present challenges to the fatigue performance of deepwater riser systems. Furthermore, one of the major concerns regarding deepwater riser design is the uncertainty in design data, particularly environmental data, which is ever changing due to recent extreme events and in the frontier regions of the world, a lack of available site data compounds the assumptions made in prior to commencing riser and design.

Due to these reasons, the focus on riser performance during extreme events and over the long term is increasing. Recent failure events, in drilling risers have led to riser monitoring campaigns in order to measure, full scale riser response in the natural environment instead of relying on small-scale test programs. In addition, riser integrity management programs have been established with BP taking the lead with an industry first full riser assurance program to cover 7 of their deepwater assets in the Gulf of Mexico [1]. Risk based techniques provide the means by which business, safety and environmental consequences of a loss of integrity of a riser are assessed against modes of failure and the probability of such a failure mode occurring [1]. This allows for active management of assets, minimizing failure probabilities with known margins while at the same time optimizing integrity monitoring efforts. In order to ensure success of integrity management plan, it is essential that information of riser in-situ response is available. This can be achieved by riser integrity monitoring systems.

RISER RESPONSE MONITORING SYSTEMS REVIEW

Riser integrity monitoring is one of the main indicators that provides critical performance data during day to day operation and in extreme events enabling effective riser management. Riser integrity monitoring also enhances the understanding of complex riser behavior leading to improvement in design practices, often referred to as "closing the loop" on design. Riser integrity response monitoring is a broad concept, and includes many disciplines. However, the focus of this paper is on monitoring of riser structural response.

Riser response monitoring systems can be categorized by the way the power is supplied and communication maintained with the monitoring equipment. Typically there are three types of riser monitoring equipment:

- Autonomous (stand-alone power and data storage)
- Real-time (continuous power and communication transmission)
- Acoustic (stand alone power, semi-continuous communication transmission)

Stand-alone monitoring instrumentation does not communicate continuously with the data processing center. Stand-alone monitoring systems are equipped with memory and battery packs. The instrumentation is periodically retrieved to download the data and install new batteries. This requires access to the monitoring equipment which is achieved either by ROV or during riser retrieval, applicable for drilling and completion risers. The data obtained is processed onshore and the response characteristics of the riser system determined.

Real-time monitoring is achieved by providing continuous power and communication link to the instrumentation devices, what ever they may be. The power and communication link is required to be provided by cables.

Acoustic systems are a combination of the real time and stand alone. Acoustic systems enable quasi real-time monitoring as power has to be supplied separately, typically in form of the batteries, but the data stream can be designed to be real-time.

For acoustic and real-time systems the information is available at the offshore facility. It can then be automatically processed by the onboard data processing equipment. Data can be displayed locally and shared with other facility monitoring and control systems as well as made available for onshore access through network connection.

The following is the comparison of the monitoring methods by the key design considerations:

Power Consumption:
In general monitoring equipment is desired to be low power (>10 W per node). Stand-alone and acoustic systems have much more stringent limits in terms of power consumption. Acoustic systems also require large battery packs to supply communication functions from the modems. Real-time systems are much more flexible in this regard and can accommodate the full range of monitoring equipment, without the need for replacement of battery packs.

Data capacity
Riser monitoring systems can generate large amount of data over long periods of time. The amount of data generated depends on the number of instruments in the system, but data rates in the range of hundreds of megabytes a day are not uncommon. Stand-alone systems are limited in the amount of data they can handle by memory size, but current technology allows for instrumentation to be working for several months at the

time. Often, the battery limit is the key driver in terms of duration of logging on a single deployment. Example stand-alone VIV motion monitoring includes recording 3D acceleration and 2 plane angular rate measurements. Measurements are taken with 10 Hz frequency for 15 minutes every 2 hours. This enables 3 months of logging period between data retrieval and battery replacement.

Acoustic systems are limited by the transfer rates, and additionally by the amount of power required to send the large data quantities, again linked to battery capacity. Acoustic system, that sends information on riser response during presence of loop currents and only summary date during calm periods allows for retrieval of instrumentation once a year. Such systems can be controlled from the facility and the logging program can be changed on demand.

Real time systems, although not without limitation, can comfortably accommodate extensive requirements in terms of data rates within conventional communication technology.

Data synchronization

In terms of data synchronization real time systems provide superior capabilities. Acoustic and stand-alone systems are limited by accuracy of the speed of sound measurement and of the internal clocks respectively. Typically stand-alone systems can only provide gross synchronization. However, gross synchronization is acceptable if processing is conducted in frequency domain, assuming stationary response over a period of time (ie 10 min). Such processing is appropriate for most of riser monitoring programs, [2], [3], [4]. The example drivers for very accurate synchronization are such phenomena as traveling wave and higher order harmonic response during VIV or studying riser response during hurricane, which may require precise synchronization with facility measurement systems.

Installation

Installation of real-time monitoring systems involving power and communication cables presents the most challenges and is one the main design interface drivers. The addition of cables to the monitoring instrumentation requires additional resources and expensive equipment. Cable installation is very hard to achieve post riser installation (i.e. with ROVs), and thus it is usually conducted together with riser installation. This increases complexity and extends riser installation time. It is particularly challenging on production and export risers, installed either by J-lay or S-lay vessels which are not set up for parallel cable installation. In the case of completion or drilling risers, the task is somewhat simpler, as various control lines are already being run together with the riser and appropriate facilities and procedures are already present.

Reliability and repair

Reliability of the monitoring system is the function of the reliability and number of its components and system architecture. Real-time monitoring systems are much more complicated and have many more components than stand-alone or acoustic systems. This is due to the requirement for cables and connectors. Thus, by definition real time monitoring systems are statistically less reliable than autonomous stand-alone systems. Repair of the real-time systems is also more complicated, if at all possible, than stand-alone or acoustic systems. Provision for the correct level of redundancy repair needs to be accounted for at the design stage and may become one of the key design drivers having significant impact on monitoring system architecture and complexity. Stand-alone and acoustic systems are easily repaired by simply replacement of the faulty components or subsystems. The reliability requirements of the components for real-time systems are much higher, as the systems are submerged over their whole life. Failure Mode Effects Analysis (FMEA) allows identifying the most critical components and improving the design to provide adequate reliability levels. Mean Time Before Failure (MTBF) analysis is required to prove that design life of the whole system.

Redundancy

Stand-alone and acoustic systems are naturally redundant. Typical designs of distributed stand-alone systems limit failure consequences to one instrument, which is not significantly detrimental to the quality of the data. Redundancy is also less of the problem, as the stand-alone and acoustic systems are easier in repair.

Real-time systems require redundancy consideration to be taken into account at design level. Additional equipment needs to be provided in order to assure single point failure is not possible. Redundancy can become one of the major design and cost drivers in case or real-time systems. Redundancy can be achieved at different levels. At single instrument level, it can be realized by providing redundant electronics and water ingress barriers. At system level, instruments can be made redundant by either adding more instruments or grouping them such that they are connected to separate power and communication lines within the same umbilical. Another level of redundancy can be achieved by providing additional umbilicals. However, this is typically avoided due to high impact on installation, interfaces complexity and cost.

Interfaces

Interfaces of riser monitoring systems can be divided into following categories:

- Riser
- Subsea equipment
- Facility

In terms of riser interface, there are no significant differences between the real-time, stand-alone and acoustic systems. However, riser interface depends greatly on the type of monitored parameters. Motion sensors are typically easies to install on the riser, as it can be achieved by simply strapping the sensors to the pipe. There is number of various types of strain monitoring systems, which significantly differ in terms of riser interface. Generally, there are two types of systems – with transducers (electrical strain gauges or fiber optic sensors) either bonded on the pipe and measuring direct strain or enclosed in a device that transfers pipe deformation and protects the transducers from water ingress. The former type is usually easier to install and more applicable for offshore use, especially for coated production risers.

In terms of interfaces with subsea equipment, the real time systems can be far more complicated than acoustic and stand-alone systems. The requirement for power and communication cables may require interfacing with field layout and other subsea equipment such as production controls. This requires making provision for the real-time riser monitoring systems at the early stage of the field development. Stand-alone systems have minimal impact on field development as the interface is practically limited to riser interface and typical ROV operations. The interface of acoustic riser monitoring systems are also relatively simple, however consideration has to be given to ensure the compatibility of the riser monitoring system with other acoustic systems used offshore.

Facility interface of the stand-alone system is very limited, if any. The acoustic systems require topside modem/receiver to communicate with the subsea instrumentation. Real-time systems need provision for entry of the subsea cabling onto the platform. Both acoustic and real-time systems require on-board cabling and equipment to store and process the data. It may be also required to provide network interface in order to share the data with other monitoring and control systems present at the facility.

RISER RESPONSE MONITORING SYSTEMS – EXAMPLES

Riser response monitoring systems can be used for range of reasons and suit various objectives. Many such systems are designed and installed to solve specific problem rather than provide general understanding of riser response. The following are the examples of riser monitoring systems that illustrate the diversity of applications:

Stand-alone:

Top tension riser and conductor monitoring. The objective of the system is to monitor the top tension riser response and it's impact on the conductor fatigue damage. The monitoring system consists of set of stand-alone motion sensors along the riser and at the lower taper joint. Data is processed onshore and fatigue tracked over a period of time. This enables to verify if conductor design is fit for purpose

Drilling riser and conductor monitoring. The objective of the system is to assess the fatigue damage accumulation in the conductor connector during drilling operations. The system consists of stand-alone motion sensors that measure BOP vibrations. The data is then used to extrapolate bending moments in conductor and assess accumulated fatigue damage over time.

Drilling riser VIV downtime support. The objective is to assess the extent of VIV fatigue damage during loop current and provide rationale for stopping or continuing drilling operations. The set of stand-alone motion sensors is deployed with ROV and data is gathered over a short period of time. The sensors are then retrieved and data is processed in-situ allowing for making operational decision.

Drilling riser long-term VIV monitoring. The objective is to understand riser VIV response during loop currents and track the VIV fatigue damage accumulation. The set of stand-alone motion sensors is deployed either during riser running or with the ROV. Logging period is approximately 3 months after which data is retrieved and transferred to shore for processing. Data is then analyzed and fatigue damage accumulation calculated. Data is also used to calibrate VIV analytical tools, such as Shear7 and which in the longer run allows for formulation of more accurate design methodology.

Real-time:

Flexible joint fatigue monitoring. The objective is to ensure flexible joint structural integrity. ROV/diver deployed real-time monitoring system measures riser bending and joint rotation. Data is processed real-time and results displayed on the rig. The gathered data allows calculating flexible joint stiffness and, by comparison with as-built parameters, assessing its integrity.

Drilling and completion riser monitoring. The objective is to track fatigue damage at several fatigue critical points and provide information for rationalizing inspection intervals and benchmarking analytical models and verify the design. Real-time strain and motion sensors are installed on the bottommost riser joints during riser installation. Power and communication is provided via umbilicals connected to riser control systems and then via riser control umbilicals. Data is processed real-time and fatigue accumulation displayed on the vessel.

Rig move support. The objective is to measure riser response during rig move in order to optimize vessel speed and ensure riser structural integrity. Acceleration and angle is measured real-time at single location on the riser near water line. This allows to calculate riser angle and provide gross assessment of riser VIV and fatigue damage rates and thus to present information supporting operational decisions.

The following are more detailed reviews of two stand-alone and real-time monitoring systems, which in view of the author utilize the inherent benefits of these two methods in particularly efficient way.

Stand-alone drilling riser monitoring systems

The stand-alone drilling riser monitoring systems have been successfully used on the number of projects in Gulf of Mexico, offshore Brazil and North Sea [1]. The typical system consists of number of stand-alone motion loggers distributed along the riser length. Motion loggers record a combination of motion parameters such as accelerations, angular rates and inclinations. The data is stored locally and retrieved either with the ROV or during drilling riser retrieval. The data is then transported on-shore and processed to establish riser global response as a function of time. This enables for calculation of the fatigue damage rates along the riser and the fatigue damage accumulation, which allows for ensuring structural integrity of the riser and provides feedback for planning of maintenance and inspection activities, and provide valuable data to calibrate VIV design tools. Accuracy in the extrapolation of response to the non-monitored regions of the riser depends on the selection of the instrumentation locations. Detailed studies are conducted in order to determine the number and locations of sensors that give optimal utilization of measured data, [3]. The example distribution of the loggers along the riser is shown in Figure 1. The 2H INTEGRIpod-M motion loggers are shown in Figure 2.

The data gathered during monitoring campaign is gathered every three months and then processed and analyzed to provide information on riser response. The example plot of acceleration amplitude spectra along the riser during 30 min period is shown in Figure 3. This information is then used to provide fatigue damage accumulation during monitored and to better understand riser response. Data shown in Figure 4, which summarizes a number of monitoring campaigns conducted on drilling risers, suggests that VIV predictions are an order of magnitude higher than actual response, and thus operating windows may be excessively tight [2].

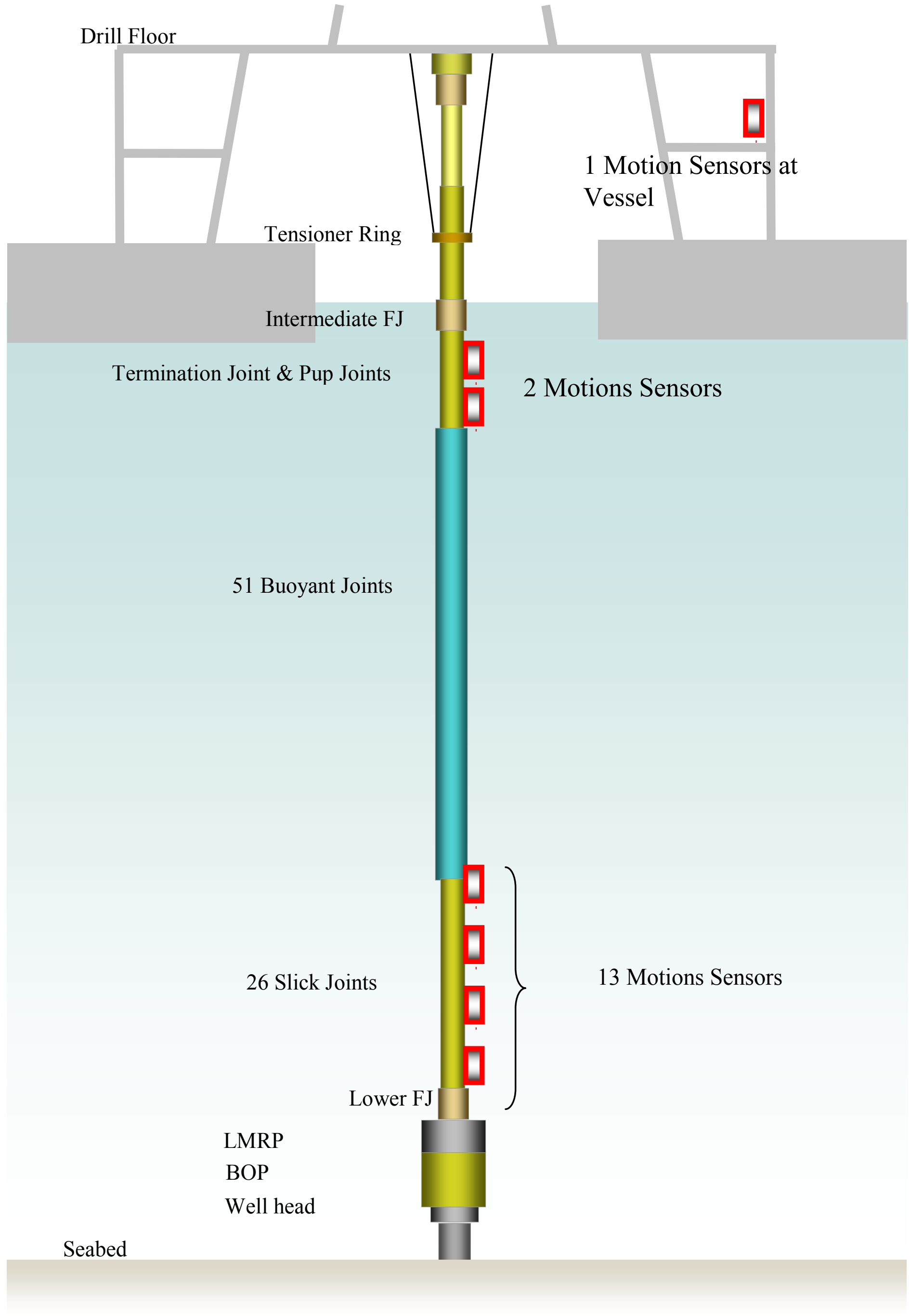


Figure 1 - Stand-alone Drilling Riser Monitoring System

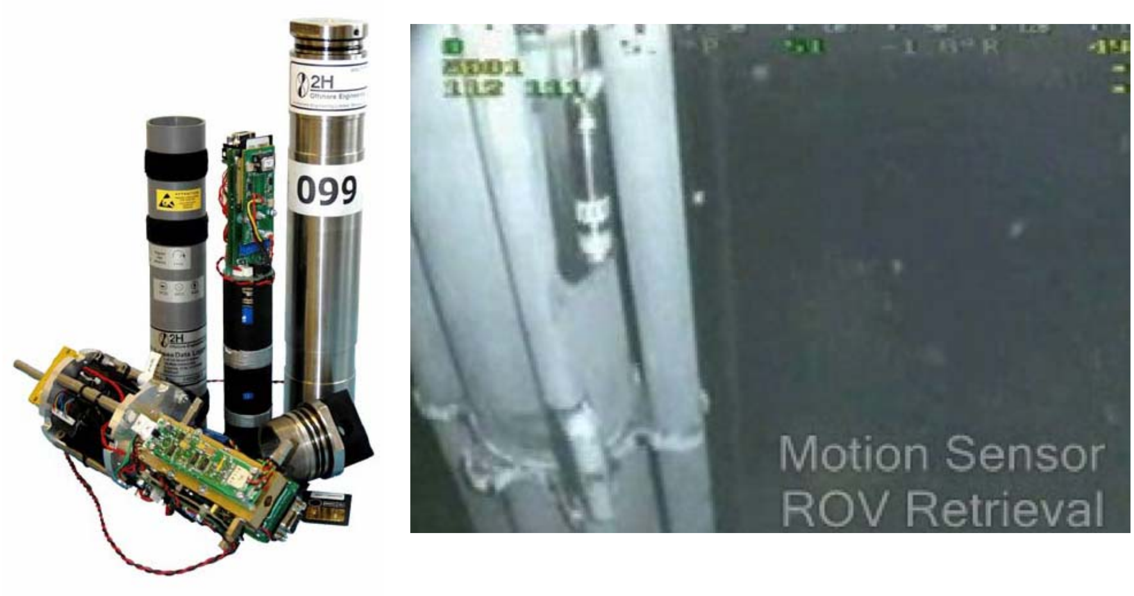


Figure 2 - 2H INTEGRIpod Stand-alone Motion Logger

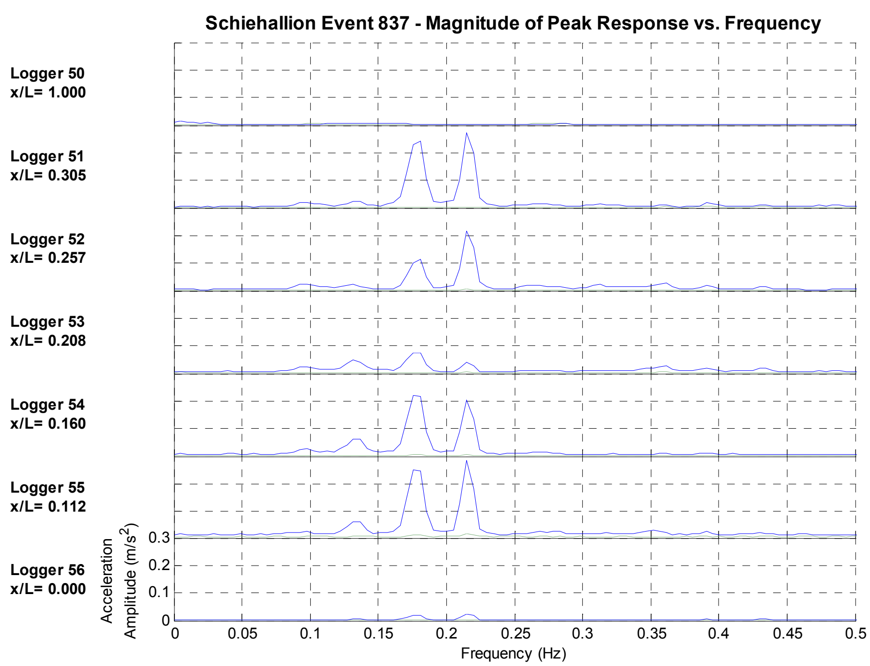


Figure 3 – Drilling Riser Spectral Response Showing Multi-Mode (3 and 4) VIV, [2]

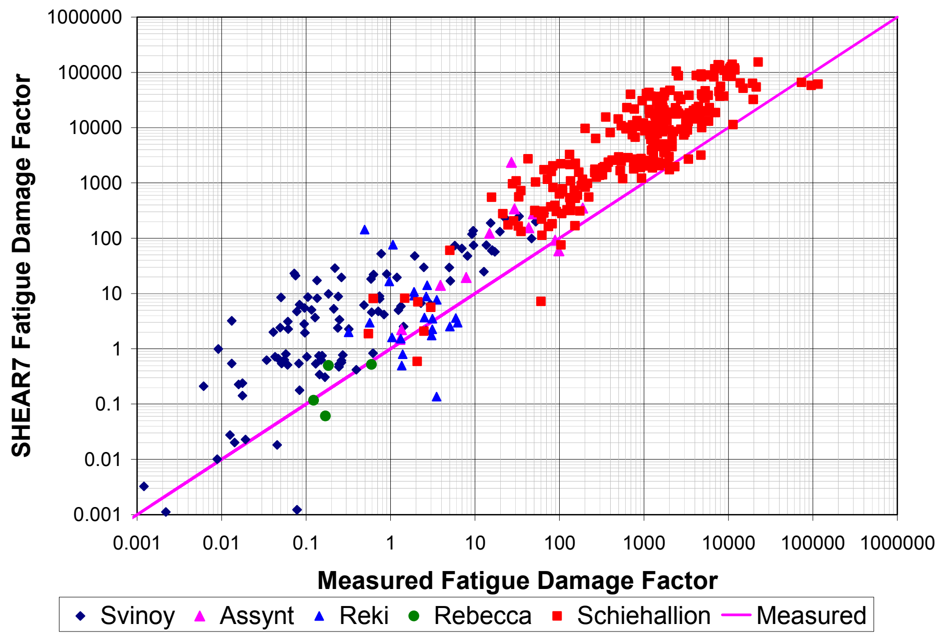


Figure 4 – Fatigue Damage Factor Comparison, [2]

Real time completion riser monitoring system
Completion risers have complex geometry as the main pipe is accompanied by the annulus pipe and relatively large control umbilical causing problem with establishing hydrodynamic response. In addition, relatively low tension is applied to the riser during installation and while connected, which causes VIV and potential fatigue problems. In order to help riser installation it is required that monitoring system provides the real-time data to the rig. The real-time system is limited to strain measurements at the top and bottom of the riser, which, based on analysis, are believed to be fatigue critical. The top measurement locations are connected via dedicated cables to the topside data acquisition center. The bottom location is connected via power and communication lines that are accommodated in the riser control umbilical, which removes the requirement of the dedicated cable. Based on strain measurements, fatigue damage rates are calculated and fatigue damage accumulation traced over time. The GA of this system is shown in Figure 5 and the example real-time user interface in Figure 7. Due to requirement of ease of installation and reparability of the strain measurement devices external (not bonded) strain measurement devices are used. The example of such device, 2H INTEGRIstick is shown in Figure 6.

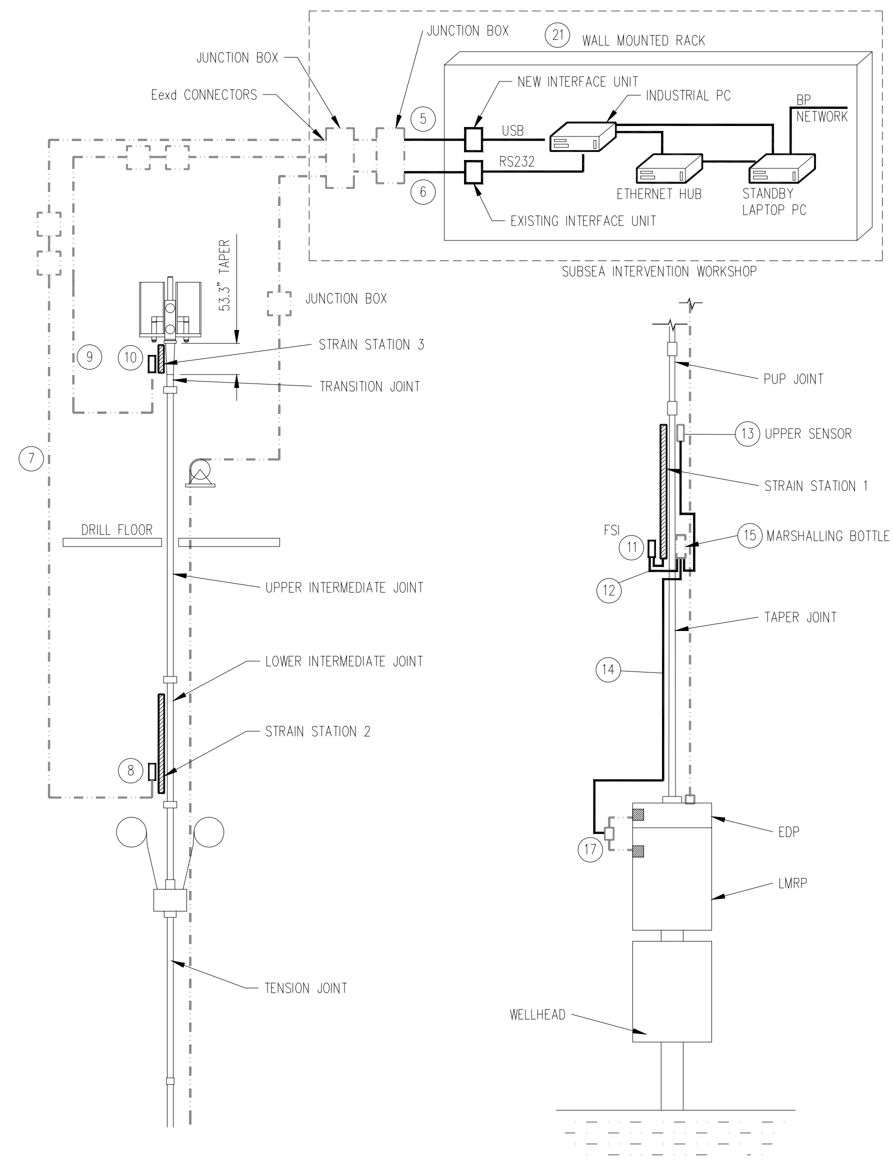


Figure 5 – Completion Riser Real-time Monitoring System

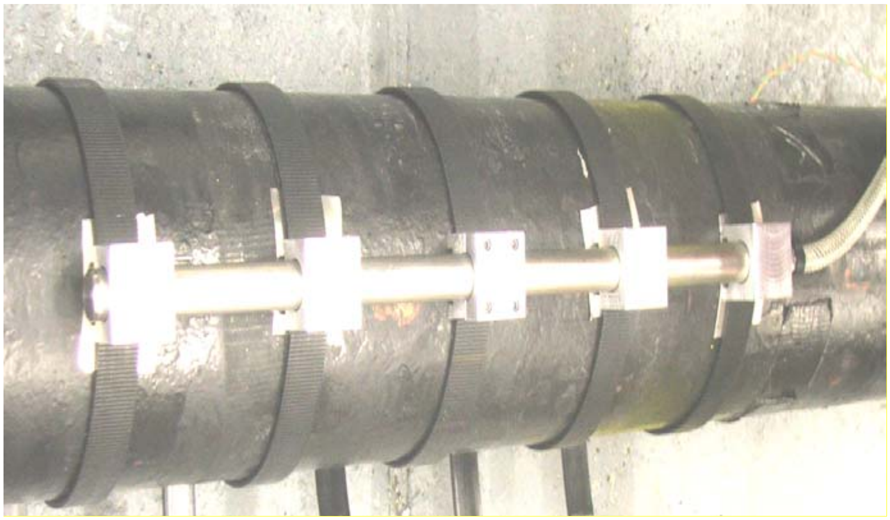
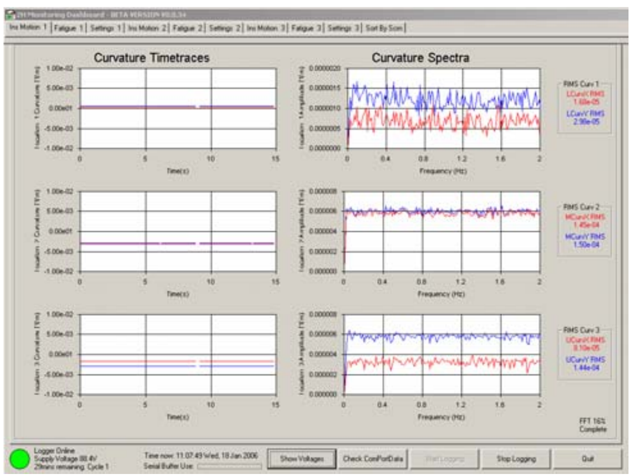
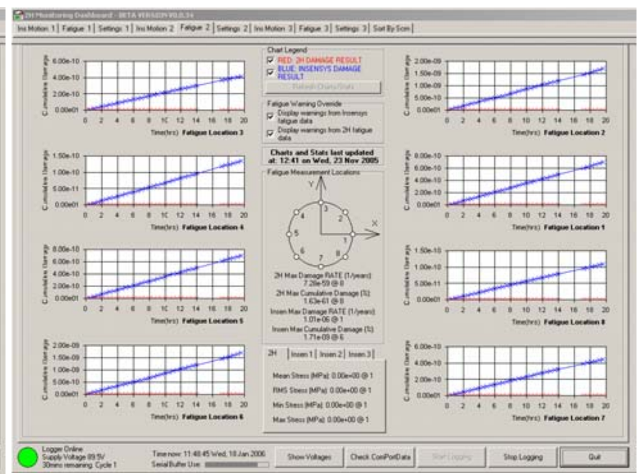


Figure 6 - 2H INTEGRIstick Curvature Monitoring Device



Curvature Data



Processed Fatigue Damage Data

Figure 7 - Real-time Monitoring System GUI

SUMMARY AND CONCLUSIONS

Riser response monitoring systems vary greatly in terms of scope and complexity. In general, key deliverables of the riser monitoring are the following:

- Reducing risk and ensuring the riser structural integrity.
- Provide information to better rationalize maintenance and inspection plans.
- Provide information about riser response to help guiding operational decisions.
- Improving the design techniques, by supplying data to verify understanding of riser behavior and provide basis for its further development.

The main division of the riser integrity monitoring systems is between real-time and stand-alone systems. Both of these solutions have their pros and cons and can suit different application.

Real-time monitoring systems are particularly applicable for discrete monitoring of limited number of locations that are believed to be critical to riser structural integrity. Real-time monitoring is also required when data is necessary on the rig to support operational decisions or when very accurate synchronization of the transducers is essential. Real-time monitoring are much more complex and expensive than stand-alone systems and thus not particularly suitable for monitoring of riser global response when coverage of long sections of riser is necessary. Real-time systems may require significant level of integration with other equipment and thus may present significant challenges if post-installation is considered.

Stand-alone systems are much simpler and less expensive than real-time systems. They are particularly applicable for monitoring riser global response, where number of transducers is required covering large percentage of riser length. By definition, they are post-installation friendly and thus can be used with existing riser systems. Stand-alone systems are not suitable if data is required to be available at the facility or when vary accurate synchronization is necessary.

Acoustic systems are the combination of the stand-alone and real-time system and could be classified as quasi real-time. They don't require umbilicals, and installation is conducted either using ROV or during drilling and completion riser installation. The acoustic link allows for real-time access to measurements. Synchronization can be achieved with acoustic signals, which should be sufficient for majority or real life riser response frequency range.

It is considered by the authors that the development of acoustic riser monitoring technology may become the system of choice in the future with its ease of installation, minimal riser and subsea equipment interfaces, and ability to provide real-time data access to assist in operational decisions.

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