

Design consideration of monitoring systems for deepwater steel catenary risers (SCRs)

Mateusz Podskarbi

Dave Walters

2H Offshore, Houston, TX, USA

Steve Hatton,

2H Offshore Engineering, Woking, UK

Metin Karayaka

Chevron, Houston, TX, USA

ABSTRACT

Steel Catenary Risers (SCR) are critical dynamic structures with a complex fatigue response. The prime fatigue contributors are vortex induced vibration (VIV) and riser-seabed interaction. There is industry wide acceptance that a reasonable level of uncertainty exists with respect to the ability to predict SCR fatigue performance. Despite this, only a small number of installed SCRs have any instrumentation to monitor dynamic response.

This paper will establish the basis for configuring monitoring systems to characterize vessel, wave and VIV induced riser response, riser-seabed interface, and discontinuities at the hang-off locations. The monitoring system configuration drivers will be reviewed in detail such as: monitoring objectives, instrumentation requirements, architecture, field development integration, and installation.

A well specified instrumentation package enables the structural integrity of the SCR to be confirmed throughout the system life. Monitoring systems can provide the operator information on riser response in support of integrity management, maintenance practices and design validation.

Monitoring objectives are discussed and event characterization methodology presented with regard to selection of sensors and location in order to adequately capture riser response with respect to VIV, wave and vessel induced motions, and riser-seabed interaction.

The key aspect of real time monitoring systems for SCR's is **system integration** with the existing infrastructure. The following areas are critical interfaces to ensure the success of a SCR real time monitoring system:

- Provision of power and communication
- Instrumentation device installation strategy and monitoring system architecture
- Post installation maintenance and redundancy provision

The paper will discuss the methods available to address these key aspects.

The paper presents in detail an example real time SCR monitoring system that maximizes monitoring capabilities and minimizes the impact on riser installation, mitigating cost and associated risk, whilst maintaining the ability to provide **added value** to the project.

The output from SCR monitoring systems will provide the industry with critical information on the dynamic response of these complex, fatigue driven structures. This enables verification of the design and reduces the uncertainty involved with response prediction and changing environmental conditions.

INTRODUCTION

Steel Catenary Risers (SCR) are critical dynamic structures with a complex fatigue response. The prime fatigue contributors are vortex induced vibration (VIV) and riser-seabed interaction. There is industry wide acceptance that a reasonable level of uncertainty exists with respect to the ability to predict SCR fatigue performance. Yet, SCRs are successfully used in water depths up to 8000ft.

Riser monitoring is employed for two primary objectives:

- Integrity monitoring
- Providing information on riser response

The paper discusses the design consideration of monitoring systems for deepwater steel catenary risers. Riser response monitoring is a key indicator that can provide the operator with critical performance data during day to day operation and in extreme events. This information further enhances the understanding of complex riser behavior in order to improve design practices. The importance of riser monitoring is further increased due to uncertainties in the design data and prediction of the riser response to complex loading environments.

Risers are monitored to provide information on riser response due to environmental and operational loads. Environmental loads include direct action of waves, currents and hydrostatic pressure. Operational loads include temperature and internal pressure. Risers are also subject to vessel motions driven by environment and operational requirements. Monitoring equipment provides data on riser response during day to day loading (fatigue monitoring) and during occasional events, such as

loo hurricanes or significant vessel offsets.

This relies on systems measuring riser dynamic response due to external loading. Physical quantities that are typically measured to characterize this response are motions and strain. Drivers for equipment selection and location of the instruments are discussed.

In addition to requirement of supplying adequate data to meet monitoring program objectives, monitoring system design is also driven by existing infrastructure and riser installation methods.

The success of the monitoring system often lays in combining these two often conflicting requirements: measurement of riser response and practicability of installation and integration with the existing infrastructure.

MONITORING OBJECTIVES

At higher level, riser monitoring objectives come under two categories:

- Integrity monitoring
- Providing information on riser response for R&D

In general, integrity monitoring focuses on critical regions and does not necessarily strive to capture riser general response that is often a requirement of more R&D driven monitoring programs. The following are prime concerns for riser design, that will also drive type, number and location of monitoring instrumentation:

- Vessel and wave induced motions
- VIV
- Riser-seabed interaction
- Discontinuities at the hang-off locations

There are two regions along the SCR that experience highest stresses and fatigue damage: hang-off location and touch down zone (TDZ). Thus both design and monitoring programs are focused on capturing the response at these locations.

Hang-off region is relatively simple to analyze and monitor. Highest stress peak are observed in the direct vicinity of the attachment point and are managed by various stress relief methods such as flexible joint, tapered joint or pull tube. Loading at this point is driven by vessel motions and riser VIV. Vessel motions are typically well understood and riser response due to them is relatively easy to measure. VIV is a more complicated phenomenon affecting the entire length of the riser and thus special measures have to be employed to adequately capture riser response due to VIV.

Stress distribution along the TDZ is much more complicated. It depends highly on soil properties and riser-seabed interaction. It is also hard to exactly establish riser touch down point (TDP) where highest riser stresses are concentrated. SCR TDP changes location depending on vessel position, riser trenching and current. Vessel position is dependant not only on selected location, but additionally driven by environmental conditions such as wave, current and wind. Thus TDP location during one event such as storm or high current maybe significantly different from another. All these has to be taken into account during the selection of parameters for measurement and placement of the instruments.

The following sections give a concise description of riser response due to various loading and discuss location and type of instruments required to capture it.

Vessel and wave induced motions

As discussed above critical regions of the SCR are at TDZ and hang-off location. Typical stress distribution along the length of the SCR in 100 year storm is shown in Figure 1. High strain regions are below riser hang-off and at TDZ.

High stress zone at hang-off is limited to 20-40 ft directly below the attachment point. To capture this stress, several strain gauges located as close to the attachment point as possible are adequate.

High stress region at the TDZ are distributed over a much longer distance of several hundred feet. In order to capture peak stress at TDP using local strain measurement it is required to take measurement every few feet over several hundreds of feet. However, this is not recommended from both practical and economical standpoint. To overcome this difficulty, it is suggested that the overall riser response be captured with system of widely distributed motion measurements and then stresses be calculated at TDP location. The drawback of such approach is that it does rely on the soil properties and riser-seabed interaction model. The verification method of such models is given in the following sections. This method allows for calculation of stresses along the whole riser length, including hang-off location.

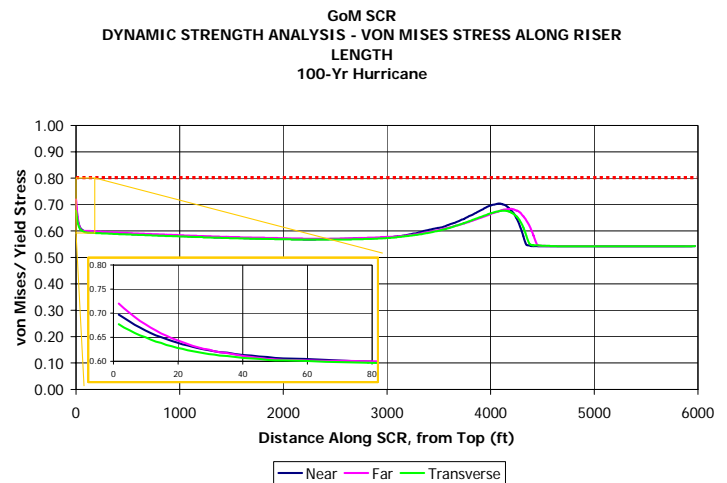


Figure 1 – Dynamic Stress along the Riser

VIV response

Riser VIV response is significantly different from wave and vessel motions driven response. The VIV response is driven by riser modal shapes. Stresses are relatively high along the whole length of the riser with distinct, localized peaks at TDP and below the hang-off location. As with wave and vessel motions driven response, touch down zone extends over several hundreds of feet. Local peak below hang-off, which is due to rotational restraint, covers the range of 20 ft as shown in Figure 2. To assess the VIV response it is required to know which modes of vibrations are excited during the event. This is achieved by capturing riser global response and performing modal decomposition of shapes of vibration. Current experience shows that number (between 5 and 15 for deepwater applications) of distributed measurement points – typically capturing motions – is most adequate to capture riser VIV response. Detailed studies are conducted to optimize number and location of sensors in order to capture expected modes with adequate accuracy.

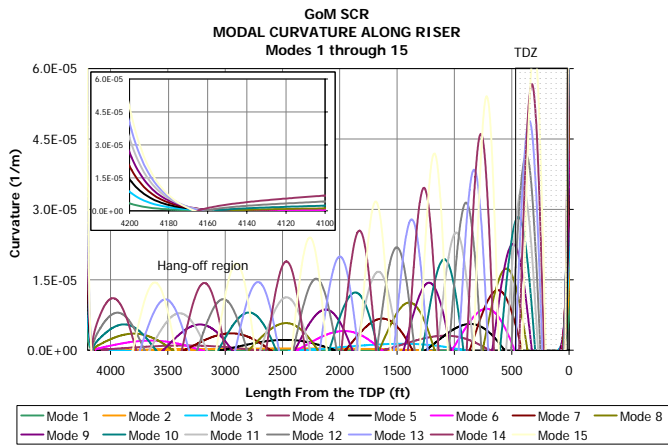


Figure 2 –SCR Modal Curvature

Riser-seabed interface

Riser seabed interface is a one of the most difficult areas in SCR design. Challenges related to riser monitoring are the following:

- No exact definition of touch down point location
- Capturing riser-seabed interaction

Riser TDP location can be captured by measuring global shape of the riser. This can be done either by strain measurement or by angle measurement. Both measurements need to be processed in order to obtain riser shape. It is hard to obtain stable, long term, static measurement of strain on the pipe. Thus, monitoring of angle for this purpose is recommended. A number of angle measurement devices distributed along the lower portion of the riser can be used to capture the TDP location with an accuracy of a few feet depending on the riser length.

Riser seabed interaction can be captured using following methodology:

1. Capture riser global response
2. Assume riser-seabed interaction model
3. Calibrate the model based on the measured riser response

An example of application of this method during STRIDE JIP is shown in Figure 3. The dynamic envelope of bending moment from various models is compared with results of dynamic strain measurement obtained using strain gauges. This allows for calibration of the riser-seabed model and calculation of the response along the entire riser length. For a deepwater SCR, strain measurements would have to be taken over several hundred feet in order to capture data required for this analysis.

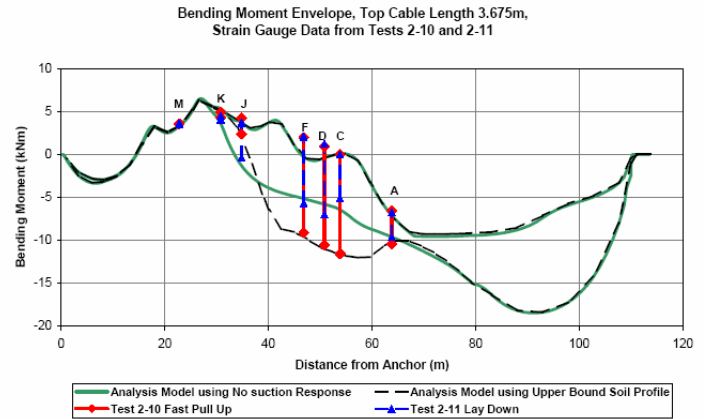


Figure 3 – Bending Moment Envelope

Monitoring System Requirements

The following points summarize the requirements for SCR monitoring systems:

Table 1 – Monitoring Objectives

Objective	Measurement type
Riser global response	Number of distributed measurements (dynamic strain or motion (acceleration))
Riser shape and TDP location	Number of inclination measurements in TDZ area
Local stress peak at hang-off location	Local strain measurement
Riser-seabed interaction	Number of distributed strain measurements in TDZ area

INSTALLATION AND FIELD INTEGRATION DRIVERS

In addition to fulfilling the requirements for measuring riser response, the configuration of riser monitoring system is heavily driven by the following aspects:

- Riser installation
- Provision of power and communication
- Instrumentation device installation method
- Post installation maintenance and redundancy provision

These factors can heavily weigh on a monitoring system configuration and compete with measurement requirements.

Riser and monitoring equipment installation

SCRs are installed either via J-lay or S-lay process. Both processes can accommodate certain level of interference in order to accommodate the monitoring system. For real time systems, there are three different areas of installation:

- Installation of monitoring equipment

- Installation of interconnecting cables between the monitoring equipment
- Installation of cables connecting the monitored regions to the facility

Installation of monitoring equipment is most straightforward and can be done either onshore or offshore. Care needs to be taken to make sure that perimeter of the hardware installed on the riser allows for passing through any obstruction during either J-lay or S-lay process.

Installation of interconnecting cables is more challenging as it extends over long sections of the riser and may affect installation process significantly. One single major issue is the crossing of the welds during installation. SCR joints are typically welded into hex-joints or quad-joints onshore and then further welded offshore during installation. Obviously no cables are allowed on the pipe during welding, thus it is either required to provide a connector between the joints or install cables after the weld is conducted. Both solutions have it's drawbacks; introducing connectors drives the cost up and decreases the reliability of the system; running the cable after offshore weld is complete may require additional hardware and may not be possible on some of the installation systems. In general, from installation point of view, it is desired to limit number of offshore weld crossings by interconnecting cables and thus also to limit the number of instrumented joints.

Typically, SCR monitoring systems consist of sections of instruments located at the riser hang-off and TDZ regions. Hang-off region, due to its vicinity to the platform can be connected independent from TDZ region via dedicated cables. Cables connecting the TDZ region with the facility are either running along the riser to the floating facility or from the riser to the existing subsea infrastructure. If cable is running along the riser, both in case of single line or cable equipped with connectors to cross over offshore welds, it may be required to use additional equipment on the installation vessel, additional space and extra time allocated during installation process. Cable that would connect TDZ region with the existing subsea infrastructure relies on allocation of power and communication lines in existing control umbilicals. This solution minimizes impact on riser installation but requires integration in control umbilical design, modification of subsea umbilical termination assembly (SUTA) and accommodation of seabed cables connecting the riser with SUTA.

Alternatives to the aforementioned solutions can be provided by using remote operated vehicle (ROV) and acoustic technology. Instruments can be installed by ROVs after riser installation, which removes this significant interface. Power and communication cables can be also installed by ROVs. While reducing the installation rig interface has definite positive effect in terms of project simplicity and limitation of risks, ROV interface can be equally challenging. Subsea installation of motion measuring instrumentation is routinely conducted on drilling and production risers, but to the author's knowledge there is no proven solution for installing strain measurement hardware via ROV. Subsea installation of cables along the riser, especially over extended lengths, may also prove to be highly complicated. Acoustic technology can be used as an alternative to cables. Acoustic modems can be used to supply communication paths between the vessel and the subsea instrumentation. However, power has to be supplied through battery packs, which need periodical replacement using ROVs. Thus, the provision of having the ROV available to perform this task has to be made.

Field integration

Field integration is related to all of the components of the real time

monitoring systems:

- Topside control equipment
- Topside cables
- Subsea instrumentation
- Seabed instrumentation and cables

Topside equipment consists of electronics and computers controlling power supply communication with subsea instrumentation as well as data management software and exchange functions with other existing systems. Topside cables join topside equipment with subsea cables that connect to monitoring instrumentation. Topside cables and associated junction boxes are typically provided by subcontractors to vessel owner. The following are the interface areas that pertain to topside equipment and cables:

- Control equipment location and installation
- Appropriate zoning of the equipment
- Provision of power and network connection to the control equipment
- Routing and length of the cables
- Interface of the data management software with other systems (ie environmental and vessel monitoring system)
- Network access and network security

Installation, discussed above, is the most significant driver with respect to riser – instrumentation interface. However, there are also other factors, such as:

- Placement of instrumentation on insulated riser either on top or under the insulation
- ROV accessibility, when required
- Integration with strakes or other VIV suppression devices

Seabed instrumentation and cables are required if power and/or communication are provided to the instrumentation via existing field infrastructure. Instrumentation that is to be placed on the seabed needs take into account geological conditions and have proper foundation (i.e. mudmat). Typically, such instrumentation would need to be elevated to allow ROV access. Routing of the cables and location instrumentation is also very critical. The following issues need to be addressed:

- Interference with existing and planned infrastructure, such as flowlines and umbilicals
- Crossing over flowlines and umbilicals and installation sequence
- Planned drilling program and mooring pattern
- Dropped objects hazard
- Installation procedures and capabilities of the existing installation companies

The interfaces and drivers described above may significantly influence scope and design of the riser monitoring system. The field integration drivers may compete with each other as well as with monitoring requirements. Including riser monitoring system during early phases of project development, significantly simplifies the interfaces and may save significant effort in system design and manufacturing.

SCR MONITORING SYSTEM EXAMPLE

SCR monitoring system design is a multidisciplinary activity that spans through many aspects of field development. The example shown in Figure 5 illustrates the complexity of such systems.

The system includes two monitoring zones: TDZ and hang-off location. TDZ zone consist of number of strain and motion monitoring devices to capture both riser-seabed interaction and riser global response. Power and communication to TDZ section are supplied through existing production control umbilical and then through SUTA and infield cable and subsea jumper connecting to riser mounted instrumentation. Hang-off zone is connected via dedicated cable running in the conduit through spar hull. Following sections discuss the key drivers and decision that shaped the final design.

Instrumentation placement and design

Requirements and drivers for instrumentation locations are listed in Table 2.

Table 2 – Instrumentation Locations Drivers

Requirement	Driver
Capture riser global response	Number of motion measurements distributed along the riser
Capture riser-seabed response	Strain measurement array in TDZ
Capture maximum and fatigue strain at hang-off location	Local strain measurement
Minimize time required during riser J-lay installation	Minimum number of joints to be instrumented
Offshore welding of joints during J-lay	Not possible to have continuous umbilical between joints
Limitations of space during joint handling	Instrumentation needs to fit into a small envelope around the riser
Riser is fully straked	Limit number of instruments and holidays in strakes

The installation and riser design drivers clearly compete with requirement for capturing riser response.

In order to capture riser response the motion monitoring instrumentation should be distributed along relatively long of risers above TDZ and below hang-off. However, riser installation requirements limit the number of joints that can be instrumented. This leads to a compromise wherein smaller number of instruments is offset by development in data processing methods.

Riser TDZ extends over a number of joints depending on vessel offset and environmental conditions. Thus, strain needs to be measured over distance of several joints. This requirement leads to crossing the offshore weld with power and communication cable. However, installation method, does not allow for cable to be continuous over weld. Thus, segmented cable is used with connectors at weld locations. Connections are made offshore, during riser installation. Cable jumper is temporarily stored below the welding station and fished out after joint completion to be mated with cable segment installed on the joint above. Special care needs to be taken during selection of connectors to ensure adequate reliability of the system. The installation diagram is shown in Figure 4.

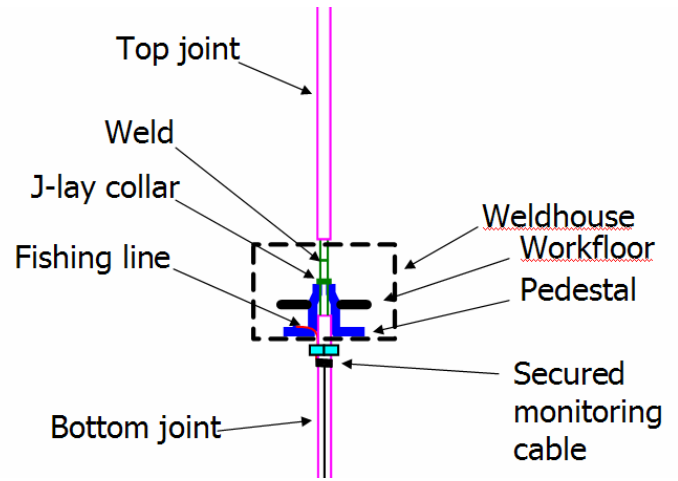


Figure 4 – Cable Installation over Offshore Weld

ROV connectors on the riser need to be easily accessible in order to connect umbilicals but at the same time all monitoring instrumentation has to pass through small envelope during installation. Special design effort needs to be undertaken to provide connector bracket that allows accommodation of both needs.

Provision of power and communication

Power and communication for the system is provided separately to hang-off and TDZ zones. This allows for a level of redundancy in the system. Connecting the hang-off zone through a dedicated cable is relatively easy due to it’s vicinity to the topsides. Provision of power and communication to TDZ requires significant planning and design effort. The following options were evaluated for the systems:

Table 3 – Power and Communication Evaluation

Option	Pros	Cons
Dedicated cable with connectors at each joint run along the riser	No seabed interface Real time data at high rates	Long time and high risk during installation Limited reliability due to number of connectors High cost due to number of connectors
ROV retrievable data loggers equipped with batteries	Simple installation Low cost	No ROV on board the production platform No synchronization of data No real time access to data
Acoustic communication	Real time access to data Simplified installation Low cost	No previous experience in this application
Using cores within the existing umbilical and providing an infield cable to connect SUTA and TDZ	Real time data at high rates Simple installation Low risk due to using existing solutions	Seabed interface Design change for SUTA and production umbilical

After detailed evaluation of the existing options, last option of using the cores in the existing umbilicals is selected due to the fact that it significantly simplifies the riser installation activities and makes use of existing infrastructure.

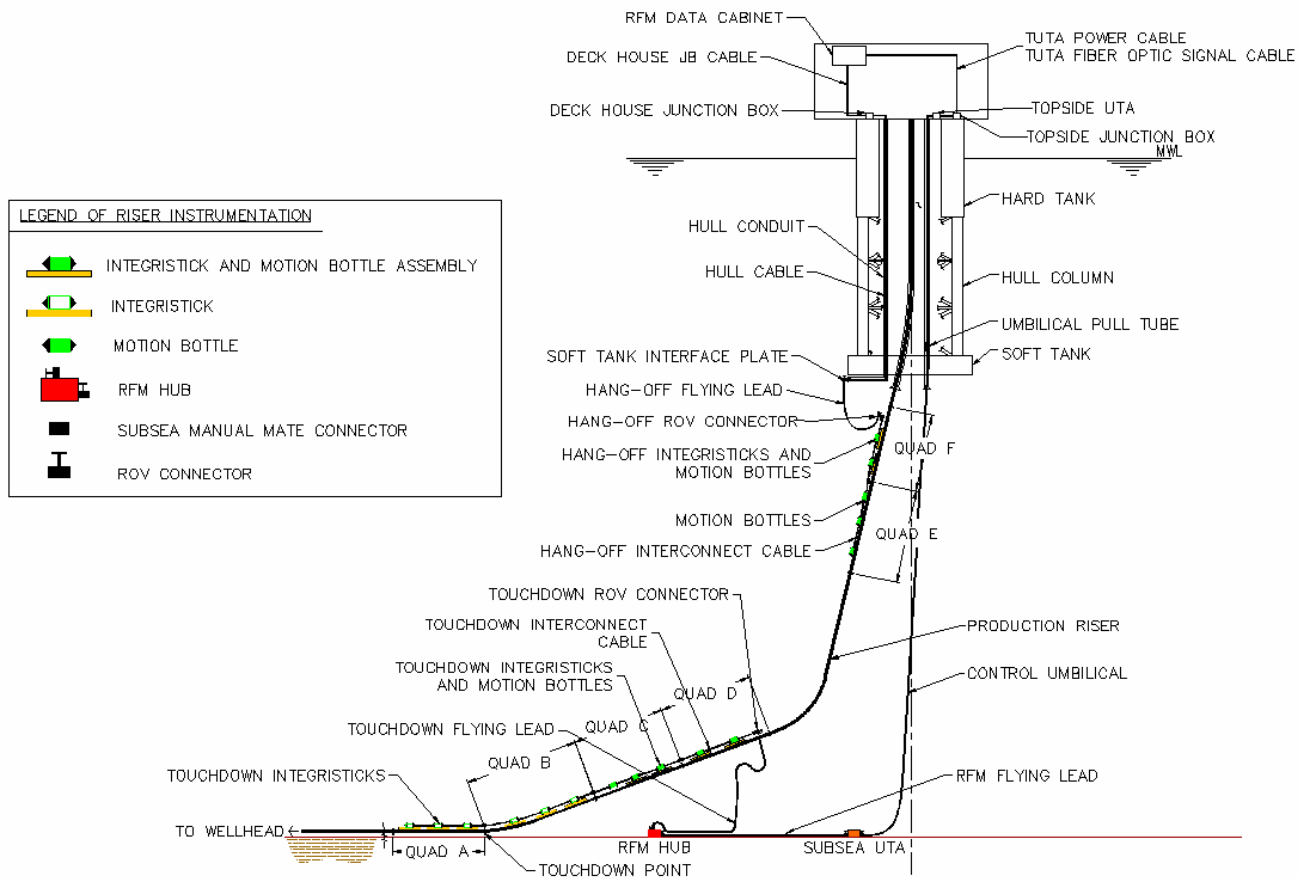


Figure 5 – SCR Monitoring System Example

CONCLUSIONS

Real time monitoring systems for SCR provide valuable data on riser response due to vessel motions and environmental conditions. This data is used to ensure structural integrity and to study riser response to further enhance design capabilities. Such systems require significant design effort in order to ensure that best decisions are made regarding choice of monitoring instrumentation, their location and number as well as integration with existing installation plans and other infrastructure. It is critical that such systems be included as part of the project at an early phase, preferably FEED. This enables allocation of resources required for best technical and economical solutions and potential risk and cost necessary to adjust monitoring system to existing conditions.

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