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STEEL CATENARY RISER RESPONSE CHARACTERIZATION WITH ON-LINE MONITORING DEVICES

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ABSTRACT

Steel Catenary Risers (SCR) are critical dynamic structures with a complex fatigue response. The offshore industry lacks verification of analytical models with full-scale response measurements. Only a small number of installed SCRs have any instrumentation to monitor dynamic response.

This paper describes an on-line monitoring system deployed on one of the Tahiti infield (production) SCRs. Tahiti is a Truss Spar Floater located in 4,000 ft water depth in the Gulf of Mexico. The system is configured with localized strain and motion measurement devices. Emphasis is placed on the selection of number and location of the monitoring devices to characterize vessel induced riser response, VIV induced riser response, riser-seabed interface, and discontinuities at the riser hang-off locations. Monitoring device sensitivity requirements and qualification programs are also discussed. The monitoring system configuration drivers are reviewed in detail such as; monitoring objectives, instrumentation requirements, specification and architecture, field development integration, and installation.

Information provided in this paper would be helpful for configuration of complex monitoring systems for deepwater steel catenary rises.

NOMENCLATURE

m : Number of modes considered for the assessment
n : Number of sensors used
$A_{i,j}$: Mode shape of j^{th} mode at i^{th} sensor location
$\kappa_{i,j}$: Mode curvature of j^{th} mode at i^{th} sensor location
W_m : Peak amplitude of mode m
$\hat{W}_m$: Peak amplitude of mode m in Fourier space
$\hat{D}$: Array of measured amplitudes from all the sensors for any peak response frequency in Fourier space
GoM : Gulf of Mexico
SCR : Steel Catenary Riser
TDP : Touch Down Point
TDZ : Touch Down Zone
VIV : Vortex Induced Vibration

INTRODUCTION

The uncertainties in the deepwater environment and the shortfalls in the riser design methodologies may pose challenges to integrity of installed riser systems.

The primary objectives of an SCR monitoring program are:

1. Calibrate riser and flowline design and analysis methods with real-time full scale response measurements
2. Characterize riser response under VIV loads wave loading, first and second order floater motions and associated fatigue damage
3. Measure riser response under extreme loads and stresses along the critical locations of hang-off and touch down region
4. Characterize the riser/soil interaction
5. Characterize flowline buckling behavior
6. Assist in integrity assessment of the Tahiti risers during operations

The SCR monitoring objectives can be accomplished by installing multiple monitoring devices, a combination of strain and motion sensors, along the entire riser length. This may be desired from a technical standpoint, however, an optimal monitoring system configuration is determined by many competing factors such as cost, installation of sensors before or after installation of the risers, sensor sensitivity, sensor types (accelerometer or strain based devices), data communication methods to topside facilities (online or remote access), integration of the monitoring system with the project teams.

The following key design considerations are adopted to achieve project goals:

1. Monitoring devices non-intrusive to riser/pipelines
2. Potential failure of monitoring devices not compromising production
3. Monitoring system will have a stand alone umbilical attached to the riser for power and data transmission

Monitoring system will have on-line/real time data communication capability. A schematic of the system configuration is provided in Figure 1. Monitoring devices will be placed in three general regions of the SCRs.

Riser hang-off: SCR region immediately below the pull tube. Monitoring devices are placed to measure riser bending stress and motions for the hang-off region 2 strain and 5 motion measurement devices are judicially placed to measure riser response covering 320 ft of the riser. The monitoring devices are connected to topside facilities for online monitoring. The monitored data (direct or derived) will be suitable to calculate hull motion induced cyclic load histograms, VIV induced cyclic load histogram, and riser loads during an extreme environmental event.

Riser touchdown: A critical monitoring location is the SCR touchdown region where the riser is making contact with the seabed monitoring devices are placed to measure riser bending stress and motions. Final configuration has 10 strain and motion measurement devices in the touchdown region judicially placed to measure riser response before the touchdown point as well as the seabed contact region, covering 720 ft of the riser. The monitoring devices are connected to topside facilities for online monitoring. The monitored data (direct or derived) will be suitable to calculate hull motion induced cyclic load histograms, riser VIV induced cyclic load histogram, riser loads during an extreme environment event, seabed soil stiffness, trenching loads on riser pipe.

Flowline: A region 1 mile away from the riser touchdown point. Monitoring devices are placed to measure flowline bending stress, axial stress, hoop stress, temperature, and curvature over a 700 ft segment. The monitored data (direct or derived) will be suitable to calculate load histograms of the pipeline, flowline deflections, and temperature. Data will be suitable to calibrate flowline buckling models and flowline walking models. More information about the flowline monitoring devices can be found in [15]

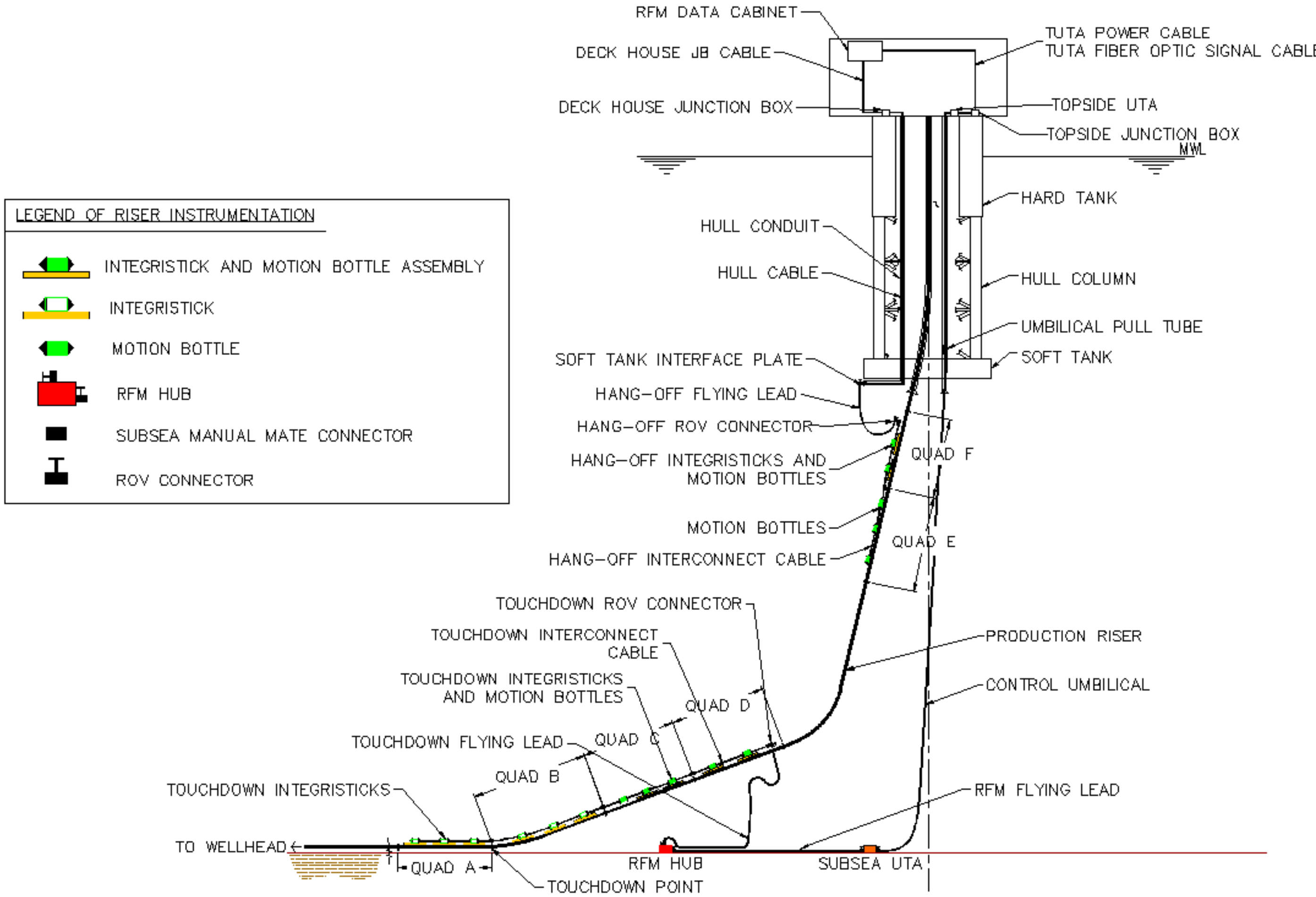

Figure 1 – SCR Monitoring System Configuration

RISER MONITORING DEVICES

INTEGRIpod Motion Sensors

A typical motion sensors arrangement strapped onto the SCR is shown in Figure 2. The motion sensor resolution, sensitivity, range and placement along the riser length is optimized to capture the entire range of modes expected during the life of the field. A more detailed explanation of sensor specification and selection is provided in section "*Sensor Accuracy Selection*"

The motion sensors measure 3 axis accelerations 2 axis angular rates, and 1 axis inclination. An overview of general specification and performance characteristics are provided in Table.1

Table.1 Motion Sensor Specification

	Resolution	Range
3Axis Acc	0.001 g (RMS)	+/- 2g
2Axis Angular/rate	+/- 0.01 deg/s	+/- 10deg/s
Inclination	+/- 0.01 deg/s	+/- 10deg/s

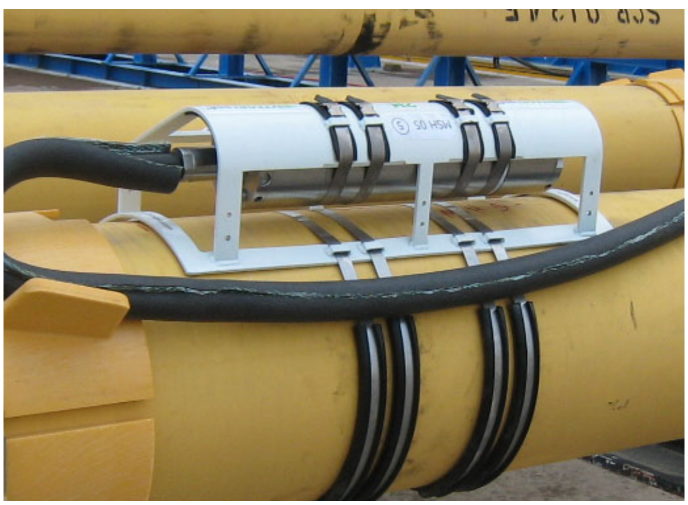

Figure 2 –INTEGRIpod Motion Sensor Installed on SCR Joint

INTEGRIstick - Dynamic Curvature Sensor

A typical strain / motion sensor arrangement is shown in Figure 3. The strain stick is installed directly on top of the insulation and near the fatigue critical locations of the riser. They are strapped to the riser with engineered compensation straps to accommodate shrinkage of the insulation layer due to hydrostatic loading at installation depth. To capture smallest dynamic curvature changes the strain stick measurement resolution is 3 micro-strain this high sensitivity allows capture of lowest bending moment onto riser.

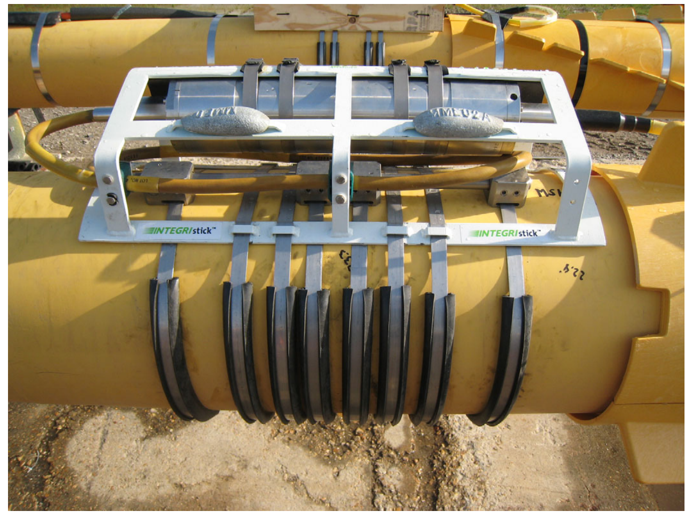

Figure 3 – INTEGRIstick Dynamic Curvature Sensor Installed on SCR Joint

MONITORING PHILOSOPHY AND RESPONSE CHARATERIZATION

Monitoring Philosophy and Approach

The monitoring system is based on measuring riser response (strain or accelerations) at discrete points along the riser. Interpretation of dynamic response of the entire riser from discrete data points is complex and requires careful consideration in the instrumentation design process.

Characterization of global riser response requires sufficient number of instruments along the riser with appropriate spacing to capture the entire range of expected response. The instrumentation can be distributed along the whole riser or clustered in groups near the critical regions. The data obtained at discrete locations need to be extrapolated along the whole riser which requires time domain or frequency domain data processing techniques as discussed in [1], [2] and [3].

The required number of measurement locations depends upon the range of modes expected to be excited, level of accuracy required, and overall system costs. In principle. to capture the VIV response, spatial extent of the instrumentation should enable to capture at least a quarter wave length of the shape of lowest mode number expected. To capture the shape of the highest mode expected, there should be at least two instruments available to capture the quarter wave length. A technique to obtain an optimum instrumentation locations and the number required is discussed in [4].

Redundancy should be built in the system to account for any sensor failure and increase the reliability of the monitoring system in the critical areas. Redundancy can be introduced by considering the following:

1. Additional sensors;
2. Sensor communication and power cables divided in to groups;
3. Employ field proven instruments;
4. Provide capability for periodical inspection and replacement.

The details of improving system reliability and installation considerations are discussed in [7].

In order to specify the monitoring system an assessment is conducted in 2 stages:

- Suitable number and locations of sensors;
- Verifying the proposed sensor specifications is adequate to capture wave and VIV induced riser response

Motion Sensor Placement

In order to interpret the global riser response, it is necessary to have sufficient number of motion sensors at an optimal arrangement. The method to determine the optimized motion bottle arrangements is called modal clarity method. The mathematical details of this method are given in [4]. In order to identify an optimum motion sensor placement a total of 73 motion sensor arrangements, as shown in Figure 4, are considered with the following variations:

- Spacing between the adjacent motion sensors;
- Location of the top and bottom motion bottle array;
- Number of motion sensors;
- Distribution of the number of motion sensors between the top and bottom array.

In order to assess the relative merit between the arrangements an index called configuration clarity index (CCI) is defined, [4]. The CCI values obtained for various arrangements are compared against the CCI value for an arrangement with a lot of motion sensors equally distributed along the riser length.

For the arrangements 1 through 20 motion sensors are spaced 60ft apart, followed by 20 arrangements with 80ft spacing and 100ft spacing. Each of the 20 arrangements include 5 motion sensors in the top and bottom array being moved towards the middle of the riser, in steps of 165 ft quad joint length. The overall cost constraints limited the number of sensor locations to around 10. The arrangements with the varied number of motion sensors between the top and bottom array 6-4, 7-3, 4-6 and 3-7. Following this, the number of motion sensors is increased to 12 with a distribution of 7-5 and 5-7 between the top and bottom arrays.

The findings from the analytical assessment is weighed against the installation constraints and cost effectiveness. For example, the configuration 15 with motion bottle arranged near the middle of the SCR would require longer length of cable to installed for power and data communication increasing the cost. Also, in order to minimize the risk involved in damaging the cable during installation a configuration with significantly shorter cable without compromising on the configuration clarity CCI is chosen.

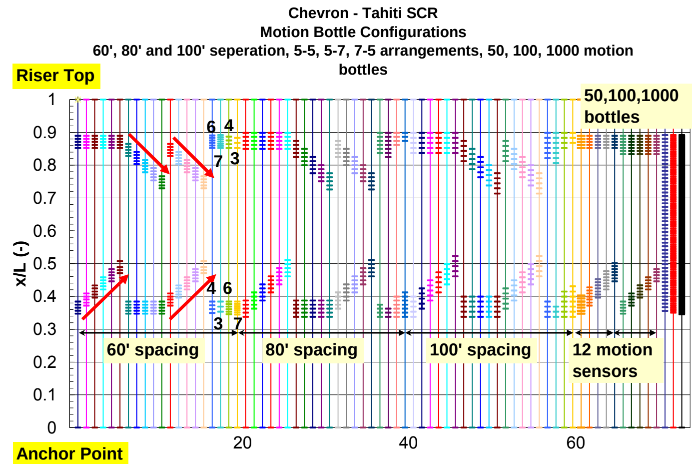

Figure 4 – Motion Sensor Arrangement Assessed

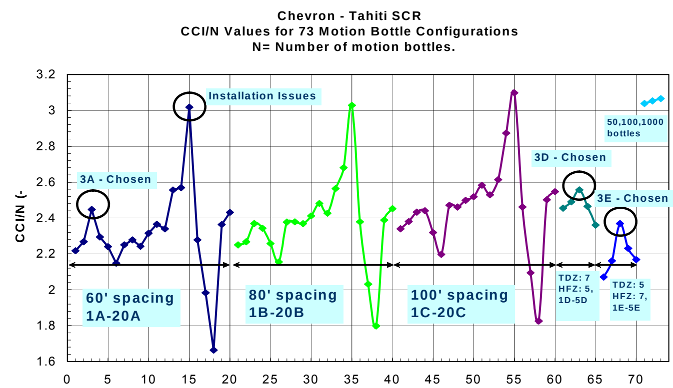

Figure 5 – Configuration Clarity Indices for 73 Motion Bottle Arrangements

Strain Sensor Placement

Strain sensors are primarily aimed at providing the following:

- Direct measurement of riser strain below the pull tubes hang off region
- Riser-soil interaction behavior by capturing riser dynamic strains during an extreme event;
- Additional independent set of instrument(s) to verify the interpreted motion bottle response

A range of environmental loading conditions, Table.2, is considered to capture the magnitude of peak stress near the touch down region, Figure 6. The vessel offsets during the extreme events will shift the location of peak strain near the TDP. Therefore, a vessel offset of 2.2% of water depth is assumed in both near and far conditions for 1 and 10 year return period events, and a 3.5% of water depth (141ft) offset is used for 100 yr event.

Table.2 – Seastates Used for Assessment

Seastate Return Period	Significant Wave Height, Hs (ft)	Time Period (sec)
1 yr	8.2	7.5
10 yr	24.6	12.5
100 yr	41.0	13.5

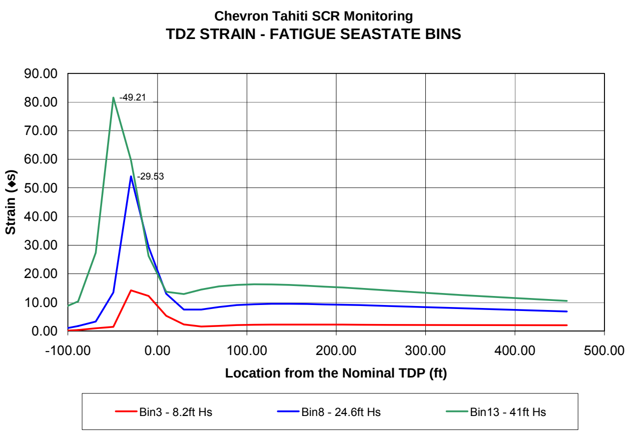

Figure 6 – Touch Down Region Strain Distribution

Strain sensor placement for the hang-off region was straightforward. The strain levels increase close to the pull tube exit of the riser and technical drivers suggest to place the sensors as close to the pull tube exit as possible. The final locations of the two strain sensor were selected based on J-Lay installation considerations and quad joint stack-up.

The strain distribution at the touchdown region is more complex. In order to obtain an optimum number of strain sensors and their locations the following 3 arrangements with strain monitoring stations located approximately 60ft apart in each quad joint are considered:

- 6 strain sensors located over 2 quad joints;
- 9 strain sensors located over 3 quad joints;
- 12 strain sensors located over 4 quad joints.

The touch down region strain response for the 3 environment events and the 3 strain sensor arrangements considered are shown in Figure 7 through Figure 9. The summary of the TDZ response characterization using strain stations are given in Table.3 The assessment shows that 6 strain sensors with coverage over 2 quad joints near the touch down zone is sufficient to characterize the TDZ response.

Table.3 – Strain Sensor Placement Assessment Summary

Strain Sensor Arrangement	1 yr	10 yr	100 yr
6 sensors / 2 quad joints	Sufficient coverage	Sufficient coverage	Sufficient coverage
9 sensors / 3 quad joints	Good coverage Sufficient window for extreme vessel offsets		
12 sensors / 4 quad joints	More than required coverage		

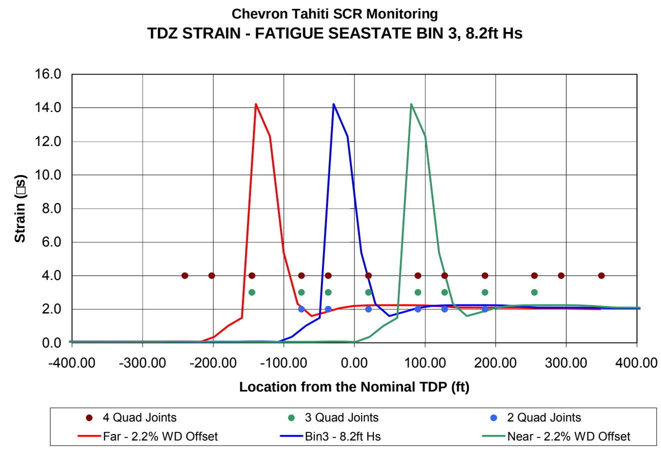

Figure 7 – 1 yr TDZ Strain vs Monitoring Locations

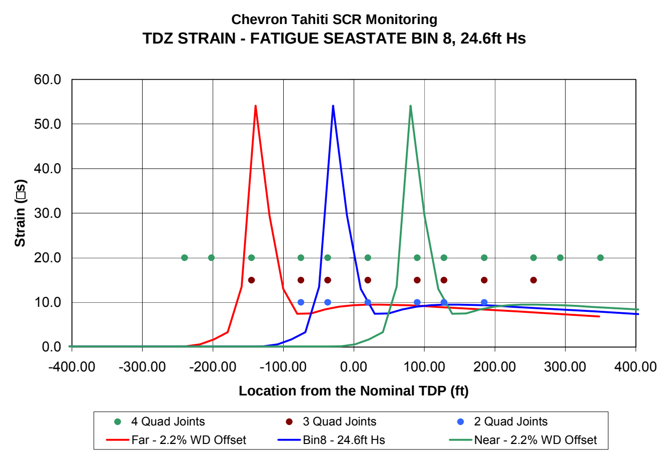

Figure 8 – 10 yr TDZ Strain vs Monitoring Locations

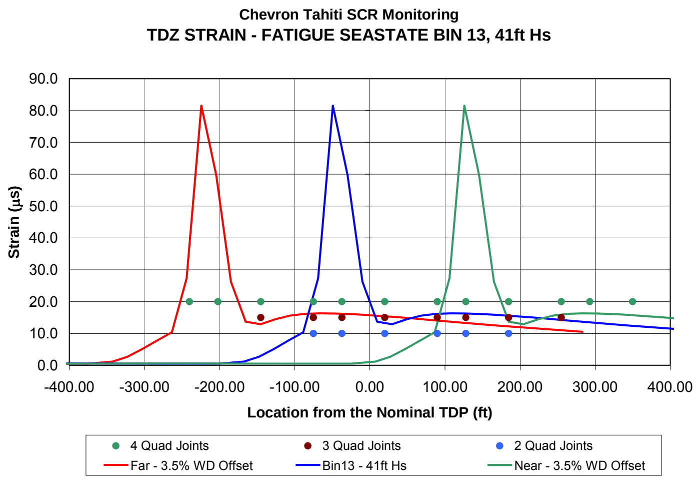

Figure 9 – 100 yr TDZ Strain vs Monitoring Locations

Combined Motion and Strain Sensor Placement Strategy

The optimum motion bottle arrangement obtained using modal clarity method is:

- 5 motion sensors with 60ft spacing distributed at the quad joints adjacent to the riser hang-off region; indicated as Quads E and F in Figure 1
- 5 motion sensors with 60ft spacing distributed 3 quad joints above the touch down region, indicated as quads B,C, and D in Figure 1.;

The optimum strain sensor configuration to capture the TDZ response is to distribute 6 strain sensors with 60 ft spacing along the quad joints at the touch down region. In order to reduce the length of cabling required over the critical TDZ and also avoid a separate UTA for the strain sensors and motion sensors, the motion bottle arrangement is distributed to the quad joints adjacent to the strain sensor location as follows:

- 5 motion sensors with 60ft spacing distributed at the quad joints adjacent to the riser hang-off region;
- 5 motion sensors with 60ft spacing distributed at the quad joints adjacent to the touch down region, Figure 10;

The modal clarity matrices obtained for configurations with motion sensors along 23 and 24th quad joints, and 27 and 28th quad joints are shown in Figure 11 and Figure 12. The clarity indices are shown for the modes excited along the X axis and the modes interpreted along the Y axis. The off-diagonal values represent the extent to which the adjacent modes can be confused with the excited mode.

The modal clarity plot for the optimized configuration shows the following:

- Good clarity in the entire range of modes expected (2 and 12) except for mode 3 and 4;
- Low clarity with the next to adjacent mode which can be distinguished based on modal frequency.

The modal clarity plot for the TDZ motion sensors in 27th and 28th quad joints shows low clarity among the low modes 1-3. However, the low modes are not anticipated to incur high fatigue damage on the riser;

Excitation modes can be interpreted incorrectly with the adjacent modes, however, results in negligible difference in terms of fatigue damage along the riser. Therefore, the motion bottle arrangement in the quad joints adjacent to the strain sensor location is considered optimum.

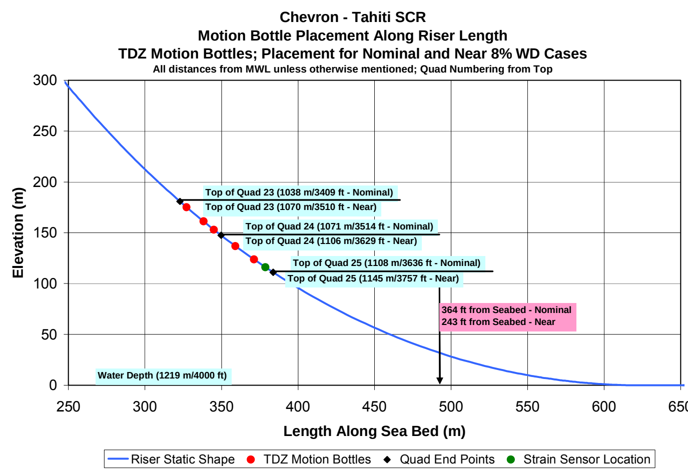

Figure 10 – Optimized (Final) Motion Bottle Location

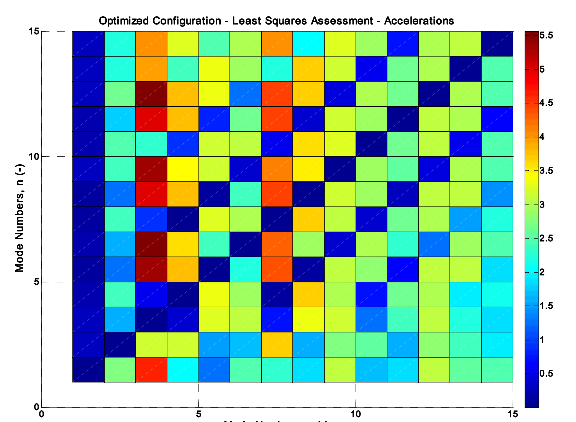

Figure 11 – Modal Clarity Matrix, Optimized for Motion Bottle Placement

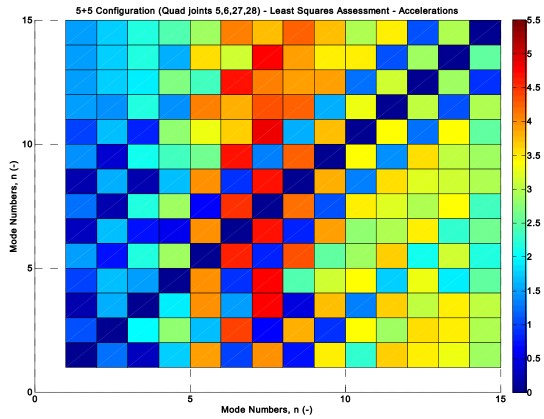

Figure 12 – Modal Clarity Matrix, Motion Sensors in Quads Adjacent to Strain Sensors

Figure 16 and Figure 17 show that the strain stations are optimally located to capture the riser stresses in the touch down region during extreme storms and offset conditions. The dynamic strains are high near the TDP, however, it is difficult to monitor the peak TDP stresses due to varying TDP location during the storms. Therefore, extensive instrumentation near the TDP may still be adequate to capture the peak stresses. Hence, the number and location of touch down region instrumentation is decided based on the expected TDP excursion during the normal and extreme seastates.

Based on the riser motion response, the wave and floater motion induced response is characterized in two levels:

1. Preliminary evaluation of measured data in terms of standard deviations of motions and strains;
2. Processed data estimating the riser loads and stresses.

An approach similar to the motion response screening discussed above can be adopted to the strain measurements in the fatigue critical areas near the hang-off and the touch down region.

Dynamic strain measurements during the extreme seastates can be used to compute the stresses and bending moments at the measurement location.

Sensor Accuracy Specification

The sensor accuracy is specified based on the knowledge that the risers are fatigue critical structures and the fatigue is typically driven by low motion levels combined with large number of cycles. The fatigue is driven by wave/vessel motion induced and VIV induced loading on the riser.

Entire range of fatigue seastates are analyzed and SCR motion response is extracted along the entire length and superimposed with the motion logger locations selected, Figure 13. The sensor accuracy of 0.002 m/s^2 is chosen to reflect such that the majority of the fatigue loading can be captured.

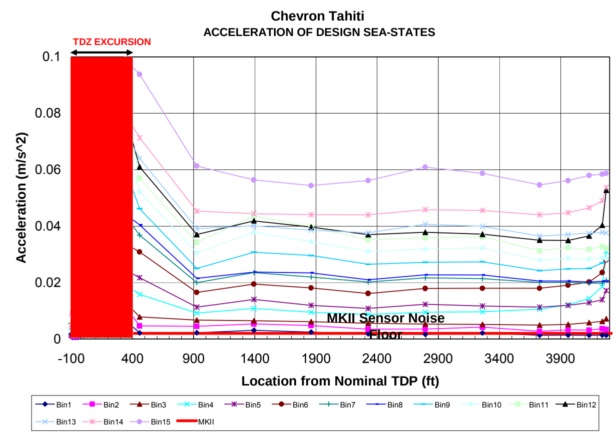

Figure 13 – Wave/Vessel Motion Induced Riser Accelerations with Motion Sensor Accuracy

Similarly, entire ranges of current profiles are analyzed for riser VIV response and motion accuracy is specified, Figure 14. The modes of interest lie between 2 and 11. The associated riser response amplitude to diameter ratio (A/D) varies between 0.02 and 0.18. The minimum riser acceleration as per the predictions is 0.0022 m/s^2, and therefore sensor accuracy of 0.002 m/s^2 is deemed sufficient to capture the entire range of VIV excitation.

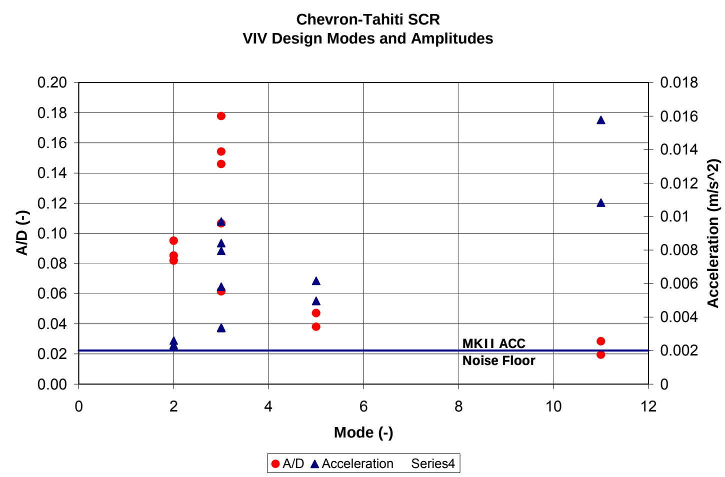

Figure 14 - VIV Response Analysis of Tahiti SCR and Comparison of Acceleration Amplitudes with Motion Sensor Accuracy

The strain sensor accuracy of 2 micro-strains are sufficient to capture the touch down region response, Figure 7 through Figure 9

MONITORING DATA INTERPRETATION

The base case arrangement of motion sensors include 5 motion sensors at the hang-off zone near the bottom of the pull tube and 5 near the touch down zone. The motions recorded at these locations will be used to interpret the response along the entire length of the riser. The dominant source of riser excitation is expected from vortex induced vibrations (VIV) and wave induced vessel motions.

The monitoring data gathered real time is aimed to provide a real time operational assistance using on-board system alerts and on-shore back analysis to better understand the system response.

Wave/Vessel Motion Induced Response

Riser accelerations along the length from various design fatigue seastate bins are shown in correlation with the measurement locations in Figure 15. Threshold motion level above which the riser fatigue damage is considerable can be determined based on the design fatigue seastate bins. Multiple threshold motion levels may be required to characterize the response at the hang-off and touch down region which can be used to set alarm to indicate the fatigue damage rates in case of real time processing.

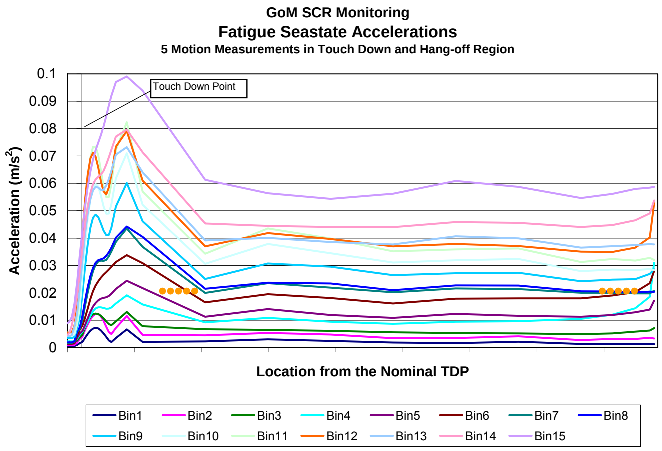

Figure 15 – Riser Accelerations for a Typical GoM SCR

Similar, alarm levels can be set for the strain measurements to monitor the TDZ response, Figure 16.

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 17. 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.

The stresses calculated at both hang-off and TDZ can be converted in to cyclic load histograms using popular cycle counting methods and fatigue damage consumed at the monitored location can be calculated. But, it should be noted that the high stress region at the TDZ are distributed over a much longer distance of several hundred feet due to vessel excursions. 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.

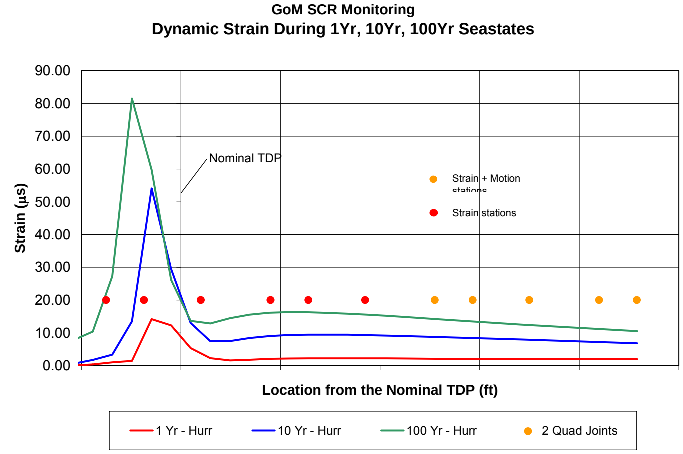

Figure 16 – Extreme Storm Riser Strains for a Typical GoM SCR

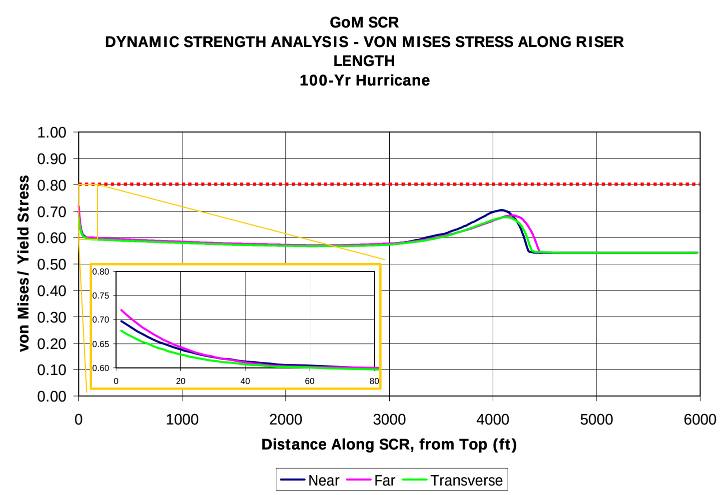

Figure 17 – Dynamic Stress along the Riser

VIV Response

A popular and a commonly used method to characterize SCR VIV response is the principle of modal decomposition. The motion measurements obtained in the form of accelerations and/or angular velocities at selected location are extrapolated along the remainder of the riser using either time domain or frequency domain methods.

Frequency domain analysis can be applied to both synchronized real time measurements and un-synchronized stand-alone measurements, [1], [2] and [3]. The approach includes the following main steps:

1. Conduct spectral analysis at each motion sensor location;
2. Identify the peak response frequencies above a threshold measurement level determined based on VIV design;
3. Correlate the response from all the motion sensors along the riser length at each peak response frequency;
4. Assume normalized theoretical mode shapes predicted by FEA for the as-installed riser configuration;
5. Using linear regression analysis identify the shape and amplitude that provides the best-fit shape through the measured response peaks along the riser, [4];
6. Re-construct the riser shape based on the mode shape and amplitude determined from shape matching;
7. Compute stresses along the riser from the re-constructed mode shape.

The frequency domain approach involves the assumption that response is stationary. In order to capture the transient nature of the response a time domain approach or a pseudo-frequency domain approach with appropriate response duration is preferred.

Time domain modal response data interpretation requires synchronized measurements. The measurements at each time instant are expressed as a sum of modal response components, as given in the equation below,

$$x_i(t) = \sum_{m=m1}^{m2} W_m(t).A_{i,m}\,; \qquad i = 1, N \tag{1}$$

Applying the above mentioned modal decomposition principle, the measured motions can be formulated in Fourier space, as given below,

$$-\omega^2 [A]\{\hat{W}\} = \{\hat{D}\} \tag{2}$$

The peak response modes and the corresponding amplitudes can be determined using the regression analysis of the system of equations given in Equation 2. Global riser response can be constructed at each instant using all the participating mode shapes along with the associated amplitudes.

Both time and frequency domain approaches may be limited by assumptions made in calculation of mode shapes. Tension, contained fluid weight and added mass may vary from the values assumed. Such variations could change the modal frequencies and mode shape of the riser and therefore the riser response could be misinterpreted. Modal decomposition method is adopted for short durations of measured data to account for the transient nature of 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. Local peak below hang-off, which is due to rotational restraint, covers the range of 20 ft as shown in Figure 18. 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 adequate to capture riser VIV response.

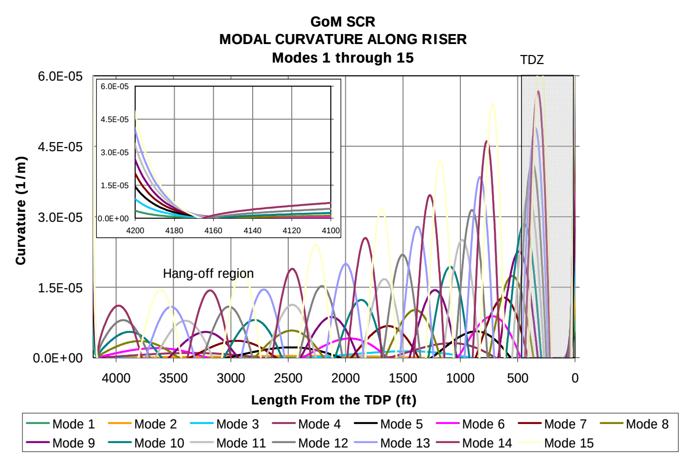

Figure 18 –SCR Modal Curvature

Riser – Soil Interaction

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 using either acceleration or strain measurement to obtain the catenary angle at the monitor locations. Since it is difficult to obtain a stable and long term static measurement of strain on the pipe, monitoring of angle for this purpose is recommended. A number of angle measurement devices distributed along the lower portion of the riser, Figure 19, can be used to capture the TDP location with an accuracy of a few feet depending on the riser length.

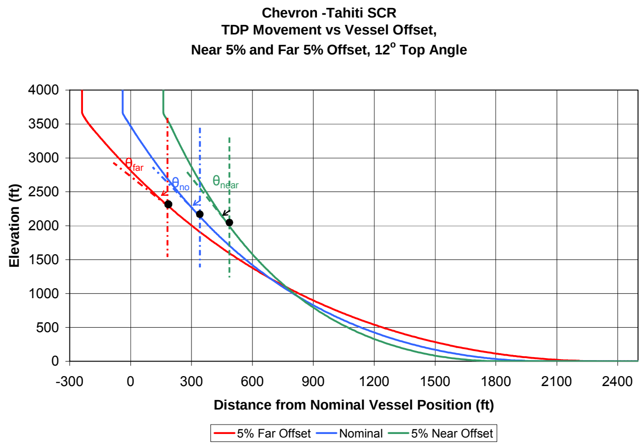

Figure 19 –SCR Catenary Angle Calculation

Current riser design methods for seabed stiffness modeling involve rigid or linear elastic seabed with axial and lateral friction coefficients. The seabed stiffness used affects the fatigue damage near the TDP, [9]. Riser seabed stiffness can be calibrated using following methodology:

1. Capture riser global response using motion sensors
2. Assume riser-seabed stiffness
3. Obtain riser touch down region response predicted by a non-linear finite element dynamic analysis during a recorded extreme event using the measured environmental and vessel motion data
4. Calibrate the FE predicted touch down region response against the measurements by varying the seabed stiffness model;

The seabed stiffness assumption can also impact the VIV fatigue life near TDP. Therefore, the global response obtained from the measurements during a VIV event can also be used to calibrate the seabed stiffness. However, it is anticipated that the VIV response may be governed by the VIV suppression device performance and hence leaving an element of unknown in this calibration study.

The literature on SCR seabed interaction obtained from as STRIDE JIP indicate that the extreme storm stresses are not sensitive to the seabed stiffness, however, they are affected by seabed friction coefficients, [10]. Based on the TDZ measurements during an extreme event the soil friction can be calibrated.

Similar methodology can be adopted to study riser-soil interaction behavior such as soil suction and trenching. An example of application of this method during STRIDE JIP is shown in Figure 20. The dynamic envelope of bending moment from various models is compared with results of dynamic strain measurement envelope obtained using strain sensors. Such calibration study can be conducted for any extreme events with evidence of trenching.

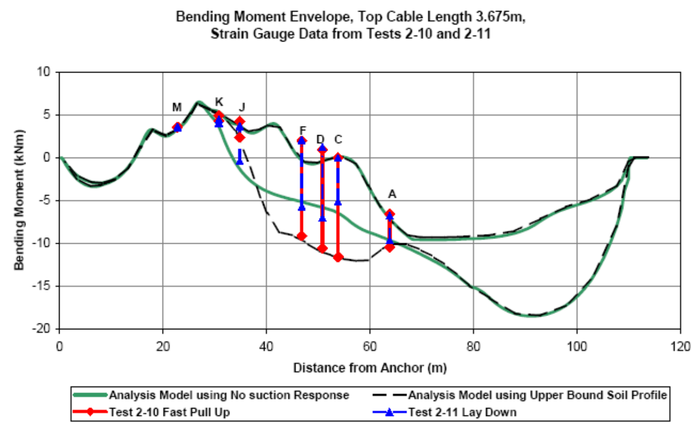

Figure 20 –Soil Suction Model Calibration, STRIDE JIP

Touch down region monitoring using strain measurements can determine the following:

1. Trace the peak stress near the TDP as the riser moves dynamically;
2. Compute the riser lateral loads;
3. Calibrate pipe/soil interaction models to dynamic strains under known current/wave loading.
4. Appropriate values for pipe/soil stiffness
5. The degradation factor to apply to soil stiffness due to soil softening effects from continues riser cycling.
6. The influence of pipe/soil suction on a field riser by comparing the difference in strain cycles from upward motions to downward motion

CONCLUSIONS

A steel catenary riser monitoring strategy that can confirm the integrity of the risers is developed and deployed through a combination of an optimized monitoring system and the state-of-the-art data processing methods.

The monitoring system is capable of capturing all the fatigue components of an SCR due to wave, VIV, and floater motions. The combination of the motion and the strain sensors placed along the critical locations of the riser with sufficient coverage provides the ability to track the extreme loads on the SCR to confirm the integrity and also provides the response along the un-monitored locations along the riser.

Real time monitoring systems for SCRs 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.

At the preparation time of this paper all monitoring devices have been deployed and communication with the hang-off monitoring devices from topside facilities has been established. The full system is expected to be operational later part of 2009.

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