Steel Catenary Riser Response Identification based on Field Measurements

L. Tran, P. Enuganti, M. Campbell - 2H
Y. Constantinides - Chevron

OMAE
June 2011
ABSTRACT

The existing riser design and analysis methodologies rely on empirically derived parameters to conservatively represent the complex dynamic behavior. With exploration moving to deeper water and the increasing need of existing asset support, there is a strong need to evaluate and refine these methodologies. This is especially true for Steel Catenary Risers (SCR) as they are the most widely used riser type and due to their complex soil-pipe interaction at the touchdown point. Given the small amount of small scale experiments that have been performed in the past, there is a strong industry need for large scale field measurements. This paper presents valuable field data collected from a deepwater SCR under storm conditions. The presented data includes riser accelerations and strains compared against vessel motions. The measured SCR response is also analyzed and qualitatively compared against the current understanding of SCR response that constitutes the industry analysis methodologies.

INTRODUCTION

Chevron is successfully monitoring the structural response of one of the deepwater production risers in the Gulf of Mexico. In addition to riser monitoring, the vessel motions and metocean conditions are also monitored. Aside from integrity management, the goal of the monitoring systems is to provide field measurements to support the research and development efforts. The current program focuses on understanding the basic mechanics of steel catenary riser (SCR) response and validating the analysis methodology and assumptions used for design.

There is a history of research in this area, especially in the early development stages of the SCR concept. One of the first efforts that studied dynamic response of SCR was the Highly Compliant Riser (HCR) Joint Industry Project [1]. The program included a series of model tests to understand SCR and other riser type response. The tests were conducted in a lake using a small scale diameter aluminum pipe, with a characteristic aspect ratio of a deepwater riser, using an idealized hard seafloor. Motions were applied at the top of the pipe to simulate vessel motions and the response was captured by a series of strain-gauges. The project combination of analysis and testing resulted in an initial understanding of SCR response in idealized conditions. A number of prediction tools, mostly finite element based were benchmarked against the tests with varying degrees of success.

Following the HCR work, the STRIDE joint industry project [2] conducted a full scale test program to investigate the effects of seabed riser interaction on SCR response and stresses. The tests were carried out at a tidal harbor with seabed properties similar to those of deepwater Gulf of Mexico. A short section of a near full scale steel pipe was tested, representing the touch-down section of an SCR. The tests provided a valuable understanding of SCR soil interaction and produced models to predict this response.

Previous programs collected valuable information in either model scale laboratory tests with ideal seafloor conditions or larger scale riser section with approximate seafloor conditions. The current program closes the gap by obtaining actual SCR measurements, large scale in field conditions. This study is focused on the analysis of field data to understand SCR response. A parallel paper describes the validation of analysis methodologies by comparing field measurements against software predictions [6].

RISER AND MONITORING SYSTEM DESCRIPTION

Riser System

The monitored riser is an oil production SCR located deepwater Gulf of Mexico at a depth of 4000 ft. It consists of a
9.625” steel pipe with a 2” thermal insulation and VIV suppression strakes throughout the length of the riser.

**Riser Monitoring System**

The production SCR is instrumented with motion and strain measurement devices distributed between hang-off and touchdown zones. The motion measurement devices (INTEGRIpod™) measure the riser acceleration in 3 directions and angular rates in 2 planes. The strain measurement devices (INTEGRIstick™) measure bending strain in 2 planes. The location of all the sensors is shown in Figure 1. A total of 8 data channels of fully synchronized data are continuously collected from each monitoring device at a sampling frequency of 10 Hz. A more detailed description of the system can be found in [3].

**Environmental and Facilities Monitoring System (EFMS)**

The production facility where the SCR is located is equipped with a continuous vessel monitoring system. The system monitors the high order vessel motion through a 6DOF accelerometer based instrumentation and the low order motions through a GPS. In addition to the vessel motions the system also monitors wind, wave and current.

**DATA PROCESSING AND ANALYSIS METHODOLOGY**

The SCR has 10 motion measurement stations distributed along its length: 5 at the Hang-off zone and 5 at the touch down zone (TDZ). The acceleration measurement station assembly at each location is installed such that the motion bottle is at 12 degrees offset from top dead center of the SCR and the strain measurement station is aligned with the top dead center of the riser. The measurements of each riser monitoring device are in the local coordinate system shown in Figure 3.

It has been observed that the riser torsionally rotates from the initial position and continues to rotate during each production start-up and shut-down operation. Therefore, the angle of each monitoring station axis is not always 12 degrees but is calculated based on mean acceleration measurements at each monitoring station and accounted for in the coordinate system transformation.

As the riser motions at each location are dynamic with several degrees of freedom and no initial frame of reference, a methodology is derived to obtain riser motions in the global frame of reference. The key features of the coordinate transformation methodology that removes g-contamination in measured accelerations are:

- Initial angles of each measurement station’s inclination and rotation are calculated from mean values of local X, Y, and Z accelerometer measurements;
- Acceleration measurements at monitoring station location are filtered to signal reduce noise:
  - High pass filter at 0.013Hz (75 seconds period) on all accelerometers and angular rate sensors;
  - Low pass filter at 1Hz (1 second period)
- Obtain transformation matrix that rotates the coordinate system from one time step to the next using angular rates.

The global coordinate system is referred to as surge, sway and heave axis. Heave is vertical, surge is horizontal aligned with the plane defined by the SCR shape and sway is out of plane. All accelerations are double integrated to obtain displacements. Detailed description of the methodology is presented in Li et al. [5]. The global coordinate system is illustrated in Figure 4.
The torsional orientation of the strain measurement stations is accounted and the strains are transformed into SCR in-plane and out-of-plane components. In this study we present only comparisons with the in-plane components, being more important for design. The strains are converted to stresses and appropriate filtering is applied similar to the accelerometers.

The data presented in this study consisted of high response seastates during 2009. After careful screening, 36 30-minute cases were identified, corresponding to wave intensities up to the equivalent of a 10-yr winter storm for the Gulf of Mexico. These are often referred to as fatigue seastates due to their frequent occurrence and dominance in riser fatigue damage accumulation.

**RISER DYNAMIC RESPONSE INTERPERATION**

The measured accelerations and stresses at the hang-off and touch down region are utilized to understand the SCR response. It is often difficult to interpret field data especially if there is limited background as this case for an SCR. To reach the current level of understanding multiple studies have been performed to understand sensor functionality and derive a methodology to interpret the data. The use of time and frequency domain analysis has been found particularly useful in addition with correlation and statistical analysis. A selected set of results is presented in this study.

**SCR TDZ Response**

Drift in short-term stress measurements is observed on the devices closest to the touch down point (TDP). However, when stresses over a period of few days are combined, an interesting correlation is discovered wherein TDZ stresses correlate with tidal heights. As shown in Figure 5, TDZ stresses follow a cyclic pattern with a 1 day period which is also the return cycle for tidal response. This unexpected finding is not accounted during any riser design analysis. Although, there is a relatively large stress cycle (~8-10MPa), the effect of tides from a fatigue standpoint is considered minimal as the stress cycle only occurs once a day.

**Frequency content**

One of the most important aspects of SCR response is the frequency content and the contributing factors for this response. A typical storm TDZ stress time series is presented in Figure 6. This was recorded during a 10-year storm and consists of various frequencies including very low frequency drift contributions. The later in attributed to touch down of the sensor on the seafloor due to a possible combination of vessel motions and operational shutdown resulting in internal pressure and temperature change. This causes a change in the catenary shape and location of the TDP along the riser span. The riser touch down at the sensor location results in minimal dynamic motions experienced by the riser at that location, as shown in Figure 6. Frequency domain analysis of various events reveals the presence of multiple frequencies as shown in the spectra of Figure 7. These riser motions are driven by the vessel movements and are attributed to:

- Vessel surge/sway ~ 100s
- Vessel pitch/roll ~ 50s
- Vessel wave frequency motions ~ 5-15s

All measurements along the riser have the same frequency content. The spectra of stresses and acceleration indicate a strong correlation between frequency content of motions and stresses, as expected. It is also observed that the driver for the motions is the wave loading on the vessel that subsequently drives the riser at the wave and vessel natural frequencies (surge, sway, pitch, roll, and heave). The absence of higher frequencies than the wave one, suggests that currents or riser oscillation through the water column have minimal impact on the riser response. This is expected, as the riser is fully covered with VIV suppression strakes, mitigating any vortex-induced motions that could be caused by the Keulegan–Carpenter flow. Without strakes, the created vortices would excite transverse motions proportional to the Strouhal shedding frequency which is a function of the riser oscillation velocity and would be observed above wave frequency range.
Figure 6: Riser TDZ stresses during a storm consisting of multiple frequencies and types of response.

Figure 7: Wave spectrum and associated TDZ acceleration and stress spectrum.

Catenary dynamic response characteristics

Time domain analysis and comparison of adjacent sensors reveals a traveling wave dynamic behavior. The unfiltered accelerations from a hang-off and a touch-down sensor are presented in Figure 8, comparing transverse and inline riser response. There is a strong correlation between hang-off and touch-down motions. As the vessel drives the riser at the hang-off, a transverse traveling wave is formed that travels down the riser and reflects back at the touch-down point, due to the near fixed boundary condition. This response is typical of a tension dominated structure, behaving as a tensioned string. All timeseries are stochastic in nature consisting of the same frequency content with modulated random amplitude with time. The signal pattern is typical of wave loading due to the random nature of sea waves.

CORELLATION OF RISER RESPONSE WITH VESSEL MOTIONS AND WAVES

Response amplitude correlation

The statistics from 36 periods are considered to evaluate the measured vessel and riser response against prevalent seastates. The measured riser and vessel responses are resolved into the three different planes: riser surge, riser sway and riser heave. It is observed that the vessel motions correlate well with wave heights, following a linear trend as expected.

The riser response at the hang-off location, obtained from response measured at monitoring station 1, is compared against wave heights in Figure 9. As in the case of vessel response, it is observed that measured riser response also scales linearly with wave height for significant wave heights up to 18ft.

The comparison between vessel accelerations at the deck and riser hang-off accelerations is shown in Figure 10. It is observed that the acceleration amplitudes at the deck are ~10 times the acceleration amplitudes at the riser hang-off location for the surge and sway directions. This is in-line with the expected Spar motion response. Riser motions increase linearly with vessels motions at the hang-off location.
Riser Surge Accelerations vs Hs

Figure 9: Riser surge response against wave height.

Comparison of Riser Hang-Off and Vessel Response

All Frequencies

Riser In-plane Accelerations

Vessel Accelerations

Riser Hang-Off Accelerations

Figure 10: Riser surge against vessel surge response.

Riser Motion and TDZ Stresses

Correlation between riser hang-off surge acceleration against TDZ stresses is excellent as shown in Figure 11, for the wave heights under consideration. Results indicate very good correlation between measurements from different riser monitoring stations and increase confidence level in sensor measurements for software benchmarking. This also suggests a “linear” like system response at small wave heights. As the riser motions increase, the behavior is expected to change with the riser pulling out of the trench resulting in a more non-linear response.

Riser Hang-Off Response Frequencies

Riser response is driven by two main contributing factors, wave activity and low frequency vessel motions. The periods under consideration are used to evaluate the dominant factors driving the riser response. The measured riser response is filtered into the following three frequency ranges:

- Wave Frequencies (3-30 sec Period)
- LF Spar Pitch-Roll Natural Frequencies (30-75 sec Period)
- LF Spar Surge-Sway Natural Frequencies (75-125 sec Period)

The riser response in each frequency range for surge, sway and heave directions is compared against wave height as shown in Figure 12 for surge motions. It is observed that wave activity is the more dominant contributing factor to resultant riser response. All frequency ranges representing different types of vessel motion correlate near linear with wave height.

CONCLUSIONS

The present study presents a first set of field measurements of a deepwater SCR in storm conditions. Analysis reveals that the SCR response is driven by motions from low frequency vessel natural frequencies and wave motions, with wave response being the more dominant factor. The riser stresses and motions correlate linearly with seastates for the wave heights under consideration. The response behavior can be characterized as stochastic dominated by a traveling wave dynamic response. In addition, it is observed that slow SCR TDZ stresses are affected by tidal variations.

Overall the findings of this study confirm that the SCR behavior is aligned with the current understanding and prediction models, for the wave heights and motion range under consideration. This study also in turn validates the riser measurements and deems them suitable for benchmarking of riser design software which is discussed in detail in [6].
ACRONYMS
Steel Catenary Riser (SCR)
Touch-down point (TDP)
Touch Down Zone (TDZ)
Riser Monitoring System (RMS)
Environmental and Facilities Monitoring System (EFMS)
Global Positioning System (GPS)
6 Degree of Freedom (6DOF)

REFERENCES