Measured VIV Response of a Deepwater SCR

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ABSTRACT

Vortex induced vibration is (VIV) is a major design issue for all deepwater riser systems operating in regions where severe current can be expected, such as the Gulf of Mexico and offshore Brazil.

Cross-flow vibrations of a riser in severe currents can diminish the riser fatigue life, dictate the riser arrangement, fabrication details, vessel layout, installation method, and thus have significant cost impacts at all stages of the field development.

In-service monitoring or full scale testing is essential to improve our understanding of VIV response and confidence in our ability to predict fatigue damage. This has been realised with the usage of motion monitoring instrumentation capable of recording riser lateral motion at various positions over the SCR length to define the riser response under VIV conditions.

This paper presents the results and subsequent data processing from a 5 month data gathering campaign conducted on the Allegheny 12in gas export SCR located in 1000m water depth in the Gulf of Mexico.

Each stage of data processing is discussed, with particular emphasis being placed on the usage of measured data to improve the understanding of multimode riser activity and its effects on riser fatigue.

KEY WORDS: VIV, SCR, Deepwater, Monitoring, Fatigue, Multimode, Instrumentation

INTRODUCTION

The VIV fatigue behavior of a deepwater steel catenary riser (SCR) is an area of offshore engineering that is not fully understood by operators and analysts alike. The catenary shape of the riser lends itself to a non-linear modal response that differs from that expected from a top tensioned riser system, and with the added complications of soil interaction and touchdown point (TDP) variation, the vortex-induced response of the riser pipe is subject to a number of external influences.

In order to define and explain the effects of these variables on the VIV response of an SCR, and to also gain evidence of single or multi-mode VIV activity, 2H Offshore Engineering Ltd. equipped a straked 12in Gas Export SCR attached to a mini-TLP on the Allegheny development in the Gulf of Mexico with 12 triaxial acceleration logging devices to capture the motion of the SCR over a 5-month period. The water depth in this region is 1000m.

This paper presents the findings from the 5-month logging campaign. An explanation of the multimode events where the riser is exciting more than one mode of vibration is provided. The mode shapes of the riser are subsequently matched to the mode shapes predicted from analytical software and the validity of VIV damage prediction is examined.

SYSTEM LAYOUT

The triaxial motion loggers were placed in the region of the strakes and below the strakes, and also in the region of the TDP where soil interaction and VIV of the lower part of the riser could be observed. The logger placement is shown in Table 1 and Figure 1, along with a photo of one of the triaxial loggers in Figure 2.

Table 1 – Logger Spacing

Logger Ref.	Riser Section	Spacing Between Loggers (m)	Position Along SCR (m)
11	On Vessel	-	-
3	Straked Section	-	87.3
4	Straked Section	51.0	138.4
5	Straked Section	43.9	182.2
6	End of Straked Section	13.7	195.9
7	Riser	12.2	208.1
8	Riser	27.4	235.6
9	Riser	38.9	274.4
10	Riser	48.8	323.2
12	Riser Near TDP	-	1113.2
14	Riser Near TDP	24.4	1137.6
13	Riser Near TDP	12.2	1149.8

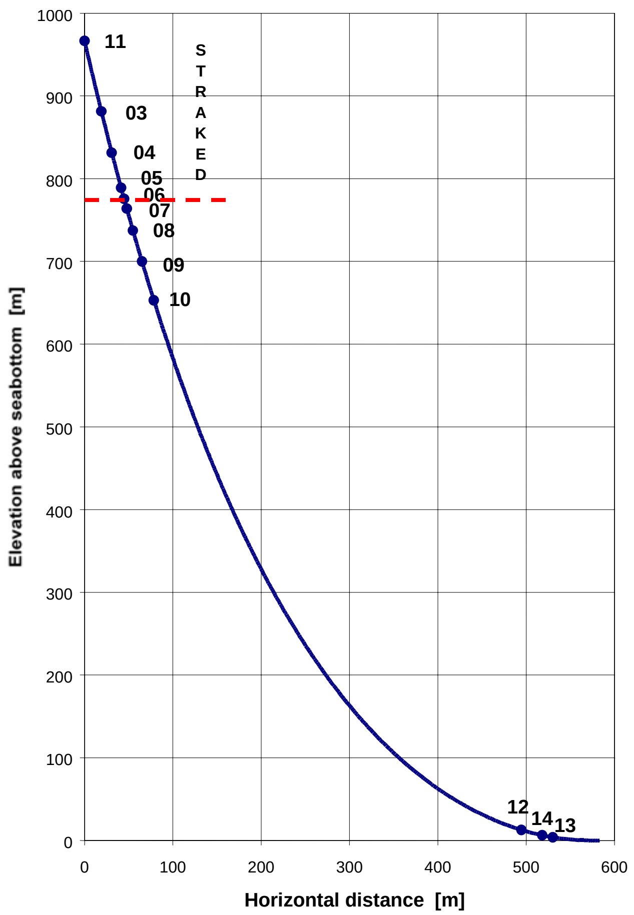

Figure 1 – Logger Placement along Riser

Figure 2 – Logger Bottle within Riser Attachment Assembly

The loggers were set up to record 20 minutes of riser motion every 6 hours and write the data to internal memory cards. The loggers were installed on the 19th August 1999 and removed when the memory was full on the 10th January 2000.

DATA PROCESSING METHODOLOGY

A brief summary of each data processing stage is given below:

- Calibrate Data – the raw acceleration data from the loggers is calibrated, and corrected for temperature variation. The program also splits the data into the separate events.
- Spectral Analysis – the X and Y axis acceleration timetraces are combined in different directions at 5 degree intervals and fast fourier transforms conducted in each direction. The peaks at each frequency are combined to give a resultant acceleration spectrum and the directions associated with each frequency noted.
- Identify Response Peaks – for each logger position, the 12 largest response peaks are identified from each resultant acceleration spectrum and the frequency, magnitude of acceleration and direction are identified.
- Component Response Processing – the 12 response peaks for each logger in an event are evaluated to identify correlating frequencies along the riser length termed response components. The response amplitudes at these correlating frequencies are then processed to determine the appropriate mode shape number, apply a gravity correction factor and identify response direction.

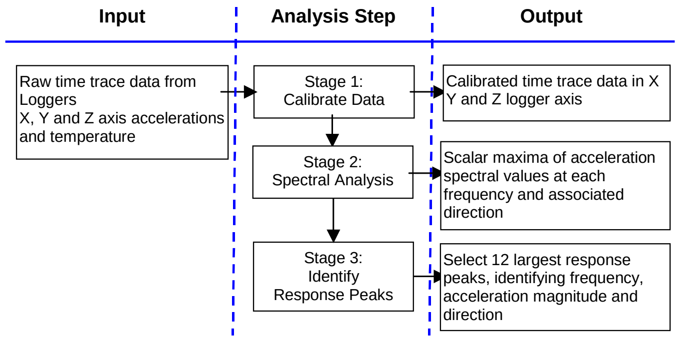

Figure 3 – Overview of Data Processing

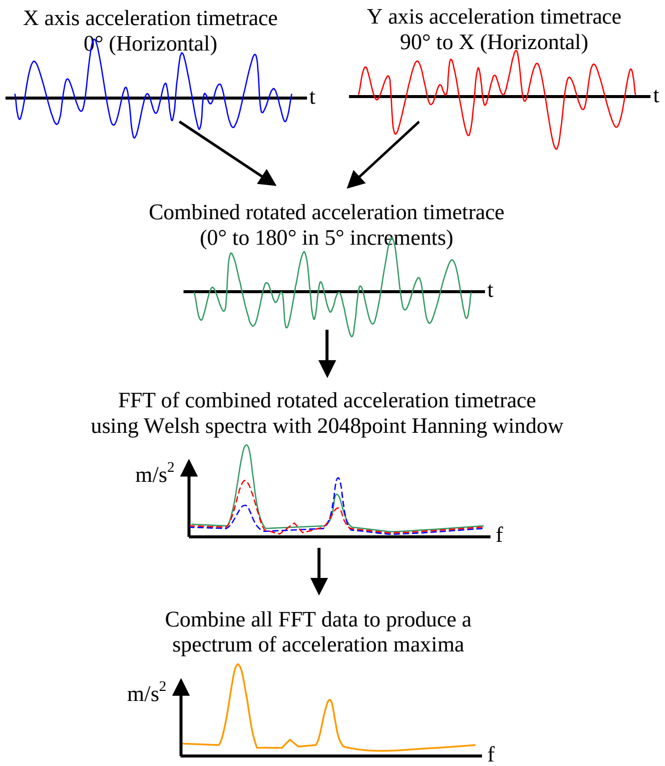

Figure 4 – Illustration of Spectral Analysis

The results are presented in two forms. The first being a spectra plot which details the acceleration maxima for a range of frequencies from which VIV activity appears as narrow peaks, and the second is a spectrogram, where individual spectra are produced at equally spaced intervals along the 20 minute logged event and these are combined to show the frequencies excited at each time step – the spectrogram is graded such that blue represents low amplitude activity and yellow to red indicates high to very high amplitude activity. A spectra plot and spectrogram for one of the loggers is shown in Figure 5 and Figure 6 where VIV activity at three distinct frequencies between 0.25Hz and 0.35Hz can be seen.

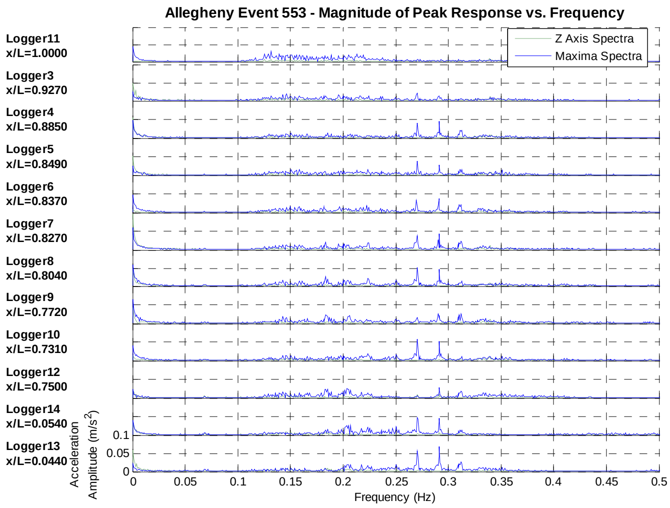

Figure 5 – Event Spectra for all Loggers (Event 553)

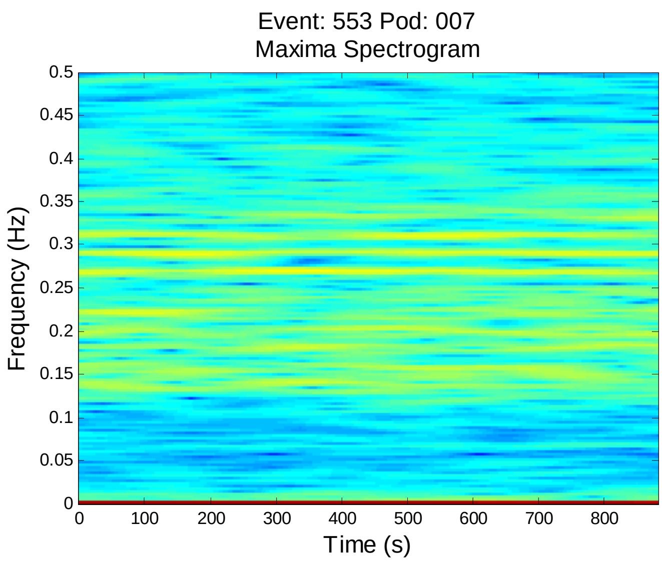

Figure 6 - Spectrogram for Logger No.7 of Event 553 (shown above)

RESULTS INTERROGATION

VIV Identification

580 riser motion events were logged between August 1999 and January 2000. Of which 220 were found to contain riser motion, much of which attributed to VIV activity. In order to understand the riser response, two events which show considerable VIV activity are extracted for further analysis. The first event is No. 553, shown in Figure 5, which exhibits VIV activity at three different frequencies, as well as low-amplitude vibration between 0.1Hz and 0.25Hz. The second event is No. 86, shown in Figure 7 and Figure 8, where three narrow peaks are observed at 0.09Hz, 0.19Hz, and 0.29Hz.

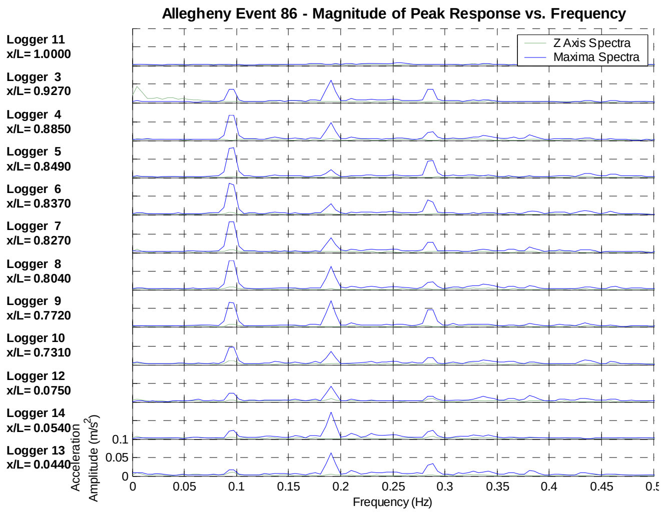

Figure 7 – Event Spectra for all Loggers (Event 86)

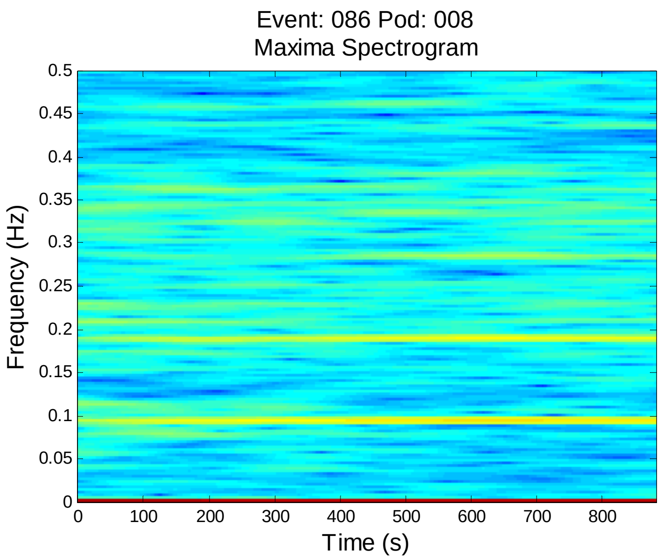

Figure 8 – Spectrogram for Logger No. 8 of Event 86 (shown above)

The spectrograms are an indication of the extent of the multimode activity during the VIV event. Event 553 shows a steady occurrence of VIV at 0.27Hz, 0.29Hz and 0.31Hz for the entire length of the event, whereas the event 86 only shows consistent VIV at 0.09Hz and 0.19Hz, with the vibrations at 0.29Hz occurring from 400secs onwards.

The uppermost logger mounted to the vessel provides valuable data on the source and validity of the VIV activity. For event 553, the uppermost logger records low amplitude vibration from 0.1Hz to 0.25Hz, which is also felt by all of the loggers beneath, but to a lesser extent. This indicates that this low frequency motion is as a result of vessel movement attributed to external factors such as wind buffeting, second order motion, or even drilling activity. Therefore this low frequency activity can be rejected as possible VIV – although the spikes that are apparent for the riser loggers around 0.27Hz that are not seen in the vessel logger can be attributed to VIV.

In a similar way, event 86 shows no response at the vessel logger for all frequencies, thus indicating that the narrow spikes seen by the rest of the loggers are as a result of riser motion and are likely to be due to VIV activity.

Mode Shape Matching

In order to observe the behavior of the SCR during multimode VIV events, the VIV accelerations are compared with accelerations from modal analysis conducted on an analytical model of the riser generated using the Modes-3D (an add-on of Flexcom-3D). From the measured accelerations, the maximum amplitude of oscillation for each selected mode can be found. The analytical modes are “gravity contaminated” to account for the gravitational accelerations which are picked up by the riser loggers and contaminate the readings.

To improve the clarity of the model shape matching, the mode shape is normalized such that all values are positive and are expressed as a percentage of the maximum displacement. The predicted modal accelerations for each logger location are compared with the actual accelerations and the most likely mode of oscillation is selected.

A comparison of the predicted with actual accelerations for Event 553 are given in Figure 9.

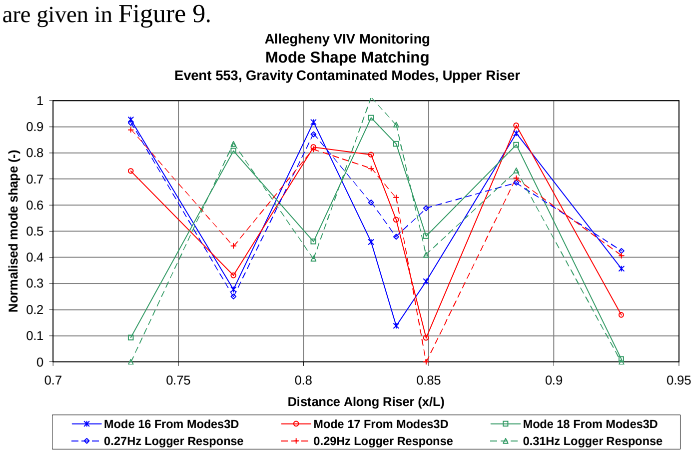

Figure 9 – Mode Shape Matching (Event 553)

The 0.29Hz and 0.31Hz response matches well with predicted accelerations for modes 17 and 18 from modal analysis. The 0.27Hz response matches well for the first 4 of the upper loggers, but correlations breaks down thereafter. In order to determine whether this mode matched is accurate, the 0.27Hz response accelerations are compared with accelerations from lower mode numbers i.e. mode 14, 15, 16. This is shown in Figure 10.

The modal comparison shows that even though the first four loggers of the upper group match well with a mode 16 response, the uppermost loggers generate accelerations more in line with a mode 15 riser response. This indicates that for this event, the riser is oscillating at three separate frequencies, but with four modes of vibration. The 0.27Hz response is actually two separate modes vibrating at the same frequency.

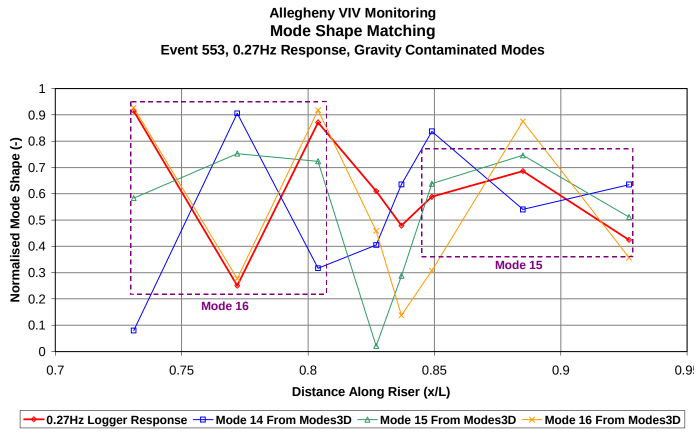

Figure 10 – Comparison with Adjacent Modal Accelerations

The final mode shape match is shown in Figure 11. This plot represents the mode shapes in terms of actual acceleration amplitudes and not normalized amplitudes. From this the degree of excitation of each mode can be observed. In the case of Event 553, the mode 15/16 response shows the greatest amplitude (and hence A/D) of vibration and therefore potentially the dominant mode, whereas the mode 17 response generates the lowest riser displacement.

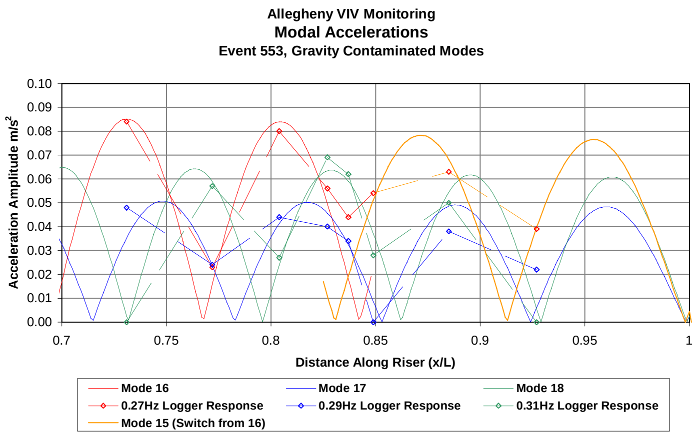

Figure 11 – Mode Shape Matching Amplitude Comparison (Event 553)

In a similar manner, the upper loggers for event 86 are matched to their corresponding modes. This is shown in Figure 12 and Figure 13 where a similar response to Event 553 is seen. Again, the riser is shown to vibrate at modes 5 and 9 at 0.095Hz and 0.19Hz respectively, but also at a combination of mode 14 and mode 13 at a frequency of 0.285Hz, with modal interaction within the region of riser between where the two modes are observed.

position of the riser by only 15m, the mode shape is matched much more effectively. This is illustrated in Figure 15.

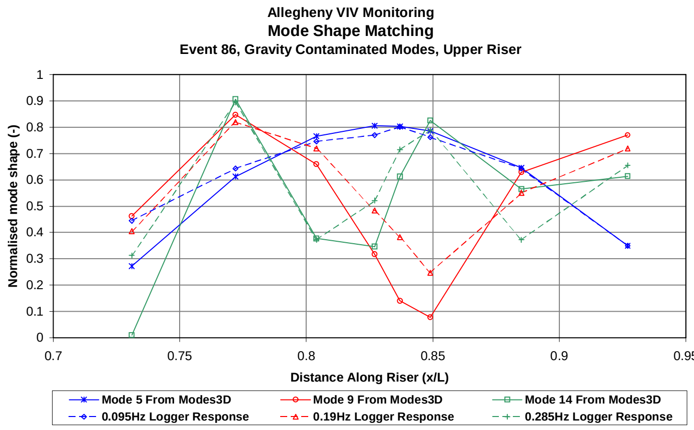

Figure 12 – Mode Shape Matching (Event 86)

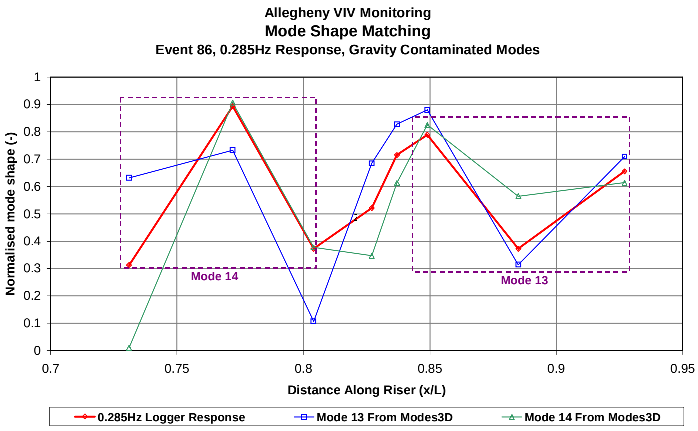

Figure 13 – Comparison with Adjacent Modes (Event 86)

The intention of installing the riser loggers in two separate groups – upper and lower – is such that analysis can be conducted separately on the two regions. By grouping more loggers at the top of the riser in the highest current velocity region the modes of vibration can be accurately determined and compared with analytical data. These modes are then extrapolated to the lower riser and compared with the acceleration measurements of the lower loggers to confirm the overall riser response.

Figure 14 shows a comparison of the measurements from the lower loggers of event 553 with the mode shapes predicted using the upper logger measurements. Although they do not show a perfect match, the overall trend of the comparison is good.

The most critical observation is that the measured accelerations show a slight shift in position from where the analytical results suggest the mode shape would be. It must be noted that the analytical model is set up to represent the as-installed configuration of the Gas Export SCR, with the TDP situated in the nominal position and no trenching or lateral excursion of the TDP position. In reality the riser has had a period of settling prior to the logging campaign at it is likely that the TDP is not in the same position as when it was installed.

Analytically, if the riser experiences trenching or if the soil suction effects reduce the motion of the riser pipe around the TDP, the bottom point of fixity will move further up the riser, this increasing the elevation of the lowermost vibratory node. By applying a shift in TDP

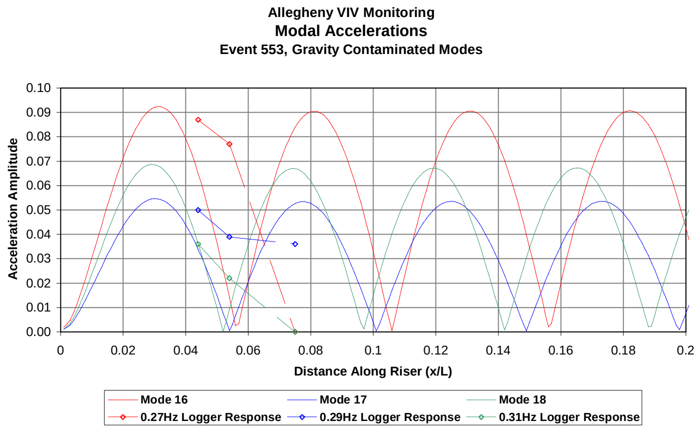

Figure 14 – Mode Shape Matching of Lower Loggers (Event 553)

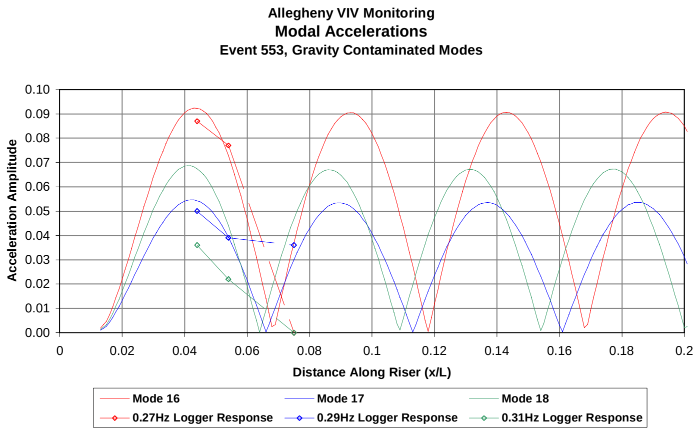

Figure 15 – Effect of TDP Shift on Mode Shape Matching (Event 553)

Furthermore, the spectra plot shown in Figure 5 indicates that the riser response at 0.31Hz is heavily damped towards the TDP compared to the accelerations measured by the upper loggers. The theoretical modal analysis does not account for modal damping and assumes constant amplitude along the length of the riser. By applying damping of approximately 50% for mode 18 response the final mode shape match is confirmed. This is illustrated in Figure 16.

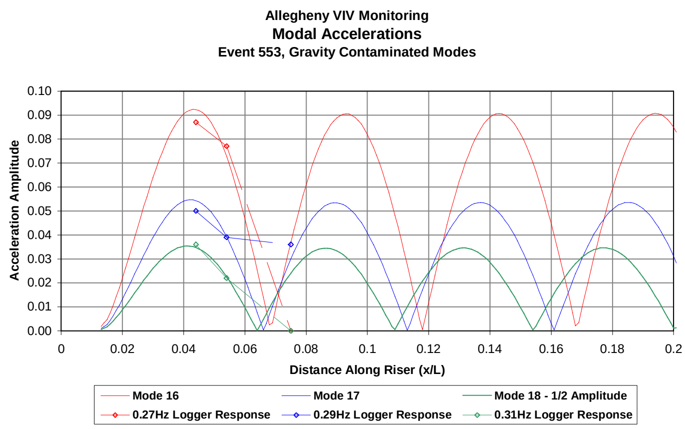

Figure 16 – Effect of Damping on Mode Shape Matching (Event 553)

It was later confirmed by British Borneo, the operators of the Allegheny field during the 1999-2000 campaign that the TDP of the SCR had shifted by a small amount due to settling. The degree of TDP movement was unconfirmed, but analyses conducted on similar SCRs by 2H Offshore Engineering Ltd. suggest that movement of ±15m or greater is not uncommon.

CORRELATION OF RESPONSE TO CURRENT DATA

As a final verification of the riser VIV response, the SCR is assessed using the commercial VIV analysis software, Shear7 (v.4.3).

During the logging campaign, current profiles and velocities were logged by the Atwood Hunter drilling rig situated on the Allegheny field between 26th December 1999 and the 9th January 2000. By extracting the current data that occurred during event 553 (4th January 2000 at 6am), the analytical modal analysis could be used in conjunction with a Shear7 model to predict the theoretical riser VIV response and compare with the actual measured data.

The Shear7 parameters used are defined in Table 2.

Table 2 – Shear7 Parameters

Parameter	Value
Strouhal no.	Code 200 (rough cylinder)
Mode cut off	0.5
Single mode reduced velocity bandwidth	0.4
Multi-mode reduced velocity bandwidth	0.2
Structural damping coefficient	0.005
Strake lift coefficient reduction factor	0.25
Straked region added mass coefficient	2.0

Based on the Strouhal code of 200 for rough cylinders, and the dimensions of the riser pipe, the resulting Strouhal number applied to the model is around 0.25. Previous analysis conducted by 2H Offshore Engineering Ltd. on top tensioned risers has concluded that the Strouhal number for a pipe in current flow is between 0.16 and 0.20. In order to identify the effect that this has on the riser response, parametric analysis is conducted to identify which modes are excited for each respective Strouhal number. This is defined in Table 3, where it can be seen that for a Strouhal number of 0.195, the predicted modal response of 16, 17, and 18 are obtained.

Table 3 – Effect of Strouhal Number on Riser Response

Strouhal Number / Code	Modes Excited in SHEAR7
Code 200 (Approx. 0.25)	20 21 22
0.16	15 16
0.17	15 16
0.18	15 16 17
0.19	16 17
0.195	16 17 18
0.20	17 18

Table 4 compares the frequencies associated with modes 16-18 above with the frequencies seen in the spectra plot (Figure 5). These are found to be very similar for all modes and thus it can be concluded that Shear7 shows a sufficient match with measured data.

Table 4 – Comparison of Predicted Modal Frequencies with Measured

Mode	Measured Response (Hz)	SHEAR7 Frequency (Hz)
16	0.270	0.288
17	0.290	0.310
18	0.310	0.332

The maximum amplitude of vibration of the SCR in Shear7 was also compared with the measured response. This is deemed to be the most significant comparison since if Shear7 does not predict similar amplitude of vibration; it will not predict the correct riser curvature and the VIV fatigue damage could be lower than that found in reality. The amplitude comparison is given in Table 5, where a difference of less than 10% is seen for modes 16 and 18, but Shear7 over predicts the mode 17 amplitude by 50%. This is considered to be an acceptable result since there are a number of external factors which affect the SCR that Shear7 cannot model such as current directionality with depth, TDP movement during oscillation, and the exact lift characteristics of the riser strakes. It is encouraging to know that Shear7 is more likely to overestimate the fatigue damage than underestimate it.

Table 5 – Comparison of Predicted Modal Amplitudes with Measured

Mode	Amplitude of Vibration (m)	
	Measured Response	SHEAR7
16	0.031	0.034
17	0.016	0.024
18	0.018	0.017

The areas of riser which generate the most lift for each mode from Shear7 results are shown in Figure 17. These regions represent the areas that VIV lock-on occurs with all other parts of the riser exposed to current damping out the VIV. The lock-on regions generate the greatest amplitude of vibration for that specific mode, and therefore by comparing Figure 17 with the spectra in Figure 5, it can be confirmed that the logger areas of lock-on do indeed correspond to loggers which see relatively high amplitude vibration compared to the lower loggers and those at the top of the straked region.

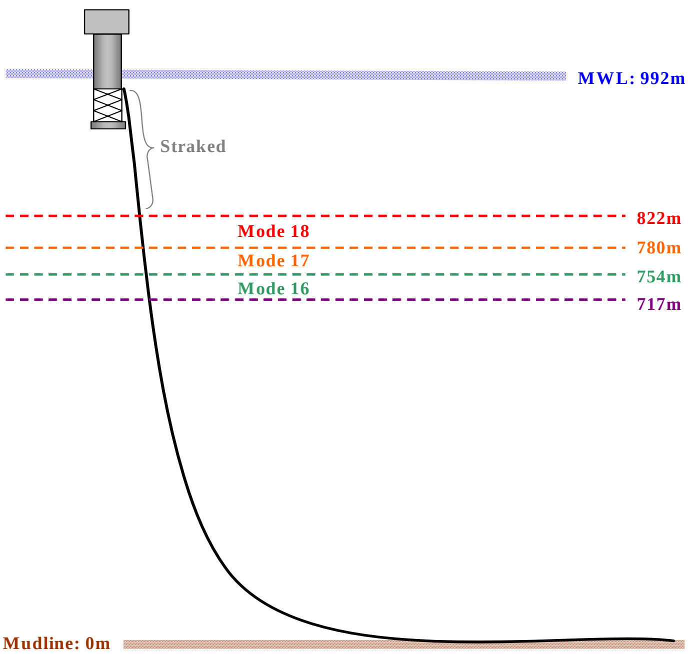

Figure 17 – VIV Lock-on Regions

CONCLUSIONS

The VIV logging campaign conducted has successfully demonstrated that multi-mode VIV can and does occur for SCRs, with the potential for three or more modes being excited simultaneously. The results have also indicated that using triaxial acceleration readings, the mode shapes defining the response can be accurately predicted, from which the VIV fatigue damage can be obtained using Shear7.

The method of riser motion logging proposed by 2H Offshore offers a commercially advantageous way of recording VIV activity using a small number of low cost loggers and a basic understanding of the expected current activity so that they can be positioned appropriately.

The VIV events also demonstrate the existence of higher (3f) harmonics as reported to Vandiver during OTC 2006.

ACKNOWLEDGEMENTS

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