Orcina

ORCAFLEX VIV TOOLBOX VALIDATION

COMPARISONS WITH MEASURED DATA FROM SCHIEHALLION DRILLING RISER

Project 648

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1 Introduction

This is one of a series of reports comparing measurements of VIV response with predictions made using the OrcaFlex VIV Toolbox. In this report we give a brief description of the test cases and present comparisons between measurement and prediction. We do not attempt to draw firm conclusions, on the grounds that conclusions based on a single set of tests would be of limited value and could be misleading. General conclusions regarding the validity and appropriate field of application for each of the VIV models in the Toolbox are drawn in a separate report (Ref. 1), in which we review comparisons over as wide a range of conditions as possible.

2 Data Obtained at Schiehallion Field

2.1 Data Sources

VIV data were obtained by BP from an instrumented drilling riser during development drilling on the Schiehallion field, west of Shetland, in May and June 2002. Some of the data were made available to the Norwegian Deepwater Programme (NDP) and a number of cases were chosen for blind trials of VIV prediction software. The chosen test cases are detailed in Ref. 2; comparisons between measurement and prediction are presented in Ref 3. All the measured data used in this report were taken without modification from Ref 3.

Comparisons were also made for a second set of measurements at the Svinøy field, located further west in deeper water in the Faroe-Shetland channel. Details of these cases are also given in Refs 2 and 3. However, the Svinøy data were incomplete in several respects and were considered by BP and NDP to be less reliable than the Schiehallion data. For this reason, the present report deals with the Schiehallion results only

2.2 Test Details

Figure 1 shows a schematic of the Schiehallion drilling riser, a conventional top-tensioned riser deployed from a semi-submersible drilling vessel in water of depth 360m. The lower marine riser package (LMRP), which incorporates the lower flex joint, was situated 18m above the mudline, giving a riser length in water of 342m, of which 311m was buoyed. The buoyed length is shown orange in Fig. 1. Key riser parameters were:

• Riser length from hang-off to LMRP	360m
• Riser diameter – buoyed	1.1m
• Riser diameter – un-buoyed	0.6m
• Length/diameter ratio based on buoyed OD	327
• Mass ratio (mass inc. contents/displaced mass of water)	1.1

Data loggers were attached at five locations on the lower part of the riser as shown in Fig. 1. Additional loggers were located on the vessel and the lower marine riser package (LMRP).

18 load cases were selected by NDP for the blind trials. Most cases were current dominated, with negligible wave excitation, but a few included waves. No details of waves or vessel motions were provided, so the analysis in each case assumed a constant current profile only.

Current velocity and direction over the full water column were measured for each load case using acoustic Doppler devices. There was very little variation of current direction over the water depth. Current direction at individual locations was between ±4° and ±10° of the mean for the selected load cases (average ±8°). For practical purposes, currents can be considered as in-plane for all load cases (though the actual current direction profile was used in the computations).

Velocity profiles for the 18 load cases are shown in Figure 2. With one exception, the profiles are characterised by near-linear shear from a maximum at the surface to about 50% of the surface value at the seabed. The exceptional case shows a substantial local reduction in current speed at mid-depth but the profile is otherwise similar to the rest.

The range of current speed in the test cases considered here was from 0.3 to 1.2m/s, which corresponds to a Reynolds number range of 2.5e5 to 1.1e6. This straddles the transition region. All the VIV models used were developed using data for sub-critical flow (Re < 2.5e5).

The data loggers recorded accelerations in two directions X and Y normal to each other and to the riser axis. Logger X axis was at 215°, Logger Y axis at 305°. Average current directions were in the range 50° to 70°. (All angles are measured clockwise from North.) Logger axes and current directions are shown in Figure 3. Logger X was closest to the in-line direction in all cases but motions in both logger directions would have included contributions from both in-line and transverse VIV. No attempt was made to identify the separate contributions.

2.3 Data Available for Comparisons

Time histories of X and Y acceleration at each of the five data loggers were recorded for most of the test cases: for some cases instrument malfunction reduced this to four loggers. The data were processed to extract RMS values and dominant frequencies of response and these were the basis for the comparisons.

It is worth noting that the dominant frequency of response differed for different loggers in the same current conditions – quite widely in some cases. This may indicate mixed mode response but we have no further information with which to confirm or reject this hypothesis.

The measurements are sparse – five locations only in the lowest third of the riser. Consequently, no reliable assessment of vibration mode shapes was possible.

2.4 g-contamination

The data loggers measured acceleration in two directions normal to each other and to the riser axis. The measured accelerations are therefore “g-contaminated” when the riser is not precisely vertical. This issue is discussed in Appendix 1.

In principle, measurements could be corrected for the effects of g-contamination if the vibration took the form of a single mode with constant amplitude and frequency, all of which are known or can be reliably estimated. In the present case, the measurements are too sparse to permit identification of a mode shape with any confidence, and it is unlikely that amplitude and frequency were constant. g-contamination can easily be added to the computed results (OrcaFlex has facilities for this), so all the comparisons reported here include g-contamination in both measurements and computations.

2.5 Accuracy and Repeatability of Measured Data

For “real world” measurements such as these, exact replication of test conditions is not possible.

The investigators were said to have selected sections of “steady state” response for the blind trials, but we have no measure of variability of response in nominally constant conditions.

3 Calculated Results

3.1 VIV Models

VIV response calculations were carried out using the OrcaFlex VIV Toolbox. In this report we present results for the following VIV models:

Three wake oscillator models:

- Milan wake oscillator with as-published parameters (‘Milan original’)
- Milan wake oscillator with Ca = 0, other parameters as published (‘Milan Ca=0’)
- Iwan and Blevins wake oscillator with as-published parameters (‘I+B’)

Two vortex tracking models:

- Vortex tracking (1) uses special techniques to group newly-shed vortices into vortex sheets and decide when a sheet detaches from the riser disk and a new sheet starts to form ('VT1')
- Vortex tracking (2) does not try to group vortices into sheets. However the sheets are still present in the pattern of vortices being shed. ('VT2')

Details of the models and references to the original publications are given in Ref 4. Note that the wake oscillator models are designed to predict transverse VIV only.

3.2 Comparisons and Presentation of Results

Comparisons are presented in graphical form. For each model, four plots are presented:

- RMS accelerations in X and Y directions averaged over all operational data loggers: predicted versus measured
- Maximum RMS acceleration in X and Y irrespective of axial location: predicted versus measured
- Dominant frequency of transverse acceleration: predicted versus measured
- Bias ratio plot (predicted/measured) for averaged and maximum accelerations: ratios plotted against current speed averaged over the whole water column.

In the first three plots, a diagonal broken line corresponds to ‘Predicted = Measured’. In the Bias Ratio plot ‘Predicted = Measured’ corresponds to a value of 1.0, shown by the red line.

Results for each model are presented as follows:

- Figure 4 Milan Wake Oscillator model with as-published parameters
- Figure 5 Milan Wake Oscillator with Ca = 0, other parameters as published
- Figure 6 Iwan and Blevins Wake Oscillator
- Figure 7 Vortex Tracking (1)
- Figure 8 Vortex Tracking (2)

All computed results include g-contamination as discussed in Section 2.4 and Appendix 1.

4 Review of Comparisons

4.1 Wake Oscillator Models

4.1.1 Milan Wake Oscillator with as-published parameters

The acceleration results mostly give bias ratios between 0.5 and 1.5, with a few outliers beyond this range. Bias ratios are greater for Y accelerations than for X, and bias ratio shows a tendency to increase with increasing current speed.

Predicted dominant frequency of vibration is typically 30% lower than observed.

4.1.2 Milan Wake Oscillator with Ca = 0

Results are very similar to those for the Milan model with as-published parameters.

4.1.3 Iwan and Blevins Wake Oscillator

Results are similar to those for the Milan model, but with more scatter in predictions of accelerations and a greater tendency to over-predict (note the different vertical scales for the Bias Ratio plots).

4.2 Vortex Tracking Models

Both Vortex Tracking models over-predict both accelerations and response frequencies strongly. Bias ratios for acceleration are typically around 4, around 3 for response frequencies.

5 Acknowledgements

Orcina Ltd. wish to thank BP and the other member companies of the Norwegian Deepwater Programme for permission to use the VIV measurements for this comparison study.

6 References

1 R648#01#02 OrcaFlex VIV Toolbox Validation: Summary and Recommendations, Orcina Ltd., 17 May 2007.

2 Trim, A.D., NDP Riser-Metocean Activity (3.2). Input and Output for CTR3: VIV Alternative Analysis. Rev 1. 8th July 2003 (Confidential).

3 King, R. and Trim, A.D., Comparison of Drilling Riser CFD Analyses for Two Offshore Sites. NDP report NDP/Blind01/05v02, June 2005 (Confidential).

4 OrcaFlex User Manual (Version 9.0 or later), Orcina Ltd.

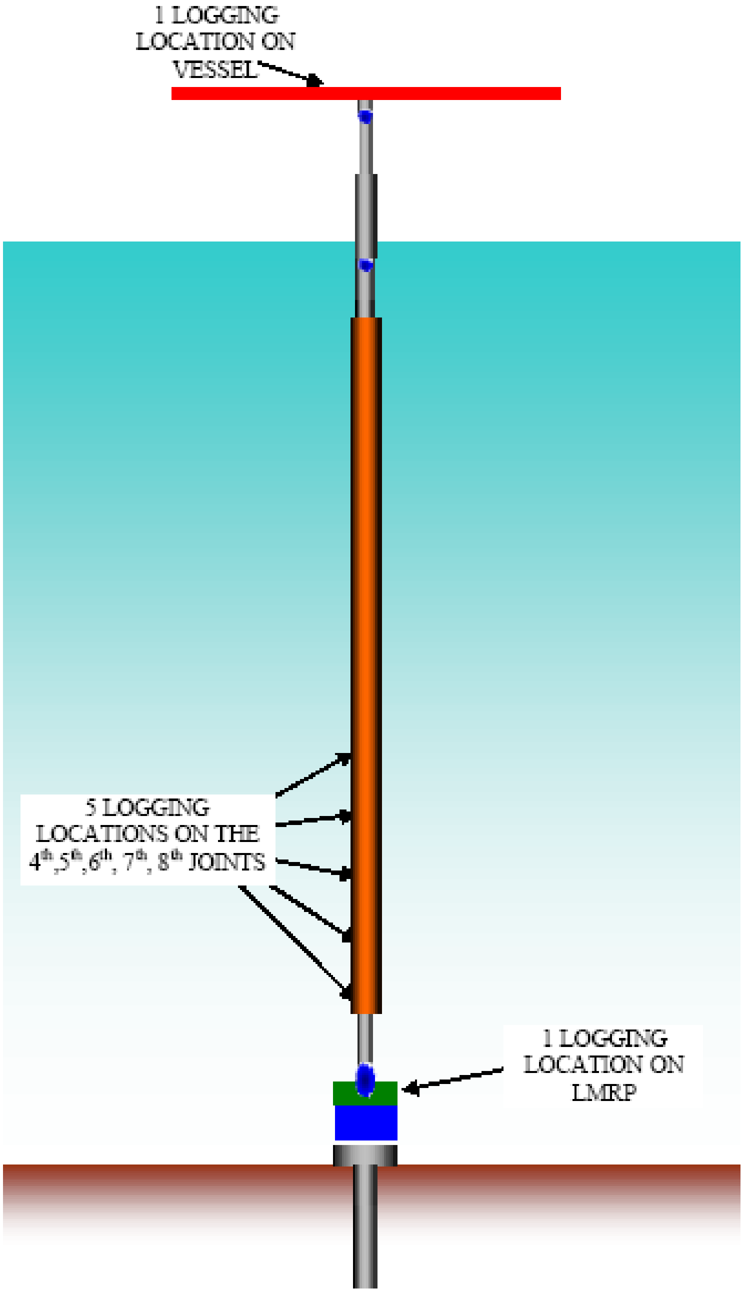


Figure 1: Schematic of Schiehallion drilling riser

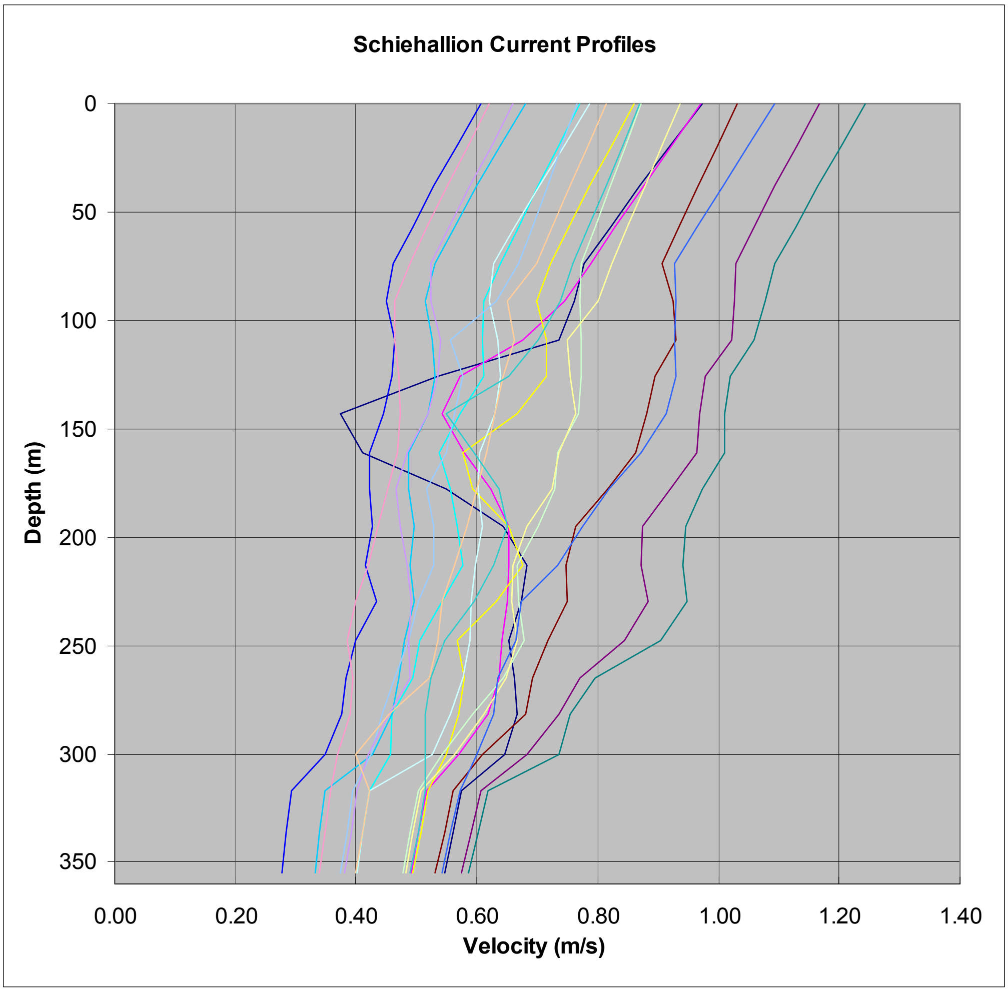


Figure 2: Schiehallion Current Profiles

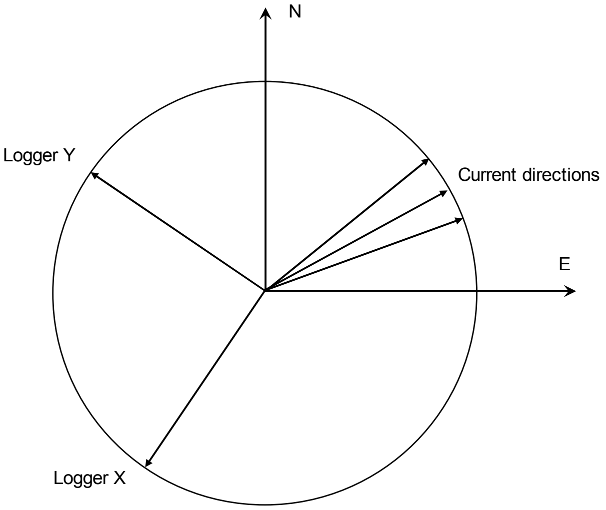


Figure 3: Logger axes and current directions

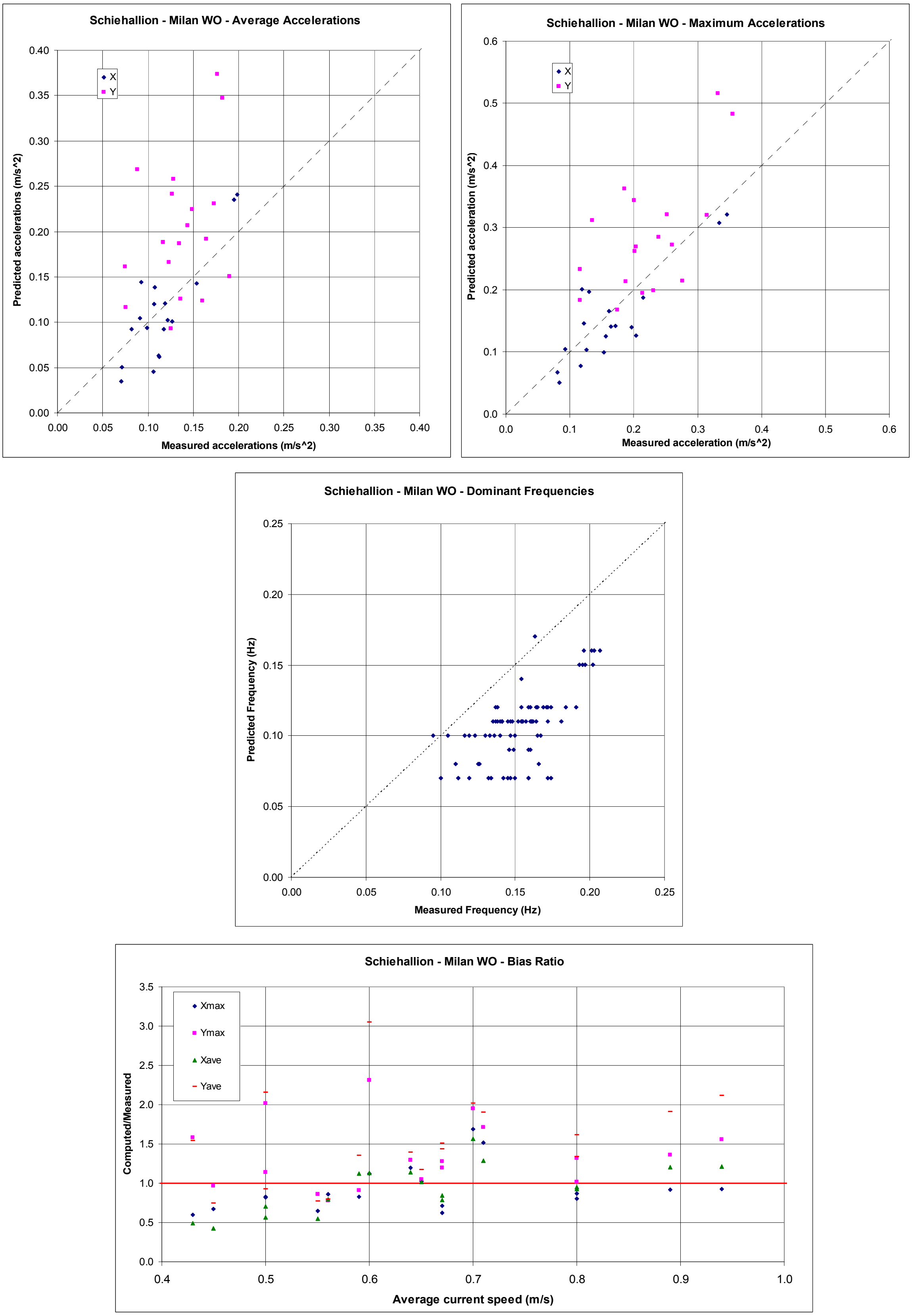


Figure 4: Milan Wake Oscillator with default parameters

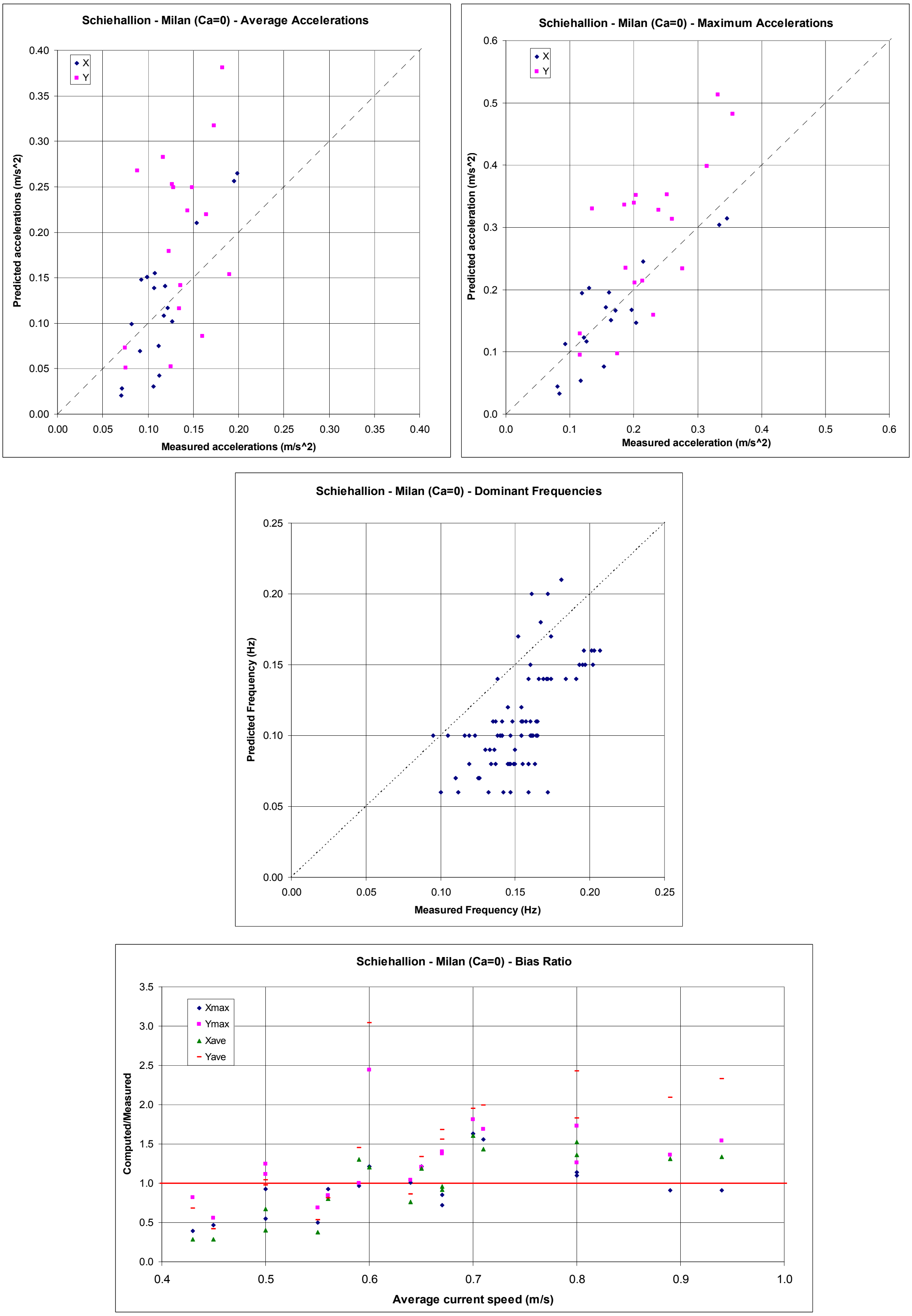
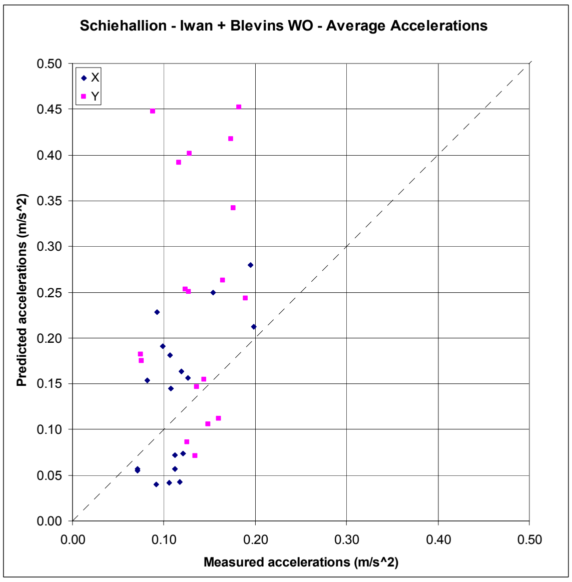
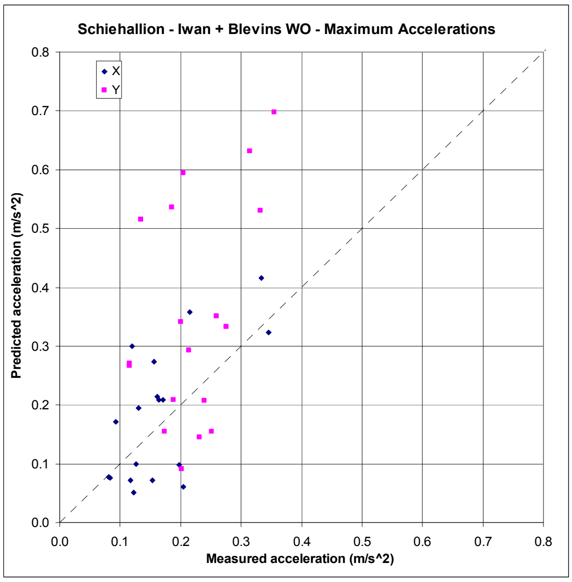
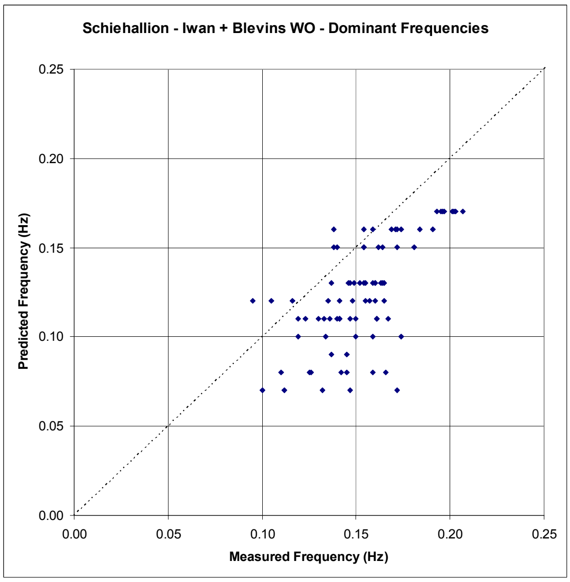


Figure 5: Milan Wake Oscillator with Ca = 0







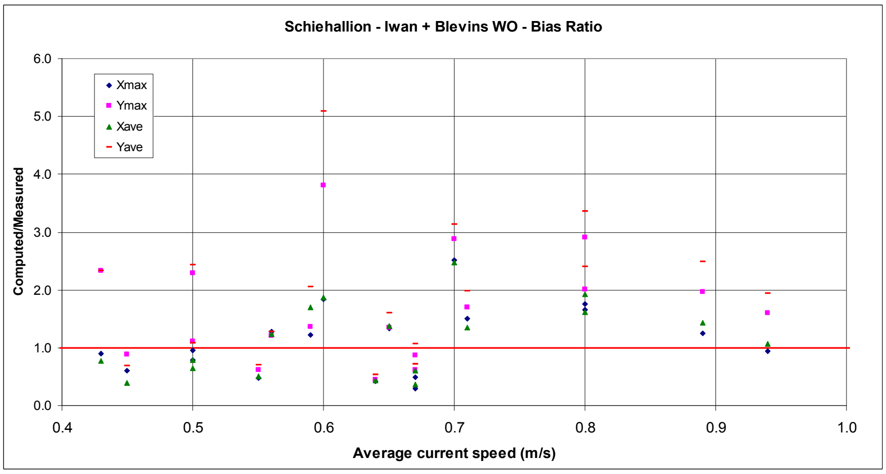


Fig 6: Iwan and Blevins Wake Oscillator

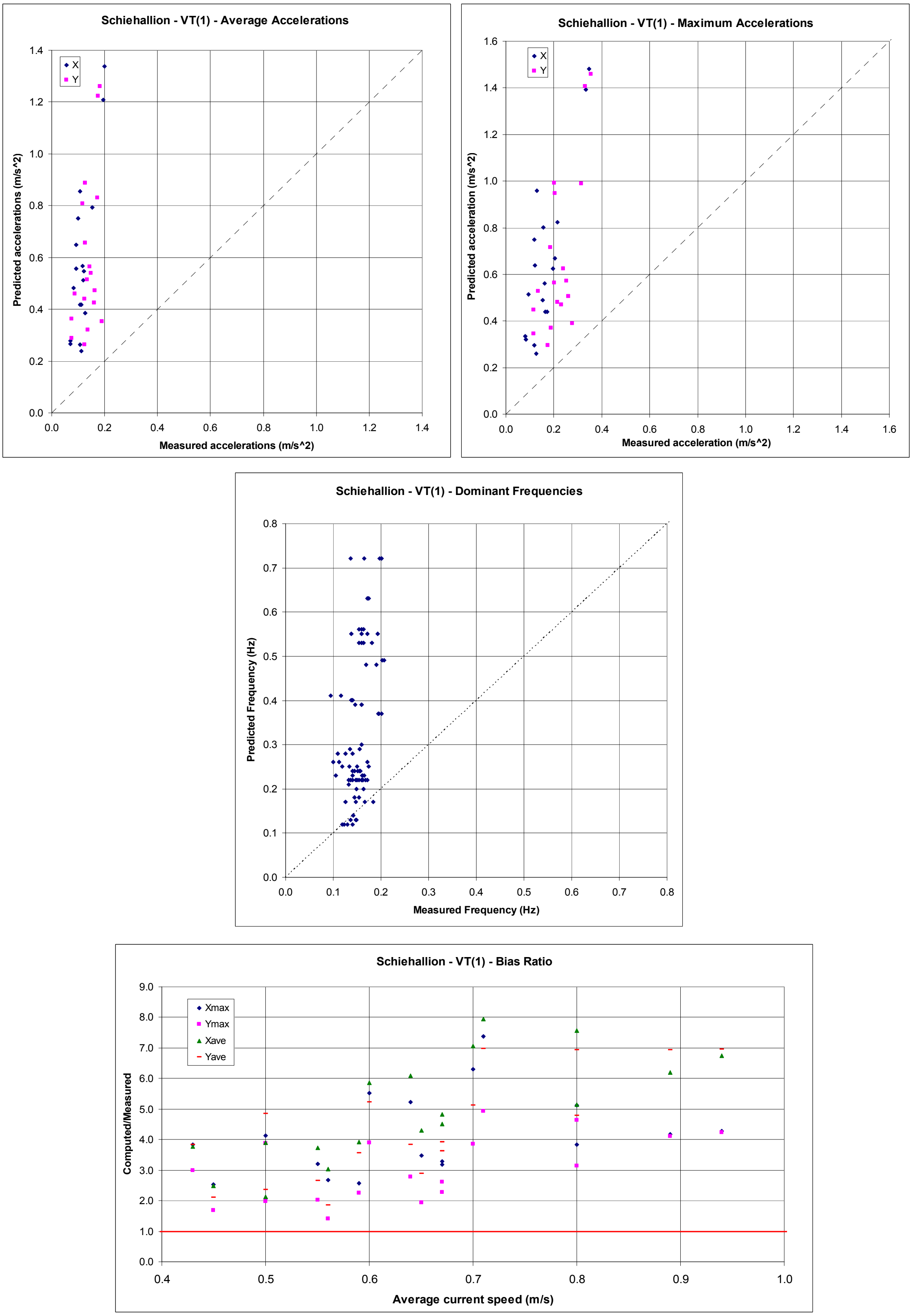


Figure 7: Vortex Tracking (1)

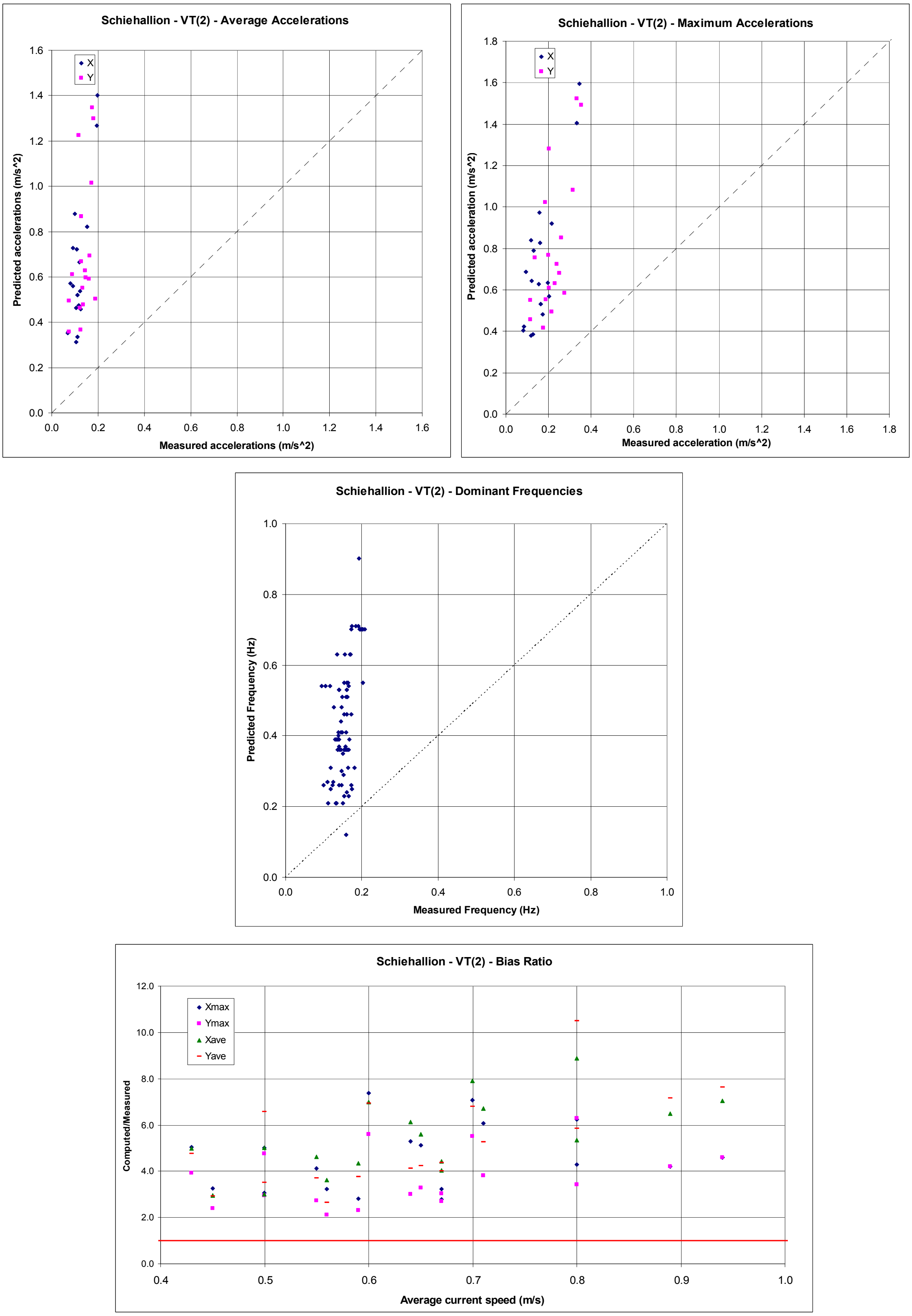


Figure 8: Vortex Tracking (2)

Appendix 1

Gravity Contamination of Accelerations

A1 Definitions

Consider a vertical tensioned riser undergoing VIV. Lateral deflections and angular deviations from vertical are everywhere small.

A data logger fixed to the riser so as to measure acceleration normal to the local axis will measure the sum of two components: the true lateral acceleration corresponding to VIV plus a gravitational component proportional to the riser angle to vertical (Figure A1.1).

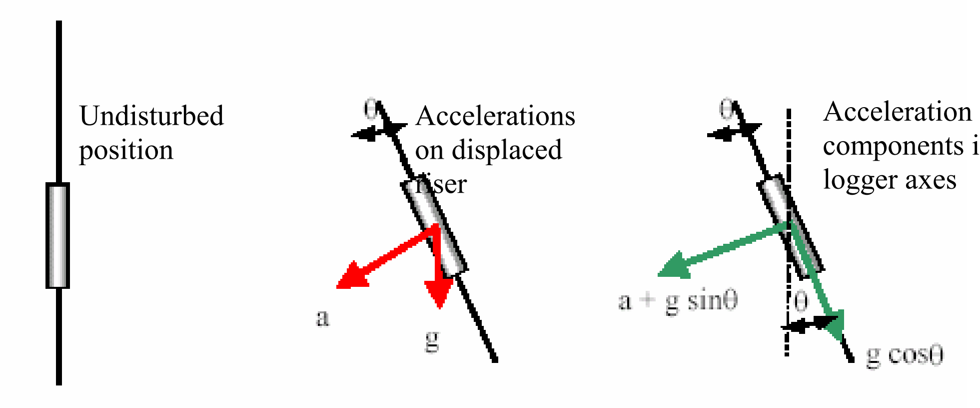


Figure A1.1: Source of Gravity Contamination

We can quantify the relative magnitudes of the two components by making some plausible simplifying assumptions:

- The riser vibrates in a single mode at constant amplitude and frequency
- The mode shape is a simple sinusoid
- All displacements are small

The lateral displacement of the riser is then given by:

$$x = A*\sin(n*\pi*z/L)*\cos(\omega t)$$

where x is displacement normal to the riser axis, A is the maximum vibration amplitude, n is mode number, z is distance along the riser axis from one end, L is riser length, ω is frequency of vibration and t is time.

Lateral acceleration a is given by

$$a = -A*\omega^2*\sin(n*\pi*z/L)*\cos(\omega t)$$

Riser angular deflection θ (assumed small) resulting from the vibration is

$$\theta = dx/dz = (A*n*\pi/L)*\cos(n*\pi*z/L)*\cos(\omega t)$$

A data logger fixed to the riser and measuring acceleration normal to the riser axis will give a logger reading R given by

$$R = a + g*\sin(\theta) = a + g*\theta \quad \text{for small displacements}$$

$$= -A*\omega^2*\sin(n*\pi*z/L)*\cos(\omega t) + g*A*n*\pi/L*\cos(n*\pi*z/L)*\cos(\omega t)$$

$$= A\cos(\omega t)*[-\omega^2*\sin(n*\pi*z/L) + g*n*\pi/L*\cos(n*\pi*z/L)]$$

The total measurement has two components which are in phase in time but whose amplitudes vary along the riser length. The variation with length is a sin term for the VIV component and a cos term for the gravitational component. The ratio of the maximum VIV amplitude to the maximum gravitational component amplitude is

$$\text{Amplitude ratio} = \omega^2 L/(n\pi g)$$

A2 Implications for Schiehallion Tests

For the Schiehallion tests, L = 360m, f is typically 0.15Hz, and the computed results show the riser vibrating mostly in mode 3 (n = 3). This gives an amplitude ratio of 3.5 – i.e. the VIV component has a maximum amplitude of 3.5 times the maximum amplitude of the gravitational component. The amplitudes of the two components and the total amplitude are shown in Figure A1.2. (Absolute amplitudes shown in the figure are arbitrary.)

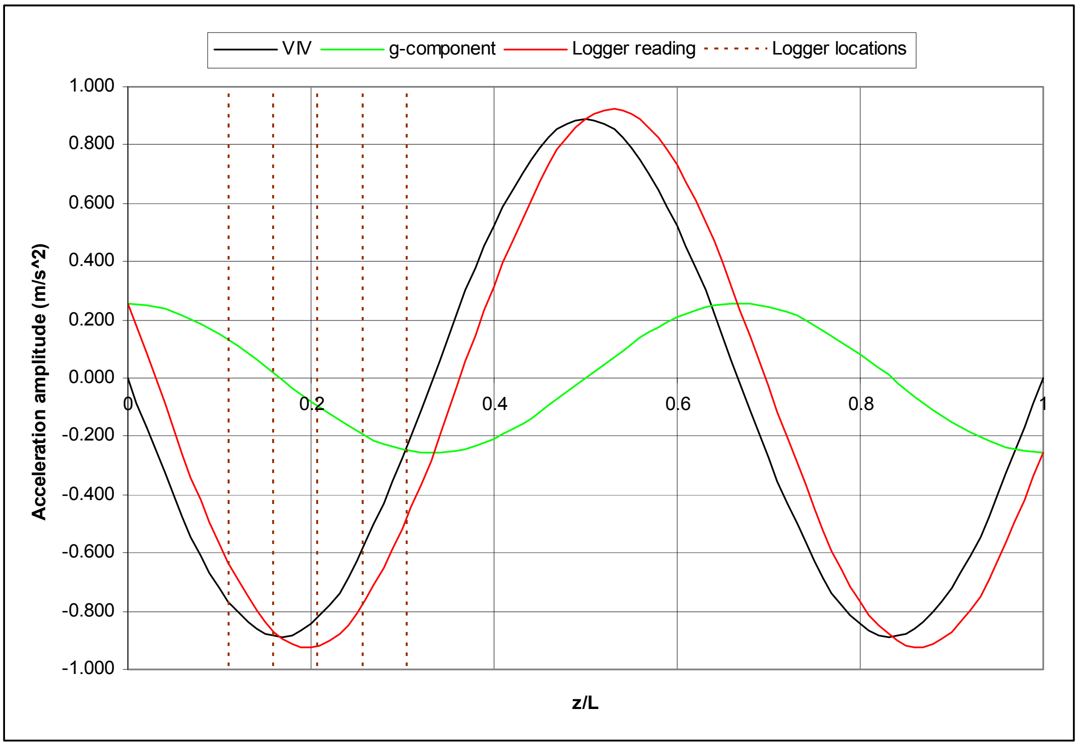


Figure A1.2: Acceleration components for typical Schiehallion conditions

Loggers were located at z/L = 0.112, 0.160, 0.208, 0.257, 0.305 as indicated in the figure.

Based on this simplified model, the effects of gravity contamination vary widely for the five data loggers (- indicates that the logger measurement will be less than the true VIV acceleration, + that it will be greater):

z/L =	g-comp/VIV
0.112	-16%
0.160	-2%
0.208	+12%
0.257	+33%
0.306	+106%

In practice, vibration is unlikely to occur in a pure single mode, and both amplitude and frequency will vary over time. This will confuse the picture and makes any attempt to correct for the effects of gravity impractical. The only meaningful comparison that can be made between measurement and prediction is of accelerations including gravity contamination.