ORCAFLEX VIV TOOLBOX VALIDATION

COMPARISONS WITH
MEASURED DATA FROM
DEEPSTAR SENECA TRIALS

Project 648

Client:	Orcina Ltd.			
Revision History:	Report No.	Issue	Report Date	Report Status
	04	02	17 May 2007	Issue
	04	01	18 July 2006	Draft
For Orcina:	Author:	R M Isherwood		R M Isherwood
	Checked:	P P Quiggin		P P Quiggin
Report file:	R648-04-02 OrcaFlex VIV Comparison with Deepstar Seneca Trials.doc			

1 Introduction

This is one of a series of reports comparing measurements of VIV response with predictions made using the OrcaFlex VIV Toolbox (Ref. 1). In this report we give a brief description of the test cases and present comparisons between measurement and prediction.

We do not attempt in this report to draw firm conclusions regarding the validity and appropriate field of application for each of the VIV models in the Toolbox, on the grounds that conclusions based on a single set of tests would be of limited value and could be misleading. General conclusions are drawn in a separate report (Ref. 2), in which we review comparisons over as wide a range of conditions as possible.

The DeepStar tests were quite recent and the project was still active when we were carrying out our computations. We were also fortunate in having access to some of the raw measurements and this, together with the detailed analysis of the data supplied by DeepStar gave some valuable insights into long riser VIV which are both important in their own right and relevant to the validation of VIV prediction software. We discuss these issues in Section 3 following a brief review of the test data in Section 2. The comparisons between measurement and prediction are presented in Section 4 and discussed in Section 5.

2 Data Obtained

2.1 Data Sources

VIV tests were carried out in 2004 as part of the DeepStar project (CTR 7402). The tests were carried out on riser models with high L/D (1800 to 4000), comparable with L/D for real world deepwater risers. Tests included bare pipe and straked pipe with various amounts of strake cover, in uniform and shear flows.

Two sets of tests were carried out, one in Lake Seneca, NY, and one offshore Miami, FL. An in-house review revealed anomalies in the Miami measured data which led us to conclude that these results are not at present suitable for software benchmarking. Accordingly, in this report we consider only the Seneca tests.

2.2 Test Details

The system general arrangement is shown in Figure 1. The railroad wheel at the bottom end was there simply as a weight to apply tension to the riser. Instrumentation for the Seneca tests consisted of accelerometers placed at intervals down the riser.

Some key parameters of the tests are tabulated below for convenience: full details are given in the references cited. Test conditions were supplied to us by DeepStar for all cases. Measured test results were supplied for the Open cases but were withheld for the Blind cases. This report therefore considers the Open test cases only.

Test series	Riser Details	Test cases		Ref.
		Open	Blind	
Seneca Bare	Bare riser; 1.31 in. OD x 401 ft. long.	6	2	3
Seneca Straked	Same riser but 201 ft. long with 100% strake cover.	3	1	4

Riser mass ratio (mass including contents/displaced mass of water) was 1.38 for based on bare riser details.

The tests took place in Lake Seneca, NY. Currents in the lake were negligible and flow relative to the riser was induced by moving the boat through the water at constant speed, giving the same constant horizontal velocity at all elevations.

Accelerations were measured at 24 locations ('pigs') equally spaced down the riser. Not all the accelerometers were working during the tests, and some logging difficulties occurred. After omitting data from non-functioning pigs, or pigs with logging difficulties, measurements from a total of 10 (in some cases 9) locations were available for each test.

The accelerometers measured acceleration in two directions normal to each other and to the riser axis. The measurement directions normal to the riser axis were nominally aligned with the in-line and transverse directions with an alignment error estimated at ±10°. No attempt has been made to correct for possible misalignment.

The accelerometers were fixed rigidly to the riser and rotated with it. In these circumstances, any variation in the angle to vertical of the riser axis causes a variation in the component of gravitational acceleration which is sensed by the accelerometer: i.e. the measured accelerations are "g-contaminated". This issue is discussed in Ref. 5, Appendix 1. In the Seneca tests, transverse vibration of the riser took place at frequencies of 2 to 3Hz. Computation showed vibration in modes around 16-18. Under these circumstances, the effects of g-contamination are minimal. Nevertheless, the g component has been included in the computed values used for the comparisons.

The acceleration data were provided in the form of RMS in-line and transverse accelerations at each measurement location for each test. RMS displacements obtained by double integration of the accelerations were also provided but are not considered in this report. Sample time histories and spectral densities of acceleration (both in-line and transverse) were also provided for each test.

3 Review of Test Results

3.1 Bare Riser Tests

3.1.1 Frequency Content of VIV Response

We expect to see transverse vibration at a "fundamental" frequency close to the Strouhal frequency with in-line vibration at twice the transverse frequency. In these tests, the spectral densities show transverse components of acceleration at 1, 3, 5 and 7 times the "fundamental" frequency, and in-line components at 2, 4 and 6 times. For example, Figure 2 shows spectral densities of measured accelerations for four locations on the riser during a single test. Since acceleration is proportional to $(\text{frequency})^2$, the higher frequency components contribute more strongly to acceleration than to displacement.

3.1.2 Variability of VIV Response

The results of the bare riser tests provided a valuable opportunity to assess quantitatively the "repeatability" or "natural variability" of VIV. Two tests were carried out under nominally identical conditions. We have had access to the detailed time histories of measured acceleration for both tests, courtesy of DeepStar/MIT.

Time histories of acceleration were measured for durations of 160 to 180s. Figure 3 shows time history plots of transverse acceleration for the same location in the upper part of the riser for the two tests. Scales are the same for both graphs. Two points stand out:

- acceleration amplitude varies substantially over time for both tests
- the average amplitude in the upper graph is around twice that in the lower graph.

There is no suggestion from either time history that the response is gradually settling to a consistent level, indeed rather the reverse from the upper graph where amplitude appears to be increasing with time. Without further evidence, we have no reason to consider any particular section of either time history as more "typical" or more representative of the "true" or "steady state" VIV response. All we can say is that the amplitude of the observed response varies over a wide range.

To quantify the variation, RMS transverse accelerations were computed for successive 20s "windows" for both tests. (20s represents about 50 cycles of transverse VIV - long enough to avoid distortion by an occasional stray cycle, short enough to capture variation of response with time.) The results are shown in Figure 4 where RMS transverse accelerations are plotted against arc length down the riser. The bold lines are the values reported by DeepStar for use in benchmarking, and were obtained from the full time histories recorded for the two tests. The lighter lines are values from the 20s window analysis.

The range of variation shown is substantial. The ratio of maximum to minimum RMS acceleration at any location is never less than 2, and approaches 5 in the upper part of the riser. Note, also, that the distribution of VIV amplitude along the riser length does not show a consistent pattern: amplitude sometimes increases from top to bottom, at other times it decreases from top to bottom, and at other times there is no clear trend.

Since lengthwise variation is not consistent, a good summary measure of response over any period of time is RMS acceleration averaged over the riser length. We have measurements for 17 x 20s windows from the two tests under consideration. The mean of these 17 measurements is $6.8 m/s^2$, with standard deviation $1.35 m/s^2$ (20% of the mean). The measured values follow a Gaussian distribution, so we can say that the response averaged over the riser length is $6.8 m/s^2 \pm 2.7 m/s^2$ (40% of the mean) with 95% confidence. This is shown in Figure 5.

3.2 100% Straked Riser Tests

It has been common practice to assume that VIV of a cylinder fitted with VIV suppression strakes is similar to that of a bare cylinder and follows the same general pattern but just at smaller amplitude. I.e. the strakes are assumed to reduce the amplitude of the lift force but to have no other effect. The OrcaFlex VIV Toolbox models include user-assignable factors to be applied to the lift force for just this purpose. (A similar practice is recommended in the SHEAR7 manual.)

The Seneca test results confound this expectation. Not only are the measured RMS accelerations reduced by 1 to 2 orders of magnitude compared with the bare riser, but the frequency content of the response is very different. Typical spectral densities show a single peak at the same frequency for both transverse and in-line response (Fig 6).

3.3 Use of Data for Software Validation

It is clear from the bare riser tests that the VIV response of a long riser is far from steady, even in steady flow conditions, so there is limited scope for making detailed comparisons between measurement and prediction. In this report, we compare average and maximum values of RMS acceleration over the riser length. We compare average values because this is the best overall measure; maximum values because this is a measure of worst fatigue damage. We do not attempt to compare distributions of response along the riser length, since the evidence suggests that the distribution is highly variable.

4 Calculated Results

4.1 VIV Models

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

Two wake oscillator models:

- Milan wake oscillator with as-published parameters (‘Milan’)
- 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 1.

4.2 Treatment of Straked Sections

OrcaFlex includes a facility to apply a reduction factor to the VIV force, which was intended as a rough and ready means of representing the suppressive effects of strakes. Our original intention was to adjust this factor for each model so as to obtain reasonable agreement with measurement for the 100% straked tests. We found that this was not practical for two reasons:

- The VIV response was very sensitive to small changes in reduction factor, and identifying the “best fit” for each VIV model and each load case by trial and error would have been very time consuming. Furthermore, the “best fit” appeared to vary from one load case to the next, making a simple “recommended reduction factor” unsuitable.
- As noted above (Section 3.2), applying a simple reduction factor fails to reproduce the actual VIV behaviour of a straked riser.

The attempt to compare measured and predicted response for the 100% straked cases was aborted and no results are presented here. As already noted in Section 3.2, the test results showed that strakes were in fact highly effective and reduced VIV amplitudes by 1 to 2 orders of magnitude. Our recommendation, therefore, is to treat a 100% straked riser as exhibiting negligible VIV.

4.3 Comparisons and Presentation of Results

Comparisons are presented for the four VIV models in Figures 7 to 10. The form of presentation is the same in each figure and is as follows:

- Top Left: RMS transverse acceleration averaged over the riser length: predicted versus measured
- Top Right: Maximum RMS transverse acceleration irrespective of axial location: predicted versus measured
- Centre: Dominant frequency of transverse acceleration: predicted versus measured
- Bottom: Bias ratio plot (predicted/measured) for each of the above three quantities plotted against flow speed

5 Review of Comparisons

Table 5.1 gives the mean and standard deviation (SD) over the test series for the bias ratios shown plotted in Figures 7 to 10. Table entries are given in the form Mean ± SD.

	Ave RMS Accel	Max RMS Accel	Dom Freq
Milan	0.80 ± 0.11	0.96 ± 0.20	1.00 ± 0.10
I+B	1.35 ± 0.22	1.58 ± 0.35	1.17 ± 0.13
VT(1)	37.5 ± 13.6	49.3 ± 11.0	18.1 ± 1.3
VT(2)	4.00 ± 0.55	4.14 ± 0.74	7.40 ± 0.42

Table 5.1: Average Bias Ratio ± Scatter for all models

Overall, the Wake Oscillator models are more successful that the Vortex Tracking models in predicting VIV amplitude and frequency. The Milan Wake Oscillator model is particularly successful.

6 Acknowledgements

Orcina Ltd. wish to thank the DeepStar project and its sponsoring companies for permission to use the VIV measurements for this comparison study.

7 References

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

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

3 Vandiver J K, et al: Benchmark Data for the Bare Pipe Test Cases from the DeepStar/MIT Lake Seneca Test conducted on July 14, 2004.

4 Vandiver J K, et al: Benchmark Data for the Straked Pipe Cases from the DeepStar/MIT Lake Seneca Test conducted on July 15, 2004.

5 OrcinaLtd: OrcaFlex VIV Toolbox Validation: Comparisons with measured data from Schiehallion Drilling Riser, 20 March 2006.

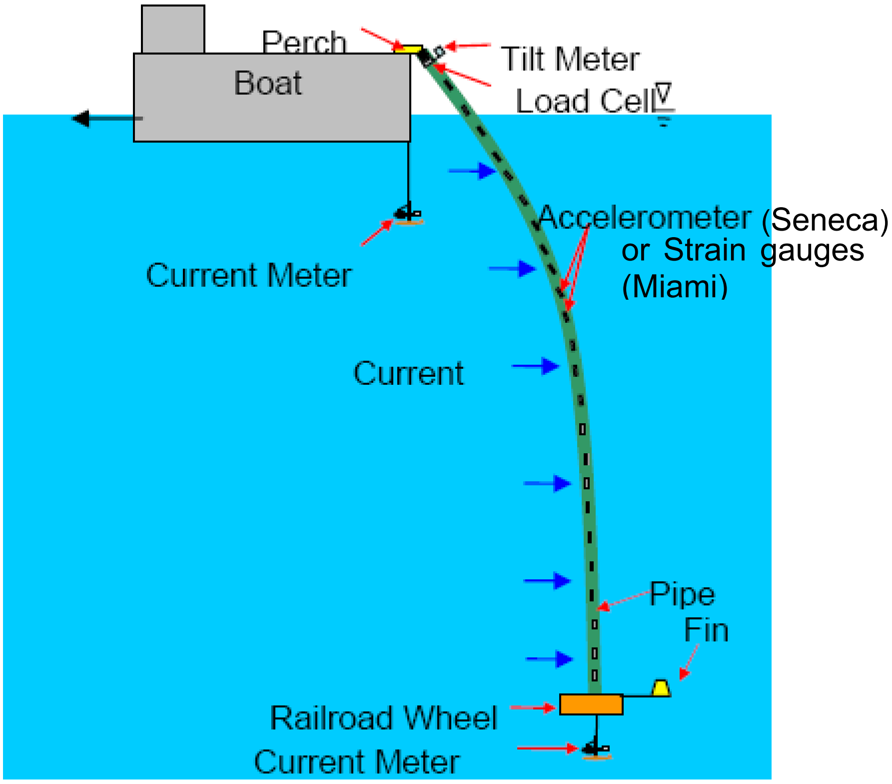

Figure 1: DeepStar VIV test general arrangement

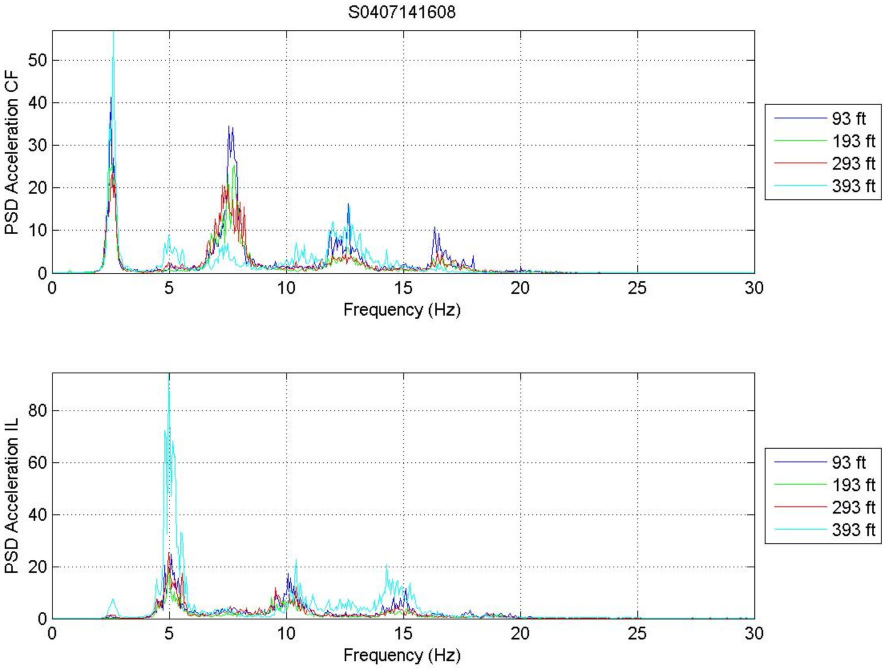

Figure 2: Spectral densities of Transverse and In-Line Accelerations

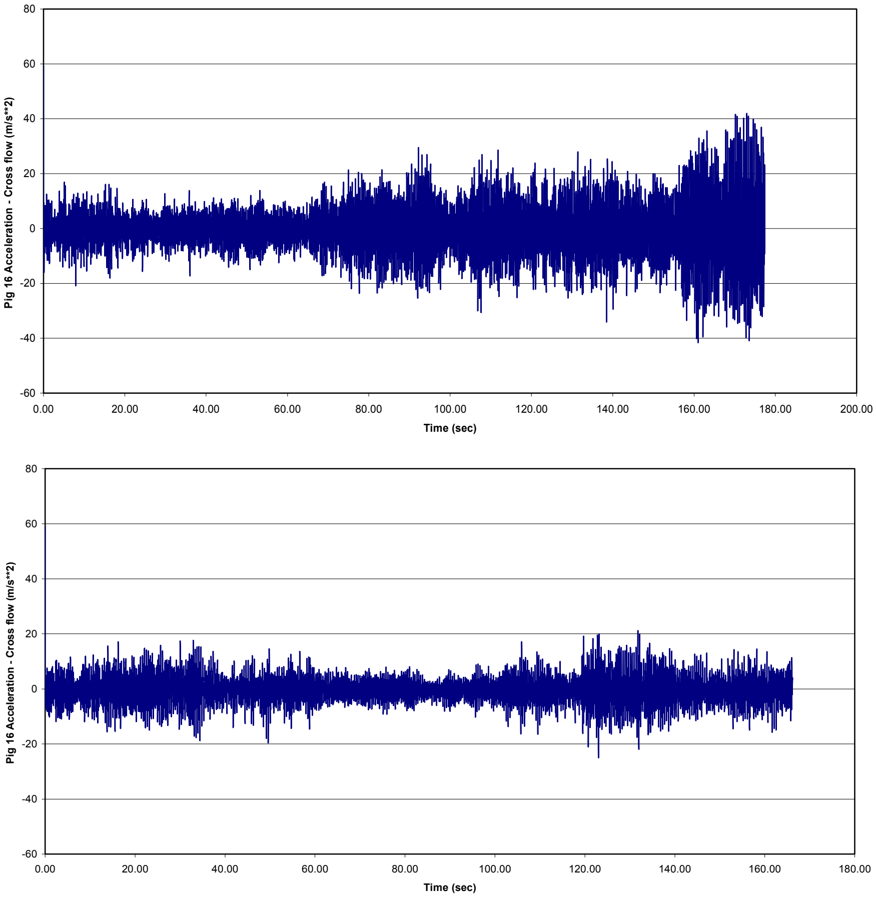

Figure 3: Measured transverse accelerations at the same location from two tests under identical conditions

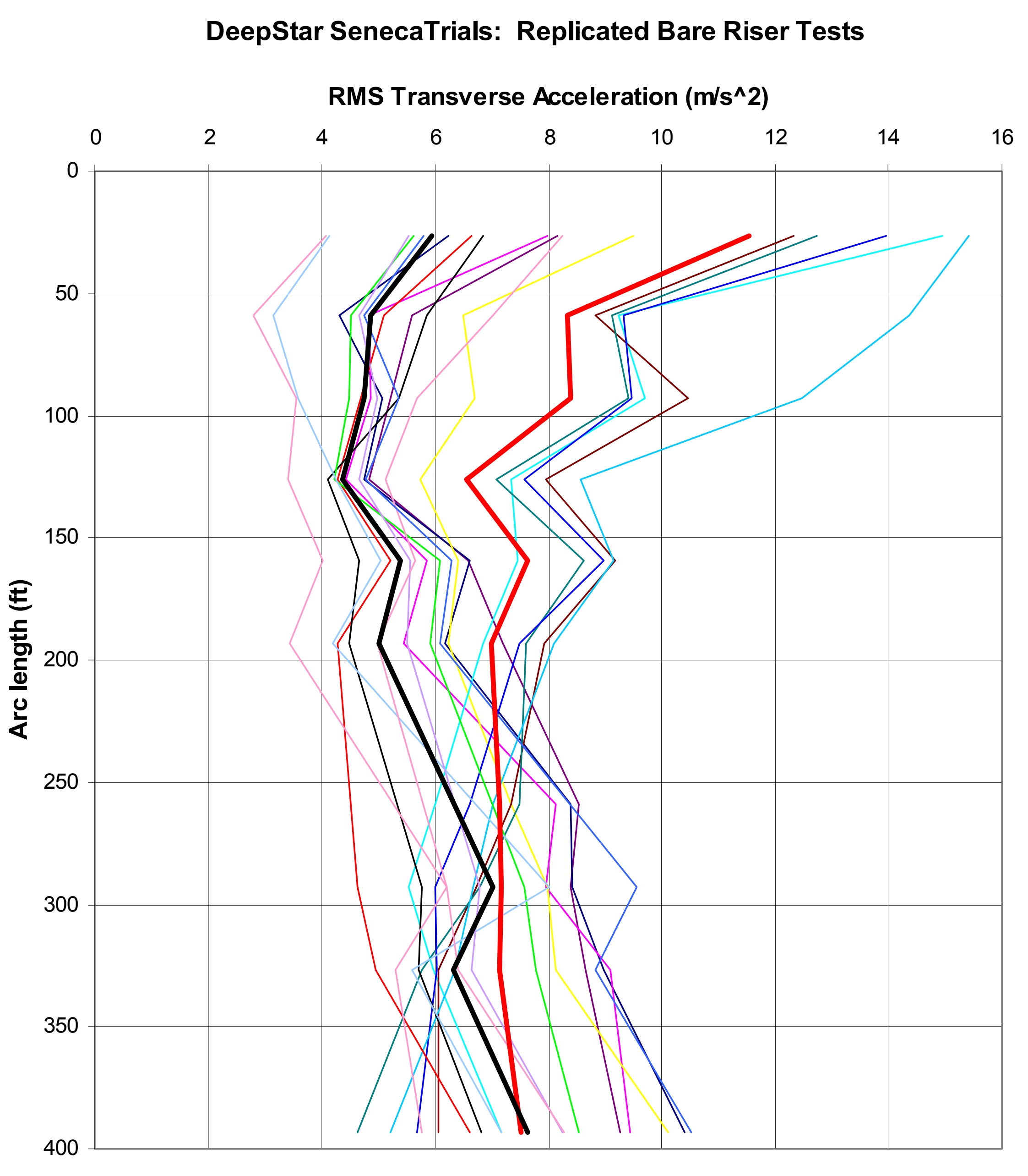

Figure 4: RMS transverse accelerations from two bare riser tests in identical conditions. Heavy lines are RMS values as reported by DeepStar for the full measured duration of each test. Light lines are RMS values computed for 20s windows

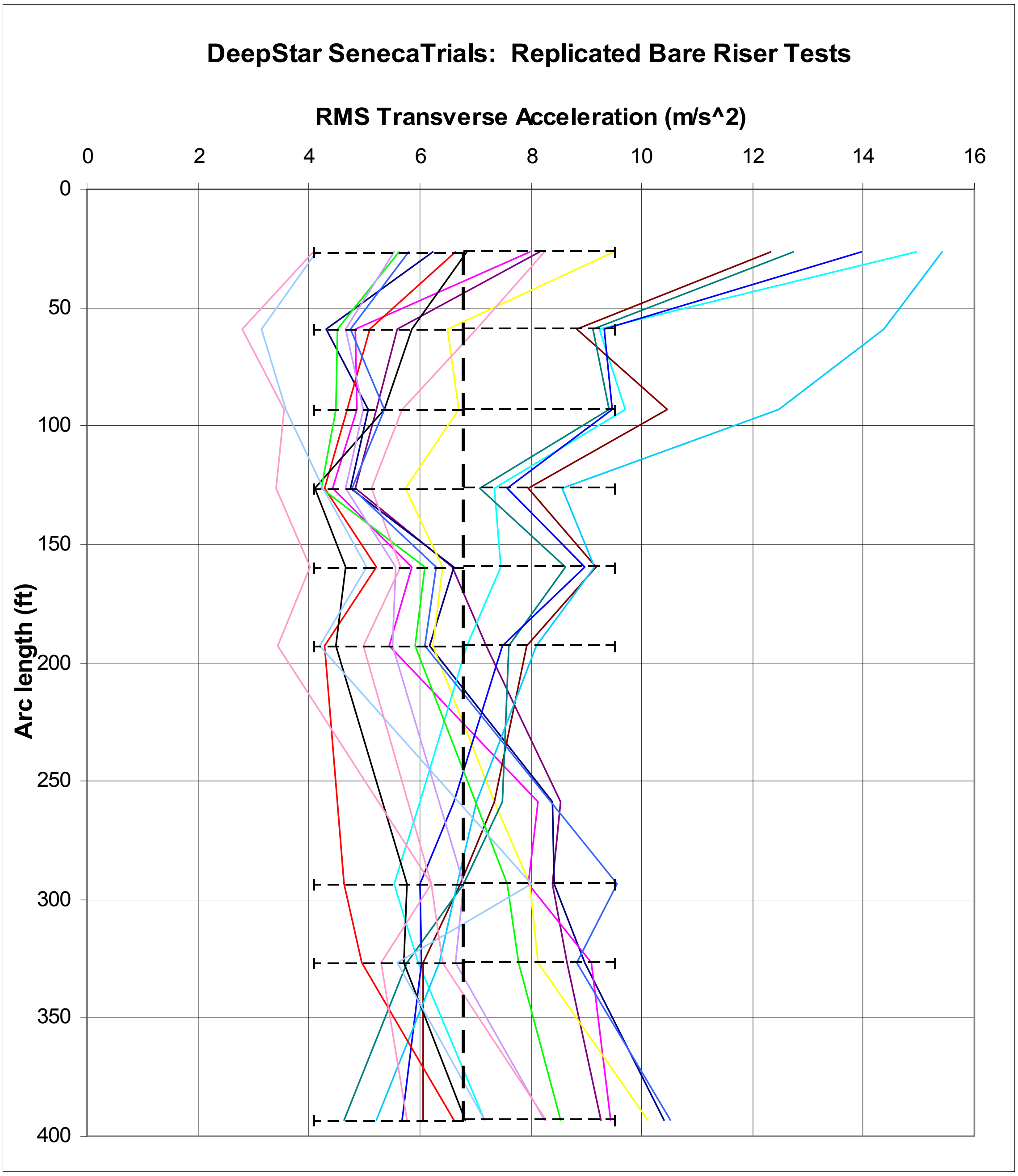

Figure 5: RMS transverse accelerations for two tests – data as in Figure 4. The vertical broken line is the overall mean value of the 20s windowed RMS accelerations from both tests, irrespective of arc length. The error bars represent ±40% about the mean value (±2*SD for the values averaged over the riser length – see text).

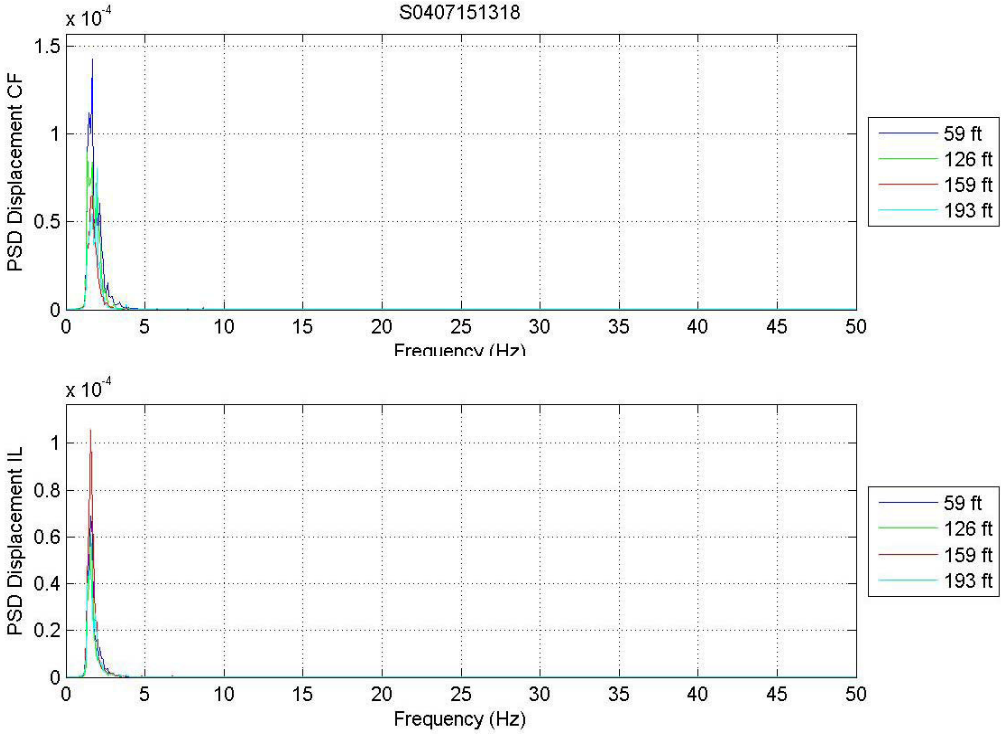

Figure 6: Spectral densities of Crossflow (transverse) and In-Line acceleration for the Seneca 100% Straked riser (Test S040715138, 2.3 ft/s flow speed)

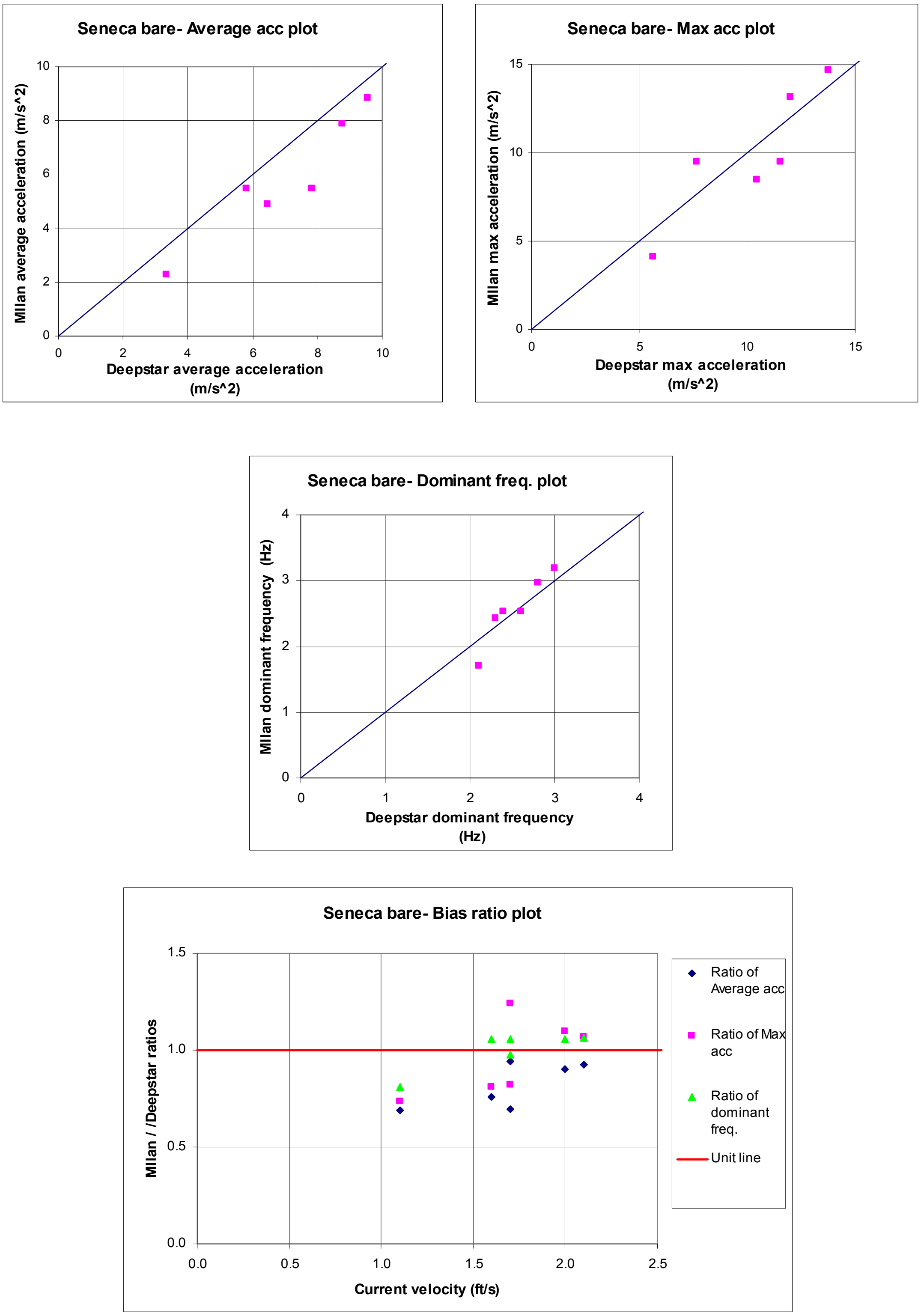

Figure 7: Milan Wake Oscillator – Results for Seneca Bare Riser Tests

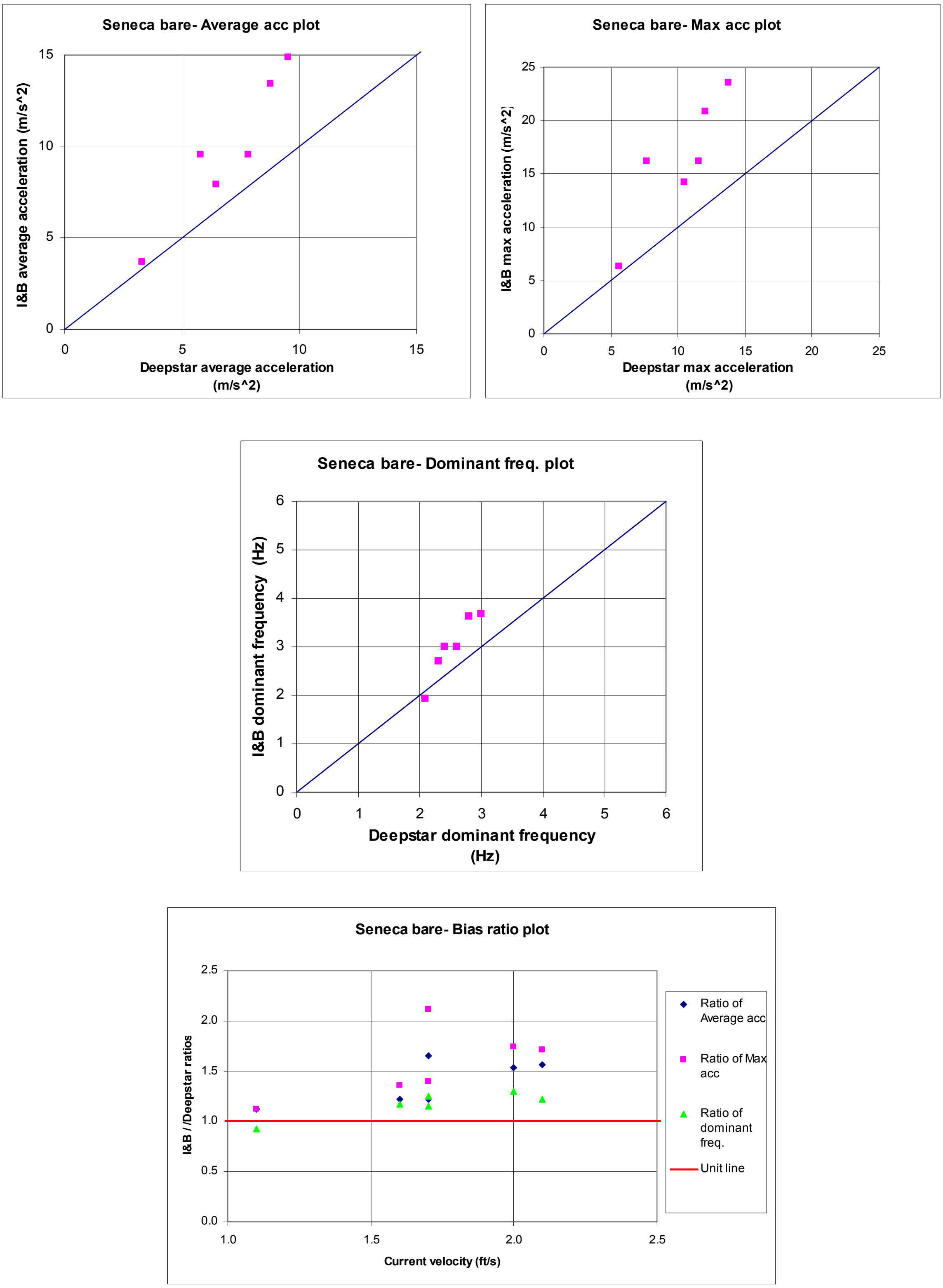

Figure 8: Iwan + Blevins Wake Oscillator – Results for Seneca Bare Riser Tests

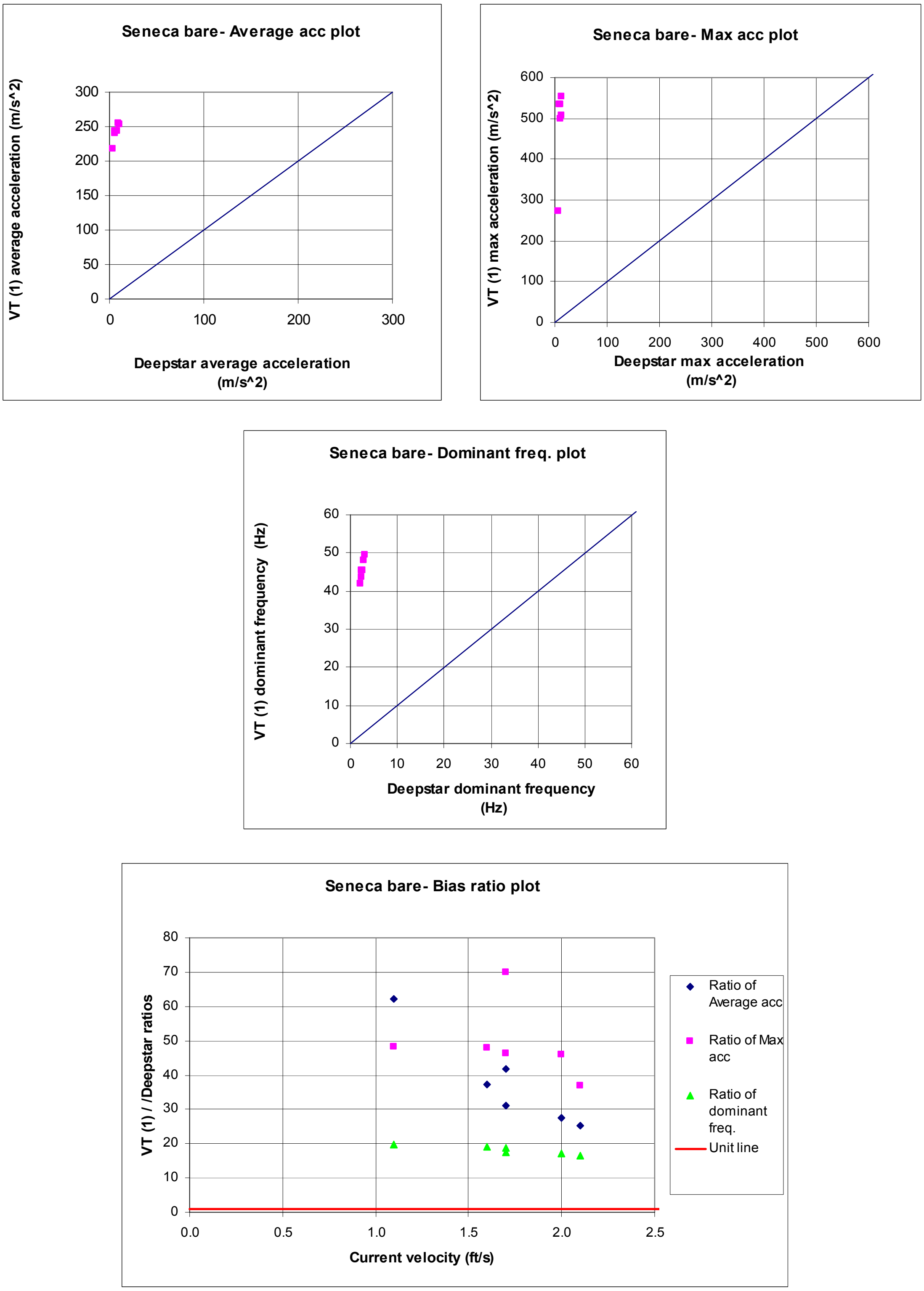

Figure 9: Vortex Tracking (1) – Results for Seneca Bare Riser Tests

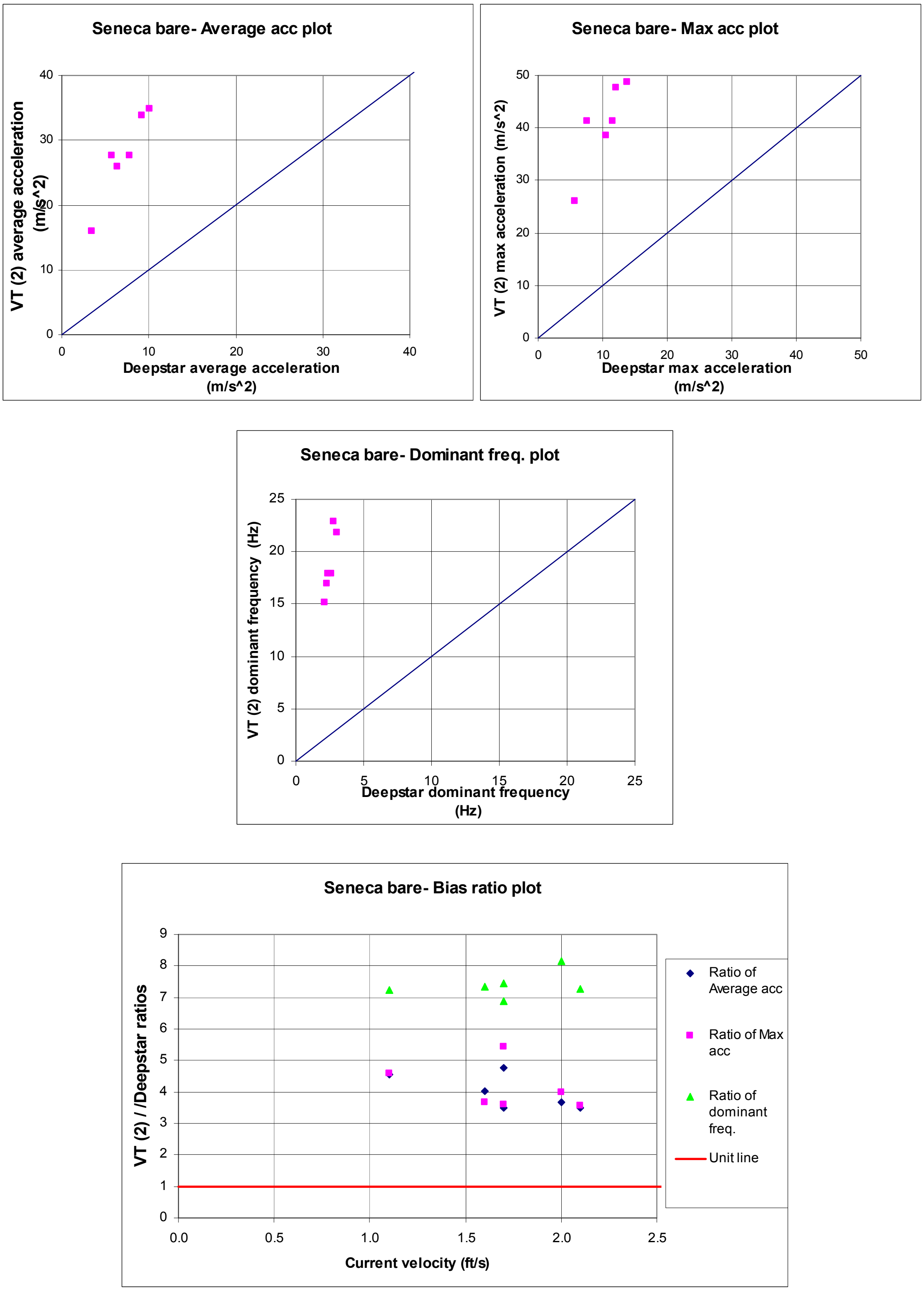

Figure 10: Vortex Tracking (2) – Results for Seneca Bare Riser Test