OrcaFlex VIV Toolbox Validation

Comparison with
Delft VIV Model Tests

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 Delft Model Tests

2.1 Data Source

A series of tests were carried out on a riser model in the large flume at the Delft Hydraulics Laboratory, and were the subject of blind trials by a number of VIV modellers. The test arrangements, test results and blind trial comparisons are described in Refs. 2 and 3. The test results are in the public domain and can be freely downloaded from the Southampton University website (Ref. 4).

2.2 Test Details

The test arrangement is shown in Figure 1. The lower half of the riser was subject to a uniform steady current generated by the velocity of the carriage moving along the flume. The upper half was in still water inside the vacuum tank.

Key riser parameters were:

Riser length	13.12m
Riser diameter	28mm
Length/diameter ratio	469
Mass ratio (mass/displaced mass of water)	3.0

The principal instrumentation was pairs of strain gauges at 32 equi-spaced locations, measuring bending strain in both in-line and transverse directions relative to the flow.

Test results are given for a total of nine load cases at increasing velocity as detailed in Figure 2. Reynolds number varied from 3.7e3 to 2.2e4. Results provided by the experimenters are:

- Maximum and minimum in-line and transverse displacements; i.e. the overall displacement envelope in both planes
- Mean in-line displacement
- RMS curvature in-line and transverse

Results are tabulated at 101 equi-spaced locations down the riser (including top and bottom ends).

2.3 Accuracy and Repeatability of Test Results

No test replications were reported, so we have no direct measure of the repeatability of the test measurements. The following extract from Ref 3., however, is relevant:

> *Measured displacements and curvatures do not always exhibit the well-behaved periodic oscillations that are assumed or are evident in most computed results. This means that*

extremes in displacements and curvatures measured over long periods are not necessarily directly comparable to peak excursions in the corresponding time series obtained from numerical models. In the laboratory, even very small disturbances can sometimes give rise to significant modulations in the weights of individual modal components, or even a complete redistribution of the response among adjacent modes. For this reason, (the experimenters) found that in order to obtain well-behaved measures of response it was often necessary to apply a window to time series of displacements and curvatures, isolating periods of almost steady state motion. The same conditioning was applied to the measured data shown here. Indeed, any comparisons between computed responses and measurements not processed in this way should be approached with some caution.

Informal discussion with the experimenters confirmed that, in some cases, quite dramatic changes in response behaviour were observed during a single test run. This inevitably sets limits on the accuracy with which a software package can be expected to replicate the test results, but there is nothing in the published results on which to base an estimate of the limits.

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 5. Note that the wake oscillator models are designed to predict transverse VIV only.

3.2 Comparisons and Presentation of Results

Comparisons are made for transverse displacements and curvatures for all models, and for in-line curvatures for the vortex tracking models only, since the wake oscillators do not model in-line response. The results are presented graphically in the Appendices:

- Appendix 1 Wake Oscillators Transverse Displacements
- Appendix 2 Wake Oscillators Transverse Curvatures
- Appendix 3 Vortex Tracking Transverse Displacements
- Appendix 4 Vortex Tracking Transverse Curvatures
- Appendix 5 Vortex Tracking In-line Curvatures

The sequence of graphs is the same in each Appendix and is as follows:

- Figures Ax.1 and Ax.2 show envelopes of transverse displacement or curvature for each of the nine test cases. Within each appendix, all the graphs are plotted to the same scale to show the different amplitudes seen for different load cases.
- Figure Ax.3 shows the variation of transverse displacement or curvature with flow speed, measured and predicted for two summary measures of displacement for all test cases:
  - a) maximum value irrespective of axial location,
  - b) value averaged over the riser length
- Figure Ax.4 shows prediction plotted against measurement for the same parameters as plotted in the previous figure. The broken lines show "computed = measured" and errors of ±25%.
- Figures A2.5 and A4.5 show prediction plotted against measurement for dominant response frequency and dominant mode number. Figure A5.5 shows mode number only since dominant in-line frequencies are not given in Ref. 4.

In all cases, displacement y and RMS curvature c_{yRMS} are shown normalised on riser diameter D as (y/D) and (c_{yRMS}*D). Envelope plots for individual load cases are shown against a vertical scale of (z/L) where z is distance up from the bottom end of the riser and L is riser length. In the figures showing plots of prediction against measurement, the lines connecting the results for each model are included for convenience in identification and have no other significance.

4 Review of Comparisons

4.1 Wake Oscillator models – Transverse only

- Displacement envelopes (A1.1, A1.2) are very similar in character to measurements. Magnitudes are generally in good agreement but differences are significant in some cases (Case 2, Case 4).
- Similar comments apply to the curvature envelopes (A2.1, A2.2)
- All three models generally give the correct dominant frequencies and mode numbers (A2.5). Milan original is marginally the best of the three. The Iwan + Blevins model performs as well on mode number but tends to overstate the dominant frequency slightly.
- Maximum displacements and maxima averaged over the riser length show little consistent variation with flow speed (A1.3). The test results show a slight tendency for amplitude to increase with increasing speed but the data are scattered. The calculated results do not show this trend.
- The calculated results are unbiased and in most cases correct to within ±25% (A1.4). The only significant exception is I+B Case 1 which shows negligible response. ("Unbiased" means that there is no consistent tendency to under or over estimate.)
- Maximum and averaged RMS curvatures show a steady increase with flow speed (A2.3). This is consistent with the observation that the displacement amplitudes are nearly constant and mode number increases with flow speed.
- The measured value of maximum curvature for Case 5 looks anomalously high (and Case 6 possibly rather low). The curvature plot for Case 5 (A2.1) confirms this – the maximum is a very large spike, over twice that at any other point on the riser. No other case shows this.

- With the exception of the maxima for Case 5, curvature results for all three wake oscillator models are within ±25% of measured values. The Iwan + Blevins model is closest to the measured maxima; Milan original is closest on averaged values.

4.2 Vortex Tracking models – Transverse

- Displacement envelopes (A3.1, A3.2) are similar in character to measurements, though it is immediately apparent that the vortex tracking models give substantially higher magnitudes throughout than measured. The error is roughly a factor of 2 for both models (A3.3).
- Much the same is true for curvatures (A4.1, A4.2). Again, both model over predict magnitudes by a factor of about 2 (A4.3). Note that this means that the vortex tracking models show close agreement with the measured maximum curvature for Case 5. We consider this agreement spurious in view of the observations above on this case.
- Both vortex tracking models over predict dominant frequency (A4.5) – typically VT(1) by 10%, VT(2) by 25%.
- The VT(1) model reproduces the measured mode number in all cases; the VT(2) model is generally one mode too high (A4.5).

4.3 Vortex Tracking models – In-line Curvature

- As for the transverse results, curvature envelopes (A5.1, A5.2) are similar in character to measurements, but both models overstate the magnitudes by typically 50-100% for all load cases (A5.3).
- The VT(1) model again shows the same mode number as the test results; the VT(2) model is generally one or two modes too high (A5.5).

5 Acknowledgements

Orcina Ltd. wish to thank Prof. J Chaplin of Southampton University for making the test results used in this report freely available, and for help and assistance with interpretation.

6 References

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

2 Chaplin, J.R., Bearman, P.W., Huera Huarte, F.J., Pattenden, R.J., 2005. Laboratory measurements of vortex-induced vibrations of a vertical tension riser in a stepped current. Journal of Fluids and Structures, Vol 21, 2005

3 Chaplin, J.R., Bearman, P.W., Cheng, Y., Fontaine, E., Graham, J.M.R., Herfjord, M., Huera Huarte, F.J., Isherwood, M., Lambrakos, K., Larsen, C.M., Meneghini, J.R., Moe, G., Pattenden, R.J., Triantafyllou, M.S., Willden, R.H.J., Blind predictions of laboratory measurements of vortex-induced vibrations of a tension riser. Journal of Fluids and Structures, 2005.

4 http://www.civil.soton.ac.uk/hydraulics/riser/riser.htm

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

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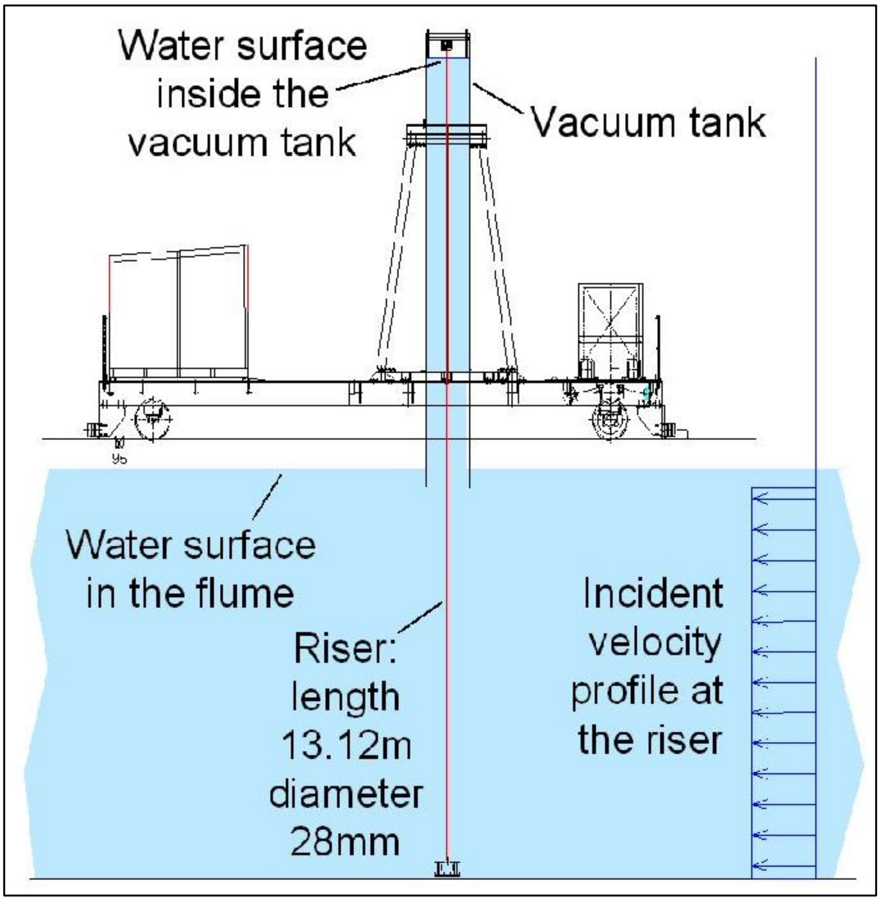


Figure 1: General Arrangement

Case	Towing speed (m/s)	Top tension (N)	Standard deviation of top tension (N)
1	0.16	405	2
2	0.21	407	3
3	0.31	457	3
4	0.40	506	8
5	0.54	598	15
6	0.60	670	14
7	0.70	743	8
8	0.85	923	14
9	0.95	1002	65

Figure 2: Load Cases

Appendix 1

Results for
Wake Oscillator Models

Transverse Displacement

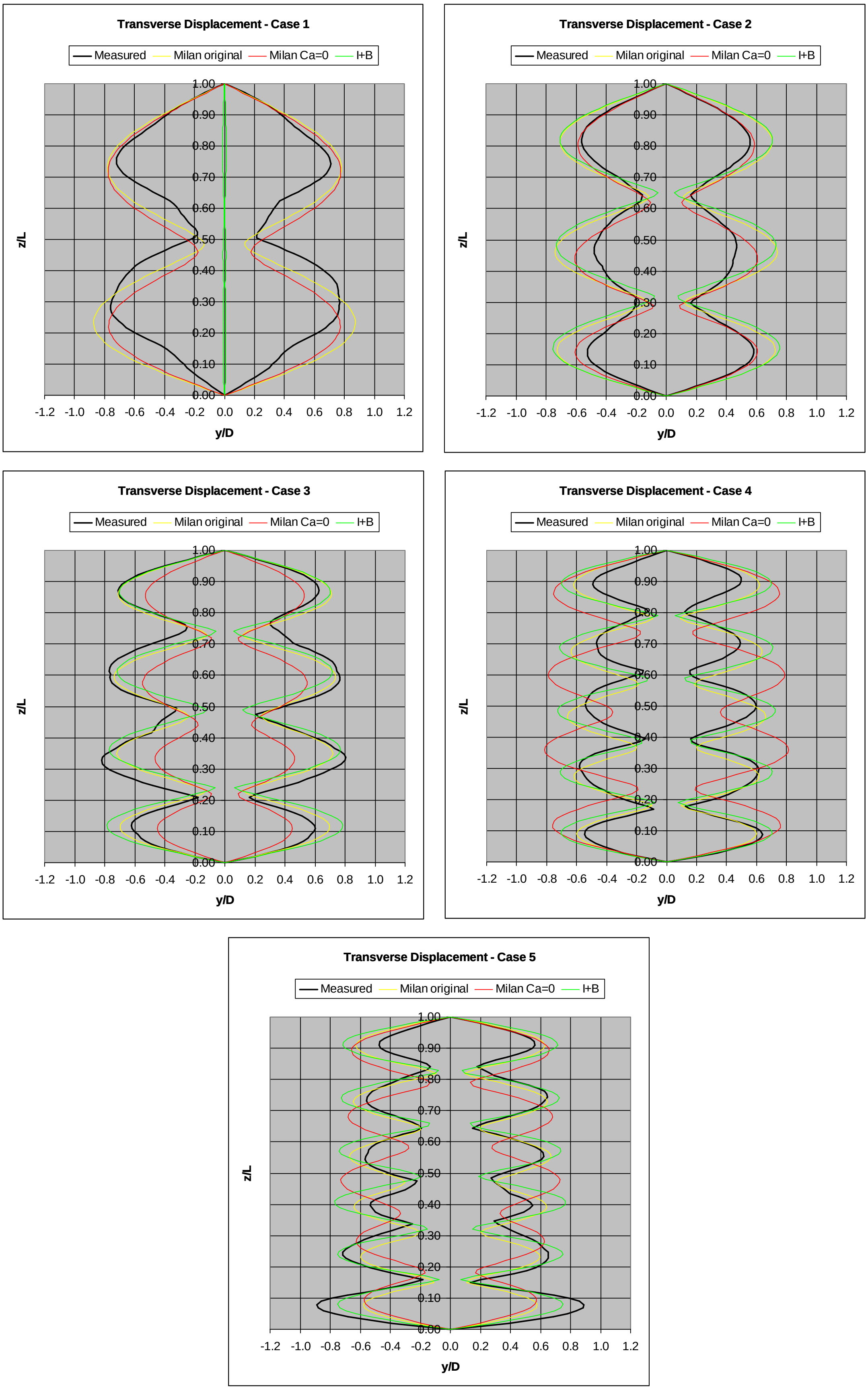


Figure A1.1 – Wake Oscillators - Transverse Displacement Envelopes, Load Cases 1 to 5

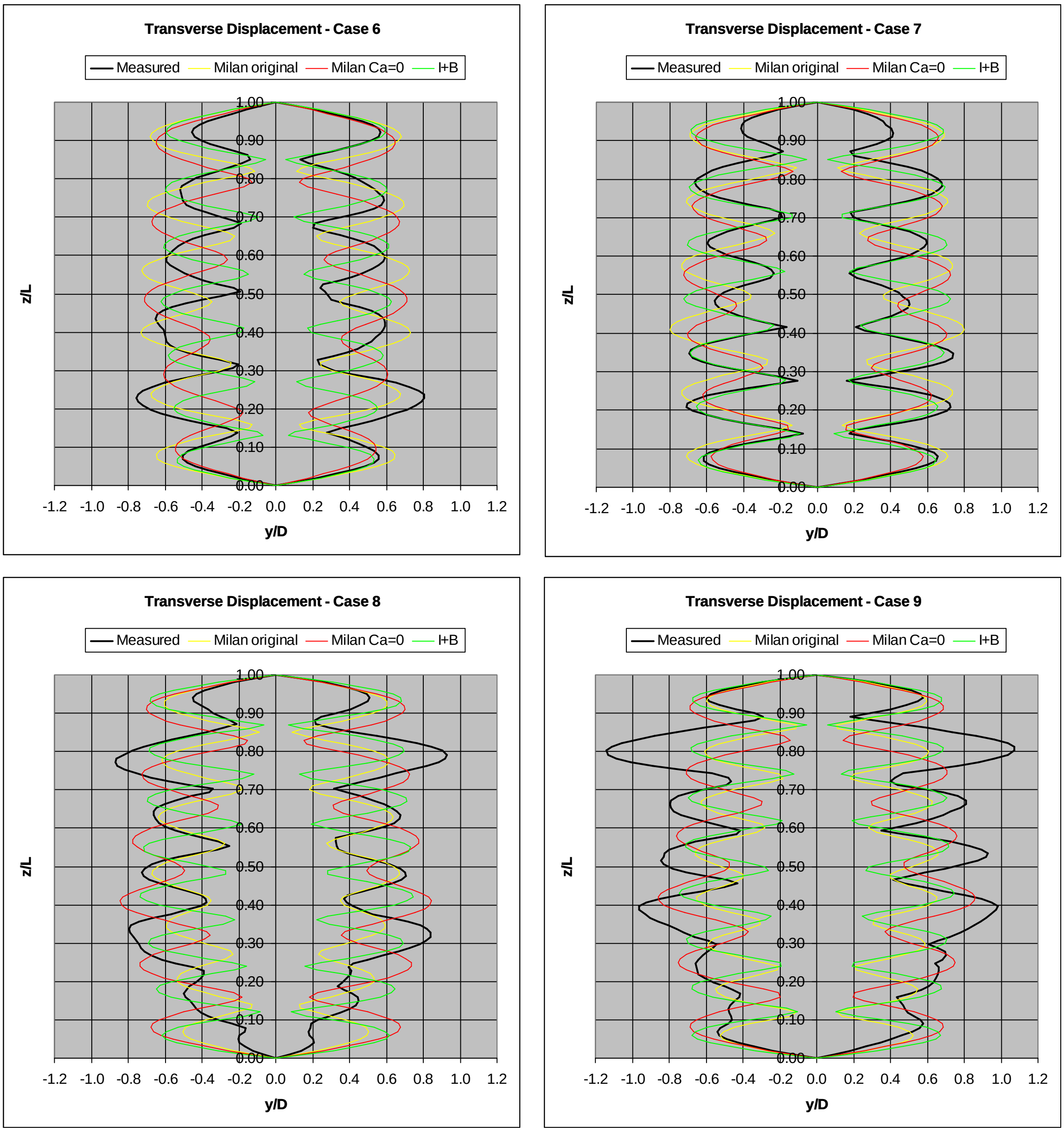
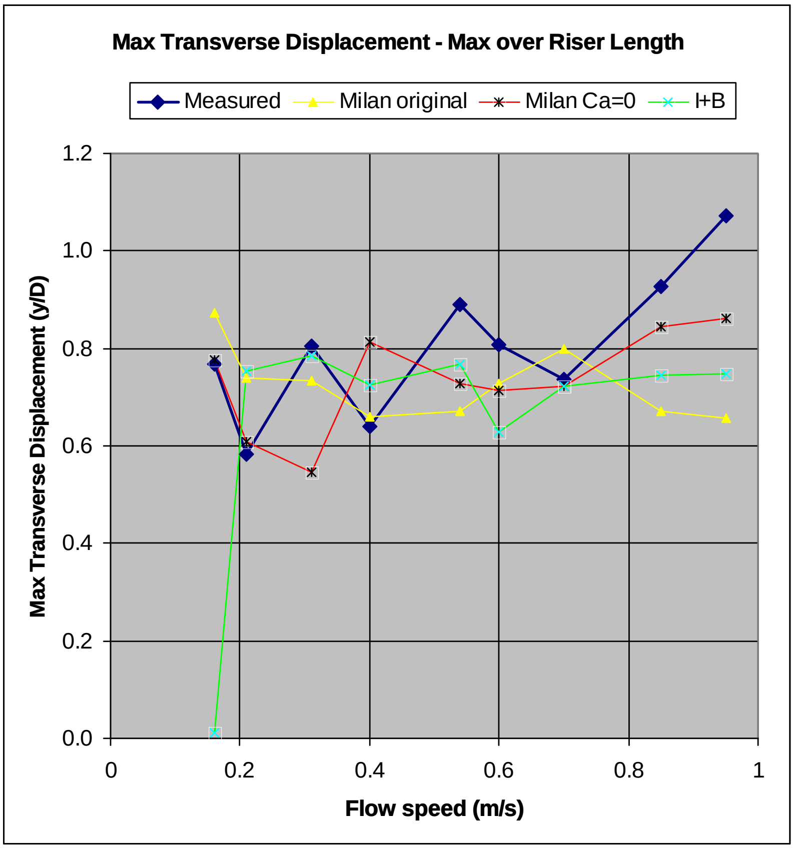


Figure A1.2 – Wake Oscillators - Transverse Displacement Envelopes, Load Cases 6 to 9



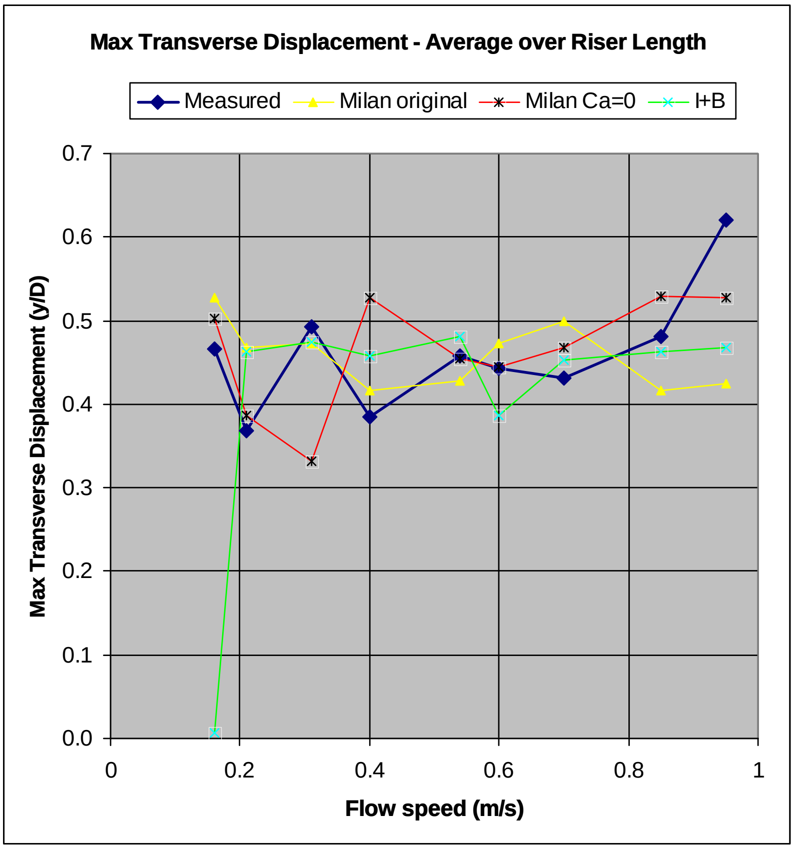
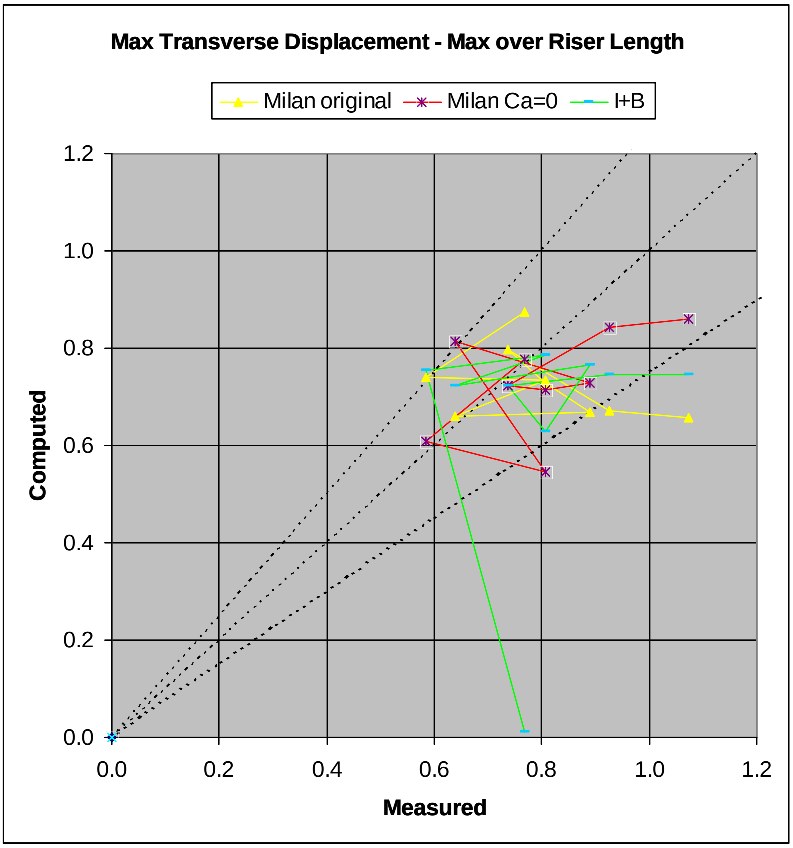


Figure A1.3 – Wake Oscillators – Max Transverse Displacement – Var. with Flow Speed



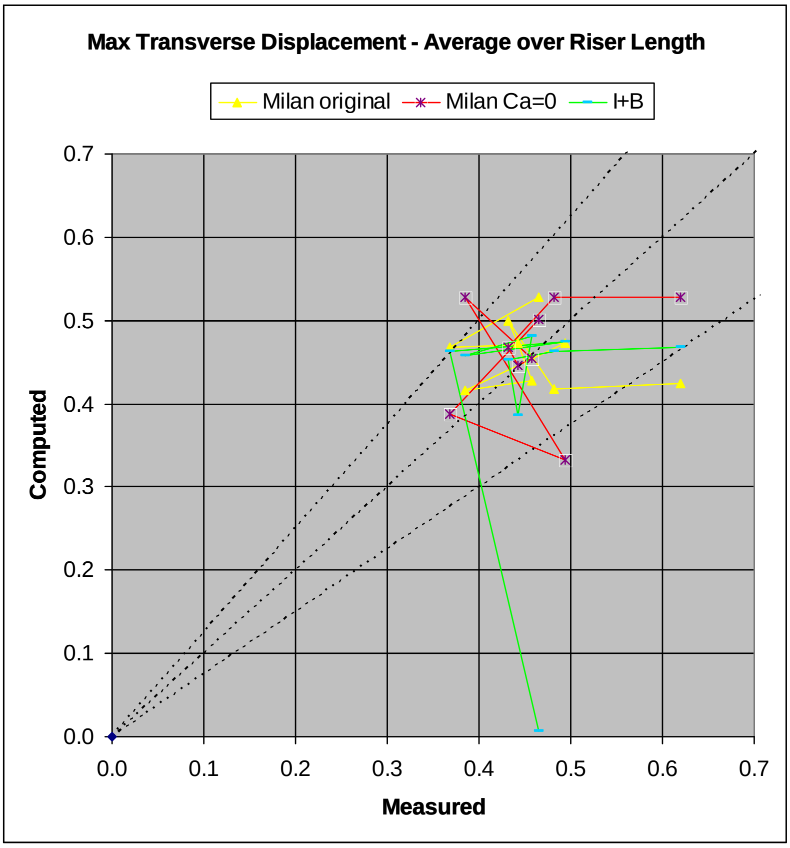


Figure A1.4 – Wake Oscillators – Max Transverse Displacement – Predicted vs Measured

Appendix 2

Results for
Wake Oscillator Models

Transverse Curvature

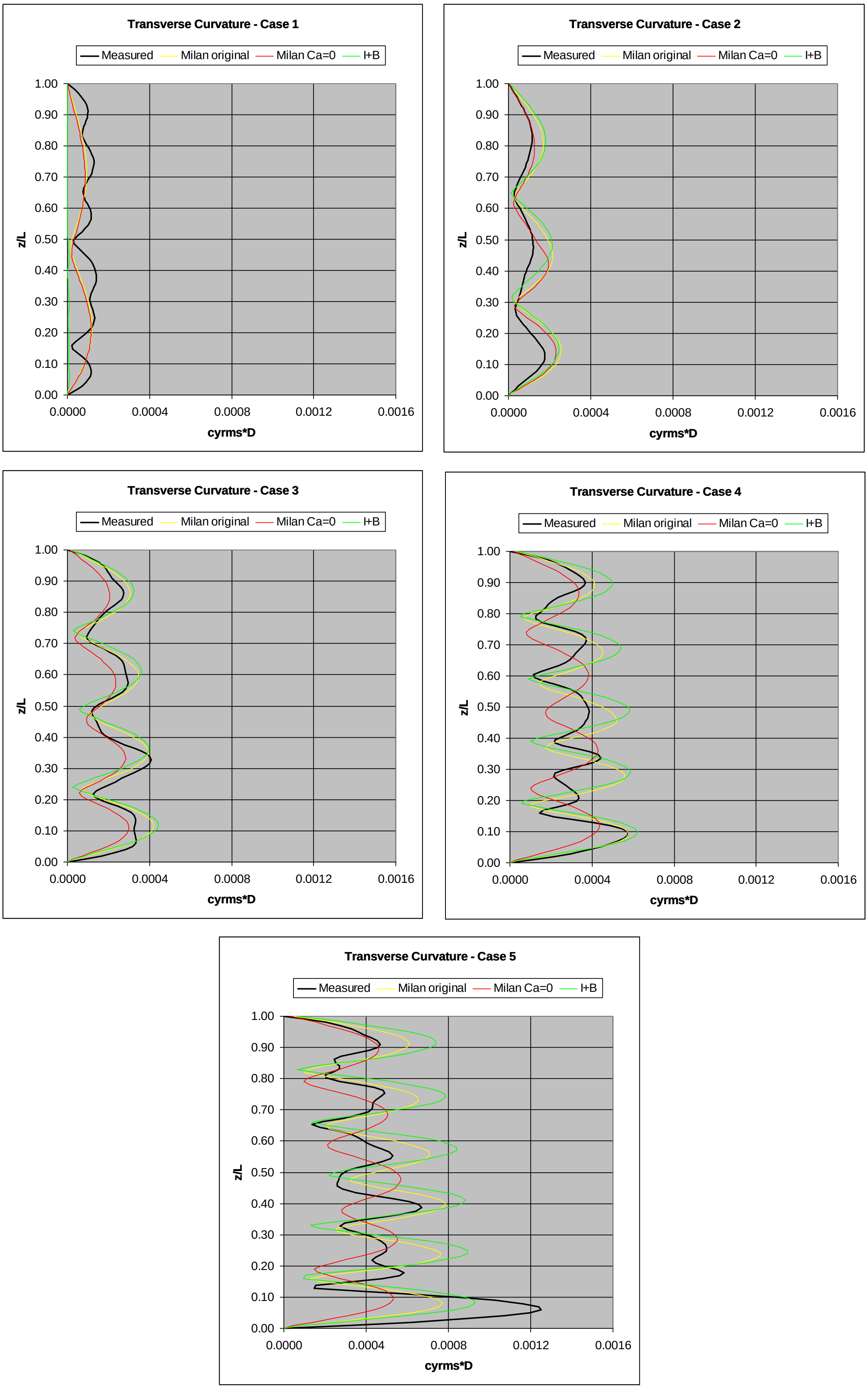


Figure A2.1 – Wake Oscillators - RMS Transverse Curvature, Load Cases 1 to 5

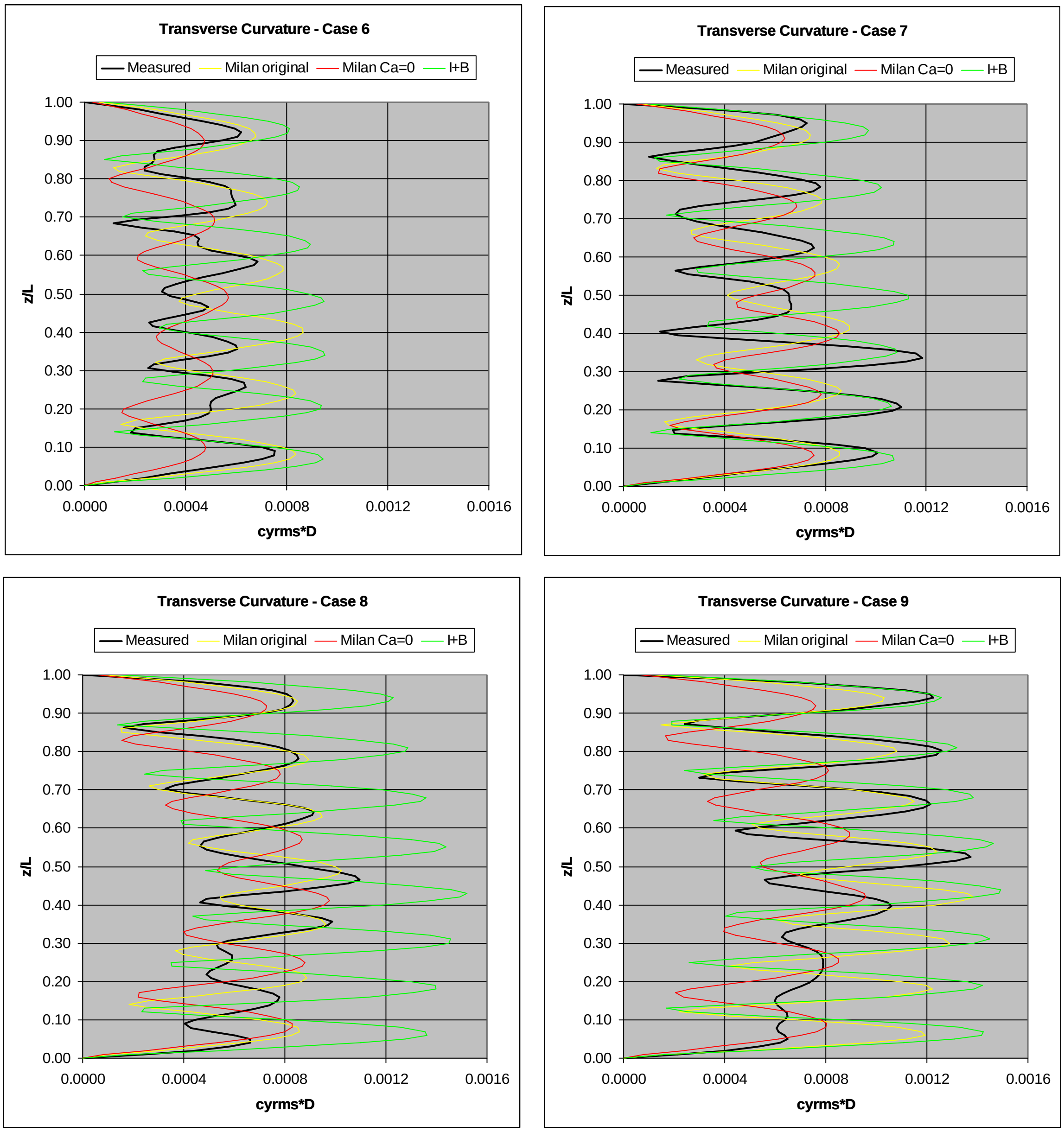


Figure A2.2 – Wake Oscillators - RMS Transverse Curvature, Load Cases 6 to 9

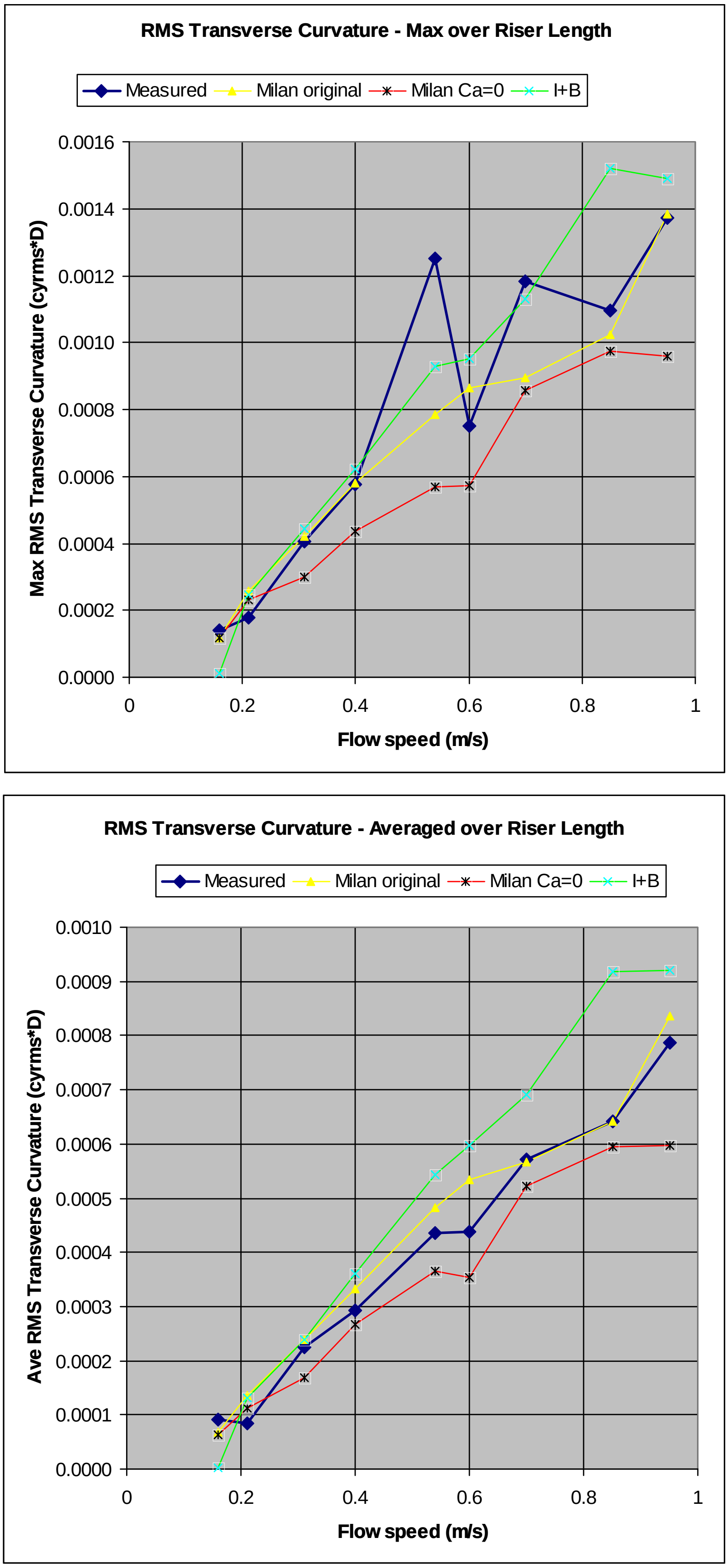
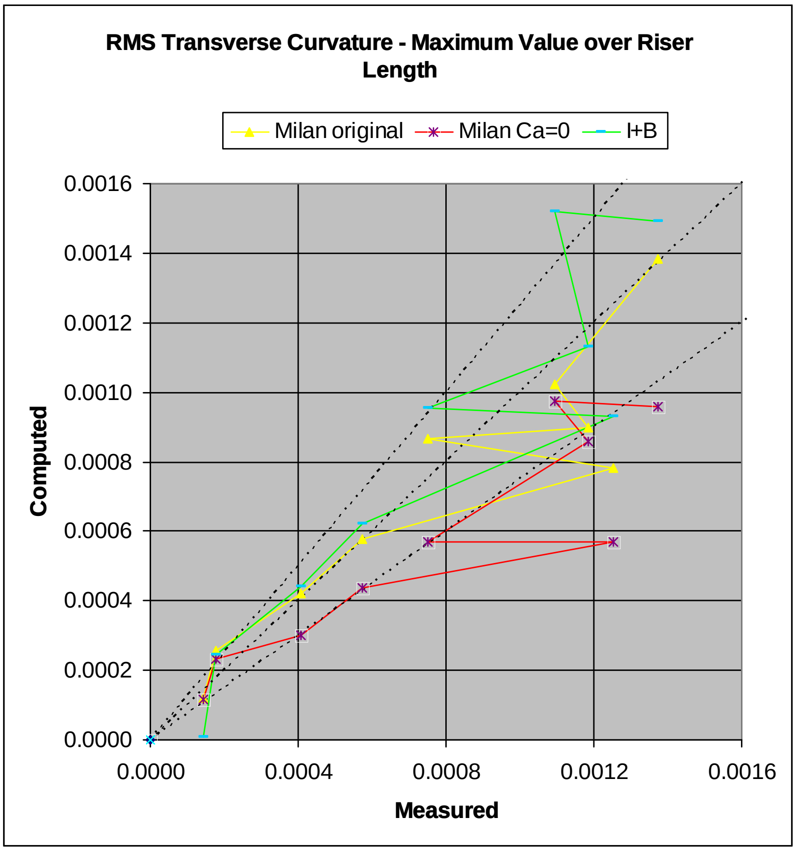


Figure A2.3 – Wake Oscillators – RMS Transverse Curvature – Var. with Flow Speed



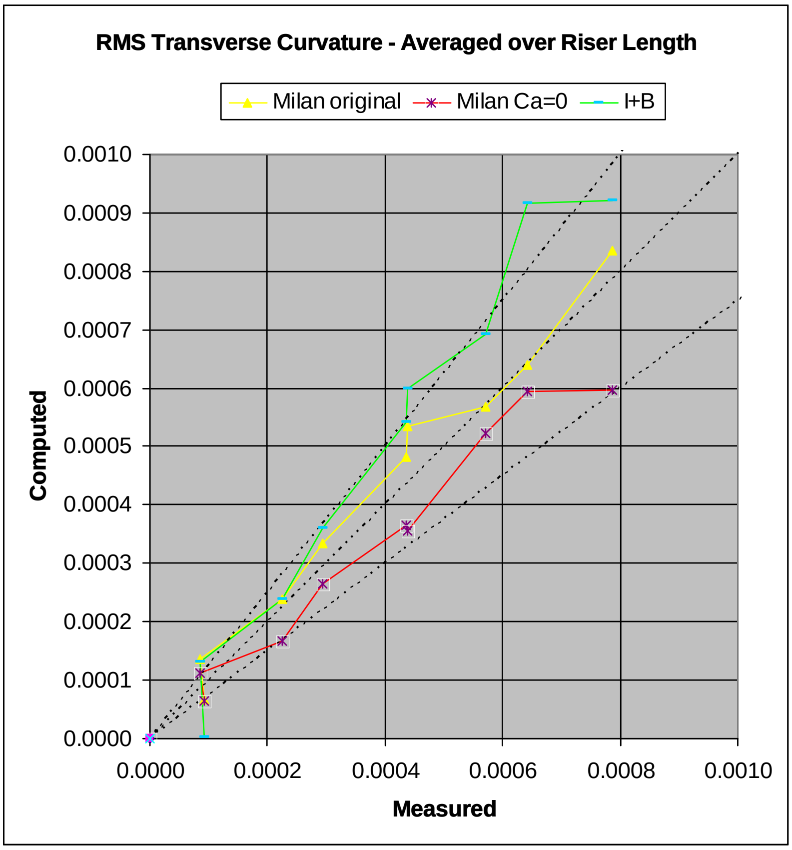
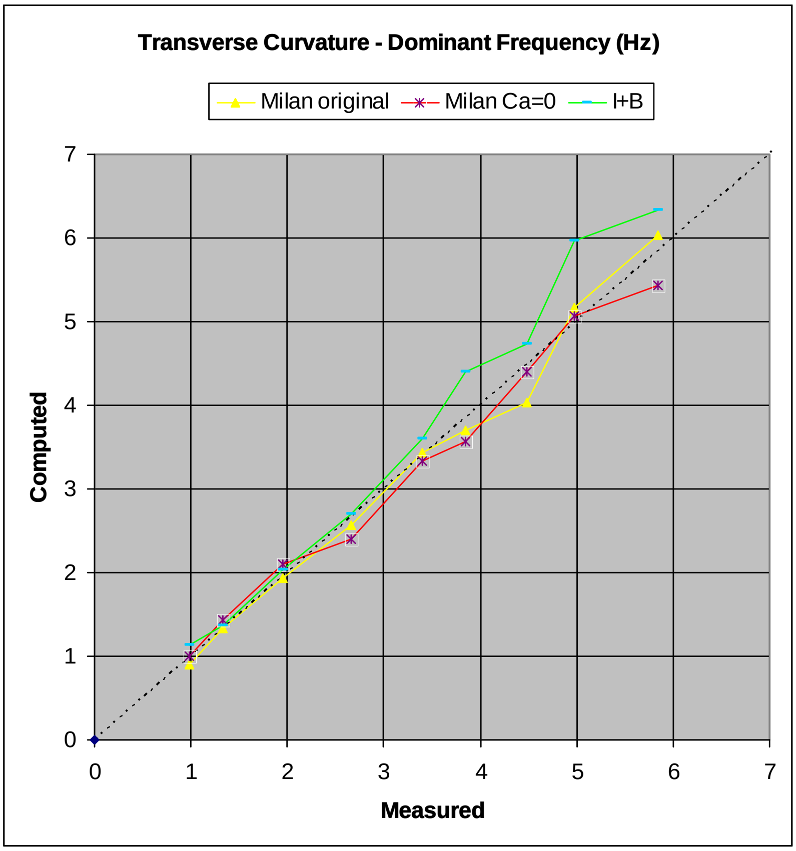


Figure A2.4 – Wake Oscillators - RMS Transverse Curvature – Predicted vs Measured



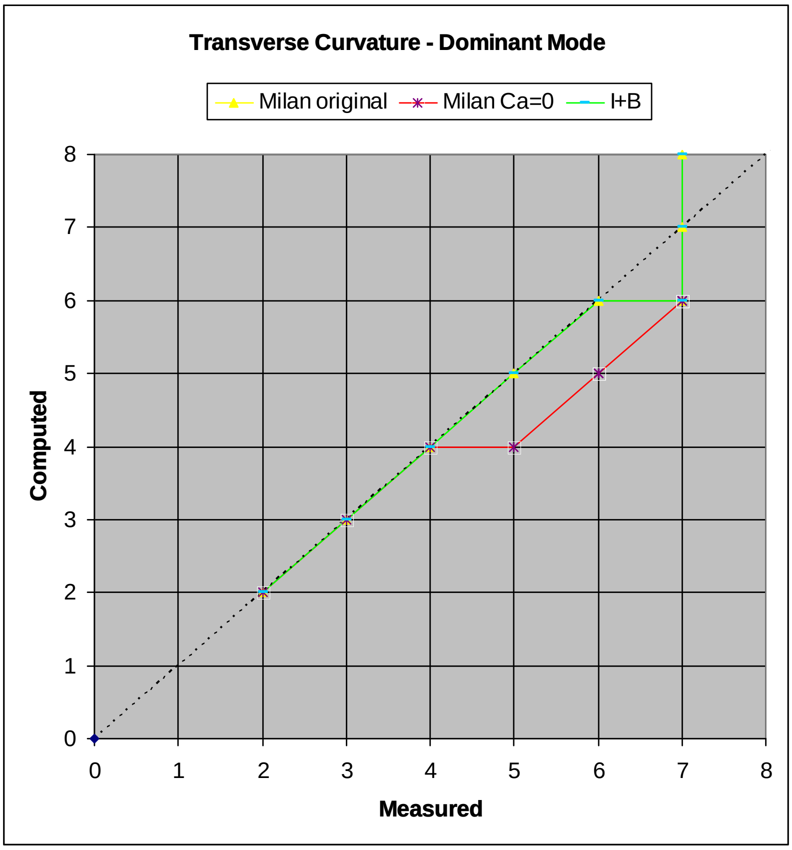


Figure A2.5 – Wake Oscillators - Transverse Frequencies and Mode Numbers

Appendix 3

Results for
Vortex Tracking Models

Transverse Displacement

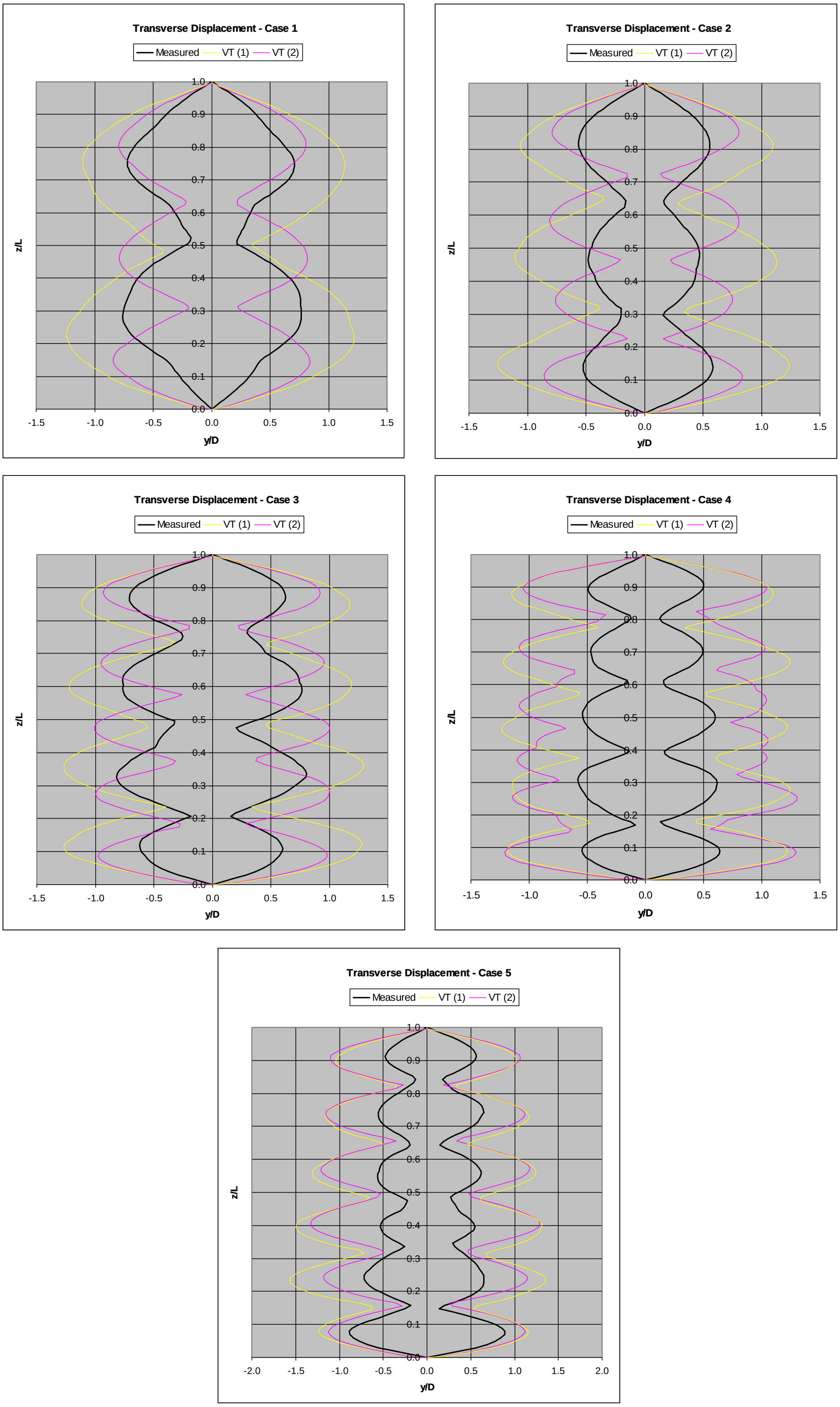


Figure A3.1 – Vortex Tracking - Transverse Displacement Envelopes, Load Cases 1 to 5

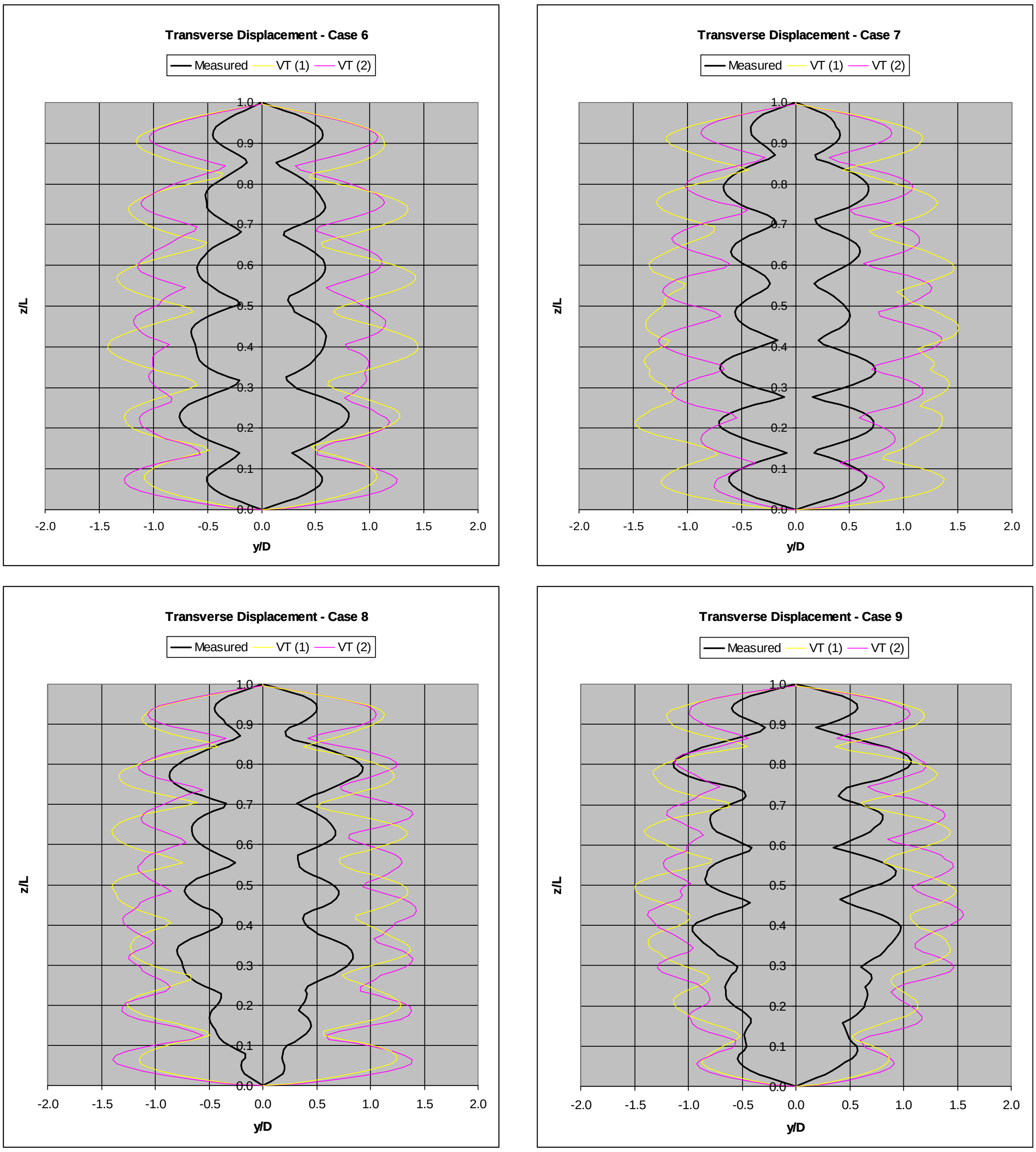
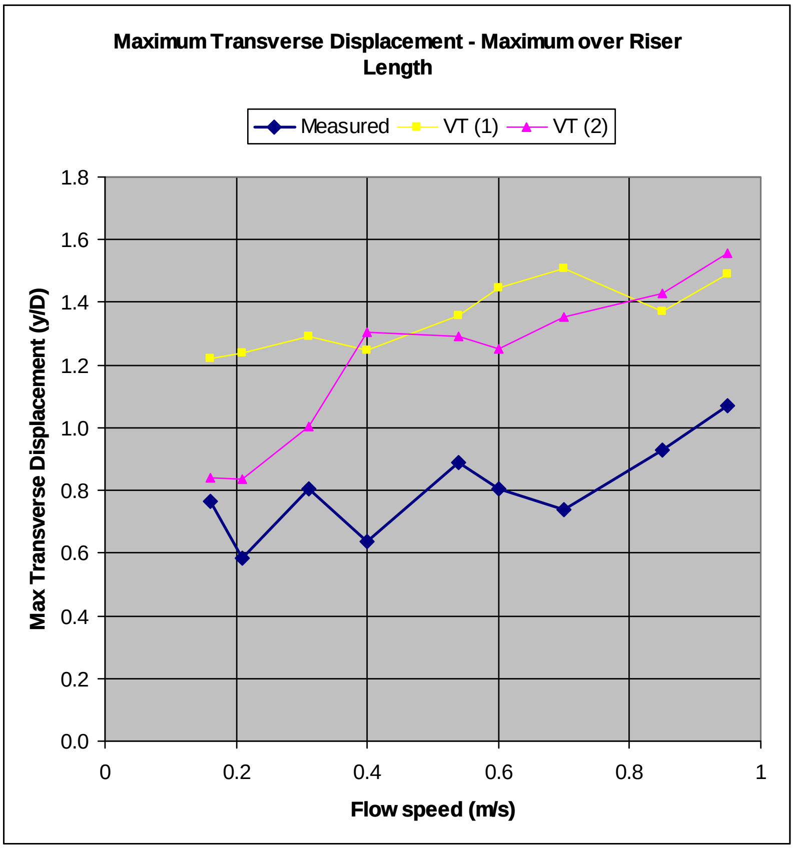


Figure A3.2 – Vortex Tracking - Transverse Displacement Envelopes, Load Cases 6 to 9



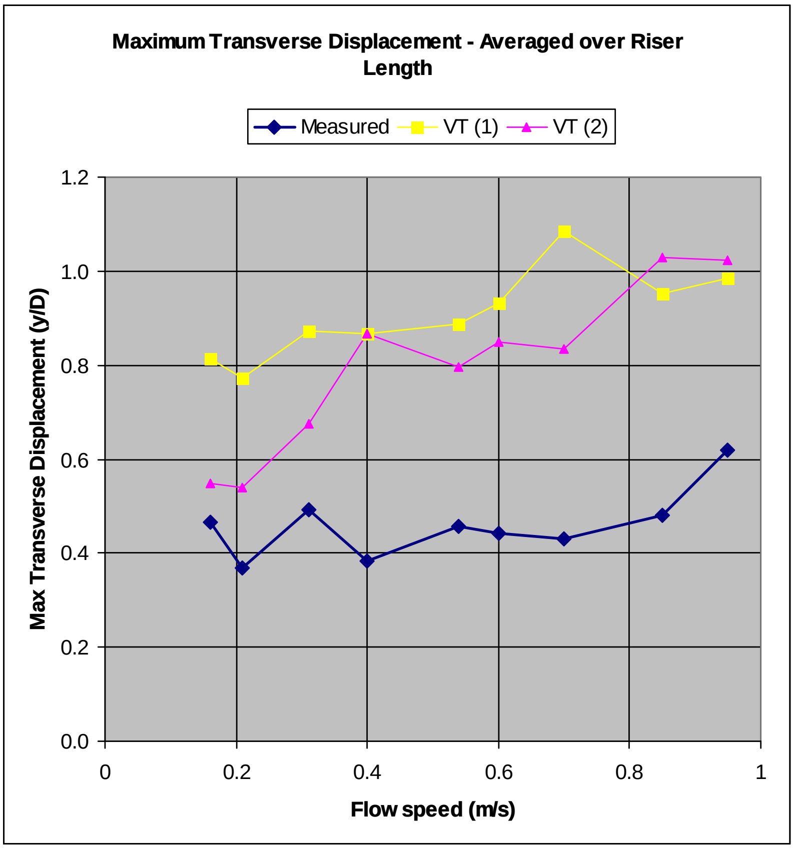
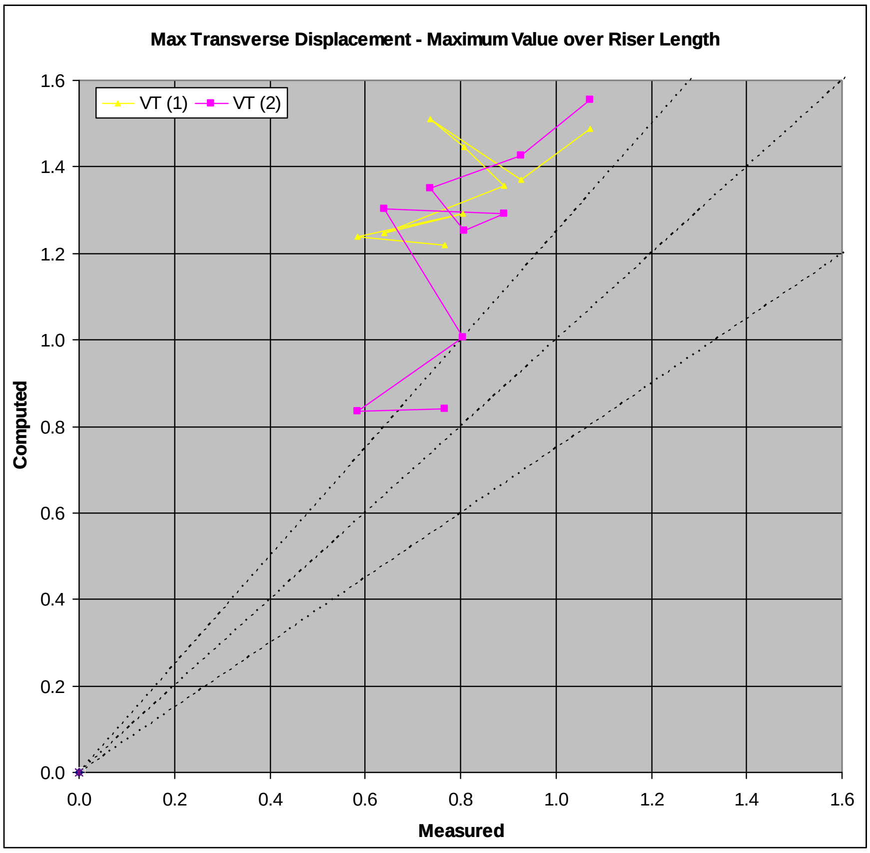


Figure A3.3 – Vortex Tracking – Max Transverse Displacement – Var. with Flow Speed



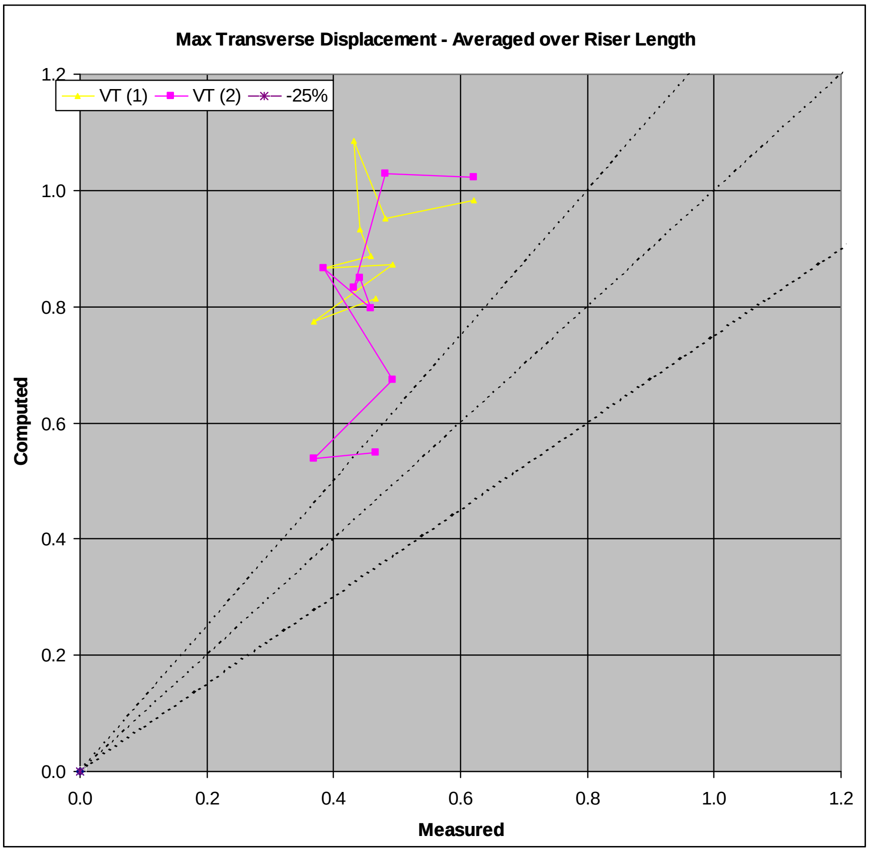


Figure A3.4 – Vortex Tracking - Transverse Displacement Results – Predicted vs Measured

Appendix 4

Results for
Vortex Tracking Models

Transverse Curvature

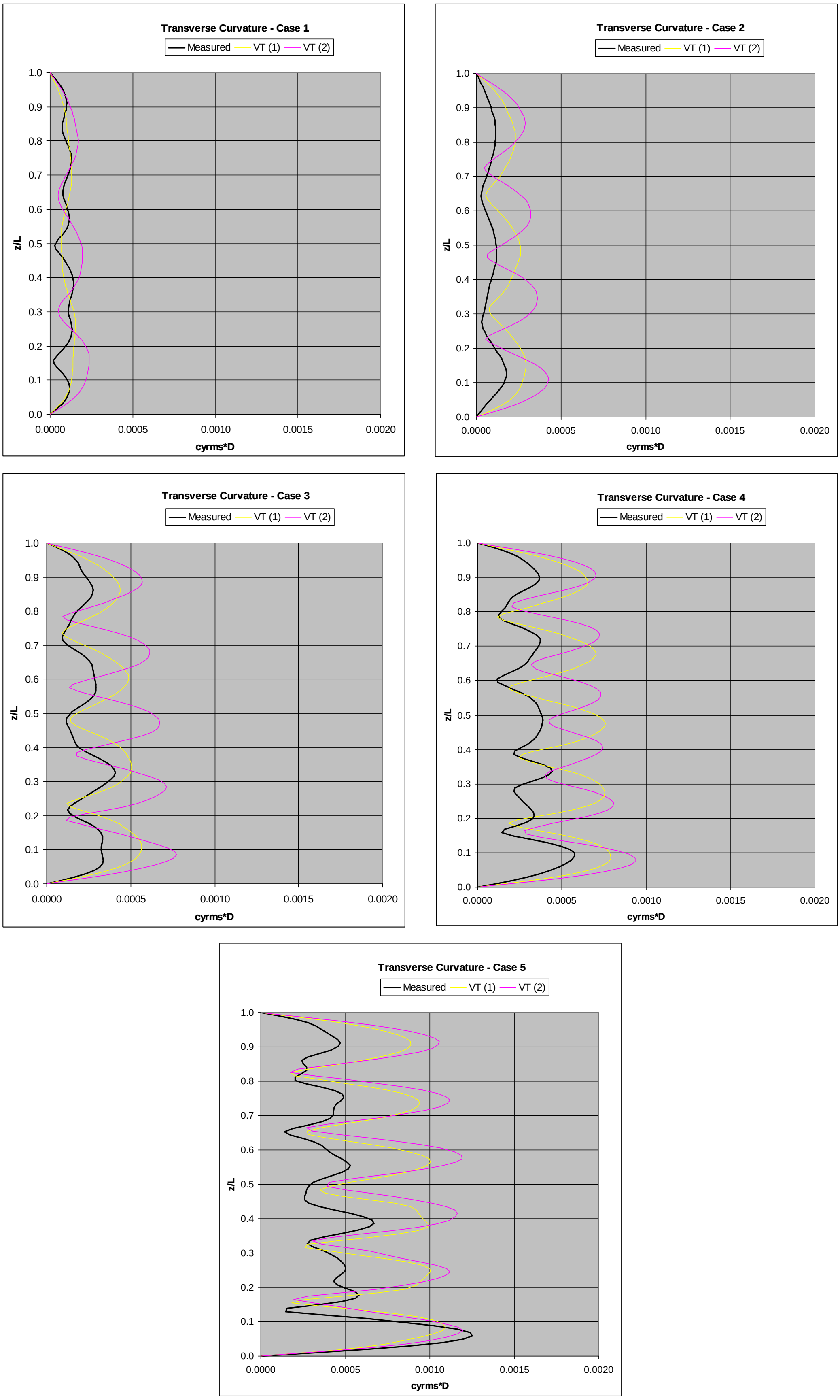


Figure A4.1 – Vortex Tracking - RMS Transverse Curvature, Load Cases 1 to 5

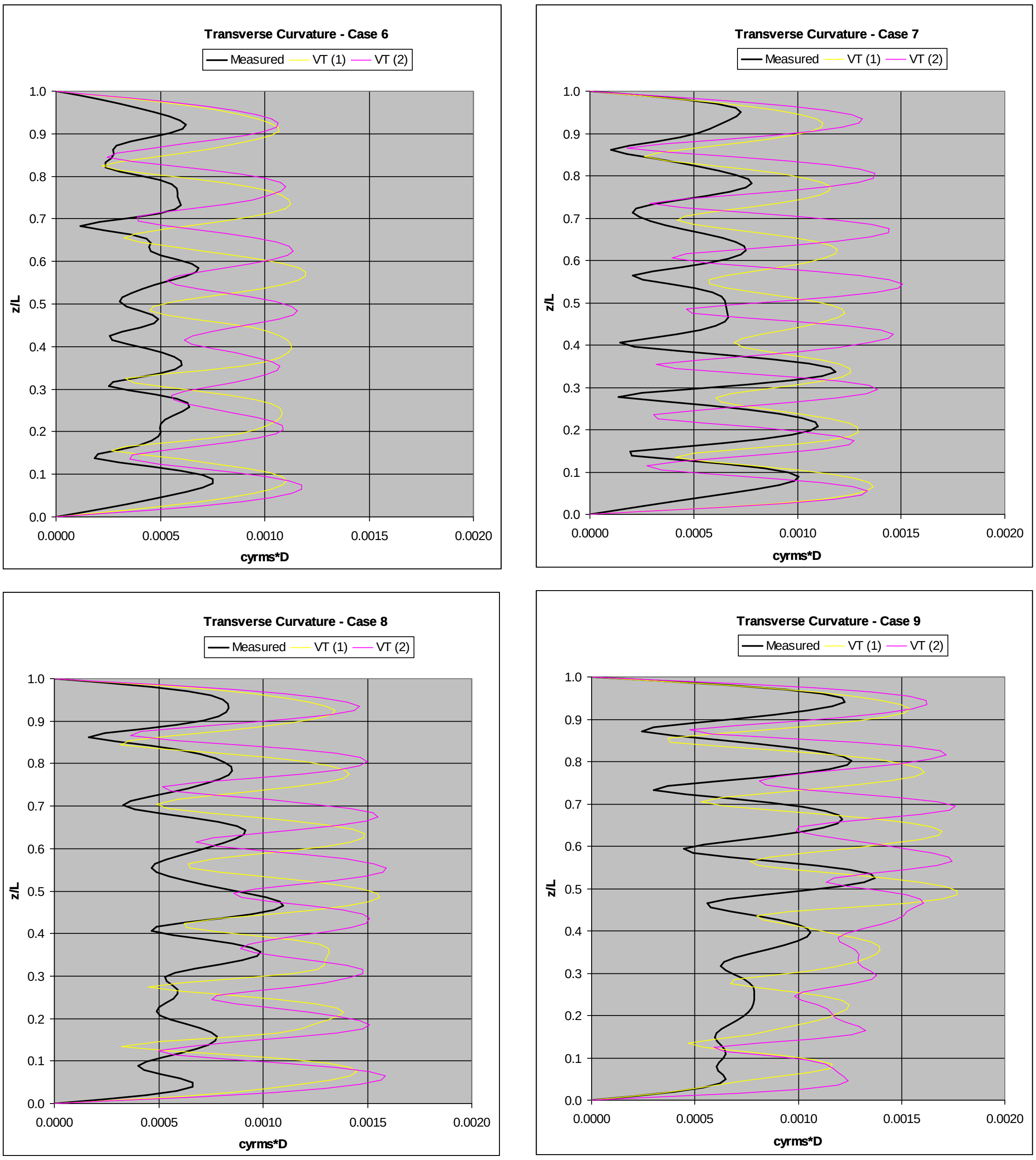


Figure A4.2 – Vortex Tracking - RMS Transverse Curvature, Load Cases 6 to 9

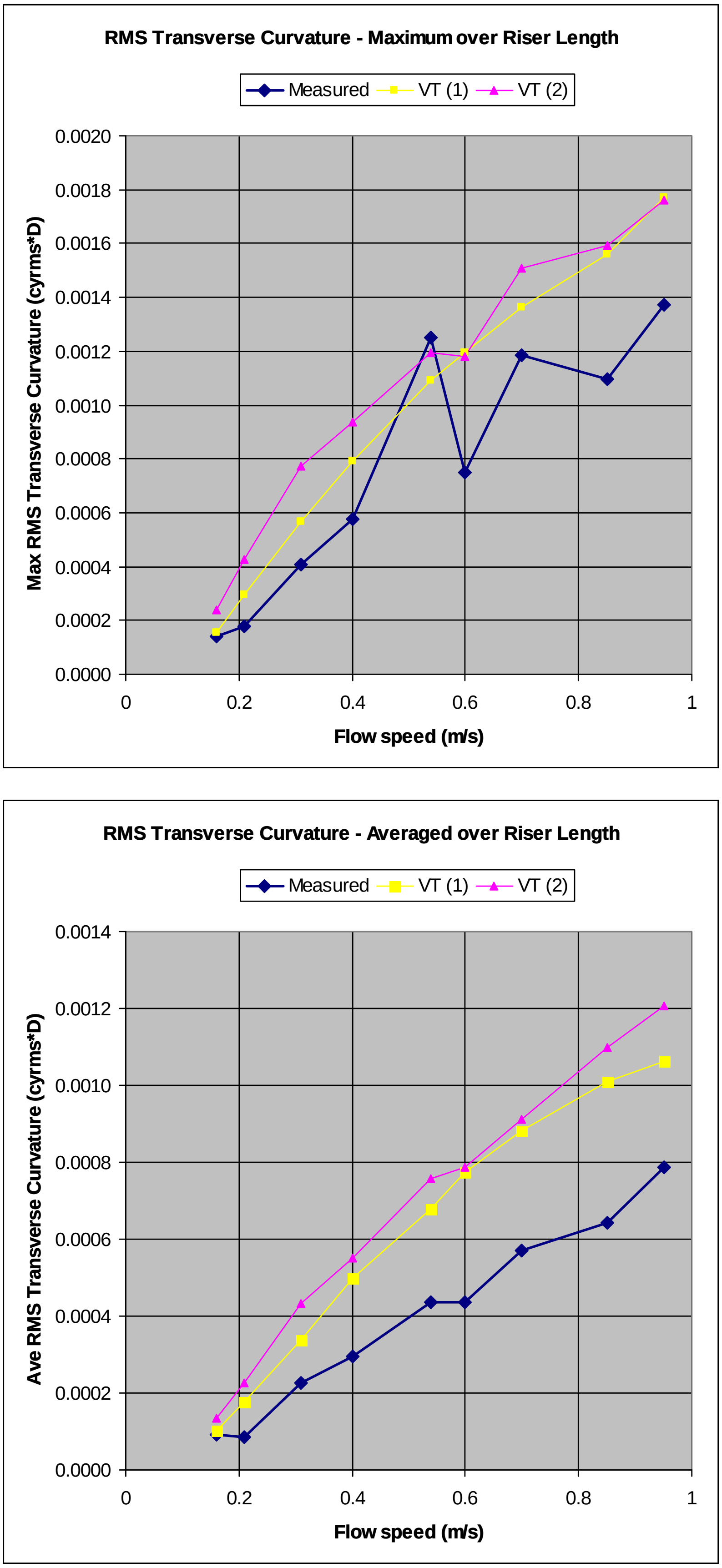
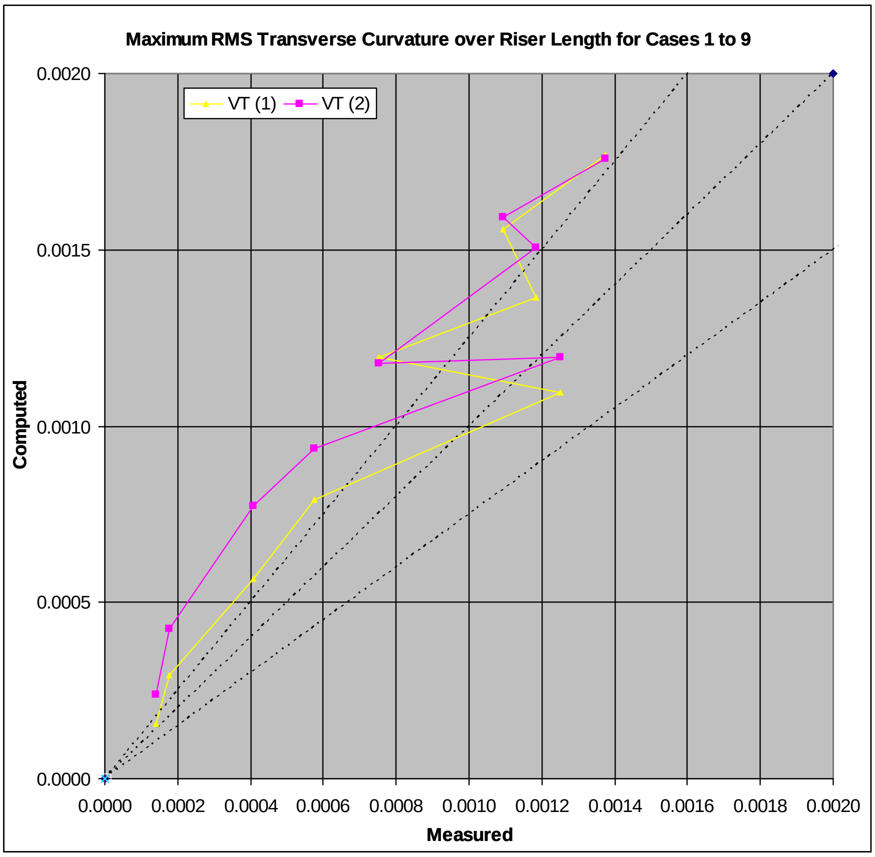


Figure A4.3 – Vortex Tracking – RMS Transverse Curvature – Var. with Flow Speed



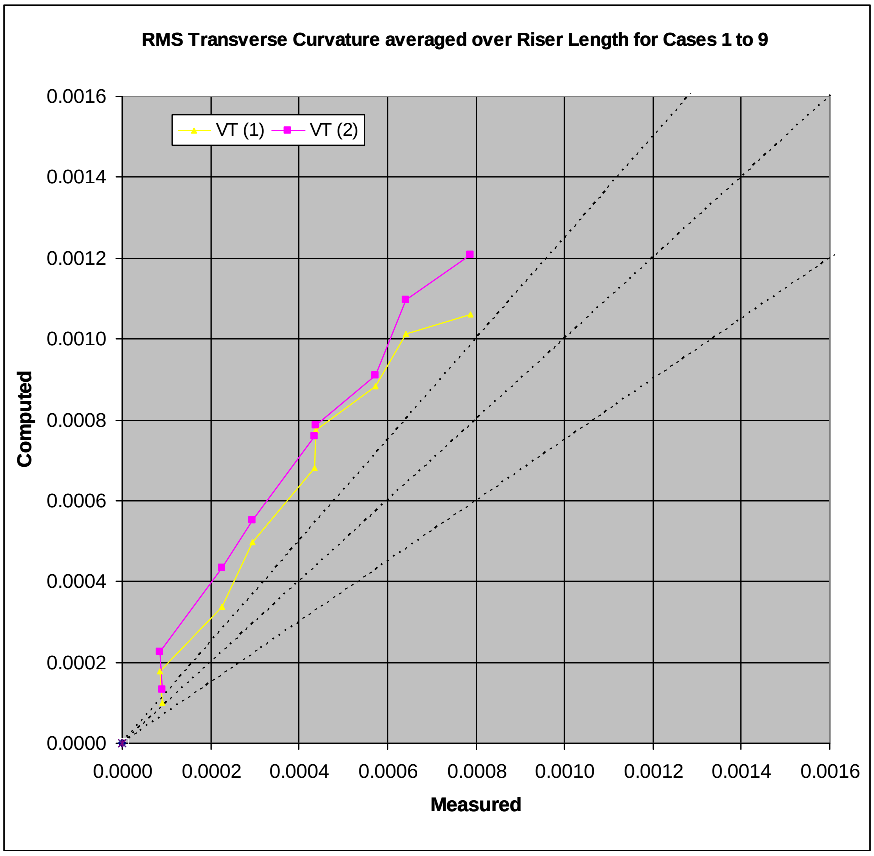
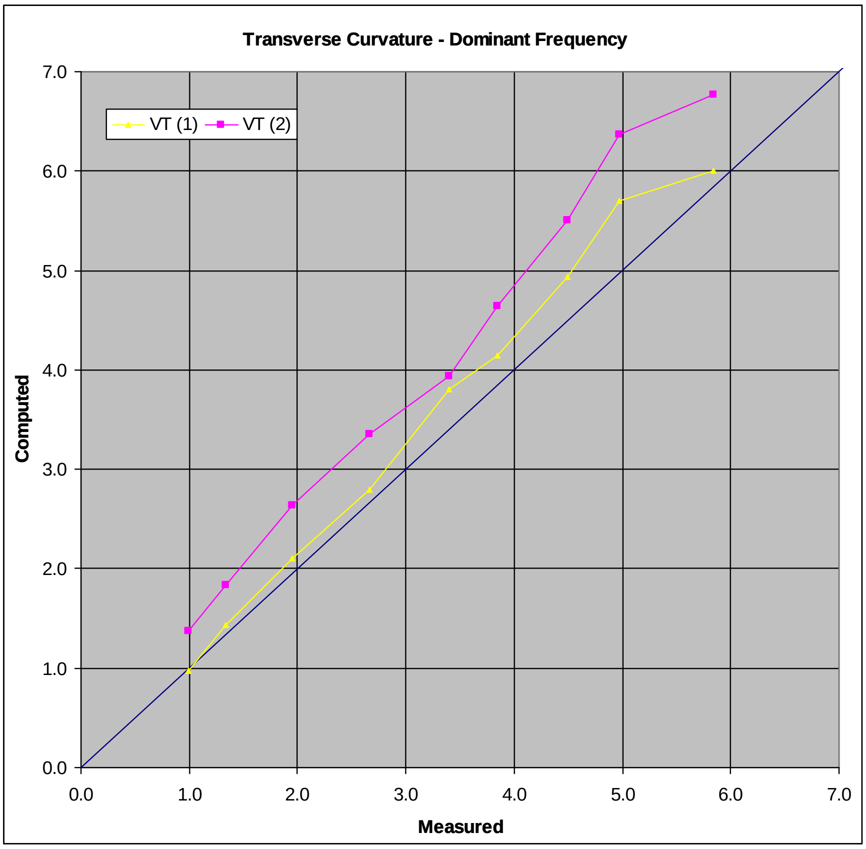


Figure A4.4 – Vortex Tracking - RMS Transverse Curvature Results – Predicted vs Measured



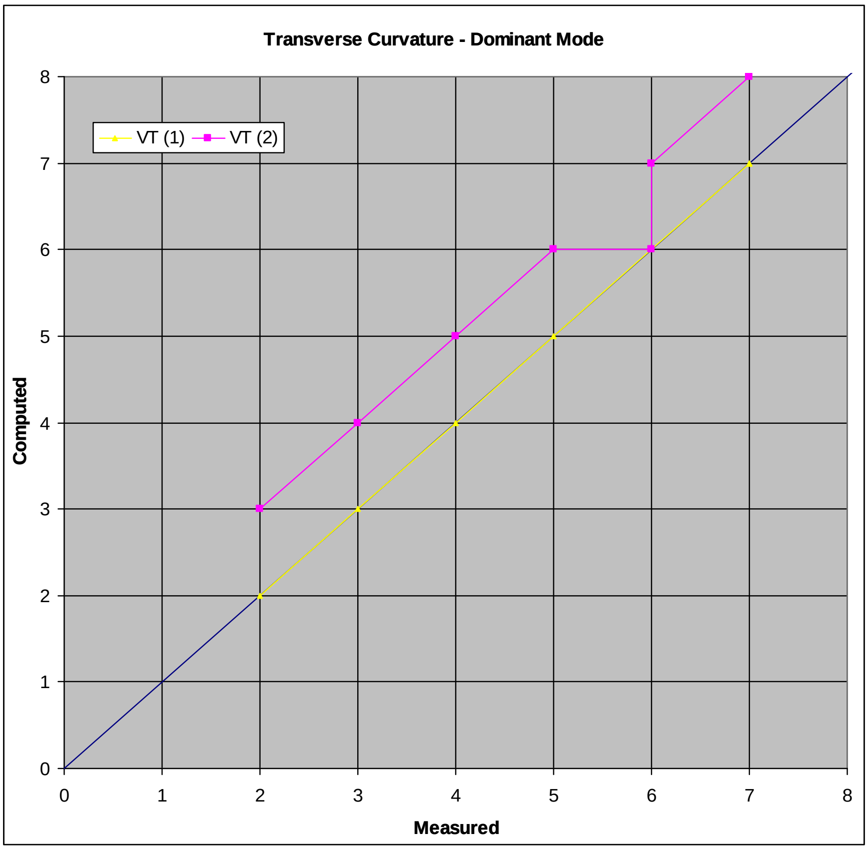


Figure A4.5 – Vortex Tracking – Transverse Frequencies and Mode Numbers

Appendix 5

Results for
Vortex Tracking Models

In-Line Curvature

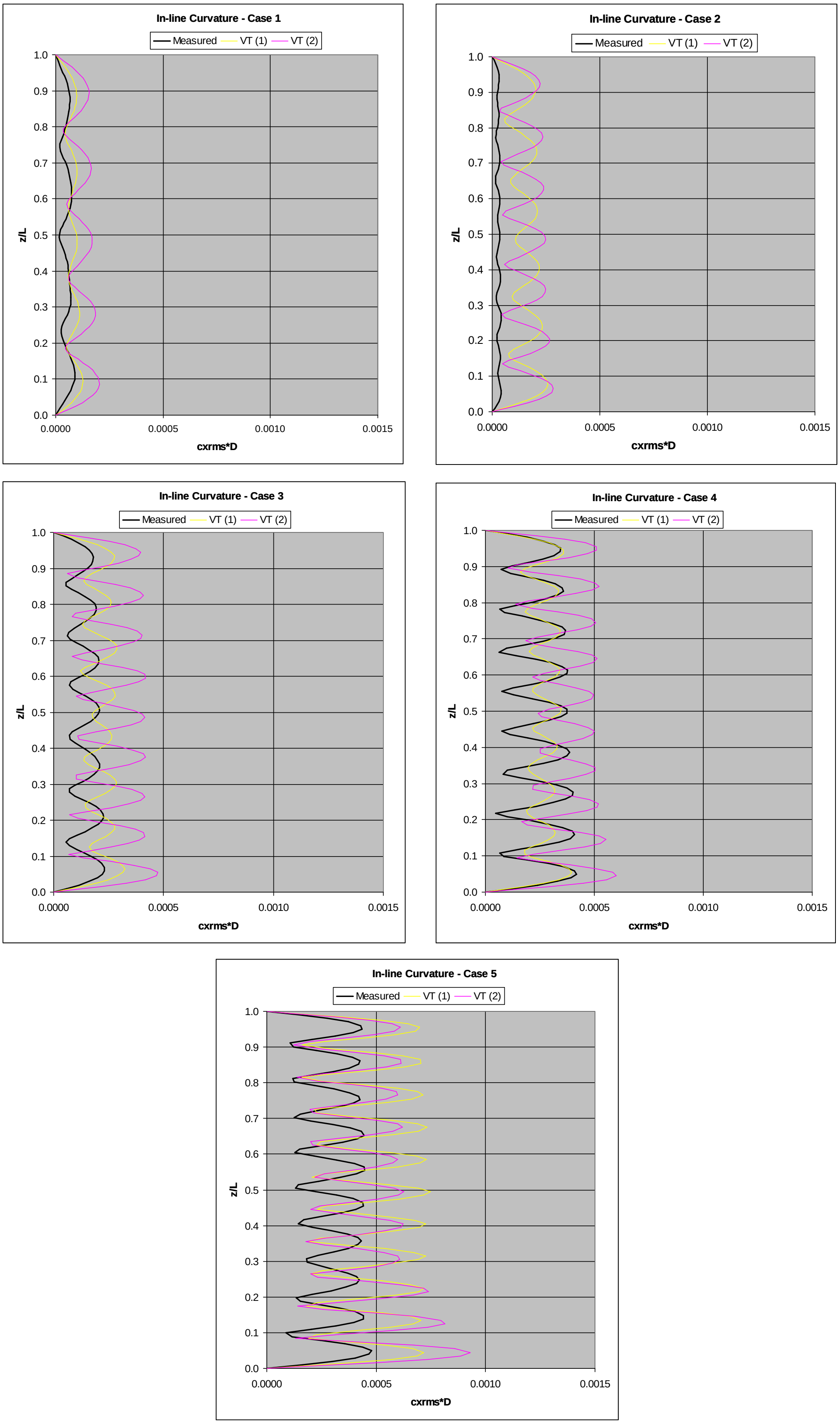


Figure A5.1 – Vortex Tracking – In-line Curvature, Load Cases 1 to 5

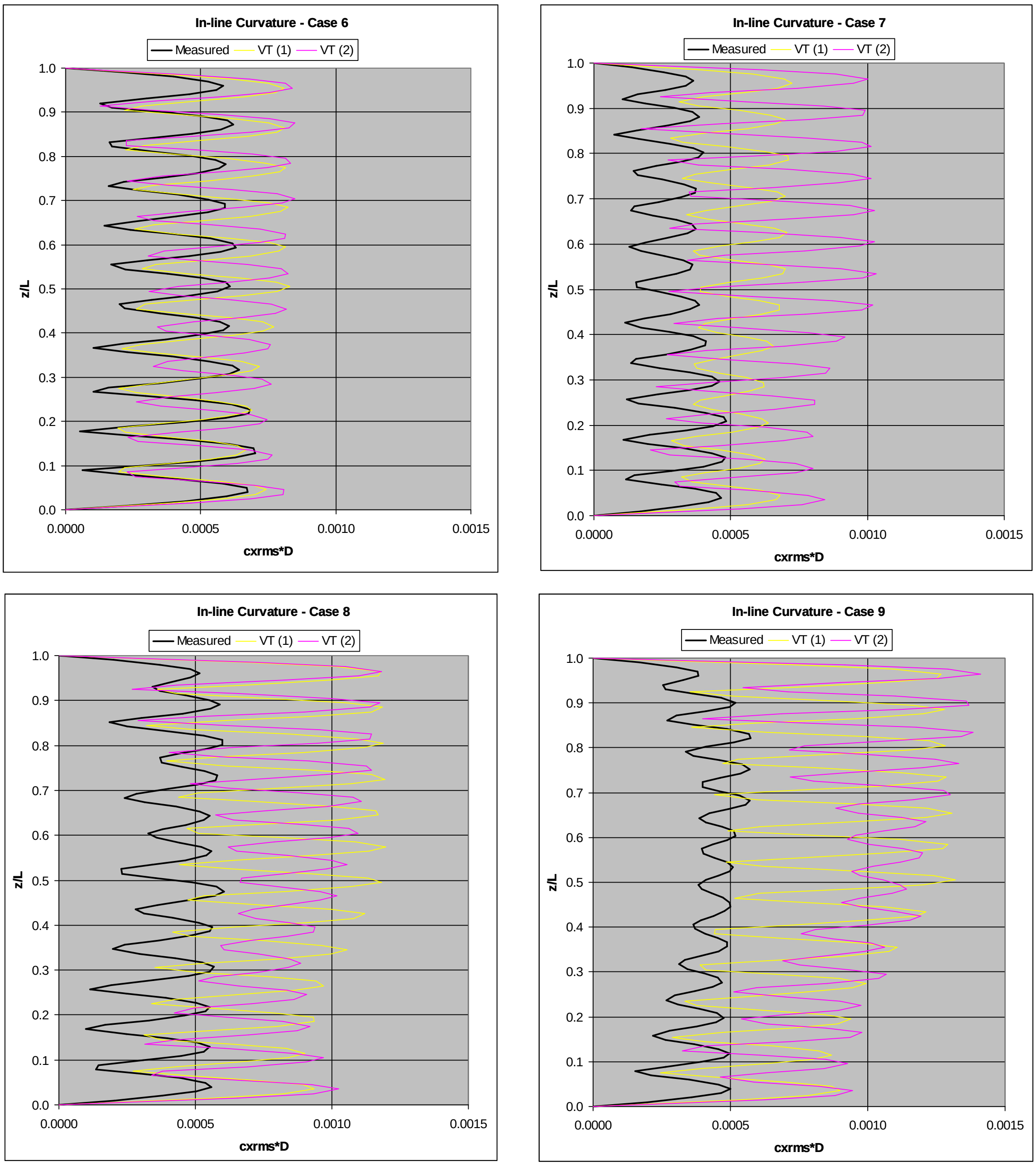
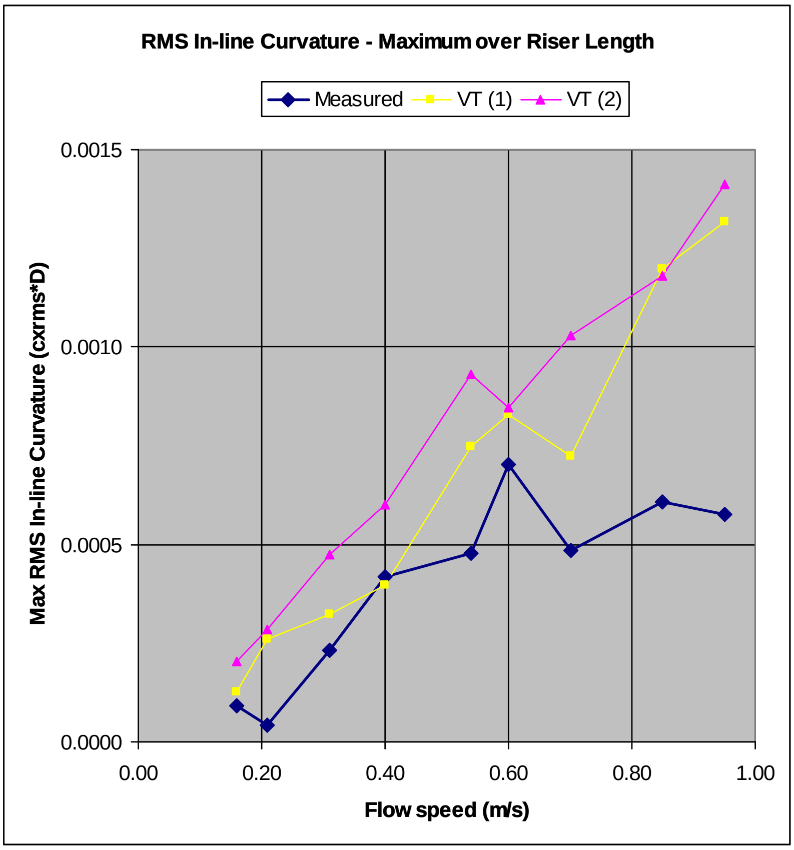


Figure A5.2 – Vortex Tracking – In-line Curvature, Load Cases 6 to 9



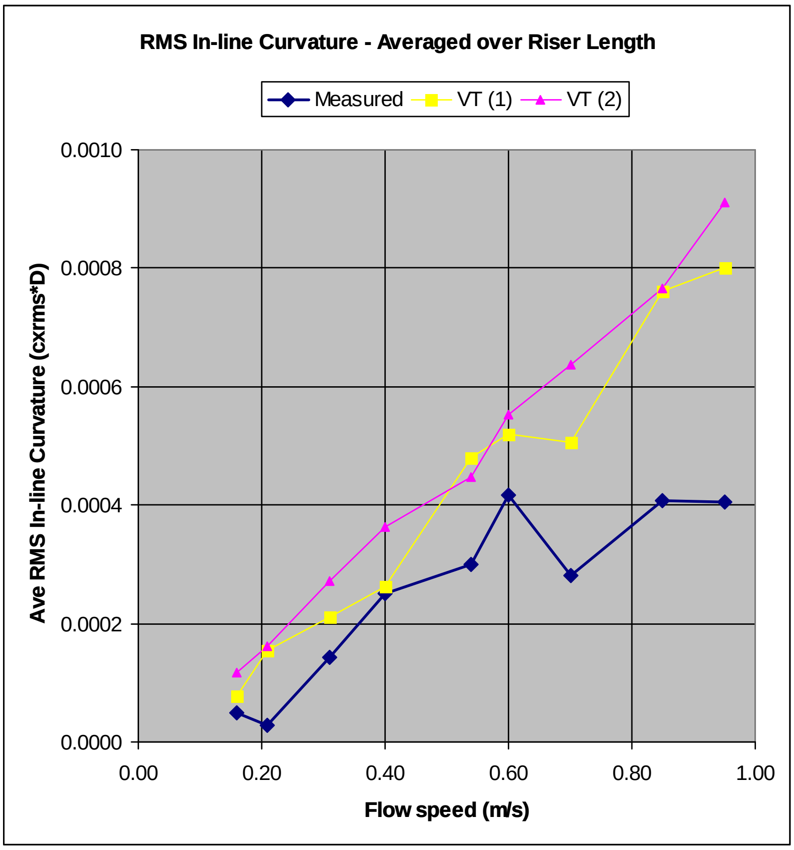
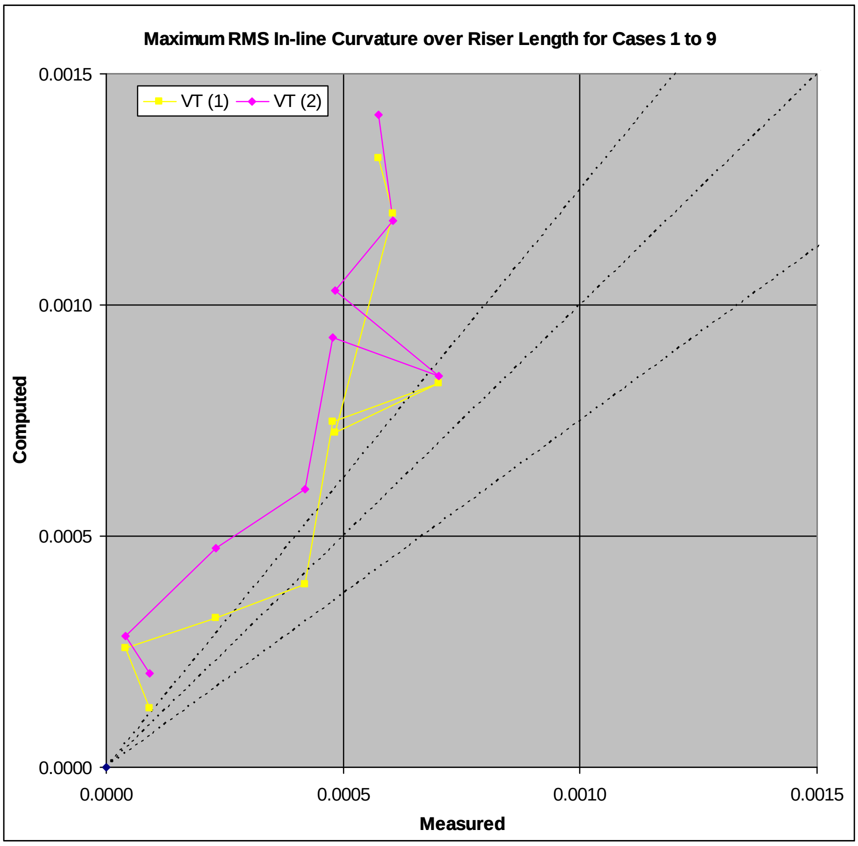


Figure A5.3 – Vortex Tracking – In-line Curvature – Var. with Flow Speed



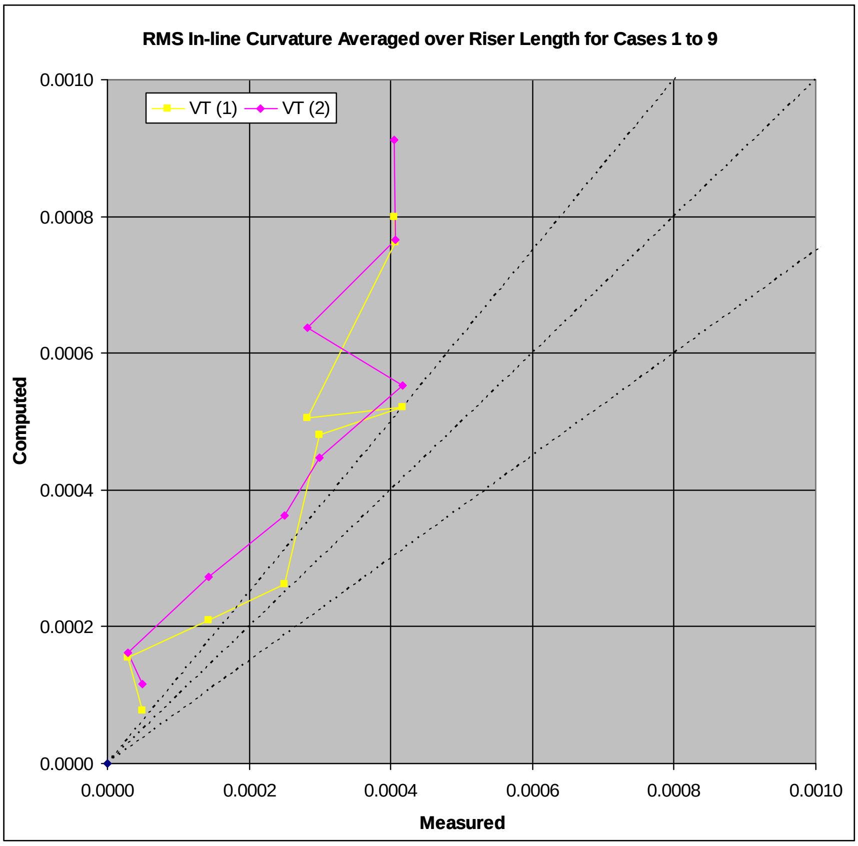


Figure A5.4 – Vortex Tracking – In-line Curvature – Predicted vs Measured

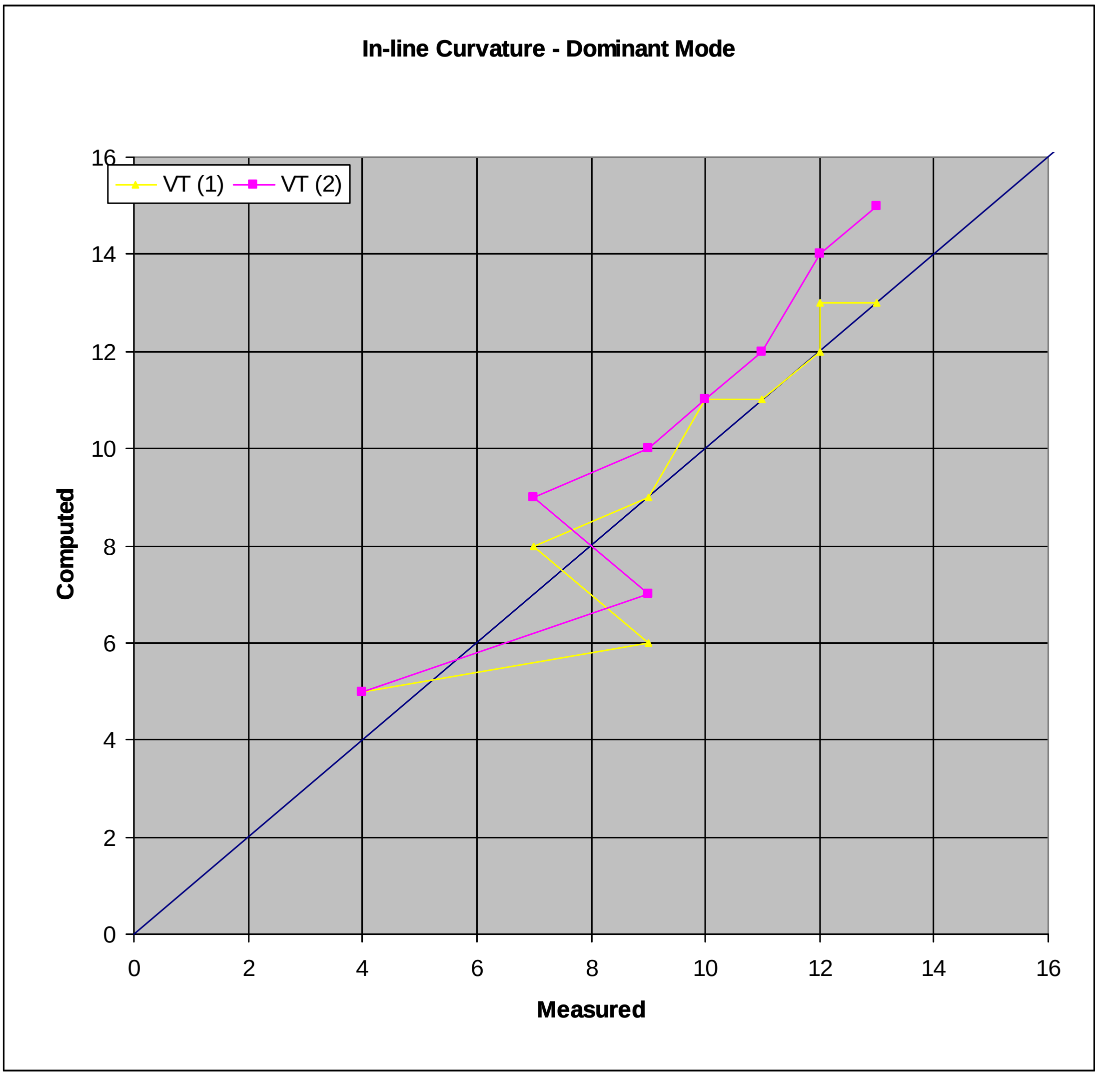


Figure A5.5 – Vortex Tracking – In-line Curvature – Mode Numbers