OrcaFlex VIV Toolbox Validation

Summary and Recommendations

Project 648

Client:	Orcina Ltd.			
Revision History:	Report No.	Issue	Report Date	Report Status
	01	02	17 May 2007	Issue
	01	01	20 Nov 2006	Draft
For Orcina:	Author:	R M Isherwood		
	Checked:	P P Quiggin		
Report file:	R648#01#02 OrcaFlex VIV Validation Summary.doc			

1 Introduction

The OrcaFlex VIV Toolbox is a special purpose extension to OrcaFlex for modelling vortex-induced vibration. The toolbox includes four different time domain VIV models in addition to links to two frequency domain packages supplied by others (SHEAR7, VIVA). This report is concerned with validation of the following time domain models:

- Two wake oscillator models, the Milan Wake Oscillator (Milan WO) and the Iwan and Blevins Wake Oscillator (IBWO)
- Two vortex tracking models. Vortex tracking model 1 (VT(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. Vortex tracking model 2 (VT(2)) does not try to group vortices into sheets; however the sheets are still present in the pattern of vortices being shed.

Details of the models and references to the original publications are given in Ref 1. The two wake oscillator models have parameters that can be adjusted by the OrcaFlex user for special purposes; for these comparisons the default "as published" parameters were used, i.e. those given in the original papers in which the models were published.

A series of validation studies have been performed and documented (Refs. 2 to 4), in which the results of these 4 time domain VIV models were compared against real-world test results from 3 different series of tests. The test results used were model tank tests conducted at Delft (Ref 2), DeepStar project test results from experiments on Lake Seneca (Ref 3), and measurements on a real full-scale drilling riser in the Schiehallion field (Ref 4).

Each of these reports includes a description of the test cases considered and presents comparisons between measurement and prediction. In this report we summarise the results from the individual comparisons and draw general conclusions regarding the validity and appropriate field of application for each of the computer models.

2 Basis for Comparisons

Different quantities were measured in the different test series, but in all cases results were presented as RMS values (RMS over time) of one or more time varying quantities (e.g. acceleration, curvature, displacement) at a number of locations. These dimensional RMS values are all measures of the magnitude of VIV, and in order to assess how well the various analytical models perform, we use a Bias Ratio, defined here as

Bias Ratio = (Predicted RMS/Measured RMS)

RMS values were available at a number of different measurement points along the riser. In order to summarise the results, the average and maximum of the RMS values were found (average or maximum over the length of the riser) and used to calculate bias ratios for each test case in each test series. We considered average values because this is the best overall measure of accuracy; maximum values because this is an indicator of worst fatigue damage. We have not attempted to compare distributions of response along the riser length, since the test evidence shows that the distribution may vary widely over time under the same flow conditions (see Ref 4).

For each test series, Table 1 tabulates the mean and standard deviation, over all the test cases in each test series, of the bias ratios of Average RMS and Maximum RMS. The mean gives a measure of the extent to which, on average, the model over or under predicts response; the standard deviation gives a measure of consistency. An ideal model would give a mean Bias Ratio of 1.0 with standard deviation zero.

Similarly, we define a Bias Ratio for the “dominant frequency” of VIV, defined as the frequency corresponding to the largest component of VIV response. For the computed responses, we identified this from the Fourier Transform of the time history of response.

3 Comparison Cases

3.1 Delft tests (Ref 2)

The Delft tests were carried out at small scale under closely controlled conditions in a model basin. Flow speed was constant over the lower half of the riser, zero over the upper half. This means that the riser was only subject to excitation at one Strouhal frequency – effectively a zero shear case with half the riser providing damping rather than excitation.

Measurements were made of curvature and acceleration, from which displacement and curvature distributions were deduced and reported. The model was densely instrumented and results reported are displacements and curvatures over the whole riser length.

Nine test cases are considered. For further details see Ref 2. Summary results are given for the following parameters:

- Transverse Displacement
- Transverse Curvature
- Dominant Frequency
- In-Line Curvature (Vortex Tracking models only)

It is worth noting at this point that a difficulty can arise in using the Bias Ratio as an indicator for cases where the magnitude of the measured response is small. In such cases, a small change in the measured value (resulting perhaps from experimental error or even from an unfortunate selection of the section of time history to be analysed) makes a disproportionate change in the Bias Ratio. There are indications that this effect may have influenced the curvature results for Case 2. In line curvature appears to be particularly affected. Fig A5.3 of Ref 2 shows measured and predicted in-line curvatures plotted against flow speed. Overall, the results show a steady trend of curvature increasing with increasing flow speed, but the measured curvature for Case 2 is extremely small, and smaller than that for Case 1. The computed values do not show this, and the resulting bias ratios for Case 2 are around 6, compared with values generally of 2 or under for the remaining cases. There is an even larger "wobble" in the measured values for Case 6, but since the absolute magnitude of the response is much larger, the effect on bias ratio is much smaller.

The figures shown in Table 1 have not been adjusted in any way for this effect. Omitting Case 2 results has little effect on the values reported for the Transverse Displacements and Curvatures, but reduces the Mean Bias Ratios for In-Line Curvature by about 0.5, and the Standard Deviations from around 1.5 to around 0.4.

3.2 DeepStar Seneca tests (Ref 3)

Tests were made on a model scale riser in a lake with no natural currents. Flow over the riser was generated by moving the top end at constant speed. Flow speed in the horizontal direction was therefore constant over the riser length, but riser deflection due to drag meant that flow speed normal to the riser was not exactly constant. However, this is very close to a slab current (zero shear) condition.

Acceleration measurements were made over the whole riser length. Unfortunately, around half of the measurements were missing, owing either to instrument failure or logging difficulties. The remaining measurements were fairly evenly distributed over the riser length, but they were not sufficiently closely spaced to define riser shape completely.

Six test cases are considered, two of which are in nominally identical conditions. Summary results are given for the following parameters:

- Transverse Acceleration
- Dominant Frequency

3.3 Schiehallion measurements (Ref 4)

Measurements were made on a full scale drilling riser during a drilling campaign on the Schiehallion field. Current profiles were measured, and are generally close to a linear sheared profile. Variation of current direction with depth was small.

Measurements of acceleration normal to the riser were made at five locations distributed over the bottom 30% of the riser length. Accelerations were measured in local X and Y directions but these were not aligned with the flow: consequently, both X and Y acceleration measurements include components of both in-line and transverse VIV response.

Eighteen test cases are considered. Summary results are given for the following parameters:

- Accelerations in X and Y directions.
- Dominant Frequency

4 Results

Summary results are shown in Table 1 for the three test series and four VIV models considered.

As an example, consider the first two figures in the table. These figures should be interpreted as follows, and the other table entries should be interpreted in the same way.

- The "Mean Bias Ratio" figure of 1.02 shows that, for the nine Delft tests, calculations with the Milan Wake Oscillator model gave predicted values of average RMS Transverse Displacement (averaged over the riser length), that were, on average, 1.02 times the measured average RMS values.
- The "Standard Deviation of BR" figure of 0.18 (standard deviation over the nine Delft tests) is a measure of how variable the Milan model's under/over-prediction was for the Delft tests. If the bias ratios for individual tests were normally distributed, then 64% of calculations for similar cases would be expected to fall in a band of ±1 Standard Deviation (SD) about the mean value, 95% within ±2SD. For the Milan/Delft case, 64% of predictions of average RMS Transverse Displacement would be expected to fall between 0.84 and 1.20 times the measured values (1.02±0.18), 95% between 0.66 and 1.38 times measured (1.02±0.36).

5 Conclusions

The following conclusions are drawn from the summary figures given in Table 1, together with consideration of the more detailed results given in Refs 2 to 4.

- The wake oscillator models work well over all the cases shown, with the exception of the Y accelerations for Schiehallion where both models over-predict significantly. We have been unable to identify a clear reason for this, but we note that the measured X and Y accelerations include contributions from both transverse and in-line VIV whilst the wake oscillators model transverse VIV only.
- Of the two wake oscillators, the Milan model is generally more accurate than the Iwan and Blevins model and shows less scatter.
- The two vortex tracking models substantially over-predict everywhere. The Vortex Tracking (1) model performs particularly poorly in the DeepStar Seneca comparisons. The reasons for this are not clear.
- The vortex tracking models are the only ones to offer predictions of in-line VIV. The Delft results show that in-line curvatures are over-predicted by a factor of 2 to 2.5, but the models may nevertheless have some qualitative value, as the detailed results show (see Ref 2). Note also that the bias ratios and standard deviations shown in the table may be over-stated (see Section 3.1 above).
- The Delft and DeepStar Seneca tests are all in effect zero shear cases (or very nearly so in the case of Seneca). The Schiehallion cases are all unidirectional and for practical purposes linear shear profiles. We do not have any cases with

highly non-linear shear or with current direction varying with depth, so no conclusions can be drawn on how the VIV models behave under such circumstances.

- The Delft and DeepStar Seneca cases show that the wake oscillator models work well in zero or low shear conditions over a wide range of modes. (We characterise Delft as "zero shear" for the reasons given in Section 3.1 above.)
- The Schiehallion cases typically have current speed varying by a factor of two from top to bottom. The models show VIV in low mode shapes – typically mode 3 or 4. We conclude that the wake oscillator models work well in this amount of shear for low mode VIV, but it would not be safe to assume that they will work equally well at higher modes where modes are more closely spaced in frequency.

6 Recommendations:

Based on these validation studies, and on our experience of using the various VIV models, our recommendations are as follows.

- As a general rule, use more than one VIV model for any investigation.
- Use the Milan wake oscillator model as the principal analysis tool for low to moderate shear conditions, with the Iwan and Blevins wake oscillator model as back up for confirmation.
- Use the vortex tracking models for investigations of in-line VIV in low to moderate shear conditions, but be aware that amplitudes are probably substantially over-predicted.
- In conditions not covered by these validation cases, use several models and treat all results with caution.

7 Acknowledgements

Orcina Ltd. wish to thank BP, the Norwegian Deepwater Programme, the DeepStar project and Southampton University for access to the VIV measurements used in this comparison study.

8 References

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

2 R048#02#02 OrcaFlex VIV Toolbox Validation: Comparison with Delft VIV Model Tests, Orcina Ltd., 2007.

3 R048#03#02 OrcaFlex VIV Toolbox Validation: Comparisons with Measured Data from Schiehallion Drilling Riser, Orcina Ltd., 2007.

4 R048#04#02 OrcaFlex VIV Toolbox Validation: Comparisons with Measured Data from DeepStar Seneca Trials, Orcina Ltd., 2007.

			Milan WO		IBWO		VT(1)		VT(2)	
Test Series	Measured Parameter	VIV Measure	Mean Bias Ratio	Standard Deviation of BR	Mean Bias Ratio	Standard Deviation of BR	Mean Bias Ratio	Standard Deviation of BR	Mean Bias Ratio	Standard Deviation of BR
Delft	Transverse Displacement	Average RMS	1.02	0.18	0.90	0.37	2.00	0.28	1.74	0.36
	Transverse Displacement	Maximum RMS	0.94	0.21	0.84	0.36	1.72	0.27	1.51	0.28
	Transverse Curvature	Average RMS	1.10	0.23	1.14	0.44	1.58	0.28	1.81	0.36
	Transverse Curvature	Maximum RMS	0.98	0.23	1.01	0.41	1.31	0.25	1.57	0.41
	Transverse Curvature	Dominant Frequency	0.98	0.05	1.09	0.06	1.07	0.05	1.27	0.09
	In-Line Curvature	Average RMS	(-)	(-)	(-)	(-)	2.01	1.33	2.29	1.34
	In-Line Curvature	Maximum RMS	(-)	(-)	(-)	(-)	2.05	1.60	2.47	1.67
DeepStar Seneca	Transverse Acceleration	Average RMS	0.80	0.11	1.35	0.22	37.53	13.59	4.00	0.55
	Transverse Acceleration	Maximum RMS	0.96	0.20	1.58	0.35	49.26	11.02	4.14	0.74
	Transverse Acceleration	Dominant Frequency	1.00	0.10	1.17	0.13	18.14	1.32	7.40	0.42
Schiehallion	X Acceleration	Average RMS	0.93	0.31	1.14	0.62	4.95	1.73	5.45	1.66
	X Acceleration	Maximum RMS	0.93	0.30	1.12	0.59	4.04	1.41	4.60	1.43
	Y Acceleration	Average RMS	1.54	0.59	1.94	1.16	4.36	1.73	5.26	2.02
	Y Acceleration	Maximum RMS	1.35	0.43	1.67	0.92	3.04	1.09	3.70	1.22
	Y Acceleration	Dominant Frequency	0.70	0.09	0.80	0.12	2.12	0.77	2.88	0.78

Table 1: Summary of Comparisons