Hydrodynamic Response Behavior of Ribbon Fairing

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***Abstract*— Ribbon fairings were developed to mimic the effectiveness of marine growth in changing the frequency response behavior of marine cables and there are a variety of practical designs that are used in oceanographic applications. An experimental investigation was conducted in a model basin to study the basic nature of suppression of flow-induced vibrations by ribbon fairing. The flexible test cylinder model with an L/D ratio of approximately 760 was towed in a horizontal orientation at speeds reflecting uniform current velocities ranging from .18 m/s to .43 m/s. The objective here is to understand the migration of flow-induced vibrations in terms of frequency content, mode shapes and modal contributions that can be used to reconstruct the original time series measurements. Spectral analysis of the data revealed the multi-modal excitation that in these experiments was typically dominated by two to three dominant spectral peaks. The increase in current velocity and introduction of the fairings resulted in the mitigation of the energy associated with each of the spectral peaks and a shifting of the remaining spectral response peaks. The ability to reconstruct the original time series measurements is shown to be sensitive to the frequency response range and the number of sensors.**

Keywords*— *ribbon fairings, flexible towed horizontal cylinder, uniform currents, vortex- induced vibrations, spectral response.

I. INTRODUCTION

Many interesting marine design innovations have been inspired by nature, often as a consequence of unexpected behavior. Ribbon fairing now commonly used in marine applications is one example and there are a number of interesting variants of this concept [1]. The objective of this study was to investigate the nature of ribbon fairing in the suppression of flow-induced vibration using data from a controlled model basin environment and a non-traditional analysis approach that would allow the reconstruction of the original time series information.

The data analyzed in this study was selected from an earlier experimental investigation that was primarily focused on assessing the effectiveness of a generic airfoil device characteristic of those used by the offshore oil industry [2]. In that study the test matrix included towing of flexible horizontal test cylinder with various percentages of suppression coverage and a limited number of cases that included regular wave excitation. A limited number of ribbon fairing cases were investigated just prior to the dismantling of the experimental setup. It is from those model tests that the data was selected for this study. The methodology used to analyze the data can be used to resolve the response frequencies, mode shapes, critical damping ratios and the modal contribution factors directly from the time series [3]. As will be discussed the information that can be obtained from experimental data using this approach is explicitly dependent on the number of sensors and their measurement frequency range. This is important to understand in the design of the experiment and is critical for resolving response information at higher frequencies.

II. ANALYSIS METHODOLOGY & EXPERIMENTAL SETUP

The major aspects involved in the analysis of time series data from multiple sensors and its subsequent reconstruction from the recovered modal information is presented conceptually in Fig. 1. Given the data from multiple sensors whose precise location is known spectral characterization [4] and the time domain decomposition (TDD) modeling of the data is pursued. The outcome is modal information that includes frequency domain information, mode shapes, critical damping ratios and modal contribution factors. It is the last aspect that is developed in this study and leads to the evaluation of the number of sensors, their placement and the frequency resolution required to reconstruct the original time series measurements of interest. A recent article comparing the effectiveness of ribbon and airfoil faring in suppressing flow-induced vibrations provides some complementary information on this methodology not covered in this article [5].

Once the modal information is recovered as indicated in Fig. 1, the reconstruction using the modal information is quite similar in mathematical form that typical of normal mode analysis [6]. The main difference is that as part of the current analysis approach it is possible to reason about which modes should be included based upon a review of the ability of the sensor to recover frequency and mode information.

The experimental setup and some of the test particulars are illustrated in Fig. 2. The tensioned horizontally suspended test cylinder was 29 m long with a length to diameter ratio, L/D, of approximately 760. Six unequally spaced bi-axial accelerometers internal to the test cylinder and a centrally located external string potentiometer were used to measure the

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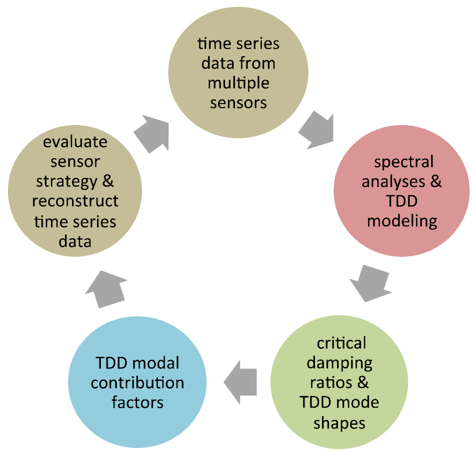

Fig. 1. Overview of the problem and solution components.

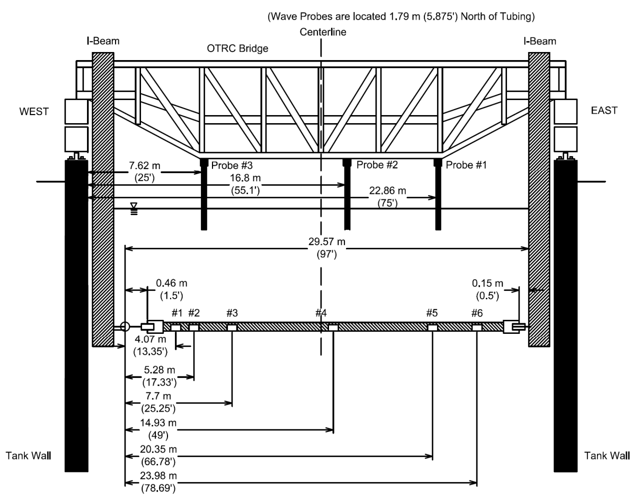

Fig. 2. Model particulars and instrument locations [2].

response behavior. The sensor locations were chosen in coordination with the pre-tensioning of the test cylinder. The test cylinder was pre-tensioned to 2.28 kN and the first three modes were expected to dominate the bare cylinder response behavior [2]. The carriage towing speed provided the simulation of uniform current velocities ranging from .18 m/s to .43 m/s. The ribbon fairings were made of a soft compliant vinyl that wrapped around the cylinder and had a fringe length of 3.3 D and a slit-to-slit width of .67D.

III. Analysis of the Experimental Data

A. *Spectral Charactrization of the Energy Shifting*

A comparison of typical spectra for the cross-flow acceleration measurements at three uniform current velocities is presented in Fig. 3. Fig. 3a illustrates the response behavior for the bare cylinder, while Fig. 3b illustrates the mitigation of the spectral response with full coverage by ribbon fairing. Clearly the magnitude of the measured response was significantly reduced but in each case the influence of the ribbon fairing was slightly different. At .18m/s for the faired case the remaining energy is shifted to higher frequencies, 5-7.5 Hz, and is essentially dissipated by the ribbon fairings. The impact using ribbon fairings at the two higher velocities shows slightly different trends. For the speed of .30 m/s the first spectral peak remained at the same frequency but was significantly reduced, as was the second spectral peak. The third spectral peak although higher that the second was mitigated and some energy was shifted to the region 5-8 Hz. For the highest flow velocity of .43 m/s the first spectral peak appeared narrower and was similarly reduced. The second spectral, which was actually the much larger peak in the 4-6 Hz region was dramatically reduced to a single peak at a frequency of about 4.25 Hz. The lower dominant modes in bare cylinder cases at .30 m/s around 1 Hz and .43 m/s around 1.5 Hz both shifted to the left and became smaller when full ribbon fairings were installed. The small increase in mass probably reduced the shedding frequencies.

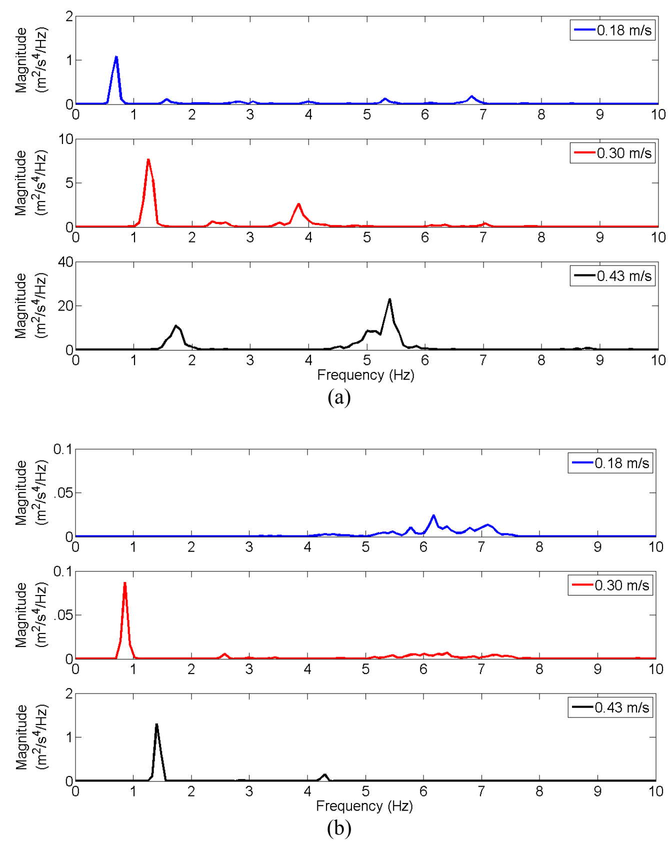

Fig. 3. Typical spectral behavior for (a) the bare cylinder and, (b) the complete cylinder coverage by ribbon fairing.

B. *Wave and Current Excitation*

The methodology presented in Fig. 1 is illustrated for a model test case where the cylinder was completely covered by ribbon fairing and the current speed was .38 m/s with the additional excitation of a regular wave with a height of .24 m and a period of 3 s. For the test cylinder without any fairings, the first six natural frequencies were estimated to be .55, 1.10, 1.65, 2.19, 2.74 and 3.29 Hz respectively. Thus, for these experiments any frequency information recovered above 3.29 Hz needs to be interpreted with caution. The time domain decomposition procedure yields modal information that includes the mode shape and the modal contribution factor as shown in Fig. 4. The internal blue dots correspond to the sensor locations. Similar information is recovered for each of the modes indicated in the measured data. Recall that this case is for the combined loading of a regular wave and constant towing speed, so some distortion of the mode shapes will occur.

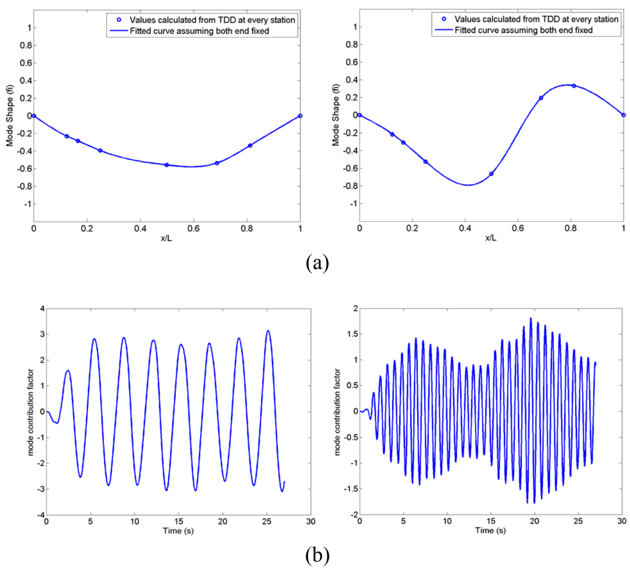

Fig. 4. The first two (a) mode shapes and corresponding (b) modal contribution factors for a current velocity of .38 m/s.

The reconstruction of the displacement time series, i.e. a comparison with the displacements directly integrated from measured accelerations is presented in Fig. 5, 6 and 7 for three different locations along the test cylinder. The displacements were reconstructed using information from the modal contribution factor from the first four modes excited at 0.31 Hz, 1.2 Hz, 1.5 Hz and 1.8 Hz.

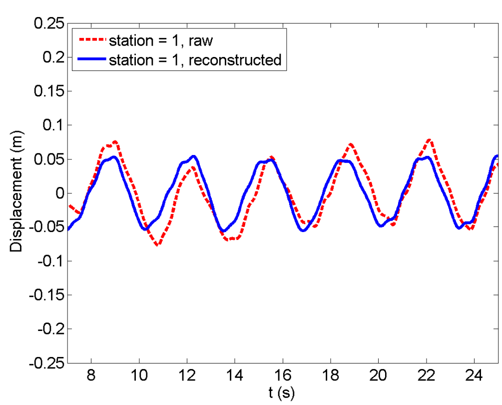

Fig. 5 Reconstruction of the displacement at position #1.

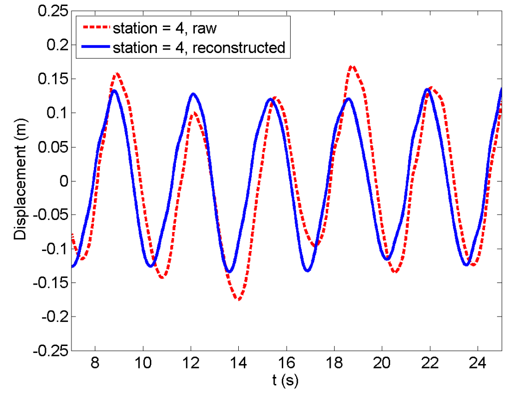

Fig. 6 Reconstruction of the displacement at position #4.

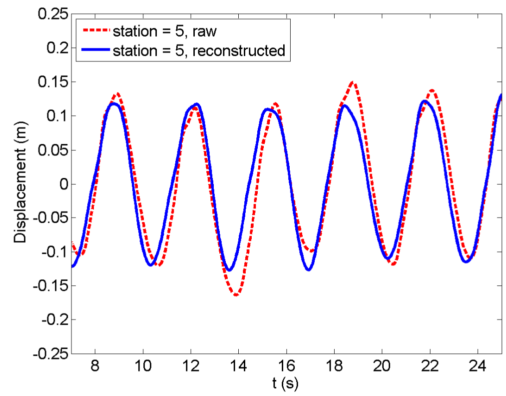

Fig. 7 Reconstruction of the displacement at position #5.

These displacements are generally well behaved, which in part may be attributed to the low noise ratio of the actual signals excited by waves and current. Further, the need for accurate higher mode information reflects the additional sensors would be required in the experiment in order to accurately assess their contributions.

C. Partial Coverage Response Behavior

One of the interesting questions that arise in practice is what happens when the fairing coverage, in this case ribbon fairing, is only a partial amount of the total length. In the original study [2] this was explored and some of the partial data is presented in Fig. 8. Here again the interior solid dots represent the information sensor locations along the test cylinder and correspond to Fig. 2. The fairings were removed in 20% increments from the right-hand side Fig. 8. Thus, the asymmetry of the dimensionless envelopes grows there and eventually overcomes the remaining cylinder coverage. A comparison or ribbon type fairing with airfoil fairing is quite interesting and probably intuitive for the case of wave and currents acting on a horizontal cylinder [5]. Basically, ribbon fairing are completely compliant and the response behavior revert to that of a bare cylinder and for these current speeds the response is dominated by the orbital motion of the fluid beneath the waves. In contrast, the airfoil fairings have a rigid form and can rotate about the cylinder, and were found to accentuate the cylinder motion as the airfoils basically fly in the water column.

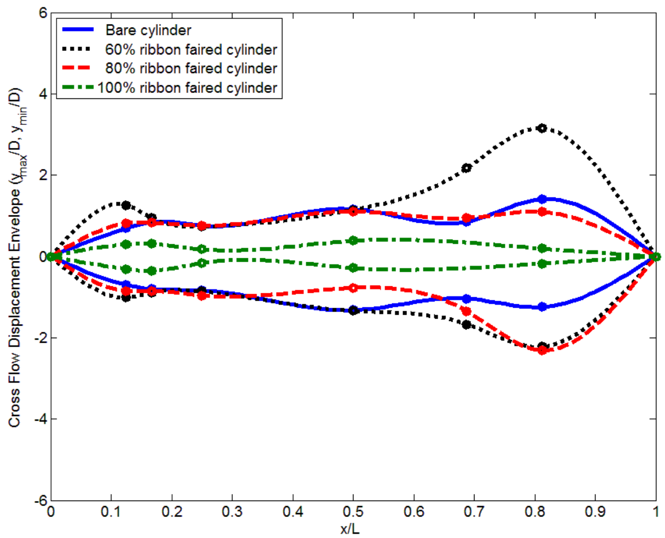

Fig. 8 Cylinder motion response envelopes reflecting partial coverage of the ribbon fairing.

IV. Closing Remarks

A different approach to the analysis of flow-induced vibrations was discussed which requires a mixed time and frequency domain procedure. It relies strictly on the analysis and interpretation of laboratory or field data. The test matrix from which the data used in this study were selected for a much larger series of experiments that included a variety of current, regular and random wave combinations. The focus of this study was to provide an example of the methodology and to explore the ability to reconstruct the original time series response behavior.

Several interesting observations can be made. First, the spectral analyses provided an example of the mitigation of spectral energy by fairing in a uniform current and the variations due to current speed. Secondly, the reconstruction of the time series response behavior is closely dependent on the sensor strategies used in the experiments and their ability to address the range of anticipated frequencies. The reduction of effectiveness of the partial coverage was introduced to give a glimpse of the effects on the response envelopes. Most recently the emphasis of our studies has focused upon modal assessment criterion, factors leading to the distortion of mode shapes, the assessment of structural strength and multi-objective optimization to guide the placement of sensors.

Acknowledgment

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