Prediction of the Flow-Induced Vibration Response of Cylinders in Unsteady Flow

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LONG-TERM GOALS

The primary long-term goal of this research is to understand, predict and devise means to suppress the structural dynamic response of long flexible cylinders excited by vortex shedding in wind or ocean currents.

OBJECTIVES

This general goal translates into a several specific objectives, which are to:

- Understand and predict vortex-induced vibration (VIV) in sheared or unsteady flows.
- Understand the effect of multiple frequency vibration components on VIV.
- Understand and predict high mode number VIV in sheared flows.
- Calibrate VIV response prediction models at super-critical Reynold's numbers.
- Develop or improve VIV response suppression devices such as dampers, fairings, and strakes.
- Develop structural dynamic modeling tools for predicting VIV response of cylinders with complex cylinder geometries, such as catenary shapes and irregular diameters.

APPROACH

Our approach is to steadily improve VIV response prediction capabilities by analyzing a sequence of model test and full-scale field experiment data. VIV is a very complex phenomenon, which has required that experiments be designed which separate the naturally complex behavior into a set of simpler phenomena that can be measured, analyzed and understood. Once the simpler phenomena are understood, we then devise analytical and numerical models, which are capable of predicting VIV response under more complex circumstances. The research loop is then completed by returning to field experiments to calibrate the new more complex response prediction tools. In this way, the research has progressed from investigations of straight constant tension cylinders in uniform flow at low Reynolds number to the current investigations of curved cylinders in sheared or unsteady flow at supercritical Reynolds number.

The ONR funding is used to leverage additional funding from an industry consortium project, which operates in parallel to this one. Its primary objectives are the development of computer programs for response and fatigue life prediction of marine drilling and production risers. The participating companies also provide opportunities for conducting laboratory and full scale experiments, which would otherwise be far to costly to perform. ONR sponsorship allows the Principal Investigator to add

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long-term basic research objectives to the often short-term pragmatic interests of the industry sponsors. The result is a synergistic mix of short and long term research goals.

WORK COMPLETED

The year ending in October 1997 emphasized a number of collaborative experiments with university and industry partners. These experiments yielded large data sets, which have been the primary focus of the 1998-year effort. The experiments included three model tests in towing tanks and one full-scale instrumented drilling riser in the North Sea. The data from these tests has been partially analyzed in a collaborative effort with research staff at other universities and in industry. The problems being addressed include the effect of multiple frequency vibration components on VIV response, an evaluation of the response reduction effectiveness of partial coverage of risers with fairings or buoyancy modules, and the response of risers to vortex shedding at supercritical Reynolds number.

New wave-based finite element modelling tools have been developed to analyze risers with large curvature and large variations in mass and tension per unit length.

RESULTS

1. In a collaboration with Prof. Carl Martin Larsen at the Norwegian Institute of Science and Technology in Trondheim, an experiment was conducted in 1997 investigating the effect of multiple frequency motion components on the VIV response of a spring-mounted cylinder[1]. The results from these experiments have been described in a recent doctoral thesis by Kyrre Vikestad[2]. An analysis of the influence of multiple frequency motion on added mass coefficients will be presented in December 1998[3] and further analysis of the data is continuing. These results will help us to better understand the multi-moded dynamic response of long cylinders in sheared flow.

2. The effectiveness of partial fairing coverage was measured in an experiment conducted at the Offshore Technology Research Center in College Station Texas in collaboration with Prof. John Niedzwecki. The results are described in a masters thesis by Scott Chitwood[4] and also briefly described in a paper presented at the 1998 Offshore Technology Conference[5]. Measurements of the effect of partial fairing coverage on a 1.5 inch diameter, 98 foot long cylinder were presented. The test cylinder was an approximately neutrally buoyant composite fiber tube under tension. Six bi-axial accelerometers measured the response at several locations.

The fairings were of very simple construction. Rectangular, 12 inch by 15 inch, pieces of ABS plastic, 1/16th inches thick, were heat softened with an hot air gun and then draped around a cylindrical mandrel forming an airfoil shape. Each section was twelve inches in span and had a chord length of approximately 6.5 inches. The maximum thickness of the airfoil shape was approximately 1.7 inches, slightly greater than the diameter of the test cylinder. The fairings were free to rotate with the flow. At very slow speed the fairings oriented with the flow. As expected the fairings completely suppressed VIV when covering the entire span, even when towed at various constant speeds, known to produce significant vibration on the bare cylinder. The fairings were progressively removed beginning at one end and moving toward the other. It was found that for 70% or greater coverage the fairings were effective at suppressing significant response everywhere on the cylinder. With progressively less coverage response steadily increased. At about 40% coverage response on the unfaired region of the model was comparable to that on the model with zero coverage. With partial coverage the response was much less in the faired portion of the riser due to heavy damping of transverse motion, caused by the fairings.

3. A full-scale riser instrumentation program in the North Sea: A drilling riser in 1300 m of water was instrumented with multiple accelerometer packages. The data from this industry-sponsored experiment have been the focus of an intensive effort by engineers in Norway, England and MIT. The most recent objective was to extract modal participation factors from the data for use in calibrating the VIV response prediction program SHEAR7(authored by Dr. Li Li and the PI several years ago and used by the industry to predict the fatigue life of marine risers). Preliminary results were presented at a very recent meeting of the Acoustical Society of America by post-doctoral research associate Caterina Stamoulis[6]. These results revealed that system identification methods, such as sub space iteration, are applicable to the estimation of complex mode shapes and natural frequencies, but that experimental constraints severely limit the utility of the results. Two experimental problems are known to exist: (1) too few sensor locations and (2) contamination of the transverse acceleration time histories with a gravitational component that arises from the tilt of the accelerometer packages.

4. Staggered buoyancy experiments: The PI planned, and supervised this experiment in February 1997. The experiment used the rotating arm facility at Marintek in Trondheim, Norway. The staff at Marintek designed and fabricated the rotating arm fixture and fabricated an instrumented 11.5m long riser model[7]. The model allowed individual attachment of up to twenty cylindrical buoyancy elements, each 0.5m long and .05m in diameter. The bare riser model was 0.02m in diameter. The model was towed from two rotating arms 4.6m in maximum radius. When vertical, the model experienced uniform flow up to 2 m/s. When inclined, a shear flow resulted. Many combinations of flow profiles and buoyancy coverage were tested. The results were published at the 1998 Offshore Technology Conference[8]. Partial buoyancy coverage was shown to lead to lower response than a riser completely covered with buoyancy modules.

5. Wave-based finite element modeling techniques have been applied to the response modelling of highly curved, lazy-wave risers. These oil production and export risers have large variations in mass and tension along their length and have unknown wave propagation properties. It is important to be able to evaluate the propagation and reflection of flexural waves, as they travel from where they are generated in the high current regions near the surface to the touch down point on the ocean floor. This work is in its initial stages as part of a doctoral dissertation.

IMPACT/APPLICATIONS

The results of this project will be useful to the designers of oceanographic moorings, ROV tethers and drilling and production risers. For example, VIV response has dramatic effect on the mean drag coefficient of mooring cables and ROV tethers. The design of an oceanographic surface mooring for a high current environment, such as the Gulf Stream, is critically dependent on the expected drag force on the system.

Vortex-induced vibration of oil exploration and production risers is often the primary limiting factor in the determination of the fatigue life of the riser. Present state of the art fatigue life prediction models are overly conservative because they are not yet calibrated for many important effects, such as the impact of multiple frequency components on VIV and response at supercritical Reynolds number.

Present prediction tools are not proven for analyzing cases with large numbers of participating modes, or large curvature.

TRANSITIONS

The data from the model test and full-scale measurement programs are being used to calibrate the program SHEAR7, which is being used by approximately thirty-five companies and universities.

RELATED PROJECTS

1. 2H STRIDE Measurement Project. This is a consortium project run by the company 2H Offshore in the UK. The PI is an advisor to this large scale VIV experiment.

2. The Highly Compliant Riser Project. This is a consortium project being run by PMB in Houston. It is a model test of steel catenary risers subjected to periodic surface displacements such as would result from vessel motion. The PI is an advisor and has made preliminary predictions of the expected VIV response due to periodic top end motion.

3. The Norwegian Deepwater Project. This is a consortium project emphasizing full-scale measurements on drilling risers in the North Sea. The PI is an advisor to this project and is analyzing data from the experiments as described above.

4. VIV Experiments at the Offshore Technology Research Center in College Station Texas in collaboration with Prof. John Niedzwecki.

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