MARINE TECHNOLOGY DIVISION
NAVAL RESEARCH LABORATORY
WASHINGTON, DC 20375

FISCAL YEAR 1984 PROGRESS REPORT:

HYDRODYNAMIC DRAG ON AND VIBRATION OF MARINE RISERS AND CABLES

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INTRODUCTION

The Marine Technology Division of the Naval Research Laboratory (NRL) is conducting for the Technology Assessment and Research Branch of the Minerals Management Service (MMS) a research program to study the effects of the hydrodynamic drag on and the vibrations of marine risers and cables. This program was initiated at NRL at the beginning of Fiscal Year 1984. The research is conducted with funds provided by the comprehensive Technology Assessment and Research Program for Offshore Minerals Operations of the MMS.

This NRL research program consists of three speparate, but related, tasks:

A. Dynamic Response of Risers and Cables.

B. Vortex-Induced Hydrodynamic Drag on Marine Structures.

C. Dynamics of Slack Marine Cables.

The first task is a contract research program being conducted by the Ocean Engineering Department at the Massachusetts Institute of Technology (MIT). Administrative, legal, and technical contract support is provided by NRL. The second and third tasks are being conducted at NRL during FY 1984. The total funding for Task A is $75K, ($10K NRL, $65K MIT, NRL Project 58-2020-0-3) and the total funding for Tasks B and C is $100K (NRL Project 58-2020-A-3).

PROGRESS

The progress achieved through 15 May 1984 on this research program is summarized in this section of the report.

A. Dynamic Response of Risers and Cables.

A proposal entitled "Prediction of the Dynamic Response of Risers and Cables" was submitted to NRL on 20 September 1983 for research to be conducted under the supervision of Professor J. Kim Vandiver of MIT's Department of Ocean Engineering. This proposal was submitted for the period 1 November 1983 through 31 October 1984 at a total estimated cost of $65K.

The proposal was judged to be acceptable and a sole source contract for $65K was negotiated with MIT. The negotiations were completed on 28 December 1983. The Contracting Officer's Technical Representative on NRL Contract N0014-84-C-2043 is Dr. Owen M. Griffin, who is also the Principal Investigator for this project at NRL funded by the MMS. The statement of work for the MIT contract research program (revised 1 May 1984) is included here as Appendix A.

A progress report covering the period 1 November 1983 to 25 April 1984 was submitted to NRL on 1 May 1984 by Professor Vandiver of MIT. Two copies were submitted under separate cover on 11 May 1984 to the Technology Assessment and Research Branch of the MMS.

B. Vortex-Induced Hydrodynamic Drag on Marine Structures.

Problems that are caused by vortex shedding and the vortex-induced oscillations of marine structures often have been ignored in the past. This is largely because a reliable experimental data base and design methods to cope with the problems have not been available. However, as marine construction has moved into deeper water and into harsher operating environments (the North Sea, offshore Brazil, offshore U.S. East Coast), the need to design slender, flexible structures and structural members against vortex shedding-related problems has increased in importance.

Many types of marine structures are susceptible to vortex-induced oscillations. These include the risers and conductor tubes that are employed in oil exploration and production, deep water pipelines, members of jacketed structures, and TLP tethers. Deep water pile installation and driving operations also are hampered sometimes by problems arising from vortex shedding. Several case studies have been documented in the open literature in recent years.

The recent underwater installation of 187m long foundation piles for a production platform in the Cognac field of the Gulf of Mexico was judged to present several potential problems due to vortex-excited oscillations. Currents of sufficient magnitude to cause resonant oscillations of the piles had been measured at the installation site. A program of laboratory tests was conducted to determine the vulnerability of model piles to resonant vortex excitation and effective suppression devices were developed. Under certain circumstances a fatigue life of four days was predicted for the bare piles.

Progress achieved to-date for this task can be summarized as follows:

1. The existing non-proprietary state-of-the-art for characterizing the hydrodynamic drag effects of vortex-induced vibrations (VIV) has been assessed. The extent of the reliable data base has increased considerably from the last thorough assessments (Griffin, NRL Memorandum Report 4157, March 1980; Griffin and Vandiver, NCEL Report CR84.004, November 1983). The most recent data has been provided by the Norwegian Hydrodynamics Laboratory/Norwegian Institute of Technology (Overvik, Ph.D. Thesis, NIT, 1982) and the British Hydromechanics Research Association, BHRA (Every, BHRA Draft Report, March 1983) for cylinders and risers, and by the U.K.'s maritime laboratory NMI Ltd. for umbilical cables for remotely-operated submersible vehicles (ROV's). The bulk of the data base from this latter program at this time is regarded as 'Commerical-in-Confidence' by the U.K. Department of Energy, but a summary of the results from the NMI Ltd. test program recently was published (Davies and Daniel, Offshore Technology Conference Paper OTC 4832, May 1984). It is hoped that all of these data will be released to the public domain at an early date.

2. A comparison of the data from all of these sources is underway and should be completed by mid-summer. The data will be employed in a re-evaluation and up-grading of an existing design

methodology for predicting hydrodynamic drag effects due to the vortex-induced vibrations of marine cables and structures (Skop, Griffin and Ramberg, Offshore Technology Conference Paper OTC 2884, 1977; Every, King and Griffin, ASME Journal of Energy Resources Technology, Vol. 104, 330-336, 1982).

3. The preliminary findings from this aspect of the overall program are scheduled for presentation at the Ocean Structural Dynamics Symposium '84 which will be held at Oregon State University in September 1984. A final report which includes an interpretation of the final data base and also guidelines for its use will be submitted to the Technology Assessment and Research Branch of the MMS in early FY 1985.

C. Dynamics of Slack Marine Cables.

Cables are employed in a wide variety of marine and offshore operations. Common examples include moorings, power supply, salvage operations, and umbilicals for remotely operated submersible vehicles (ROV's). Most of the computer models developed to date assume that the tension in the cable elements is above a threshold level such that the vibrational behavior of the cable is essentially that of a taut string. For many applications this is an appropriate assumption, but for deep water applications in which catenary effects are important, and umbilical applications where the cable tension may be required to be small, as a significant amount of cable slack may be realized. Examples of slack cable applications include deep water moorings, horizontal cable segments between vertical legs of a cable array, the downstream vertical leg of a multiple-leg cable array, and guy lines of deep water guyed towers and semi-submersible platforms. Design analysis of cable structures such as these using conventional taut cable techniques can lead to incorrect conclusions and to inappropriate selection of the required cables.

A common method of analysis involves the modeling of the cable as a taut string. It is assumed that the deflections of the string are small and, hence, no variation from the static tension is realized; that the string is perfectly flexible (no flexural stiffness); and that the slope of the deflected cable is always small. When the tension in the cable is large it is apparent that these assumptions are reasonably well satisfied. However, when there is appreciable slack in the cable deflections, dynamic variations in tension, flexural stress relative to the tensile stress, and the slope of the deflected cable are no longer small.

The slack cable problem has been analyzed by a number of investigators using time-domain finite element solution techniques and, for marginally slack cables, extended linear analysis numerical models. Simple analytical approaches also have been developed. These solutions have indicated a significantly different modal behavior of slack cables relative to the taut cable solutions. However, to date none of the existing slack cable solutions have validated. Consequently, verification of the accuracy of the slack cable solutions and the predicted anomalous behaviors is an objective of this task.

Progress achieved to date on this task can be summarized as follows:

1. An assessment has been made of the present state-of-the-art (SOTA) for modeling slack marine cable dynamics. The available literature has been identified and surveyed through 1984. Several inconsistencies in the dynamic analysis of slack cables also have been identified. These are discussed in more detail below. Several computational modelling approaches are available but as yet they have not been compared with one another. These include two NRL-developed codes and one MIT-developed code. One of the NRL codes is capable of computing the

dynamics of inclined and horizontal cables with and without arrays of attached masses. The other two codes are capable of computing only the dynamics of bare cables.

The experimental data base for the dynamics is relatively sparse. The single extensive set of in-air experiments was conducted at NRL (Ramberg and Griffin, ASCE Journal of the Structural Division, Vol. 103, 2079-2092, 1977; Ramberg and Bartholomew, ASCE Journal of the Structural Division, Vol. 108, 1662-1664, 1982). No in-water experiments to study the dynamics of slack marine cables have been identified.

2. The dynamics of horizontal slack cables are characterized by a complex "frequency crossover" behavior associated with the effects of elasticity on slack cables with small sag-to-span ratios (Irvine and Caughey, Proc. Royal Society of London, Vol. A341, 299-315, 1974). At this crossover three modes of the cable have the same natural frequency and include a symmetric in-plane mode, an anti-symmetric in-plane mode, and an out-of-plane or say mode. The symmetric modes contain an even number of nodes along the cable while the anti-symmetric modes contain an odd number of nodes. It had been assumed until recently that this same cross-over behavior was characteristic of the dynamics of inclined slack cables (Henghold, Russell and Morgan, ASCE Journal of the Structural Division, Vol. 103, 1127-1136, 1977; Irvine, ASCE Journal of the Structural Division, Vol. 104, 343-347, 1978). However, Triantafyllou (Offshore Technology Conference Paper OTC 4498, 1983; Quarterly Journal of Mechanics and Applied Math., Vol. 37, to appear, 1984) has proposed a different sort of behavior for the case of slack cables. Instead of a frequency cross-over, a complex transition involving so-called hybrid modes occurs. The hybrid modes are combinations of the anti-symmetric and symmetric modes. The hybrid mode that originates from a symmetric mode becomes anti-symmetric and vice versa.

In order to clear up this misunderstanding a study has been made at NRL using an independent method of computation (Rosenthal, Journal of Sound and Vibration, Vol. 78, 573-583, 1981). Computations were made of the inclined slack cable modes and frequencies at five angles of inclination of the cable (chord line) from the horizontal: 0° (horizontal), 5°, 15°, 30° and 60°. These computations clearly show that there is no frequency crossover for the inclined slack cable, but rather that the hybrid modal transition proposed by Triantafyllou is indeed the correct one.

A final report covering this portion of the project will be submitted to the Technology Assessment and Research Branch of the MMS in early FY 1985. Included will be an assessment of the effects of attached masses on the slack cable dynamics, the status and relative merits of available computer codes, and recommendations for modifications/improvements and alternate approaches which may be identified.

APPENDIX A

Contract #N00014-84-C-2043 ATTACHMENT #1

Statement of Work

For

Prediction of Dynamic Response of Risers and Cables

1. INTRODUCTION/SCOPE. Flow induced vibration poses a threat to most deep ocean systems. The legs on tension leg platforms, drilling and production risers, and mooring lines of all kinds are subject to vibration caused by the shedding of vortices in the presence of a current. To estimate fatigue life and mean drag coefficients the designer is confronted by the underlying problem of the predictions of vibration response amplitudes. At the present time such predictions can be reliably made only for the case of a uniform cylinder exposed to a uniform flow under lockin conditions. In actual field conditions non-lockin vibration is often observed due to the simultaneous excitation of several natural modes. This less well understood non-lockin response can actually present greater hazards to the safety of the structure, because occasional peak motions exceed those experienced under lockin conditions. The purpose of this work is to develop models for the prediction of non-lockin response to flow-induced vibrations on long flexible ocean-deployed cylinders.

2. TASKS. MIT shall perform the following research tasks.

2.1 Develop a lift coefficient prediction model, using the wake oscillator concept. This concept has been used to estimate the lift coefficient from cylinder response for the lockin case. Wake oscillator model equations can be utilized if it is assumed that the cylinder response is a Gaussian random process under non-lockin conditions. Evaluation of previous experimental data confirms this assumption.

2.2 Investigate the non-linear correlation between in-line and cross flow vibration. Use bi-spectral analysis techniques to investigate the properties of a quadratic relationship between lift and drag excitation. Develop a non-lockin random process model of the lift and drag excitation on long cylinders which includes quadratic properties revealed during the course of the research.