Fluid-Induced Nonlinear Dynamic Tensioning of Cables

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LONG-TERM GOAL

The long-term goal of this research is to identify the dominant mechanisms that control the dynamic tension in submerged cables. This goal addresses the need to suppress or alleviate the dynamic component of cable tension that may adversely affect the performance of underwater cables and any mission they are used to support. For instance, large dynamic tension forces may degrade the positioning and performance of instruments attached to cable suspensions, may adversely affect the station-keeping of ocean structures and vessels, and may promote cable fatigue, fretting and wear.

OBJECTIVES

This research will provide a fundamental understanding of the dynamic tensioning mechanisms that exist in cables that are suspended in a surrounding fluid. This understanding will follow from two research thrusts that focus on two broad classes of cable/fluid interaction. Thrust I concerns cables immersed in a quiescent fluid (no mean flow) in which the fluid interaction is dominated by inertial and dissipative forces. Thrust II concerns the resonant, vortex-induced vibration of cables subjected to a cross flow.

APPROACH

For the case of a cable in a quiescent fluid (Thrust 1), the fluid loading is modeled using a Morrison relation. In this case, cable excitation is prescribed and representative of external sources including, for example, wave motion or the motion of attached instruments, buoys or vessels. Tension dynamics is then investigated on two frequency/length scales. The first scale concerns relatively low frequency/long wavelength dynamics describable by standing waves. Here, low-order nonlinear dynamical system models are utilized to examine classes of resonant tensioning mechanisms. Asymptotic methods are employed to evaluate resonant solutions. These closed-form solutions are then used to examine the influence of controlling parameters and, for particular parameters, these analytical solutions are validated by comparison with companion numerical solutions. This research was conducted by the principal investigator and by Dr. B. Newberry who completed his doctoral degree in 1997. The second scale concerns relatively high frequency, short wavelength dynamics describable by propagating waves. This description is particularly well suited for evaluating the dynamics of long suspensions (little influence from boundaries), or suspensions subjected to rapid transient excitation. Numerical methods are employed to evaluate the characteristics of nonlinear wave propagation along

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underwater cable suspensions. This research was conducted by the principal investigator and by Dr. M. Behbahani-Nejad who completed his doctoral degree on 1997.

The findings of Thrust 1 identify fundamental mechanisms that control the dynamic tensioning of cables in a quiescent fluid medium. The findings are restricted to regimes where the cable/fluid interaction is decidedly one-way. Full two-way coupling, however, is essential to the description of vortex-induced vibrations of underwater cables, the focus of Thrust 2. This second thrust begins with marrying realistic (curved, geometrically nonlinear) models of cables with phenomenological models for vortex shedding (e.g., wake-oscillator models). Low-order nonlinear dynamical system models are presently being used to evaluate resonant responses during lock-in. Recent analytical and numerical results have identified significant effects due to cable geometric nonlinearities. This study is being conducted by the principle investigator and by current doctoral candidate, Mr. W. J. Kim.

WORK COMPLETED

The analytical and numerical tasks for Thrust 1 (cables in a quiescent fluid) have been completed and present attention is focused on Thrust 2 (cables in cross flow) as described below.

RESULTS

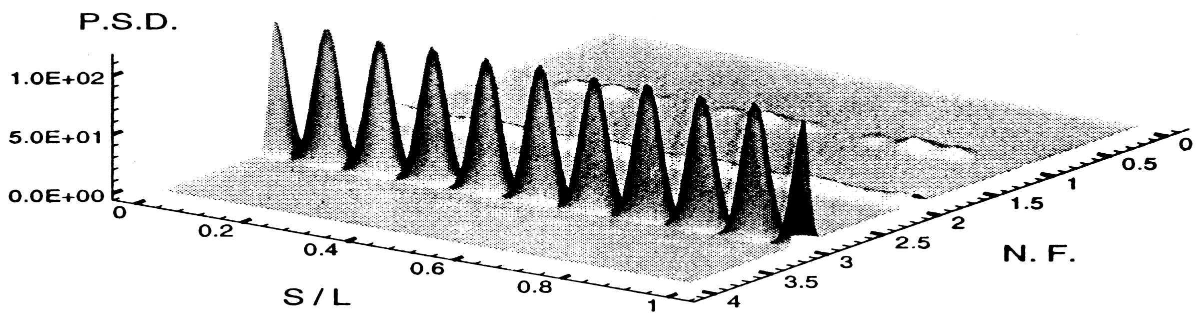

Figure 1. Tension resonance created by a 1:3 internal resonance. Power spectrum of dynamic tension shown as a function of position (S/L) and excitation frequency (N.F.). Note that maximum tension occurs at three times the excitation frequency (N.F.=3).

Accomplishments resulting from Thrust 1 (cables in a quiescent fluid) include the identification of fluid-drag as a major mechanism that couples transverse and longitudinal cable motions. This coupling strongly influences dynamic cable tension since the transverse motion, which is most readily excited, can energize the longitudinal motion of the cable, which controls the dynamic cable tension. The studies (Newberry and Perkins, 1996 and 1997a) lay forth one example of how this coupling can drive dynamic cable tension through a one-to-three internal resonance between a transverse cable mode and a longitudinal cable mode; refer to Figure 1. In this resonance, a transverse cable mode that is directly excited by an external excitation field resonantly drives a second cable mode (having three times the natural frequency of the transverse mode) that is dominated by longitudinal (stretching) cable motion. These findings were extended to describe a second resonance mechanism that couples transverse and longitudinal cable modes through a one-to-one internal resonance (Newberry and Perkins, 1997b). In this resonance, the coupling derives from linear drag force components that channel energy from the directly driven transverse mode to the lightly damped longitudinal mode. Similar findings have resulting from our studies of propagating waves along fluid-loaded cables. The relative importance of fluid and cable nonlinearities have been carefully evaluated in focused studies of out-of-plane (Behbahani-Nejad and Perkins, 1997a) and in-plane (Behbahani-Nejad and Perkins, 1997b) cable wave propagation. Recent results focusing on the resonant response of cables in cross-flows provide new insights regarding the role of geometric nonlinearities produced by a sagged cable. Prior analysis of vortex-induced cable vibration has utilized linear models for the cable element. Nevertheless, the cable element can be significantly influenced by the geometric nonlinearities responsible for stretching the cable centerline. For instance, Figure 2 illustrates a comparison of the response in the lock-in region using an established 'wake-oscillator model' (Skop and Balasubramanian, 1997) coupled to: 1) a linear cable theory, and 2) a nonlinear cable theory. Note that the nonlinear cable model generates *multiple* periodic motions (distinguishable as large or small amplitude responses) that qualitatively differ from the results obtained using a linearized cable model.

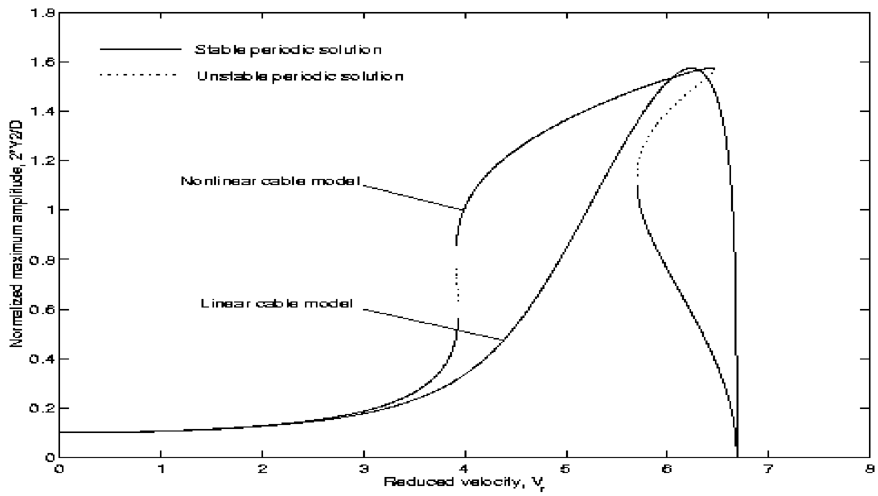

Figure 2. Predicted vibration amplitude during lock-in for a single in-plane cable mode. Amplitude of periodic response shown as a function of reduced fluid velocity. Analysis employing a nonlinear cable theory reveals the existence of multiple periodic motions in the lock-in region, which exhibit a hysteretic jump between low amplitude and high amplitude (stable) motions.

IMPACT/APPLICATION

The mechanical performance of underwater cables is often compromised when there exists excessive dynamic tension. This dynamic tension may accelerate cable fatigue, fretting and wear as well as degrade the performance and positioning of attached instruments or bodies. This research provides a fundamental understanding of how dynamic cable tension develops for cables immersed in quiescent fluids (Thrust 1) and for cables immersed in cross flows (Thrust 2).

TRANSITIONS

Our ongoing efforts in the modeling cable suspensions have resulted in new analysis capabilities for engineers at the Naval Facilities Engineering Service Center (NFESC). In particular, we have distilled our theoretical cable models to two computational codes for: 1) assessing the vibration modes of low tension cable/mass (hydrophone array) systems in 1993 (contact: S. Karnoski), and 2) predicting the reaction forces of vibrating cables as part of the prediction of cable abrasion and wear in 1994 (contact: C. Stevens). We have also discussed a possible extension of our work on cable/mass systems to model lightweight air-deployed cables being developed at the Naval Air Warfare Center (NAWC) (contact: D. Hammond). Prior research on the nonlinear mechanics of cables under torsion/thrust has generated renewed interest in understanding the occurrence of hockling in cables under low tension. Our prior results have recently been communicated to NFESC (contact: W. Bartel) to assist in the design of S-tether cables.

RELATED PROJECTS

This research effort furthers fundamental knowledge in all ocean engineering systems that employ cable elements as the means of transmitting forces or electrical or optical signals. Thus, this research supports developments in advanced moorings and buoys, remotely operated vehicle (ROV) systems, measurement and remote survey operations, oceanographic survey systems, cable communications systems, and the like. Other program efforts related to this research include: 1) numerical modeling of flow-induced vibrations of cables by G. Karniadakis (Brown Univ.), 2) analysis of flow-structure interaction for marine cables by M. Triantafyllou (MIT), and 3) the modeling of vortex-excited vibrations of cylindrical structures by R. Skop (Univ. Miami).

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