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Investigation of Resonant Tensioning in Submerged Cables Subjected to Lateral Excitation

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ABSTRACT

Cables are used in a variety of ocean engineering applications and are often selected for their inherent flexibility. As compliant elements, cables possess vastly different stiffness properties in the tangential and lateral directions. For submerged cables, this stiffness anisotropy is augmented by drag anisotropy; heavy lateral drag verses light tangential drag. These stiffness and drag properties come to bear on a resonant tensioning mechanism that is controlled by nonlinear fluid/cable interaction. Numerical simulations herein demonstrate the tension resonance to be the result of 3:1 internally resonant energy transfer between in-plane vibration modes. The tension resonance is further shown to scale with the square of the normal coordinate response. The source of the tensioning is identified through systematic inspection of the nonlinear fluid/cable model.

INTRODUCTION

Cables are used in many ocean engineering applications ranging from moorings, in which cable elements may be required to withstand large tensile loads, to umbilicals, in which cable elements may provide little if any structural support. Often, cables are selected for their inherent lateral flexibility, which facilitates deployment and provides structural compliance. As compliant elements, however, cables are susceptible to dynamic response, the analysis of which is of paramount importance in design. Cables possess vastly different directional stiffness characteristics, being extremely stiff in the tangential direction compared to any lateral direction. When submerged in a heavy fluid such as water, this stiffness anisotropy is augmented by damping anisotropy, the cable being heavily damped in any lateral direction and lightly damped in the tangential direction. These combined attributes make submerged cables rather unique structural elements, requiring special care in modeling and analysis.

Hydrodynamic drag represents the dominant nonlinearity for submerged cables and, as such, needs to be accurately modeled. This investigation summarizes a tension resonance mechanism that exists as a result of this fluid drag. Such dynamic tension magnification has been reported in both laboratory (Papazoglou et al., 1990; Welch and Tulin, 1993) and full-scale (Berteaux et al., 1993; Grosenbaugh, 1995) experiments on submerged cables under qualitatively different excitation regimes. Papazoglou et al. (1990) consider harmonic excitation delivered in the tangential direction by an external mechanical shaker. By contrast, Welch and Tulin (1993) generate conditions for locked-on strumming in a tow tank in which the cable is subjected to (dominantly) harmonic excitation in the lateral direction. Berteaux et al. (1993) and Grosenbaugh (1995) propose tangential excitation due to surface wave motion as the dominant excitation source for long vertical oceanographic mooring cables. Tangential excitation directly energizes longitudinal cable response, which, being relatively lightly damped, may induce resonant dynamic tensioning. The surrounding fluid may indeed preferentially arrest motion in the lateral (heavily damped) direction thereby focusing energy in the tangential (lightly damped) direction. This arresting of the lateral motion may result in increased dynamic tension even for excitation frequencies well below the elastic modes of the cable (Papazoglou et al., 1990). Nonlinear tensioning mechanisms exist, however, that do not require direct tangential excitation of the cable. For instance, lateral excitation energy may couple to tangential response, resulting in resonant dynamic tensioning.

The objective of the present investigation is to highlight one such mechanism. As a means to understand this resonant tensioning phenomenon, the cable herein is subjected to a prescribed harmonic excitation in the direction normal to the cable centerline. It will be shown that a resonant tensioning mechanism results from a nonlinear energy transfer between two in-plane cable modes, one dominantly tangential and the other dominantly normal, having natural frequencies in the ratio of three to one (3:1). Inspection of the numerical simulations further indicates the magnitude of the tension resonance scales with the drag coefficient value and the square of the normal response amplitude. The underlying physical mechanism governing the tension resonance is revealed by systematic inspection of the nonlinear fluid/cable model.

FLUID LOADED CABLE MODEL

Fig. 1 defines the system of interest that consists of a horizontally suspended, shallow-sag cable submerged in an otherwise quiescent fluid. The cable material is assumed to be homogeneous and to obey a linear stress-strain relation. A Lagrangian strain relation governing axial cable extension is adopted and cable flexural, torsional and shear rigidities are neglected. The response of the cable is measured relative to the equilibrium configuration using the Serret-Frenet basis (tangential-normal-binormal directions). A complete derivation of the three-dimensional equations of cable motion, sans fluid effects, can be found in the work of Perkins (1986).

The fluid/cable interaction can be decomposed into hydrostatic loading, hydrodynamic added inertia, and hydrodynamic drag. In this study, additional (static) cable strain from hydrostatic pressure is neglected. This assumption is made for simplicity — tak-

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