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Chaotic Heave Motion of Marine Cable-body Systems

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ABSTRACT

Marine cable-body systems deployed from surface support vessels are widely used in ocean mining. The present paper addresses their dynamic heave response under severe external excitation due to the heave motion of the surface support vessel. A single-degree-of-freedom model and a multi-degree-of-freedom model are presented. The former is to reveal the fundamental characteristics of the system under extreme excitation while the latter is for predicting the snap loading in the cable. The numerical examples illustrate that under such excitation the dynamic response of marine cable-body systems can lose its stability and become chaotic.

INTRODUCTION

Marine cable-body systems, deployed from and attached to surface support vessels, are widely used in ocean mining operations. In these, the dynamic response and the level of tensile loading under which the marine cable-body system is operated is of particular interest both to designers and operators from the point of view of safety, effectiveness and efficiency. To ensure system integrity, the cable tension needs to be limited, or a limiting condition must be imposed such as, for example, a maximum operational seastate. It is, therefore, of great practical importance to be able to predict with confidence the dynamic response and the maximum cable tension of marine cable-body systems and to provide guidelines for design and operational purposes.

If the marine cable-body is deployed in a weak current, or it is constrained by taut vertical guide lines, the whole system can be approximated as a one-dimensional problem and only the heave motion needs to be considered (Huang, 1992). An inherent feature of marine cables is that they cannot resist compressive loading. Due to the relative motion between the surface support vessel and the tethered body, an initially taut cable may start to operate in an alternating taut-slack condition under severe excitation, resulting in snap loading. In this case, depending upon the rate of transition from the slack to the taut state, the cable can experience severe snap loading with possible detrimental effects. The traditional approach of imposing limits on conditions under which a marine cable-body system can be operated is to define an allowable tension and avoid zero tension in the cable. The allowable tension is related to the break strength of the cable, whereas avoiding zero tension is directed at preventing the taut-slack condition and its associated snap loading. However, avoiding zero tension is not always attainable.

In contrast to the practical significance of predicting snap loading, only limited research effort has been expended to tackle this problem (Niedzwecki and Thampi, 1991; Huang and Vassalos, 1993; Hara and Yamakawa, 1994). Most research work is based upon the assumption that the cable remains taut, i.e., cable slack has not been addressed (Chung and Whitney, 1983; Niedzwecki and Thampi, 1988; Huang and Vassalos, 1992).

In this study, two numerical models have been devised for simulating the heave motion and the associated snap loading of a marine cable-body system operating in an alternating taut-slack condition under severe excitation. The first model focuses upon the application of non-linear dynamical systems theory to the present problem in order to reveal the fundamental difference between a taut system and a taut-slack system. The second model predicts the snap loading of the cable-body system operating in the alternating taut-slack condition. Numerical examples illustrate that the system response can lose its dynamic stability and become chaotic under severe excitation. These results are confirmed by the on-going experimental study carried out by the Cable Dynamics and Engineering Analysis Group at the Marine Technology Centre, of the University of Strathclyde.

MATHEMATICAL MODELLING

With reference to Figure 1, for the vertical heave motion a single-degree-of-freedom model is used for the cable-body system where the top end is under forced vertical sinusoidal excitation $a\sin(\omega_f t)$. By replacing the cable with a spring of bi-linear stiffness, and assuming linear fluid damping, we have

$$m\ddot{x} + c\dot{x} + kx = w + ka\sin(\omega_f t) \qquad (1)$$

where