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Numerical Simulations of Cable/seabed Interaction

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ABSTRACT

This paper contributes a method with which to model the interactions of low-tension cables with the seabed. The cable is modeled as an elastica, and it can support tension, torsion and 2-axis bending. It is subjected to hydrodynamic forces as well as self-weight, buoyancy and seabed contact. The seabed is modeled as an elastic foundation with linear damping and prescribed topology. A numerical algorithm is briefly described and then used to simulate cable laying. Several examples are studied, including a cable towed in deep water, dropped onto an uneven seabed, and finally towed across an uneven seabed.

INTRODUCTION

Predicting the shape of a cable subjected to hydrodynamic forces has remained a crucial issue in marine and ocean engineering applications. In some applications, cables are laid on the seabed by paying them out from a surface ship and allowing them to fall through the water column. It is important to lay the cables in known regions on the seabed to insure their proper function and survivability. In the particular case of telecommunication cables, knowledge of the cable slack and geometry is very important, because it allows operators to foresee and prevent the formation of tight loops and/or tangles. Loops and tangles are undesirable, because they can potentially kink the cable and block the transmission of signals. This research is directly motivated by the need to simulate the contact regions between the cable and the seabed, where loops and tangles are most likely to form.

The literature on cable dynamics recognizes 2 major classes of cable models. These are highly tensioned or taut cables, and low-tension cables for which the total tension (dynamic and static) is close to or less than zero. The governing equations for a taut, perfectly flexible, cable need not include the bending and torsional stiffness of the cable, and for the simplest towed cable examples, they can even be solved analytically (Karnoski, 1991). One of the earliest numerical studies was performed by Ablow and Schechter (1983), who provided a code for computing the 3-dimensional motion of a towed cable. They approximated the dynamic model, using a finite difference method in which they carried out the time integration through an implicit method. Their work was reviewed by Milinazzo et al. (1987), who presented a new technique for computing the steady-state solution and proposed a new spatial difference scheme for discretizing the equations of motion. In a perfectly flexible cable model, energy travels in the cable at a speed of propagation that is proportional to the square root of the tension (Rao, 1986). If the tension vanishes at a point along the cable, the energy no longer propagates. This singularity generates numerical instability, and most previous studies have avoided the problem by considering a point "very near to," but not including, the point where the tension is zero. To remove the singularity, it is necessary to introduce the cable's bending stiffness, at least in the vicinity of the point of zero (and possibly negative) tension (Triantafyllou and Triantafyllou, 1991; Triantafyllou and Howell, 1994). A model that includes bending stiffness requires greater computational load, but is also necessary in order to capture the physics of compression, as in the target applications studied here. Howell (1992) investigated 2 techniques for analyzing cables under zero or low tension. An explicit finite difference formulation of the equations for a perfectly flexible cable was possible if dissipation were added to stabilize the scheme. Incorporation of bending stiffness within an implicit formulation eliminated the zero-tension singularity encountered in other finite difference schemes. The results confirmed that bending stiffness has a significant impact on cable dynamics in the low-tension regions. At the same time, Burgess (1992) derived the equations of motion for the deployment of an underwater cable using a local reference frame. He presented a complete 1-dimensional elastic continuum model able to support tension, 2-axis bending and torsion. He formulated the equations in terms of curvatures and rotation rates. In a subsequent paper (1993), Burgess employed a centered-centered finite difference algorithm for numerical simulation. The results showed that, because the bending stiffness was small, sharp gradients in the shear forces and bending moments occurred at the boundaries. In their study of a system of serially connected cables, Sun, Leonard and Chiou (1994) and Sun (1996) presented a new algorithm, in which the time integration was performed by a stable, Newark-like implicit scheme, and the space integration was achieved using a direct integration method.

Several prior studies have focused on the interaction of a cable, pipeline or chain with the seabed. Jeng and Lin (2000) developed a model for a porous seabed with variable permeability and shear modulus. Webster (1995) uses a finite element procedure to model cable mooring systems. In particular, he uses an elastic foundation to model the cable/seabed contact. Gobat and Grosenbaugh (2001) use a similar approach (including linear damping) in modeling the fall of a hanging chain onto the bottom of a water tank.

This paper begins with a brief summary of an elastica model and numerical algorithm used to simulate cable dynamics. Several

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