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Nonlinear Response Analysis of a Towed Seafloor Plow

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ABSTRACT

Towing a plow along the seafloor is often the preferred method for burying cables, recovering seafloor minerals or measuring seafloor soil properties. This paper presents a nonlinear time-domain numerical model for simulating the global response of the seafloor plow as it traverses a seafloor with rapid changes in elevation. This model is useful for planning the course of the tow ship, determining changes in the length of the tow cable, and analyzing the efficiency of the plow operation. Even for highly erratic plowing maneuvers, the model exhibits a surprisingly high level of nonlinear solution robustness.

INTRODUCTION

A complete seafloor plow system consists of 3 distinct substructures: ship, cable and plow, as shown in Fig. 1. The plow has a blade that penetrates the seafloor and a sled that rides on the seafloor surface. The ship tows the plow in any azimuthal direction using a cable that is somewhat longer than the water depth. By adjusting the length of cable, the ship pulls the plow along a desired seafloor route, following changes in seafloor elevation.

Many physical parameters determine the efficiency of the overall cable plow operation. These time-varying parameters include the tow path, dynamic ship motion, hydrodynamic drag, plow design, seafloor bathymetry, soil type, and rate at which cable is paid out or reeled in. Optimal plowing performance means minimum plow weight, maximum plow depth, minimal spikes in cable tension, and maximum adhesion to the desired seafloor route.

Recognizing the obvious difference in physical behavior of the 3 local substructures, an ideal numerical simulation model for the complete seafloor plow system should include 3 coupled submodels, one each for the ship, cable and plow. Given cable resistance forces at the tow point, the ship submodel computes dynamic motions. Given dynamic soil resistance, the plow submodel computes plow forces and movement along the seafloor. The cable submodel transmits the forces from the ship to the plow and vice versa.

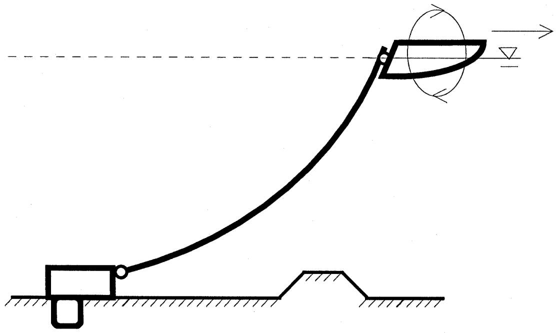

Fig. 1 Seafloor plow system

The collective solution of the 3 coupled submodels requires a time-domain solution due to extreme nonlinearities in each submodel. These nonlinearities include changes in seafloor slope, soil type, direction of the plow, direction of the ship and cable catenary shape. In addition, extreme nonlinear response results from stick/slip soil resistance, plow liftoff, plow landing, slackening cable, tensioning cable, quadratic viscous drag, cable pay-out and cable reel-in.

The limited size of this paper does not permit a detailed description of the fully coupled seafloor plow model nor allow demonstration of all its complex features. A complete description of the theory behind all 3 submodels and their collective nonlinear solution in the computer program called MBDSIM (Multi-Body Dynamics Simulation) is available (Zueck, 1996).

In this paper, we specifically focus on the development of a simple plow submodel and show the development path for the more complex plow submodel. Assuming a simple one-element plow submodel and assuming that the ship simply imposes motions at the top of the cable, we can create a simplified computer model, easily described in this short technical paper. This simplified model is adequate for predicting the general global response of the overall seafloor plow system, but not sufficient for designing the plow substructure itself.

NUMERICAL SIMULATION MODEL

For our simplified computer model of a seafloor plow system, we choose to discretize the cable submodel into several cable finite elements connected serially by nodes. We attach the simple plow element to the bottom node and move the top node according to the prescribed motion of the ship.

Simple Plow Element

The plow element has a blade that penetrates the seafloor and a sled that rides on the seafloor surface. If we assume that the plow blade always determines the azimuth direction of travel for the plow, we can develop a simple two-dimensional plow element that works in the three-dimensional seafloor plow system. We assume that this simple plow element remains flat on the bottom and oriented in the same azimuth direction as the last cable element. The simple plow element has one node, with only 2 (translational) degrees of freedom, as shown in Fig. 2. All forces act through the single node (I), which also connects the plow to the tow cable above it. By design, the plow's center of gravity is gen-

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Unit Conversion: 1m = 3.281 ft.

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KEY WORDS: Nonlinear, dynamic, analysis, cable, seafloor, plow.