International Journal of Offshore and Polar Engineering
Vol. 2, No. 4, December 1992 (ISSN 1053-5381)

Assessment of Dynamic Coupled Bending-Axial Effects for Two-Dimensional Deep-Ocean Pipes by the Discrete Element Method

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ABSTRACT

A new discrete element method (DEM) is developed for the coupled nonlinear analysis of deep ocean pipes and risers. The DEM pipe formulation is based upon a system of rigid elements connected with concentrated axial and bending stiffnesses, and is somewhat simpler than an implicit finite element approach. Although the DEM employs an explicit time integration scheme that is conditionally stable, it does not have the stability problems experienced in previous implicit finite element pipe procedures. The two-dimensional DEM model is used to perform nonlinear dynamic analyses of an 18,000-ft. (5,486 m) deep-ocean mining pipe. In these calculations the bending and axial deformations are coupled, and the top of the pipe is hinged at the ship, and its bottom is free. The numerical results of the DEM analyses are compared to solutions obtained previously by an implicit finite element method. The analyses further examine dynamic coupling, and show that bending-to-axial dynamic coupling is significant, while the axial-to-bending coupling effect is very small. The vertical damping of a buffer at the bottom end of the pipe is shown to influence the dynamic coupling effect. It is concluded that the bending-to-axial dynamic coupling can significantly alter the magnitude of the axial pipe oscillations.

INTRODUCTION

A typical deep-ocean mining system consists of a slowly continuous moving ship that maneuvers a deep-ocean pipe (Fig. 1). The development of this system, which has been identified by the industry as one of the most crucial, involves the analysis and control of the transient behavior of the pipe bottom end caused by the ship's oscillatory and maneuvering motion, and hydrodynamic loading due to ocean waves and current. The transient response of the pipe system consists of nonlinear large coupled bending-axial-torsional deformation of the pipe.

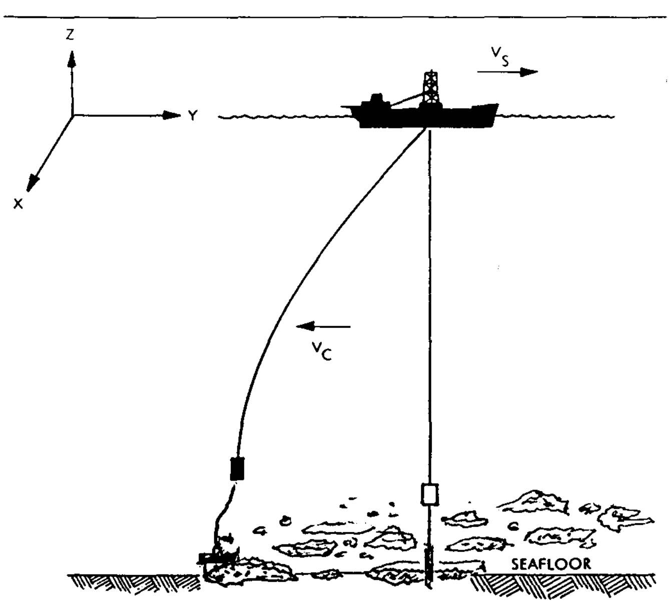

Fig. 1 Pipe system concept

The most crucial problem for a deep-ocean mining system, whose motion is coordinated with the continuous movement of a surface ship, is the design of a reliable pipe system. This task requires the development of an accurate method to predict the transient response of the pipe system and an extensive set of test data. The major technical development issues are: (i) design of a pipe system; (ii) transient performance of the ship and pipe and control of the continuously moving/tracking mining system; and (iii) uncertainties in monitoring or predicting physical environments such as water column flows and the associated hydrodynamic forces along the pipe. Previous numerical solutions to the coupled axial-bending deformation of a deep-ocean pipe by a state-of-the-art finite element model (FEM), with realistic hydrodynamic force models, have been obtained by Chung et al. (1980, 1981) and Felippa and Chung (1981). However, numerical instability and inaccuracies can occur when pipe velocities relative to the surrounding fluid particle velocity exceed certain critical values. It should also be noted that some simulations required excessive CPU time. Further work by Whitney et al. (1981) solved the uncoupled axial dynamics of an 18,000-ft. (5,486 m) pipe and demonstrated that oscillating axial stresses can be a very critical design parameter. Subsequently, research has focused on the uncoupled case involving axial oscillations of marine risers and long pipes (Aso et al., 1991). A three-dimensional pipe geometry has been dealt with by Huang (1991), for the case of a stationary position. Aso et al. (1991) solved axial vibrations by Galerkin's method for a free pipe bottom end condition. In the works performed by Aso and Huang, simple hydrodynamic forces were modeled.

In contrast to the substantial work focused on axial deformations of pipes and risers described above, somewhat less effort has been undertaken to provide a more robust analysis of the nonlinear dynamic deep-ocean pipe problem, which is crucial in the development of a deep-ocean mining system.

In this paper an alternative numerical analysis procedure based upon the discrete element method (DEM) is developed for the nonlinear coupled dynamic analysis of deep-ocean pipes and risers. For further DEM details, see Mustoe et al., 1989, which con-

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Received March 28, 1992: revised manuscript received by the editors August 27, 1992. The original version (prior to the final revised manuscript) was presented at the Second International Offshore and Polar Engineering Conference (ISOPE-92), San Francisco, USA, June 14-19, 1992.
KEY WORDS: Deep ocean, pipe, coupled bending-axial, discrete element method.