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Three Dimensional Analysis on Behaviour of Mining Pipe of Deep Seabed Mineral Resources

S. Hong
Korea Research Institute of Ship and Ocean Engineering
Taejon, Korea

Abstract

A dynamic simulation model of a vertical pipe has been developed for the purpose of investigating three-dimensional dynamic behaviour of a ocean mining pipe. Dynamics of vertical pipe string is modeled by the modified Kirchhoff's beam theory including large deflections and nonlinear viscous drag forces. A lumped-mass method is developed for numerical analysis of 3-D nonlinear pipe behaviour. 3-D nonlinear simulations of a vertical mining pipe are carried out in time-domain by using the Newmark-β method. Effect of underwater pump modules and buffer on the dynamics of pipe string is investigated.

KEY WORDS: vertical pipe string, Kirchhoff's beam theory, lumped-mass method, three-dimensional, nonlinear, Newmark-β method, pump modules, buffer

Introduction

For production of deep seabed mineral resources from 5000m mean water depth, e.g. manganese nodules, a vertical pipe string connecting the surface unit with the collector on the seabed is of great importance. A pipe string lifting up the mineral resources and simultaneously supporting various power lines and signal cables at the outside wall plays the role of the main artery of total mining system.

A 5000m pipe string must withstand the static load due to its own weight and the dynamic load caused by ship motions, waves and current. It is pointed out repeatedly in the literature, that the dynamic stresses due to axial oscillation is a critical parameter for design of ocean mining pipe or riser(Chung and Whitney 1981 and 1983, Sparks et al. 1982, Pakarinen 1988). Its first natural period, about 6 seconds, is in the high energy region of wave spectra, and therefore the resonance in axial vibration mode is a serious problem. A series of investigations for reduction of the axial vibration using vibration absorbers have been conducted by Aso et al.(1992, 1994 and 1995). Also by the authors the shape-efffects of buffer on the axial vibration of a long pipe string has been investigated(Aso et al. 1991a, 1991b and 1993). Cheng et al.(1995) have studied the effects of flexible joints on the three-dimensional behaviour including the effects on the reduction of axial vibrations.

In the mining operations the vertical pipe string shows a three-dimensional nonlinear coupled behaviour, which is caused by ship motion and flow-induced forces and torsional moments on the pipe(Chung and Whitney 1993, Chung et al. 1994). This 3-D nonlinear coupled behaviour of pipe string is dominantly responsible for the relative motions between ship and collector on the seafloor. A contact of pipe string with ship structure by an excessive relative motion can induce an extreme pipe bending stress and can be linked to the collapse of total mining system. For prevention of the stress induction beyond allowable limit and positioning of the collector in the wanted mining route, a reliable dynamic simulation model of vertical pipe string is essential.

Ishikawa et al.(1992) has simulated 3-D behaviour of a lifting pipe towing the collector on seafloor. Chung et al.(1994) has developed a new FEM for analysis on the 3-D nonlinear coupled responses of 4000-ft lifting pipe for production of cobalt-rich crust. Cheng et al.(1995) suggested possibilities to reduce the axial vibration and torsional oscillation of pipe string by equipping flexible joints.

In this paper a lumped-mass method is developed for analysis of 3-D nonlinear coupled behaviour of a long vertical pipe. Pipe string is idealized as a beam, and pump-modules and buffer are assumed as a rigid element. The dynamics of pipe string is modeled by modification of the classical Kirchhoff's beam theory(Love 1927). For evaluation of external forces the Morison's equations are used. An incremental-iterative solution scheme using Newmark-β method is employed in nonlinear simulation of pipe response in time-domain.

Lumped-mass model

The efficiency of lumped-mass method, especially in analysis of line structures such as mooring lines, cables and risers, is validated through various applications(Ractliffe 1984, van den Boom 1987 and Hong 1992 etc.) A pipe string is descretized in a finite number of straight elements so that the sectional properties remain constant in an element. The mass of each element is evenly lumped at two end nodes. The pump modules and buffer are idealized as a rigid element with infinite structural rigidities.

It is assumed that pipe deformation appears only at node points. Fig. 1 shows the adopted lumped-mass model of pipe string.

Mathematical model

Assumptions

The basic assumptions for dynamics modeling of pipe string are as follows:

- a pipe string is idealized as a beam element
- pipe material is homogeneous, isotropic and linear elastic
- plane cross-sections remain plane after bending
- shear deformation is neglected
- thermal effects are not considered