

Assessment of Options in Design of Deep-Ocean Mining Pipe Systems

J. S. Chung
Colorado School of Mines
Golden, Colorado, USA

ABSTRACT

Previously, a very long vertical pipe was modeled and used for the simulation of its dynamic behavior for lifting manganese nodules or crusts from 800 to 6,000-m deep seafloor. Recently, a pipe with elastic (flexible) joints was introduced (Cheng and Chung, 1995; Chung, Cheng and Zheng, 1995) with the merit of changing eigenfrequencies and changing 3-D response characteristics, including torsion. Also, it was shown that the mass or buffer at the bottom end of the pipe (Chung and Whitney, 1981) and the axial vibration absorbers along the pipe with no joints (Aso, 1992 and 1994) can also effectively reduce the axial stress near its resonance, through uncoupled axial pipe response analysis. In the present paper, deep-ocean mining pipe systems of 4,000 and 18,000 ft in length are reviewed, and the 3-D dynamic coupled behaviors of 4 pipe systems of 18,000 ft in length are compared through the 3-D nonlinear coupled analyses, using a nonlinear code, 3DNLPIPE, analyzing the effects of axial dampers along the pipe (Cheng and Chung, 1996), both with and without elastic joints, and the axial, as well as bending, stiffness of the elastic joints. It is found that the axial dampers on the pipe with the elastic joints, when the axial damping is large, give very favorable dynamic responses near the axial resonance. The axial damping does not make the biaxial and torsional vibrations reach steady state, as the elastic joints do, and furthermore greatly reduces the axial, as well as the bending, stresses. The axial dampers slightly decrease the pipe deflection, while the elastic joints increase it slightly. The ship motion excites the horizontal (x-) and vertical (z-) motions concurrently of the pipe in its initial static equilibrium configuration, which is deflected by the ocean current along the pipe and torsional moments. Wave components of 5-s period, which is the axial pipe resonance period, are very commonly encountered in the ocean.

Unit conversion: 1 m = 3.281 ft, 1 ft/s = 0.305 m/s.

KEY WORDS: Pipe, deep ocean mining, design, elastic joints, axial dampers, 3-dimensional coupled responses, torsional coupling.

INTRODUCTION

It is now a general consensus that many new researchers appear to prefer a self-propelled, seafloor miner (or collector) to operate at

4,000-6000-m depth, which is similar to those of Chung and Chung et al. (1980-1995). Further research of such a self-propelled miner is likely to change the pipe system concepts (e.g., a pipe for tow-sled), as well, to some kinds of free bottom end of the pipe (Fig. 1). Subsequently, it is expected from the field experience (Chung, Whitney and Loden, 1980) that the connecting systems of the lift (vertical flow) pipe to the miner will also change. For such mining systems (Chung and Tsurusaki, 1994), it is desirable for the designers and operators to explore ways to reduce the lateral deflection and axial motion and stress of a vertical pipe, while keeping minimal interruption in the vertical slurry transport or lift.

Among many possible pipe problems, the oscillating axial stresses have been found to be a very critical design parameter for designers and operators of such a deep-ocean pipe (Chung and Whitney, 1981). It was first investigated by Chung and Whitney (1981). Since 1981, the offshore industry has adopted it as a very critical design parameter. Recently, more significant findings have been revealed: For the first time, the importance of torsion and its coupling was demonstrated (Chung and Whitney, 1993; Chung, et al, 1994b): the flow-induced torsional moments and the associated pipe torsional moments caused by asymmetric arrangements of power cables and equipment around the long pipe, and lateral (or lift) force. The previous implicit time integration and a finite element modeling (FEM) (Chung and Felippa, 1981; Chung, Whitney and Loden, 1981), which were regarded as one of the most advanced in the major participating oil companies (Huang, 1991), encountered numerical instability, as the pipe velocity relative to the surrounding fluid particle velocity exceeds certain critical values. Moreover, details of this proprietary technology have not been made available to the public. This numerical instability problem was overcome by another FEM modeling of the above 3-D coupled dynamic problems on PC (Chung, Cheng and Huttelmaier, 1994), even when the specific effects of 3-D coupling, the flow-induced torsional moment, and updating of the fluid-structure interactions at each state are included. The numerical stability is very sensitive to the torsional coupling.

In order to evaluate pipe system concepts and their improvement, the present code, 3DNLPIPE, simulating nonlinear coupled axial-bending-torsional (x, y, z and θ_z) pipe behavior, is developed, validated and updated for both static and transient cases. The present code now