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Effects of Axial Dampers and Elastic Joints on the 3-D Dynamic Responses of a Deep-Ocean Pipe with Torsional Coupling

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ABSTRACT

The 3-D nonlinear pipe code, 3DNLPIPE, is updated with the modeling of axial vibration dampers and elastic joints installed on a very long vertical pipe. During ocean mining operations in the deep ocean, the vertical pipe undergoes a large deflection (Chung, Cheng and Zheng, 1995), with coupled bending (x- and y-), axial (z-) and torsional (θ_Z-) displacements. For this case, the present analysis of the 3-D nonlinear coupled responses shows that proper arrangements of the axial vibration dampers at proper positions along the pipe without the elastic (or flexible) joints can effectively reduce the axial stress. The axial dampers can slightly decrease the mean bending deflection, while the elastic joints slightly increase it. The elastic joints can be arranged along the pipe to be effective in reducing the axial stress as well as bending moments. Furthermore, the best combination of the multiple elastic joints and the axial dampers along the pipe can be achieved to reduce static, as well as mean dynamic, deflections, axial stress, bending moments and torsional deformation. The elastic joints can make the biaxial and torsional vibrations reach steady state, while the axial dampers do not. The 5-s axial resonance period of the present example of an 18,000-ft pipe is a very commonly encountered wave period in the ocean, and it can excite axial pipe vibration.

INTRODUCTION

Dynamic axial stress of very long vertical pipe is one of the primary concerns for designers and operators. It was first investigated by Chung and Whitney (1981), and the offshore industry has adopted it as a very critical design parameter. For the recent status of deep-ocean mining systems research, see the review by Chung (1996) and Chung and Tsurusaki (1994).

Static, as well as dynamic, interactions of the pipe bottom end with the miner maneuvering on the seafloor are one of the most crucial operational parameters. One of the initial concepts was to install elastic joints along the pipe, and a model of the elastic joints was successfully developed and updated in the 3DNLPIPE code. Previously, Cheng and Chung (1995) demonstrated that the elastic (flexible) joints installed along the pipe can be arranged to be effective in reducing the bending moment and stress, and the axial stress slightly, when a certain number of joints with proper stiffness is installed at proper positions along the pipe. They also showed that the elastic joints help make the coupled biaxial bending and torsional vibrations steady. Also, reduction in the axial stress near its axial resonance was previously achieved by Chung and Whitney (1981) with the axial damping of a buffer: equipment with a mass attached to the bottom end of a long vertical pipe. Several options in the pipe system were reviewed by Chung (1995). Recently, a method to reduce the dynamic axial stress of a long vertical pipe was investigated by Aso et al. (1991, 1992, 1994), applying axial vibration absorbers along the pipe. Their analysis is based on uncoupled axial motion in the frequency domain. The absorbers can effectively reduce the axial stress at the axial resonance.

During ocean mining control operations in the deep ocean (Brink and Chung, 1980 and 1982), the vertical pipe undergoes a large deflection, with the 3-D bending (x- and y-), axial (z-) and torsional (θ_z-) displacements being coupled. For such 3-D nonlinear coupled vibrations, axial vibration dampers along a long pipe will influence not only the axial vibration, but also the bending and torsional vibrations.

In this paper, the 3-D analysis is done, showing more comprehensive examples of the 1-, 2- and 3-D examples, including the torsional responses along the vertical pipe and effects of the elastic (or flexible) joints, and ring-shaped axial vibration dampers attached along a very long pipe with its bottom end free (Fig. 1). In order to test the effectiveness of the axial dampers, the damping of a buffer at the bottom end of the pipe is not included, but the buffer mass is included. The best combination of the multiple elastic joints and the axial dampers along the pipe is investigated, arranging the positions and sizes of the multiple elastic joints and the axial dampers to reduce mean dynamic deflection and the axial stress and bending moments. The theoretical backgrounds and computational modelings in the previous works should be referred to: 3-D nonlinear pipe modeling with torsion (Chung and Whitney, 1981; Chung, Cheng and Huttelmaier, 1994a and b); modeling of elastic joints (Cheng and Chung, 1995 and 1996; Chung and Cheng, 1995); and progress in modeling of both elastic joints and axial dampers (Chung, 1995). A model of hydrodynamic forces is referred to in Chung (1978), Chung et al. (1980), Chung and Felippa (1980) and Felippa and Chung (1980). A model of vortex-induced vibrations can be found in Whitney and Chung (1981). Also, the authors' previous works (1994-1996) are

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

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KEY WORDS: Axial dampers, elastic joints, three-dimensional responses, torsional coupling, deep-ocean mining, vertical pipe.