International Journal of Offshore and Polar Engineering
Vol. 6, No. 3, September 1996 (ISSN 1053-5381)

Effects of Elastic Joints on 3-D Nonlinear Responses of a Deep-Ocean Pipe: Modeling and Boundary Conditions

Jin S. Chung*
Department of Engineering, Colorado School of Mines, Golden, Colorado, USA

B.-R. Cheng†
Tsinghua University, Beijing, China

ABSTRACT

Pipe vibration is often excited in the deep ocean by ship motions, wave forces and vortex shedding. Elastic joints along the pipe are modeled in an attempt to move the resonance frequencies away from the pipe system. The numerical examples focus on the investigation of single and multiple elastic joints along a long pipe and their effect on three-dimensional (3-D) nonlinear coupled pipe responses, including torsional coupling. The multi-substructure technique is introduced in order to get the governing equation of the entire pipe system. The pipe is subjected to a vertically varying current flow in establishing the static equilibrium configuration. Dynamic responses are excited by large-amplitude horizontal as well as vertical ship or pipe-top motion. Ocean-mining pipes 4,000 ft and 18,000 ft in length are used to investigate the effects of the joint stiffness and position on the pipe responses. The bending stiffness can affect the bending moments along the pipe and the associated maximum values, but has little influence on the bending deflection. However, the axial stiffness of the joint can greatly change the axial fundamental frequency, as well as static axial displacement, while it has little effect on the static internal axial force. The appropriate position of joints can have a greater influence on the static responses. The dynamic responses to the external excitation of a pipe with multiple elastic joints can be greatly reduced. The results are presented for both free and pinned bottom-end conditions of the pipe.

INTRODUCTION

The importance of the axial stress of a long pipe for design was first pointed out by Chung and Whitney (1981, 1983) with uncoupled oscillatory axial motions of an 18,000-ft vertical pipe and later with 3-D coupled responses of 4,000-ft and 18,000-ft pipes (Chung, Cheng and Huttelmaier, 1994; Cheng, Chung and Huttelmaier, 1994). Among many possible problems, the oscillating axial stresses have been found to be a critical design parameter for such a deep-ocean pipe (Chung and Whitney, 1981). Changes in or control of the axial or bending resonance frequencies are often desired in design and ocean operations. One of the methods applied here is to change the fundamental axial frequency and the static equilibrium state of a pipe. A concept of elastic joints on a marine riser (Caldwell et al., 1976, and Ortloff et al., 1976) was previously tested for the purpose of reducing the bending stress. It was applied in actual design. However, the paper does not present substantiating technical data, and it can only be used as qualitative information.

In the previous paper (Chung and Cheng, 1995), the pipe eigenfrequencies are calculated with different arrangements of elastic joints along a vertical pipe in the ocean. This was investigated as a means to control or change the resonance frequencies of the axial and bending vibrations. Extending this work, actual responses of the pipe with joints to the hydrodynamic forces are presented in this paper, and favorable nonlinear 3-D coupled responses of a deep-ocean pipe can be obtained, using elastic joints on a long vertical pipe.

The two-substructure technique is successfully adopted to treat an eigenvalue problem of a pipe with examples of multiple elastic joints (Chung and Cheng, 1995). This technique is extended in this paper to multi-substructures and is used for solving static and dynamic nonlinear responses of a pipe with multiple joints. The vertically varying, unidirectional steady current flow influences the static equilibrium configuration of the pipe and its static stress state. In practice, the pipe vibration is often excited by horizontal as well as vertical ship or pipe-top motion and the vortex shedding. This is the first modeling and technical analysis about effects of elastic joints along a long pipe on 3-D nonlinear coupled static and dynamic responses. A previous paper (Chung, Cheng and Zheng, 1995) is updated with new examples of multiple joints and a case of pinned bottom-end condition of the pipe such as for a deep-ocean marine riser.

MODELING OF VERTICAL PIPE WITH MULTIPLE JOINTS

Let a pipe system be divided into N-segments with (N-1) elastic joints. Every segment is considered as a substructure. Every elastic joint is modeled by a special pin with springs in the direction of bending-rotation and axial displacements, as shown in Fig. 1. The stiffness of these springs may be determined by material properties of the joints. For the modeling, the assumptions are made as follows:

- Length of the joint is very short, as compared to the pipe element length, and can be neglected.
- Two adjacent pipe segments, connected by an elastic joint, have equal transverse displacements, as well as an equal twist

*ISOPE Member.

† A visiting research scholar at Colorado School of Mines. Golden, Colorado, USA.

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

Received September 15, 1995: revised manuscript received by the editors December 18, 1995. The manuscript was submitted directly to the Journal.

KEY WORDS: Nonlinear finite element, elastic joints, modeling, static and dynamic responses, vertical pipe, coupled axial, bending and torsional responses, pipe boundary conditions, deep-ocean mining.