International Journal of Offshore and Polar Engineering
Vol. 1, No. 2, June 1991 (ISSN 1053-5381)

The Shape-Effect of Buffer on the Longitudinal Vibration of a Pipe-String in the Deep Sea

K. Aso, K. Kan, H. Doki and M. Mori
Department of Mechanical Engineering, Mining College, Akita University, Akita, Japan

ABSTRACT

In order to analyze the longitudinal vibration of the pipe-string in the deep sea, first, the drag and added mass coefficients of various buffer-models vibrating axially in water were evaluated by the method developed by the authors. Then, the forced longitudinal vibration of the pipe-string equipped with a pump-module and a buffer was analyzed theoretically by introducing the fluid forces evaluated with the above-obtained coefficients. Furthermore, the axial stress induced in the pipe-string was calculated. The results indicate that the buffer whose shape causes a higher drag force is more useful for reducing the amplitude of the vibration and the axial stress in the pipe-string, and that the highest-drag buffer used in this study causes a half amplitude of the vibration and about 63% axial stress at the first resonance as compared with those produced by the lowest-drag model.

INTRODUCTION

For mining mineral resources from deep-sea bottoms, a pipe-string is needed to connect the mining ship on the sea surface with the collector or miner on the seafloor. Furthermore, in the pump-lift system of ore, the string must be equipped with pump-modules for pumping the mineral resources up to the ship, and with a buffer that regulates the slurry-density of the ore-fluid mixture in the pipe-string and plays the role of a weight to stabilize the mechanical behavior of the string. Hence, the longitudinal and lateral vibrations of the string, caused or initiated by the ship motions, must be analyzed for the design of the above mining system. In addition, to analyze these vibrations, the fluid forces acting on the pump-modules and buffer must be evaluated, and to calculate these forces by Morison's formula (Morison et al., 1950), the drag and added-mass coefficients of the pump-modules and buffer vibrating in water must be known in advance.

Up to the present, the behavior of the pipe-string with a buffer at its lower end has been studied by many researchers mainly in relation to the air-lift system of ore. However, only a few papers have been reported on the behavior of the pipe-string with a buffer and pump-modules in case of the pump-lift system. Chung and Felippa (1981a), Felippa and Chung (1981), Tikhonov et al. (1984) and Yuan et al. (1988) have done the static analysis on the lateral deflection of the string in the pump or air-lift system when it was towed horizontally. Chung et al. (1981b), Whitney et al. (1981), Aso et al. (1988a) and Yuan et al. (1989) have solved the lateral motion of the string.

Furthermore, Chung and Whitney (1981c, 1983), Sparks et al. (1982) and Aso and Kan (1987) have studied the longitudinal vibration of the pipe-string caused by the ship's heave-motion. The results of these studies indicate that longitudinal vibration is the prime factor as far as the strength of the pipe-string is concerned.

In this study, first, various buffer models — whose shapes were cylindrical, cylindro-conical and of another configuration designed to cause higher drag force — were selected. Second, the drag and added-mass coefficients of those models vibrating axially in water were evaluated by the method developed by the authors (Aso et al., 1988b, 1989). Then, the system for developing the cobalt-crust deposit at the 2500-m depth of water was assumed. Next, the forced longitudinal vibration of the pipe-string equipped with a pump-module and a buffer was analyzed theoretically by introducing the ship's heave-motion and the fluid forces evaluated with the above-obtained coefficients. Further, the axial stress induced in the pipe-string was calculated. Finally, the shape-effects of the buffer on the longitudinal vibration of the string and on the axial stress were studied.

Received August 17, 1990: revised manuscript received by the editors November 28, 1990.
KEY WORDS: Longitudinal vibration, pipe-string, shapes of buffers, drag and added mass coefficients, fluid forces, amplitude, axial stress.

ANALYSIS

The analytical model of this problem is shown in Fig. 1, in which the vertical pipe-string of length, L, equipped with a buffer (mass; $\overline{M}_2$) at its lower end (at $x=\ell_2$) and a pump-module (mass; $\overline{M}_1$) in between (at $x=\ell_1$), is suspended from the mining ship on the sea surface and connected to the miner on the sea floor through a flexible pipe. Here, it is assumed that the top of the pipe-string is forced to vibrate vertically in the harmonic function of $a \sin \omega t$ by the heaving motion of the ship. At the beginning of this analysis, first, the fluid forces acting on the buffer and pump-module must be determined.

Fluid Forces Acting on the Buffer and Pump-Module

The shapes of the buffer and pump-module assumed in this study are shown in Fig. 2, which indicates three kinds of models: cylindrical (MODEL A), cylindro-conical (MODEL B) and cylindrical with a rugged side (MODEL C). In this study, the shape of the pump-module was fixed as MODEL A with L_m/D of 7, and the shape of the buffer was replaced in the above-mentioned three models with L_m/D of 3. According to Morison et al. (1950), the fluid forces acting on those models can be calculated by the following equation:

$$F(t) = C_m m_a \frac{d^2 u_m}{dt^2} + 0.5 \rho C_d S \frac{du_m}{dt}\left|\frac{du_m}{dt}\right| \qquad (1)$$

where C_d, C_m, m_a, S, ρ, u_m are a drag coefficient, added-mass coefficient, the mass of water displaced by the model, the cross-sec-