Experimental and Analytical Investigation of Dynamic Stability of a Cantilevered Pipe Aspirating Fluid

Yongqi Ma1, Yunxiang You1,2,3, Aichun Feng1,2,3*, Ke Chen1,2,3

1 State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai, China
2 School of Naval Architecture, Ocean & Civil Engineering, Shanghai Jiao Tong University, Shanghai, China
3 Shanghai Jiao Tong University Yazhou Bay Institute of Deepsea Technology, Sanya, China

ABSTRACT

This paper considers the dynamics stability of a slender, flexible, cantilevered pipe transporting water flow from the free end to the clamped end. In the experimental, a cantilevered pipe of about 4 meters long was partially immersed in water. The vibration frequency and amplitude of the pipe were measured for various pipe internal flow velocity. For the analytical approach, the linear pipe vibration equation is briefly discussed and then solved by the harmonic differential quadrature (HDQ) method in order to determine its stability characteristics. The experimental results found that the internal flow velocity have a significant effect on the pipe vibration. The cantilevered pipe will become unstable due to flutter beyond a critical velocity. The increasing of flow velocity will increase the pipe motion amplitude. In addition, it has been observed that the pipe shows a complex motion consisting of two alternating phases: an approximately flutter motion and a vibration similar to noise with a small amplitude.

KEY WORDS: dynamic stability; experimental and analytical; harmonic differential quadrature method; flutter;

INTRODUCTION

The cantilevered pipe is a novel and most challenging device in the floating structure for deep-sea mining. The internal flow causes the instability of the cantilevered pipe, which may lead to failure of mining operations. The theory of internal flow induced vibration of cantilevered pipe has been extensively studied in the past few decades. Detailed research progress of pipe conveying fluid can be found in the corresponding published papers, such as Paidoussis (1970; 2014); Ge et al. (2019); Khodabakhsh et al. (2020); Ma et al. (2021). Paidoussis and Luu (1985) conducted the dynamic characteristics of the cantilevered aspirating pipe applied in deep-sea mining. Paidoussis (1999) reevaluated the problem of cantilevered pipe aspirating fluid, and considered that the negative pressure at the pipe inlet is the main reason for the stability of the cantilevered pipe. Kuiper and Metrikine (2005, 2008) utilized theoretical and experimental methods to study the dynamic stability of a vertical cantilevered pipe aspirating fluid. They captured the instability of the pipe with increasing flow velocity. Giacobbi and Rinaldi et al. (2012) and Rinaldi and Paidoussis (2020) independently conducted experiments with air-flow. It was found that aspirating pipe appeared flutter motions. Debut et al. (2010) conducted experimental studies on two configurations of partially submerged articulated pipe structures based on the theoretical model by Axisa (2010). Adiputra and Utsunomiya (2019) examined the stability of cold-water pipe conveying internal fluid for different pipe material, top joint configuration and bottom supporting.

The present paper intends to study the fluid-induced vibration phenomena of partially immerged cantilevered pipe aspirating fluid. The experimental device is mainly composed of a circulating flow system, a vertical cantilever pipe and measuring instrument. A cantilevered pipe of about 4 meters long was partially immersed in water. The vibration frequency and amplitude of the pipe were measured for different pipe internal flow velocity. Based on the experimental data, three different boundary conditions are discussed respectively.