VIV of Flexible Riser Conveying Internal Fluid Subjected to Uniform Current

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ABSTRACT

Vortex-induced vibration (VIV) of a riser in consideration of both internal and external flows is numerically studied based on the in-house CFD solver viv-FOAM-SJTU. The main objective of the study is to investigate effects of the internal flow on VIV responses of the riser, when the velocity ratio of internal flow against external current varies. The results from dynamic analysis indicate that the internal flow does play a greatly important part in determining the typical VIV characteristics of the riser including vibration amplitude, vibration frequency and the dominant mode in both CF and IL directions. In addition, multi-modal vibration and mode transition phenomenon may occur when the internal flow velocity is relatively high.

KEY WORDS: Vortex-induced vibration; internal flow; viv-FOAM-SJTU; velocity ratio.

INTRODUCTION

The flexible riser is an important part of the structure of deep-sea oil exploitation system. When a circular cylinder is exposed to a flowing fluid, it is easy to excite the vortex-induced vibration (VIV). When the vortex shedding frequency is close to the natural frequency of the riser, the phenomenon of "lock-in" (Yang and Li, 2009) will occur. Under this circumstance, the vibration of the riser is significantly amplified and the vortex shedding frequency becomes very close to the vibration frequency, which may cause structural fatigue damage of the riser. Therefore, it is of great significance to accurately predict the VIV response of the marine risers for the practical design of deep-sea structures.

Since the past decades, researchers have extensively studied the vortex-induced vibration of flexible risers. Systematic experimental studies were conducted, such as Chaplin (2005), Trim (2004) and Huera-Huarte (2009). These experimental data provided reliable references for later studies. In addition, massive numerical studies on VIV problems of both rigid and flexible cylinders can be found such as Yamamoto et al. (2004), Kaja et al. (2016) and Willden et al. (2001).

In practical engineering, the flexible riser works in the complex environment, where external environment loads such as wind, wave and current interact with the structure. Meanwhile, marine risers are usually utilized for oil gas transportation. Though there exist massive works carried out for VIV of the riser subjected to external current, the VIV dynamic behavior of the flexible riser with internal flow has rarely been studied relatively. When the internal fluid travels along the curved pipe, it will generate Centrifugal acceleration and Coriolis acceleration, so that the fluid dynamic pressure will periodically affect the dynamic response of the riser and excite the additional vibration. It has been proved that complicated phenomenon can emerge due to both internal and external flows (Modarres and Paidoussis, 2013). Housner (1952) concluded that the fluid inside the riser could cause the reduction of natural frequency of the riser. The results indicate that when the internal flow velocity increases to a certain critical velocity, the dynamic dissipation and instability will occur in the riser. Paidoussis et al. (1974) studied the dynamic characteristics of vertical pipes transporting fluid through physical experiments as well as mathematical models, and then analyzed the influence of Coriolis force and Centrifugal force on the whole vibration system.

Empirical methods such as Van Der Pol wake oscillator model have been used to calculate VIV of the riser with internal flow. Duan et al. (2018) investigated VIV of a riser numerically considering both internal and external flows based on the semi-empirical method proposed by Thorsen et al. (2014). Typical VIV characteristics such as the dominate mode and frequency in both IL and CF directions are analyzed, as well as the Root Mean Square (RMS) of the amplitudes, standing and traveling waves for the IL and CF responses. By using a CAE technology which combines structural software with the CFD technology, Chen et al. (2012) performed the numerical study about VIV of a flexible riser model in consideration of internal flow progressing inside. According to the result from dynamic analysis, it has been found that the existence of upward-progressing internal flow plays an important part in determining the dynamic behaviors of VIV. Dai et al. (2013) focused on the VIV dynamic response of a hinged–hinged pipe with internal fluid velocities ranging from the subcritical to the supercritical regions.