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Numerical investigation of vortex-induced vibration of a riser with internal flow

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ABSTRACT

Vortex-induced vibration (VIV) of a riser considering both internal and external flows is investigated numerically. The model is firstly verified based on the comparison of the experimental data and numerical results. Then the internal flow is taken into account while VIV of a riser subjected to external flow in the subcritical regime of the Reynolds number is studied. Correspondingly, typical VIV characteristics such as the dominating mode and frequency in the in-line (IL) and cross-flow (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. The results indicate that the IL and CF dominating modes are obviously influenced by the internal flow while the dominating frequency and RMS in both IL and CF directions are slightly changed during the investigation. The dominating modes for both IL and CF responses increase with the internal flow velocity increasing. Moreover, conspicuous traveling wave response is detected for both IL and CF responses while the internal flow interacts with the external flow for VIV.

1. Introduction

Vortex-induced vibration (VIV) can arise when a circular cylinder is exposed to a flowing fluid. While passing the cylinder, the fluid separates on the surface of the cylinder, resulting in shedding of vortices in the wake. As a consequence, hydrodynamic forces exerting on the cylinder oscillate periodically, which causes that the cylinder vibrates periodically too, especially for a slender cylinder. Meanwhile, the vibrating cylinder influences the hydrodynamic forces in turn. Therefore, VIV is a phenomenon considering the interaction between fluid and structure. When the cylinder vibrating frequency is equal to or approximating to the vortex shedding frequency, lock-in occurs. Under this circumstance, the cylinder vibrating amplitude is extremely amplified, which may lead to structure failure due to rapid damage fatigue accumulation. Since VIV can be detected in many engineering fields, especially in ocean engineering, it is of great significance to take into account the dynamics of VIV while the offshore and deep-sea structures are designed.

As comprehensively reported by Sarpkaya [1], Gabbai and Benaroy [2], Williamson and Govardhan [3] and Wu et al. [4], the mechanism and characteristics of VIV have been intensively investigated experimentally and numerically for decades. At the very beginning, Feng [5] conducted an experiment on a rigid cylinder subjected to VIV in the air. Besides the comprehensive descriptions of the vibrating amplitude and frequency, two response branches, the initial and lower branches, were observed. Afterward, Khalak and Williamson [6] detected three response branches (the initial, lower and upper branches) for VIV on a low mass-damping cylinder by experiments. Besides VIV of rigid structures, the dynamics of VIV on slender structures also draws much attention. By conducting an experiment on a slender cylinder, Brika and Laneville [7] investigated the VIV behaviors through loop jumps, vortex shedding modes and phase differences. During the experiment of Trim et al. [8], multimode responses were found under different external fluid velocities and the damage fatigue was proved largely influenced by response amplitudes. In addition, plenty of other experimental researches on VIV can be also found in the work of Blevins and Coughran [9], Raghavan and Bernitsas [10], Bourdier and Chaplin [11], Srinil et al. [12], Goncalves et al. [13] and Gao et al. [14].

As some risers are relatively long in practical production, it is almost impossible to conduct experiments to investigate the dynamics of VIV on such risers in full scale. Therefore, numerical method plays an important role in investigating the dynamical behaviors of VIV. And some numerical methods, such as computational uid dynamics (CFD), wake oscillator models and semi

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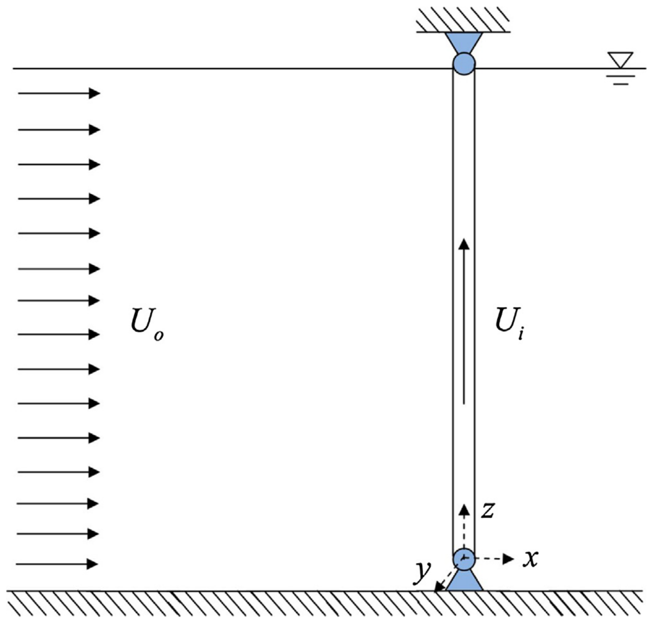

Fig. 1. The model of a riser subjected to internal and external flows.

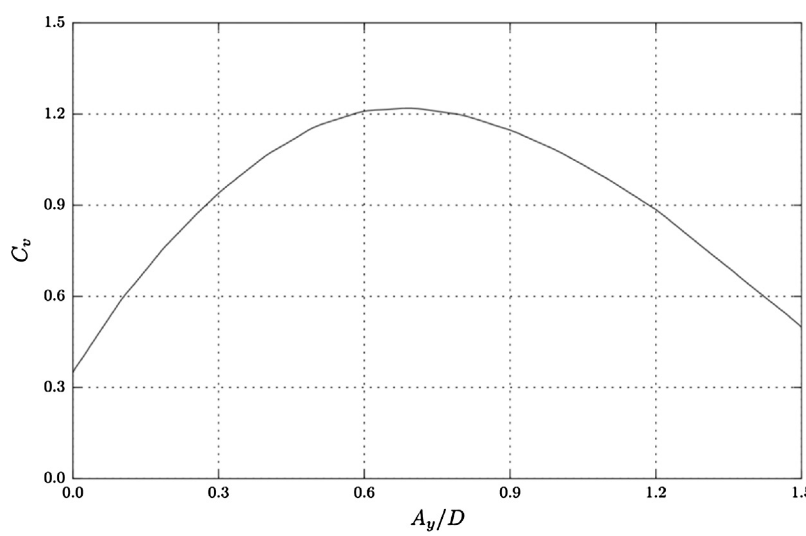

Fig. 2. Excitation force coefficient [29].

empirical models, are usually utilized to predict VIV. Correspondingly, massive numerical works about VIV can be found for rigid and slender cylinders [15–21]. Among these studies, the application of CFD requires high performance of computers if precise results are expected, which may be limited by fund. For wake oscillator model, its key parameters are sometimes difficult to be determined. Compared to these two methods, semi-empirical models are not highly dependent on the performance of computers. Softwares based on semi-empirical models such as SHEAR7 and VIVANA are widely used for the prediction of VIV [22,23]. Accurate results can be obtained by utilizing these methods in some cases [24]. However, the inherent weaknesses of the semi-empirical models prevent obtaining accurate results of VIV under unsteady flow. Hence, new semi-empirical time domain methods are developed by Lie [25], Finn et al. [26], Maincon [27] and Thorsen et al. [28,29]. Among these methods, the results of an alternative method considering synchronization of hydrodynamic forces and structure vibrations proposed by Thorsen et al. [28,29] show a great agreement to the experimental results. This method is proved efficient and accurate for response mode, vibrating frequency and damage fatigue.

Though much work has been done to investigate the dynamics of VIV, these foresaid researches are mainly focused on VIV subjected to external flow. However, structures such as marine risers are utilized for oil gas transportation. It is inevitable that the structures suffer the dynamics caused by both internal and external flows. Even when the riser is only subjected to internal flows, it has been proved that complicated responses such as quasi-periodical vibration and bifurcation phenomenon can occur [30–35]. Hence, the dynamical behaviors of VIV may be more complicated due to both internal and external flows. Correspondingly, researches on VIV considering both internal and external flows arise recently. Meng et al. [36] proved that the influences of external flow, large overall motions and internal fluid velocity should be considered while VIV of a pipe with internal flow is investigated. Dai and Wang