Experimental Study on the Vortex-Induced Vibration of Catenary Flexible Riser under Sheared Flows

Hongjun Zhu, Jie Hu, Honglei Zhao, Yue Gao
State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University
Chengdu, Sichuan Province, P.R. China

ABSTRACT
In this paper, we investigated the vortex-induced vibration of a catenary flexible riser under log-law sheared flows. Two high-speed cameras are employed to capture the in-plane and out-of-plane displacements, respectively. The experimental results indicate that the mode transition is out-of-sync in the in- and out-of-plane. Nevertheless, the out-of-plane response affects the in-plane response, and the influence becomes weaker with increasing the reduced velocity.

KEY WORDS: vortex-induced vibration; flexible riser; sheared flow; mode transition.

INTRODUCTION
The dynamic response of a circular cylinder exposed to flows is widely encountered in engineering applications. Particularly, in offshore oil and gas engineering, the elongated flexible riser as a result of the increasing water depth experiences more complicated vortex-induced vibration (VIV) with the presence of multiple frequencies and mode competition. The vigorous VIV response is the main reason of structural fatigue damage, which potentially brings huge economic loss and serious environmental pollution. Thus, the comprehensive understanding of VIV response of flexible cylinders with a large aspect ratio is urgently required to predict and prevent the fatigue failure (Wang et al., 2019; Zhu et al., 2020). VIVs of flexible cylinders in uniform flows have been extensively investigated in past decades. The considered flexible cylinder in the experiments conducted by Song et al. (2011) has a large aspect ratio of 1750. Although the cylinder is subject to uniform flow, asymmetric response was observed with the highest mode reaching the sixth in the cross-flow direction. Sun et al. (2012) reported that the excited mode increased with the incident current velocity. Due to the mono-frequency response, standing wave pattern was observed by Zhang et al. (2013) in their experimental study on the VIV of a straight flexible cylinder in uniform current, Travelling wave pattern emerges in the presence of multiple frequencies, as reported in Fan et al. (2019) and Feng et al. (2019). In order to meet the nonlinear velocity profile of currents, Srinil (2011) numerically investigated the dynamic behavior of a variable-tension riser in linearly sheared currents. An asymmetric response with mode switching over time was observed. Experimental study conducted by Gao et al. (2015) illustrated the multi-mode characteristics of a straight flexible pipe in linearly sheared flows. The space-varying frequency was observed by Mao et al. (2015) for the response of a drilling riser under sheared flow. As the submarine risers are usually deployed in catenary configuration, Assi et al. (2012) experimentally investigated the VIV of a rigid-curved cylinder in both concave and convex configurations in uniform flows. The distinguished feature was found in the curved cylinder as compared to a straight one. The cylinder in concave configuration exhibited a relatively high amplitude that persisted beyond the typical synchronization region.

The associated literature involving the catenary flexible cylinder subject to non-linear flows is scanty. Therefore, the VIV of a catenary flexible pipe with aspect ratio of 158 under log-law sheared flows is experimentally investigated in present work. The aim of this study is to improve the understanding of spatial-temporal dynamic behavior of curved flexible cylinder in nonlinear flows and the associated mode transition.

EXPERIMENTAL SET-UP
A series of experiments was conducted in a recirculating water flume in the Offshore Oil and Gas Laboratory of Southwest Petroleum University (SWPU). The water flume composed of three glass walls on the horizontal bottom and two vertical sides, leaving the top open, and has a test section of 1000 mm × 500 mm × 2000 mm (height × width × length). In the tests, the water depth was set as 0.6 m, and stable sheared flows with mean velocities ranging from 0.01 m/s to 0.8 m/s can be achieved with this water depth. The schematic of experimental set-up is depicted in Fig.1. The catenary flexible riser model made of silica gel tube was fixed at both ends in the concave orientation facing to the approaching flow. The length and external diameter of riser model are 95 cm and 6 mm, respectively, yielding an aspect ratio of 158. The riser was filled with water and immersed in the oncoming flow, resulting in a mass ratio m of 1.025, where \( m = m_i / m_t \), \( m_i \) is the total mass including the riser and the internal water and \( m_t \) is the displaced fluid. The key parameters are summarized in Table 1. The nonintrusive measurement with high-speed cameras proposed in our previous studies (Zhu et al., 2016, 2018, 2019a) is employed to monitor the response displacements. As shown in Fig.1, two high-speed cameras are placed underneath and beside the water flume to record the out-of-plane and in-plane displacements, respectively, with sampling frequency of 100 Hz. To provide the tracking points for high-speed cameras, the riser...