Ocean Engineering 156 (2018) 596–612

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

An experimental investigation on concomitant Vortex-Induced Vibration and axial top-motion excitation with a long flexible cylinder in vertical configuration

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ARTICLE INFO

Keywords:
Vortex-induced vibrations
Vertical flexible cylinder
Top-motion effect
Experiments
Modal analysis

ABSTRACT

An experimental investigation of concomitant Vortex-Induced Vibration (VIV) and top-motion excitation with a long and vertical flexible cylinder is presented. Underwater optical instrumentation allows to directly measure the cartesian coordinates of 43 targets placed along the model. Standard analyses, based on statistical evaluation of local displacement time-histories and on spectral analysis, are carried out. Additionally to the standard approach, modal decomposition is adopted, allowing to obtain modal-amplitude time-histories.

It was found that the concomitant VIV and top-motion excitation significantly affects the flexible cylinder response when compared to the pure VIV tests. When the top-motion excitation has frequency twice the first natural frequency in still water ($f_t : f_{N,1} = 2:1$), parametric instability of the first vibration mode occurs concomitant to VIV phenomenon. Such instability leads to a marked increase in the oscillation amplitudes for the whole range of towing speed tested.

1. Introduction

VIV is a fluid-structure interaction phenomenon that has received attention from both academic and industrial communities. Comprehensive reviews regarding VIV can be found, for example, in the papers by Bearman (1984, 2011), Sarpkaya (2004), Williamson and Govardhan (2004, 2008) and Gabbai and Benaroya (2005).

Up to the 2000's, VIV was mostly investigated for rigid cylinders mounted on elastic supports allowing displacements only in the cross-wise direction, i.e., the direction transverse to the free-stream direction. For low values of the combined mass-damping parameter $m^*\zeta$ (m^* is the ratio between the oscillating mass and the mass of fluid displaced by the cylinder and ζ is the damping ratio), Khalak and Williamson (1999) emphasized the existence of three distinct branches (initial, upper and lower branches) in the oscillation amplitude curve *versus* reduced velocity $V_R = U_\infty/f_N D$ (U_∞ is the free-stream velocity, f_N is the natural frequency in still water and D is the diameter). Other aspects investigated for the one degree-of-freedom (1-dof) system with low mass-parameter are the effects of the Reynolds number on the amplitude peak (Govardhan and Williamson (2006)) and the amplification of the force coefficients within the lock-in range (Sarpkaya (1995), Khalak and Williamson (1999) and Franzini et al. (2012a)).

Motivated by new technological demands, especially those from the offshore industry, the problem of a rigid cylinder elastically mounted on two degrees-of-freedom (2-dof) apparatuses has received attention from several research groups. Considering a system with $m^* < 6$, Jauvtis and Williamson (2004) pointed out that the in-line oscillations strongly affect the vortex-shedding pattern and also increase the maximum cross-wise oscillation amplitude. Additionally, the parametric experimental investigations described in Stappenbelt and Lalji (2008) showed that the in-line oscillations become negligible for the conditions in which the combined parameter $m^*\zeta < 0.066$.

Particularly in the risers dynamics scenario, the investigations on VIV of flexible cylinders are crucial matters in structural design. A comprehensive literature review concerning VIV on long and flexible cylinders can be found in Wu et al. (2012).

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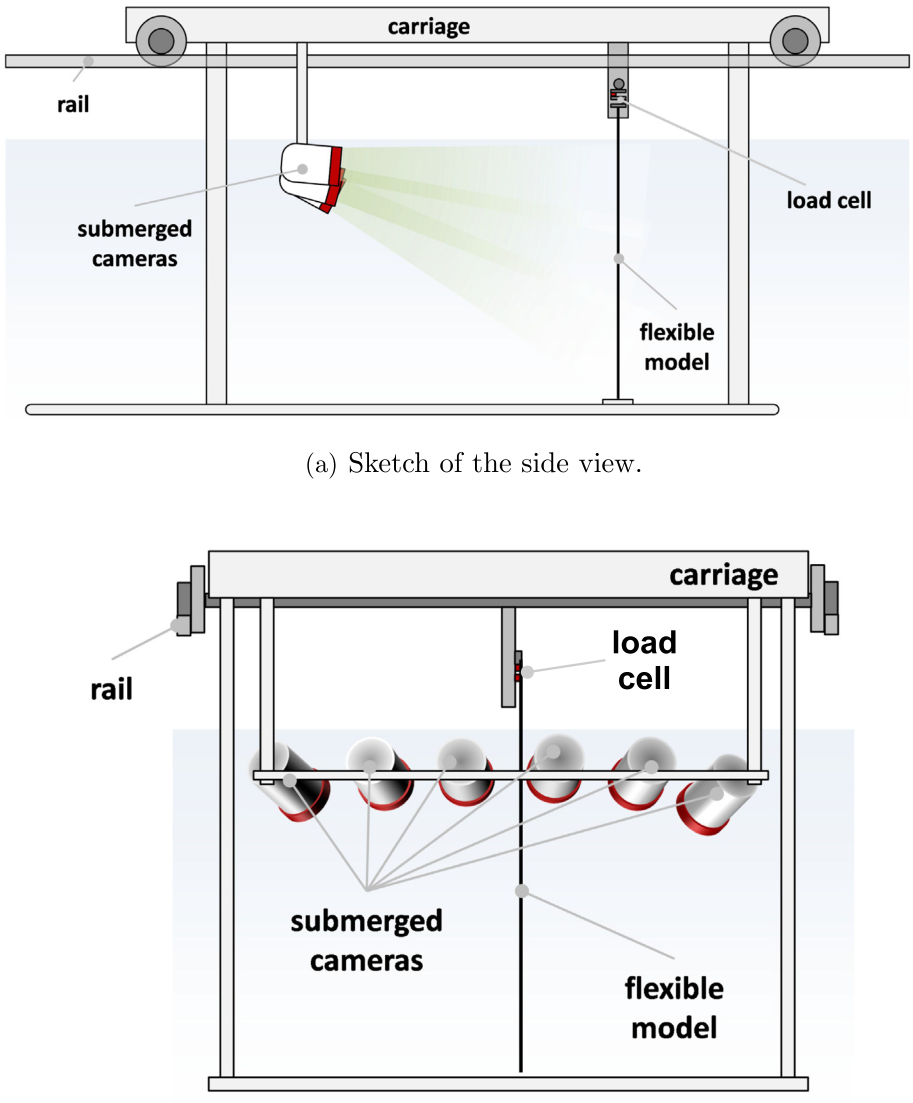
https://doi.org/10.1016/j.oceaneng.2018.02.063
Received 13 September 2016; Received in revised form 9 January 2018; Accepted 24 February 2018



(a) Sketch of the side view.

(b) Sketch of the back view.

Fig. 1. Schematic representations of the experimental arrangement. Carriage speed is from left to right. Extracted from Franzini et al. (2016a).

Considering firstly the experimental approach, Pesce and Fujarra (2000) studied VIV on a cantilevered cylinder and observed that the peak of the first mode amplitude response was shifted to a higher value of V_R when compared to the 1-dof results. A few years latter, Pesce and Fujarra (2005) replotted those results onto Jauvtis and Williamson (2004), obtained with a 2-dof rigid cylinder, revealing a remarkable similarity.

In Fujarra et al. (2001), experiments with a cantilevered cylinder with distinct stiffness in the in-line and cross-wise directions were analyzed. Among other aspects, the authors reported the existence of a high-speed mode of response outside the principal synchronization regime. This high-speed mode is associated to the in-line/cross-wise coupling combined to bending-torsional responses.

Chaplin et al. (2005a, b) present experimental results of a long flexible cylinder subjected to a stepped current and comparisons with numerical codes developed by several researches groups. In these papers, only the lower segment of the model was subjected to the free-stream, whereas the upper part was kept immersed inside a vacuum tank. Similar experiments are described in Huera-Huarte et al. (2006), Huera-Huarte and Bearman (2009a, b), with the cylinder immersed only in its lower portion. Field experiments described in Vandiver et al. (2009) pointed out that the geometric stiffness provides a favorable scenario for the appearance of traveling waves instead of stationary wave patterns. Huang et al. (2011) investigated the amplification of the mean drag coefficient due the VIV in flexible cylinders.

The VIV of flexible cylinders was also studied using computational fluids dynamics (CFD). The papers written by Willden and Graham (2001, 2004) pointed out that the added mass may play an important role in the structural oscillations. Yamamoto et al. (2004) employed the Discrete Vortex Method (DVM) aiming at investigating the response of a flexible model to a sheared current profile. Shear flow excitation was also the focus of the Direct Numerical Simulations (DNS) described in Bourguet et al. (2011), who pointed out, among others aspects, a mixture of standing and traveling waves. Bourguet et al. (2012) investigated mono-and multi-frequency response of a flexible cylinder subjected to shear flow. The authors emphasize that the transition between these two response behaviors are affected by the in-line static curvature, which depends on the mean drag force acting along the line.

From the analytical point of view, non-linear equations are employed