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A model test investigation on vortex-induced motions of a buoyancy can

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ABSTRACT

This paper presents an experimental investigation on 6-DOF vortex-induced motion response of a tethered buoyancy can under conditions of different tether lengths. The buoyancy can was mounted vertically, with the diameter of 150 mm and the length of 700 mm. The responses of trajectory, amplitude, frequency and other parameters were analyzed in detail under conditions of different tether lengths and height above the water. In addition, during the experiment, obvious yaw motion is observed and the yaw characteristics were investigated. The results show that when the reduced velocity is small (less than about 3.5), the motion amplitude is small and irregular and when the reduced velocity is large ($3.5<U_r<15$), the in-line vibration frequency is two times the transverse vibration frequency and the trajectory of the cylinder is in "figure 8" shape. A strong connection between the yaw motion frequency and the vibration frequency was also found. Moreover, the mean drag coefficient of the buoyancy can was measured and the amplification effect of VIV on drag coefficient was observed.

1. Introduction

Buoyancy cans are widely applied in offshore engineering to tension a riser and keep it vertical, which is exposed to the currents in the ocean. The flow will separate, causing an alternating trailing vortex street when flowing through the bluff body. With smaller *L/D* value, and more degrees of freedom, the motion characteristics of the buoyancy can is different with that of the riser, which is mainly investigated in the existing research. To distinguish between them, common terminologies are used to abbreviate the former as VIM (vortex-induced motion) and the latter as VIV (vortex-induced vibration).

To investigate the characteristics of VIM, model tests are effective research methods since reliable theoretical analyses are still not available. Many achievements have been obtained with this method. Govardhan [1] carried out a model test on vortex-induced motion of a tethered sphere in the steady fluid flow. The influences of the mass ratio and tether length of the spherical structure were studied. He found that the trajectory of the sphere had a Fig. "8" shape and the maximum non dimensional transverse amplitude, A_{max}/D, can reach about 1. Moreover, The RMS amplitude of these oscillations was found to be independent of the tether length and the value of the RMS was found to vary with the mass ratio. Hout [2] investigated the vortex-induced vibrations (VIV) of a positively buoyant (light) tethered sphere in uniform flow as well as its wake characteristics were measured in a closed loop water channel, finding that the amplitude response increases with Re and asymmetric vortex shedding is observed. Meanwhile, the vortex pinch-off phase decreases with increasing Re. Wang and Yang

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et al. [3] carried out a VIM experiment with current around a cylinder to study the effects of VIM and the mechanism of this fluid-structure coupled system.

Beyond these, most model tests for VIM are about offshore platforms. Dijk [4,5] carried out model tests on Truss Spar platform to study the influence of scale effect, surface roughness and mooring system on VIM response, and the results of the platform's motion responses in shear current are compared. Magee [6] conducted a VIM model test on TLP (Tension-leg platform) and studied the impact of velocity, current angle and platform draft on motion responses. Liu [7] carried out an experimental study on VIM of deep-draft semi-submersibles (DDS) to examine the effects of pontoons and column configuration, and found that the incidence angle related to columns has more significant effect on the VIM of DDS than that related to the platform. Gonçalves [8] carried out an experimental study on Vortex-Induced Motion (VIM) of the semi-submersible platform concept with four square columns to check the influence of different headings and hull appendages (riser supports located at the pontoons; fairleads and the mooring stretches located vertically at the external column faces; and hard pipes located vertically at the internal column faces). His results comprise in-line, transverse and yaw motions, as well as combined motions in the XY plane, drag and lift forces and spectral analysis, finding that the hull appendages located at columns had the greatest influence on the VIM response of the semi-submersible.

Seen from above, currently, the studies on VIM phenomenon are mostly concentrated on motion characteristics of Spar, TLP and Semi platforms, researches on VIM mechanisms of typical cylinder structures are insufficient. Moreover, in the existing VIM research, the rotating phenomenon is seldom investigated. Rotation phenomenon was firstly observed by Wilde [9], who carried out a VIM model test on free-standing riser system with buoy to study the system's response in different vibration modes. It was observed that at a certain current velocity, the buoy will produce yaw motion (rotation phenomenon). However, the yaw motion was not deeply investigated in his work. Besides, in actual engineering, devices such as mooring systems and minus vortex boards are widely applied in marine platforms, which will have a great influence on their VIM responses, and it is not conducive for us to study the mechanism of VIM.

From the available information, many similarities can be found between buoyant cans and Spar platforms. Moreover, considering that there are few studies to focus on the relationship between the yaw and the motion in the in-line and cross-flow directions, a typical cylindrical buoyancy can was adopted in this experiment, and the model test was carried out under different tethering conditions to investigate the mechanism of VIM. The tether length and draft position of the buoyancy can were changed to study their effects on the motion characteristics in the in-line & cross-flow directions as well as the yaw motion. Change trends of the trajectory, frequency and amplitude versus reduced velocity were analyzed. Meanwhile, the average drag coefficient was also calculated.

2. Experimental setup

In this experiment, the buoyancy can model was made of glass fiber reinforced plastic, which was manufactured with great precision ensuring that the center of gravity was located in the geometric center. The arrangement of the buoyancy can is shown in Fig. 1, where h is the distance from the top of the cylinder to the water surface, L is the length of the cylinder, and l is the length of the tether line. The parameters of the buoyancy can are listed in Table 1.

This model test was carried out in the towing tank in Harbin Engineering University. The tank is 108 m long, 7 m wide and 3.5 m deep. The motion capture system QUALISYS, a kind of high speed precision motion capture camera was used to capture the motions of the buoyancy can, which was derived from the motion response of three light balls fixed on it.

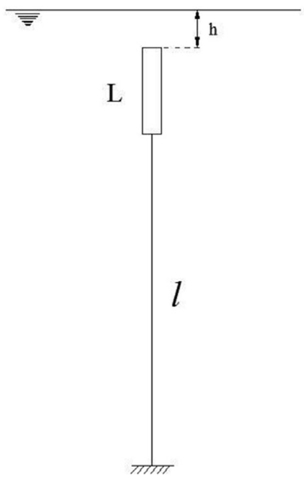

Fig. 1. Schematic diagram of the buoyancy can.