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Performance of two- and three-start helical strakes in suppressing the vortex-induced vibration of a low mass ratio flexible cylinder

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ABSTRACT

Experiments have been conducted on a low mass ratio flexible cylinder with two- and three-start helical strakes, which was free to vibrate in both in-line and transverse water flow directions under the subcritical Reynolds number. The studied parameters included the cross-flow amplitude response, the frequency response in the in-line and cross-flow directions and the mean drag coefficient. The effects of different helical strakes heights (h = 0.05 *D*, 0.10 *D* and 0.15 *D*) and pitches (p = 5 *D*, 10 *D*, 15 *D*) were investigated for five different configurations in two- and three-start helical strakes, respectively. The present study has indicated that the strakes pitch changes the occurrence of the lock-in region, but only the three-start p = 10*D* model can suppress the high mode frequency. Strakes height is one of the important variables in reducing the amplitude responses of a cylinder while the number of helix is the most significant variable in affecting the performance of helical strakes. The less effectiveness of two-start helical strakes is due to the strakes coverage that is inadequate to disrupt the regular vortices efficiently. The most effective helical strake configuration based on the configurations that are examined in the present study is the three-start p = 10 *D* h = 0.15 *D* model.

1. Introduction

Vortex-induced vibration (VIV), which is one of the most critical issues that cause fatigue damage in risers, have received substantial attention during the last few decades because of the high demand for oil and gas resources (Vandiver and Tae, 1988; Huera-Huarte and Bearman, 2009; Song et al., 2011; Han et al., 2017; Domala and Sharma, 2017). Many attempts have been made to understand the VIV phenomenon. For example, Raghavan and Bernitsas (2011) reported that the Reynolds number was a major parameter in influencing the VIV response and character. Chen et al. (2012) revealed the VIV amplitude depended on the wave number, the axial tension and the stiffness of the riser. Lee et al. (2013) used a numerical model to simulate the vortex shedding and discovered that the vorticity moved further from the cylinder as the velocity increased.

Because the exploration of hydrocarbon has moved into deeper ground water, a longer flexible riser with a higher aspect ratio is required, which induces higher VIV risk, particularly at high velocity. The possibility of VIV significantly increases if the structure has a low mass and damping ratio (Khalak and Williamson, 1999). In other words, an effective suppression device that suits the long flexible riser with a low mass ratio is notably necessary. However, most previous studies on passive-suppression techniques focused on short and rigid cylinders (Assi et al., 2010; Huang, 2011; Korkischko and Meneghini, 2010). The features that differentiate the rigid and flexible cylinder are that bending is not allowed for a rigid cylinder and the aspect ratio is usually small. The aspect ratio is defined as the length over the diameter of the structure. On the other hand, the aspect ratio of a flexible cylinder is usually high, and hence able to be bending in both in-line (IL) and cross-flow (CF) directions, where the IL movement is parallel to the flow direction. Therefore, a better understanding of this matter is necessary.

To ensure the safety of the long structure and to suppress the VIV, suppression devices are required. Some researchers have examined the suppression devices that modify the boundary layer separation and vortex wake. These devices can be grouped as active- or passive-control devices. Because of the low manufacturing cost, simple manufacturing process and simple installation, passive-control devices are satisfactory and commonly used. Zdravkovich (1981) classified the technique of passive control into several types. Among these techniques, controlling

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the boundary layer of fluid using surface protrusion such as tripping wire, helical strakes and fins are found to be more effective (Kim et al., 2009; Zhou et al., 2011).

Although several of passive suppression devices are available, only helical strake is discussed in the present study because it is proven as one of the most effective devices that can be implemented in various applications to suppress VIV (Allen et al., 2008). In general, helical strakes with three-start helix are the commercial model that is implemented in the offshore industries. The change of the helix number has gained less attention in the investigation. In the recent study of highway lighting towers (NCHRP, 2012), it was reported that two-start helical strakes were very effective in reducing the VIV compared to a single-start helical strakes. Zdravkovich (1981) also reported that strakes with single- and eight-starts were less efficient in reducing the VIV. In the VIV study in water, on the other hand, Baarholm and Lie (2005) had studied the suppression efficiency between 3-start and 4-start strakes. The efficiency of both configurations were almost the same. However, the mean drag coefficient increased as the start number increased. Therefore, they proposed that 3-start helical strakes was preferable compare to a 4-start strakes. Besides, Halkyard et al. (2006) also discovered that three-start helical strakes were more practical compared to four-start helical strakes. To the best of our knowledge, the response of the two-start helical strakes in reducing the VIV in water is still unexplored. In fact, it has the advantage of lesser weight and is easier to be manufactured compare to three-start helical strakes. Besides, good performance was found in the application of wind-based structure. Therefore, it gains our interest to investigate the effects of two-start helical strakes towards the suppression of the VIV of a flexible cylinder in water. In addition, the force responses of two-start helical strakes are inaccessible publically. The force responses are very important as excessive force especially at the well head joint of flexible riser will result fracture on the structure. Hence, the hydrodynamic response of a flexible cylinder with low mass ratio fitted with two- and three-start helical strakes is presented in the present study to shed some light on this issue. The main objective of the present study is to identify the effectiveness of the two-start and three-start helical strakes in suppressing the vortex-induced vibration (VIV) of a long flexible cylinder with low mass ratio under uniform current. It is believed that outputs of the present work is useful in reducing VIV and fatigue life of riser. Three different strakes heights and three different strakes pitches are tested separately on two-start and three-start helical strakes to identify the parameter that has more contributions in suppressing the VIV of cylinder. The vibration amplitude, the frequency response and the mean drag coefficient are of interest. In the following sections, the experimental details and the identified parameters are carefully discussed before drawing a conclusion.

2. Methodology

The experiment was conducted in the towing tank of the Department of Naval Architecture and Ocean Engineering of Osaka University. The experiment basin is 100 m in length, 7.8 m in width and 4.35 m in depth. The cylinders were submerged 0.35 m from the still-water level to avoid the free-surface effects on the response of the cylinders. The cylinders were horizontally towed by the carriage to produce a uniform flow. The towing speed was varied from 0.1 m/s to 1 m/s at intervals of 0.03 m/s so that the Reynolds number was between 1380 and 13800, as shown in Table 1. Fig. 1 shows the layout of the experiment, where it comprised of the mounting frame, tensioning system and universal joints. The details of the experimental facility can be referred to Sanaati and Kato (2012a).

Table 1
Model parameters of the cylinder.

Outer diameter (D)	18 mm
Inner diameter (d)	13 mm
Length (L)	2.92 m
Pre-tension (T)	147 N
Bending stiffness (EI)	9.0 Nm^2
Spring stiffness (k_s)	6.5 N/mm
Cylinder axial stiffness (EA/L)	100 N/mm
Cylinder air weight	1.64 N/m
Total weight including internal water (m)	2.97N/m
Mass ratio ($m^* = 4m/\rho\pi D^2$)	1.17
(structural + viscous) damping ratio (ζ)	0.0280
Applied strakes' height (h)	0.05D, 0.10D, 0.15D
Applied strakes' pitch (p)	5D, 10D, 15D
Number of helix	Two- and three-start
Flow speed (U)	0.1–1.0 m/s
Subcritical Reynolds number range (Re)	1380–13800

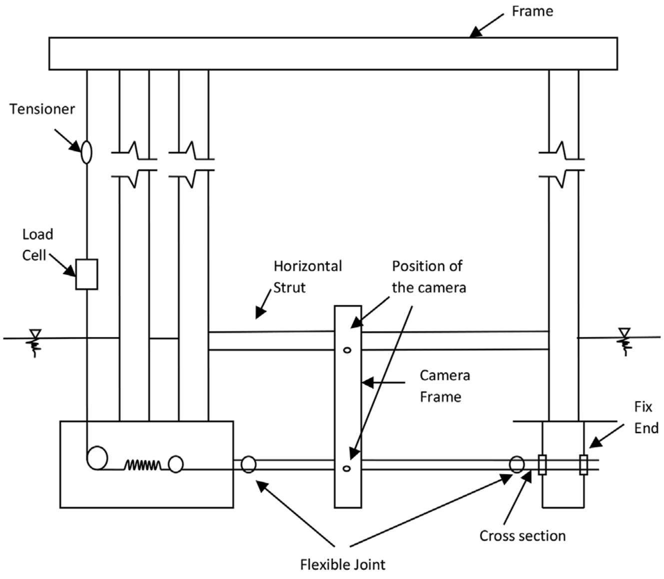

Fig. 1. Schematic diagram of the experiment facilities and instrumentations.

The polyvinyl chloride (PVC) cylinder with a diameter D of 18 mm and a length l of 2.92 m, which results in an aspect ratio of 162, offers high flexibility with low bending-dependence. The helical strakes were made of rubber (Fig. 2(a)) and designed to have either two-start or three-start helical pattern, as shown in Fig. 2(b). Three different helical strakes heights, h = 0.05 D, 0.10 D and 0.15 D, and three pitches, p = 5 D, 10 D and 15 D, were examined, where D is the diameter of the cylinder. An adhesive was used to attach the strakes onto the cylinder. The mass ratio of the cylinder is relatively low, where $m^* = 1.17$ when the cylinder is filled with water. Both ends of the cylinder were pinned with universal joints to allow the cylinder to bend in the IL and CF directions, but the cylinder was constrained in torsion. The directions of IL and CF are represented as y and x axis respectively in Fig. 3. A moveable (sliding) end in the axial direction was designed at one end of the cylinder with an initial tension of 147 N. A spring with a stiffness of 6.5 N/mm was attached between the universal joint and the sliding end to prevent excessive tensile stress from accumulating when the water current flows around the cylinder. The schematic diagram of the explained model set-up is shown in Fig. 3.

The test cases were named based on the pitch size and the strake height. There were five strake arrangements based on the strake configurations: pitch p = 10 D, height h = 0.05 D; p = 10 D, h = 0.10 D; p = 10 D, h = 0.15 D; p = 5 D, h = 0.10 D; and p = 15 D, h = 0.10 D. A total of 308 runs were performed for these experimental cases. Starting from still water, 75 s of measurements were recorded for each run of the cases. However, only the data with a constant speed were analysed to ensure the consistency of the outputs. To avoid the flow transient effects, a rest interval of 10 min was implemented between each test. Due to the size of towing tank and the operational condition