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Experimental investigation of the effects of the coverage of helical strakes on the vortex-induced vibration response of a flexible riser

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ABSTRACT

The effects of different helical strake coverage on the vortex-induced vibration (VIV) of a model flexible riser were studied experimentally, with the aim of further improving the understanding of VIV responses. Uniform and linearly sheared currents were simulated to study response parameters such as non-dimensional displacement, fatigue damage, suppression efficiency, and the comprehensive evaluation is further studied. Test results of the bare model for a uniform current showed that the behavior of both the standing wave and traveling wave dominated VIV displacement. However, for a linearly sheared current, traveling wave behavior dominated VIV displacement in the high-velocity range. The results of the straked model tests indicated that the response was strongly dependent upon the amount of coverage of helical strakes. The flexible riser with 75% strake coverage gave the best comprehensive evaluation in a uniform current, and 50% strake coverage gave the best comprehensive evaluation in a linearly sheared current.

1. Introduction

When vortices are shed in fluid flowing in a cylinder, it is subjected to time-dependent drag and lift forces over a certain Reynolds number range. If the cylinder is flexibly mounted, these forces may induce vibration of the cylinder. The lift may induce cross-flow (CF) vibration, and the drag may induce in-line (IL) vibration. This phenomenon is called vortex-induced vibration (VIV) [1]. The VIV problem has been studied experimentally and numerically many times in the past decade [2–8].

High-amplitude oscillating VIV may cause extensive fatigue damage to the cylinder. The two main methods for suppressing VIV are active control and passive control [9]. These methods differ in that the former applies a vibration opposing VIV and therefore requires a power source, whereas the latter does not [10–12]. Because passive control is more readily manufactured and implemented than active control, it is widely used in offshore engineering applications. Various passive control methods of suppressing VIV have been reported in the literature [13–17].

Of the various geometrical forms of devices for passive suppression of VIV in risers, helical strakes are among the most commonly used. The VIV suppression mechanism of helical strakes is widely understood to be a combination of two effects: firstly, they destroy regular vortex shedding in the flow direction; secondly, they prevent coincident shedding normal to the flow direction.

As shown in Table 1, the pitch, height and coverage of strakes are three basic geometrical parameters affecting VIV response. In the past decades, much effort has been exerted in the study of strake height and pitch [18–28]. From the studies cited in Table 1, several observations may be made:

(a) The VIV amplitude is decreased by about 60% for low strake heights (0.1*D*, where *D* is the external diameter of the riser), but is almost completely suppressed for high strakes heights (0.2*D*, 0.25*D*).
(b) Strake height has greater influence than strake pitch on VIV.
(c) 17.5*D* strake pitch produces the most efficient VIV suppression.
(d) The drag exerted on the riser increases with strake pitch and height.

As seen in Table 1, most studies on helical strakes have focused on strake pitch and height. Fewer studies of the effect of strake coverage have been reported [18,20,22]. Frank et al. [18] studied the VIV amplitudes and frequencies of a riser for different strake coverages in both uniform and sheared currents, and found that the maximum VIV displacement basically decreased with increasing strake coverage in uniform and sheared currents. Trim et al. [20]

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Table 1
Studies of risers fitted with helical strakes in the past decade.

Investigators	Year	Aspect ratio	Reynolds number	Investigative aspect	Current profile
Frank et al.	2004	481.5	3.0×10^3–3.6×10^4	pitch/height/coverage	Uniform currents/sheared currents
Allen et al.	2004	32.0	1.5×10^5–3.4×10^5	pitch/height/coverage	Uniform currents
Trim et al.	2005	1400	6.2×10^3–5.0×10^4	pitch/height/coverage	Uniform currents/sheared currents
Branković and Bearman	2006	8.6	3.0×10^3–2.1×10^4	pitch/height	Uniform currents
Vandiver et al.	2006	4137	9.2×10^3–7.0×10^4	pitch/height/coverage	Uniform currents/sheared currents
Allen et al.	2006	22.6	2.0×10^5–1.5×10^6	pitch/height	Uniform currents
Korkischko and Meneghini	2007	21.9	2.0×10^3–1.0×10^4	pitch/height	Uniform currents
Korkischko and Meneghini	2010	24.7	1.0×10^3–1.0×10^4	pitch/height	Uniform currents
Zhou et al.	2011	20.0	1.1×10^4–4.1×10^4	pitch/height	Uniform currents
Zhu et al.	2013	15	3.9×10^4	pitch/height/coverage	Uniform currents
Gao et al.	2014	263.3	1.8×10^4–6.5×10^4	pitch/height	Uniform currents/sheared currents

discussed fatigue damage and VIV suppression in a riser partially or fully covered with helical strakes in both uniform and linearly sheared currents. They found no significant change in VIV suppression when strake coverage was increased to 82%. Vandiver et al. [22] examined the VIV responses for 40% and 70% helical strake coverage in a gulf and lake respectively, and found that 70% staggered strake coverage did not create the same stress concentration as 40% coverage.

From the above, it is seen that very few recent studies on the effect of helical strake coverage have been reported. Furthermore, in the design of helical strakes, it is difficult to find a strake coverage that not only to suppress VIV but also minimize the associated costs. Conventional knowledge is that fluid flow changes from laminar flow to turbulent flow with increased flow velocity. Thus, several questions about bare and straked risers remain unanswered; for example (a) how are VIV displacement and frequency responses indicated with increased flow velocity in uniform and in sheared currents?; and (b) what strake coverage simultaneously suppresses VIV most efficiently and at the lowest cost?

To answer the above questions, the outcomes of the present study are reported in Section 4. Sections 4.1 and 4.2 discuss the VIV displacement and frequency response characteristics of the bare riser model. Sections 4.3 and 4.4 discuss the effects of strake coverage on VIV response in uniform and linearly sheared currents. During the analysis of strake coverage, many parameters were considered, including non-dimensional amplitude, fatigue damage and suppression efficiency. Finally, in order to consider simultaneous suppression and cost efficiency, comprehensive evaluation is further discussed.

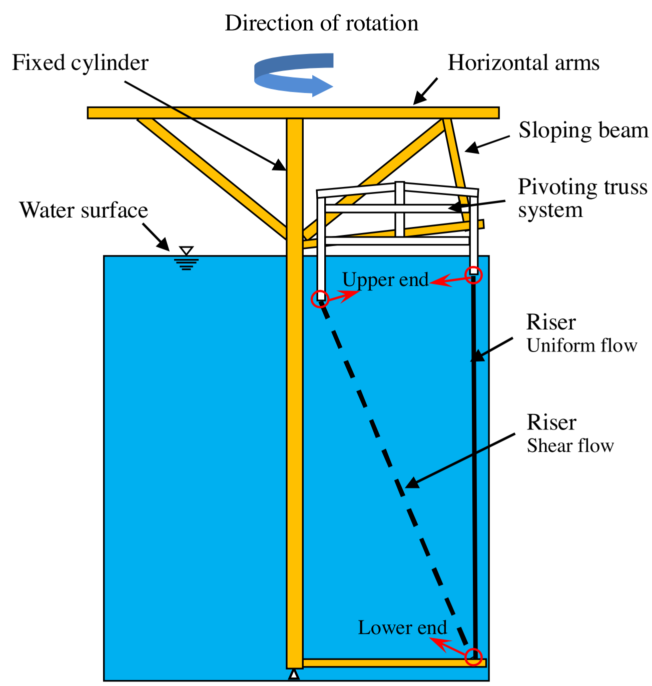

Fig. 1. Sketch of experimental arrangement.

2. Description of experimental facility

The ranges of the parameters in the present study followed the MARINTEK report *VIV suppression tests on high* L/D *flexible cylinders* [29]; the properties of the risers in those tests are listed in Table 2.

The experiment was performed in a towing tank measuring 80 m × 10.5 m × 10 m. A sketch of the main features of the experimental arrangement is shown in Fig. 1. The upper end of the riser was attached to the pivoting truss system; the lower end was fixed to the sloping beam. As Fig. 1 shows, the riser model was positioned for uniform flow tests (solid line) and for linearly sheared flow tests (dashed line). The riser was rotated by rotating the pivoting truss and sloping beam to form uniform flow and linearly sheared flow between riser and flow field. As shown in Fig. 2, for linearly sheared currents, different proportions of helical strakes were placed along the riser axis for the range of high flow velocity tests.

The riser model has an external diameter of 0.02 m and length of 9.63 m; its main properties are listed in Table 2. A total of 52 strain sensors and 16 displacement sensors were installed around the flexible riser, uniformly distributed in both the cross-flow (CF) and in-line (IL) directions to measure the VIV response. As shown in Fig. 3, the origin of the z axis is defined as the upper end, thus, the values of z/L are 0 and 1 at the upper end and the lower end, respectively. 35 strain sensors were positioned in the IL direction (labeled D01–D35) and 17 in the CF direction (F01–F17). Eight displacement sensors in the IL direction (E01–E08) and eight in the CF direction (G01–G08).

Table 2
Key parameters of the riser model.

Parameter	Value	Unit
Cylinder model length	9.63	m
External diameter	0.02	m
Wall thickness	0.00045	m
Moment of inertia	1.32×10^{-9}	m^4
Modulus of elasticity	1.025×10^{11}	N/m^2
Bending stiffness	135.3	$N\,m^2$
Aspect ratio	481.5	Dimensionless
Pretension	700	N
Total mass in water	1.0	Kg/m
Mass of displaced volume	0.314	Kg/m
Mass ratio	3.18	Dimensionless
Damping ratio in still water	0.028	Dimensionless
First natural frequency in still water	1.38	Hz
Velocity range	0.2–2.38	m/s
Kinematic viscosity	1.3×10^{-6}	m^2/s
Reynolds number range	3.08×10^3–3.66×10^4	Dimensionless