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Towards an understanding of marine fouling effects on VIV of circular cylinders: Aggregation effects

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ABSTRACT

The current study is aimed at getting a further insight into the changes the fouling brings to the Vortex Induced Vibration (VIV) of circular cylinders. Instead of regular patterns considered in previous studies, using the Poisson Cluster Process, an aggregated spatial distribution was considered for the artificial marine fouling. This is believed to better simulate the natural settlement of the marine biofouling. Different coverage ratios and fouling shapes plus regular and aggregated distributions were considered. The towing tank VIV tests were conducted on elastically mounted rigid cylinders. The Reynolds number ranged from around 7.8×10^3 to 4.9×10^4.

On the whole, the maximum oscillation amplitude and the maximum lift force coefficient were meaningfully smaller in cylinders with either aggregated or regular fouling, as compared to those from the corresponding clean cylinder. Both aggregated and regular fouling were, thus, acting as VIV suppression devices. The suppression effectiveness increased by reduction in the coverage ratio of the artificial fouling. The effectiveness, however, reduced by the aggregation as compared to that with regular distribution. In general, the maximum VIV oscillations and the force coefficients appeared to be sensitive, in descending order, to coverage ratio, aggregation, flow incidence and the fouling shape.

1. Introduction

For a structure placed in seawater, it is only a matter of time before its immersed surface is covered by marine fouling. Fouling expands the outer dimensions of the structure, increases its surface roughness, alters the flow regime around the structure and changes the hydrodynamic forces acting on it. As a result, the dynamics of vortices shed past the structure and its vortex-induced vibrations (VIVs) change.

Numerous studies have already been conducted on the VIV of circular smooth cylinders. Comprehensive reviews on the subject can be found in Khalak and Williamson (1999), Blackburn et al. (2001), Sarpkaya (2004), Gabbai and Benaroya (2005), Williamson and Govardhan (2008), Bearman (2011) and Sumner (2013).

A number of researchers also addressed vortex shedding around rough cylinders. These studies can be grouped into stationary and oscillatory cylinders. For example, pressure distribution, mean and fluctuating force coefficients, boundary layers, flow separation and Strouhal numbers in the stationary rough cylinders were studied by Achenbach (1971), Sarpkaya (1976), Güven et al. (1980), Buresti (1981), Achenbach and Heinecke (1981), Bearman and Harvey (1993), Schoefs and Boukinda (2004), Yamagishi and Oki (2004, 2005), Fuss (2011) and Zhou et al. (2015a, 2015b).

Previous studies on VIV of oscillatory rough cylinders, which is more relevant to the subject of the current study, are less frequent. For example, Wooton (1969) conducted a series of wind-tunnel tests on freely oscillating smooth and rough cylinders in subcritical and supercritical Reynolds numbers. Okajima et al. (1999) studied the aeroelastic instability of a roughened cylinder in a wind-tunnel and reported that the amplitude of oscillations reduced over a range of critical Reynolds numbers. However, larger amplitudes were observed at Reynolds numbers higher than the critical value.

VIV of circular cylinders, with tripping wires on their surface, was studied by Hover et al. (2001). The results indicated that the wires reduce the maximum amplitude of the oscillations. They also reported a plateau of constant amplitude over the synchronisation range. Bernitsas and Raghavan (2008) carried out VIV experiments on a circular cylinder with strips of sandpaper and reported reductions in the oscillations amplitude. The marine fouling effects on the VIV of circular cylinders with helical strakes were studied by Skaugset and Baarholm (2008) and Resvanis et al. (2014). They found that marine fouling increases the amplitudes of

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Nomenclature

Symbol and description

A^*	Non-dimensional amplitude $= A_y/D_e$
A^*_{max}	Maximum non-dimensional amplitude
A_y	Cross-flow oscillation amplitude (m)
C	Standard variate of the sample population
C_{Dmax}	Maximum drag force coefficient
C_{Dmean}	Mean drag force coefficient
C_{LRMS}	Root mean square of the lift force coefficient
D_b	Basal diameter of a barnacle (m)
D_e	Effective diameter of the artificially biofouled cylinder (m)
D_o	Outer diameter of the circular cylinder (m)
e	Relative roughness $= k/D_e$
f^*	Non-dimensional frequency $= f/f_N$
f	Oscillation frequency (Hz)
f_N	Natural frequency (in water) (Hz)
f_s	Shedding frequency (Hz)
k	Roughness height (m)
K	System stiffness (N/m)
L	Immersed length of the cylinder (m)
m^*	Mass ratio $= m_{osc}/m_d$
m_d	Displaced water mass (kg)
m_{osc}	Oscillating mass of the system (kg)
N	Total number of single-size barnacles on a surface
n	A cluster of points following a given point process; children
$\bar{r}_A$	The mean distances to the nearest neighbour (m)
$\bar{r}_E$	The mean distance to nearest neighbour expected in an infinitely large random distribution of density of ρ (m)
R	The index of departure from randomness
Re	Reynolds number $= U\,D_e/\upsilon$
St	Strouhal number $= f_s\,D_e/U$
U^*	Reduced velocity $= U/D_e\,f_N$
U	Flow velocity (m/s)
x	Parents; centre of each cluster
ρ	Density; number of individuals per unit of area (1/m^2)
ζ	Damping ratio
υ	Kinematic viscosity (m^2/s)
φ	Phase angle
Φ	Poisson cluster process
Φ_p	Poisson point process generating parents

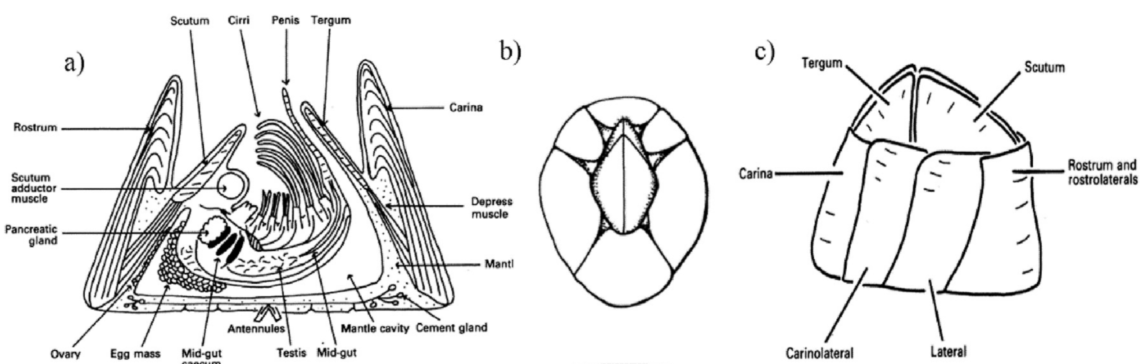

Fig. 1. (a) Anatomy, (b) top view and (c) side view of *Balanus*, a sessile barnacle (Rainbow, 1984).

oscillations in cylinders with suppression device and greatly reduces the suppression effectiveness of helical strakes.

Kiu et al. (2011) studied the VIV of cylinders covered by sandpapers at subcritical Reynolds numbers. The relative roughness, i.e. roughness height over diameter, varied from 0.28×10^{-4} to 1.38×10^{-2}. They reported that the width of the lock-in region, maximum amplitude, and maximum drag coefficient reduce as the roughness increases. On the contrary, Nedrebø (2014) and Henry et al. (2016) reported an increase in the mean drag coefficient for cylinders with high relative roughness.

A comprehensive review on vortex shedding behind stationary and non-stationary cylinders with surface roughness can be found in Zeinoddini et al. (2016). They also conducted VIV experiments on circular cylinders entirely covered by regular single-size pyramidal protrusions to model the biofouling effects. Their results showed that the maximum amplitude, the lock-in range and the maximum lift and drag coefficients are reduced by the surface protrusions. In another study, Zeinoddini et al. (2017a) conducted VIV tests on cylinders covered by regular single-size hemispherical protrusions. Three different coverage ratios were considered. Differences in the coverage ratio had, reportedly, small influences on the maximum lift and drag coefficients, however, cylinders with lower coverage ratios had lower peak amplitudes and had narrower lock-in ranges. Shape of the protrusions (pyramidal or hemispherical) was reported to have also small impacts on the peak oscillation amplitude and on the maximum lift and drag coefficients. They also stated that despite previous efforts, a systematic understanding of the fundamental mechanism of VIV in biofouled circular cylinders is still missing. Further studies, therefore, are required to better understand the impacts of the marine fouling (growth) on the VIV of bluff bodies (Zeinoddini et al., 2017a).

Fig. 2. A community of acorn barnacle species known as *Chthamalus stellatus* (Fenwick).

The current study is aimed at getting a further insight into the effect of marine biofouling on the VIV of circular cylinders and extends the