FIELD EXPERIMENTS ON WAVE FORCES ACTING ON A HORIZONTAL CYLINDER COVERED BY BARNACLES

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ABSTRACT

A field experiment was carried out to study the influence of marine fouling on wave forces on a horizontal cylinder. Field tests were performed directly at sea at the Marine Energy Laboratory (MEL) of the University of Reggio Calabria. The experimental set-up was composed by an iron frame support, placed at a 1.5 m depth, carefully anchored on the sea bed, supporting a horizontal cylinder 3 m long. Half the length of the cylinder surface had a smooth surface, the second half had a rough surface. The roughness was created artificially through sealed barnacles. A battery of eight pressure transducers was placed in the middle of each cylinder (smooth and rough) to evaluate the wave forces, while two ultrasonic probes were used to detect the free surface and to deduce the wave direction and the values of undisturbed kinematic field at the cylinder.

INTRODUCTION

Horizontal cylindrical structures are quite diffused at the sea and subject to the action of water waves. This type of structures can be placed on-bottom, near or at a certain distance from the bed (e.g., Aristodemo et al., 2011). Under operating conditions, every structure into the marine environment is subject to the settlement and growth of the so-called biofouling. Generally, marine biofouling causes an increase in the diameter and in the projected area causing an increasing into the hydrodynamic loading on structures, due to modifications of the near flow field, especially if the growth is abundant on a relatively small structure (Zdravkovich, 1997). This mean that the more a surface is rough, the more it is possible to observe a change into the near flow field with a huge impact in the vortex regime. Marine growth can be either hard, or soft and flexible, or indeed a mixture of both. It is necessary a deep understanding of how this affects the evaluation of forces induced by waves on structures to provide models and abacus for an easy evaluation of the hydrodynamics coefficients. To study the effects of marine growth on structures, a common practice is to carry out scaled laboratory experiment using artificial roughness. Waves, current or a combination of both are used in wave flume or tanks, where a cylindrical-type structure is placed (e.g., Zeinoddini et al., 2017; Marty et al., 2021). Looking at the technical literature, substantial gaps can be highlighted. Indeed, mostly of the experiences were carried out in controlled laboratory conditions and under the action of regular waves. In addition, barnacles that are one of the most common types of marine roughness are not modelled in literature. For the above reasons, this work discusses on field tests conducted at the Marine Energy Laboratory of the University of Reggio Calabria to investigate the features of random wave forces acting on a rough horizontal cylinder with printed barnacles along its external surface. The starting point of this study was the experience made by Boccotti et al. (2013), in which the authors investigated the accuracy of Morison and transverse equations to determine the wave forces acting on vertical and horizontal smooth cylinders conducting field experiments.

EXPERIMENTAL INSTALLATION SET-UP

The experimental tests were conducted using the facilities of the Marine Energy Laboratory (MEL) of the University of Reggio Calabria at the eastern coast of the Strait of Messina. This site is quite unique due to the high stability of local wind blowing from Messina to Reggio Calabria, the geomorphology and the orientation of the coast. These conditions allow us to operate directly at sea with laboratory measurement techniques. The structure of the experiments was designed to be easily assembled and disassembled. It was composed by three iron frames supporting two iron cylinders of D = 0.127 m having a length of 1.5 m (Fig 1a). The structure was place at a water depth of 1.5 m through three tilting basements of 0.65 m x 0.65 m. The cylinders were placed at half water depth (0.75 m) so we can assume that they are isolated from the seabed. One of the cylinders was covered with artificial barnacles, with a coverage ratio of 49%, prototyped like a truncated shape cave cone with an height of 3.5 mm and a base diameter of 7.5 mm. The barnacles were reproduced with an industrial 3D printer (Fig 1b). A battery of 8 pressure transducers were placed in the middle section of each cylinder, through stainless steel L-joints, to deduce the time series of the horizontal and vertical forces (Fig 1c).

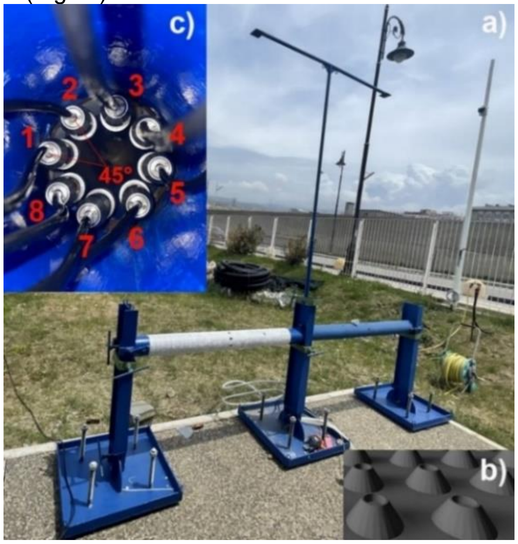

Figure 1. a) Experimental installation set-up, b) prototype of the printed barnacles, c) placement of transducers inside a cylinder.

To detect the free surface and to deduce the wave direction and the values of undisturbed kinematic field at the cylinder, two ultrasonic probes were mounted at 1.5 m from each other on top of the structure. The approximate Froude scale of the installation was 1:10.

METHODOLOGY

In the present work, each test has a duration of 5 minutes, that is optimal to represent a stationary Gaussian sea state (Boccotti, 2000). In the space-time domain, it is possible to obtain, as sum of many N small periodic waves, from the Stokes expansion at the first order of approximation the surface elevation η

$$\eta(x,y,t)=\sum_{i=1}^{n} a_i\cos(k_i x sin\vartheta_i + k_i y cos\vartheta_i - \omega_i t + \varepsilon_i) \qquad [1]$$

where k_i is the wave number, a_i is the wave amplitude, ω_i is the angular frequency, ε_i is the phase angle and θ_i is the wave direction.

Thanks to the Fourier series associated to the time series of surface elevation, recorded by two ultrasonic probes placed at a distance of 1.5 m from each other, it is possible to obtain the angles θ_i. Knowing that we have 3001 data, sampling at 10 Hz, N = 1500 elementary components, due to the fact that the duration of each test is 300 s, it is possible to evaluate the time series of particles kinematics from the 1500 quadruplets a_i, ω_i, ε_i, θ_i (Boccotti et al., 2013)

$$v_y(t)=g\sum_{i=1}^{N} a_i A_i(z_c)\frac{k_i}{\omega_i}\cos(\vartheta_i)\cos(-\omega_i t+\varepsilon_i) \qquad [2]$$

$$a_y(t)=g\sum_{i=1}^{N} a_i A_i(z_c)\,k_i\cos(\vartheta_i)\sin(-\omega_i t+\varepsilon_i) \qquad [3]$$

$$a_z(t)=-g\sum_{i=1}^{N} a_i B_i(z_c)\,k_i\cos(-\omega_i t+\varepsilon_i) \qquad [4]$$

$$A_i(z)=\frac{cosh[k_i(d+z)]}{\cosh(k_i d)}\ ;\ B_i(z)=\frac{sinh[k_i(d+z)]}{\cosh(k_i d)} \qquad [5]$$

Considering the constancy of the dynamic pressures Δp over the influence area of each pressure sensor, we then obtain the time series of the horizontal F_H and vertical F_V hydrodynamic forces as follows

$$F_H=\left(1/2-\sqrt{2}/4\right)D[\Delta p_1(t)+\Delta p_8(t)-\Delta p_4(t)-\Delta p_5(t)]+\left(\sqrt{2}/4\right)D[\Delta p_2(t)+\Delta p_7(t)-\Delta p_3(t)-\Delta p_6(t)] \qquad [6]$$

$$F_V=\left(1/2-\sqrt{2}/4\right)D[\Delta p_6(t)+\Delta p_7(t)-\Delta p_2(t)-\Delta p_3(t)]+\left(\sqrt{2}/4\right)D[\Delta p_5(t)+\Delta p_8(t)-\Delta p_1(t)-\Delta p_4(t)] \qquad [7]$$

The hydrodynamic coefficients of Morison and transverse semi-empirical schemes were deduced from the experimental kinematics and forces at the cylinders through the evaluation of the performances of different time domain methods.

RESULTS

About 100 sea states were recorded. The values of H_s ranged between 0.2 m and 0.6 m, while the values of T_p ranged between 2 s and 3.5 s for wind generated waves and between 6 s and 9 s for swell components.

The effects of the presence of the barnacles are shown in Fig. 2 in which a time window is extracted from an example sea state which is characterized by H_s = 0.33 m and T_p = 2.48 s. Looking at the time series of experimental hydrodynamic forces at a smooth and rough horizontal cylinder, some consideration can be done. If compared to the smooth cylinder, the roughness causes a mean increasing in the peaks of horizontal and vertical forces of 6.20% and 15.98%, respectively. This difference is caused by the increase of the cylinder section and the distribution of the dynamic pressures related to the increasing in the complexity of the near flow field around the rough cylinder with respect to the smooth one.

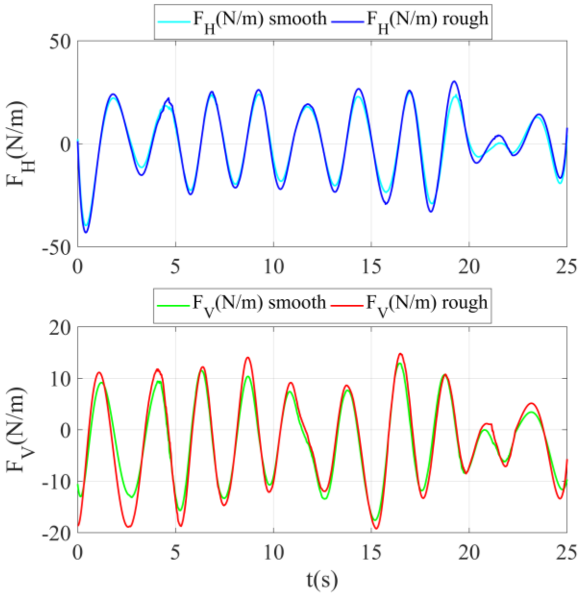

Figure 2. Time series of the experimental horizontal F_H and vertical F_V hydrodynamic forces at the smooth and rough horizontal cylinder (H_s = 0.33 m and T_p = 2.48 s).

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