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Forces on and Flow Around Oscillating Roughened Cylinders — Part 1: Effect of Roughness Height

Koji Otsuka*, Futoshi Niwa and Yoshiho Ikeda*
Department of Marine System Engineering, University of Osaka Prefecture, Osaka, Japan

ABSTRACT

In this paper, the viscous forces on and the flow field around oscillating circular cylinders with various roughness height are experimentally investigated. In-line and lift forces on oscillating roughened cylinders have been measured in a small water tank. The results show that the drag, inertia and lift coefficients depend on relative roughness height (K/D), which is the ratio of the roughness height (K) to the cylinder diameter (D). The dependency of the drag coefficient on the relative roughness height drastically changes at K/D of about 0.025, where the roughness height is almost the same as the boundary layer thickness of a smooth cylinder. Lift force frequency shifts to higher values at K/D larger than 0.025. Flow velocity near the cylinder surface has also been measured by a hot-wire anemometer in air. The instantaneous fluid velocity profiles obtained near the cylinder surface have been observed to also be affected by the relative roughness height.

INTRODUCTION

The roughness effect associated with marine growth is one of the most important factors to be considered in the estimation of wave loads on offshore structures. It has been pointed out that the roughness effects on hydrodynamic forces on an oscillating cylinder depend on several parameters: the roughness height, the roughness plugging density, the shape of the roughness elements, and so forth. Most researchers on the roughness effects have focused their attention on the relationship between the forces and the relative roughness height (K/D), which is defined as the ratio of the roughness height (K) to the cylinder diameter (D).

In this field of research, roughened cylinders are generally divided into two types according to their relative roughness height. One division corresponds to the so-called sand-roughened cylinder, which has small relative roughness height; another is the so-called heavily roughened cylinder, which has large relative roughness height. Sarpkaya et al. (1977) measured hydrodynamic forces on sand-roughened cylinders in plane oscillatory flow, and reported that the drag coefficient increases with increasing relative roughness height at high Reynolds numbers due to the activation of transition in the flow. Viscous forces acting on heavily roughened cylinders were investigated by several researchers. Kato (1982) and Motora et al. (1982) suggested that the inertia coefficients for various levels of roughness height are in good agreement with each other if the representative diameter including the roughness height is used instead of the cylinder diameter in the definition of the inertia coefficient. Theophanatos et al. (1987) and Wolfram et al. (1989a, 1989b, 1991) carried out the force measurements of cylinders with pyramid-type roughness, and showed that the drag and lift coefficients of roughened cylinders are much larger than those of smooth cylinders.

However, the boundary between sand- and heavily roughened cylinders is ambiguous, and the systematic investigation of the effect of relative roughness height on the hydrodynamic forces has not been carried out yet. For this paper, viscous forces acting on oscillating sand- and heavily roughened cylinders have been measured systematically, which has enabled clarification of the dependencies of the drag, inertia and lift forces on the relative roughness height. The second purpose of this paper was to obtain knowledge of the roughness effects on the boundary layer of oscillating cylinders. In order to achieve this, fluid velocities near the surface of the oscillating cylinders with various roughness height have been measured by using a hot-wire anemometer in air.

*ISOPE Member.

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KEY WORDS: Oscillating cylinder, viscous force, roughness effect, boundary layer.

EXPERIMENTS AND ANALYSIS

Test Cylinders

For the present series of experiments, cylinders with different roughness were prepared based on two smooth circular cylinders with diameter D = 75 mm and 79 mm. The length L of both of these provided cylinders is equal to 550 mm. A summary of the test-cylinder conditions is in Table 1. In this table, K denotes the roughness height and K/D the relative roughness height as shown in Fig. 1. The roughness plugging density α, which is the ratio of the attached area of the roughness elements to the cylinder surface area, has been varied from 21% to 53.5%. The test cylinders of small roughness height are either randomly covered by sandpaper or by spherical particles to achieve each K/D value (see Photo 1). The cylinders for large roughness height are covered by cylindrical projections in regular arrays. An example of the roughness distribution on a cylinder is shown in Fig. 1.

D (mm)	K (mm)	K/D	α(%)
79	0	0	0
79	0.2	0.0003	—
75	0.5	0.007	35.9
75	1.0	0.013	28.9
79	2.0	0.025	25.9
79	2.8	0.035	26.2
79	4.1	0.051	25.7
79	6.0	0.076	24.2
75	8.0	0.11	21.3
75	14.0	0.19	53.5

Table 1 Summary of test cylinders