Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 116 (2015) 111 – 117

Procedia Engineering

www.elsevier.com/locate/procedia

8th International Conference on Asian and Pacific Coasts (APAC 2015)

Hydrodynamic coefficients of the transverse force on a circular cylinder oscillating sinusoidally in still water

Zhida Yuan[a] and Zhenhua Huang[b]*

[a] *Neptune Offshore Engineering Development Co., LTD, Tianjin China*
[b] *Department of Ocean and Resources Engineering, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, HI 96822 USA*

Abstract

The alternating nature of vortex shedding and the induced transverse or lift forces are of significant importance in predicting structural responses, such as vortex-induced vibration and the associated fatigue. This paper reports a set of experimental results of the transverse force acting on a circular cylinder oscillating sinusoidally in still water. The measured transverse forces were analyzed using FFT(Fast Fourier Transform), and the coefficients of the mean and first four dominant frequency components, which are important for fatigue analysis, are examined for frequency parameter (β) ranging from 417 to 2083 and Keulegan-Carpenter number (*KC*) ranging from 4.8 to 28. The results showed that dominant transverse force component had a frequency double the oscillation frequency for most combinations of β and *KC*. We also found that for the transverse force coefficient it was possible to scale the force coefficient and the *KC* number to better correlate the scaled force coefficient with the scaled *KC* number. These scale factors reflect the influence of the frequency parameter on the measured transverse force coefficients.

Peer- Review under responsibility of organizing committee , IIT Madras , and International Steering Committee of APAC 2015

Keywords: wave transverse force; wave loading; oscillating cylinder; force coefficient; lift force

* Corresponding author. Tel.: +1-808-956-8100; fax: +1-808-956-3498.
E-mail address: zhenhua@hawaii.edu

Peer- Review under responsibility of organizing committee , IIT Madras , and International Steering Committee of APAC 2015
doi:10.1016/j.proeng.2015.08.271

1. Introduction

When a cylinder oscillating in still water or a fixed cylinder in regular waves, the total force will have an in-line component (in-line force) and a transverse component (transverse force or lift force). The transverse force is induced by the cyclic vortex shedding which gives an asymmetrical pressure gradient across the wake, and can be larger than the in-line force in some cases. The transverse force may have multiple frequencies (Isaacson and Maull,1976; Obasaju, et al.,1988; Justesen, 1989; Justesen, 1991), and may trigger resonance at frequencies different from the wave frequency. Understanding of transverse force is important when designing offshore foundations for oil & gas platforms, wind turbines and substations, and performing fatigue analysis of these structures.

For certain values of Reynolds number and Keulagen-Carpenter number (KC number, defined as *UT/D* with *D* being the diameter of the cylinder, *T* the oscillation/wave period and *U* the oscillation/wave velocity), the vortex shedding may take place mainly on one side of the cylinder and the cylinder may also have a steady component in the transverse force in addition to the fluctuating component (Williamson, 1985; Obasaju, et al., 1988; Lam, et al., 2010). Therefore, a mean steady component should be included in the mathematical model describing the transverse force. In the literature, the transverse force $F_L(t)$ has been described using several transverse force coefficients. If the main concern is maximum transverse force, then a maximum transverse force coefficient may be more appropriate (Isaacson and Maull, 1976; Maull and Milliner, 1978; Justesen, 1991). Since the transverse force fluctuates around a mean with certain degree of irregularity, the Root-Mean-Square (RMS) transverse force coefficient is frequently used in the literature (Shankar, et al., 1988; Chaplin, 1988; Skomedal, et al., 1989; Vengatesan, et al., 2000). When performing fatigue analysis, it is desirable to know the harmonic components in the transverse force. For this purpose, it seems appropriate to use Eq. (1) to express the transverse force (Isaacson and Maull, 1976; Maull and Milliner, 1978; Obasaju, et al., 1988; Justesen, 1991; Wang, 1997).

$$F_L(t) = \overline{F}_L + \frac{1}{2}\rho D L U_m^2 \sum_{n=1}^{N} C_L^n \cos(2\pi n f t + \psi_n),\ \overline{F}_L = \frac{C_{Lmean}}{2}\rho D L U_m^2 \,, \qquad (1)$$

where $\overline{F}_L$ is the mean transverse force with C_{Lmean} being the mean transverse force coefficient; *D* and *L* are the diameter and length of the cylinder, respectively; U_m is the maximum horizontal velocity component of the flow; C_L^n is the transverse coefficient for the n-th harmonic force component and is a function of both the KC number and Reynolds number; *f* is the fundamental frequency of oscillatory flow, which is the frequency of cylinder oscillation in this study; *N* the number of harmonic components used in the analysis; and ψ_n is the phase angle associated with the *n*-th harmonic force component. A lift force coefficient for the dominant mode can also be defined. Note that the Strouhal number *S* is related to the dominant frequency in Eq. (1).

The transverse force acting on an oscillating cylinder is directly related to vortex shedding from the cylinder. Investigations in the past decades have revealed that certain repeatable vortex shedding patterns can occur for certain flow amplitudes (Maull and Milliner, 1978; Williamson, 1985; Obasaju, et al., 1988; Lam, et al., 2010). Each of these repeatable patterns reflects the shedding of a particular number of vortices per half cycle; as the flow reverses in another half cycle, the shed vortices in the first half cycle are carried back over the cylinder, and one or more pairs with vortices of opposite sign can be formed. The pairs of vortices usually are carried away from the body through convection at a large angle to the direction of the main flow.

Transverse force on a circular cylinder have been studied by using a cylinder fixed in oscillatory flow (CFIOF)(Bearman, et al., 1984; Maull and Milliner, 1978; Obasaju, et al., 1988; Williamson, 1985; Chaplin, 1988; Skomedal, et al., 1989), a cylinder oscillating in still water (COISW) (Wang, et al., 1997), a vertical cylinder fixed in waves (VCFIW) (Stansby, et al., 1983; Vengatesan, et al., 2000; Yang and Rockwell, 2002), and a horizontal cylinder fixed in waves (HCFIW) (Shankar, et al., 1988). However, data about the hydrodynamic coefficients of harmonic transverse force are scarce and available data are found in the literature only for selected values of frequency parameter β, defined by $D^2\nu/T$ with ν being the kinematic viscosity of the water. Results available in the literature about hydrodynamic coefficients of harmonic transverse force and the β and *KC* numbers used in these studies are summarized in Table 1.