Hydrodynamic Forces on a Transverse Oscillating Circular Cylinder in Regular Waves

Zhida Yuan and Zhenhua Huang
School of Civil and Environmental Engineering, Nanyang Technological University
Singapore

ABSTRACT

This paper presents some experimental measurements of wave forces on a transversely oscillating slender cylinder which represents a slender offshore member in waves. An integrated Program based on Labview graphical language is described in detail which allows controlling the cylindrical model to undergo a desired orbital motion. The phase shift between the arrival of the crest of the incident wave and the crest of the cylinder trajectory, ratio of the cylinder oscillation frequency to the wave frequency \( f_c / f_w \) and ratio of the oscillation amplitude to diameter \( (A/D) \) are effectively controlled so that all tests are repeatable. Results indicate that the phase shift may affect the wave force time history due to wake biasing effect; both the amplitude ratio and frequency ratio may have a significant influence on hydrodynamic coefficients \( C_M \) and \( C_D \). 

KEY WORDS: Wave force; Oscillating cylinder; Phase control and shift; Amplitude ratio; Frequency ratio.

INTRODUCTION

Vortex-Induced-Vibration (VIV) is an important topic in ocean engineering which involves fluid-structure interactions of small structural members. In uniform flow cases, if the vortex shedding frequency approaches the natural frequency of a lightly damped cylinder, the vibration of the cylinder may become stronger, and this strong vibration can drive the eddies to be shed at a frequency ranging between the natural frequency \( f_N \) of the cylinder and the Strouhal frequency \( f_S = S U / D \). This phenomenon is usually called “lock-in” between the frequency of vortex shedding and the frequency of the vibrating cylinder. Under lock-in conditions, strong resonant vibration occurs and the lift forces are amplified by the increase of vortex strength. Reviews on this topic have been given by Blevins (1990) and Sarpkaya (2004). A similar phenomenon may also occur under certain conditions for an elastically mounted cylinder in waves. However, compared with the VIV problems in uniform flows, our understanding of the fluid-structure interactions for a flexibly mounted cylinder in non-uniform flows is still in its infancy due to the complexity of the driving forces and response processes. The exploitation of oil in deep water and extreme sea states has resulted in the natural frequency of fixed structures approaching that of the major wave components (Borthwick and Herbert 1990). Also, some buoyancy and spar hulls, flexible marine cables and mooring lines are subjected to wave forces. In waves, the transverse force caused by vortex shedding may also activate the resonant response if the vortex shedding frequency approaches the natural frequencies of these structures.

Laboratory experiments on flexible vertical surface piercing cylinders have confirmed the importance of the frequency ratio (between wave frequency and structural natural frequency) in determining resonant or non-resonant conditions. Bullock and Warren (1976) measured bending strains on a cantilevered flexible cylinder and found that both root-mean-square in-line and transverse strains peak when \( f_c / f_N = f_w / f_{sw} \) (\( f_w \) - wave frequency, \( f_{sw} \) -Structural natural frequency) is an integer sub-multiple. Bullock and Warren (1976) suggested that the highly repeatable behaviors might be related to the stable vortex shedding associated with resonant motions of the cylinder. Borthwick and Herbert (1988) measured in-line and transverse forces and the responses of a spring-mounted cylinder in waves. They found that the in-line force coefficients are consistently larger than those obtained by Bullock (1983) for the same cylinder but with a fixed mounting. Borthwick and Herbert (1990) again measured the forces and responses of a spring-mounted cylinder in waves for a constant surface KC of 8 over a range of frequency ratios finely tuned to \( f_c / f_{sw} = 1/2, 1/3 \). They observed the behavior of the drag coefficient \( C_D \) is very sensitive to the ratio of wave frequency to still natural frequency \( f_c / f_{sw} \). Peak values occur as \( f_c / f_{sw} \) approaches integer sub-multiples. Kaye and Mauill (1993) measured the bending moments and responses of a flexible cylinder over a range of KC numbers. They also found that the peak response in the transverse direction occurs at a ratio of \( f_c / f_{sw} = 1/2 \) and this response is not influenced by the motion in the in-line direction. The maximum in-line response occurs at a frequency ratio \( f_c / f_{sw} = 1 \), but in this case it is influenced by motion in the transverse direction. They also found that the increase in the in-line response for an unrestrained cylinder during vortex excited resonance is due to an increase in the drag coefficient only. The drag coefficient for a freely responding cylinder may be up to twice that for a fixed cylinder, while the inertia coefficient is comparable to that of a fixed cylinder. The drag and inertia coefficients for a flexible cylinder restrained to respond in only the in-line direction are comparable to those for a fixed cylinder. Hayashi and Chaplin (1998) further