Journal of Fluids and Structures ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Journal of Fluids and Structures

journal homepage: www.elsevier.com/locate/jfs

Experimental study on aerodynamic coefficients of yawed cylinders

Manh Cuong Hoang [a,*], André Laneville [b], Frédéric Légeron [a]

[a] Génie civil, Université de Sherbrooke, Sherbrooke, QC, Canada J1K2R1
[b] Génie mécanique, Université de Sherbrooke, Sherbrooke, QC, Canada J1K2R1

ARTICLE INFO

Article history:
Received 1 October 2013
Accepted 10 January 2015

Keywords:
Aerodynamic coefficients
Yawed cylinders
Independence Principle

ABSTRACT

This paper presents wind tunnel tests on a stationary cylinder inclined with the flow. The cylinder was positioned at different sets of yaw and vertical angles. The flow regime of the tests remained in the subcritical state. Two load cells were designed and installed to measure the aerodynamic forces, with enough sensitivity to measure vortex shedding frequencies. In this paper, the three aerodynamic force coefficients are normalized using the free stream velocity instead of its normal component. The results show that the drag coefficient and the resultant of the lift and side forces coefficients can be described by an empirical function of the incidence angle. The lift and side force coefficients remain however functions of both the horizontal yaw and vertical angles and cannot be expressed as functions of the incidence angle only. The Independence Principle was observed to become inaccurate for yaw angles larger than 40°. However, the measured Strouhal numbers indicate that the vortex shedding frequencies of a yawed cylinder can be predicted using the Independence Principle.

1. Introduction

Cylinders are widely used in engineering applications such as cable stayed-bridges, cable suspension bridges, overhead cables and offshore structures. in situ, the flow may approach the structures from any direction, thus making an incidence angle with them. This incidence angle, ϕ, combines the effects of θ and β, respectively the vertical inclination and horizontal yaw of the structure with respect to the flow direction. The flow phenomena around a normal cylinder have been studied extensively and the results of these studies have been observed as partly applicable to the more complicated case of the flows past a yawed cylinder by using the Independence Principle also known as the cross-flow principle or cosine law. According to this principle, the flow velocity component tangent to the cylinder axis may be ignored because of its minor effects and the aerodynamic forces of the yawed cylinder can be determined using the force coefficients of the normal cylinder and the flow velocity component normal to the cylinder axis. The Independence Principle was shown accurate over a limited range of the yaw angles, a range that structures in situ may well exceed.

According to several investigations dealing with the measurement of the vortex shedding frequency and the pressure distribution on yawed cylinders (Bursnall and Loftin, 1951; Hanson, 1966; Van Atta, 1968; Smith et al., 1972; Ramberg, 1983), the range of accuracy for the Independence Principle is restricted to angles of incidence smaller than 40° or 45°. The level of

* Corresponding author. Tel.: +1 819 821 8000x67140; fax: +1 819 821 7974.
E-mail address: manh.cuong.hoang@usherbrooke.ca (M.C. Hoang).

http://dx.doi.org/10.1016/j.jfluidstructs.2015.01.002

inaccuracy is consistently observed to increase with the value of the angle of incidence. According to other flow investigations past yawed cylinders, an axial flow develops in the near wake as the angle of incidence increases; in addition, the wall shear stress on the cylinder becomes more important. Concerning the flow pattern around the yawed circular cylinder, Shirakashi et al. (1986) pointed out the existence of an intense secondary axial flow in the near wake along the cylinder axis, which plays a role of disturbing the regular Karman vortex shedding. Matsumoto et al. (1990) confirmed that this axial flow plays a role very similar to that of a splitter plate submerged in the wake. Furthermore, the axial flow velocity increases with yawing angle to approaching wind and distributes non-uniformly along cable axis from the upstream cable end to the downstream one (Matsumoto et al., 1992, 2001, 2010). In the case of bluff bodies such as cylinders, the pressure drag mostly contributes to the total drag force since the wall shear stress due to friction is of second order, especially in the cross flow configuration. The measurements made by Tournier and Py (1978) nevertheless indicate that the wall shear stress (along the cylinder axis) increases from almost 0 to 25% of the maximum wall shear stress as the cylinder is yawed from 0° to 30°.

Most of the previous contributions (Bursnall and Loftin, 1951; Smith et al., 1972; Hayashi et al., 1992; Cheng et al., 2008) adopted an experimental methodology based on the measurement of the surface pressure distributions at different axial locations on the cylinder: this approach allows identifying the flow regime and integrating the distributions in two local directions. Bartoli et al. (2006) measured the reactions at the supports in the along-wind direction to evaluate the drag coefficient of a normal horizontal flexible cable as a whole. The determination of the three aerodynamic force coefficients in the case of a cylinder inclined and yawed with respect to the flow has not been achieved to the authors' knowledge.

The purpose and contribution of this research work are to define the three aerodynamic force coefficients normalized using the free stream velocity instead of its normal component. These aerodynamic force coefficients, as well as the Strouhal number, are investigated for Reynolds numbers in the range of 8500 and 90,000. The contribution of both the pressure and friction stresses will be included in the aerodynamic force coefficient since the incident angle will exceed 30°. The effects of Reynolds number, vertical inclination and horizontal yaw angles of the cylinder as well as incidence angle of the flow on the aerodynamic force coefficients are discussed in the global axes system. Some empirical functions are then proposed to estimate the aerodynamic force coefficients of yawed cylinders. The total aerodynamic forces are calculated based on these functions, and then compared to that determined by the simplified method using the Independence Principle. The results have been used to calculate the aerodynamic forces on stay cables, and compared to that determined by the simplified method using the Independence Principle. Moreover, the Strouhal numbers are also evaluated as a function of the incidence angle.

2. Experimental setup

2.1. Experimental setup

Tests were performed in S1, the larger subsonic wind tunnel of the Université de Sherbrooke; the tunnel is of the closed circuit type, with a square working section of 1.82 m, and a maximum wind speed of 30 m/s. Based on regular measurement of flow in the wind tunnel, the turbulence intensity and the boundary layer thickness are respectively within 1.5% and 8 cm.

The experimental set-up is shown in Fig. 1. It consists of one vertical column outside of the wind tunnel and one horizontal beam under the wind tunnel floor. The cylinder is pined to two three axis load cells at the extremities of cylinders, the first on the beam, and the second on the column. These load cells measure the instantaneous fluid forces acting over the span of the cylinder exposed inside the wind tunnel. The horizontal yaw angle of cylinder is changed by

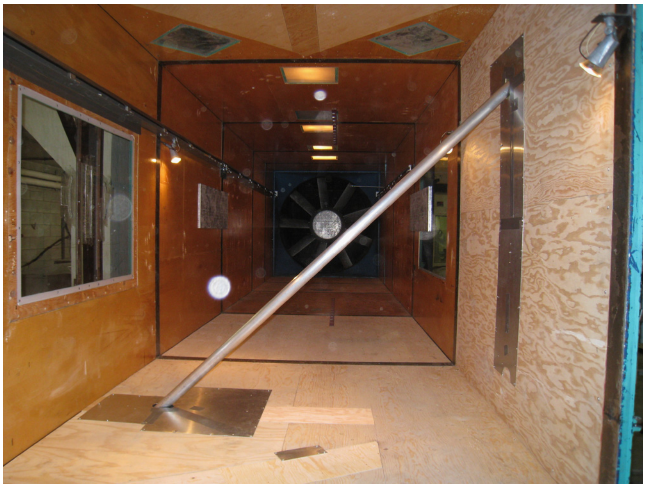

Fig. 1. Experimental set-up.

Please cite this article as: Hoang, M.C., et al., Experimental study on aerodynamic coefficients of yawed cylinders. Journal of Fluids and Structures (2015), http://dx.doi.org/10.1016/j.jfluidstructs.2015.01.002