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Aerodynamic admittance functions of rectangular cylinders

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Abstract

This paper shows comparison between analysis and measurement of aerodynamic admittance functions for lift and pitching moment of bluff bodies. The authors have proposed a new method for estimating aerodynamic admittance function using flutter derivatives. In this paper, the estimation method was applied to rectangular cylinders with and without triangular fairing. The directly measured aerodynamic admittance functions were in good agreement with the identified ones using flutter derivatives. However, the obtained aerodynamic admittance functions had different tendency when compared to Sears' function. It was obvious that the discrepancy between the obtained ones and Sears' function was due to the different growing process of the transient aerodynamic forces (i.e., identified equivalent Wagner's functions). Comparison with Scanlan's formula was also discussed.

Keywords: Aerodynamic admittance function; Flutter derivatives; Gust response; Rectangular cylinder; Sears' function

1. Introduction

Buffeting response analysis is vital in a wind-resistant design of a long span bridge. The analysis is generally conducted using a frequency domain approach (Davenport, 1961). The accuracy of the result depends greatly upon quasi-steady aerodynamic force, power spectral density function of wind gust, aerodynamic admittance function, joint mode acceptance function, mechanical admittance function and so on.

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Among the abovementioned parameters special attention was paid to the aerodynamic admittance function and a new estimation method of aerodynamic admittance functions for lift and moment forces utilizing flutter derivatives was proposed (Hatanaka and Tanaka, 2002). The predicted aerodynamic admittance functions for NACA0012 airfoil and flat box girder sections were compared with the directly measured ones in turbulent flows which were generated by active gust generators with flapping plates and airfoils (Kobayashi et al., 1994). Our proposal was verified to be very practical. In addition, we pointed out that the discrepancy between the aerodynamic admittance function of the flat box girder section and Sears' function (Fung, 1969) (i.e., theoretical aerodynamic admittance function for a thin airfoil subjected to sinusoidal wind gust) was caused by the different growing process of the transient aerodynamic forces.

In a previous paper (Hatanaka and Tanaka, 2002), cross sections near streamline shape with small effects of separation bubbles from leading edges were examined. This paper describes applications of the new method for estimation of aerodynamic admittance functions of various rectangular cylinders where effects of separation bubbles from leading edges were considerably different. In addition, we explored the relationship between aerodynamic admittance functions and transient aerodynamic forces (i.e., identified equivalent Wagner's functions) which can be calculated in the process of identifying aerodynamic admittance functions using flutter derivatives and considered generation mechanism of aerodynamic force due to wind gust.

Scanlan (2000) has given perspective aerodynamic admittance functions as functions of measured flutter derivatives based on relationship between quasi-steady buffeting forces and motion-induced aeroelastic forces with flutter derivatives. Scanlan's proposal is corresponding to our idea on the point to estimate aerodynamic admittance functions using flutter derivatives and this is very interesting. Therefore, comparison with Scanlan's formula was also discussed.

2. Estimation procedure of aerodynamic admittance function using flutter derivatives

2.1. Extension of Sears' function

The lift and moment acting on an airfoil, flying at a uniform speed U and entering a sinusoidal gust with amplitude W, can be given by (Fung, 1969)

$$L = \pi\rho c U W e^{i\omega t}\phi(k), \quad M_{1/2} = L\cdot\frac{c}{4}, \quad \phi(k) = [J_0(k) - iJ_1(k)]\cdot C(k) + iJ_1(k), \tag{1}$$

where ρ is the air density; c the wing chord length; $\phi(k)$ the aerodynamic admittance function (Sears' function); $C(k)$ the Theodorsen's function; $J_n(k)$ the Bessel functions $(n = 0,1)$ k $(= b\omega/U)$ the reduced frequency; b the half chord length; and $\omega(= 2\pi f)$ the natural circular frequency.

For the theoretical aerodynamic force given by Eq. (1), the unsteady aerodynamic theory for a thin airfoil subjected to forced oscillation due to a periodic excitation was applied. The relative velocity on the airfoil varies according to whether the airfoil experiences harmonic oscillation or is subjected to a sinusoidal gust. In either case, however, the circulation lift is determined via Theodorsen's function.

Therefore, the authors thought that Eq. (1) might be applicable to bridge deck sections by replacing Theodorsen's function $C(k)$ for an airfoil with equivalent Theodorsen's