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TIME DOMAIN APPROACH TO TURBULENT WIND RESPONSE

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Introduction

The wind-structure interaction has long been a standing problem involving complexities in the force-response relationship. The problem is narrowed down to the representation of forces associated with wind and the consequent structural response which is limited by an acceptable stability criteria. The forces and pressures on bluff bodies such as bridge decks under natural wind are observed to be fluctuating, arising from some forms of mechanisms which may include turbulence or gustiness in the incident wind, unsteady flow around and behind the body, and the motion of the structure itself. On the other hand, the aerodynamic stability verification leads to a critical velocity which is dependent on the bridge and the deck section properties. This paper examines the forces associated with turbulence and an approach to express them in the time domain.

Wind and Aerodynamic Forces

The gustiness (or turbulence) in natural wind causes buffeting which induces fluctuating forces on the structure immersed in the flow. Such fluctuating forces could be attributed to (a) the turbulence inherent in the free stream flow, (b) the wake, also vortex shedding, and (c) structural motion (which can include body initiated turbulence).

The energy of the wind (including turbulence) is communicated to the structure in terms of forces which is dependent on the aerodynamics of shape. Under such wind action, a structure, say bridge deck, displaces predominantly in the vertical, horizontal, and rotational directions. During this motion, the wind flow is disturbed creating further aerodynamic forces which, under certain conditions, may lead to an instability phenomena. This time dependencies between external excitation and induced response has been shown in previous studies. In this case, the time domain approach can be an efficient tool to gain insight into the instantaneous wind-structure behavior and the non-linear response of the structural system subjected to random excitation. The problem now lies in transforming the instantaneous wind velocities into forces on the sections of structural systems to describe their responses.

Wind Forces

There are several ways of representing the wind forces, the usual one would be to assume two separate kinds [1]: (a) the time-dependent (proportional to the fluctuating velocities) and (b) the motion-dependent (or self-excited).

The time-dependent buffeting forces are functions of section properties and turbulence characteristics (intensities and scales). These forces are usually expressed by a quasi-steady formulation using the steady-state aerodynamic force coefficients, their derivatives, and the incident turbulence. The spanwise decay of coherence is assumed to be due to the loss of coherence of the atmospheric turbulence. The buffeting lift, moment, and drag per unit span may be written as

$$L_b = 1/2\,\rho\bar{U}^2 B\,[2C_L\,u/\bar{U} + (dC_L/d\alpha + C_D)\,w/\bar{U}]\,\chi_L$$

$$M_b = 1/2\,\rho\bar{U}^2B^2\,[2C_M\,u/\bar{U} + (dC_M/d\alpha + C_D)\,w/\bar{U}]\,\chi_M$$

$$D_b = 1/2\,\rho\bar{U}^2B\,[2C_D\,u/\bar{U}]\,\chi_D \qquad (1)$$

The above forces are directly attributable to the fluctuating velocities and are corrected by the aerodynamic admittance, χ.

In the spectral analysis, aerodynamic coupling between modes is neglected and the non-linear dependence of aerodynamic force coefficients upon the wind angle and the vibration amplitude is ignored. Due to the non-linearity of the forces, the time domain approach becomes a suitable method which necessitates formulation of the aerodynamic admittance as a time series.

The movement of a body (say bridge deck) under wind generates interactive or <u>aeroelastic forces</u> which is motion dependent. These forces influences the stability of the structural response by quantifying the aerodynamic damping (either positive or negative). A linear form of the aeroelastic forces per unit span may be written as

$$L_{ae} = 1/2\,\rho\bar{U}^2B\,[H_1\dot{h}/\bar{U} + H_2B\dot{\alpha}/\bar{U} + H_3\alpha + H_4h/B]$$

$$M_{ae} = 1/2\,\rho\bar{U}^2B^2\,[A_1\dot{h}/\bar{U} + A_2B\dot{\alpha}/\bar{U} + A_3\alpha + A_4h/B]$$

$$D_{ae} = 1/2\,\rho\bar{U}^2B\,[P_1\dot{p}/\bar{U} + P_2B\dot{\alpha}/\bar{U} + P_3\alpha + P_4p/B] \qquad (2)$$

where H_i, A_i, P_i : self-excited coefficients

h, α, p : displacements

Aerodynamic Admittance

In dealing with structural response under turbulence, it is assumed that turbulence effects remain perfectly correlated. But due to the differences in eddy sizes this assumption may not hold and it is normal to include an adjustment factor to be acceptable.

In the frequency domain, it is normal to express the linear relationship between the fluctuating forces and the fluctuating velocity of turbulence by a transfer function which is the aerodynamic admittance. In such case, the fluctuating velocities and the forces are expressed as spectral functions and the admittance function is usually considered as a frequency dependent function. A need to express this as a time series is indicated if the time domain approach will be used to consider system non-linearity.

An approach that can be used is to obtain experimentally the aerodynamic admittance as a frequency function and generate the time series by a Fourier transform. This time series can then be modeled as a stochastic process (ARMA models). The admittance function can thus be expressed as a time function.

Concluding Remarks

The use of quasi-steady theory to approach the buffeting problem requires a modification of the forces through the use of aerodynamic admittance. However, to consider non-linearity of forces, a time domain approach is suitable which requires a time series expression for the aerodynamic admittance function. This study is presently being carried out considering the variation of aerodynamic admittance with mean wind velocity and angle of attack, variation in the shape of structure, dependencies with frequency inherent in the wind and the frequency of the structure.

Acknowledgement

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Reference

[1] Scanlan, R.H., "Wind dynamics of long-span bridges", <u>Proc. 1st Int'l Symp. on Aerodynamics of Large Bridges.</u>, Denmark, 19-21 Feb. 1992, pp.47-57.