# IDENTIFICATION OF FLUTTER DERIVATIVES OF TRUSS BRIDGE DECK FROM GUST RESPONSE

# トラス橋桁のガスト応答からの非定常空気力係数の同定

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## Abstract

Long-span cable supported bridges are highly susceptible to wind excitation and the aerodynamic instability such as flutter phenomenon play an important role in the design of these bridges. This phenomenon is well represented in term of flutter derivatives that are function of the reduced frequency and body shape and can be identified from section model test by using system identification method.

System identification techniques which have been applied to identify the flutter derivatives can be classified into two broad groups. A deterministic system identification technique, that is applied for only free decaying vibration signal or impulse response. Therefore, in this system the buffeting force and their responses are considered as external noise, so this causes more difficulties at high wind velocity such as noise increase due to turbulence. The other is a stochastic system identification technique that is not only applied for free decaying signal but also buffeting response. In this system identification technique the deterministic knowledge of the input is replaced by the assumption that the input is a realization of a stochastic process.

The wind in the atmospheric boundary layer is always turbulence. Therefore any research of wind-induced vibration problems must consider this issue. Not many researchers have focused clearly on the effects of turbulence on aero-elastic forces, especially at high turbulence intensity.

This study is to clarify the effects of oncoming turbulence on the self-excited force of a suspended long span bridge deck. In the study reported herein, the more challenging is the application of a system identification method to identify flutter derivatives from gust responses for the section model. The gust response is obtained by an experimental wind tunnel test for a trussed deck section. The output only time domain analysis stochastic system identifications: covariance stochastic system (SSI_cov) and data driven stochastic system (SSI_data) methods are proposed to extract simultaneously all flutter derivatives (FDs) from two degrees of freedom system. The results are also compared with those from smooth flow as well as free decay response.

Both covariance stochastic system and data driven stochastic system methods show a good identification results even under turbulent flows because a feature of those methods treat buffeting force and response as inputs instead of noises. The SSI_data method is appreciably faster than SSI_cov method. An identification of flutter derivatives from buffeting responses is plausible. The advantage of this technique is easier to obtain buffeting response under turbulent flows. This is less time consuming than free decay test. Especially at high wind velocity it can avoided that the vertical free decay data is too short causing less accuracy.

Turbulent flows significantly affect dynamic responses and flutter derivatives of the truss bridge deck section. Buffeting raises the response amplitude level progressively in proportion to the reduced wind speed and turbulent intensity. Specifically, turbulence induces buffeting response but increase flutter critical velocity.

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## NOMENCLATURE

$V_r$ = reduced wind velocity
$U$ = mean wind velocity
$f$ = frequency
$B$ = deck width
$D$ = deck height
$A_i^*$ = torsional flutter derivatives
$H_i^*$ = vertical flutter derivatives
$I_u$ = horizontal turbulent component
$I_w$ = vertical turbulent component
$m$ = mass
$I$ = mass moment of inertia
$h$ = vertical displacement
$L_{se}$ = self-excited lift force
$M_{se}$ = self-excited moment
$L_b$ = buffeting lift force
$M_b$ = buffeting moment
$C$ = system damping matrix
$C_h$ = mechanical damping of vertical mode
$C_\alpha$ = mechanical damping of torsional mode
$M$ = mass matrix
$C^e$ = effective damping matrix (gross damping matrix)
$K^e$ = effective stiffness matrix (gross stiffness matrix)
$L_{hR}$, $L_{\alpha R}$ flutter derivatives
$K$ = reduced frequency, $B\omega/U$
$k$ = reduced frequency, $b\omega/U$
$b$ = half model width
$K_h$ = reduced frequency, $B\omega_h/U$
$K_\alpha$ = reduced frequency, $b\omega_a/U$
$A$ = state matrix
$x$ = state vector
$E$ = Expectation
$T$ = Toeplitz matrix
$H$ = Hankel matrix

$Y_p$ = past output

$Y_f$ = future output

P = projection matrix

O = observation matrix

Dc = transmission

$w_k$ = process noise

$v_k$ = measurement noise

QR = QR factorization

$K_k$ = Kalman gain

$I_i$ = turbulence intensity

$L_i^x$ = turbulence integral length scale

$R_{xx}$ = autocorrelation

$S_u$ = power spectrum density function

$\sigma$ = standard deviation

$\omega_h$ = circular frequency of heaving mode

$\omega_\alpha$ = circular frequency of peaching mode

$f_h$ = frequency of heaving mode

$f_\alpha$ = frequency of peaching mode

$\delta$ = logarithmic decrement

$\rho$ = air density

$\alpha$ = torsional displacement

$\varepsilon$ = frequency ratio

$\xi$ = damping ratio

$\xi_h$ = vertical damping ratio

$\xi_\alpha$ = torsional damping ratio

$\omega$ = natural circular frequency

$\delta$ = logarithmic decrement of damping

$\hat{X}$ = Kalman filter state sequence

$k_a^{'}, k_a^{''}, k_b^{'}, k_b^{''}$ *and* $m_a^{'}, m_a^{''}, m_b^{'}, m_b^{''}$ "Küssner coefficients"

$\Phi$ = mode shape

$\Psi$ = eigenvector; $\Sigma$ = covariance matrix

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