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Wind Force Estimation on a Nonlinear Base Isolated Building by Equivalent-Input-Disturbance (EID) Method

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Wind force estimation Base-isolation Nonlinear model
Wind force responses EID Method Linear Quadratic Regulator

1. Introduction

Due to the increase of the implementation of base-isolation in tall buildings, the tall base-isolated structures exposed to strong wind forces are at risk of the structural elements of the isolation exceeding the system's elastic limits. If this happens, the structure must be analyzed by time-history analysis to consider its nonlinear characteristics. To perform time-history analysis, an accurate estimate of the wind forces is necessary. In this paper, the wind forces acting on a nonlinear base-isolated building is estimated using the Equivalent-Input-Disturbance (EID) method.

2. Theoretical Background

2.1. Wind Force Estimation by EID Method

In this section, the estimation of wind forces by EID method based on [1] is discussed. The equation of motion for a system subjected to external wind forces, $\{F(t)\}$ is given by:

$$M_s\ddot{x}(t) + C_s\dot{x}(t) + K_s x(t) = E_d F(t) + E_u u(t) M_s \tag{1}$$

where M_s, C_s, and K_s are the property matrices, namely, mass, damping, and stiffness, respectively. The acceleration, velocity, and displacement responses are given by $\{\ddot{x}(t)\}$, $\{\dot{x}(t)\}$, and $\{x(t)\}$, respectively. E_d and E_u are the force-input and control-input channels, respectively and $u(t)$ is the control input. To derive the estimation of wind forces by EID method, a virtual control input is employed. However, it must be noted that the system does not have a real control input. The state space representation of the system is given by:

$$\dot{z}(t) = Az(t) + B_d d(t) + B_u u(t) \tag{2}$$

$$y(t) = Cz(t) \tag{3}$$

$$\begin{cases} A = \begin{bmatrix} 0 & I_N \\ -M_s^{-1}K_s & -M_s^{-1}C_s \end{bmatrix} \quad B_d = \begin{bmatrix} 0 \\ -M_s^{-1}E_d \end{bmatrix} \\ B_u = \begin{bmatrix} 0 \\ E_u \end{bmatrix} \quad z(t) = \begin{bmatrix} x(t) \\ \dot{x}(t) \end{bmatrix} \\ d(t) = F(t) \end{cases} \tag{4}$$

where A is the system matrix, B_d is the disturbance input matrix, B_u is the control input matrix, $d(t)$ is the disturbance or the wind force applied and $z(t)$ is the state of the system. The output matrix, C indicates the placement of the sensors and $y(t)$ is the output of the system. Only the velocity responses are assumed to be known in this paper. Thus, $C = [0 \quad 1]$. Since there is no active control, $u(t) = 0$ and $B_u = B_d$.

Figures 1(b) and 1(c) show the block diagram of the system with an equivalent disturbance, $d_e(t)$ and estimated output, $\bar{y}(t)$. If $y(t) = \bar{y}(t)$, it follows that $d_e(t) = d(t)$. The full state observer of Eq. (2) is given by (Figure 2):

$$\begin{cases} \dot{\hat{z}}(t) = A\hat{z}(t) + LC\,[z(t) - \hat{z}(t)] \\ \hat{y}(t) = C\hat{z}(t) \end{cases} \tag{5}$$

where $\hat{z}(t)$ is an estimated $z(t)$ and L is the observer gain. Since the system is considered to be controllable, there exist a signal $\Delta d(t)$ that satisfies the following:

$$\Delta\dot{z}(t) = A\Delta z(t) + B_d \Delta d(t) \tag{6}$$

where $\Delta z(t)$ is the difference between $z(t)$ and $\hat{z}(t)$. Combining Eqs. (2) and (5) and equating the result with Eq. (6) yields the value for the estimated wind load, $\hat{d}_e(t)$:

$$\begin{cases} \hat{d}_e(t) = {B_d}^{+} LC\Delta z(t) \\ \hat{d}_e(t) = d_e(t) - \Delta d(t) \end{cases} \tag{7}$$

where ${B_d}^{+}$ is the pseudo inverse matrix of B_d given by the following equation.

$${B_d}^{+} = \left({B_d}^T B_d\right)^{-1} {B_d}^T \tag{8}$$

Figure 2 shows the block diagram of the wind force estimation by EID method for a base-isolated system with nonlinear dampers.

2.2. Design of Observer Gain

The observer gain, L is designed using the Linear Quadratic Regulator (LQR) by solving the algebraic Ricatti equation:

$$\begin{cases} A^T P + AP - PCR^{-1}C^T P + Q = 0 \\ L = -R^{-1}C^T P \end{cases} \tag{9}$$

where P is the solution to the Ricatti equation and Q (positive semi-definite) and R (positive definite) are the weighing matrices of the state. The Ricatti equation is solved by minimizing the quadratic performance index, J.

$$\begin{cases} J = \int_0^{\infty} \{ {z_p}^T(t) Q z_p(t) + {u_p}^T(t) R u_p(t) \} dt \\ u_p = -L^T z_p \end{cases} \tag{10}$$

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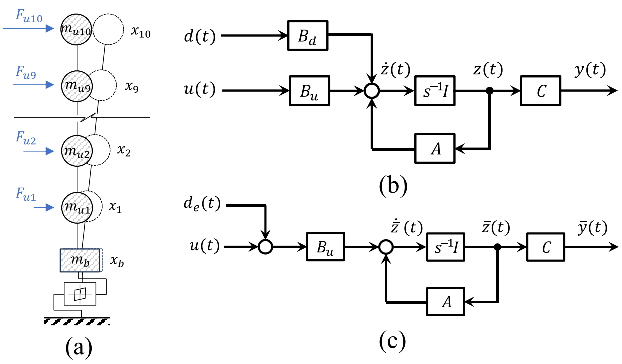

Figure 1. Wind estimation by EID

3. Analytical Model

Table 1 shows the properties of the base-isolated building modeled as an 11-degree-of-freedom (DOF) system shown in Figure 1(a). The wind forces in the analysis were taken from a wind-tunnel experiment [2] with a 500-year return period in the along-wind direction with design wind velocity of 63.8 m/s. Different observer gain values were investigated as follows: 10^8, 10^{10} and 10^{16} herein referred to as low, mid, and high observer gain values.

Table 1. Properties of the 11-DOF model

	Upper structure	Isolation layer
Natural period	$T_u = 2.0$ s	$T_b = 4.0$ s
Density	$\rho_u = 1715$ N/m^3	$\rho_b = 2551$ kg/m^2
Height	$H = 100$ m	
Area	$A = 625$ m^2	$A = 625$ m^2
Damping ratio	$\zeta_u = 2$ %	$\zeta_b = 20$ %
Yield shear coeff.		$\alpha_{by} = 0.03$
Yield deformation		$x_{by} = 3$ cm

4. Results

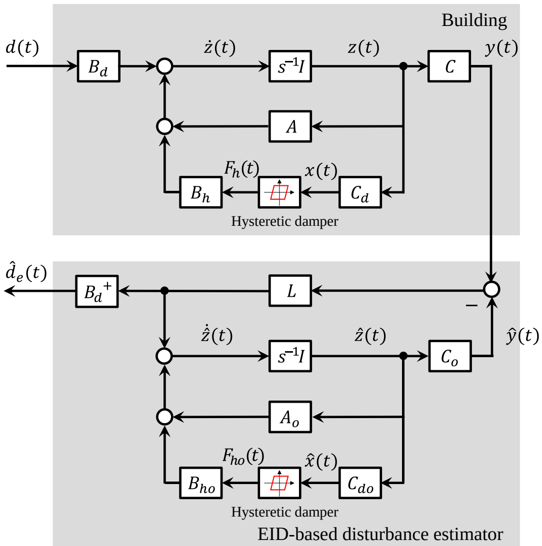

Figure 2. EID block diagram for nonlinear model

Figures 3 and 4 show the results of the wind force estimation. It

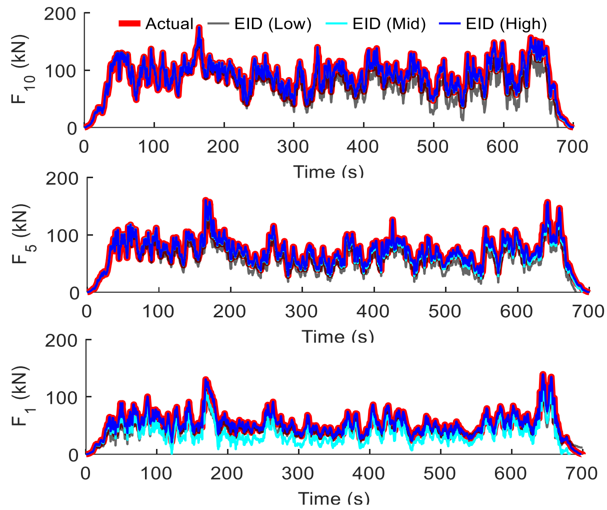

Figure 3. Estimated wind force time-history.

can be seen here that the EID method can estimate the wind forces accurately when the observer gain value is high. Also, less accurate estimates were obtained from mid and low observer gain for lower stories than that of the higher stories. The errors from the lower observer gain value are from the inaccuracies obtained in the low frequency estimate of the wind forces as shown in the power spectral density plots (PSD) in Figures 4(b)~(d).

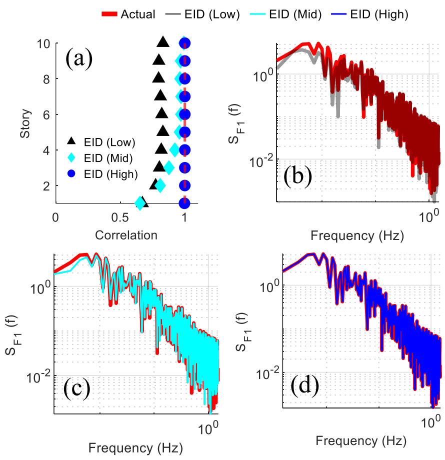

Figure 4. Correlation and PSD plot of the estimated wind forces

5. Conclusion

This paper estimated the wind forces on a nonlinear 11-DOF base-isolated building using EID method. It was assumed that only the velocity responses are available and different observer gain values were investigated. The results showed that the wind forces can be accurately estimated by EID method when a high observer gain value is used.

References:

[1] Miyamoto, K., Sato, D., She, J., Chen, Y., & Nakano, S. (2022, July). Wind-load estimation with equivalent-input-disturbance approach. In *2022 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)* (pp. 921-925). IEEE.

[2] Marukawa, H., Ookuma, T., Kitamura, H., Yoshie, K., Tsurumi, S., & Sato, D. (2010). Nergy input of local wind forces for high-rise buildings based on wind tunnel test-Part2 local wind force characteristics of rectangular high-rise buildings. In *AIJ annual conference in Hokuriku* (pp. 193-194).

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