論文 / 著書情報
Article / Book Information

論題(和文)	
Title(English)	Wind Force Estimation on Tall Buildings with Different Damping Ratios using Incomplete Acceleration Response by Modal Analysis
著者(和文)	SORIANO Razelle Dennise A, 佐藤大樹, Alex Shegay
Authors(English)	Razelle Dennise Agoba Soriano, Daiki Sato, Alex Shegay
出典(和文)	日本建築学会大会学術講演梗概集, II, , pp. 863-864
Citation(English)	, II, , pp. 863-864
発行日 / Pub. date	2022, 9
権利情報	一般社団法人 日本建築学会

Wind Force Estimation on Tall Buildings with Different Damping Ratios using Incomplete Acceleration Response by Modal Analysis

正会員 ○ SORIANO, Razelle Dennise A.*1
同 佐藤大樹*1
同 SHEGAY, Alex*1

Wind force Modal analysis FDD Method
Natural frequency Damping ratio Field Measurement

1. Introduction

The increase in height and the development of lighter materials used in the construction of modern structures have made consideration of wind forces a crucial part of the design process. One way to estimate wind forces is by using the recorded response from monitoring systems installed on the structure [1]. Soriano et al. [2] used the Frequency Domain Decomposition (FDD) method formulated by Brincker et al. [3] to estimate the dynamic parameters of a building model subjected to wind forces and used the known responses to back calculate the wind forces by modal analysis. However, the aforementioned approach assumed that all responses are known (i.e., displacement, velocity, acceleration on all floors), which is not the case for actual structures with monitoring systems. Also, the classical formulation of the FDD method is limited only to low-damped structures and its validity for models with high damping ratios has yet to be investigated.

This paper aims to extend the use of modal analysis in estimating the wind forces on models with different damping ratios and whose known responses are only the acceleration response on limited stories.

2. Theoretical Background

2.1. Response Identification

A 10-degree of freedom structural model shown in Figure 1 is used as the subject of this study. The locations of the acceleration sensors are shown in Figure 1. The unknown accelerations are identified using the cubic spline function (*spline*) in MATLAB and the velocity, $\dot{x}(t)$ and displacement, $x(t)$ are calculated by frequency domain integration of the acceleration responses, $\ddot{x}(t)$.

2.2. Frequency Domain Decomposition (FDD) Method

The FDD technique based on Brincker et al. [3] is employed to determine the 1st mode shape $\{{}_1\phi_i\}$, 1st and 2nd mode natural frequencies $({}_1\omega,\ {}_2\omega)$ and damping ratios $({}_1\zeta,\ {}_2\zeta)$.

2.3. Modal Analysis

The parameters estimated from the FDD method are then substituted into the following equations to determine the stiffness $[K]$ and damping $[C]$ matrices of the given model.

$$k_i = \frac{{}_1\omega \cdot m_i \cdot {}_1\phi_i + k_{i+1}({}_1\phi_{i+1} - {}_1\phi_i)}{{}_1\phi_i - {}_1\phi_{i-1}} \qquad (1a)$$

$$[K] = \begin{bmatrix} k_1 + k_2 & -k_2 & 0 & \dots & 0 \\ -k_2 & k_2 + k_3 & -k_3 & \dots & 0 \\ 0 & -k_3 & k_3 + k_4 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & k_N \end{bmatrix} \qquad (1b)$$

$$[C] = \alpha[M] + \beta[K] \qquad (2a)$$

$$\begin{Bmatrix} \alpha \\ \beta \end{Bmatrix} = 2 \begin{bmatrix} 1/{}_1\omega & {}_1\omega \\ 1/{}_2\omega & {}_2\omega \end{bmatrix}^{-1} \begin{Bmatrix} {}_1\zeta \\ {}_2\zeta \end{Bmatrix} \qquad (2b)$$

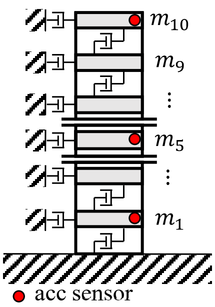
where $[M]$ is the mass matrix, ${}_1\phi_i$ is the first mode shape value at the i^{th} story, α and β are the Rayleigh damping coefficients and k_i is the stiffness of the i^{th} story. The wind forces, $P(t)$ are estimated by substituting the identified responses and the calculated structural matrices to

$$[M]\{\ddot{x}(t)\} + [C]\{\dot{x}(t)\} + [K]\{x(t)\} = \{P(t)\} \qquad (3)$$

The correlation between the estimated and actual wind forces is calculated using Eq. (4) where $\hat{y}$ is the actual wind force value and $\bar{y}$ is the mean of the estimated wind force value y.

$$Correlation = \left(1 - \frac{\sqrt{\sum_{k=1}^{N}\left(\hat{y}(k) - y(k)\right)^2}}{\sqrt{\sum_{k=1}^{N}(y(k) - \bar{y})^2}}\right) \qquad (4)$$

3. Numerical Model



Height, H (m)	100
Floor area, A (m^2)	625
Density, ρ (kg/m^3)	180
Mass per floor m_i (ton)	1125
Natural period, T (s)	2.5
1st mode damping ratio, ${}_1\zeta$	1, 2, 5, 10 %
2nd mode damping ratio, ${}_2\zeta$	1, 2, 5, 10 %

Sensor locations: 1st, 5th and 10th stories

Figure 1. Analytical model properties

Figure 1 shows the model to be analyzed and its given properties. The wind force used in the analysis is a 400-minute steady-state data in the across-wind direction.

Wind Force Estimation on a Tall Building using Incomplete Acceleration by Modal Analysis
SORIANO Razelle, SATO Daiki, SHEGAY Alex

4. Analysis Results

4.1. Response Identification

Figure 2 shows the accuracy of the identified responses using cubic spline interpolation for the acceleration and integration for the velocity and displacement. It can be seen from Figure 2a that the acceleration response calculated from interpolation obtained an average correlation of 85%. The error is due to the limitation of the method to estimate the high frequency peaks of the actual acceleration response as shown in the time-history and amplitude spectra of the 2nd story acceleration in Figure 3. Despite that, the obtained velocity and displacement responses from the integration of the calculated acceleration still obtained high accuracy as shown in Figures 2b and 2c. It can also be noticed that the change in damping ratio did not greatly affect the accuracy of the response identification results.

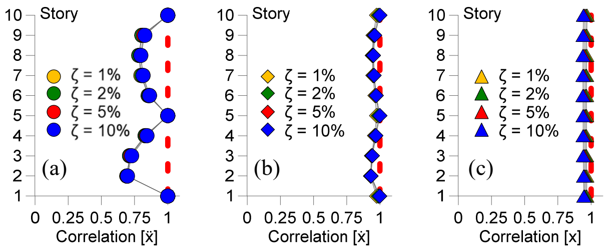


Figure 2. Correlation of identified responses

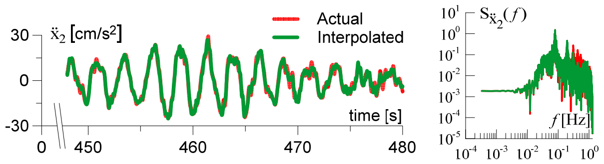


Figure 3. Time-history and amplitude spectra of acceleration

4.2. System Identification by FDD Method

Shown in Figure 4 is the accuracy of the obtained modal parameters by FDD analysis. It can be seen from this figure that the 1st mode shape and natural frequencies are in very good agreement with the theoretical values. As for the damping ratio, a slight deviation can be observed for the higher damping models ($\zeta = 5$ and 10%) with a maximum error of less than 10% for the 1st mode damping ratio estimate.

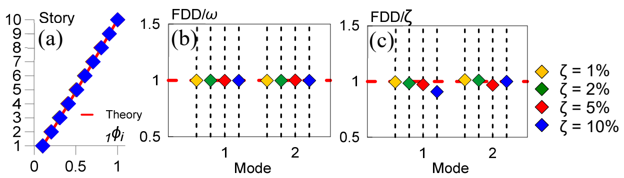
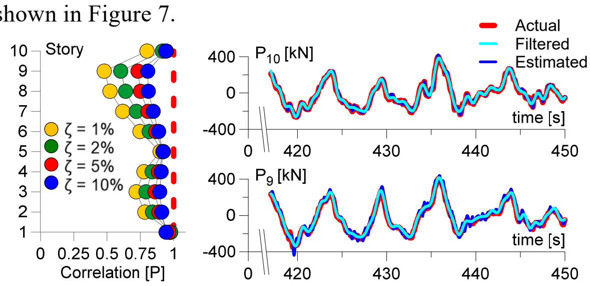


Figure 4. FDD analysis results. (a) 1st mode shape, (b) natural frequency, (c) damping ratio

4.3. Wind Force Estimation by Modal Analysis

Using the identified responses and the property matrices calculated using the FDD parameters, the wind forces can be estimated. The correlation between the actual and the estimated wind forces (Modes 1~10) is shown in Figure 5a. It can be observed that the higher the damping ratio, the better the accuracy of the estimated wind forces is, despite the errors obtained from the FDD parameters. Also, the stories with known acceleration response obtained better correlation than the stories with interpolated acceleration. This is because the inability of the interpolation to estimate the high frequencies of the actual response resulted in unwanted high frequency peaks in the estimated wind forces as shown in Figures 5b and 6 (9th story). Removing these high frequencies by using a low-pass filter increases the average correlation of the estimated wind forces (to at least 88%) especially for the low damping models as shown in Figure 7.



(a) accuracy (b) time-history

Figure 5. Estimated wind forces by modal analysis

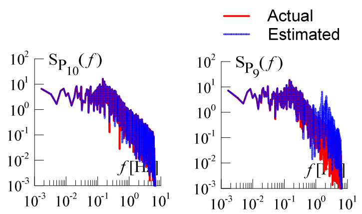


Figure 6. Amplitude spectra of estimated wind forces

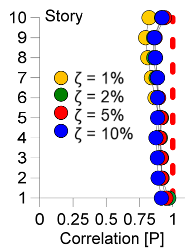


Figure 7. Filtered wind correlation

5. Conclusion

Based on the results of modal analysis it is possible to estimate the wind forces of a model with incomplete acceleration response and high damping ratio ($\zeta = 10\%$) with at least an average correlation of 88%.

References

[1] Xue, H., Liu, H., Peng, H.Y., Luo, Y., & Lin, K.. (2019). Wind Load and Structural Parameters Estimation from Incomplete Measurements. Shock and Vibration. 2019. 1-20. 10.1155/2019/4862983.

[2] Soriano R., Sato D., & Osabel D. Parameter Identification and Wind Force Estimation on a Tall Building by FDD Method and Modal Analysis, 日本建築学会大会（東海）学術講演会, 日本建築学会大会学術講演梗概集, Architectural Institute of Japan, pp. 99-100, Sept. 2021.

[3] Brincker, R., Zhang, L., & Andersen, P. (2000). Output-Only Modal Analysis by Frequency Domain Decomposition. In P. Sas, & D. Moens (Eds.), Proceedings of ISMA25: 2000 International Conference on Noise and Vibration Engineering (pp. 717-723). Katholieke Universiteit, Leuven.

*1 東京工業大学

*1 Tokyo Institute of Technology