T2R2 東京工業大学リサーチリポジトリ
Tokyo Tech Research Repository

論文 / 著書情報
Article / Book Information

論題(和文)	
Title(English)	Accuracy of Modal Analysis and Effect of Natural Period and Damping Ratio Errors in Wind Force Estimation of a High-Rise Building
著者(和文)	Razelle Dennise SORIANO, 佐藤大樹, Dave OSABEL
Authors(English)	Razelle Dennise Agoba Soriano, Daiki Sato, Dave M Osabel
出典(和文)	日本建築学会大会学術講演梗概集, , , pp. 67-68
Citation(English)	Summaries of technical papers of annual meeting, , , pp. 67-68
発行日 / Pub. date	2020, 9
権利情報	一般社団法人 日本建築学会

Powered by T2R2 (Tokyo Institute Research Repository)

Accuracy of Modal Analysis and Effect of Natural Period and Damping Ratio Errors in Wind Force Estimation of a High-Rise Building

正会員 ○ SORIANO Razelle[*1] 同 佐藤 大樹[*2] 同 OSABEL Dave [*3]

Wind Force Estimation Modal Analysis Natural Frequency Damping Ratio

1. INTRODUCTION

Recent advancement in construction materials and technology has paved the way for the development of lighter and taller buildings. These modern structures are more susceptible to larger dynamic wind excitation. For this reason, accurate estimation of the actual wind forces acting on the structure has become of great importance.

Not only the wind forces, but also the dynamic properties of the structure, particularly the natural period and damping ratio, must be given more careful consideration. Natural period and damping ratio are considered greatly necessary but highly uncertain dynamic parameters of a structure. The uncertainty of the estimation of these two properties contributes additional amount of error in the depiction of the wind forces subjected on the structure.

This study uses modal analysis to estimate the wind forces acting upon a 10 degree-of-freedom (DOF) model. Also, the necessary number of modes to include in modal superposition in order to obtain an accurate estimation of the wind forces is investigated. Lastly, the effect of errors of natural period and damping ratio on the estimated modal forces is observed.

2. BACKGROUND OF THE ANALYSIS

2.1 Multi-degree of Freedom (MDOF) Responses

The responses of a 10 MDOF model subjected to wind loading is calculated using the equation of motion for an MDOF system subjected to external dynamic forces $\{P(t)\}$ shown in Equation (1).

$$[M]\{\ddot{x}(t)\}+[C]\{\dot{x}(t)\}+[K]\{x(t)\}=\{P(t)\}. \qquad (1)$$

Here, $[M]$, $[C]$ and $[K]$ are the mass, damping and stiffness matrix, respectively. Also, $\{\ddot{x}(t)\}$, $\{\dot{x}(t)\}$ and $\{x(t)\}$ are the acceleration, velocity and displacement vectors, respectively.

2.2 Single-degree of Freedom (SDOF) / Modal Analysis

The modal responses are calculated by substituting the MDOF responses to Equation (2),

$$\{\ddot{x}(t)\} = [\emptyset]\{\ddot{q}(t)\} \qquad (2.a)$$
$$\{\dot{x}(t)\} = [\emptyset]\{\dot{q}(t)\} \qquad (2.b)$$
$$\{x(t)\} = [\emptyset]\{q(t)\} \qquad (2.c)$$

where $[\phi]$ = modal matrix, and $\{q(t)\}$, $\{q(t)\}$, $\{q(t)\}$ = modal responses.

2.3 Force Calculation

The modal responses are substituted to Equation (3) to calculate the generalized modal forces and Equation (4) is used to get the actual value of these modal forces, where $[_sM]$, $[_sC]$, $[_sK]$ and $\{_sP(t)\}$ are the generalized mass, generalized damping, generalized stiffness matrices and generalized force vectors, respectively.

$$[\,_sM]\{\ddot{q}(t)\}+[\,_sC]\{\dot{q}(t)\}+[\,_sK]\{q(t)\}=\{\,_sP(t)\} \qquad (3)$$
$$\{P(t)\}=[\emptyset]^{T^{-1}}\{\,_sP(t)\} \qquad (4)$$

The above equations are also used to observe the effect of errors in the natural period and damping ratio on the accuracy of the estimated modal forces.

3. OVERVIEW OF THE ANALYTICAL MODEL

The model is a simplified lumped mass 10-DOF system with a height H = 100 m, density ρ_u = 180 kg/m^3 and each floor area A = 625 m^2. The structure has a natural period T = 0.025H s.

The wind force applied in the analysis was derived from a calculated typhoon simulation. The wind direction analyzed was the along-wind direction without mean component. Stiffness-proportional damping is used in the analysis where damping ratio h = 2%.

An error of ±10% of the natural period and damping ratio used in the 10-DOF model was applied to the first mode forces to observe the effect of the uncertainty of these dynamic parameters on the fundamental mode to the accuracy of the succeeding relevant modal forces. The specific values are shown in Table 1.

Table 1. Dynamic Parameters Tested

Error	-10%	0%	+10%
Natural Period (s)	2.25	2.5	2.75
Damping Ratio (%)	1.8	2.0	2.2

4. RESULTS AND DISCUSSIONS

4.1 Modal Forces vs. Actual Wind Force

Figure 4 shows the correlation of the calculated modal forces and the actual wind forces. The lower floors of the model, 1st to 5th stories, have low correlation values as compared to the remaining floors. These values can be disregarded since the lower floors experience relatively low wind forces compared to the upper part of the structure (6th to 10th stories). Hence, the upper floors are more critical to wind forces and therefore will be the main focus in the analysis. From Figure 4, it can be seen that in order to obtain at least 80% correlation for the upper part of the structure, the modal superposition of forces should contain at least the first three modes of vibration.

Accuracy of Modal Analysis and Effect of Natural Period and Damping Ratio Errors in Wind Force Estimation of a High-Rise Building

SORIANO Razelle, SATO Daiki, OSABEL Dave

4.2 Modal Forces with Natural Period Error

Figure 5 shows the correlation of the calculated modal forces and the actual wind forces when an error of ±10% was introduced in the natural frequency of the modal analysis. It can be observed here that the correlation of the upper floors decreased from above 80% to 70% for the modal superposition of the first three modes. This change in correlation values can be clearly seen in Figure 2. It is shown here that the forces with natural period error have varying time-history to that of the forces obtained without error in the natural period for the first three modes of vibration. The correlation values of the lower part of the structure on the other hand, did not change significantly.

4.3 Modal Forces with Damping Ratio Error

Figure 6 shows the correlation of the calculated modal forces and the actual wind forces when an error of ±10% was introduced in the damping ratio of the modal analysis. In this figure, it can obviously be seen that an error of either ±10% on the damping ratio did not cause any significant changes in the correlation values of the actual forces and the modal superposition of the first three modes of vibration. This can be seen further in Figure 3, where the time-history of the forces for the top floor with and without damping ratio error overlapped each other.

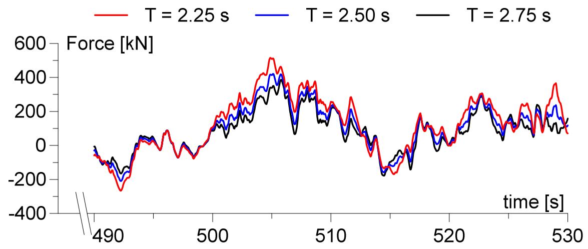

Figure 2. Force time-history of the topmost story for the first three modes with varying natural period

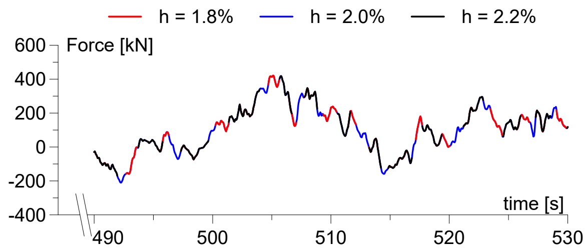

Figure 3. Force time-history topmost story for the first three modes with varying damping ratio

5. CONCLUSIONS

Based on the results of the analysis, modal analysis can be used to accurately estimate the actual wind forces on a structure. Also in this method, natural period errors have a more significant effect on the estimated forces as compared to errors in the damping ratio.

REFERENCES:

[1] Japan Society of Seismic Isolation (2018), JSSI Guideline for Wind-resistant Design of Seismically Base-Isolated Buildings (in English)

[2] Chopra, A. K. (1995). *Dynamics of Structures: Theory and Applications to Earthquake Engineering*. Englewood Cliffs, N.J: Prentice Hall.

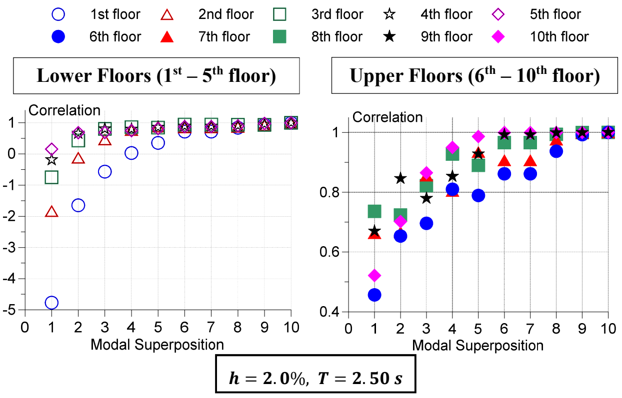

Figure 4. Correlation of modal forces vs. actual wind forces

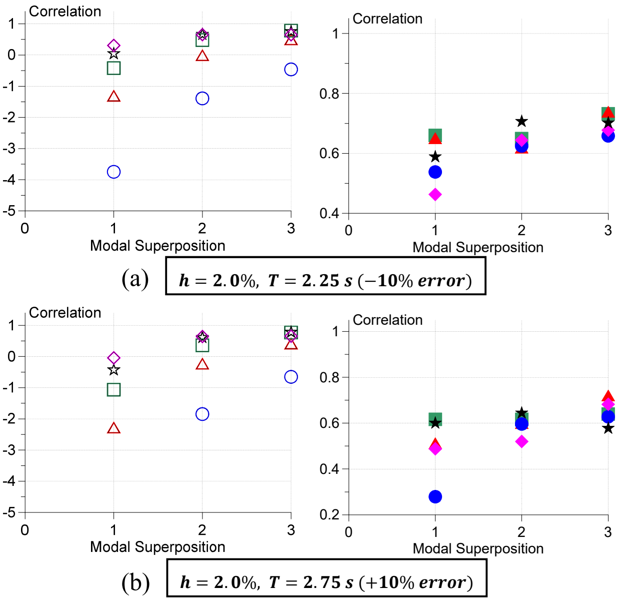

Figure 5. Effect of ±10% natural period error to the correlation of the modal forces and actual wind forces

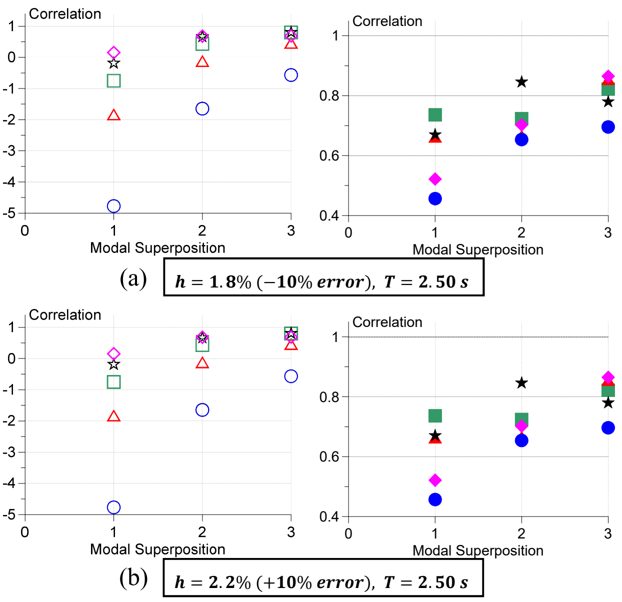

Figure 6. Effect of ±10% damping ratio error to the correlation of the modal forces and actual wind forces

*1 東京工業大学 研究生
*2 東京工業大学 准教授・博士（工学）
*3 東京工業大学 大学院生

*1 Research Student, Tokyo Institute of Technology
*2 Assoc. Prof., Tokyo Institute of Technology, Dr. Eng.
*3 Graduate Student, Tokyo Institute of Technology