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Comparison of Across and Torsional Wind Response by Spectrum Analysis and FEM Analysis of Square Plan Structures

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ABSTRACT

With the recent increase in high-rise buildings, the significance of wind-resisting design has been progressively magnified for validating theoretical analysis and accurately predicting actual response behaviors (Ryu et al., 2019). The general approach for analyzing wind loads is to perform a wind tunnel test. The Korean design standard (KDS 41 12 00:2022) specifies the criteria for conducting wind tunnel tests for structures with an aspect ratio of 3 or higher to determine the special wind loads. Based on the wind tunnel test data, there are multiple methodologies for evaluating wind load. The aim of this study is to compare the frequency domain responses of response spectrum analysis and finite element method (FEM) analysis on the across and torsional wind responses. Response spectrum analysis assumes the structure as a single-degree-of-freedom (SDOF) system. FEM analysis was performed as a linear time history analysis, which considers the dynamic responses by incorporating the vibrations of multiple modes using multi-degree-of-freedom (MDOF) analysis, enabling a more accurate examination of displacement responses.

1. INTRODUCTION

Response spectrum analysis is a simplified and widely used method for assessing wind-induced responses in structures, considering a single mode of vibration for each direction. Neglecting the contributions of second or higher modes can lead to an underestimation or overestimation of the actual response. On the other hand, linear time history analysis considers multiple modes of vibration and provides a more accurate prediction of the structural response compared to response spectrum analysis. This method accounts for the combined effects of all relevant modes, leading to a more precise dynamic behavior of the structure. By comparing the displacement response and resonance of these two methods, differences were analyzed under the assumption that only the wind direction was zero degree.

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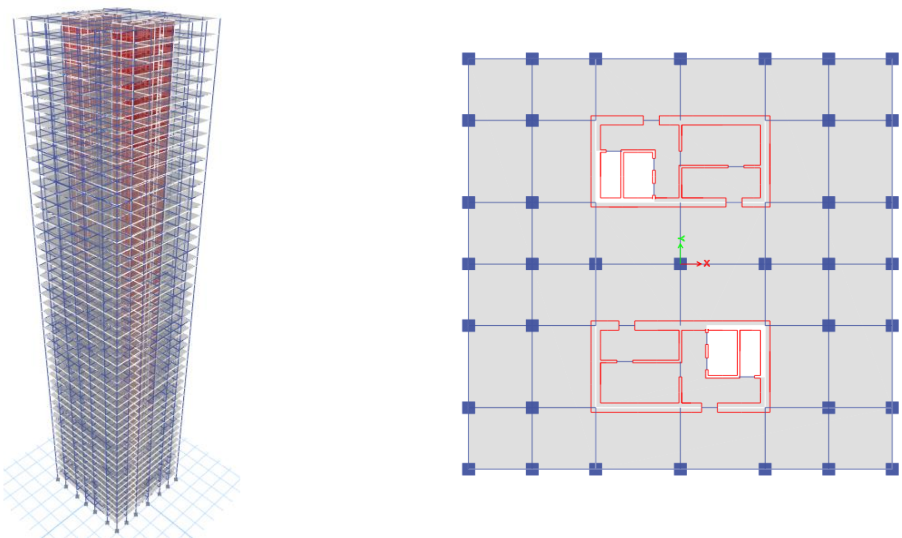
2. LINEAR TIME HISTORY ANALYSIS

In the analysis model of the 40 m^2 square plan structure, parameters of height (120, 160, and 200 m) with different mass, stiffness, and natural frequency were applied. A damping ratio of 1.2% has been applied based on the ISO 4354 standard. Three different models were examined, and the analysis was performed using the ETABS software (Fig. 1). The study aimed to analyze difference in response between the results of response spectrum analysis and linear time history analysis.



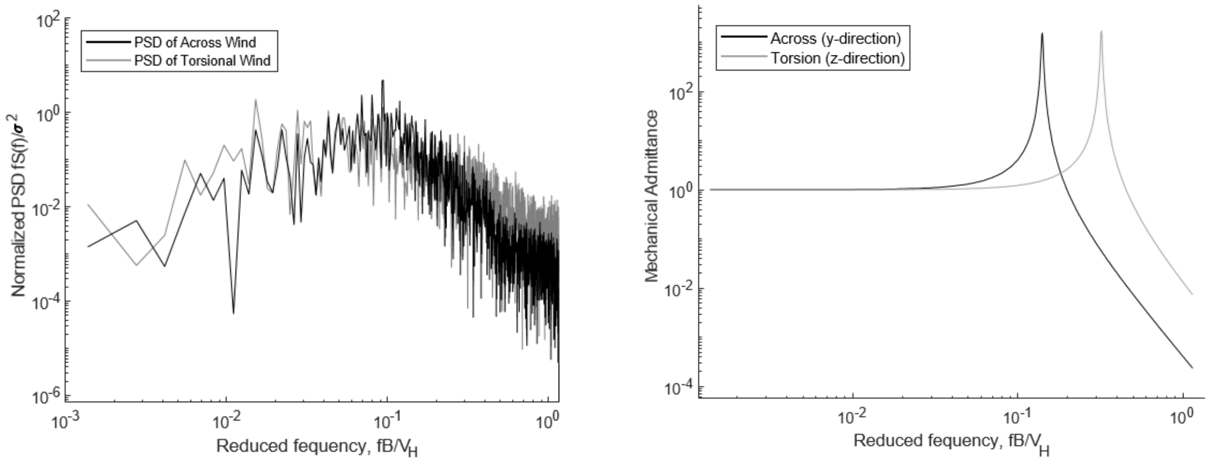
(a) 3D view of ETABS model (b) ETABS model plan view

Fig. 1 Analytical model of square plan structure

Through a wind tunnel test, the base overturning moment is calculated in each direction. The base overturning moment is divided into non-resonant (background) and mean components, which are then converted into time history wind loads as an input for the linear time history analysis. The non-resonant component is assumed to have a uniform distribution for each floor, while the mean component follows the mean wind pressure coefficient distribution. In case of a wind direction of 0 degree for both across-wind and torsional wind, the mean wind pressure distribution is assumed to be zero.

3. RESPONSE SPECTRUM ANALYSIS

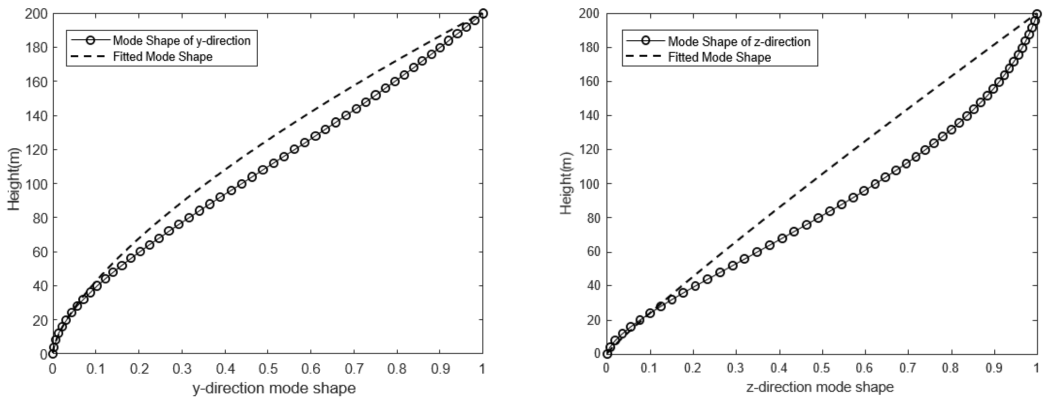
In response spectrum analysis, the displacement response of a structure to dynamic loads is determined using a simplified approach. The displacement response of a structure is determined by multiplying the power spectral density (PSD) of the external wind force with the mechanical admittance. PSD is the distribution of power in the frequency domain (Fig. 2(a)). The mechanical admittance indicates a dynamic response of the structure, which contains generalized stiffness, mass, and damping ratio (Fig. 2(b)).



(a) Power spectral density (b) Mechanical admittance

Fig. 2 PSD and mechanical admittance distributions

When calculating the mechanical admittance, the required generalized mass and generalized stiffness are assumed from the mode shapes of the ETABS model. The least squares method is used to estimate intermediate values since the mode shape values obtained from ETABS are discrete. The parameter β in the formula $(z/H)^{\beta}$ is adjusted to fit the discrete values (Fig. 3).

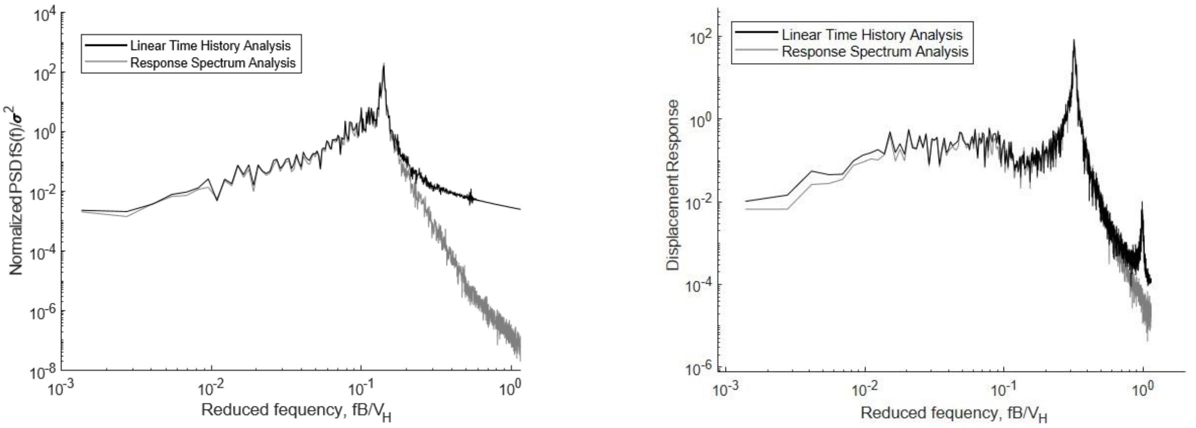


(a) Fitted mode shape of across direction (b) Fitted mode shape of torsional direction

Fig. 3 Adjusted mode shapes of across and torsional direction

4. RESULT AND DISCUSSION

The comparison of displacement response between the two analyses indicates significant differences in the low-frequency range, while the differences in the high-frequency range were relatively small and had a minor impact on the overall results (Fig. 4). However, both methods exhibit similar response curves. Therefore, it can be interpreted that the inconsistency in the response results is mainly due to differences in the low-frequency range with respect to the resonance frequency.



(a) PSD displacement response of across-wind (b) PSD displacement response of torsional-wind

Fig. 4 Comparison of PSD displacement response

The standard deviation of displacement response was larger in the across-wind direction with the increase in the height of the model. A similar tendency was observed in the torsional direction, although somewhat irregular. The standard deviation represents the differences in the range of 7-14% for across-wind and 24-30% for torsional-wind responses (Table 1).

Table 1 Result comparison of both analysis

Model Parameters (m)				Across (mm)		Torsion (rad)		ETABS-Spectrum Difference Ratio (Standard Deviation)	
Model	*B*	*D*	*H*	ETABS S.D.	Spectrum S.D.	ETABS S.D.	Spectrum S.D.	Across (%)	Torsion (%)
#1	40	40	200	176.12	204.81	0.000333	0.000449	14.006862	25.833865
#2	40	40	160	76.68	85.25	0.000337	0.000480	10.050400	29.702419
#3	40	40	120	34.77	37.60	0.000179	0.000238	7.537086	24.691930

Note: S.D. indicates standard deviation

5. CONCLUSIONS

It can be observed that for all parameters, the standard deviation in the response spectrum analysis is larger, indicating the response spectrum analysis can potentially overdesign the structure. Furthermore, in addition to the shape aspect ratio, more comprehensive research is required for analyzing various factors, such as aspect ratio and wind direction. It is also essential to conduct further examination to investigate the factors contributing to the differences observed in this study.

REFERENCES

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