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An analytical study on the performance-based wind design considering the corner modification

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ABSTRACT

In this study, nonlinear finite element analysis based on wind tunnel test results, which was performed on high-rise RC buildings with three different types of corner modification, was conducted. The wind-resistant performance according to each type of corner modification was compared. High-Frequency Force Balance (HFFB) tests were conducted on 1:600 scaled test models of 160 m high RC buildings. From the test, the power spectral density (PSD) of the base shear force, overturning, and torsional moment of each model was acquired. As a result of the test, the effect of wind load reduction and the corresponding response of buildings according to corner modification were compared.

1. INTRODUCTION

Wind tunnel tests have been carried out on various planar shapes, as wind tunnel tests for wind design have been emphasized since the Korea Building Code 2016 (KBC 2016). Accordingly, many researchers have also conducted studies on structural performance of tall building with various planar shapes through the wind tunnel test. In tall buildings, across wind load induced by separated vortex at the corner of building acts on the building, and substantial dynamic behavior may be caused in the frequency contents of the vortex. Because vortex sheds at the corner of a building, dynamic behavior of tall buildings is naturally affected by the corner shape. Therefore, design strategy of modification of the corner shape to reduce the wind-induced dynamic behavior is commonly applied. Most studies related to corner modification have focused on wind-induced vibration (e.g., Ha et al., 2001). In this study, the effect of corner modification is investigated in the perspective of reduction of wind load and wind resistance performance of buildings, by performing both wind tunnel tests ad numerical analyses.

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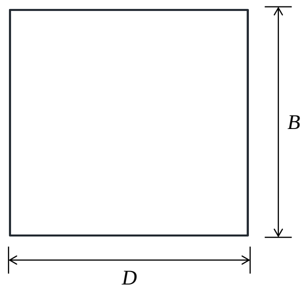
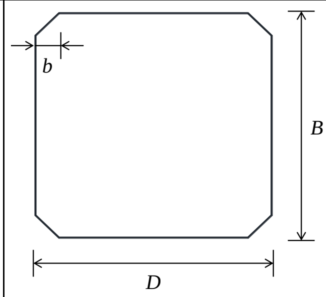
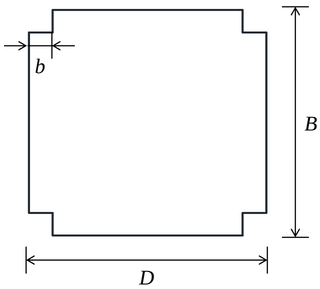
2. WIND TUNNEL TEST

In this study, 1:600 scale models of tall buildings with 160 m height were used for High-Frequency Force Balance (HFFB) test. Based on the square shape, which is the reference shape, two types of corner modification were introduced: 1) Chamfer and 2) Recession (see Table 1). The features and dimensions of the scale-down models are summarized in Table 1. Since the modification width, *b*, is a variable that affects reduction of wind response, it was assumed to be 10% of the width (*B*) or depth (*D*) of the building based on the relevant studies (Miyashita et al., 1993; Tse et al., 2009).

Table 1. Summary of planar shape

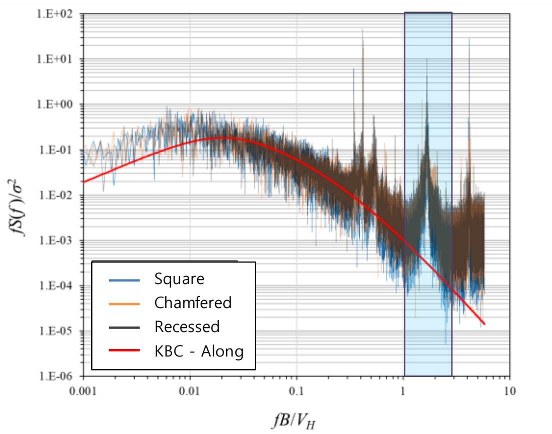
Specimen	Sq-160	Ch-160	Re-160
Corner shape	Square	Chamfer	Recession
Planar shape			
B (mm)	0	6.67	6.67
D and *B* (mm)	66.7	66.7	66.7

The wind tunnel test was conducted with 3 types of corner modification, and the PSD of measured responses was calculated. Figure 1 shows the PSD of along, across, and torsional wind loads according to the corner type. The PSD was also compared with the design PSD derived from the design wind load formula in the KBC code (red solid line). The formulas of the design PSD are shown in Eqs. (1), (2), and (3).

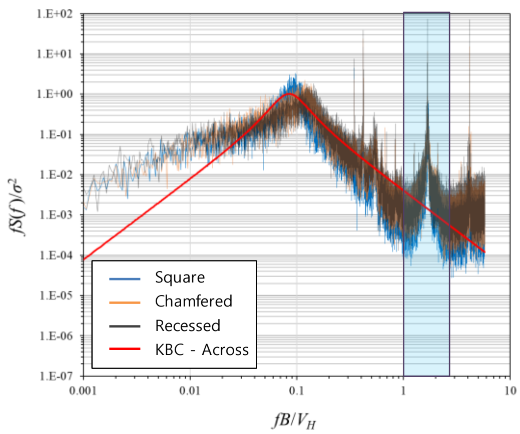
Along wind:
$$\frac{fS_v(f)}{\sigma_v^{\,2}} = \frac{4\,fL_H/V_H}{\left\{1+71\left(fL_H/V_H\right)^2\right\}^{5/6}} \tag{1}$$

Across wind:
$$\frac{fS_L(f)}{\sigma_{M,L}^2} = \sum_{j=1}^{m} \frac{4k_j\left(1+0.5\beta_j\right)\beta_j}{\pi} \frac{\left(f/n_{pj}\right)^2}{\left[\left\{1-\left(f/n_{pj}\right)^2\right\}^2 + 4\beta_j^{\,2}\left(f/n_{pj}\right)^2\right]} \tag{2}$$

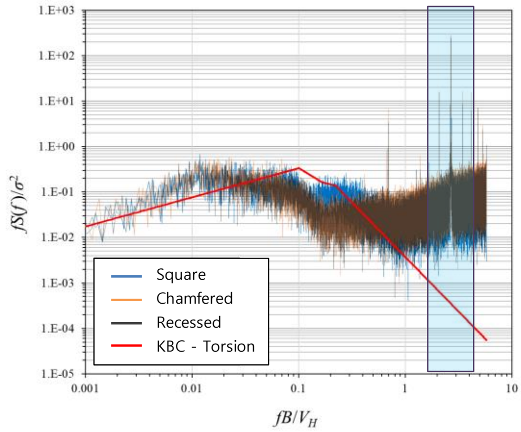
Torsional wind:
$$\frac{fS_T(f)}{\sigma_T^2} = \begin{cases} \dfrac{0.14K_T^2\left(V_T^*\right)^{2\beta_T}}{\pi} \dfrac{D\left(B^2+D^2\right)^2}{L^2B^3} \\ S_{T,4.5}\exp\left[3.5\ln\left(\dfrac{S_{T,6}}{S_{T,4.5}}\right)\ln\left(\dfrac{V_T^*}{4.5}\right)\right] \end{cases} \tag{3}$$



(a) Along wind



(b) Across wind

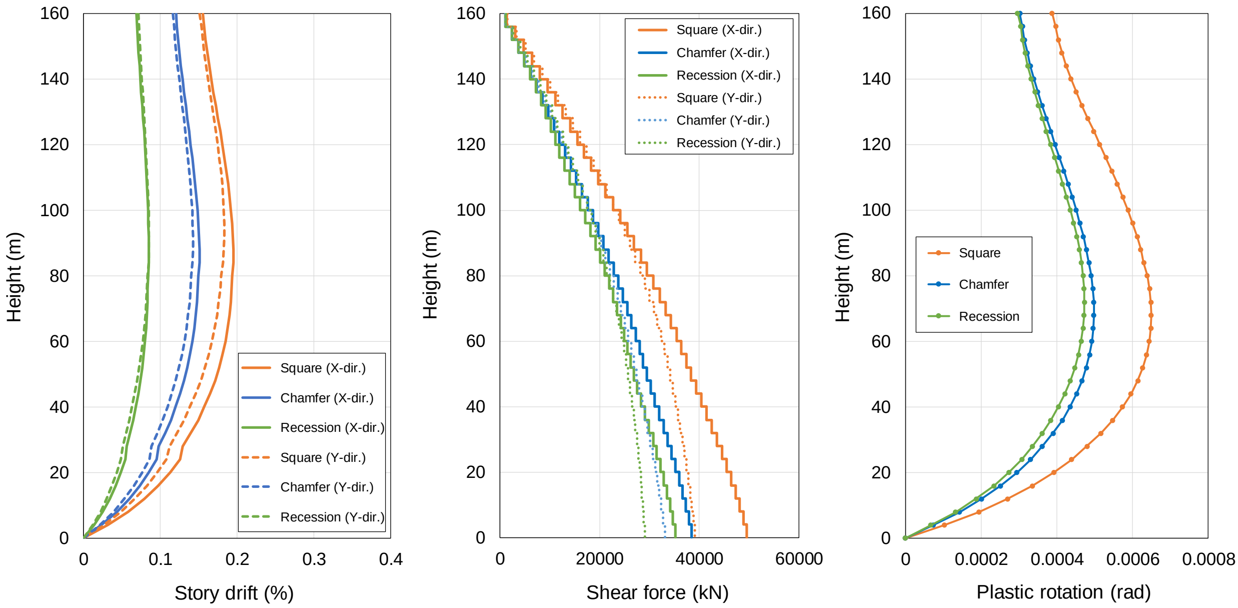


(c) Torsional wind

Fig. 1 PSD of wind loads for test models

3. NUMERICAL ANALYSIS

To investigate the response of real scale structural system and members using time history wind load data acquired from wind tunnel test, numerical analysis models were established. Nonlinear dynamic time history analysis was carried out. Structural system and members were initially designed based on the code. The basic wind speed and exposure category were assumed to be 38 m/s and exposure C, respectively, as were assumed for the wind tunnel test. The hysteretic behavior of coupling beams of core walls was modeled based on the previous test result of coupling beam specimens. The time history wind load data acquired from the wind tunnel test was restored into the real time-domain scale and applied to the numerical model. Figure 2 shows the results of story force, story drift, and maximum plastic rotation of coupling beams along the height. Although all three models were simulated under the same wind condition, such as basic wind speed and exposure category, story force was reduced according to the corner modification. Similarly, story drifts also were reduced according to the corner modification. The maximum plastic rotation was reduced similarly to two other responses. However, each value was significantly low compared to the yield strength, and most of the coupling beams remained elastic.



(a) Story force (b) Story drift (c) Max plastic rotation of coupling beams

Fig. 2 Nonlinear analysis results

4. CONCLUSION

As a result of this study and as well known, it is found that the wind load acting on the structural system could be reduced by corner modification of planar shape building. The results of nonlinear time history analysis show that most of the members remain elastic under the design level of wind load. This implies that the current philosophy of wind design has general conservatism in terms of the strength of coupling beams and structural systems.

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