Wind Engineering Joint Usage/Research Center
FY2016 Research Result Report

Research Field: Wind disaster and wind resistant design
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Research Number: 162002
Research Theme: Characteristics of aerodynamic damping ratios of super tall buildings with various unconventional configurations

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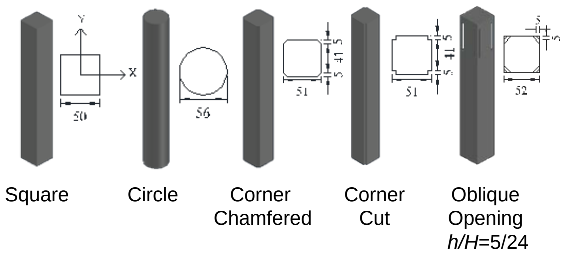
1. Research Aim

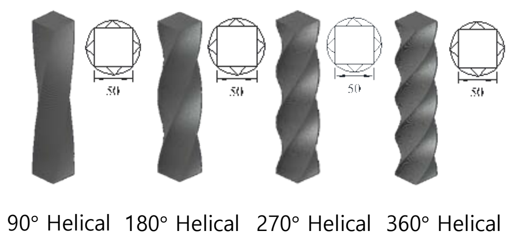
The purpose of this study is to investigate the aerodynamic damping and aeroelastic instability of super tall buildings with various unconventional configurations through an aeroelastic wind tunnel test.

2. Research Method

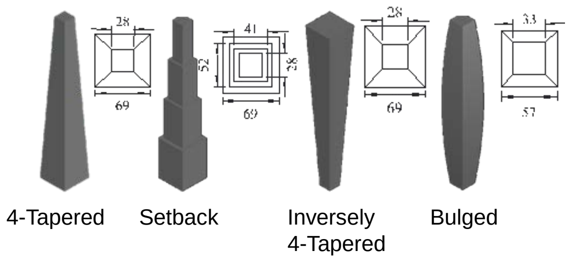
The aerodynamic damping of super tall buildings with various unconventional configurations was through the rocking vibration model (RVM) tests. The RVM test requires scaling of the dynamic properties (mass, stiffness, and frequency) of a building in the fundamental sway modes based on the similarity theory. Fig. 1 shows the rocking vibration models used on this study. Seventeen types of the super tall buildings were considered. Table 1 lists the specifications of the RVM.



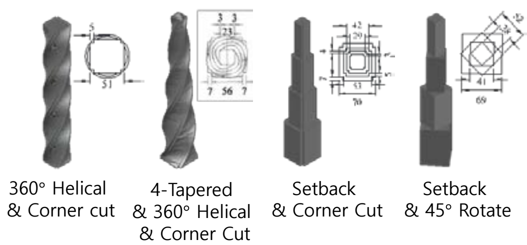
(a) Basic & corner modification models



(b) Helical models



(c) Tapered models



(d) Composite models

Fig. 1 Rocking vibration models

Table 1. Specification of rocking vibration models

	Height (m)	Moment of inertia $I_{x,y}$ (kg·m²)	Natural frequency (Hz)	Ave. structural damping ratio (%)	Model scale λ_m	Velocity scale λ_v	Design Wind speed (m/s)
Prototype	400	9.03×10^{12}	0.1	1.0	1/1	1/1	62.4
Square	0.4	0.00919	13.489	1.1	1/1000	1/7.4	8.4
Circular	0.4	0.00937	11.627	1.0	1/1000	1/8.5	7.3
Corner Chamfered	0.4	0.00889	14.160	1.07	1/1000	1/7.1	8.1
Corner Cut	0.4	0.00895	14.886	1.1	1/1000	1/6.8	9.2
Oblique opening h/H = 5/24	0.4	0.00914	11.187	1.0	1/1000	1/8.9	7.0
90° Helical Square	0.4	0.00909	12.512	1.15	1/1000	1/8.0	7.8
180° Helical Square	0.4	0.00887	12.329	1.27	1/1000	1/8.1	7.7
270° Helical Square	0.4	0.00866	12.451	1.15	1/1000	1/8.0	7.8
360° Helical Square	0.4	0.00887	12.329	1.11	1/1000	1/8.1	7.7
360° Helical & Corner Cut	0.4	0.00907	11.108	1.03	1/1000	1/9.0	6.9
4-Tapered	0.4	0.00896	12.268	1.10	1/1000	1/8.1	7.7
Inverse tapered	0.4	0.00875	11.902	1.00	1/1000	1/8.4	7.4
Setback	0.4	0.00904	11.841	1.06	1/1000	1/8.4	7.4
Bulged	0.4	0.00887	11.779	1.14	1/1000	1/8.5	7.3
Setback & Corner cut	0.4	0.00930	11.291	1.14	1/1000	1/8.9	7.0
Setback & 45° Rotate	0.4	0.00909	11.536	1.06	1/1000	1/8.7	7.2
4-Tapered & 360° Helical & Corner Cut	0.4	0.00857	11.597	1.06	1/1000	1/8.7	7.2

The full-scale dimensions of the building were 50 m and 400 m as the width and height, respectively, and its aspect ratio (H/B) was 8. The model scale was set at 1/1000 by a limit of the mass ratio. The mass ratio was estimated as $I_{x,y}/\rho B^2 H^3$ using the moment of the inertia $I_{x,y}$ in the x and y directions for a rigid body rotation at the ground level, where, ρ is the density of air (= 1.22 kg/m^3) and B and H are the breadth and height, respectively, of the building. The density of the building was set as 176 kg/m^3 because super tall buildings are typically lightweight. The first mode frequency of the real building was assumed as 0.1 Hz. The structural damping ratio was set to 0.5%. Damping estimation from response of a system is generally used for auto correlation function technique, the half power band width technique and the random decrement technique (RDT). However, the auto-correlation function technique and the half power bandwidth technique both require strict stationary of data to estimate accurate damping. The RDT can be useful to estimate more accurate damping for non-stationary and non-linear response of a system. Further, the RDT can redeem the problems encountered in damping estimation from the half power bandwidth of the spectral densities estimated using the FFT algorithm. Therefore, the RDT is chosen to evaluate aerodynamic damping in this study.

3. Research Result

Figs. 2 and 3 show the normalized mean and rms of the displacement responses of super tall buildings with various unconventional configurations at the design wind velocity which is the reduced velocity was 12.4. As shown in Figs. 2 and 3, the dashed line indicates the normalized mean and rms displacement responses for square model. From Fig. 2, Normalized mean displacements for all test models were smaller than those of the square model. Notable observation was that normalized mean displacement responses for composite model were most effective for reducing the mean wind loads. In Fig. 3, interesting observation was that both normalized along-wind and crosswind rms responses for basic and corner modifications, helical, tapered and composite models were smaller than those of the square model expect in inversely 4-tapered and bulged models. Particularly the helical and composite models showed a better aerodynamic behavior in crosswind direction.

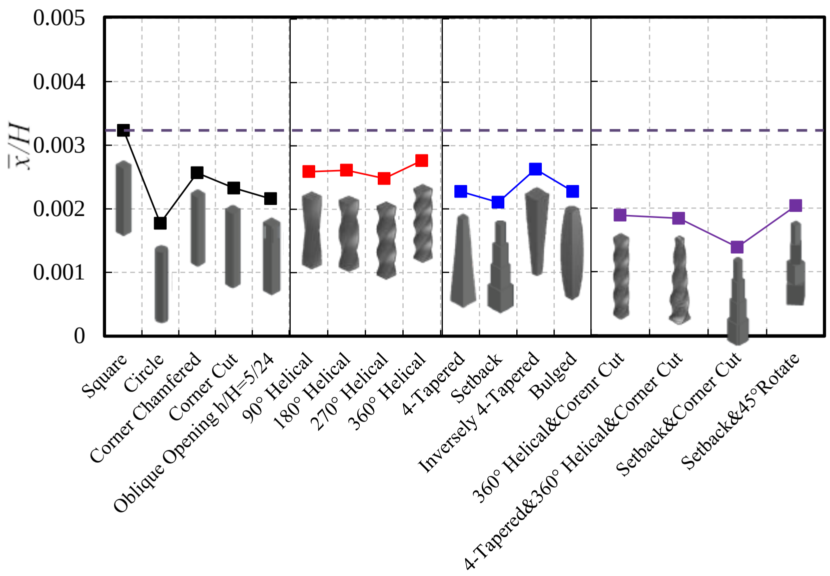


Fig. 2 Normalized mean displacements on super tall building at design wind speed

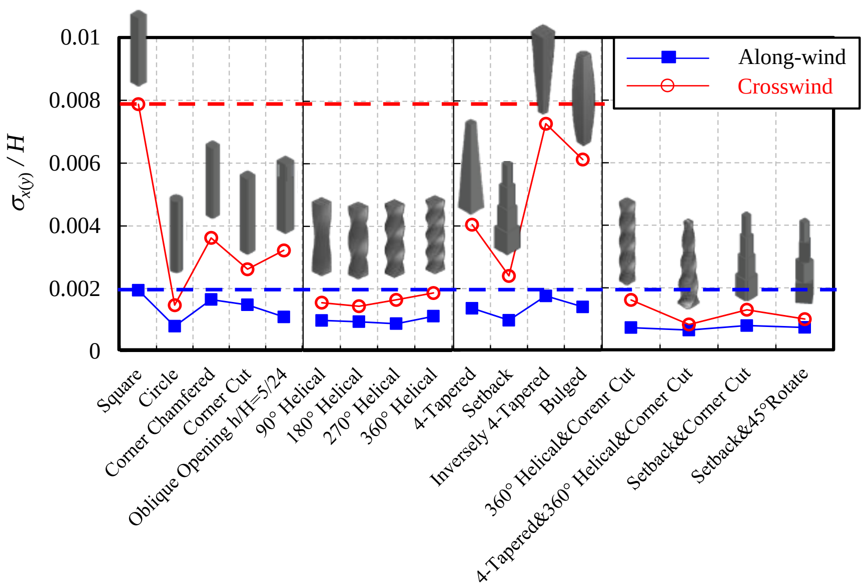


Fig. 3 Normalized rms displacements on super tall building at design wind speed

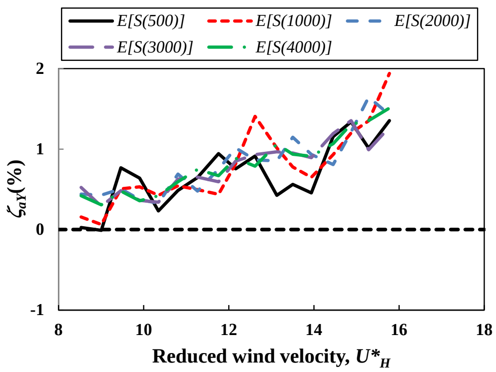
In the evaluation of the aerodynamic damping ratios, the RDT is widely used to identify the dynamic characteristics of the structures subjected to ambient loads as employed in this study, as follows:

$$a(\tau) = \frac{1}{N}\sum_{i=1}^{N} \omega(t_i) x(t_i + \tau)\Big|_C \tag{1}$$

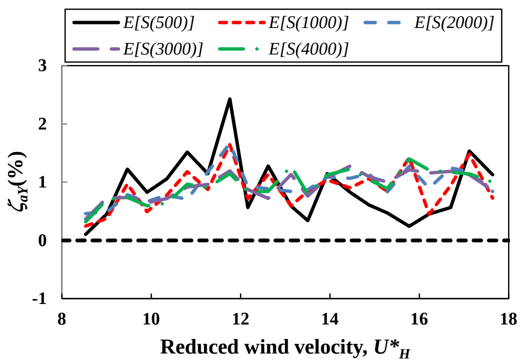
where, $a(\tau)$ represents the random decrement (RD) signatures, and N, $\omega(t_i)$, and C are the number of samples, weight coefficients, and triggering level for determining the time segment. In this study, the standard deviation of the displacement response was used to determine the triggering level. Superimpositions were carried out using the data extracted outside the natural frequency using a band-pass filter. The number of samples to evaluate the total damping ratio was chosen to be > 4500 samples. Next, the aerodynamic damping ratio ζ_a is calculated by subtracting the structural damping ratio ζ_s from the total damping ratio ζ_t as follows:

$$\zeta_a = \zeta_t - \zeta_s \tag{2}$$

In an RDT, it is important to define the length of the time segment that is extracted from response time histories, and approximate the number of the time segments to obtain the desired effects of the time segment averaging of the RD signature. Here, the effect of the number of time segments (triggering points) in the evaluation of the aerodynamic damping was investigated. Figs. 4-5 show the effect of the time segments for estimating the aerodynamic damping ratio of the 180° helical and square models. As can be seen from Figs. 4-5, the aerodynamic damping ratios for the 180° helical and square models exhibit a similar trend, regardless of the shape of the model and the along-and across-wind direction. It is found when the number of time segments is small, a higher fluctuation in the aerodynamic damping ratio with the reduced velocity is observed In contrast, when the number of time segments is large, the aerodynamic damping ratio converges to a constant value with an increase in the number of time segments. It should be noted that it is necessary to conduct tests on at least 2,000 time segments in order to obtain the appropriate aerodynamic damping ratio as shown in Figs. 4–5.

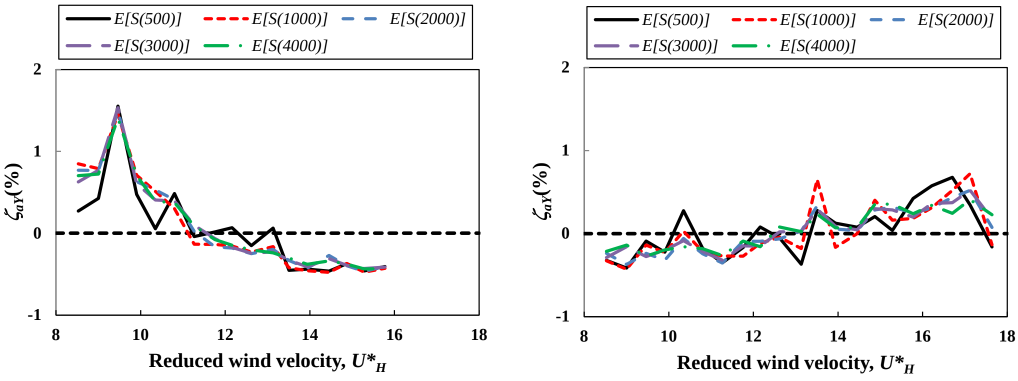


(a) Square model



(b) 180° helical model

Fig. 4 Effect of the time segments in estimating the aerodynamic damping ratio in the along-wind direction



(a) Square model (b) 180° helical model

Fig. 5 Effect of the time segments in estimating the aerodynamic damping ratio in the across-wind direction

The aerodynamic damping ratio and aeroelastic instability of super tall buildings with various unconventional configurations were studied through wind tunnel experiments using RVM. Aerodynamic damping ratios for super tall building models with various unconventional configurations were evaluated by RDT. The major results are summarized below:

(1) For normalized mean displacement responses, all super tall building models showed better aerodynamic behaviors except in tapered models as such inversely 4-tapered and bulged models.

(2) For normalized along-wind rms displacement responses, circular, oblique opening, 4-tapered, setback, helical and composite models showed better aerodynamic behaviors except in corner modification models such as chamfered and corner cut models, and tapered models such as inversely 4-tapered and bulged models whose are similar trends or slightly decrease from that of square model.

(3) For normalized crosswind rms displacement responses, corner modification models, helical models, tapered models and composite models show better aerodynamic behaviors except in tapered models as such inversely 4-tapered and bulged models.

(4) Aeroelastic instability for super tall building models with various unconventional configurations was not observed for any of the reduced velocities except inversely 4-tapered and bulged models.

(5) In along-wind direction, the distribution of aerodynamic damping ratios for corner modification models, helical models, tapered models and composite models showed similar to those of the square model except in case of circular model. However, the amplitudes of the aerodynamic damping ratios were similar or slightly higher than those of the square model.

(6) In crosswind direction, the aerodynamic damping ratios of helical and composite models were quite different from those of the square model. The aerodynamic damping ratios of helical and composite models were distributed near zero, or slightly increased while the aerodynamic damping ratio for the square model rapidly decreased when the reduced velocity > 9, and the positive aerodynamic damping ratio changed to a negative aerodynamic damping ratio.

(7) There was almost no effect on changing of the twist angle for helical model in aerodynamic damping ratios, and displacement responses in along-wind and crosswind directions. It implies that the aerodynamic characteristics have not been improved by the changing of the twist angle of helical model.

4. Published Paper etc.
[Underline the representative researcher and collaborate researchers]

[Published papers]

1. Wonsul Kim, Akihito Yoshida, Yukio Tamrua, Kazuo Ohtake, Jin-Hak Yi (2017), Experimental Study of Aerodynamic Damping of a Twisted Supertall Building, Journal of Wind Engineering Industrial Aerodynamics (Under reviewed)
2. Wonsul Kim, Jin-Hak Yi, Yukio Tamura (2017), Characteristics of Aerodynamic Damping on Helical-Shaped Super Tall Building, Journal of the Korean Society of Civil Engieers, Vol. 37, No. 1, pp. 9-17 (In Korean)

[Presentations at academic societies]

1. Wonsul Kim, Jin-Hak Yi, Yukio Tamura, Kazuo Ohtake, Akihito Yoshida (2016), Aerodynamic Damping of Helical Shaped Super Tall Building, The 2016 World Congress on Advances in Civil, Environmental and Materials Research (ACEM16), Jeju Island, Korea, August 28-September 1

[Published books]
1. None.

[Other]
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