Wind Engineering Joint Usage/Research Center
FY2018 Research Result Report

Research Field: Wind Hazard Mitigation/Wind Resistant design
Research Year: FY2018
Research Number: 182004
Research Theme: Interfered structural responses of square and tapered prisms due to vibrating identical prisms
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Budget [FY2018]: 260000Yen

*There is no limitation of the number of pages of this report.
*Figures can be included to the report and they can also be colored.
*Submitted reports will be uploaded to the JURC Homepage and etc.

1. Research Aim

From the JURC 2015 project, Lo et al. (2016) demonstrated the significant amplified responses of high-rise buildings due to critical interference locations, not only the location (x, y) = (2B, 2B) but also the close downstream location (-2B, 0). Two dimensional CFD simulation technology was adopted to enhance the explanation of the downstream interference mechanism. Besides that, an inclined elliptical response trajectory was found at (-1.5B, 1.5B) under reduced velocity of 6.0, which was also mentioned by Bailey and Kwok (1985). From the JURC 2016 project, Lo et al. (2016) adopted three different configurations for the principal building model to demonstrate the aerodynamic modification performance on reduction efficiency of wind force and dynamic response. It was indicated that wind forces could be largely suppressed at most interference locations; however, with the aerodynamic modification provided by the tapered model, dynamic response could be amplified severely and critical interference effect may occur at different locations. On the other hand, the aerodynamic modification provided by the helical tapered model not only lower the wind force in general, but also the dynamic responses at all locations. Reduction efficiency in terms of interference factor was also discussed. The JURC 2017 project continued to investigate how a vibrating interfering model affect the aero-dynamic behavior of the principal model by manufacturing an identical model with the same fundamental frequencies. Although no significant difference was found except for upwind locations, aero-dynamic damping ratios and structural frequencies were identified with varying reduced velocities for a better understanding of upstream and downstream interference effects. Moreover, Lo et al. (2017) examined the force-driven responses with measured responses, fluctuating displacement and peak acceleration, to show the difference caused by different experimental approaches. Generally speaking, tapered model has better performance in reducing wind-induced response at most reduced velocities. From these preliminary results from JURC 2015, 2016 and 2017 projects, systematic experiments were well established. Table 1 lists the parameters adopted in the past three years.

Interference effects caused by the neighboring buildings could be categorized into many parametric studies and last for long times. It is always possible to change the configurations of the principal buildings or the interfering buildings, or to change the flow conditions, interference locations, number of interfering buildings, and so on, to have a huge amount of experimental data for analysis.

Table 1 Parameters for both principal and interfering buildings in JURC 2015, 2016, and 2017

Flow Condition	ABL $\alpha = 0.19$
Flow Velocity	2.0 ~ 8.0 m/sec at boundary layer height in 0.5 m/sec resolution
Principal Building	[1] Square prism model (SQ) [2] Tapered model (TA) [3] 180° helical tapered model (HT)
Scale factors	$\lambda_{Length} = 1/400$ $\lambda_{Velocity} = 1/20$ $\lambda_{Time} = 1/20$
Data acquisition	$f_s = 550$ Hz Segment length: 16,384 Segment No.: 10
Interference location	x/B = -3.0 ~ 3.0 y/B = 0.0 ~ 3.0 (Grid resolution 0.5B)

Principal Building	SQ	TA	HT
Generalized mass	100g ~ 150g		
Structural freq. f_x	6.0 Hz ~ 6.7 Hz		
Structural freq. f_y	6.0 Hz ~ 6.7 Hz		
Damping ratio ξ_x	0.5% ~ 1%		
Damping ratio ξ_y	0.5% ~ 1%		
$H/(BD)^{0.5}$	8		

Interfering Building (Square and Tapered)
Rigid square prism model of $H/(BD)^{0.5} = 8$
Vibrating square prism model of $H/(BD)^{0.5} = 8$

In the application status, the research work in the JURC 2018 project intends to extend the studies of square and tapered prism models under interference effects via the observation of vibration responses and aerodynamic damping ratio identifications with the installation of accelerometers on the rooftop of the principal models. Besides that, the interfering model is manufactured to be able to vibrate in the same frequency of the principal model and in the same shape of the square prism model. Figure 1 and 2 show the accelerometer and the diagram of the vibrating interfering model.

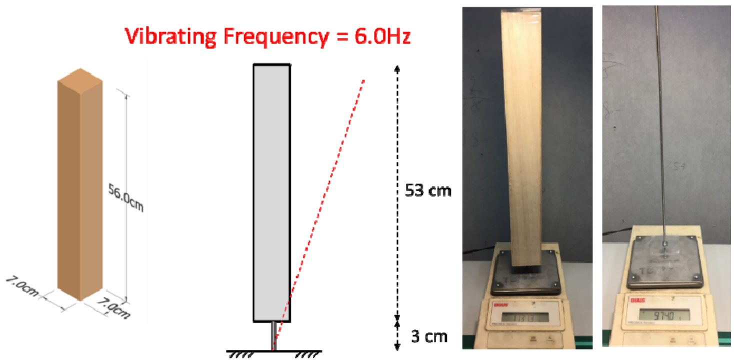

Figure 1 Vibrating interfering building model for JURC 2017

Figure 2 Photo of accelerometer

Scruton numbers for the principal prism models in the JURC 2015 – 2017 were assumed to be small to be sensitive to the reduced velocity change. In the JURC 2018 project, the systematic damping ratio is adjusted to achieve higher Scruton numbers by tuning the height of the magnetic damper under the principal model. Figure 3 shows the photo of the magnetic damper.

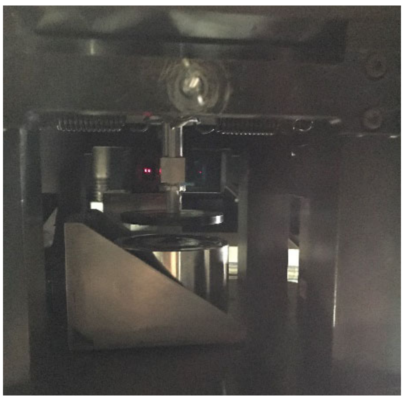

Figure 3 Photo of magnetic damper

2. Research Method

The main research tool applied in this study is the aero-elastic vibration test under various reduced velocities. The test is conducted in the 18.0 × 1.8 × 2.2 m boundary layer wind tunnel of Wind Engineering Research Center at Tokyo Polytechnic University. A 1/400 scale turbulent flow over a sub-urban terrain with a power law index exponent for mean velocity profile of 0.19 is simulated with properly equipped spires, saw barriers, and roughness blocks. Figure 4 shows the turbulence characteristics of oncoming winds.

Due to the limitation of budget and time, the research team decided to ignore the cases of tapered prism model as the principal model and focused on the variation of Scruton numbers for the cases of square prism model. The square prism model is 0.07 m in both width (B) and depth (D) and 0.56 m in height (H), which make the aspect ratio (H/B) 8. Two Scruton numbers are obtained based on parameters in Table 2.

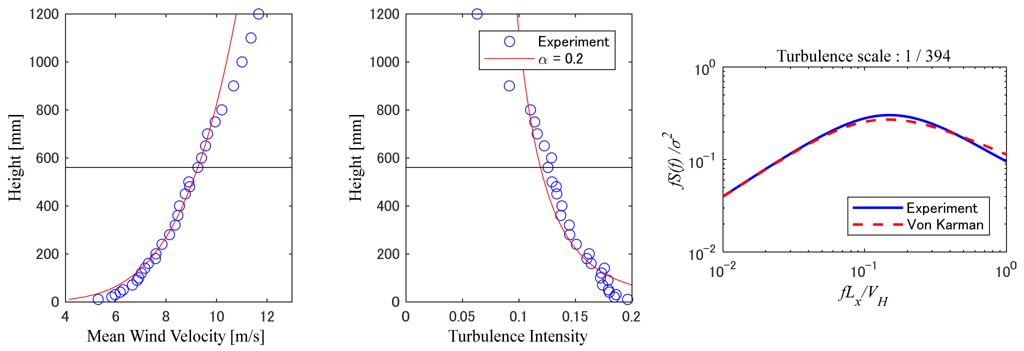

Figure 4 Turbulence characteristics of approaching flow

Table 2 Parameters for Scruton numbers

	Direction	Generalized mass (kg)	Frequency (Hz)	Damping ratio	S_{cr}
Low S_{cr}	Along-wind	0.13	5.98	0.0134	1.59
	Across-wind	0.13	5.74	0.0152	1.80
High S_{cr}	Along-wind	0.13	5.74	0.0293	3.47
	Across-wind	0.13	5.49	0.0380	4.50

The corresponding mass-damping parameter is determined by

$$\delta = \frac{M\xi}{\rho B^2 H} \tag{1}$$

where ρ is the air density. M is the generalized mass. ξ is the damping ratio. Scruton numbers can be estimated based on the linear mode shape assumption of its rigid elastic feature. Generally speaking, in this range of lower Scruton numbers, the across-wind response of an isolated square prism model will increase significantly when the reduced velocity rises to values larger than 9 or 10. The displacement signals of both directions are recorded by two laser sensors at the sampling rate of 550 Hz. The sampling length is 16,384 for one sample record and the ensemble size is 10 in order to obtain a statistical result. Besides that, the acceleration signals in the two directions are also measured by the setting in the photo in Figure 5.

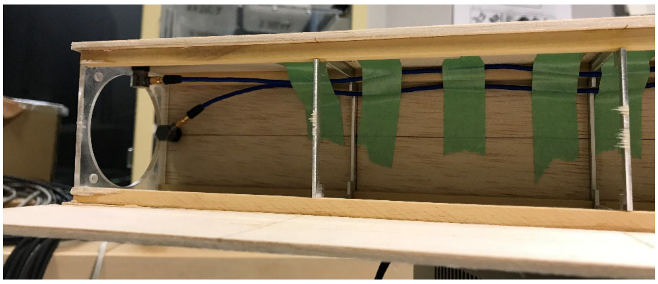

Figure 5 Two accelerometers installed at the rooftop

The interfering building model is made of Basald wood and has the identical size as the square prism model. In order to make the interfering model vibrate at the same frequency of the principal model, the diameter of the rod is adjusted and free vibration test is carried out. Figure 1 shows the rod inside the wooden surface of the model and the integrated model. The interference locations of interest are focused on those considered significant in the surrounding area, as shown in Figure 6. Both the principal and interfering models are orientated with one face normal to the wind when both tests are carried out. Five location series including the upwind series, the oblique-upwind series, the side series, the oblique-downwind series and the downwind series are selected for observing different interference mechanisms.

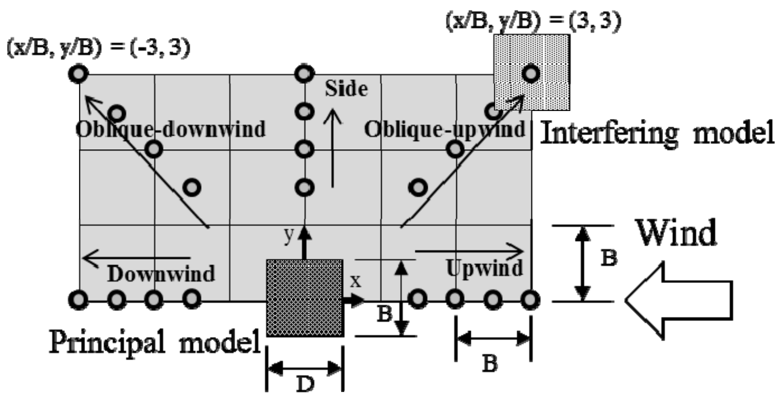

Figure 6 Interference locations concerned in this study

3. Research Result

Results are focused on those significantly affected typical interference locations, (x/B, y/B) = (2, 2) and (-2, 0), and their nearby locations for gradual variation observation. Across-wind responses due to two Scruton numbers are plotted in Figure 8 and 9 for directly measured acceleration signals and derived acceleration responses from laser displacement sensors compared to the isolated case in

Figure 7.

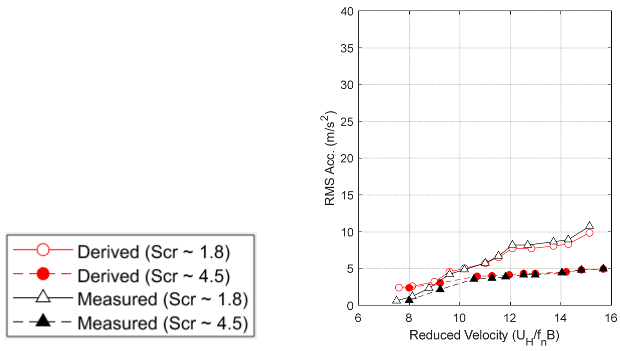

Figure 7 Across-wind response of the isolated case

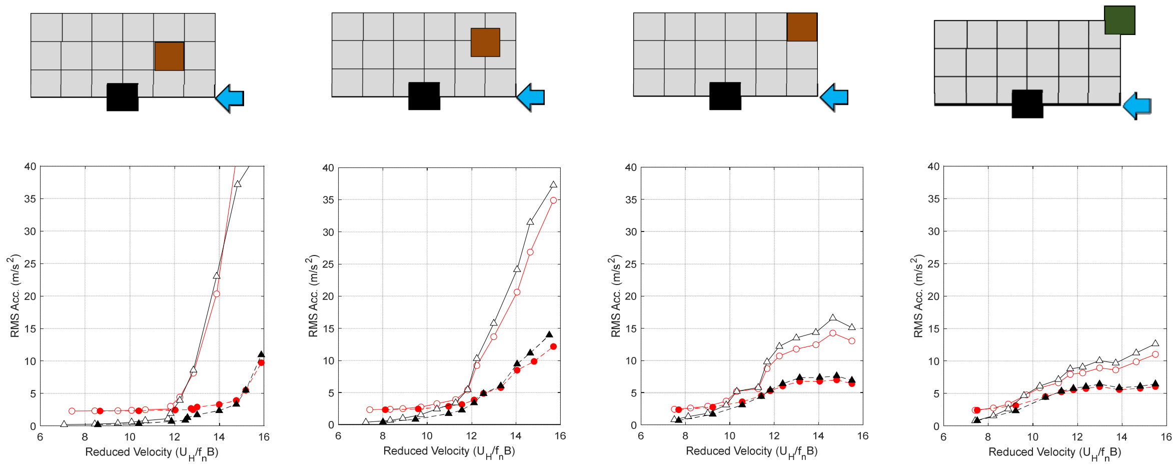

Figure 8 Across-wind responses of oblique-upwind locations

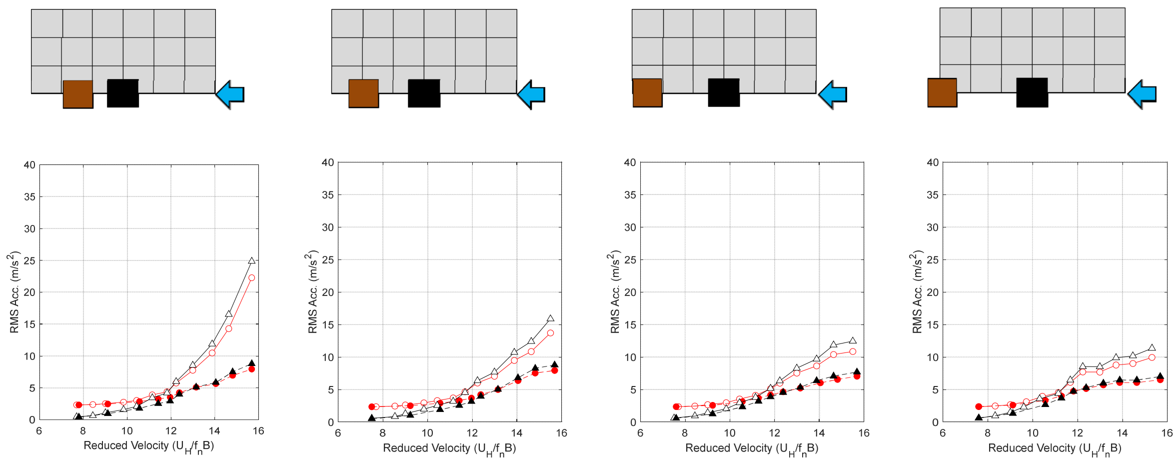

Figure 9 Across-wind responses of downwind locations

Figure 8 shows those cases of oblique-upwind locations for the dummy model located from far locations to close locations to the principal model. It is clear that the measured acceleration signals agree quite well with those derived from displacement signals. Strictly speaking, farther than the location of (3, 3), less interference effect can be seen. For the two cases nearest the principal model, (1.5, 1.5) and (2.0, 2.0), the across-wind responses are dramatically increased from reduced velocity at 11. Two Scruton numbers have quite different interference effects from the oblique-upwind dummy models. The lower Scruton number cases seem to be in the galloping range according to its amplified amplitude ratio of response to its width. The higher Scruton number cases are largely suppressed, which corresponds to previous observations and conclusion from literature, i.e., only small Scruton number makes the interference effect clear.

Again, from Figure 9, the higher Scruton number cases show almost the same results as the isolated case. The downstream interference effect only shows at the location of (-1.5, 0) and (-2.0, 0) in the lower Scruton number cases. This also corresponds to previous conclusions from the JURC 2015 – 2017 reports. Recalling those settings in JURC 2015 -2017 reports, Scruton numbers were about 1.0, even lower than the lower Scruton number cases here. Therefore, in those reports, the downstream interference effect was clearly observed and made quite difference estimated responses from those based on HFFB tests.

Previously in the presumed schedule, a tapered prism model was attempted for shape comparison discussion and more Scruton numbers were expected for a better parametric analysis. However, the adjustment of changing damping ratio and the control of Scruton number were difficult for this current status. From this year's results, the accelerometers are proved to be able to provide good information for discussion, and the variation of interfered responses due to the variation of Scruton numbers is pointing out the differences of upstream and downstream interference effects. There are several potential research issues left for the future work:

1. Upstream/downstream interference effect mechanism due to different Scruton number range under wider reduced velocities.
2. Aerodynamic damping approximations for upstream/downstream interference effects for estimation compared with HFFB test results.
3. Investigation on the elliptical response trajectory at the location oblique-downwind location at reduced velocity of 6.
4. Shape modification of the principal model to the amplification/reduction of interference effects.

4. Published Paper etc.

[Underline the representative researcher and collaborate researchers]
[Published papers]

[1] Yuan-Lung Lo, Yong Chul Kim, Estimation of Wind-induced Response on High-rise Buildings, Journal of Applied Science and Engineering (ESCI, Under Reviewing).
[2] Yuan-Lung Lo, Yong Chul Kim, Akihito Yoshida, 2017 Sep., Effects of aerodynamic modification mechanisms on interference from neighboring buildings, Journal of Wind Engineering and Industrial Aerodynamics, Vol.168, p271-287. (SCI) https://doi.org/10.1016/j.jweia.2017.06.018
[3] Yuan-Lung Lo, Yong Chul Kim, Yi-Chao Li, 2016 Dec., Downstream interference effect of high-rise buildings under turbulent boundary layer flow, Journal of Wind Engineering and Industrial Aerodynamics, Vol.159, p19-35. (SCI) https://doi.org/10.1016/j.jweia.2016.10.002

[Presentations at academic societies]

[1] Yuan-Lung Lo, Yi-Chao Li, Yong Chul Kim, Jun 2018, Interference Effects of High-rise Building Based on Idealized CFD Simulation, The 7th International Symposium on Computational Wind Engineering 2018. Seoul, Korea.
[2] Yuan-Lung Lo, Yong Chul Kim, Akihito Yoshida, Jul 2017, Aero-elastic Behavior of High-rise Buildings under Downstream Interference Effects, European and African Conference on Wind Engineering 2017. Liege, Belgium.
[3] Yuan-Lung Lo, Yong Chul Kim, Yi-Chao Li, Oct 2016, Downstream Interference Effect of High-rise Buildings under Turbulent Boundary Layer Flow, 14th International Symposium on Structural Engineering. Beijing, China.
[4] Yuan-Lung Lo, Yong Chul Kim, Jul 2016, Downstream Interference Effects between Two Identical Square Buildings under Turbulent Boundary Layer Flow, 2016 Asian Conference on Civil, Material and Environmental Sciences. Sapporo, Japan.
[5] Yuan-Lung Lo, Yong Chul Kim, Nov 2015, Interference Effects on Across-wind Response of a Square Prism Based on Aero-elastic Tests, 2015 Symposium on Progress in Wind Engineering and Structural Dynamics. Tamsui, Taiwan.

[Published books]
No.

[Other]
No.

5. Research Group

1. Representative Researcher
   Yuan-Lung Lo
2. Collaborate Researchers
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   2. Akihito Yoshida
   3. Yi-Chao Li

6. Abstract (half page)

Interfered structural responses of square and tapered prisms due to vibrating identical prisms

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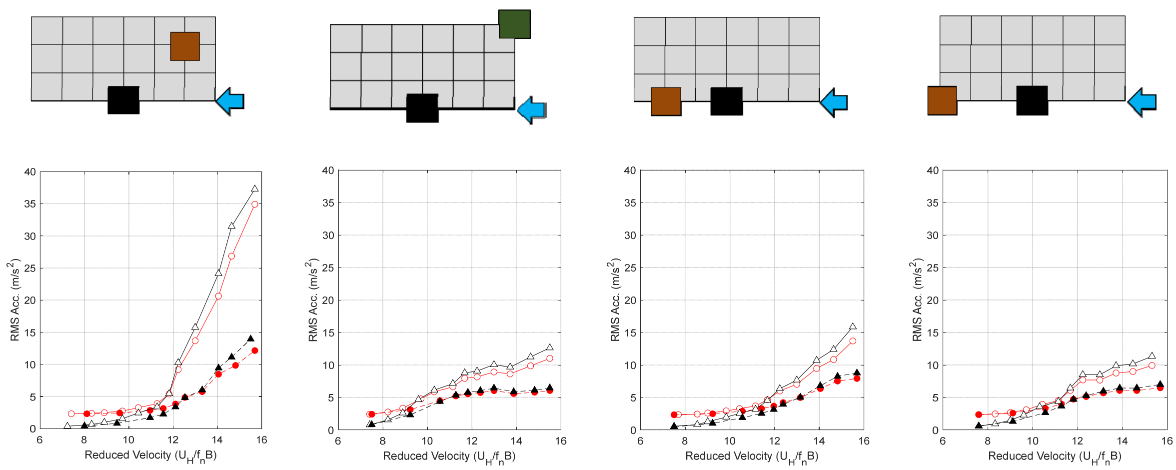
Summary

The main methodology adopted for this research is vibration measurement tests in a well simulated boundary layer flow. The square cross section model is adopted for the principal model and the interfering building has the identical geometric size. Two Scruton numbers are adjusted by changing the height of the magnetic damper. Displacement and acceleration signals are simultaneously measured. Results show that the measured acceleration signals agree quite well with those derived from displacement signals. Two Scruton numbers have quite different interference effects for the oblique-upwind dummy models. The lower Scruton number cases seem to be in the galloping range according to its amplified amplitude ratio of response to its width. The higher Scruton number cases are largely suppressed, which corresponds to previous observations and conclusion from literature, i.e., only small Scruton number makes the interference effect clear. For the downstream interference, the higher Scruton number cases show almost the same results as the isolated case. The downstream interference effect only shows at the location of (-1.5, 0) and (-2.0, 0) in the lower Scruton number cases. This also corresponds to previous conclusions from the JURC 2015 – 2017 reports. Recalling those settings in JURC 2015 -2017 reports, Scruton numbers were about 1.0, even lower than the lower Scruton number cases here. Therefore, in those reports, the downstream interference effect was clearly observed and made quite difference estimated responses from those based on HFFB tests.



(x/B, y/B) = (2, 2) (x/B, y/B) = (3, 3) (x/B, y/B) = (-2, 0) (x/B, y/B) = (-3, 0)

Figure 1 Typical cases for two Scruton number variation