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Research on wind-induced interference effect of adjacent super tall buildings based on two-aeroelastic-model wind tunnel test

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SUMMARY:
Due to the close proximity of super high-rise buildings in densely populated urban centers, the significant impact of wind-induced interference on adjacent structures must be taken into consideration. Previous research did not employ two aeroelastic models to investigate the wind-induced interference effect between two adjacent super-tall buildings. As a result, the aeroelastic effect and wind-induced interference effect could not be well reflected. In this paper, based on a series of two-aeroelastic-model wind tunnel experiments, the aerodynamic interference effect of the across-wind response of two adjacent square high-rise buildings is studied. The influences of interference location, reduced wind speed, dynamic characteristics, and model type on the aerodynamic interference factors of across-wind acceleration response are analyzed. The wind tunnel experiments were conducted at 35 interference locations, with 18 reduced wind speeds tested at each location, and contour maps of the interference factors were obtained as a result. Subsequently, wind tunnel experiments are performed on a one-rigid-one-aeroelastic building model at typical interference locations. Upon comparing the results of two kinds of wind tunnel experiments, it was observed that there were significant variations in aerodynamic damping and interference factors. These findings prompted an exploration of the wind-induced dynamic interference mechanisms.

Keywords: Aeroelastic model wind tunnel test; Interference factor; Aerodynamic damping.

1. INTRODUCTION

As urbanization accelerates, an increasing number of super high-rise buildings are being constructed in close proximity to each other in city centers. These buildings are characterized by their slender and flexible design, with low structural damping values that increase their vulnerability to wind-induced excitations. Aerodynamic interference is widely recognized as one of the most significant factors affecting wind-induced response. The mutual interference effects of adjacent buildings can either amplify or suppress aerodynamic forces and dynamic responses, potentially leading to vortex-induced resonance or aerodynamic instabilities (Lo et al., 2020). Furthermore, the aeroelastic effect of super high-rise buildings can amplify the interference effect, resulting in a negative aerodynamic damping ratio of the structure, which is another important factor influencing wind-induced response (Gu et al., 2014). This paper systematically investigates the aerodynamic interference and aeroelastic effect of super high-rise buildings through two-aeroelastic-model wind tunnel experiments designed to replicate a more realistic aeroelastic effect.

2. WIND TUNNEL TEST

Table 1 provides details of the aeroelastic model based on similarity theory, which consists of skeletons, coats, bases, and mass blocks. Fig. 1 shows the skeleton of the model, which can simulate the dynamic characteristics of the structure and ensure the accuracy of the aeroelastic test results. The principal building used in the model was a square-section prism with dimensions of 0.09 m in width, 0.09 m in length, and 0.81 m in height, with an aspect ratio of 9. To simplify interfering factors, the interfering building was identical to the principal building. The wind tunnel experiments were conducted at the TJ-1 boundary layer wind tunnel at the State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University. The turbulent boundary layer flow corresponding to category D in the Chinese code was generated, and the profile of the inflow of wind tunnel experiments is shown in Fig. 2. During the test, acceleration sensors were used to measure the wind-induced response of the model. The reduced wind speeds for the test were set to include 18 different speeds between 4 and 18. The sampling frequency of the accelerometer was set at 1024 Hz, and the total sampling time for each channel at each wind direction angle was 3 min. The sampling length was 184,320.

In the experiment, the isolated condition test will be carried out first, followed by the two-aeroelastic-model wind tunnel experiments covering the range of $0 \leq X \leq 3B$ and $-3B \leq Y \leq 3B$ at 35 interference locations. The variables '*X*' and '*Y*' represent the relative position of the axes between the two models, while the variable '*B*' represents width. Each location will be tested at 18 reduced wind speeds. The results obtained from the two-aeroelastic-model tests will help identify the typical interference locations where the interference effect is more significant. Finally, experiments were conducted where the aeroelastic model at a selected location was replaced by a rigid model while keeping other variables unchanged, in order to investigate how the mechanisms of the elastic effect affect the interference effect.

Table 1. Specification of the aeroelastic model

	Prototype	Aeroelastic model	Similarity parameters
Structure height (m)	486	0.81	1/600
The mass density (kg/m^3)	220	220	1/1
Primary frequency (Hz)	0.14	12.0	85.7/1
Structure damping ratio (%)	0.55	0.55	1/1

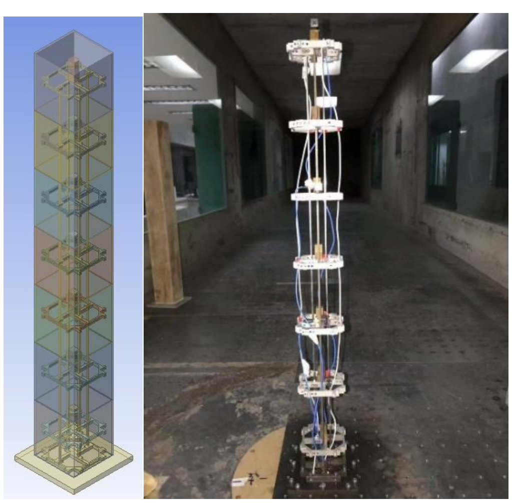


Figure 1. Skeleton of aeroelastic model

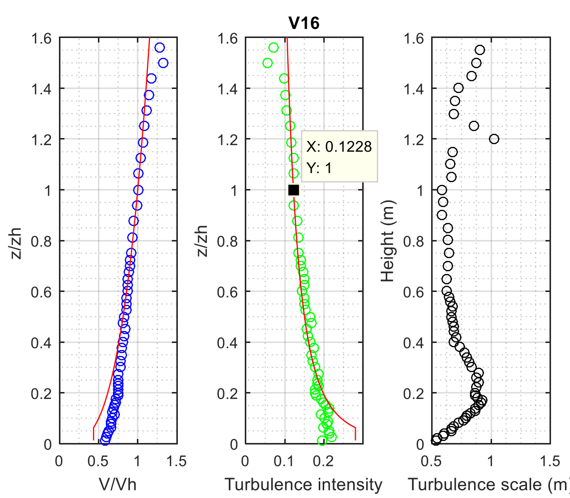


Figure 2. Simulated wind field features

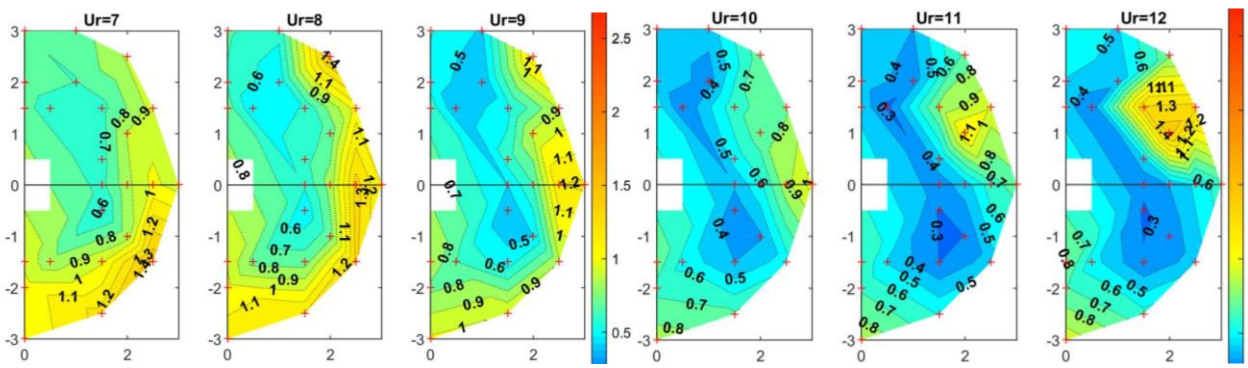
3. RESULTS AND DISCUSSION

3.1. Results of interference factor

The dynamic interference factor (*IF*) is defined as follows:

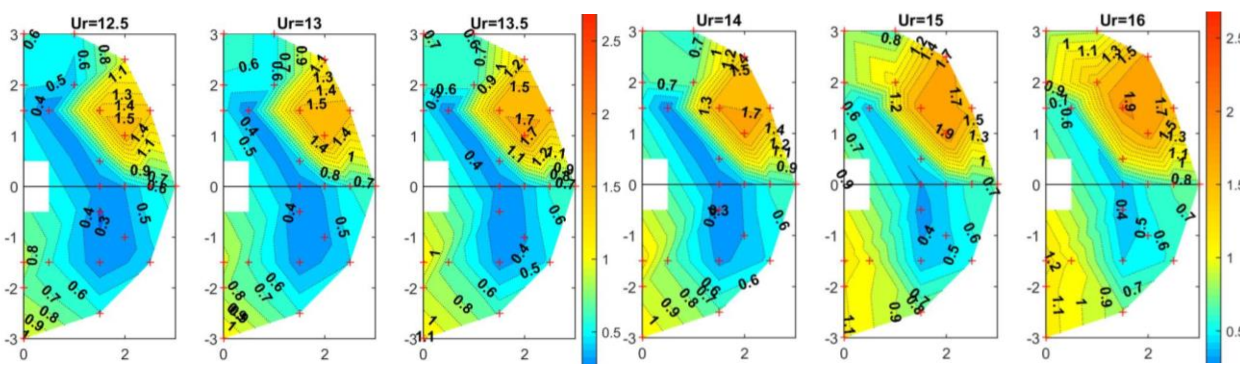
$$IF = \frac{RMS\ across\text{-}wind\ acceleration\ response\ (interferenced\ condition)}{RMS\ across\text{-}wind\ acceleration\ response\ (isolated\ condition)} \quad (1)$$

Figures 3 and 4 depict the *IF* contours for two aeroelastic models at reduced wind speeds ranging from 7 to 16. These contours reveal areas of interference suppression and amplification, enabling designers to swiftly identify hazardous and conservative interference spots. As wind speed decreases, the interference suppression area steadily shrinks, and the minimum value of *IF* remains between 0.3 and 0.4 at (1.5*B*, -0.5*B*). Conversely, the interference amplification area near (2.0*B*, 1.0*B*) continues to expand, and the maximum value of IF increases from 1.4 to 1.9. Locations with notably larger *IF* will be analyzed in further detail.



(a) U_r range from 7 to 9. (b) U_r range from 10 to 12.

Figure 3. Contours of IF of two-aeroelastic-model with medium reduced wind speeds *Ur*.



(a) U_r range from 12.5 to 13.5. (b) U_r range from 14 to 16.

Figure 4. Contours of IF of two-aeroelastic-model with high reduced wind speeds *Ur*.

3.2. Characteristics of aerodynamic damping ratio

Random decrement method (RDT) is used to identify the across-wind aerodynamic damping ratios ξ_a which is considered the main component of the aeroelastic effect. Fig. 5 shows that all ξ_a located at inclined upstream areas are negative under high reduced wind speeds which can amplify structural vibration. However, all ξ_a of paralle locations are positive under high reduced wind speeds shown in Fig. 6. That is the main reason that the interference factors (*IF*) of parallel locations are suppressed less than 1.0.

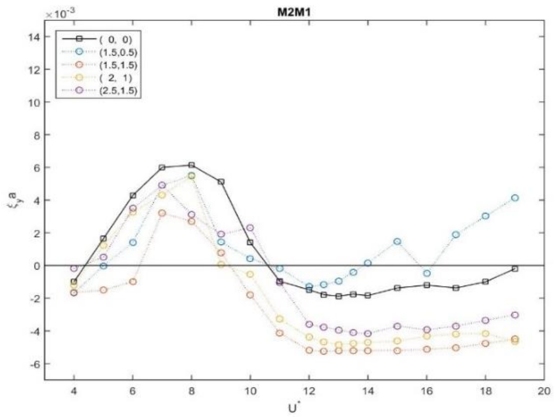


Figure 5. ξ_a of inclined upstream locations.

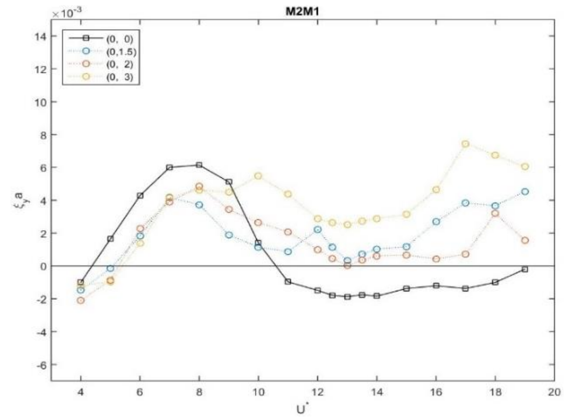


Figure 6. ξ_a of parallel locations.

3.3. Mechanism of aeroelastic effect

To investigate the mechanism of the aeroelastic effect, the location with the maximum interference factor was selected and two kinds of test results were compared at (2.0*B*, 1.0*B*). Fig. 7 and Fig. 8 illustrate the interference factors IF_a, IF_r and the aerodynamic damping ratios ξ_a, ξ_r. The subscript 'a' and 'r' denote the two-aeroelastic-model test and the one-rigid-one-aeroelastic model test, respectively. According to Fig. 7, IFr is more stable and smaller than IFa when the reduced wind speed is greater than 11. On the other hand, Fig. 8 indicates that ξ_r is more stable, and its absolute value is smaller than ξ_a when the reduced wind speed is greater than 11. Both results imply that the aeroelastic effect in the two-aeroelastic-model test is more significant than in the one-rigid-one-aeroelastic model test.

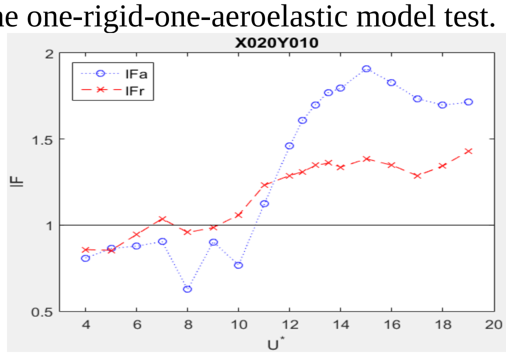


Figure 7. Interference factor at (2.0*B*, 1.0*B*) location.

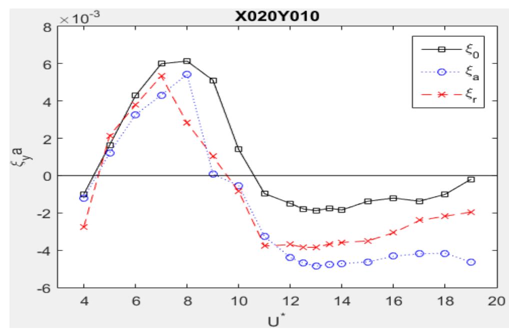


Figure 8. Aerodynamic damping at (2.0*B*, 1.0*B*) location.

4. CONCLUSIONS

In this paper, the *IF* contours of adjacent building model under reduced wind speeds are obtained by two-aeroelastic-model wind tunnl experiments. The maximum value of *IF* can reache 1.9 at the inclined upstream areas, such as (2.0*B*, 1.0*B*) where all ξ_a are negative at high reduced wind speeds, which causes the reduction of structural damping . Then, the interference aeroelastic model is replaced by the rigid model to study the real aeroelastic effect. Results point out the aeroelastic effect of two-aeroelastic-model test is more significant in most locations.

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