ICWE 16
August 27-31, 2023
FLORENCE - ITALY
16th International
Conference on
Wind Engineering

# The dynamic response of a circular cylinder using combined wind loads from two sets of data

Zhenhua Jiang [1], Yin Fai Li [1], Quincy Ma [2], Richard G.J. Flay [1]

*[1]Department of Mechanical and Mechatronics Engineering, University of Auckland, Auckland, New Zealand, zjia709@aucklanduni.ac.nz*
*[2]Department of Civil and Environmental Engineering, University of Auckland, Auckland, New Zealand*

**SUMMARY:**

A pressure-tapped circular cylinder wind tunnel model was built and used to study the segmented model test method where building response is determined by combining results from separate tests on separate part models. The circular cylinder model is assumed to be a 1: 300 scale cantilevered chimney subject to a uniform wind flow. The wind-induced dynamic responses are calculated using the time-stepping method. It is found that the coherence of the sectional lift force coefficient is underestimated if it is obtained from several independent model tests. Thus the dynamic response of the structure calculated from combining such wind loads would be severely underestimated. The dynamic responses calculated from the wind loads based on the proposed method for combining the independent wind data from separate part model tests are very close to the dynamic responses calculated from the wind loads measured from a complete model of the entire chimney. Hence the proposed method is a rational way of determining the loads and response of slender structures where independent larger scale part models have been wind tunnel tested separately.

*Keywords: Synthetic wind load, Sectional model test method, Combine wind tunnel tests*

## 1. INTRODUCTION

The traditional boundary wind tunnel faces some new challenges in testing rapidly emerging super-tall and super-slender buildings, with large aspect ratios. Complete models are difficult to test in wind tunnels due to their slenderness and low Reynolds number. Limited research has been conducted to overcome this issue by combining wind tunnel test results from multiple part-model sections in separate tests. One such study was carried out by Zhou et al. (2010), who tested separate segmented models of the Guangzhou TV tower using the High-Frequency Force Balance (HFFB) method. Since the segmented models were tested separately, the wind force spectral matrix was incomplete. To get the complete wind force spectral matrix, the authors modified a coherence function proposed by Davenport (Simiu and Yeo, 2019) for turbulence fluctuations at two different points in space and used this modified coherence function to obtain the cross-spectrum of the wind loads between the different sectional models. The present authors have developed the synthetic wind load (SWL) method for combining the sectional model test results to derive a set of wind load time histories for the entire structure (Zhenhua et al., 2022). This paper validates the approach by discussing the differences in the predictions of the dynamic response from using the SWL and wind loads from tests on the whole model.

## 2. EXPERIMENTAL MODEL AND SETUP

In this study, the surface pressures on a 2.5 m high circular cylinder model with a diameter of 0.16 m under a uniform flow were sampled simultaneously in the boundary layer wind tunnel in the Mechanical and Mechatronics Engineering Department at the University of Auckland. The reference wind speed was ~7.9 $m \cdot s^{-1}$ and the turbulence intensity was 12.8%. Two separate sets of pressure data were acquired in the wind tunnel in the same flow conditions. The sampling frequency and period of each acquisition were 400 Hz and 2 minutes, respectively.

## 3. RESULTS AND DISCUSSION

The data measured in the two separate tests are named A and B. Numbers 9, 10 and 11 correspond to the test results obtained from a ring of 16 pressure taps at instrumented levels 9, 10 and 11, respectively, as shown in Fig. 1 (a). Therefore, A10 refers to the wind load at instrumented level 10 obtained from test A and so on. The heights of the instrumented levels 9, 10 and 11 are 0.92 m, 0.96 m and 1 m above the floor, respectively. This is to avoid the influence of the boundary layer. It is found that the means and standard deviations of the wind loads from the two separate tests at the same levels are virtually identical. The normalised spectra of the lift forces from the two independent tests are also repeatable, as shown in Fig. 2 (a). The coherence between different instrumented levels is markedly affected by whether it was obtained from the same or different tests, as shown in Fig. 2 (b). The near zero coherence between A10 and B9 means that the cross-spectrum of the lift force coefficient between A10 and B9 is near zero, as expected, much reduced compared with the coherence between B10 and B9 measured simultaneously. The authors have developed the synthetic wind load (SWL) method (Zhenhua et al., 2022) for synthesising new signals based on the theoretical concept described in Fig. 1 (b), which enables the characteristics of the signal to be embodied as if it were sampled simultaneously. Fig. 2 (c) and (d) show the cross-spectra and the coherence between the synthetic lift force $A9_{syn}$ and A10, which shows that the $A9_{syn}$ data has virtually inherited the complete statistical characteristics of the $A9$ data sampled simultaneously from Test A.

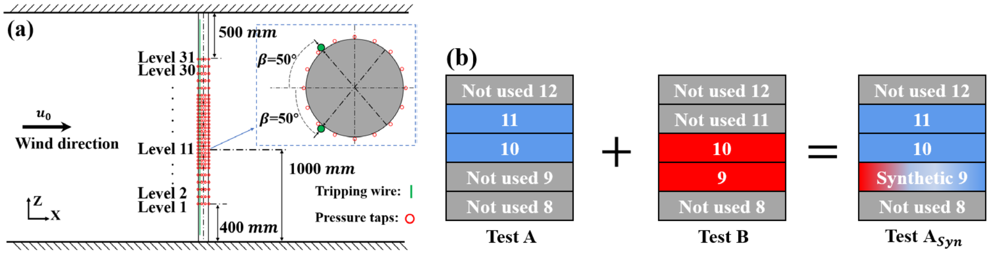

**Figure 1.** (a). Sketch showing the experimental setup; (b). Schematic diagram showing the new method concept.

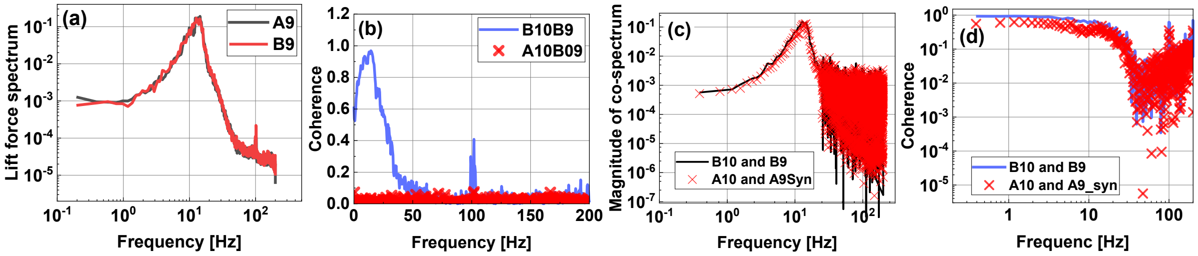

**Figure 2.** (a). Lift force spectra from two independent tests; (b) coherences between test B levels 10 and 9, and between test A level 10 and test B level 9; (c) co-spectra between B10 and B9, and between A10 and $A9_{Syn}$; (d) coherences between B10 and B9, and between A10 and $A9_{Syn}$.

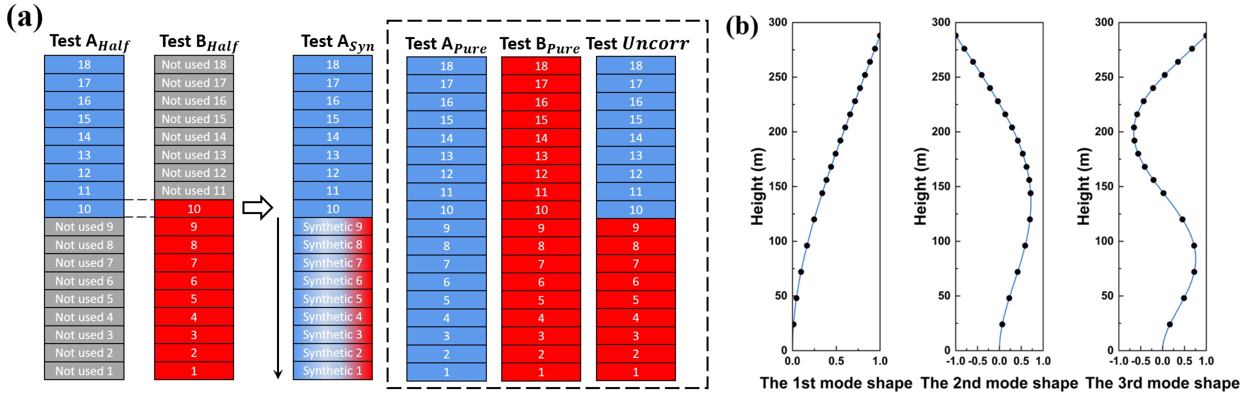

**Figure 3.** (a) Schematic figure showing how the wind loads from two part model test results are combined in the SWL approach; (b) the first three mode shapes of the chimney.

Fig. 3 (a) shows the principal concept for combining the wind loads from two part model test results where each level represents a ring of pressure taps. Test $A_{Pure}$ and Test $B_{Pure}$ refer to wind loads measured from two independent wind tunnel tests. The wind loads at levels 10 to 18 from Test $A_{Pure}$ and the wind loads at levels 1 to 10 from Test $B_{Pure}$ labelled Test $A_{Half}$ and Test $B_{Half}$, respectively. A set of wind load time histories for the entire structure can be obtained using the SWL method using the wind loads from $A_{Half}$ and Test $B_{Half}$, labelled Test $A_{Syn}$. Test *Uncorr* is a set of wind loads obtained by directly combining data from Test $A_{Half}$ and Test $B_{Half}$ without special treatment.

The circular cylinder is assumed to be a concrete chimney of uniform cross-section and mass distribution. The model scale is 1:300, resulting in a full scale chimney height and outside diameter of 288 m and 48 m, respectively. The damping ratio $\zeta$ and the wall thickness of the chimney are 3% and 0.5 m. The mode shapes and natural frequencies of the chimney have been determined using standard vibration theory and are shown in Fig. 3 (b).

The time-stepping method and modal analysis were employed to calculate the dynamic responses of displacement, velocity and acceleration (Chopra, 2017; Flay et al., 2007). Fig. 4 (a) and (b) show the standard deviations of the displacement in the $x$-and $y$-directions, respectively. The standard deviations of the displacements in the $x$- and $y$-directions from both Test $\mathrm{A}_{Pure}$ and Test $\mathrm{B}_{Pure}$ are identical, and are only slighter larger than those from Test $A_{Syn}$ derived using the SWL approach. The displacement standard deviations from Test *Uncorr* are much smaller especially in the $y$-direction.

The differences in the standard deviations of displacements between $TA_{Pure}$ the others were obtained using $Diff\ (\%) = \left|\frac{(Target-TA_{Pure})}{\mathrm{TA}_{Pure}}\right| \times 100$. Fig. 5 shows clearly that using the SWL approach to obtain the $TA_{syn}$ results gives a much smaller difference from the $TA_{pure}$ results compared with directly combining the part-model results from separate Tests A and B without regard for the lack of correlation between the independent test results, especially for the $y$-direction.

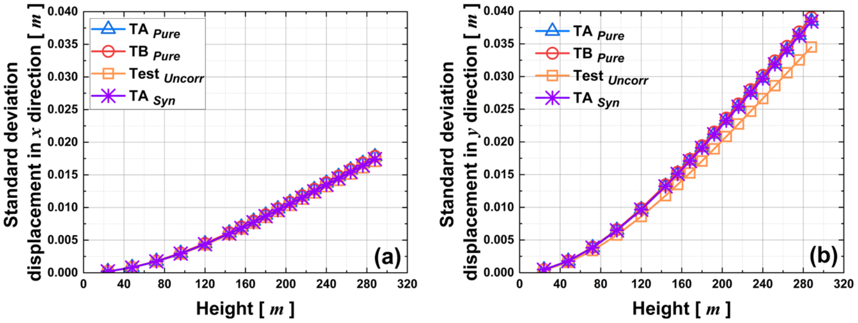

**Figure 4.** Standard deviations of the displacements across all levels in the: (a). $x$-direction; (b). $y$-direction.

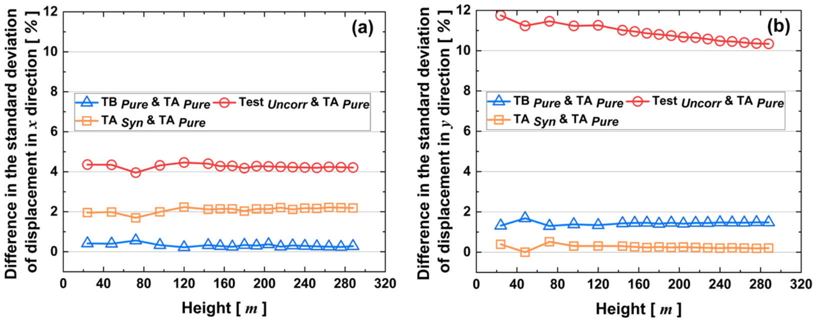

**Figure 5.** Differences in the standard deviations of displacements between $TA_{Pure}$ and the other results: (a). $x$-direction; (b). $y$-direction.

## 4. CONCLUSIONS

This paper confirms that the coherence of the sectional lift force coefficient is zero when it is obtained from models tested independently. Hence the standard deviations for the simulated chimney structure calculated from the uncorrected independent wind loads from the two part-model tests A and B are considerably underestimated as expected. When the authors used the SWL method to merge the results from the two independent wind tunnel tests on part models the coherences between the sectional lift forces, and the dynamic responses are very similar to those obtained from simultaneous tests on a complete model. Thus the SWL method has been shown to work well for both the $x$- and $y$-direction response calculations.

## ACKNOWLEDGEMENTS

The authors would like to thank the China Scholarship Council (NO.201906370045) for providing financial support to the first author.

## REFERENCES

Emil Simiu, & Yeo, D. (2019). *Wind Effects on Structures: Modern Structural Design for Wind*: Wiley.

Flay, R. G. J., & Li, Y. F. (2007, July 1-6, 2007). *On predicting accelerations in tall buildings from wind tunnel model tests using spectral and time history methods*. Paper presented at the Proceedings of the 12th International Conference on Wind Engineering (ICWE12), Cairns, Australia

Zhenhua, J., Li, Y. F., Ma, Q., & Flay, R. G. J. (2022, 4-8 December). *A new method for synthesising wind loads from the results of two independent wind tunnel tests*. Paper presented at the 23rd Australasian Fluid Mechanics Conference, Sydney, Australia

Zhou, X., Huang, P., Gu, M., Zhu, L., & Pan, H. (2010). Wind Loads and Wind-Induced Responses of Guangzhou New TV Tower. *Advances in Structural Engineering, 13*(4), 707-726. 10.1260/1369-4332.13.4.707