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

# A wind load distribution approach for tall buildings based on high frequency force balance measurements

M. Mahdi Salehinejad [1], Yin Fai Li [1], Quincy Ma [2], Richard George James Flay[1]

[1]*Department of Mechanical and Mechatronics Engineering, Faculty of Engineering, University of Auckland, Auckland, 1023, New Zealand, msal381@aucklanduni.ac.nz*

[2] *Department of Civil and Environmental Engineering, Faculty of Engineering, University of Auckland, Auckland, 1023, New Zealand*

## SUMMARY

The High Frequency Force Balance (HFFB) technique has been widely used to measure the base moments, forces, and torsion of tall buildings. Using this experimental technique, it is not possible to directly obtain the distribution of varying fluctuating wind loads throughout the height of tall buildings. Several researchers have developed different approaches to predict the wind load distribution based on HFFB results. However, most of the existing approaches are focused on estimating the generalised wind forces and dynamic wind loads. Also, they are generally complex and not particularly practical for wind and structural engineers. In this research, a straightforward HFFB-based wind load distribution approach is presented in the time domain for tall rectangular buildings. A 1:300 scale model of a tall building was chosen as the subject for the HFFB-based wind load distribution approach study. A pressure-tapped model of the same building was used to obtain surface pressure distributions to validate the HFFB predictions. The results show that the proposed approach predicts the vertical distributions of the wind loads with acceptable accuracy for carrying out the concept stage of tall building design.

*Keywords: tall building, wind tunnel test, high frequency force balance, wind load distribution*

## 1. INTRODUCTION

The fundamental principle of the High Frequency Force Balance (HFFB) approach is that the generalised wind forces can be estimated from the measured base results on a rigid model (Salehinejad and Flay 2021). Although this technique is an effective tool for buildings with idealised mode shapes, for the general case of complicated mode shapes, it needs appropriate assumptions and correction factors (Boggs and Peterka 1989; Holmes et al. 2003) and the distribution of the varying fluctuating wind loads over the height of the buildings is unknown. Numerous researchers have developed different methods to predict the generalised wind forces and dynamic wind loads. On the other hand, some limited or complex methods have been presented to provide the wind load distribution along the height of the building using HFFB results (Xie and Irwin 1998; Chen and Kareem 2005). However, there is still a gap for conveniently predicting the spatio-temporally varying fluctuating wind loads on buildings based on HFFB measurements. In this paper, a straightforward HFFB-based wind load distribution method is proposed for time domain application for tall rectangular buildings. 1:300 HFFB and pressure-tapped scale models of Building A, a benchmark tall building (Holmes and Tse 2014) were built and wind tunnel tested. The base shears and moments of the rigid model were measured with a high frequency force balance. From these measurements the proposed HFFB-based approach was used to predict the vertical distributions of the wind loads along the principal axes. On the pressure model 396 pressure time histories were acquired from 18 levels of 22 taps at each level at 10° intervals. The high frequency pressure integration (HFPI) wind tunnel technique was used to determine the surface pressure distributions. The HFFB-based predictions of the vertical loading distribution are compared with the measured pressure distribution reference results and discussed in the paper.

## 2. THE NEW APPROACH

The fluctuating wind loads in the translational directions ($x$- and $y$-directions) at building height $z$ can be generally expressed as

$$f_x(z,t) = a(t) \times A(z) + b(t) \times B(z) \tag{1}$$
$$f_y(z,t) = c(t) \times A(z) + d(t) \times B(z) \tag{2}$$

where $A(z)$ and $B(z)$ in Eq. (1,2) are two arbitrary space functions which determine the vertical force distributions and for the present investigation are defined as in Eq. (3,4)

$$A(z) = u^2(z) \times \Delta H(z) \tag{3}$$
$$B(z) = \left(2\left(\frac{z}{H}\right) - 1\right) \times A(z) \tag{4}$$

where $u(z)$ is the wind speed at height $z$, $\Delta H(z)$ is the inner-storey height of the building, and $H$ is the overall height of the building. The time functions $(a(t), b(t), c(t), and\ d(t))$ can be uniquely determined from the measured HFFB results and the space functions, as follows

$$a(t) = \frac{1}{\Delta}\left[F_x(t)\int_0^H z\,B(z)\,dz\; -\; M_y(t)\int_0^H B(z)\,dz\right] \tag{5}$$
$$b(t) = \frac{1}{\Delta}\left[M_y(t)\int_0^H A(z)\,dz\; -\; F_x(t)\int_0^H z\,A(z)\,dz\right] \tag{6}$$
$$c(t) = \frac{1}{\Delta}\left[F_y(t)\int_0^H z\,B(z)\,dz\; +\; M_x(t)\int_0^H B(z)\,dz\right] \tag{7}$$
$$d(t) = \frac{1}{\Delta}\left[-M_x(t)\int_0^H A(z)\,dz\; -\; F_y(t)\int_0^H z\,A(z)\,dz\right] \tag{8}$$
$$\Delta = \int_0^H A(z)\,dz\int_0^H z\,B(z)\,dz\; -\; \int_0^H z\,A(z)\,dz\int_0^H B(z)\,dz \tag{9}$$

where $F_x(t), M_x(t), F_y(t),\ and\ M_y(t)$ in Eq. (5-9) are the measured base shears and bending moments in the $x$ and $y$ directions, respectively. The sectional wind load coefficients along the principal axes, $x$ and $y$, are defined in Eq. (10, 11)

$$C_{F_l} = \frac{f_{l_{section}}}{0.5\,\rho\,U_H^2\;w(z)} \qquad with\ l = x, y \tag{10}$$

$$f_{l_{section}} = \frac{f_l}{\Delta H(z)} \qquad with\ l = x, y \tag{11}$$

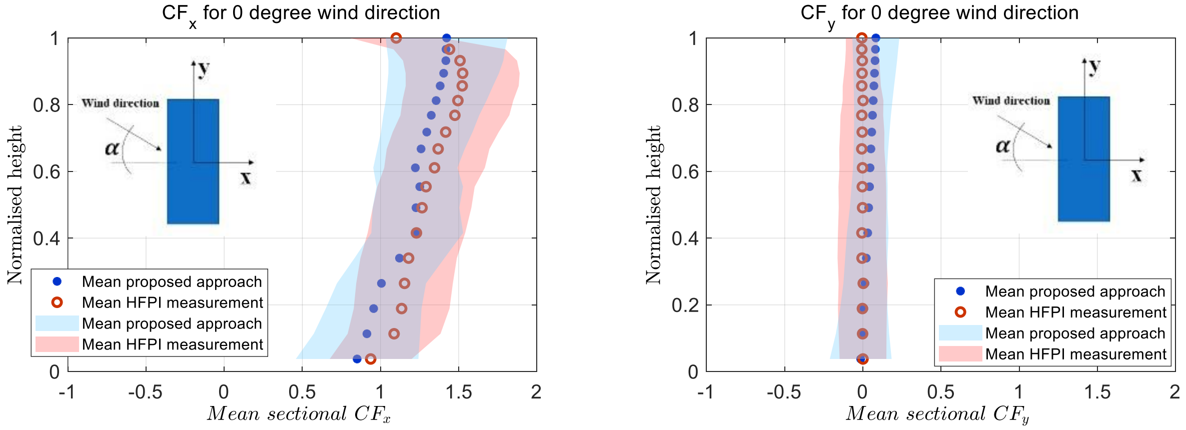
where $f_l$, $f_{l_{section}}$, $U_H$, $w(z)$, and $\rho$ are the wind load, the sectional wind load, the wind speed at the top of the building, the width of the building and the air density, respectively.

## 3. EXPERIMENTAL SETUP

The HFFB and HFPI tests were conducted in the University of Auckland wind tunnel. A suburban terrain flow was simulated. The mean wind speed profile followed a power law with an exponent $\alpha = 0.25$ and a roughness length of 0.2 m. This is consistent with Terrain Category 3 (TC3) as defined in the Standard AS/NZS 1170.2 (Salehinejad et al. 2022). Building A is a 240 m high rectangular cross-section building with plan dimensions 72 m by 24 m. HFFB data were acquired at a sampling frequency of 1000 Hz and sampling period of 120 s. Pressure data were acquired at a sampling frequency of 400 Hz and sampling period of 120 s. The two models were installed at the centre of the wind tunnel turntable to allow testing for 36 directions at $10^{\circ}$ intervals. Due to page limitations, only some selected results for the two wind directions of $0^{\circ}$ and $70^{\circ}$ are presented in this paper. The methodology and further results and analysis will be included in the oral presentation.

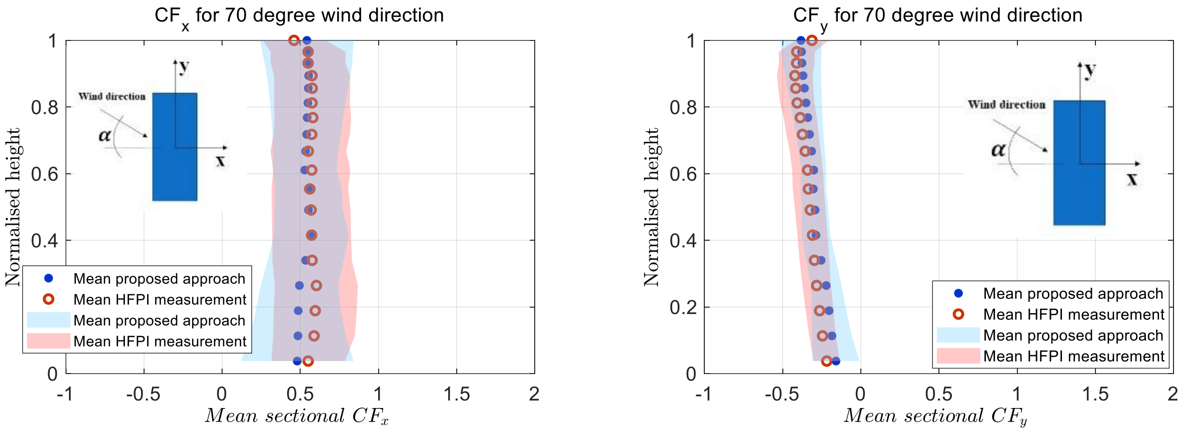
## 4. RESULTS AND DISCUSSION

To validate the proposed HFFB-based approach, mean sectional wind load distributions along the principal axes were calculated and are shown in Figure 1, where the HFFB predictions are compared with the HFPI reference data for the wind directions of 0° and 70°. A range of +/- 1 standard deviations of the data are illustrated using coloured bands. The light blue bands show results from the proposed approach and the pink bands show the pressure measurement results.



a

b



c

d

**Figure 1.** Comparison of mean sectional force coefficients for Building A estimated by the proposed HFFB-based approach (blue dots) and the HFPI reference (red circles) coefficients.

In general, the predictions from the proposed HFFB-based and HFPI approach follow similar trends and show good agreement. However, the results are also very close for other wind directions as well 70° and 0°. Differences in Figure 1 also arise due to discrepancies between the actual wind tunnel HFFB and HFPI base force and moment test results for these two wind directions.

## 5. CONCLUSIONS

In this paper, a straightforward HFFB-based approach is presented for time domain application to estimate the wind load distributions over the height of a tall building based on HFFB measurements. HFPI measurements were used to check the accuracy of the proposed approach. The results demonstrate that the proposed approach can predict the wind loads in the translational directions with reasonable accuracy.

## REFERENCES

Boggs, D. W., and Peterka, J. A. 1989. Aerodynamic model tests of tall buildings, Journal of Engineering Mechanics, 115: 618-35.

Chen, X., and Kareem, A. 2005. Validity of wind load distribution based on high frequency force balance measurements, Journal of Structural Engineering, 131: 984-87.

Holmes, J., Rofail, A., and Aurelius, L. 2003. High frequency base balance methodologies for tall buildings with torsional and coupled resonant modes. In Proc., 11th International Conf. on Wind Engineering, 2381-88. Texas Tech Univ.

Holmes, J. D., and Tse, T. K. 2014. International high-frequency base balance benchmark study, Wind and Structures, 18: 457-71.

Salehinejad, M. M., and Flay, R. G. J. 2021. A review of approaches to generate equivalent static and synthetic wind loads on tall buildings for the preliminary stage of design, Journal of Wind Engineering and Industrial Aerodynamics, 219: 104823.

Salehinejad, M. M., Li, Y. F., Ma, Q., and Flay, R. G. J. 2022. A comparison of force balance and pressure integration techniques for predicting wind-induced and dynamic responses of tall buildings. In 23rd Australasian Fluid Mechanics Conference AFMC2022. Sydney, Australia: The University of Sydney.

Xie, J., and Irwin, P. 1998. Application of the force balance technique to a building complex, Journal of Wind Engineering and Industrial Aerodynamics, 77: 579-90.