CWE-8
June 7-11, 2026
London, ON, Canada

Comparison of Wind Tunnel Tests of Peak Pressures over the TTU WERFL Building with Full-scale Measurements

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Summary

Boundary-layer wind-tunnel tests have advanced the building wind load design in the past few decades and will continue to do so in the foreseeable future. However, it is well known that peak pressure coefficients measured in traditional wind tunnels with scaled building models are underestimated compared to those of full-scale tests owing to the scaling effects. Recent efforts have been put in large-scale testing by using a much larger building model and in an open-jet type of wind tunnel with a large test section. This work aims to evaluate rooftop surface pressure distributions over a 1:6 Texas Tech University (TTU) Wind Engineering Research Field Laboratory (WERFL) building model subjected to a cornering wind of 45°, measured at the FIU WOW experimental facility, and compared against the full-scale test data archived at TTU. Results of this careful comparison of both inflow characteristics and rooftop peak pressures will shed light on strategies for improving wind-tunnel simulation and interpretation of full-scale field data.

Keywords: *ASCE wind load provision, full-scale field test, large-scale wind tunnel test, peak pressure coefficient*

1 INTRODUCTION

Wind-induced pressures are a critical factor contributing to the failure of low-rise buildings. In particular, strong suction pressures developing on roof edges and roof corner can trigger severe roof damage. The Wind Engineering Research Field Laboratory (WERFL) building at Texas Tech University (TTU) is a unique experimental facility for acquiring full-scale wind pressure data along with monitoring incoming wind conditions (Levitan and Mehta, 1992; Pruitt, 2000; Smith et al., 2018). Prior wind-tunnel studies have reported mean pressure coefficients similar to the full-scale test values; however, reproducing full-scale peak pressure coefficients has been challenging, particularly at the roof corners/edges for cornering wind directions. Recent studies using large-scale building models in open-jet wind facilities aim to reduce the scaling issue and achieve near-full-scale Reynolds numbers to address the discrepancies of peak pressures in wind tunnel tests compared to those of the full scale tests (Moravej et al., 2024). In this study, a specific case under cornering wind (45°) is examined to assess the mean pressure coefficient, the standard deviation of the pressure coefficient, and the peak pressure coefficient on the rooftop of the TTU WERFL building in large-scale wind tunnel tests and full-scale measurements.

2 EXPERIMENTAL AND DATA ANALYSIS METHODS

2.1 ABL Flow Simulation at the Wall of Wind Experimental Facility

The NHERI 12-fan Wall of Wind (WoW) Experimental Facility (EF) at Florida International University (FIU) was used to simulate the ABL inflow over open terrain. The WOW EF can generate an ABL wind reaching the maximum speed of 71.5 m/s (160 mph) in the large test section of 6.10 m (wide) $\times$ 4.27 m (high). Incoming wind velocities were measured using a vertical rake of three

TFI cobra probes at the turntable center at 2000 Hz. At the roof height, the “High Speed” wind condition generates U_H = 22.12 ms^{-1}, $Re_H = 0.92 \times 10^6$, and a turbulence intensity I_u = 13%.

2.2 TTU WERFL Building Model and Pressure Measurements

A 1:6-scale model of the TTU WERFL building was constructed with dimensions of L = 2.286 m, W = 1.524 m, and ridge height H = 0.648 m. In contrast to the 1:100 or 1:200 scaled building models, the 1:6 TTU building model allows for achieving near full-scale Re_H. The wind pressure distribution on the roof surface was measured using a Scanivalve DSM4000 and ZOC33 pressure scanning system. A total of 228 pressure taps were installed on the model’s roof, with a higher tap density near the windward corner of interest.

2.3 Full-scale Field Data

The field test facility is situated at TTU in Lubbock, Texas, and it comprises a test building and an adjacent meteorological tower. The WERFL building is a prefabricated metal building with plan dimensions of 9.1m × 13.7m and height of 4.0 m, Levitan and Mehta (1992). A total of 90 pressure taps were installed on the roof to measure the differential pressure, which is later converted to pressure coefficient (Levitan et al., 1991). The pressure coefficients and relevant meteorological data for different wind speeds and angles of attack are stored locally, and selected cases are available from the DesignSafeCI website. This study specifically concentrates on the roof pressure distribution for a 45° corner wind attack and the mean wind profile is shown in Figure 1 (a). Data was obtained at a sampling rate of 30 Hz for 15 minutes each run. The peak value was obtained as the single minimum value from the time history at each tap location (Levitan et al., 1991). For this selected case, the mean wind speed at the roof height and corresponding Reynolds Number are U_H = 8.01 ms^{-1}, $Re_H = 2.2 \times 10^6$, respectively.

3 RESULTS AND DISCUSSION

3.1 Compare Inflow Characteristics

Vertical profiles of the mean incoming wind speed (for Exposure C) normalized by the wind speed at roof height are depicted for the full-scale and model-scale tests in Fig. 1.

3.2 Rooftop Pressure Coefficients

Fig. 2 shows the statistics of surface pressure coefficients over the roof obtained by the FIU WOW tests, which exhibit significantly stronger suctions along the windward edges and roof corners induced by conical vortices. The region of dynamic vortices also has a higher standard deviation C_p', as noted in Shelley et al. (2023). The baseline case shows a $\overline{C_p}$ range of – 4.43 to – 0.14 and C_p' range of 0.03 to 1.48. The peak pressure $C_{p,peak}$ minimum is -8.74, which falls in the range of – 4 to – 14 in prior studies (Kopp et al., 2005; Moravej et al., 2024). For the full-scale test case (Fig. 3), the average pressure coefficient $\overline{C_p}$ ranges from – 2.84 to – 0.23, standard deviations C_p' are of the range 0.098 to 1.54, and the peak values have a range of – 15.78 to – 0.99. Both datasets clearly capture the signature of conical vortices developed along the roof edges. The standard deviation C_p' shows good agreement between wind tunnel data and full-scale field data. However, $\overline{C_p}$ covers a larger range in wind tunnel tests and the minimum of $C_{p,peak}$ is about 50% of that of the full-scale test case.

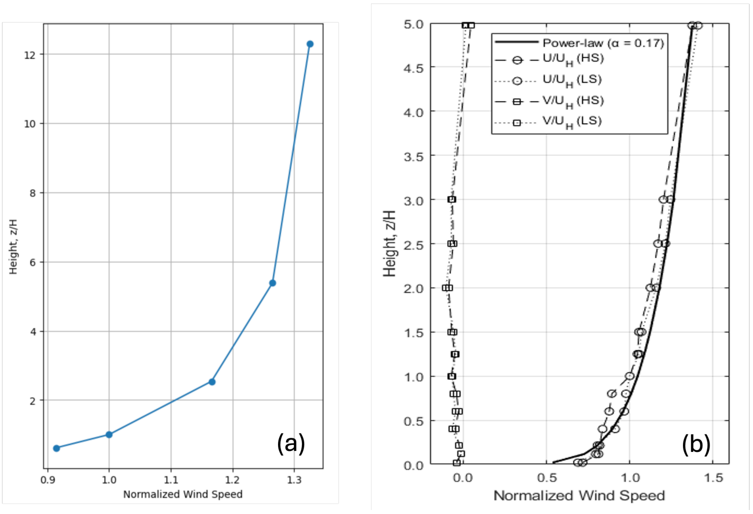

Figure 1: Vertical profiles of mean wind speeds: (a) full-scale case and (b) model-scale case.

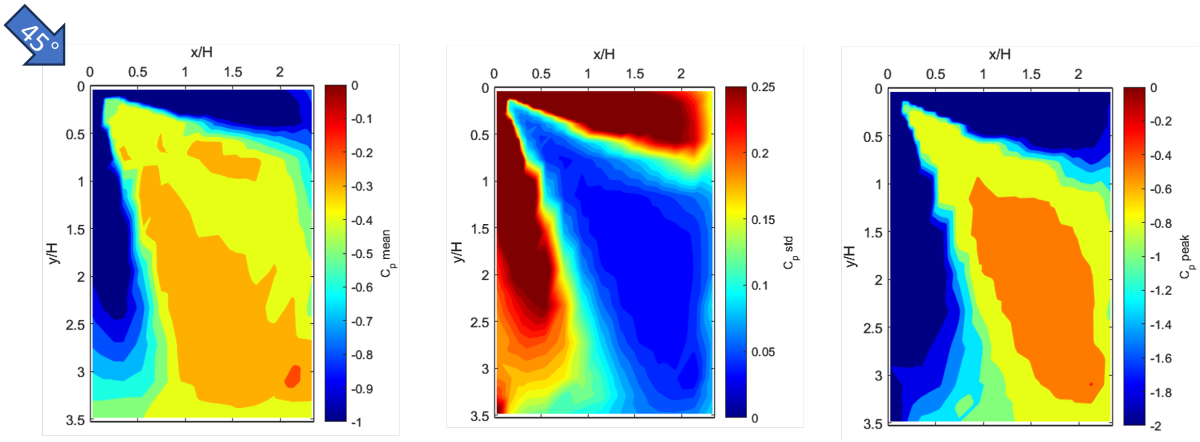

Figure 2: Contours of mean pressure coefficient $\overline{C_p}$ (left), standard deviation C_p' (middle), and peak pressure coefficient $C_{p,peak}$ (right) over the roof at 45° wind and $Re_H = 0.92 \times 10^6$ measured at FIU WOW EF.

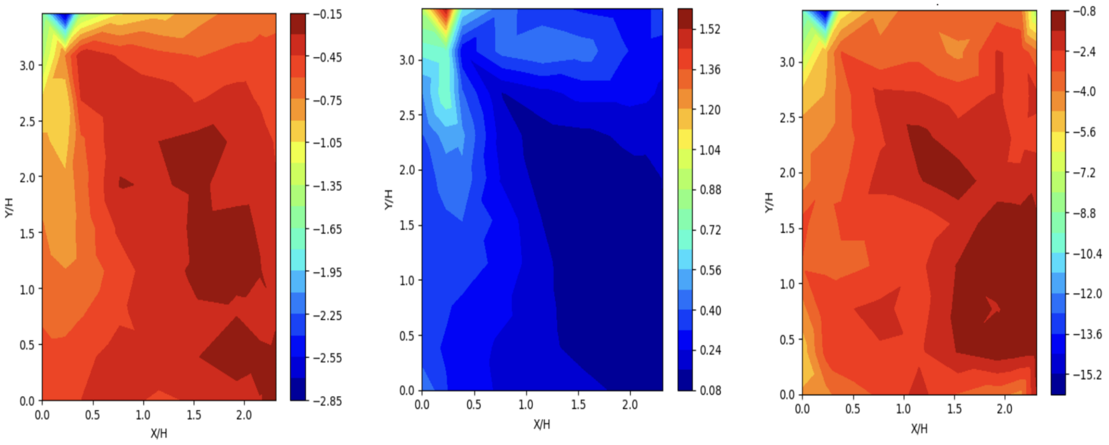

Figure 3: Contour plots of mean pressure coefficient $\overline{C_p}$ (left), standard deviation C_p' (middle), and peak pressure coefficient $C_{p,peak}$ (right) over the roof at 45° wind and $Re_H = 2.2 \times 10^6$ from the full-scale data.

4 CONCLUSIONS

Pressure coefficients over the TTU WERFL building from large-scale wind tunnel tests at FIU WOW facility for a cornering wind (45°) are compared with a selected full-scale test case. To better understand the discrepancies in mean and peak pressure coefficients between the two datasets, future work will examine the stationarity and turbulence statistics of the full-scale wind measurements.

ACKNOWLEDGEMENTS

E. Shelley and W. Zhang acknowledge the support of the National Science Foundation CAREER grant (Award# 253328) and Cleveland State University Graduate Student Research Award. G. Kirtonia acknowledges the support by the Civil, Environmental and Construction Engineering Department at TTU. The authors are grateful for Dr. Douglas A Smith's guidance on archived full-scale datasets.

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