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

A Field Study of Wind Pressure Loads on Building Components during Hurricanes Ian and Nicole

J. Zhang [1], A. Lebbar[2], S. Sridhar[2], C.S. Subramanian[2], J-P. Pinelli[2], S. Lazarus[2], J. Wang[2]

[1]*Florida Institute of Technology, Melbourne, USA, zhangj2014@my.fit.edu*
[2] *Florida Institute of Technology, Melbourne, USA, subraman@fit.edu*

SUMMARY:
To study hurricanes' impact on low-rise residential buildings in coastal areas, a research team from the Florida Institute of Technology developed a portable wireless sensor network system. Under certain conditions, the system has a performance similar to lab equipment in wind tunnels and is easy to carry and deploy in field tests. The researchers deployed pressure and anemometer sensors at multiple locations on a single-family home during Hurricanes Ian (Category 3) and Nicole (Category 1). Pressure and wind speed data are analyzed and compared to wind tunnel measurements from previous experiments, as well as to the ASCE 7-22 standard. The paper also compares the instantaneous differential pressure at various locations of the house and dynamic pressure approximated from the anemometer measurements. This preliminary work shows that the differential pressure measured above the roof is highly related to the dynamic pressure with a verified time lag difference. The change in dynamic pressure while the peak wind speed is leading the change of pressure on the building. The experimental data is being further analyzed and shall be published shortly on DesignSafe-ci.

Keywords: Wireless Sensor Network, Pressure Sensor, Anemometer, Field Measurements

1. INTRODUCTION

Hurricanes and tropical storms repeatedly bring severe damage to residential buildings on Florida coastlines. To study the pressure variations on low-rise buildings in such natural events, the authors developed a Wireless Sensor Network System (WSNS). It includes multiple pressure sensors to be deployed on the building envelope surfaces, a reference pressure sensor to be deployed at ground level, and anemometers to measure wind speeds and wind directions above the building. The system is easy to install, affordable, and non-intrusive (Wang et al. 2021; Zhang et al. 2021). The authors carried out a series of wind tunnel experiments in the past to study the pressure distribution on non-structural components and cladding of residential buildings under hurricane winds (Subramanian, et al. 2021; Zhang, et al., 2022; Sridhar, et al., 2022). The complete data from these wind tunnel experiments shall be published soon on DesignSafe-ci.

To further analyze the pressure distributions on a residential building under hurricane conditions, the research team deployed the WSNS on a low-rise building during Hurricanes Ian and Nicole, in Satellite Beach, Florida. In these field study tests, WSNS pressure sensors were placed on the single gabled-roof surface, window, garage door, and soffits, to measure the real-time pressure response. Anemometers were deployed above the roof level to estimate the freestream wind speeds. A reference pressure sensor was deployed at ground level, measuring the local ambient pressure (see Figure 1 for the setting of Hurricane Ian, the setting of Hurricane Nicole is slightly different).

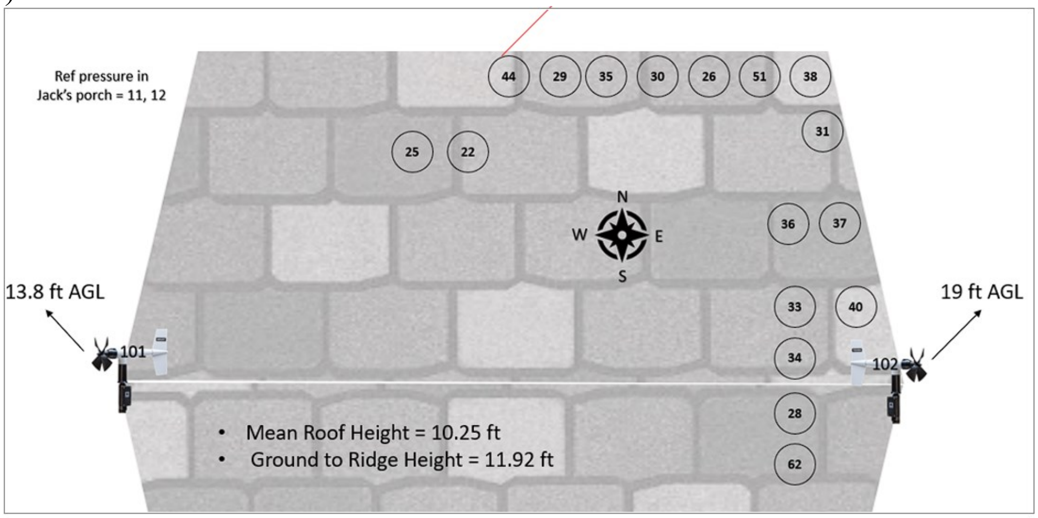

Figure 1. Building Model and Sensor Locations in Hurricane Ian

The pressure loads and coefficients of pressure were computed from the measurements. The objective of the tests was to characterize the pressure distributions on non-structural components and cladding surfaces and compare the measurement results against data from previous wind tunnel tests, as well as the ASCE 7-22 standards.

2. METHODOLOGY

WSNS sensors can capture the wind pressure fluctuations at a 10 Hz sampling rate with 0.1 mbar accuracy, and Young's anemometers can capture the wind speed at a 1 Hz sampling rate with 0.3 m/s accuracy. For both hurricanes, the maximum 3-sec gust wind speed measured above the building's roof reached over 20m/s. Figure 2 shows a 15-minute measurement window of the anemometer readings while the peak winds of Hurricane Ian reached Satellite Beach. Anemometer 102 was deployed 19 ft above ground level, and Anemometer 101 was 13.8 ft above ground. The average wind direction was 180 degrees (with 0 degrees corresponding to the North direction).

The pressure and anemometer measurements are processed into 3-sec average readings to represent the gust wind speed and the response pressure distributions. In some cases, the response time of the two-dimensional anemometer is not fast enough to record the sudden change in wind speed and direction, resulting in extremely low or high readings in a short time. For better comparisons, the data are passed into a triangular moving average filter, to eliminate the hardware limitations on high-frequency fluctuations.

To relate the pressure distribution on different surfaces with respect to the freestream conditions, the dynamic pressure measured from the field will be compared to the real-time differential pressure at multiple locations.

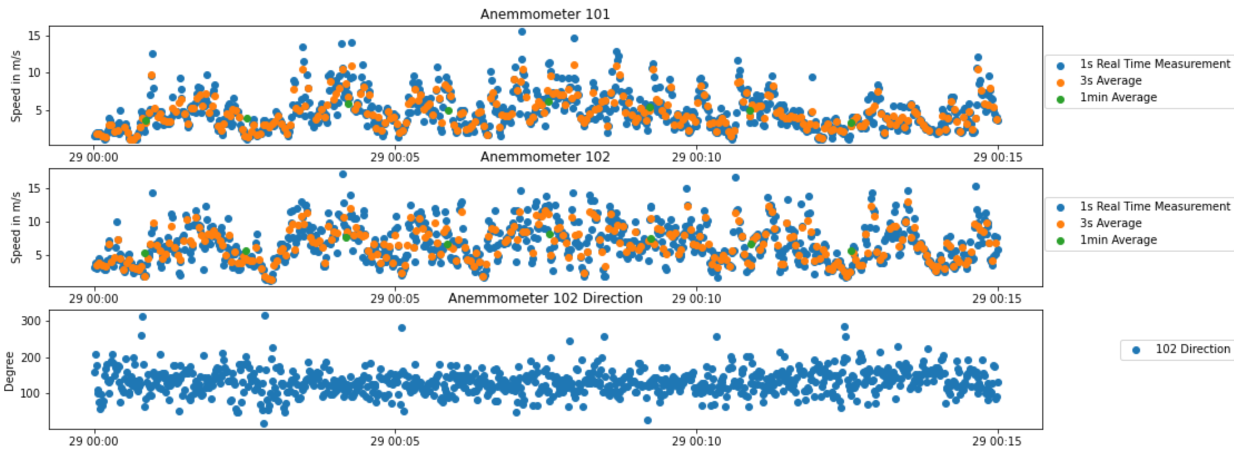

Figure 2. Anemometer Readings During Hurricane Ian

The dynamic pressure in field tests is approximated from the wind speed readings from the anemometers:

$$P_{dyn} = \frac{1}{2}\rho U^2 \qquad (1)$$

The differential pressure at each sensor location is calculated as the difference between the absolute pressure and the ground reference pressure:

$$P_{diff} = P_{sensor(i)} - P_{ref} \qquad (2)$$

P_{dyn} - Freestream Dynamic Pressure
P_{diff} – Differential Pressure
P_{ref} – Reference upstream static pressure from ground-level sensor
ρ - Air Density
U – Freestream velocity from anemometer above the roof

3. RESULTS AND DISCUSSION

In Figure 3, the raw wind speed readings from 1 anemometer 102 (at 9ft) are filtered and averaged into 3-sec gusts. The 3-sec dynamic pressure is then estimated assuming constant wind direction and constant air properties. The differential pressure between roof sensor 28 (see Fig. 1) and the ground-level reference pressure sensor is used as an example to demonstrate the relationship between freestream dynamic pressure and local pressure load. The comparisons are directly related to pressure coefficient predictions in future engineering designs. Figure 3 shows that the dynamic pressure (medium plot) correlates to the differential pressure on the roof (bottom plot in Fig. 3). The R-squared test yields a performance R2 score close to 0.45, after data filtration. Selective data filtering techniques could further improve the correlation between the freestream dynamic pressure and the building surface pressure readings. A time lag between 0.8 to 1.0 seconds exists between the dynamic pressure changes and the corresponding surface pressures. The data need to be further analyzed to determine the dynamic pressure and differential pressure relationship at multiple locations, including the roof, the soffit, the windows, and the garage door of the building. The paper and presentation shall also include comparisons of the field surface pressure distributions against similar results from previous full-size wind tunnel experiments (also with the WSNS), as well as against ASCE 7-22 prescribed values.

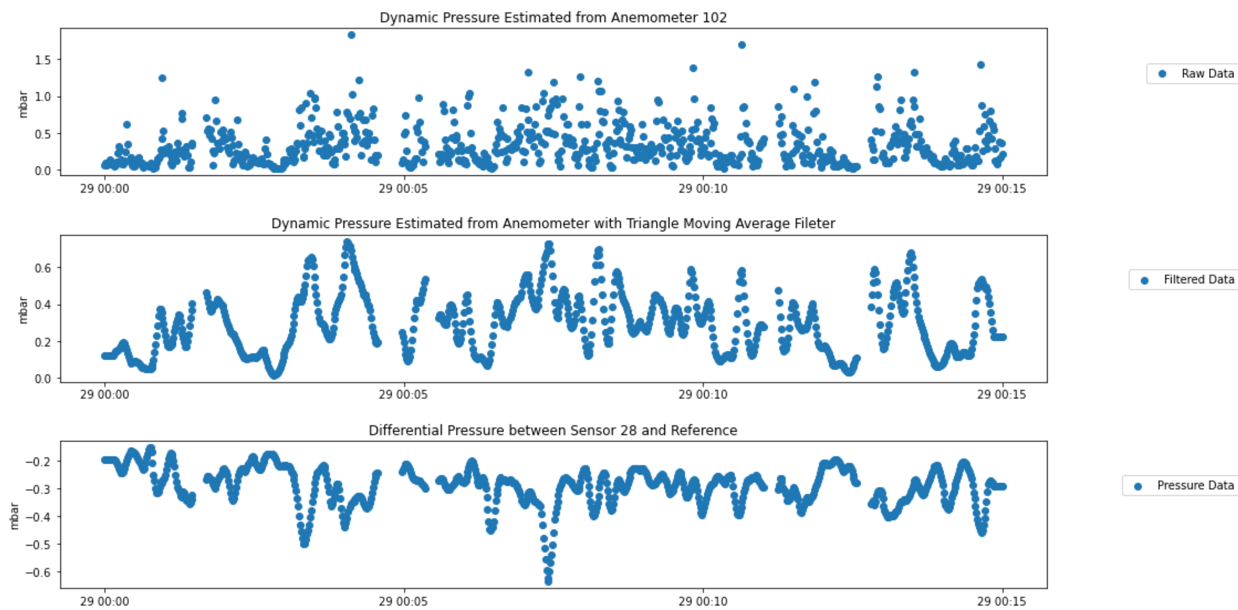

Figure 3. Estimated Dynamic Pressure vs. Differential Pressure of Roof Sensor 28

4. CONCLUSIONS

This research presents the results of a series of field tests, including pressure, wind speed, and wind direction measurements on low-rise buildings. This is a work in progress that investigates the relationship between dynamic pressure and surface differential pressures. Further analyses will provide a systematic study of the pressure distribution on low-rise buildings under hurricane impacts, with direct comparisons between field and full-size wind tunnel results, and ASCE 7-12.

ACKNOWLEDGEMENTS

We gratefully acknowledge the support of the National Institute of Standards and Technology (grant 70NANB19H088).

REFERENCES

ASCE 7-22, 2022 Edition, 2022 - MINIMUM DESIGN LOADS AND ASSOCIATED CRITERIA FOR BUILDINGS AND OTHER STRUCTURES

Wang, J., Sun, J., Subramanian, C., Pinelli, J-P., and Lazarus, S., 2021. "Development of a Wireless Sensor Network for Hurricane Monitoring." 6th American Association for Wind Engineering Workshop. Clemson, SC, USA.

Zhang, J., et al., 2021. "Performance Testing and Calibration of the Generation –IV Wireless Sensor Network System." 6th AAWE Conference Presentation. NC, USA.

Subramanian, C., Pinelli, J-P., and Lazarus, S., 2021. (PRJ-2890) Lab Tests with Wireless Sensor Network (WSN) system for the characterization of strong wind loads on non-structural components.

Zhang, J., et al., 2022. "Full-Scale Testing and Performance Evaluation of the Florida Tech Wireless Sensor Network System" 14th Americas Conference on Wind Engineering. Texas, USA.

Sridhar, S., et al., 2022. "Measurement of Wind Loads on Glass Sliding Doors using a Wireless Sensor Network System" 14th Americas Conference on Wind Engineering. Texas, USA.