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Field measurement and wind tunnel simulation of hurricane wind loads on a single family dwelling

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ABSTRACT

During landfall of Hurricane Ivan on the Florida 'panhandle' in 2004, pressure time-history data were recorded on multiple pressure sensors installed on the roofs of six single-family homes. An analysis approach was developed to determine the peak negative, mean, peak positive, and standard deviation of pressure coefficients for these datasets. This paper presents a comparison of the full scale pressure coefficients from one of these homes, which experienced sustained hurricane force winds, with the results of wind tunnel experiments on a 1:50 scale model of that home. It was determined that the wind tunnel and full-scale mean and rms pressure coefficients matched very closely at almost every monitored location on the roof, while the peak negative pressure coefficients in the wind tunnel study generally underestimated the full-scale values, consistent with observations from previous full-scale/wind tunnel comparative studies. Field-measured hurricane wind loads may prove useful for evaluating existing wind load provisions. However, recommendations in that regard are premature without the analyses of multiple homes in multiple storms, performed by more than one wind tunnel facility. Future work will focus on building such a joint study.

1. Introduction

Current wind design code provisions in North America were developed using wind tunnel datasets of forces on generic building models [1–4]. Wind loads on low-rise structures have been studied for decades, and the subject is covered in many excellent reviews [5–10]. Full-scale experiments for wind loads on low-rise buildings have helped improve the understanding of the wind/structure interaction, and to validate wind tunnel results Cochran and Cermak (1992), [11–17]. Despite efforts (e.g. [18]), the collection of hurricane force full scale pressure data on typical residential structures sited in suburban neighborhood-type terrain has been elusive. It remains a high priority to obtain full-scale measurements of hurricane wind fields and wind loads to refine the current understanding of the interaction between severe hurricane winds and structures, and to validate or evolve current wind tunnel simulation techniques and results interpretation.

The Florida Coastal Monitoring Program (FCMP) landfalling hurricane data collection project, captured wind velocity and residential rooftop wind pressure data in multiple hurricanes in the 2004 and 2005 seasons [24]. Roof pressure datasets from occupied residential structures measured during sustained hurricane force winds, were analyzed and compared with wind tunnel experiments on scaled models of those homes. A description of the methodology used to measure and analyze full-scale wind pressures and compare them with wind tunnel results is presented for a single family house located in the Florida 'panhandle'.

2. Field data collection program, instrumentation, and subject house (FL-27)

FCMP

The Florida Coastal Monitoring Program (FCMP) is a unique research endeavour, focusing on measurement of near-surface hurricane wind velocity, wind loads on residential structures, and the evaluation of the effectiveness of residential retrofits. The FCMP portable meteorological towers are designed to collect wind velocity data at 5 m and 10 m heights, as well as barometric pressure, temperature, and relative humidity during a landfalling storm. A second FCMP field data collection system measures pressures at multiple locations on the rooftops of occupied residential structures. Subject houses are pre-selected and outfitted to receive the

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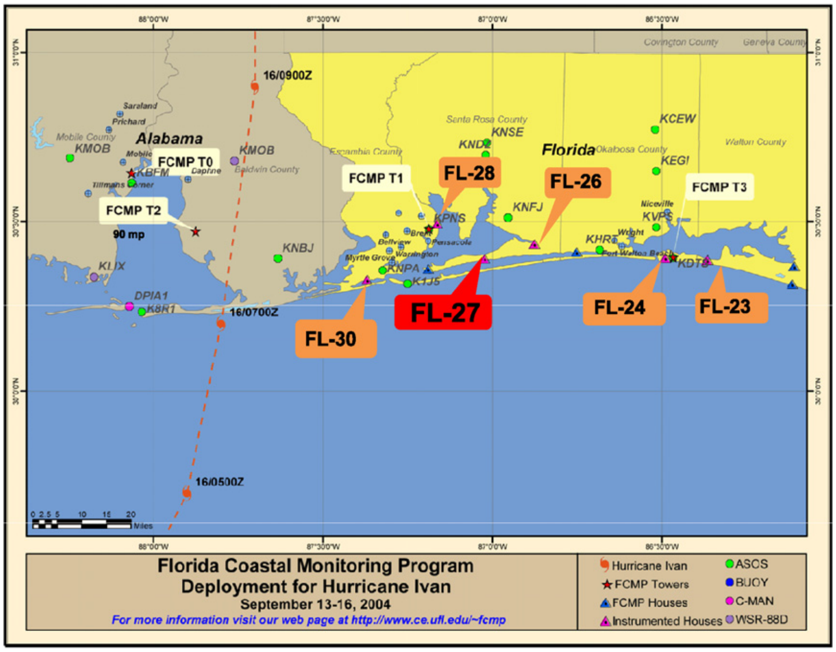

Fig. 1. FCMP deployment map for Hurricane Ivan, 2004.

pressure sensors, which are installed within days prior to a landfalling hurricane. These homes are upgraded with retrofits to reduce their wind vulnerability. More detail on the FCMP instrumentation program development, deployment, and data analysis can be found in [32,27,30,25,26,24,28].

Hurricane Ivan

Hurricane Ivan (2004) made landfall at Gulf Shores, Alabama around 0700 (UTC) on 16 September 2004, approximately 75 km west of the subject house designated FL-27. The highest official sustained wind speed measured at the Pensacola Naval Air Station at landfall was 39 m/s, with wind gusting to 48 m/s. Hurricane Ivan progressed inland across eastern Mobile Bay in a north northeasterly direction at a forward speed of 5–7 m/s, weakening to a tropical storm 12 h after landfall [33].

Subject house FL-27

FL-27 is one of 42 homes in the FCMP program, and one of six houses that were instrumented during hurricane Ivan. Four mobile FCMP wind towers were deployed as well (Fig. 1). FL-27 is a one-story single-family residence located in Gulf Breeze, Florida. It is situated 8.0 m above sea level within a suburban neighborhood of similar-sized homes. The neighborhood is bounded on the east, west and south sides by pine forests (Figs. 2 and 3), approximately 850 m inland from the Gulf of Mexico coastline. The exposure terrain can be categorized as suburban in accordance with ASCE 7-05 [23]. The gable roof consists of multiple levels, with the main ridge at 6 m elevation above grade (Fig. 4). Typical roof slopes were 20°.

Instrumentation

Twenty-four absolute pressure transducers were mounted at corner and edge locations on the roof to measure external dynamic pressures. An additional absolute pressure sensor is connected to an RM Young pressure port to minimize dynamic wind pressure. This unit is mounted 0.9 m above ground on the property, as far from the house as practical, to provide a barometric pressure reference. Two 3-cup Gill anemometers were mounted on the roof, 1.4 m above the ridge (Fig. 4). Fig. 5 presents a roof plan of the FL-27 house showing the locations of the rooftop pressure sensors on the wind tunnel and on the full-scale house.

Each pressure sensor unit consists of a Microswitch 142 PC 15-A absolute pressure transducer installed in a 300 mm diameter

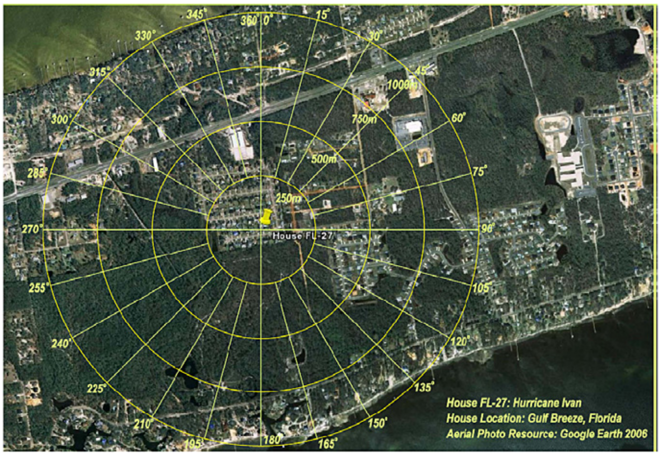

Fig. 2. Aerial view of the terrain surrounding House FL-27 (Courtesy of Google Earth).

Fig. 3. Aerial view of the House FL-27 and neighboring houses (Courtesy of Google Earth). Circle indicates the extent of turntable for wind tunnel experiments.

Fig. 4. Photographs of FL-27 showing anemometer location and pressure sensors.

aluminum pan, and attached to the roof using pre-installed brackets. The pressure transducers are customized to operate over a range of 825 mbar to 1017 mbar (-17.86 kPa – +1.20 kPa relative to 1005mb) to cover the pressure range associated with both drops in atmospheric pressure and with the wind induced suction [31]. Data acquisition equipment is contained in a waterproof steel box, with enough battery power to run for approximately 12 h after local power failure. Data was recorded at sample rates of 100 Hz, and stored digitally in 15-min segments using a 16-bit analog to digital converter.

The portable FCMP meteorological tower T1 was deployed at Pensacola Airport, approximately 18 km north-west of FL-27 in open terrain exposure due south, south-easterly and south-westerly directions.

3. Analysis of full-scale house pressure data

Each 15-min data segment from the house instrumentation system includes the pressure measurements from the absolute pressure sensors and wind velocity measurements from the house anemometers. The wind-induced pressure on the building surface is taken as the pressure differential between the total dynamic pressure recorded at a roof sensor, minus the ambient barometric pressure measured by the ground level sensor, expressed as:

$$P_i(t) = (\Delta p_i(t) + \Delta p_{i-Temp}) - (\Delta p_0(t) + \Delta p_{0-Temp}) \qquad (1)$$

where $P_i(t)$ is the wind pressure at channel i at time-step t; $\Delta p_i(t)$ is pressure differential between the channel i sensor pressure and the mean pre-storm pressure at time-step t; $\Delta p_0(t)$ is the pressure differential on the atmospheric reference pressure sensor between pressure at time-step t and the mean pre-storm pressure; Δp_{i-Temp} and Δp_{o-Temp} are the temperature correction factors on channels i and the reference pressure channel, respectively.

The wind pressure on the roof determined using (1), was converted to non-dimensional pressure coefficients, $C_p(t)$ normalized to the peak 3-s gust wind speed at mean roof height measured during the 15-min record. The pressure coefficient is determined as:

$$C_p(t) = \frac{P_i(t)}{1/2\rho \cdot U_{3s}^2} \qquad (2)$$

where U_{3s} is the peak 3 s gust wind speed estimated at mean roof height, and ρ is air density.

Three sources of wind speed data were considered in determining the reference 3-s gust wind speeds; a) anemometers installed on FL-27, b) anemometers on the portable meteorological tower T1, and c) the hurricane wind field model developed by Applied Research Associates (ARA) [19]. ARA's wind projections were developed using a combination of their empirical hurricane model and field data collected from several sources, including data from all four FCMP wind towers. After a review of all available data and wind engineering reference texts (e.g. [20]), it was decided to use wind speed and directional data projected by the ARA hurricane wind model at the subject house location, converting to a 3-s gust mean roof height value and appropriate local roughness using methods given by Simiu and Scanlan [21]. A companion paper will discuss and quantify the effects of various uncertainties (including wind speed reference) on pressure coefficient calculations, comparisons with wind tunnel data, and the associated impact on any codes and standards recommendations. As one example of uncertainty to be addressed in forthcoming studies, Table 1 presents the reference winds speeds at the subject house, as projected from 15-min mean winds recorded using the house anemometer, and as projected from the ARA wind field model (used as the wind speed reference in this study).

During Hurricane Ivan, a total of 211 consecutive 15-min data segments were collected at FL-27. These 53 h of data included calm conditions well before and after the passage of Ivan. Eight consecutive pressure data segments (two hours of data) corresponding to the strongest Ivan wind speeds were analyzed, referred to as segments #135 through #142. ARA's wind projections indicated a corresponding range of incident wind directions from 125° to 154°.

Table 1
Peak full-scale wind velocity and directions at Prototype House FL-27 during Hurricane Ivan.

House data segment no.	Segment start time (UTC)	Wind velocity measured by FL-27 house anemometer at 6.5 m height r (z_0=0.74 m)		Estimated gust wind speed from ARA wind field data, and adjusted to FL-27 mean roof height.	
		15-min mean wind speed (m/s)	3-s gust wind speed (m/s)	3-s gust wind speed (m/s)	Wind direction (degrees)
135	5:53	15.5	27.8	30.9	125
136	6:08	15.4	36.5	30.7	128
137	6:23	16.6	31.2	33.1	132
138	6:38	16.1	34.9	32.0	136
139	6:53	16.0	29.8	31.9	140
140	7:09	15.4	30.2	30.7	145
141	7:24	14.4	31.5	28.7	150
142	7:39	14.7	26.8	29.3	154

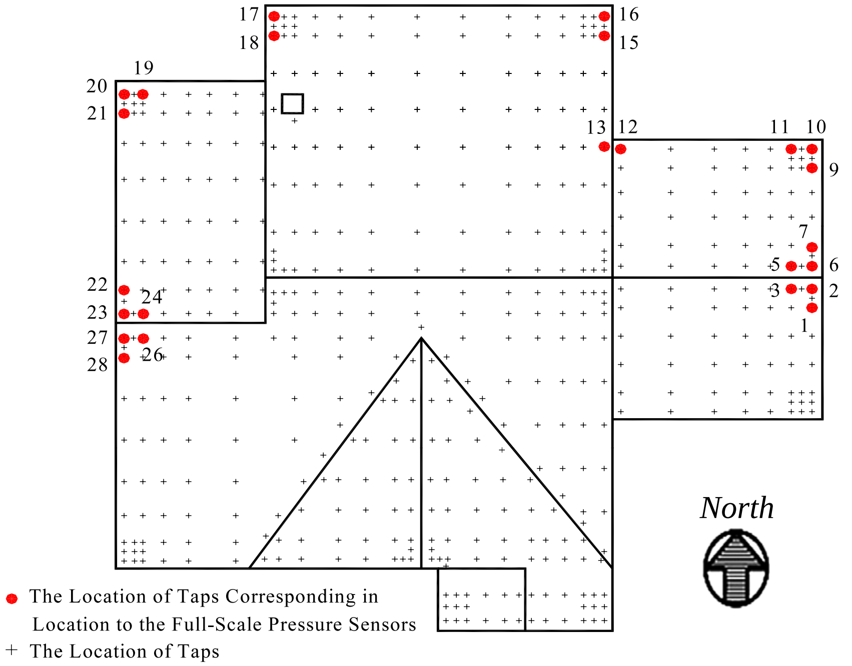

Fig. 5. FL-27 roof plan showing pressure tap locations on wind tunnel model (+). Solid circles are the locations corresponding to full-scale tap locations.

Pressure taps were placed on the roof in nine groups of two and three taps. These groups were located in four roof ridge and five eave locations, shown as solid circles in Fig. 5. Pressure sensor data was sampled at 100 Hz and low-pass filtered to 10 Hz. The instantaneous 10 Hz pressure values were then used to determine the instantaneous 10 Hz peak pressure coefficient values, referenced to a 3-s gust wind speed at mean roof height. The mean and standard deviation pressure coefficient values were also determined over each 15-min segment using the 10 Hz data.

Figs. 6a–6d present the peak negative, mean, peak positive and standard deviation of pressure coefficients recorded for each 15 min segment over the two hours of highest winds at FL-27. The cluster of three pressure taps #5, #6 and #7 located at the windward edge ridge consistently had the most extreme pressures for incident winds flowing generally from the south-east direction. The pressure coefficients within other sensor clusters were also consistent with each other.

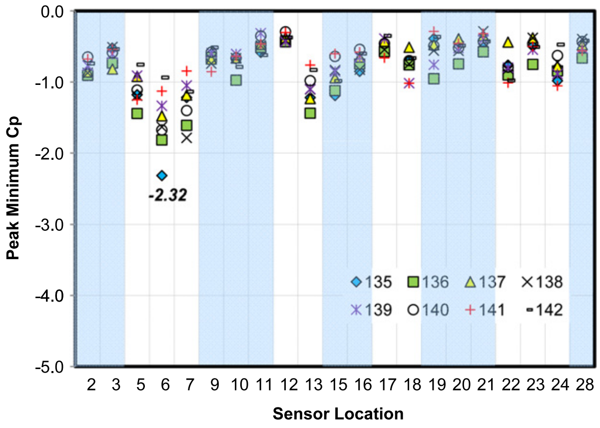

Fig. 6a. Peak negative C_p (instantaneous gust within 15 minutes) on House FL-27 from Hurricane Ivan. Sample frequency: 10 Hz; Data records 135–142, UTC time: 9/16/2004 05:53–07:53.

4. Wind tunnel simulation of hurricane wind load on the subject house (FL-27)

A scale model of House FL-27 was used to evaluate the pressure coefficients near corner, ridge and eave locations on the roof. The wind tunnel configuration, scale model construction, instrumentation and test procedures are described in the following sections. A detailed description of the configuration of the wind tunnel and the roughness elements used to simulate suburban terrain can be found in [29].

Wind tunnel

Wind tunnel studies were conducted on a 1:50 scale model of FL-27 subject house using Clemson University's boundary layer wind tunnel. This open-return wind tunnel has an 18 m long by

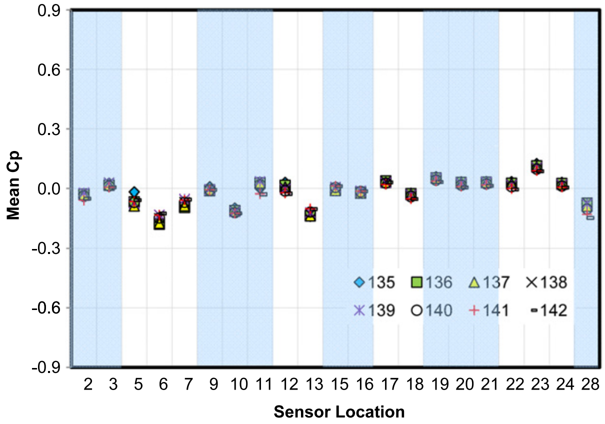

Fig. 6b. The 15-minute mean C_p on House FL-27 from Hurricane Ivan, 2004. Sample frequency: 10 Hz; Data records 135–142, UTC time: 9/16/2004 05:53–07:53.

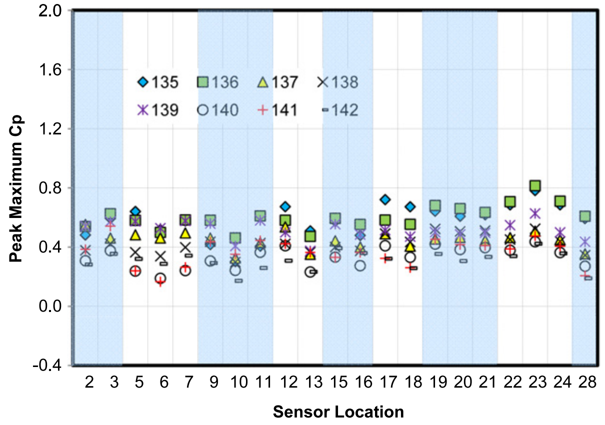

Fig. 6c. Peak positive C_p (instantaneous gust within 15 minutes) on House FL-27 from Hurricane Ivan. Sample frequency: 10 Hz; Data records 135–142, UTC time: 9/16/2004 05:53–07:53.

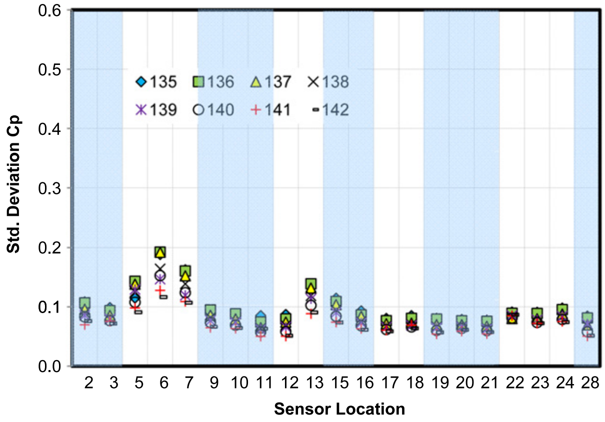

Fig. 6d. The standard deviation of C_p (over 15-minutes) on House FL-27 from Hurricane Ivan, 2004. Sample frequency: 10 Hz; Data records 135–142, UTC time: 9/16/2004 05:53–07:53AM.

3 m wide by 2.1 m tall test section, and it is powered by two 1.8 m diameter fans. Wind flows through a settling chamber, contraction cone and screens and honeycombs before entering the test section with near uniform wind speed and minimal turbulence. Test models are mounted on the 2.7 m diameter turntable, approximately 15 m from the test section entrance. To initiate the growth of an atmospheric boundary layer, trip plates and spires are set up at the entrance to the test section, and slant boards and roughness elements are arranged along the test section.

A suburban terrain wind velocity profile was simulated in the tunnel with a roughness length z_0 of 0.22 m (Fig. 7). For 1:50 scale modeling, the wind tunnel has along-wind turbulence intensities of between 21% and 26% at mean roof height of the model. The along-wind and across-wind turbulence length scales were 0.6 m and 0.2 m (30 m and 10 m at full-scale), respectively.

Scale model and pressure measurement system

Pressure taps were installed on a 1:50 scale model of the FL-27 prototype house at the locations corresponding to the twenty-four pressure sensors on the full-size structure. 472 additional pressure taps were installed over the roof surface, as shown in Fig. 5. The immediate adjacent homes were also constructed to scale and installed on the turntable around the FL-27 instrumented scale model (Fig. 8).

The wind tunnel pressure data was collected using eight Scanivalve ZOC33 electronic pressure scanning modules connected to a RAD3200 digital remote analog to digital converter. This system allows near-simultaneous sampling of a maximum of up to 512 pressure taps. Tap pressure data were sampled at 400 Hz and low-pass filtered to 200 Hz. The mean wind speed at mean roof height of the model was 6.0 m/s, and the reference wind speed (measured by a reference pitot tube 300 mm below the top of the tunnel) was 9.5 m/s.

Tubing system

A 300 mm (12 in.) long tubing system was used to connect each pressure tap to the pressure scanning modules. The tubing system consists of a 200 mm long, 1.37 mm (0.054 in.) internal diameter (ID) vinyl tube connected to the model, a 100 mm long, 0.86 mm (0.034 in.) ID vinyl tube connected to the pressure scanner, and an 18 mm long 1.37 mm (0.054 in.) ID brass tube connecting the two vinyl tubes (top of Fig. 9).

The tubing system's frequency response was determined by comparing the direct (no tubing) measurement of a white noise signal with the measurement after passing through the tubing system. The tubing response was determined up to 300 Hz, as shown in Fig. 9, along with a sketch of the tubing system arrangement. The worst case dynamic amplification was less than +/-10%. The dynamic amplification for each tap was removed by adjusting the signal in the frequency domain before analyzing the wind tunnel data.

Pressure coefficients

The pressure coefficient $C_{p,\text{pitot}}$ was determined as follows:

$$C_{p,\text{pitot}} = \frac{p_i}{1/2\rho U^2_{\text{pitot},z0,\text{mean}}} \tag{3}$$

where, the pressure coefficient $C_{p,\text{pitot}}$ is the ratio of tap pressure p_i divided by the dynamic pressure at reference height, ρ is the air density, and $U_{\text{pitot},z0,\text{mean}}$ is the mean wind velocity at the reference height, characterized by its roughness length z_0.

In order to compare the wind tunnel results to the full-scale pressure coefficients, the wind tunnel pressure coefficients must be normalized to a 3-s gust wind speed at mean roof height, $U_{3s,roof}$, for equivalence with the wind speed reference in Eq. (2). An adjustment factor ϕ, defined in Eq. (4) below, is necessary to convert the wind tunnel pressure coefficients $C_{p,\text{pitot}}$ to the equivalent coefficient $C_{p,\text{roof}}$ referenced to the 3-s gust wind speed at mean roof height.

$$C_{p,\text{roof}} = \phi \cdot C_{p,\text{pitot}} = \left(\frac{U^2_{\text{Pitot},z0,\text{mean}}}{U^2_{3s,\text{roof}}}\right) \cdot C_{p,\text{pitot}}. \tag{4}$$

The adjustment factor ϕ was experimentally determined using simultaneous measurements of the wind speeds and the reduced frequency velocity scaling relationship. Simultaneous hot wire anemometer measurements of wind speeds (sampled at 2000 Hz)

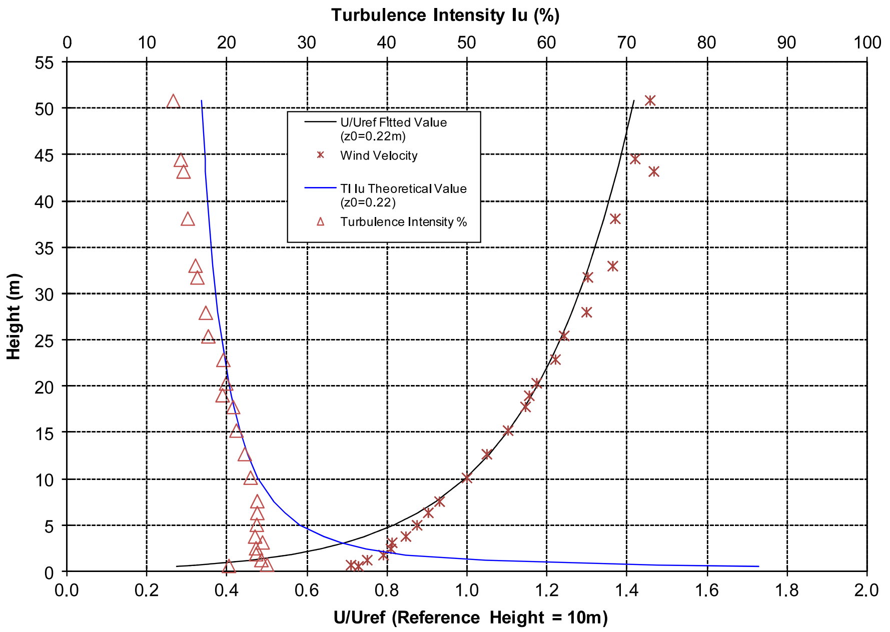

Fig. 7. Velocity and turbulence intensity profiles for 1:50 scale suburban terrain, measured at center of turntable with model removed.

were taken at the wind tunnel reference height and at the mean roof height of the house at the center of the turntable with the models removed. A moving average was used to determine the peak 3-s gust wind speed. The adjustment factor is given by the squared ratio of the mean wind speed at reference height (9.5 m/s) to the equivalent gust wind speed (8.0 m/s) at mean roof height, resulting in an adjustment factor ϕ of 1.41.

Wind tunnel results

Pressure tap data was recorded on the house model for 120 s for incident wind directions from 0° to 350° at 10° intervals. Further, for comparison with peak winds observed at FL-27 during Hurricane Ivan, 16 additional data sets were taken for 52 s periods at a wind direction of 130°, to provide equivalency with the full-scale data normalized to 15 min mean wind speeds. The sampling period at model scale is equivalent to a 15 min period at full scale is 52 s.

The peak negative and positive, averaged, and standard deviation of wind tunnel model pressure coefficients (at the full-scale tap locations) occurring for incident wind direction of 130° is presented along with enveloped peak values for all wind directions (0° to 350°), shown in Fig. 10. A contour plot of the peak negative pressure coefficients on the roof for the wind incident angle 130° and enveloped for all wind directions is shown in Fig. 11(a) and (b), respectively. It can be observed that the absolute peak pressure coefficients from all wind directions exceed the peak pressure coefficients occurring for 130° incident wind. This indicates that the peak pressure coefficients observed in the direction-limited full-scale dataset are not the most severe possible pressure coefficients. For example, the largest negative pressure coefficient occurring at Tap #15 (−3.3) was 120% greater than the negative pressure coefficient of −1.5 measured at the same pressure tap when the wind directions was 130°.

5. Comparison of full-scale and wind tunnel test results

A regression analysis of the full-scale and wind tunnel pressure coefficients was performed to identify and remove steady offset. The linear regression for full-scale and wind-tunnel mean pressure coefficients at a wind direction of 130° yields a correction of −0.11 for the wind tunnel data to match the full-scale values. This offset correction was applied to the wind tunnel data from each pressure sensor to calculate the mean and peak coefficient values. This offset produces a reasonably small pressure correction of less than 1.5 psf and it does not affect the pressure coefficient standard deviation. Fig. 12a presents the comparison of the full-scale and wind tunnel mean pressure coefficients before (bottom plot) and after (top plot) the offset correction to the wind tunnel data.

Fig. 8. The 1:50 scale model of House FL-27 and surrounding models installed on turntable.

The pressure coefficients obtained from the House FL-27 wind tunnel tests for wind angle 130° are compared to the full-scale results (Figs. 12a–12d). Each of these plots contain a legend where FS is Full-Scale, WT is Wind Tunnel, and No. 137, 138 and 139 refer to three sequential full-scale data records, each 15 min long, which occurred during the peak winds with incident wind direction very close to 130°. There is excellent agreement between full-scale and wind tunnel results for the standard deviation of pressure coefficients (Fig. 12b). This strong matching of second order statistics provides confidence in the turbulence intensity of the wind tunnel flow field, while validating the relevance and significance of the differences observed between full-scale and wind tunnel peak values in Figs. 12c and 12d.

Fig. 12c shows the full-scale observations of instantaneous (10 Hz) peak negative pressure coefficients (three observations for each tap) compared with the wind tunnel expected value peak minimum pressure coefficients calculated as the average

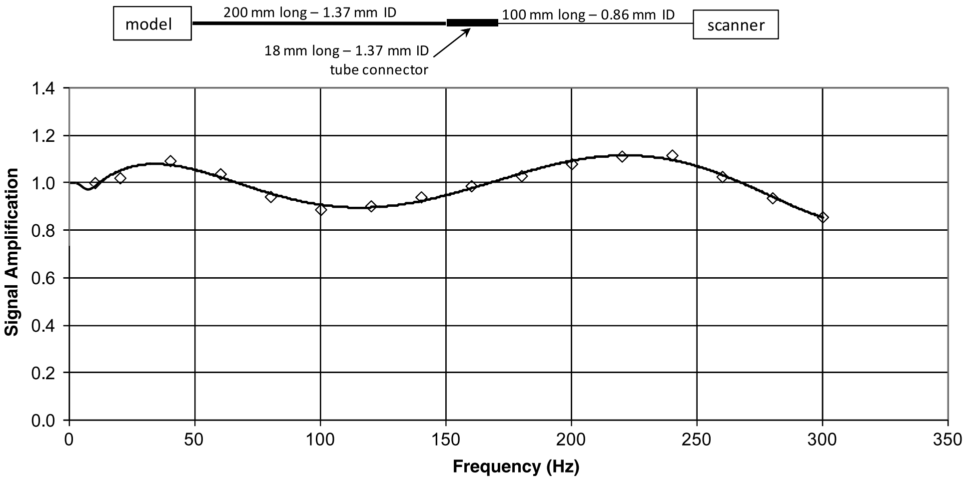

Fig. 9. Frequency response characteristics of the pressure tubing system.

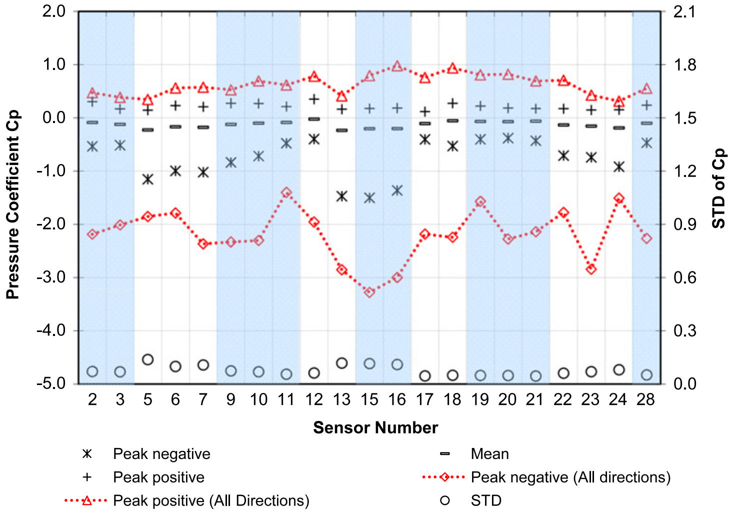

Fig. 10. Wind tunnel C_p values for 130° wind direction ($*$, $+$, $-$, o) and the maximum and minimum pressure coefficients for all wind directions (averaged from 16 test runs).

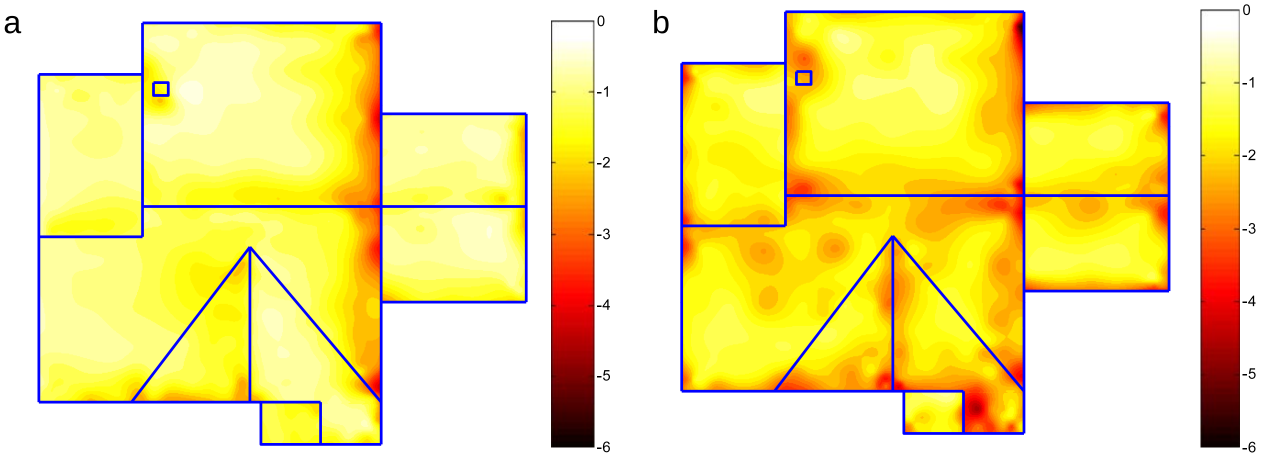

Fig. 11. Wind tunnel contour maps of peak negative pressure coefficients. (a) Wind direction 130°. (b) All tested wind directions.

of 16 observations (each from one wind tunnel test with a full scale equivalent 15-min duration). Differences between results of full-scale and model peak negative coefficients can be observed at individual sensor locations (e.g. ridge sensors #6, and #7 and corner sensors #15 and #16). The full-scale peak negative pressure coefficients at most taps exceeds the corresponding wind tunnel values, in agreement with the findings of previous studies on full-scale vs. wind tunnel peak pressure data. The trend in peak values, moving from one tap location to another, is well matched.

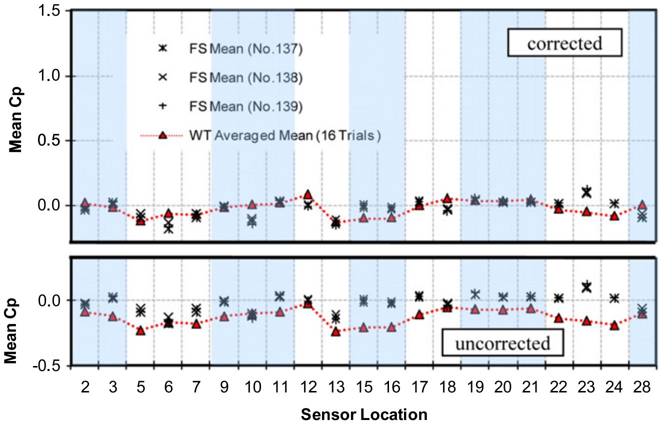

Fig. 12a. Comparison of mean pressure coefficients from full-scale (record sections: No. 137–139) vs. wind tunnel tests wind direction 130°. Top plot — corrected full-scale. Bottom plot — uncorrected full-scale.

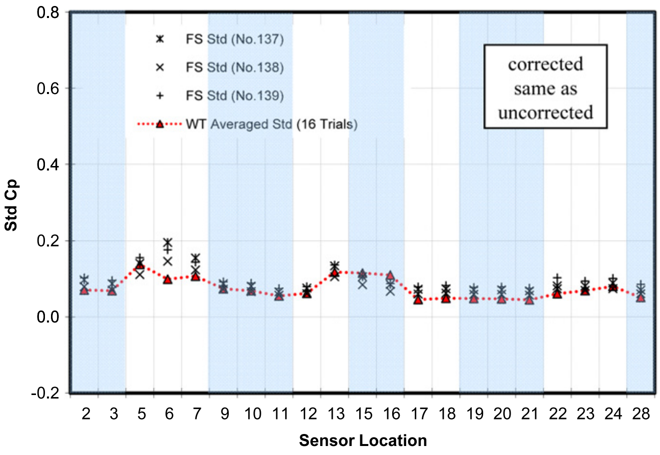

Fig. 12b. Comparison of standard deviation of pressure coefficients from full-scale (record sections: No. 137–139) vs. wind tunnel tests wind direction 130°.

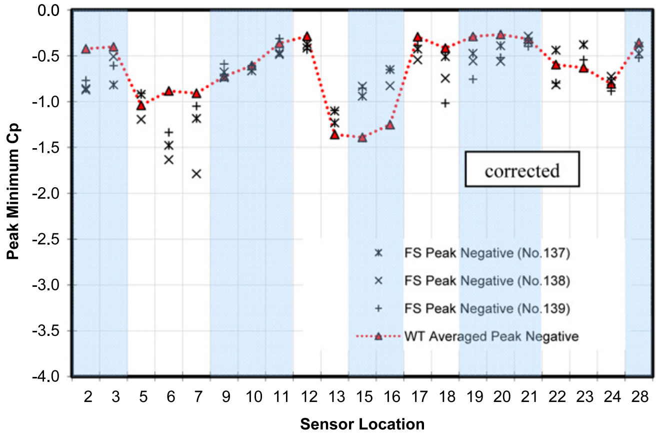

Fig. 12c. Comparison of peak negative pressure coefficients from full-scale (record sections: No. 137–139) vs. wind tunnel tests wind direction 130°.

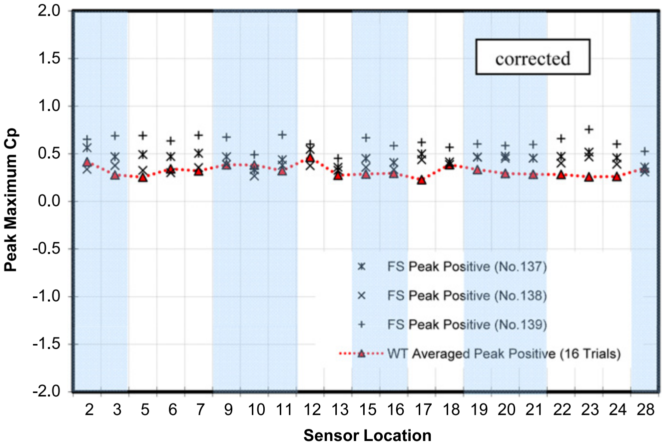

Fig. 12d. Comparison of peak positive pressure coefficients from full-scale (record sections: No. 137–139) vs. wind tunnel tests wind direction 130°.

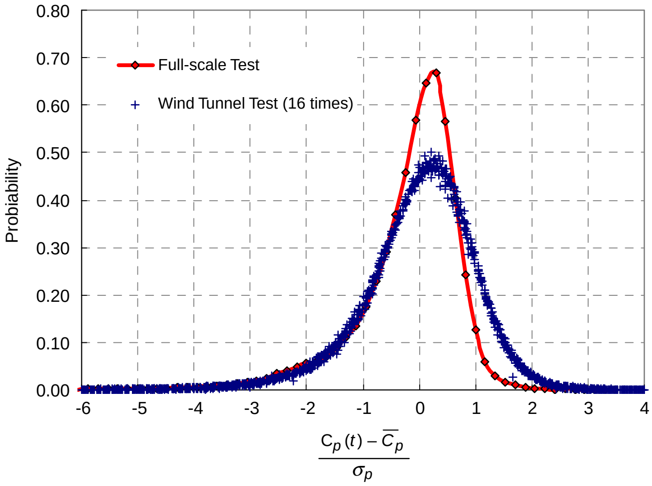

Fig. 13. Comparison of PDF of pressure coefficients observed at the Sensor #7 location between the full-scale and wind tunnel model tests (wind direction 130°).

The comparisons between full-scale and wind tunnel peak values in Fig. 12c does not include any visual representations of uncertainties in the data collection and analysis process. A follow-up study will focus on quantifying the various sources of uncertainty in the full-scale and wind tunnel data, and results will be presented with probabilistic uncertainty bounds. As an example of one source of uncertainty, the variability of the observed peak pressure coefficients from the 16 wind tunnel trials was quantified as a coefficient of variation (COV). The COV among the 16 trials at each of the taps ranged from a minimum of 0.07 at tap #3 to a maximum of 0.30 for tap #18 (see Fig. 5), with an average COV of 0.11.

The deviations between the peak minimum pressure coefficients at full scale and wind tunnel (Fig. 12c) are made more significant by the excellent matching of first and second moments (Figs. 12a and 12b). This is indicative of a difference in the probability distributions. The empirical probability density functions (PDFs) obtained from the wind tunnel tests and the full-scale data of each sensor were estimated. In general, the PDFs of the full-scale data were found to be more highly skewed than those of the wind tunnel tests, corresponding to the left tails (negative pressures) of full-scale data containing heavier probability than those from the wind tunnel tests. This can help explain why the wind tunnel tests underestimated the negative peak wind pressure and overestimated positive peak wind pressure, even when first and second order statistics are well matched.

As an example, the probability density functions of full-scale and wind tunnel results of sensor #7 are displayed in Fig. 13, where the abscissa is the non-dimensional standardized pressure coefficient. Both data have almost identical moments through second order. The coefficient of skewness in the full-scale data is −1.97 and that of the wind tunnel data is −0.95. This corresponds well with the resulting good match in the mean and standard deviation of pressure coefficients, and the deviation between full-scale and model-scale peak minimum and maximum coefficients. This may represent a departure between full-scale and scaled model in the behavior of the dynamics in the separation regions.

6. Discussion and future work

These preliminary results suggest that the peak uplift loads prescribed in ASCE-7 (ASCE/SEI, 2006) for components and cladding may be non-conservative for homes in suburban settings. However, such preliminary indications, based upon one house and one storm, are not sufficient evidence to support recommendations regarding existing wind load provisions.

Validation of, or changes to current prescriptive wind load practice should be determined by a consensus effort from the wind engineering community. The comparison of full-scale vs. model peak loads should be performed by multiple independent wind tunnel laboratories, and should include more than one house and more than one storm. Resources are being sought to conduct a multi-wind tunnel laboratory study on the FCMP dataset. The premise is to give each participating wind tunnel lab the metadata (house dimensions, pressure tap layouts, etc.) necessary for that lab to generate their own model(s) at their own chosen scale and turbulence profile, using their own methods. Such a multi-laboratory study will not be influenced by forcing a common scale, shared models, or common turbulence profile. Such multi-laboratory studies have been conducted to investigate variabilities among labs (e.g., [22]). However, no such comprehensive study has been completed that includes full-scale residential datasets. Therefore, recommendations regarding ASCE 7 are not yet appropriate.

Concurrent with the need to investigate more than one house and more than one storm by more than one wind tunnel lab, recommendations regarding wind load provisions are also premature without a more thorough treatment of the uncertainties in the data collection and analysis. A study is now underway to quantify and directly incorporate uncertainties associated with full-scale and wind tunnel data collection and analysis of the subject FL-27. This study will focus on the confidence limits of the full-scale and wind tunnel pressure coefficients. In addition, analysis continues on five other FCMP homes using the methodologies presented here.

7. Conclusions

The Florida Coastal Monitoring Program successfully recorded high-resolution wind pressure time-histories from 24 pressure sensors installed on the roof of a residential structure during Hurricane Ivan. An analysis methodology was developed to determine the statistical quantities for external pressure coefficients at the sensor locations. A wind tunnel study was conducted using a 1:50 scale model of the house; yielding external pressure coefficients for comparable roof locations on the roof, for a 360° range of wind directions. A comparison of the full-scale and model scale data sets (for incident wind direction 130°) showed the following:

(1) There is strong agreement in the means and standard deviations of the external pressure coefficients developed between wind tunnel and full-scale data;
(2) The wind tunnel results demonstrate a departure from full-scale in the case of peak minimum and maximum Cp values;
(3) The peak negative pressure coefficients obtained in the wind tunnel study generally underestimated the full-scale values, consistent with observations in previous studies comparing full-scale and wind tunnel measurements;
(4) Recommendations regarding the wind load provisions are premature in the absence of both a joint-facility study of the multi-house multi-storm FCMP dataset (and companion wind tunnel experiments), and a more thorough treatment of uncertainties in data collection and analysis.

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