

# Component and Cladding Wind Loads for Soffits

Peter J. Vickery, M.ASCE<sup>1</sup>

**Abstract:** The wind induced failure of soffits of low rise structures is a failure mechanism commonly observed in post hurricane damage investigations. The failure of the soffits has the potential to allow both wind and water to enter the attic space of the building. The current US national wind loading standard (ASCE 7) provides no guidance as to the wind load requirements for the design of soffits. In order to address this deficiency, wind tunnel tests on 1:50 scale models of one-, two-, and three-story hip and gable roof buildings were performed where measurements of the wind induced pressures and suctions on the soffits, roofs, and walls were obtained. The wind tunnel tests were performed in open and suburban terrain conditions, with and without surrounding buildings in place. The results of the tests clearly show that the soffit pressures are nearly fully correlated with nearby wall pressures, and a simple and accurate solution to the soffit loading deficiency in ASCE 7 is to prescribe that the component and cladding pressures for use in the design of soffits be identical to the component and cladding loads used for the design of wall components.

**DOI:** 10.1061/(ASCE)0733-9445(2008)134:5(846)

**CE Database subject headings:** Wind loads; Structural failures; Buildings, low-rise; Walls; Structural design.

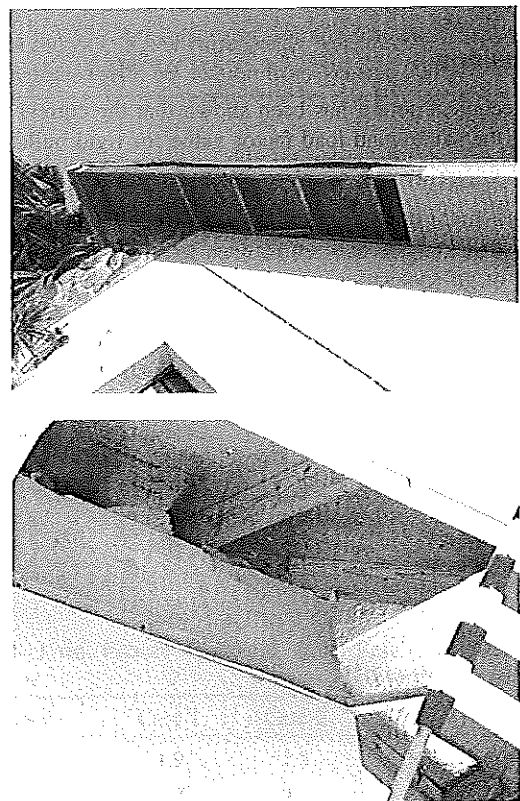
## Introduction

The wind induced failure of soffits of low rise structures is a failure mechanism commonly observed in posthurricane damage investigations. Fig. 1 presents example photographs of soffit damage to residential buildings taken following the landfall of Hurricane Charley in southwest Florida. The failure of the soffits is often followed by the intrusion of significant amounts of water into the attic and living spaces of residential buildings (FEMA 2005a,b), but the current US national wind loading standard, ASCE 7 (ASCE 2006) provides no guidance as to the wind load requirements for the design of soffits. Here, we report on the results of wind tunnel tests carried out on 1:50 scale models of simple one-, two-, and three-story buildings with hip and gable roofs. Wind induced pressures were measured on the soffits, walls, and roof surfaces for buildings located in standard open and suburban terrains. In most cases, the measurements were performed for an isolated building situated in the center of the rotating turntable; however, for a few cases, additional surrounding buildings were mounted on the turntable. The objective of the wind tunnel tests and subsequent data analysis was to derive simple, easy to apply rules that can be readily incorporated into wind loading design standards to address the lack of provisions for component and cladding loads for soffits. Time series of pressure measurements on the soffit were correlated with time series of pressure measurements at nearby roof and wall locations. The results indicate that the soffit loads are invariably highly corre-

lated with the wall loads, and much less correlated with the nearby roof loads.

## Wind Tunnel Tests

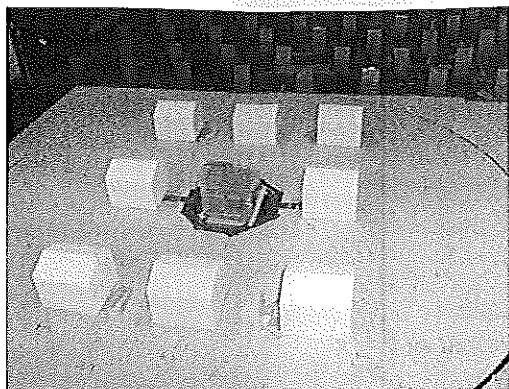
The wind tunnel tests on the 1:50 scale model buildings were performed at the Boundary Layer Wind Tunnel Laboratory at the



**Fig. 1.** Examples of wind induced soffit failures on residential buildings

<sup>1</sup>Principal Engineer, Applied Research Associates, Inc., 8540 Colonnade Center Dr., Ste. 307, Raleigh, NC 27165. E-mail: pvickery@ara.com

Note. Associate Editor: Kurtis R. Gurley. Discussion open until October 1, 2008. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this technical note was submitted for review and possible publication on August 30, 2006; approved on July 23, 2007. This technical note is part of the *Journal of Structural Engineering*, Vol. 134, No. 5, May 1, 2008. ©ASCE, ISSN 0733-9445/2008/5-846-853/\$25.00.



**Fig. 2.** Photograph of two-story gable model house in the wind tunnel. Large roughness elements required to generate the suburban terrain are seen in the background.

University of Western Ontario, in flow conditions designed to approximate standard open terrain and standard suburban terrain (i.e., ASCE 7 Exposures C and B, respectively). Fig. 2 shows the two-story gable roof model in the wind tunnel for a configuration tested to examine the effects of surrounding buildings on the measured pressures.

### Mean and Turbulence Intensity Profiles

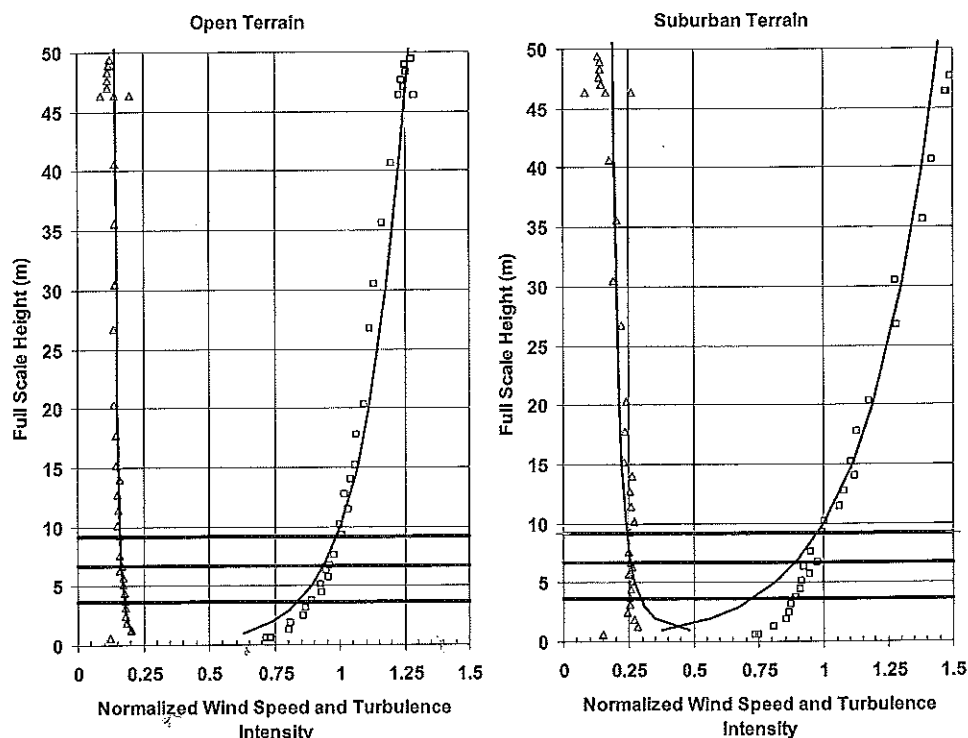
Fig. 3 shows the variation of the modeled mean and turbulence intensity with height resulting from the open terrain and suburban terrain simulation. Shown also in Fig. 3 are the theoretical variations of the mean and turbulence intensity with height derived from the ESDU (1982) models for atmospheric turbulence. The

comparison of the measured and observed mean velocity profiles given in Fig. 3 indicate an acceleration of the mean wind over the lower 10 m associated with the wind leaving the large upstream roughness elements and approaching the location of the model buildings over a smooth fetch of approximately 60 m. Additional details describing the development of the scaled atmospheric boundary layer are presented in Kopp et al. (2005) and are not repeated here.

### Pressure Measurements

The full scale plan dimensions of the model buildings is length  $L=10.36$  m (34 ft) by depth  $D=9.14$  m (30 ft) with overhangs (soffits) of 0.51 m (1.67 ft) on all sides. The roof is modeled with a 4:12 roof slope. The eave heights of the one-, two-, and three-story buildings are 3.6 m (11.8 ft), 6.7 m (22 ft), and 9.2 m (30.2 ft), respectively. The model buildings are symmetric about both the  $x$  and  $y$  axes, requiring that the wind tunnel tests need only be performed for wind directions of 0 through 90 deg. The model buildings are instrumented with a total of 350 pressure taps for the gable roof building and 356 taps for the hip roof building. A total of 30 soffit taps are located on the gable building, with five located on each soffit running along the soffits located at the end of each side of the sloped roof section and 10 at each of the gable ends. A total of 32 soffit taps are used on the hip roof building, with seven soffit taps located along each of the long walls, and nine soffit taps located along each of the short walls. Pressure tap diagrams are given in Figs. 4 and 5 for the gable and hip roof cases, respectively.

Wind tunnel tests were performed with a wind speed of 14 m/sec (46 ft/sec) measured at a height of 1.6 m (5.25 ft) above the floor of the wind tunnel. Pressures were sampled at a



**Fig. 3.** Normalized mean velocity (open squares) and turbulence intensity (open triangles) profiles for the open and suburban terrain simulations. ESDU profiles (solid lines) given for  $z_0$  values of 0.02 m and 0.25 m for open and suburban terrains, respectively. Solid horizontal lines represent the eave heights for one-, two-, and three-story buildings.



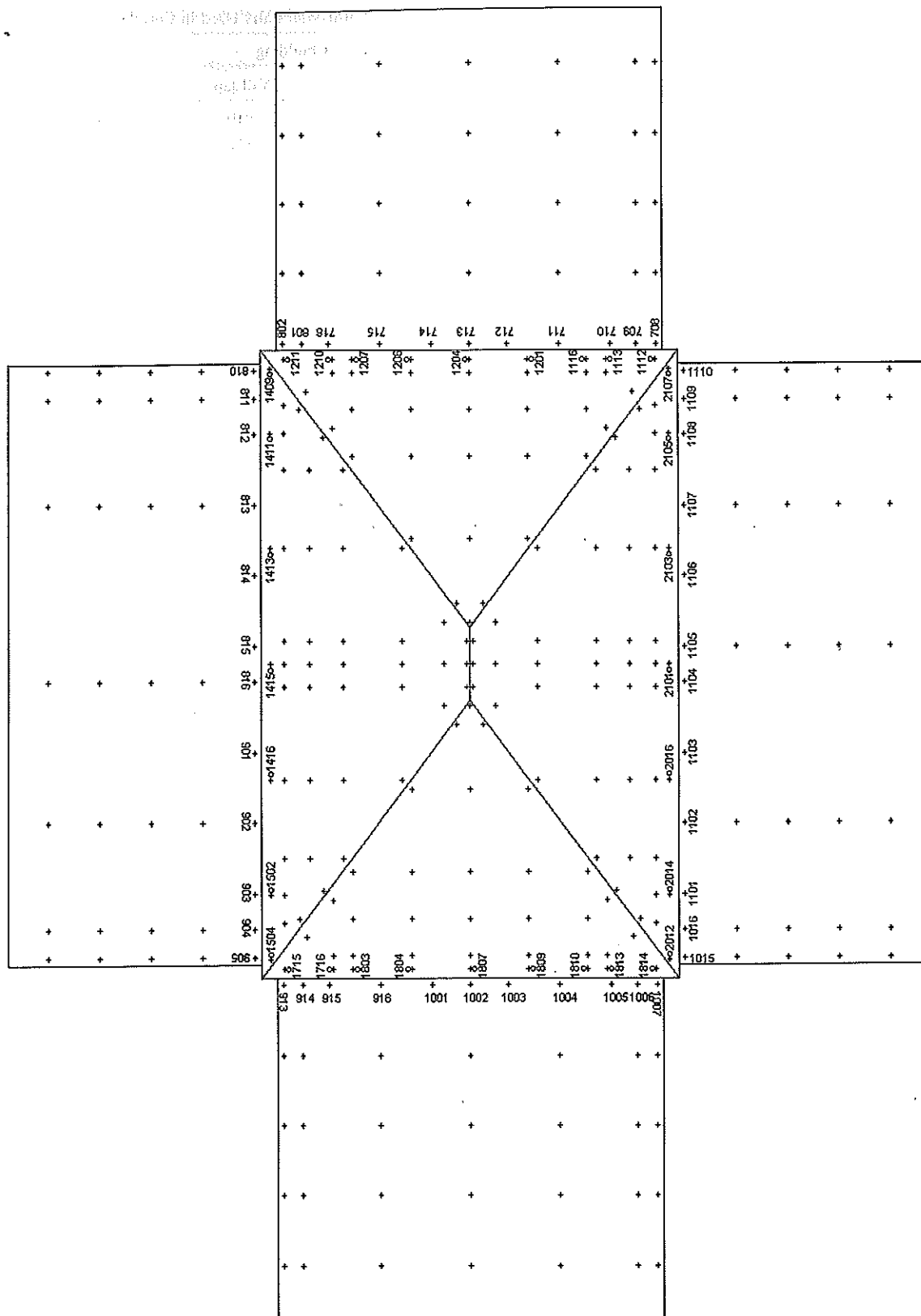


Fig. 5. Pressure tap layout for hip roof building

rate of 400 samples per sec for a period of 120 (20–30 min full scale equivalent depending on the design wind speed) sec using a system with a pneumatic frequency response flat to approximately 100 Hz. The pressures were digitally filtered with a cutoff frequency of 30 Hz (~3 Hz full scale) after the data were collected. All pressures are normalized by the mean dynamic pressure measured using a pitot-static tube mounted at a height of 1.6 m [80 m (262 ft) full scale] above the floor of the wind tunnel.

Isolated building tests were performed for 12 of the 14 cases examined (three heights, two roof shapes, and two terrains). For the remaining two cases (2-story gable roof in suburban terrain), the test buildings were surrounded with two-story buildings. The two surrounding building cases, denoted “Neighbor A” and “Neighbor B” were studied to examine the effect of nearby buildings on the pressures. In the “Neighbor A” case, eight neighboring buildings were positioned a distance of  $2L$  (clear spacing) apart in the direction perpendicular to the roof ridge line, and  $1L$  apart in the direction parallel to the roof ridge line. In the “Neighbor B” case, eight neighboring buildings were positioned a distance of  $2L$  (clear spacing) apart in the direction perpendicular to the roof ridge line, and  $L/2$  apart in the direction parallel to the roof ridge line.

### Soffit Wall Load Correlations

The correlation between the wall and soffit taps was examined through a simple comparison of the extreme (maximum or minimum) pressures measured at each soffit-wall pair on an angle-by-angle basis, as well as more formally, through the use of a correlation coefficient  $R$  defined as

$$R = \frac{\sigma_{xy}^2}{\sigma_x \sigma_y}$$

where  $\sigma_{xy}^2$  = covariance of the pressures measured on the walls and soffits,  $\sigma_x$  = standard deviation of the soffit pressure, and  $\sigma_y$  = standard deviation of the wall pressure.

Table 1 presents the soffit-wall tap pairings used in the soffit-wall pressure correlation analysis. Figs. 6 and 7 present plots showing the comparisons of the peak positive and negative pressures, as well as plots showing the cumulative distribution of the correlation coefficient for each building/terrain configuration examined. Results are given for each wind direction soffit-wall pair examined. The comparisons of the minimum and maximum peak pressures are presented on the same plots, with the regression analysis results (slope and  $r^2$  values) given separately for the peak positive and negative pressures. The regression statistics given in Figs. 6 and 7 show that while both the positive and negative peak soffit pressures are highly correlated with the wall pressure peaks, this correlation is stronger in the case of the positive peaks. In the case of the hip roof building (Fig. 6), on average, the peak negative pressures on the hip roof soffits were only 2 to 3% lower than the wall peak negative pressures, whereas, on average, the peak positive soffit pressures are approximately equal to the peak positive wall pressures. The cumulative distribution of the correlation coefficient  $R$  indicates that in 90% of the cases, the value of  $R$  is 0.95 or greater. In general, the locations having the lowest values of  $R$  are associated with the corner soffit-wall pairs (e.g., pairs 2107,1110, and 1112,708), and those locations with the largest horizontal separations (e.g., pairs 1116,711 and 1201,712). Fig. 6 suggests that there is a weak tendency for the correlation between

**Table 1.** Soffit-Wall Pairs Used in Correlation Analysis

Hip roof building		Gable roof building	
Soffit tap	Wall tap	Soffit tap	Wall tap
1409	810	2005	1113
1411	812	1813	1115
1413	814	1715	1201
1415	816	1607	1202
1416	901	1415	1204
1502	903	1512	902
1504	905	1704	904
2012	1015	1812	906
2014	1101	1910	907
2016	1103	2102	909
2101	1104	2309	1004
2103	1106	2307	1005
2105	1108	2305	1006
2107	1110	2303	1008
1715	913	2302	1010
1716	915	2215	1010
1803	916	2213	1015
1804	1001	2211	1015
1807	1002	2209	1101
1809	1003	2208	1102
1810	1004	1208	708
1813	1005	1209	709
1814	1007	1211	711
1112	708	1213	713
1113	710	1215	715
1116	711	1302	715
1201	712	1303	802
1204	713	1305	804
1206	714	1307	806
1207	715	1309	807
1210	716		
1211	802		

the wall and soffit pressures to increase with increasing building height.

In the case of the gable roof building, the difference between the wall and soffit peak negative and positive pressures is a little more than seen in the hip roof case, where here, the peak negative soffit pressures are, on average, 5% lower than the peak negative wall pressures, but the peak positive soffit pressures are about 5% higher than the peak positive wall pressures. The cumulative distribution of the correlation coefficient  $R$  indicates that there are more cases of low values of  $R$  ( $R < 0.8$ ) in the gable roof case than in the hip roof case. It is also noteworthy that the addition of neighboring buildings increased the frequency of soffit-wall pairs with low values of  $R$ .

Fig. 8 presents plots showing the comparisons of the peak positive and negative pressures as well as plots showing the cumulative distribution of the correlation coefficient for the gable roof building case with the side wall and gable end wall soffit-wall pairs presented separately, but with all building/terrain cases combined together. This figure clearly shows that along the side walls, the wall-soffit pressures are extremely well correlated with the regression analyses of both the peak positive and negative wall and soffit peaks yielding  $r^2$  values of ~0.99 with slopes of ~1. The minimum value of  $R$  is greater than 0.97. The wall-soffit

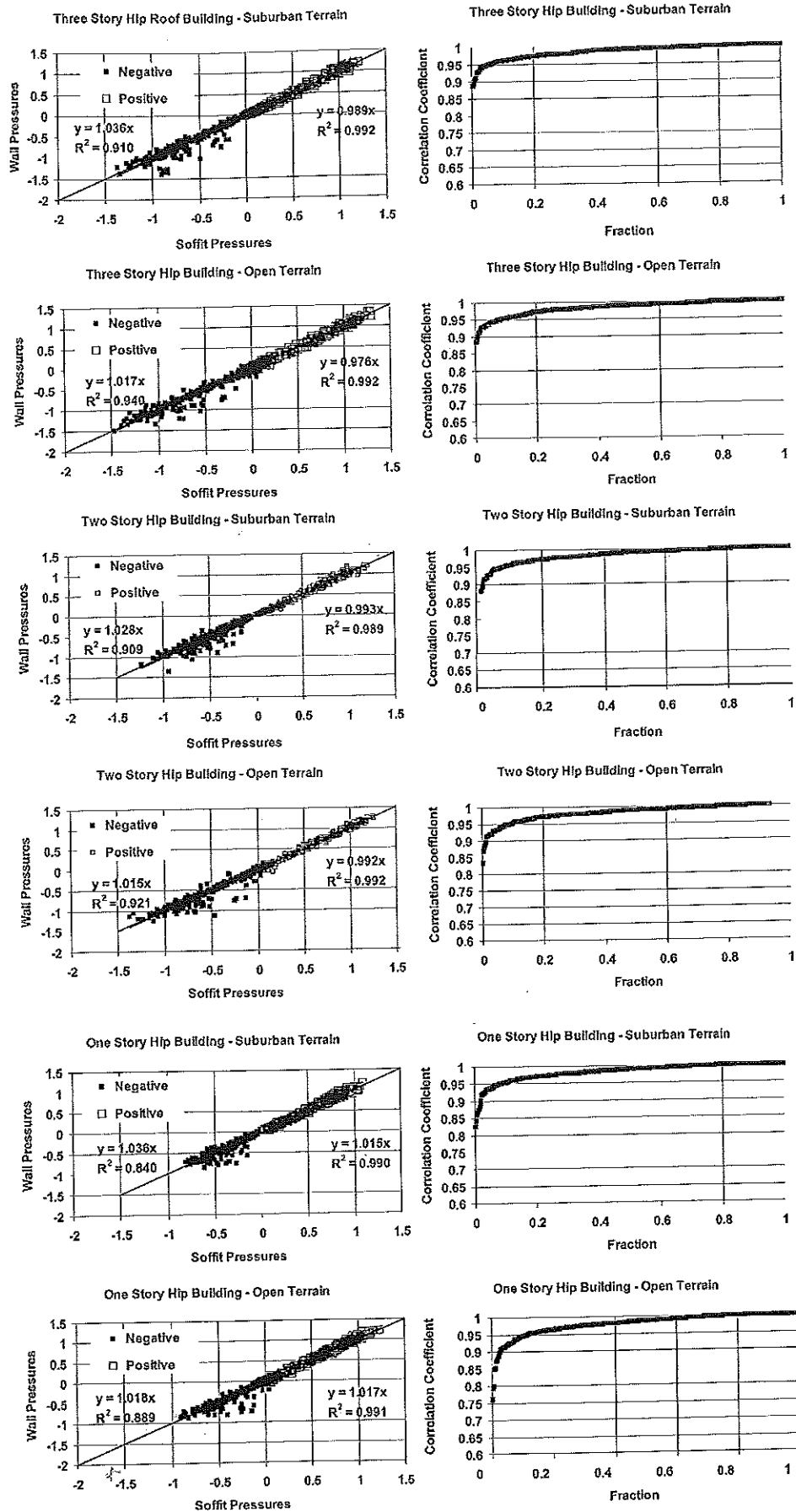


Fig. 6. Soffit and wall pressure correlations for hip roof buildings

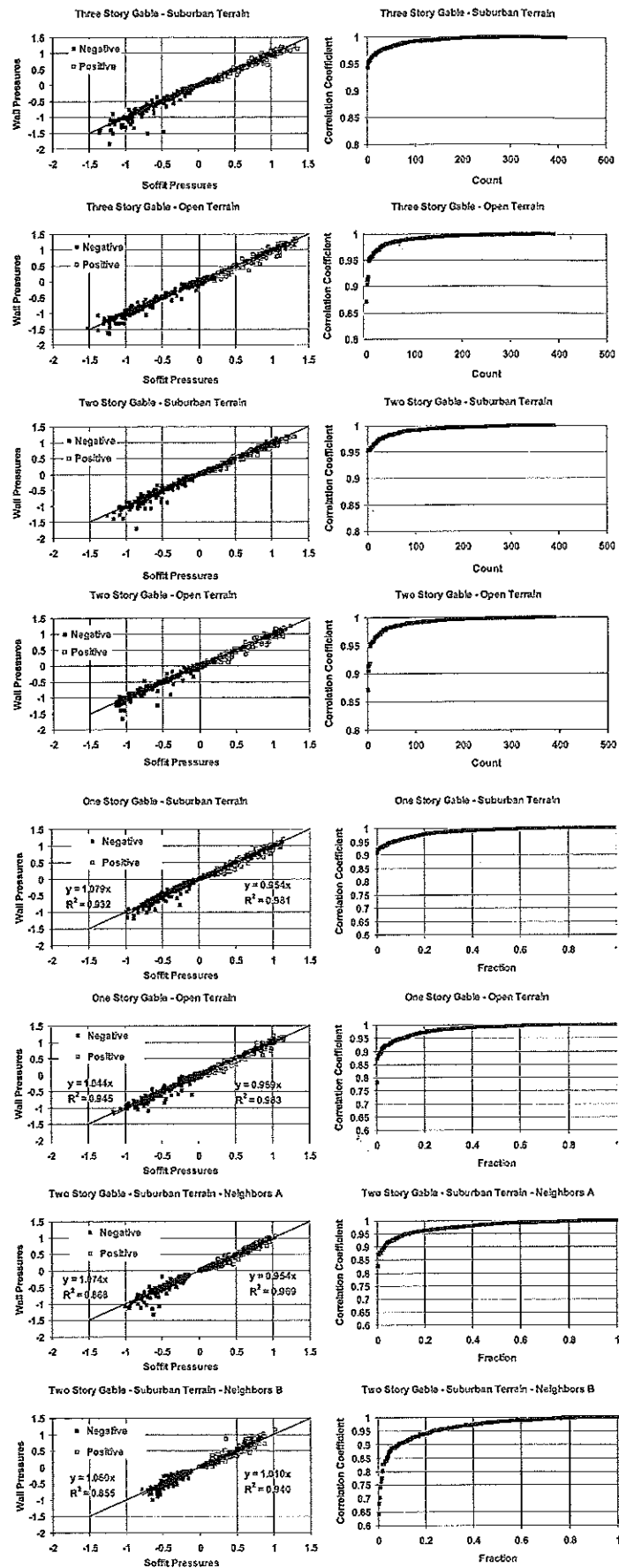


Fig. 7. Soffit and wall pressure correlations for gable roof buildings

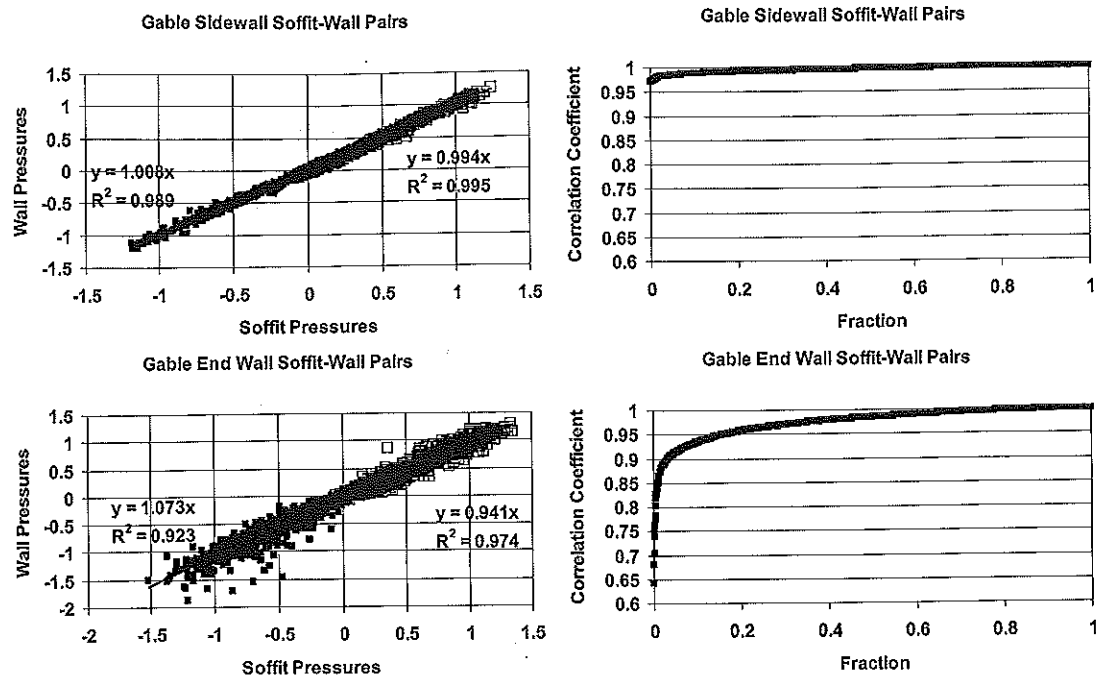


Fig. 8. Soffit and wall pressure correlations for gable roof buildings. Side wall and gable end walls examined separately.

correlation, while still very high, is clearly weaker in the case of the gable end soffits, with the average peak negative soffit pressure being approximately 7% lower than the corresponding peak negative wall pressure. The average positive soffit pressure, on the other hand, is approximately 6% higher than the average wall pressure. It should be noted that the wall taps on the gable ends are located further away from the soffit taps (lower) than those on the side walls, and thus, any vertical pressure gradient that exists over the wall between the locations of the taps and the top of the wall will appear as a lack of correlation. It is not clear how much of the reduced correlation at the gable ends is associated with the distance between the taps or the more three-dimensional flow that would be expected to occur in this region as compared to the side walls.

## Conclusions

The results of the experimental program clearly indicate that wall and soffit pressures are highly correlated. The high correlation of the soffit-wall loads suggest that the reduction in pressures with increased area for the soffits will be consistent with that which occurs along the walls. The results indicate a simple and accurate solution to the soffit loading deficiency in ASCE 7 is to prescribe that the component and cladding pressures (both negative and positive) for use in the design of soffits to be identical to the component and cladding loads used for the design of wall components.

An effective means to include soffit loads within ASCE 7 for buildings with heights less than 60 ft is to add an additional note at the bottom of Figs. 6–11B through 6–11D, Fig. 6–12, Fig. 6–13, Fig. 6–14, and Fig. 6–15 stating that “Component and clad-

ding for soffits and overhangs shall be designed using the wall pressures given in Fig. 6–11A considering both positive and negative pressures.” All figures are those given in ASCE 7-05 (ASCE 2006). Similarly, for buildings with heights greater than 60 ft, a similar note at the bottom of Figure 6–17 stating “Component and cladding for soffits and overhangs shall be designed using the wall pressures given in this figure.”

## Acknowledgments

This study was funded by the Florida Department of Community Affairs and the State Farm Mutual Insurance Company. The views and opinions expressed in this paper are those of the writer.

## References

- ASCE. (2006). “Minimum design loads for buildings and other structures.” *ASCE 7-05*, Reston, Va.
- ESDU. (1982). “Strong winds in the atmospheric boundary layer. Part I: Mean hourly wind speed.” *Engineering sciences data unit item No. 82026*, London.
- FEMA. (2005a). “Mitigation assessment team report: Hurricane Charley in Florida, observations, recommendations, and technical guidance.” *FEMA Rep. No. 488*, FEMA, Washington, D.C.
- FEMA. (2005b). “Mitigation assessment team report: Hurricane Ivan in Alabama and Florida, observations, recommendations, and technical guidance.” *FEMA Rep. No. 489*, FEMA, Washington, D.C.
- Kopp, G. A., Surry, D., and Mans, C. (2005). “Wind effects of parapets on low buildings: Part I. Basic aerodynamics,” *J. Wind. Eng. Ind. Aerodyn.*, (93), 817–841.