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The development of a field measurement instrumentation system for low-rise construction

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Abstract. In the last three decades several comprehensive field measurement programs have produced significant insight into the wind effects on low-rise structures. The most notable and well published of these efforts are measurements being collected at the Wind Engineering Field Laboratory (WERFL) at Texas Tech University, measurements on low-rise structures in Silsoe, England and measurements on groups of low-rise structures collected in Aylesbury, England. Complementary to these efforts, an additional full-scale field investigation program has recently collected meteorological, pressure, strain and displacement data on a low-rise structure in Southern Shores, North Carolina. To date over seventy-five hundred data sets have been collected at the Southern Shores site in a variety meteorological conditions up to and including hurricane-force winds. This paper provides details of the system, its development, and preliminary assessment of its performance. A description of the field site, the instrumented structure, and the instrumentation system is provided. In addition, an example of the data collected during three hurricanes is presented. The primary goal of this paper is to provide the reader with the necessary technical details to appropriately interpret data from this experiment, which will be presented in future publications currently under development.

Key words: low-rise; full-scale; field measurements; extreme-wind; hurricanes; data collection.

1. Introduction

1.1. Motivation

Each year devastating windstorms cause considerable losses to property in the United States and other developed and developing nations worldwide. As populations continue to migrate toward coastal areas, the number of structures susceptible to wind-related losses continues to increase. In the last decade many storms have acted as seemingly constant reminders of this ever-increasing vulnerability. Each year tornadoes sweep a destructive path through the Midwest and other areas of the United States. Hurricane Hugo in 1989, Hurricane Bob in (1991), Hurricanes Andrew and Iniki in (1992), Hurricane Fran in (1996), Hurricane Bonnie in (1998), and Hurricanes Dennis and Floyd in (1999), through their landfalls, have demonstrated this vulnerability. The losses are staggering. Hurricane Andrew alone, for example, caused $15 billion in insured losses and an estimated $25 billion in total losses (AAWE 1997). It is important to note that none of the previously mentioned storms have been worst-case events in either strength or path, yet they clearly demonstrated the

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potential for wind-related structural losses in the United States (Jones *et al.* 1995).

Low-rise buildings, in particular residential and light industrial construction, tend to be the hardest hit in these severe storms (Uematsu and Isyumov 1999). A large portion of these vulnerable low-rise structures are “marginally engineered”, relying primarily on deemed-to-comply code provisions for their “engineering”. Currently the wind-load provisions of ASCE 7-98 are based primarily on the results of wind tunnel investigations (ASCE 1998). Therefore, comprehensive full-scale field measurements are considered necessary to assess the suitability of these wind load provisions. This is particularly important given that a number of recent comparisons of wind tunnel and full-scale results (e.g., Richardson and Blackmore 1995, Hoxey and Richards 1995, Richardson *et al.* 1997, Lin *et al.* 1995, Sill *et al.* 1995, Milford *et al.* 1992, Cochran and Cermak 1991) have shown that wind tunnel data seem to have difficulty replicating the peak pressures observed in field measurements.

1.2. Background

In the past three decades, several full-scale field measurement programs have been undertaken to study the wind effects on low-rise structures. The most relevant of these include measurements on low-rise structures in Aylesbury England (Eaton and Mayne 1975), on low-rise structures in Silsoe England (Hoxey and Richards 1993), and most recently on a low-rise structure at Texas Tech University (Levitan and Mehta 1992a, 1992b). These field studies were recently reviewed by Uematsu and Isyumov (1999). For context, a brief description of each will be provided below.

1.2.1. Aylesbury

Field measurements were taken on a specially designed experimental building as well as several two-story houses in Aylesbury, England in the 1970's. The experimental building was designed to house the data acquisition equipment and to act as a comparison point for measurements taken on homes in a nearby housing development. By comparing measurements taken at the experimental building with measurements taken on houses in the development, the effects of building geometry and exposure on pressure measurements could be evaluated. The experimental building was constructed on flat, open terrain upwind (from the prevailing wind direction) of the housing development. A unique feature of the experimental building was the ability to change the pitch of the roof from 5 degrees to 45 degrees. Differential sensors were used and the pressure inside a manhole (assumed to be atmospheric) was used for the reference pressure (Eaton and Mayne 1975).

1.2.2. Silsoe

Several portal frame structures have been instrumented at the Silsoe Research Institute in England. The terrain surrounding these structures is described as “open country, with scattered wind breaks” (Hoxey *et al.* 1993). Data were collected on a number of structures with varying characteristics to study the effects of roof pitch, span and height on the distribution of pressures. Differential pressure sensors were used in these investigations. A static pressure probe located in upstream from the structure was used as reference pressure. This was calibrated by comparing its output to the value of pressure measured from a hole in the ground. In addition, strain measurements have been collected on structural members.

1.2.3. Texas Tech University

Measurements continue to be taken at the Wind Engineering Field Research Laboratory (WERFL) on the campus of Texas Tech. The instrumented structure is a prefabricated metal building located in flat, open terrain. Like the Aylesbury building, the WERFL can be rotated so that the angle of attack of the wind can be controlled. Differential sensors are again used at this site and the pressure is referenced to a hole in the ground near the structure. This region of Texas is frequented by strong winds from the passage of frontal systems and thunderstorms. These can bring sustained winds of 9 to 16 m/s or more (Yeatts and Mehta 1993).

All these experiments were carried out in natural but arguably somewhat idealized conditions. The structures were relatively simple box-like structures located in relatively flat open terrain. Because of their moderately controlled conditions, these studies contributed greatly to the fundamental understanding of the aerodynamic behavior of these types of structures (Uematsu and Isyumov 1999). Numerous wind tunnel and computational studies have been done on models of these structures and the results compared to the full-scale data.

Other full-scale studies have been conducted by Cermak Peterka Petersen, Inc. on roof systems (Peterka *et al.* 1997), by the National Bureau of Standards on a mobile home (Marshall 1975, 1977), and by the Division of Building Technology of South Africa on a low-rise aircraft hangar (Milford *et al*. 1992).

None of these field studies previously described have collected data on wind loads on structures in a hurricane or other severe wind events. There is a general lack of data in severe winds such as hurricanes, especially in the eye-wall region (Cermak 1998). This inherent lack of data about wind effects on structures in severe wind hinders efforts to validate codes of practice for building systems in hurricane-prone regions (National Research Council 1999). Even though the presence of surrounding structures has been found to have profound effects on the wind and pressure field (Kasperski and Niemann 1999) few studies have looked at buildings in more typical conditions (e.g., structures with more complex geometric configurations and more complex surrounding terrain).

2. The Southern Shores project

Full-scale field measurements of the wind loading and structural response have been (and continue to be taken) on a low-rise structure in Southern Shores, North Carolina beginning in 1997. The experiments being conducted in Southern Shores have the potential to fill some of the important existing data gaps. These experiments are being carried out on a structure with a complex geometric configuration (that closely resembles local construction), in a fairly typical suburban terrain. The surrounding area consists of gently sloping dunes, trees, and other low-rise construction. Because of the complexities of the structure itself and the surrounding environment, the main goal of this research is to assess the suitability of local and national wind load provisions, although it is expected that this project will also contribute to the fundamental understanding of bluff body aerodynamics. In addition, these experiments should be able to add severe wind data to the database of wind effects on structures. To date, the system has collected data in a variety of wind conditions up to and including hurricane-force winds. Some of the data comes from the passage of frontal systems, but data have also been collected in several northeasters and three land-falling hurricanes.

2.1. Site

The field site is located in the Town of Southern Shores, on the Outer Banks of North Carolina, about a quarter mile west of the Atlantic Ocean close to the most easterly point of the mid-Atlantic coast. The Outer Banks of North Carolina is frequented by severe windstorms. Northeasters hit the coast nearly every winter, and historically this region has been a target for land-falling hurricanes. The past decade has seen an unusually high number of hurricanes in this area. Hurricanes Hugo (1989), Bertha and Fran (1996), Bonnie (1989), and Dennis and Floyd (1999) have all made landfall at or near the North Carolina coast. The frequency of storms in this region makes it attractive for field studies.

The area immediately surrounding the instrumented structure (Fig. 1) and the field site is characterized by other low-rise construction, low trees and shrubbery, and gently sloping dunes. The low-rise town hall building is the closest obstruction and is located south-south east of the structure. Based on the comparison of data from two anemometers, the proximity of the town hall to the Pitts Center does influence the wind flow around the instrumentation system from some wind directions. Although this complicates data analysis, this terrain is representative of the terrain surrounding much local construction. Although Fig. 2 was included primarily to show the meteorological instrumentation, a view of the surrounding terrain and low-rise construction east of the instrumented structure can be observed in the background of this picture. The construction shown in Fig. 2 is representative of the other low-rise structures that surround the Pitts Center (e.g., the town hall building).

2.2. Structure

The instrumented structure (Fig. 1), the Kern P. Pitts Center, is located adjacent to the Town Hall in Southern Shores. The two-story structure was conceived as a wind hazard training, research, and demonstration facility as part of a program called *Blue Sky*. The structure was designed to resemble

Fig. 1 Front view of the Kern P. Pitts Center before instrumentation was installed. Arrows indicate approximate sensor locations. Note : structure faces east

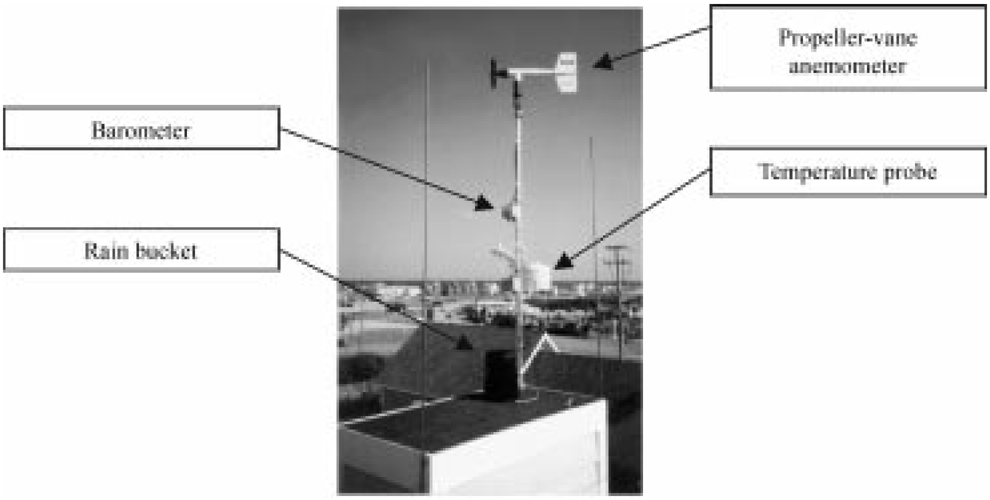

Fig. 2 View of meteorological instrumentation on mast above chimney

low-rise residential construction in the area. The Pitts Center has many interesting architectural features, including a cupola and dormers. In addition, the Pitts Center's structure is composed of three structurally independent sections, each made from a different construction material. The north section of the structure has traditional wood framing. The southwest section is built from concrete masonry units and the southeast section has a galvanized light-gage steel frame. Since the Pitts Center closely resembles residential construction in the area, data from this structure will be of direct relevance to local construction. Since it was built as a research, training and demonstration facility, some of the barriers associated with instrumenting private homes are avoided. For example, sections of drywall have been left off so the structural frame remains exposed. This allows for easy access to potential instrumentation points. In addition, the owners of the Pitts Center allowed holes to be drilled in the roof and walls of the structure for pressure measurements. A cabling network was pre-installed throughout the Pitts Center to allow for modifications or expansions to the current instrumentation system.

2.3. Overview of instrumentation system

The instrumentation system was designed to measure wind loads and structural resistance in a variety of wind conditions up to and including hurricane force winds.

2.3.1. Meteorological instrumentation

Meteorological data are collected at two locations in the vicinity of the structure. Wind speeds are measured along three axes by an ultrasonic anemometer that is located on an anemometry tower approximately 18 meters east of the structure. A propeller-vane anemometer, located on an instrumentation pole above the chimney (see Fig. 2), measures wind speed and direction. Both anemometers are located 10 meters above ground level. Clearly in the relatively complex terrain environment surrounding the Southern Shores structure, the placement of the anemometers is very important. The anemometers were strategically placed to measure the flow in the prevailing wind directions as uninterrupted as possible. Some concern was expressed about the influence of the instrumented structure on the measurements from the anemometers on the chimney, but it is believed that this anemometer is sufficiently high above the structure to avoid most structural interference to the flow. The primary reason for this placement was so wind-flow measurements could be obtained as close to the points of pressure measurements as possible.

The ultrasonic unit is located so that southeasterly winds could approach the anemometer relatively uninterrupted. A comparison of the data collected from the two anemometers from the prevailing wind directions indicates that in most storms the measurements are in good agreement. Comparative data have suggested, however, that the close proximity of the town hall building to the ultrasonic anemometer does indeed influence results in southerly winds. This influence is easily identifiable when comparing the results from the anemometers. Concern has been expressed about the performance of the ultrasonic unit in heavy rain. Although occasional electrical transients have been observed in the data from this instrument, it has performed reliably even in severe environments. Barometric pressure, rainfall, and temperature are measured with sensors located on or near the instrumentation pole above the chimney.

2.3.2. Pressure measurements

The pressure sensors are currently concentrated on the second floor, in the southeast corner room. This room was selected for the installation of both the pressure sensors and strain gages for two reasons. First, the structural frame in this room is light-gage galvanized steel. Steel is more readily suitable for strain gage application than wood (which is found in other sections of the structure). Second, there are few obstructions for the wind coming from the southeast direction – it is a fairly open exposure. Other sections of the structure can be easily instrumented using the pre-installed cabling network.

Differential pressure sensors are used to measure surface pressures at ten exterior points on the structure. The sensors come from the factory specified to measure pressures in the range of 0 to 6800 Pa (0 to 1 psi). They were then adjusted electronically to measure −3400 Pa to 3400 Pa so that both positive pressures and suctions can be measured. Although this relatively large range obviously affects the resolution of the instruments (this is especially apparent in low wind speed records), it was thought to be important to have a large dynamic range, as the system was designed to capture high-wind events. Preliminary analysis indicated that the pressure system is most suitable for measurements in winds greater than about twenty miles per hour. The general locations of the sensors were highlighted on Fig. 1. Fig. 4(a-d) illustrates the spacing and specific locations of the pressure sensors. Six sensors monitor pressures on the walls (three along the south wall, three along the east wall). Additionally, three differential sensors have been installed to measure pressures on the roof and one has been installed to measure pressure on the eave. An additional differential pressure sensor monitors internal pressure in the room.

Since wind-induced pressure fluctuations are small compared to standard atmospheric pressure, and changes in atmospheric pressure can be large in severe winds, it is potentially difficult and costly to find instruments with the accuracy and resolution to measure barometric pressure and its fluctuations as well as the wind-induced pressure components. For example, the stagnation pressure associated with a 100-mph wind (at standard atmospheric conditions) is approximately 1.2 kPa (0.179 psi). This is small compared to standard atmospheric pressure of 101 kPa (14.7 psi) (1.2%).

Most off-the-shelf absolute pressure sensors are not sufficiently accurate to capture the small pressure fluctuations associated with wind. Models that do have the accuracy, resolution, and

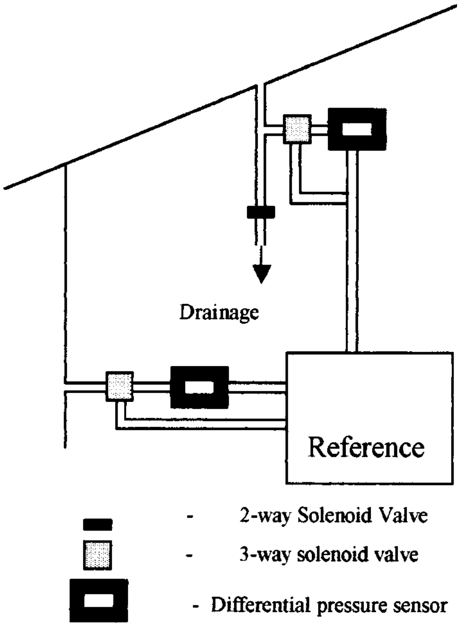

Fig. 3 Schematic of pressure system

dynamic response to measure small wind-induced fluctuations are expensive, and therefore not a cost-effective means of making multiple pressure measurements. In order to address this problem, differential pressure sensors can be used, which are typically relatively inexpensive compared to absolute sensors. The challenge in using these devices, however, is in establishing a stable reference pressure. In field applications, barometric pressure is often used as the reference pressure. At the Texas Tech Wind Engineering Research Field Laboratory, for example, differential sensors are all referenced to the pressure in a hole in the ground near the structure. This pressure is assumed to be barometric (Levitan 1991).

At Southern Shores, a Texas-Tech-style reference pressure system was not a feasible solution. The sandy soils would make it difficult to maintain a hole in the ground without considerable expense, and the heavy rain expected in hurricane events would make it difficult to keep the hole drained. In addition, there was a strong desire to maintain a stable and measured reference pressure to assure fidelity of the other pressure estimates.

The system that was developed has the differential sensors referenced to the pressure inside a sealed steel air tank. Fig. 3 shows a schematic of the pressure system. The pressure in the tank is monitored with a high-accuracy (0.005% of full scale) absolute pressure transducer and is regularly compared to barometric pressure. To keep the pressure close to barometric, the tank is vented to the atmosphere on a regular basis. Since the pressure in the tank is measured, actual absolute surface pressures can be estimated reliably. Data analysis suggests that the tank pressure remained close to barometric. During storms the system is vented to the atmosphere for 2 minutes out of every 12, giving the system ample opportunity to stay close to barometric even in cyclonic storms where the barometric pressure may be changing relatively rapidly.

As shown in Fig. 3, the wind-induced pressure acts through the holes drilled in the exterior of the structure, through a normally open 3-way solenoid valve to the differential sensor. The three-way solenoids are used to control which air supply feeds into the active side of the pressure sensors. During normal operation, the air from outside is in contact with the active side of the gage. While regular "shunt calibrations" are being performed, the solenoid valve closes off exterior air and puts the pressure in the tank on the active side of the gage. This allows the zero offsets on the transducers to be calculated since reference pressure is seen on both sides of the gage.

Water intrusion was also a concern for the roof taps, so a drainage system using normally closed

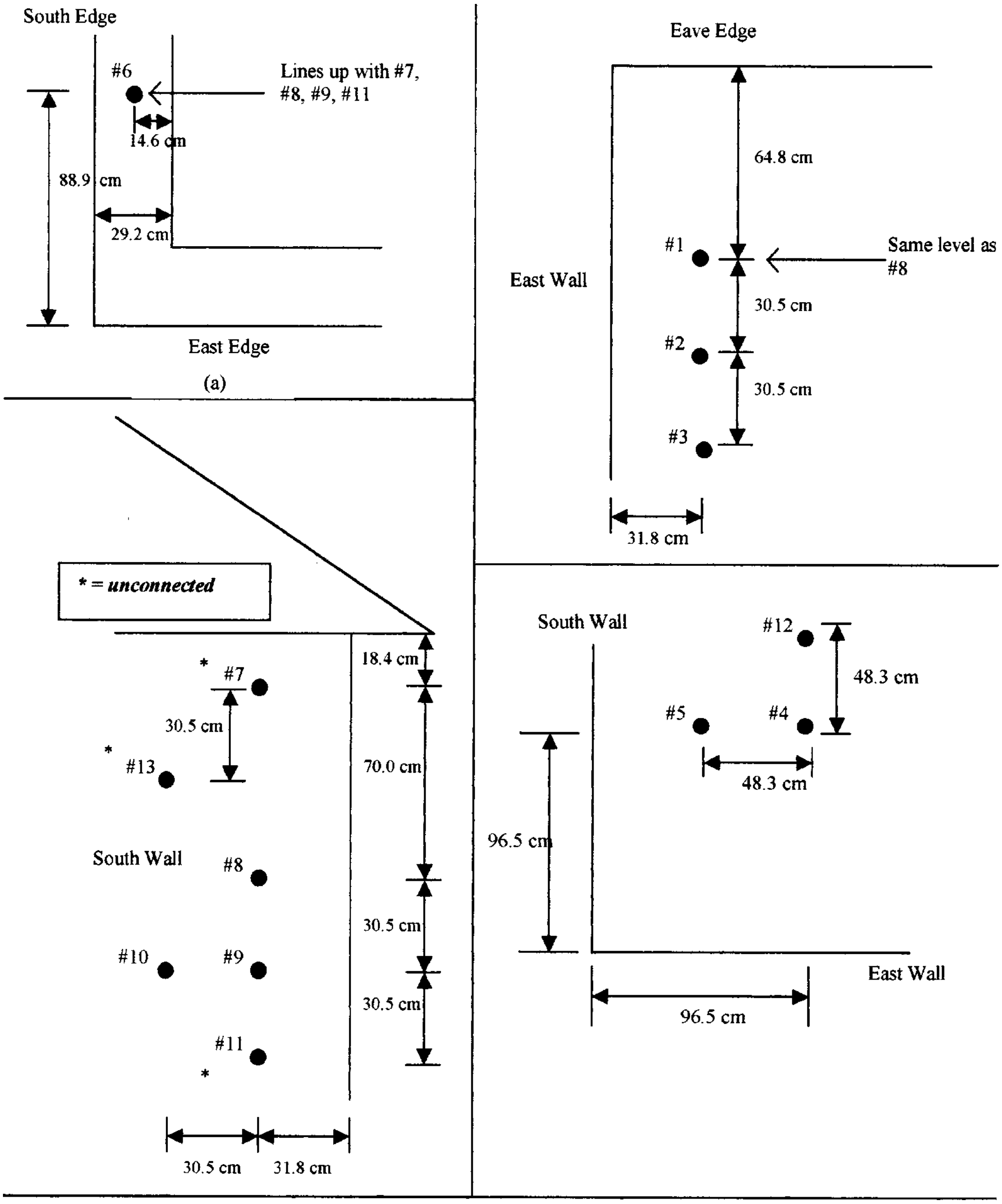

Fig. 4 Locations of pressure taps: (a) plan view of location of eave tap; (b) elevation view of location of taps along east wall; (c) elevation view of location of taps on south wall; (d) plan view of location of taps on roof

two-way solenoid valves was developed. During the shunt calibration, the water drainage system for the roof taps is also activated. The two-way solenoid valves in the roof tap systems are opened allowing water to drain to the outside of the structure. This system works well most of the time, but on occasion during extremely heavy rainfall, water intrusion to the tubes has occurred. These records can be clearly identified by a sudden offset in the mean of the pressure records. In addition to water intrusion problems, the system has experienced insect intrusion problems. Apparently mud daubers, a species common in this region, tend to nest in small holes and have found the pressure taps to be favorable for nesting. These intruder problems are also identifiable in the records because the mud daubers quickly block the entire pressure port. Routine maintenance is performed on the system to ensure that the pressure lines are free from obstructions. In addition, the lines are again checked for blockages before any major storm.

Recently an expansion to the pressure system was designed and built, and will soon be added to the existing system. This expansion includes a dense matrix of sixteen additional differential pressure sensors that are being included to help study in detail the spatial correlation of pressure as well as the effects of area averaging on reported pressures.

2.3.3. Strain and displacement measurements

Twenty strain gages have been installed on the rafters and studs of the second-floor, southeast corner room of the Pitts Center. Currently eight of the strain gages are being used for acquiring data (four on the rafters, four on the studs). The studs and rafters in this section of the structure are steel channels. As shown in Fig. 5, a gage was placed on each of the interior flange surfaces to allow the axial and bending strains to be separated. The instrumented rafters and studs are 198 cm and 244 cm long, respectively. Gages were placed 152 cm from the ground on the studs and 124 cm from the roof crest on the rafters. The gages are 350 ohm, temperature compensated, linear gages. Special epoxy known for long-term performance was used to bond the gages to the structural members.

There are many challenging issues associated with long-term strain gage installations. For example, strain gages tend to drift in the mean. In addition, strain measurements are sensitive not only to wind velocity fluctuations, but also to changes in temperature, humidity, barometric pressure, and internal pressure. The primary goal in installing the gages was to obtain wind-induced strain fluctuations in structural members during extreme winds. During these events the parameters that potentially affect recorded strains in structural members are closely monitored, and preliminary analysis has indicated that variations in both mean and fluctuating strains due to wind velocity components have been observed.

A linear potentiometer has been installed along the large, wood-framed north wall of the structure

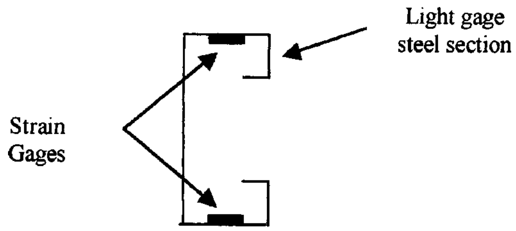

Fig. 5 Strain gage configuration

to measure structural displacements. This device has a six-inch travel and was installed to measure "racking" in extreme wind events. To date this instrument has provided data of significance only in a few instances of very high wind.

2.3.4. General system information

The 31-channel data acquisition system was designed to run unattended. A commercially available remote control and file transfer software package is used with a modem to make system changes and to download data to the remote control and data processing location at the Johns Hopkins University in Baltimore, Maryland. A commercially available data acquisition and process control software program is used to control the data gathering processes. All channels are sampled at 25 Hz; all analog inputs are filtered at 10 Hz using 4-pole Bessel filters.

By default, the system monitors and collects summary statistics on all the channels. When a pre-determined trigger threshold (currently set to 3-second gust of 20 mph (~9 m/s)) is exceeded, the system performs a one-minute shunt calibration on all the differential pressure sensors. The system then records data from all channels at 25 Hz for two back-to-back five-minute segments[1]. Finally, before returning to the default-monitoring mode, the system performs an additional shunt calibration on the differential sensors.

The system has been installed and operational since October 1997. Since that time, over 7,500 data sets have been collected. The remainder of this paper will provide a brief introduction to some of the data collected at the site.

3. Overview of collected data

Data have been collected during the passage of frontal systems, thunderstorms, several northeasters, and three land-falling hurricanes. These storms have provided the opportunity to test the system in a variety of wind conditions up to and including hurricane-force. Examples of some of the summary data that have been collected at the field site are discussed below. Detailed analysis of the data will be presented in future publications. Table 1 below shows a summary of the wind speed data collected during hurricanes Bonnie, Dennis, and Floyd.

As shown in Table 1, hurricane-force winds were measured during the passage of Hurricane Floyd. Although all of these storms were either minimal hurricanes or tropical storms by the time they reached the Pitts Center, they provided an invaluable opportunity to collect data over a short duration in a variety of wind conditions. Figs. 6 and Fig. 7 show the evolution of barometric pressure and wind speed, respectively, during the passage of Hurricane Bonnie over the Pitts Center, recorded using the system described above.

As seen in Figs. 6 and Fig. 7, the regions of large temporal barometric pressure variation are accompanied by the clusters of highest wind gusts. These regions correspond to the passage of the leading and trailing sides of the storm's eye wall. Decreased wind speeds accompany the region of

[1] Ten-minute segments were desired. However, when detailed verification of results in the design phase of the project was performed, timing inconsistency issues were observed shortly after five minutes in the records. The software development company was notified of these difficulties. After much research, it was determined that these were platform-independent operating system level issues unresolved in even recent versions of the operating system. To avoid possible data corruption, the two-five minute segment scheme was adopted.

Table 1 Summary of wind speed data collected during hurricanes Bonnie, Dennis, and Floyd

Parameter	Bonnie	Dennis	Floyd
Minimum Barometric Pressure (hPa) [in. of Hg]	(989.8) [29.3]	(1002.6) [29.6]	(974.3) [28.7]
Max sustained* horizontal wind speed (mph) [m/s]	(37.8) [16.8]	(50.0) [22.2]	(60.5) [27.0]
Max sustained vertical wind speed (mph) [m/s]	(3.8) [1.7]	(6.1) [2.7]	(4.0) [1.8]
Max horizontal wind gust** (mph) [m/s]	(51.8) [23.0]	(62.1) [27.0]	(82.5) [36.9]
Max vertical wind gust (mph) [m/s]	(11.5) [5.1]	(19.4) [8.7]	(15.8) [7.1]

*max sustained winds are defined as the maximum of the one-minute average wind speeds.
**max wind gusts are defined as the maximum of the 3-second wind gusts.

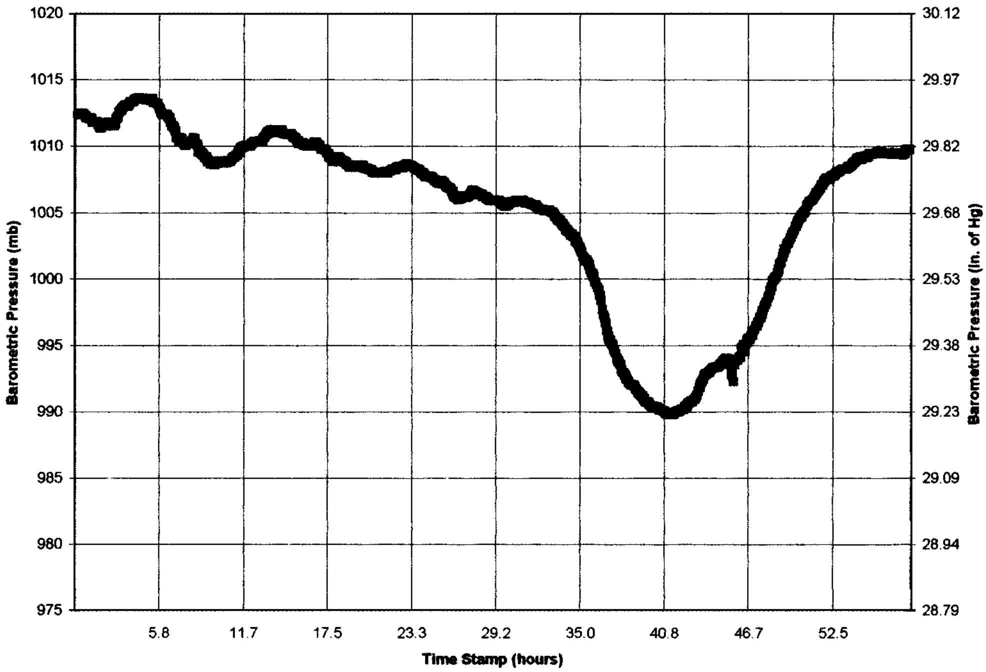

Fig. 6 Evolution of mean barometric pressure during Bonnie

minimum barometric pressure: the relatively calm eye of the storm. As indicated in Fig. 7, the second cluster of high wind gusts is somewhat lower in magnitude than the first cluster of peaks. This is probably due to the fact that Bonnie continued to degrade rapidly as she passed over the Carolinas and by the time the trailing eye wall again passed over the Pitts Center, Bonnie was a considerably weaker storm. It is also possible that the second cluster is of lesser magnitude than the first due to wind directionality effects.

Fig. 8 shows typical time histories of wind speed, wind direction, and pressure measured during Hurricane Bonnie. The data, although in the preliminary stages of analysis, have already provided much insight relative to the characteristics of these cyclonic storms. Besides routine statistical and spectral analysis, some of the issues currently being studied in detail include:

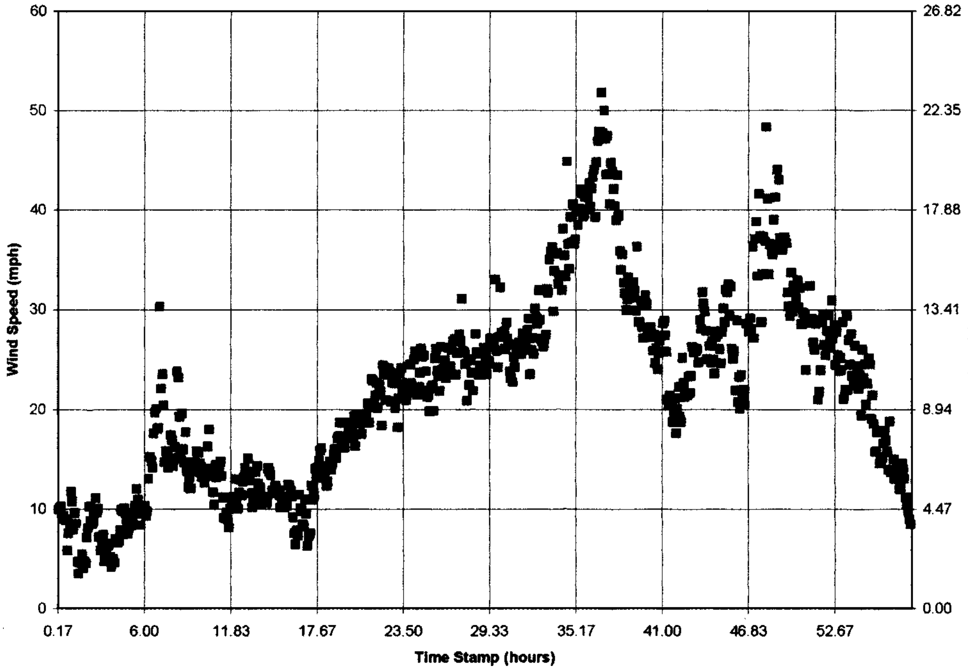

Fig. 7 Evolution of 3-second wind gusts in Bonnie

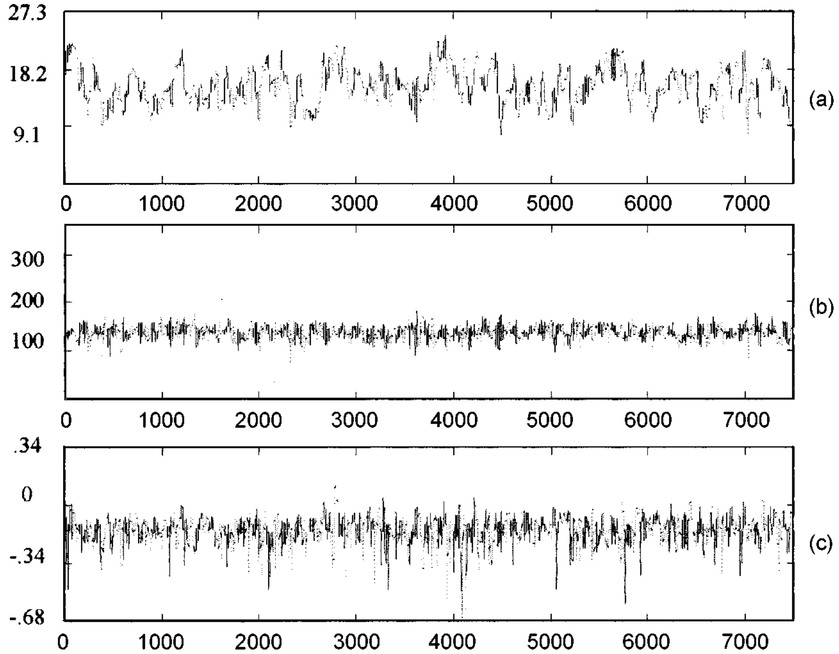

Fig. 8 Typical time histories collected during Bonnie from: (a) wind speed in m/s (propeller-vane anemometer); (b) wind direction in degrees; and (c) pressure in kPa (from eave tap). Note : units on horizontal axis are time. 25 units=1 second; records shown are 5-minutes long

- Comparison of the meteorological characteristics of measured cyclonic and non-cyclonic storms;
- investigation of the importance of measured vertical wind gusts and the use of sonic anemometry;
- development of appropriate methods of analysis of highly gusty, non-stationary wind velocity records;
- development of appropriate methods of analysis for pressure records exhibiting highly intermittent behavior; and
- comparison of measured quantities to loads estimated from ASCE 7-98

Results of these and other quantities will be presented in future publications currently under development.

4. Conclusions

The goal of this paper was to present in detail the technical components of the field study being conducted in Southern Shores, North Carolina. Details of the field measurement program to study the wind effects on a low-rise structure in a region subjected to frequent cyclonic and non-cyclonic storms were presented. The preliminary instrumentation system was installed in October, 1997 and to date over 7,500 data sets have been collected in a variety of weather conditions up to and including hurricane force winds.

An example of data collected at the site was presented. The Southern Shores project is a unique opportunity to collect important full-scale data on a real low-rise structure without the barriers often associated with instrumenting residential properties. Although the complexities of the structure itself and the surrounding terrain present some challenges for data analysis and interpretation, data from the Southern Shores site should augment the existing database of full-scale data.

As noted in the text, this measurement program differs from some of the previous full-scale investigations in that both the instrumented structure and the surrounding terrain are complex. Although it may be difficult to directly extrapolate these results to structures in other situations, the present study offers a good opportunity to assess the suitability of wind load provisions for a structure and terrain typical of local construction. In addition to comparing in detail the pressure measurements to those pressure estimated from ASCE 7-98, future publications will present comparative analysis of the meteorological data to established models in wind engineering and meteorology. These analyses would include, but not be limited to, data on the effects of averaging time on reported wind gusts, spectral content of wind velocity fluctuations, turbulence intensities, and surface drag coefficients.

Acknowledgements

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References

AAWE (American Association for Wind Engineering). (1997), *Wind Engineering: New Opportunities to Reduce*

Wind Hazard Losses and Improve the Quality of Life in the USA. Notre Dame, Ind.: AAWE.
American Society of Civil Engineers (ASCE), (1998), *ASCE Standard. Minimum Design Loads for Buildings and Other Structures*., ASCE 7-98, ASCE Press, Reston, V.A.
Cermak, J.E. (1998), "Wind damage mitigation: Wind engineering challenges in wind effects on buildings and structures", Rotterdam: Balkema. 335-352.
Cochran, L.S. and J.E. Cermak. (1992), "Full-scale and model-scale cladding pressures on the Texas-Tech University Experimental Building", *J. Wind Eng. Ind. Aerod*., **43**(1-3), 1589-1600.
Eaton, K.J. and J.R. Mayne. (1975), "The measurement of wind pressures on two-storey houses at Aylesbury", *J. Ind. Aerody.*, **1**(1), 67-109.
Holmes, J.D., M.J. Syme and M. Kasperski. (1995), "Optimized design of a low-rise industrial building for wind loads", *J. Wind Eng. Ind. Aerod.*, **57**, 391-401.
Hoxey, R.P. and P.J. Richards. (1995), "Full-scale wind load measurements point the way forward", *J. Wind Eng. Ind. Aerod.*, **57**(2-3), 215-224.
Hoxey, R.P. and P.J. Richards. (1993), "Flow patterns and pressure fields around a full-scale building", *J. Wind Eng. Ind. Aerod.*, **50**(1/3), 203-212.
Jones, N.P., D.A. Reed and J.E. Cermak. (1995), "National wind hazards reduction program", *ASCE J. Professional Issues in Education and Practice*, **121**(1), 41-46.
Kasperski, M. and H.J. Neimann. (1999), "Wind loading aspects of building in groups: mass housing developments in South Africa", *Pro. 10th Int. Conf. Wind Eng.*, Copenhagen, Denmark.
Levitan, M.L. and K.C. Mehta, (1992a), "Texas the field experiments for wind loads: Part I. Building and pressure measuring systems", *J. Wind Eng. Ind. Aerod*., **41-44**, 1565-1576.
Levitan, M.L. and K.C. Mehta, (1992b), "Texas the field experiments for wind loads: Part II. Meteorological instrumentation and terrain parameters", *J. Wind Eng. Ind. Aerod.*, **41-44**, 1577-1588.
Lin, J.X., D. Surry and H.W. Tieleman. (1995), "The distribution of pressures near roof corners of flat roof low buildings", *J. Wind Eng. Ind. Aerod*., **56**(2-3), 235-265.
Marshall, R.D. (1975), "A study of wind pressures on a single-family dwelling in model and full scale", *J. Ind. Aerod*., **1**(2), 177-200.
Marshall, R.D. (1977), "The measurement of wind loads on a full scale mobile home." National Bureau of Standards (currently National Institute of Standards and Technology). Report NBSIR 77-1289. Gaithersburg, Md.: National Bureau of Standards.
Mehta, K.C. and R.D. Marshall. (1998), *Guide to the Use of the Wind Load Provisions of ASCE 7-95*. ASCE Press.
Milford, R.V., A.M. Gliger and J.L. Waldeck, (1992), "Jan Smuts experiment- Comparison of full-scale and wind tunnel results", *J. Wind Eng. Ind. Aerod*., **43**(1-3), 1705-1716.
Milford, R.V., J.L. Waldeck and A.M. Goliger. (1992), "Jan Smuts Experiment: Details of full-scale experiment", *J. Wind Eng. Ind. Aerod*., **41-44**, 1693-1704.
National Research Council. (1999), "Review of the need for a large-scale test facility for research on the effects of extreme winds on structures", Washington, D.C.: National Academy Press.
Peterka, J.A., J. Cermak, L. Cochran, B. Cochran, N. Hosoya, R. Derickson, C. Harper, J. Jones and B. Metz. (1997), "Wind uplift model for asphalt shingles", *J. Arch. Eng.*, American Society of Civil Engineers, New York, NY **3**(4), 147-155.
Richardson, G.M., R.P. Hoxey, A.P. Roberstson and J.L. Short, (1997), "The Silsoe Structures Building: Comparison of pressures measured at full-scale and in two wind tunnels", *J. Wind Eng. Ind. Aerod.*, **72**(1-3), 187-197.
Richardson, G.M. and P.A. Blackmore. (1995), "The Silsoe-Structures Building-Comparison of 1/100 model scale data with full-scale data", *J. Wind Eng. Ind. Aerod*., **57**(2-3), 191-201.
Sill, B.L., N.J. Cook and C. Fang. (1992), "The Aylesbury comparative experiment - a final report", *J. Wind Eng. Ind. Aerod.*, **43**(1-3), 1553-1564.
Uematsu, Y. and N. Isyumov. (1999), "Review: Wind pressures acting on low-rise buildings", *J. Wind Eng. Ind. Aerod*., **82**, 1-25.
Yeatts, B.B. and K.C. Mehta. (1993), "Field experiments for building aerodynamics", *J. Wind Eng. Ind. Aerod.*, **50**, 213-224.

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