WIND UPLIFT RESISTANCE OF ASPHALT SHINGLES

By
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To my parents, Jorge and Ana Romero, and my brother, Michael
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<td>American Society of Civil Engineers</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>CSU</td>
<td>Colorado State University</td>
</tr>
<tr>
<td>ESDU</td>
<td>Engineering Science and Data Unit</td>
</tr>
<tr>
<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
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<tr>
<td>IBHS</td>
<td>Institute of Business &amp; Home Safety</td>
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<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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Abstract of Thesis Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Master of Engineering

WIND UPLIFT RESISTANCE OF ASPHALT SHINGLES

By

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Roof cover damage is one of the most critical, recurring building performance issues in hurricanes. Loss of roof cover can lead to water ingress, which can cause severe damage of the building contents. The focus of this study is the wind resistance of asphalt shingle systems, which are the most common roof cover type in the US. Under the oversight of industrial and government stakeholders, multiple experiments were initiated to investigate the resistance of asphalt shingles to wind uplift in extreme wind events. This research necessitated the development of several unique testing apparatuses such as a portable universal testing machine. A field-deployable mechanical uplift testing apparatus was designed and implemented. The device was successfully used in a field trial to determine the static wind uplift strength of asphalt shingle tiles. The mean uplift resistance of ASTM D6381 Procedure B specimens was 16.8 kg (37 lb). The main failure modes observed were cohesive failure in the adherend (42%) and combined cohesive and cohesive failure in the adherend (58%). As a result the strength of the sealant strip did not appear to be weakened by prolonged natural aging. Further, a computer-controlled load sequence was developed to simulate time-varying wind loading on asphalt shingle seals for evaluating their fatigue resistance. A
dynamic test sequence was designed using historical hurricane records and results from a particle image velocimetry study provided by the University of Western Ontario. Using quasi-steady theory, a testing methodology was developed to simulate dynamic wind loading on asphalt shingles. Modifications to the mechanical uplift testing apparatus to recreate dynamic loads are currently underway.

Wind velocity characteristics near the roof plane were investigated using multi-port pitot tube instrumentation in a full scale wind load test facility to validate speed-up values above the roof plane measured in a boundary layer wind tunnel. As expected, the highest wind velocities were found to occur near the ridge. Observed peak speed-up values were consistent with wind tunnel measurements. The maximum speed-up value measured was 2.55, which was within 2% of the recommended safety factor of 2.5 for wind uplift design of asphalt shingles. Full-scale roof mockups were also constructed on-site in preparation system level testing in late summer 2012.
CHAPTER 1
INTRODUCTION

After storm surge damage, roof cover damage is the second largest cause of hurricane-induced residential insurance losses (Liu et al., 2010). Asphalt shingles are the most common type of residential roof system in hurricane prone areas (Marshall, 2010). An asphalt shingle roof system consists of individual shingle sections nailed over wood sheathing and an impermeable water barrier. The shingles are loose laid in a staggered pattern, and sealed using a heat activated strip. The two most common types are three-tab and laminate shingles (Figure 1-1), which consist of a 30 x 91 cm (12 in x 36 in) fiberglass mat coated in asphalt that is covered with granules on the side of the shingle exposed to the sun. Three-tab shingles include two cut-outs on the lower half of the section. Laminate shingles are composed of top and bottom laminates, with the top including cutouts on the bottom half of the section. Two sealant patterns are primarily used: a continuous sealant strip, usually 12 to 19 mm thick (0.5 to 0.75 in), or a thicker strip in a discontinuous application. Both patterns are shown in Figure 1-2. Shingle installation requires four fasteners per sheet driven just below (down the slope) the sealant strip in normal wind areas, and six fasteners in high wind areas as classified by ASCE 7-10. The nail location is intended to cause the fastener to penetrate two shingles simultaneously and increase blow-off resistance. In a high wind area, a typical three tab shingle will have nails driven approximately 2.5 cm (1 in) from each end, and fasteners on each side of the two cutouts. A typical laminate shingle will be fastened by six nails evenly spaced along the sheet, as seen in Figure 1-3.

Wind-induced uplift on a sealed shingle is caused by differential pressures on the shingle tab. The most critical section of an asphalt shingle is the leading edge directly in
front of the sealant. A stagnation region at the leading edge, coupled with negative pressures (suction) on top of the shingle causes it to lift up (Peterka et al. 1997). The wind resistance of an asphalt shingle primarily depends on the: 1) quality of fastener installation, 2) sealant strength, and 3) physical properties of the asphalt (Noone and Blanchart, 1993). Shingle failure can be defined as complete detachment of a surface shingle from its underlying shingle through sealant failure. Once a sealant fails, a tab is free to lift up and flutter in the wind. The tab is likely to tear from the top of a shingle if the wind speeds are sufficiently enough. As shown in Figure 1-5, three failure modes are possible: [1] cohesive failure in the adherend (the underlying shingle), [2] adhesive failure in the tab sealant, and [3] a combined (cohesive and adhesive) failure. Cohesive failure in the adherend causes tearing of the bottom shingle specimen, leaving the sealant strip intact. Adhesive failures are defined by failure at the sealant/shingle interface. Combined failures are observed when failure of part of a shingle specimen is at the adherent, and another part is adhesive within the same tab. When a sealant strip fails, the fasteners restrain the shingle and carry the entire load path. Missing or incorrectly driven fasteners can make a shingle more prone to tearing out during high winds.

**Scope of Research**

The research objectives of this study are as follows:

Develop and implement a field-deployable apparatus to measure the mechanical uplift resistance of asphalt shingles subjected to natural exposure on residential structures. The apparatus will replicate current mechanical uplift tests on asphalt shingles. The Portable Mechanical Uplift Apparatus developed will provide insight into the performance characteristics of older asphalt shingles exposed to natural aging.
under the effects of heat, rain, and ultraviolet light. Results from field experiments will determine whether shingles retain their sealant strength, or weaken when aged for long periods.

Compare results from Peterka et al. (1997) and Cochran et al. (1999) near-roof wind speed measurements on model and full scale structures using modern wind flow measurement instrumentation. Conduct flow measurement studies on a full scale building at the Insurance Institute for Business & Home Safety (IBHS) test facility. Wind vector direction and approach direction will be measured, adding to the knowledge base of near roof wind behavior provided by the Particle Image Velocimetry (PIV) study completed at the University of Western Ontario (UWO). Velocities were measured using five TFI Cobra Probes placed 25 mm (1 in) above the roof surface. The full scale structure consisted of half gable and hip roof sections. Probe locations were selected based on high near roof wind speeds measured by Cochran (1999).

Plan and prepare for full-scale wind flow experiments to identify the failure capacity of shingles on gable and hip roofs. In July 2011, 9 monoslope roof sections and 9 hip roof sections were constructed and left on-site and to naturally age until the scheduled test date. The asphalt shingles were installed according to manufacturer’s specifications on a 6:12 roof structure located in the High Velocity Hurricane Zone. Specimens will be subjected to a 30 minute time-varying trace consisting of three 10-minute segments of increasing intensity using an open country exposure profile.

**Organization of this Document**

Chapter 2 provides a review of asphalt shingle research. In Chapter 3, the design and development of a portable mechanical uplift apparatus is discussed. Successful field deployment results are presented where a standard laboratory shingle uplift
experiment was performed on a field residential structure using the new apparatus. Chapter 4 details planned testing of the fatigue resistance of asphalt shingles using the portable apparatus introduced in the previous chapter. Chapter 5 discusses the test setup, procedures, and results of wind speed ratios measured above the roof plane of a full scale one-story structure at the IBHS test facility in Chester, South Carolina. Results are then compared to previous mean speed ratios measured in wind tunnel and full scale experiments using similar wind approach directions. Chapter 6 discusses full scale tests scheduled for the summer of 2012 at the IBHS test facility using half roof mockups. Specimens were constructed a year prior to testing, and will envelope asphalt shingle performance as well as mean speed ratios over the one-story structure. Key findings are discussed in Chapter 7.
Figure 1-1. Typical 3-tab and laminate shingles

(a) Continuous sealant with varying thickness; three tab shingle
(b) Discontinuous sealant; three tab shingle
(c) Continuous sealant; three tab shingle

Figure 1-2. Typical sealant patterns from different shingle manufacturers. Photo courtesy of Dany Romero, University of Florida.
Figure 1-3. Asphalt shingle fastener and ASTM D6381 specimen detail.
Figure 1-4. Typical shingle layout. Fasteners are required to have a minimum 2.67 mm (0.105 in) shank and 9.5 mm (0.375 in) head. The figure also shows the relative location of ASTM D6381 Procedures A and B on a typical roof cover layout.
Figure 1-5. Shingle failure modes during ASTM D6381 uplift tests. Cohesive failures were not observed in the top shingle.
CHAPTER 2
BACKGROUND ON WIND RESISTANCE OF ASPHALT SHINGLES

This chapter provides an overview of improvements in the wind resistance of asphalt shingles through the evolution of standard test methods. The chapter summarizes research analyzing the loading mechanisms governing shingle uplift in high winds. Near roof velocity experiments describing wind acceleration over the roof plane are also described. Shingle performance during land-falling hurricanes is evaluated through summarized damage reports.

Early Test Method for Asphalt Shingle Uplift Resistance

The earliest test method for asphalt shingle wind performance certification involved subjecting a shingle test deck at a 2:12 slope to a 27 m/s (60 mph) wind blowing horizontally against the leading edges of the shingle tabs for 2 hours (ASTM D3161 and UL 997) as seen in Figure 2-1. If no tabs lifted or broke loose during the test, the shingles were assigned a passing notification. With mounting pressure from code bodies and insurance groups for manufacturers to produce more wind resistant asphalt shingles, proposals recommended increasing the test wind speed in ASTM D3161 to achieve higher ratings (Shaw, 1991). However, shingle uplift was frequently observed at lower wind speeds by Lamb and Noe (1989) during wind tunnel tests, with general failures near eaves and rake edges (edge along a gable roof). These failure patterns were also observed by Shaw (1991) in the field during Hurricane Hugo. These failures demonstrated a limitation in the ASTM D3161 test method that did not predict the performance of shingles in field conditions. The standard test method applied a non-separated flow with a turbulence intensity of approximately 17% on the leading edge of the shingle deck (Peterka et al., 1983). Through the request of Owens Corning to
develop improved roofing shingle wind testing methods, Peterka et al. (1983) developed an improved wind testing procedure for roofing shingles. He demonstrated that the current test, involving a jet of air directed at a shingle test deck at close range excluded many of the physical mechanisms that cause shingle uplift.

The Wind Uplift Model for Asphalt Shingles

Peterka et al. (1983) developed the wind load model for asphalt shingles as part of roofing industry-sponsored research in the 1980s and 1990s. By applying a nearly instantaneous pressure differential across the tab, he observed significant pressure equalization due to the air permeability around the shingle. He concluded that wind-induced shingle uplift forces were not caused by flow separation over the roof structure. A second experiment examined the pressure distribution on a shingle tab in the path of wind flowing up a roof. The obstruction a shingle creates forces flow separation over the top surface, and induces a stagnation region at the leading edge as seen in Figure 2-2. The separated flow accelerates, causing a negative pressure on the top (suction), and flow impinging on the shingle step causes positive pressures on the bottom surface.

Formulation of the shingle load model developed by Peterka (1983) was based on the validity of the quasi-steady assumption for wind loading, which implies that fluctuations in near roof surface wind flow are equal to fluctuations in the local upwind vector. As a result, the quasi-steady theory is valid when uplift pressure on a shingle varies only with the square of the velocity.

\[
\frac{\bar{P}}{\bar{U}} = \left[ \frac{\bar{U}}{\bar{U}} \right]^2
\]

Where:

\( \bar{P} \) = Peak uplift pressure across the shingle

\( \bar{P} \) = Mean uplift pressure across the shingle
\( \bar{U} \) = Peak wind speed over the roof

\( \bar{U} \) = Mean wind speed over the roof.

The quasi-steady relationship states that the peak shingle pressure can be calculated from either (1) mean pressure coefficient and a peak wind speed, or (2) a peak pressure coefficient and a mean wind speed.

\[
\bar{p} = \frac{1}{2} \rho \bar{U}^2 \bar{C}_p = \frac{1}{2} \rho \bar{U}^2 \bar{C}_p \tag{2-2}
\]

Where:

\( \rho \) = Air density

\( \bar{C}_p \) = Peak pressure coefficient

\( \bar{C}_p \) = Mean pressure coefficient

and \( \bar{U}, \bar{U} \) as defined above.

Further, the peak uplift pressure on a shingle can be calculated using the approach conditions, near roof conditions, and pressure difference across the shingle.

\[
D\bar{p} = \frac{1}{2} \rho \bar{U}_{ref}^2 \left( \frac{U_{roof}}{U_{ref}} \right)^2 D\bar{C}_p \tag{2-3}
\]

Where:

\( \bar{p} \) = peak uplift pressure on the shingle

\( U_{ref} \) = mean approach wind velocity at the eave height of the building

\( U_{roof} \) = peak gust wind speed on the roof

\( D\bar{C}_p \) = pressure coefficient across the shingle.

Peterka (1997) validated the model using a brass replica of a 3-tab shingle containing 27 pressure taps on both top and bottom surfaces. Validity of the quasi-steady assumption could be determined by comparing the differential pressure and velocity squared time histories measured. Wind tunnel tests by Peterka et al. (1997) at
Colorado State University found that the best match between time histories was measured when the data was filtered to 12 Hz, which established the upper limit of the frequency that affects shingle loading.

Peterka et al. (1997) also performed experiments to quantify near-roof wind speeds over a low-rise building at the Colorado State University Meteorological Wind Tunnel using three 1:25 scale models with roof slopes: 2:12, 5:12, and 9:12, with equal building geometries. Velocity measurements were recorded 1 mm (0.04 in) above the model, or 25 mm (1 in) above a full scale structure. The maximum ratio of peak wind speed over the roof to mean reference wind speed observed was approximately 2.5 (Figure 2-3), making it a reasonable upper bound for design of a one story building. Full scale validation followed with the construction of a test house on a windy location in Colorado outfitted with pressure taps, and wind monitors with temperature sensors installed on an adjacent tower. The house consisted of a 7.0 x 10.7 m (23 x 34.5 ft) base structure with a 5:12 slope gable roof, and was mounted on a 6.1 m (20 ft) diameter crane rail to permit rotation.

Wind Flow Near the Roof Plane

Cochran et al. (1999) investigated wind speed distributions near the roof plane through a wind tunnel experiment using 1:25 scale models of typical house geometries with gable ends in a boundary layer wind tunnel. Wind speed accelerations near the roof plane were recorded using a high-response omnidirectional TSI hot probe anemometer. Maximum wind speeds were observed along corners and ridge lines. A limitation of this instrument was that it recorded wind velocity magnitudes in all directions, meaning that a predominant wind direction could not be established. As a result, mean speeds in re-circulating flows may be overestimated and under-predicted.
in regions where the wind separates from the roof surface. Cochran et al. (1999) also noted that, similar to Peterka et al. (1997), the highest average wind speeds were observed during cornering wind cases as seen in Figure 2-4.

**ASTM D6381 Test Method for Mechanical Uplift Resistance**

Peterka et al. (1997) showed that a pressure differential results in a net upward load on the shingle. The loading mechanism on the shingle is partially a direct tension type load and partially peel-type exerted on the sealant from either side. ASTM D6381 separates the loading mechanisms into two test procedures. Procedure A applies a vertical upward load on the shingle using an aluminum clamp attached to the top layer (Figure 2-5) at a constant rate of 127 mm/min (5 in/min) (Figure 2-6). The top piece is loose laid over the bottom piece to align with the manufacturer’s required location. Procedure B applies a direct tension vertical load by attaching an aluminum T section to the top piece (with matching dimensions) of the specimen using high strength epoxy (Figure 2-7). The specimen is attached to the UTM using two light gauge steel chains approximately 127 mm (5 in) long. The uplift rate applied directly over the sealant is the same as in Procedure A.

ASTM D7158 determines uplift pressure coefficients created by a moving air jet of 15.6 m/s (35 mph) and measuring net pressures across the shingle. The shingle test deck is required to be no less than 1.27 m (50 in) wide by 1.68 (66 in) long, and has a slope of 2:12. Shingles must be installed as required by the manufacturer. Once a pressure coefficient is estimated, an equivalent uplift force ($F_T$) is calculated resulting from design wind speeds by adding the effects of the uplift force in front ($F_F$) and behind the sealant ($F_B$).
\[ F_F = 0.00256k_z k_{zt} k_d V^2 (L_1 w) \bar{C}_{p_1} \]  
(2-4)

\[ F_B = 0.00256k_z k_{zt} k_d V^2 \left( \frac{L_2}{2} w \right) \bar{C}_{p_2} \]  
(2-5)

\[ F_T = F_F + F_B \]  
(2-6)

Where:

- \( V \) = basic wind speed (mph)
- \( w \) = width of shingle sample (in)
- \( \bar{C}_{p_1} \) = wind uplift coefficient measured in front of the shingle sealant
- \( \bar{C}_{p_2} \) = wind uplift coefficient measured behind the sealant
- \( L_1 \) = distance measured from the centerline of the sealant pattern to the windward edge of the fixed shingle tab (in)
- \( L_2 \) = distance measured from the centerline of the sealant pattern of the shingle tab to the windward edge of the shingle directly above (the tributary length is half of this distance) (in)
- \( K_z \) = velocity pressure exposure coefficient
- \( k_{zt} \) = topographic factor (1.0 for flat terrain)
- \( k_d \) = directionality factor (0.85 from ASCE 7-10).

The uplift resistance values measured from ASTM D6381 (\( R_A \) and \( R_B \)) are then used to calculate the total uplift capacity of a shingle (\( R_T \)) by adding the effects of peeling (first term) and direct tension (second term)

\[ R_T = \left[ \frac{(F_B - F_F)}{F_T} \right] R_A + \left[ \frac{2F_F}{F_T} \right] R_B \]  
(2-7)

The total resistance is then compared to the mechanical uplift resistance measured in ASTM D6381. If the measured uplift resistance (\( R_T \)) is greater than the strength design load (\( F_T \)) generated by the design wind speed, then the shingle specimen is appropriate for the wind region analyzed.
Roof Cover Performance

Damage to shingle roof systems following Hurricane Hugo (1989) was observed to vary widely. Smith and McDonald (1990) suggested that high damage rates were attributed to inadequate installation practice, and that it pointed to deficiencies in the ASTM D3161 method of measuring shingle wind resistance. Improvements in building materials and roofing products over the next decade led to decreased damage rates of new homes following hurricane impacts. Later, FEMA (2005) reported that homes in hurricane prone areas built after 2004 generally performed better in hurricanes due to improved quality of building materials. Tear out and failure of shingles with hurricane wind ratings was attributed to roof structures having incorrect placement of fasteners, as well as missing fasteners altogether (FEMA 2005). Examples of improper nailing include placement too high or too close to the sealant as well as placement too far from the ends of the shingle tabs. Hurricane prone areas typically require six fasteners per shingle, while most roof structures suffering significant damage were observed to have only four. Marshall (2010) noted that out of 11 fiberglass asphalt shingle roofs selected for inspection following Hurricane Frances, ten of them had improper fastening patterns.

A damage survey performed by Marshall (2010) after Hurricane Frances in 2004 identified four main factors that influence shingle failure: 1) weathering of shingles, 2) design deficiencies, 3) manufacturing problems, and 4) installation problems. Shingles installed within the last 10 years were observed to perform better overall (RICOWI, 2009).

Summary

Early standardized test methods did not adequately address wind field intensity, direction, duration, and turbulence. Experiments performed in the Colorado
State University (CSU) Meteorological Wind Tunnel examined the load distribution over an asphalt shingle, and is defined as the shingle load model. The step a shingle tab creates causes flow separation, causing a negative pressure on the top (suction), and positive pressures on the bottom surface. The pressures exerted on asphalt shingles are dependent on the accelerated wind speeds near the roof plane. Wind acceleration over a roof was the basis for other wind tunnel experiments at CSU, where velocities near the roof plane were measured on model scale structures. The investigation showed that the wind velocity over the roof can increase in comparison to the mean approach wind speed by as much as 2.5 times the mean wind speed immediately upwind of the structure, with the highest accelerations occurring near edges and ridgelines. Current test standards were adapted to account for near roof accelerations and load distributions along the shingle tab to provide a more accurate uplift resistance. Shingle failures were still observed, however, during named storms such as Frances in 2004 which had measured 3 s gusts of 52 m/s (116 mph) (NOAA H*Wind). Damage surveys (FEMA 2005, Marshall 2010) attributed most of these failures to improper fastener patterns, and incorrect fastener location. In response to near-roof measurements and noted shingle failures, experiments will be developed to investigate wind conditions and asphalt shingle uplift resistance during high wind events.
Figure 2-1. Test mockup for ASTM D3161

Figure 2-2. Wind Uplift Model
Figure 2-3. Reprint from Peterka et al. (1997): Peak velocity over building as related to mean approach velocity and mean velocity over roof.
Figure 2-4. Reprint from Cochran et al. (1999): Mean roof surface wind speed ratios over a 1:25 model scale gable roof structure.
Figure 2-5. ASTM D6381 Procedure A uplift test. The bottom tab is 17.8 cm (7 in) long by 9.5 cm (3.75 in) wide and the top section is 11.5 cm (4.5 in) long by 9.5 cm (3.75 in) wide. Photo courtesy of Dany Romero, University of Florida.

Figure 2-6. Universal Testing Machine showing a Procedure A uplift test setup. Photo courtesy of Dany Romero, University of Florida.
Figure 2-7. ASTM D6381 Procedure B. The bottom section is 15.2 cm (6 in) long by 10.2 cm (4 in) wide and the top section is by 9.5 cm (3.75 in) long by 3.8 cm (1.5) in wide. The bottom restricted from uplift by an aluminum plate, and the top section is attached to an aluminum T-section for uplift. Photo courtesy of Dany Romero, University of Florida.
Cohesive Failure in the Adherend

Adhesive Failure

Combine Failure

Figure 2-8. Observed Failure Modes. Photo courtesy of Dany Romero and Craig Dixon, University of Florida.
CHAPTER 3
DESIGN OF THE PORTABLE MECHANICAL UPLIFT APPARATUS

This chapter discusses the development of a field deployable apparatus capable of performing standard mechanical uplift tests on existing shingle roofs. Future uplift tests on naturally aged shingles will seek a relationship between uplift resistance and prolonged aging time. The uplift apparatus’ first field deployment is discussed in the chapter. Suggestions for future design modifications to improve system efficiency are given.

Standard Mechanical Uplift Test

The mechanical uplift test specified by ASTM D6381 is performed with a Universal Testing Machine (UTM). Samples are heated in a forced air dark oven for 16 hours at 70 °C (158 °F), and allowed to cool to room temperature for at least one hour prior to testing. The mechanical uplift resistance of each sample is then measured with the UTM. A constant displacement rate of 12.7 cm/min (5 in/min) is applied until the sealant fails.

The author, working with Mr. Craig Dixon, developed a portable mechanical uplift testing system in the fall of 2010. The objective was to design a portable apparatus capable of performing ASTM D6381 procedures on an existing roof. The device would perform the standard mechanical uplift test on naturally aged asphalt shingles on existing structures.

Test Apparatus

The apparatus will perform functions similar to those of a UTM but in a field environment. The ASTM required uplift rate of 12.7 cm/min (5 in/min) is applied using a Tritex TLM20 electric linear actuator by Exlar Technologies mounted on the Portable
Mechanical Uplift Apparatus as shown in Figure 3-1. All components are mounted to a custom built aluminum frame constructed out of 2.5 cm (1 in) square tubing. The two-stack actuator houses a brushless servo motor with a 5.08 mm (0.2 in) resolution per motor revolution. This configuration can achieve a maximum uplift force of 836 N (188 lb) at a maximum speed of 0.287 m/s (11.3 in/s). The actuator is powered by a 48 Volt unregulated power supply. An 890 N (200 lb) Futek low profile load cell is connected in series with the actuator to provide force feedback. An electrical box bolted to the aluminum frame houses a National Instruments 6211 data acquisition card for simultaneous measurement of position and velocity. An RS-485 converter also in the electrical box allows calibration adjustments to be made to the actuator (current and position limits) using Exlar’s proprietary software. The ASTM D 6381 specimen clamps were modified to have rigid connections between the load cell and the clamps. The uplift rate is applied using Labview Virtual Instruments on an Xplore Technologies rugged tablet PC running Windows 7. The actuator is also programmed to stop moving if the load reading decreases below 40% of the maximum applied load. Ceasing motion allows the tester to perform a visual inspection of a specimen failure without further damage to a failed sealant.

**LabVIEW control interface**

The LabVIEW Virtual Instrument (Figure 3-2) created for mechanical uplift testing controls the actuator using an analog feedback, which provides higher response rates in comparison to a digital feedback option. Previous attempts using digital control resulted in slow response rates because the actuator was required to communicate with the program using Modbus. An analog signal, on the other hand, uses only voltage to
command the actuator to a required position. The actuator’s 0-15 cm position (0-6 in) is regulated by creating a position to voltage scale (0-10 V) and regulating the voltage.

**Specimen clamp fixture**

The apparatus’ base plate was designed to perform tests in the laboratory and and the field. The lab mount consists of the specimen fixture used in ASTM D6381 Procedure A with a steel base plate 9.53 cm wide by 24.13 cm long (3.75 in x 9.5 in) with two toggle clamps. The clamps hold the ends of the shingle securely against the base plate. This base plate is bolted to the laboratory attachment of the Mechanical Uplift Apparatus. An L-shaped clamp secures the leading edge of the specimen for uplift. The steel base plate specified by Procedure A can also be interchanged with the fixture detailed by Procedure B. The fixture is constructed out of 4.1 cm (1-5/8 in) electrical channel. Inside the fixture sits an aluminum restrictor plate 152 x 102 mm (6 in x 4 in) with a 102 x 45 mm (4 in x 1.75 in) center cutout where the top section of the Procedure B specimen protrudes.

The fixture designed for field use consists of a base plate having a 9.53 cm x 17.78 cm (3.75 in x 7 in) center section cut out. These dimensions match the size of the specimen detailed in Procedure A. During a Procedure A field experiment (Figure 3-3), a shingle section matching these dimensions is isolated on the roof, and the L-clamp is attached to the leading edge in the same fashion as the lab procedure. The actuator can then pull up on the leading edge through the center cut out. For a Procedure B uplift test (Figure 3-4), the restrictor plate is held in place by the self weight of the apparatus.

**Field Testing of Shingles**

Field experiments involving mechanical uplift resistance require permanent alteration of the asphalt shingles. Procedure A uplift tests involve isolating a 9.5 cm
(3.75 in) wide shingle specimen by cutting, and Procedure B specimens require isolating a shingle strip directly above the sealant. Following testing, repairing tested sections would require replacing the entire shingle tab. For this reason, current field mechanical uplift tests have only been performed on residential structures scheduled for demolition by the State of Florida.

Through an ongoing research program, the Department of Community Affairs grants the University of Florida access to residential structures scheduled for demolition. These structures are bought out by the state because they either lie on a flood plain, or have been flooded. Test deployments in Florida have occurred at least once a year for the past five years in cities including Orange City, Daytona Beach, Pace, and Ormond Beach, and are dependent on the availability of the homes provided by the State of Florida.

Test Procedure on Specimen Homes

The mechanical uplift apparatus measured the uplift resistance of asphalt shingles during field experiments in Orange City, Florida on November 11, 2011 on a nine year old residence (Figure 3-5). The home had been submerged under 15 to 20 cm (6 to 8 in) of water during Tropical Storm Fay in August 2008. No damage the roof covering was reported. The interior furnishings and cabinetry were removed following the storm, and the house remained abandoned until the date of the field experiments. Volusia County purchased the home from the owner, and scheduled demolition to follow the University of Florida’s field experiments.

The residence is located in Orange City, FL and consisted of a 237 m² (2550 ft²) floor plan built with traditional wood framed walls. The roof plan (Figure 3-6) was listed to have a 371 m² (4000 ft²) surface area according to Volusia County Property
Appraiser Records. Except for a small sloped section on the north side (4:12 slope), the entire roof plan had a 6:12 slope, and consisted of wood trusses spaced at 61 cm (24 in) covered with 1.27 cm (1/2 in) plywood sheathing. Roof obstructions include a chimney on the northwest side of the roof, and a solar water heating panel measuring 7.3 m by 3.7 m (24 by 12 ft) on the south side. The laminate (architectural) shingles were installed in September 2002, and had experienced over nine years of environmental exposure at the time of testing.

The planned test matrix included 100 samples for each ASTM D6381 procedure on the roof. Procedure A on the Orange City structure proved difficult. Placement of the Procedure A clamp over the leading edge of the sealant resulted in unintentional detachment of the sealant strip in every attempted test. The standard (ASTM D6381) allows a special metal connector to be adhered to the edge of the top shingle where the uplift clamp can then be attached as seen in Figure 3-7.

Every Procedure A uplift test performed on the Orange City structure resulted in failure of the epoxy bond between the special metal connector and the leading edge of the top shingle rather than failure of the bond itself. Failure loads were still recorded, but mechanical uplift resistance values for Procedure A were not valid.

Procedure B was completed on 80 specimens, with an average uplift resistance of 16.8 kg (37 lb). The maximum and minimum values measured were 33.5 kg (73.9 lb) 5.5 kg (12.2 lb) respectively, with a standard deviation of 5.5 kg (12.3 lb). Similar ranges were observed on the three roof orientations tested (north, south, and west) as seen in Figure 3-8. The top sections of the specimens were isolated the previous day, and the specified T-sections were attached with high strength epoxy. The epoxy was allowed to
cure for 12 hours prior to testing. There was no observed correlation between uplift resistance and roof slope exposure (north, south, etc.) or shingle temperatures, which ranged from 24 to more than 60 °C (75 to 140 °F). Results are shown in Figure 3-8. Temperature did however affect the dominate failure mode in ASTM D6381, shifting from a mix of cohesive failure in the sealant and combined failure in the sealant and the adherend, to a failure mostly dominated by a combined failure of the sealant and the adherend. Adhesive failure was also observed.

Results

The first field deployment of the Portable Mechanical Uplift Apparatus proved successful in obtaining mechanical uplift resistance values for Procedure B of naturally aged asphalt shingles. The inability to complete Procedure A uplift tests was not a limitation of the system capabilities, but rather failure of the epoxy bond between the special connector outlined by ASTM D6381 and the shingle’s leading edge.

The field deployment team did not experience any significant setbacks in transporting the system from ground level to the roof structure. The aluminum frame proved light enough to be hoisted up a ladder safely by a single person, with the electrical box containing the unregulated power supply following. The rugged tablet PC outfitted with an All-View TFT display allowed computer operation in direct sunlight. The rubber padding covering the base of the frame prevented the apparatus from slipping on the 6:12 slope.

Suggested System Modifications for Field Use

Field deployment of the Mechanical Uplift Apparatus prompted several suggested modifications to the system to improve efficiency.
1. The current weight distribution of the frame created an overturning moment on the system sitting on the 6:12 slope. This required an extra person to hold the system firmly against the roof slope. Addition of a counter weight on the upslope side of the frame will allow the actuator to sit flush on the roof, removing the need for an extra person.

2. The 3 m (10 ft) cord length powering the actuator from the unregulated power supply proved too short to provide an efficient working radius for multiple tests. Following four or five tests, the electrical box required repositioning due to insufficient cord length. If the current power cord is replaced with a longer, 15 m (50 ft) cord, field deployment of typical residential structures will allow the electrical box to be fixed in one location, while giving the apparatus free range over the majority of the roof.

3. Insufficient battery life from the rugged tablet PC required a second power cord posing a safety hazard to foot traffic during field experiments. The electrical box will be adapted to also provide power to the tablet PC. With this solution, power for all onboard components will be provided through a single electrical cord.

Once modifications are complete, the Portable Mechanical Uplift Apparatus will be a more efficient tool during field research to investigate the uplift resistance values of naturally aged asphalt shingles.

**Summary**

Standard measurement of the mechanical uplift resistance of asphalt shingles is performed on new shingles in a Universal Testing Machine. The prolonged effects of natural heat aging on uplift resistance remains unknown due to the lack of a portable system to perform standard tests on existing structures. The University of Florida developed a portable mechanical uplift apparatus capable of performing ASTM D6381 on shingles in an existing structure. The apparatus was successfully field tested in November 2011 on a nine year old residence in Orange City, Florida. The residence was vacated and purchased by the State of Florida following flood damage during Tropical Storm Fey in August 2008. No damage was reported on the roof. Procedure A tests were unsuccessful due to repeated sealant failures in attempts to attach the
Procedure A uplift clamp to the leading edge of the roof shingles. Eighty Procedure B tests were completed. Completion of the field deployment also provided suggested modifications to the portable apparatus still pending completion. Modifications will include addition of a counterweight to eliminate an overturning moment on the system, replacement of a short power cord currently limiting the working radius of the actuator, and inclusion of a power supply to provide constant power to the rugged tablet PC.
Figure 3-1. Mechanical Uplift Apparatus. Photo courtesy of Dany Romero, University of Florida.

Figure 3-2. LabVIEW control interface to perform ASTM D6381
Figure 3-3. Field specimen fixture for Procedure A. Photo courtesy of Dany Romero and Craig Dixon, University of Florida.

Figure 3-4. Field specimen fixture for Procedure B. Photo courtesy of Dany Romero and Craig Dixon, University of Florida.
Figure 3-5. Field deployment of mechanical uplift apparatus. Photo courtesy of Craig Dixon, University of Florida.
Figure 3-6. Residential roof plan in Orange City, FL. Future tests will include uplift resistance measurements of shingles not directly exposed to sunlight, such as the specimens below the solar water heater to provide a direct comparison of uplift values.
Figure 3-7. Special metal connector for Procedure A used when the distance between the leading edge of the top shingle and the sealant strip below is too small to allow an adequate connection of the Procedure A uplift clamp. Photo courtesy of Dany Romero, University of Florida.

Figure 3-8. Mechanical uplift resistance results of ASTM D6381 Procedure B
CHAPTER 4
FATIGUE RESISTANCE OF ASPHALT SHINGLES

Summary

This chapter discusses the development of dynamic load sequences created to test the fatigue resistance of shingle sealants. Shingle loading will be applied using the mechanical uplift apparatus described in Chapter 3. The test sequences were derived from historical track and intensity data of land-falling hurricanes, and near roof velocity measurements collected by PIV studies at the University of Western Ontario. Velocity data are converted to corresponding loads on shingles using ASTM D7158, and a resultant uplift force is formulated from loads in front and behind the sealant strip.

Fatigue Resistance of Asphalt Shingles

Standard asphalt shingle mechanical uplift tests have provided insight into the ultimate resistance of asphalt shingles by applying a constant uplift rate on sealant strips. This, however, is much different than the loads induced by naturally occurring wind events, which produce dynamic pressure fluctuations controlled by factors such as gust durations, wind direction, and intensity. It is important to subject specimens to loading scenarios that mimic the effects of wind as closely as possible in order to understand the real behavior and failure mechanisms of shingles during extreme wind events. Although fatigue is a critical agent of distress in asphalt (Baburamani, 1999) test and design requirements for shingles do not address dynamic loading.

The Portable Mechanical Uplift Apparatus described in Chapter 3 will be crucial for the next step in fatigue studies through its application of stochastic loading scenarios on asphalt shingles. Once properly tuned, the apparatus will be capable of replicating dynamic load sequences up to 10 Hz. Tuning for the apparatus has required the
development of a custom control system to account for the non-linear behavior of asphalt shingles, and this has taken longer than originally planned. As a result fatigue resistance conclusions will not be provided in this report. This chapter will discuss the development of a representative test sequence for fatigue testing of asphalt shingles.

**Determination of Representative Storm Velocity Sequences**

The experiment is based on a simulation of wind loading throughout a hurricane passage, which is dependent on the storm’s structure, intensity and forward speed. After a review of historical track and intensity data, two generalized wind speed envelopes were created:

1. A compact intense hurricane representative of a design level event, e.g. Camille (1969), Andrew (1992), Charley (2004). Storm winds typically increase from tropical force winds to the peak wind conditions in a few hours.

2. A broader, non-design level event hurricane, e.g. Frances (2004). Due to size and/or forward speed, these events are characterized by a more gradual increase in wind speed and lower peak intensity than Case 1.

Figure 4-1 depicts the 3 s gust velocity at the coastal crossing point of the front right quadrant for nine Atlantic hurricanes (from the NOAA Hurricane Research Division H*Wind surface wind field analyses). Each storm’s time axis was shifted to group the storms in a common time frame reference. The velocities are plotted as peak 3 s values at 10 m (33 ft) in open exposure conditions, which is equivalent to the basic design wind speed in ASCE 7-10 (Chapters 26-30). The two red lines are the enveloped sequences selected for this study (details provided below). The solid red line depicts the envelope for the compact, fast-moving design level event (Case 1), and the dotted red line depicts the envelope for the broad, slow-moving, non-design level event (Case 2). The dashed blue line depicts the rated value for a class H shingle (un-factored design: 150 mph, 67
m/s), and the solid blue line corresponds to the ASCE 7-05 factored design wind speed $(X \sqrt{1.6}$, where 1.6 is the load factor for wind).

The gust envelopes were selected based on the following assumptions:

1. Enveloping the peak wind speeds of the sample set is a reasonable representation of all storms (a limited number of wind fields were available for analysis), and is more conservative than taking a worst single storm approach

2. Linear interpolation between data points in Figure 4-1 is reasonable

3. Shingle loads resulting from $\leq 35$ m/s gust speeds are not significant, thus the envelope lines (in red) begin at 35 m/s (78 mph)

4. Ignoring wind directionality is conservative

The mean wind speed at the eave height of the subject building ($U_{Eave}$) is required to convert the wind tunnel velocity measurements to full-scale. However, Figure 4-1 presents 3 s gust velocities at 10 m (33 ft), and the model has an eave height, $h = 6.7$ m (22 ft) using an open terrain.

A two-step conversion is required to get $U_{Eave}$. First, the mean wind speed is computed at 10 m using a gust factor. The 20 min mean at 10 m is computed as $1/1.47 = 68\%$ of the gust speed ($1.47$ = the gust factor for a 3 sec gust in a 20-min record in open exposure at 10 m). Second, the mean wind speed is converted from 10 m to the eave height of the building using the log law:

$$U_z = \frac{u_*}{k} \ln \left( \frac{z}{z_0} \right)$$  \hspace{1cm} (4-1)

where $U_z$ is the mean wind speed at height $z$, $k = 0.40$ is von Karman’s constant, $u_*$ is the shear velocity, and $z_0$ is the aerodynamic roughness length. The $u_*$ from the open terrain and $k$ values are constants, therefore Eq. 4-1 can be evaluated at 6.7 m and 10 m to develop the following relationship,
\[ U_{Eave} = \frac{\ln(6.7/z_0)}{\ln(10/z_0)} U_{10m} = 0.93 U_{10m} \]  

where the roughness length \( z_0 = 0.03 \text{ m} \) (open country terrain), \( U_{10m} \) is the 10 m mean wind speed and \( U_{Eave} \) is the mean wind speed at eave height. Values are summarized in Table 4-1.

**Particle Image Velocimetry Experiments**

The velocity record was derived from Time-Resolved Particle Image Velocimetry (TR-PIV) data collected by Dr. Greg Kopp at the University of Western Ontario. PIV is a convenient method to quantify flow velocities in a plane (Figure 4-2). The TR-PIV system is capable of capturing many cycles of low frequency flow features as well as high frequency turbulence. A laser projects a light swath over the building through which particles released upwind pass. A high-speed camera films the swath, and the particles’ movement is used to calculate the trajectory and speed of the flow in the laser plane. Images were captured using a Photron FASTCAM-1024PCI CMOS camera. This camera is capable of streaming the images continuously to a PC at a rate of 1000 Hz with a spatial resolution of 1024 pixels x 1024 pixels and a 10 bit dynamic range. Illumination was provided by a double head, diode pumped, Q-switched. Nd:YLF laser (Darwin-Duo by Quantronix). The particles in the flow were atomized 1\( \mu \)m diameter oil droplets. Further details of the TR-PIV system are provided in Taylor et al. (2010).

Experiments were performed in the Boundary Layer Wind Tunnel II at the University of Western Ontario. Both open \( (z_0 = 0.03 \text{ m}) \) and suburban \( (z_0 = 0.30 \text{ m}) \) exposures were investigated; only the open exposure data is used here. Approach flow conditions were calibrated to meet Engineering Science and Data Unit (ESDU) requirements. The subject building was a two-story gable roof building with a
rectangular plan form. Six 1:50 scale acrylic models were built for the following roof pitches: flat, 4:12, 5:12, 6:12, 7:12, 9:12 and 12:12. Plan dimensions were 89.25 cm (4.5 m at full-scale) by 72.00 mm (3.6 m at full-scale), and the lowest eave height was 134 mm (6.7 m at full-scale).

Using PIV, the velocity field is computed from a statistical average of displacements over small sub-regions (interrogation windows) of the image. The displacement is then calculated with information from two images using a cross-correlation approach, with the manufacturer’s Insight3G software (TSI Inc. 2008), to compute the 2D velocity field at each time step. A data filtering process is needed in order to identify the spurious vectors to avoid any erroneous contribution to the statistical calculations. A median filtering was applied in order to identify vectors that are outliers. This method checks each velocity vector individually by comparing its magnitude with the median value over its nearest neighbors (typically 3 x 3). The velocity vector was rejected if the absolute difference between its magnitude and the median value over its neighbors is above a certain threshold. This was applied to the $u$ and $v$ components of the vector. After having validated PIV data, missing vectors were filled using bilinear interpolation. Since the replacing scheme uses eight neighboring vectors (in the case of 3 x 3), this might yield another outlier if there were spurious vectors within the neighborhood. Many vectors had to be removed near the roof surface where high laser reflections and intermittent absence of particles caused dropouts and outliers. The validation technique was applied for the second time in order to capture the outliers from the first scheme.
The post-processed data were evaluated to (1) characterize the overall flow conditions near the roof plane and (2) to extract the most extreme velocity record from the entire dataset for analysis using a rainflow technique. The key finding relevant to this research component is that the largest wind speeds were confined to the upper region (near the ridgeline) of the 6:12 and 7:12 roofs. For this study, the 6:12 roof will be used given its widespread use in low-rise residential construction. Item (2) provides critical information for the physical simulation of dynamic loads and is now discussed.

**Computation of the Wind Velocity above the Roof Plane**

The PIV data are stored as orthogonal velocity components \((u,w)\), which correspond to the horizontal and vertical directions relative to the floor of the wind tunnel. These data are converted to the roof coordinate system \((x,y)\) through Eq. 4-3:

\[
\begin{bmatrix}
x \\
y
\end{bmatrix} = \begin{bmatrix}
cos \theta & -\sin \theta \\
\sin \theta & \cos \theta
\end{bmatrix} \begin{bmatrix}
u \\
w
\end{bmatrix}
\]  

(4-3)

where \(\theta\) = the angle between the roof and the horizontal axis (floor of the wind tunnel), \(x\) = the component of the flow parallel to the roof plane and \(y\) = the component of the flow perpendicular to the roof plane (Figure 4-3).

**Conversion to Model Velocity Data to Full-Scale**

The velocity records from the scale model need to be converted to a full-scale equivalent in order to develop the physical test load sequences. This is a two-part process. First the appropriate full-scale sampling frequency must be identified based on the wind tunnel scale-model sampling frequency and other parameters. This is referred to as ‘time scaling’. Second, the model-scale mean and fluctuating speeds must be converted to their full-scale equivalents. This is referred to as ‘velocity scaling’. The details of time scaling and velocity scaling are provided next.


**Time Scaling**

This conversion requires maintaining a proper balance between sampling frequency, model dimensions, and wind speed at both full and model scales. This is expressed as the well-known reduced frequency relationship:

\[
\left( \frac{fL}{U} \right)_m = \left( \frac{fL}{U} \right)_{fs}
\]  

(4-4)

where the subscripts \(m\) and \(fs\) denote model and full-scale, respectively. The values \(f\), \(L\), and \(U\) are:

\(f\) = sampling rate (Hz). The PIV experiment set the scale model sampling rate as \(f_m = 500\) Hz. The sampling rate of the full-scale equivalent \((f_{fs})\) is to be determined using Eq. (4-4), i.e. the goal of time scaling here is to find the appropriate value for \(f_{fs}\).

\(L\) = physical size. The 1/50\(^{th}\) scale model used in the UWO PIV experiment produces the needed ratio of \(L_{fs} / L_m = 50\).

\(U\) = mean wind speed at eave height. \(U_m\) values are known from the UWO PIV experiment (nominally 9.5 m/s). \(U_{fs}\) equals the \(U_{Eave}\) values in Table 4-1.

Thus five of the six terms in Eq. 4-4 are known, and \(f_{fs}\), is then solved to compute the full-scale time stepping increment \(dt\):

\[
dt = 1/f_{fs}
\]  

(4-5)

Full-scale fluctuating loads will be synthesized using this time step. 15-minute time histories will be generated. Determining the appropriate full-scale magnitude of the mean and fluctuating loads is discussed next.
Velocity Scaling

The model velocity measurements must be scaled to the actual flow conditions (mean wind speed + fluctuations) above the real building. Adopting the following notation, the scaling factor is now shown to be the ratio of the mean velocities of full- to model-scale.

\[ x_m = \text{the instantaneous velocity parallel to the roof plane of the model} \]
\[ \bar{x}_m = \text{the mean velocity parallel to the roof plane of the model} \]
\[ x_{fs} = \text{the instantaneous velocity parallel to the roof plane of the full-scale building} \]
\[ \bar{x}_{fs} = \text{the mean velocity parallel to the roof plane of the full-scale building} \]
\[ \bar{U}_m = \text{the mean velocity at the eave height of the model building} \]
\[ \bar{U}_{fs} = \text{the mean velocity at the eave height of the full-scale building} \]
\[ \sigma_{x,m} = \text{the standard deviation of the velocity parallel to the roof plane of the model} \]

The full-scale instantaneous velocity record is computed from the superposition of the mean wind speed (first term) and a fluctuating component (second term):

\[ x_{fs} = \bar{x}_{fs} + \left( \frac{x_m - \bar{x}_m}{\sigma_{x,m}} \right) \left( \frac{\sigma_{x,m}}{\bar{x}_m} \right) \left( \bar{x}_{fs} \right) \] (4-6)

The fluctuating component is the product of the standardized (zero mean and unit variance) model roof velocity and the standard deviation of the full-scale velocity, which is computed as the product of the turbulence intensity \( \left( \sigma_{x,m}/\bar{x}_m \right) \) and the full-scale mean wind speed \( \left( \bar{x}_{fs} \right) \). Eq. 4-6 can be simplified to show that \( x_{fs} \) is directly proportional to \( x_m \) by the ratio of the full-scale to model mean wind speeds, irrespective of the variance.

\[ x_{fs} = \bar{x}_{fs} + \left( x_m - \bar{x}_m \right) \left( \frac{\bar{x}_{fs}}{\bar{x}_m} \right) \] (4-7)

\[ x_{fs} = \bar{x}_{fs} \left[ 1 + \frac{x_m}{\bar{x}_m} - \frac{\bar{x}_m}{\bar{x}_m} \right] \] (4-8)
Here it is of interest to relate $x_{fs}$ to wind speeds at eave height (i.e. the $U_{Eave}$ values in Table 4-1). Assuming that the scaling is the same for the flow above the roof and in the approach flow, the following condition must be satisfied.

$$\frac{\bar{x}_{fs}}{\bar{x}_m} = \frac{\bar{u}_{fs}}{\bar{u}_m}$$  \hspace{1cm} (4-10)

Substituting $\bar{x}_{fs}$ from Eq.4-9 into the first term in Eq. 4-10,

$$x_{fs} = \frac{\bar{u}_{fs}}{\bar{u}_m}x_m$$  \hspace{1cm} (4-11)

**Load Test Sequence Assembly**

Time and velocity scaling were performed on the PIV data for each value in Table 4-1, setting $\bar{U}_{fs}$ equal to $U_{Eave}$. These segments are then low-passed filtered using a 3rd order Butterworth filter with a 10 Hz corner frequency, re-sampled to 50 Hz (the loop rate of the PID control in the mechanical uplift device; discussed later), and truncated to a 15 min duration. Finally, the segments are concatenated to form the velocity sequences for Load Case 1 (Figure 4-4) and Load Case 2 (Figure 4-5). These velocities are converted to pressures in the next section.

**Conversion of Velocity Sequences to Shingle Pressures**

Three load components act on a sealed shingle: (1) negative pressure on the top of the shingle caused by the building generated pressures and flow separation at the windward edge of the shingle, (2) positive pressure below the shingle caused by the stagnation beneath the shingle tab, and (3) shear stress resulting from the no-slip condition between the flow and the shingle. Peterka et al. (1997) has shown that the
quasi-steady theory assumption can be applied to determine the additive pressure for Loads 1 and 2 using:

\[ p = \frac{1}{2} \rho_{air} x_{fs}^2 \tilde{C}_p \]  \hspace{1cm} (4-12)

where \( \rho_{air} \) = the density of the air, \( \tilde{C}_p \) is the pressure coefficient computed from the sum of the mean pressures above and below the shingle, and \( x_{fs} \) is the instantaneous velocity computed in the previous section. The mean pressure coefficient \( \tilde{C}_p \) is product specific and in practice, is determined experimentally following the procedure set forth in ASTM D 7158. Peterka et al. (1997) used this approach to compute the single largest peak pressure \( \hat{\rho} \) given the single largest velocity value \( x_{fs} \). Here we compute \( p \) for each value in the \( x_{fs} \) to create the corresponding pressure sequence that acts on the shingle.

**Determination of Loads on Shingle Specimens**

The final step is to convert the pressures computed in the previous section to the corresponding forcing of the shingle. These load sequences will be the basis for the experimental testing using the linear actuator. Adopting the methodology of ASTM D7158, using the stepwise load distribution shown in Figure 4-6. \( F_F \) and \( F_B \) are calculated using Eq. 2-4 and Eq. 2-5 discussed in Chapter 2.

To reduce the number of trials, only the resultant load,

\[ R = F_F + F_B \]  \hspace{1cm} (4-13)

will be applied to the shingle specimens in this experiment. Substituting \( F_F \) and \( F_B \), the resultant load may be found:

\[ R = 0.00256 K_2 K_{zt} K_d V^2 (w) \left( L_1 \tilde{C}_{p_1} + \frac{L_2}{2} \tilde{C}_{p_2} \right) \]  \hspace{1cm} (4-14)
In this form, $R$ is a function of the basic wind speed $V$. Since we have the full-scale velocities above the roof, it is not necessary to use Eq. 4-14 to compute the forcing. The loads can be computed directly from Eq. 4-12. Therefore,

$$R = \frac{1}{2} \rho_{\text{air}} x_f^2 \left( L_1 \bar{C}_{p_1} + \frac{L_2}{2} \bar{C}_{p_2} \right) \quad (4-15)$$

The line of action of the resultant force will only pass through the sealant if the windward and leeward uplift forces balance, which requires that

$$L_1 \bar{C}_{p_1} = \frac{L_2}{2} \bar{C}_{p_2} \quad (4-16)$$

When Eq. 4-16 is not satisfied, the eccentricity of the resultant force can be calculated by summing moments about the centerline of the sealant (Figure 4-7). The sum of the moments is

$$\sum M_{\text{sealant}} = F_F \left( \frac{L_1}{2} \right) - F_B \left( \frac{L_2}{4} \right) - Rx \quad (4-17)$$

$$Rx = F_F \left( \frac{L_1}{2} \right) - F_B \left( \frac{L_2}{4} \right) \quad (4-18)$$

where $x$ represents the distance from the centerline of the sealant to $R$. Rearranging for $x$,

$$x = \frac{F_F \left( \frac{L_1}{2} \right) - F_B \left( \frac{L_2}{4} \right)}{R} \quad (4-19)$$

Substituting Eqs. 2-4, 2-5 and 4-14, $x$ may be found with the knowledge of the uplift coefficients and tributary lengths,

$$x = \frac{\bar{C}_{p_1} \left( \frac{L_1}{2} \right) + \bar{C}_{p_2} \left( \frac{L_2}{4} \right)}{\bar{C}_{p_1} \left( L_1 \right) + \bar{C}_{p_2} \left( \frac{L_2}{2} \right)} \quad (4-20)$$

A positive $x$ value represents a force located in front of the sealant centerline (towards the leading edge), and a negative value denotes that the force is behind the center of the sealant.
Comparison of PIV-Derived Wind Speeds to the ASCE 7 Basic Wind Speed

The corresponding basic wind speed cannot be computed directly by setting Eqs. 4-14 and 4-15 equal to each other. There are two reasons. First, the speed-up factor used in ASTM D7158 is equal to 2.5 whereas the PIV result is on the order of 1.6. Peterka et al. (1997) suggested a speed up factor of 2.5 to envelop all possible variation in velocity due to factors such as eave height and roof pitch, making the design load more conservative. Here we are only examining one wind direction and one roof shape. Second, the load factor is not explicitly considered. ASTM D7158 uses the importance factor from ASCE 7-02 to factor the load, while we have framed our analysis to relate the forcing to a given load condition. The analysis is more straightforward in this regard. The gust values we compute can be compared directly to the new basic wind speed maps in ASCE 7-10, which are calibrated to 300, 700 and 1700 mean recurrence intervals. A load factor need not be applied.

Expected Results from Fatigue Resistance Experiments

Application of the designed loading scenario is expected to degrade the asphalt in the fiberglass mat, as well as the sealant strip. Asphalt damage due to repetitive stresses and strains can manifest itself as fatigue cracking, which is considered a primary distress mechanism (Baburamani, 1999). Despite unsuccessful attempts to replicate the dynamic load sequence assembled in this chapter, changes in the shingle properties were observed by applying repetitious sinusoidal loading scenarios. A sinusoidal load sequence having a 3 Hz frequency, 0.23 kg (0.5 lb) amplitude, and 1.36 kg (3 lb mean) was applied using the LabVIEW interface. Tuning was unsuccessful due to the load response of the system overshooting the load by 5.4% up to 1.68 kg (3.70 lb) from the target 1.59 kg (3.5 lb), seen in Figure 4-8. The important thing to note,
however, is that sealant failure was observed in several cases where the sequence ran for more than two hours. Cracking in the fiberglass mat was also observed during these prolonged loading sequences. These failures were observed even though the loading sequence applied only loaded the asphalt shingles to 15% of the average failure load of the sealant strips, which measured at 10.7 kg (23.6 lb) during ASTM D6381 Procedure A mechanical uplift tests.

The observations described above provide significant insight into the results that can be expected once adequate tuning of the Mechanical Uplift Apparatus is complete. Application of the lengthy loading sequence could cause failures in the asphalt sealant despite generating only a fraction of the mechanical uplift resistance of an asphalt shingle. This implies that the uplift loads imposed on structures consisting of asphalt shingles can still be subject to failure during extreme wind events, despite being significantly lower than the ultimate mechanical uplift resistance.

**Summary**

Following the development of a tuning sequence, the Mechanical Uplift Apparatus will be capable of applying dynamic load sequences to asphalt shingles to study the fatigue resistance of sealant strips during extreme wind events. Using historical track and intensity data, two generalized wind speed envelopes were created, separating intense and short duration hurricanes from longer duration storms with more gradual increases in peak wind speeds. The flow conditions near the roof plane were characterized using a Particle Image Velocimetry study completed at the University of Western Ontario. In order to develop physical test load sequences, model scale velocity measurements were converted to full scale using the reduced frequency relationship. Uplift forces throughout the windward edge and behind the sealant of asphalt shingles
caused by near-roof velocities were consolidated into a single resulting uplift force. The resulting force is located at the point of equilibrium between the forces in front and behind the sealant strip detailed by ASTM D7158. A single rigid connection is then attached to the linear actuator in-line with a low profile load cell. A dynamic load sequence will be applied to a specimen until sealant failure is observed. Tuning of the control system is not complete, but sealant failure and cracks in the fiberglass mats were observed during 2 hour sinusoidal loading sequences at 3 Hz. Similar behavior can be expected once tuning has completed.
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Figure 4-1. Peak gust values for historical hurricanes

Figure 4-2. Particle image velocimetry study at the University of Western Ontario. Photo courtesy of Dr. Greg Kopp, University of Western Ontario.
Figure 4-3. Coordinate Axes

Figure 4-4. Load Case 1: Velocity sequence near the roof plane developed for compact intense hurricanes.

Figure 4-5. Load Case 2: Velocity sequence near the roof plane developed for broader, non-design level events.
Figure 4-6. ASTM D 7158 Force Distribution (FF>FB Shown, which is Case 1)

Load Distribution on an Asphalt Shingle According to ASTM D 7158

Resulting Equivalent Uplift Force on Shingle

Test Clamp

Figure 4-7. Loading Schematic
Figure 4-8. Initial tuning results from a 3 Hz sinusoidal loading function.
CHAPTER 5
CHARACTERIZATION OF WIND VELOCITIES NEAR THE ROOF PLANE

Overview

Full scale experiments were completed at the Insurance Institute for Business & Home Safety (IBHS) in July 2011 to investigate the aerodynamics above the roof plane of a single story building with hip and gable roofs. The purpose of the study was to characterize the accelerated wind velocities near roof shingles to analyze how shingle uplift is affected during high winds. Results were compared to measurements completed by Peterka et al. (1997) and Cochran et al. (1999) on model and full scale structures. Modern turbulent flow instrumentation (TFI Cobra Probes) allowed measurement of higher frequency wind fluctuations not attainable from the omnidirectional anemometers used by Peterka and Cochran. The experiment measured wind speed 25.4 mm (1 in) and 304 mm (12 in) over the roof plane of the bluff body and in the approach flow (free stream).

Test Structure

The test structure is a 12.2 m by 9.1 m (40 ft by 30 ft) rectangular wood frame building with a gable roof on one end and a hip roof on the other end (Figure 5-1). The eave height is 2.4 m (7.8 ft) and its slope is 6:12 throughout the roof. The building sits on a 16.7 m (55 ft) turntable to permit rotation and control the wind direction.

Instrumentation

Five Series 100 TFI Cobra Probes (Figure 5-2) recorded high resolution 10 minute wind speed time histories 1 in (2.54 cm) above the roof plane at 20 locations for three approach wind directions. The sampling frequency of the instrument is 2000 Hz. The four ports on the probe head allow the instrument to decompose the three components
of velocity and local static pressure in real time. At high wind speeds the anemometers record reliable measurements, but at low wind speeds or sudden changes in wind speeds, our mechanical anemometers are not sufficiently reliable because their inertia alters the measurements. The Cobra Probes do not have this problem since there are no inertial effects.

The TFI Cobra Probes were mounted at twenty locations on the building to measure wind speed during 10 minutes while the building was immersed in the flow approaching from a given direction. Measurements were first collected for three different approach wind directions at five locations at a time over the roof (five Cobra Probes were available). The wind speed time histories were reviewed for completion and proper data acquisition (i.e., no voltage spikes in the data). The Cobra Probes were subsequently mounted at five different locations to collect measurements for the three different wind directions. This process was repeated until data was acquired for 20 roof locations.

**Test Procedure**

Velocity measurements above the roof were recorded at 20 locations for three wind directions. Measurements were recorded 25.4 mm (1 in) above the roof slope to provide a direct comparison with Peterka et al. (1997) and Cochran et al. (1999) scaled wind tunnel experiments. Secondary test runs were then completed at the locations observed to have the highest wind speeds with probes recording data at 25.4 mm (1 in) and 304.8 mm (12 in) above the roof surface simultaneously. Each test consisted of subjecting the building to the flow during 10 minutes in a standard open terrain exposure.
Selection criteria for instrumentation of the 20 locations on the test building was based on the regions of the roof expected to sustain the highest pressures (ridge and edge areas). Three approach wind directions were tested (Figure 5-3):

- Perpendicular to the ridge line (0°)
- Cornering wind on the hip end of the roof (45°)
- Cornering wind on the gable end of the roof (315°)

The instrumented locations were concentrated around the gable end of the structure to compare with wind accelerations measured by Peterka et al. (1997) and Cochran et al. (1999). A preceding experiment at the IBHS test facility had instrumented our test building with 73 Irwin Probe sensors to measure surface pressure coefficients on the roof. These Irwin Probes were used as the mounting locations for the Cobra Probes. The Cobra Probe mounts consisted of a copper pipe placed through the Irwin Probe’s central circular opening fastened with a set screw. The test locations were identified with the same numerical scheme as the previous IBHS experiment. As a result, the selected test points were assigned values between 8 and 69 (Figure 5-3), rather, than 1-20. Time and budget constraints of the test facility limited the instrumented locations to 20.

Individual tests consisted of subjecting the building to the flow during 10 minutes in a standard open terrain exposure. The wind velocity profile on the free stream (i.e., approach flow) was created by regulating the output velocity of the electric vane axial fans. Fluctuations in the wind field were regulated by rotating airfoils at the test section transition. The peak 3 second gust wind speed at mean roof height was measured upstream at 26.8 m/s (60 mph).
Wind velocities in the approach flow were recorded by an RM Young wind monitor (Model 05103V, Figure 5-4) at an elevation of 5 m (16.4 ft). Dynamic characteristics of the wind monitor’s four-blade polypropylene helicoid propeller include a 2.7 m (8.9 ft) 63% recovery distance constant and a damped natural wavelength of 7.4 m (24.3 ft). The wind monitor is rated for a 100 m/s (224 mph) gust survival, meaning it can record measurements in category 5 storms. The sensor has a 50% recovery vane delay distance of 1.3 m (4.3 ft), and full 360° rotation capabilities. Velocity readings are accurate to ±0.3 m/s (0.6 mph) and 1% of the measured wind direction (±3°). Velocity measurement synchronization between the wind monitor and Cobra Probes was achieved using a triggering application created via LabVIEW Virtual Instrument.

**Measurement Results**

The ratios of peak N-second wind speeds to 10-minute mean reference wind speeds are shown in Figure 5-5 and are compared to those obtained by Peterka et al. (1997). The maximum velocity ratio (2.55) was recorded for perpendicular winds (0°), and occurred at the corner of the gable end near the ridge (location 57).

Peterka’s recommendation of a 2.5 mean speed ratio as a reasonable upper bound for low rise structures is within 2% of the full scale results. The results depicted in Figure 5-5 are also above the speculative lower limit for turbulent flow specified in Figure 16 of Cochran et al. (1999). The lower limit defined by Peterka et al. (1997) is based on the knowledge that the largest peak gust wind speed can never be lower than the mean flow value; thus, turbulent fluctuations cannot fall on or below the laminar flow limit (Cochran, 1999). Cochran (1999) elaborates on this by explaining that atmospheric flows over roofs are turbulent, the lower limit is actually higher than the lower limit.
assumed by laminar flow. The measured mean speed ratios are listed in Table 5-1 for the 20 locations on the roof and for the three different approach wind directions.

Maximum speed-up factors obtained from the PIV data analyzed at the University of Western Ontario (UWO) are 1.69 for a wind loading case perpendicular to the ridgeline of the structure. This value is significantly lower than the maximum value measured at IBHS; however, the PIV measurements were recorded at the centerline of the structure. Values near the centerline measured at full scale at IBHS (1.88) are in better agreement with the 1.69 provided by UWO.

Cochran (1999) observed that one of the consequences of comparing model to full scale mean speed ratios was that the smoother surface on the roof slope of the model caused model scaled values to overestimate the full scale values by up to 24%. Values matched closer together when the roof of the model was roughened using steps similar to the scaled thickness of asphalt shingles. The full scale building tested at IBHS consisted only of plywood sheathing, presenting the possibility of overestimation. Introducing asphalt shingles (similar to a finished roof) would roughen the surface, thereby lowering the values of the mean speed ratios. With this assumption in place, every value measured during the experiment would result in mean speed ratios lower than 2.5 on a completed roof. An additional source of uncertainty identified by Peterka et al. (1997) and Cochran (1999) includes the use of an omnidirectional hot wire anemometer. Peterka et al. (1997) and Cochran et al. (1999) emphasized that wind velocity measurements near the roof vortex regions could be inaccurate when obtained with this type of instrument. The TFI Cobra Probes used during the tests conducted at IBHS is especially suited for three dimensional turbulent flow measurements (up to 30%
turbulence intensity), a feature not available at the time Peterka et al. (1997) and Cochran et al. (1999) completed their studies on wind acceleration near the roof plane. The experiments completed at IBHS build on their work by providing more accurate and higher resolution measurements on roofs.

The trends observed by Cochran (1999) and Peterka et al. (1997) were also observed for the PIV wind tunnel tests and the full scale tests conducted at UWO and IBHS, respectively. The highest wind speeds were always observed near the ridge and edges. Even though the highest peak wind velocity was recorded for the perpendicular wind direction case (0°), higher average values were observed during the cornering wind tests, especially the 315° direction.

**Summary**

A full scale wood frame structure consisting of a 6:12 pitch, and gable and hip roof sections was instrumented with Series 100 TFI Cobra Probes to characterize the distribution of wind velocities near the roof plane. The resulting velocities were compared to wind velocities in the approach flow to identify the areas of highest acceleration. Similar to wind tunnel experiments by Peterka (1997) and Cochran (1999), larger average wind accelerations were observed during cornering approach conditions, but peak values were measured near the ridge line during perpendicular approach conditions (0° approach angle). Results confirmed Peterka’s recommendation of a 2.5 factor for mean speed ratios near the roof plane implemented in uplift forces on asphalt shingles in ASTM D7158.
Table 5-1. Resulting Mean Speed Ratios

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<th>( x / U ) ( \theta = 0^\circ )</th>
<th>( x / U ) ( \theta = 315^\circ )</th>
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<th>% Missing Data ( \theta = 0^\circ )</th>
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Figure 5-1. Full scale test structure at the IBHS test facility in Chester, SC. Photo courtesy of Craig Dixon, University of Florida.

Figure 5-2. Series 100 TFI Cobra Probe
Figure 5-3. Roof measurement locations and wind approach angles. An approach wind direction perpendicular to the hip section was not performed due to time constraints.
Figure 5-4. RM Young Wind Monitor at IBHS. Photo courtesy of Craig Dixon, University of Florida.

Figure 5-5. Mean speed ratios measured at IBHS without data filtering.
CHAPTER 6
FULL SCALE ASPHALT SHINGLE TESTING

The test specimens were constructed in July 2011 at the IBHS Research Center in Chester, SC to evaluate the system level wind resistance of asphalt shingles on full scale residential structures in the summer of 2012 and left in an open field exposed to natural weathering effects for one year (Figure 6-2, and Figure 6-3). A period of one year is assumed to give the shingles enough time and temperature cycles to allow sufficient activation of the sealant strips.

A total of 27 roof sections were constructed, including 18 monoslope and 9 hip. All specimens have 6:12 slopes to integrate seamlessly with the permanent roof section on the test structure. The monoslope sections will be tested in pairs, fastening together at the ridge to form a single gable end section, then covered with ridge caps. The hip roof specimens will attach to the permanent roof section already in place. This will total 18 experiments at the IBHS facility. The final roof structure will have a 30.5 cm (12 in) overhang throughout. The specimens were built over 25 cm (1 ft) diameter concrete caps and wood blocking to avoid direct contact of the shingles with the soil surface.

Three asphalt shingle products, two laminate and one three-tab, were installed by a licensed contractor conforming to manufacturer specifications for a 6:12 roof pitch in a High Velocity Wind Zone (Class H). Shingle temperatures are continuously monitored with Omega SAIXT-T-SRTC Thermocouples installed on every roof section to compare the shingles’ uplift resistance to their heat exposure during the year leading up to testing.

The aged specimens will be transported to the test section using a Lull 944E-42 Telehandler. Racking of the specimens will be prevented by sheathing the bottom,
sides, and interior of all trusses. Additional stability will be provided by 76 mm x 180 mm (3 in x 7 in) steel beams running beneath the trusses.

**Test Structure**

A one story wood frame structure measuring 9.1 m by 12.2 m (30 by 40 ft) will be constructed surrounding an existing steel frame located at the test facility. Half the roof section will be fitted with a permanent 6:12 pitch gable end. The unoccupied half of the roof structure will allow interchangeable testing of gable or hip sections (Figure 6-1). The structure will be constructed on the 16.7 m (55 ft) diameter turntable installed in the facility’s test section, allowing testing of variable approach wind directions.

The structure will consist of a steel moment-resisting frame used for multiple test structures at IBHS. The frame sits on W12x30 steel supports to allow the structure to be moved in and out of the facility’s test section. Sheathing for the exterior walls and roof will be completed with 12 mm (15/32 in) 4-ply plywood. The permanent gable roof covering one half of the structure will have 30.5 cm (12 in) overhangs on all sides. Fan-type wood trusses spaced at 60 cm (24 in) will make up the roof structure of both the permanent section and test samples.

**System Level Wind Resistance of Asphalt Shingles**

The experiment will evaluate the wind resistance of asphalt shingle roofs by identifying regions most susceptible to uplift, and by quantifying the flow characteristics near the roof surface. Each test specimen will be subjected to a 30 minute time-varying trace consisting of three 10 minute segments of increasing intensity, with peak gusts ranging from 40 m/s (90 mph) to 60 m/s (134 mph). This phase will subject the specimens to three approach wind directions, with any one specimen subjected to only one of these directions. Approach directions (Figure 6-4) will include parallel to the
ridgeline (0°) perpendicular to the ridgeline (90°) and a cornering wind direction (45°). The approach profile will resemble that of open country conditions in ASCE 7-10 (Exposure C).

Following completion of the 30 minute wind record, a visual and physical inspection will be completed before the specimen is removed from the test structure. For each gable roof, two high-definition cameras will be employed for live monitoring and documentation of shingle performance. The hip roofs will require three cameras to monitor a greater number of surface planes. Location of the camera mounts will be decided nearing the test dates, and selected based on areas producing minimum flow distortion while providing the best visual results. A damage rating system will also be employed following the table developed by Lamb and Noe (1989), where damage values are assigned to observed damage types such as “shingle tearing” and “shingle pulls from fastener.” Lamb and Noe (1989) also note that failures observed at lower wind speeds are assigned a higher damage rating than the same failures observed at higher wind speeds. Any unsealed shingle tabs prior to testing will be accounted for by gently lifting on the leading edge. If resistance is not encountered and the tab lifts up freely, that shingle will be considered unsealed and its location will be noted. The locations will be monitored during the test sequence for any signs of tab uplift. Following testing, tabs that were observed to have lifted will be analyzed to record visible damage, as well as sealant strip failure modes. Specimens that do not experience any significant shingle damage will be transported back to their original position for further aging.

**Summary**

Full scale gable and hip roof test specimens constructed outdoors at the IBHS test facility in Chester, SC will be subjected to experiments evaluating the near surface wind
velocities over the roof plane. Wind loading of roof specimens will identify regions most susceptible to uplift and subsequent tear-off using visual inspection as well as high-speed footage recorded along the roof plane. Following testing, specimens will be assigned a damage rating based on points assigned to different failures observed.
Figure 6-1. Full scale test structure

Figure 6-2. Gable end, full scale roof section. Photo courtesy of Craig Dixon, University of Florida.
Figure 6-3. Hip end, full scale roof section. Photo courtesy of Craig Dixon, University of Florida.

Figure 6-4. Approach wind directions: Wind resistance of asphalt shingles
A mechanical uplift apparatus was designed and built to perform ASTM D6381 tests asphalt shingles in the field. The mechanical uplift resistance of laminate asphalt shingles exposed to over nine years of natural aging was measured during a field deployment in Orange City, FL, generating the following observations:

The design and construction of a portable apparatus capable of performing ASTM D6381 uplift tests on existing structures was completed and measured the uplift resistance of naturally aged shingles during its first field deployment. The system proved light-weight enough to be carried by a single person up to the roof, but stiff enough to resist damage due to transportation and handling.

Uplift resistance values measured showed that asphalt shingles naturally aged in existing residential structures maintain their strength when the sealant strip has properly activated, but ignores the effects of peeling loads on shingles since Procedure A could not be completed. The mean uplift load measured during field testing on a nine year old roof was 16.8 kg (37 lb) compared to 19.5 kg (43 lb) for a new shingle (aged 16 hours). Generating 16.7 kg (37 lb) of uplift on an asphalt shingle would require wind speeds in excess of 180 m/s (400 mph). The uplift force measured corresponds to equivalent wind speeds more than 90 m/s (200 mph) greater than those recorded by any named tropical cyclone using the approach described in Peterka et al. (1997)

Field deployment of the mechanical uplift apparatus resulted in several suggested modifications to improve the system’s efficiency. The addition of a counter-weight on the upslope side of the frame will eliminate an overturning moment currently requiring an additional person to operate the device. A 120 Volt connection will be added to the
frame’s electrical box to supply continuous power to the tablet PC, eliminating the need for a power cable. The system’s unregulated power supply will be outfitted with a 15 m (50 ft) power cable to increase the frame’s mobility without relocating the power supply.

Wind velocities near the roof plane were measured at the IBHS facility using five Series 100 Cobra Probes. Roof velocities were compared as ratios of velocity near the roof plane to mean approach wind speed, yielding the following observations:

The highest peak observed single mean speed ratio occurred when the wind flow was perpendicular to the ridge line. However, higher average mean speed ratios were measured during cornering wind approach directions in comparison to the perpendicular approach. These results confirm earlier observations by Peterka et al. (1997) and Cochran (1999) during model- and full-scale experiments. The maximum value measured by the Cobra Probes (2.55) exceeded the Peterka et al. (1997) near roof wind acceleration factor (2.50) by 2%, which supports the use of the 2.5 speed-up coefficient for calculating the uplift forces generated on asphalt shingles near the roof plane.

The mean speed ratios on an asphalt shingle roof are expected to be lower than the values measured at IBHS due to the presence of rougher surface elements, in comparison to the smooth wood sheathing covering the test structure. Cochran et al. (1999) showed that roughening a wind tunnel model to more closely resemble the “steps” on a roof created by shingles lowered the mean speed ratios by as much as 24% when compared to a smooth roof surface.

Preliminary tuning of the portable mechanical uplift apparatus in preparation for dynamic testing subjected asphalt shingle specimens to cyclic loading. Although tuning
was unsuccessful (a more sophisticated controller is required), several important observations were noted:

It was observed that cyclic loading even in load ranges as low as 15% of the average mechanical uplift resistance of similar specimens led to failure of the sealant strip after exposure to sufficient load cycles (2 hr cycle duration with load applied at 3 Hz). Cyclic loading also produced surface cracks on the shingle specimens near the aluminum T-section epoxied to the top shingle.

Future testing at the IBHS test facility will evaluate the uplift resistance of asphalt shingles through wind loading on a full scale one story structure. Areas with noted tab uplift will be compared to the areas on the roof with the highest wind accelerations.
LIST OF REFERENCES


BIOGRAPHICAL SKETCH

Dany Romero was born in 1987 in Havana, Cuba. At the age of 7, he moved to the city of Miami, Florida. The son of a mechanical engineer, he was always fascinated by design, science, and mathematics. Following his graduation in 2005 from Miami Coral Park Senior High he pursued an Associate of Arts degree from the University of Miami. In the Fall of 2007, Dany transferred to the University of Florida, and began research as an undergraduate student for the Civil and Coastal Engineering department. During his time as an undergraduate student, he assisted in the completion of the University of Florida Hurricane Simulator, as well as research directed at water ingress through building fenestration.

After graduating in the Fall of 2009, he entered graduate school under the mentorship of Dr. Forrest J. Masters, and began researching water ingress rates through idealized openings as well as mechanical uplift resistance of asphalt roofing shingles. Shingle research included variations in mechanical uplift resistance with artificial aging time, as well as shingle performance during application of full scale Gaussian uplift loads. His research allowed him to work side by side with top researchers and executives of roofing companies and government institutions on projects that garnered national recognition.

Dany was also a member of the Florida Coastal Monitoring Program, a unique joint venture to that focuses on experimental methods to quantify tropical cyclone wind behavior and the resulting loads on residential structures. He assisted in preparation of field deployable instruments to quantify near-surface cyclone winds for named storms in 2008, 2009, and 2011.
Dany Romero is a student member of Tau Beta Pi, Chi Epsilon, and the American Association for Wind Engineering. Following his graduate work, Dany will be an engineer at Loadtest in Gainesville, Florida in the Spring of 2012.