A Case for Standardized Dynamic Wind Uplift Pressure Test for Wood Roof Structural Systems

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ABSTRACT

Wood roof sheathing in residential construction is an important component of structural wood roof systems, and their failure can exacerbate progressive failure of the roof trusses in addition to providing entry for water that causes damage to the interior of the structure[1]. The damage to residential wood roofs is a major contributor to the billions of dollars in economic losses caused annually by the passage of hurricanes along the southeastern coast of the United States. In real world conditions wind loading of residential structures is dynamic and varies spatially. However current wind uplift test methods for determining the structural resistance of residential wood roof sheathing systems use uniform pressures applied statically to evaluate their capacities.

This research evaluates the structural behavior of wood roof sheathing panels subject to realistic wind loading in order to determine whether dynamically tested panels perform the same as statically tested panels. Further, results are presented on in-situ nail withdrawal capacity and uplift capacity of existing roof panels from 29 year old Florida single-family residential homes.

The goal of this investigation is to evaluate the wind uplift performance of wood roof sheathing panel systems subjected to uniform static and dynamic pressure traces. 20 test specimens were constructed of 4 ft by 8 ft by ½ in. oriented strand board roof sheathing, where half were tested by conventional test protocol and the other half tested by a dynamic test protocol reported by Datin et al. in this conference. It was found that dynamic loading of wood roof sheathing panels causes a reduction in capacity, and further that current uplift testing methods may be non-conservative.

INTRODUCTION

Wind damage to residential structures accounts for billions of dollars of annual economic losses in damage to residential structures, and studies of post hurricane damage confirm that roof failures are a large contributor to overall loss [2-5]. Indeed, roof sheathing damage may even occur in events where wind speeds do not exceed design level wind speeds, see Figure 1. Although premature failure can be attributed to faulty construction and environmental degradation of materials, it is possible that inadequate testing procedures may over-predict the wind uplift resistance of wood roof panels.
Figure 1: Wind damage to roof structures of two Alabama homes during Hurricane Ivan occurred in wind speeds 111 to 125 mph [2], approximately 60 to 80% of design wind pressure (at 140 mph, 3-second gust).

Wood roof sheathing panels are important components of residential wood roof structures, and their failure results in instability of roof trusses and interior damage from water entering through openings [1-5]. The primary failure mechanism of wood roof panels observed in hurricane-damaged homes is the removal of the sheathing from the roof trusses by nail withdrawal failure, nail pull-through (where sheathing is removed leaving the nail in place) and by fracture of the sheathing itself.

Engineers rely upon test data to estimate the ultimate structural resistance of wood roof panels, which is determined by wind uplift testing. However, unlike commercial roofing systems such as standing seam metal panels and single-ply membranes, there exist no industry-standard test methods for determining the uplift capacity of wood framed roof structures. Uplift pressure testing measures the system performance of a sheathing panel that is attached to framing members with nails (or staples), and the panel failure is defined as the failure of the first nail (or fracture of the panel or wood member), and this failure (nail withdrawal) usually occurs rapidly as pressure is increased. A review of past uplift test reports [6-8] of wood sheathing show that several non-standard test protocols were used, limiting the value of direct comparison of results. Without knowing test specifics such as pressure traces and application and details of sheathing, framing member properties and nail dimensions extrapolation of the data becomes difficult. Despite this limitation the results of previous testing, partially summarized in Figure 2, have been the basis of numerous probabilistic studies predicting the performance of wood roof structures in hurricanes. The inherent large variability in wood structural properties would suggest studies with limited repeats may not be statistically reliable.

These questions and the wide range of failure capacities observed provided the motivation for the present study, to revisit procedures for wind uplift failure testing of wood roof sheathing developed in the later after evidence of vulnerable wood structures became known after Hurricanes Hugo in 1988 and Andrew in 1992. This study seeks to understand the critical parameters that determine the wind uplift testing of residential wood roof structures.

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Figure 2: Previous results of wood roof sheathing wind uplift failure pressures. *Note: The NAHB tests conducted using airbags.
TYPICAL WOOD ROOF CONSTRUCTION

The roof structure of a typical Florida residential home consists of 4 ft. by 8 ft wood roof sheathing (oriented strand board or plywood) panels attached using metal nails or staples to wood trusses or rafters, see Figure 3. Wood trusses are toe-nailed or strapped with metal ties to wood wall plates. Generally two nail sizes are used to attach roof sheathing; a 2 in. long .113 in. shank diameter with .257 in. head diameter 6d common and a 2-1/2 in. long .131 in. shank diameter with .284 in. head diameter 8d common. The structural performances of these nailed connections vary widely depending on the manufacture of the nail used. Since 1994, the Florida Building Code has mandated the 8d common nail as the minimum fastening size for roofing. However, the vast proportion (over 90%) of existing residential homes were built before this change and they are more likely to have either stapled connections of 6d common nails. Nail spacing’s in older (pre-1994) homes are 6 in/12 in., i.e. 6 in. o.c. in exterior panel trusses and 12 in. o.c. on the interior trusses.

The key connection in the roof system is the sheathing to wood connection and for nails, this connection strength is determined as the nail withdrawal strength per ASTM D-1761 [9]. Field studies provide anecdotal evidence of the effects of aging and environmental loads (UV, thermal & moisture effects) on roof panel strength. As yet no systematic relationship has been established between individual nail pull tests and uplift pressure testing of roof sheathing panels.

Figure 3: Characteristics of residential structures investigated

Wind flow around a residential structure produces dynamic and spatially varying loads on its exterior surfaces, however most industry-standard test protocols use uniform pressure test methodologies applied statically to the specimen [10-12]. These testing protocols do not adequately reproduce the true wind loading characteristics and it is unknown whether they accurately predict the uplift capacities of the installed systems. While some test protocols do use dynamic pressure traces [13, 14], with current equipment only the simple sinusoidal trace can be
followed. A unique test apparatus developed by the University of Western Ontario has enabled researchers at the University of Florida to evaluate wood panel behavior under realistic dynamic wind loading. The two main goals of this investigation were:

1) to evaluate and compare the performance of wood roof panels subjected to dynamic and static uplift pressure test protocols and

2) to determine the as-built capacity of roof sheathing and individual nails from existing Florida homes.

To accomplish these tasks 20 new wood roof sheathing panels were fabricated and tested under static and dynamic pressure traces to determine their uplift failure pressure. Four roof panels were harvested from an existing house in Port Orange, FL and tested under static pressure and the withdrawal capacities of approximately 500 nails from five single-family residential structures were also determined.

**DESTRUCTIVE TESTS ON EXISTING HOMES**

**NAIL WITHDRAWAL CAPACITY OF EXISTING ROOF SHEATHING**

A portable nail extraction device developed by Sutt [15] (Figure 4), was used to evaluate nail withdrawal capacity. The device consists of a metal frame supporting a 2,000 lb load cell, power source, and digital display. Hardened steel jaws attached to the load cell are fitted under each nail head and the device is operated by lever arms. Peak load was recorded in this process. A 2 in. diameter hole is cut in wood sheathing around each nail and the extractor jaws paced below the nail head. 500 nail extraction tests were performed on five homes in Port Orange, FL and the results are shown in Table 1 below.

![Figure 4: Graduate civil engineering student using the nail extraction device on existing roof](image)

**Table 1: Nail withdrawal strength for 2 in. (6d common) galvanized nails from 5 Port Orange, FL homes**

<table>
<thead>
<tr>
<th>Source ID</th>
<th># of Samples</th>
<th>Mean Withdrawal (lbs)</th>
<th>COV</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>102</td>
<td>207</td>
<td>49%</td>
</tr>
<tr>
<td>B</td>
<td>101</td>
<td>166</td>
<td>61%</td>
</tr>
<tr>
<td>C</td>
<td>97</td>
<td>202</td>
<td>58%</td>
</tr>
<tr>
<td>D</td>
<td>101</td>
<td>137</td>
<td>60%</td>
</tr>
<tr>
<td>E</td>
<td>99</td>
<td>244</td>
<td>45%</td>
</tr>
</tbody>
</table>
UPLIFT PRESSURE TESTING OF EXISTING WOOD ROOF PANELS

Four roof sheathing panels were harvested from a Port-Orange, FL home and transported to UF’s Hurricane Research laboratory for testing (Figure 5). Approximately seven days prior to harvesting the panels, a 3 in. thick layer of closed-cell spray-applied polyurethane foam was applied to one panel. The panels consisted of a 4 ft. by 8 ft. wood panel attached to framing members with nails. The panel was plywood and the framing member was a metal truss plate connected truss composed of 2 in. by 4 in. members. It was found that the standard wood used for truss makers in the area was southern yellow pine (SYP) #2 Grade lumber. The nails used were 2 in. long 6d common with a shank diameter of .113 in. and a head diameter of .257 in. The test protocol used is described in the test procedure section below.

Figure 5: Harvested roof panels

UPLIFT PRESSURE TEST METHOD

Wind uplift pressure testing was conducted at the University of Florida’s Hurricane Research Laboratory using a 4’-6” by 8’-6” by 6 in. deep steel pressure chamber. The new roof panel tests were conducted on 4 ft by 8 ft by ½ in. thick OSB panels fastened to southern yellow pine wood studs placed 24 in. apart. The two fastening schedules were 6 in./12 in. and 6 in. /6 in. for the two groups of 10 panels. Hot dipped galvanized nails (nominal size 6d common), shank diameter 0.113 in and 2 in. long, were used for these tests to match the dimension of the nails found in the harvested panels. A 2 mils thick plastic sheet was inserted between the wood stud and OSB sheet during fabrication of the panels and the plastic sheet was sealed to the side of the steel chamber using duct tape. The tests on the four harvested panels were conducted by covering the panel with the plastic sheet. Panels were installed as shown in Figure 6.
The pressure is held for 10 seconds, if the panel does not fail the chamber pressure is increased by 15 psf and again held constant for 10 seconds. The pressure is increased in this manner until failure occurs, and the pressure is recorded. The chamber pressure was monitored using a differential pressure transducer installed through the chamber wall. Note that the harvested panels were tested with negative pressure (sheathing side down) and the new panels with positive pressure (sheathing side up).

**Figure 6:** a) Pressure Chamber with positive pressure setup b) Pressure Load Actuator (PLA)

**Figure 7:** a) Test Arrangement Used for Harvested Panels Figure b) Test Arrangement for New Panels, positive pressure

**Pressure Load Actuator (PLA)**

The pressure load actuator (PLA) was used to generate the realistic wind pressure fluctuations in the chamber. The PLA system utilizes a 12 hp regenerative blower and computer-controlled feedback loop to actuate a valve. The active valve control system and powerful blower enabled very responsive control of the chamber pressure that closely followed the large amplitude
pressure fluctuations and rapid 10 Hz response of the simulated dynamic wind pressure (Figure 8). Details of the PLA are provided in [16].

![Figure 8: Sample of target Static and Dynamic pressure traces](image)

**PRESSURE TEST PROTOCOL**

No consensus standard exists for determining the wind uplift capacity of performance of wood sheathing panels. Therefore, a testing method was developed based on the ASTM E330-02 standard (Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain walls by Uniform Static Air Pressure Difference) [17]. The following modifications were made:

- Apply pressure in one direction only, i.e. only in suction (or only in positive pressure)
- No deflection readings are taken to observe permanent deformation of the panels
- Reduce chamber pressure in 0.72 kPa (15 psf) increments and hold for 10 seconds, and
- Eliminate recovery period for stabilization.

The test pressure sequence is increased in the above manner until panel failure occurs. A panel failure was defined as any separation or sheathing fracture, split in lumber or nail withdrawal or pull through. The peak suction (negative pressure) reached at failure is recorded and the location and failure mechanisms of the fasteners noted. After failure, the plastic sheet was removed and the panel examined to determine the locations and types of fastener, panel, or wood failures.

The dynamic pressure trace was developed using wind tunnel testing of a 1:50 scale model of a residential house in suburban terrain[18]. The simulated pressure trace was measured at a tap at equivalent distance of (8.4 in., 21.6 in.) from the roof corner and a tributary area of 2 sq. ft. A companion paper in this conference provides details of this derivation[19]. The peak pressure trace is scaled every 10 sec. to match the peak pressure level (i.e. 15 psf, 30 psf, 45 psf etc.) of the static test protocol.

**RESULTS**

The wind uplift pressure test results are presented in Table 2. As expected, the panels having the 6”/12” fastening schedules failed at lower pressures than the panels having 6”/6” fastening
schedules for both the static tests (62 psf versus 108 psf) and the dynamic tests (52 psf versus 90 psf). The interesting observation is the near 20% reduction in uplift capacity of the panels tested dynamically. It was also observed that the failure pressure of the 3 panels harvested from the 29 year old home were higher than the mean failure pressure of the new panels (101 psf versus 62 psf). This result suggests that aging and environmental effects may not have weakened the structural system, although the small sample size makes it impractical to be statistically certain. It is noted that the failure pressure of the harvested panels is within the order of magnitude of previous studies by some of the authors [20] revealing the sensitivity of uplift capacity to type and size of nails used and indeed manufacturer.

A derived statistic, the $R_{mp}$ ratio, was computed as the mean 10 second pressure (just before failure) divided by the peak pressure. This statistic provides a measure of the dynamic load effect on the samples. Another interesting result was that while the $R_{mp}$ ratio for the static pressure test was 0.81, it fell to about 0.60 for the dynamically testing panels. The dynamic pressure traces apparently is producing a pseudo-fatiguing effect on the panels that appears to increase the severity of loading on the nailed connections. Thus the dynamically loaded panels failed at lower peak pressure and the mean 10-second pressure just prior to failure was only 60% of the peak pressure (as opposed to 80% for the static tests). The implications of this result for existing residential roof systems subjected to wind loading is that their assumed performance may be overestimated, and failure could occur below design level events.

### Table 2: Summary result of uplift failure pressure static and dynamic tests

<table>
<thead>
<tr>
<th>Fastener Schedule</th>
<th># of Test Panels</th>
<th>Peak Pressure recorded (psf)</th>
<th>10 sec mean pressure just prior to failure (psf)</th>
<th>Mean 10 s to Peak pressure ratio, $R_{mp}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Harvested Panels:</strong> 4 ft by 8 ft plywood panels fastened as specified to five 2 in. by 4 in. truss members at 24 in. o.c, 29 yrs old</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static 6”/12”</td>
<td>3</td>
<td>101</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Static 6”/12” plus ccSPF</td>
<td>1</td>
<td>249</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>New Panels:</strong> 4 ft by 8 ft OSB panels fastened as specified to five 2 in. by 4 in. SYP wood members at 24 in. o.c.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static 6”/12”</td>
<td>5</td>
<td>62</td>
<td>49</td>
<td><strong>0.79</strong></td>
</tr>
<tr>
<td>Static 6”/6”</td>
<td>5</td>
<td>108</td>
<td>91</td>
<td><strong>0.84</strong></td>
</tr>
<tr>
<td>Dynamic 6”/12”</td>
<td>5</td>
<td>52</td>
<td>31</td>
<td><strong>0.60</strong></td>
</tr>
<tr>
<td>Dynamic 6”/6”</td>
<td>5</td>
<td>90</td>
<td>53</td>
<td><strong>0.59</strong></td>
</tr>
</tbody>
</table>

### CONCLUSIONS

This research evaluated the wind uplift failure capacities of wood roof sheathing panels using static and dynamic pressure test methods. A review of previous test results showed considerable scatter in the data as well as variability in test methodologies used. A standard test methodology was proposed for wood roof panels based on a modification of the ASTM E330 static procedure. Tests conducted on sheathing panels harvested from 29-year old residential structures revealed similar uplift capacities as were observed with newly constructed sheathing panels. Research continues to relate the individual nail withdrawal capacity to the system performance failure pressure of the roof panel. When the results from the static test method were compared with a
dynamic uplift testing, nearly 20% reduction in failure pressure was observed in two direct comparisons. The results suggest that current static pressure test methods may not be appropriate for evaluating wind resistance of wood roof panels, and they likely over-estimate the failure capacities for panels fastened using nails. However, these existing static uplift pressure tests do have value as they can provide a comparative measure of performance of various components.

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REFERENCES


