CLEMSON
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Subject: **Field Tests of Orage Corporation Hurricane Harness Tie-Down System**

Introduction:

During 2001 and 2002, Clemson University was given the opportunity to test the effects of retrofits on a number of residential homes that were purchased as a part of a FEMA and State of South Carolina funded repetitive flood buyout program. These homes were damaged by floodwaters generated by the rains from Hurricane Floyd. The buyout program required that the buildings be removed and the lots returned, in perpetuity, to an undeveloped state. Since it was not feasible to move most of the homes, they were slated for demolition. This provided an opportunity for destructive testing of the houses to investigate their wind resistance with and without various retrofits.

The Orage Corporation's over-the-roof strapping system referred to as the "Hurricane Harness Tie-Down System," was installed as one of the retrofits evaluated during field tests that were conducted in November 2001. This system employs stainless steel anchors installed in the foundation wall or footing and a strapping system with a ratchet type tightening device to pull the straps tight. The steel bracket attached to the stainless-steel anchor is shown in Figure 1. In this demonstration test, the anchors were positioned four feet apart, on opposite sides of the house, along the exterior walls of the house below the eaves. A strap is placed over the roof between the two opposite anchor points and a ratchet device is used to tighten the strap so that it tends to anchor the roof to the foundation. Figure 2 shows the two Orage Straps installed at 3656 Eagle Trace in Horry County, South Carolina. This photograph was taken at a point in time when the straps had not been straightened out and tightened. An Orage Corporation employee performed the installation. The only deviation from a typical installation, that we are aware of, was that we connected a load cell between one of the anchors and its associated strap in order to monitor the load in the strap.

The house at 3656 Eagle Trace was well built for its time. Each roof truss was connected to the top plate of the wall using a H2.5 hurricane strap. In addition a single H2.5 strap was used to connect the top plate to each wall stud and each wall stud to the sole plate. Finally, the sole plate was anchored to the foundation using mudsill anchors. Thus, this house had a relatively well-developed internal structural load path for resisting uplift loads.

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Figure 1. Anchor Bracket Attached to Foundation Using Epoxy Grouted Stainless Steel Anchor Bolt.

Figure 2. Orage Corporation Over the Roof Straps on 3656 Eagle Trace.

Test Methods:

Vertical uplift loads on the roof structure were applied using the 40 Ton Crane shown in Figure 3. The portion of the house used for the Orage Corporation retrofit test is the right hand end of the house as shown in Figure 3. The portion of the roof structure engaged in the uplift tests was isolated from the rest of the building by cutting through the roof sheathing and ceiling sheetrock to the left of the farthest left loading bracket. The cut in the roof sheathing is visible in Figures 2 and 3. A loading tree was used to apply uplift loads to each truss in the roof segment to be tested as shown in Figure 4. In addition to the load cell used to monitor the load in the strap, load cells were also connected between the loading tree and each of the loading brackets (Figure 4). A final load cell was connected between the top of the loading tree and the crane hook (also see Figure 4). This load cell provided an overall measurement of the total load applied to the segment of the roof being tested. The six load cells were monitored simultaneously by a PC based data acquisition system for the duration of the test. The load cells were obtained from Omega Engineering and each had its own calibration certificate traceable to NIST. The load cells were bought within 6-months of this series of tests, so their calibrations were within 6-months of the tests. The load cells were connected to Vishay strain gage conditioning amplifiers with gains set at 200 and excitation voltages set at 10 volts. The outputs of the Vishay strain gage amplifiers were connected directly to the Computer based data acquisition system.

Before testing commenced, tension in the straps was released and the output of each load cell was set to zero. This provided a zero load reference for the strap and allowed the weight of the loading apparatus to be removed from the measurements. Each load cell was then loaded by hand and trial measurements were taken to ensure that the system was operating properly. Just before the testing, the straps were pre-tensioned. The test sequence involved starting the computer data acquisition followed by uplift loading of the roof using the crane. The loading was slowly increased until the roof structure separated from the walls. Figure 5 shows the roof segment after vertical loading has been applied until failure occurred in the roof-to-wall connection.

Figure 3. Crane Used to Conduct Uplift Tests with 3656 Eagle Trace in Background.

Figure 4. Loading Tree and Load Cells Used in Uplift Tests

Figure 5. Roof of 3656 Eagle Trace with Orage Corporation Straps After Testing.

Test Results:

Figure 6 provides a graphic illustration of the relationship between the load in one of the straps and the overall loading of the roof segment up to and beyond the point of failure of the roof-to-wall connection. This Figure illustrates several features of the load deformation characteristics associated with the strapping system and the performance of the internal structural system of the building. First, the initial load in the strap was about 365 pounds. An attempt was made to increase this preload by moving the ratchet one additional step. The load in the strap increased to about 600 pounds as the ratchet handle was moved but the operator was physically unable to force the ratchet to the next step. Consequently, the preload was limited to about 365 pounds in each strap. Second, the load in the strap increased linearly but at a much slower rate than the overall uplift load on the roof segment. Thus, the loads on the internal structure of the house increased much more rapidly than the loads in the straps. Third, the highest loads in the straps occurred well after the roof-to-wall connection failed and at a much lower overall load capacity. Finally, the actual increase in capacity achieved in any particular installation will depend significantly on the amount of pre-tension developed in the straps.

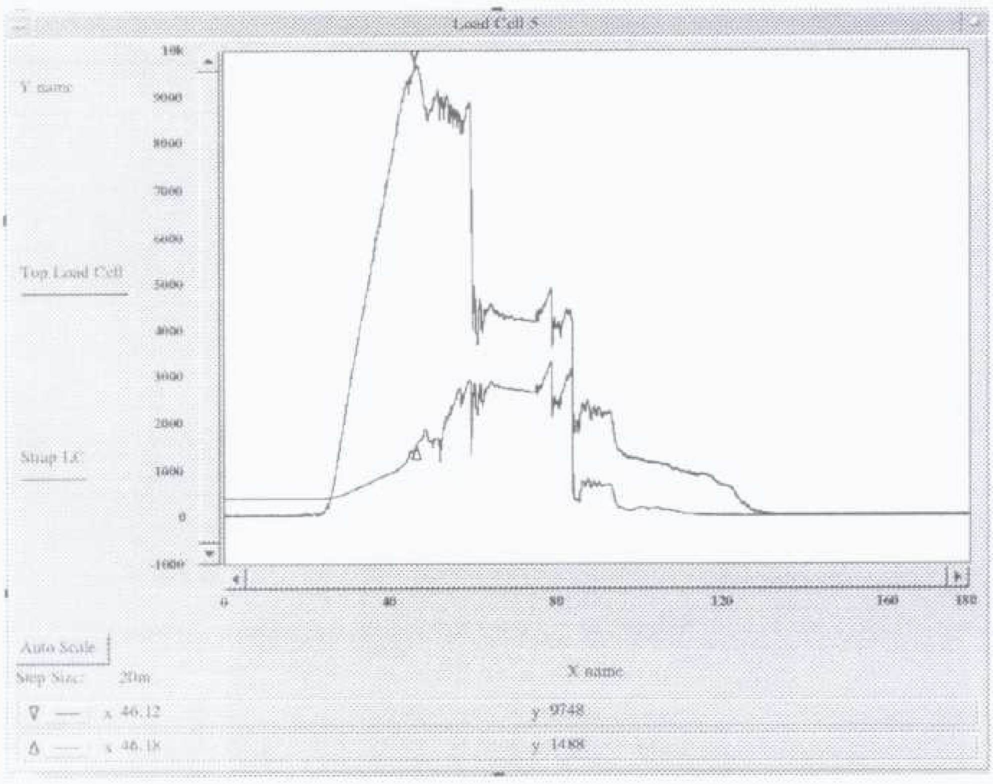

Figure 6. Time History of Loading on The Roof Segment and in One of the Straps

Since two straps were installed on the roof segment involved in these tests and the roof segment included four trusses that were anchored to the walls, the overall load is divided by four to get the load per truss and the load in the strap is divided by two to get its contribution on a per truss connection basis. At the point in time when the roof-to-wall connection gave way, the load per truss was 2,440 pounds and the load per truss attributed to the tension in the straps was 744 pounds. This implies that the ultimate load capacity of the internal structural connection was about 1696 pounds. This is consistent with results of a separate uplift test on an as-built segment of the roof that yielded and average ultimate uplift capacity of 1588 pounds per truss connection. Thus, at the point of failure of the roof connection, the strapping provided an increase in capacity in this particular installation of about 44 percent. This would translate into an increase of about 20 percent in wind speed, over the base case, to reach the failure load for this particular mode of failure.

From a design standpoint, engineers stay away from ultimate capacities because that means that failure has occurred. The typical design capacities of hurricane straps for timber framed structures are based on the lesser of 1/3rd the ultimate capacity, the load at which 1/8th inch of deflection occurs or the allowable capacity of the fasteners as calculated using the National Design Standard for wood. If the allowable design load for the base connection is set at 1/3rd of 1696 pounds, the allowable load for the connection would be 565 pounds. At that load level, the load developed in the strap, for this installation, is about 280 pounds per connection. Figure 7 provides an expanded view of the loads per connection in the strap and in the internal roof-to-wall connection. The values in the graph were extracted from the original test data using a set of on-screen markers.

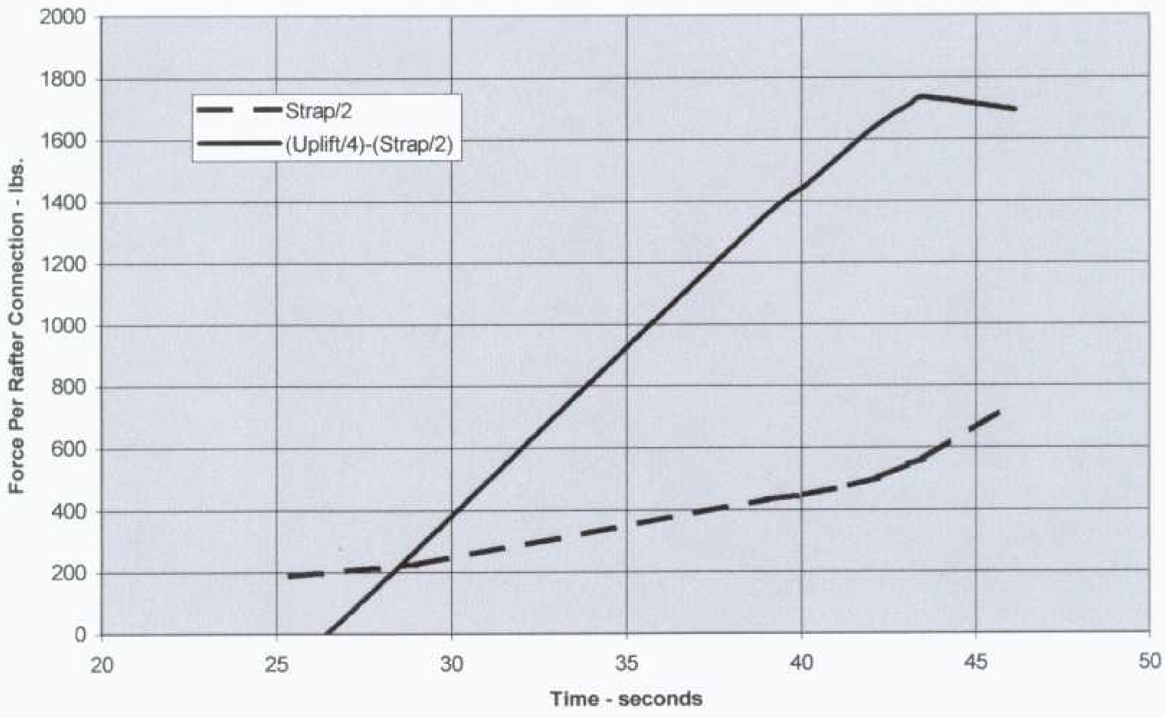

Figure 7. Expanded Plot of Load Time Histories on a Force per Rafter Connection Basis for the Structural Connection and the Orage Strapping.

It is clear from the test results that the straps apply large forces to the edges of the roof that may damage the edge of the roof covering and even the roof decking. Most fascia boards along the edges of roofs are attached to the trusses using nails driven into the end grain of the trusses or rafters. As such, these fascia boards may not provide a significant amount of resistance to the large vertical component of the loads applied by the straps. The left hand strap clearly cut through the roof sheathing (see Figure 5).

Summary and Recommendations:

The Orage Corporation Hurricane Harness Tie-Down System clearly provided an increase in uplift capacity in the retrofit application tested in Horry County, South Carolina. At a design load level for the underlying structure, the straps contributed about 280 pounds of uplift resistance per truss connection in this particular application. At the point where the roof-to-wall connection failed, the straps provided about 744 pounds of uplift resistance per truss connection in this particular application. For this specific installation, this load represented an increase in resistance to this particular failure mode that would correspond to resisting a 20 percent increase in wind speed.

The actual increase in capacity for a particular installation will clearly depend on the amount of pre-tension applied to the straps. A finer stepping system and/or a better moment arm in the ratchet mechanism would make it easier to produce higher pre-tension loads. The straps apply large concentrated axial and vertical loads to the edges of the roof that may produce localized damage to the roof.

The increase in uplift capacity provided by the Orage Corporation strapping, in this particular case, is about equal to the increase in loading on the roof that could occur if a large window or double door on the windward side of the house were to fail. Consequently, opting for the strapping instead of protecting windows and doors could produce a wash in terms of overall protection of the roof-to-wall connection. In seeking to obtain support from the insurance industry for this strapping system, Orage Corporation should think of it's strapping system as one component of the overall protection scheme for a home; a component that should be coupled, at a minimum, with protection of vulnerable openings.

Sincerely,

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