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Wind Loads on Houses

Destructive Model Testing of a Residential Gable Roofed House

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INTRODUCTION

In August 1992 Hurricane Andrew struck southern Florida. Thirty people died and 250,000 were left homeless. Damage from this Category 4 hurricane was estimated at 30 billion dollars [1]. After this storm, there was a strong interest to identify the type of damage associated with the large insurance costs. Residential subdivisions located in this region that were relatively unsheltered from the full force of the storm incurred the most damage. The damage to these houses presented a unique opportunity to investigate the type and extent of damage to this type of structure.

Major roof failure was the single most common and abundant type of damage. The investigation concluded that the main types of roof failure were:

1. local failure (loss of sheathing);
2. discrete roof truss failure; and
3. global roof failure (whole roof) due to roof-to-wall connection failure.

In the high damage areas, sheathing failures were the most common type of roof failure recorded.

In the current study, a 1:20 scale destructive model of a low-rise gable roofed house was tested in the Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario. The goal was to study the failure of roofs and roof elements. The term 'destructive' is used to describe the model because it was designed to fail in the wind tunnel. Both local (roof sheathing panel) and global (whole roof) failures were investigated. A number of different variables were studied to determine their effects on roof and roof panel failure, such as: dominant openings and their location with respect to the wind direction, background leakage, roof-to-wall connection strength, roofing panel hold down strength, the ratio of ridge and soffit vent area to the roof area, and the presence or absence of sheathing panels. The trajectory of airborne sheathing panels (after local roof failure) was studied as in a severe wind event airborne debris from damaged buildings could cause damage to neighbouring structures.

EXPERIMENTAL PROCEDURE

The model used in the testing was designed to capture an accurate measurement of the failure of roofs and roof sheathing on typical low-rise gable roofed houses. The model represented a two-story gable-roofed house with a 4:12 roof pitch. A close-up of the model is shown in Figure 1, while Figure 2 shows the model in the wind tunnel. This model was designed to fail in the manner that an actual roof would fail in a wind storm; therefore, the model roof and four 'sheathing panels' were mass-scaled to represent the actual roof and actual 1.2x2.4m (4'x8') sheathing panels (such as plywood). The sheathing panels are shown in Figure 1 as white rectangles on the yellow roof (they are taped with grey tape in this figure). The roof and simulated sheathing panels could then be 'blown off' the model when in the wind tunnel. Electromagnets were used to simulate the connections between the roof and the supporting walls and the sheathing and the roof trusses (resistance values taken from [2] and [3], respectively). Electromagnets were used because the hold-down force could be varied to represent different construction methods (i.e., different nailing patterns, etc.).

Results from the testing were obtained by video recording the experiments. To measure the trajectory of the failed panels, a scaled grid was laid out on the wind tunnel floor. Data were collected at 10-degree increments. The model and upstream terrain were symmetrical and therefore the model was tested over 90 degrees. During testing, the wind speed was increased at 60 second time intervals until failure was observed.

RESULTS AND DISCUSSION

1. Global roof failure testing:

Three types of global roof failure were observed: the initial movement of the windward edge, sudden failure and dislocation of the roof, and slower gradual uplift of the roof. In all cases, the windward edge was always first part of roof to uplift. It was observed that global roof failure was due to rotation of the roof about the leeward (downwind) edge, not simple uplift of the roof. The lowest failure speed was recorded when the gable-end was facing the wind (i.e. the wind was parallel to the roof ridge), although the failure wind speed did not vary significantly with wind angle. The maximum possible wind speed in this wind tunnel did not cause a global failure of the roof when the wind direction was perpendicular to the roof ridge.

2. Sheathing panels:

Four sheathing panels were placed on the model roof in locations of interest (see Figure 1): two panels were located on the model edge (near the ridge) and were windward for most wind angles tested. Two panels were located downwind of the mostly windward edge. A sequence of images taken from the recorded video during the ridge panel failure is shown in Figures 3 (a) to (e) and shows one trajectory pattern of the ridge panel at failure. The trajectory of failed panels varied considerably.

The distance that the failed sheathing panels travelled was not consistent for one particular wind angle. Certain factors affected the travelled distance, such as: the initial failure position, the orientation of the panel to the incident wind, and the wind speed. The critical wind angle for the roof panel failure was for a cornering wind. The cornering wind generates a turbulent effect over the ridge of the roof, as well as a turbulent effect triggered by the windward gable end. The resulting effect is a large suction on the roof that occurs in the vicinity of the panel. At a wind angle perpendicular to the ridge panel failure was caused by an uplift of the edge nearest the ridge, and the panel was overturned. At a wind angle parallel to the ridge panel failure was due to pure uplift. Initially, the panel failure lifted slightly and remained on the roof. Eventually, a gust of wind would catch the dislocated panel and become airborne, but this was not considered the primary failure event. In all cases the panel nearest the ridge of the roof was most affected.

3. Effects of dominant openings:

The effects of dominant openings on the internal pressure of a building and resulting roof failures are already well known. Dominant windward openings in a building, such as open or failed doors and windows, will increase the internal pressure, and cause an uplift force on the roof from the inside of the building. This pressure adds to the exterior suctions on a roof, causing a greater uplift load and reduces the failure wind speed. Alternatively, a dominant leeward opening will create a negative internal pressure inside the building, which helps the roof stay on the building with downward forces. The following effects were observed during the experiments: the failure wind speed decreased when there was a windward dominant opening, and increased when there were significant leeward dominant openings.

4. Roof venting:

Different attic venting area to roof area ratios were tested to monitor the effect on panel failures. Attic venting was found to have a small effect on the failure speeds of sheathing panels, but this effect is insignificant with respect to the effect of changing wind angle. By increasing the attic venting, the failure speeds of the sheathing panels increased slightly, which indicates that a larger negative internal pressure was created within the attic space and helped to keep the roof panels on.

CONCLUSIONS AND FUTURE WORK

Only one model has been tested to date. However, considerable data were collected and analyzed. Critical failure wind speeds for all wind angles, effects of dominant wind openings, sheathing panel failures (speeds and trajectories), and venting effects on sheathing panel failures were recorded.

The critical failure wind angle for global roof failure was when the ridge was parallel to the wind. When comparing the effects of dominant wall openings on global roof failure with those from background leakage only, results were as expected. When there was a large dominant opening on the windward face of the building, the failure wind speed of the roof was much less due to the increased positive internal pressure that resulted. When all dominant leeward wall openings were present, the failure wind speed significantly increased, since the negative pressures present near the side walls had a great influence on the internal pressure of the model.

At a wind angle perpendicular to the ridge, where the panel is located at the leeward slope of the roof, the panel failure was caused by an uplift of the edge closest to the ridge as the panel overturned and becomes airborne, resulting in a substantial trajectory distance. However, trajectory distances were rarely consistent. There are many variables that play a large role in the resulting trajectory of a panel such as panel orientation to the wind, wind speed, and wind gusts. These variables could not always be duplicated with every test, so there is a significant amount of scatter in the data. Also, trajectories seemed to be essentially straight in the windward direction when the wind was perpendicular to the ridge. Again, there is scatter present in the results, but as an average, this pattern was observed. At a wind angle parallel to the ridge, the panel failure seemed to be nearly a pure uplift.

Attic venting had a small effect on the failure of sheathing panels. With increased venting, a greater negative pressure was established inside the attic, slightly increasing the failure wind speed of the panel. With respect to the effect of changing wind angle, attic venting has a rather insignificant effect on the contribution towards failure.

This model will be tested in another wind tunnel where it can be tested under higher wind velocities. The effects of partial roof damage on global roof failure will be investigated in future experiments. The effects of different construction methods on panel failure will be investigated by varying the hold-down force in the electromagnets.

REFERENCES

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[2] Applied Research Associates, Inc. Development of Loss Relativities for Wind Resistive Features of Residential Structures. North Carolina, November 2001.

[3] Applied Research Associates, Inc. HAZUS Wind Loss Estimation Methodology – Volume 1. North Carolina, October 2002.

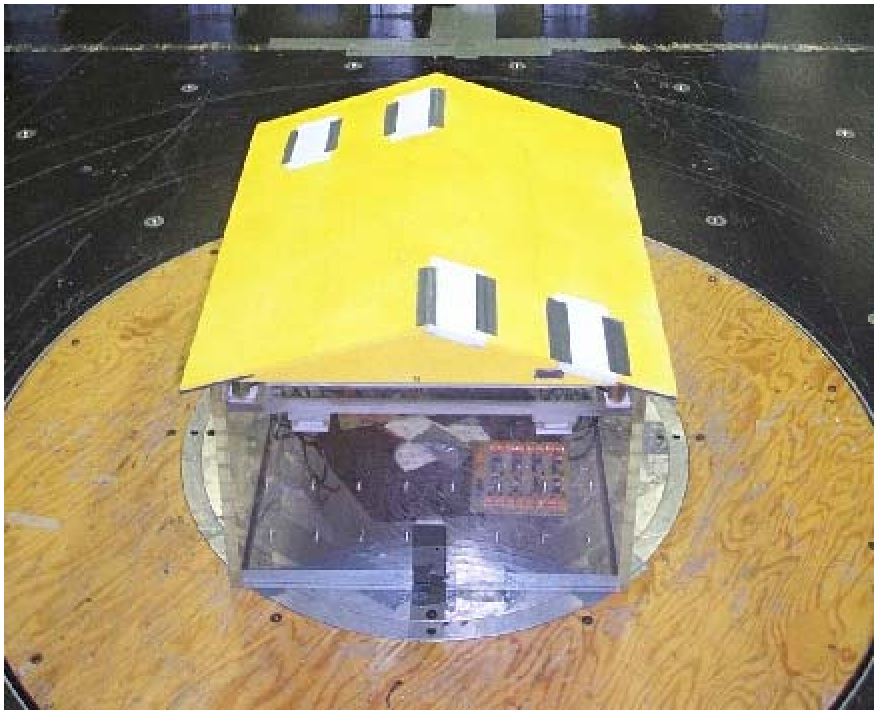

Figure 1. Destructive model used in experiments.

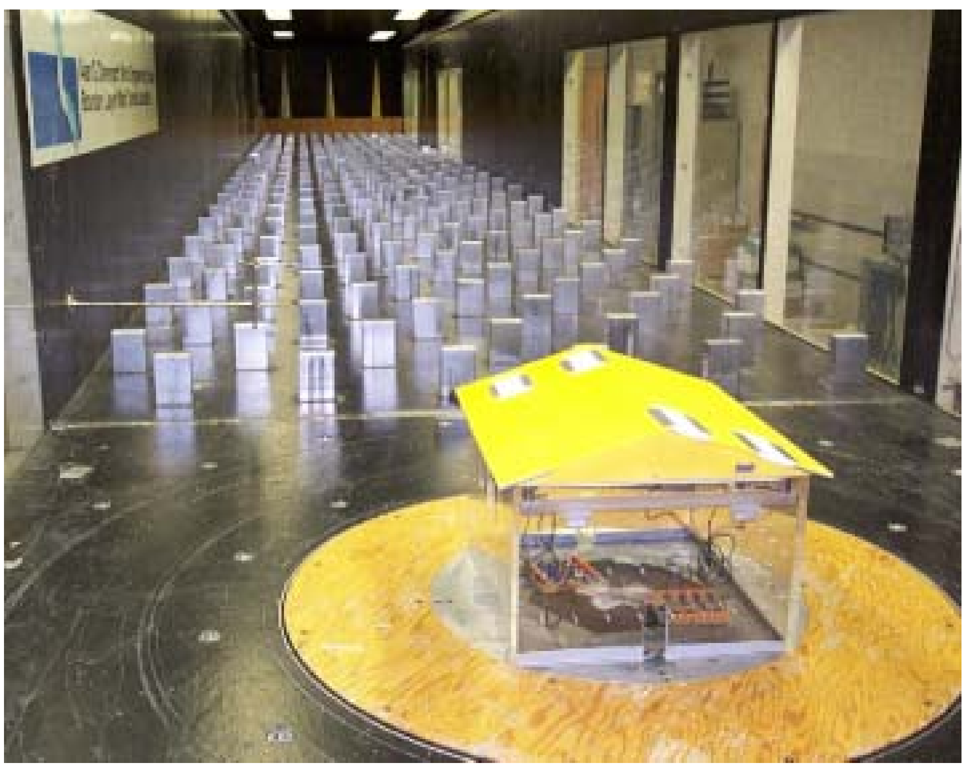

Figure 2. Destructive model in the wind tunnel.

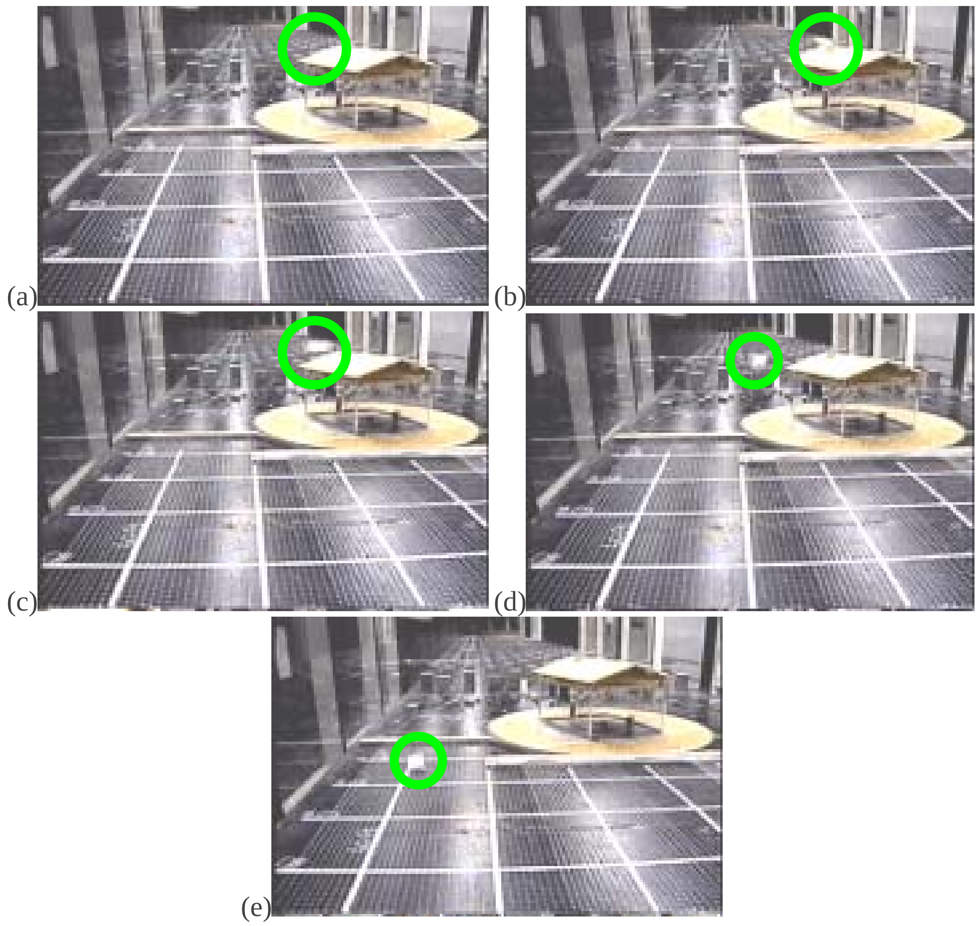

Figure 3. Sequence of images looking upstream showing a failure and trajectory of a 1.2x2.4m (4’x8’) sheathing element.