Vaughan Ontario Damage Investigation – The August 20, 2009 Tornadoes

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Summary
Following the damage investigation conducted on August 21, 2009, it is believed that two separate tornadoes are responsible for the damage in Woodbridge near Martin Grove Rd. and Highway 7, and the damage off of Jane St. between Teston Rd. and Major Mackenzie Dr. Damage indicators at both sites are consistent with F2 tornadoes. Several repeated failures were observed, and these are also discussed.

Damage Investigation

Track Information
An overview of the region(s) covered in the damage investigation is provided in Figure 1; the red shaded areas indicate regions where structural damage was observe, the yellow areas are locations of tree damage and debris, while the green areas are where no damage was observed. Significant damage was isolated to two neighbourhoods: the first, Woodbridge, where damage was observed between Martin Grove Rd and Islington Ave, north of Highway 7 while the second was located on either side of Jane St. between Teston Rd. and Major Mackenzie Dr. Specific details of the track(s) are given below. (There were also reports of damage at the Vaughan Mills Shopping Centre, although members of the survey team drove around the perimeter of the shopping centre late Thursday evening (20/08/09) and no obvious signs of damage were found.)

Figure 2 provides a detailed view of the damage sites in the Woodbridge area. The overall track of the damage is also indicated by the black line and the direction of damage indicated by the white arrow. Minor damage to the flashing and signs on a commercial building was observed on the West Side of Martin Grove Rd (MGR) at Highway 7 (Hwy7). The debris was found north of Hwy7, east of MGR, and had travelled in a North Easterly direction. Significant structural damage to masonry walls, roof structures, along with sheathing and shingle loss was observed along Button Road (BR), North Humber Drive (NHD), Andrew Park (AP) and Marilyn Place (MP), with damage locations indicated in Figure 2. The damage follows a narrow North Easterly track, crossing Rainbow Creek Park, where structural (wall, roof) and cladding damage was observed on Houston Road (HR), Oakhill Road (OR) and Moonstone Place (MSP). While the amount of structural damage decreased further along this North Easterly track, damage to trees and debris from the houses continued to be observed along Kipling Ave., Rosebury
Lane, Clarence St., Davidson Dr. and Waymar Heights Blvd., locations indicated in yellow in Figure 2. Isolated structural damage to roof shingles and sheathing was again observed on Gamble St. while a single garage door was damaged on Hayhoe Lane. No further damage was observed past this point along this North Easterly track.

Figure 3 and Figure 4 show several trees which were observed to have blown over in a North Westerly direction (location of the trees are indicated by the ‘Tree’ symbols in Figure 2), which is inconsistent with the predominant North Easterly direction of the damage track. Furthermore, debris impacts were found on the north side of a house on Oakhill Rd, shown in Figure 5. The direction of travel of the debris that caused this damage is inconsistent with the overall direction of the damage track (North East). Splatter was also observed over many house and car surfaces in a manner consistent with tornados. For these reasons, the damage in Woodbridge was concluded to be the result of tornadic winds. (There were also witness statements, but these are not discussed herein.)

Similar to the damage at the Woodbridge Site, the damage at the Jane St. location followed a narrow path as shown in Figure 6. Damage was observed to the west of Jane St. and extended to Teston Rd. and Keele St. where hydro poles had been damaged. No further damage was observed North of Teston or West of Keele St. Large flower planters on the ground were found to have been moved in the opposite direction than the prevailing debris field direction near Jane St. and Burnhaven Ave., suggesting that the damage was, again, likely caused by tornadic winds.

Figure 1: Overview of the damage sites in Vaughan
Figure 2: Damage sites in Woodbridge near Martin Grove Rd and Hwy 7

Figure 3: Meetinghouse Rd. and Clarence St, trees down in the direction of North-West
Figure 4: Woodbridge Ave. and Kipling Ave., trees down in the multiple directions

Figure 5: 15 Oakhill Rd, damage to the garage door due to debris impact
**Damage Indicators**

**Woodbridge Damage Site(s)**

The structural damage to houses in Woodbridge was extensive. Nearly all houses in this area are built with unreinforced masonry walls and pitched roof construction. Significant damage to roof shingles and sheathing were observed and an example of this type of damage is shown in Figure 7. In some cases, houses lost more than 50% of their roof sheathing and shingles. Substantial damage to the structural components of the roof, specifically roof trusses, was also observed. This type of damage ranged from having several trusses removed to nearly complete failures of roofs. Examples of the damage are shown in Figure 8, Figure 9, and Figure 10.

All of this structural debris became entrained in the wind field and caused significant damage to downwind houses, an example in Figure 11 shows 2x6’s embedded in the roof of another house. Nearly all of the housing in the region was brick veneer which likely reduced the damage to the walls of houses due to wind borne debris than would have otherwise been seen if the house had vinyl siding, which could have also added to the wind borne debris.

Other damage observed included:

1. A car that was moved from its parked position to the grass in front of the catholic school on Andrew Park as shown in Figure 12. It had clearly rolled, as indicated by marks in the ground.
2. Significant damage to the roof of a catholic school where the roof decking was removed.
3. Several roof top air conditioners were removed from the roof of the Catholic school (Figure 13), parts of which were found over 75 m away. Inspection of the roof where the air conditioners were mounted revealed that there were no structural hold downs for these units. In addition, they did not appear to roll on the roof surface prior to falling from the roof.

**Jane St Damage Site(s)**

Similar to the Woodbridge site, there was significant damage to roofs of houses as shown in Figure 14 and Figure 15. Common failures of roof sheathing and roof shingles are similar to those found in the Woodbridge area. Since construction in this region was newer than that in the Woodbridge area the roof structures in this region were built with pre-fabricated roof trusses rather than the pitched roof construction found in Woodbridge. Despite the difference in roof construction the failures are similar and occur at the roof to wall connections. The observed failures appear to be coupled with internal pressurization of the structure due to the breaches in the building envelope. Wall collapses were observed, as shown in Figure 16 but are believed to have occurred following the failures of the roof.

**Conclusions**

Both damage sites had significant damage to roof structures and in the authors opinion is consistent with F2 damage at both locations. Although the houses at each site are built differently failures observed at each site are similar, involving the connections of the roof sheathing/shingles and connections of the roof structure to the walls. The track data collected indicates that it is likely that the damage at each site is due to two separate tornadoes, rather than single vortex that de-intensified east of Islington and then re-intensified near Jane Street, since this would require the Woodbridge tornado to make a significant deviation to the North. The grey line in Figure 1 extends the track of the Woodbridge tornado and comes into close proximity to the Vaughan Mills Shopping Centre. It is therefore likely that, if damage is confirmed at the shopping centre (there was also video of this on one of the television stations), it is possible that it was caused by the same tornado that caused the damage in Woodbridge. This would also confirm that the damage at Jane St. was caused by a separate tornado. The damage at Vaughan Mills Shopping Centre, would have to have been extremely isolated since damage was not observed further East of this location, and there were no indications of strong winds at the Weston 400-North Industrial Area to the West, which contained structures that would have been very susceptible to any reasonably high winds. Thus, based only on these damage observations, it is our conclusion that there were two tornadoes in Vaughan.
Figure 7: 35 Marylin Pl., loss of shingles and roof sheathing

Figure 8: 80 & 82 Button Rd., Nearly entire roof structure was removed
Figure 9: 55 North Humber Ave., Complete roof failure in the front half of the structure

Figure 10: 53 North Humber Ave., Roof and wall top plate are missing, portion of the top plate on the far right is lifted off of the masonry blocks
Figure 11: 19 Oakhill Rd., 2 x 6’s embedded in roof and bush in front of the house

Figure 12: Car moved by wind onto lawn in front of the Catholic School on Andrew Park
Figure 13: Air conditioning unit removed from the roof of catholic school on Andrew Park

Figure 14: 53 Burnhaven Ave., shingle, sheathing and flashing loss on the upper roof, whole roof on the garage is gone
Figure 15: 25 Burnhaven Ave., complete roof failure and debris impacts to the interior of the house.

Figure 16: 35 Burnhaven Ave, Collapse of a portion of a 2nd story wall.
Discussion of Observed Damage

The following discussion will examine the observed damage in additional detail, and evaluate the structural performance of the construction. The failures observed are typical of damage to residential housing under high winds, with failures most commonly occurring at the connections, in almost all cases, the nails. The house construction in Woodbridge was mostly unreinforced masonry blocks with pitched roof construction (independent rafters spanning from the external walls to the ridge), while the newer houses built at the Jane St. location have wood framed walls with prefabricated roof trusses and are typical of current construction techniques. The primary difference between the two construction types is that the wood framed walls become very weak and are prone to collapse when the roof is removed, while masonry walls are better able to remain standing (although they collapse too). While wall collapses were observed at both locations, it is believed that these are secondary to the roof failures.

Debris Impacts and Internal pressurization

At both damage locations there was a significant amount of debris that had been entrained in the wind field. This debris posses not only a life safety issue to people in the area but also to downwind structures. Debris impacts on structures can cause breaches in the building envelope, in the current investigation the most common observed breaches were to windows (example shown in Figure 17) and garage doors (example shown in Figure 18). These types of openings in the building envelop can cause internal pressurization of the structure, which can lead to an increase in loading on the roof by as much as 70% (in wind tunnel studies). This added load can cause failures that would have otherwise remained undamaged. Moreover, once failure has occurred, additional debris becomes entrained in the wind field and cause further damage downstream.

It is noted that in Figure 17, the roof of the house on the right hand side of the photo with the broken window had a failure of the roof structure at the back of the house, while the roof of the attached house on the left remained intact. It is possible that the internal pressurization could be responsible for this discrepancy; however, with the evidence available it is not possible to make a definitive conclusion. In the example shown in Figure 18 it is likely that the internal pressurization of the garage due to the failure of the garage door lead to the failure of the front half of the gable roof, while the hip roof on the second story remained attached.
As shown in Figure 7 and Figure 14, sheathing panel failures were common at both the Woodbridge and Jane St. locations. Examining some of the sheathing panels that had failed (example is shown in Figure 19) a significant number of panels had a large number of nails that had missed the roof...
trusses, reducing its hold down capacity. This finding is consistent with findings following Hurricane Andrew in Florida in 1992 where nails were often found to have missed the roof trusses. When examining the nails around the perimeter of the panel as shown in Figure 20, in nearly every case the nails had been sheared through the edge of the plywood rather than the expected failures, where the nails either pull through the plywood or withdraw from the roof truss. Moreover, standard nailing patterns place more nails along the perimeter of the panel than in the interior and the perimeter nails are less prone to construction errors (nails missing trusses), coupled with the shear failure mode described above, this may result in a lower uplift resistance than would have otherwise been expected.

Figure 19: Sheathing panel found in front of 56 Burton Rd.
Figure 20: Nail hole on the edge of a sheathing panel, where the nail has been pulled out the side of the panel

**Roof Structure**

While there were differences in construction at the two damage sites, the structural failures at both locations were mainly due to the connections between the roof and the walls. Figure 21 shows a failure of a roof in the Woodbridge area. The roof rafters were spaced approximately 1 ft apart which is closer than the typical 2 ft spacing commonly used for roof trusses. This closer spacing provides addition connection points to connect the roof to the wall and would make the roof much stronger. However in the case of the house in Figure 21 few if any hold downs were observed attaching the roof to the masonry walls, as a result it is likely that the majority of the uplift resistance of this roof came from the roofs weight, which for the case of this particular roof is relatively small. Figure 22 shows a portion of a typical roof truss (origin of this truss could not be ascertained), the truss was held down with only a single 8-d toe-nail, while the National Building Code of Canada specifies that roof rafters/trusses be held down with 3 8-d toenails.
Figure 21: 55 North Humber Dr., failure of roof structure

Figure 22: Portion of a Roof Truss found on Fairmont Ave., a single 8d nail was used for a roof to wall connection