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Publisher’s version / Version de l'éditeur:
https://doi.org/10.4224/20375126
Internal Report (National Research Council of Canada. Institute for Research in Construction), 1994-11

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Internal Report No. 669

Date of Issue: November 1994

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Canada

TORNADO DAMAGE IN AYLMER, QUEBEC ON AUGUST 4, 1994

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ABSTRACT

Building damage caused by a moderately strong tornado in the Pilon subdivision of Aylmer, Quebec on Thursday, August 4, 1994 is described. Atmospheric Environment Services classified this tornado as "Force 3" (on a scale of 0 to 5) with winds as high as 270 km/h. The most severe structural damage observed, however, seems to indicate peak speeds in the 150 to 200 km/h range. There were no deaths and few serious injuries, but insurance claims for housing repair alone were expected to reach $10 million. To reduce future tornado losses, recommendations are made for improving quality control of critical connections.

INTRODUCTION

A tornado began a 2 km path of damage at 3:00 p.m. on Thursday, August 4, 1994, at a school (Polyvalente Grande-Rivière) in the Pilon subdivision of Aylmer, Quebec. At its estimated forward speed of 70 km/h, the tornado completed its path in less than two minutes. The maximum wind speed within the disturbance is the sum of the tangential speed of the rotating air mass (close to the core of the vortex), and the forward speed, and occurs on that side of the tornado core where the rotational speed is in the same direction as the forward motion. Judging from the width of the path of damage, winds strong enough to lift roofs, or parts of roofs, extended about 3-4 house widths, or 50 m; thus, passage over an individual house might take approximately 5 seconds.

The tornado was part of a large low-pressure system that started in the American Mid-West, crossed Lake Michigan and Lake Huron, and touched down at Calabogie and Carp before reaching Aylmer. The total length of the path in eastern Ontario, stretching from Calabogie to St. Pascal 45 km east of Ottawa, was about 120 km. Tornado strikes were said by a person with Environment Canada to occur on average 2 to 3 times per year in a 200-km radius of Ottawa.

About 30 houses were so heavily damaged that authorities at first prevented their owners from returning, to protect them from fire or further structural collapse. Fortunately, there were no deaths, and only 4 or 5 injuries requiring a visit to the hospital. At least 150 other houses had varying degrees of damage, ranging from being spattered with wet cellulose insulation from attic spaces, to punctures from missiles, removal of shingles and roof sheathing, broken windows, and stripping off of vinyl or brick cladding. Insurance companies estimated that the cost of repairing the houses alone would reach $10 million.

This note briefly describes the damage, relates it to observations of other tornados in eastern Ontario [1,2][1], and makes recommendations for improving quality control of critical details.

DAMAGE IN PILON SUB-DIVISION

The trail of damaged buildings is shown in Figure 1, starting with Polyvalente Grande-Rivière on Foran, traveling from WSW to NNE, and ending at Conrad Valera. Many of the news photos featured damage at the eastern end of Beausoleil, shown at the top of Figure 2

Damage to roofs seemed to begin, and was often limited to, removal of shingles and roof sheathing in the region of the SW corner of the building (Figure 3). Often there were punctures of roofs and walls by missiles carried by the wind from earlier damage sites (Figures 4, 5,6). Another common form of damage was the stripping of cladding from walls (Figure 7). Although more often occurring on walls parallel to the tornado path, sometimes windward walls suffered the same fate (Figure 8).

Removal of roofs

More serious for both building structure and contents, some roofs in the path of the tornado were completely lifted off the walls (Figure 9). The house in Figure 9 had a large living-room window that was shattered about the same time, and air rushing into the room would cause an increase in pressure, adding to the uplift of the wind accelerating over the roof. As seen in Figure 10, the loss of the roof allowed the gable-end wall to sway left, away from the chimney, which remained plumb. Although a missile crashed through another windward window, narrowly missing an occupant in another room, the main hazard was flying glass from the living-room window, resulting in lacerations to the lady of the house.

A car at the curb in front of the house in Figure 9 was picked up by the wind, rolled across the lawn, and jammed upright against a tree.

Collapse of walls

The progression of damage following loss of top support for walls when the roof lifts off, is illustrated well by the damage to the house in Figure 11, which also lost its attached garage on the west (windward) side. The same is true of the house in Figure 12, of which the upper storey has lost both the south wall parallel to the tornado path, and the east (leeward) wall. Usually the walls were sucked out, but the south wall in Figure 11 blew in after failure of the connection between the south and west walls.

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[1] 10/12/94 [...] are references, listed at the end of the note.

Just across the street and downwind, the house in Figure 13 lost its roof, and suffered total collapse of the attached garage, crushing the car inside. The roof of the garage can be seen resting on the ground in Figure 14, a photo taken from the down-wind side (looking west).

Missing or inadequate connectors

When the roof is damaged as shown in Figure 15, damage to walls often follows, but in Figure 16 we see a similar house just downwind with no visible damage to the roof. The east (leeward) wall, however, was pulled away, and there did not appear to be any nails that would have connected it firmly to the south and north walls (Figure 17). Note also that both header plates end at the same location, just below the eave gutter.

Roof trusses are often poorly attached to the top of the walls on which they sit, making it relatively easy for wind to lift the whole roof off. Figure 18 shows that a shard of wood broke off from the truss, below the toe nailing into the top plate. The shallower the angle of the toe nailing, the weaker the resistance to uplift.

Individual shingles, too, are vulnerable if the nails used to hold them down are not well-anchored into the sheathing (Figure 19).

Broken windows and sprayed insulation

Broken windows on windward and side walls parallel to the tornado path were relatively common (Figure 20), as was wet cellulose insulation splattered over surfaces of buildings along the damage path. The source of insulation is not yet clear for buildings with the roof intact; did it come from the attic space of the building itself, or from another building upwind that lost its roof?

MAXIMUM WIND SPEEDS BASED ON DAMAGE

The tornado is a whirling mass of air resembling a miniature cyclone embedded in the general wind flow, and somewhere near the core, or centre of this embedded disturbance, the maximum tangential speeds occur. If the rotation is counter-clockwise (looking down from above), the forward speed of the whole air mass is added to the tangential speed to the right of the core, but it is subtracted from that to the left. This means that for a forward speed of 70 km/h, the peak speed to the right of the core may be about 140 km/h more than that on the left. Consequently, one should expect little or no direct wind damage to the left of the core of only moderately strong tornados.

Wind creates the greatest uplift on the corner of a roof when approaching from an angle of about 45 degrees. The combination of forward speed and rotational speed means that the direction of the wind veers sharply as the tornado approaches, which may increase the likelihood of hitting the roof at the critical angle.

If a wind speed quoted by Atmospheric Environment Services as 270 km/h for an F3 tornado is used to calculate structural forces, the uplift would be approximately 150 psf and the wall pressure approximately 100 psf. As shown later, however, well-placed truss-to-wall anchorage can resist an uplift of only 50 psf. This means that no conventional house directly exposed to such wind pressures would survive. Figure 2, however, shows that some houses in the direct tornado path survived while others failed. While this may be partly due to local variations in wind speed, the damage pattern in Figure 2 indicates that a more likely explanation is a variation in the strength of critical connections.

The damage observed in Aylmer was of about the same level as that seen on two earlier investigations. Structural calculations done for the tornado damage to housing in the Barrie/Orangeville area [1], and for the Blue Sea Lake and Nicabong area [2] do not support wind speed estimates greater than 200 km/h for an F3 tornado.

Given the discussion above about the combination of rotational and forward speed, the rotational speed would only have to be in the neighbourhood of 130 km/h to reach a maximum of 200 km/h, and the net speed on the other side of the eye would be only about 60 km/h, not enough to cause any real damage, apart from transporting missiles that already had significant momentum. It should be borne in mind that estimates of wind speed based on observed damage are extremely rough, very localized, and subject to error because of the variable resistance offered by the structures that suffer damage.

QUALITY CONTROL OF ANCHORAGE DETAILS

Unfortunately, an investigation of critical anchorage details was not carried out (other than those in Figures 17-19), due partly to police barriers preventing entry of severely damaged houses and partly to the removal of debris on the ground prior to the site visit. The Aylmer and previous tornados (1, 2) however, indicate that an improvement in quality control would reduce the losses in terms of replacement and repair of the house and contents (usually damaged by rain) and disruption of the occupants.

The achievement of a significant loss reduction requires quality control of nailing in three locations: 1) roof trusses to wall header plates; 2) sheathing to roof trusses; and 3) shingles to sheathing (in decreasing order of priority).

Roof Trusses to Wall Header Plates. Figures 18 and 21 (the latter is a motel roof in Toronto, removed by wind in August 1970) show that the strength is controlled more by the placing of toenails than by their number. Testing [3] shows that well-placed toenails approximately 3 inches long provide an uplift resistance of approximately 350 lb. each. Three toenails therefore provide an uplift resistance of 1050 lb. which corresponds approximately to 50 psf wind uplift pressure minus 10 psf dead load. Tornado experience shows that well-placed toenails usually provide sufficient anchorage to prevent failure. The problem, therefore, is primarily quality control, which for truss anchorage is difficult to check without a ladder. Possible solutions include 1) the use of hurricane straps; or 2) an extension of the heel truss plate with holes for guiding the toenails at the proper angle into the top plate of the wall, plus an increase of the nail length to 4 inches.

Sheathing to Roof Trusses: This detail was not investigated, although the tornado damage (e.g. Figure 2) indicates variations in quality control. For example, Hurricane Andrew has shown that there is a quality control problem with the use of stapling guns for attaching sheathing, because the carpenter gets no direct indication if the staples miss the roof truss.

Shingles to Sheathing: Figure 19 shows a problem of quality control. This may be due to a widening of the nail hole due to cyclic moisture changes in the wood. To avoid loss of anchorage, spiral shingle nails should be used.

Other connections: Figure 17 indicates a weakness in quality control of anchorage of stud walls to each other. Such failures are relatively rare compared to uplift of roof trusses or roof sheathing, thus indicating that wall interconnection is usually adequate for tornados provided the roof does not lift off. The weakness in Figure 17 appears to be in the top plates to the stud wall, with both plates apparently cut at the same location (i.e. just below the eave gutter).

It is recommended that Forintek be consulted on achieving quality control of the above critical anchorage details. The solution should also take account of material cost and buildability.

CONCLUSIONS

The damage to houses would have been reduced considerably if there were better quality control of critical anchorage connections. Not only does adequate anchorage limit the damage to the structure itself, it reduces the secondary damage to other buildings from roof fragments acting as high-velocity missiles. Perhaps even more important economically, the contents of the building, as well as occupants, are protected from the extensive losses caused by torrential rains that usually accompany tornados.

Although the chances of an individual homeowner suffering loss may be small, the insurance settlements over the years would appear to be significant. This suggests that insurance companies might serve their customers well by offering lower premiums for wind coverage when effective measures are taken to tie buildings together, and to ensure sufficient resistance to uplift or sliding of the building as a whole.

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21		Detail of upside down roof of Toronto motel showing failure of rafter anchorage during a thunderstorm in August 1970.

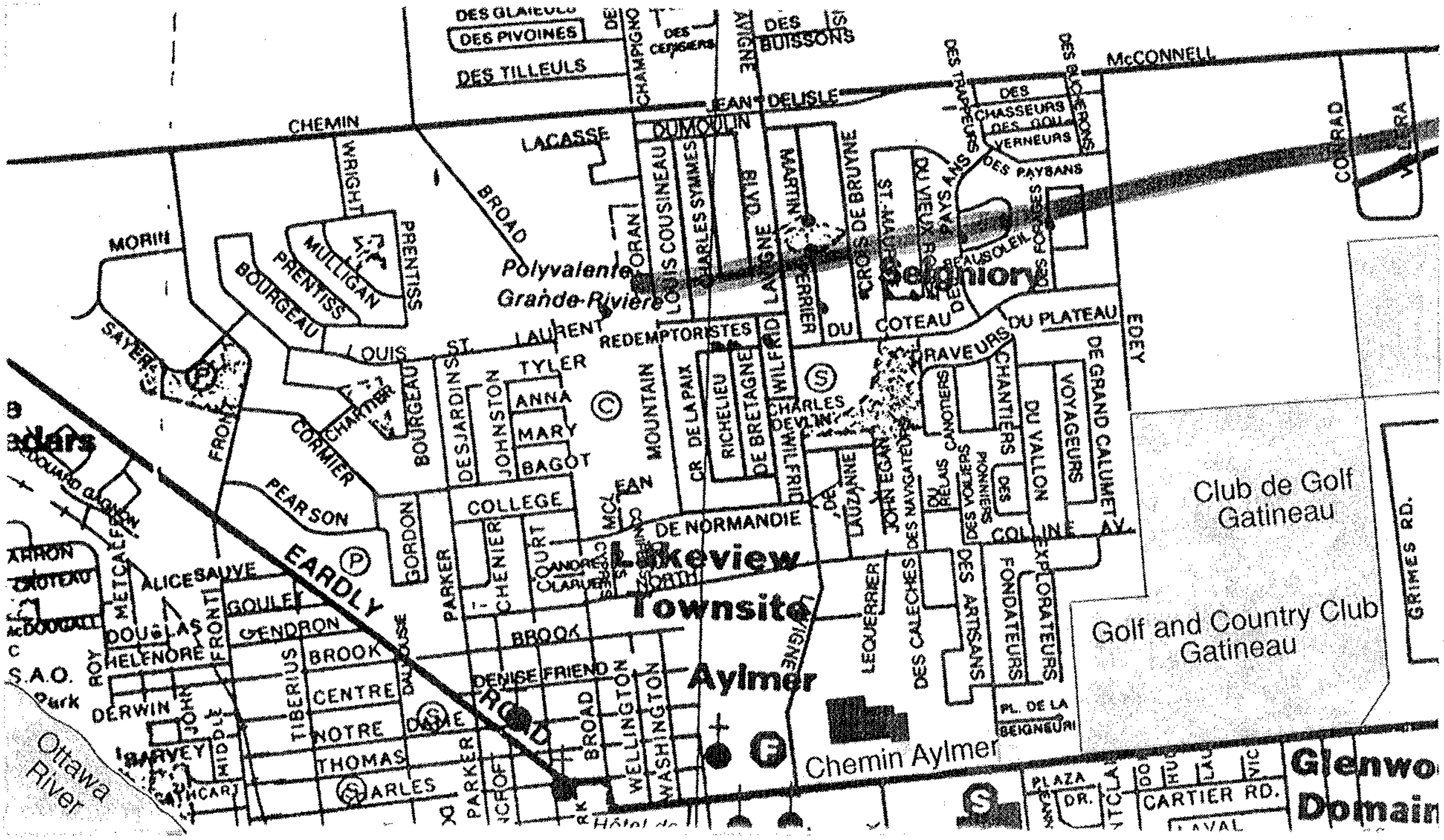

Figure 1 Map showing tornado path through Pilon subdivision, Aylmer, Quebec.

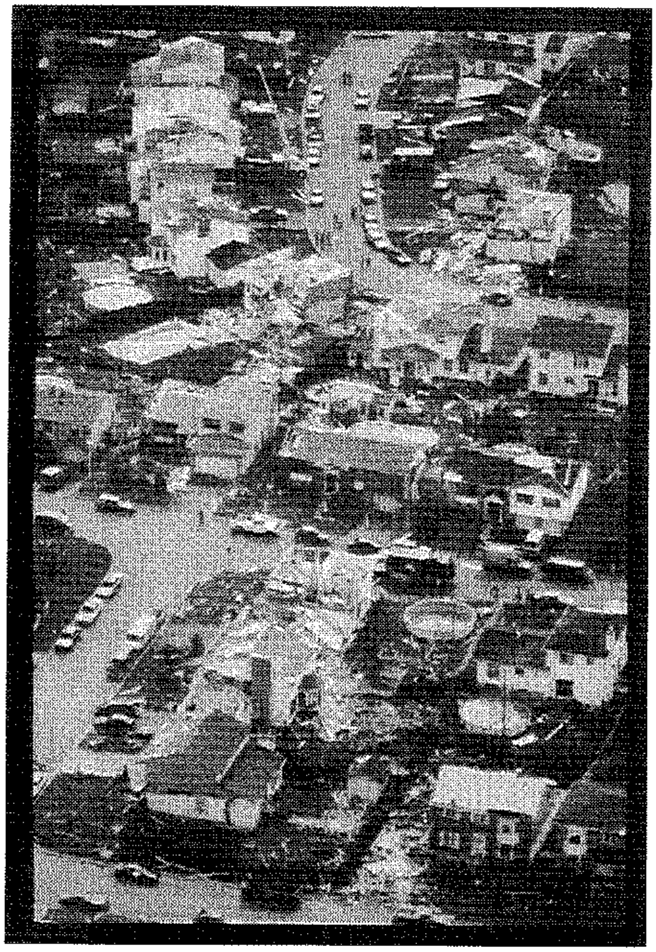

Figure 2 Aerial view looking back at trail of damage along tornado path.

Figure 3 Wind damage limited to eave area at southern end of hip roof.

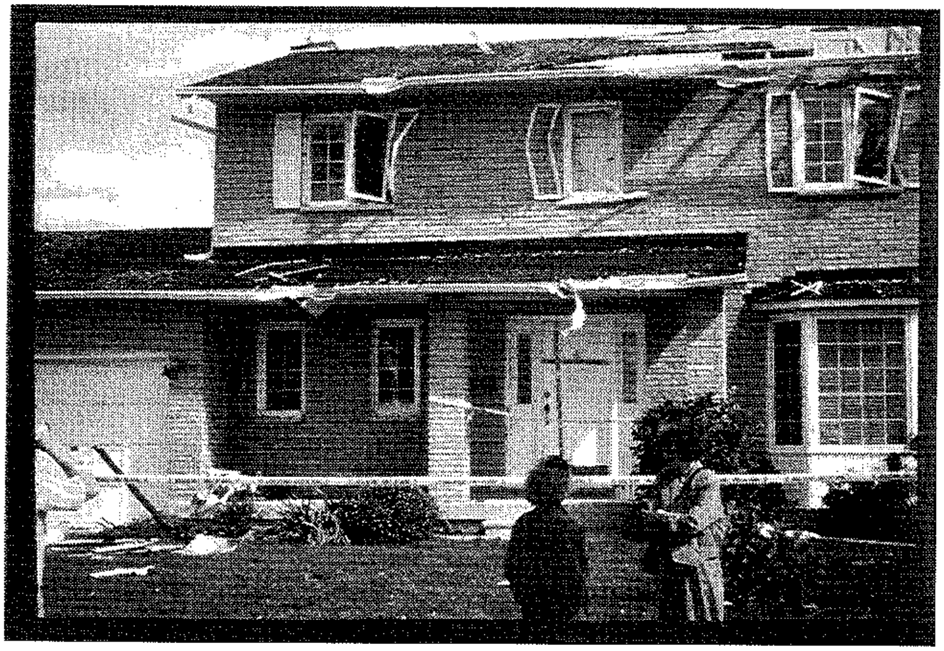

Figure 4 Roofing and sheathing failure of southern third, (both slopes) of gable roof, plus missile damage.

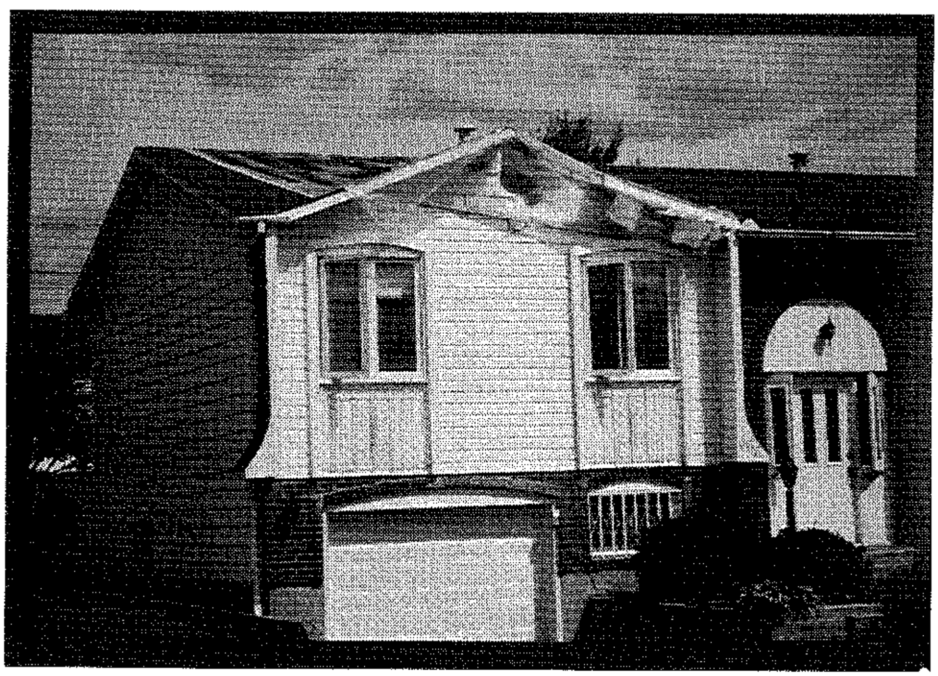

Figure 5 Puncture of top of windward wall by missile.

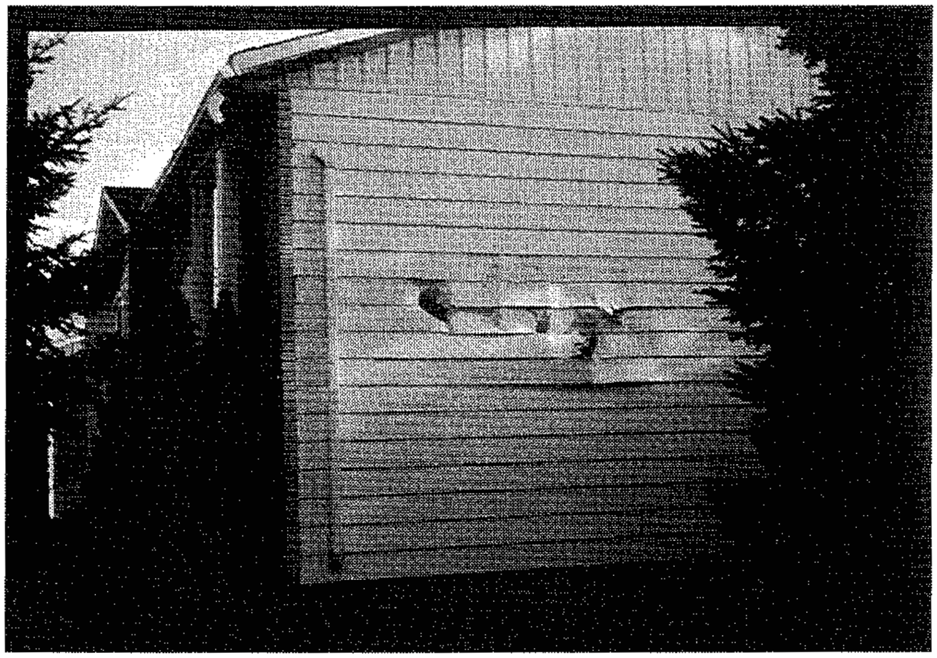

Figure 6 Siding punctured at mid-height of wall by missiles.

Figure 7 Siding stripped off south wall, roughly parallel to tornado path, with insulation splattered on east (leeward) wall.

Figure 8 Siding stripped from west (windward) wall of house in Figure 7.

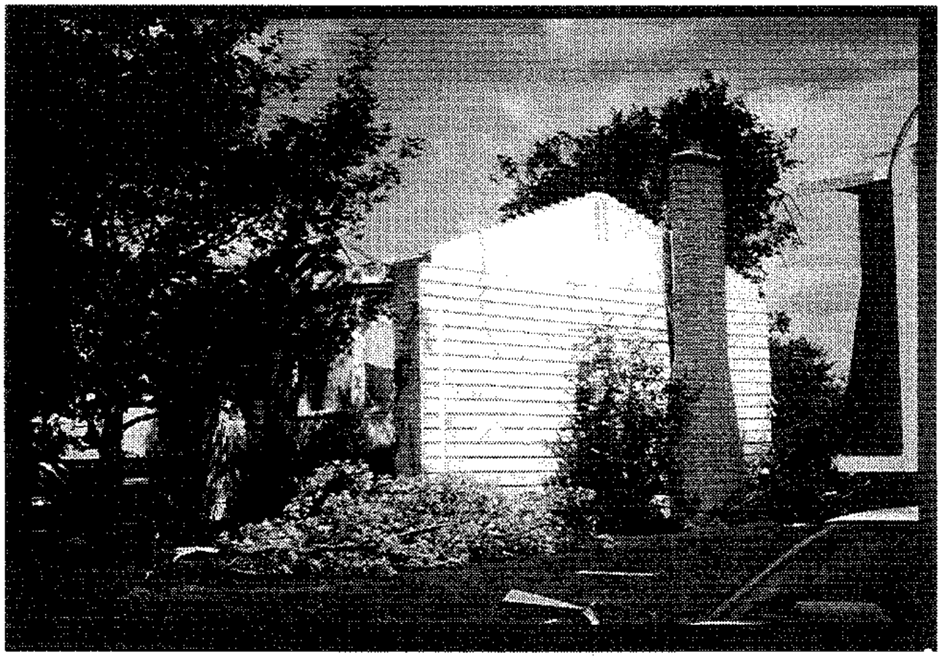

Figure 9 Gable roof lifted off single-storey house, showing south wall, roughly parallel to tornado path.

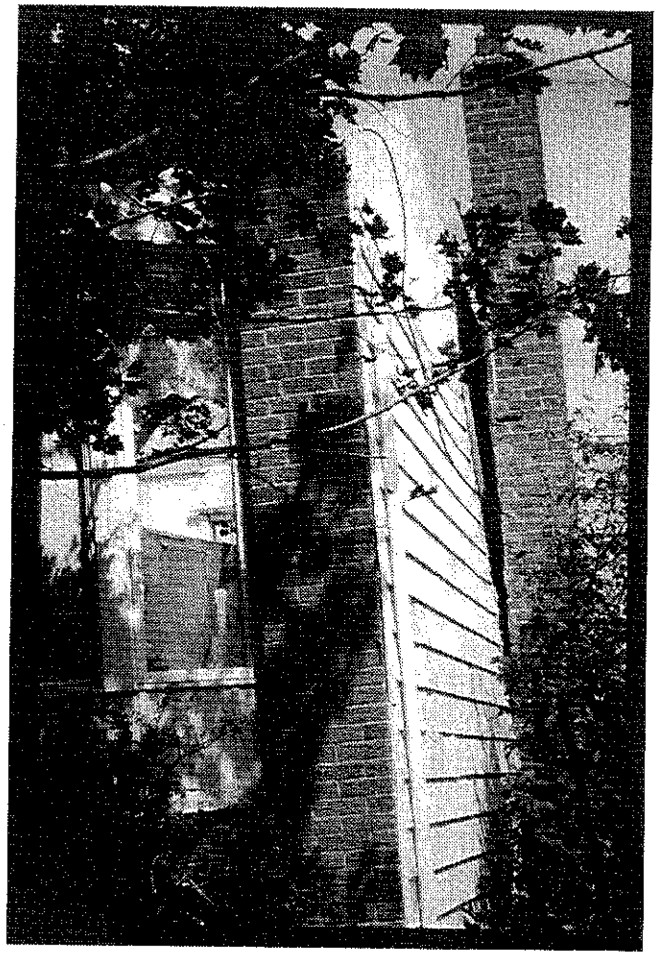

Figure 10 South wall of house in Figure 9, leaning left away from chimney, which is still plumb.

Figure 11 Brick wall collapse showing progressive failure once roof is gone and connection to west (windward) wall is lost.