P 1.6 THE LA PLATA, MD TORNADO: ISSUES REGARDING THE F-SCALE

Timothy P. Marshall*
Haag Engineering Co.

1. INTRODUCTION

On the evening of 28 April 2002, a violent tornado traveled 103 km (64 mi.) across portions of Charles and Calvert Counties in southeast Maryland. The tornado killed three people and injured more than 100. Property damage exceeded $100 million. Officials initially rated the tornado F5 on the Fujita scale (see Fujita, 1971) as several homes were literally "swept clean" from their foundations. However, the National Weather Service wanted to study the damage in greater detail to determine if the preliminary F5 rating was warranted. Within days after the tornado, the National Weather Service assembled a team of damage experts, including the author. Our damage survey team spent three days examining specific buildings within the tornado damage path.

Several issues were raised with regard to assigning F-scale values to the damage. One issue was the fact that the tornado damage path extended 103 km (64 miles) in an area that seldom experiences long-tracked tornadoes. The last F4 tornado in this area occurred in 1926 killing 14 children as it traveled 39 km (24 miles) through Charles and Calvert Counties.

Another issue was the quality of home construction. Wood-framed homes were supposed to have been built in accordance with the local building code. Some people thought these homes were built better than average since they were in a hurricane prone area. Unfortunately, our survey team found that most destroyed homes had been constructed poorly with minimal attachment to their foundations. Homes simply slid off their foundations at wind speeds estimated to be as low as 45 m/s (100 m.p.h).

Other issues involved seemingly extraordinary events such as the collapse of the steel water tower and removal of precast concrete planks from the roof of a school. Flying debris also struck several homes and produced more intense looking damage.

*Corresponding author address: Timothy P. Marshall, Haag Engineering Co., 2455 S. McIver Dr., Carrollton, TX 75381. Email: timpmarshall@cs.com

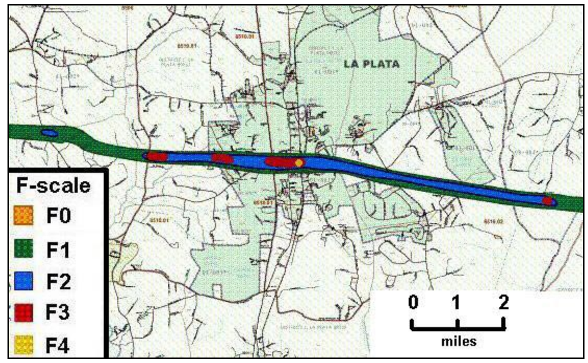

Figure 1. Tornado damage path through La Plata, MD as determined by our damage survey team. Courtesy of the National Weather Service.

2. DAMAGE SURVEY METHODOLOGY

Our survey team conducted both aerial and ground surveys. An aerial survey was necessary to determine the overall length of the tornado damage path and to quickly find areas that warranted closer examination on the ground. Most of the tornado path was in rural areas. Thus, the survey team concentrated their efforts in and around the town of La Plata, MD where building damage was concentrated. The tornado passed literally through the center of town (Figure 2).

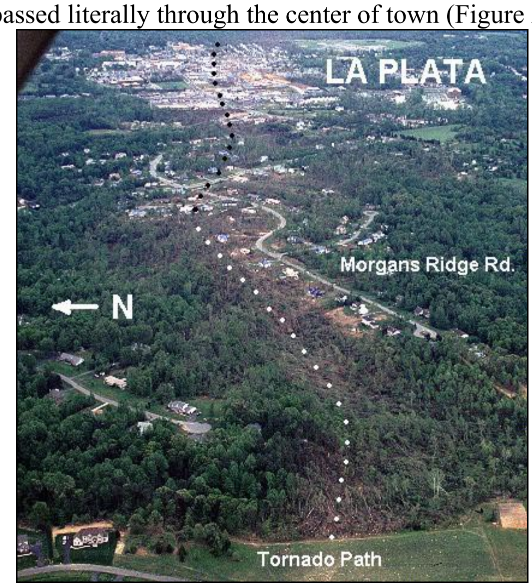

Figure 2. View of tornado damage path looking east showing Quailwood subdivision (in foreground) and La Plata, MD (in background).

The damage survey team assigned F-scale numbers to individual houses based on increasing severity of the damage. House damage was rated F0 if they lost roof shingles, windows, some siding, a chimney, or garage door (Figure 3). House damage was rated F1 if a portion of the roof was removed, or if garage door failure caused collapse of the garage roof or walls (Figure 4). House damage was rated F2 if most of the roof structure was removed but perimeter walls remained intact (Figure 5). House damage was rated F3 if most of the roof structure and perimeter walls were removed leaving interior walls standing (Figure 6). House damage was rated F4 if the house structure collapsed leaving a pile of debris on the foundation (Figure 7).

Figure 3. Typical F0 damage to house involved the loss of siding, fascia, roof shingles, and/or a toppled chimney.

Figure 4. Typical F1 damage involved partial removal of the roof structure.

Figure 5. Typical F2 damage involved the removal of the entire roof.

Figure 6. Typical F3 damage involved the removal of most of the roof and exterior walls.

Figure 7. F4 damage involved the collapse of two, two-story houses in downtown La Plata, MD.

3. F-SCALE ISSUES

The primary issue with this event involved rating homes that literally were swept off their foundations (Figure 8). The author termed these houses as "sliders". Such homes had wooden floor systems supported on hollow-block masonry foundation walls or poured concrete foundation walls. These poorly anchored homes disintegrated when they moved off their foundations. The debris did not travel very far downwind indicating relatively low wind speeds.

Figure 8. Homes with poor attachment to their foundations slid off their foundations (in the direction of the arrows).

Wooden sill plates were placed between the floor joists and the tops of the foundation walls. Some sill plates merely rested on the top of the foundation walls with no attachments. Other sill plates were secured with metal straps embedded in the tops of the concrete foundation walls or in grouted cells in the tops of the concrete masonry foundation walls (Figure 9).

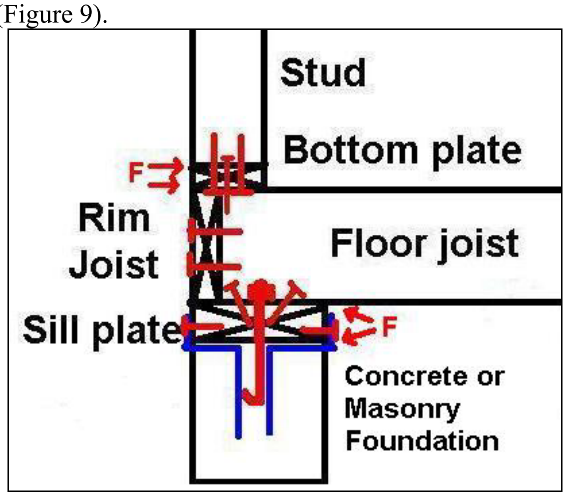

Figure 9. Wall-floor cross section at the foundation on a typical home in our survey. Nailed and bolted connections are in red, metal straps are in blue. Straps were not always present nor attached to the sill plates.

The team recognized two modes of failure with sliding homes. Homes slid off their foundations with or without the floor platform. Homes that slid away with the floor typically were split-level. The windward side of the home was situated on grade whereas the leeward side of the home had an exposed basement wall that usually faced a ravine. Frequently, the rear basement wall rotated outward as the home and floor slid away. The house then disintegrated as it tumbled into the ravine (Figures 10 and 11).

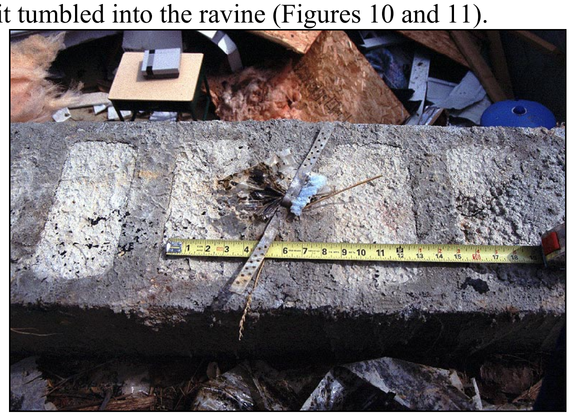

Figure 10. Metal straps had been installed on top of this concrete masonry basement wall but were not bent and secured to the sill plates. Therefore, this home was not attached to its foundation.

Figure 11. Split-level home on concrete masonry basement wall fell into ravine as rear wall collapsed.

In some instances, a door or sliding glass door along the rear basement wall weakened the wall against lateral forces (Figure 12).

Figure 12. A door (circled) separated the concrete wall foundation reducing its strength. Also, the wall was not anchored to the footing and fell outward as the home slid off its foundation. Steel reinforcement was installed only at the wall corners.

Another failure mode involved removal of the home but the floor platform remained intact. Failure occurred where the wall bottom plate was straight-nailed into the floor. Nails rarely penetrated into the floor joists. Walls simply rotated, pulling out the fasteners and the home collapsed (Figures 13 and 14).

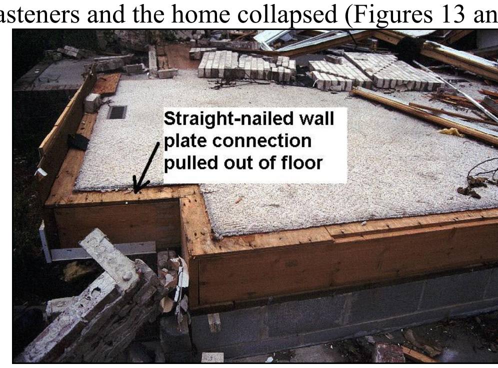

Figure 13. This home slid off its foundation when the straight-nailed bottom plate pulled out of floor. The sill plate was attached to the foundation with straps.

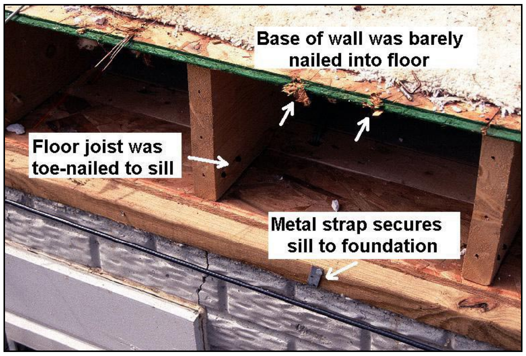

Figure 14. This floor remained on the concrete foundation while the rest of the home slid way. The sill plate was anchored to the concrete foundation wall with metal straps. However, nail holes at the edge of floor indicated the wall bottom plate was barely nailed. Nails had been driven into open joints between the floor and rim joists.

3.1 RATING POORLY ANCHORED HOMES

When encountering homes that had slid off their foundations, team members found that it was even more important to examine the surroundings in order to determine an appropriate F-scale rating. We frequently noticed minimal tree damage along with undamaged mailboxes, storage sheds, flagpoles, light poles, and vegetation (Figure 15). In one instance, we found a two-story home that had slid partially off its foundation; the first floor collapsed but only minor wind damage to the roof (Figure 16). It was decided that such homes could slide off their foundations with wind velocities as low as 100 miles per hour. Therefore, poorly anchored homes were rated F1 to F3 depending on the severity of the surrounding damage.

Figure 15. This poorly anchored home slid off its foundation into a ravine. Mailboxes remained intact, indicating winds were probably less than 45 m/s (100 m.p.h.).

Figure 16. A two-story home was reduced to one-story as first story walls simply rotated and pulled out the straight-nailed connections between the bottom plate and floor. There was minimal damage to the roof and trees indicating winds probably were no greater than about 45 m/s (100 m.p.h.).

Fujita (1992) recognized that corrections were needed to the F-scale ratings if buildings were poorly constructed. He showed that the damage rating to a building could be reduced as much as three F-scale numbers for poorly built structures. Such corrections must be applied to reduce overestimating the damage intensity.

3.2 RATING POORLY ATTACHED ROOFS

Team members encountered one instance where the roof slid off a house intact. Wooden roof trusses spanned the width of the home (about 10 meters) and were toenailed to the wooden top plates at each wall. However, bottom chords of the trusses were not connected to the interior wall partitions. Broken windows and doors caused internal pressure to help lift the roof structure off the house. Only a few roof shingles were removed. (Figure 17).

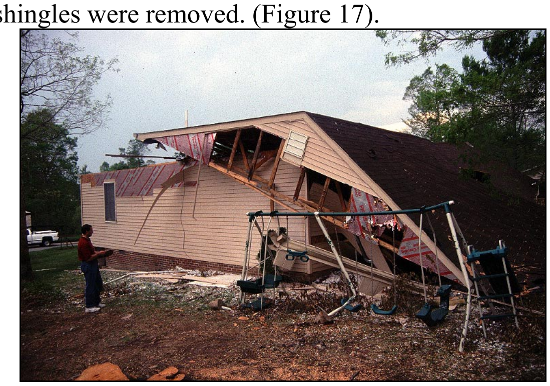

Figure 17. This roof slid off the house. Trusses were toenailed to the tops of the walls. However, only a few roof shingles were displaced.

Normally, a house that loses its roof structure would be assigned an F2 damage rating. However, it was decided to reduce the damage rating to F1 given the limited anchoring of the roof and lack of damage to the roof shingles and surroundings. It was determined that winds of about 32 m/s (70 m.p.h.) lifted this roof.

3.3 STEEL WATER TOWER

The 100 year old La Plata water tower had toppled during the tornado. The tower was located on the north end of the tornado damage path. Four steel legs buckled and the tower fell to the southwest sending a torrent of water that flooded three houses. Each leg was attached to a concrete footing with a single bolt. Bolts on the north legs failed in tension leading to the collapse of the tower. Although, bending of the steel legs was impressive, the water tower was situated in an area where F1 damage occurred to wood-framed buildings (Figure 18).

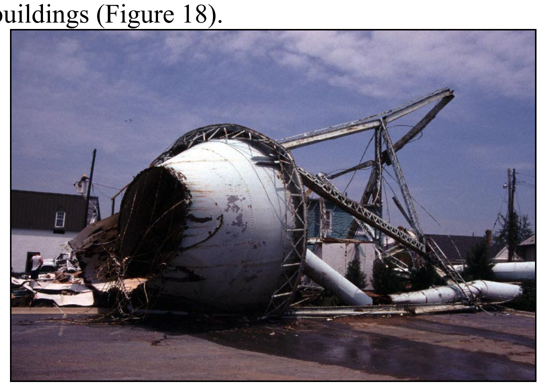

Figure 18. Toppled steel water tower was impressive but occurred in an area of F1 damage.

3.4 CONCRETE ROOF PLANKS

Numerous concrete roof planks were removed from the Arch Bishop Neale School on the west side of La Plata. Each concrete plank measured eight feet long by four inches thick. The planks were supported by precast concrete beams but were not anchored to the beams (Figure 19). Again, the damage was impressive, however, the school was adjacent to a residence that sustained F1 damage. Also, two manufactured homes adjacent to the school sustained F1 damage.

3. 5 DEBRIS IMPACT

The intensity of the tornado damage appeared to increase as the tornado crossed Highway 301 and entered downtown La Plata. The increase in tornado intensity actually was due to the increase in the amount of debris that was generated impacting other buildings downwind. A large roof on a lumber company was uplifted and open web steel joists were deposited up to three blocks to the east. Some of the steel joists impacted other buildings causing additional damage. Team members believed the that the increase in the amount of debris generated by the tornado produced greater damage, not an increase in wind velocities.

Figure 19. Loss of concrete roof planks on a school was impressive but occurred in an area of F1 damage.

4. REVIEW OF THE LOCAL BUILDING CODE

The building code in effect for Southern Maryland is the International Residential Code for One and Two-Family Dwellings published by the International Code Council (2000). This code requires that sill plates be secured to the foundation with anchor bolts spaced a maximum of six feet apart. Also, anchor bolts must be located within 12 inches of the ends of each plate section. Foundation anchor straps are acceptable as long as they provide the same strength as 1.27-cm (1/2-inch) bolts. Therefore, homes not anchored or strapped to their foundations did not conform to provisions in the building code. Interestingly, the code also indicates that foundation walls must have vertical steel reinforcement to provide a continuous load path for both gravity (dead) loads and wind uplift. We found that none of the homes that slid off their foundations met this requirement.

The building code also states that wood-framed walls and floors must have a continuous load path for gravity (dead) and wind loads. However, the code allows end nailing of wall studs to the bottom plates using a pair of 16d (8.9 cm or 3.5 in) nails. We have seen that such connections are weak and easily pulled apart when uplifted. Unfortunately, this apparent contradiction in the building code led to many homes sliding off their foundations in wind speeds below code value. The minimum design wind speed for Charles and Calvert Counties is a 41 m/s (90 m.p.h.)

three-second gust at 10 m (33 ft.) above the ground in open, unobstructed terrain (Exposure C).

The building code also allows the bottom plates to be straight-nailed into the flooring with a pair of 16d nails. However, the nails must be driven into the floor joists at 40-cm (16-inch) intervals. Our team found that bottom plates had been nailed into the floor indiscriminately and usually did not hit the floor joists.

5. F-SCALE DETERMINATION

The most intense damage found was F4 on the Fujita scale and occurred in a small portion of the path, a few hundred meters long. F0 damage occurred nearly continuously along the entire 103 km (64 mi.) long path. There was 42 km (26 mi.) of F1 damage (40 percent of the path length), 12 km (7-1/2 mi.) of F2 damage (12 percent of the path length), and 2 km (1-1/4 mi.) of F3 damage (two percent of the path length. Wind speeds necessary to cause the observed damage were estimated to range from 36 m/s (80 m.p.h.) to 72 m/s (160 m.p.h.).

6. SUMMARY

The tornado that struck La Plata, MD caused F4 damage in only a small area of its 64 mile-long path. This tornado was significant as it had one of the longest path lengths on record for the area. However, the F4 damage rating was determined independently of the record path length. Team members agreed that the tornado damage was not as intense as observed with F5 rated tornadoes at Plainfield, IL, Jarrell, TX, Bridge Creek-Moore, OK or Andover, KS.

Houses that slid off their foundations were not attached adequately and failed at relatively low wind speeds. In some instances, failures were the result of building code violations, however, in other instances, there were contradictions in the building code. It is the author's opinion that straight- and toe- nailing of wooden connections must be augmented by straps or clips to provide better pull-out resistance necessary to meet or exceed the wind uplift requirements in the building codes.

7. ACKNOWLEDGEMENTS

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