5.3 Damage Survey of the Tuscaloosa-Birmingham Tornado on 27 April 2011

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1. INTRODUCTION

On 27 April 2011, a large and destructive tornado

-scale to rate the damage and to estimate failure wind speeds. We found many houses were swept clean from their concrete masonry unit (CMU) foundations. This foundation type offered minimal lateral and uplift resistance to tornadic wind forces. Thus, there was no safe place for people to seek appropriate shelter against such a violent tornado. However, in many instances, front porches, which typically had concrete slab floors, remained intact. Therefore, we will discuss the concept of installing porch shelters as a way to save lives.

The Tuscaloosa-Birmingham tornado was just one of 62 tornadoes that struck Alabama on 27 April 2011. There were more than 1110 km of tornado tracks in the Birmingham National Weather Service (BMX) county warning area alone. Surveying the tornado tracks as soon as possible was a difficult task as debris cleanup began almost immediately. The BMX office dispatched numerous survey teams to determine the path length, path width, and EF-scale rating of the tornadoes. Three tornadoes in particular were subjected to more detailed evaluations since they were so violent. One such tornado struck the town of Hackleburg, AL and continued through portions of Phil Campbell. This tornado was rated EF-5. Another violent tornado struck the town of Cordova, AL and was rated EF-4. The Tuscaloosa-Birmingham tornado traveled through densely populated regions giving us an opportunity to determine EF-scale ratings on a variety of building types.

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Figure 1. Large tornado moving through Tuscaloosa. AP photo.

2. BMX OPERATIONS

2.1 Before the Event

For almost a week prior to 27 April 2011, BMX predicted this significant weather event, and by 25 April, provided numerous products and services forecasting the potential for several waves of severe weather, including violent, long-track tornadoes. Some of these services included working with local TV stations and conducting radio interviews, numerous Emergency Management briefings on the statewide 800 MHz EMA radio system, and providing high impact web graphics and multimedia presentations.

Within the office, plans were made to provide extra staffing on the 27th from 0900 UTC through the end of the event, as well as provisions for storm damage survey teams in the days after the event. The office electronics staff and Information Technology Officer (ITO) were also scheduled strategically to ensure any problems with communications or computer systems could be addressed and resolved as quickly as possible.

As a result, prior to the most intense activity on the afternoon of 27 April, key decision makers and the general public alike were alerted to the potential for a significant severe weather outbreak. Based on information and forecasts provided by BMX, numerous schools across the County Warning Area (CWA) were either closed for the day or closed early, and government agencies and businesses closed early. By mid-morning, Governor Bentley signed a declaration of

the EF

emergency in anticipation of the expected outbreak, and the Alabama State Emergency Operations Center was activated at the same level as a landfalling hurricane.

2.2 During the Event

The first wave of activity associated with the squall line passage in the early morning hours was more intense than originally expected, and resulted in widespread wind damage and isolated tornadoes. In addition to the damage to homes and businesses, the extent of damage caused widespread damage to power distribution and communications infrastructure over the northwestern third of the CWA, including communications to the Winfield, AL NOAA Weather Radio transmitter. Unfortunately, this communications outage became a factor in keeping citizens and officials aware of the continued threat through the afternoon hours.

In the wake of the morning activity (a major severe weather event in and of itself), some of the staff continued to evaluate the developing threat for the afternoon hours, while others made efforts to collect as much storm damage information as possible. Communication with key customers and partners continued throughout the day, confirming the highest level of concern for the threat for violent long-track tornadoes. Shortly after 1900 UTC, as the collection of initial storm reports from the morning event was nearing completion, the surreal onslaught of tornado producing supercell thunderstorms began with the first warning of the afternoon.

The frenetic pace of warnings continued through the late afternoon and into the evening hours, with situational awareness displays confirming many warnings in real time with live video feeds from local stations. First responders and recovery crews dealing with storm damage from the morning storms were forced to take shelter and in some instances became victims of the afternoon storms. At peak activity, there were four confirmed long track tornadoes on the radar display across north-central Alabama. At approximately 0050 UTC, warning operations came to a halt locally and were transferred to the Peachtree City forecast office, as a supercell with a history of producing damage headed directly for BMX.

After returning from shelter, warning operations continued until the last warning in the CWA was cancelled at 0343 UTC as the final supercell of the day moved out across the state line into Georgia. At the end of the day, a total of 49 tornado warnings were issued, with a total of 29 confirmed tornadoes affecting the CWA, of which 18 were strong or violent.

2.3 After the Event

Upon realizing the magnitudes and multitudes of tornadoes that occurred across the northern two-thirds of Alabama, the BMX office established a response strategy on the morning of 28 April 2011with three main objectives: 1) to have damage survey teams provide rapid updates on tornado tracks and locations to key partners, such as EM (Emergency Management) and FEMA (Federal Emergency Management Agency), as well as local, state and federal agencies, 2) to provide hour-by-hour decision support services through forecasts and briefings to ensure the safety of the thousands of recovery and response personnel, volunteers, and the general public, and 3) to respond to numerous requests from media, public, and government officials for additional information.

In order to accomplish the objectives of the response strategy, the BMX office took the following steps:

1) Tasked the MIC (Meteorologist-In-Charge) and WCM (Weather Coordination Meteorologist) to respond to numerous local, state and national requests for event information. This included live on-scene interviews, and press conferences in Tuscaloosa.

2) Brought in additional staffing to handle the additional workload. This included: a) bringing in a member of the staff from Southern Region Headquarters (SRH) to coordinate with and to provide all information to National Weather Service Headquarters (NWS HQ) and Department of Commerce (DOC), b) having four extra forecasters work operational shifts, allowing BMX personnel to conduct a majority of the damage surveys within their known CWA, and 3) allow the NWS Mobile Warning Coordination Meteorologist to conduct damage surveys, primarily in the southern sections of the CWA.

3) Requested activation of a Quick Response Team (QRT) was requested through SRH. Tim Marshall from Haag Engineering, Jim LaDue from the Warning and Decision Training Branch (WDTB), and Kevin Scharfenberg from the NWS Office of Climate, Weather and Water Services (OCCWS), provided assistance in conducting surveys. Due to intense media presence and requests for damage information from local, state, and federal officials, BMX assigned the

highest priority tracks (those passing through Tuscaloosa and Hackleburg) to the QRT.

4) Designated one person at BMX to remain in the office each day to coordinate all aerial and ground surveys over the next week. An additional person would coordinate all other requirements.

The severity and tragedy of this tornadic event coupled with eight consecutive days of performing damage assessments surveys and ongoing response and recovery efforts, took a tremendous emotional toll on those involved.

3. DAMAGE SURVEY LOGISTICS

In order to cover the damaged areas as quickly as possible, we conducted aerial surveys using helicopters and crews provided by the Alabama National Guard. Specific locations of high intensity damage were identified from the air. The helicopter then landed nearby and local police escorted us to specific damage locations. In this way, we could survey several tornado tracks in a given day. One problem encountered was that clean-up operations began almost immediately after the tornado. Streets were cleared of debris and power crews began restoring electrical grids. Neighbors and volunteers assembled to clear away debris. Thus, it was literally a race to complete the damage surveys before sites were cleared.

The vast majority of buildings damaged by the tornado were residences. We determined the degree of damage (DOD) using the EF-scale developed by the Wind Science and Engineering Research Center (WISE, 2006). This scale involves the use of 28 damage indicators (DIs). However, only five building types have expected values of 200 mph or more to reach EF-5 levels. For a residence to be assigned an EF-5 rating, it must be "well-built" and swept clean from its foundation.

The definition of a well-built house can vary among individual damage surveyors. We defined a well-built house as one that had a continuous load path of straps and anchors from the roof to the ground, without weak connections in the horizontal or vertical planes. Unfortunately, we did not find a single house that was well-built. Almost all homes in the tornado path had CMU foundations. The concrete masonry consisted of hollow cells stacked in a common bond pattern. Wood sill plates rested on top of the foundations but rarely were attached to the masonry (Fig. 2). In a few instances, anchor bolts connected the sill plates to grouted top cells in the foundations. Regardless, such connections had little lateral strength and the bolts either broke out of the cells or the top block broke out of the foundation.

Floor joists were supported by the sill plates and we found many instances where the floor joists were not attached to the sill plates (Fig. 3.) Such homes were prone to sliding off their foundations (termed "sliders"). The EF-scale lists the expected failure wind speed as 54 m s^{-1} (121 mph) for homes that slide off their foundations. However, we adjusted the failure wind speeds based on other DOD's to the house (i.e. extent of roof damage) and/or the DOD of adjacent buildings that remained on their foundations (Fig. 4).

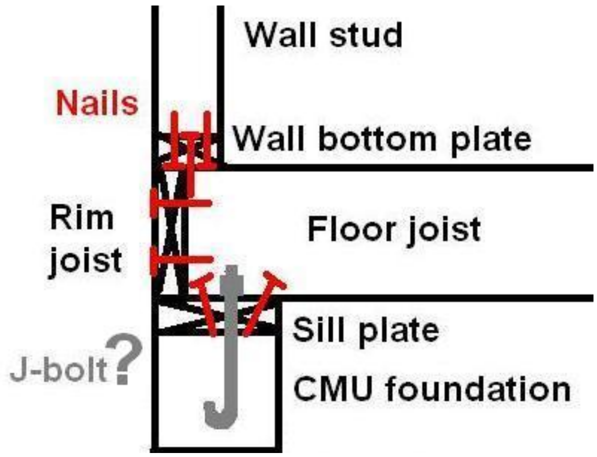

Figure 2. Typical cross section of the base of a house supported on a CMU foundation. Nails are indicated in red. J-bolts were rarely used to attach the sill plates to the foundations.

Figure 3. An unanchored home on a CMU foundation that slid into the backyard. The DOD to the roof covering suggests failure wind speeds were probably less than 45 m s^{-1}(100 mph). Note the front porch slab remained.

Figure 4. Sill plates were bolted to the grouted top cells in the foundation. However, the floor joists were not fastened to the sill plates.

Unfortunately, Alabama has no statewide residential building code and no enforcement requirements for the building codes. Because there are no statewide code requirements, there is no state program for certification of building inspectors. Thus, builders police themselves. For these reasons, the Institute for Business and Home Safety, (IBHS, 2011) gave Alabama a score of 18 out of 100 on building code requirements. Tuscaloosa and Birmingham have adopted the International Residential Code (IRC, 2009). However, there are many rural counties where there is no oversight in building construction. The IRC requires that a house be constructed to resist a 40 m s^{-1} (90 mph) three-second wind gust at 10 m above the ground in open, unobstructed terrain (Exposure C). However, other requirements in the IRC actually conflict with the basic design wind speed. For example, the IRC still allows end nailing of walls studs to bottom plates with pairs of 16d nails. Such nailed connections can be pulled apart easily, by lateral and/or uplift forces induced by wind speeds less than the 40 m s^{-1} basic design wind speed.

4. THE TUSCALOOSA TORNADO

This tornado touched down approximately 38 km southwest of Tuscaloosa, or about 7 km northwest of the Union community in Greene County. It traveled through rural areas damaging a few homes and other buildings before moving into southwest Tuscaloosa County and the city of Tuscaloosa. The tornado entered the Industrial District on the southwest edge of town and cut a diagonal path extending northeast across the city. Several metal buildings collapsed (DI 21, DOD 8) in and around the Tamko Roofing Plant (Fig. 5). We estimated failure wind speeds to be 69 m s^{-1} (155 mph) or EF-3. Across the street from the Tamko Plant was the Curry Building (Fig. 6). This was a steel-framed warehouse type building with a flat roof that collapsed (DI 23, DOD 7). Failure wind speeds were estimated to be 71 m s^{-1} (158 mph) or EF-3. According to FEMA (2012), the emergency operations center (EOC) was located at the south end of the building and lost all functionality during the tornado.

The tornado crossed Interstate-359, overturning several vehicles before traveling through the densely populated area of south Tuscaloosa. Many wood-framed homes sustained up to EF-4 damage while unanchored homes slid off their foundations and collapsed. The tornado passed directly over the Charleston Square Apartments off 27th Street. This large, rectangular-shaped building was a two-story, wood-framed structure constructed on a concrete slab foundation. The roof and second story walls blew off (DI 5, DOD 5) and the east end of the south building collapsed (Fig. 7). Failure wind speeds were estimated to be about 71 m s^{-1} (158 mph), or EF-3.

Figure 5. Collapse of metal buildings at the Tamko Roofing Plant.

Figure 6. Collapse of the steel-framed Curry Building.

Figure 7. Removal of the roof and second story walls at the Charleston Square Apartments.

After passing through another residential area, the tornado struck the University Place Elementary School off 18th Street. The two-story school was T-shaped in plan and constructed with CMU perimeter walls. Open web steel joists supported the roofs over the classrooms. The joists were attached to masonry bond beams along the tops of the walls. Several joists were lifted and portions of the south and west masonry walls fell inward (DI 16, DOD 10). Such uniform failure along the bases of the walls suggested that the walls were not attached securely to the concrete floor. We estimated a failure wind speed of 71 m s^{-1} (158 mph) or EF-3 (Fig. 8). A gymnasium at the south end of the school had a large span roof supported by steel trusses. The south end wall collapsed and most of the steel roof decking blew away (DOD 7). Collapse of the tall masonry wall indicated a failure wind speed of about 51 m s^{-1} (114 mph). Outside the building, we noticed that light standards remained upright in the parking lot with a few that were slightly bent (DI 26, DOD 2). Wind speeds estimated to fail such light poles would be around 46 m s^{-1} or 102 mph.

Figure 8. Aerial view of the University Place Elementary school looking southeast. Roofs over the classrooms and gymnasium were removed including many of the steel joists.

The tornado traveled through another residential area causing EF-4 damage to several houses then crossed Forest Lake before passing through a busy intersection at 15th Street and McFarland Blvd. The tornado literally "threaded the needle" between the University of Alabama and University Mall but hit the Wood Square Shopping Center along McFarland Ave. The shopping center consisted of unreinforced CMU perimeter walls and steel interior beams and pipe columns that supported relatively flat built-up roofs. Large portions of the north and west ends of the shopping center collapsed (DI 10, DOD 9). Estimated failure wind speeds were about 76m s^{-1} (171 mph) or EF-4 (Fig. 9). Several light standards in the parking lot were broken (DI 26, DOD 3). Estimated wind speeds to fail such light poles would be about 53 m s^{-1} (118 mph) or EF-2.

Figure 9. Northwest elevation view of the Wood Square Shopping Center. Large portions of the building collapsed.

The tornado then struck a number of businesses along University Boulevard before striking the Alberta Elementary School. The school consisted of four (each), one-story buildings that had both perimeter and interior CMU walls and wood-framed roofs. Portions of the perimeter walls were constructed with brick veneer over steel studs.

The core of the tornado passed just to the north, subjecting the school to strong south and west winds. Both south and west buildings collapsed (DI 15, DOD 10). South and north walls fell to the north while east and west walls fell to the east. Walls pivoted about their bases (Figs. 10 and 11). According to FEMA (2012), rebar was placed every 1.3 m along the foundation perimeter and extended into grouted cells in the masonry with two-inch overlaps with the wall rebar. Such lapped splices simply pulled apart as the walls toppled. Such wall construction provided little in the way of lateral wind resistance. Due to such poor construction, we reduced our failure wind speeds to the lower bound of 68 m s^{-1} (152 mph) or EF-3. We believe actual wind speeds may have been even lower as light poles remained upright in the parking lot. Both tall steel poles (street lights) and shorter poles (lantern type lights) remained. Only a few poles were bent (DI 26, DOD 2) indicating expected failure wind speeds could have been as low as 46m s^{-1} (102 mph) or EF-1.

Figure 10. Aerial view of the Alberta Elementary School looking north. Two of the four buildings collapsed. Note the light standards (red boxes) in the parking lot remained upright.

Figure 11. **S**outheast corner of the Alberta Elementary School. Stacked masonry walls were anchored poorly to the foundation and fell over in the directions indicated (red arrows).

After causing EF-4 damage to residences, the tornado struck the Chastain Manor Apartments located in northeast Tuscaloosa along 34th Avenue East. There were two, wood-framed apartment buildings oriented east-west and constructed on the side of a hill that faced south. These buildings were "split-level", with one-story on the north elevations and two-story on the south elevations. The gable type roofs were constructed with manufactured wood trusses that were attached to the tops of the walls with metal "hurricane" straps. However, the bases of the walls were fastened to the concrete slabs with cut nails instead of anchor bolts. The tornado removed the one story framing down to the slab along the east end of the south building (DI 5, DOD 5 to 6). Given the poor connection between the wall framing and foundation, we estimated failure wind speeds to be lower than 76 m s^{-1} (170 mph) or EF-4 (Figs. 12 through 14).

There was a one-story, wood-framed office building on site that was completely leveled by the tornado (Fig. 15). Close examination of this building revealed the wood-frame walls had been bolted to the concrete slab foundation. However, wall failure occurred when the straight-nailed connections between the wall studs and bottom plates pulled apart (Fig. 16). Walls fell outward except for the front (southeast) wall that blew away. Given the weak stud-plate connection, the survey team decided failure likely occurred at or below the EF-4 level. There was a third wood-framed apartment building southwest of the office building. This one-story, wood-framed building was constructed on level grade and sustained less severe damage than the two other buildings constructed on the hillside. Interestingly, a steel manhole cover lifted off a storm drain and was found in a nearby ravine.

Figure 12. Aerial view of the Chastain Manor Apartments looking north. A portion of the concrete floor slab was exposed on the east end of the south building.

Figure 13. Ground level view looking northwest at the Chastain Manor Apartments. The tornado removed the top story.

Figure 14. Closer view of the slab foundation at Chastain Manor Apartments. Wall plates were secured to the slab with cut nails instead of anchor bolts. Such connections had little pull out resistance from lateral or upward forces.

Figure 15. The office building at Chastain Manor Apartments was leveled. The walls fell outward, leaving the slab foundation exposed.

Figure 16. Closer view of the wall bottom plate at the office building. Straight-nailed connections between the wall studs and the bottom plates had pulled apart, as they had little resistance to lateral or uplift wind forces.

The tornado continued into rural areas northeast of Tuscaloosa but remained intense, causing EF-4 damage to residences. Several mobile homes were destroyed by strong winds on either side of Crescent Ridge Road. Boats were tossed more than 100m from a boat storage facility. The tornado toppled a railroad bridge that spanned Hurricane Creek near the town of Holt. Five, tapered, steel towers supported the bridge. Three towers fell over with the smallest tower being flipped (Fig 17). The bases of the towers were bolted to concrete pier caps. Failure of the towers occurred when the bolted connections failed. In a few instances, the pier caps had broken. The tornado continued through hilly and forested terrain, toppling and uprooting thousands of trees. Refer to Karstens et al. (2012) for a detailed study of tree damage from this tornado. The tornado also destroyed a marina on the south shore of the Black Warrior River. Aerial photography of downed trees indicated the tornado was widest here (approximately 1600 m), yet DIs other than trees were not available.

Figure 17. Toppled steel towers that had supported a railroad bridge over Hurricane Creek, northeast of Tuscaloosa.

5. THE BIRMINGHAM TORNADO

The tornado entered western Jefferson County about 9 km west of North Johns and traveled through Concord, Pleasant Grove, McDonald Chapel, Pratt City, and Fultondale, all northern suburbs of Birmingham (Fig. 18). More than 200 homes had all walls knocked down or were removed from their CMU foundations (DI 2, DOD 9). In many cases, front porch slabs remained in place, and cars remained in their driveways or garages (Figs. 19 and 20). Thus, we estimated failure wind speeds to have been at or below 76 m s^{-1} (170 mph) or EF-4.

Interestingly, the tornado crossed a coal loading facility just east of Pleasant Grove. Several empty railroad cars overturned and one car traveled (leaving the steel wheels behind) approximately 120 m (Fig.

21). According to McCaul et al. (2012) each rail car weighed 36 tons. Calculations will have to be done to estimate the wind speed necessary to overturn and transport the coal cars. Note, this DI is not listed in the EF-scale, presently. However, a nearby power pole, fence, and cart were not damaged.

After passing through another residential area and causing up to EF-4 damage, the tornado struck the Southbrook Apartments on Cherry Avenue in Pratt City. This apartment complex comprised of five, two-story, wood-framed buildings oriented north-south. The tornado removed most of the gable roofs and portions of the second stories (DI 5, DOD 5). We estimated failure wind speeds to be 71 m s^{-1} (158 mph) or EF-3. Several cars in the parking lot were pushed sideways and crashed into each other (Fig. 22).

Nearby, the tornado struck the Bethel Baptist Church. The main building consisted of a large, tall, star-shaped sanctuary that was supported with glulam (glue laminated) beams, columns and purlins. Steel bolts and brackets connected intersecting purlins and beams. The roof deck consisted of tongue-and-grooved boards straight-nailed to the tops of the beams and purlins; walls were framed conventionally. Exterior walls were brick masonry veneer. The tornado removed most of the roof decking, wall framing, and brick masonry, leaving the glulam frame intact. Unfortunately, there is no DI in the current EF-scale criteria for churches. Therefore, we used the DI for Junior High Schools as this DI contained a provision for the collapse of tall masonry walls such as a gymnasium or auditorium (DI 16, DOD 7). An adjacent metal building exhibited buckling of purlins and loss of most of the roof panels (DI 21, DOD 5). Light poles remained in the parking lot; a few were bent (DI 26, DOD 2). Given these three observations, we estimated the expected failure wind speed for the area was around 51 m s^{-1} (115 mph) or EF-2 (Fig. 23).

The tornado then paralleled Interstate 65 before it entered Fultondale. Hundreds of trees were toppled and several light poles were bent along the interstate. The tornado struck the Super 8 Motel located at the intersection of U. S. Highway 31 and Interstate 65. The motel was constructed with CMU walls. Wood top plates were attached to grouted cells in the top courses of the masonry using steel J-bolts with nuts and washers. The gable roof was comprised of manufactured wood trusses that were toe-nailed to the wall top plates. The tornado removed a large portion of the roof and toppled several second story walls (DI 7, DOD 5). We estimated failure wind speeds to be 59 m s^{-1} (133 mph) or EF-2 (Fig. 24). The tornado began to weaken as it paralleled U. S. Highway 31 and lifted just west of AL Hwy 79, about 6 km north of Tarrant.

Figure 18. Large wall cloud with tornado passing northwest of downtown Birmingham. AP Photo.

Figure 19. An unanchored home on a CMU foundation. The front porch slab (foreground) and vehicle (background) remained although the unanchored slab did shift**.**

Figure 20. Unanchored home that slid off its CMU foundation. Note front porch slab remained.

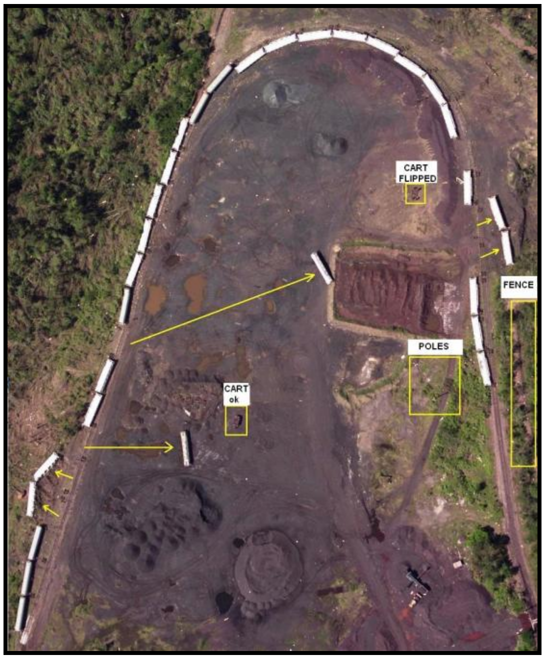

Figure 21. Empty railcars that were blown off the tracks at this coal loading facility.

Figure 22. Tornado damage to the Southbrook Apartments in Pratt City. The roof and most second story walls were blown away.

Figure 23. Tornado damage to the Bethel Baptist Church in Pratt City. The roof decking and wall framing were blown away leaving the primary glulam framing.

Figure 24. Tornado damage to the Super 8 Motel in Fultondale. A large portion of the roof blew away and several second story masonry walls toppled.

6. HOUSING DAMAGE

We rated a total of 4533 homes per the EF-scale using NOAA Aerial Imagery, Google Earth and Streets, and our own survey images. Detailed maps are appended to this paper. In general, homes were rated EF-0 if they lost less than 20 percent of their roof coverings or siding (DOD=2). Homes were rated EF-1 if they lost most of their roof coverings or had minor damage to the roof structure such as missing gable ends (DOD=4). Homes were rated EF-2 if they lost most of their roof structure but had their walls standing (DOD=6). Homes were rated EF-3 if they had lost exterior walls but some interior walls remained standing (DOD=8). An EF-4 rating was given to those homes that had all walls down and only a pile of debris remained on their foundations (DOD=9). Homes that slid off their foundations were rated according to the DOD they sustained above floor level, or based on the DOD of adjacent homes. The default rating for a slider home was DOD 6 with failure wind speeds estimated to be 54 m s^{-1} (121 mph). We identified at least 100 homes that slid off their foundations.

The tornado was remarkably consistent in intensity except at the beginning and end of the track where it was noticeably weaker. The EF-1, 2, 3, 4 damage paths were approximately 400, 300, 200, and 100 m wide, respectively.

Table 1 summarizes the numbers of damaged homes by EF-scale in this tornado. Most homes in the tornado path were rated EF-0. This damage was primarily due to strong inflow winds. The number of homes rated EF-1 through EF-4 ranged between 8 and 10 percent of the total homes affected, per category. Such similar percentages of damaged homes were attributed to the uniform width of the damage track. There was a steady increase or consistent gradient of damage towards the tornado core.

TABLE 1
SUMMARY OF DAMAGE TO RESIDENCES IN THE TUSCALOOSA-BIRMINGHAM TORNADO

EF-scale	Tuscaloosa	Birmingham	Total
0	1000+	2000+	3000+
1	210	224	434
2	198	201	399
3	131	217	348
4	115	237	352
Total	1654	2879	4533

As mentioned earlier, the vast majority of homes in the damage path had CMU, pier and beam type, foundations. In some instances, the masonry piers had mortared joints while in other instances, the CMU blocks were loosely stacked. Regardless, floor platforms had little or no anchorage to the foundations. Even where sill plates were bolted to grouted cells along the tops of the foundations, the attachments were ineffective in resisting lateral and uplift wind forces. Either the bolts broke out of the CMU or individual CMU blocks were transported with the sill plates. Such homes were not safe havens during such an intense tornado. Prevatt et al. (2011) reached a similar conclusion in their study of building damage in the wake of this tornado.

According to NOAA (2011), many people died in their homes, both conventionally constructed and manufactured homes. In cases where homes sustained complete destruction, we noticed many front porches remained intact. We believe that porch type shelters would have been effective in saving lives. These concrete or steel box shelters are placed partially below grade and can provide substantial occupant protection (Figs. 25 and 26). Unfortunately, few companies make porch shelters. A general internet search showed them to cost between $3,000 to $5,000. We did not observe any porch shelters during our survey.

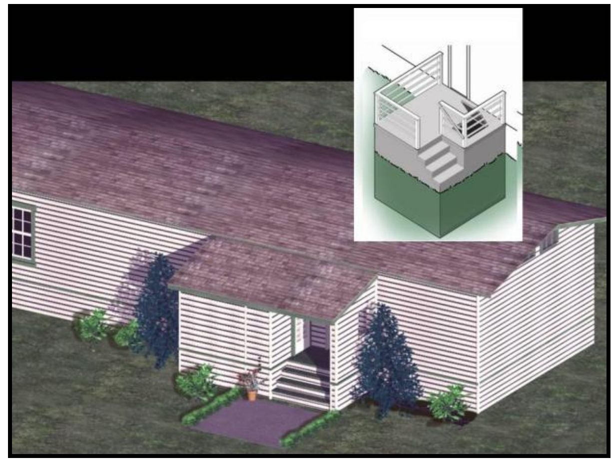

Figure 25. The porch shelter.

Figure 26. Example of an installed concrete porch shelter with steel entry door.

7. SUMMARY

The supercell that produced the Tuscaloosa tornado developed in eastern Mississippi and tracked across northern Alabama, northwest Georgia, and into southern North Carolina. The storm traveled approximately 500 km in 8.5 hours, at an average forward speed of 59 km/hr. The tornado that tracked from Tuscaloosa through the Birmingham suburbs was just one of many produced by this storm. The Tuscaloosa-Birmingham tornado traveled through several residential, commercial, and industrial areas and provided damage surveyors opportunities to assess the performance of various building types. Thousands of homes and hundreds of other structures were damaged or destroyed by this tornado. Initially, we targeted specific buildings for detailed inspection. Later, aerial and ground imagery were studied to assign a damage rating to each home. We found that many buildings suffered catastrophic failures due to poor foundation, wall, and roof anchorage. There were many critical connections that would not meet current building code requirements. Many houses collapsed or slid off their CMU foundations and did not provide adequate occupant protection. Given the high frequency of long tracked, violent tornadoes that strike this area, we advocate the use of storm shelters to provide for occupant protection.

We learned from this survey that additions and corrections are needed to the EF-scale. Churches should to be added as a DI and appropriate DODs established. Explanations are needed about how to incorporate non DIs such as toppled railroad trestles and tossed rail cars. Cross correlation corrections are needed for specific DODs. For example, expected value wind speeds for uplift of the roof decking and significant loss of the roof covering is much lower for residences (DI 2, DOD 4) than for apartments (DI 5, DOD 3). However, pitched roofs generally are constructed the same on these buildings.

8. ACKNOWLEDGEMENTS

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MAP ATTACHMENTS

We have attached damage maps developed from our analysis of the Tuscaloosa-Birmingham tornado. Only populated areas are shown. Rural areas were omitted. Houses were rated EF-0 to EF-4 per the EF-scale. Boxes around the numbers indicated where homes had slid off their foundations. The maps are contoured EF-1 through EF-4.

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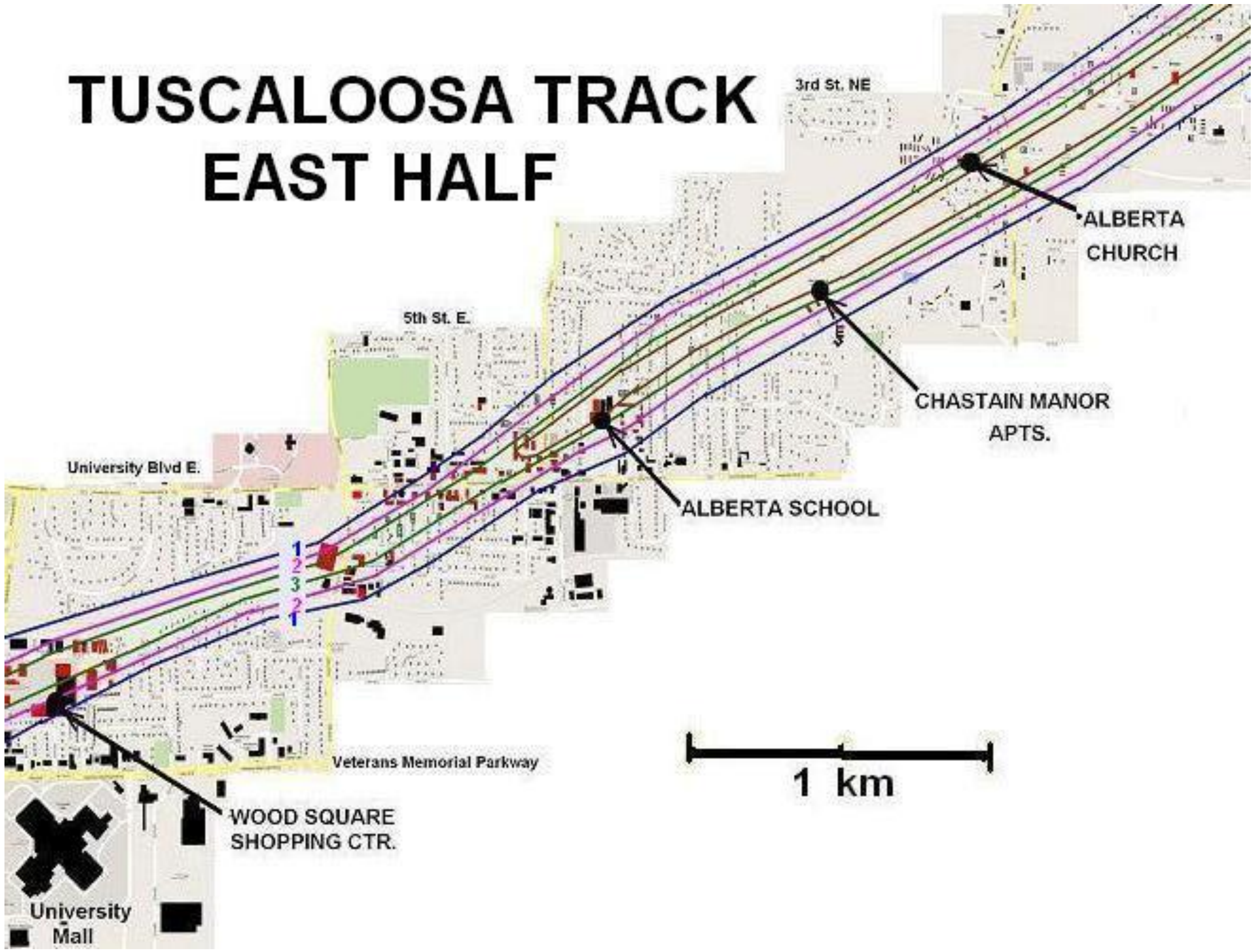
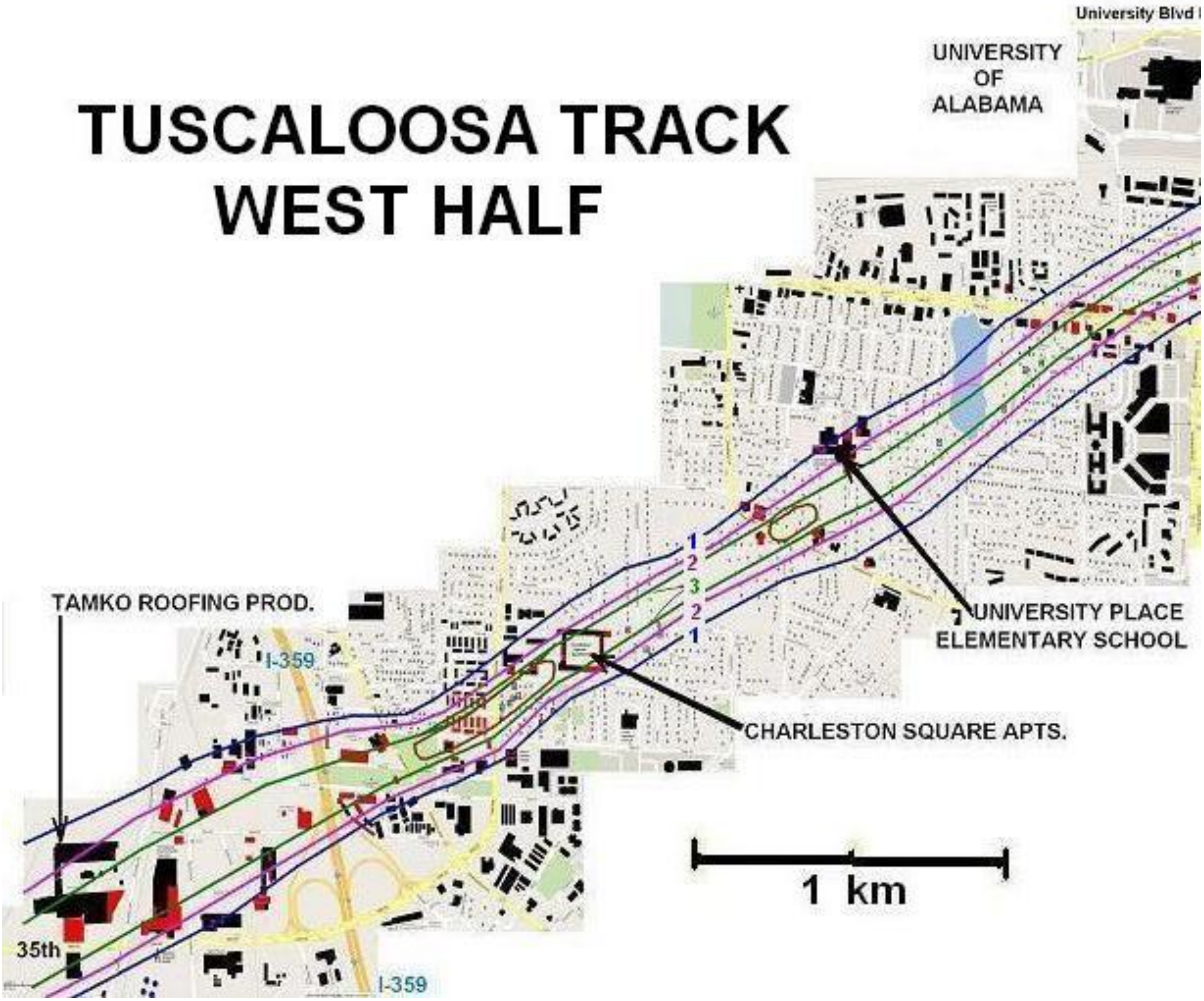
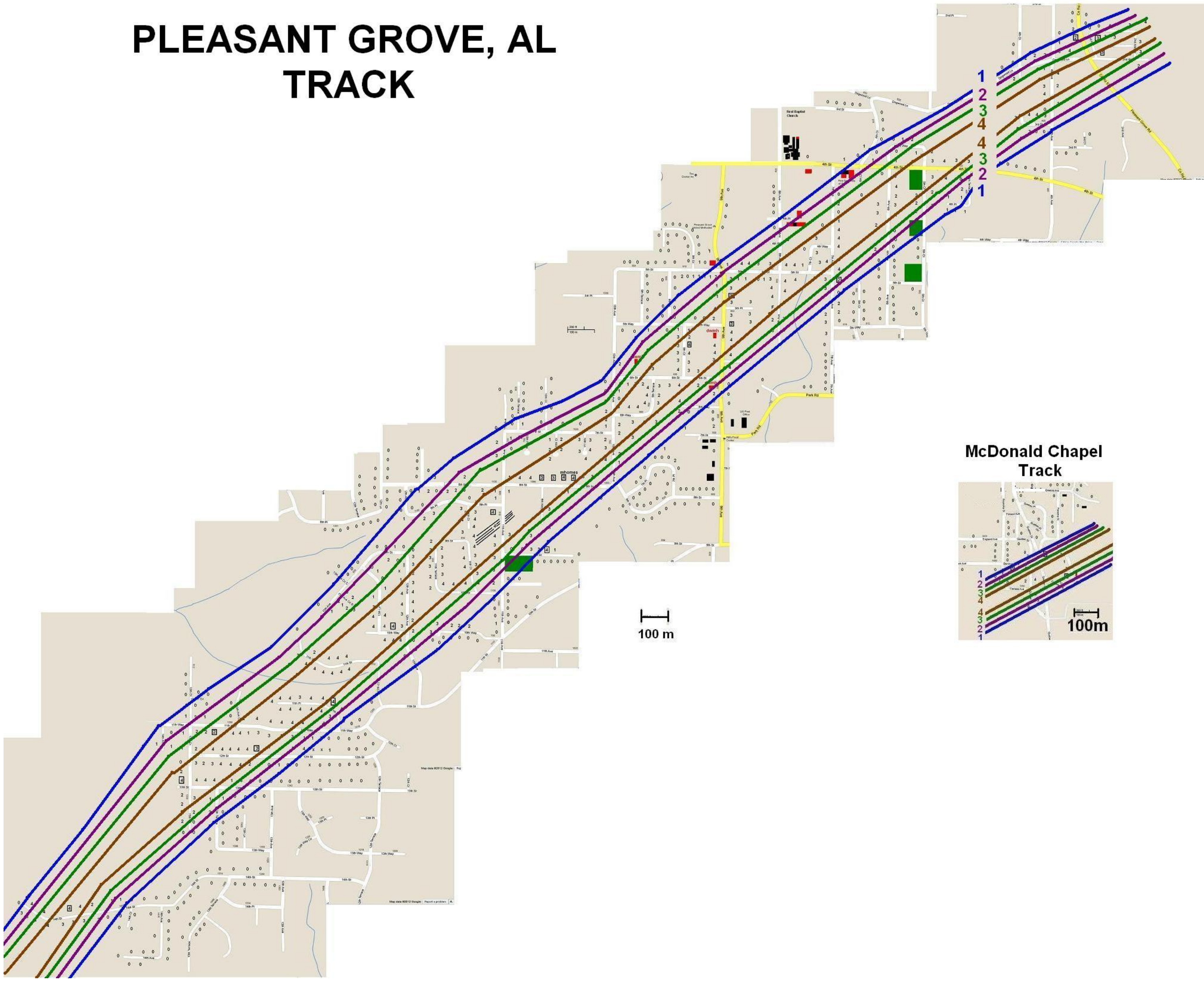
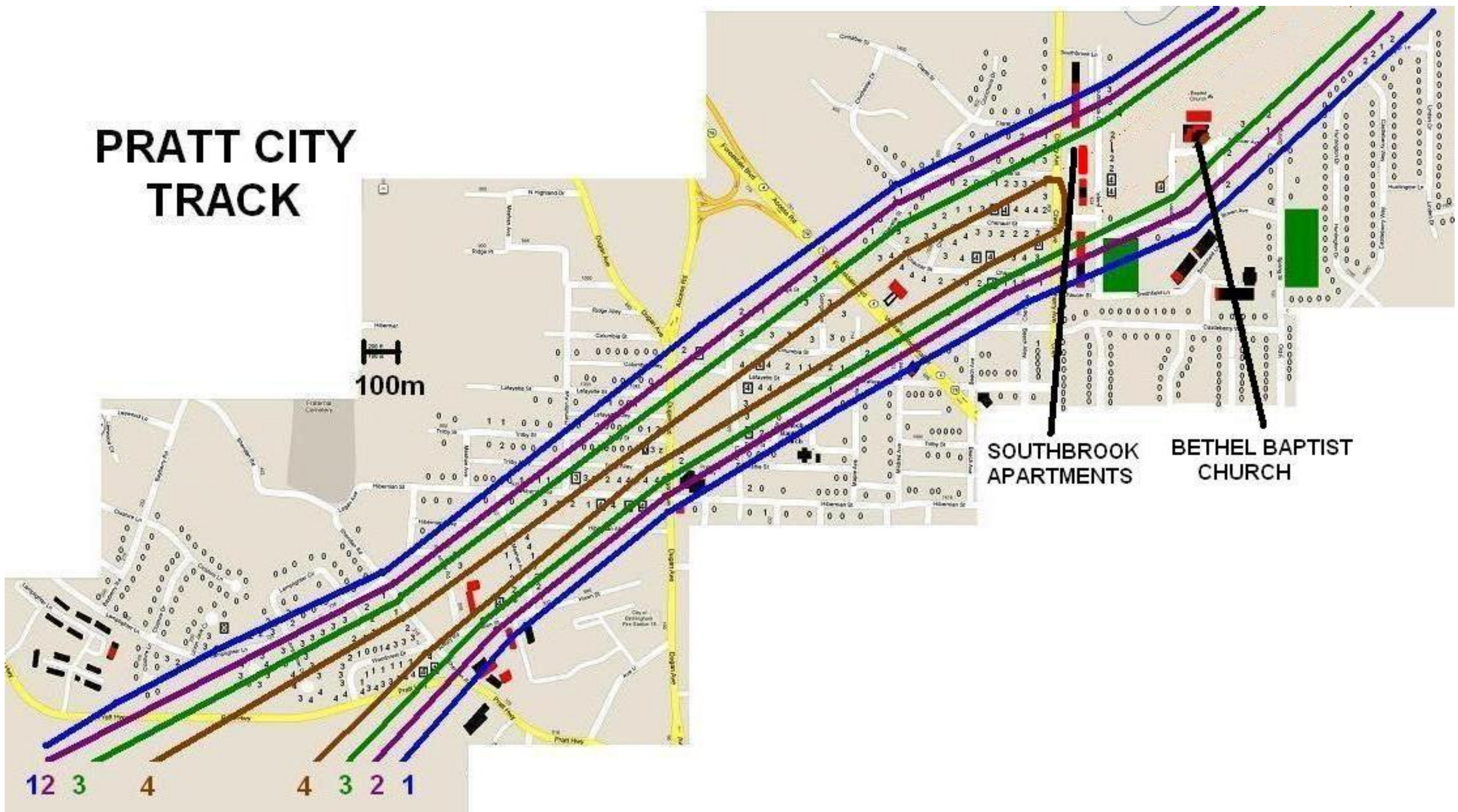

TUSCALOOSA TRACK
EAST HALF
3rd St. NE
ALBERTA CHURCH
CHASTAIN MANOR APTS.
5th St. E.
ALBERTA SCHOOL
University Blvd E.
1
2
3
2
1
Veterans Memorial Parkway
1 km
WOOD SQUARE SHOPPING CTR.
University Mall

TUSCALOOSA TRACK WEST HALF

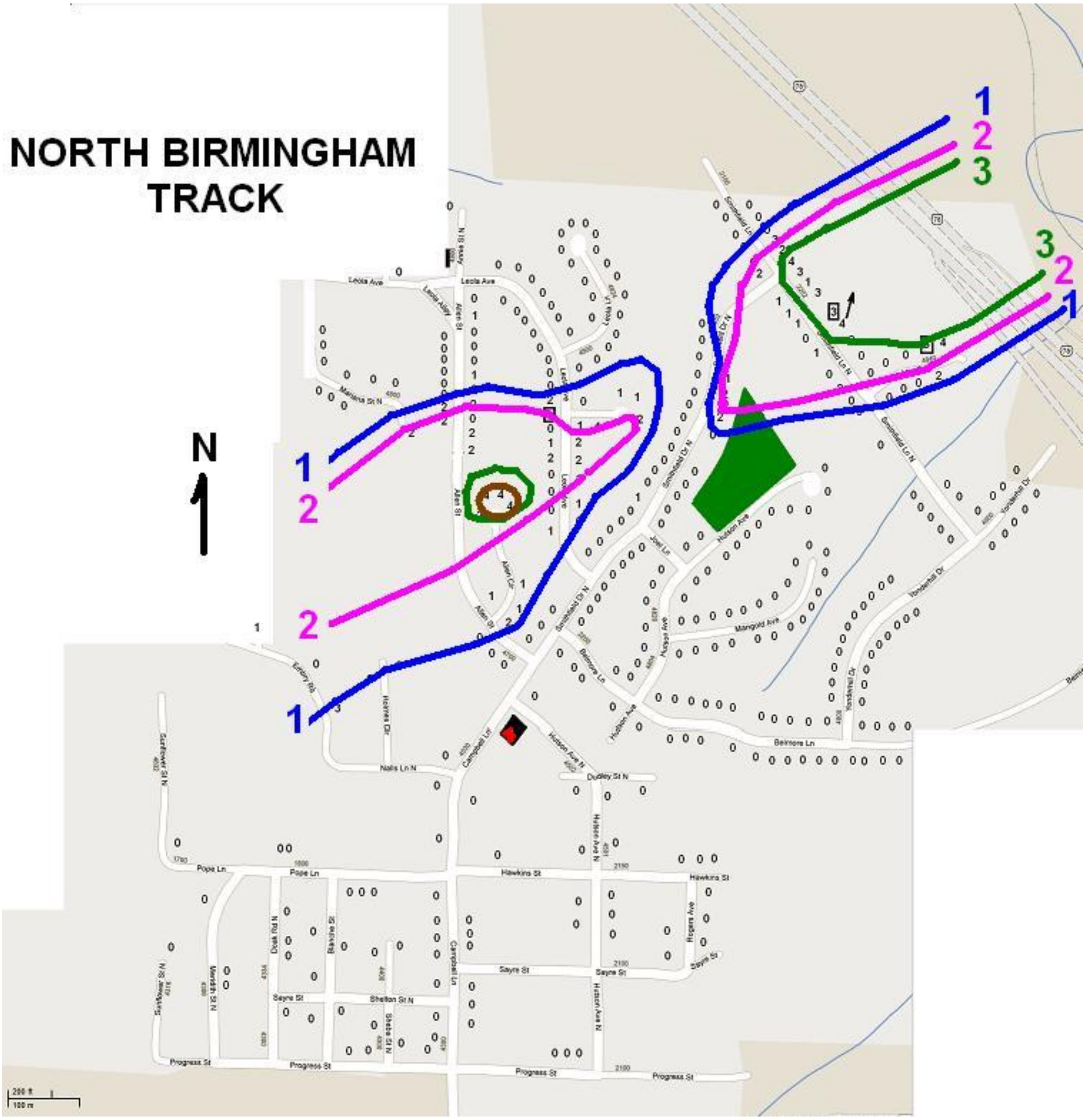


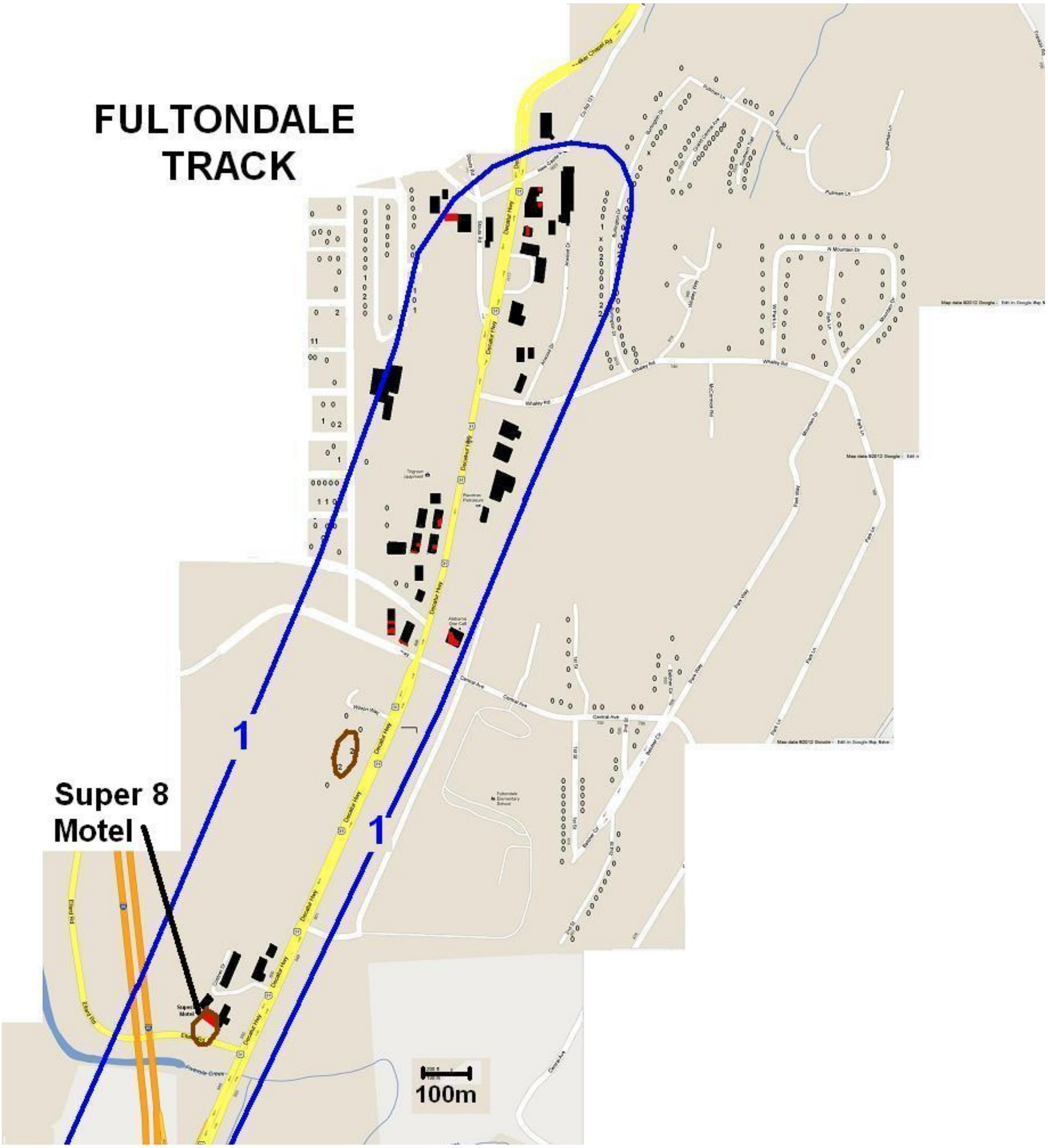
PLEASANT GROVE, AL
TRACK




PRATT CITY
TRACK
100m
SOUTHBROOK
APARTMENTS
BETHEL BAPTIST
CHURCH
1 2 3 4
4 3 2 1

NORTH BIRMINGHAM TRACK




FULTONDALE
TRACK
1
Super 8
Motel
1
100m