Damage Survey of the Nashville, TN Tornado: 3 March 2020

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1. INTRODUCTION

On the evening of March 2-3, 2020, a supercell storm produced 10 tornadoes in-a-row from near Bradford to Lancing, Tennessee. The longest tornado track was the fourth in the series and traveled 102 km (63.13 mi) through the cities of Nashville, Donelson, Hermitage, Mount Juliet, and Lebanon, paralleling Interstate 40. The tornado caused 5 deaths and about 220 injuries. Refer to Figure 1.

This paper summarizes the findings from our damage survey, herein called the Nashville tornado. The authors spent several days traveling the damage path and documented the degree of damage (DoD) to specific damage indicators (DIs) using the EF damage scale (WERC, 2006). The EF-scale was adopted by the National Weather Service (NWS) in 2007.

The NWS determined the maximum damage intensity of this tornado was EF 3. They recorded and plotted specific locations utilizing the damage assessment toolkit (DAT). They also determined the path length, path width, and most intense damage rating for the tornado.

The survey team wanted to sample as many different DIs as possible. Drones were especially useful during the survey to obtain aerial views of specific building details that were not visible from the ground. Google Street View and Google Earth also were helpful in determining what the buildings looked like before the tornado.

It is anticipated that results from this damage survey will help improve the next iteration of the EF-scale. A new standard currently is being developed by the American Society of Civil Engineers (ASCE), Structural Engineers Institute (SEI) and the American Meteorological Society (AMS) to estimate wind speeds in tornadoes from damage to buildings and other objects. The standard should be published in a few years.

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Fig. 1. The tornado going through Nashville.

2. TORNADO DAMAGE PATH

The Nashville tornado first developed around 0632 UTC on March 3, 2020, in the Bells Bend area of the Cumberland River, blowing down numerous trees. The first substantial damage to buildings occurred in an industrial park, west of John C. Tune Airport where several large warehouses were destroyed. In particular, the 305 m (1000 ft) long Materials Handling Resources building on Cockrell Bend Road collapsed. This two-story, steel-framed structure had pre-cast concrete wall panels extending around the perimeter of the building. Nearly the entire roof was removed, and most wall panels toppled. Several metal building systems on Cockrill Bend Circle were destroyed including Aramark Uniform Services and Stone World.

Thirteen metal building hangars were destroyed at John C. Tune Airport causing substantial damage to private aircraft. Continuing eastward, the tornado damaged several stone buildings and outbuildings at the vacant Tennessee State Prison. Several steel transmission towers were toppled as the tornado again crossed the Cumberland River.

The tornado entered north Nashville causing up to EF 2 damage to dozens of homes, apartments, church buildings, and businesses just north of Interstate 40, then crossed Interstate 65 where it entered the Germantown neighborhood and maintained its damage intensity of EF 2. The gable roof on the Mount Bethel Baptist Church was partially removed and a nearby metal

building had roof and wall panels removed and three bays of steel framing were bent. Both the O'Reilly Auto Parts and Auto Zone stores collapsed on Rosa Parks Boulevard.

The tornado again crossed the Cumberland River and intensified to EF 3 in the Five Points area collapsing several small retail buildings and strip shopping centers along Woodland Street. Two people died when they were caught out in the open and struck by flying debris. The tornado crossed South 10th Street and removed roofs off two restaurants before entering a residential area comprised of old, two-story wood homes. The East End United Methodist Church lost part of its roof and brick wall along with its masonry bell tower.

The tornado continued east through older residential areas causing up to EF 2 damage in the Lockeland Springs and Barclay Drive neighborhoods. Then, the tornado crossed the Cumberland River again and traveled through Donelson Hills and Lincoya Hills neighborhoods. The wood-framed sanctuary building at the St. John's Lutheran church, off McGavock Park Road, collapsed but the two-story office and classroom buildings remained.

In Standford Estates, several wood-framed homes collapsed and were rated EF 3 by the NWS. The south wing of the Donelson Christian Academy partially collapsed. This one-story building had wood roof trusses toe-nailed to wood top plates that were bolted to the top of bond beams at the top of CMU walls. The steel frame of a manufactured home was deposited on the remaining roof section.

The tornado crossed Lebanon Pike and Stones River destroying four metal buildings at a storage facility, then removed roof and wall panels from four metal buildings along Central Pike. Continuing to the east, the tornado destroyed the Dodson Chapel United Methodist Church and adjacent classrooms on Dodson Chapel Road. The church was a two-story brick clad building with steep gable roof comprised of wood rafters while the classroom building was one-story. To the south, the Dodson Chapel Childcare school building was heavily damaged. The flat roof on the gymnasium was removed leaving steel joists intact and the south end wall had toppled inward. The flat roof also was removed over a classroom and windows on the south wall blew inward.

The tornado continued eastward across Old Hickory Boulevard where it struck a strip shopping center removing portions of the roof and west-facing facade. Behind the shopping center to the east was the Meridian Hermitage Apartment Homes where six buildings sustained various degrees of damage to roofs and siding.

Dozens of homes sustained up to EF 2 damage as the tornado proceeded across Chandler Road and through the Triple Crown subdivision in Mount Juliet. Then, the tornado leveled numerous homes along Catalpa Drive and Clearview Drive where one elderly couple was killed in their home.

Next, the tornado crossed Mount Juliet Road striking the West Wilson Middle School. This large, one-story building had a flat roof supported by steel decking welded to open web steel joists. Ends of the joists were welded to plates imbedded into a concrete bond beam on top of CMU walls. The roof was removed over five classrooms at the southwest corner of the building and south and west CMU walls toppled in one classroom.

Just to the east of this school was Stoner Creek Elementary School. This school was also a one-story building with similar construction to the West Wilson Middle School. The roof was removed over the southernmost four classrooms. West walls were toppled inward and east walls were toppled outward.

Farther east, the tornado traveled through an industrial park comprised of several large warehouses. The CEVA warehouse on Athletes Way North was destroyed killing a security guard. The building was a three-story, steel-framed structure with interior steel framing. South and west wall panels fell inward while north and east wall panels fell outward. To the east on Volunteer Boulevard, the Dell building had similar construction, and was also destroyed. Then on Eastgate Boulevard, the similarly constructed Optoro building was also destroyed. The NWS rated the tornado damage in this area as high-end EF 3, the most severe damage in the path of the Nashville tornado.

After this industrial area, the tornado weakened to EF 2 as it traveled into Lebanon damaging many homes including a strip shopping center. The tornado finally lifted east of Highway 141 southeast of Gordonsville around 0735 UTC. Refer to Figure 2.

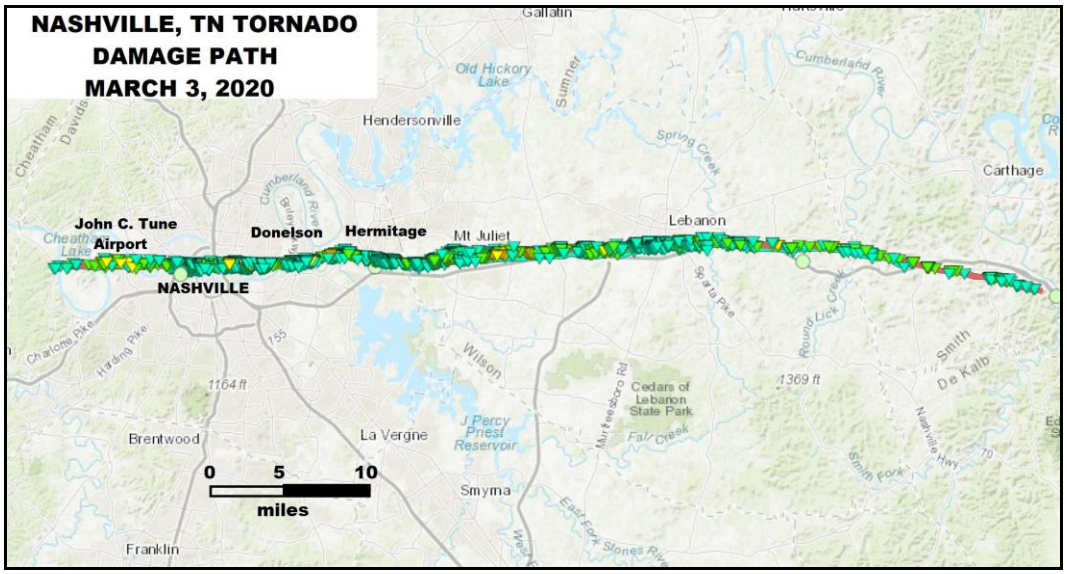

Fig. 2. DAT track of the Nashville tornado. Source: NWS

3. DAMAGE SURVEY

Given the thousands of buildings in the tornado path, it was not possible to closely examine every building. Cleanup began almost immediately with the first task being clearing the busiest roads. Therefore, our survey concentrated on evaluating the most severely damaged buildings with emphasis on studying different building types. The damage was "perishable" given that it occurred in a highly populated area with ample people and equipment to assist in rapid cleanup. This made it imperative for us to evaluate as many building types as possible within a short period of time. Measurements of path length, path width, and greatest damage intensity were of primary importance for the NWS. The survey was completed within days after the event. The following examples are presented to various DIs.

3.1 Residences (DI 2)

Hundreds of wood-framed residences were damaged by this tornado. The typical damaged home had a pitched roof with wood trusses or rafters toenailed to wall top plates. This was a "weak link" as toenailed connections were pulled out when the roofs were uplifted and removed. It was common to see roofs removed with most walls still standing.

Wood framed walls were erected on floor platforms where the wall bottom plates were straight nailed to the floor. Nails were placed indiscriminately in wall bottom plates and usually missed the floor joists; thus, walls were attached to the floor sheathing. This attachment was the another "weak link" and these walls had little lateral wind resistance once the roof was removed. We saw several homes where exterior walls fell over. Refer to Figure 3. In the 2006 EF-scale, the loss of the roof and some exterior walls is equivalent to DoD 6 in DI 2 with expected failure wind speeds of 55 m/s (122 mph). Refer to Table 1.

Floor joists were toenailed to sill plates resting on pier and beam or perimeter foundations. Sill plates were bolted to the top blocks of the CMU (concrete masonry unit) foundations.

Other homes had sill plates that were not anchored at all to their foundations. This was another "weak link" and these homes were susceptible to sliding off their foundations. As noted in the 2006 EF-scale document DI 2, a home sliding off its foundation has an expected failure wind speed of 54 m/s (121 mph).

The worst damage to residences was found in Donelson and Mt. Juliet where houses lost their roofs and had collapsed exterior walls with only interior rooms remaining. This damage was assigned DoD 8 with estimated failure wind speeds of 68 m/s (152 mph).

Table 1. DoDs for residences.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	65	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Exterior walls collapsed	132	113	153
8	Most walls collapsed, except small interior rooms	152	127	178
9	All walls	170	142	198
10	Destruction of engineered and/or well constructed residence; slab swept clean	200	165	220

* DOD is degree of damage

Fig. 3. Damaged home due to the tornado: A) loss of roof and a portion of the exterior frame wall, and B) failure point was where frame walls were attached to the floor (outlined in red).

3.2 Manufactured Homes (DI 3)

As expected, manufactured homes performed poorly in the tornado. These homes usually were anchored in the ground with metal straps and auger type anchors. However, either the straps broke, or the anchors pulled out of the ground as manufactured homes shifted off their stacked CMU piers. Some homes were not anchored at all as was the case with one we found at the Donelson Christian Academy. This home had been located just south of the school and was not anchored. The home disintegrated during the tornado and the steel frame was lofted to the north and deposited on the school. Refer to Figure 4.

According to the 2006 EF scale, complete destruction of a manufactured home (DI 3) is listed as DoD 9 with estimated failure wind speeds of 57 m/s (127 mph). Refer to Table 2.

Fig. 4. Steel frame of unanchored manufactured home deposited on the Donelson Christian Academy.

Table 2. DoDs for manufactured homes.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	61	51	76
2	Loss of shingles or partial uplift of one-piece metal roof covering	74	61	92
3	Unit slides off block piers but remains upright	87	72	103
4	Complete uplift of roof; most walls remain standing	89	73	112
5	Unit rolls on its side or upside down; remains essentially intact	98	84	114
6	Destruction of roof and walls leaving floor and undercarriage in place	105	87	123
7	Unit rolls or vaults; roof and walls separate from floor and undercarriage	109	96	128
8	Undercarriage separates from unit; rolls, tumbles and is badly bent	118	101	136
9	Complete destruction of unit; debris blown away	127	110	148

DOD is degree of damage

3.3 Apartments (DI 5)

Several apartment buildings were damaged or destroyed by the tornado in north Nashville. These buildings were up to three-stories and mostly wood-framed structures built on concrete foundations. Exterior walls were brick masonry, painted wood siding, or exterior insulation and finish system (EIFS).

Three studio style apartments collapsed in the 100 block of north 8th Street. These units were three-story, wood-framed structures. Close examination revealed failure occurred where the bottom plates were straight nailed into the ends of the wall studs. The nailed connections pulled out as the walls leaned to the north. Adjacent buildings lost windows due to flying debris but remained intact. There also was little to no damage to trees around the building. Refer to Figure 5.

According to the 2006 EF scale, the collapse of a three-story apartment building (DI 5) is not listed. However, total collapse of the top two stories is listed as DoD 6 with failure wind speeds of 80 m/s (180 mph). But given the failure of the straight nailed connections and lack of damage to the building surroundings, we lowered the failure wind speed to just 45 m/s (100 mph). Refer to Table 3.

Fig. 5. Part of a three-story apartment building that collapsed: A) outline of building, and B) closer view showing floor platform where base of wall was straight nailed.

Table 3. DoDs for apartment buildings.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	76	63	95
2	Loss of roof covering (<20%)	99	82	121
3	Uplift of roof decking; significant loss of roof covering (>20%)	124	107	146
4	Uplift or collapse of roof structure leaving most walls standing	138	120	158
5	Most top story walls collapsed	158	138	184
6	Almost total destruction of top two stories	180	155	205

* DOD is degree of damage

3.4 Small Retail Buildings (DI 8)

Several small, stand-alone retail buildings were damaged or destroyed by this tornado. One such building studied in detail was the Auto Zone store at 1210 US Highway 41 Alternate in north Nashville. This one-story building was constructed with load-bearing CMU perimeter walls and pre-cast, double tee concrete roof planks. Google Street View imagery, taken before the tornado, showed an array of large windows extended along the front of the building, which faced west. Strong west winds blew these windows inward and blew out the front half of the CMU walls causing that portion of the roof to collapse. Refer to Figure 6.

According to the 2006 EF scale, the partial collapse of a small retail building (DI 8) would be equivalent to DoD 7 with expected failure wind speeds of around 62 m/s (138 mph). Refer to Table 4.

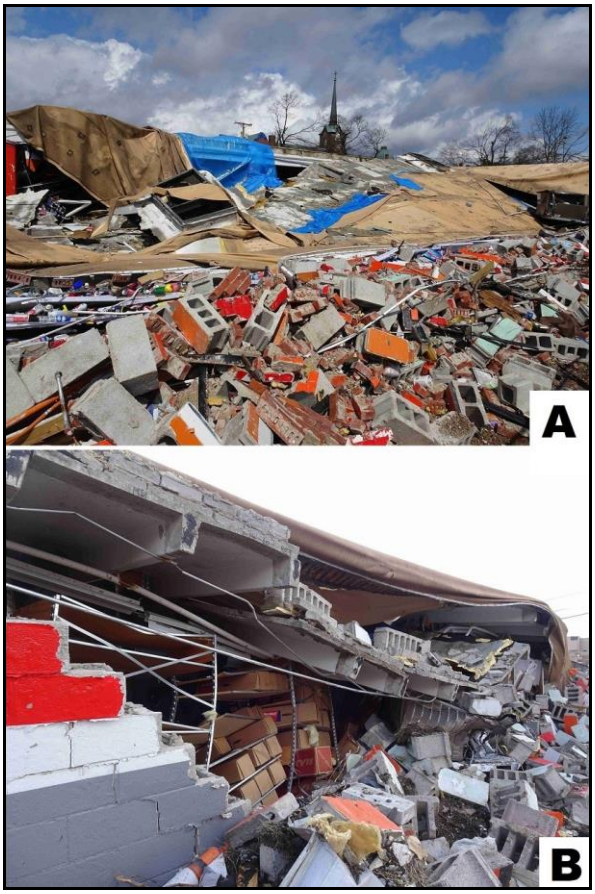

Fig. 6. Collapse of Auto Zone store: A) unreinforced, loadbearing, masonry walls, and B) heavy concrete tee roof deck.

Table 4. DoDs for small retail buildings.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	65	54	81
2	Loss of roof covering (<20%)	78	65	98
3	Broken glass in windows and doors	86	72	103
4	Uplift of roof decking; significant loss of roof covering (>20%)	98	81	119
5	Canopies or covered walkways destroyed	98	83	114
6	Uplift or collapse of entire roof structure	119	101	140
7	Collapse of exterior walls; closely spaced interior walls remain standing	138	120	159
8	Total destruction of entire building	167	143	193

* DOD is degree of damage

3.5 Strip Mall (DI 10)

We closely examined a strip mall at 943 Woodland Street in Nashville. This rectangular-shaped building was oriented northeast-southwest; the front faced southeast. The building was constructed with CMU walls. The two southwesternmost stores had open web steel roof joists supporting steel roof decking whereas the remainder of the building had been roofed with precast concrete tees. Large windows were located along the front of the building.

The strongest winds from the tornado were from the southwest which caused the southwest end of the building to topple inward. Roof joists and decking also were uplifted on the two southwesternmost stores. Close examination revealed the ends of the steel roof joists were welded to plates that were nailed to a wood nailer secured to the tops of the CMU walls. The nailed connections pulled apart as the steel joists were uplifted. Refer to Figures 7 and 8.

According to the 2006 EF scale for strip shopping malls (DI 10), collapse of exterior walls with interior walls remaining would be DoD 8 with an expected failure wind speed of 63 m/s (140 mph). Refer to Table 5.

Fig 7. Strip shopping center: A) before the tornado on Google Street View, and B) after the tornado.

Fig 8. Damage to a strip mall: A) toppling of the southwest unreinforced masonry wall, B) loss of roof decking, C) steel joist hanging off wall, and D) nails (circled) in steel plate had pulled out of wood nailer secured to the top of the CMU wall.

Table 5. DoDs for strip malls.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	65	54	81
2	Uplift of roof covering at eaves and roof corners	80	66	100
3	Broken windows or glass doors	88	72	105
4	Uplift of roof decking	101	84	122
5	Collapsed façade or parapet walls	103	85	125
6	Covered walkways uplifted or collapsed	103	86	125
7	Uplift or collapse of entire roof structure	122	103	143
8	Collapse of exterior walls; closely spaced interior walls remain standing	140	117	165
9	Complete destruction of all or a large section of building	171	147	198

* DOD is degree of damage

3.6 Elementary Schools (DI 15)

We studied tornado damage to four schools. These were the Donelson Christian Academy, Dodson Chapel Childcare, Stoner Creek Elementary, and West Wilson Middle School.

3.6a Donelson Christian Academy

The Donelson Christian Academy in Nashville was a large complex of interconnected one- and two-story buildings located on the east side of Nashville. The tornado struck only the south wing of the school which was a one-story structure with CMU walls and had wood-framed roof trusses. Ends of the trusses were toenailed to wood nailers at the tops bolted to bond beams on top of the CMU walls. The exterior walls were clad with brick masonry. Each classroom contained a pair of windows adjacent to steel exit doors.

The strongest winds from the tornado were from the west. Masonry walls failed in V-shaped

patterns centered on the doors and windows. Thus, the west ends of the roof trusses were no longer attached to the walls. The interior hallway remained intact, although, most of the gypsum board clad ceiling fell to the floor. Refer to Figure 9.

According to the 2006 EF scale for elementary schools (DI 15), collapse of loadbearing walls would be DoD 9 with total destruction of a large section of the building being DoD 10. However, less than half of this building was totally destroyed. Therefore, the survey team selected DoD 9 with an estimated failure wind speed of 68 m/s (158 mph). Refer to Table 6.

Fig 9. Damage to Donelson Christian Academy: A) collapse of south wing, B) masonry wall collapse around doors and windows (yellow outlines) with bond beams remaining (arrows), C) toe nailed roof truss, and D) interior hallway.

Table 6. DoDs for elementary schools.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	65	47	80
2	Loss of roof covering (<20%)	79	66	99
3	Broken windows	87	71	106
4	Exterior door failures	99	85	118
5	Uplift of some roof decking; significant loss of roofing material (>20%); loss of rooftop HVAC	101	82	121
6	Damage to or loss of wall cladding	108	92	127
7	Uplift or collapse of roof structure	125	108	148
8	Collapse of non-bearing walls	139	117	162
9	Collapse of load-bearing walls	153	130	180
10	Total destruction of a large section of building or entire building	176	152	203

* DOD is degree of damage

3.6b Dodson Chapel Childcare

Dodson Chapel Childcare in Hermitage was with an old, L-shaped school building that was a wood-framed structure with red brick exterior with large windows. The long dimension of the school was north-south. The school had a hip type roof covered with asphalt shingles. A gymnasium, at the southwest end of the school, was constructed with unreinforced CMU walls with open web steel roof joists.

The strongest winds from the tornado were from the south. South windows blew inward, and internal pressure helped remove the roof over the southern end of the school. Similarly, the south end wall of the gymnasium fell inward, and the roof deck was removed leaving the steel joists intact. Refer to Figures 10 and 11.

Damage to this school was consistent with DoD 9 for DI 15 in the 2006 EF scale with estimated failure wind speeds around 68 m/s (158 mph). Refer to Table 6.

Fig. 10. Damage to classroom at the Dodson Chapel United Methodist Childcare: A) windows toppled inward at hinge line (red line and arrow), B) closer view showing wood nailer (arrow), and C) nails pulled out of wood window frame.

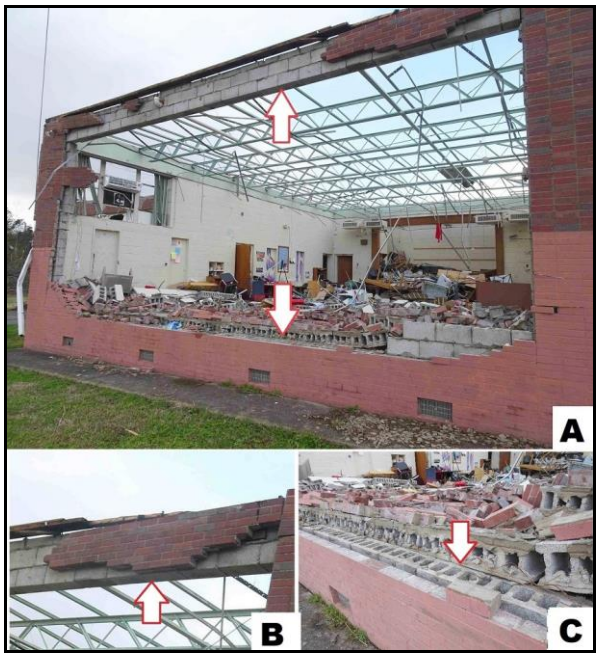

Fig. 11. Damage to the gymnasium at the Dodson Chapel United Methodist Childcare: A) removal of roof deck and toppling of masonry end wall (arrows indicate failure plane), B) lack of vertical steel reinforcement at the top of wall, and C) lack of vertical steel reinforcement at base of wall.

3.6c West Wilson Middle School

The West Wilson Middle School in Mt. Juliet was a sprawling, one-story school constructed with unreinforced loadbearing CMU walls and exterior brick masonry. There were steel reinforced bond beams at the tops of the CMU walls that supported open web steel roof joists and steel roof decking.

The tornado struck the southern portion of this school toppling the south and west walls into four classrooms and removing the roof decking and steel joists above six classrooms. Masonry bond beams were left hanging as a catenaries between columns. The vast majority of the school remained intact without structural damage. Refer to Figure 12.

Damage to this school was consistent with DoD 9 for DI 15 in the 2006 EF scale with estimated failure wind speeds around 68 m/s (158 mph). Refer to Table 6.

Fig.12. Damage to West Wilson Middle School. A) Drone image looking east, B) destruction of southwest classrooms, C) base of masonry wall toppled inward, and D) bond beams (arrow) hanging between supports.

3.6d Stoner Creek Elementary

Just east of the West Wilson Middle School was Stoner Creek Elementary. This was a one-story building with three wings extending northeast, northwest and southeast. Only the southeast wing of the school was damaged by the tornado. The building was comprised of CMU walls with bond beams at the tops of the walls and open web steel roof joists. Ends of the joists were welded to steel plates with welded studs that were embedded into the concrete bond beams. However, the welded studs were too long to fit into the troughs of the bond beams, and so they had been mechanically bent. The steel roof deck was topped with lightweight concrete fill.

The tornado toppled west facing CMU walls into two of the southwesternmost classrooms and removed the roof system above these rooms. Debris crashed through the roof of one classroom on the opposite side of the school wing. Refer to Figure 13.

Damage to this school was consistent with DoD 9 for DI 15 in the 2006 EF scale with estimated failure wind speeds around 68 m/s (158 mph). Refer to Table 6.

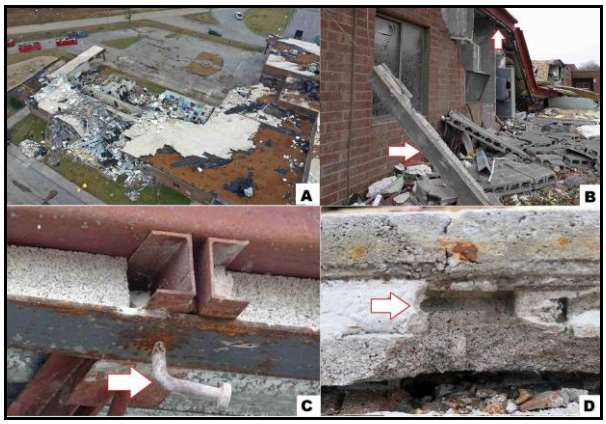

Fig. 13. Damage to Stoner Creek Elementary: A) collapse of CMU walls and roof due to poor attachments, B) lack of bond beam (horizontal arrow) attachment to wall, C) bent pegs at roof that were merely set into mortar channel along D) tops of bond beams.

3.7 Metal Building Systems (DI 21)

Several metal building systems were destroyed by the tornado including 13 hangars at John C. Tune Airport. However, we were not able to access the airport property during our survey due to tight security. According to the 2006 EF scale, total destruction of a metal building is DoD 8 with expected failure wind speeds of 69 m/s (155 mph).

We closely examined the metal building system containing the Nashville Boating Center. Strong south winds pushed the south wall inward and anchor bolts securing the column base plates broke. By contrast, the north half of the building remained intact. Damage to the building was between DoD 5 and 7 in the 2006 EF scale with an average expected failure wind speed of 58 m/s (130 mph). Refer to Figure 14 and Table 7.

Table 7. DoDs for metal building systems.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	67	54	83
2	Inward or outward collapsed of overhead doors	89	75	108
3	Metal roof or wall panels pulled from the building	95	78	120
4	Column anchorage failed	117	96	135
5	Buckling of roof purlins	118	95	138
6	Failure of X-braces in the lateral load resisting system	138	118	158
7	Progressive collapse of rigid frames	143	120	168
8	Total destruction of building	155	132	178

* DOD is degree of damage

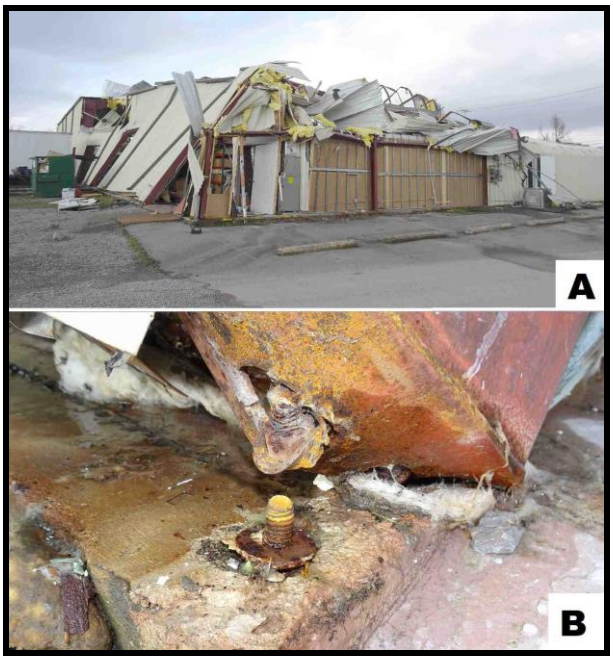

Fig. 14. Metal building that was surveyed: A) progressive collapse of steel frames leaning north, and B) typical broken anchor bolt and deformed base plate at base of column.

3.8 Warehouse Buildings (DI 23)

Several large warehouse-type buildings were damaged or destroyed in Mt. Juliet including the three-story, CEVA Logistics building on Athletes Way North. This 274 m (900 ft) long building was completely flattened by the tornado except for the wall panels at the southwest and southeast corners of the building. There was a steel framed interior enclosed with precast concrete wall panels. The bases of the wall panels were anchored to the concrete slab. As the wall panels toppled, the anchor rods either broke or were pulled out of the concrete slab foundation. Refer to Figure 15.

According to the 2006 EF scale, total destruction of a warehouse type building is DoD 7 with estimated failure wind speeds of 71 m/s (158 mph). Refer to Table 8.

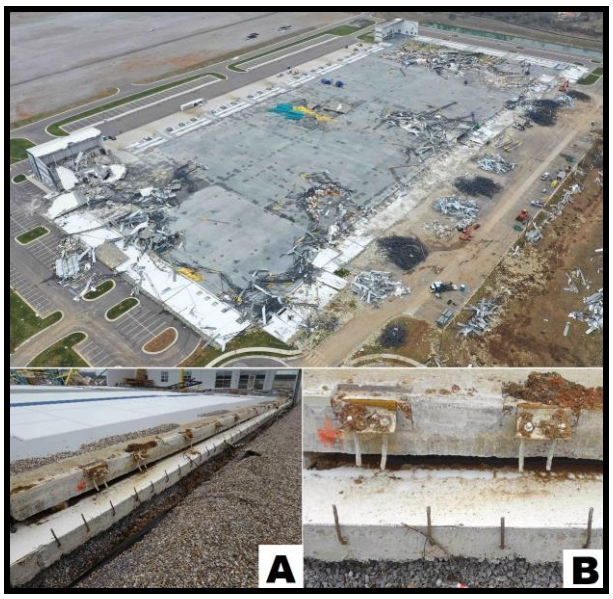

Fig. 15. Complete destruction of warehouse building: A) drone view of collapsed building, B) fallen wall panel, and C) closer view showing connection details at base of wall.

Table 8. DoDs for warehouse buildings.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	68	55	83
2	Loss of roofing material (<20%)	83	69	105
3	Inward or outward collapse of overhead doors	88	75	107
4	Uplift of roof deck; significant loss of roofing material (>20%); loss of rooftop HVAC equipment	103	88	122
5	Collapse of other non-bearing exterior walls	114	93	126
6	Collapse of pre-cast concrete tilt-up panels	124	102	144
7	Total destruction of a large section of building or entire building	158	131	186

* DOD is degree of damage

3.9 Electrical Transmission Lines (DI 24)

Several steel trussed towers, tapered steel poles, and wood poles were toppled by the tornado. According to the 2006 EF-scale, the collapse of a steel truss tower is DoD 6 with an estimated failure wind speed of 63 m/s (141 mph). The bent, tapered steel pole is DoD 5 with an estimated failure wind speed of 62 m/s (138 mph) and the broken wood pole is DoD 4 with an estimated failure wind speed of 53 m/s (118 mph). Refer to Figure 16 and Table 9.

Fig 16. Damage to electrical transmission systems: A) toppled steel truss tower, B) bent tapered steel pole, and C) broken wood pole.

Table 9. DoDs for electrical transmission systems.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	83	70	98
2	Broken wood cross member	99	80	114
3	Wood poles leaning	108	85	130
4	Broken wood poles	118	98	142
5	Broken or bent steel or concrete poles	138	115	149
6	Collapsed metal truss towers	141	116	165

* DOD is degree of damage

3.10 Free-Standing Light Poles (DI 26)

Free-standing, tapered steel light poles were bent or toppled in sports fields and parking lots of Donelson Christian Academy, West Wilson Middle School, and Stoner Creek Elementary School. There also was a steel flagpole bent to the south at Donelson Christian Academy. Some of the steel light poles at West Wilson Middle School were mounted on concrete piers which broke as the poles collapsed. Refer to Figures 17 and 18.

According to the 2006 EF-scale, the collapse of a free-standing pole is DoD 3 with an estimated failure wind speed of 53 m/s (118 mph) while bent poles are DoD 2 with an estimated failure wind speed of 46 m/s (102 mph). Refer to Table 10.

Table 10. DoDs for free-standing poles.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	81	67	100
2	Bent pole	102	85	120
3	Collapsed pole	118	99	138

* DOD is degree of damage

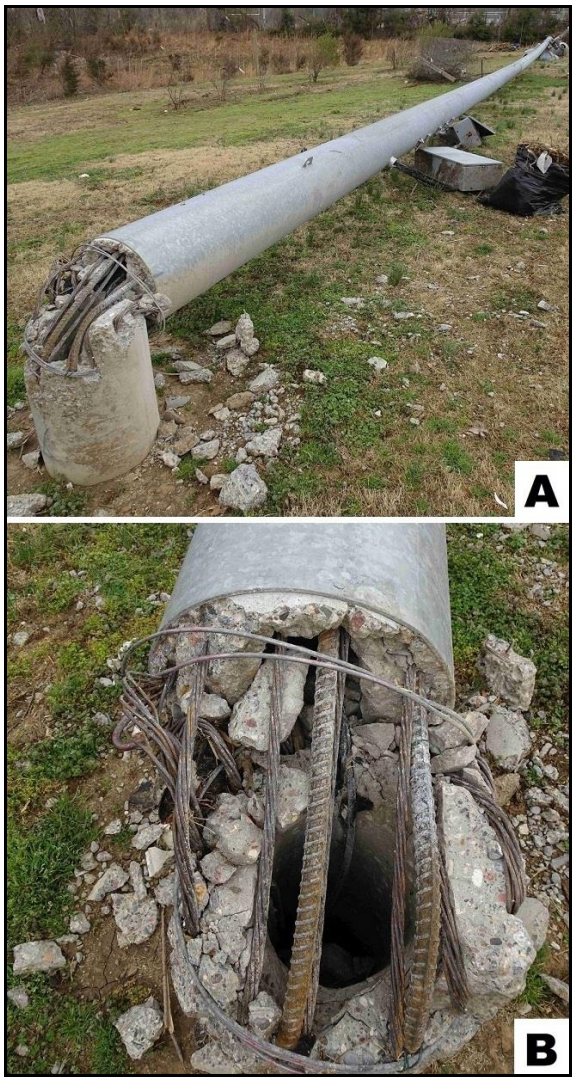

Fig. 17. Broken pier cap which supported tapered steel light pole: A) overall view, and B) close-up view of broken concrete pier.

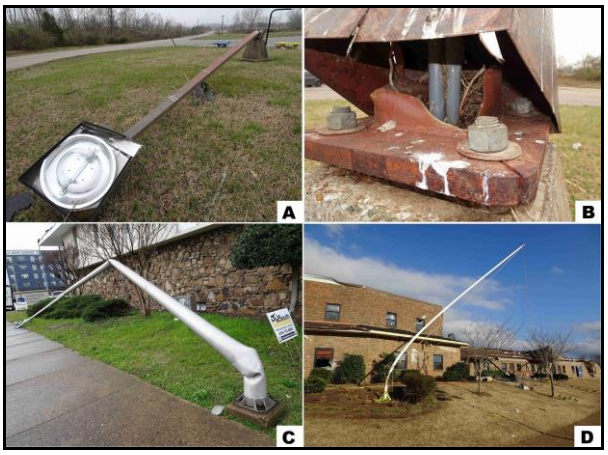

Fig. 18. Pole failures: A) failed steel pole, B) torn steel pole, C) toppled aluminum light pole, and D) bent steel flagpole.

3.11 Religious Buildings (new proposed DI)

Dozens of church buildings were damaged or destroyed by this tornado. Several church buildings were studied in detail since religious buildings will be added to the updated version of the EF-scale. In this paper, church buildings were considered low-rise buildings in the 2006 EF-scale.

The Mount Bethel Baptist Church was a one-story brick masonry building with gable roof comprised of steel trusses. Wood nailers were bolted to the tops of the steel trusses and wood roof joists were toenailed to the nailers. Strong south winds from the tornado removed the entire south roof slope with the failures occurring at the toenailed connections. Steel roof trusses remained intact. Using the 2006 EF-scale, the DoD for this building was between 3 and 6 with an average estimated failure wind speed of 55 m/s (122 mph). Refer to Figure 19 and Table 11.

The Liberty Christian Church was a one- and one-half story brick masonry building with steep gable roof comprised of steel trusses. The building was rectangular in plan with the long dimension oriented north-south; the front faced south. The back (north) wall was built with CMU (concrete masonry units). Strong south winds from the tornado pushed the south gable end inward and internal pressure helped topple the north end wall.

Again, using the 2006 EF-scale, the DoD for this building was between 3 and 6 with an average estimated failure wind speed of 55 m/s (122 mph). Refer to Figure 19 and Table 11.

The East End United Methodist Church was a large, two story, L-shaped building oriented north-south; the front faced north. This building had a steep gable roof and failed in a similar manner to the Liberty Christian Church. However, this church also had a four plus story bell tower which completely collapsed. In addition, the small wing of the building contained classrooms and lost its flat roof and east wall. This building sustained damage closer to DoD 6 with estimated failure wind speeds around 64 m/s (143 mph).

The St. John's Lutheran Church was comprised of three interconnected wood-framed buildings that were one and two stories. The easternmost building contained the sanctuary and had a steep, gable roof. Strong east winds toppled the east wall of the sanctuary and this building completely collapsed. By contrast, the adjacent building with low-pitched hip roof sustained only shingle damage while the building to the north experienced inward failure of the east masonry wall and partial loss of the east gable end. All three buildings had different degrees of damage, ranging from DoD 3 to DoD 7. Thus, we averaged the DoDs to obtain an estimated failure wind speed of 65 m/s (145 mph).

Fig. 19. Various degrees of damage to churches: A) loss of roof, B) toppled end wall, C) toppled bell tower and brick façade, and D) collapse of sanctuary.

Table 11. DoDs for low-rise buildings.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	68	55	83
2	Loss of roof covering (<20%)	80	67	103
3	Uplift of metal roof decking at eaves and roof corners: significant loss of roofing material (>20%)	101	83	120
4	Broken glass in windows, entryways or atriums	101	83	122
5	Uplift of lightweight roof structure	133	114	157
6	Significant damage to exterior walls and some interior walls	143	122	167
7	Complete destruction of all or a large section of building	188	161	221

* DOD is degree of damage

4. NON-DAMAGE INDICATORS

We documented damage to various other items not included in the original EF-scale document such as rolled up chain link fencing and toppled stone monuments at a cemetery. Both these items were located adjacent to the West Wilson Middle School in Mt. Juliet. Recall we estimated the failure wind speed at the school as 68 m/s (158 mph). Refer to Figures 20 and 21.

Fig 20. Rolled up chain-link fence at West Wilson Middle School.

Fig. 21. Toppled gravestones adjacent to West Wilson Middle School.

5. SUMMARY

A long-tracked tornado tracked through Nashville then eastward through adjacent communities on March 3, 2020, damaging more than one dozen different building types including four schools and dozens of churches. Several metal buildings, and large, isolated retail buildings collapsed. The authors spent the next several days surveying the damage as assigning DoDs to various DIs using the 2006 EF-scale. The NWS determined the maximum damage intensity of this tornado was EF 3 with the worst damage being in Donelson and Mt. Juliet areas. Several dozen homes and small retail buildings sustained EF 3 damage. We also found EF 3 damage to a strip mall, elementary school, metal building systems, warehouse buildings, and religious buildings. We found that use of a drone helped ascertain degrees of damage, especially damage to roofs that could not been observed from the ground.

This survey also provided additional information to update the next version of the EF-scale which is now in progress. Religious buildings will be a separate DI, so the survey team paid particular attention to this building type.

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7. REFERENCES

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