

**APA**

DECEMBER 2015

# Texas Tornado

**DAMAGE ASSESSMENT REPORT**



STRUCTURAL PERFORMANCE OF  
MODERN HOMES CONSTRUCTED  
IN THE DALLAS SUBURBS OF  
GARLAND AND ROWLETT, TEXAS

# Findings From Texas Tornado Inform High Wind Design

On December 26, 2015, a tornado tore through the suburban Dallas, Texas, towns of Garland and Rowlett, causing significant damage to homes. Shortly after the storm occurred, APA sent a team into the impact area to assess and study the damage. The findings of the damage assessment are presented in this report. The extensive forensic evidence suggests that while the tornado may have reached the EF4 rating in some isolated areas, much of the damage occurred along the outer edges of the storm's path, where wind speeds appeared to be much lower.

It is challenging to design homes to withstand the higher force winds of an EF3, EF4, or EF5 tornado. There are, however, cost-effective design details that builders and designers can implement to significantly mitigate storm damage, especially in areas along the outer reaches of the area influenced by the storm vortex. By understanding how high wind forces work and how good design and construction practices can improve the storm resistance of a home's structural shell, home damage in future storms can be minimized.





## OVERVIEW OF DAMAGE ASSESSMENT

Damage observations were conducted by APA after the December 26, 2015, tornado that heavily impacted the suburban Dallas towns of Garland and Rowlett, Texas. The tornado resulted in EF4 damage in Garland, the first EF4 or stronger tornado ever recorded in December in Texas. According to the National Weather Service, this tornado resulted in at least 13 fatalities and was part of a larger winter storm that included 12 confirmed tornadoes, mainly across North Texas. Three of the 12 tornadoes were rated by the National Weather Service as EF2 or greater with the most intense damage occurring with the Garland-Rowlett tornado between 6:45 and 7:02 PM CST.

Tornadoes are classified according to the maximum rating that occurs along the tornado path. Despite the EF4 maximum rating for this tornado, less than two percent of the total area impacted along the 13-mile path was estimated to be rated EF4, producing maximum winds estimated between 170–180 MPH. Based on the damage indicators such as effects on one- and two-family homes (loss of roof coverings, structural damage) and the effect on trees (broken limb sizes, uprooting), estimates were made as to wind speed. On the ground, a high degree of variability in maximum wind speeds was observed, often varying widely from one block to the next.

Note that exact data on wind speeds in the area of the actual event is unavailable. As stated on the National Weather Service website devoted to the EF-Scale, “IMPORTANT NOTE ABOUT ENHANCED F-SCALE WINDS: The Enhanced F-Scale still is a set of wind estimates (not measurements) based on damage. It uses three-second gusts estimated at the point of damage based on a judgment of 8 levels of damage. These estimates vary with height and exposure. Important: The 3 second gust is not the same wind as in standard surface observations. Standard measurements are taken by weather stations in open exposures, using a directly measured, and ‘one-minute mile’ speed.”

This study focused on the performance of more recently constructed homes. Newer homes tend to contain newer materials, larger interior spaces and more open floor plans that may have an effect on building design and strength to resist wind forces.

Observations of the tornado damage found that structural failure in homes was often due to a lack of adequate connections. Engineers use the term “load path” to describe how forces flow through a structure and connections from the point of origin to the foundation. A continuous load path from the roof coverings and siding (exterior cladding) to the framing and to the foundation must be provided for reliable building performance. As with many post-damage assessments, most of the homes observed failed as a result of poor continuity along the structural load path.

Despite a tornado watch that was in effect for the area, falling darkness, heavy rain, and rapid forward movement acted to obscure the tornado from visual detection. The National Weather Service reports that most tornadoes last less than 10 minutes, so there is often little warning to those who are in the tornado path. Tornado sirens and other warning systems are not a given and depend largely on varying local infrastructure for implementation. For these reasons, storm shelters cannot always be relied upon as the only option for tornado safety. The first line of defense against high wind events should always be a house constructed with a wind-resistant shell that can protect the building and contents against catastrophic loss in all but the most severe tornado conditions. Because key structural upgrades can be done in a cost-effective manner, the additional consideration of a storm shelter can still be within many homeowners’ budgets.

## HIGH WIND CONSTRUCTION RECOMMENDATIONS

After the April 2011 Tornado Super Outbreak in the southeastern United States, the largest, costliest, and one of the deadliest tornado outbreaks ever recorded, APA developed a list of recommendations that can be applied to homes designed according to the International Residential Code (IRC), *Building for High Wind Resistance in Light-Frame Wood Construction*, Form M310.

The recommendations in APA's high wind construction guide were largely reproduced in the state of Georgia's wind-resistive recommendations now contained in the *Georgia Disaster Resilient Building Code (DRBC)*. These recommendations were developed through a grant from the U.S. Department of Housing and Urban Development (HUD) by a publicly-formed task group of stakeholders organized by the Georgia Department of Community Affairs. Implemented as Appendix R to the IRC, the DRBC Appendices are optional regulations that local jurisdictions may adopt, in whole or in part, through local ordinance.

### Observations

In the recent Texas tornado of December 26, 2015, failures observed along the structural load path were often located at the roof-to-wall intersection. Most of the roof rafter-to-wall connections in this area were made using toenails through the roof framing and into the top plate of the exterior walls. Toenail connections are weak because they rely upon the withdrawal strength of nails, which is limited. Commonly available light-gauge metal connectors provide good performance in wood framing because the load is resisted in the directions perpendicular to the nail shank, instead of pulling the nail straight out. These metal connectors were only observed in one case among the homes where loss of the roof structure occurred.

A number of different types of failures were observed:

- Failures along roof-to-wall construction
- Breaches in the building envelope
- Inadequate attachment of exterior walls to the foundation
- Failures associated with flexible wall sheathing

#### Failures along roof-to-wall construction

Toenail rafter connections are still prescriptively allowed in most non-hurricane areas by modern building codes. It is generally recognized that toenail connections do not provide the capacity to resist wind pressure requirements of buildings in high wind areas, as indicated in the code-referenced document ASCE 7, *Minimum Design Loads for Buildings and Other Structures*.

#### Breaches in the building envelope

Breaches in the building envelope and the resulting pressurization of the building interior caused significant failure in many of the damaged homes. Openings in walls due to loss of doors, windows, and cladding systems were common. Large breaches from loss of weak garage doors and exterior cladding systems resulted in interior pressurization and exacerbated deficiencies within the aforementioned load path. Pressurized buildings often fail suddenly with catastrophic results. Total garage failures were observed in a multitude of locations and in areas with low to moderate wind speeds.



### ***Inadequate attachment of exterior walls to the foundation***

Another common observation across a wide range of wind severity was the loss of exterior walls due to poor attachment to the foundation. In many of these cases, powder-actuated pins of varying lengths were used to attach the bottom of support walls to the concrete-slab foundations. Although equivalent systems are allowed to be substituted, modern building codes generally specify deformed steel anchor bolts to be embedded into reinforced concrete foundations for attachment of wood framing.



### ***Failures associated with flexible wall sheathing***

Most of the homes observed as a part of this survey were sheathed on exterior walls with a flexible laminated-fiber sheathing that measured approximately 1/8 inch in thickness. The walls were either fully or mostly clad with brick veneer on the exterior. Common problems in the strength of walls sheathed with laminated fiber included poor load-path continuity of framing within wall systems, especially at wall corners, and within wall systems stacked vertically between stories. These walls also performed poorly in resisting racking forces from lateral wind loads.



Relatively flexible walls sheathed with laminated fiber were found to be largely incompatible with brittle brick veneer. In many cases, brick veneer walls were observed to have been damaged due to excessive out-of-plane (transverse) or in-plane deformation, which was exacerbated by poor installation of brick ties. Falling brick from veneered walls, columns, and chimneys were observed in many cases in the impacted areas and across a wide range of wind speeds. Falling brick represents a considerable threat to life safety. In an area with widespread use of brick in single-family homes, cracked and collapsed brick were major contributors to residential property damage in this event.

## **BUILDING FOR GREATER RESILIENCY**

This survey focused on the performance of homes constructed within the last 10 to 15 years. In most cases, engineers can point to one of several common weak links as the cause of structural failure in homes damaged in this event. It is difficult to learn much, if anything, from homes that are completely or mostly destroyed by tornadoes. For this reason, damage assessment of homes in this report are mostly limited to those in the lower EF0 through EF2 tornado wind speed ratings.

It is possible to do a far better job of protecting a home's occupants and their possessions than the homes that were observed within the affected areas of this tornado. Similar to common designs found in hurricane-prone areas, wind-resistant structural-shell designs are straightforward and easy to implement. They also represent a relatively small increase in construction cost over houses built to code minimums. By following a few simple guidelines, the chances of a home surviving a tornado can be improved dramatically over homes constructed to residential-code minimums.

The following APA recommendations, many of which exceed the minimum requirements of current residential codes, address the most common weak links and provide guidance in constructing a wind-resistant shell. Besides labor, the additional expense for materials is largely from additional nails, roof-to-wall metal connectors, anchor bolts and larger plate washers at anchor-bolt locations. All of these are commonly available and are compatible with standard prescriptively constructed homes based on the IRC. These recommendations include:

1. Nail roof sheathing with 8d ring shank (or deformed shank) (0.131 inch x 2-1/2 inches) nails at 4 inches on center along the ends of the sheathing and 6 inches on center along intermediate framing.
2. Tie gable-end walls back to the structure. One of the weakest links in residential structures during high wind events is the connection between the gable end and the wall below.
3. Sheath gable-end walls with wood structural panels, such as plywood or oriented strand board (OSB). In the 2011 tornadoes, gable-end wall failures were frequently observed when non-structural sheathing was used under vinyl siding.
4. For the roof framing-to-wall connection, use an H1 or equivalent metal connector attached on the exterior (sheathing side) of the exterior walls. The roof-to-wall connection under high wind loads is subject to both uplift and shear due to positive or negative wind pressure on the walls below.
5. Nail upper story sheathing and lower story sheathing into common wood structural panel Rim Board®. The most effective way to provide lateral and uplift load continuity is to attach adjacent wall sheathing panels over common framing, such as rim board.
6. Nail wall sheathing with 8d common (0.131 inch x 2-1/2 inches) nails at 4 inches on center at end and edges of wood structural panels and 6 inches on center in the intermediate framing. This enhanced nailing will improve the resistance of the wall sheathing panels to negative wind pressure. Staples offer less resistance to blow-off than nails, so a greater number of them are required to achieve the same level of resistance.
7. Continuously sheath all walls with wood structural panels including areas above and below openings, such as windows and doors.
8. Ensure that wood structural panel sheathing overlaps and is properly fastened to the sill plate. When the first story floor is framed over a basement or crawlspace, extend wood structural panel sheathing over the rim board to lap the sill plate. The connection of the wall sheathing panel to the sill plate is important because this is where lateral forces are transferred from the wall into the sill plate and then into the foundation through the anchor bolts.
9. Space 1/2-inch anchor bolts 32 inches to 48 inches on center with 0.229 x 3 x 3-inch square plate washers with slotted holes.

## SUMMARY

It is important to learn from forensic assessments of storm damaged buildings. The objective of such research is not to place blame or find fault, but rather to improve construction practices so that home damage can be minimized in future wind events. The concept of building a storm-resistant shell or building envelope has attracted greater interest in recent years due to severe weather events and their impact on densely populated residential areas. Misconceptions about tornado strength are often used to justify a lack of attention to structural details. A common myth is that all tornadoes are too powerful, and structural failure is unavoidable no matter how well a building is constructed. This rationale results in homes that lack adequate attention to important structural details.

In truth, homes can easily be built to survive a majority of tornadoes. Statistically, weaker tornadoes rated as EF0, EF1 and EF2 comprise 95 percent of all tornadoes. These smaller, less-violent tornadoes produce winds which a carefully constructed home can be expected to withstand.

Stronger tornadoes with a maximum rating of EF3, EF4 and EF5 are statistically much rarer and represent less than 5 percent of the total. Although the maximum wind forces in stronger tornadoes are harder to resist, improvements in design can still help. This is especially the case when a building is located along the periphery of a strong tornado path. Stronger building components combined with more intentionally constructed connections can mean the difference between homes that survive tornadoes and those that don't.

In response to these facts, APA developed wind-resistant details for creating more robust homes with little added expense. Based on previous damage assessments, APA believes that much of the tornado damage observed as a part of this report could have been prevented by following the guidelines in *Building for High Wind Resistance in Light-Frame Wood Construction*, Form M310. Since publication of these guidelines in 2011, many have been incorporated into local building codes such as the *Georgia Disaster Resilient Building Code*. These recommendations do not represent a departure from the International Residential Code, but are supplemental to the code provisions for wood systems that are most commonly used for residential construction in North America.

Builders and homeowners should understand that there are measures that can make homes safer in storms. By following simple guidelines, the chances can be improved dramatically that a home might survive a tornado. First, securely attach OSB or plywood sheathing to integrate the framing. Thoughtful location of horizontal joints in the wall sheathing can eliminate common discontinuities in wall framing and at the floor system Rim Board. Next, connect roof framing to the walls using metal connectors instead of just toenails. Lastly, to complete the load path, attach the bottom plate of the wall to the foundation with anchor bolts and large plate washers.

This type of construction can improve building performance and safety for occupants in areas susceptible to tornadoes. Builders who incorporate these details can improve marketability of their products, resulting in better peace of mind for their customers. Once homeowners become aware of these options, demand is likely to increase for better safety provisions in single-family home construction.



FIGURE 1:

This damage survey map is from the National Weather Service. Contours shown on the map are based on damage assessment observations made on the ground after the event. Source: National Weather Service.

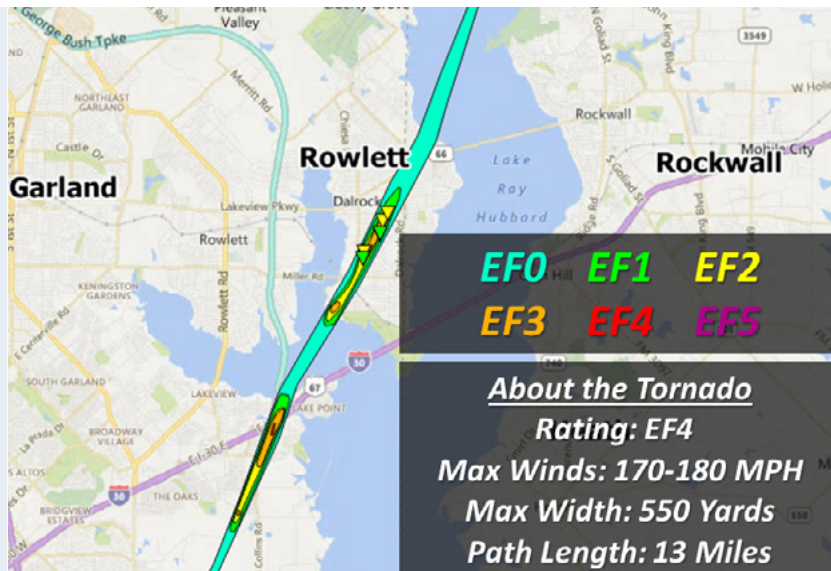








FIGURE 2:

This is a chart of EF-Scale with wind speeds and relative frequencies of all tornadoes. Note the description of damage and the guidance it gives for tornado ratings. The EF-Rating for a given tornado is the maximum rating for which the tornado is assessed along its path. The maximum rating for the Sunnyvale/Garland/Rowlett tornado was EF4. However, the EF4 rating was given for only a small percentage of the tornado impact area. Source: National Weather Service.

Scale	Wind Speed (Estimated)	Relative Frequency	Potential Damage	Example of Damage
EF0	65-85 mph	53.5%	<b>Minor or no damage.</b> Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over. Confirmed tornadoes with no reported damage (i.e., those that remain in open fields) are always rated EF0.	
EF1	86-110 mph	31.6%	<b>Moderate damage.</b> Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.	
EF2	111-135 mph	10.7%	<b>Considerable damage.</b> Roofs torn off well-constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.	
EF3	136-165 mph	3.4%	<b>Severe damage.</b> Entire stories of well-constructed houses destroyed; severe damage to large buildings such as shopping malls; trains overturned; trees debarked; heavy cars lifted off the ground and thrown; structures with weak foundations are badly damaged.	
EF4	166-200 mph	0.7%	<b>Extreme damage.</b> Well-constructed and whole frame houses completely leveled; cars and other large objects thrown and small missiles generated.	
EF5	>200 mph	<0.1%	<b>Total destruction of buildings.</b> Strong framed, well-built houses shifted off foundations and swept away; steel-reinforced concrete structures are critically damaged; tall buildings collapse or have severe structural deformations; some cars, trucks and train cars can be thrown approximately 1 miles (1.6 kilometres).	



**FIGURE 3:**

A damage indicator is a group of objects that can be used to evaluate a tornado's severity. The EF-Scale currently has 28 damage indicators, or types of structures and vegetation, each with a varying number of degrees of damage. The larger the degree of damage, the higher the estimated wind speed and corresponding tornado rating. The primary damage indicators used in the analysis for this report are one- or two-family residences and hardwood trees.

**DAMAGE INDICATOR #27 TREES, HARDWOOD**

Degree of Damage	Damage
1	Small limbs broken (up to 1" diameter)
2	Large branches broken (1-3" diameter)
3	Trees uprooted
4	Trunks snapped
5	Trees debarked with only stubs of largest branches remaining

Source: National Weather Service (See References, pg. 26)

**FIGURE 4:**

Damage indicators in this area impacted by the tornado in Rowlett, TX, include homes and trees. The degree of damage observed to trees in this area (branches broken 1 to 3 inches in diameter,) is consistent with a rating of EF1. Damage to homes visible in this photo is consistent with other homes in this area that were found to be poorly constructed.

**FIGURE 5:**

A home on Barton Creek Drive, Rowlett, TX, constructed in 1992. In areas where lower wind speeds were experienced, homes fully clad with brick veneer commonly experienced cracking in the veneer adjacent to corners. This is likely due to excessive lateral displacement, or drift, for brick veneer walls sheathed with the relatively flexible laminated-fiber wall sheathing. A vertical crack that widens toward the top is visible in the brick veneer near the left-front corner of this home. Laminated-fiber wall sheathing is visible behind the brick veneer at this crack. Based on damage indicators such as nearby trees and high-resolution wind-speed contour maps by NWS, the tornado in this area is rated as EF0 rating or below. EF0 is around or below the design wind speed from ASCE 7.





FIGURE 6:

National Weather Service map showing the northern impact area of the tornado as it passed through Rowlett, TX. This is the general location of the Barton Creek Drive home in Rowlett, TX, shown in the previous image. Source: National Weather Service.



FIGURE 7:

Construction on this new home on Chianti Drive in Rowlett, TX, was completed in 2015. There were two separate failure modes observed on this wall, both of which may have been connected to the use of a flexible wall system (foam sheathing) married to a stiff and brittle brick veneer. The first is cracking observed in the brick at the corners and the second is loss of brick at the gable end. Relative to the flexible wall systems, the brick veneer is stiff and brittle. Cracking was observed in the brick at the corners of this newly constructed home, and loss of brick veneer occurred at the top of the gable-end wall. Since deflection or drift of the walls is greater at the top of the walls than at the base, cracks in brick veneer generally increased in size toward the top of walls when this type of failure was observed. Wind speeds and pressures in this area due to the tornado were relatively low and do not account for the loss of brick veneer on the gable end of this home. Loss of brick veneer in this case is likely due to wind-induced drift at the roof and the top of the wall, resulting in failure of the cladding system.



FIGURE 8:

Chianti Drive, Rowlett, TX. This is the adjacent corner of the home shown in the previous photo. Cracking in the brick at the corners of the garage door opening are present in addition to the collapsed brick. Loss of stone veneer was also observed where it stacks continuously from the foundation to an area above the roof, visible on the right of this photo.





FIGURE 9:

This is the approximate location of the home on Chianti Drive in the previous image, as shown on a NWS map of the tornado path on the southern portion of Rowlett that was impacted by the tornado. The home in the previous two images is located at the edge of the area mapped with tornado-induced winds. Source: National Weather Service.

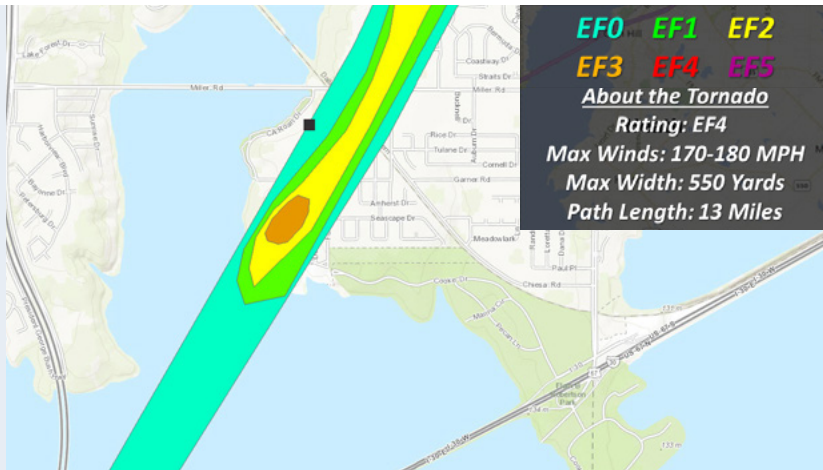


FIGURE 10:

This home is located in the vicinity of Chianti Drive in Rowlett where the tornado was rated EF0, or possibly not rated due to being outside of the tornadic wind area. This is consistent with the degree of damage observed within the relatively unaffected roof coverings on this home.

This photo is representative of the type of wall construction observed in most of the storm-damaged areas of Rowland and Garland, TX. Walls consisted primarily of brick veneer and laminated-fiber exterior wall sheathing over 2x4 framing spaced 16 inches on center. Lateral flexibility within these structures is incompatible with rigid and brittle brick-veneer wall coverings. Lateral translation of the home pictured, due to wind forces on the tall roof, has resulted in collapse of a significant portion of the side-wall cladding. Very few homes contained any wood structural panel wall sheathing, with the vast majority constructed atop concrete slabs.





FIGURE 11:

This home located in Rowlett, TX, is typical of many homes partially destroyed by the tornado. Failures were initiated adjacent to the large openings such as this garage door. Wind in this area was consistent with a rating of EF0 to EF1 based on the degree of damage to roof coverings and nearby trees. Garages are more vulnerable to damage since they are less structurally redundant and often lack adequate lateral bracing at the walls containing the large vehicular opening. When a garage door opening is breached and wind force is exerted on the interior of the garage, internal pressure combines with those already on the exterior, often resulting in sudden and catastrophic failure.



FIGURE 12:

This home has sustained damage primarily at the garage location despite relatively low wind speeds. Damage indicators on the home and nearby vegetation suggest a tornado rating of EF0 in this area. Pressurization in garages and low strength of the structural systems (note narrow width of laminated-fiber sheathing at return wall) resulted in a large number of homes with damage initiated from the garage area. Lateral flexibility of the walls subjected to wind forces resulted in brick veneer that has collapsed into, and away from, the interior homes.



FIGURE 13:

Racking of this garage end wall occurred in an area affected by only moderate winds (note virtually no loss of roof coverings.) Inadequate resistance to lateral forces by return walls on each side of the garage door opening was a common observation in the storm-damaged areas of Garland and Rowlett. These narrow walls were typically sheathed with laminated fiber and were unable to transmit lateral forces around the openings. The narrow wall segments adjacent to the garage opening are important for structural safety and must be properly constructed in accordance with the code.





FIGURE 14:

As wind forces on homes increased, damage observations commonly included racking of wall systems around garage openings and loss of brick veneer. As with previous storm observations, garages were often the location in homes where damage was initiated. After a breach in the garage, loss of roof and walls in adjacent living spaces was often seen as a result.



FIGURE 15:

In the outer reaches of the tornado, homes were often observed with damage at the garage only. Attached garages represent the weakest area of many homes and this was typical in the areas of Garland and Rowlett. Pressurization of the garage at this location resulted in loss of the walls and roof, despite relatively low tornado wind speed ratings of EF0 and EF1. Laminated fiber stapled to wall framing, visible on the left side of this garage, offers relatively low strength and lateral stiffness.



FIGURE 16:

Garages that project past the front or rear of homes are more vulnerable to lateral forces and structural failure. This garage failure represents the majority of damage sustained by this home. Based on the damage indicators of vegetation and roof coverings, the tornado rating was between EF0 and EF1 in this location.





**FIGURE 17:**

This home on Windjammer Way in Rowlett, TX, is near the tornado landfall on the southeast side of the Rowlett peninsula. Damage in this area is consistent with an EF2 rating. Wall racking resulted from inadequate capacity in the narrow bracing segments. Rotation at the top of the garage return wall on the right is evident in this photo.

Portal frames around garage openings, or other force-resisting systems, are generally required by codes in locations such as this. Through careful detailing of the wall sheathing at the narrow return walls, site-built portal frames resist rotation by incorporation of the return walls with an extended garage-door header. Garages with living space above are more likely to require portal frames since the taller walls and roofs above present a larger area for wind pressure to act.



**FIGURE 18:**

Constructed in 2012, this 1-1/2 story home on Lindsey Drive in Rowlett, TX, was impacted by the tornado within the range of EF1 to EF2 rating, based on the degree of damage to vegetation and roof coverings of nearby intact homes. The large roof formerly covering the garage and upper-level living space was probably lost after the garage opening was breached and the interior was pressurized. Poor load-path continuity made damage to this home much worse than what would be expected in a well-constructed home. The survival of the second floor walls surrounding the living space can be largely attributed to the interior drywall, since foam sheathing on the exterior of these walls has no significant strength.





FIGURE 19:

This is the home on Lindsey Drive that is shown in the previous image, but prior to the storm, using Google Street View. The large roof was likely lost after a breach occurred at the garage door opening. Source: Google Street View.



FIGURE 20:

Stud walls rely on wall sheathing to provide continuity around corners by tying corner studs together. On this home, laminated-fiber wall sheathing was observed to be torn through where the edge fasteners attached it to corner studs, failing to provide a wall-to-wall connection. To the uninformed, brick homes may appear strong. However, wind loads acting on the roof transfer through the walls, not through a veneer of brick. If the walls behind the brick are weak, brick can easily become unstable and collapse.



FIGURE 21:

Historically, a common failure location in wind events is at gable ends, where the wall framing is not continuous. This is especially true where the gable ends occur at an interior vaulted ceiling, such as in this home where ceiling diaphragms do not coincide with the wall top plate. The top plate of the gable-end wall at this location is effectively a hinge that has little lateral support. It requires additional detailing.

Diagonal lumber bracing is visible in this photo, supplementing the strength of the laminated-fiber sheathing.





FIGURE 22:

Cracking in brick veneer at the corner of this relatively new home on Lindsay Drive, Rowlett, TX, resulted from excessive lateral drift of the exterior walls during the storm. Wind forces in this area were relatively small as evidenced by minimally affected nearby vegetation and intact roof coverings on the home.



FIGURE 23:

Built in 2012, this home on Lindsay Drive, Rowlett, TX, lost brick veneer along the sidewall. Cracks in brick and stone veneer near the corner (marked with arrow) were also observed. Wind forces in this area were moderate as evidenced by minimal effect on damage indicators such as vegetation and roof coverings.

A closer look at the failed wall sheathing and brick veneer in the photo shows the use of OSB to secure the breach on the interior of the building. While the adequacy of the brick veneer attachment was not verified, the brick veneer failure could have been affected by the wall sheathing's lack of stiffness when exposed to transverse or in-plane wind forces, as was the case with other houses observed in this area. (This area of Lindsay Drive experienced relatively low wind speeds based on available damage indicators, as noted in Figure 42.)





FIGURE 24:

Brick columns are a common feature on the front of homes located in this area. Where present, brick columns were often found to be toppled, such as on this home located on Lakeway Drive, Rowlett, TX. Design details should be provided to builders that take into account the risk of toppling should supporting elements blow away.



FIGURE 25:

This home is on Lagoon Drive in Rowlett, TX, on the west side of the Rowlett peninsula. The tornado was rated between EF1 and EF2 in this area. Loss of the roof and brick veneer might have been prevented by following the guidelines in *High Wind Resistance in Light-frame Wood Construction*, Form M310. Top plates of the second level walls were mostly lost in this case, since the laminated-fiber wall sheathing does not incorporate the entirety of the double top plate.



FIGURE 26:

This all-brick two-story home on Harbor Drive in Rowlett sustained significant damage after losing the roof. Many of the second-level brick-covered walls have collapsed inward. Brick veneer that collapsed adjacent to the front corner of the home was most likely toppled due to excessive lateral drift of the structure. Torn laminated-fiber wall sheathing is visible where falling brick pulled away from wall framing members. Maps by NWS rate the tornado at a maximum of EF2 along this section of the path, although damage to vegetation indicates it may have been rated lower at this particular location. A home with a better constructed and continuous load path would have likely survived with minimal damage in this location.





**FIGURE 27:**

Overturning failures such as this one are rare. In this case, however, the storage shed is fully sheathed with panel siding. Buildings that are fully sheathed with wood structural panels on walls are inherently strong due to integration of the framing into the box-like configuration. Connection to the foundation is the last connection along the load path that was inadequate in this case to resist overturning for this building.



**FIGURE 28:**

The end wall on this home is adjacent to a two-story space with a cathedral ceiling. Despite being two stories in height, the end wall is framed as two one-story walls with plates occurring at roughly mid-height. This results in a hinge at the mid-height that has very little resistance to horizontal pressure exerted on the wall during a storm. Walls such as this should be designed using balloon framing or some other means of laterally bracing the wall. Guidance for proper selection of engineered wood framing for this application can be found in the manufacturer's literature or, for lumber framing, in the *Wood-Frame Construction Manual* by the American Wood Council.



**FIGURE 29:**

This home located on Willowbrook Drive was intermittently sheathed on walls with WSP and infilled with laminated-fiber sheathing. Soft-story failure in this home resulted from inadequate capacity of wall systems to carry lateral wind forces. Collapses such as this obviously represent a serious life-safety issue. An abundance of openings on the first story walls of this home should signal the designer to pay special attention to the wall bracing specified in the building code for lateral resistance. In addition, a very limited number of brick veneer ties were observed on this building.





**FIGURE 30:**

Google Street View prior to the tornado at the Willowbrook residence featured in the previous image. Inadequate bracing on the front and rear first story walls of this home led to premature collapse of the structure. Source: Google Street View.



**FIGURE 31:**

These homes are located on Eagle Drive. Pressurization due to a breach in bay windows likely resulted in the loss of the roof segment on the home on the left.

The roof has been entirely lost on the home on the right and collapsed brick veneer on the second story fell inward onto the second floor level. A large porch overhang across the entire front of this home (see next photo) likely contributed to the loss of this home's roof.



**FIGURE 32:**

These are the homes on Eagle Drive in Rowlett as shown on Google Street View prior to the tornado. A breach at the second story bay windows on the left building likely resulted in pressurization of the interior of the home and loss of the roof over this area.

A large porch overhang on the home on the right and a lack of uplift connectors made this roof vulnerable to uplift forces. Large positive pressures acting upward on the porch ceiling are roughly equal to the positive "stagnation" pressure exerted inward on the second-story walls. This upward pressure on the ceiling combines with negative pressure on the top roof surface, making this section of roof more likely to fail. Source: Google Street View.



FIGURE 33:

This is the approximate location of Eagle Drive houses in Rowlett, which is also near the Linda Vista Drive home depicted in the next image. Source: National Weather Service.

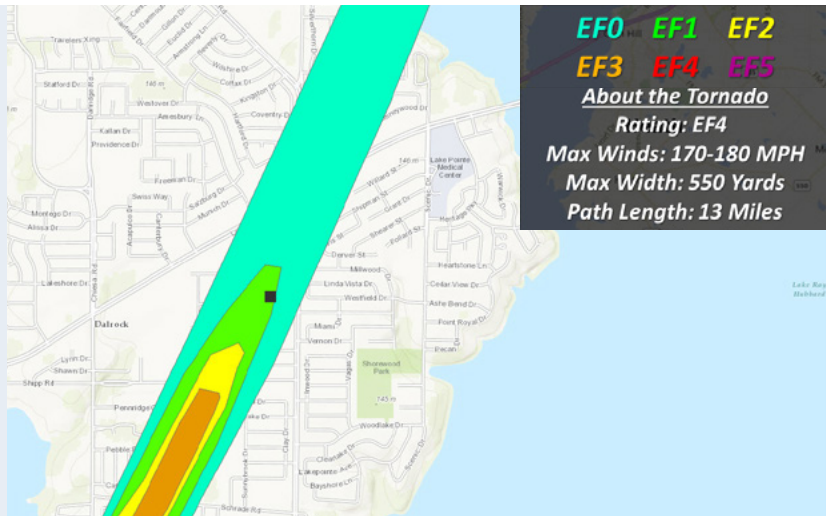


FIGURE 34:

This home is located on Linda Vista Drive in Rowlett. Weakness at wall corners is noted in this and the following image.



FIGURE 35:

In this home located on Linda Vista Drive in Rowlett, staples were pulled through the edge of the wall sheathing at the corner studs resulting in loss of the front wall. Continuity of walls at outside corners was observed to be poor in homes sheathed with laminated fiber. (See Figure 20).

An observation after this storm is that the common practice of connecting the wall top plates with the studs using the exterior wall sheathing was not used. In some cases, the upper top plate was only nailed together to the lower top plate or the studs. In other cases, neither plate was connected to the studs with the laminated-fiber wall sheathing.





FIGURE 36:

Laminated-fiber sheathing used as wall bracing was observed to be torn in this location near the corner of this home. In addition, note that the top plate is not lapped by the wall sheathing.



FIGURE 37:

Performance of fasteners used to attach laminated-fiber wall sheathing to studs was affected when one or more staple legs missed the framing (circled), and staple crowns pulled through the sheathing (indicated by arrows).



FIGURE 38:

Walls are racked on the rear of this home located on Windjammer Way on the southern tip of Rowlett where the tornado made landfall. A small percentage of the homes affected by the storm were sheathed with foam plastic wall sheathing, including extruded polystyrene as shown in this photo. A few homes using foil-faced polyisocyanurate foam sheathing panels were also observed.





**FIGURE 39:**

This home, located on Lindsay Drive in Rowlett, was in a less affected area of the storm, yet cracking of brick veneer still occurred at the corners. This failure was commonly observed in less affected areas of the storm, especially at the inside corners of garage-door openings. In addition to the use of flexible wall sheathings, the large openings in garage end walls result in more flexibility in the wall system when subjected to lateral loads parallel with the opening.



**FIGURE 40:**

Built in 2011, this home on Lindsay Drive in Rowlett has a crack in the brick at the corner that extends the full height and widens toward the top of the two-story brick cladding. The in-plane wall deflection is not commonly considered in design, but it may be important to do so when the wall is constructed with brittle brick veneer and flexible sheathings such as laminated fiber and foam plastic sheathing.



**FIGURE 41:**

This newly constructed two-story home on Lindsay Drive in Rowlett sustained vertical cracks near the corners after exposure to relatively light winds. Failures of this type have not been commonly observed in past damage assessment observations after similar high wind events, as use of laminated-fiber wall sheathing is very limited outside of Texas, and the use of laminated-fiber sheathing combined with brick veneer is even more rare.





FIGURE 42:

This is another home on Lindsay Drive in Rowlett which was constructed in 2011. Flexibility of walls adjacent to garage doors resulted in cracks near corners in brick veneer. In areas of lower wind speed, cracking and loss of brick veneer were the primary areas of damage to many homes. Note the standing fence in the backyard, indicating low wind speeds.



FIGURE 43:

The exterior walls on this Lagoon Drive house in Rowlett have been destroyed, with only double-sided gypsum-sheathed interior walls remaining in this area. Collapsing brick veneer represents a serious life-safety issue.

The laminated-fiber wall sheathing appears to have lost its strength, as shown by it draping over edge of the floor system.



FIGURE 44:

This home on Harbor Drive in Rowlett was built in 1992. Laminated-fiber wall sheathing did not provide enough rigidity to support the brick veneer. This is especially true on two-story homes. Brick was observed to collapse both inward or outward and represents a danger to occupant safety. (Note the laminated-fiber sheathed wall from second story draped over edge of floor system.) Also note that surrounding vegetation is largely intact. Based on affected vegetation, damage indicators from nearby homes, and high resolution contour maps of the tornado by the NWS, the tornado rating is estimated to be EF1 in this area.



FIGURE 45:

A common observation of tornado damaged homes in the Garland/Rowlett tornado was poor integration of the top plates of exterior walls by the laminated-fiber wall sheathing. The top plate in this example is not lapped by the wall sheathing and results in partial loss of the top plate. Loss of the top plate framing would have likely been the weakest link in the uplift load path, had rafters been better connected to the top of the wall.



FIGURE 46:

Laminated-fiber wall sheathing on this home does not overlap either of the top plates. In some locations this has resulted in loss of the top plate along with the loss of roof rafters. Longer wall sheathing or metal strapping should be considered or additional detailing is required to incorporate both the top and bottom plates with the vertical wall studs.



FIGURE 47:

While there may have been others, only one home observed by APA was found to contain uplift framing connectors tying the roof rafters to the top of supporting exterior walls. In this case, the Simpson H2.5A twist strap was observed with nails driven through the connector adjacent to the intended location instead of penetrating the connector precisely at the hole location, clearly not installed according to the connector manufacturer's recommendation.





**FIGURE 48:**

The exterior walls of many homes were observed to be partially or completely lost from the connection to the foundations. In this case, powder-actuated pins were used to connect the bottom plate of the walls to the foundation. In most cases, the penetration of these pins into the concrete foundations was observed to be minimal. In every case where this condition was observed, pins were inadequate to function as a replacement for code-required foundation anchorage.



**FIGURE 49:**

In very few cases, damaged walls were observed to contain anchor bolts embedded in the concrete slabs for wall connections. Anchor-bolt connections are more predictable and robust than those created using powder-actuated pins. Anchor-bolt connections can be further enhanced by using larger plate washers atop the bottom plate for better resistance to bottom plate splitting.

In this case, the wall sheathing was inadequate to provide continuity between the bottom plate and the wall studs. A notch in the outside edge of the bottom plate is visible in this photo where diagonal bracing was used to supplement the lateral resistance of the wall bracing. A combination of laminated fiber and XPS foam exterior wall sheathing is visible on the right side. Foam wall sheathing has no structural capacity and is not acceptable for use as wall bracing.



**FIGURE 50:**

In newer homes affected by the tornado, the primary means of attachment for the wall bottom plates to the concrete slab was powder-actuated pins. In many cases these fasteners protruded only 1/2 inch or less below the bottom of the wall plates. Small conical-shaped holes in the concrete were typically observed at these fastener locations. Some manufacturers of powder-actuated pins recommend embedment of 1-1/4 inches into concrete.



## REFERENCES

- APA – The Engineered Wood Association. 2015. *Building for High Wind Resistance in Light-Frame Wood Construction*, Form M310.  
<http://www.apawood.org/publication-search?q=M310>
- APA – The Engineered Wood Association. 2011. *Tornados of the South*, Form SP-1154.  
<http://www.apawood.org/publication-search?q=SP-1154>
- APA – The Engineered Wood Association. 2007. *Data File: Retrofitting a Roof for High Wind Uplift*, Form A410.  
<http://www.apawood.org/publication-search?q=a410&tid=1>
- State of Georgia. 2012. *Georgia State International Residential Code, Appendix R, Disaster Resilient Construction* (2012 Edition).  
[http://www.dca.state.ga.us/development/constructioncodes/programs/documents/AppendixR-IRC-2013-effective\\_000.pdf](http://www.dca.state.ga.us/development/constructioncodes/programs/documents/AppendixR-IRC-2013-effective_000.pdf)
- American Society of Civil Engineers. 2013. *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10.  
<http://ascelibrary.org/doi/book/10.1061/9780784412916>
- National Weather Service. 2014. Enhanced Fujita Scale.  
<http://www.spc.noaa.gov/efscale/>

## ACKNOWLEDGEMENTS

Bryan Readling, Wood Works Engineering, P.A., Davidson, North Carolina, contributed to this report.

## About APA

APA – *The Engineered Wood Association* is a nonprofit trade association of and for structural wood panel, glulam timber, wood I-joist, structural composite lumber, cross-laminated timber, and other engineered wood product manufacturers. Based in Tacoma, Washington, APA represents approximately 165 mills throughout North America, ranging from small, independently owned and operated companies to large integrated corporations.

Always insist on engineered wood products bearing the **mark of quality**—the APA or APA EWS trademark. Your APA engineered wood purchase is not only your highest possible assurance of product quality, but an investment in the many trade services that APA provides on your behalf. The Association's trademark appears only on products manufactured by member mills and is the manufacturer's assurance that the product conforms to the standard shown on the trademark.

For panels, that standard may be the Voluntary Product Standard PS 1-09 for Structural Plywood, Voluntary Product Standard PS 2-10, Performance Standards for Wood-Based Structural-Use Panels or APA PRP-108 Performance Standards and Qualification Policy for Structural-Use Panels. Panel quality of all APA trademarked products is subject to verification through APA audit.

APA's services go far beyond quality testing and inspection. Research and promotion programs play important roles in developing and improving construction systems using wood structural panels, glulam, I-joists, and structural composite lumber, and in helping users and specifiers to better understand and apply engineered wood products. For more information, please see the back cover.





## Damage Assessment Report: Texas Tornado

We have field representatives in many major U.S. cities and in Canada who can help answer questions involving APA trademarked products. For additional assistance in specifying engineered wood products, contact us:

### **APA HEADQUARTERS**

7011 So. 19th St. ■ Tacoma, Washington 98466  
(253) 565-6600 ■ Fax: (253) 565-7265

### **PRODUCT SUPPORT HELP DESK**

(253) 620-7400 ■ [help@apawood.org](mailto:help@apawood.org)

### **DISCLAIMER**

*The information contained herein is based on APA – The Engineered Wood Association’s continuing programs of laboratory testing, product research, and comprehensive field experience. Neither APA, nor its members make any warranty, expressed or implied, or assume any legal liability or responsibility for the use, application of, and/or reference to opinions, findings, conclusions, or recommendations included in this publication. Consult your local jurisdiction or design professional to assure compliance with code, construction, and performance requirements. Because APA has no control over quality of workmanship or the conditions under which engineered wood products are used, it cannot accept responsibility for product performance or designs as actually constructed.*

Form No. SP-1177/Issued May 2016



REPRESENTING THE ENGINEERED WOOD INDUSTRY