In the Path of the Storm

A firsthand look at the damage inflicted on new wood-frame homes by the April 2011 tornados in North Carolina and Alabama

by Bryan Readling, P.E.

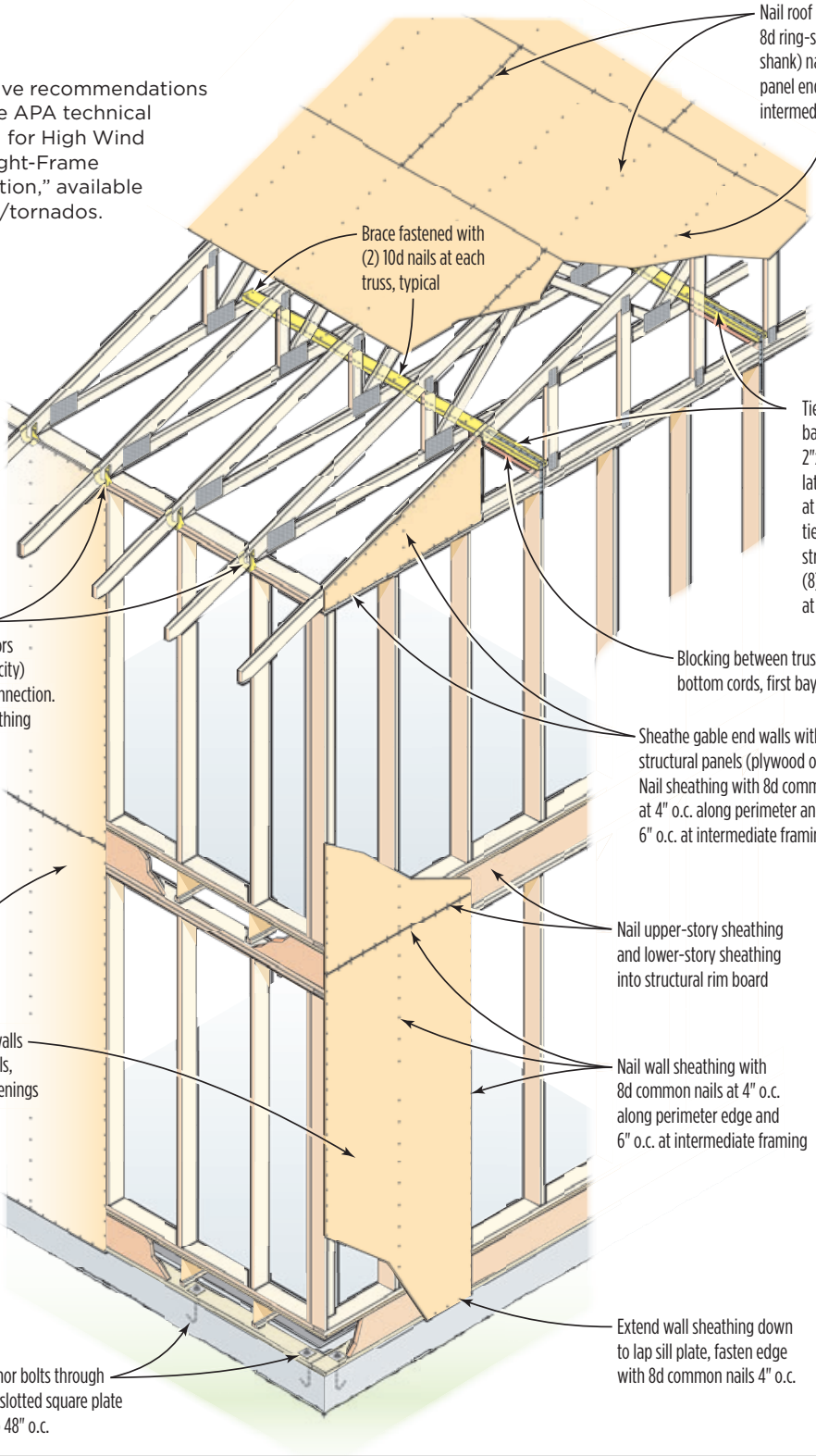
As a structural engineer with the APA/Engineered Wood Association, I perform forensic assessments of single-family homes after hurricanes and tornados. On April 16, severe tornados damaged and destroyed many homes in the eastern part of my home state of North Carolina. While I was there on assignment, documenting the destruction around Fayetteville, Raleigh, and Wilson, news came of a much more destructive batch of tornados passing through Mississippi, Alabama, Georgia, and Tennessee. Back on the road the following week, I visited areas of Alabama that had been damaged by the most severe wind forces I have ever documented — places where buildings, trees, signs, and other familiar landmarks were simply gone, causing residents to become disoriented in their own neighborhoods.

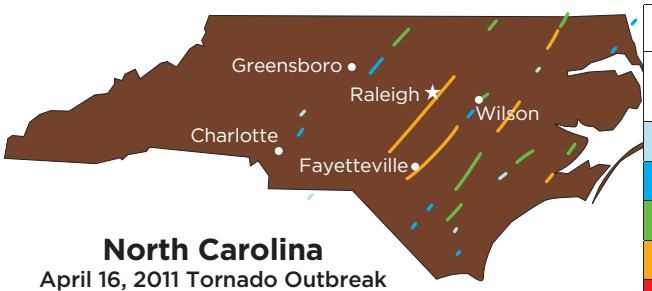
After visiting storm-damaged areas, empathy for those who have lost their homes often leaves me with a sort of post-traumatic stress that lasts for a few weeks as I return to normal life. This time I had a different reaction, however, as I realized that recent APA test results on foundation anchors could be used to protect homes from future storms. The study, which looked at walls sheathed with plywood and OSB, filled some gaps in our understanding of the critical connection between exterior walls and the foundation. It showed that closely spaced anchors used in conjunction with 3-inch-by-3-inch plate washers dramatically increases the capacity of walls to resist simultaneous shear (racking) and uplift forces. In the recent tornado outbreaks, exterior wall anchorage often made the difference between a structure that provided some level of protection to occupants and one that was swept clean from the foundation. In many cases, the roofs and walls themselves were strongly built, but poor wall-to-foundation anchorage resulted in sudden and catastrophic failure.

In tracking the tornados in eastern North Carolina and Alabama, I focused on the performance of homes built within the last 10 years. In many cases I could see weak links in the load paths that contributed to structural failure. Unfortunately, there's a common

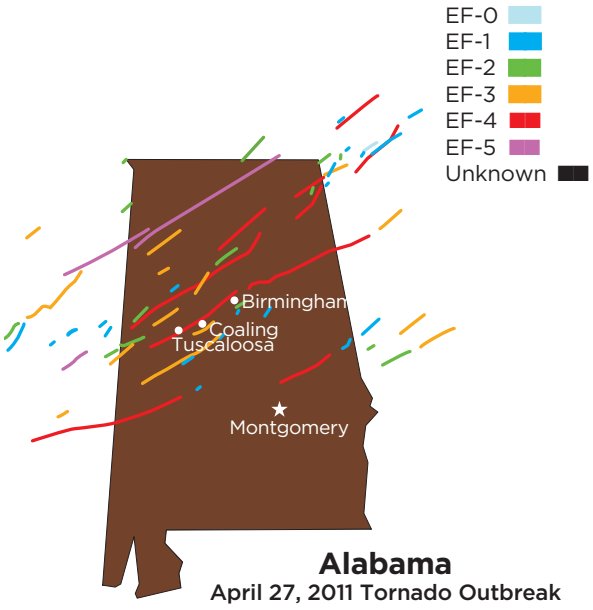
Improving Tornado and Hurricane Resistance of Wood-Frame Buildings

These prescriptive recommendations are based on the APA technical report "Building for High Wind Resistance in Light-Frame Wood Construction," available at apawood.org/tornados.





North Carolina
April 16, 2011 Tornado Outbreak



Alabama
April 27, 2011 Tornado Outbreak

Enhanced Fujita Scale (EF Scale)	
Tornado Class	**Three-Second Gust (wind speed, mph)**
EF0	65–85
EF1	86–110
EF2	111–135
EF3	136–165
EF4	166–200
EF5	>200

Table 4.

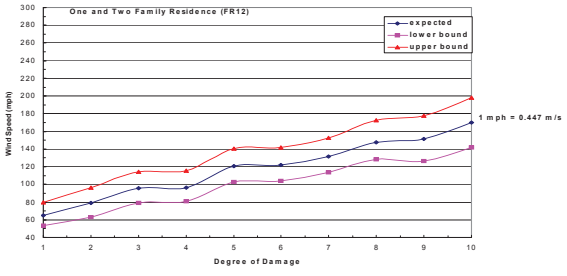
One- and Two-Family Residences (FR12)

Typical Construction

- Asphalt shingles, tile, slate or metal roof covering
- Flat, gable, hip, mansard or mono-sloped roof or combinations thereof
- Plywood/OSB or wood plank roof deck
- Prefabricated wood trusses or wood joist and rafter construction
- Brick veneer, wood panels, stucco, EIFS, vinyl or metal siding
- Wood or metal stud walls, concrete blocks or insulating-concrete panels
- Attached single or double garage

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 or outward; 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	Top floor exterior walls collapsed	132	113	153
8	Most interior walls of top story collapsed	148	128	173
9	Most walls collapsed in bottom floor, except small interior rooms	152	127	178
10	Total destruction of entire building	170	142	198

* DOD is degree of damage



The storms that blew through North Carolina and Alabama in April helped make 2011 one of the worst years for tornados in U.S. history (see maps, above). Tornados are classified according to the Enhanced Fujita Scale (top right); since wind-measuring equipment will not survive the strongest tornados, this scale uses assessment of actual damage to buildings to make a correlation to wind speed. At right is a sample page from a document developed by Texas Tech University (available at spc.noaa.gov/efscale/ef-scale.html) that explains how damage indicators apply to homes.

misconception that all tornados are too violent to resist, no matter how strong the framing. In fact, 95 percent of tornados are rated EF0, EF1, or EF2 by the National Weather Service; these weaker tornados produce winds that a well-built home can be expected to withstand.

In response to the recent storms, APA has developed construction recommendations designed to strengthen the overall structural shell so that it can better withstand the forces of tornados and hurricanes. The recently published document "Building for High Wind Resistance in Light-Frame Wood Construction" (available for download at apawood.org/tornados) provides prescriptive details that rely on standard framing and sheathing materials, with a minimum of additional hardware. The intent is to show builders how to optimize the structural performance of their homes without great expense, to help prevent the kind of damage described on the following pages.

While stronger tornados (EF3 to EF5) are harder for a home to survive, these details may still help, especially for buildings located along the periphery of the tornado's path — away from the vortex — where wind speeds are lower.

Bryan Readling *is a structural engineer with APA's Field Services Division in Davidson, N.C.*

Story continues on next page

In the Path of the Storm

Fayetteville, N.C.

Damage to this home (1) most likely started with the failure of the garage doors. Subsequent pressurization of the garage blew out the sidewall and pushed out the back wall. A close look showed inadequate nailing of the drywall ceiling and the bonus-room floor sheathing (2) to the bottom chord of the gable-end truss, seen here from behind (3). The gable triangle was intact, with the OSB sheathing still in place — it's the connections that failed.

The same home, seen from the rear (4), also lost sheathing at the step-down trusses of the hip roof, a type of failure I observed several times. Top-chord nailing surfaces on step-down trusses do not neatly align with the roof sheathing, which makes it more difficult to attach the sheathing adequately.

A nearby home (5) also lost gable-end attic trusses in two places. The garage doors (barely visible at the left end of the house) were breached, allowing the gable wall and roof to be blown off.

1

2

3

4

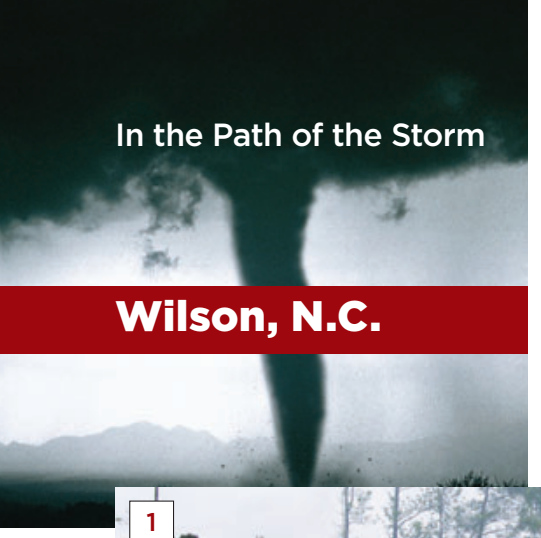
5

Another home in the same subdivision fared much worse **(6)**; most likely the garage walls were blown out due to pressurization through the large garage-door opening, seen in the foreground. A closer look at the left-hand garage wall **(7)** shows that the OSB sheathing was poorly attached to the bottom plate with 8-penny nails 16 inches on-center. Foundation anchor bolts with round washers were spaced 48 inches on-center along the sill plate. The home's roof trusses had been attached with toenails **(8)**.

The rafters on another house in the neighborhood were attached with metal connectors **(9)**; note, however, that the metal ties were nailed to the inside of the top plate. They should have been installed on the outside of the wall, in alignment with the load path through the plywood sheathing.

Another collapsed home **(10)** was fully sheathed with OSB, which lapped the rim board and sill plate but was fastened only to the rim board with 16-penny nails at approximately 16 inches on-center. I could see no nails through the sheathing into the sill plate.

These two homes **(11)** lost much of their fiber-cement siding, but there were no breaches in the OSB sheathing.



In the Path of the Storm

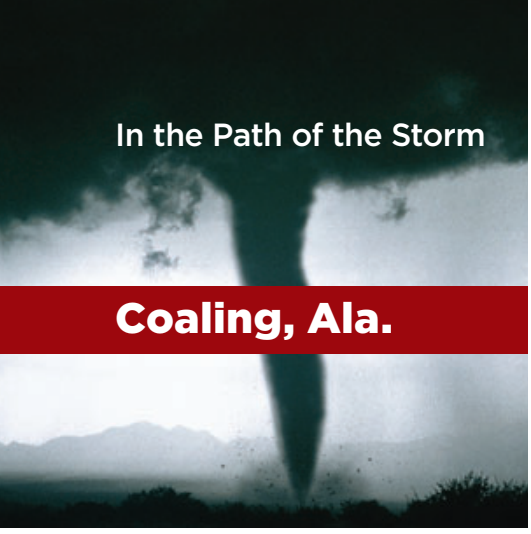
Wilson, N.C.

The homes I studied in Wilson were all built between 2004 and 2009. This home was almost completely destroyed **(1)**; shown here is an end wall, which was braced at the corners with OSB and had nonstructural extruded polystyrene as infill sheathing. The home's bottom plate — shown with bits of the foam sheathing still attached — was intact **(2)**; structural wall sheathing would have greatly strengthened this connection between the wall studs and the bottom plate.

A nearby home used plywood corner bracing and foam infill **(3)**; a closeup view reveals that interior drywall — which would not have been present on the attic gable above — probably helped hold the wall together **(4)**. The opposite gable **(5)** showed similar damage.

Though this home's roof remained largely intact **(6)**, several of the exterior walls were blown out — a testament to both the tornado's lack of strength and the inability of poorly executed framing connections to maintain integrity of the

building envelope. The back corner is still supported by the OSB corner bracing panel (7). A braced corner in front was pulled off when its connection to the bottom plate failed (8). On the opposite side of the house, the foam sheathing at the gable truss is almost completely stripped from the framing (9). Below, the foam-sheathed portion of the wall was lost, though the OSB corner bracing is still in place.



In the Path of the Storm

Coaling, Ala.

This home in western Alabama (1) was completely blown off its foundation by a tornado that came through the area around 5:30 a.m. on April 27. Remarkably, the family inside the home was swept away from the building, though no one was seriously injured. A length of sill plate was the only piece of the exterior walls that remained on the slab (2); the sills had been attached with rectangular cut nails.

A nearby home lost all its exterior walls (3); its sill plates had been fastened with spiral shank nails 24 to 48 inches on-center (4, 5).

Another home in the same neighborhood lost its garage door and had its front garage wall pushed in — apparently by wind pressure, as there was no sign of impact. Gable-end failures occurred on the front and right side of the house (6). The home's masonry safe room, at the front center (7), was undamaged, and may have helped strengthen the home against the tornado's forces.

Seen here (8) is the back right corner, where the gable roof over the children's bedrooms was lost. Like most of the homes in the neighborhood, this one was fully sheathed with OSB; pink housewrap and vinyl siding covered the sheathing. A closeup (9) shows a typical truss-to-top-plate connection; the four toenails, placed in opposing pairs, caused the bottom chord to split.

The gable end was stripped from this

home **(10)**. The bottom chord of the gable truss had been attached to the plate below with 16-penny toenails more than 2 feet on-center **(11)**; the roof sheathing was secured with nails every 48 inches and staples every 12 inches between the nails **(12)**.

Though heavily damaged, this house **(13)** may have fared better than nearby homes because it has a hip roof, which is better than a gable roof at resisting high winds. The wall seen here was knocked in by an impact that occurred between the two windows in the middle of the photo. Though the wall was sheathed with OSB — which helped hold the framing together — the connection at the top plate failed.

Another view of the same home shows missing sheathing on one section of the roof, probably related to loss of the lightweight vinyl soffit directly below **(14)**.