Prescriptive Details for Wind Resistant Envelopes based on Observations of Newly Built Homes Damaged in 2011 Tornados

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ABSTRACT

Damage observations conducted by APA after recent tornados focused on homes built within the last 10 years. Unfortunately many of the damaged homes were built in compliance with existing building codes and were robustly constructed minus a few relatively inexpensive techniques that provide structural continuity. In non-hurricane areas, now assigned with design wind-speed as low as 85 mph, this indicates a need for building practices that take advantage of the inherent strengths of roof, wall and floor assemblies in tornado-prone areas.

To this end APA engineers compiled a set of reinforcement techniques for each of the common weak points along the load path resulting from code-minimum attachment schedules, and commonly used construction techniques. The resulting publication *Building for High Wind Resistance in Light-Frame Wood Construction*, APA form M310 was published in August 2011.

Instrumental in offering these recommendations is recent testing at APA performed to determine the design capacity of shearwalls subjected to simultaneous shear and uplift forces. Recommendations are prescriptive and apply to many homes otherwise constructed to IRC minimums. The aim was optimization of material assemblages already commonly in-use, while minimizing the effect on cost. Recommendations apply when a higher degree of safety is desired for resisting severe straight-line winds and tornados on the lower end of the EF-scale.

SUMMARY OF FIELD OBSERVATIONS.

Damage observations conducted by APA after the April 16, 2011 tornados in Eastern North Carolina and the powerful EF-4 and EF-5 storms that struck Tuscaloosa, Alabama on April 27 found that a lack of attention to detail along the uplift load-path often leads to weakness on the route through which high-wind forces must travel within the framing and into the foundation. Following a review of the findings, the Association has published a set of construction recommendations for improving tornado or hurricane resistance in light-frame wood construction.

The investigation focused on the performance of homes constructed within the last 10 years. The most common roof-to-wall framing failures were attributed to the use of toe-nailed connections, still prescriptively allowed in many non-hurricane areas. In addition, many homes observed were poorly anchored to the foundations. This was especially true in Alabama where nails were often used, instead of anchor bolts, to attach the bottom plate of walls to the concrete or masonry foundation. Not exclusive to just the top and bottom of structures, load path failures were witnessed at every connection location in between.

Another common theme observed along the tornado paths is that homes constructed with non-structural exterior wall sheathing, especially if used in conjunction with vinyl siding, failed at wind speed much lower than called for in the building codes. Walls that are fully sheathed with OSB or plywood and constructed with proper connections have stronger resistance to the damaging forces of high winds and even when siding has been lost still offer strength and weather protection.

Figure 1 –Building Envelopes Fully Sheathed with Wood Structural Panels.

In a field survey of damaged structures, APA observations indicated that structural failure along the critical load-path was often located at the roof-to-wall connection. Most of these connections were made using toe-nails through the roof framing and into the top plate of the exterior walls. Toe-nail connections are weak because they rely upon the withdrawal capacity of nails, which is limited. Light-gauge metal connectors provide good performance in wood framing because load is applied perpendicular to the nail shank, instead of pulling the nail straight out. Toe-nail rafter connections are still prescriptively allowed in most non-hurricane areas by modern building codes through "grandfathered" language. It is generally recognized that these connections do not provide the capacity to resist the range of pressure requirements of the *International Building Code*.

Figure 2. Toe-nailed Connection of Roof Framing-to-Wall.

Metal roof-to-wall connectors should be installed in-line with the load-path. Failure was observed when metal roof framing connectors were installed on the inside face of the wall top plate instead of on the exterior of the wall and in-line with the load-path in the structural wall sheathing. Roof framing connector manufacturers' specifically advise against such applications.

In each of these tornado outbreaks, regardless of the tornados intensity, anchorage of the exterior walls to the foundation was most often the difference between a structure that continued to provide some level of protection to occupants, or one that was swept clean from the foundation. Among severely damaged homes it was observed that wall-to-foundation anchorage was often woefully inadequate. In many of these cases roofs and walls were strongly built, but poor connections to the foundation resulted in sudden and catastrophic failure. In many cases hand-driven cut masonry nails were used to attach the bottom of support walls to the concrete or masonry foundations. In some cases the nails were observed to be pneumatically-driven framing nails. Modern building codes generally require anchor-bolts to be embedded into concrete or grouted concrete masonry units.

Figure 3 – Failed Nail Connection of Wall Bottom-Plate to Slab.

Breaches or openings in the building envelope, and the resulting pressurization of the building interior caused catastrophic failure of homes in many examples. Openings in walls due to failure of doors, windows, and cladding systems were common. These often resulted in heavy damage to home interiors due to rainwater infiltration and flying debris penetration. Larger breaches from loss of weak garage doors and exterior cladding systems often acted to initiate catastrophic failure and exacerbated deficiencies along the aforementioned load-path.


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Figure 4 – Envelope Failure of Foam Sheathed Exterior Walls

In homes with gable roofs, failures were most notable at the bottom of the gable-end roof and ceiling framing where they are connected to the top of the gable-end wall below. This joint is often not well connected laterally to the rest of the building and is weak to resist negative pressure on the exterior gable-end surfaces.

Figure 5 – Failure of Gable-end Framing.

The gable-end is also a vulnerable location for cladding systems since walls within the roof cavity are not backed by drywall like the exterior walls within the living space. Material failure was commonly observed when non-structural foam wall sheathing was used in conjunction with low-strength siding. Besides vulnerability to wind pressure, these products provide little resistance to the flying debris.

Figure 6 – Non-Structural Sheathing at Gable-end after minor wind event.

In most observations where buildings were at least partially intact, wood wall and roof sheathing loss could be attributed to improper attachment. When nails were used as prescribed in the building codes good performance was observed. Staples performed poorly since they generally offer less resistance to pull-out than nails and must be used in greater quantity. Greater structural failure often resulted from poor roof sheathing attachment to the last rafter or gable-end truss. Enhanced nailing of roof sheathing to the gable-end truss or rafter such as is recommended for panel edges provides necessary enhancement at minimal cost.

BUILDING FOR GREATER WIND RESISTANCE.

New recommendations are meant to optimize structural performance of prescriptively built homes while adding as little cost as possible. A different approach was taken from most design scenarios where the resisting elements are selected based on the anticipated loads. In this case the resisting elements were optimized to utilize the inherent strength of wood wall and roof systems as already constructed. The aim was to develop a single set of recommendations to ensure structural continuity and provide similar resistance levels within each of the structural links to the foundation.

In many cases observation of structural damage points to one of several common weak links as the cause of catastrophic failure in homes that are affected by hurricanes and tornados.

Figure 7 – With thoughtful layout, continuous structural sheathing can resist both shear and uplift forces, providing cost-effective continuity between the foundation and roof framing connections. Oversize panels may be used to eliminate blocking by locating horizontal panel joints at the rim joists and to match the dimensions of taller wall systems.

RECOMMENDATIONS

The following APA recommendations address these weak links and provide tips for building a wind-resistant shell:

1. **Nail roof sheathing with 8d ring shank (or deformed shank) (0.131 in. x 2-1/2 in.) nails at 4 inches on center along the edges of the wood structural wall sheathing and 6 inches on center along the intermediate framing.** *Comments: deformed-shank nails are the best option for resisting withdrawal forces on roof sheathing fasteners due to negative pressure on the exterior surface of the building envelope. It is important to maintain consistency in this operation since one missed nail can be expected to limit the pressure resistance of the roof before a breach occurs.*
   Note that the panel edge nailing of 4 inches on center for roof sheathing is appropriate for nails that penetrate the gable-end roof framing, as this is the panel diaphragm boundary.
2. **Sheath gable end walls with wood structural panels, such as plywood or oriented strand board (OSB).** *Comments: Gable end wall failures are frequently observed when non-structural sheathing is used. Most non-structural foam sheathing materials are required to be used in conjunction with gypsum wall board inside of the house. This is frequently neglected in the construction of gable end walls. The easiest way to avoid the need of installing interior gypsum at the gable end walls is to use wood structural panel sheathing on the exterior.*
3. **Tie gable end walls back to the structure using continuous lateral braces 6'-0 on center on top of the ceiling framing and connecting these to the gable-end wall using steel straps nailed on each side of the connection using (8) 10d common nails.** *Comments: One of the weakest links in residential structures during high wind events is the connection between the roof gable-end and the wall below. The prescriptive codes provide no guidance on how to properly attach these two important elements and failures at this joint are, unfortunately, quite common. Construction details that have been developed to properly secure and tie back a gable end may be used. Also common in high wind areas is to eliminate the gable through the use of hip roofs or, if the gable is an architectural necessity, use balloon framing. (Detail courtesy of Standard for Hurricane Resistant Residential Construction, SSTD 10-93 Section 306.4.2.)*
4. **For the roof framing-to-wall connection, use a hurricane anchor attached on the exterior (sheathing side) of the exterior walls.** *Comments: The roof-to-wall connection under high wind loads is subject to both uplift and shear. For this reason the best option is to use a connector that is intended to provide restraint in all 3 directions such as the H1 connector by Simpson Strong-Tie. A simple twist-strap may also be used for the uplift component in combination with toenails to provide lateral restraint.*
5. **Nail wall sheathing with 8d common (0.131 in. x 2-1/2 in.) nails at 4 inches on center at end and edges and 6 inches on center in the intermediate**

framing. *Comments: This enhanced nailing will improve the resistance of the wall sheathing panels to negative wind pressure as well as improve performance in resisting racking and uplift forces. Staples offer less resistance to blow-off than nails and so a greater number of them are required to achieve the same level of resistance.*

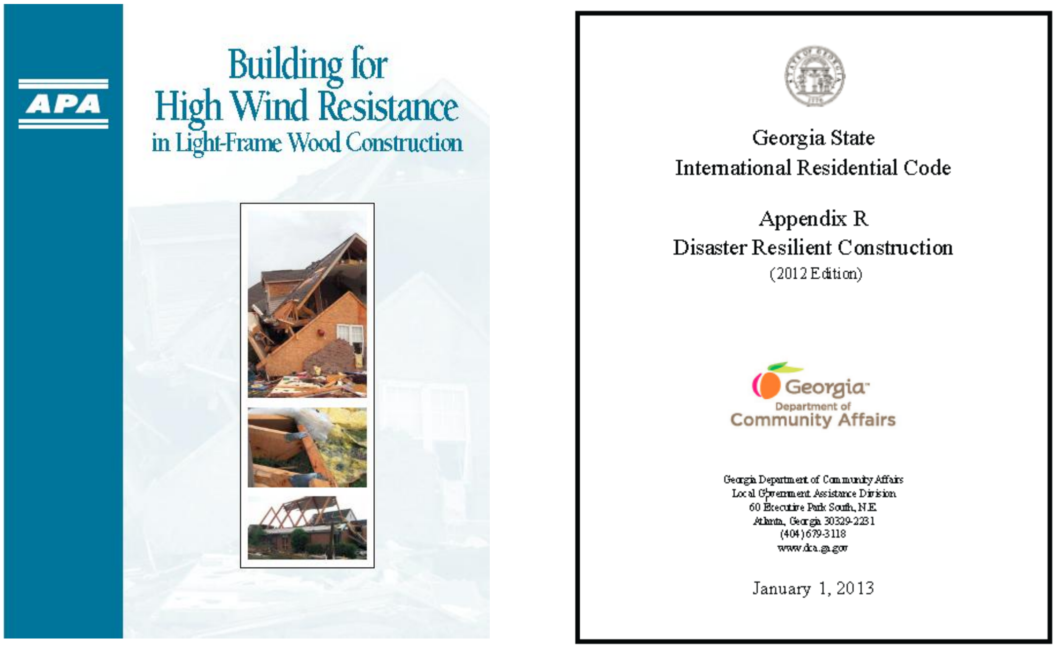
6. **Nail upper story sheathing and lower story sheathing into common wood structural panel Rim Board®.** *Comments: The most effective way to provide lateral and uplift load continuity is to enlist the use of continuous wall sheathing to bridge joints in the wall plane. Long length OSB Rim Board can be used as this common framing member to ensure shear and uplift continuity, which eliminates the need for horizontal blocking. Being at least 9-1/2" in depth and 1" in thickness, commonly available Rim Board makes an excellent "target" for mating adjacent panels. Otherwise horizontal blocking may be utilized at panel joints to enhance continuity in wall sheathing panels. For use around windows and doors or as an alternative to this detail, metal strap anchors designed for such applications may be used. For designed applications, additional information is available in* APA Data File: *Shear Transfer at Engineered Wood Floors, Form* Y250.
7. **Continuously sheath all walls with wood structural panels including areas around openings for windows and doors.** *Comments: Continuous wood structural panel wall sheathing on the entire building exterior improves redundancy and resistance to wind-borne debris during high-wind events. Since all wall, floor, and roof elements are restrained by attachment to adjacent diaphragm elements, buildings constructed in this manner behave more like a box, and less like a collection of independent plates. In addition, the use of continuous sheathing provides both strength and protection if the exterior siding is blown off or damaged by flying debris.*
8. **Extend wood structural panel sheathing to lap the sill plate which is bolted to the slab or foundation-wall.** *Comments: Nailing of the wall sheathing panels to the sill plate is important because this is where uplift forces are transferred into the foundation through the anchor bolts. Too often bottom sill-plates are observed to be the only remaining wall element still attached to the foundation. Nailing the wall sheathing to the sill plate utilizes the nails in shear and provides an economical, strong, and redundant attachment at this point along the load-path.*
9. **Space ½ in. anchor bolts 32 inches to 48 inches on center with 0.229 in. x 3 in. x 3 in. square plate washers with slotted holes.** *Comments: Plate washers of this size are able to incorporate most of the bottom-plate width and more effectively prevents cross-grain stresses and splitting from occurring in the bottom plate material. Tests performed by APA prior to the tornados scrutinized anchor bolt spacing for use in the engineering of walls sheathed with plywood or OSB and subjected to simultaneous shear (racking) and uplift wind and seismic forces. The results revealed tremendous gains in capacity of walls with more closely spaced anchors when used in conjunction with larger 3" x 3" plate washers.*

More information and illustrations of these construction details can be found in the APA guide: *Simplified Tips for Improving Tornado or Hurricane Resistance of Light-Frame Wood Construction*, Form M310, available for download at www.apawood.org .

APPLICATIONS FOR ENHANCED BUILDING CODES.

The state of Georgia Department of Community Affairs (DCA) was awarded a grant through the U.S. Department of Housing and Urban Development (HUD) to develop Disaster Resilient Building Code (DRBC) Appendices for the International Building Code (IBC) and the International Residential Code (IRC). The DRBC Appendices are optional regulations that local jurisdictions may adopt, in whole or in part, through local ordinance to improve resilience from hurricane, flood, and tornado events.

The optional appendix, ***Georgia State International Residential Code Appendix R Disaster Resilient Construction*** contains increased prescriptive requirements for non-hurricane 90 mph regions based largely on APA's new publication *Building for High Wind Resistance in Light-Frame Wood Construction.* The appendix may be adopted in whole or part by local jurisdictions in the State of Georgia beginning January 1, 2013.



Building for
High Wind Resistance
in Light-Frame Wood Construction

Georgia State
International Residential Code

Appendix R
Disaster Resilient Construction
(2012 Edition)

Georgia Department of Community Affairs

Georgia Department of Community Affairs
Local Government Assistance Division
60 Executive Park South, N.E.
Atlanta, Georgia 30329-2231
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www.dca.ga.gov

January 1, 2013

Figure 8 – APA publication M310 – *Building for High Wind Resistance in Light-Frame Construction* (August 2011,) and Georgia State IRC Appendix R, Disaster Resilient Construction, January 1, 2013.

A cost estimate was performed by Georgia DCA for these structural enhancements for a one-story 2100 square foot home with a 6:12 roof pitch with three dormers. The additional costs related to these upgrades including labor and materials were approximately $595.00.

CONCLUSION

Many homes built in compliance with existing prescriptive building codes are robustly constructed minus a few relatively inexpensive techniques that provide structural continuity. New recommendations from APA seek to optimize structural performance of prescriptively built homes while adding as little cost as possible. A collection of best practices was developed to provide a level of performance for prescriptive construction that is above code-minimums. These recommendations were subsequently codified through use in recently adopted codes aimed at providing a level of performance above the current minimum-code level. Due to the inherent strengths of building systems as already prescriptively constructed, these enhancements offer a great value for protection of life and propery.

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