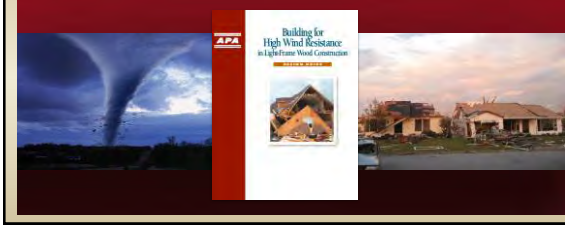
After the Storm

Designing Wood Buildings for High Wind Resistance

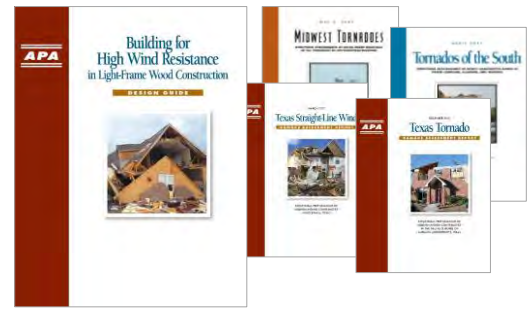


Learning Objectives

1. Recognize the fundamental behavior of wood structures.
2. Identify common failure modes.
3. Discuss preventive methods that can reduce damage.
4. Understand the importance of a complete load path.

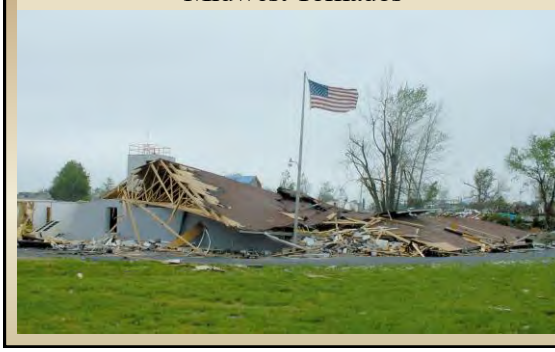
APA Publications

APA Publications



Publications from Others

May 2003
Midwest Tornados



April 2011
Tornados of the South

December 2015
Texas Tornado

March 2017
Texas Straight Line Winds

June 2017
Nebraska Tornado

July 2017
Maryland Tornado

Tennessee Tornado
March 2018

Enhanced Fujita Scale

EF-Scale	Tornado description	Wind Speed (3-sec gust)	Description of Expected Damage
EF-0	Gale tornado	65-85	Minor or no damage. Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over.
EF-1	Moderate tornado	86-110	Moderate damage. Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.
EF-2	Significant tornado	111-135	Considerable damage. 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.
EF-3	Severe tornado	136-165	Severe damage. Entire stories of well-constructed houses destroyed; trains overturned; trees debarked; heavy cars lifted off the ground and thrown.
EF-4	Devastating tornado	166-200	Extreme damage. Well-constructed and whole frame houses completely leveled; cars and other large objects thrown and small missiles generated.
EF-5	Incredible tornado	>200	Total Destruction. Strong framed, well built houses leveled off foundations and swept away;

Tornado Facts

- 96% of all tornados are EF2 and below.
- Damaging winds outside vortex are slower than max.
- Unrealistic to protect against EF4, EF5, and some EF3.
- The Enhanced F-scale is a set of wind estimates (not measurements) based on damage. Tornado loads – more unknown than seismic!
- Safe rooms are NOT a universal remedy.
  - There is often little warning to those who are in the tornado path
  - Need recommendations to protect building shell

Damage Indicators

- Group of objects that can be used to evaluate a tornado severity.
- EF scale currently has 28 damage indicators (DI) or types of structures and vegetation, each with varying number of degrees of damage (DoD).
- The larger the DOD, the higher the wind speed and corresponding tornado ratings.
- Primary Damage Indicators used in the this report:
  - One- or two-family residences
  - Hardwood trees

Damage Indicator-2 (FR12)

One- and Two-Family Residences (FR12)
(1000 – 5000 sq. ft.)

- Typical Construction
  - Roof coverings
  - Roof sheathing and framing
  - Roof geometry
  - Wall claddings
  - Wall sheathing and framing
  - Wall geometry and openings, including attached garages

Damage Indicator – 2 (FR12)

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 of 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 = Degree of Damage
EXP = Expected Wind Speed
LB = Lower Bound Wind Speed
UB = Upper Bound Wind Speed

Damage Indicator – 27 (TH)

27. Trees: Hardwood

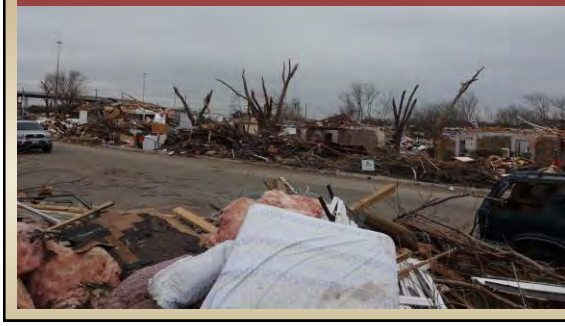
- Typical Construction
  - Hardwood: Oak, Maple, Birch, Ash

DOD	Damage Description	EXP	LB	UB
1	Small limbs broken (up to 1" diameter)	60	48	72
2	Large branches broken (1"-3" diameter)	74	61	88
3	Trees uprooted	91	76	118
4	Trunks snapped	110	93	134
5	Trees debarked with only stubs of largest branches remaining	143	123	134

DOD = Degree of Damage
EXP = Expected Wind Speed
LB = Lower Bound Wind Speed
UB = Upper Bound Wind Speed

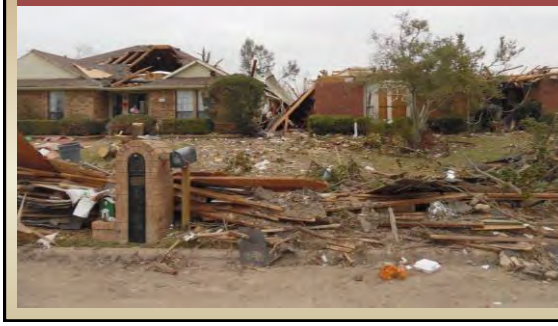
EF-3 Severe damage. Entire stories of well-constructed houses destroyed; trains overturned; trees debarked; heavy cars lifted off the ground and thrown.

Texas Tornado – December 2015



EF-1 Moderate damage. Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.

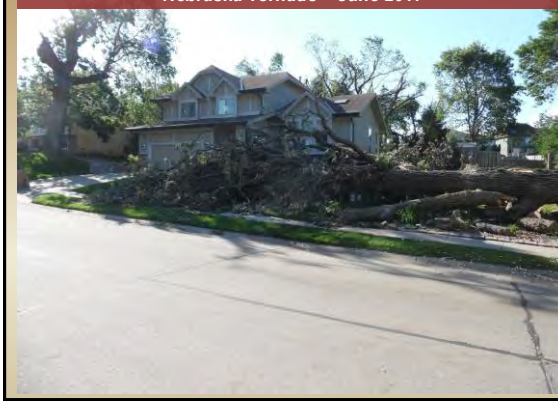
Texas Tornado – December 2015



Damage Indicators

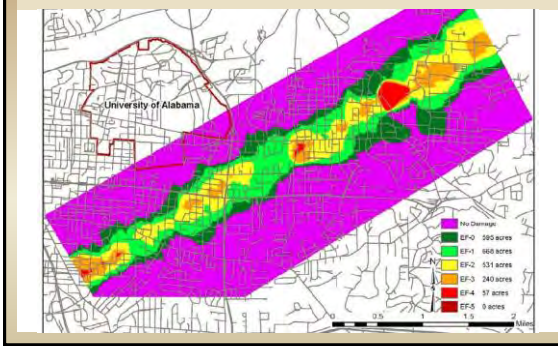
Texas Tornado – December 2015

Nebraska Tornado – June 2017



Nebraska Tornado – June 2017

Tornado Intensity Along Path



December 2015 Texas Tornado

- Tornados are classified according to the maximum rating that occurs along the tornado path.
- Despite the EF-4 maximum rating for this tornado, less than two-percent of the total area impacted along the 13-mile path was estimated to be rated EF-4.

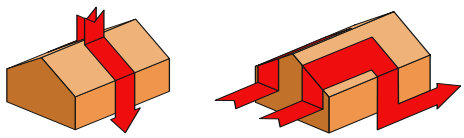
Percentage of Occurrence

EF-Scale	Wind Speed (3-sec gust)	Relative Frequency	Cumulative Percentage	Examples of Damage
EF-0	65-85	53.5 %	53.5 %	
EF-1	86-110	31.6 %	85.1	
EF-2	111-135	10.7 %	95.8	
EF-3	136-165	3.4 %	99.2	
EF-4	166-200	0.7 %	99.9	
EF-5	>200	< 0.1	100	

Load Path

IBC 2018 1604.4

"Any system of method of construction to be used shall be based on a rational analysis in accordance with well established principles of mechanics. Such analysis shall result in a system that provides a complete load path capable of transferring loads from their point of origin to the load-resisting elements."



Vertical Load Path | Lateral Load Path

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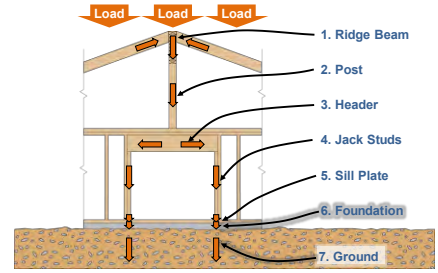
Load Path

Vertical (Gravity) Load Path Issues



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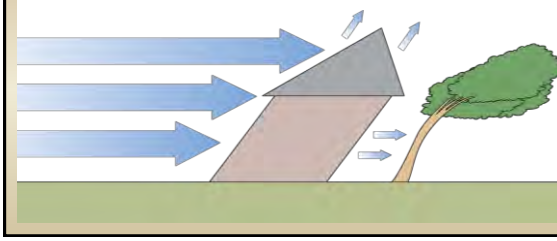
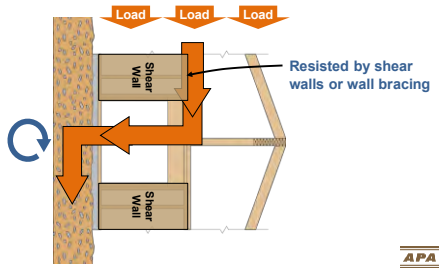
Load Path Continuity

Load Path



Load Path

Lateral (Sideways) Load Path Issues



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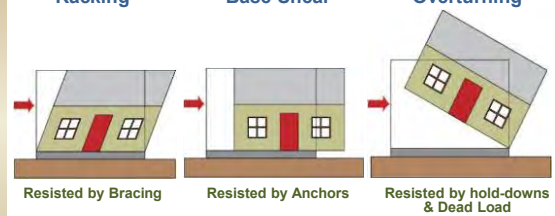
Lateral Forces

Effects of Forces



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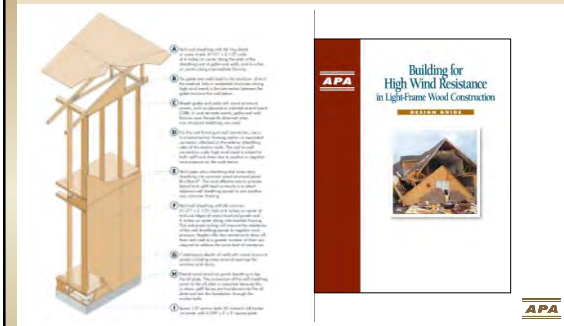
Building for High Wind Resistance



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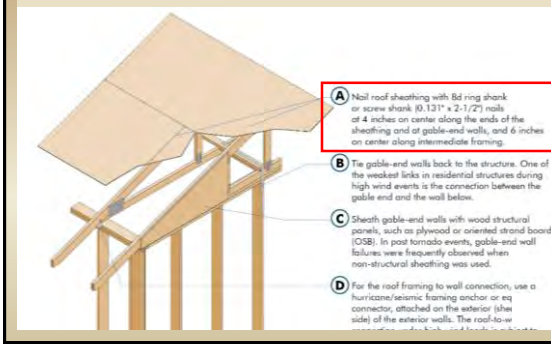
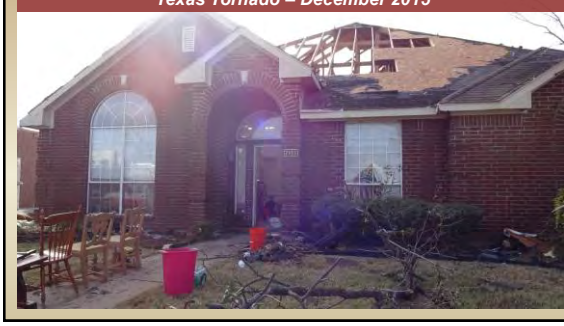
Roof Sheathing Connection

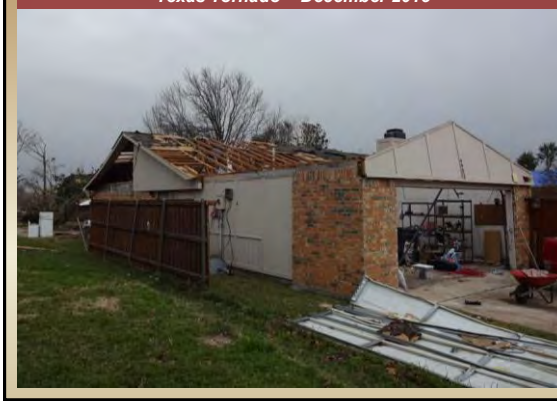


Roof Sheathing Connection

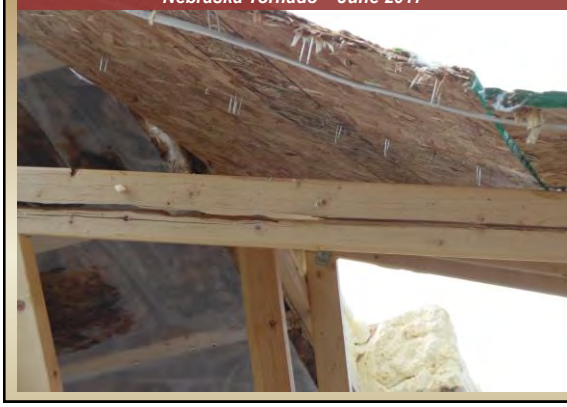
Texas Tornado – December 2015



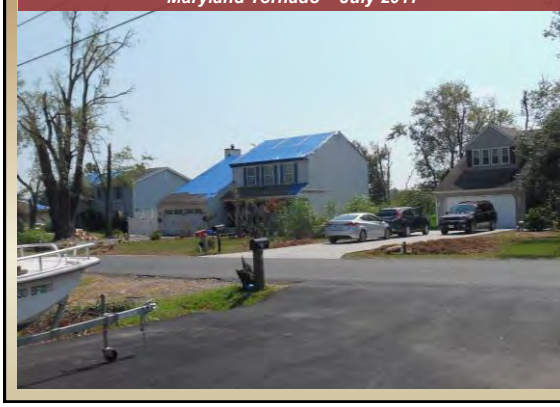
Texas Tornado – December 2015



Nebraska Tornado – June 2017

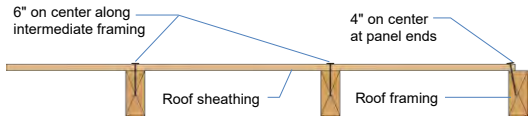


Maryland Tornado – July 2017



Roof Sheathing Attachment

Nail roof sheathing with at 4" on center at panel ends and edges and 6" on center in the intermediate framing



Code Minimum: 6" on center at panel ends and edges and 12" on center in the intermediate framing

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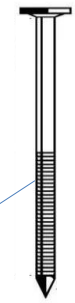
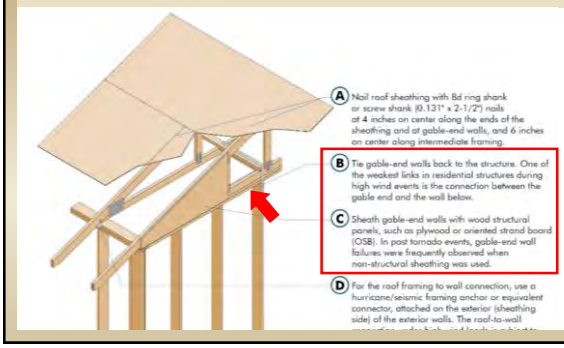
Fastener Recommendations

8d (0.131" x 2-1/2") screw or ring shank nails



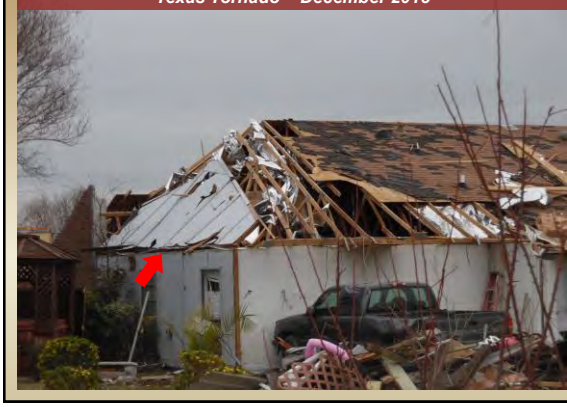
Enhanced pullout is achieved with ring or spiral shanks nails for enhanced uplift resistance

Gable Ends

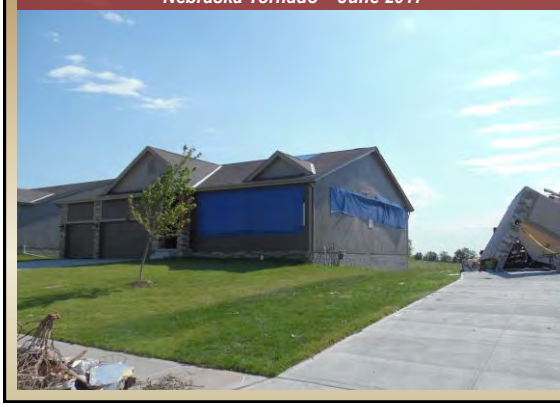


Fayetteville, North Carolina – 2011 Tornados

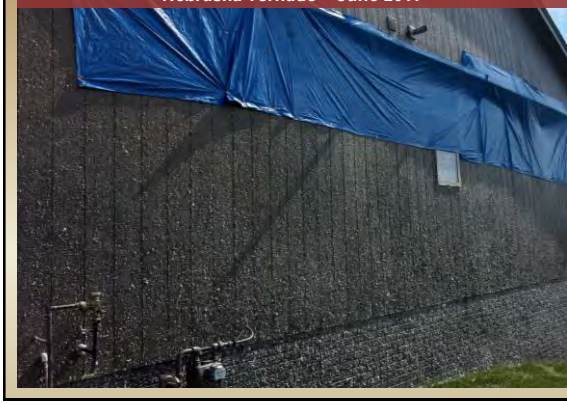
Texas Tornado – December 2015



Nebraska Tornado – June 2017



Nebraska Tornado – June 2017



Nebraska Tornado – June 2017

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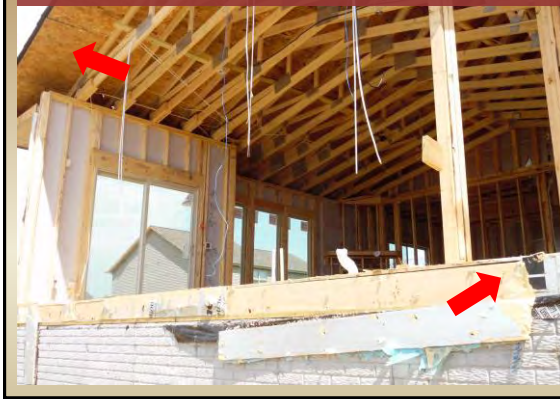

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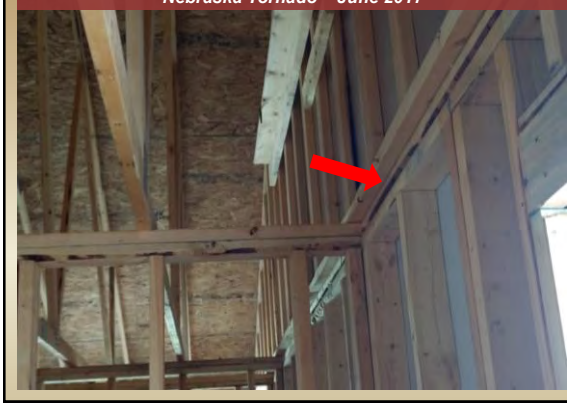
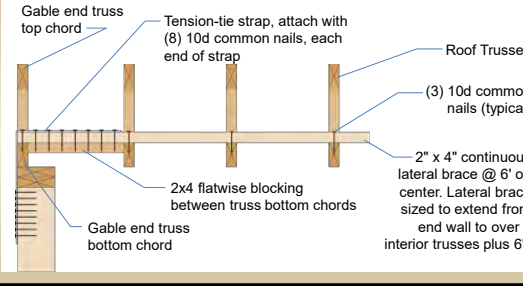
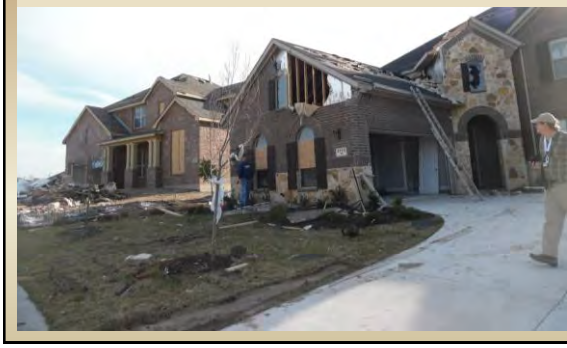


Gable-end Framing

Tie gable-end walls back to the structure



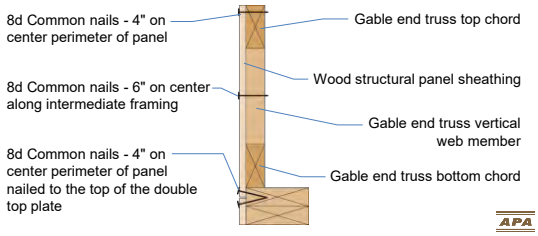
Gable Ends



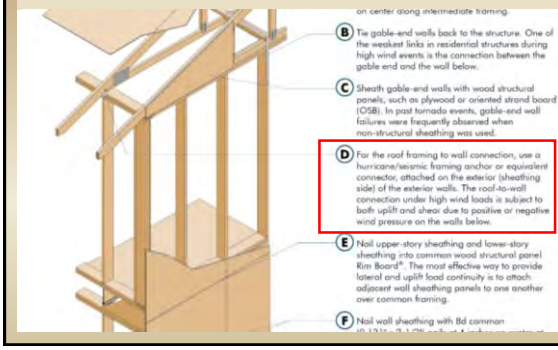
Maryland Tornado – July 2017

Resisting Pressure on Components and Cladding

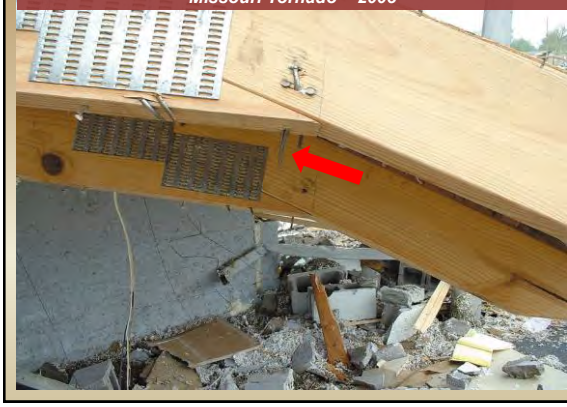
Sheath gable-end walls with wood structural panels, such as plywood or oriented strand board (OSB)



Top Plates



Missouri Tornado – 2003



Missouri Tornado – 2003

Coaling, Alabama – 2011 Tornados

Tornados of the South – 2011

Texas Tornado – December 2015

Top Plates

Garland, Texas – 2015

Top Plates

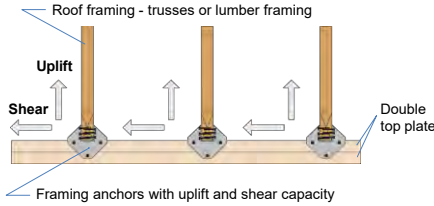
Garland, Texas – 2015

Top Plates

Garland, Texas – 2015

Roof to Wall Connection

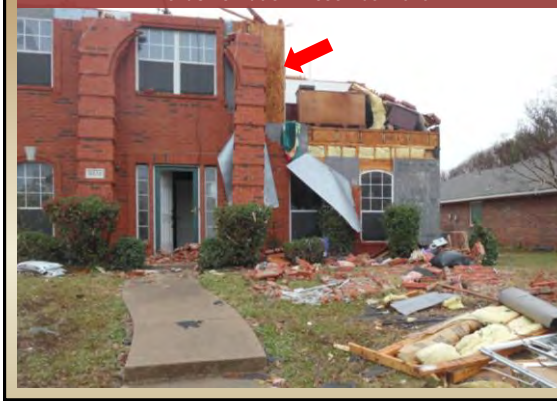
Roof framing to wall connection with hurricane/seismic framing anchor or equivalent connector attached on sheathing side of the exterior walls



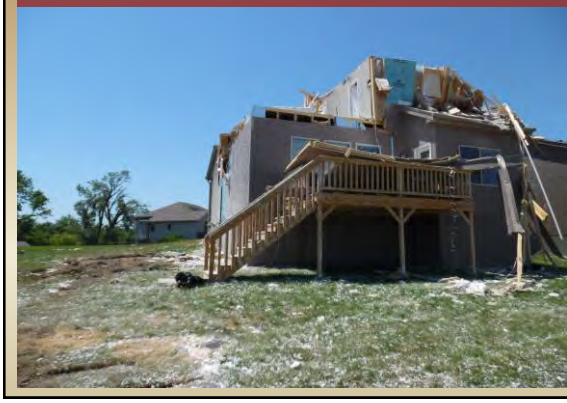
Rim Board Connections

Texas Tornado – December 2015

Texas Tornado – December 2015



Nebraska Tornado – June 2017



Rim Board Connections

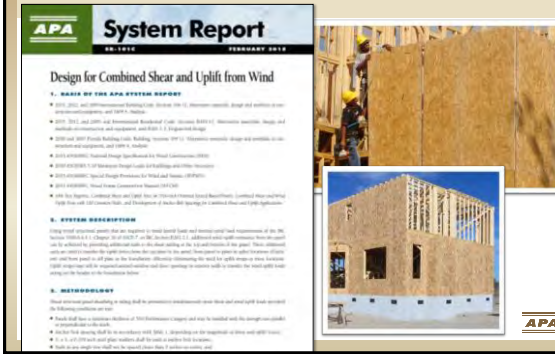
Garland, Texas – 2015

Maryland Tornado – July 2017

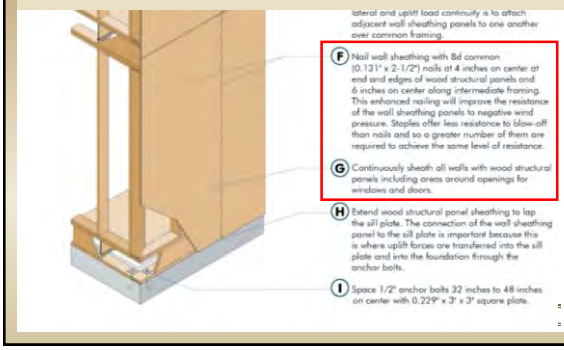
Rim Board Connections

Rim Board Connections

Rim Board Connections



Wall Sheathing



lateral and uplift load continuity is to attach adjacent wall sheathing panels to one another over common framing.

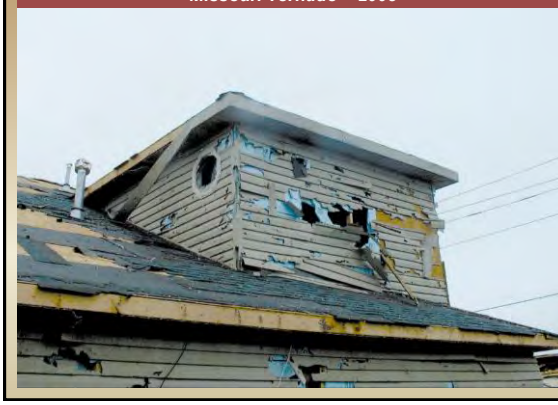
(F) Nail wall sheathing with 8d common (0.131" x 2-1/2") nails at 4 inches on center at end and edges of wood structural panels and 6 inches on center along intermediate framing. This enhanced nailing will improve the resistance of the wall sheathing panels to negative wind pressure. Staples offer less resistance to blow-off than nails and so a greater number of them are required to achieve the same level of resistance.

(G) Continuously sheath all walls with wood structural panels including areas around openings for windows and doors.

(H) Extend wood structural panel sheathing to lap the sill plate. The connection of the wall sheathing panel to the sill plate is important because this is where uplift forces are transferred into the sill plate and into the foundation through the anchor bolts.

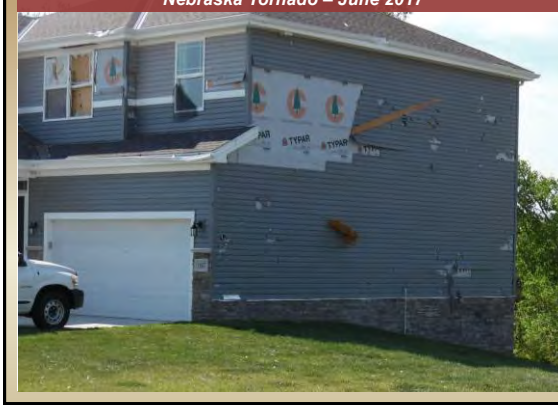
(I) Space 1/2" anchor bolts 32 inches to 48 inches on center with 0.229" x 3" x 3" square plate.

Missouri Tornado – 2003



Missouri Tornado – 2003

Nebraska Tornado – June 2017



Missouri Tornado – 2003

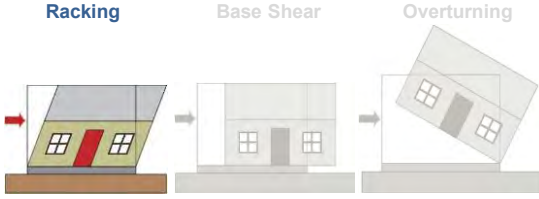
Wall Sheathing

Texas Straight Line Wind – March 2017

Lateral Forces

Effects of Forces

Racking | Base Shear | Overturning

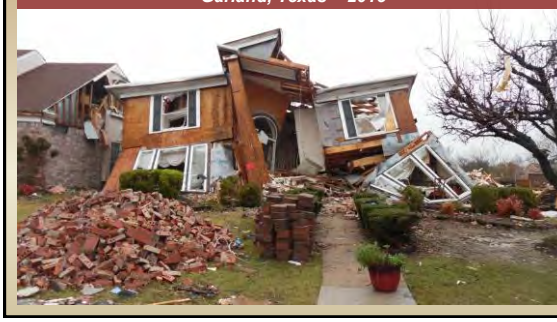


Resisted by Bracing | Resisted by Anchors | Resisted by hold-downs & Dead Load

APA

Wall Sheathing

Garland, Texas – 2015

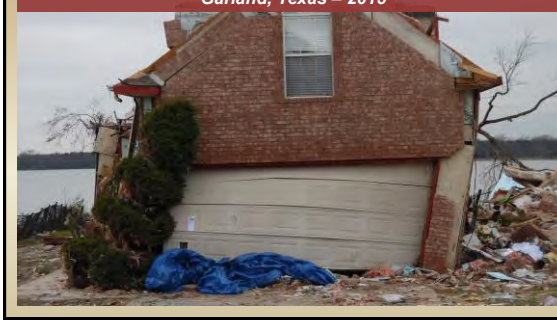


Wall Sheathing

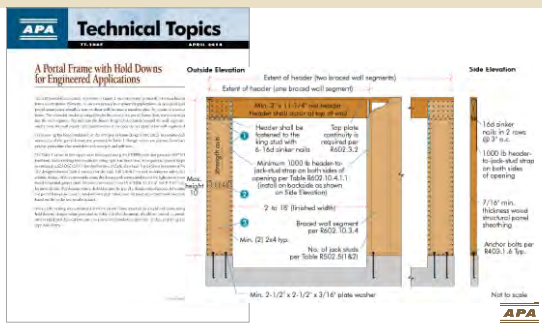
Texas Straight Line Wind – March 2017

Wall Sheathing

Garland, Texas – 2015



Portal Frames



Portal Frame

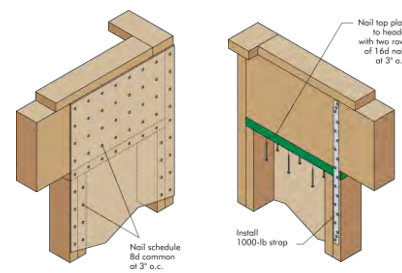
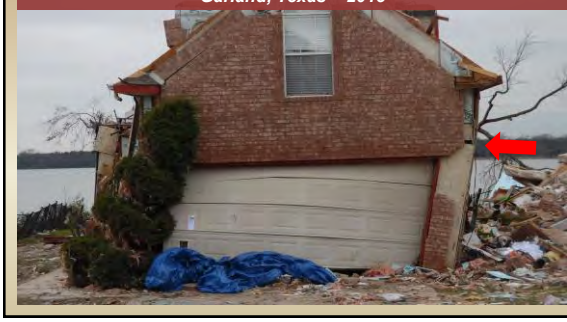


Figure R602.10.6.2

APA

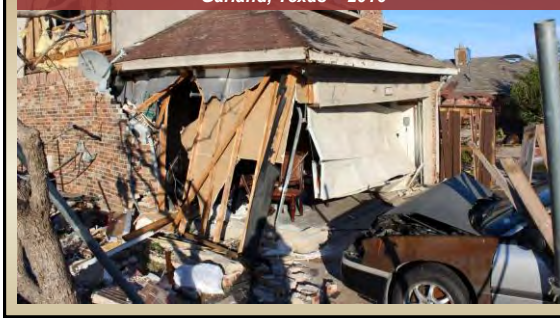
Wall Sheathing

Garland, Texas – 2015

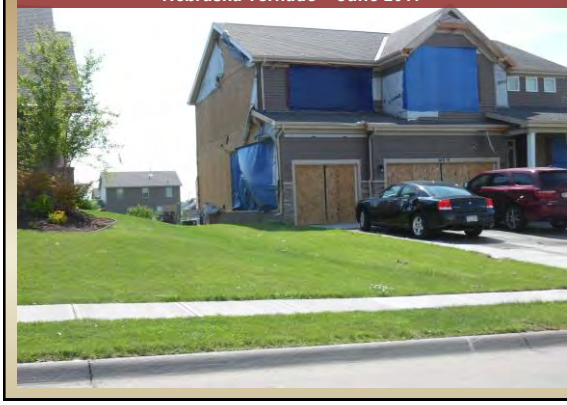


Wall Sheathing

Garland, Texas – 2016



Nebraska Tornado – June 2017



Wall Sheathing

Garland, Texas – 2015

Veneer Failures

Garland, Texas – 2015

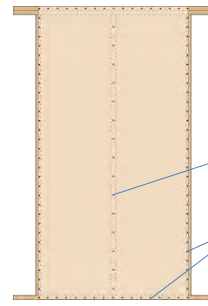
Veneer Failures

Garland, Texas – 2015

Wall Sheathing

Texas Straight Line Wind - 2017

Wall Sheathing Attachment



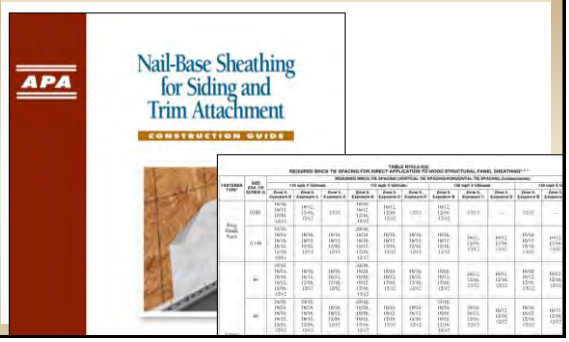
Nail wall sheathing with 8d common (0.131" x 2-1/2") nails at 4" on center in the boundary of wood structural panel wall sheathing and 6" on center in the intermediate studs

8d Common nails at 6" on center at intermediate supports

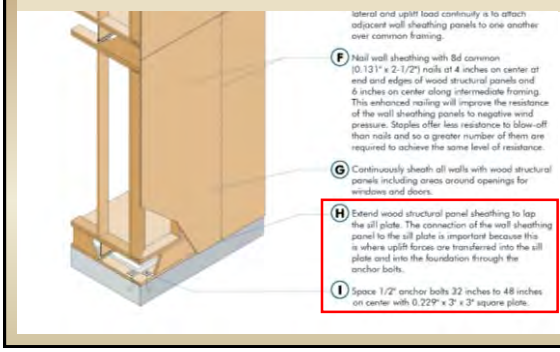
8d Common nails at 4" on center at panel ends and edges

APA

Wall Sheathing Attachment



Sill Plates and Anchor Bolts



lateral and uplift load continuity is to attach adjacent wall sheathing panels to one another over common framing.

(F) Nail wall sheathing with 8d common (0.131" x 2-1/2") nails at 4 inches on center at end and edges of wood structural panels and 6 inches on center along 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 and so a greater number of them are required to achieve the same level of resistance.

(G) Continuously sheath all walls with wood structural panels including areas around openings for windows and doors.

(H) Extend wood structural panel sheathing to lap the sill plate. The connection of the wall sheathing panel to the sill plate is important because this is where uplift forces are transferred into the sill plate and into the foundation through the anchor bolts.

(I) Space 1/2" anchor bolts 32 inches to 48 inches on center with 0.229" x 3" x 3" square plate.

Lateral Forces

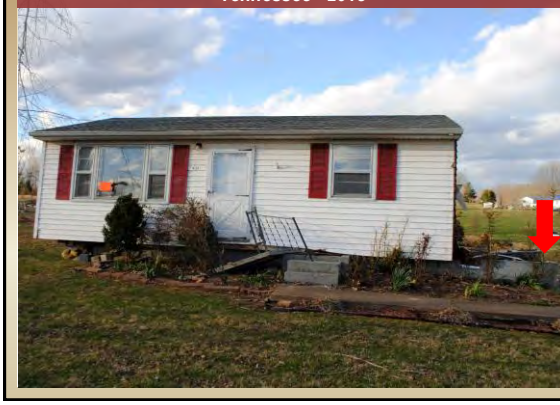
Effects of Forces

Racking — Base Shear — Overturning

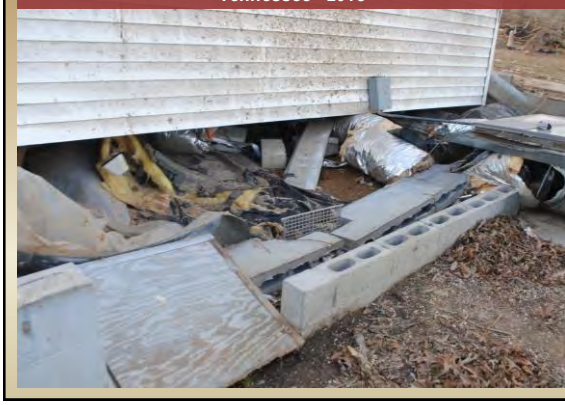
Resisted by Bracing — Resisted by Anchors — Resisted by hold-downs & Dead Load

APA

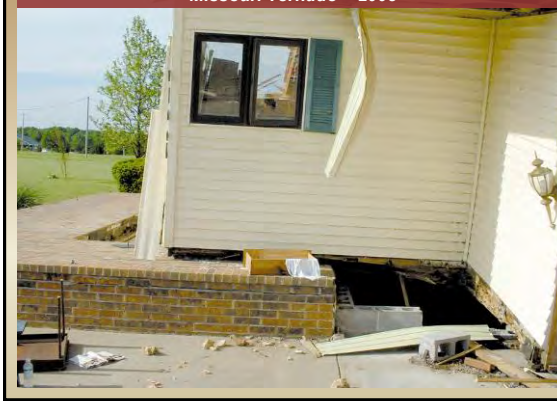
Tennessee - 2018



Tennessee - 2018

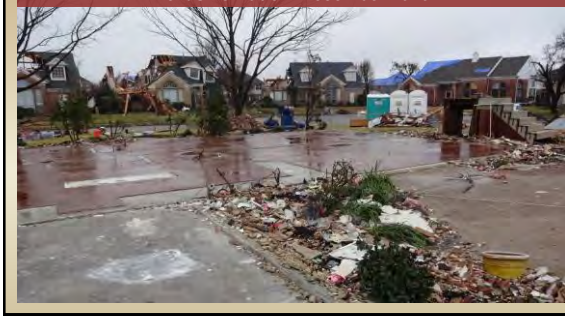


Missouri Tornado – 2003



Anchor-Bolt Connection to Foundation

Texas Tornado – December 2015



Anchor-Bolt Connection to Foundation

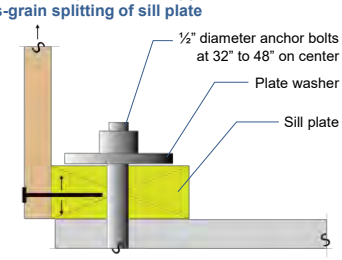
Texas Tornado – December 2015

Nebraska Tornado – June 2017

Maryland Tornado – July 2017

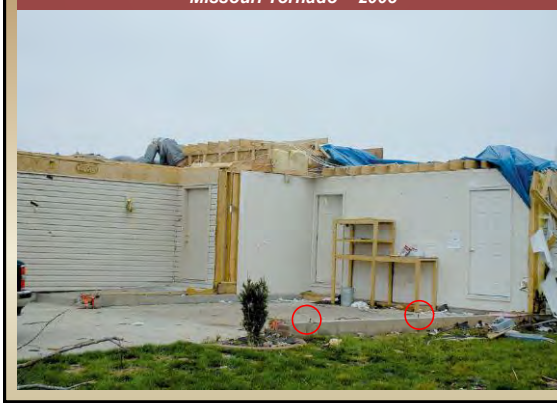
Anchor Bolt Installation

Large plate washers (3"x3"x0.229") prevent cross-grain splitting of sill plate



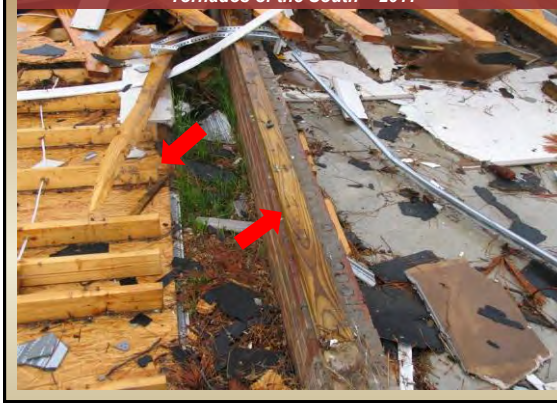
APA

Missouri Tornado – 2003



Missouri Tornado – 2003

Tornados of the South – 2011



Wall Sheathing

Garland, Texas – 2015

Wall Sheathing

Texas Straight Line Wind - 2017

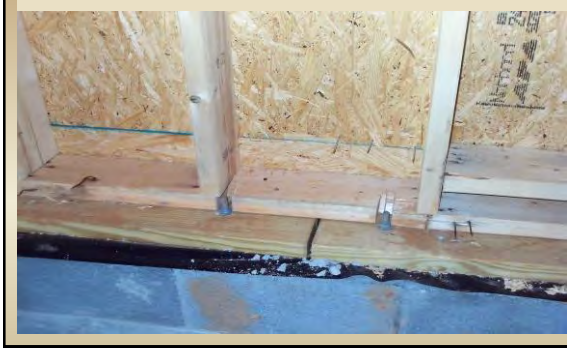
Wall Sheathing

Texas Straight Line Wind - 2017

Wall Sheathing

Nebraska Tornado – June 2017

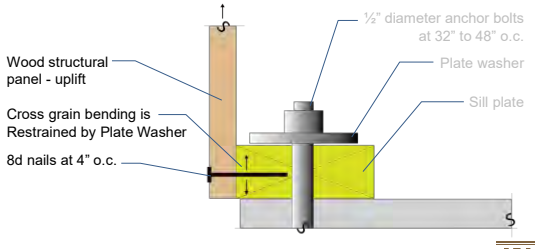
Tennessee 2018



Tennessee 2018

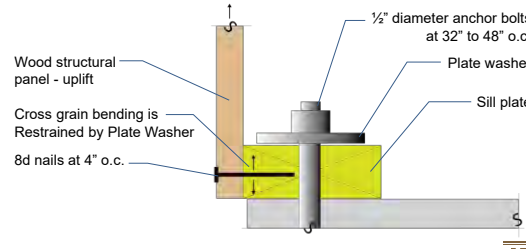
Larger Washer Increases Uplift Capacity

Large plate washers (3"x3"x0.229") prevent cross-grain splitting of sill plate



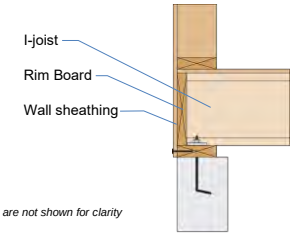
Larger Washer Increases Uplift Capacity

Large plate washers (3"x3"x0.229") prevent cross-grain splitting of sill plate



Wall Framing to Sill Plate Connection

Extend wood structural panel sheathing at bottom of wall to sill plate intersection



Other connections are not shown for clarity

APA

Lateral Forces

Effects of Forces

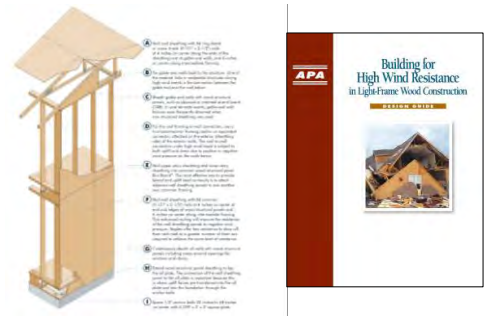
Racking | Base Shear | Overturning

Resisted by Bracing | Resisted by Anchors | Resisted by hold-downs & Dead Load

APA

Overturning

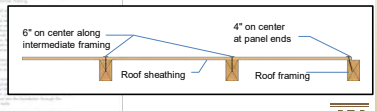
Building for High Wind Resistance



APA

High Wind Resistance Guidelines

- 4" o.c. at panel edges and ends
- 6" o.c. along intermediate framing
- 8d deformed shank nails



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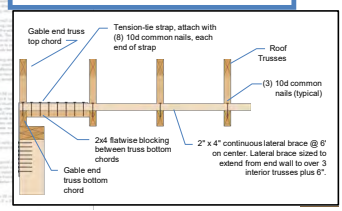
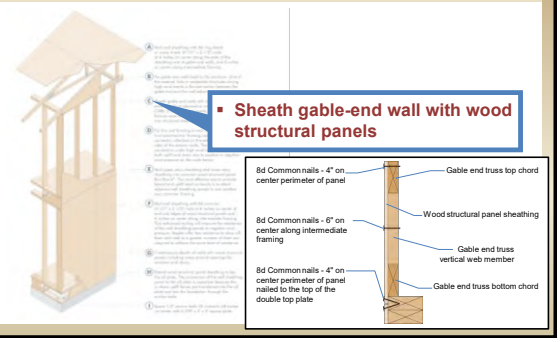
High Wind Resistance Guidelines

- Gable wall bracing

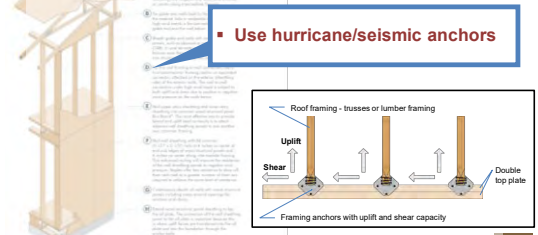


High Wind Resistance Guidelines



- Sheath gable-end wall with wood structural panels

High Wind Resistance Guidelines

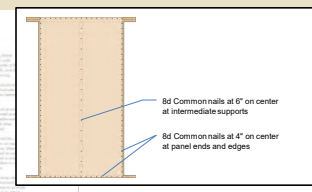


- Use hurricane/seismic anchors

High Wind Resistance Guidelines

- Nail upper and lower story sheathing to a common Rim Board

High Wind Resistance Guidelines

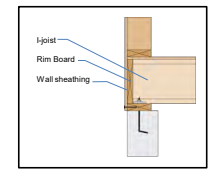


- 8d common nails
- 4" o.c. at panel edges and ends
- 6" o.c. along intermediate framing

High Wind Resistance Guidelines

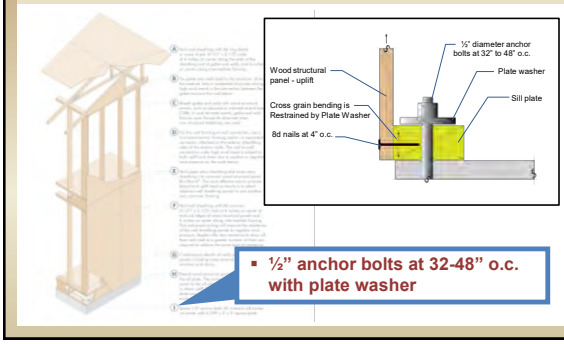
- Sheath all walls with wood structural panels including above and below openings

High Wind Resistance Guidelines



- Extend sheathing to sill plate

High Wind Resistance Guidelines



- ½" anchor bolts at 32-48" o.c. with plate washer

Conclusions

www.apawood.org/wind-weather-seismic

APA Designers Circle Newsletter (www.apawood.org/designerscircle)

Questions?

Karyn Beebe, PE, LEED AP
www.apawood.org
www.apawood.org/help