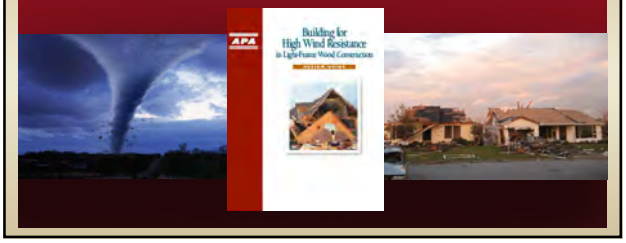
After the Storm

Lessons Learned about Building for High Wind Resistance



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American Institute of Architects (AIA) Continuing Professional Education

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

2

Course Description

This session will discuss structural failures observed during storm damage assessments and the behavior of wood structures during high wind events. An overview of how high wind forces work, the importance of a complete load path, and how good design and construction practices can improve the storm resistance of buildings will be provided. Both code requirements and APA's above-code recommendations which contribute to improved overall performance in the structural shell will be discussed. They focus on good connection details and common failure modes seen in storm damage assessments and help builders cost effectively build a safer home. By understanding key code requirements and lateral load concepts, home damage in future storms can be minimized.

3

Learning Objectives

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

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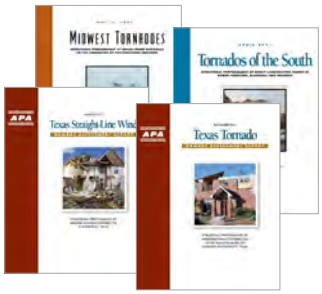
APA Publications



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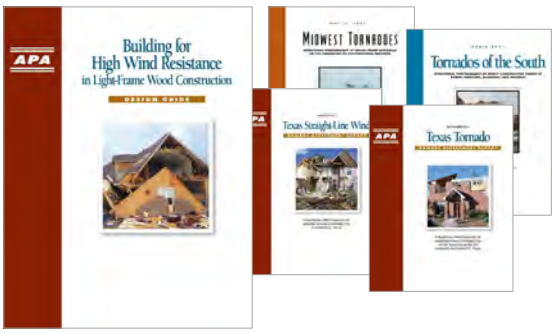
APA Publications



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Publications from Others

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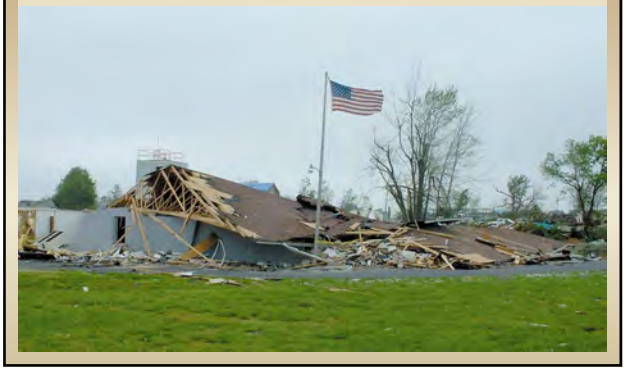
May 2003 Midwest Tornados



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April 2011 Tornados of the South

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December 2015
Texas Tornado

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March 2017
Texas Straight Line Winds

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June 2017
Nebraska Tornado

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July 2017
Maryland Tornado

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Tennessee Tornado
March 2018

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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;

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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 still 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

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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 degree of damage, the higher the wind speed and corresponding tornado ratings
- Primary Damage Indicators used in the this report
  - One- or Two-family residences
  - Hardwood Trees

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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

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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

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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

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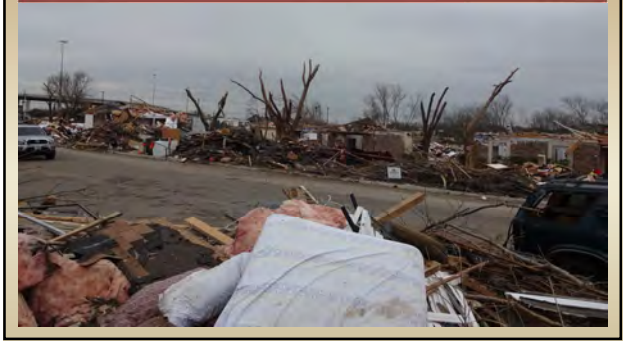
EF-3 Severe damage. Entire stories of well-constructed houses destroyed; trains overturned; trees debarked; heavy cars lifted off the ground and thrown.

Texas Tornado – December 2015



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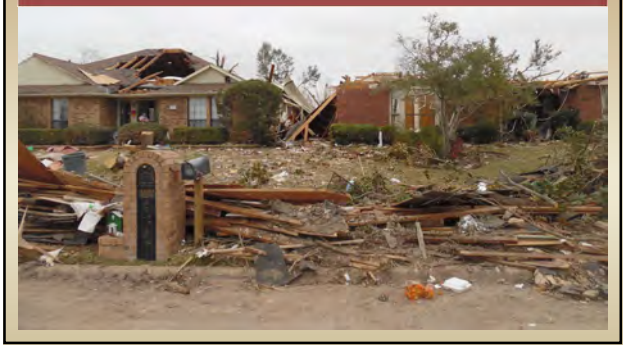
EF-1 Moderate damage. Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.

Texas Tornado – December 2015



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Damage Indicators

Texas Tornado – December 2015

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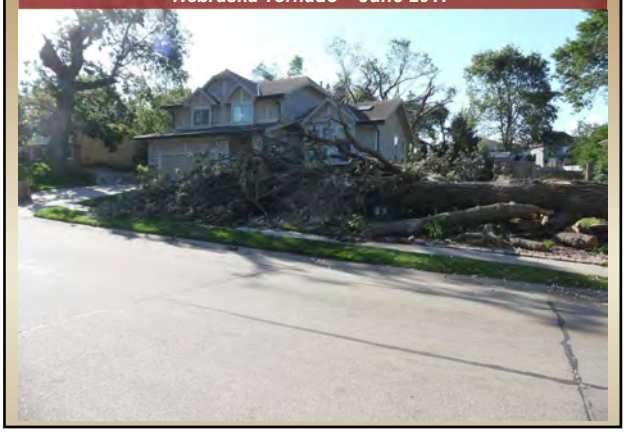
Nebraska Tornado – June 2017



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Nebraska Tornado – June 2017

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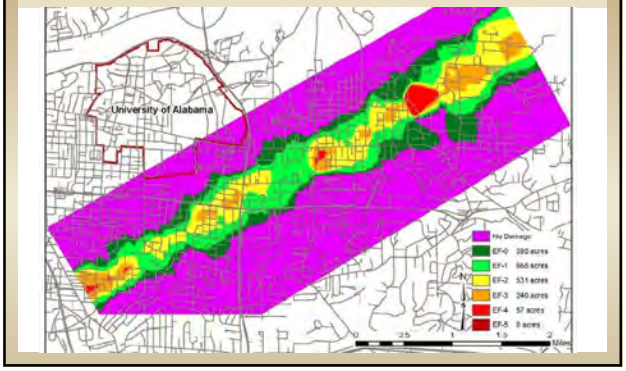
Tornado Intensity Along Path



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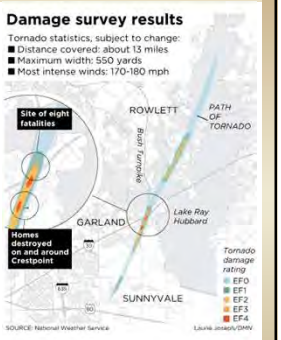
December 2015 Texas Tornado

- **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.**



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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	

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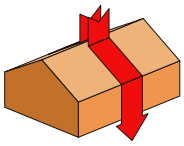
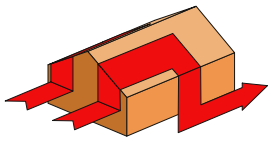
Load Path

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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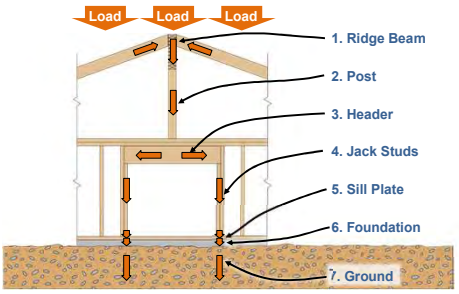
Load Path

Vertical (Gravity) Load Path Issues



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Load Path Continuity

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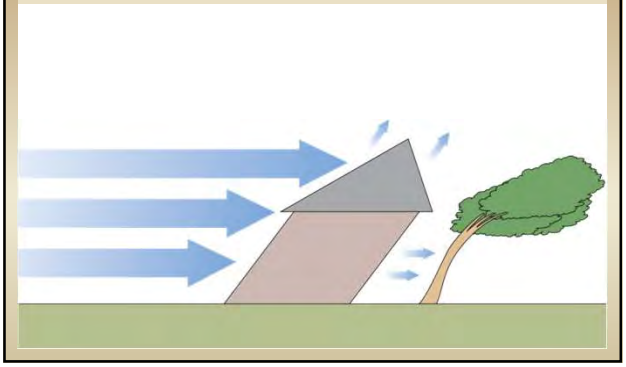
Load Path



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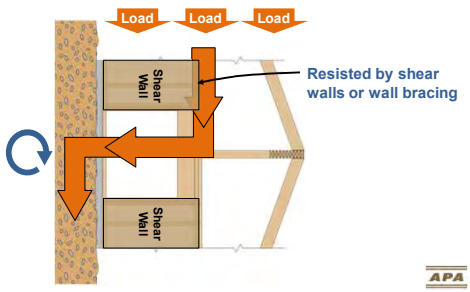
Load Path

Lateral (Sideways) Load Path Issues



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Lateral Forces

Effects of Forces

Racking	Base Shear	Overturning
		
Resisted by Bracing	Resisted by Anchors	Resisted by hold-downs & Dead Load

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Building for High Wind Resistance

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Roof Sheathing Connection

(A) Nail roof sheathing with 8d ring shank or screw shank (0.131" x 2-1/2") nails at 4 inches on center along the ends of the sheathing and at gable-end walls, and 6 inches on center along intermediate framing.

(B) 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.

(C) Sheath gable-end walls with wood structural panels, such as plywood or oriented strand board (OSB). In past tornado events, gable-end wall failures were frequently observed when non-structural sheathing was used.

(D) For the roof framing to wall connection, use a hurricane/seismic framing anchor or eq connector, attached on the exterior (shea side) of the exterior walls. The roof-to-w

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Roof Sheathing Connection

Texas Tornado – December 2015

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Texas Tornado – December 2015

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Tornados of the South – 2011

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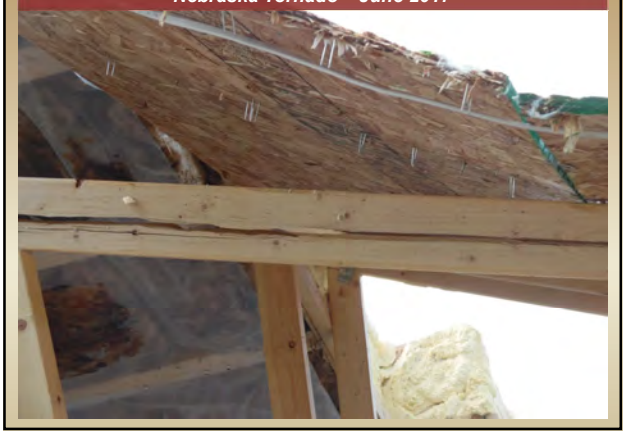
Nebraska Tornado – June 2017



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Maryland Tornado – July 2017

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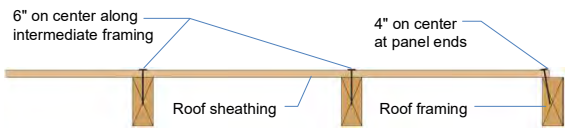
Roof Sheathing Attachment

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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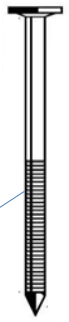
Fastener Recommendations

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

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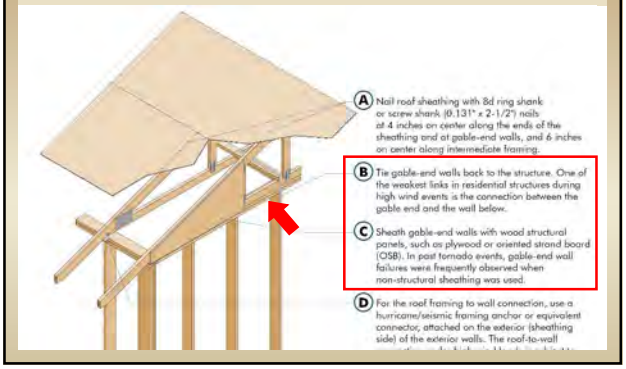
Gable Ends



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Fayetteville, North Carolina – 2011 Tornados

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Texas Tornado – December 2015

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Nebraska Tornado – June 2017

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Nebraska Tornado – June 2017

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Nebraska Tornado – June 2017

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Nebraska Tornado – June 2017

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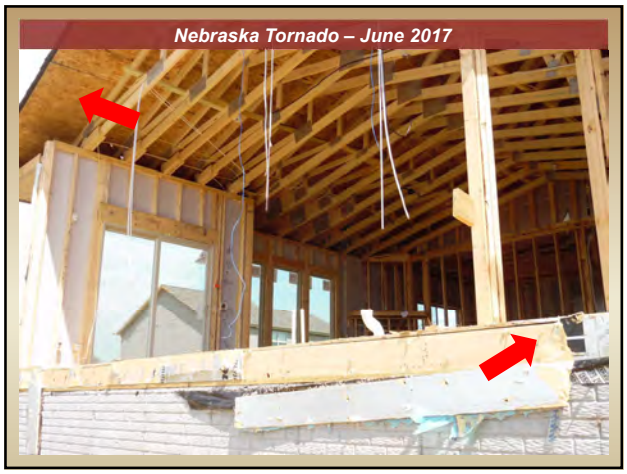
Nebraska Tornado – June 2017

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Nebraska Tornado – June 2017

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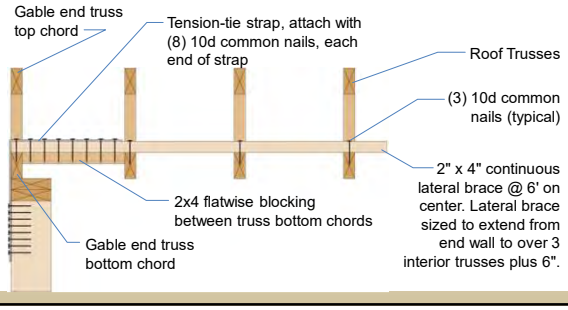
Gable-end Framing

Tie gable end walls back to the structure



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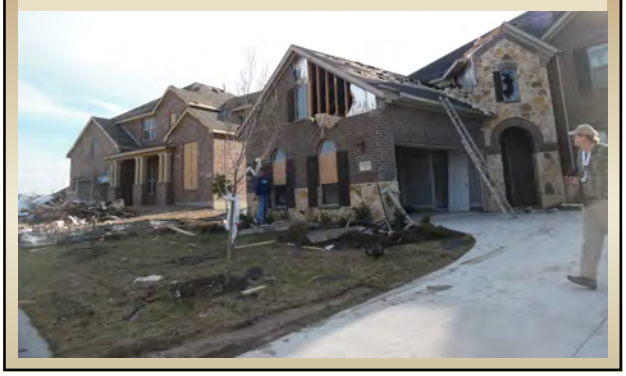
Gable Ends



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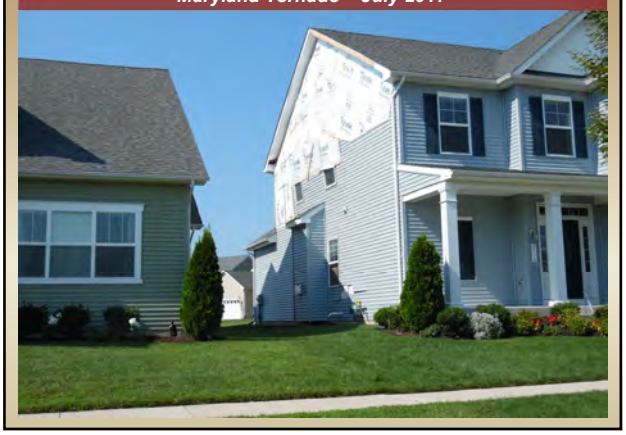
Maryland Tornado – July 2017



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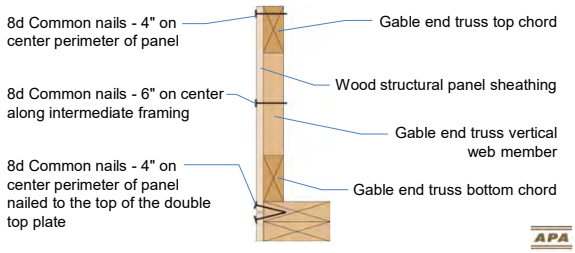
Resisting Pressure on Components and Cladding

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



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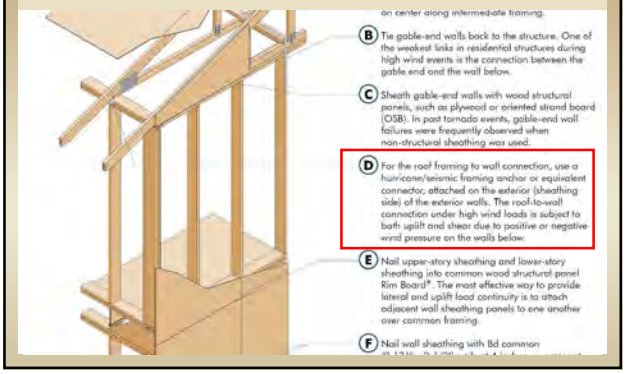
Top Plates



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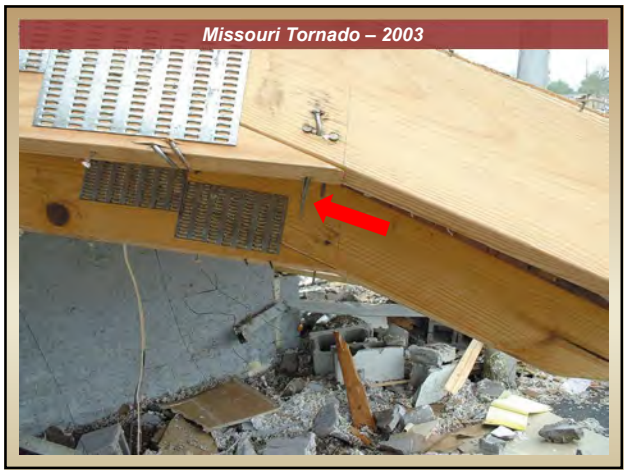
Missouri Tornado – 2003

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Missouri Tornado – 2003

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Coaling, Alabama – 2011 Tornados

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Tornados of the South – 2011

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Texas Tornado – December 2015

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Top Plates

Garland, Texas – 2015

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Top Plates

Garland, Texas – 2015

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Top Plates

Garland, Texas – 2015

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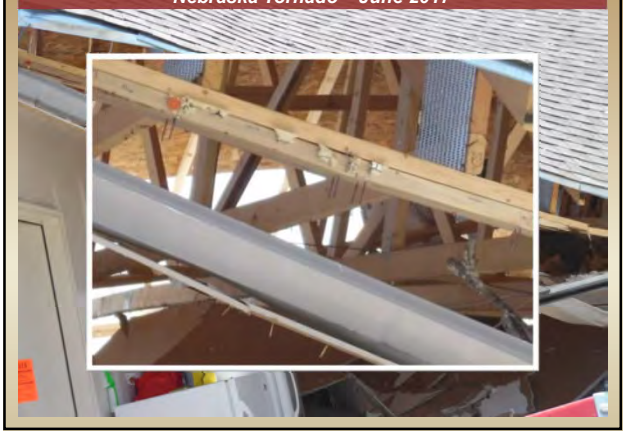
Nebraska Tornado – June 2017



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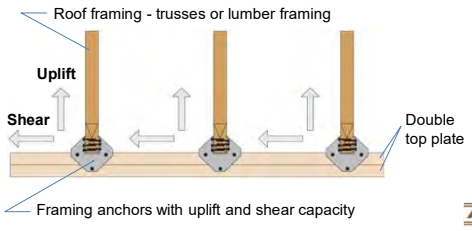
Roof to Wall Connection

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



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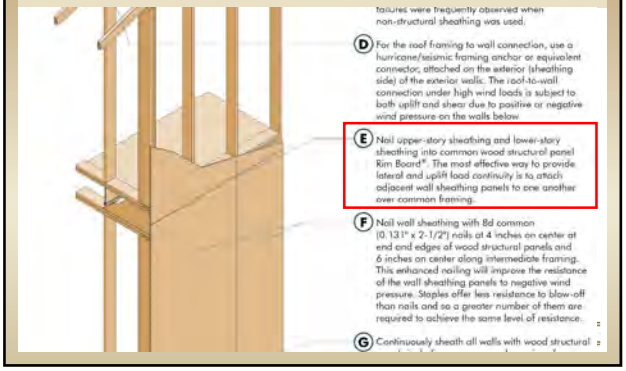
Connections between floors



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Texas Tornado – December 2015

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Texas Tornado – December 2015

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Nebraska Tornado – June 2017

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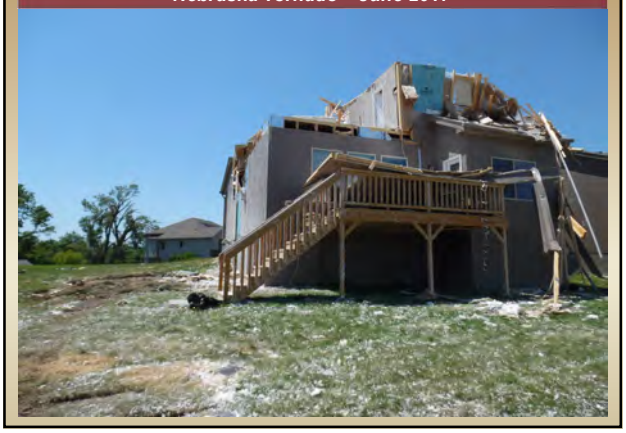
Nebraska Tornado – June 2017



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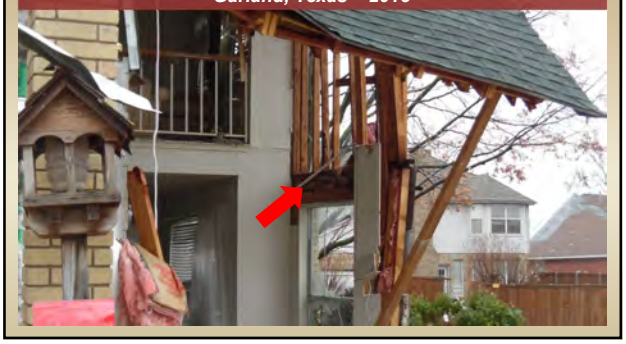
Rim Board Connections

Garland, Texas – 2015



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Maryland Tornado – July 2017

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Rim Board Connections

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Rim Board Connections

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Rim Board Connections

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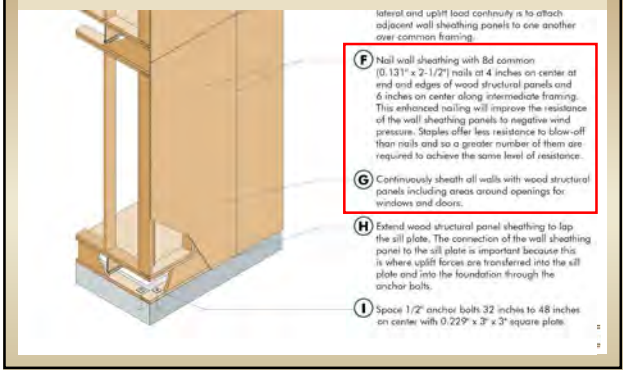
Wall Sheathing



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Missouri Tornado – 2003

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Missouri Tornado – 2003

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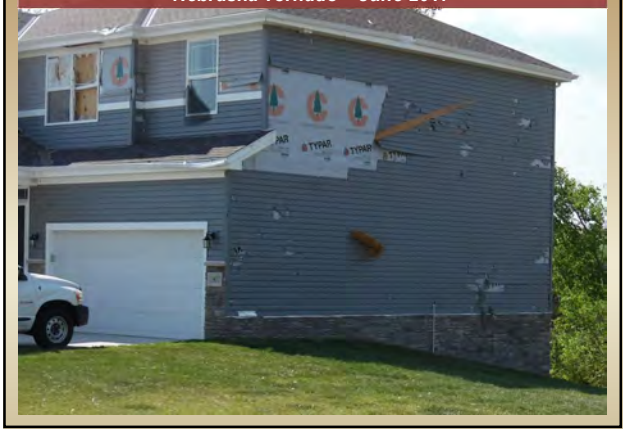
Nebraska Tornado – June 2017



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Missouri Tornado – 2003

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Wall Sheathing

Texas Straight Line Wind – March 2017

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Lateral Forces

Effects of Forces

Racking Base Shear Overturning

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

APA

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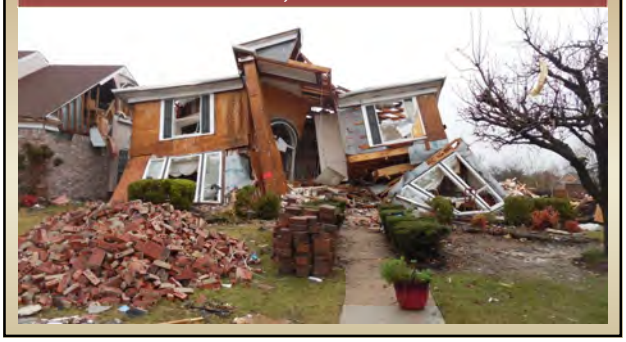
Wall Sheathing

Garland, Texas – 2015



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Wall Sheathing

Texas Straight Line Wind – March 2017

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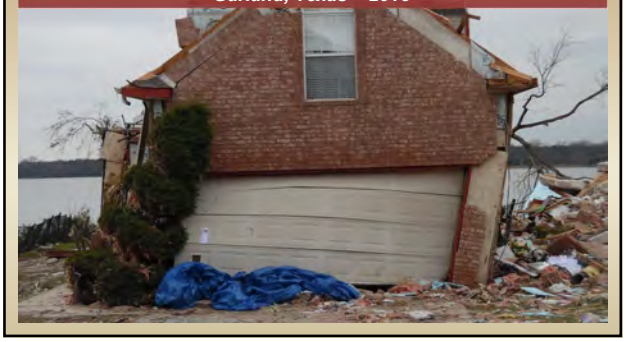
Wall Sheathing

Garland, Texas – 2015



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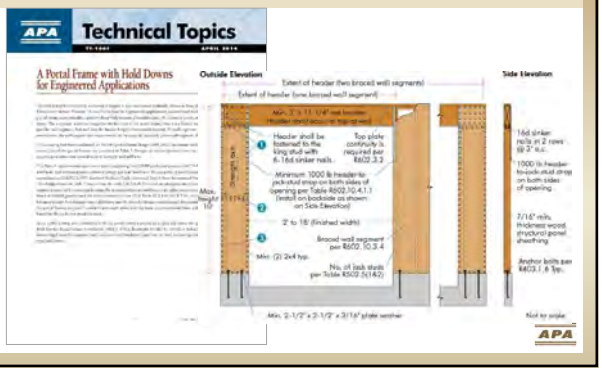
Portal Frames



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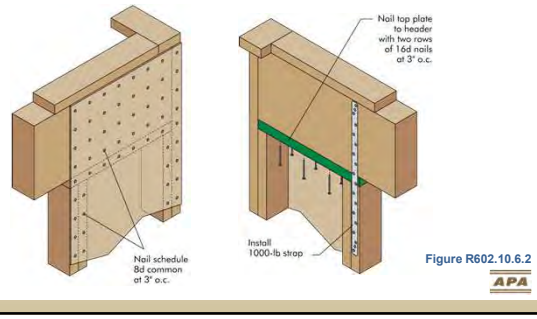
Portal Frame



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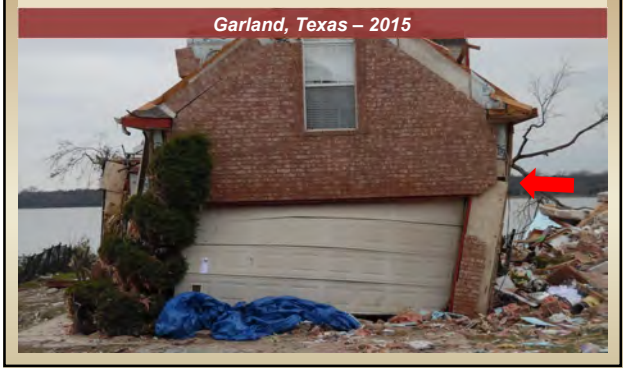
Wall Sheathing



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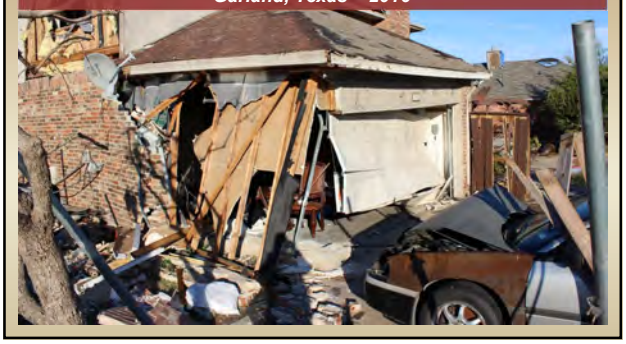
Wall Sheathing

Garland, Texas – 2016



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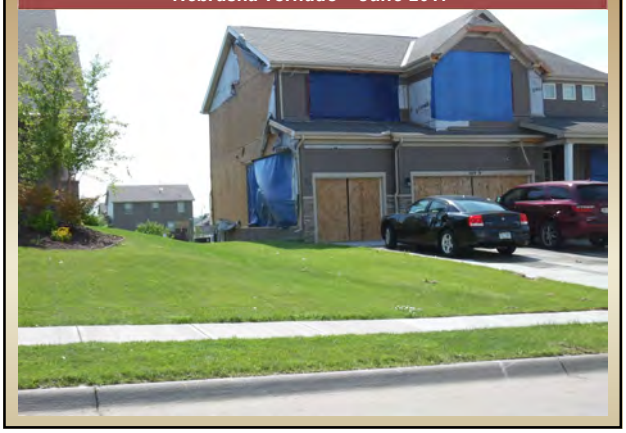
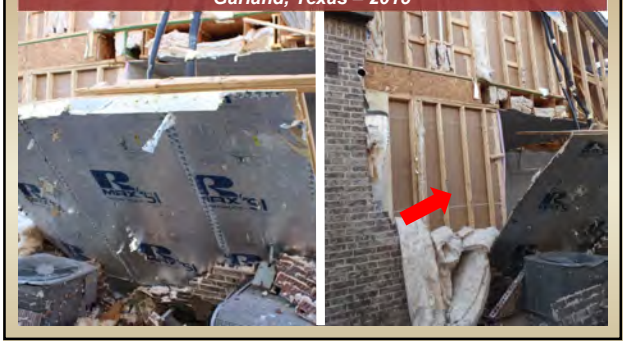
Nebraska Tornado – June 2017



92

Wall Sheathing

Garland, Texas – 2015



93

Veneer Failures

Garland, Texas – 2015

94

Veneer Failures

Garland, Texas – 2015

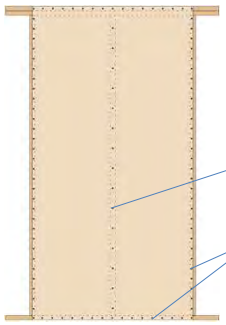
95

Wall Sheathing

Texas Straight Line Wind - 2017

96

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

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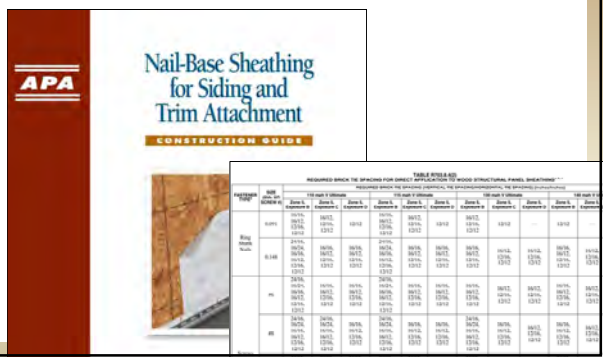
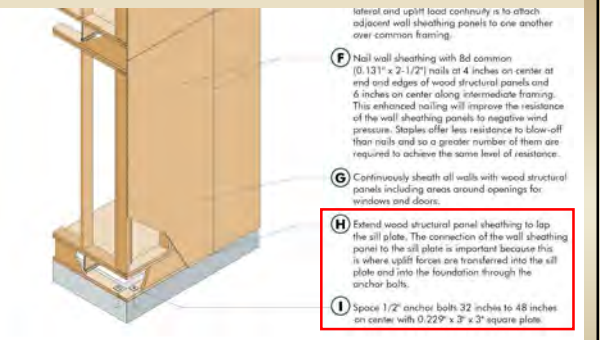
Wall Sheathing Attachment



98

Sill Plates and Anchor Bolts



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

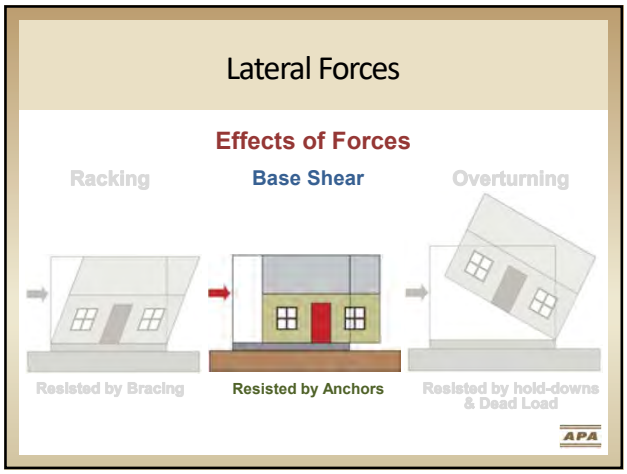
(F) Nail wall sheathing with 8d common (0.131" x 2-1/2") nails at 4 inches on center at end and edges of wood structural panels and 6 inches on center along intermediate framing. This enhanced nailing will improve the resistance of the wall sheathing panels to negative wind pressure. Staples offer less 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.

99


Lateral Forces
Effects of Forces
Racking
Base Shear
Overturning
Resisted by Bracing
Resisted by Anchors
Resisted by hold-downs & Dead Load
APA

100

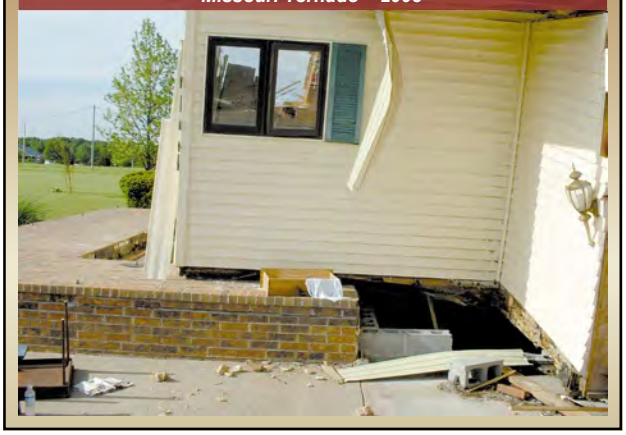

Tennessee - 2018

101


Tennessee - 2018

102

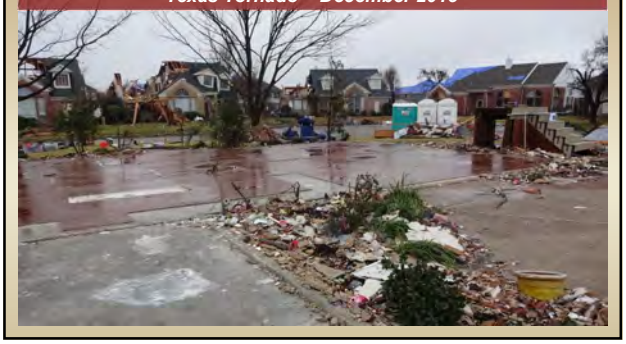
Missouri Tornado – 2003



103

Anchor-Bolt Connection to Foundation

Texas Tornado – December 2015



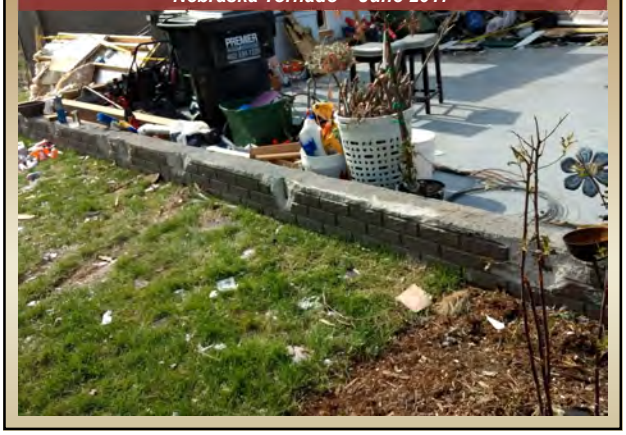
104

Anchor-Bolt Connection to Foundation

Texas Tornado – December 2015

105

Nebraska Tornado – June 2017



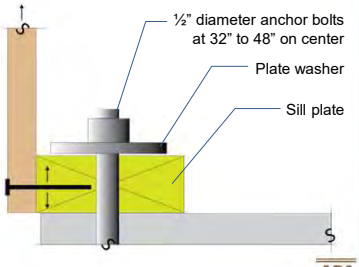
106

Maryland Tornado – July 2017

107

Anchor Bolt Installation

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



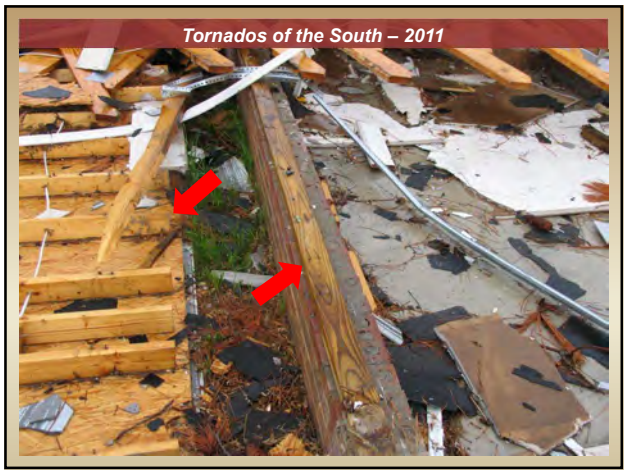
108


Missouri Tornado – 2003

109


Missouri Tornado – 2003

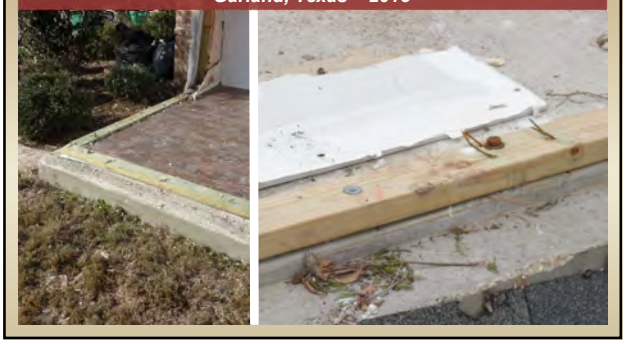
110


Tornados of the South – 2011

111

Wall Sheathing

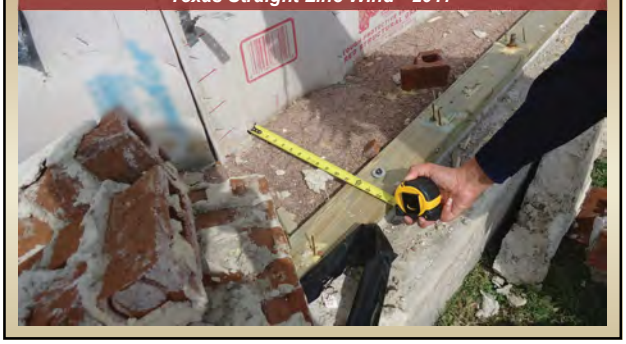
Garland, Texas – 2015



112

Wall Sheathing

Texas Straight Line Wind - 2017



113

Wall Sheathing

Texas Straight Line Wind - 2017

114

Wall Sheathing

Nebraska Tornado – June 2017

115

Tennesee 2018

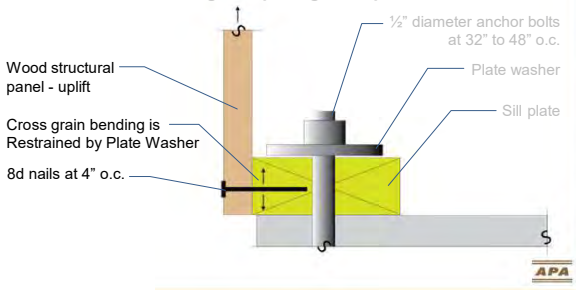
116

Tennessee 2018

117

Larger Washer Increases Uplift Capacity

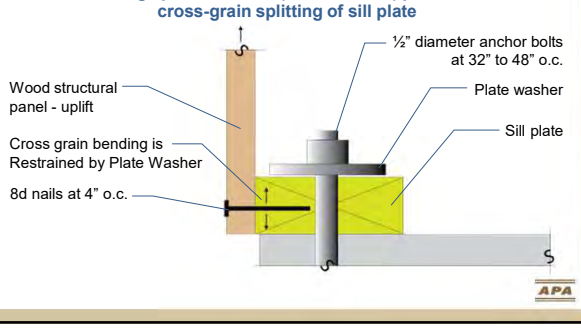
Large plate washers (3"x3"x0.229") prevent cross-grain splitting of sill plate



118

Larger Washer Increases Uplift Capacity

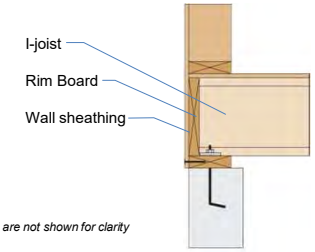
Large plate washers (3"x3"x0.229") prevent cross-grain splitting of sill plate



119

Wall Framing to Sill Plate Connection

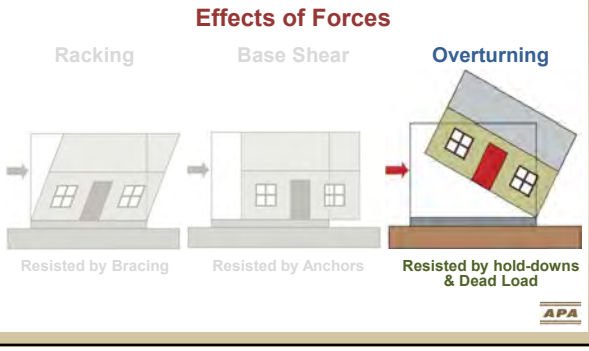
Extend wood structural panel sheathing at bottom of wall to sill plate intersection



Other connections are not shown for clarity

120

Lateral Forces



121

Overturning

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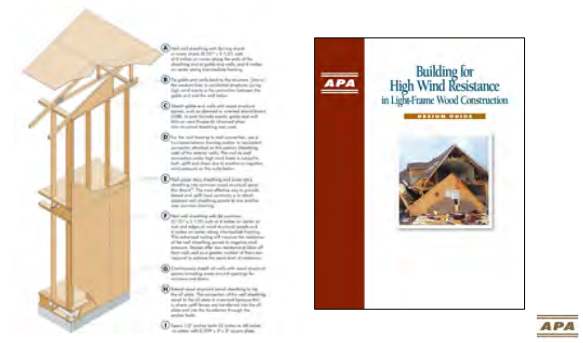
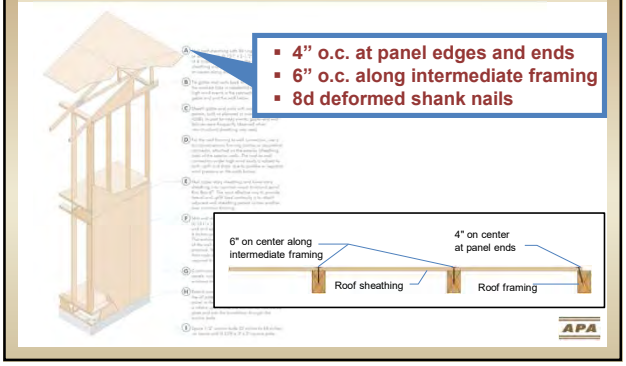
Building for High Wind Resistance



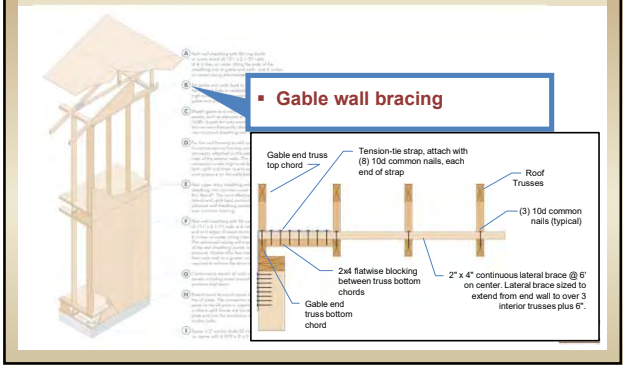
123

High Wind Resistance Guidelines



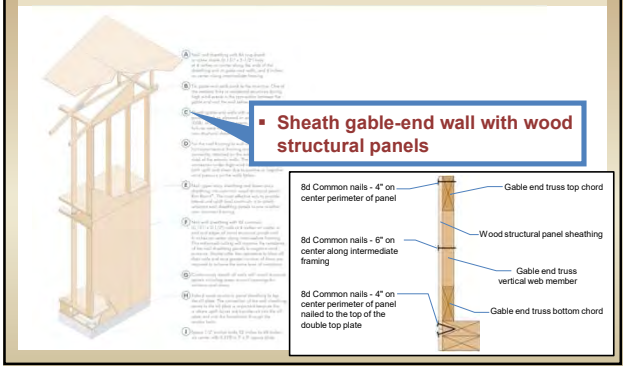
124

High Wind Resistance Guidelines



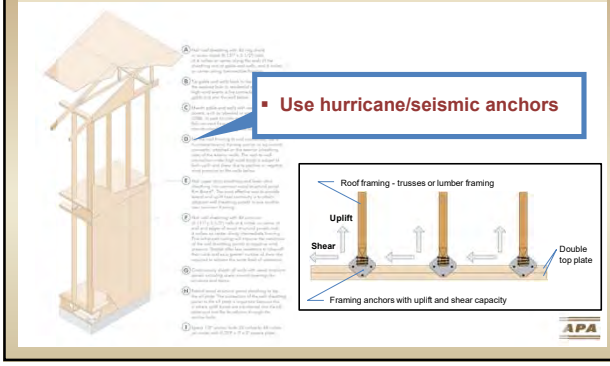
125

High Wind Resistance Guidelines



126

High Wind Resistance Guidelines



127

High Wind Resistance Guidelines

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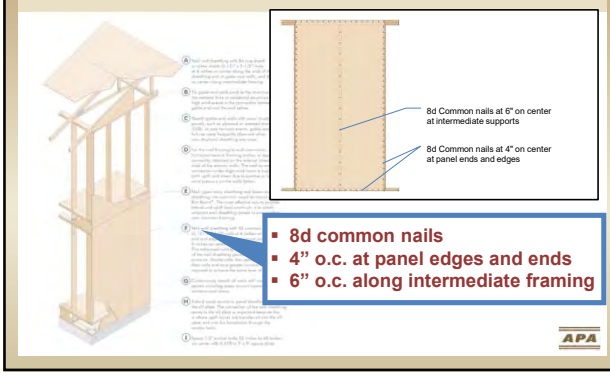
High Wind Resistance Guidelines



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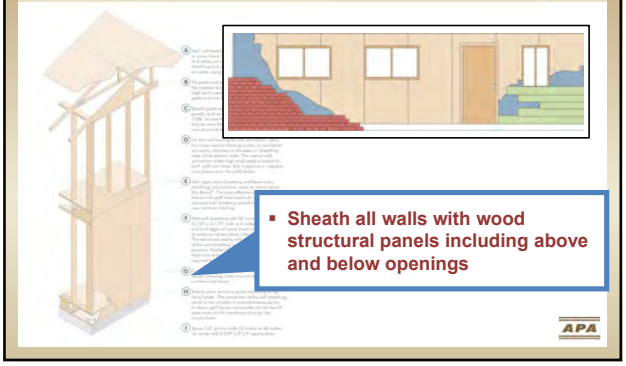
High Wind Resistance Guidelines



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

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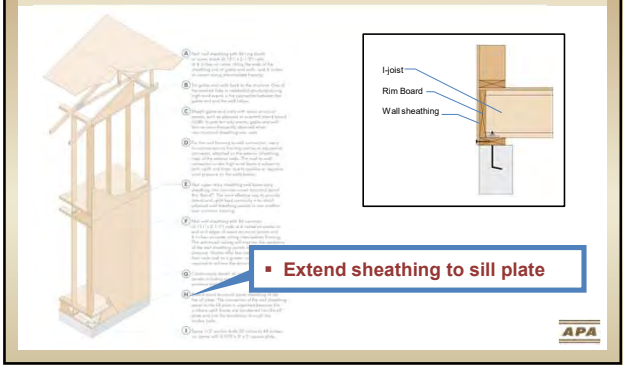
High Wind Resistance Guidelines



- Extend sheathing to sill plate

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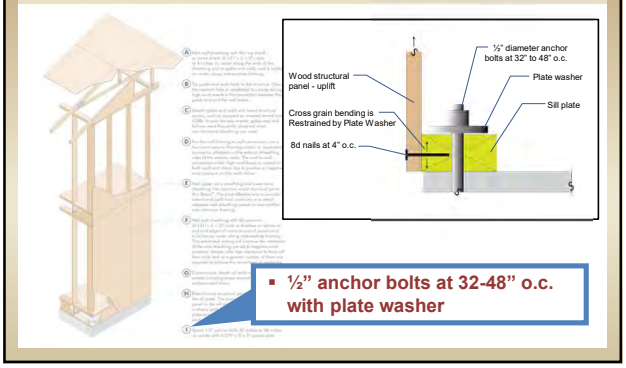
High Wind Resistance Guidelines



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

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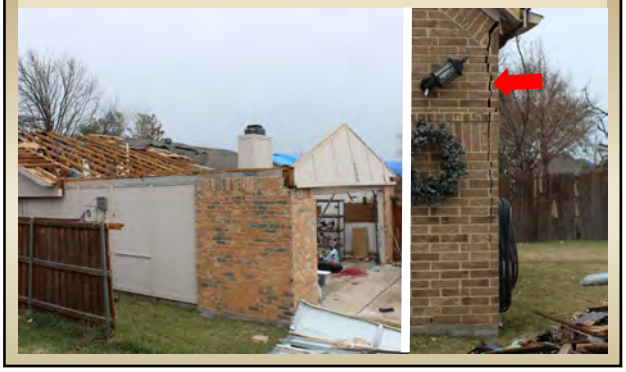
Conclusions



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www.apawood.org/wind-weather-seismic

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Questions?

Mary Uher
www.apawood.org
www.apawood.org/help

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APA Update Newsletter
(www.apawood.org)

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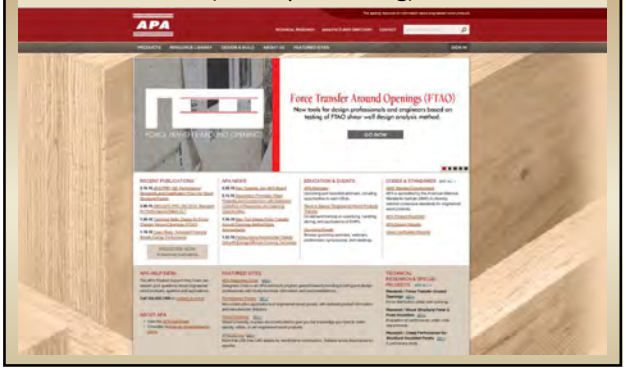
APA Update Newsletter
(www.apawood.org)



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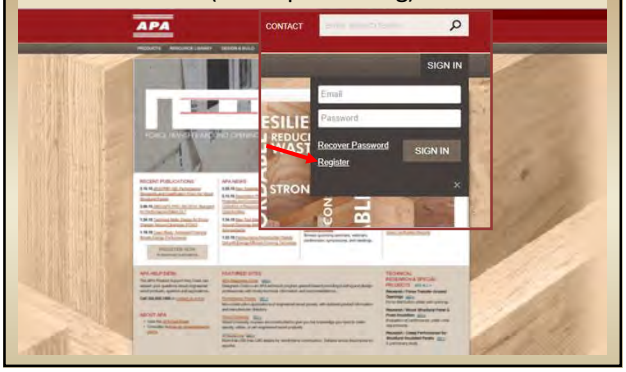
APA Update Newsletter
(www.apawood.org)



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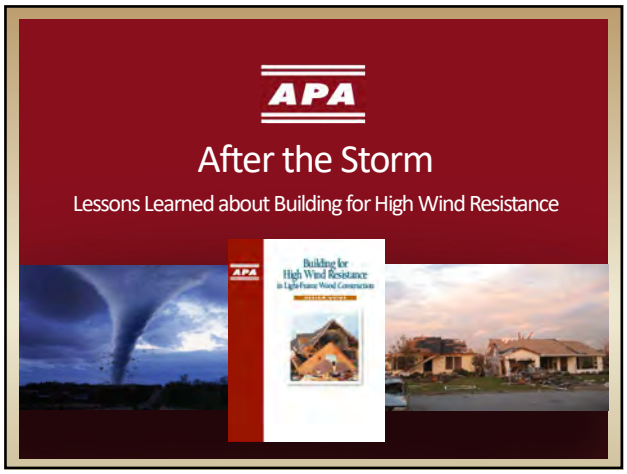
APA
After the Storm
Lessons Learned about Building for High Wind Resistance
Building for High Wind Resistance

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