The Shear Path – Roof to Foundation

For Wood Framed Structures

Karyn Beebe, P.E., LEED AP

APA – The Engineered Wood Association

Quality Services Division

Technical Services Division

Field Services Division

Market Communications Division

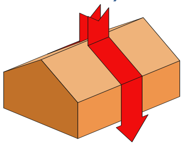
Learning Objectives

- Understand the complete lateral load path
- Identify common framing errors within this path
- Discuss code requirements for critical details

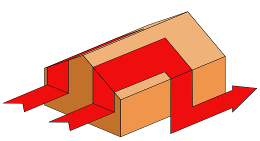
Load Path

"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."

(CBC 2010 1604.4)



VERTICAL



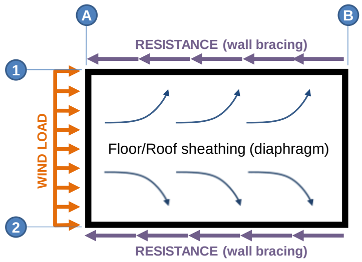
HORIZONTAL

Vertical (Gravity) Load Path

Lateral Load Path

Big Picture

Loaded wall versus resisting walls



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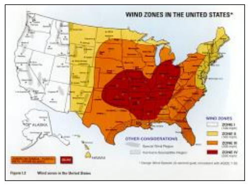
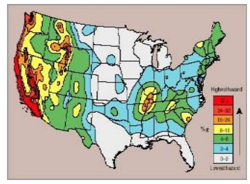
Lateral Loads: National Issue

Wind Hazard



Earthquake Hazard



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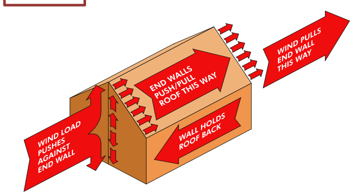
Lateral Loads(Wind)

F = PA

Effort is devoted to determining:
P – wind pressure



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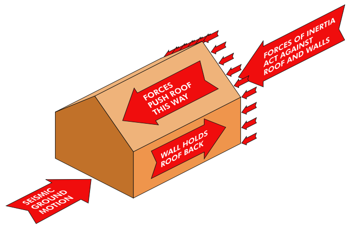
Lateral Loads(Seismic)

F = ma

Effort is devoted to determining:
a – acceleration



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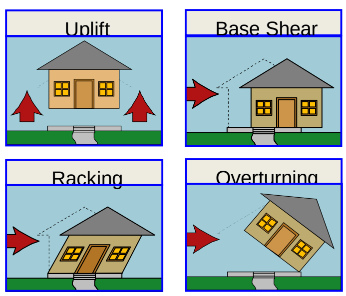
Wood – Light and Flexible

General Modes of Failure



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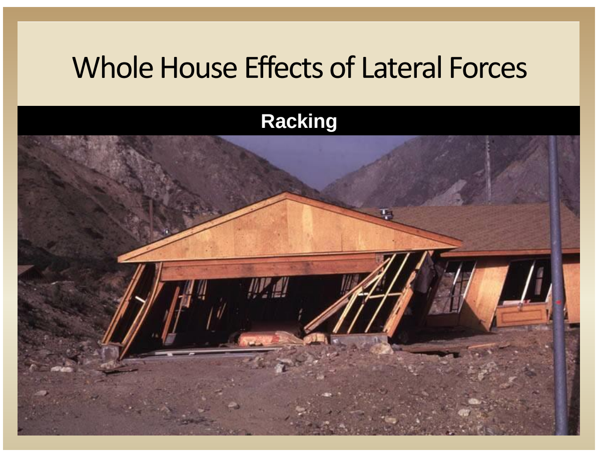
UPLIFT


3-D Connector

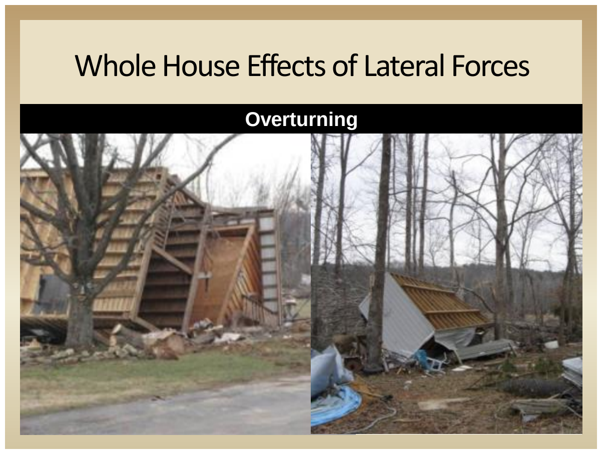

Whole House Effects of Lateral Forces
Racking

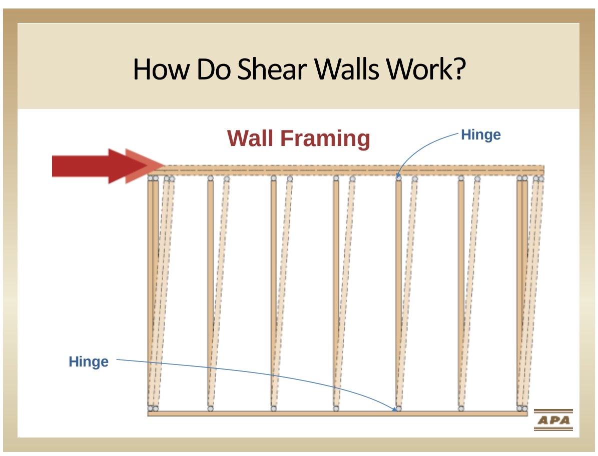

Lateral Forces
Racking – Rowlett/Garland Tornados 2015

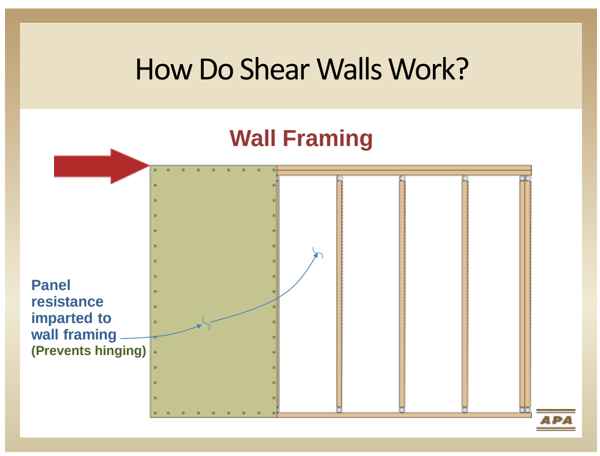

Base Shear


Whole House Effects of Lateral Forces
Base Shear


Overturning


Whole House Effects of Lateral Forces
Overturning


How Do Shear Walls Work?
Wall Framing
Hinge
Hinge
APA


How Do Shear Walls Work?
Wall Framing
Panel resistance imparted to wall framing
(Prevents hinging)
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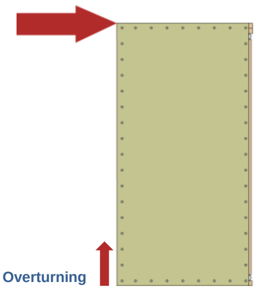
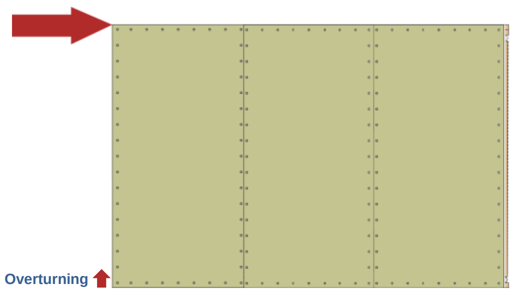
Overturning



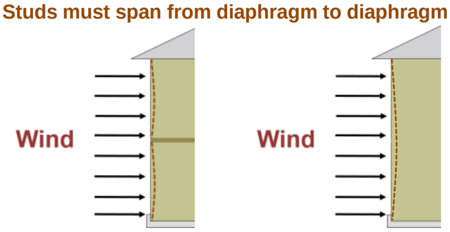
Overturning



Studs – to – Structure

Lateral Load

- Cladding transfers the wind load to the studs
- Studs transfer the wind load to the roof and floor diaphragms
- Studs must span from diaphragm to diaphragm

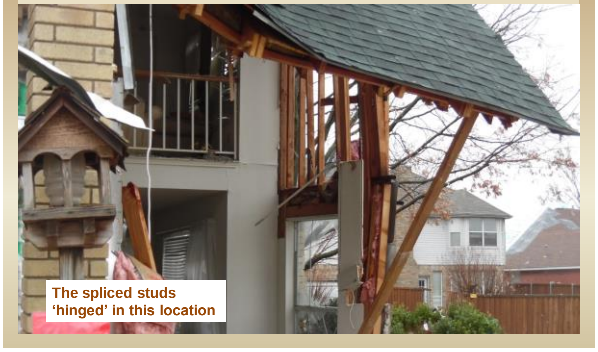


Studs – to – Structure

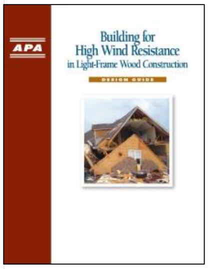
Lateral Load - Tall Walls

Studs – to – Structure

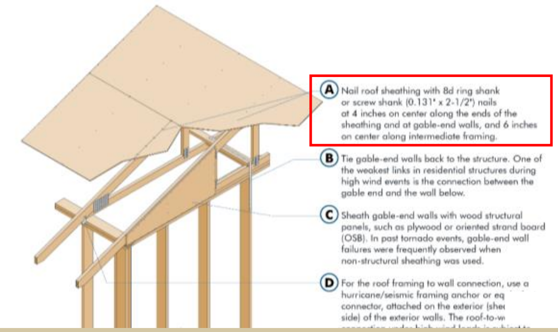
Lateral Load - Tall Walls



Building for High Wind Resistance



Roof Sheathing Connection



Roof Sheathing Connection

Texas Tornado – December 2015

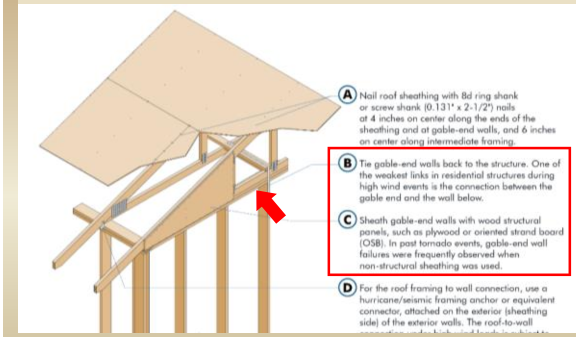
Roof Sheathing - to - Roof Rafters/Trusses

Uplift Load

Nebraska Tornado – June 2017

- Proper spacing of staples (Table R602.3(2))
- Proper orientation of staples to ensure both legs are engaged

Gable Ends



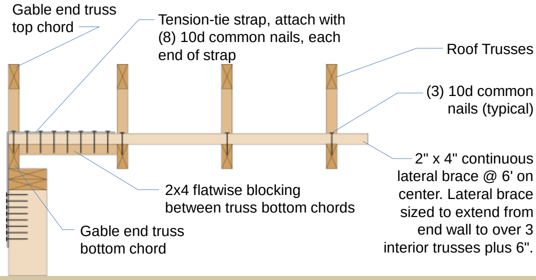
Fayetteville, North Carolina – 2011 Tornados

Texas Tornado – December 2015

Nebraska Tornado – June 2017

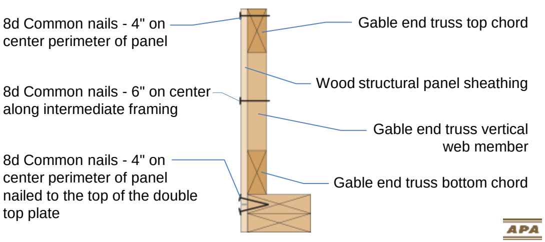
Gable-end Framing

Tie gable end walls back to the structure



Resisting Pressure on Components and Cladding

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

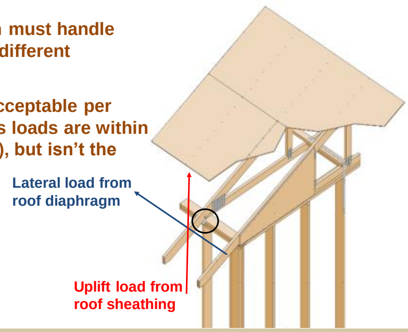


Roof Rafters/Trusses - to - Top Plates

Lateral and Uplift Loads

This connection must handle loads from two different directions.

Toe-nailing is acceptable per code (as long as loads are within allowable limits), but isn't the best option.



Roof Rafters/Trusses - to - Top Plates

Lateral and Uplift Loads

Coaling, Alabama – 2011 Tornados

Roof Rafters/Trusses - to - Top Plates

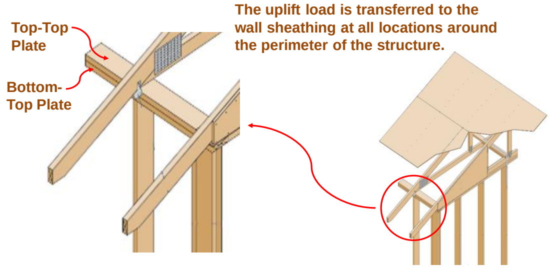
Lateral and Uplift Loads

Missouri Tornado – 2003

Top Plate – to – Wall Sheathing

Uplift Loads

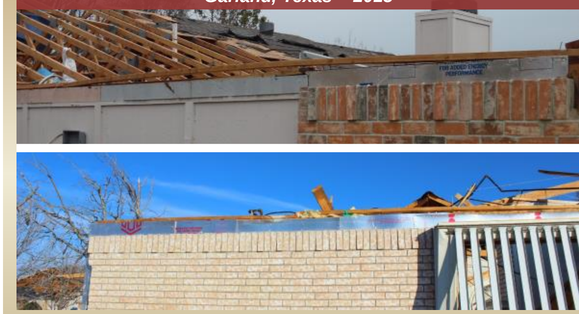
Wall sheathing should be fastened to both top plates, but the top-top plate at a minimum – and not just at braced wall panels



Top Plate – to – Wall Sheathing

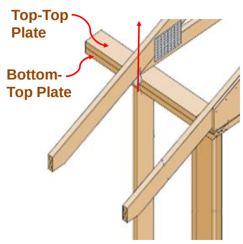
Uplift Loads

Garland, Texas – 2015



Top Plate – to – Wall Sheathing

Uplift Loads



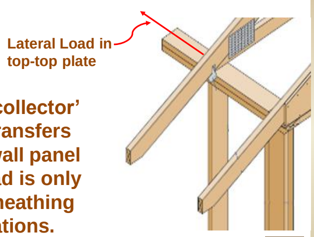
Uplift loads must be accounted for all the way down to the foundation (just like any other load).

Dead load of structure can be used to counteract it.

Top Plate – to – Wall Sheathing

Lateral Loads

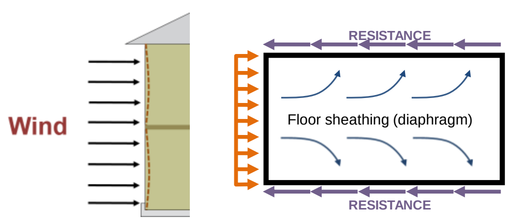
Wall sheathing should be fastened to both top plates, but the top-top plate at a minimum.



The top plate acts as a 'collector' for the lateral load and transfers that load to the braced wall panel locations - the lateral load is only transferred to the wall sheathing at braced wall panel locations.

Floor Sheathing – to – Wall Sheathing

Lateral Loads



Floor Sheathing – to – Wall Sheathing

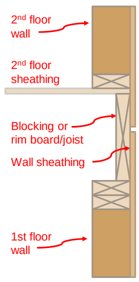
Lateral Loads

The load is transferred from the floor sheathing into the joist blocking or rim board/joist.

The blocking or rim board/joist acts as a 'collector' for the lateral load and transfers that load to the braced wall panel locations

The load is transferred into the sheathing at the braced wall panel locations – depends on how/where the braced wall panels are attached.

Wall sheathing should be fastened to the rim board or the top plates.



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Wall Sheathing – to – Framing

Lateral Loads

- **The wall sheathing and framing work together to move the lateral load down to the base of the wall**
- **The engineer may require a tighter fastener spacing than the standard spacing required by code (6" o.c. edges, 12" o.c. field for WSP) if the panel is a shear panel (engineered).**

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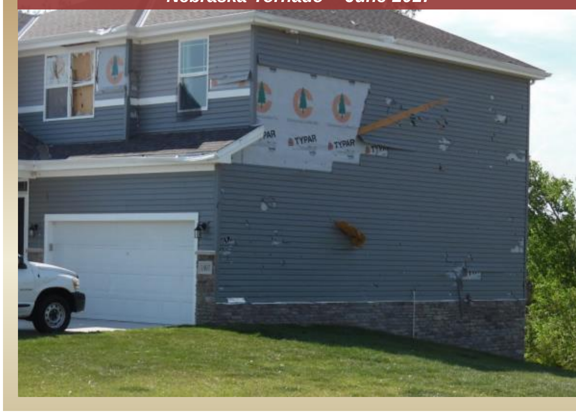
Missouri Tornado – 2003

Nebraska Tornado – June 2017



Wall Sheathing

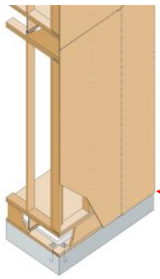
Texas Straight Line Wind – March 2017

Wall Sheathing

Texas Straight Line Wind – March 2017

Wall Sheathing – to – Sill Plate

Lateral and Uplift Loads



- Sheathing must be fastened to the bottom plate.
- Make sure staples are aligned parallel to the bottom plate to ensure both legs are engaged.
- At this point, uplift loads from the suction on the roof are at their smallest due to dead load of the structure.

Attachment to sill plate

Wall Sheathing – to – Sill Plate

Lateral and Uplift Loads

Wall Sheathing – to – Sill Plate

Lateral and Uplift Loads

Tornados of the South – 2011

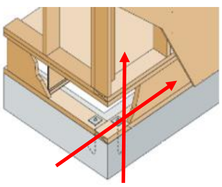
Wall Sheathing – to – Sill Plate

Lateral and Uplift Loads

Garland, Texas – 2015

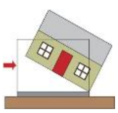
Sill Plate – to – Foundation

Lateral and Overturning Loads



- At this point, the lateral loads and the overturning loads are at their maximum.

- Anchor bolts transfer the lateral loads from the sill plate to the foundation.



- Hold downs transfer the overturning loads from the structure to the foundation

Sill Plate – to – Foundation

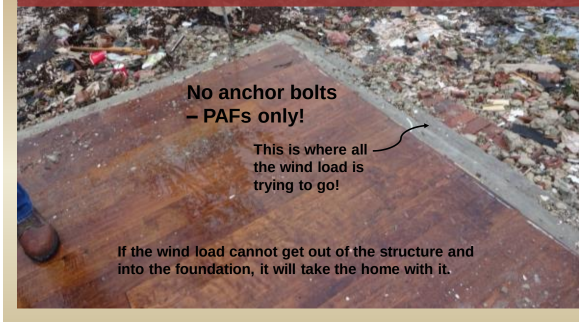
Lateral and Uplift Loads

Texas Tornado – December 2015

Sill Plate – to – Foundation

Lateral and Uplift Loads

Texas Tornado – December 2015



Governing Codes for Engineered Wood Design

2016 CBC (2015 IBC)

- Chapter 23 Wood
- NDS-2015 (National Design Specification for Wood Construction)
- SDPWS-15 (Special Design Provisions for Wind and Seismic)

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Wood Structural Panels are by definition either Plywood or OSB (2302 & R202)

Wood Shear Wall and Diaphragms Design

- Function of: fastener's size, spacing and panel thickness
- Values in Tables in SDPWS-08
- Alternately, capacities can be calculated by principles of mechanics

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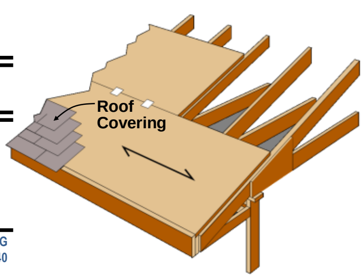
Wood's Strength Direction

- Rated Sheathing
  - Floor, wall or roof
  - Plywood or OSB

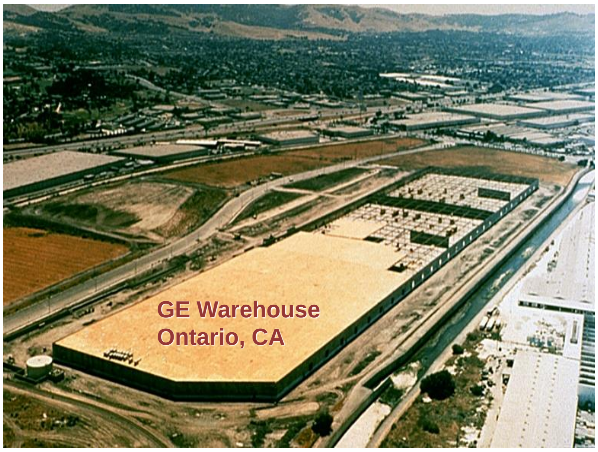
A P A

RATED SHEATHING
32/16
SIZED FOR SPACING
EXPOSURE 1
THICKNESS 0.451 IN.
000
PS 2-10 SHEATHING
PRP-108 HUD-UM-40
15/32 CATEGORY



APA

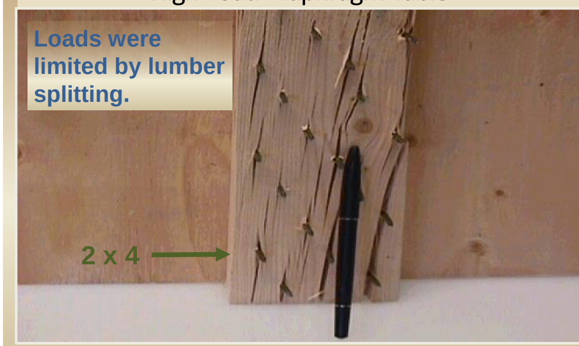
High load diaphragms



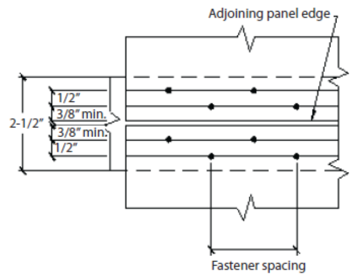
High Load Diaphragms

- SDPWS-08 4.2.7.1.2
- Uses multiple rows of nails
- ASD capacity up to 1800 plf (seismic)
- ASD capacity up to 2520 plf (wind)
- Shall be subject to special inspection IAW CBC Section 1704.6.1

Footnotes to High-Load Diaphragm Table



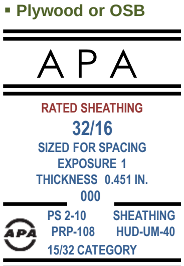
High-Load Diaphragm Fastening Pattern (SDPWS-15 Fig 4C)

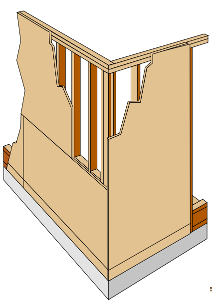


3" nominal, two lines of fasteners

Wood's Strength Direction

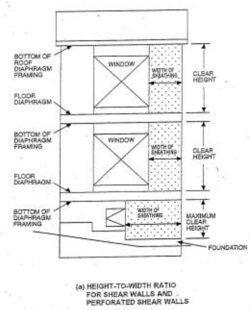
- Rated Sheathing
  - Floor, wall or roof
  - Plywood or OSB





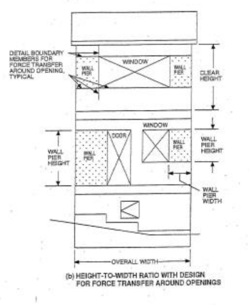
Height to width ratio (SDPWS-08 Figure 4D & 4E)

- For shear walls and perforated shear walls
- h:w must not exceed 2:1 or 3.5:1 ratio



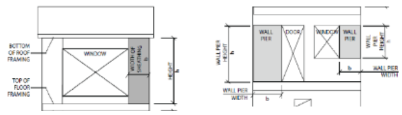
Height to width ratio (SDPWS-08 Figure 4F)

- For force transfer around opening shear walls
- h:w must not exceed 2:1 or 3.5:1 ratio



Aspect ratio (SDPWS-15 4.3.4.2)

- Definition of h and w is the same as previous code
- ALL shear walls with 2:1 < aspect ratios <= 3.5:1 shall apply reduction factor, aspect ratio factor
- Aspect Ratio Factor (WSP) = 1.25-0.125h/bs
  - Formerly applied only to high seismic

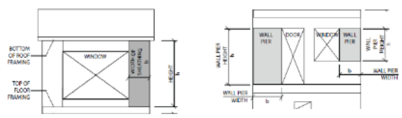


Excerpt Fig 4D
h:w ratio Segmented

Excerpt Fig. 4E
h:w ratio FTAO

Shear distribution to shear walls in line (SDPWS-15 4.3.3.4.1)

- Individual shear walls in line shall provide the same calculated deflection. Exception:
  - Nominal shear capacities of shear walls having 2:1<aspect ratio<=3.5:1 are multiplied by 2bs/h for design. Aspect ratio factor (4.3.4.2) need not be applied.

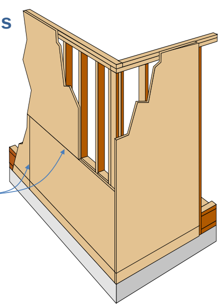


Excerpt Fig 4D
h:w ratio Segmented

Excerpt Fig. 4E
h:w ratio FTAO

Wood Moves

- Wall sheathing expands



Space panels 1/8" min.
(ends & edges)

Wood Moves

- High Risk Application
  - Parallel to supports
  - Edge nailing 4" o.c. or closer
  - Long lasting rainy weather

TECHNICAL NOTE

Minimizing Buckling of Wood Structural Panels

Form D481N
September 2012

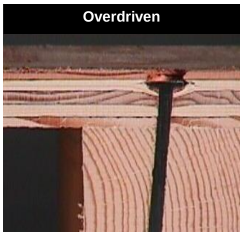
Buckling of wood structural panel sheathing such as plywood or oriented strand board (OSB) occasionally results when increased moisture conditions cause the wood to expand. Such buckling may occur between supports or between nails along supports. Although structural properties are unaffected, the waviness affects the building's appearance and may lead to complaints. Builders can significantly reduce the potential for buckling by assuring minimal moisture-content increase in service and/or providing for its natural effects.

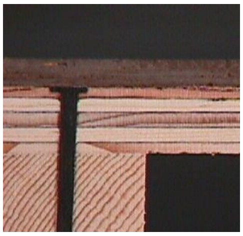
High risk because the conditions may reduce edge gap's effectiveness in absorbing panel expansion.

Wood Moves

Consistency Counts

- Overdriven fasteners





Consistency Counts

Overdriven Fasteners

Overdriven Fasteners	Overdriven Distance	Action
≤ 20%	< 1/8"	None
> 20%	< 1/8"	Add 1 for every two overdriven
Any	> 1/8"	

APA Publication TT-012

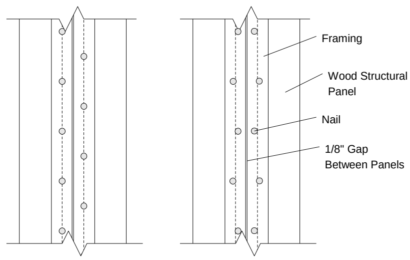
Consistency Counts

Overdriven Fasteners

Overdriven Fasteners	Overdriven Distance	Action
Any	Due to Thickness Swelling	None

APA Publication TT-012

Staggered Nailing

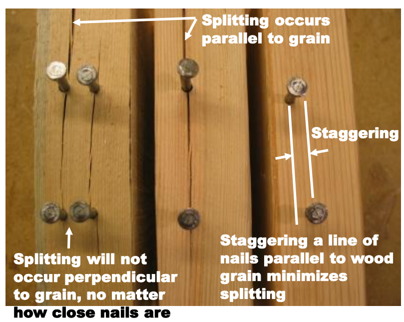


Nailing not staggered　　Nailing staggered

Material Properties of Wood

- Splitting happens because wood is relatively weak perpendicular to grain
  - Nails too close (act like a wedge)

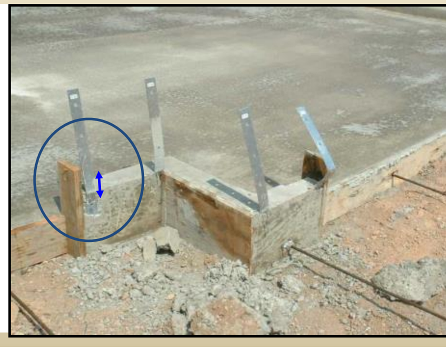
Material Properties of Wood



Material Properties of Wood

- Staggered nailing in tightly nailed shear wall helps prevent splitting of framing

Load Path Continuity



Load Path Continuity

Shear Wall Design Challenges

Shear Wall Design Challenges (SDPWS 4.3.5)

Segmented

1. Aspect Ratio up to 2:1 for wind and seismic
2. Aspect ratio up to 3.5:1, if allowable shear is reduced by 1.25-0.125h/bs

Force Transfer

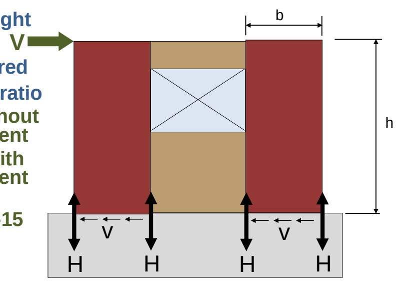
1. Code does not provide guidance for this method
2. Different approaches using rational analysis could be used

Perforated

1. Code provides specific requirements
2. The capacity is determined based on empirical equations and tables

Segmented Wood Shear Walls (SDPWS-08/15 Section 4.3.5.1)

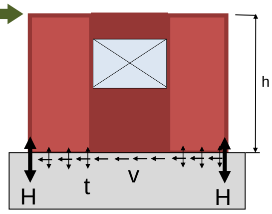
- Only full height segments are considered
- Max aspect ratio
  - * 2:1 – without adjustment
  - * 3.5:1 – with adjustment
  - * New to SDPWS-15



Aspect ratio h:b_s as shown in figure

Perforated Shear Wall (SDPWS-15 4.3.5.3)

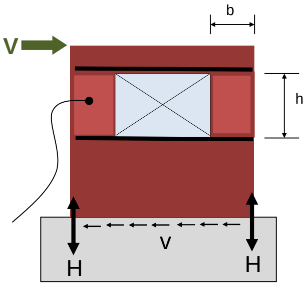
- Openings accounted for by empirical adjustment factor
- Hold-downs only at ends
- Uplift between hold downs, t, at full height segments is also required
- Limited to 870 plf (ASD, seismic)



Aspect ratio applies to full height segment (dotted)

FTAO (SDPWS-08/15 Section 4.3.5.2)

- Openings accounted for by strapping or framing
  - "based on a rational analysis"
- Hold-downs only at ends
- H/w ratio defined by wall pier



Aspect ratio h:b as shown in figure

Test Data

Test Plan

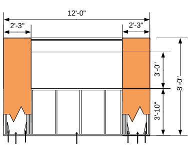
- 12 wall configurations tested (with and without FTAO applied)
- Wall nailing; 10d commons (0.148" x 3") at 2" o.c.
- Sheathing; 15/32 Perf Cat oriented strand board (OSB) APA STR I
- All walls were 12 feet long and 8 feet tall
- Cyclic loading protocol following ASTM E2126, Method C, CUREE Basic Loading Protocol

Test Plan

Wall1

Objective:
Est. baseline case for 3.5:1 segmented wall

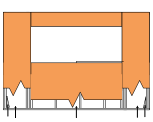
Segmented



Wall 2

Objective:
No FTAO, compare to Wall 1. C_o = 0.93. Examine effect of sheathing above and below opening w/ no FTAO. Hold down removed.

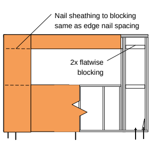
Perforated



Wall 3

Objective:
No FTAO, compare to Wall 1 and 2. Examine effect of compression blocking.

Wall is symmetric, sheathing on right pier not shown for clarity

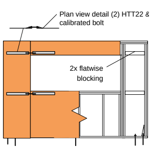


Wall 4

Objective:
FTAO, compare to Wall 1. Examine effect of straps

Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity

FTAO

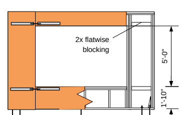


Test Plan

Wall 5

Objective:
FTAO, compare to Wall 4. Examine effect of straps with larger opening

Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity

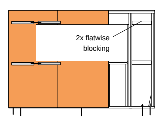


FTAO with bigger opening

Wall 6

Objective:
Compare to Wall 4. Examine effect of sheathing around opening

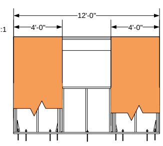
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



FTAO with C-shaped panel

Wall 7

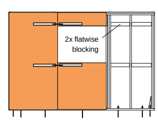
Objective:
Est. baseline case for 2:1 segmented wall



Wall 8

Objective:
Compare FTAO to Wall 7

Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity

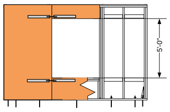


Test Plan

Wall 9

Objective:
Compare FTAO to Wall 7 and 8. Collect FTAO data for wall with larger opening

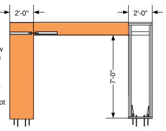
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



Wall 10

Objective:
FTAO for 3.5:1 Aspect ratio pier wall. No sheathing below opening. Two hold downs on pier (fixed case)

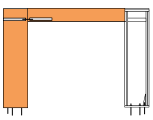
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



Wall 11

Objective:
FTAO for 3.5:1 Aspect ratio pier wall. No sheathing below opening. One hold downs on pier (pinned case)

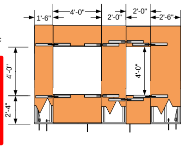
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



Wall 12

Objective:
FTAO for asymmetric multiple pier wall.

FTAO with multiple openings and asymmetric piers

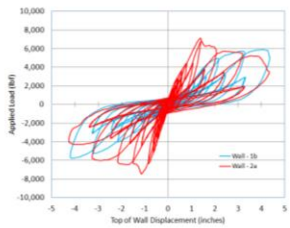


Measured vs Predicted Strap Forces

Wall ID	Measured Strap Forces (lbf) (1)		Error (2) For Predicted Strap Forces at ASD Capacity (%)						
			Drag Strut Technique		Cantilever Beam Technique		Diekmann Technique	SEAOC/Thompson Technique	
	Top	Bottom	Top	Bottom	Top	Bottom	Top/Bottom	Top	Bottom
Wall 4a	687	1,485	178%	82%	652%	183%	132%	406%	115%
Wall 4b	560	1,477	219%	83%	800%	184%	133%	499%	115%
Wall 4c (3)	668	1,316	183%	93%	670%	207%	149%	418%	129%
Wall 4d	1,006	1,665	122%	73%	445%	164%	118%	278%	102%
Wall 5b	1,883	1,809	65%	68%	327%	256%	173%	204%	160%
Wall 5c (3)	1,611	1,744	76%	70%	382%	265%	187%	238%	166%
Wall 5d	1,633	2,307	75%	53%	377%	201%	141%	235%	125%
Wall 6a	421	477	291%	256%	1063%	571%	410%	663%	357%
Wall 6b	609	614	201%	199%	735%	444%	319%	458%	277%
Wall 8a	985	1,347	118%	86%	808%	359%	138%	269%	120%
Wall 8b (4)	1,493	1,079	78%	108%	533%	449%	124%	177%	150%
Wall 9a	1,675	1,653	69%	70%	475%	383%	185%	217%	166%
Wall 9b	1,671	1,594	69%	73%	476%	397%	185%	218%	172%
Wall 10a	1,580	n.a. (5)	73%	n.a. (5)	496%	n.a. (5)	n.a. (5)	n.a. (5)	n.a. (5)
Wall 10b	2,002	n.a. (5)	58%	n.a. (5)	391%	n.a. (5)	n.a. (5)	n.a. (5)	n.a. (5)
Wall 11a	2,466	n.a. (5)	47%	n.a. (5)	318%	n.a. (5)	n.a. (5)	n.a. (5)	n.a. (5)
Wall 11b	3,062	n.a. (5)	38%	n.a. (5)	256%	n.a. (5)	n.a. (5)	n.a. (5)	n.a. (5)
Wall 12a	807	1,163	81%	94%	593%	348%	128%	n.a. (5)	n.a. (5)
Wall 12b	1,083	1,002	60%	109%	442%	403%	138%	n.a. (5)	n.a. (5)

Local Response

- The response curves are representative for wall 1 & 2
- Compares segmented piers vs. sheathed with no straps
- Observe the increased stiffness of perforated shear (Wall 2) vs. the segmented shear (Wall 1)



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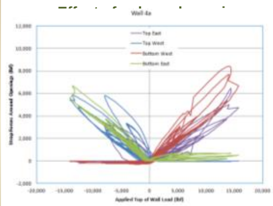
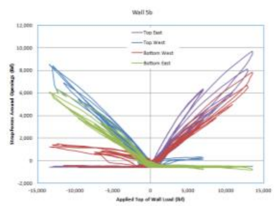
Local Response

Comparison of opening size vs. strap forces

- Compared Wall 4 to 5





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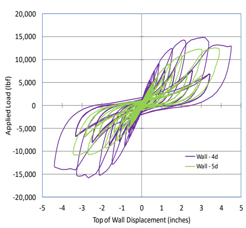
Global Response

- Comparison of opening size vs. strap forces
- Wall 4 vs. 5 reduction in stiffness with larger opening
- Wall 4 & 5d demonstrated increased stiffness as well as strength over the segmented walls 1 & 2
- Larger openings resulting in both lower stiffness and lower strength.
- Relatively brittle nature of the perforated walls
- Shear walls resulted in sheathing tearing



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Conclusions

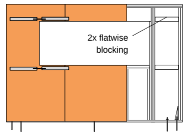
- 12 assemblies tested, examining the three approaches to designing and detailing walls with openings
  - Segmented
  - Perforated Shear Wall
  - Force Transfer Around Openings
- Walls detailed for FTAO resulted in better global response

Conclusions

- Comparison of analytical methods with tested values for walls detailed as FTAO
  - The drag strut technique was consistently un-conservative
  - The cantilever beam technique was consistently ultra-conservative
  - SEAOC/Thompson provides similar results as Diekmann
  - SEAOC/Thompson & Diekmann techniques provided reasonable agreement with measured strap forces
- Better guidance to engineers will be developed by APA for FTAO
  - Summary of findings for validation of techniques
  - New tools for IRC wall bracing

C-shaped Panels

- APA FTAO Test Wall 6
- Framing status quo
- Reduce/eliminate strap force



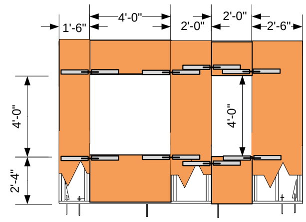
Advancements in FTAO

Strapping Above and Below Openings

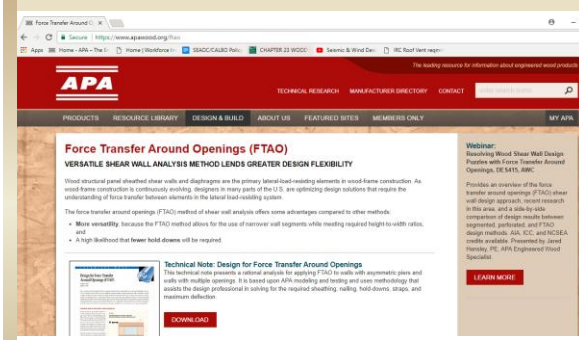
- SDWPS Section 4.3.5.2 specifies collectors
  - Full length horizontal elements. Top & Bottom Plates, drag struts, beams, etc..
  - Transfer forces from diaphragm into shear wall
- Strapping is not a collector
  - Can be discontinuous
  - Resists internal tension forces not shear
  - Similar to hold downs at end of wall

Multiple Openings

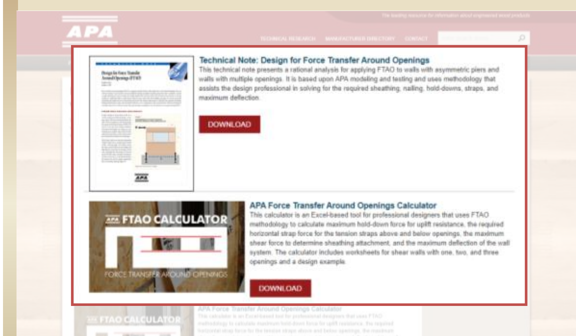
- APA FTAO Testing Wall 12
  - Multiple openings
  - Asymmetric pier widths
- Diekmann Rational Analysis



www.apawood.org/FTAO

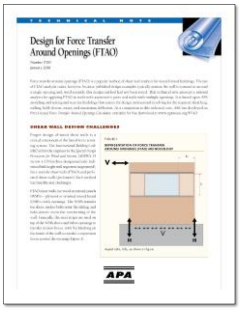


www.apawood.org/FTAO



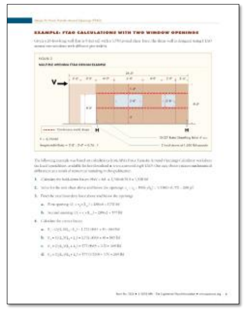
FTAO Technical Note: Form T555

- Technical Note: Design for Force Transfer Around Openings (FTAO)
  - APA Form T555
- Presents a rational analysis for applying FTAO to walls with asymmetric piers and walls with multiple openings
- Based on Wall 12 testing configuration



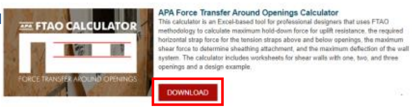
FTAO Technical Note: Form T555

- Provides a design example for FTAO wall with two window openings
- FTAO Calculator: Companion to Technical Note



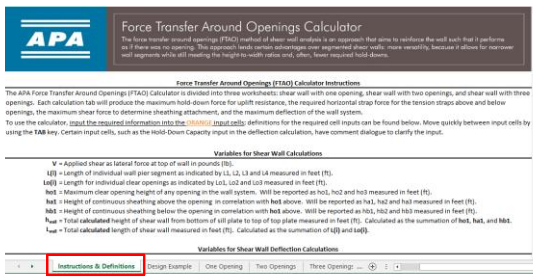
APA FTAO Calculator

- Excel-based tool released January 2018
- Based on design methodology developed by Diekmann
- Calculates:
  - Max hold-down force for uplift resistance
  - Required horizontal strap force above and below openings
  - Max shear force for sheathing attachments
  - Max deflection
- Design exa
  Note (Form



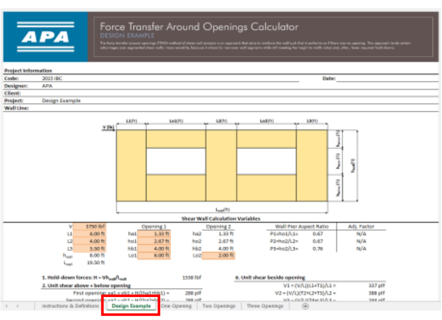
APA FTAO Calculator

www.apawood.org/FTAO



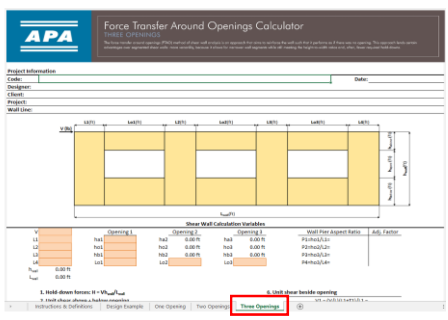
FTAO Calculator: Design Example

www.apawood.org/FTAO



FTAO Calculator: Three Openings

www.apawood.org/FTAO



FTAO Calculator: Design Output

Design output:
- Required sheathing capacity
- Required strap force above and below openings
- Required hold-down force
- Maximum deflection

Design Summary

Req. Sheathing Capacity	388 plf	4-Term Deflection	0.316 in.	3-Term Deflection	0.335 in.
Req. Strap Force	865 lbf	4-Term Story Drift %	0.013 %	3-Term Story Drift %	0.014 %
Req. HD Force (H)	1538 lbf		See Page 2		See Page 3

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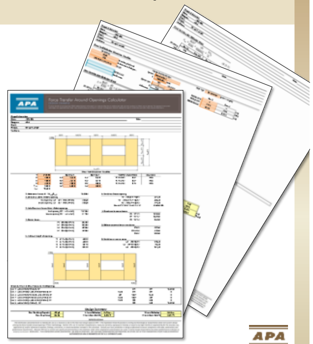
FTAO Calculator: Final Output

Final Design Output
- Summary of input parameters
- FTAO shear wall analysis
- Summary of final design requirements
- Total calculated deflection
- Three-page shear wall design to include in calculation package
  - Print directly from Excel
  - Save as PDF



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2015/2018 IRC Wood Wall Bracing Provisions

- http://shop.iccsafe.org/a-guide-to-the-2015-irc-wood-wall-bracing-provisions-1.html

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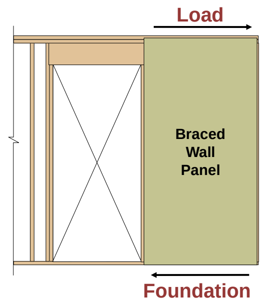
Load Path



R301.1 Application

The construction of buildings… shall result in a… complete load path… for the transfer of all loads… to the foundation.

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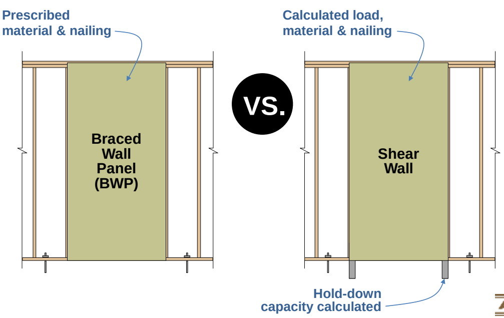
Stiffened Walls



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Wall Bracing

R602.10 Wall Bracing

"Where a building, or portion thereof, does not comply with one or more of the bracing requirements in this section, those portions shall be designed and constructed in accordance with Section R301.1."

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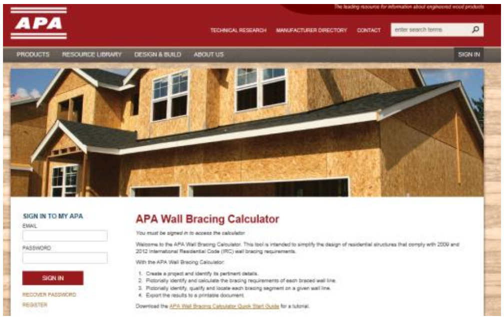
APA Wall Bracing Calculator

www.apawood.org/calculator



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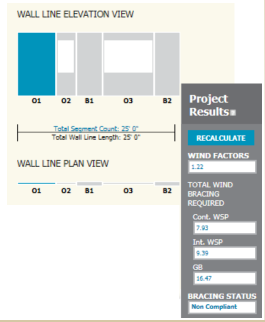
APA Wall Bracing Calculator

Benefits:

- The user locates the bracing segments, which offers user creativity while automating the code check flagging incorrect or insufficient design.
- The output makes plan review clear, concise, and implementation into the construction plans straightforward.



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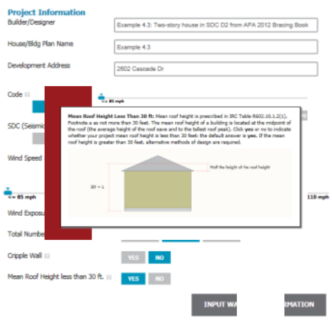
APA Wall Bracing Calculator

Benefits:

- Integrated code sections for quick reference
- Designer control over the project details
- Storage on your personal computer



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IRC Wall Bracing Primer

1. Establish Design Criteria
2. Define BWLs
3. Define BWPs in each BWL
4. Define the required length of bracing per BWL in accordance with the Wind & Seismic tables
5. If step 3 > 4, done. If step 3 < 4, add additional BWPs.

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APA Wall Bracing Calculator

Step 1

- Entering Project Information
  - New Project
  - Import Existing Project

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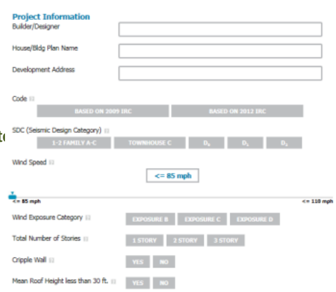
APA Wall Bracing Calculator

Step 1

- Design Criteria
  - Code
  - SDC
  - Wind Speed
  - Number of Stories, etc



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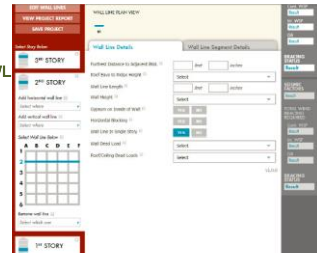
APA Wall Bracing Calculator

Step 2

- Wall Line Details
  - Distance to adjacent BWL
  - Line Length
  - Wall Height
  - Gypsum, Blocking, etc.



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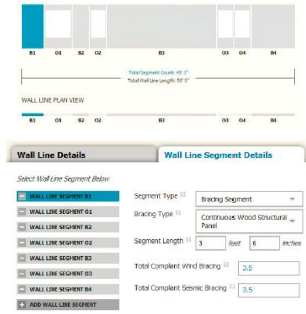
APA Wall Bracing Calculator

Step 3

- Wall Line Segment Details
  - Length BWPs
  - BWP material
  - BWP spacing
  - Total Compliant Bracing: Wind/Seismic



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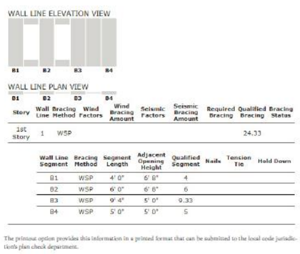
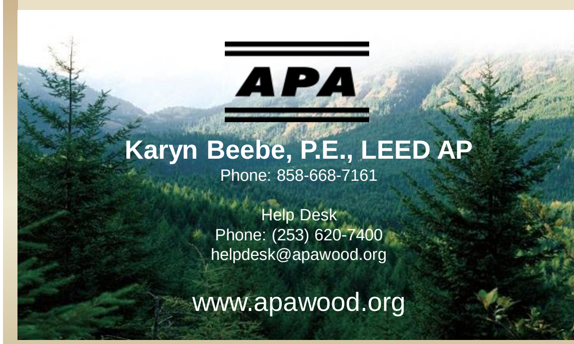
APA Wall Bracing Calculator

Step 4

- Producing a Project Report
  - PDF or Print
  - Summary Elevations
  - Wind & Seismic factor
  - Qualified Bracing vs. Required Bracing





Karyn Beebe, P.E., LEED AP
Phone: 858-668-7161

Help Desk
Phone: (253) 620-7400
helpdesk@apawood.org

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