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)

Learning Objectives

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

Big Picture

Loaded wall versus resisting walls

WIND LOAD

RESISTANCE (wall bracing)

Floor/ Roof sheathing (diaphragm)

RESISTANCE (wall bracing)

Lateral Loads: National Issue

Wind Hazard

Earthquake Hazard

Lateral Loads(Wind)

F = PA

Effort is devoted to determining:
P – wind pressure

Lateral Loads(Seismic)

F = ma

Effort is devoted to determining:
a – acceleration

General Modes of Failure

Wood – Light and Flexible
Whole House Effects of Lateral Forces

Lateral Forces

Racking

Racking – Rowlett/Garland Tornados 2015
How Do Shear Walls Work?

Wall Framing

Hinge

Panel resistance imparted to wall framing (Prevents hinging)
Studs – to – Structure

- 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

The spliced studs "hinged" in this location
Roof Sheathing Connection

Texas Tornado – December 2015

Nebraska Tornado – June 2017

Uplift Load

Fayetteville, North Carolina – 2011 Tornadoes

**Texas Tornado – December 2015**

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

Tie gable end walls back to the structure

- Gable end truss top chord
- Tension-tie strap, attach with (8) 10d common nails, each end of strap
- Roof Trusses
  - (3) 10d common nails (typical)
- 2x4 flatwise blocking between truss bottom chords
- Gable end truss bottom chord

2x4 flatwise blocking between truss bottom chords
- Gable end truss bottom chord

Resisting Pressure on Components and Cladding

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

- 8d Common nails - 4" on center perimeter of panel
- Wood structural panel sheathing
- Gable end truss bottom chord
- Gable end truss vertical web member
- Gable end truss top chord

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

Watch for splitting of the member when toe-nails are aligned along the grain

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.
- The uplift load is transferred to the wall sheathing at all locations around the perimeter of the structure.

Top Plate – to – Wall Sheathing
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

- 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.
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.

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).
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

Tornados of the South – 2011

Garland, Texas – 2015

Sill Plate – to – Foundation
Lateral and Overturning Loads

- Anchor bolts transfer the lateral loads from the sill plate to the foundation.
- At this point, the lateral loads and the overturning loads are at their maximum.
- Hold downs transfer the overturning loads from the structure to the foundation.

Texas Tornado – December 2015
Sill Plate – to – Foundation
Lateral and Uplift Loads

Texas Tornado – December 2015

No anchor bolts – PAFs only!
This is where all the wind load is trying to go!

If the wind load cannot get out of the structure and into the foundation, it will take the home with it.

Governating Codes for Engineered Wood Design

2016 CBC (2015 IBC)
- Chapter 23 Wood
- SDPWS-15 (Special Design Provisions for Wind and Seismic)

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

Wood’s Strength Direction

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

APA Rated Sheathing
32/16 Size For Spacing Exposure 1
Thickness 0.451 in.

High load diaphragms

APR 3-15 Sheathing
PRP-108 HUD-UM-40
1032 CATEGORY

APA RATED SHEATHING
32/16 SIZED FOR SPACING EXPOSURE 1
THICKNESS 0.451 IN.
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

Loads were limited by lumber splitting.

2 x 4

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

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.

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

Minimizing Buckling of Wood Structural Panels

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

- Overdriven fasteners

Consistency Counts

<table>
<thead>
<tr>
<th>Overdriven Fasteners</th>
<th>Overdriven Distance</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any</td>
<td>Due to Thickness Swelling</td>
<td>None</td>
</tr>
</tbody>
</table>

Consistency Counts

Staggered Nailing

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

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

Load Path Continuity

Load Path Continuity

Shear Wall Design Challenges

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

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

Aspect ratio h:b, 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)

![Perforated Shear Wall Diagram]

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

![FTAO Diagram]

Test Data

- 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

Wall 1

- Est. baseline case for 3.5:1 segmented wall
- 2'-3” 2'-3”
- 8'-0” 3'-0” 3'-10”

Wall 2

- No FTAO, compare to Wall 1. Examine effect of sheathing above and below opening w/ no FTAO. Hold down removed.

Wall 3

- 2:1 segmented wall
- 4'-0” 4'-0”

Wall 4

- FTAO, compare to Wall 2. Examine effect of straps with larger opening

Wall 5

- 2:1 segmented wall
- 4'-0” 4'-0”

Wall 6

- FTAO, compare to Wall 5. Examine effect of straps with larger opening

Wall 7

- Est. baseline case for 2:1 segmented wall

Wall 8

- Compare FTAO to Wall 7. Examine effect of straps with larger opening

Test Plan

Wall 5

- FTAO, compare to Wall 2. Examine effect of straps with larger opening

Wall 7

- Est. baseline case for 2:1 segmented wall

Wall 8

- Compare FTAO to Wall 7. Examine effect of straps with larger opening
**Test Plan**

Wall 9
- Objective: Compares FTAO to Wall 7 case
  - Wall is symmetric, no straps, no sheathing below
  - No sheathing below wall
  - Measure FTAO with multiple openings and asymmetric piers

Wall 10
- Objective: Compares FTAO to Wall 8 case
  - Wall is symmetric, no straps, no sheathing below
  - Measure FTAO with multiple openings and asymmetric piers

Wall 11
- Objective: Compares FTAO to Wall 11 case
  - Wall is symmetric, no straps, no sheathing below
  - Measure FTAO with multiple openings and asymmetric piers

**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)

**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

**Measured vs Predicted Strap Forces**

<table>
<thead>
<tr>
<th>Wall ID</th>
<th>Measured Strap Forces (lbf)</th>
<th>ASD Capacity (lbf)</th>
<th>SEAOC/Thompson Technique</th>
<th>Drag Strut Technique</th>
<th>Cantilever Beam Technique</th>
<th>Comparison of opening size vs. strap forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall 4c</td>
<td>807 1,161 1,144 1,144 1,144</td>
<td>1,132</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Wall 5c</td>
<td>1,161 1,144 1,144 1,144 1,144</td>
<td>1,132</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Wall 6c</td>
<td>1,161 1,144 1,144 1,144 1,144</td>
<td>1,132</td>
<td>50%</td>
<td>50%</td>
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<tr>
<td>Wall 7c</td>
<td>1,161 1,144 1,144 1,144 1,144</td>
<td>1,132</td>
<td>50%</td>
<td>50%</td>
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<td>50%</td>
</tr>
<tr>
<td>Wall 8c</td>
<td>1,161 1,144 1,144 1,144 1,144</td>
<td>1,132</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
</table>

**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

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

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C-shaped Panels

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

Multiple Openings

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

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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

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 example accompanies FTAO Technical Note (Form T555)

FTAO Calculator: Design Example

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FTAO Calculator: Three Openings

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FTAO Calculator: Design Output

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

<table>
<thead>
<tr>
<th>Design Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Req. Sheathing Capacity</td>
</tr>
<tr>
<td>Req. Strap Force</td>
</tr>
<tr>
<td>Req. Hold-Down Force</td>
</tr>
</tbody>
</table>

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


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.

Stiffened Walls

**Prescribed material & nailing**
- Braced Wall Panel (BWP)
- Hold-down capacity calculated

**Calculated load, material & nailing**
- Shear Wall

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."
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.

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

**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.

**APA Wall Bracing Calculator**

**Step 1**
- Entering Project Information
  - New Project
  - Import Existing Project

**Wall Bracing Calculator**

Welcome to the APA Wall Bracing Calculator (WBC). This tool is designed to provide the user with the ability to input the necessary data and receive accurate wall bracing solutions quickly and efficiently. The WBC is a part of the APA's wall bracing suite, and it is compatible with any wall bracing product.

- Project Information
  - House/Building Name
  - Building Height
  - Number of Stories
  - Code
  - SDC
  - Wind Speed
  - Number of Stories, etc.

**Step 1**
- Design Criteria
  - Code
  - SDC
  - Wind Speed
  - Number of Stories, etc.
Step 2
- Wall Line Details
  - Distance to adjacent BWL
  - Line Length
  - Wall Height
  - Gypsum, Blocking, etc.

Step 3
- Wall Line Segment Details
  - Length BWPs
  - BWP material
  - BWP spacing
  - Total Compliant Bracing: Wind/Seismic

Step 4
- Producing a Project Report
  - PDF or Print
  - Summary Elevations
  - Wind & Seismic factors
  - Qualified Bracing vs. Required Bracing

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