Multi-Story Considerations
Day’s Overview

• Load Path Overview
• Introduction to Codes & Standards
• Diaphragm Design and Detailing
• Shear Wall Design and Detailing
• Prescriptive Design Options for Wood Systems
• Uplift including Combined Shear
• Wall Design
• Multi-Story Considerations
Multi-Story Considerations

- Summary of Day’s Design Topics
- Multi-Story Stacked Shear Wall Effects
- Accumulation of Shear Loads
- Accumulation of Overturning Loads
- Shear Wall Deflection
Multi-Story Wind Load Design

Design Principles are the Same

Remember our mantra:
FOLLOW THE LOAD!
Multi-Story Wind Load Design

WIND SURFACE LOADS ON WALLS
Multi-Story Wind Load Design

WIND INTO DIAPHRAGMS AS UNIFORM LINEAR LOADS
Multi-Story Wind Load Design

- Diaphragms span between shearwalls.
- Wind is directed into shearwalls as concentrated loads.
Multi-Story Wind Load Design

- Diaphragm wind forces do not accumulate—they are isolated at each level.
- Shearwall wind forces do accumulate—upper level forces add to lower level forces.
Design Example: Five over One Wood-Frame

Free download at woodworks.org
Multi-Story Wind Design

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Multi-Story Wind Design

Floor Plan

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Multi-Story Wind Design

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example

Shearwall Layout
Multi-Story Wind Design

Shearwall Layout

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Multi-Story Wind Design

Building Section

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Stacked Shearwall Elevation
\[
F_5 = 5.2k \\
F_4 = 3.8k \\
F_3 = 3.7k \\
F_2 = 3.6k \\
F_1 = 3.4k \\
F_P = 1.7k \\
\]

Wind Forces Per Story

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
\[ F_5 = 5.2k \]
\[ F_{5+4} = 9k \]
\[ F_{5+4+3} = 12.7k \]
\[ F_{5+4+3+2} = 16.3k \]
\[ F_{5+4+3+2+1} = 19.7k \]
\[ F_{5+4+3+2+1+P} = 21.4k \]

Wind Forces Accumulated

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Multi-Story Shear Accumulation

- Shear forces are additive from floor to floor
- “Base shear” at the bottom or base of a structure is equal to the sum of all story shears
- Sole plate attachment of each wall must adequately transfer accumulative shear forces to the wall/foundation below

Typical wall to wall attachment:
- Fasteners (nails, screws, etc.), angles, sheathing

Typical wall to foundation attachment:
- Anchor bolts
Multi-Story Shear Accumulation

Source: Strongtie
Multi-Story Shear Accumulation

Figure 5. Typical Floor Framing at Wall

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Multi-Story Shear Accumulation

Figure 5A. Typical Platform Floor Framing at Wall Using Sawn Joists

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Multi-Story Shear Accumulation

Source: Strongtie
Multi-Story Shear Accumulation
Multi-Story Shear Accumulation
Accumulated Shear Load Transfer

Source: FEMA P752
Making our Buildings Safe + Wind
Visual Cue

Floor Beam with Bearing Wall Above = Stacked Shear Walls
Visual Cue

Floor Beam with Bearing Wall Above = Stacked Shear Walls
Stacked Shearwall Elevation

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Wind Forces Per Story

\[ F_5 = 5.2k \]
\[ F_4 = 3.8k \]
\[ F_3 = 3.7k \]
\[ F_2 = 3.6k \]
\[ F_1 = 3.4k \]
\[ F_P = 1.7k \]

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
\[ F_5 = 5.2 \text{k} \]
\[ T = C = 5.2 \text{k} \times 50'/29' = 9.0 \text{k} \]

\[ F_4 = 3.8 \text{k} \]
\[ T = C = 3.8 \text{k} \times 40'/29' = 5.2 \text{k} \]

\[ F_3 = 3.7 \text{k} \]
\[ T = C = 3.7 \text{k} \times 30'/29' = 3.8 \text{k} \]

\[ F_2 = 3.6 \text{k} \]
\[ T = C = 3.6 \text{k} \times 20'/29' = 2.5 \text{k} \]

\[ F_1 = 3.4 \text{k} \]
\[ T = C = 3.4 \text{k} \times 10'/29' = 1.2 \text{k} \]

\[ \Sigma = 21.7 \text{k} \]

Overturning Wind Forces Per Story Method
\[ F_5 = 5.2k \]
\[ F_{5+4} = 9k \]
\[ F_{5+4+3} = 12.7k \]
\[ F_{5+4+3+2} = 16.3k \]
\[ F_{5+4+3+2+1} = 19.7k \]
\[ F_{5+4+3+2+1+P} = 21.4k \]

**Wind Forces Accumulated**

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
\[ F_5 = 5.2k \]
\[ T = C = 5.2k \times \frac{10'}{29'} = 1.8k \]

\[ F_{5+4} = 9k \]
\[ T = C = 9k \times \frac{10'}{29'} = 3.1k \]

\[ F_{5+4+3} = 12.7k \]
\[ T = C = 12.7k \times \frac{10'}{29'} = 4.4k \]

\[ F_{5+4+3+2} = 16.3k \]
\[ T = C = 16.3k \times \frac{10'}{29'} = 5.6k \]

\[ F_{5+4+3+2+1} = 19.7k \]
\[ T = C = 19.7k \times \frac{10'}{29'} = 6.8k \]

\[ \Sigma = 21.7k \]

Overturning Wind Forces
Accumulative Method
Overturning Compression Accumulation

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Sole Plate Crushing
Sole Plate Crushing

Compression forces perpendicular to grain can cause localized wood crushing. NDS values for $F_{c\perp}$ with metal plate bearing on wood result in a maximum wood crushing of 0.04”. Relationship is non-linear

$$\Delta = 0.02 \times \left( \frac{f_{c\perp}}{F_{c\perp0.02 \text{ in}}} \right)$$  

$$\Delta = 0.04 - 0.02 \times \frac{f_{c\perp}}{0.27 \text{ in}}$$  

$$\Delta = 0.04 \times \left( \frac{f_{c\perp}}{F_{c\perp0.04 \text{ in}}} \right)^3$$

$\Delta =$ deformation, in

$f_{c\perp} =$ induced stress, psi

$F_{c\perp0.04 \text{ in}} = F_{c\perp} =$ reference design value at 0.04 in deformation, psi ($F_{c\perp}$)

$F_{c\perp0.02 \text{ in}} =$ reference design value at 0.02 in deformation, psi ($0.73 F_{c\perp}$)
Sole Plate Crushing

Figure 12. $F_{C\perp}$ Load Deformation Curve  
(Eq. 3.0 Derived from Bendtsen-Galligan, 1979)
Sole Plate Crushing

NDS Commentary C4.2.6: when a joint is made of two wood members and both are loaded perpendicular to grain, the amount of deformation will be approximately 2.5 times that of a metal plate to wood joint.

Table 13. Deformation Adjustment Factor for Bearing Condition

<table>
<thead>
<tr>
<th>Bearing Condition</th>
<th>Deformation Adjustment Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wood-to-wood (both perpendicular to grain)</td>
<td>2.5</td>
</tr>
<tr>
<td>2. Wood-to-wood (one parallel to grain and one perpendicular to grain)</td>
<td>1.75</td>
</tr>
<tr>
<td>3. Metal-to-wood (wood loaded perpendicular to grain)</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
## Compression Post Size & Sole Plate Crush

<table>
<thead>
<tr>
<th>Level</th>
<th>Compression</th>
<th>Required Bearing Area</th>
<th>Post Size</th>
<th>Story Sole Plate Crush</th>
<th>2.5x Accum. Sole Plate Crush</th>
</tr>
</thead>
<tbody>
<tr>
<td>5(^{th}) Floor</td>
<td>1.8 k</td>
<td>4.2 in(^2)</td>
<td>(2)-2x4</td>
<td>0.011”</td>
<td>0.028”</td>
</tr>
<tr>
<td>4(^{th}) Floor</td>
<td>4.9 k</td>
<td>11.5 in(^2)</td>
<td>(2)-4x4</td>
<td>0.013”</td>
<td>0.06”</td>
</tr>
<tr>
<td>3(^{rd}) Floor</td>
<td>9.3 k</td>
<td>21.9 in(^2)</td>
<td>(2)-4x4</td>
<td>0.032”</td>
<td>0.14”</td>
</tr>
<tr>
<td>2(^{nd}) Floor</td>
<td>14.9 k</td>
<td>35.1 in(^2)</td>
<td>(3)-4x4</td>
<td>0.037”</td>
<td>0.23”</td>
</tr>
<tr>
<td>1(^{st}) Floor</td>
<td>21.7 k</td>
<td>38.4 in(^2)</td>
<td>(4)-4x4</td>
<td>0.024”</td>
<td>0.29”</td>
</tr>
</tbody>
</table>

Floors 2-5 use S-P-F #2 Sole Plate, \(F_{cperp} = 425\) psi
Floor 1 use SYP #2 Sole Plate, \(F_{cperp} = 565\) psi
Story to Story Compression Force Transfer

**Figure 13. Load Transfer from Compression Posts to Compression Posts**

Notes for Figure 13: Detail A (at platform framed) may have a single block with a drilled hole for the tie-down rod (see Figure 15).
Rim Joist Buckling & Crushing
Rim Joist Buckling & Crushing
Increasing Compression Post Size

Figure 10. Example Plan Section at Boundary Members

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Increasing Compression Post Size
Overturning Tension Accumulation

Source: Strongtie
Overturning Tension Accumulation

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Using Dead Load to Resist Overturning

Load Combinations of ASCE 7-10:

06.D + 0.6W

Dead load from above (Wall, Floor, Roof) can be used to resist some or all overturning forces, depending on magnitude.
Overturning Resistance Options

Figure 3: Methods of Providing Overturning Restraint

- Embedded Hold-Down
- Hold-Down with Threaded Anchor
- Threaded Rod with Bearing Plate

Source: Strongtie
Threaded Rod Tie Down

Source: Strongtie

Source: hardyframe.com
Threaded Rod Tie Down
Threaded Rod Tie Down w/Take Up Device

Source: Strongtie
Threaded Rod Tie Down w/o Take Up Device
Threaded Rod Tie Down w/o Take Up Device
Tie Down Take Up Device Purpose

Source: Strongtie
Threaded Rod Tie Down

TRIMMER STUD

END OF SHEAR WALL

BOUNDARY MEMBERS (COMPRESSION POSTS)

COUPLER DEVICE

TIE-DOWN ROD

TIE-DOWN ROD

BOUNDARY MEMBERS (COMPRESSION POSTS)

BOUNDARY PLATE WITH SHRINKAGE COMPENSATING DEVICE

CONSTANT DISTANCE FROM WALL END

EDGE NAILING TO COMPRESSION POSTS

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Threaded Rod Tie Down - Couplers

Reducing Coupler

Source: Strongtie
Tie Down with Bearing Plate

Figure 14. Load Transfer from Uplifting Posts to Bearing Device

Notes for Figure 14:
Detail A (at platform framed) may have a single block with a drilled hole for the tie-down rod (see Figure 15).
Bearing Plate Area

Figure 14A. Bearing Zone Through Framing from Uplifting Posts to Bearing Device
Tie Down with Bearing Plate
Bearing Plate Crushing
# Tie Down Rod Size & Elongation

<table>
<thead>
<tr>
<th>Level</th>
<th>Plate Hght</th>
<th>Tension</th>
<th>Rod Dia.</th>
<th>Steel</th>
<th>Rod Capacity</th>
<th>Rod Elong.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th Floor</td>
<td>10 ft</td>
<td>1.8 k</td>
<td>3/8”</td>
<td>A36</td>
<td>2.4 k</td>
<td>0.10”</td>
</tr>
<tr>
<td>4th Floor</td>
<td>10 ft</td>
<td>4.9 k</td>
<td>5/8”</td>
<td>A36</td>
<td>6.7 k</td>
<td>0.09”</td>
</tr>
<tr>
<td>3rd Floor</td>
<td>10 ft</td>
<td>9.3 k</td>
<td>5/8”</td>
<td>A193</td>
<td>14.4 k</td>
<td>0.17”</td>
</tr>
<tr>
<td>2nd Floor</td>
<td>10 ft</td>
<td>14.9 k</td>
<td>3/4”</td>
<td>A193</td>
<td>20.7 k</td>
<td>0.18”</td>
</tr>
<tr>
<td>1st Floor</td>
<td>10 ft</td>
<td>21.7 k</td>
<td>7/8”</td>
<td>A193</td>
<td>28.2 k</td>
<td>0.19”</td>
</tr>
</tbody>
</table>
# Bearing Plate Size & Thickness

<table>
<thead>
<tr>
<th>Level</th>
<th>Bearing Plate</th>
<th>Bearing Load</th>
<th>Allow. Bearing Capacity</th>
<th>Bearing Plate Crush</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>W</strong></td>
<td><strong>L</strong></td>
<td><strong>T</strong></td>
<td><strong>Hole Area</strong></td>
<td><strong>A_{brng}</strong></td>
</tr>
<tr>
<td>5th Floor</td>
<td>3 in</td>
<td>3.5 in</td>
<td>3/8”</td>
<td>0.25 in²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.25 in²</td>
</tr>
<tr>
<td>4th Floor</td>
<td>3 in</td>
<td>3.5 in</td>
<td>3/8”</td>
<td>0.518 in²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.98 in²</td>
</tr>
<tr>
<td>3rd Floor</td>
<td>3 in</td>
<td>5.5 in</td>
<td>1/2”</td>
<td>0.518 in²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15.98 in²</td>
</tr>
<tr>
<td>2nd Floor</td>
<td>3 in</td>
<td>5.5 in</td>
<td>1/2”</td>
<td>0.69 in²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15.8 in²</td>
</tr>
<tr>
<td>1st Floor</td>
<td>3 in</td>
<td>8.5 in</td>
<td>7/8”</td>
<td>0.89 in²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24.6 in²</td>
</tr>
</tbody>
</table>
Bolted Hold Down Device

Sandwiched T2
As Concentric Hold-Down
Tie Down with Bolted Device

Figure 15. Load Transfer from Uplifting Posts to Bolted Device

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Tie Downs: Skipped Floors vs. All Floors

Skipped Floor System:
- Increased cost for posts and rods
- Increased drift
- Lack of vertical redundancy
- Inefficient load path
- Shrinkage not accommodated at each floor
- Lack of construction stability

All Floors Tied-Off System:
- Cost savings on posts and rods
- Reduced drift
- System redundancy
- Efficient load path
- Shrinkage accommodated at each floor
- Construction stability

Source: Strongtie
Shearwall Deformation – System Stretch

Total system stretch includes:

• Rod Elongation
• Take-up device displacement
• Bearing Plate Crushing
• Sole Plate Crushing

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
Shearwall Tie Down Displacement

SDPWS Definition of $\Delta_a$: “Total vertical elongation of wall anchorage system (including fastener slip, device elongation, rod elongation, etc.) at the induced unit shear in the wall.”

Figure 11. Effect of $\Delta_a$ on Drift

Notes for Figure 11:
Where:  
$\Delta = d_a \frac{h}{b}$  
h = floor-to-floor height  
b = the out-to-out dimension of the shear wall

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example
## Accumulative Movement

### With Shrinkage Compensating Devices

<table>
<thead>
<tr>
<th>Level</th>
<th>Rod Elong.</th>
<th>Shrinkage</th>
<th>Sole Plate Crush</th>
<th>Bearing Plate Crush</th>
<th>Take Up Deflect. Elong.</th>
<th>Total Displac.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th Floor</td>
<td>0.10”</td>
<td>0.03”</td>
<td>0.028”</td>
<td>0.01”</td>
<td>0.03”</td>
<td>0.20”</td>
</tr>
<tr>
<td>4th Floor</td>
<td>0.09”</td>
<td>0.03”</td>
<td>0.033”</td>
<td>0.02”</td>
<td>0.03”</td>
<td>0.20”</td>
</tr>
<tr>
<td>3rd Floor</td>
<td>0.17”</td>
<td>0.03”</td>
<td>0.08”</td>
<td>0.02”</td>
<td>0.03”</td>
<td>0.33”</td>
</tr>
<tr>
<td>2nd Floor</td>
<td>0.18”</td>
<td>0.03”</td>
<td>0.093”</td>
<td>0.03”</td>
<td>0.03”</td>
<td>0.36”</td>
</tr>
<tr>
<td>1st Floor</td>
<td>0.19”</td>
<td>0.03”</td>
<td>0.06”</td>
<td>0.01”</td>
<td>0.03”</td>
<td>0.32”</td>
</tr>
</tbody>
</table>
# Accumulative Movement

## Without Shrinkage Compensating Devices

<table>
<thead>
<tr>
<th>Level</th>
<th>Rod Elong.</th>
<th>Shrinkage</th>
<th>Sole Plate Crush</th>
<th>Bearing Plate Crush</th>
<th>Total Displac.</th>
<th>Accum. Displac.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5&lt;sup&gt;th&lt;/sup&gt; Floor</td>
<td>0.10”</td>
<td>0.17”</td>
<td>0.028”</td>
<td>0.01”</td>
<td>0.31”</td>
<td>1.96”</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; Floor</td>
<td>0.09”</td>
<td>0.17”</td>
<td>0.033”</td>
<td>0.02”</td>
<td>0.31”</td>
<td>1.65”</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Floor</td>
<td>0.17”</td>
<td>0.17”</td>
<td>0.08”</td>
<td>0.02”</td>
<td>0.44”</td>
<td>1.34”</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Floor</td>
<td>0.18”</td>
<td>0.17”</td>
<td>0.093”</td>
<td>0.03”</td>
<td>0.47”</td>
<td>0.9”</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; Floor</td>
<td>0.19”</td>
<td>0.17”</td>
<td>0.06”</td>
<td>0.01”</td>
<td>0.43”</td>
<td>0.43”</td>
</tr>
</tbody>
</table>
Shearwall Deflection Methods

Multiple methods for calculating accumulative shearwall deflection exist.

Mechanics Based Approach:
- Uses single story deflection equation at each floor
- Includes rotational & crushing effects
- Uses SDPWS 4 part equation

Other methods exist which use alternate deflection equations, FEM.
Tie Down Attachment to Concrete

Source: Strongtie
Tie Down Bolt with Washer

Source: Strongtie
Tie Down Bolt with Washer

Source: Strongtie
Tie Down Bolt with Washer - Reinforcing

Source: Strongtie
Hold Off Tie Down Anchor

Shallow Podium Slab Anchor Kit

ABL
U.S. Patent 8,381,482

SAR
U.S. Patent Pending

Source: Strongtie
Hold Off Tie Down Anchor

Source: Quicktie
Tie Down Anchor Chair

Source: Earthbound Anchors
Tie Down Anchor Chair in Cast Slab

Source: Earthbound Anchors
Tie Down Anchor Chair on Foundation Wall

Source: Earthbound Anchors
Reinforcing Around Anchor Chairs

Source: Earthbound Anchors
Reinforcing Around Anchor Chairs

Source: Earthbound Anchors
Embedded Steel Plates – Weld on Rods

Fig. RD.5.2.9—Anchor reinforcement for tension.
Tie Down Anchors – Precast Through Bolt
Post Installed Tie Down Anchor

Source: Strongtie
Post Installed Sleeve Anchors
Tie Down to Steel Beam Attachment

Source: Strongtie
Tie Down to Steel Beam Attachment
What do we need when placing anchor chairs, reinforcing, tie down rods, embedded plates, etc. in concrete slabs, especially podium slabs?

Coordination!
**Lateral Load Path Continuity: Wall Elevation**

- Header distributes upper shear wall end post concentrated load to wall below.
- Header also distributes upper shear wall shear to wall below.
- Posts in lower wall transfer upper wall end post concentrated loads to foundation.
- Wall plates act as drag struts to transfer shear loads from upper wall to lower wall.
Offset Shear Wall Overturning Resistance

Source: FEMA 55
Offset Shear Wall Overturning Resistance

Source: Strongtie
Questions?

This concludes The American Institute of Architects Continuing Education Systems Course

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