Multi-Family Wood Construction: Engineering Mid-Rise Buildings

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Structural Engineers Association of Ohio Conference
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THE POWER OF A CATCHPHRASE
The EARLY BIRD catches the WORM!
TIME IS MONEY
NO PAIN
NO GAIN
FOLLOW THE LOAD
Complete Load Paths

Load path, load path, load path!
...You’re the one in the basket!
FOLLOWING THE LOAD...
Load Path Continuity

Photo credit: Matt Todd & PB Architects

Karuna I
Holst Architecture

Photo: Terry Malone
Multi-Story Considerations

- Building and Construction Types
- Accommodating Wood Shrinkage
- Gravity Design
- Lateral Design
Wind Load Distribution to Shearwalls
Multi-Story Wood Design

Design Principles are the Same

Remember to:
FOLLOW THE LOAD!
Mid-Rise Construction Types

Type V
• All building elements are any allowed by code

Type III
• Exterior walls non-combustible
• Interior elements any allowed by code

Types III and V are further divided to A (protected) or B (unprotected)

Type IV (Heavy Timber)
• Exterior walls non-combustible
• Interior wood elements are Heavy Timber
Type III Exterior Walls – FRT

Type III and IV Construction - IBC Section 602.3: Fire-retardant-treated wood framing complying with Section 2303.2 shall be permitted within exterior wall assemblies of a 2-hour rating or less.
FRT Wood Design Values

NDS 2.3.4: Adjusted design values, including adjusted connection design values, for lumber and structural glued laminated timber pressure-treated with fire retardant chemicals shall be obtained from the company providing the treatment and redrying service.

**TABLE 2—DESIGN VALUE ADJUSTMENT FACTORS FOR PYRO-GUARD® TREATED LUMBER**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PYRO-GUARD® WALL/FLOOR SERVICE TEMPERATURE TO 100°F/38°C</th>
<th>PYRO-GUARD® ROOF FRAMING, SERVICE TEMPERATURE TO 150°F/66°C,</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Douglas fir</td>
<td>Southern pine</td>
</tr>
<tr>
<td>Extreme fiber stress in bending, $F_b$</td>
<td>0.97</td>
<td>0.91</td>
</tr>
<tr>
<td>Tension parallel to grain $F_t$</td>
<td>0.95</td>
<td>0.88</td>
</tr>
<tr>
<td>Compression parallel to grain, $F_c$</td>
<td>1.00</td>
<td>0.94</td>
</tr>
<tr>
<td>Horizontal shear $F_v$</td>
<td>0.96</td>
<td>0.95</td>
</tr>
<tr>
<td>Modulus of elasticity, $E$</td>
<td>0.96</td>
<td>0.95</td>
</tr>
<tr>
<td>Compression perp. to grain $F_{cz}$</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Fasteners/connectors</td>
<td>0.90</td>
<td>0.90</td>
</tr>
</tbody>
</table>
Material Design Considerations

All Materials have unique design considerations
This doesn’t mean we can’t use them. We simply need to fully understand them so we can appropriately design and detail the structure to account for them

Steel – thermal expansion/contraction, thermal bridging
Concrete – low strength in tension, cracking, heavy
Wood – shrinkage
WHY DOES WOOD SHRINK?
Basic Wood Shrinkage Theory

Moisture changes cause dimensional changes perpendicular to grain

Growing tree is filled with water

As wood dries, it shrinks perp. to grain

Wood Structure And Moisture Content

Water exists in wood in two forms: Free Water & Bound Water

**Fiber Saturation Point**: Point at which cell walls are completely saturated, cell cavities are empty (i.e. no free water but still has all its bound water)
Moisture Content at Manufacture

<table>
<thead>
<tr>
<th>Product</th>
<th>Moisture Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumber – S-Dry</td>
<td>19% or less</td>
</tr>
<tr>
<td>Lumber – S-Green</td>
<td>Usually over 19%</td>
</tr>
<tr>
<td>Panel products (OSB, plywood)</td>
<td>4-8%</td>
</tr>
<tr>
<td>I-Joists</td>
<td>4-16%</td>
</tr>
</tbody>
</table>

$M_i = 19\%$

$M_i = 28\%$
Key Factors Influencing Shrinkage

- Initial Moisture Content at construction (MC)
- In-service equilibrium moisture content (EMC)
- Cumulative thickness of cross-grain wood contributing to shrinkage

Wood species has relatively little impact since most species used in commercial construction have similar shrinkage properties.
In-Service Moisture Content

Shrinkage will continue to occur linearly until the wood’s equilibrium moisture content (EMC) has been reached.

EMC is the point at which the wood is neither gaining nor losing moisture. However, this is a dynamic equilibrium as it is a function of temperature and relative humidity.

USDA FPL “Wood Handbook”

WWPA Technical Report 10

Table 1. Average Outdoor and Indoor EMC

<table>
<thead>
<tr>
<th>Location</th>
<th>Average Outdoor EMC (%)</th>
<th>Average Indoor EMC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles, CA</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>San Diego, CA</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Twentynine Palms, CA</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>San Francisco Bay Area</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>Sacramento Valley (CA)</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>N. Coast Red. (CA)</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>Sierra Nevada (CA)</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>San Joaquin Valley (CA)</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>Phoenix, AZ</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 13–1. Recommended average moisture content for interior use of wood products in various areas of the United States.
Wood Structure And Moisture Content

Shrinkage varies in each of the 3 orthogonal directions:
• Longitudinal
• Radial
• Tangential
2304.3.3 Shrinkage. Wood walls and bearing partitions shall not support more than two floors and a roof unless an analysis satisfactory to the building official shows that shrinkage of the wood framing will not have adverse effects on the structure or any plumbing, electrical or mechanical systems, or other equipment installed therein due to excessive shrinkage or differential movements caused by shrinkage. The analysis shall also show that the roof drainage system and the foregoing systems or equipment will not be adversely affected or, as an alternative, such systems shall be designed to accommodate the differential shrinkage or movements.
Zone of Movement

Shrinkage occurs primarily in horizontal members
• Wall plates
• Floor/rim joists

Be aware of cumulative shrinkage.
Quick Shrinkage Estimates

See Western Woods Product Association (WWPA) Tech Note No 10

\[ S = D \cdot M \cdot C \]

- \( S \) = shrinkage (in inches)
- \( D \) = initial dimension (in inches)
- \( M \) = Change in Moisture Content
- \( C \approx 0.0025 \) for many softwood framing species

Average Shrinkage Rate
Example Shrinkage Calculation

Assume: S-Dry lumber
Find: Shrinkage in Plates & Floor Joist

Shrinkage Zone:
2x4 Upper Plate
2x12 Floor Joist
4x4 Lower Plate
16.25” Total
Example Shrinkage Calculation

Again assuming the initial MC \((M_i)\) is 19 percent and the final MC \((M_F)\) is 12 percent

Our approximated shrinkage is:

For Doug Fir Larch:

\[
S = CD_i \left( M_F - M_i \right) = 0.00319 \times 16.25 (12 - 19) = -0.36\text{inch}
\]

For S-P-F or Southern Pine:

\[
S = CD_i \left( M_F - M_i \right) = 0.00263 \times 16.25 (12 - 19) = -0.3\text{inch}
\]
Minimizing Shrinkage

Semi-balloon framing
• incorporates floor framing hanging from top plates
• Eliminates tangential shrinkage in zone of movement
• Floor framing doesn’t contribute to overall building shrinkage

Non-standard stud lengths and increased hardware requirements are a result.
Example Shrinkage Calculation

Assume: S-Dry lumber
Find: Shrinkage in 2x4 Upper Plate & 4x4 Lower Plate

Shrinkage Zone:
2x4 Upper Plate
4x4 Lower Plate
5" Total
Example Shrinkage Calculation

Again assuming the initial MC \( M_i \) is 19 percent and the final MC \( M_F \) is 12 percent

Our approximated shrinkage is:
For Doug Fir Larch:

\[
S = CD_i (M_F - M_i) = 0.00319 \times 5(12 - 19) = -0.11\text{ inch}
\]

For Southern Pine:

\[
S = CD_i (M_F - M_i) = 0.00263 \times 5(12 - 19) = -0.09\text{ inch}
\]
MEP Considerations

Vertical vent stacks should be installed after completion of framing.

Vent stacks require special attention and must be designed to allow for vertical movement due to shrinkage between floors.
MEP Joint Options

A variety of expansion or slip joint connectors are available which address this issue and allow vertical movement in MEP items due to building shrinkage and/or thermal change without causing damage to them.
Structural Wood Design: Codes

IBC: References National Design Specification (NDS) for design of wood construction

National Design Specification (NDS): Provides design procedures and reference design values used in the structural design of wood framing members and connections
Multi-Family Gravity Design

2 Topics Frequently Come Up When Discussing Multi-Story Wood Building Gravity Design

• Floor Framing Design
• Wall Design
FLOOR DESIGN
Example Multi-Family Floor & Roof Spans

1 BR Unit: 23’-6”x26’-6”

Corridor: 5’-0” Wide
**Structural Floor Design**

**Common Loadings:**
- Residential Floor Live Load: 40 psf
- Corridor Floor Live Load: 80/100 psf
- Common Wood Frame Floor Dead Load: 25-35 psf

**24 ft – 30 ft spans:**
18” – 28” Deep I-Joists or Parallel Chord Trusses @ 16” o.c.
Structural Floor Design

Common Wood Floor Assembly:

- LW Concrete Topping
- Acoustical Mat
- Wood Floor Sheathing
- Wood Trusses/I-joists
- Batt Insulation
- Resilient Channel
- Gypsum Ceiling
Multi-family floor spans in the 24’-30’ range work well from a layout perspective. Floor design of wood members in this span range are often governed by vibration and/or deflection control, not structural capacity.

Live Load Deflection Chart, Courtesy: Redbuilt
Floor Design: Occupant Comfort

Tools available to designers

Vibration Analysis: FP Innovations (Spreadsheet available upon request)

Joist Manufacturer’s Rating Systems

Image of a chart titled "Floor Performance Expectations" with categories such as Storage, Warehouse, Mezzanine, Affordable housing, Manufacturing, Hotels and multifamily: private room, and more demanding rooms like Office, Retail, Patient room, Tract housing, Reading room, Hotels and multifamily: public room, Classroom, Lobby, Laboratory, Operating room, High-end residential, Dance hall, Gymnasium.

Image of a conference poster titled "NOISE AND VIBRATION CONTROL OF LIGHT FRAME WOOD JOIST FLOORS TOPPED WITH CONCRETE" by Lin Hu, Mohammad Mohammad, and Sylvain Gagnon.

Abstract: Light frame wood joist floors have reduced sound insulation because of their lightweight nature. The popular solution to the noise transmission problem is to float a 38mm or thicker cementitious topping over the floor. Although this solution efficiently improves sound insulation of light frame floors, it makes normal walk-induced vibrations more perceivable than with the floors without the topping. Currently, more than half of the housing market in Canada is multi-family construction. As more multi-family light frame wood buildings are being built, more and more complaints about excessive feelable vibrations through concrete topped wood joist floors are being received. This paper explains the myths behind this phenomenon, and more importantly, sheds some lights on available solutions.

Keywords: Light frame, multi-family building, wood joist floor, concrete topping, noise control, vibration control.
Example Corridor Floor Framing

Corridor floor framing often shallower than adjacent rooms: accommodate main MEP runs, shorter spans

Approximate Max Corridor Width for Solid Sawn Floor Framing Options

<table>
<thead>
<tr>
<th></th>
<th>@ 16”</th>
<th>@ 24”</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x6</td>
<td>6’-2”</td>
<td>5’-0”</td>
</tr>
<tr>
<td>2x8</td>
<td>7’-10”</td>
<td>6’-4”</td>
</tr>
<tr>
<td>2x10</td>
<td>9’-6”</td>
<td>7’-10”</td>
</tr>
<tr>
<td>2x12</td>
<td>11’-0”</td>
<td>9’-0”</td>
</tr>
</tbody>
</table>

SPF #2, DL = 30, LL = 100
# Assembly Performance: Fire Resistance

## Key Differences in Fire Ratings for Construction Types

<table>
<thead>
<tr>
<th></th>
<th>IIIA</th>
<th>IIIB</th>
<th>VA</th>
<th>VB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior Wall</td>
<td>FRT</td>
<td>FRT</td>
<td>No FRT</td>
<td>No FRT</td>
</tr>
<tr>
<td>Exterior Bearing Wall</td>
<td>2 hr</td>
<td>2 hr</td>
<td>1 hr</td>
<td>0 hr</td>
</tr>
<tr>
<td>Exterior (Non-Bearing) Wall</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 or 0. See IBC Table 602</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interior Bearing Wall^</td>
<td>1 hr</td>
<td>0 hr</td>
<td>1 hr</td>
<td>0 hr</td>
</tr>
<tr>
<td>Roof Assembly^</td>
<td>1 hr</td>
<td>0 hr</td>
<td>1 hr</td>
<td>0 hr</td>
</tr>
<tr>
<td>Floor Assembly^</td>
<td>1 hr</td>
<td>0 hr</td>
<td>1 hr</td>
<td>0 hr</td>
</tr>
</tbody>
</table>

**IBC Tables 601 & 706.4**

Note: FRT = Fire Retardant Treated

^Residential Occupancies require ½ or 1 hr separation between units per IBC 420
Example Simple Floor Framing Pattern

Floor framing direction can have an impact on fire protection requirements, structure depth, MEP
Exterior Walls – Bearing vs. Non-Bearing

If framing parallel to long exterior walls is possible, minimizes area of load bearing exterior walls.

Unit floor framing from interior wall to interior wall. I-Joists or Trusses: Example size: 20” to 24” Deep

Corridor Framing Example Size: 2x6

Typical Unit
Exterior Walls – Bearing vs. Non-Bearing

- 686 ft of Interior Bearing Wall: 0.5 or 1 Hr
- 336 ft of Exterior Non-Bearing Wall: 0 or 1 Hr
- 140 ft of Exterior Bearing Wall: 0, 1, or 2 Hr
Exterior Walls – Bearing vs. Non-Bearing

- 336 ft of Interior Bearing Wall: 0 or 1 Hr
- 336 ft of Exterior Bearing Wall: 0, 1, or 2 Hr
- 140 ft of Exterior Non-Bearing Wall: 0 or 1 Hr
Bearing Wall Studs: Stacking Loads

In mid-rise structures, bearing wall loads accumulate – may result in increased stud requirements at lower levels

Example: 5 Story Building, Exterior Bearing Wall Supports 28’ Span Trusses

Roof: DL = 20 psf, SL = 40 psf
Floor: DL = 30 psf, LL = 40 psf
Wall: DL = 10 psf

Total Bearing Wall Load at Lowest Level = 4650 plf or 6200 lbs per stud @ 16” o.c.

Need 2-2x6 studs @ 16” o.c.
Bearing Wall Studs: Stacking Loads

Options for lower level, stacked bearing wall studs:

• Specify SP or DF plates – up to 40% increase in allowable loads
  – $F_c \text{ perp} = 565 \text{ psi to 625 psi}$
• Specify LSL or LVL plates – 75% increase in capacity
• Decrease stud spacing from 16” o.c. to 12” o.c. - 33% increase in capacity
• Double studs – 100% increase in capacity
• Increase the depth of the wall – 2x6 at upper, 2x8 at lower
• Add interior bearing walls at lower levels
Bearing Wall Studs: Stacking Loads

If Type III Exterior Walls:
Specify the FRT treatment with the lowest Fc perp reduction. Manufacturers reduction values can vary between 5% and 13%
WIND LOAD DESIGN
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 INTO SHEARWALLS AS CONCENTRATED LOADS
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
Published Multi-Story Shear Wall Design Examples

Free download at woodworks.org

SEAOC Structural/Seismic Design Manual Volume 2
Published by ICC
Components of Shear Wall Design

Collector & Drag Design

Shear Wall Construction

Shear Transfer Detailing

Shear Resistance
Components of Shear Wall Design

- Holdown
- Boundary Posts
- Anchorage
- Overturning Resistance
- Tension
- Compression
Overturning Force Calculation

\[ T = C = F \times \frac{h}{L} \]

\[ T \text{ and } C \text{ are cumulative at lower stories} \]

\[ L \text{ is moment arm, not entire wall length} \]

Assume \( L = 29\text{ft} - 1\text{ft} = 28\text{ft} \)

- \( F = 5.2k \)
- \( F = 9k \)
- \( F = 12.7k \)
- \( F = 16.3k \)
- \( F = 19.7k \)
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

\begin{align*}
\text{Eq. 1.0} & \quad f_{c\perp} & \leq F_{c\perp0.02 \text{ in}} \\
\Delta &= 0.02 \times \left( \frac{f_{c\perp}}{F_{c\perp0.02 \text{ in}}} \right) \\
\text{Eq. 2.0} & \quad F_{c\perp0.02 \text{ in}} < f_{c\perp} < F_{c\perp0.04 \text{ in}} \\
\Delta &= 0.04 - 0.02 \times \frac{f_{c\perp}}{0.27 \text{ in}} \\
\text{Eq. 3.0} & \quad f_{c\perp} > F_{c\perp0.04 \text{ in}} \\
\Delta &= 0.04 \times \left( \frac{f_{c\perp}}{F_{c\perp0.04 \text{ in}}} \right)^3
\end{align*}

\(\Delta\) = deformation, in

\(f_{c\perp}\) = induced stress, psi

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

\(F_{c\perp0.02 \text{ in}} = \text{reference design value at 0.02 in deformation, psi (} 0.73 \ F_{c\perp}\)
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
Overturning Tension

Tension

Compression

Equal and Opposite Forces
Using Dead Load to Resist Overturning

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

Load Combinations of ASCE 7-10: \(06.D + 0.6W\)

Source: Strongtie
Shear Wall Holdown Options

Strap Holdown Installation

6+ kip story to story capacities

Standard Holdown Installation

13+ kip capacities

Continuous Rod Tiedown Systems

100+ kip capacities
20+ kips/level
Threaded Rod Tie Down w/Take Up Device

Source: Strongtie

Source: hardyframe.com
Threaded Rod Tie Down w/o Take Up Device
Components of Shear Wall Design

**Overturning restraint at bearing plate at top of story**

- F = 5.2k
- F = 9k
- F = 12.7k
- F = 16.3k
- F = 19.7k

**Tension accumulates in rod. Bearing plates see local overturning only. Tension zone boundary framing in compression!**

**Continuous Rod Holdown System**
Bearing Plate Crushing
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
Shear Wall Deflection

Deflection

SDPWS 2008 Eq 4.3-1

$$\delta_{sw} = \frac{8\nu h^3}{EAb} + \frac{\nu h}{1000G_a} + \frac{h\Delta_a}{b}$$

SDPWS 2008 Eq. C4.3.2-1

$$\delta_{sw} = \frac{8\nu h^3}{EAb} + \frac{\nu h}{G_v t_v} + 0.75 h e_n + \frac{h}{b} \Delta_a$$

IBC 2000 to 2015 Eq. 23-2

$$\Delta = \frac{8\nu h^3}{EAb} + \frac{\nu h}{Gt} + 0.75 h e_n + d_a h$$

Bending of boundary elements
Shear Wall Deflection

Shear Deformation of Sheathing Panels
&
Slip of nails @ panel to panel connections

**SDPWS 2008 Eq 4.3-1**

\[
\delta_{sw} = \frac{8vh^3}{EAb} + \frac{vh}{1000G_a} h\Delta_a
\]

**SDPWS 2008 Eq. C4.3.2-1**

\[
\delta_{sw} = \frac{8vh^3}{EAb} + \frac{vh}{G_v t_v} + 0.75h e_n + \frac{h}{b} \Delta_a
\]

**IBC 2000 to 2015 Eq. 23-2**

\[
\Delta = \frac{8vh^3}{EAb} + \frac{vh}{Gt} + 0.75h e_n + d \frac{h}{b}
\]
Shear Wall Deflection

Shear Wall Deflection

**Deflection**

*SDPWS 2008 Eq 4.3-1*

\[ \delta_{sw} = \frac{8vh^3}{EAb} + \frac{vh}{1000Ga} + \frac{h\Delta a}{b} \]

*SDPWS 2008 Eq. C4.3.2-1*

\[ \delta_{sw} = \frac{8vh^3}{EAb} + \frac{vh}{Gvt_v} + 0.75he_n + \frac{h}{b}\Delta a \]

*IBC 2000 to 2015 Eq. 23-2*

\[ \Delta = \frac{8vh^3}{EAb} + \frac{vh}{Gt} + 0.75he_n + d\frac{h}{ab} \]

**Rigid Body Rotation**
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 3 part equation

Other methods exist which use alternate deflection equations, FEM
Shearwall Deflection Criteria for Wind

Unlike seismic, no code information exists on deflection/drift criteria of structures due to wind loads

Serviceability check to minimize damage to cladding and nonstructural walls

**ASCE 7-10:**

*C.2.2 Drift of Walls and Frames.* Lateral deflection or drift of structures and deformation of horizontal diaphragms and bracing systems due to wind effects shall not impair the serviceability of the structure.

*What wind force should be used?*

*What drift criteria should be applied?*
Shearwall Deflection Criteria for Wind

*Wind Forces*

Consensus is that ASD design level forces are too conservative for building/frame drift check due to wind

- Commentary to ASCE 7-10 Appendix C suggests that some recommend using 10 year return period wind forces:
  - ~70% of 700 return period wind (ultimate wind speed for risk category II buildings)
- Others (AISC Design Guide 3) recommend using 75% of 50 year return period forces

*Drift Criteria*

Can vary widely with brittleness of finishes but generally recommendations are in the range of H/240 to H/600
Diaphragm Modeling Methods

Possible Shear Wall Layouts

Not using all shared walls for Shear

Robust Diaphragm Aspect Ratio
Diaphragm Modeling Methods

Possible Shear Wall Layouts

Robust Diaphragm Aspect Ratio

But maybe not much wall available on exterior
Rigid or Flexible Diaphragm?

Light Frame Wood Diaphragms often default to Flexible Diaphragms

Code Basis: ASCE 7-10 26.2 Definitions (Wind)

Diaphragms constructed of wood structural panels are permitted to be idealized as flexible
Hypothetical Flexible Diaphragm Distribution

Changing wall construction does NOT impact load to wall line

Large portion of load on little wall

Area tributary to corridor wall line

Area tributary to exterior wall line

Hypothetical Flexible Diaphragm Distribution
Changing wall construction impacts load to wall line.

Longer, stiffer walls receive more load.

Narrow, flexible walls receive less load.

Diaphragm assumed to be rigid body.

Hypothetical Rigid Diaphragm Distribution
Can a Rigid Diaphragm be Justified?

ASCE 7-10 12.3.1.3 (Seismic)

[Diaphragms] are permitted to be idealized as **flexible** where the computed maximum **in-plane deflection of the diaphragm under lateral load** is more than two times the average story drift of adjoining vertical elements of the seismic force-resisting system of the associated story under equivalent tributary lateral load as shown in Fig. 12.3-1.

IBC 2012 Chapter 2 Definition (Wind & Seismic)

A diaphragm is **rigid** for the purpose of distribution of story shear and torsional moment when the **lateral deformation of the diaphragm** is less than or equal to two times the average story drift.
Some Advantages of Rigid Diaphragm

• More load (plf) to longer interior/corridor walls
• Less load (plf) to narrow walls where overturning restraint is tougher
• Can tune loads to walls and wall lines by changing stiffness of walls

Some Disadvantages of Rigid Diaphragm

• Considerations of torsional loading necessary
• More complicated calculations to distribute load to shear walls
• May underestimate “Real” loads to narrow exterior walls
• Justification of rigid assumption
Two More Diaphragm Approaches

Semi-Rigid Diaphragm Analysis

• Neither idealized flexible nor idealized rigid
• Explicit modeling of diaphragm deformations with shear wall deformations to distribute lateral loads
• Not easy

Enveloping Method

• Idealized as BOTH flexible and rigid.
• Individual components designed for worst case from each approach
• Been around a while, officially recognized in the 2015 SDPWS
Wind Load Distribution to Shearwalls
Tie Down Attachment to Concrete

Source: Strongtie
Tie Down Bolt with Washer

Source: Strongtie
Tie Down Bolt with Washer - Reinforcing

Source: Strongtie
Embedded Steel Plates – Weld on Rods

Fig. RD.5.2.9—Anchor reinforcement for tension.
Tie Down Anchors – Precast Through Bolt
Tie Down Anchors – Through Podium
Offset Shear Wall Overturning Resistance

Source: Strongtie
Tie Down to Steel Beam Attachment

Source: Strongtie
Tie Down to Steel Beam Attachment
Recap

- Building and Construction Types
- Accommodating Wood Shrinkage
- Gravity Design
- Lateral Design
Questions?

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