# Accommodating Shrinkage

## in Multi-Story Wood-Frame Structures


Image: Pollack Shores, Matrix Residential

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# Shrinkage Resource

Code provisions, detailing options, calculations and more for accommodating differential material movement in wood structures

Free resource at **woodworks.org**


WoodWorks
WOOD PRODUCTS COUNCIL

## Accommodating Shrinkage in Multi-Story Wood-Frame Structures

In wood-frame buildings of three or more stories, cumulative shrinkage can be significant and have an impact on the function and performance of finishes, openings, mechanical/electrical/plumbing (MEP) systems, and structural connections. However, as more designers look to wood-frame construction to improve the cost and sustainability of their mid-rise projects, many have learned that accommodating wood shrinkage is actually very straightforward.

Wood is hygroscopic, meaning it has the ability to absorb and release moisture. As this occurs, it also has the potential to change dimensionally. Knowing how and where wood shrinks and swells helps designers detail their buildings to minimize related effects.

Wood shrinkage occurs perpendicular to grain, meaning that a solid sawn wood stud or floor joist will shrink in its cross-section dimensions (width and depth). Longitudinal shrinkage is negligible, meaning the length of a stud or floor joist will essentially remain unchanged. In multi-story buildings, wood shrinkage is therefore concentrated at the wall plates, floor and roof joists, and rim boards. Depending on the materials and details used at floor-to-wall and roof-to-wall intersections, shrinkage in light-frame wood construction can range from 0.05 inches to 0.5 inches per level.

This publication will describe procedures for estimating wood shrinkage and provide detailing options that minimize its effects on building performance.

The Brooklyn Riverside
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a longitudinal cell in the wood. Water can be free water stored in the straw cavity or bound water absorbed by the straw walls. At high moisture contents, water exists in both locations. As the wood dries, the free water is released from the cell cavities before the bound water is released from the cell walls. When wood has no free water and yet the cell wall is still saturated, it is said to be at its fiber saturation

https://www.woodworks.org/resources/accommodating-shrinkage-in-multi-story-wood-frame-structures/

# Shrinkage Code Requirements

**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.

# Shrinkage Design Considerations

Image: Schaefer

# Shrinkage Design Considerations

Designing and detailing to accommodate shrinkage is a design criteria but it doesn't need to be difficult

With proper calculations, detailing & an understanding of how and why wood shrinks, it simply becomes a very approachable design topic

# Agenda: Shrinkage Design Topics

- Wood Science
- Shrinkage Calculations
- Minimizing Shrinkage
- Differential Movement
- Structural Connections


Why Does
Wood Shrink?

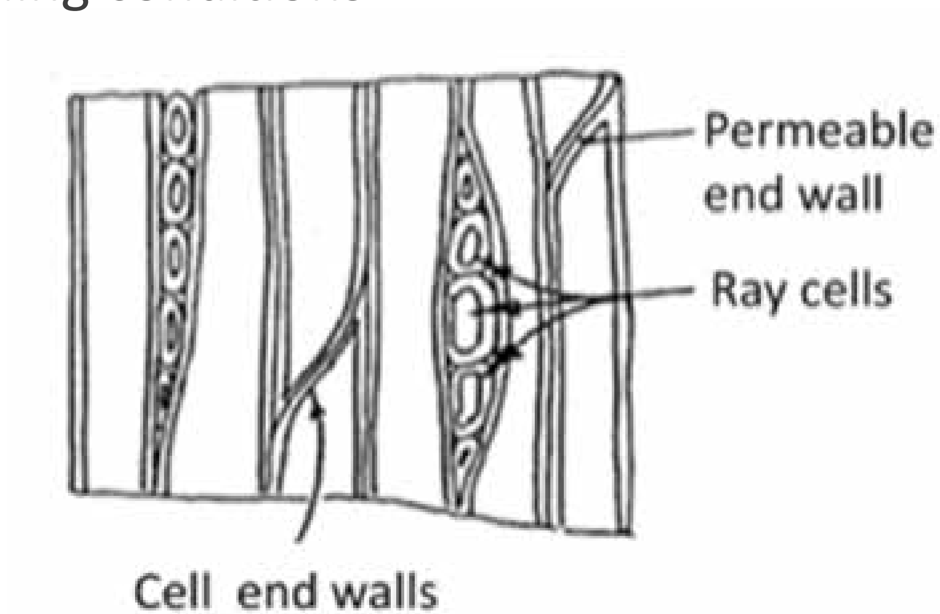
# Wood Science




# Wood Science – Cellular Makeup

Wood is a hygroscopic material

» Has the ability to take on or give off moisture – acclimates to its surrounding conditions



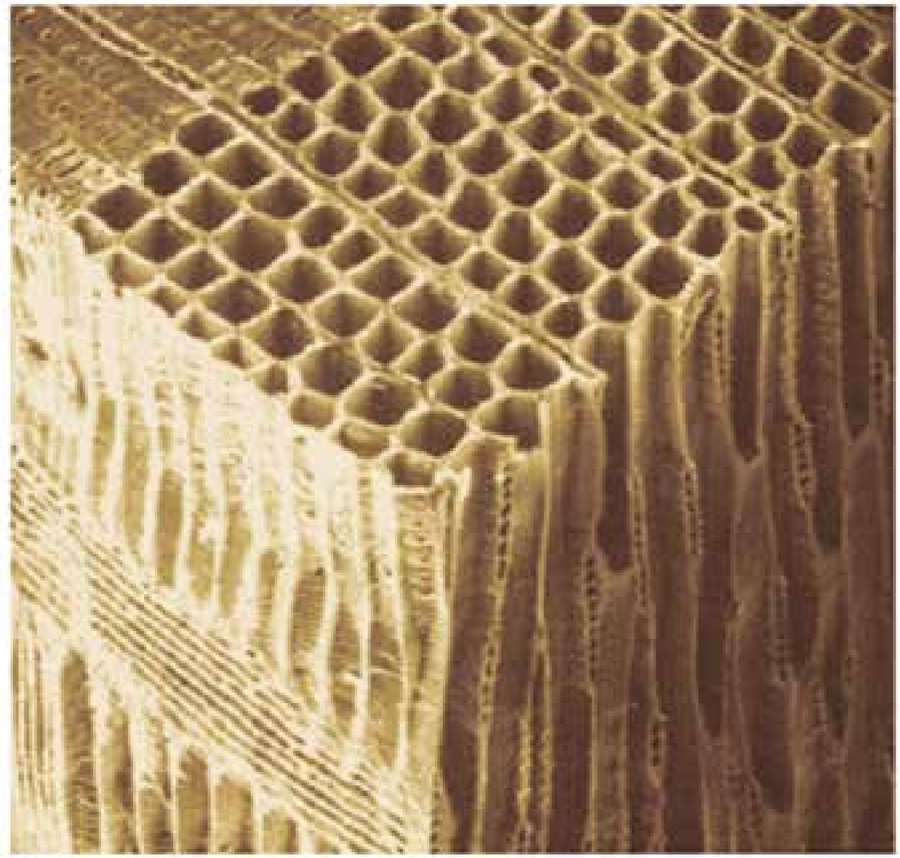
# Wood Science – Moisture in Wood

**Water exists in wood in two forms:**

- Free Water – water in cell cavity
- Bound Water – water bound to cell walls

**<u>Fiber Saturation Point (FSP):</u>**

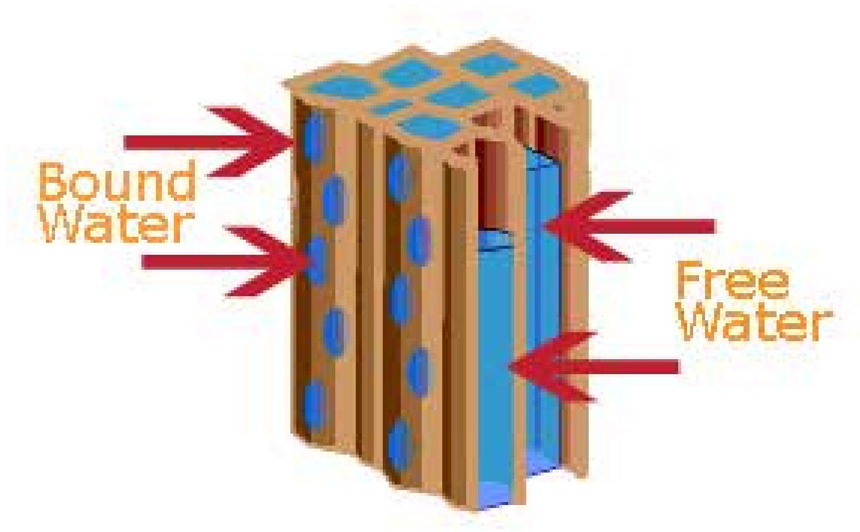
- Point at which cell walls are completely saturated but cell cavities are empty (i.e. no free water but still has all its bound water)



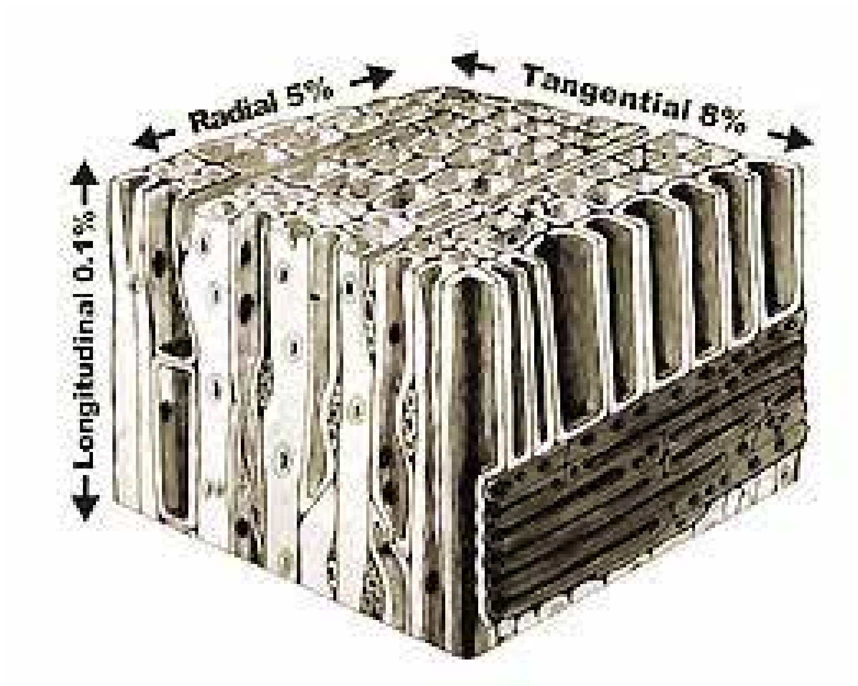
Southern yellow pine cellular makeup

*Source: USDA Forest Service Agricultural Handbook (1972)*

# Wood Science – Moisture in Wood




# Wood Science - Shrinkage




**When does wood shrink?**

» After MC drops below FSP – bound water is removed

**Why does wood shrink?**

» Loss of moisture bound to cell wall changes thickness of cell wall

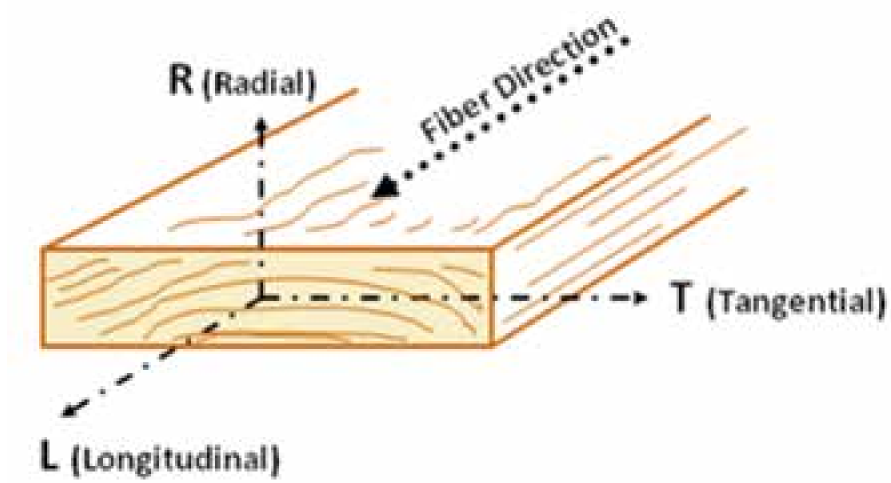
**Is shrinkage uniform across all dimensions of a piece of lumber?**

» No…

# Wood Science

Wood is orthotropic, meaning it behaves differently in its three orthogonal directions: Longitudinal (L), Radial (R), and Tangential (T)

- Longitudinal shrinkage is negligible
- Can assume avg. of radial & tangential or assume all tangential



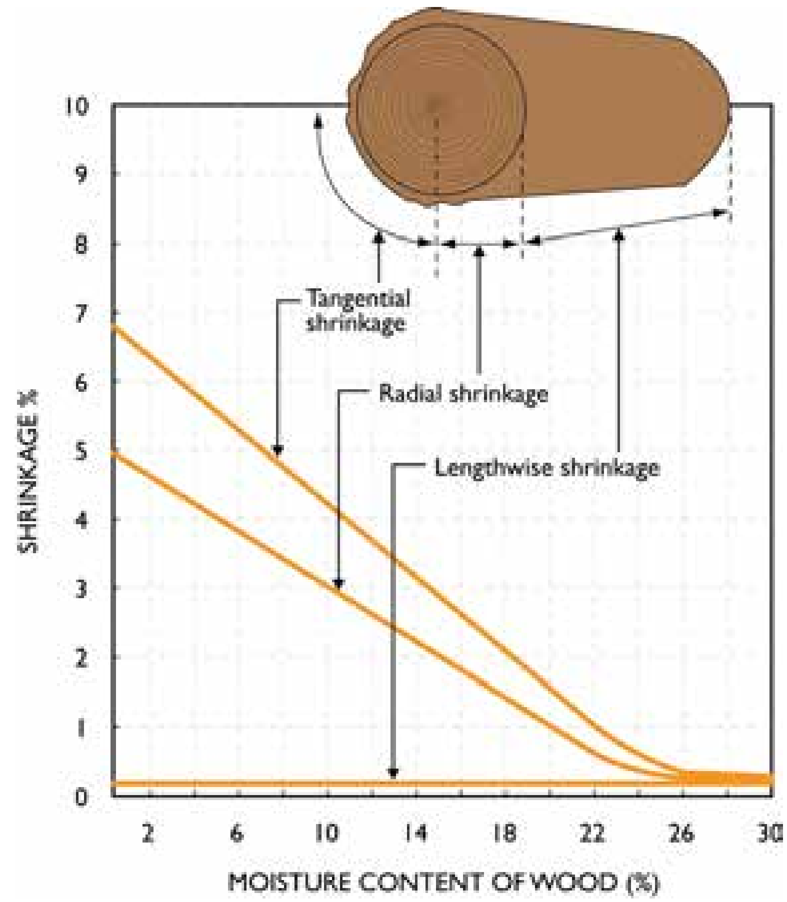




Image: RDH Building Science, Inc.

# Wood Science - Moisture Content

Fiber Saturation Point is generally around MC 30%

$$MC = \frac{W_{wet} - W_{dry}}{W_{dry}} * 100\%$$

Where:

MC = Moisture Content

$W_{wet}$ = current weight of wood

$W_{dry}$ = oven dry weight of wood

# Wood Science - Moisture Content

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

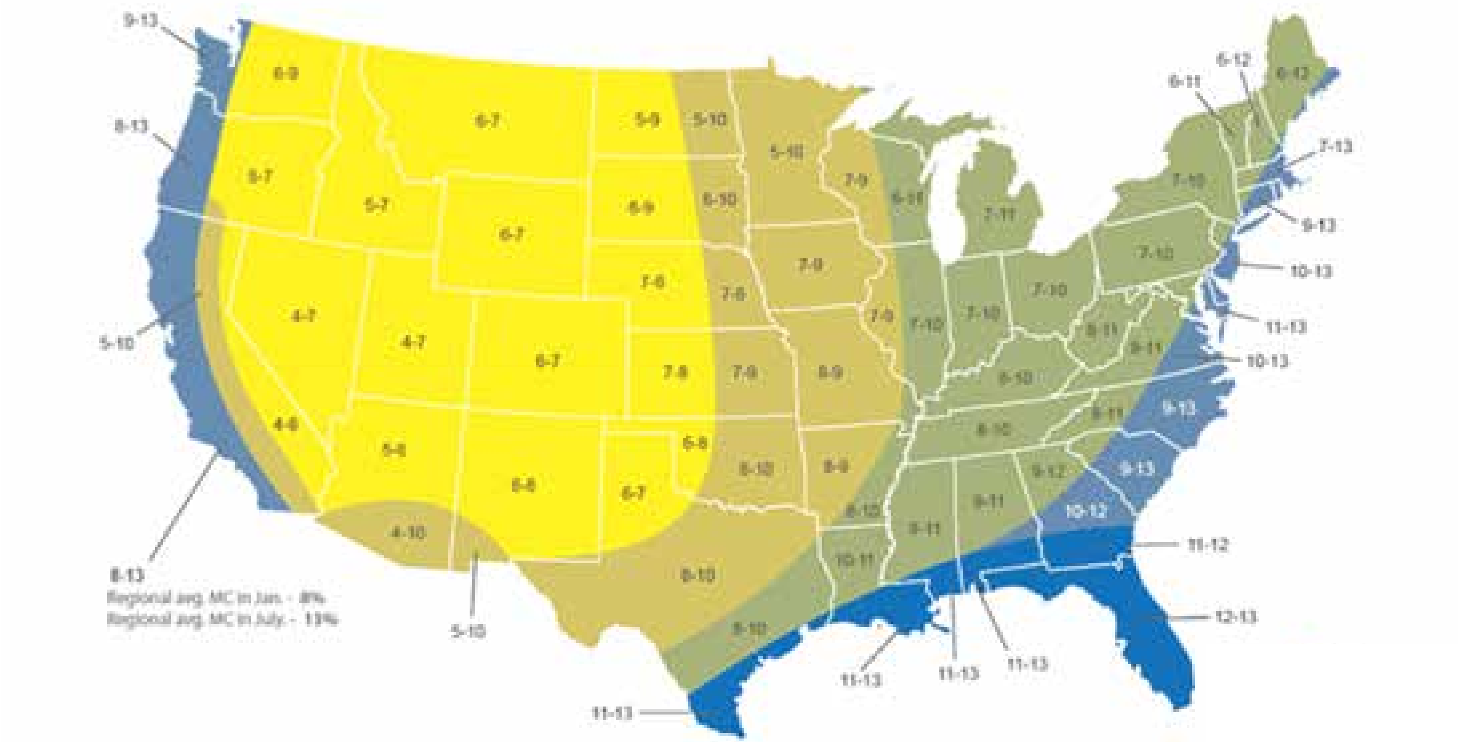
- Function of temperature & relative humidity

| Moisture Content of Wood at Various Temperatures and Relative Humidity | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature (F)** | | | | | | | | | | | | | | |
| **60** | 4.6 | 5.4 | 6.2 | 7.0 | 7.8 | 8.6 | 9.4 | 10.2 | 11.1 | 12.1 | 13.3 | 14.6 | 16.2 | 18.2 |
| **70** | 4.5 | 5.4 | 6.2 | 6.9 | 7.7 | 8.5 | 9.2 | 10.1 | 11.0 | 12.0 | 13.1 | 14.4 | 16.0 | 17.9 |
| **80** | 4.4 | 5.3 | 6.1 | 6.8 | 7.6 | 8.3 | 9.1 | 9.9 | 10.8 | 11.7 | 12.9 | 14.2 | 15.7 | 17.7 |
| | **20** | **25** | **30** | **35** | **40** | **45** | **50** | **55** | **60** | **65** | **70** | **75** | **80** | **85** |
| **Relative Humidity (percent)** | | | | | | | | | | | | | | |

Source: Wood Handbook, USDA Forest Service

# Wood Science - Moisture Content

EMC is the point at which the wood is neither gaining nor losing moisture. However, this is a dynamic equilibrium and can vary throughout the year.



# Wood Science - Moisture Content

USDA Forest Products Lab's Wood Handbook is a useful resource for EMC and other shrinkage related data

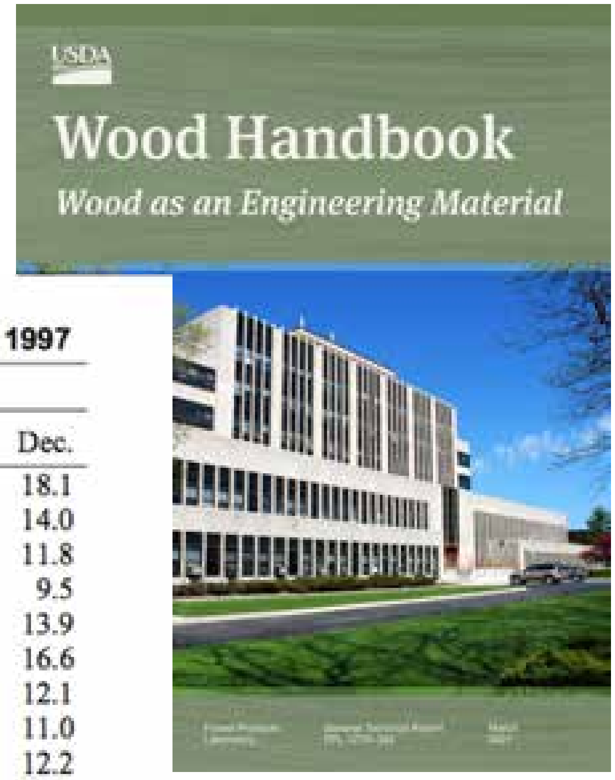
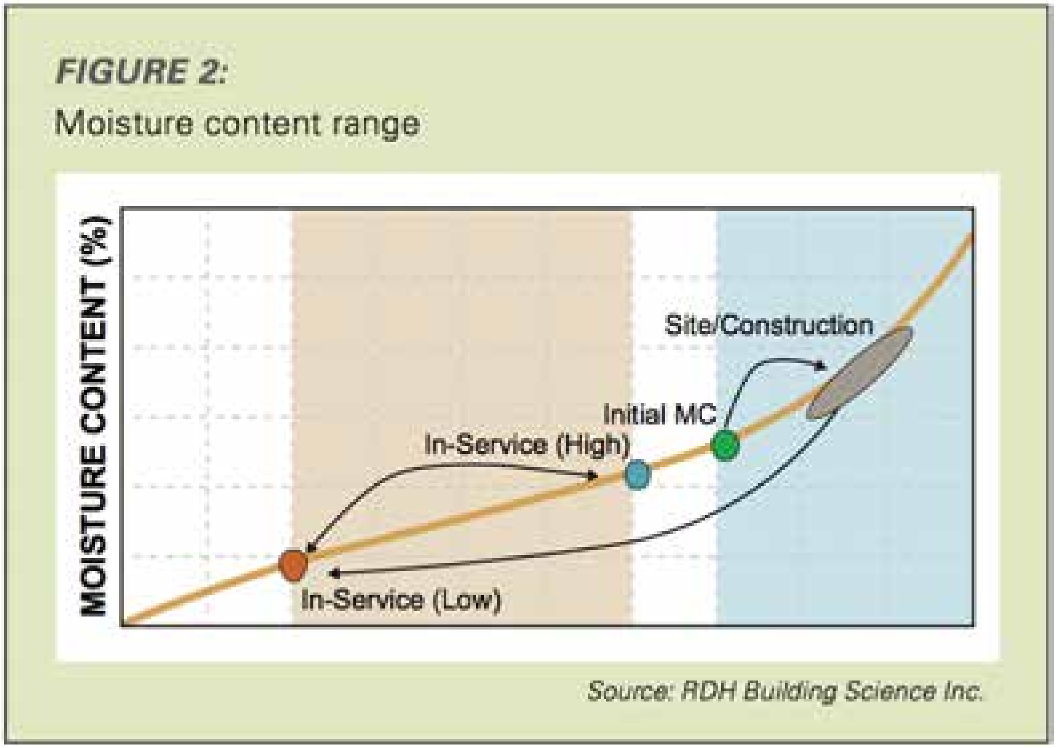



**Table 13–1. Equilibrium moisture content for outside conditions in several U.S. locations prior to 1997**

| | | Equilibrium moisture content[a] (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State | City | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
| AK | Juneau | 16.5 | 16.0 | 15.1 | 13.9 | 13.6 | 13.9 | 15.1 | 16.5 | 18.1 | 18.0 | 17.7 | 18.1 |
| AL | Mobile | 13.8 | 13.1 | 13.3 | 13.3 | 13.4 | 13.3 | 14.2 | 14.4 | 13.9 | 13.0 | 13.7 | 14.0 |
| AZ | Flagstaff | 11.8 | 11.4 | 10.8 | 9.3 | 8.8 | 7.5 | 9.7 | 11.1 | 10.3 | 10.1 | 10.8 | 11.8 |
| AZ | Phoenix | 9.4 | 8.4 | 7.9 | 6.1 | 5.1 | 4.6 | 6.2 | 6.9 | 6.9 | 7.0 | 8.2 | 9.5 |
| AR | Little Rock | 13.8 | 13.2 | 12.8 | 13.1 | 13.7 | 13.1 | 13.3 | 13.5 | 13.9 | 13.1 | 13.5 | 13.9 |
| CA | Fresno | 16.4 | 14.1 | 12.6 | 10.6 | 9.1 | 8.2 | 7.8 | 8.4 | 9.2 | 10.3 | 13.4 | 16.6 |
| CA | Los Angeles | 12.2 | 13.0 | 13.8 | 13.8 | 14.4 | 14.8 | 15.0 | 15.1 | 14.5 | 13.8 | 12.4 | 12.1 |
| CO | Denver | 10.7 | 10.5 | 10.2 | 9.6 | 10.2 | 9.6 | 9.4 | 9.6 | 9.5 | 9.5 | 11.0 | 11.0 |
| DC | Washington | 11.8 | 11.5 | 11.3 | 11.1 | 11.6 | 11.7 | 11.7 | 12.3 | 12.6 | 12.5 | 12.2 | 12.2 |
| FL | Miami | 13.5 | 13.1 | 12.8 | 12.3 | 12.7 | 14.0 | 13.7 | 14.1 | 14.5 | 13.5 | 13.9 | 13.4 |
| GA | Atlanta | 13.3 | 12.3 | 12.0 | 11.8 | 12.5 | 13.0 | 13.8 | 14.2 | 13.9 | 13.0 | 12.9 | 13.2 |
| HI | Honolulu | 13.3 | 12.8 | 11.9 | 11.3 | 10.8 | 10.6 | 10.6 | 10.7 | 10.8 | 11.3 | 12.1 | 12.9 |
| ID | Boise | 15.2 | 13.5 | 11.1 | 10.0 | 9.7 | 9.0 | 7.3 | 7.3 | 8.4 | 10.0 | 13.3 | 15.2 |

# Wood Science - Moisture Content

Not only can wood's MC vary during a year, it can vary much more drastically during construction



# Shrinkage Calculations

Three variables influence amount of shrinkage:

» Installed moisture content (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.

# Shrinkage Calculations

**Initial or Installed moisture content (MC)**

- Typically specified by Structural EoR
- 19% max MC is common
- Green or 15% max MC also available in select markets
- Important to keep in mind this is the MC when it is manufactured
- MC at time of finish install can be much higher or lower

# Shrinkage Calculations

| Product | Moisture Content |
|---|---|
| Lumber – S-Dry | 19% or less |
| Lumber – S-Green | Usually over 19% |
| Panel products (OSB, plywood) | 4-8% |
| I-Joists | 4-16% |

→ $M_i = 19\%$

→ $M_i = 28\%$

## Key Terms

***Dry lumber*** – Lumber of less than nominal 5-inch thickness which has been seasoned or dried to a maximum moisture content of 19 percent

***Equilibrium moisture content (EMC)*** – The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature

***Green lumber*** – Lumber of less than nominal 5-inch thickness which has a moisture content in excess of 19 percent or, for lumber of nominal 5-inch or greater thickness (timbers), as defined in accordance with applicable lumber grading rules

***Heat treated (HT)*** – Lumber or other wood product that has been heated in a closed chamber, with or without moisture content reduction, until it achieves a minimum core temperature of 132.8°F for a minimum of 30 minutes

***Kiln dried (KD)*** – Lumber that has been seasoned in a chamber to a predetermined moisture content by applying heat

***Moisture content (MC)*** – The weight of the water in a piece of lumber expressed in a percentage of the weight of the piece after being oven dried.

***Fiber saturation point (FSP)*** – The point in drying wood at which all free moisture has been removed from the cell itself while the cell wall remains saturated with absorbed moisture

Example lumber grade stamps


***Grade Stamp Markings:***

S-GRN: surfaced green

S-DRY: surfaced dry

KD: kiln dried

HT: heat treated

# Shrinkage Calculations – Construction Moisture

1. Minimize storage of material on site where rain and standing water can increase moisture content.
2. Keep unused framing material covered
3. Inspect pre-built wall panels prior to installation for proper material and quality of mechanical fasteners.
4. “Dry-in” the structure as quickly as possible.
5. Immediately remove any standing water from floor framing after rain showers.
6. Ensure that installed lumber MC is lowered to 19% or calculated max MC before installing finishes & insulation

# Shrinkage Calculations – Cross Grain Wood

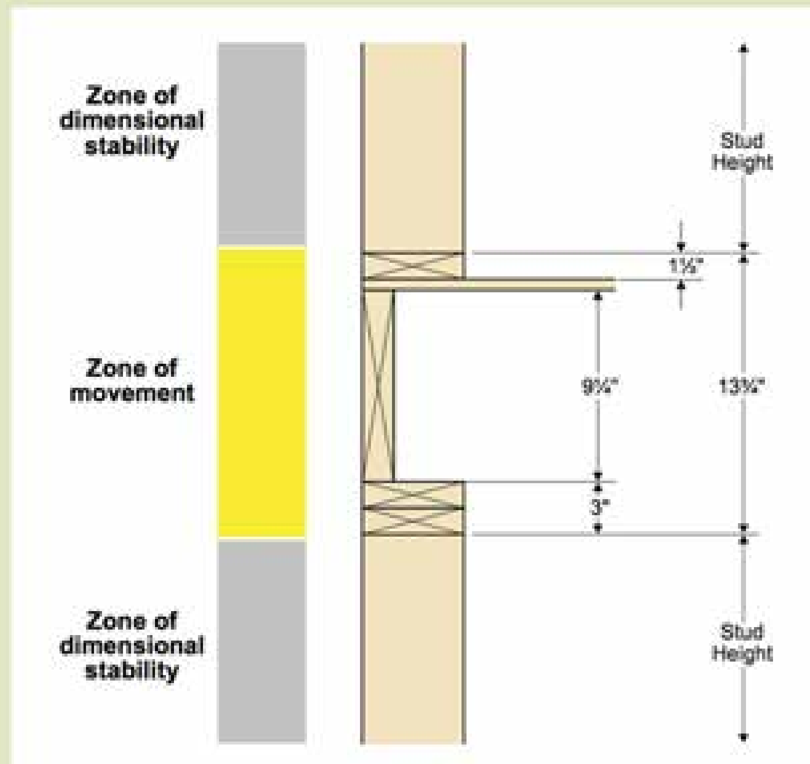
Shrinkage occurs in cross-grain, but not longitudinal, wood dimensions

- Primarily in horizontal members
- Wall plates
- Floor/rim joists

Engineering judgement required when determining what to include in shrinkage zone

- Should Sheathing, I-Joists, Trusses, other products manufactured with low MC be included?

***FIGURE 5:***
Shrinkage zone in platform-framed detail



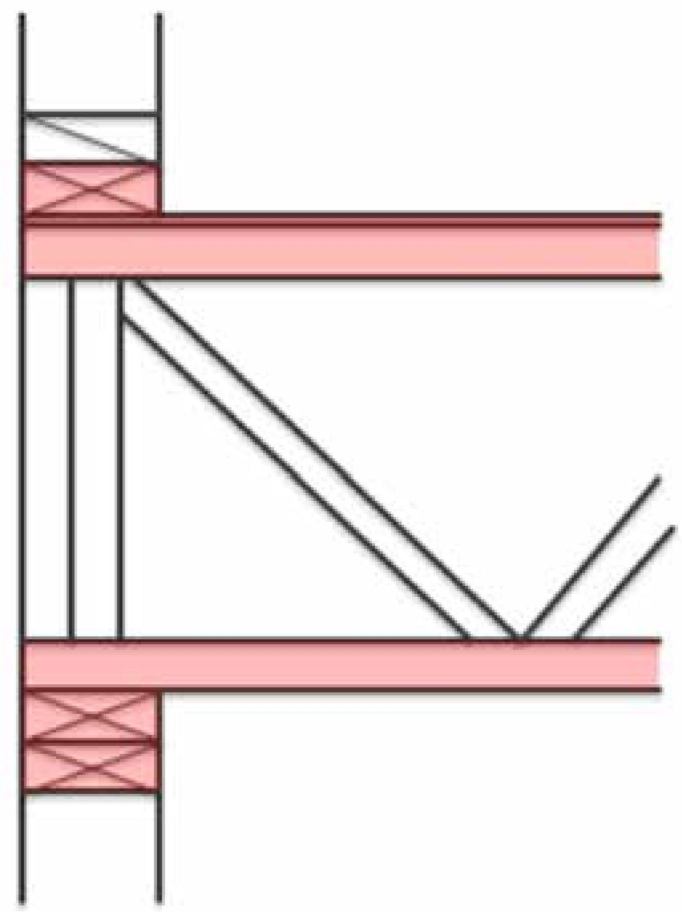
# Shrinkage Calculations – Cross Grain Wood

Be aware of cumulative shrinkage

Image: Matt Todd & PB Architects

# Shrinkage Calculations – Cross Grain Wood

In parallel chord trusses, only chords contribute to shrinkage, vertical and diagonal webs don't.



# Shrinkage Calculations – Running the Numbers

Species-Specific Method:

**$S = C*D_i*(M_F-M_i)$**

**Table 13-5. Dimensional change coefficients ($C_R$, radial; $C_T$, tangential) for shrinking or welling within moisture content limits of 6% to 14%**

| Softwood Species | Dimensional change coefficient[a] $C_R$ | $C_T$ |
|---|---|---|
| Baldcypress | 0.00130 | 0.00216 |
| Cedar, yellow- | 0.00095 | 0.00208 |
| Cedar, Atlantic white- | 0.00099 | 0.00187 |
| Cedar, Eastern Red | 0.00106 | 0.00162 |

Wood Handbook: www.fpl.fs.fed.us

$S$ = shrinkage (inches)

$D_i$ = initial dimension (shrinkage zone)

$C = C_T$ or $C_R$ = dimension change coefficient, tangential or radial direction

$C_T$ = 0.00263 for Douglas Fir-Larch

$C_T$ = 0.00245 for Hem-Fir

$C_T$ = 0.00234 for Spruce-Pine-Fir

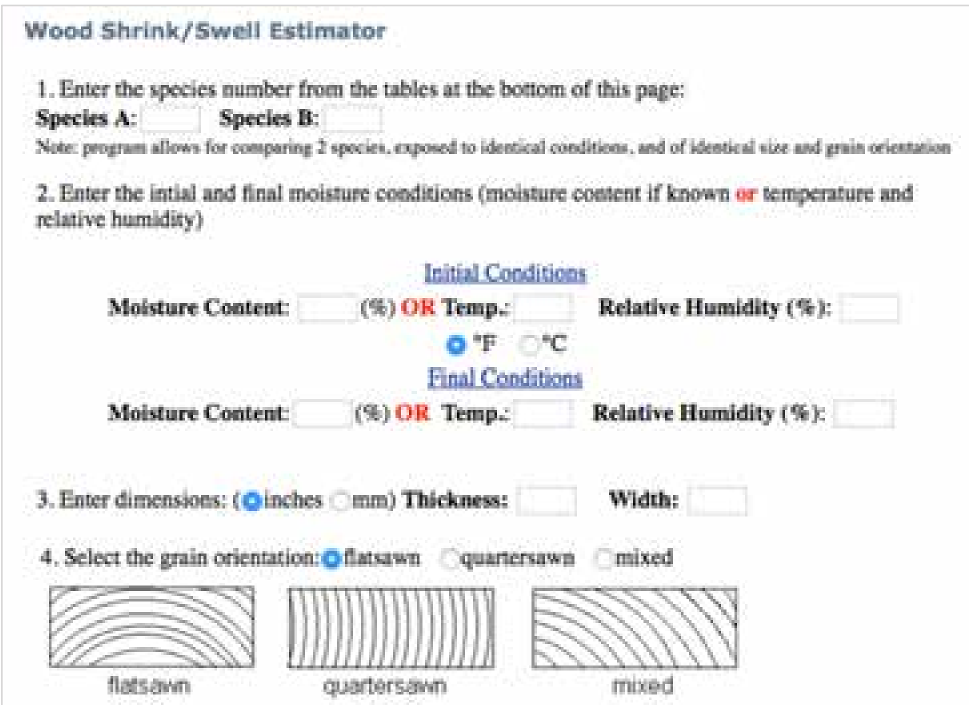
$C_T$ = 0.00263 for Southern Pine

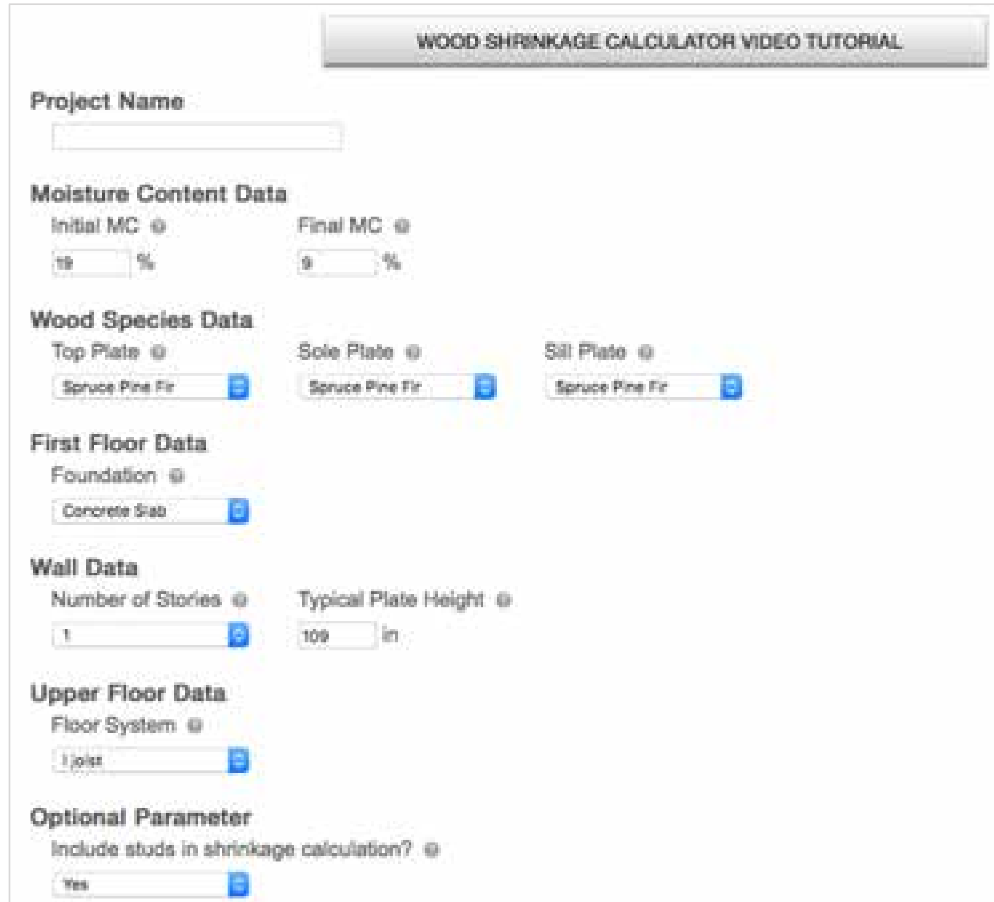
$M_F$ = final moisture content (%)

$M_i$ = initial moisture content (%)

# Shrinkage Calculations

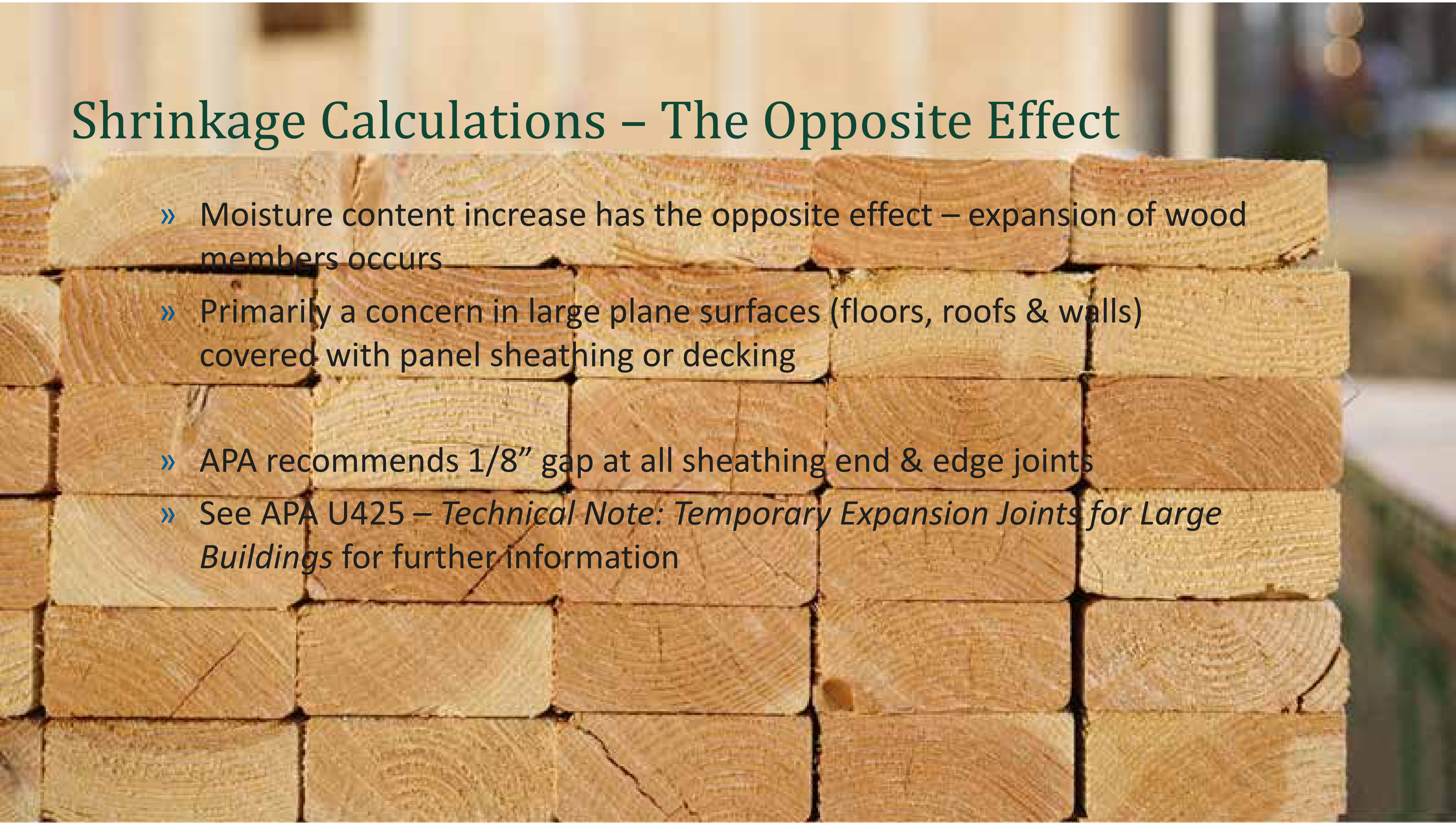
Several free shrinkage calculators available online




Sources: Oregon State University & Simpson Strongtie

# Shrinkage Calculations – The Opposite Effect

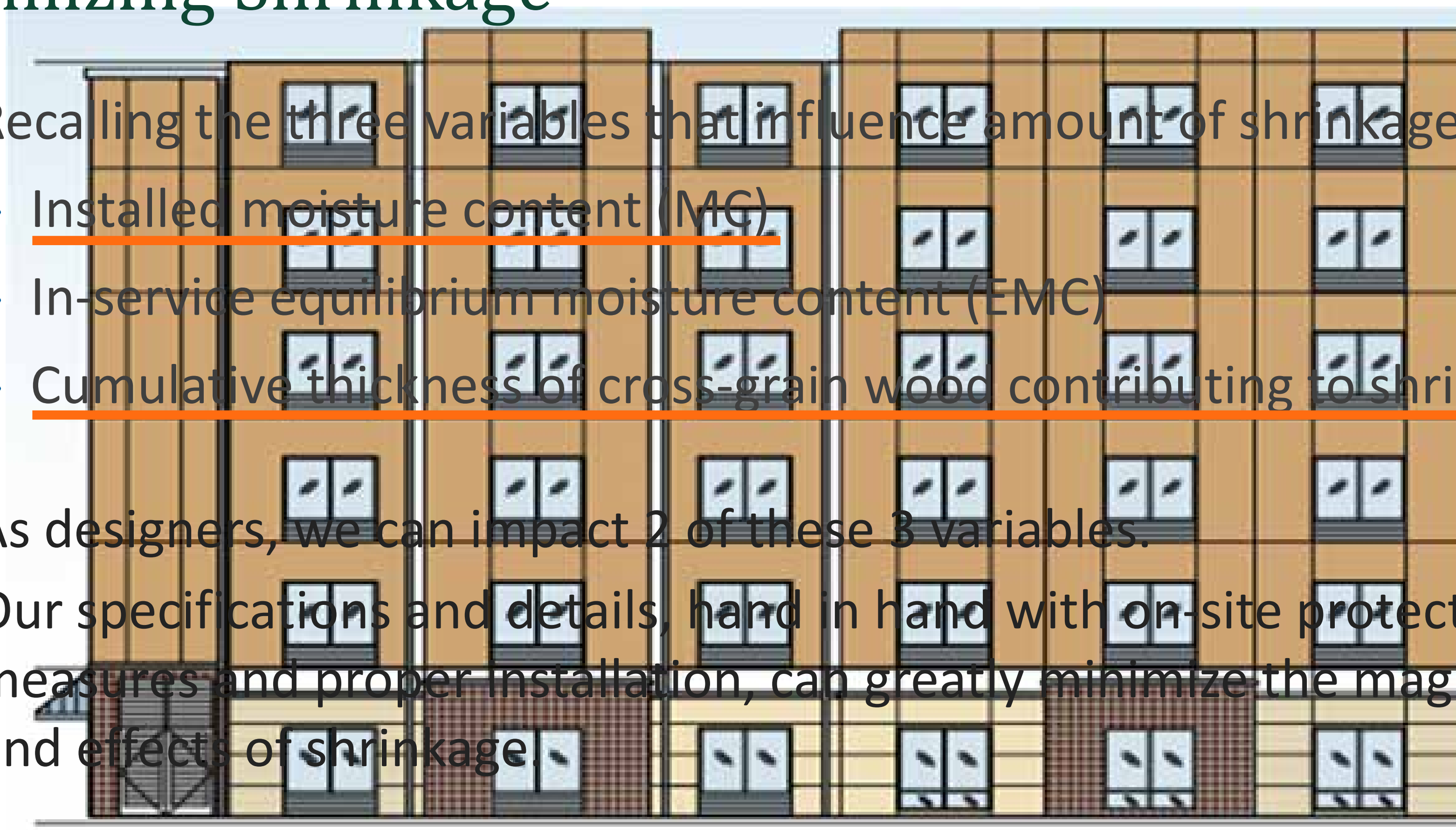


- Moisture content increase has the opposite effect – expansion of wood members occurs
- Primarily a concern in large plane surfaces (floors, roofs & walls) covered with panel sheathing or decking

- APA recommends 1/8” gap at all sheathing end & edge joints
- See APA U425 – *Technical Note: Temporary Expansion Joints for Large Buildings* for further information


1/8" space
Edge and End Joints: 1/8" spacing is recommended at all panel edge joints unless otherwise recommended by the manufacturer.
Source: APA – The Engineered Wood Association

# Minimizing Shrinkage



Recalling the three variables that influence amount of shrinkage:

» Installed moisture content (MC)

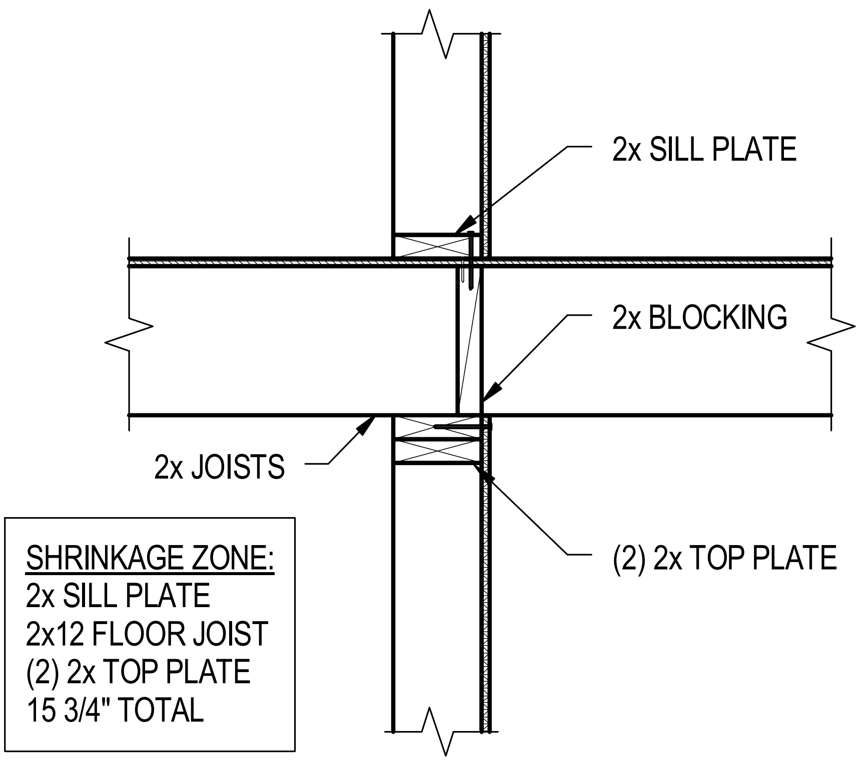
» In-service equilibrium moisture content (EMC)

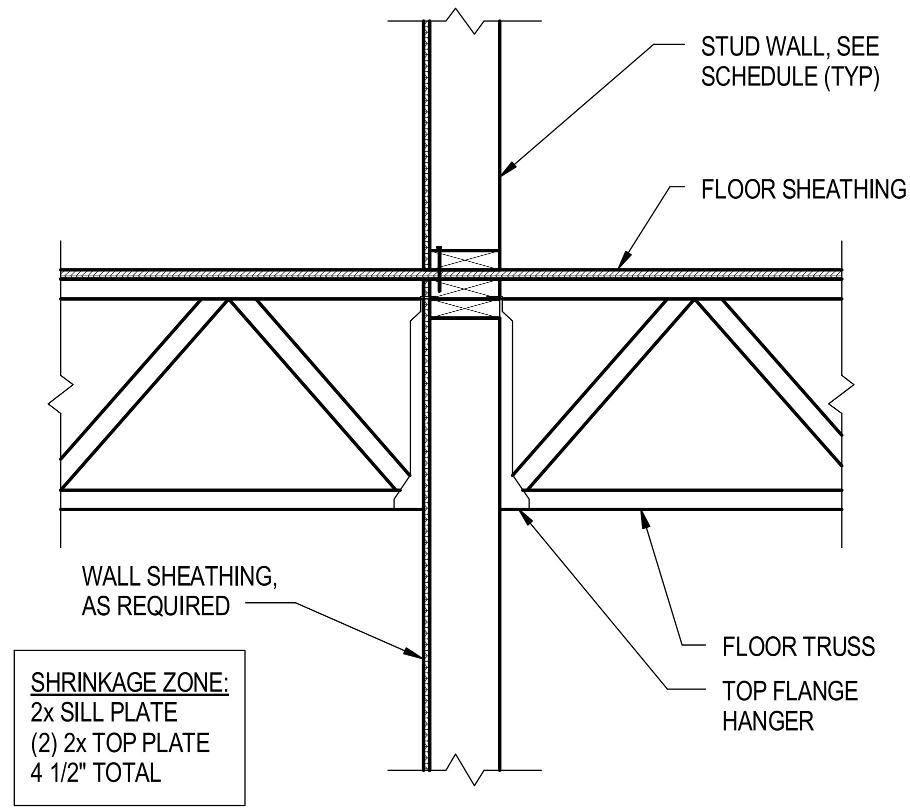
» Cumulative thickness of cross-grain wood contributing to shrinkage

As designers, we can impact 2 of these 3 variables.

Our specifications and details, hand in hand with on-site protection measures and proper installation, can greatly minimize the magnitude and effects of shrinkage.

# Minimizing Shrinkage – Detailing




Images: Schaefer

# Minimizing Shrinkage – Detailing

**Platform Detail:**

15.75” Shrinkage Zone

19% MC Initial

12% EMC

S = (0.0025)(15.75”)(12-19) = **0.28”**

5-story building: **1.4” total**

**Semi-Balloon Detail:**

4.5” Shrinkage Zone

19% MC Initial

12% EMC

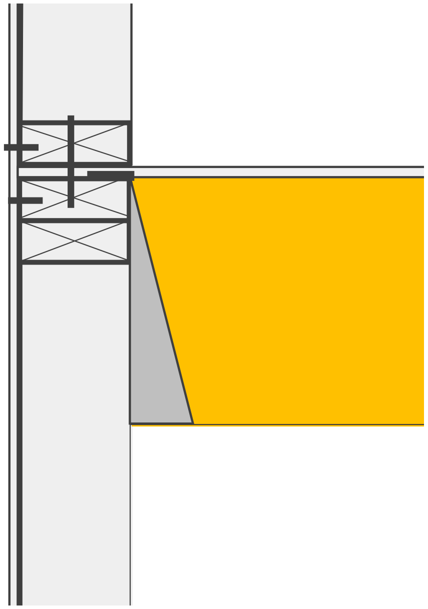
S = (0.0025)(4.5”)(12-19) = **0.08”**

5-story building: **0.4” total**

# Minimizing Shrinkage – Detailing

**Semi-balloon framing:**

- Incorporates floor framing hanging from top plates
- Floor framing/rim joist doesn't contribute to shrinkage



**Non-standard stud lengths and increased hardware requirements should be considered**

# Minimizing Shrinkage – Detailing

**The same concepts apply to post & beam wood-frame structures**

Photo: Alex Schreyer

Photo: Marcus Kauffman

# Minimizing Shrinkage – Detailing

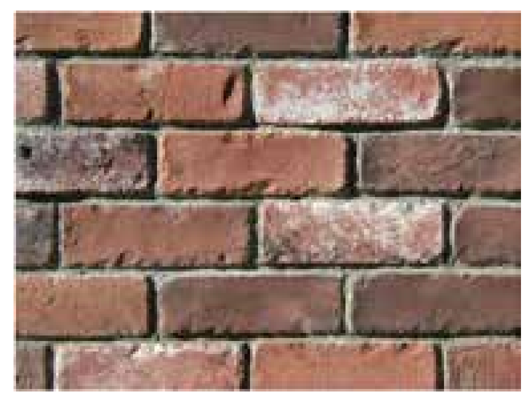
Photos: StructureCraft

# Differential Movement

**Need to consider differential movement between wood frame elements and other materials that...**

- Expand due to moisture or thermal changes
- Do not change with moisture but do change with thermal fluctuations
- Shrink much less than wood



# Differential Movement – Masonry Walls

# Differential Movement – Masonry Walls

**Mixing masonry walls with wood floor framing can create several issues**:

- Differential shrinkage between wood and masonry needs to be considered
- Best practices include seismically isolating masonry shaft walls, only tie wood floor to masonry shaft if/where required (i.e. at elevator door threshold)

**Other considerations**:

- Masonry shaft walls often become part of building's lateral force resisting system
- This increases seismic forces and adds mass
- Difference in stiffness between wood & masonry shear walls may need to be considered

# Shaft Wall Resource

For these reasons, many are finding value in switching to wood-frame shaft walls

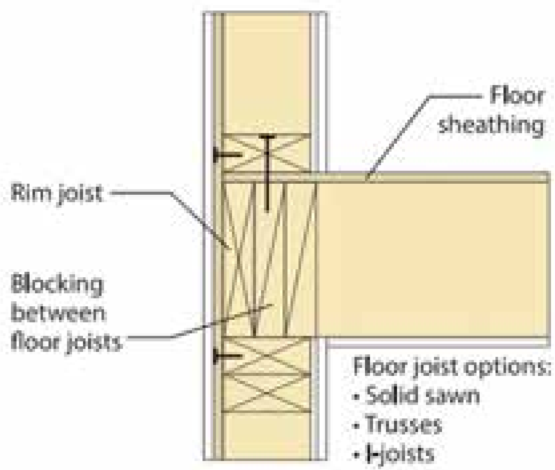



**FIGURE 11:** Floor-to-shaft wall intersection with blocking between floor joists

WOODWORKS

## Shaft Wall Solutions for Light-Frame and Mass Timber Buildings

**An overview of design considerations, detailing options and code requirements**

### Fire Resistance

**Fire Barrier Construction**

**CONTENTS**

**Fire Resistance – Page 1**

**Assembly Options – Page 6**

**Detailing Floor-to-Wall Intersections – Page 9**

**Mass Timber – Page 18**

https://www.woodworks.org/resources/shaft-wall-solutions-for-wood-frame-buildings/

# Differential Movement – Masonry Walls

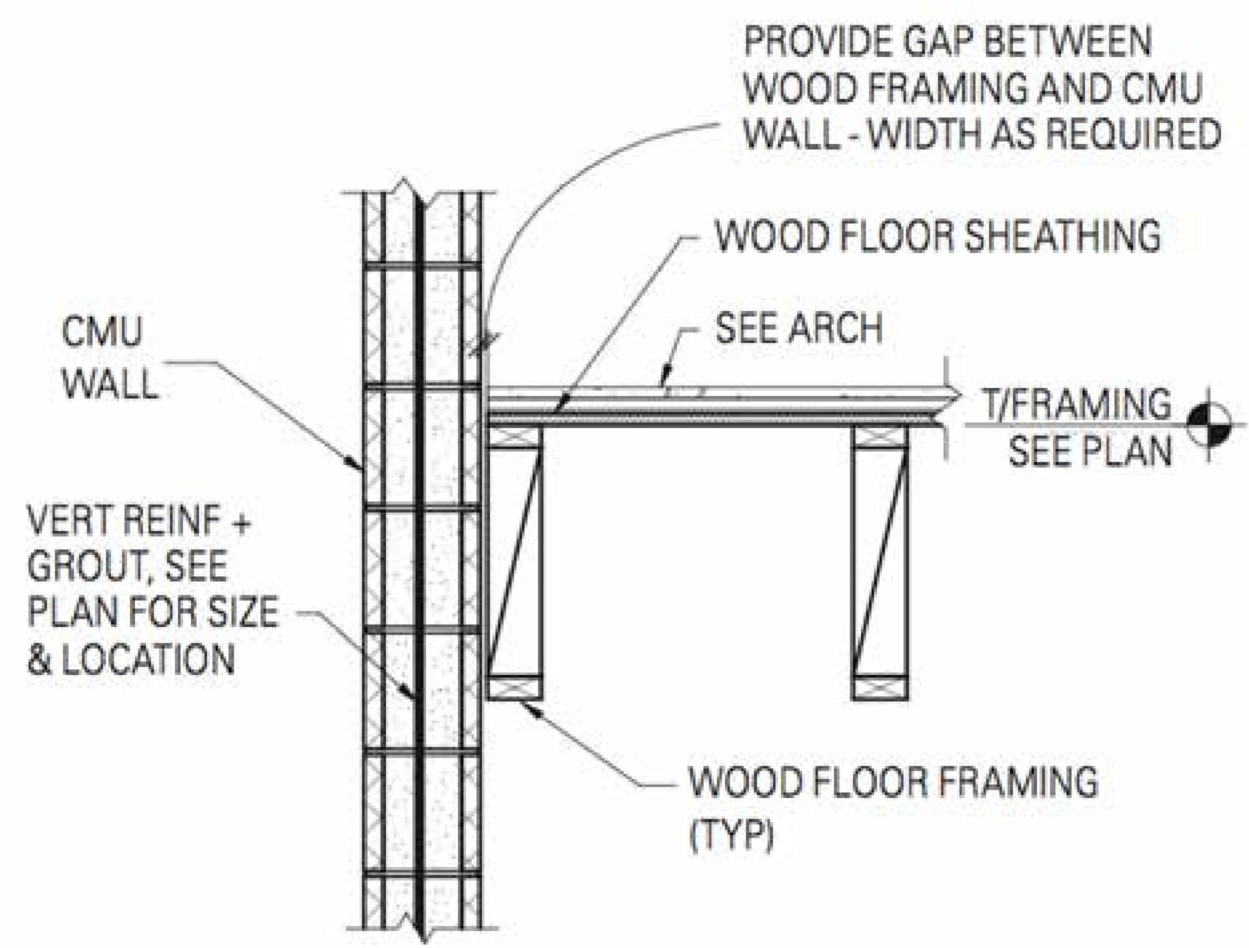



Image: Schaefer

# Differential Movement – Masonry Walls

Consider accumulated differential movement effects on:

- » Roofing/flashing
- » Finishes at roof intersection

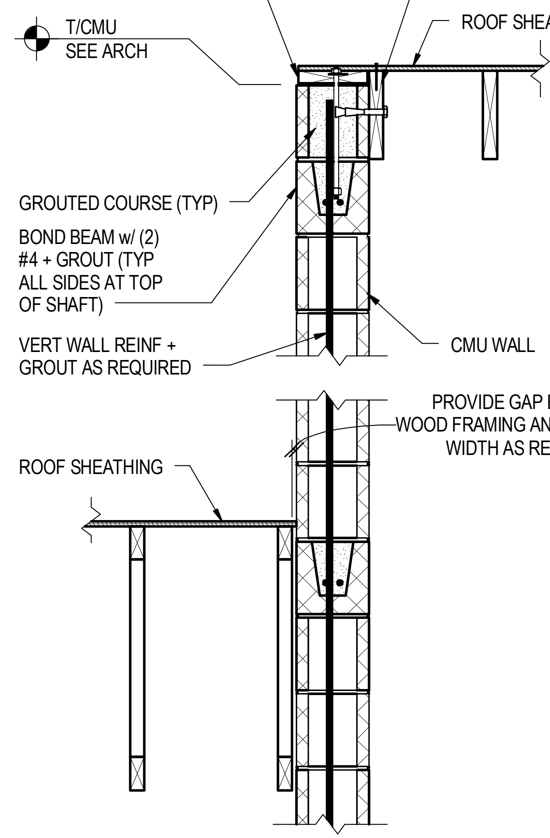



Image: Schaefer

# Differential Movement – Masonry Walls

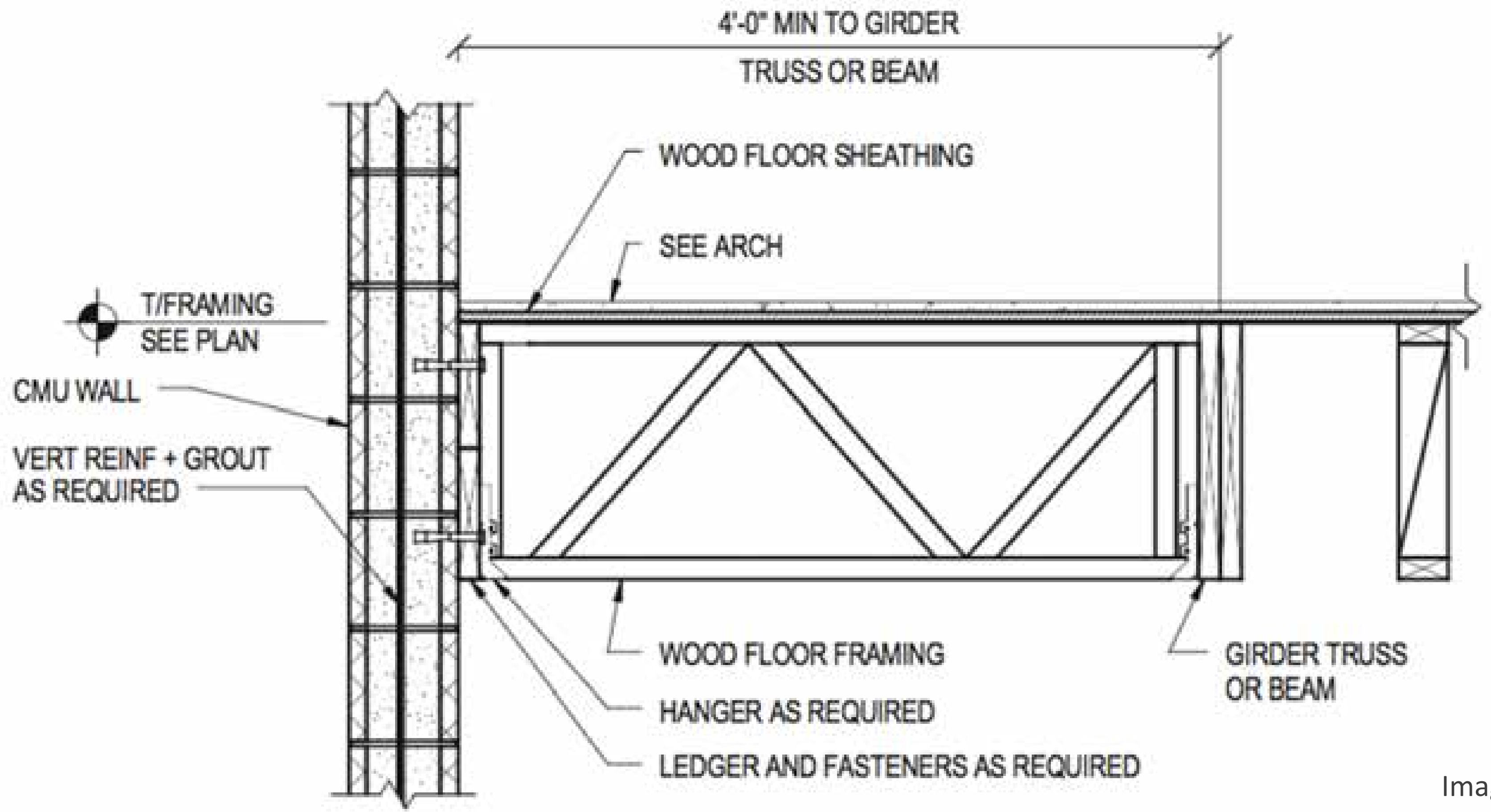



Image: Schaefer

# Differential Movement – Masonry Walls

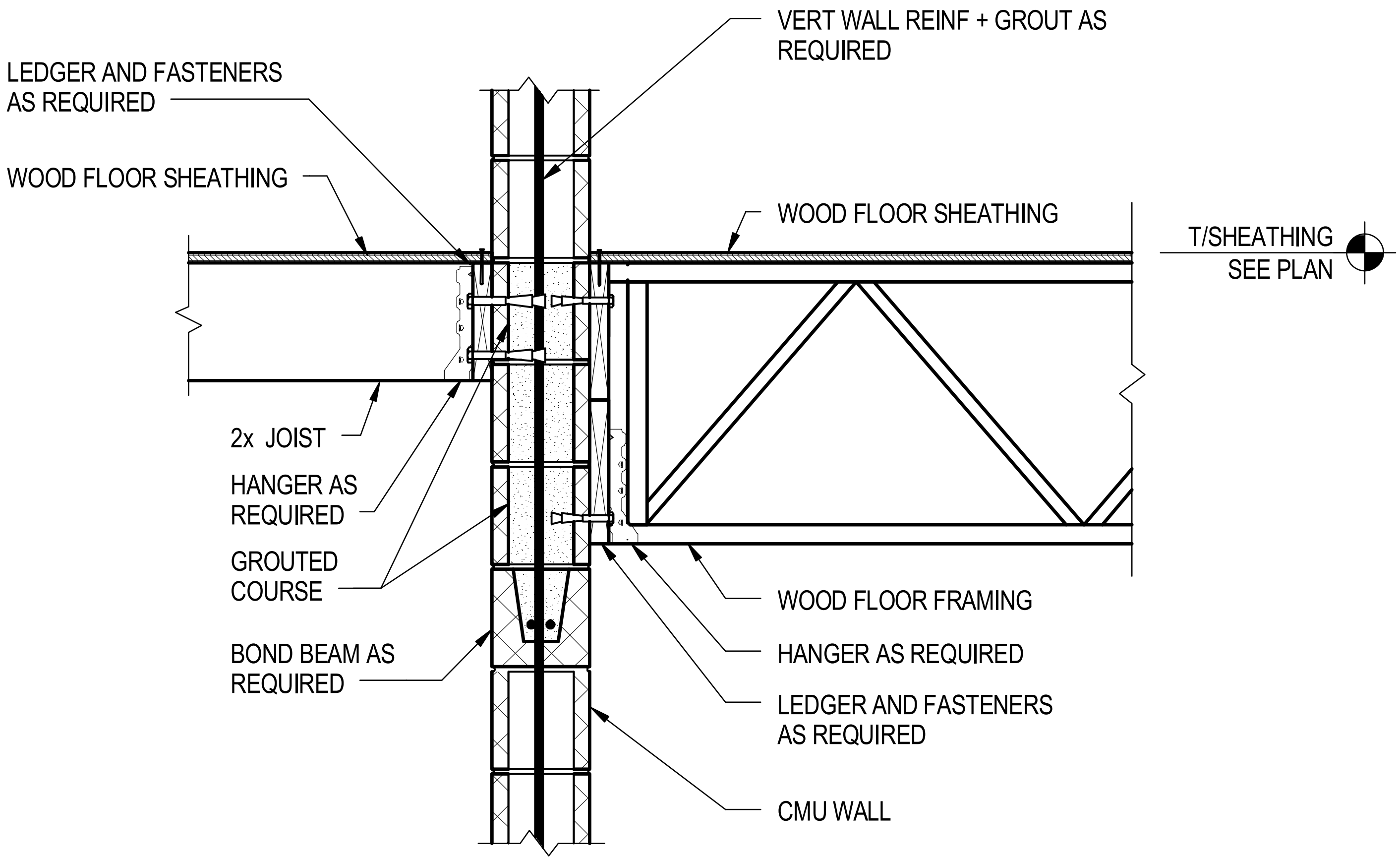



Image: Schaefer

# Differential Movement

At multi-story architectural finish applications, such as atriums and shafts, may need to consider shrinkage or differential movement effects

# Differential Movement – MEP

MEP main runs often start at base or top of structure, extend throughout height, with horizontal tees at each floor.

Horizontal tees often installed in wood stud partitions

# Differential Movement – MEP

Wood framing shrinks, vertical MEP runs remain stationary or expand with thermal fluctuations

Differential movement should be allowed for

Helpful to wait as late as possible after wood framing is erected to install MEP

Note anticipated wood shrinkage at each level on construction documents – MEP contractor should provide methods of accommodating

# Differential Movement – MEP

- Vertically slotted holes in studs allow differential movement
- Verify structural adequacy of studs

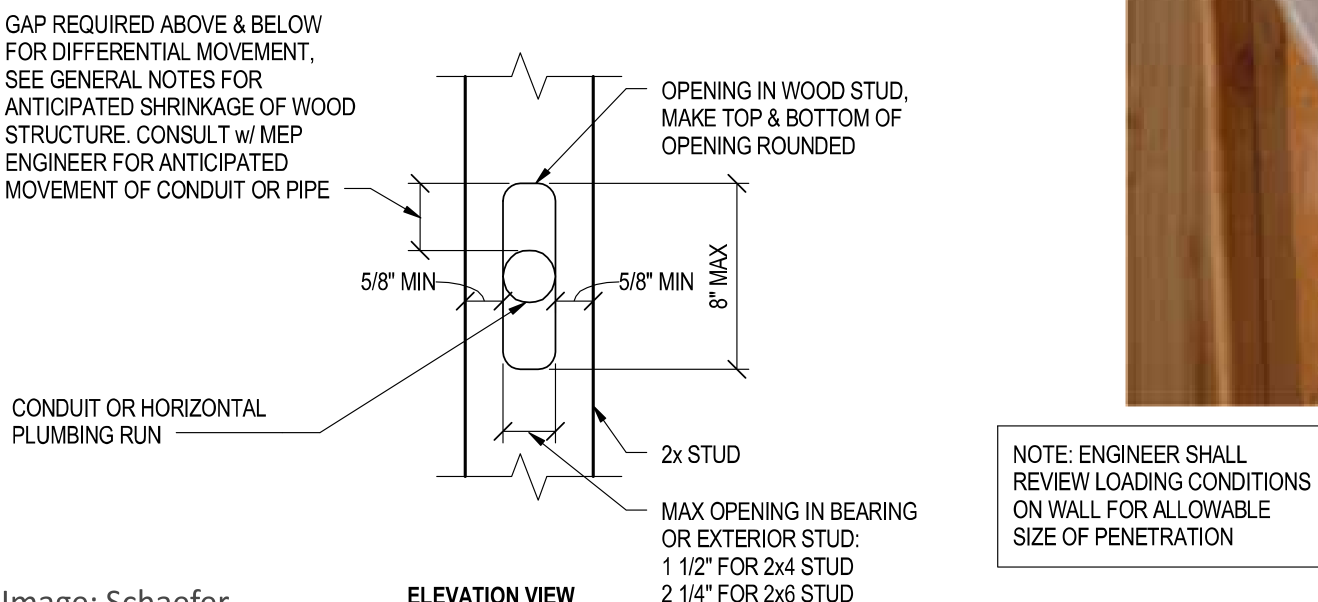



Image: Schaefer

Image: Louisiana-Pacific Corporation

# Oval cutout options for horizontal pipe

# Differential Movement - MEP

A variety of expansion or slip joint connectors are available – allow vertical MEP runs to move with the wood structure

# Vertical Stacks – Compensation Devices Installed

# Structural Connections - Beams

Due to cross grain shrinkage, consider effects of shrinkage at connections, especially bolted connections

Avoid restraining shrinkage – can result in shear cracking/splitting

# Structural Connections - Beams

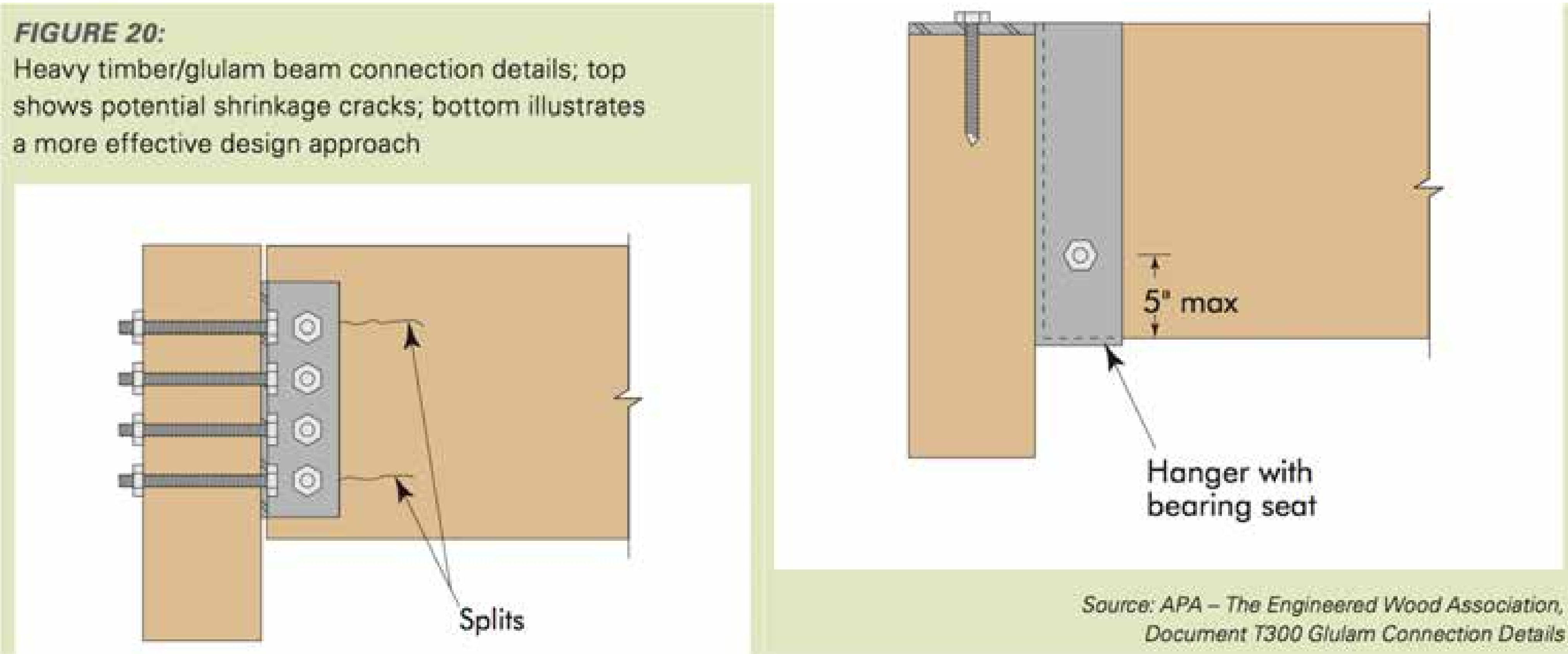


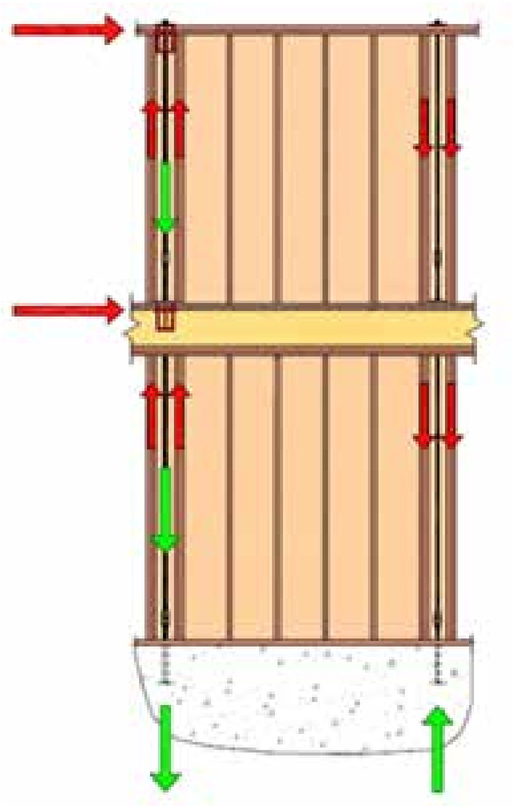

***FIGURE 20:***
Heavy timber/glulam beam connection details; top shows potential shrinkage cracks; bottom illustrates a more effective design approach

*Source: APA – The Engineered Wood Association, Document T300 Glulam Connection Details*

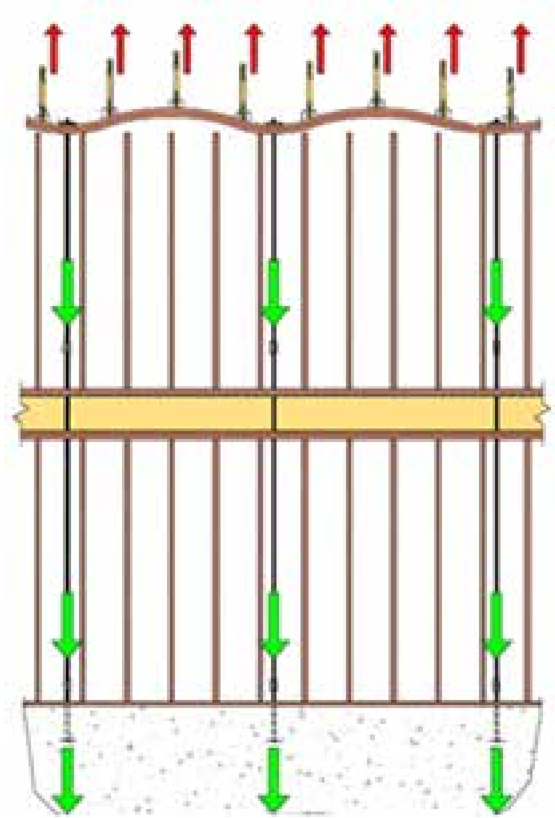
# Structural Connections – Uplift & Overturning

- Wind and seismic forces generate uplift and overturning forces on structures
- Methods of resisting these forces should take shrinkage into account, detail to mitigate its effects

# Structural Connections – Uplift & Overturning



**Shear Wall Overturning Resistance**



**Uplift Resistance**

Images: Simpson Strong-Tie

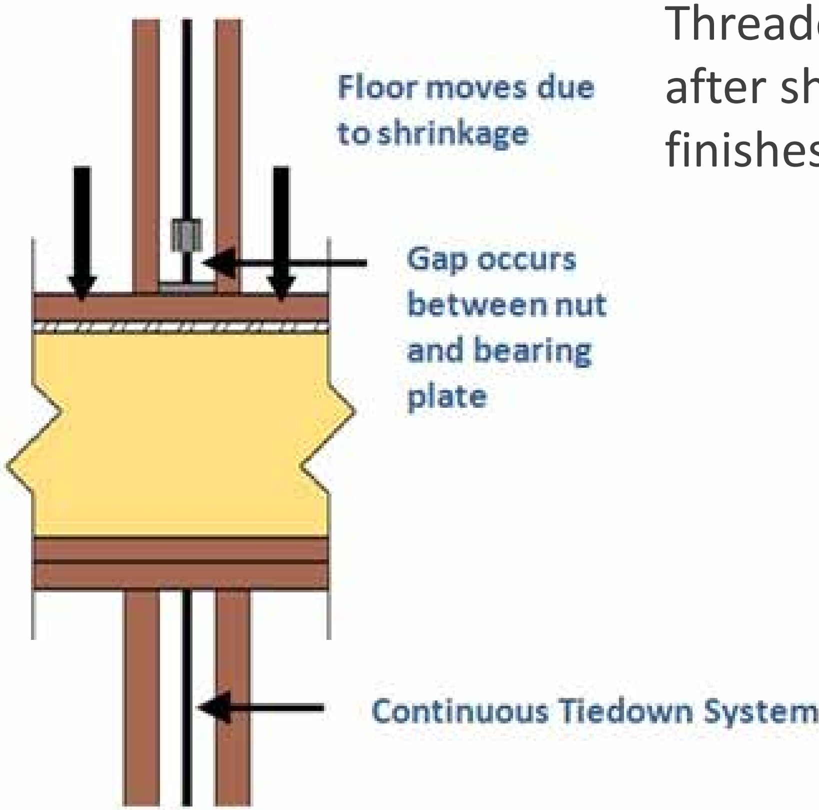
# Structural Connections – Uplift & Overturning

Uplift connections spanning through floor

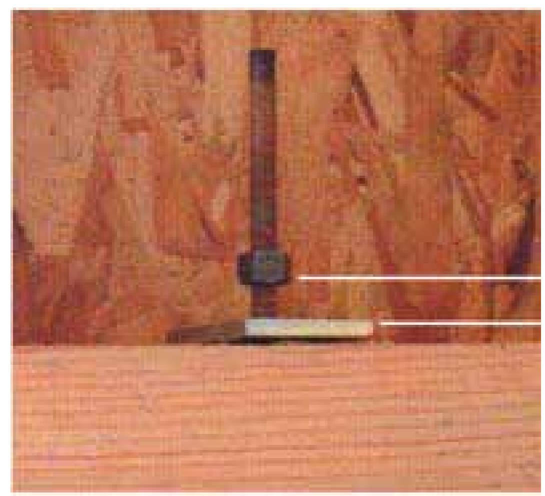
Image: Simpson Strongtie

# Structural Connections – Uplift & Overturning

# Structural Connections – Uplift & Overturning




Threaded Rod nuts would require re-tightening after shrinkage has occurred – difficult to do as finishes will likely already be installed



# Structural Connections – Uplift & Overturning

- Products available that allow building shrinkage while keeping threaded rods engaged in tension
- Shrinkage compensation device or take up device

Images: Simpson Strongtie & CLP

# **Questions?** Ask us anything.

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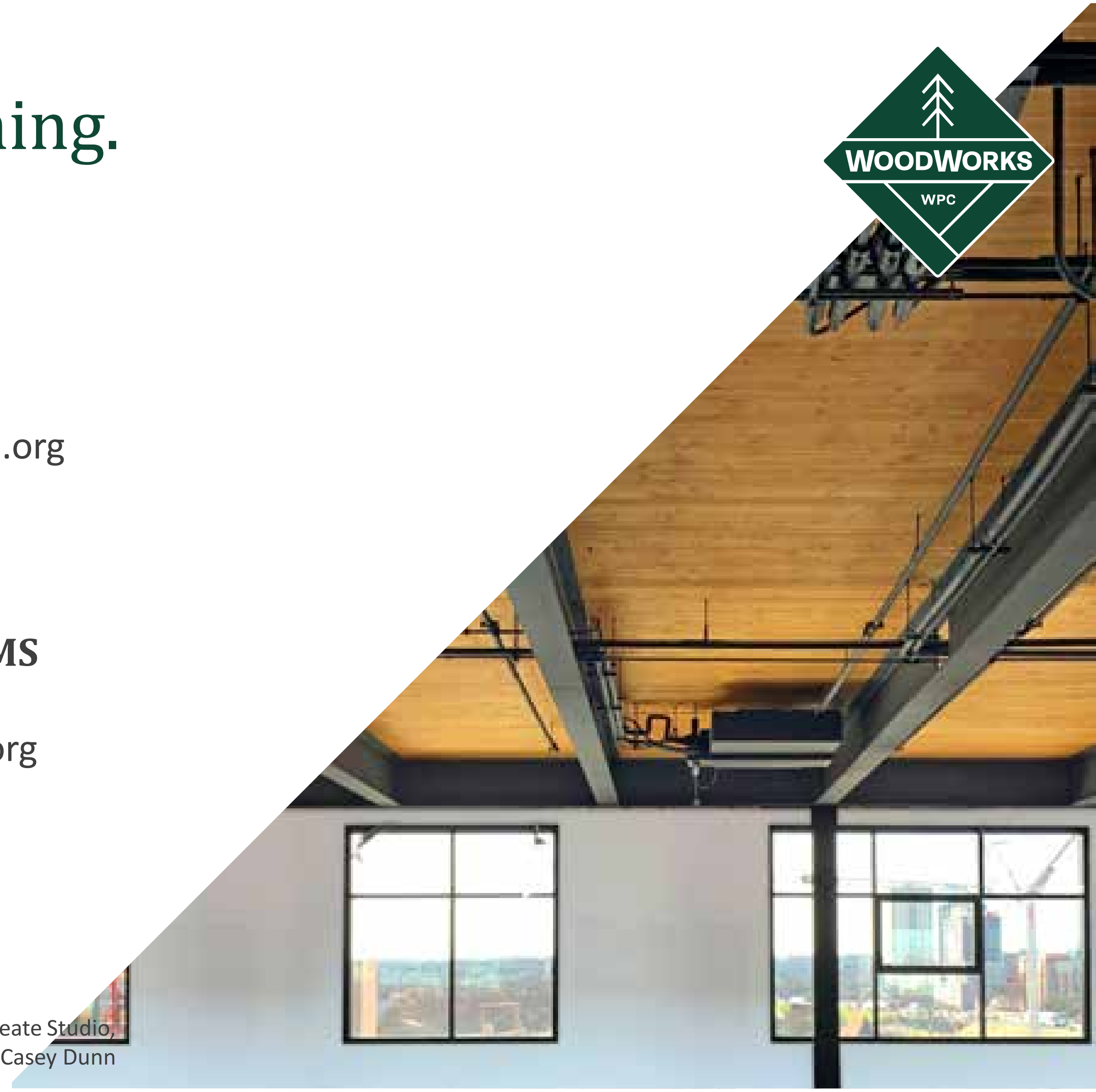

901 East Sixth, Thoughtbarn-Delineate Studio,
Leap!Structures, photo Casey Dunn