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Accommodating Shrinkage in Multi-Story Wood-Frame Structures

Image: Pollack Shores, Matrix Residential

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Course Description

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

Learning Objectives

1. Discuss the cellular structure of wood in order to understand how moisture and wood interact, and identify the paths that moisture typically travels.

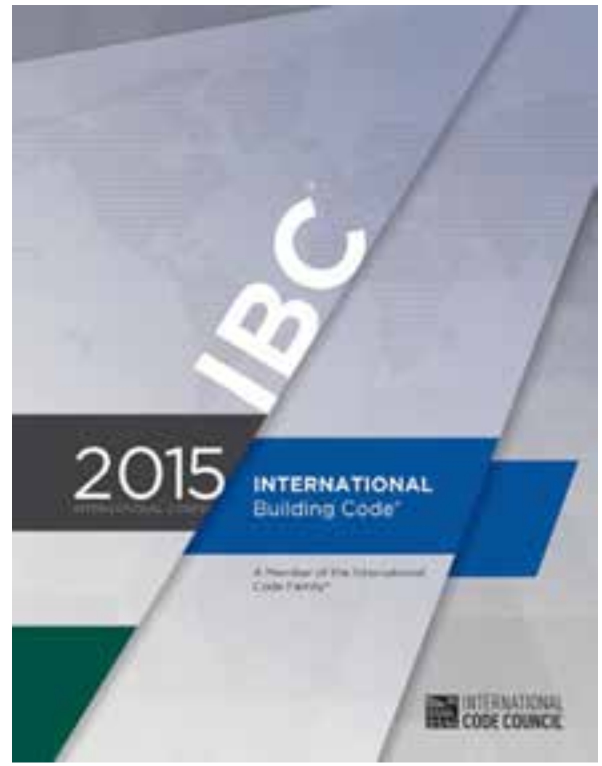
2. Explain methods of calculating expected shrinkage in multi-story wood-frame buildings.

3. Highlight best practice details for accommodating wood shrinkage and differential material movement at conditions such as opening sills, MEP lines and shaft wall connections.

4. Review considerations and solutions associated with shrinkage effects on structural connections.

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


Why Does
Wood Shrink?

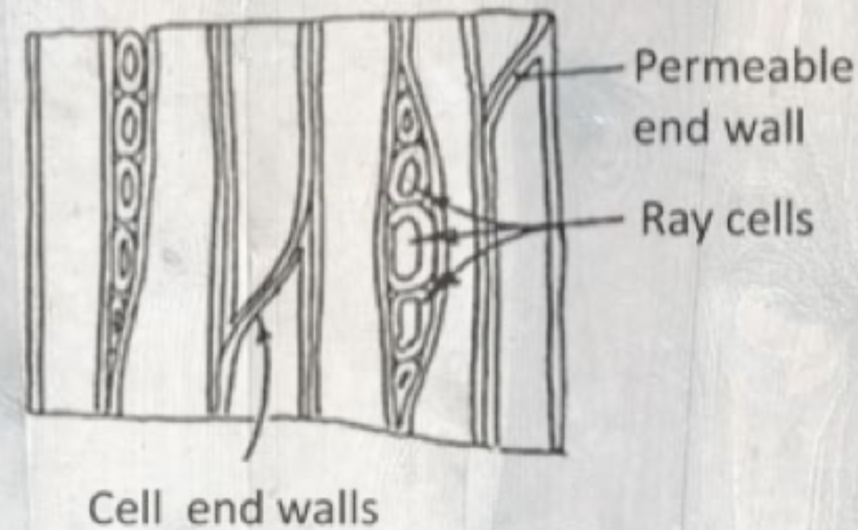
Wood Science




Wood Science – Cellular Makeup

Wood is a hygroscopic material

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



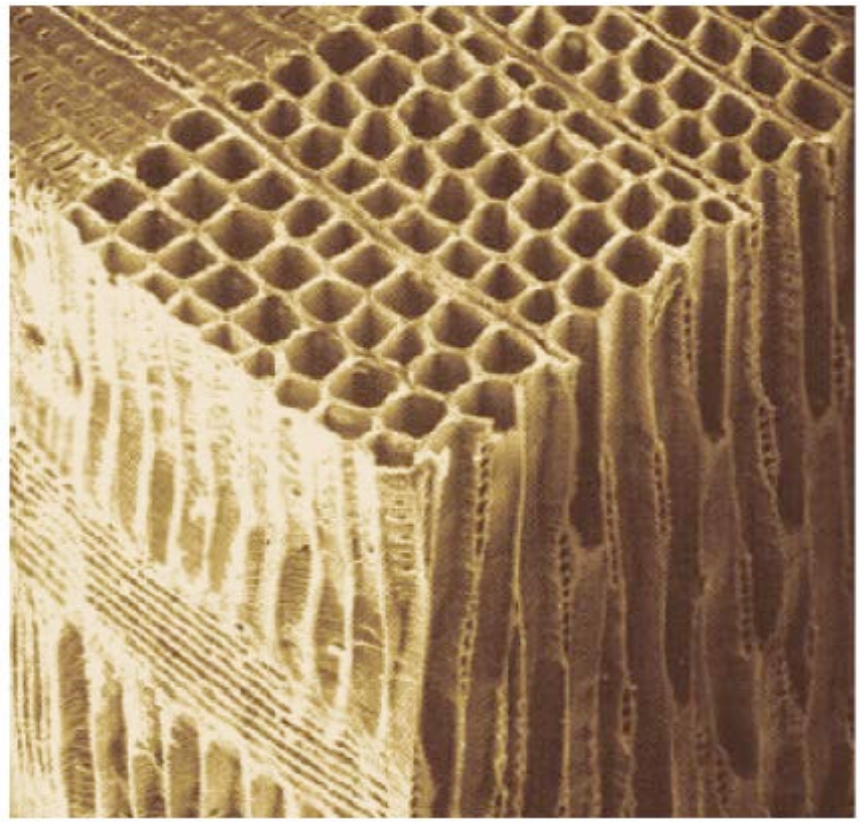
Wood Science – Moisture in Wood

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>:

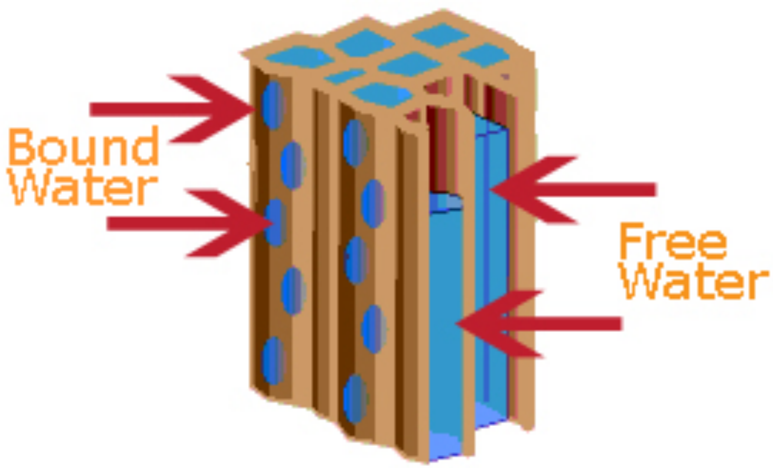
- Point at which cell walls are completely saturated but cell cavities are empty (i.e. no free water but still has all its bound water)



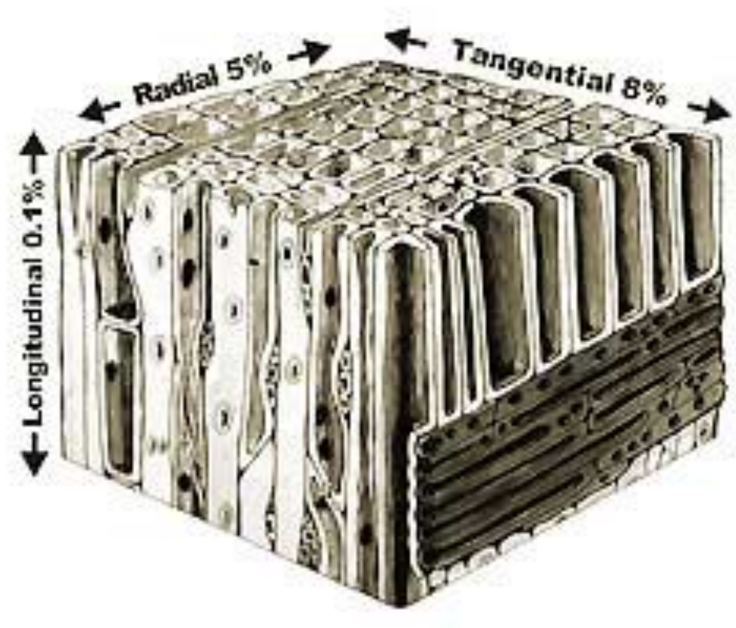
Southern yellow pine cellular makeup

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

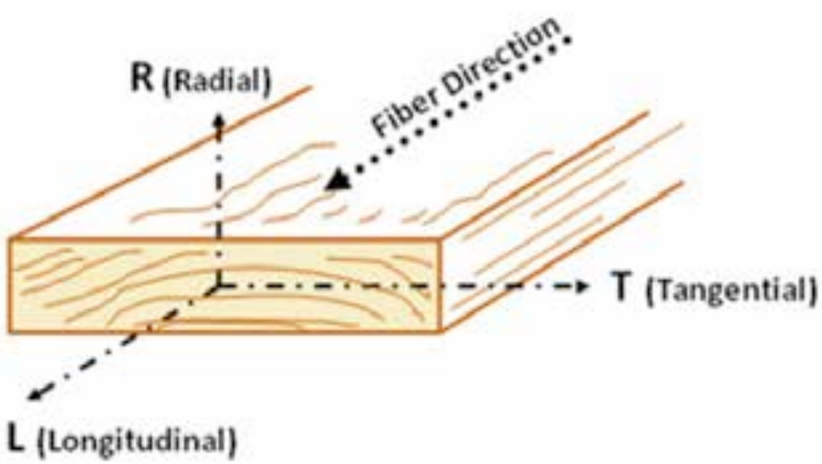
Is shrinkage uniform across all dimensions of a piece of lumber?

- 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



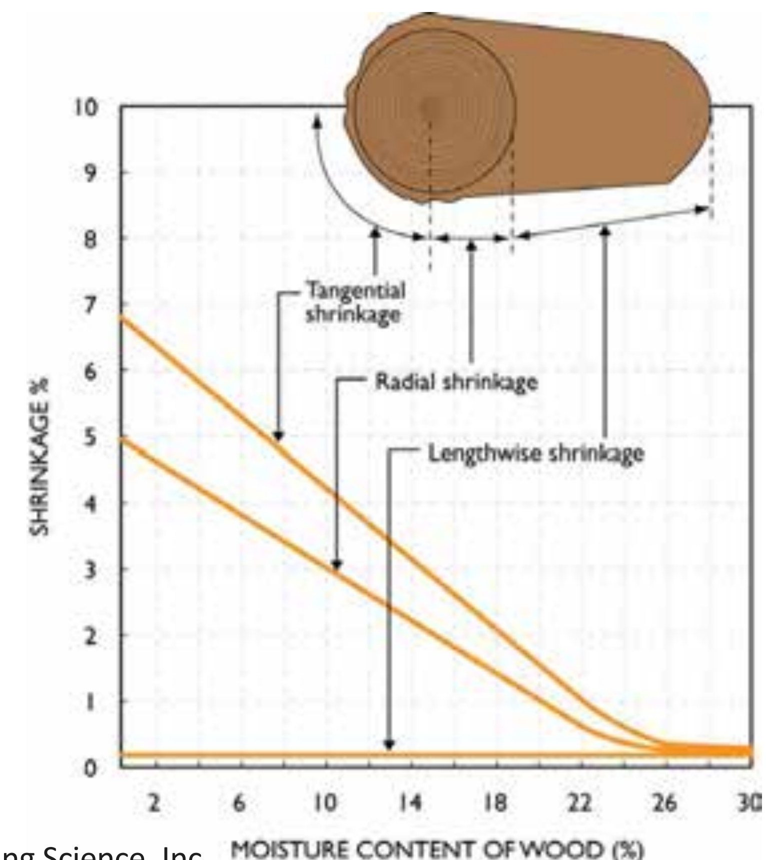


Image: RDH Building Science, Inc.

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.

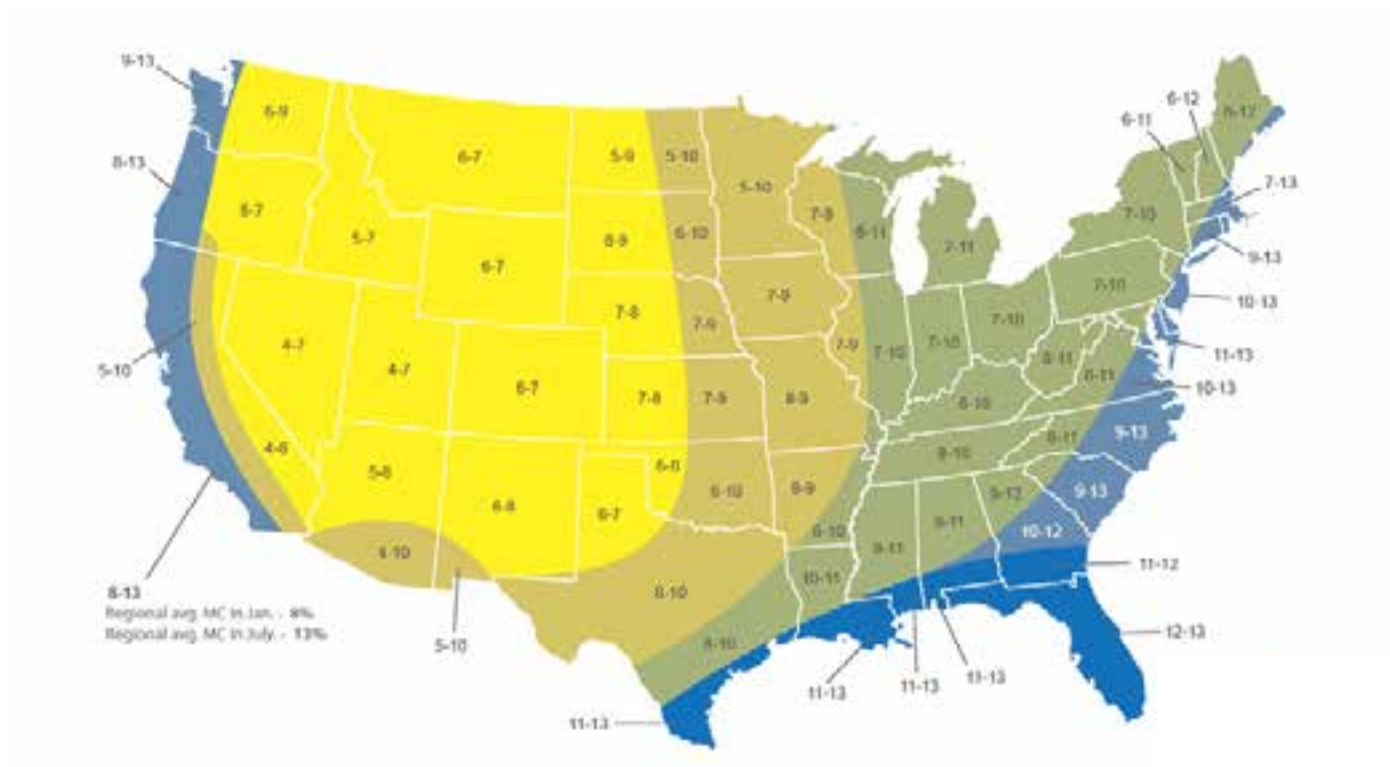
- Function of temperature & relative humidity

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

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

FIGURE 2:
Moisture content range

Source: RDH Building Science Inc.

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
- 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%

$M_i = 19\%$

$M_i = 28\%$

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

Source: APA – The Engineered Wood Association

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. Immediately remove any standing water from floor framing after rain showers.
5. “Dry-in” the structure as quickly as possible.
6. Ensure that installed lumber MC is lowered to 19% or calculated max MC before installing finishes & insulation

Shrinkage Calculations – Cross Grain Wood

Be aware of cumulative shrinkage

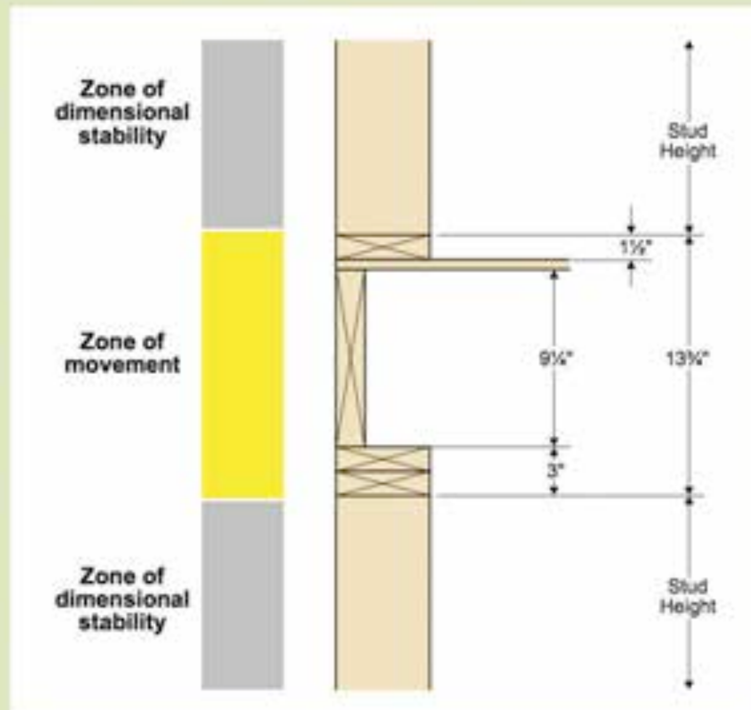
Shrinkage Calculations – Cross Grain Wood

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?

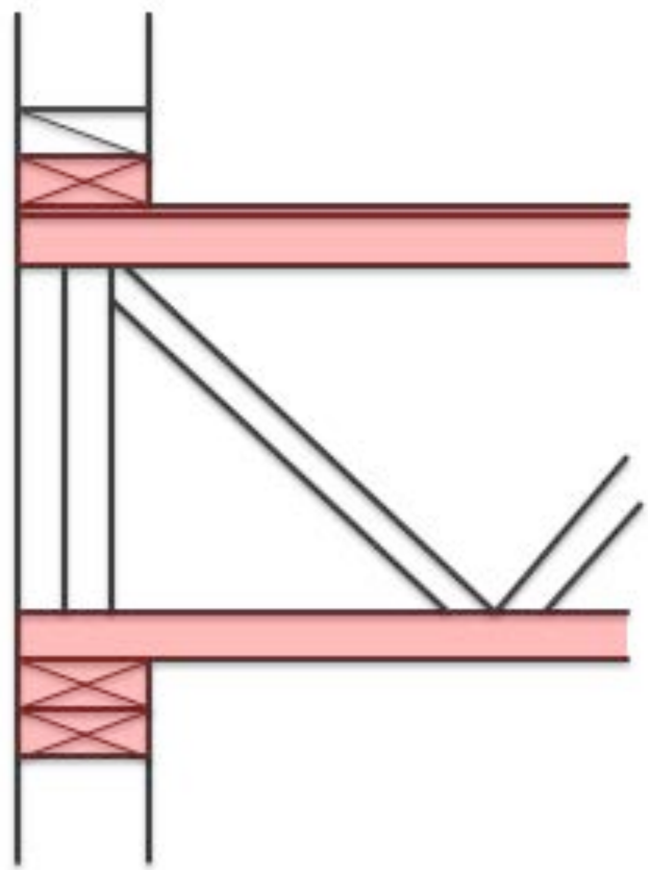
FIGURE 5:

Shrinkage zone in platform-framed detail



Shrinkage Calculations – Cross Grain Wood

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



Minimizing Shrinkage

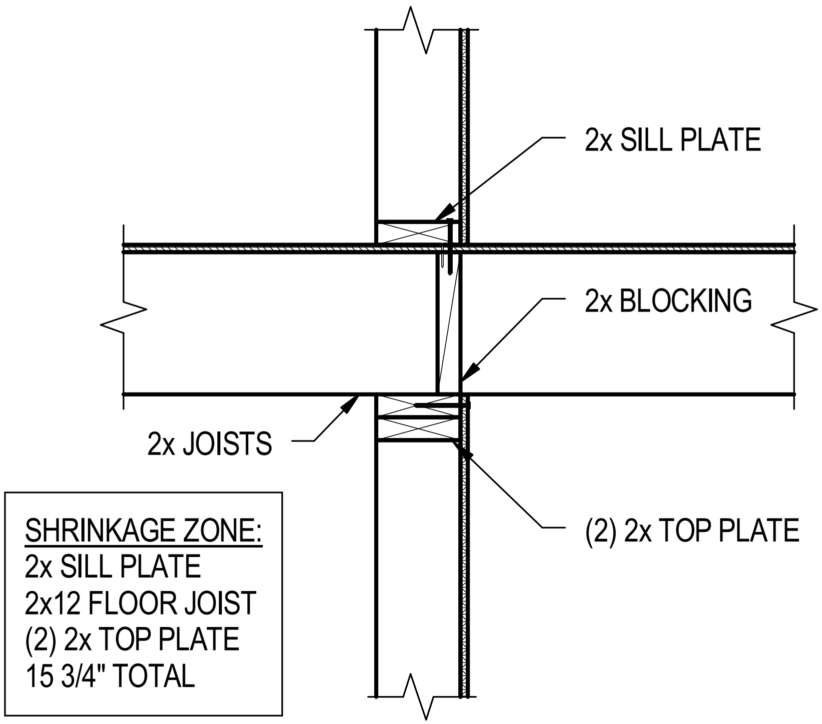
Recalling the three variables that influence amount of shrinkage:

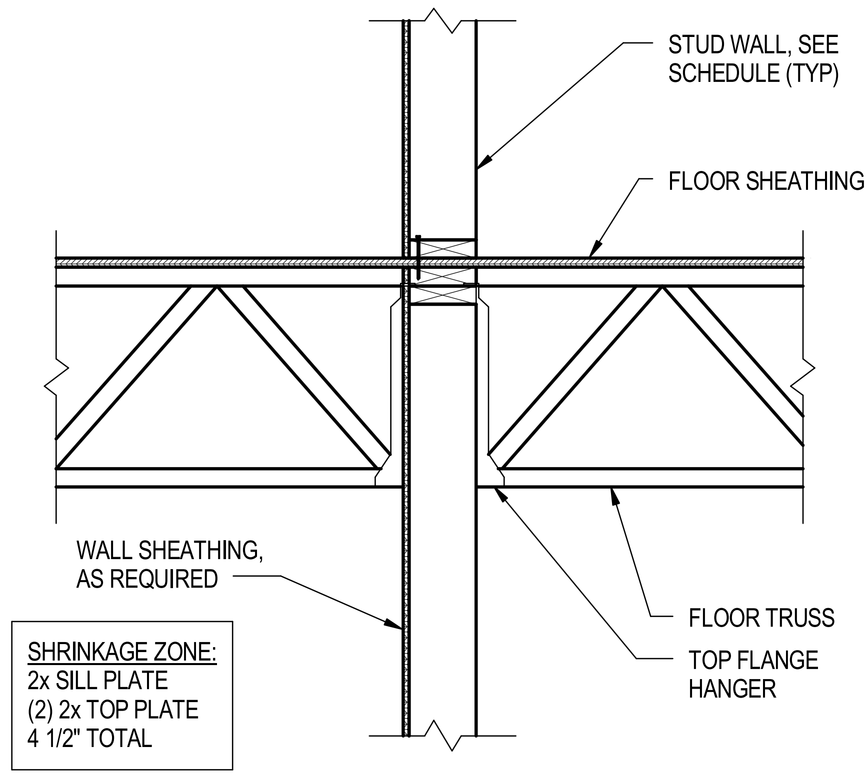
- Installed moisture content (MC)
- In-service equilibrium moisture content (EMC)
- Cumulative thickness of cross-grain wood contributing to shrinkage

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”**

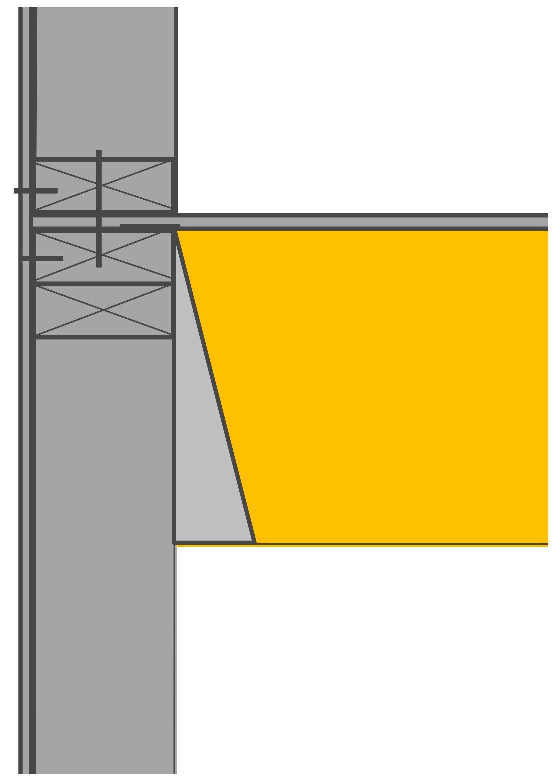
5-story building: **0.4” total**

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

Wood Framing & Veneer:

- Veneer Type Transitions
- Openings (Sill, Head, Jambs)

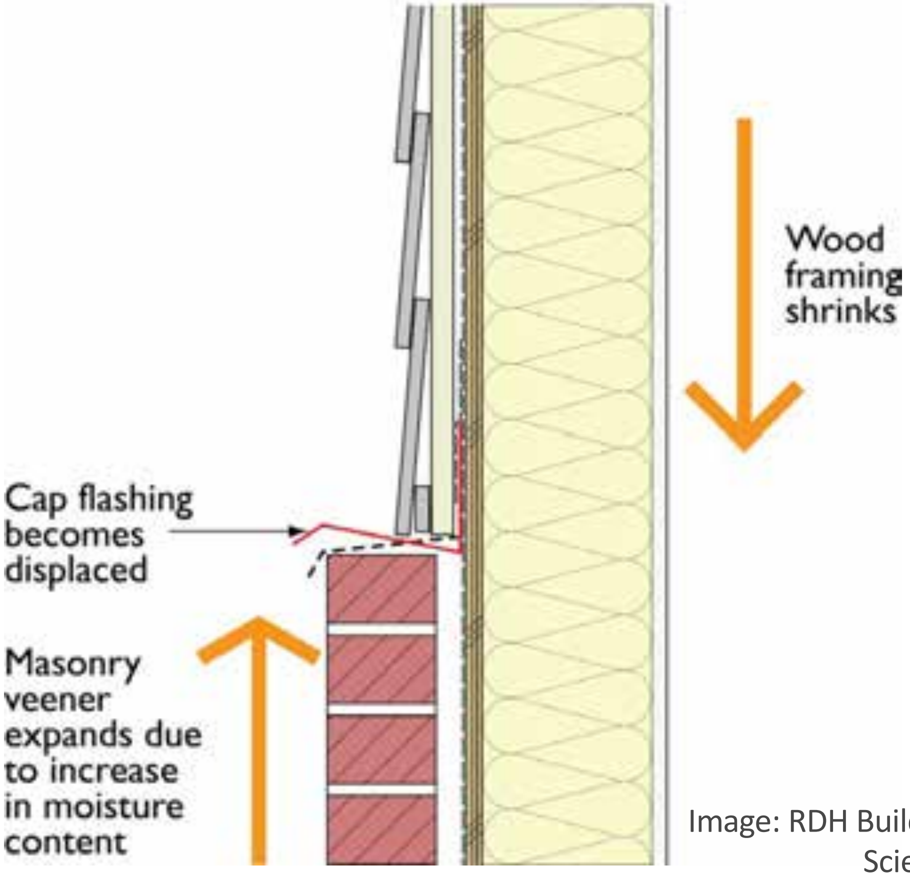


Image: RDH Building Science

Differential Movement – Veneer Transition

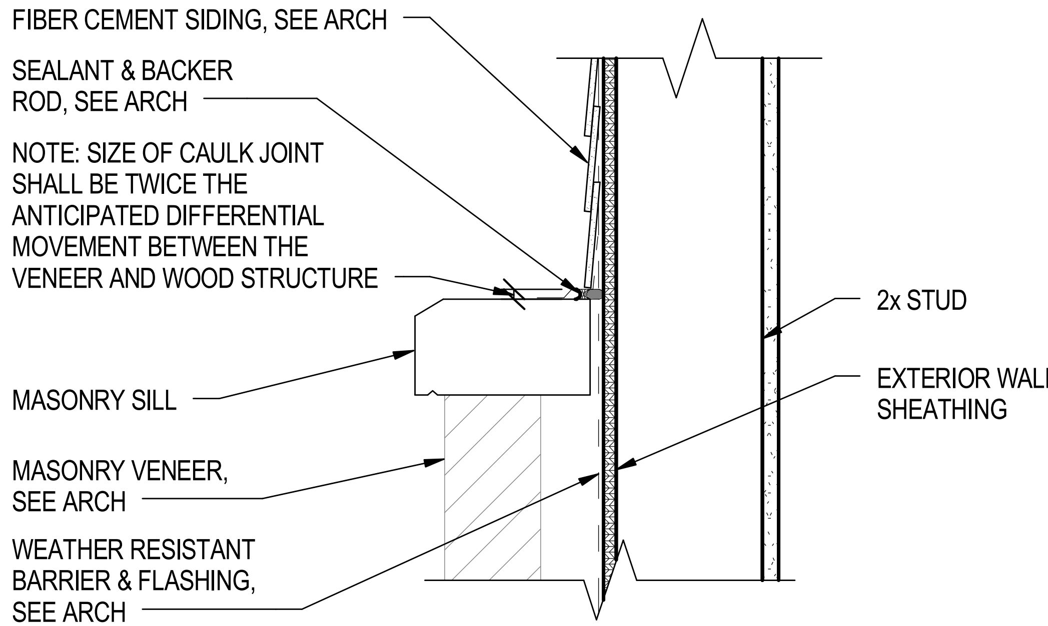
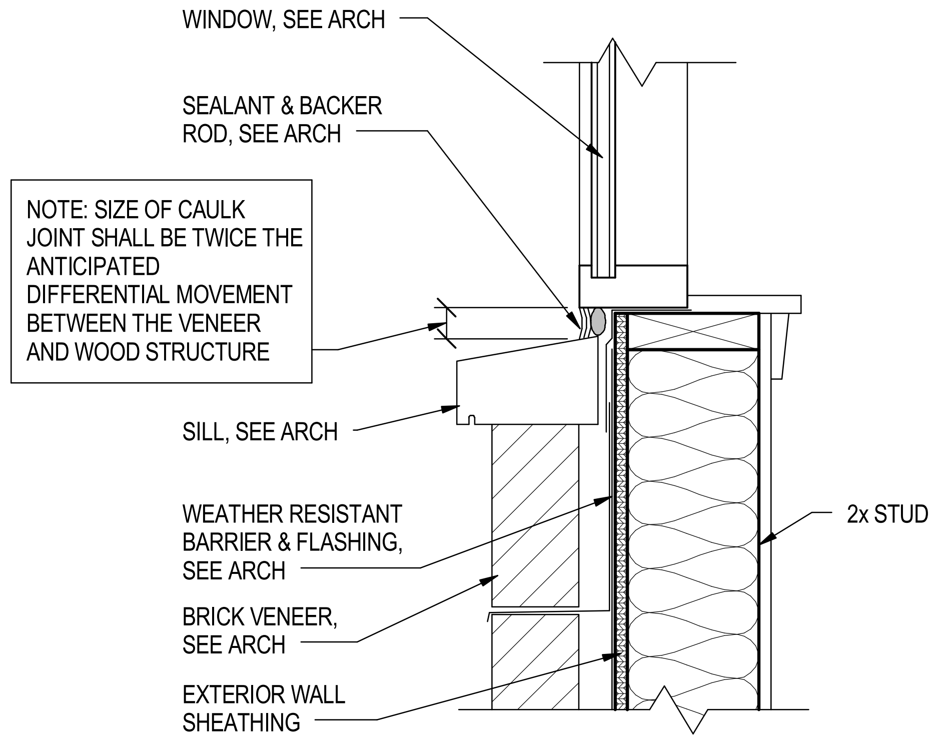


Image: Schaefer

Differential Movement – Veneer Opening



Images: Schaefer

Differential Movement – Veneer Opening

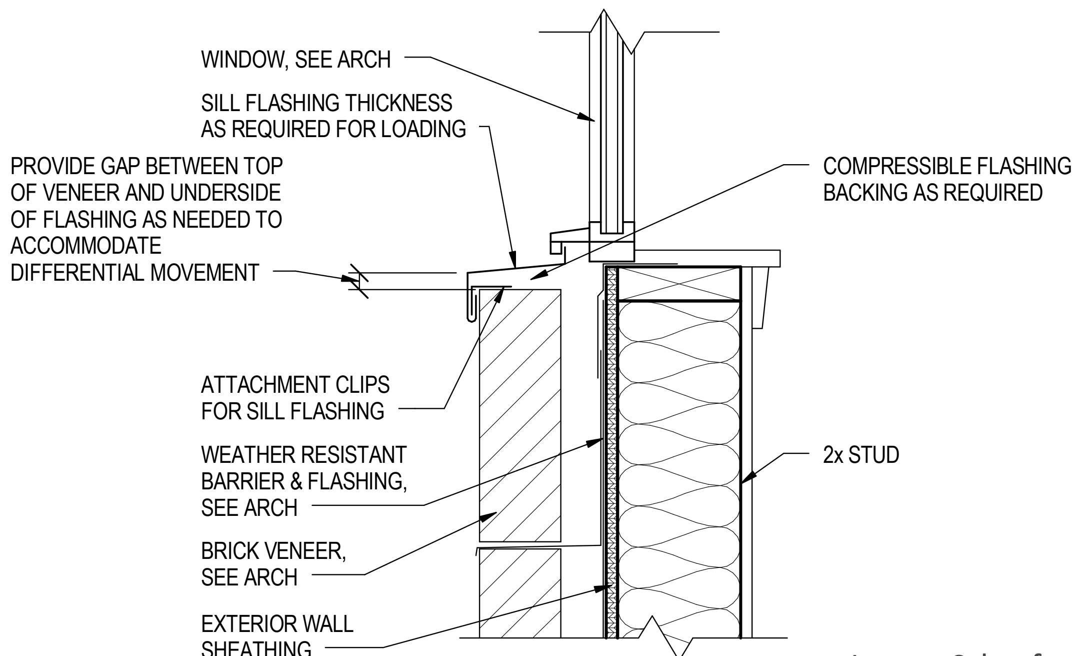


Image: Schaefer

Differential Movement – Veneer Opening

Image: RDH Building Science

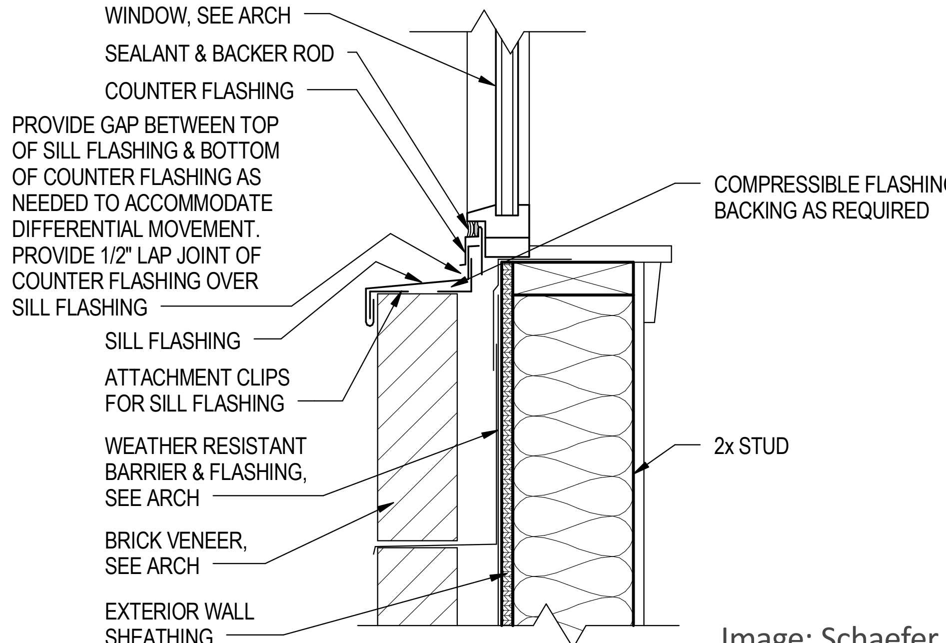


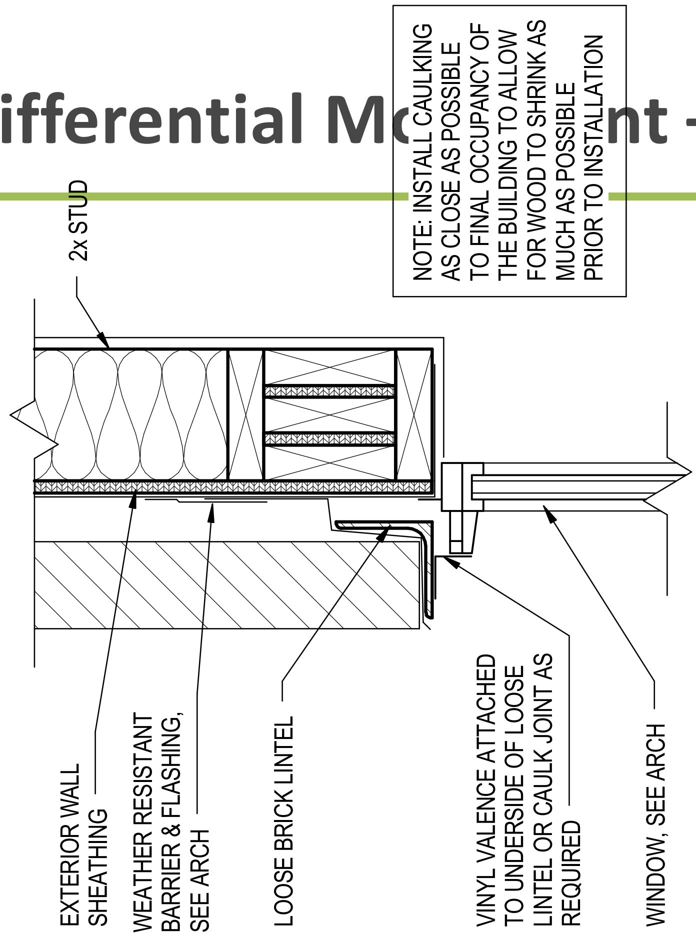
Image: Schaefer

Brick Veneer Resource

Code provisions, detailing options, and more for accommodating multiple stories of brick veneer on wood structures

Free resource at woodworks.org

Differential Movement – Veneer Opening



Images: Schaefer

Differential Movement – Veneer Opening

- Consider installing caulking at openings as late as possible to allow differential movement to occur
- Differential movement can cause shearing cracks in caulk
- Periodic inspection and re-caulking may be warranted

Image: Schaefer

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

Differential Movement – Masonry Walls

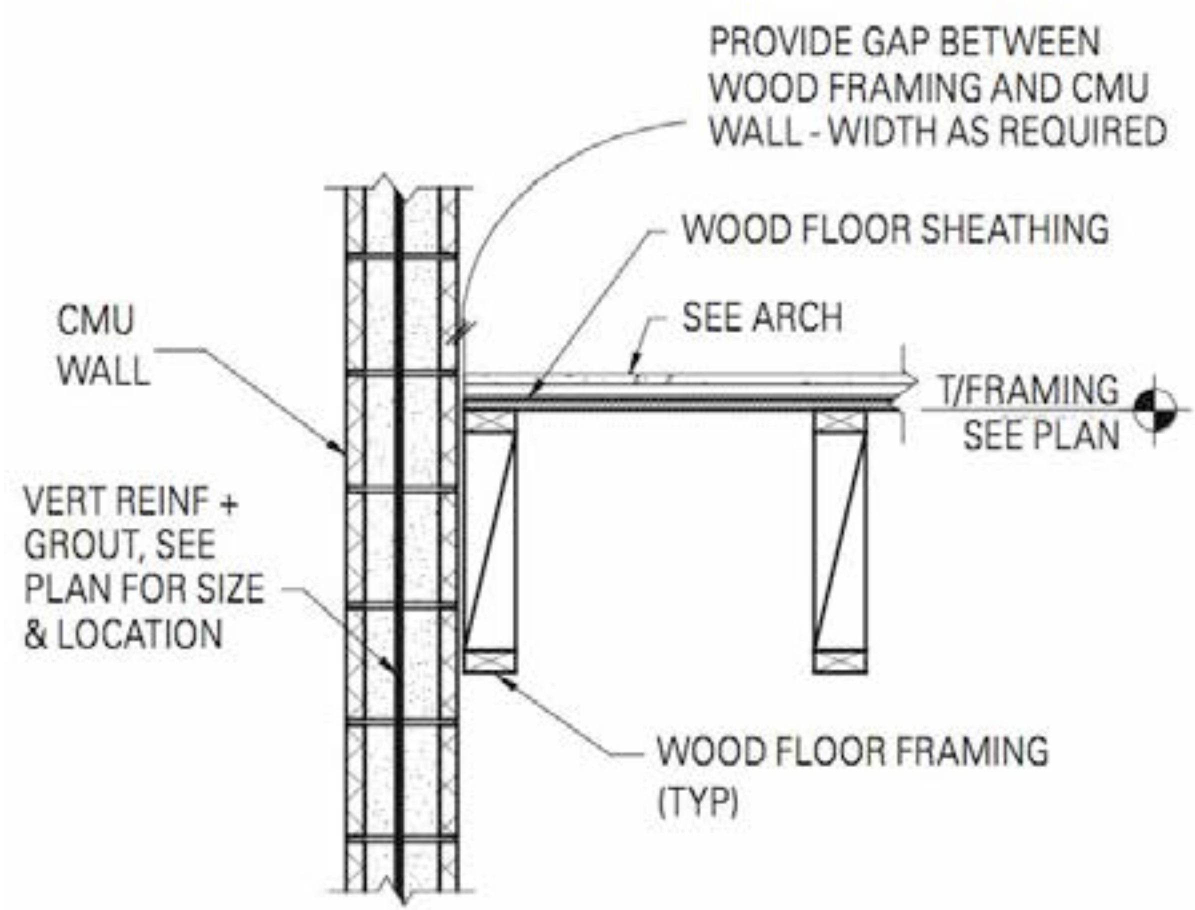


Image: Schaefer

Differential Movement – Masonry Walls

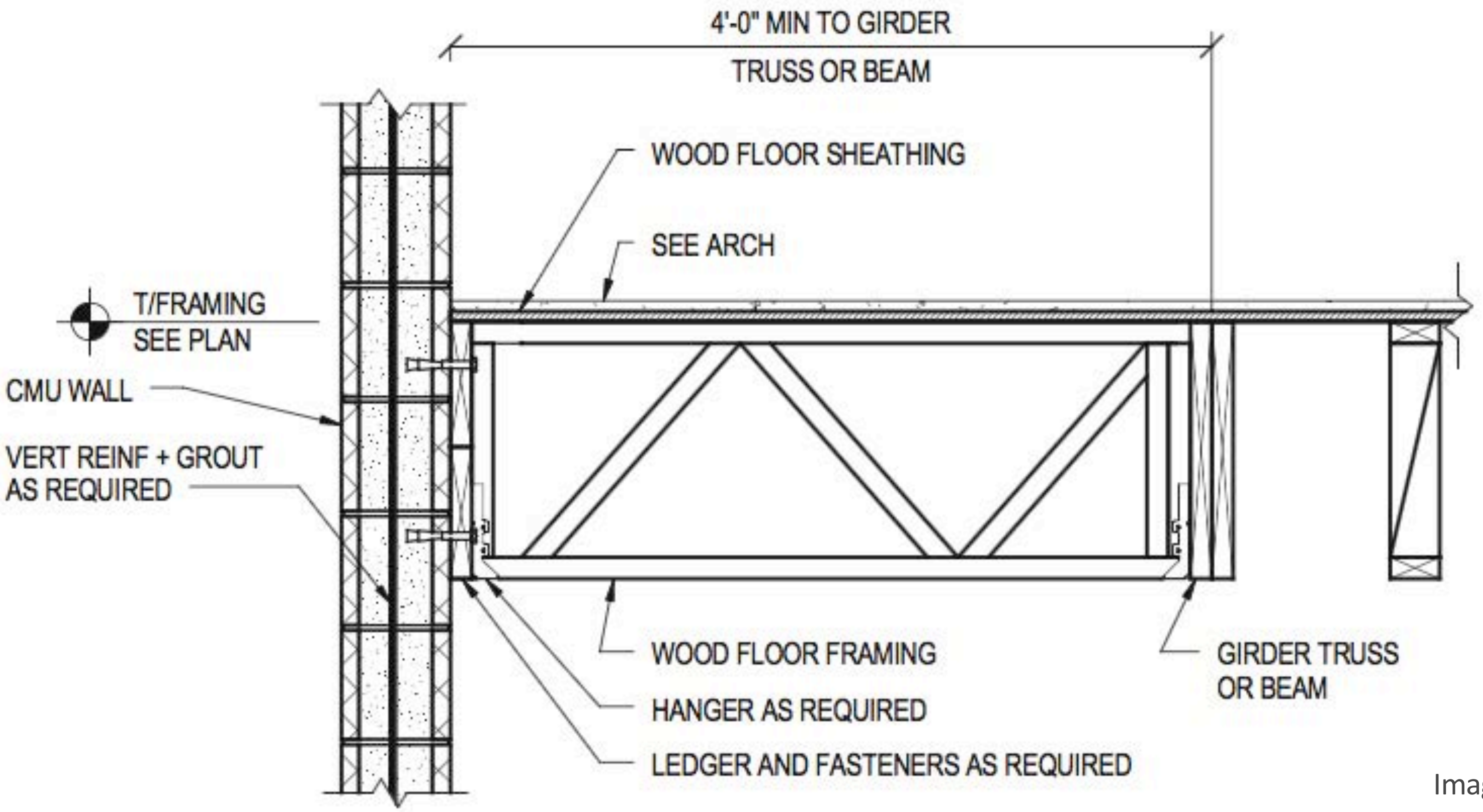


Image: Schaefer

Differential Movement – Masonry Walls

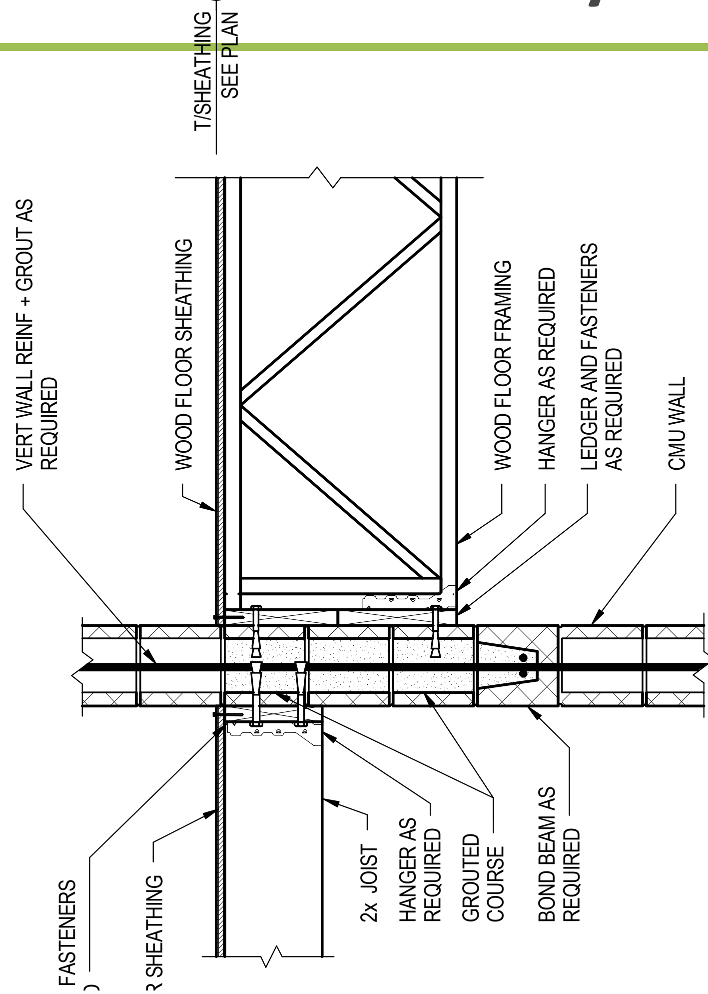


Image: Schaefer

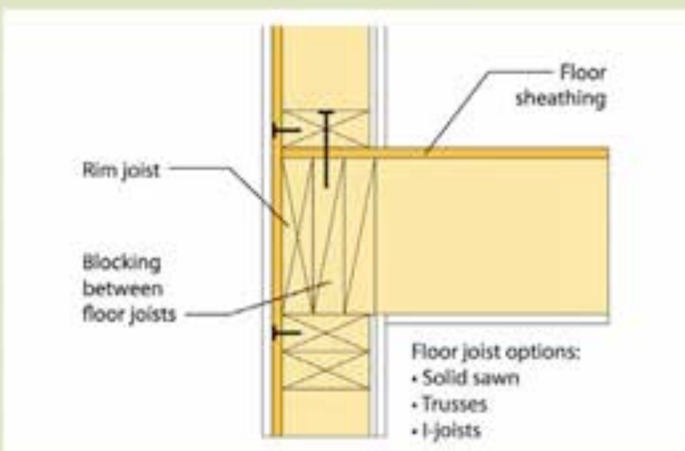
Differential Movement

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

Shaft Wall Resource

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

FIGURE 15:
Example wood-frame shaft wall detail



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Shaft Wall Solutions For Wood-Frame Buildings

Richard McLain, MS, PE, SE • Technical Director • WoodWorks

Wood shaft walls can reduce costs and shorten the construction schedule.

It is fairly common for light wood-frame commercial and multi-family buildings to include shaft walls made from other materials. However, with the heavy use of wood structure in mid-rise construction, many designers and contractors have come to realize that wood-frame shaft walls are in fact a code-compliant means of reducing cost and shortening construction schedule.

A shaft is defined in Section 202 of the 2012 International Building Code (IBC) as "*an enclosed space extending through one or more stories of a building, connecting vertical openings in successive floors, or floors and roof.*" Therefore, shaft enclosure requirements apply to stairs, elevators, and MEP chases in multi-story buildings. While these applications might be similar in their fire design requirements, they often have different construction constraints and scenarios where assemblies and detailing may also differ.

This paper provides an overview of design considerations, requirements, and options for wood-frame shaft walls under the 2012 IBC. While some of the IBC-referenced section numbers may be different in different editions, none of the main shaft wall provisions have been modified in the 2015 IBC.

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

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

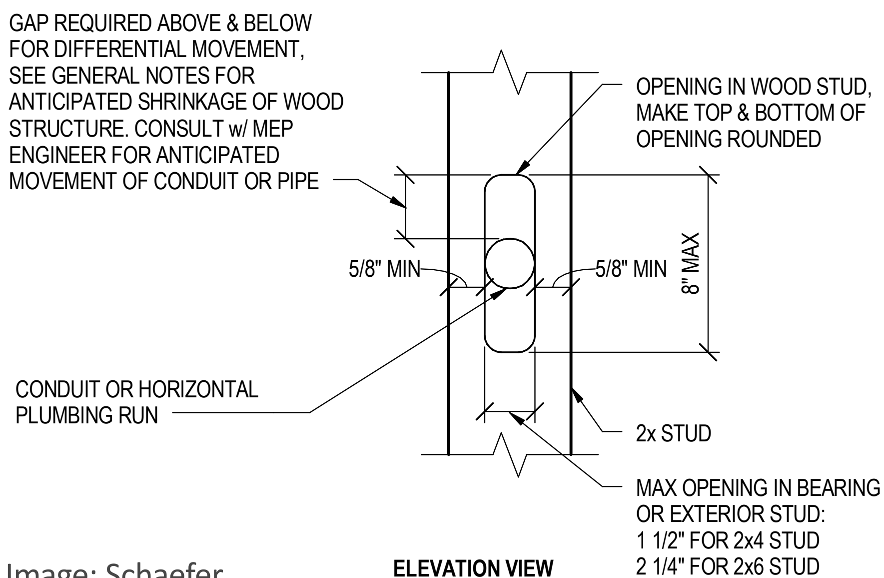


Image: Schaefer

NOTE: ENGINEER SHALL REVIEW LOADING CONDITIONS ON WALL FOR ALLOWABLE SIZE OF PENETRATION

Image: Louisiana-Pacific Corporation

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

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

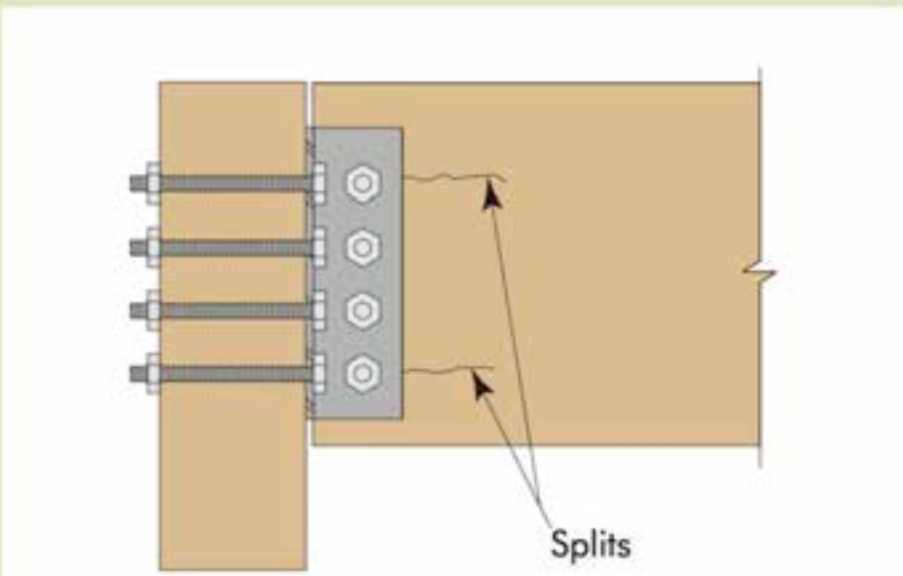
Structural Connections - Beams

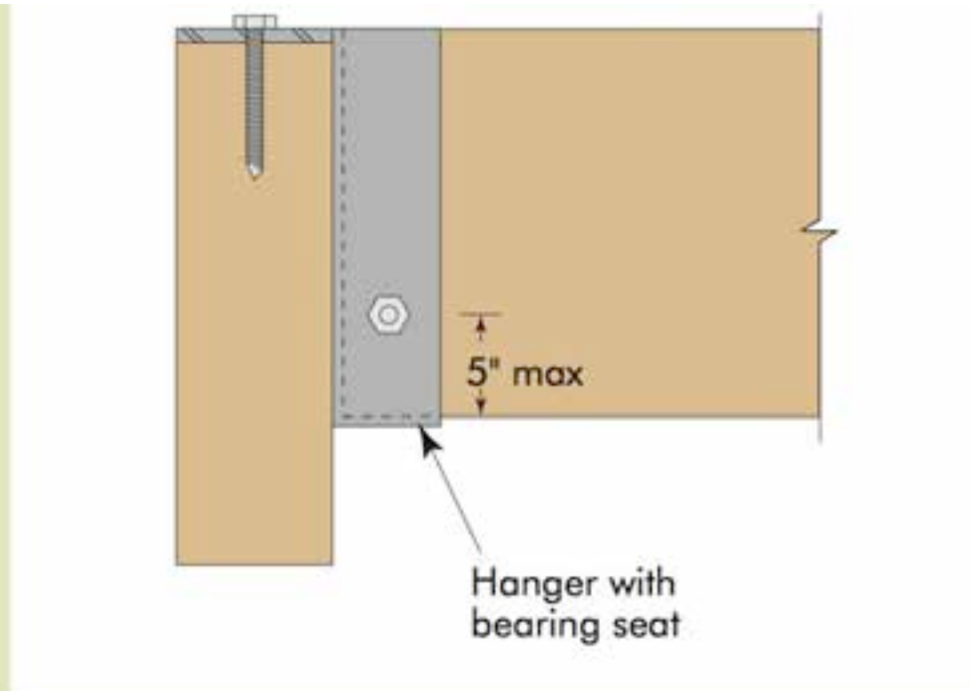
Due to cross grain shrinkage, consider effects of shrinkage at connections, especially bolted connections

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



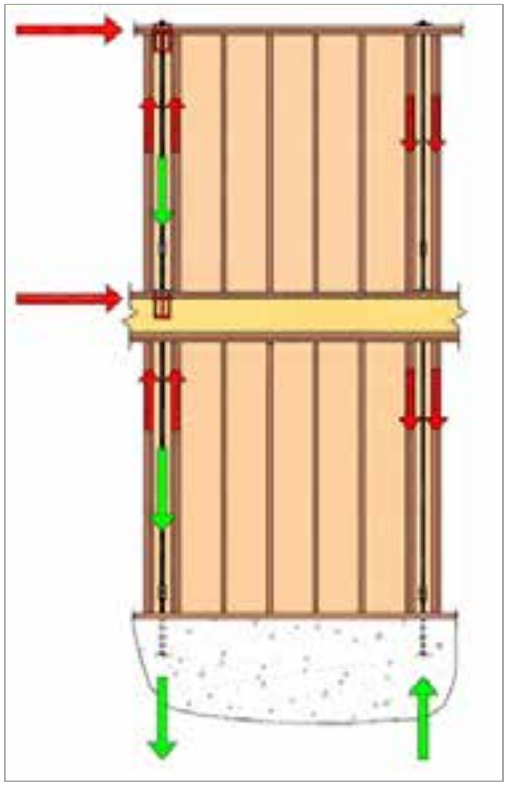


Source: APA – The Engineered Wood Association, Document T300 Glulam Connection Details

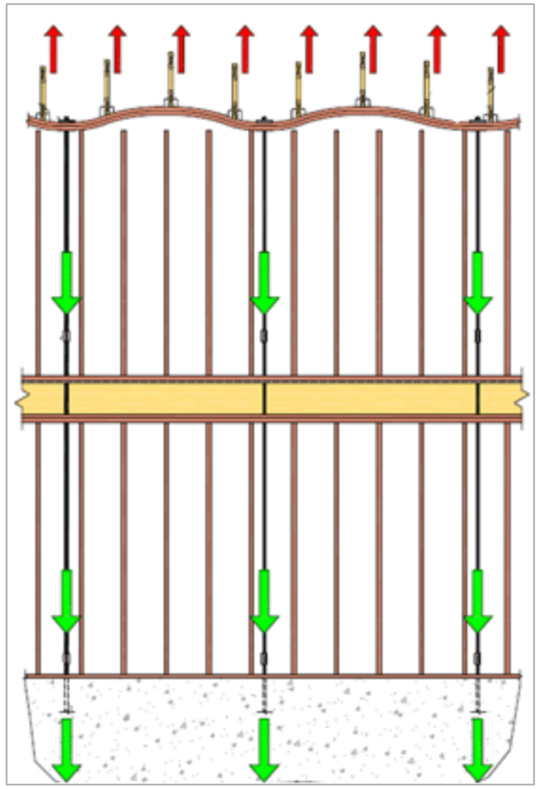
Structural Connections – Uplift & Overturning

- 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 Strongtie

Structural Connections – Uplift & Overturning

Uplift connections spanning through floor

Image: Simpson Strongtie

Structural Connections – Uplift & Overturning

Image: Simpson Strongtie

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

Shrinkage Resource

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

Free resource at woodworks.org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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
Jacksonville, Florida
Architect: Dwell Design Studio
Structural Engineer: M2 Structural Engineering

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

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

QUESTIONS?

This concludes The American Institute of Architects Continuing Education Systems Course

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