Accommodating Shrinkage in Multi-Story Wood-Frame Structures

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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.

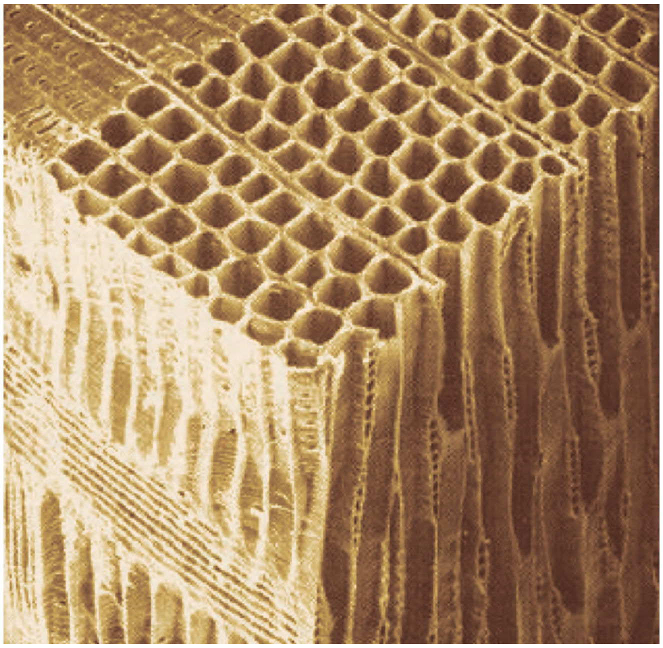
This publication will describe procedures for estimating wood shrinkage and provide detailing options that minimize its effects on building performance.

The Brooklyn Riverside
Jacksonville, Florida
Architect: Dwell Design Studio
Structural Engineer: M2 Structural Engineering

Photo: Pollack Shores, Matrix Residential

Wood Science & Shrinkage

Understanding the cellular structure of wood allows us to understand how moisture and wood interact and identify the paths that moisture typically travels. Within wood, moisture is present in two forms: (1) free water in cell cavities, and (2) bound water in cell walls. Simplistically, wood's cellular structure can be imagined as a bundle of drinking straws held together with a rubber band, with each straw representing 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 point (FSP). Imagine a sponge that has just been taken out of a bucket filled with water. As the sponge is lifted from the bucket, water comes out of the pores. When the sponge is squeezed, more water comes out of the pores. The moment when no water can be squeezed out of the sponge but yet it still feels damp is analogous to the FSP. The moisture retained in the sponge is the bound water and water that has been squeezed out is the free water.



Southern yellow pine cellular makeup

Source: USDA Forest Service Agricultural Handbook

Moisture Content

Wood moisture content (MC) is the weight of water in wood as a percentage of the completely dry wood weight. During the life of a tree, its MC can exceed 200 percent, meaning the total water weight in a given volume of wood makes up two thirds or more of the total weight.

The FSP of different species of wood varies but for most common softwoods is around 28-30 percent. The MC of lumber in service is typically 7-14 percent, much lower than the FSP. Wood remains dimensionally stable above the FSP; i.e., it doesn't change in dimension with an increase or decrease of moisture as long as it remains above the FSP at all times. This is because the water being absorbed or released is largely free water, not bound water. Once the moisture content drops below the FSP (i.e., bound water is being removed), the wood starts to change dimensionally. Since water is now being released from cell walls, both the walls and surrounding structure shrink, causing the overall cross-section of wood to shrink. For structural wood members, the MC of the wood is reduced after milling, either by air or kiln drying.

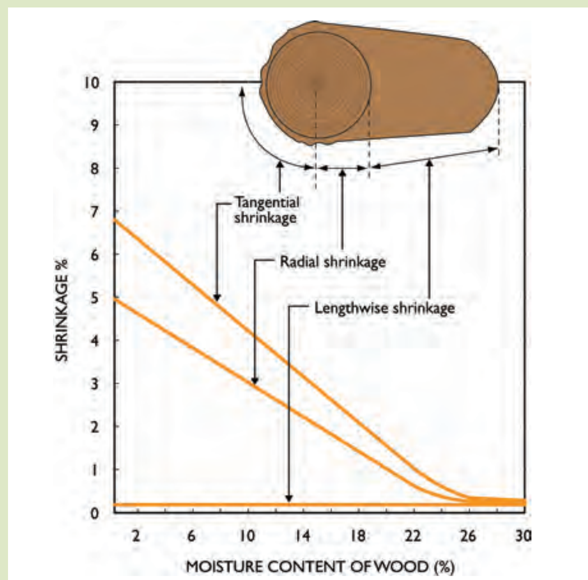
As a side note, moisture absorption has the opposite effect—expansion. As the MC of a piece of wood increases (up to the point that it reaches its FSP), it will expand in cross-section based on the same principles (increase of bound water).

While wood shrinkage is noticeable in both cross-section dimensions (width and depth), the two are typically not equal. Wood shrinks most in the direction tangential to the growth rings, and about half as much in the radial direction (see Figure 1). Table 13-5 of the *Wood Handbook*[1] published by the USDA Forest Products Laboratory provides shrinkage values for a number of softwood species (see Figure 6).

Wood shrinkage can be calculated using exact grain orientation and species-dependent shrinkage coefficients. However, it is impossible to predict grain orientation (tangential, radial or a combination) of members such as wall plates and floor joists. Due to this, it is either assumed that both radial and tangential grain orientation will be present and the amount of shrinkage will be an average of the two or the worst case of all tangential grain orientation is used.

For most structural applications, a simplified method is considered sufficiently accurate. The common approximation is that wood shrinks 1 percent in the cross-sectional dimension for every 4 percent MC change from 0-30 percent.[2] This translates to a dimensional change of 0.0025 inches per inch of cross-sectional dimension for every 1 percent change in MC. An example calculation using this technique is included in the section Calculating Shrinkage beginning on page 5.

FIGURE 1:
Moisture content-shrinkage curves



Source: RDH Building Science Inc.

In wood-frame construction, the three variables influencing the magnitude of shrinkage are:

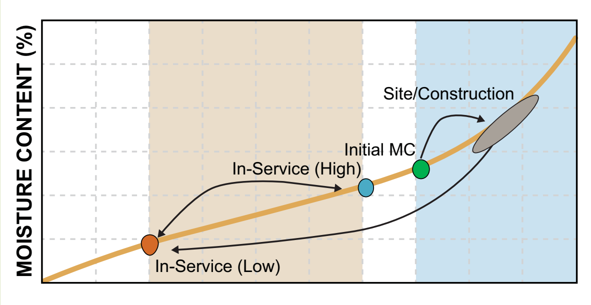
1. Installed MC
2. In-service MC or equilibrium moisture content (EMC)
3. Cumulative thickness of cross-grain wood elements

Initial MC, or MC at the time of manufacture, is typically specified on a project's structural drawings. In many parts of the country, the specification would read "a maximum MC of 19 percent." In order to achieve this, lumber is generally kiln dried. Although there are regional variations, less commonly used green lumber (which typically hasn't been kiln dried and has a MC above 19 percent), surface dried lumber or KD-15 (i.e., kiln dried lumber with a maximum MC of 15 percent at time of manufacture) may also be specified. The American Softwood Lumber Standard, PS 20-15, defines dry lumber as "lumber of less than nominal 5-inch thickness which has been seasoned or dried to a maximum moisture content of 19 percent." Engineered wood products, including wood structural panels such as plywood and oriented strand board (OSB), glued-laminated timber (glulam) and structural composite lumber (SCL), are manufactured with lower moisture contents, in the range of 2-15 percent. Engineered wood manufacturers generally provide initial moisture contents for their products.

Lumber that has been dried to a maximum MC of 19 percent at the time of manufacture does not necessarily maintain that MC over the course of its pre-construction life (distribution, transport and storage), nor does it necessarily stay at that same MC for the duration of construction. It is possible for the pre-construction or construction-phase MC of framing members to rise significantly above 19 percent if they are not protected well. Proper protection of the lumber, both when stockpiled on site and after installation, is critical to good performance. See the section *Minimizing Shrinkage* below for ways to avoid moisture accumulation during construction. Designers may also consider specifying a maximum MC at the time of installation as this is the value that will provide a more accurate shrinkage calculation. Ideally the MC should be measured at time of installation and compared to initial assumptions.

After close-in, the framing in a conditioned building eventually reaches its in-service MC, or EMC, in the range of 7-15 percent. Until that point, the wood framing is subject to inevitable shrinkage (see Figure 2). EMC is a function of temperature and relative humidity as shown in Figure 3. It is worth noting that EMC is a dynamic equilibrium, meaning it can change throughout the year with climate changes. It also varies across the country based on local climatic conditions (see Figure 4). Generally, for wood exposed to exterior (non-conditioned) atmospheric conditions, variations in EMC of 1-3 percent exist between the driest months and wettest months. The EMC of wood within a conditioned building follows the same trends but varies with interior conditions. Typically, the average annual EMC for a given project's climate is used for shrinkage estimation purposes. Several examples exist of projects that have tracked lumber moisture content fluctuations, both during construction and after occupancy.[3]

FIGURE 2:
Moisture content range



Source: RDH Building Science Inc.

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

Sources: (left) Western Wood Products Association (WWPA); (right) Northeastern Lumber Manufacturers Association (NELMA)

Grade Stamp Markings:

S-GRN: surfaced green

S-DRY: surfaced dry

KD: kiln dried

HT: heat treated

FIGURE 3:

Equilibrium moisture content – relative humidity vs. temperature

Table 4–2. Moisture content of wood in equilibrium with stated temperature and relative humidity

Temperature		Moisture content (%) at various relative humidity values																		
(°C	(°F))	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%
−1.1	(30)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
4.4	(40)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3
10.0	(50)	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3
15.6	(60)	1.3	2.5	3.6	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	20.7	24.1
21.1	(70)	1.3	2.5	3.5	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	20.5	23.9
26.7	(80)	1.3	2.4	3.5	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	20.2	23.6
32.2	(90)	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3
37.8	(100)	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9
43.3	(110)	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4
48.9	(120)	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0
54.4	(130)	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5
60.0	(140)	0.9	1.9	2.8	3.6	4.3	5.0	5.7	6.3	7.0	7.7	8.4	9.1	10.0	11.0	12.1	13.6	15.3	17.7	21.0
65.6	(150)	0.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4
71.1	(160)	0.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.3	10.3	11.4	12.7	14.4	16.7	19.9
76.7	(170)	0.7	1.5	2.3	3.0	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.2	9.0	9.9	11.0	12.3	14.0	16.2	19.3
82.2	(180)	0.7	1.4	2.1	2.8	3.5	4.1	4.7	5.3	5.9	6.5	7.1	7.8	8.6	9.5	10.5	11.8	13.5	15.7	18.7
87.8	(190)	0.6	1.3	1.9	2.6	3.2	3.8	4.4	5.0	5.5	6.1	6.8	7.5	8.2	9.1	10.1	11.4	13.0	15.1	18.1
93.3	(200)	0.5	1.1	1.7	2.4	3.0	3.5	4.1	4.6	5.2	5.8	6.4	7.1	7.8	8.7	9.7	10.9	12.5	14.6	17.5
98.9	(210)	0.5	1.0	1.6	2.1	2.7	3.2	3.8	4.3	4.9	5.4	6.0	6.7	7.4	8.3	9.2	10.4	12.0	14.0	16.9
104.4	(220)	0.4	0.9	1.4	1.9	2.4	2.9	3.4	3.9	4.5	5.0	5.6	6.3	7.0	7.8	8.8	9.9			
110.0	(230)	0.3	0.8	1.2	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.3	6.0	6.7						
115.6	(240)	0.3	0.6	0.9	1.3	1.7	2.1	2.6	3.1	3.5	4.1	4.6								
121.1	(250)	0.2	0.4	0.7	1.0	1.3	1.7	2.1	2.5	2.9										
126.7	(260)	0.2	0.3	0.5	0.7	0.9	1.1	1.4												
132.2	(270)	0.1	0.1	0.2	0.3	0.4	0.4													

Source: Wood Handbook, USDA Forest Products Laboratory

FIGURE 4:

Equilibrium moisture content for a sample of regional cities

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
IL	Chicago	14.2	13.7	13.4	12.5	12.2	12.4	12.8	13.3	13.3	12.9	14.0	14.9
IN	Indianapolis	15.1	14.6	13.8	12.8	13.0	12.8	13.9	14.5	14.2	13.7	14.8	15.7
IA	Des Moines	14.0	13.9	13.3	12.6	12.4	12.6	13.1	13.4	13.7	12.7	13.9	14.9

Source: Wood Handbook, USDA Forest Products Laboratory

Shrinkage Code Requirements

Section 2304.3.3 of the 2018 International Building Code stipulates when shrinkage consideration is required in wood-frame building design.

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 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.

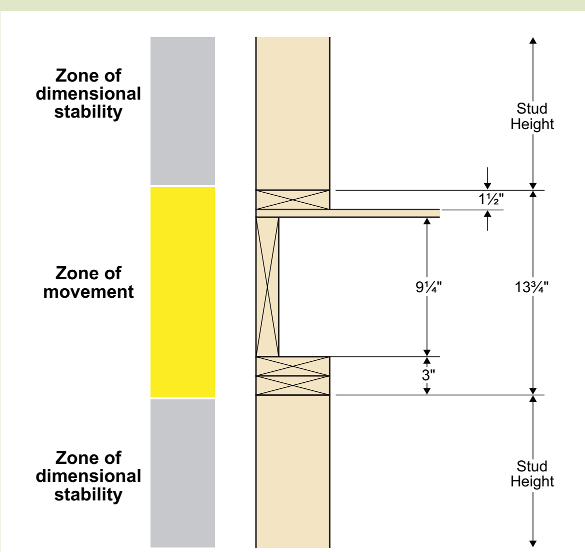
Calculating Shrinkage

Although there are several ways to calculate the amount of shrinkage in wood members, it is important to remember that, regardless of the equations used, they are simple calculations. With proper planning, the amount of wood shrinkage can be accurately predicted with relative ease.

As noted, one simple calculation is to assume a dimensional change of 0.0025 inches per inch of cross-sectional dimension for every 1 percent change in MC. For example, the anticipated shrinkage in a platform-framed, solid sawn lumber floor-to-wall detail that includes a 13.75-inch shrinkage zone (see Figure 5), starting at a MC of 19 percent with an EMC of 12 percent, would be:

Shrinkage = (0.0025)(13.75")(12-19) = - 0.24"

FIGURE 5:
Shrinkage zone in platform-framed detail



Note that the shrinkage is shown as a negative number since it is a loss in cross-section size. Although the difference in shrinkage between common softwood species is minimal, this can be taken into account when running shrinkage calculations. Figure 6 from the *Wood Handbook* shows dimensional change coefficients for a number of softwood species.

FIGURE 6:
Softwood species-specific shrinkage coefficients

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
Cedar, incense	0.00112	0.00180
Cedar, northern white-[b]	0.00101	0.00229
Cedar, Port-Orford-	0.00158	0.00241
Cedar, western red[b]	0.00111	0.00234
Douglas-fir, Coast-type	0.00165	0.00267
Douglas-fir, Interior north	0.00130	0.00241
Douglas-fir, Interior west	0.00165	0.00263
Fir, balsam	0.00099	0.00241
Fir, California red	0.00155	0.00278
Fir, noble	0.00148	0.00293
Fir, Pacific silver	0.00151	0.00327
Fir, subalpine	0.00088	0.00259
Fir, grand	0.00112	0.00245
Fir, white	0.00112	0.00245
Pine, eastern white	0.00071	0.00212
Pine, jack	0.00126	0.00230
Pine, loblolly	0.00165	0.00259
Pine, pond	0.00165	0.00259
Pine, lodgepole	0.00148	0.00234
Pine, Jeffrey	0.00148	0.00234
Pine, longleaf	0.00176	0.00263
Pine, ponderosa	0.00133	0.00216
Pine, red	0.00130	0.00252
Pine, shortleaf	0.00158	0.00271
Pine, slash	0.00187	0.00267
Pine, sugar	0.00099	0.00194
Pine, Virginia	0.00144	0.00252
Pine, western white	0.00141	0.00259
Redwood, old-growth[b]	0.00120	0.00205
Redwood, second-growth[b]	0.00101	0.00229
Spruce, black	0.00141	0.00237
Spruce, Engelmann	0.00130	0.00248

Source: Wood Handbook, USDA Forest Products Laboratory

The equation for wood shrinkage utilizing these coefficients is as follows:

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

Where:

S = Shrinkage

C = Dimensional change coefficient (from the *Wood Handbook*; conservatively, the worst case of C_T is typically used)

D_i = Cross-sectional dimension of wood subject to shrinkage (shrinkage zone)

M_F = Final wood MC

M_i = Initial wood MC

Using the example above, for a longleaf pine (southern pine) member, C_T = 0.00263 and shrinkage is:

S = (0.00263)(13.75")(12-19) = - 0.25"

The result when accounting for the species-specific coefficient is similar to the simplified calculation above. Several free shrinkage calculators can also be found online.

When utilizing other types of floor joists such as I-Joists and parallel chord trusses, a degree of engineering judgement is required to determine what to include in the shrinkage zone. For example, floor sheathing is often manufactured with a low moisture content that could be near or even below the EMC. The same could be true for I-Joists. There is also a possibility that these materials slightly expand as they take on moisture during construction, only to shrink again after the building is closed in. Although the final determination should take into account how well the framing materials are protected from the weather during construction, some engineers choose not to include these members in the shrinkage zone—i.e., they expect no shrinkage contribution from them. For parallel chord trusses in a platform-framed condition, only the top and bottom chords are typically included in the shrinkage zone. This is due to the fact that a vertically-oriented member usually exists at the end of the truss, separating the top and bottom chords, and no longitudinal shrinkage is assumed in this member.

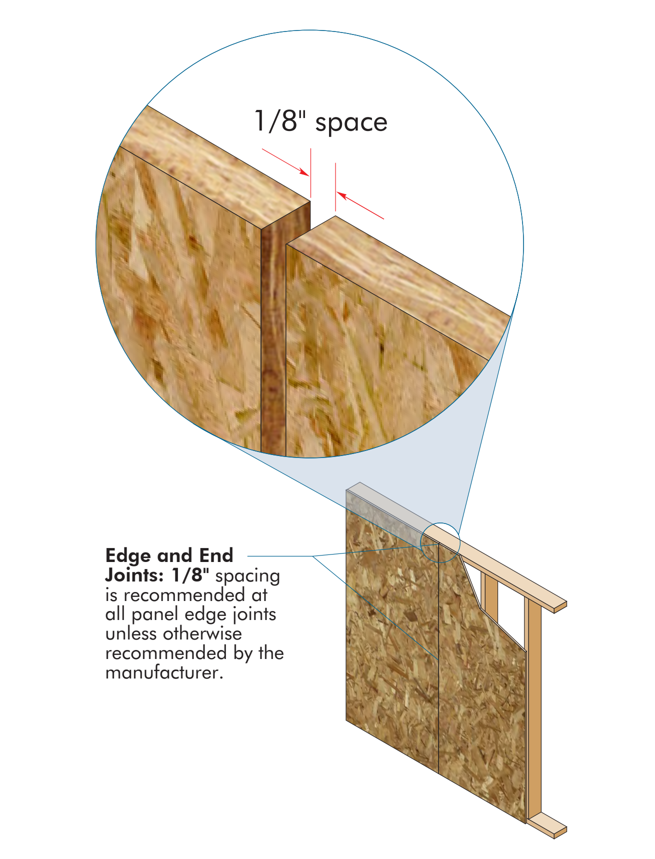
Accommodating Expansion of Wood Products

Although this paper is dedicated to accommodating shrinkage of wood products due to loss of moisture, wood products also have the ability to increase in moisture content and expand in cross-section. This typically occurs during construction as the wood framing may be completed several months before building enclosure systems are installed and made functional. Under these temporary moisture increase conditions, it is important to consider the potential for temporary expansion of wood framing products, particularly panel products such as wall, floor and roof sheathing which may be installed to cover a large expanse in the same plane (e.g., large floor plate or wall elevation).

In order to account for this, APA – The Engineered Wood Association recommends a 1/8-inch space between sheathing panel edges and end joints. If the wood structural panels are tightly butted, there is no room for expansion and buckling can occur. For more information, see the APA publications, M300S – *Builder Tip: Prevent Buckling with Proper Spacing* and U425 – *Technical Note: Temporary Expansion Joints for Large Buildings*.

In addition to consideration of expansion of panel products, mass timber floor and roof decking systems such as nail laminated timber (NLT), glued-laminated timber (sometimes known as GLT in panel applications) and tongue and groove decking also require expansion considerations. These mass timber decking systems utilize solid timber panels composed of solid sawn lumber members stacked horizontally. Knowing that wood increases in its cross-sectional dimensions with increases in MC, it is important to detail gaps between plies or panels to allow expansion to occur during construction without adversely affecting finishes and plumbness of supporting walls and columns.

FIGURE 7:
Example of edge and end joints



Source: APA – The Engineered Wood Association

Rate of Shrinkage

Although it would be convenient to calculate how long it would take a building's wood framing to reach its EMC (and therefore experience its maximum anticipated shrinkage), there are many variables and such a prediction isn't usually feasible. Some of the variables include:

- How well the wood is protected from moisture during construction (both in material stockpiles and once erected)
- Species (or combination of species)
- Time of year the building is constructed
- Regional climatic conditions
- How soon after framing installation the HVAC systems are installed and activated
- How soon after framing installation interior finishes and exterior envelope systems are installed

The wood framing in a building may partially dry during construction (at a relatively slow rate) and then finish drying (at a faster rate) once the building is enclosed and HVAC services are activated. Alternatively, the framing could stay at a relatively high moisture content throughout construction and only begin drying once the building is complete or close to it. Ideally, the majority of a building's shrinkage would occur prior to installation of finishes as this minimizes the effect on those finishes.

Minimizing Shrinkage

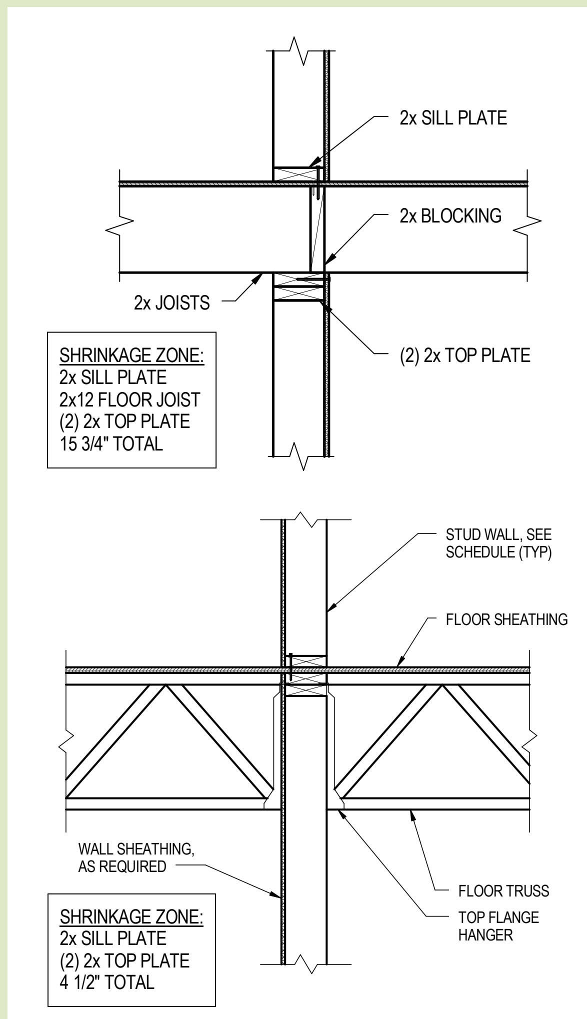
Of the significant variables affecting shrinkage, EMC is the only one largely out of the designer's control. It is heavily influenced by the building's conditioning, including temperature, relative humidity and local climatic conditions. However, a project's design and construction team can influence the two remaining variables—installed moisture content and combined thickness of the wood in cross-grain orientation.

While the initial MC of wood can be specified by the design team, it is subject to change before, during and after construction. The amount of change depends to a large degree on the protective measures taken by the contractor. To minimize moisture accumulation on site:

1. Avoid storing material where it is exposed to rain or standing water.
2. Keep unused framing materials covered.
3. Inspect building enclosure layers such as weather-resistive barriers for proper installation.
4. "Dry-in" the structure as quickly as possible.
5. Immediately remove any standing water from floor framing after rain showers.

Because cross-grain wood members contribute to shrinkage, reducing the total thickness of cross-grain wood members in the vertical load path is one way to minimize shrinkage and its effects. Traditionally, wood-frame construction has been platform-frame, where floor framing and rim or band joists bear on the top plates of supporting walls. However, switching to a semi-balloon-frame system, where only the floor sheathing bears on the lower walls and floor joists are hung from the walls, can significantly reduce per-floor and cumulative building shrinkage. Figure 8 illustrates the difference. The upper platform detail has a shrinkage zone of 15.75 inches per floor, resulting in shrinkage per floor of 0.28 inches, or approximately 1.4 inches for a five-story building. The lower semi-balloon frame detail has a shrinkage zone of 4.5 inches per floor, resulting in shrinkage per floor of 0.08 inches, or approximately 0.4 inches for a five-story building. These values are based on an initial MC of 19 percent and an EMC of 12 percent.

FIGURE 8:
Typical platform-framed detail (top) and semi-balloon-frame detail (bottom)



Source: Schaefer

In modern multi-story heavy or mass timber buildings where column and beam structural framing systems are used, detailing the column-to-floor deck and beam connections should include shrinkage consideration.

One option consists of an upper column bearing directly on the mass timber deck, which bears directly on the support beam and lower column. This is the equivalent of the platform-frame detail described above; because the shrinkage zone per floor is relatively deep, shrinkage per floor is at the higher end of the expected range. In a multi-story building, this per floor shrinkage accumulates and can exceed 1 inch overall.

An alternate detailing strategy that minimizes accumulated shrinkage involves column-to-beam connections that isolate the upper column from bearing on the decking and support beam. Detailing strategies involve either notching the column to allow the beam to bear on a shelf or creating a vertical load path where columns above bear directly on columns below.

Alternatively, columns can be single-story with steel connectors aligned with each floor level, which isolates the columns from bearing on the floor deck and beams. The image below illustrates an example of this condition.

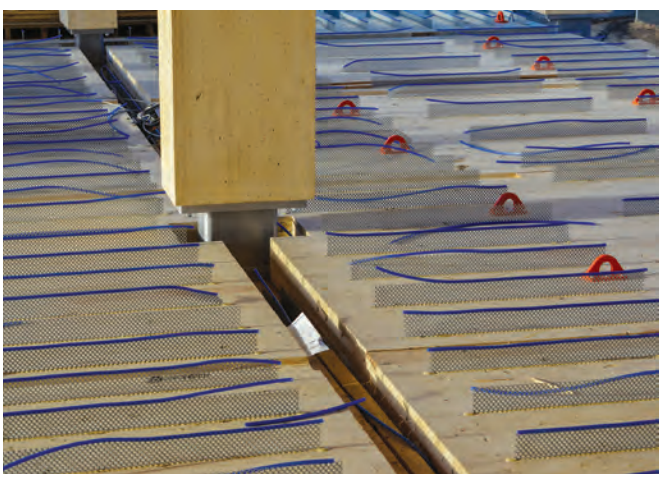
Differential Movement

When considering how and when wood framing is likely to shrink, it is also important to consider how wood interacts with other building materials and building components. Other materials may exhibit significantly different shrinkage and swelling characteristics. For instance, some materials:

1. Expand due to moisture or thermal changes (brick veneer)
2. Do not shrink due to moisture change but may move with thermal changes (steel framing, and steel/cast iron/PVC piping)
3. Shrink much less (concrete masonry and cementitious veneers)

Brick Veneer and Openings

Openings in wood-frame buildings with brick veneer or other similar cladding materials require special attention to detail. Not only do wood-frame buildings shrink, veneers such as brick can expand, further exaggerating the differential movement. At openings, items such as head and sill flashing and jamb sealing require unique consideration to accommodate this movement. Without proper detailing and installation, issues with drainage and opening operations (i.e., window won't open) can occur.



Column to column isolation detail at mass timber floor deck
Photo: Alex Schreyer, University of Massachusetts

Veneer sill has been installed too close to the underside of the window
Photo: Schaefer

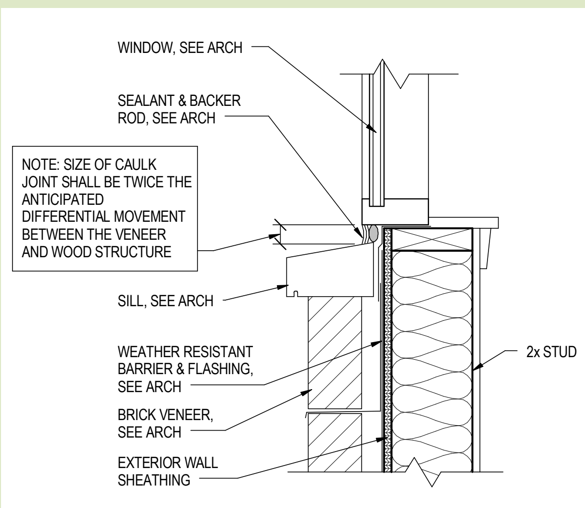
Settlement of Multi-Story Wood Structures:

Although shrinkage is the main cause of multi-story wood-frame building movement, small amounts of movement can also be caused by small gaps between studs and plates, studs and headers and other similar framing conditions. These gaps occur during construction for reasons that include uneven member end cuts, lack of fully engaged fasteners connecting one member to adjacent members, twisting or warping members, etc. However, they tend to close as the building is constructed and additional dead loads are applied prior to installation of finishes and building occupancy. Some engineers include this additional movement in total building shrinkage calculations (1/8-inch per floor is a common assumption for this settlement amount) while others choose to ignore it.

Opening Sill

One detailing strategy to address differential movement at opening sills is to provide a gap between the top of the veneer sill and underside of the wood-frame opening extension/sill. The gap should be appropriately sized to accommodate the anticipated accumulated differential movement for each level. This gap is often filled with a compressible material that is weather resistant and visible in the final condition from the outside of the building. It is important to note that these filler materials can often only compress to half their original thickness, meaning the gap height should be twice the anticipated accumulated differential movement. See Figure 9 for an example of this detail. If the full height of the veneer is supported on the ground level, the gap will need to be larger on each consecutive higher level as differential movement accumulates. Alternatively, the same size gap can be specified for all levels based on the worst case differential at the top level. However, if this option is chosen, the gaps will appear different aesthetically as the upper levels will experience more cumulative shrinkage (less of the gap will be visible) while the lower floors will experience less cumulative shrinkage (more of the gap will be visible). If the veneer is vertically supported at intermediate levels, the accumulated differential shrinkage is reduced based on the distance from the support location to the detail under consideration.

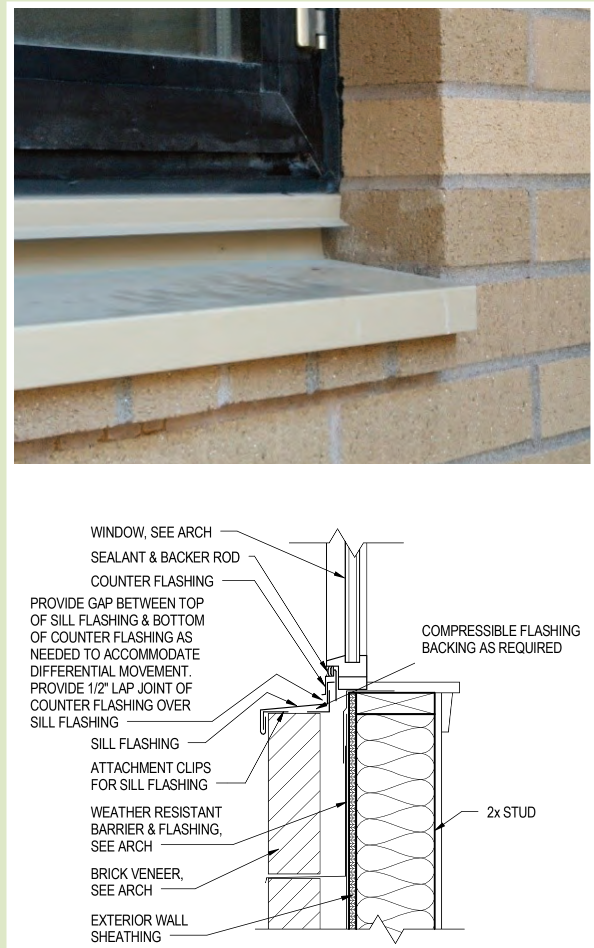
FIGURE 9:
Example window sill detail with gap and compressible filler between veneer and window



Source: Schaefer

Another detailing strategy at opening sills is to provide a double flashing condition with a vertical gap between the two flashing sections to allow vertical differential movement. This allows the two pieces of flashing to move independently while still overlapping and maintaining proper flashing function. See Figure 10 for an example of this detail.

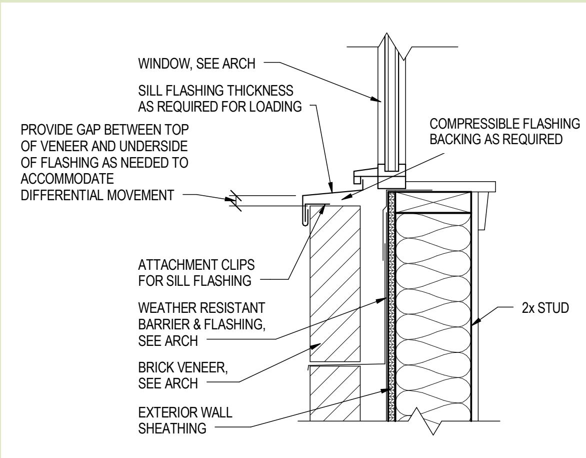
FIGURE 10:
Example window sill detail with double, lapped flashing



Sources: (top) RDH Building Science Inc.; (bottom) Schaefer

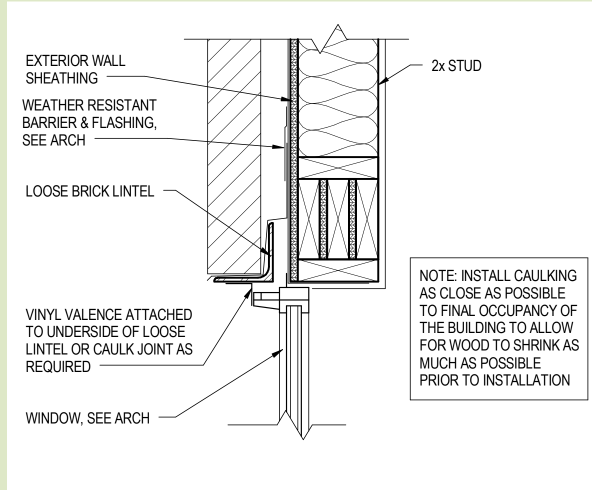
A third detailing strategy is to extend the window sill flashing beyond the veneer sill cap. Under this condition, a gap is provided between the underside of the flashing and top of the veneer cap to allow vertical movement to occur. The flashing is extended down the exterior face of the veneer cap such that coverage occurs at all times regardless of whether any building shrinkage has occurred. See Figure 11 for an example of this detail.

FIGURE 11:
Example window sill detail with flashing extending over face of the veneer cap



Source: Schaefer

FIGURE 12:
Example window head detail



Source: Schaefer

Opening Head

Although sills are more commonly discussed, the heads of openings also require unique attention to detail. As the wood-frame wall shrinks, the header shrinks down with the wall, whereas the veneer may expand upward or maintain its location. This can result in potential failure of the sealed joint between the head of the window and underside of the veneer support.

A common detail at this condition is to utilize a flexible sealant such as caulk. With this solution, care must be taken as the caulk may be prone to pulling apart if the differential movement is not accounted for in the detail used or caulk specified (e.g., the caulk joint can be designed to expand). Also, consider installing the caulk as late as possible in the construction schedule. The closer the building is to its EMC, the less differential movement. That said, delaying installation may not always be possible (or desirable) as it can prevent the ability to weather-proof the building. The building owner should also be notified that periodic inspections and potential re-caulking of these joints may be necessary.

Opening Jamb

Opening jambs can experience similar issues with regard to differential wood-frame and veneer movement. A common detail at jambs is to leave a small gap between the window frame and veneer, which is eventually filled with a flexible, weather-resistant sealant such as caulk. However, as differential movement occurs, failure of the caulk can occur, appearing in the form of shear/diagonal cracks in the caulk. This is because the caulk has bonded to both the veneer and window and, as the two move differentially, shear failure of the caulk occurs. The images to the right illustrate examples of this condition.

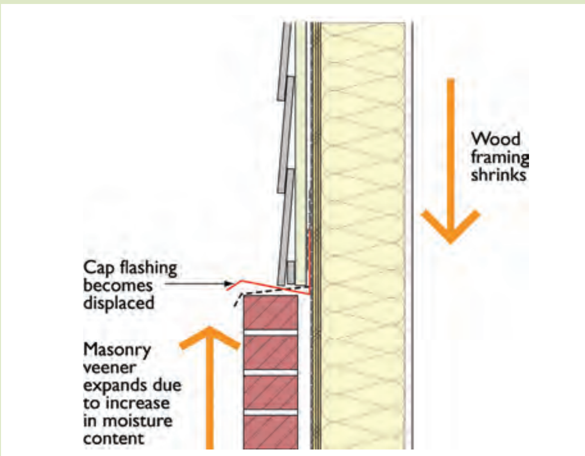
Window jamb and head caulk joint issues
Photos: Schaefer

To avoid this issue, the caulk joint should be designed for the potential differential movement—i.e., consider where accumulated differential movement is highest, which is often at the uppermost story, and design for this scenario. As with the opening heads, consider delaying the caulk joint installation and alert the building owner that periodic inspection and potential re-caulking may be necessary.

Cladding to Brick Veneer Transition

In addition to differential movement considerations at openings, some buildings that include brick veneer transition to a different cladding system at some point in the exterior elevation. A flashing detail at this cladding transition is common. Accommodating differential movement in this flashing detail is important in order to avoid collecting water in this flashing step rather than draining it as shown in Figure 13.

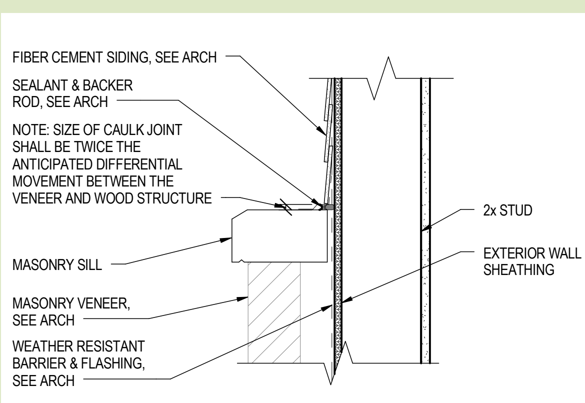
FIGURE 13:
Veneer transition issues due to lack of shrinkage accommodation



Source: RDH Building Science Inc.

Figure 14 shows an example of how this differential can be included in such a flashing detail. The concept is very similar to those discussed at opening sills. A gap is left between the top of the brick veneer cap and bottom of the upper cladding system. Flashing is provided at the transition and the gap is filled with a compressible filler. The gap and filler are sized to match the anticipated differential movement at that elevation, accounting for the ability of the filler to compress.

FIGURE 14:
Example cladding to brick veneer transition detail



Source: Schaefer

For more information, see the WoodWorks publication, *Options for Brick Veneer on Mid-Rise Wood-Frame Buildings.*

Other Architectural Finishes

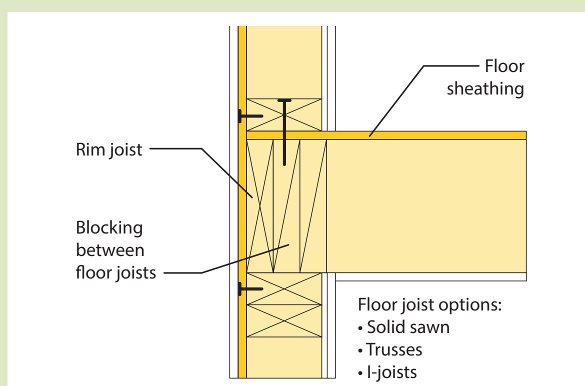
Interior finishes such as gypsum wall board are typically installed on a floor-to-floor basis and therefore only need to accommodate isolated shrinkage per floor. This isolated shrinkage is typically handled by small gaps at the top and base of the gypsum wall covering, where it meets the floor and ceiling framing. However, at some areas of a multi-story building, such as shafts and atriums, where multiple stories of wall finish are continuously installed directly to the wood framing, shrinkage effects should be considered. One approach is to install expansion joints between each gypsum wall board panel to allow the total building shrinkage to be accommodated over the height of the shaft, atrium, etc. This detailing strategy may require the use of compressible fire-safing materials in expansion joints.

Wood-frame shaft wall with continuous gypsum wall board

Masonry Walls

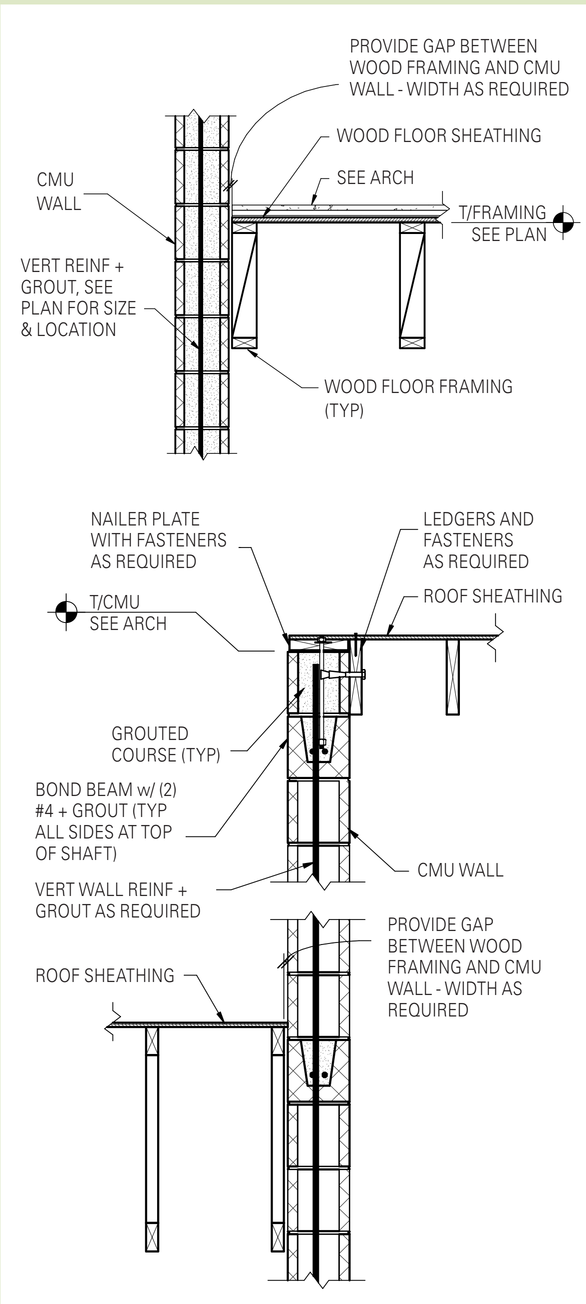
It is fairly common for light wood-frame commercial and multi-family buildings to include shaft walls made from other materials, notably masonry. However, many design professionals are shifting to the use of wood-frame shaft walls in order to realize benefits such as material compatibility (for differential movement as well as seismic force resistance) and cost and schedule savings. For a discussion of the design and detailing of wood-frame shaft walls, see the WoodWorks publication, *Shaft Wall Solutions for Wood-Frame Buildings*.

FIGURE 15:
Example wood-frame shaft wall detail



For multiple reasons, including differential material movement and seismic compatibility issues, a best practice detail when utilizing masonry shaft walls in wood-frame buildings is to provide isolation between the two materials. This is typically accomplished in the form of a small gap. When using this detail, illustrated in Figure 16, the floor/roof framing and diaphragm are not tied to the shaft wall, and wood beams or bearing walls are installed just inboard of the masonry walls to support the ends of the wood framing members.

FIGURE 16:
Example details at masonry shaft to wood-frame floor or roof with gap

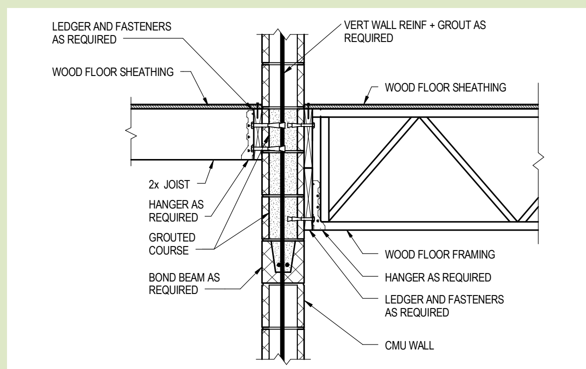


Source: Schaefer

The one exception to this detail is to directly connect the wood framing to the masonry walls only at the door threshold in order to avoid a small difference in floor elevation. This requires attention to detail and the recognition that a small amount of floor slope may occur at this location because the floor is attached to both the masonry wall and adjacent wood-frame walls or support beams. See Figure 17 for an example detail of this condition. Alternatively, the wood floor can be kept independent of the masonry shaft walls and a plate provided across the threshold to cover the gap and account for small amounts of differential movement.

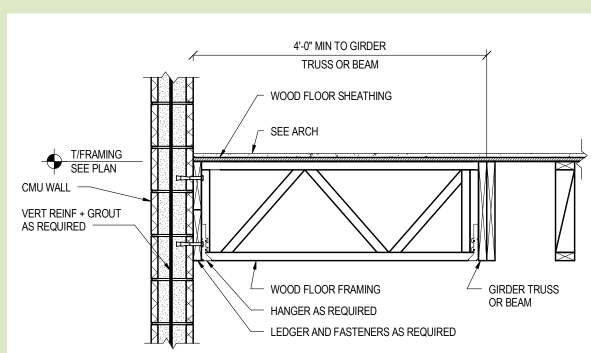
Alternatively, some engineers choose to attach the wood floor or roof system to the masonry shaft walls not only at the door thresholds but all around the shaft. Under this condition, in order to avoid differential floor elevations depending on whether the floor is spanning parallel or perpendicular to the masonry, a detail may include the integration of support beams/girder trusses parallel with the shaft wall, allowing all framing members around the perimeter of the shaft to span to and be attached to the wall. An example of this condition is shown in Figure 18.

FIGURE 17:
Example detail at masonry shaft to wood frame floor or roof with direct connection



Source: Schaefer

FIGURE 18:
Example detail at masonry shaft to wood-frame floor or roof with direct connection where framing typically spans parallel to shaft wall



Source: Schaefer

Mechanical/Electrical Plumbing (MEP)

It is common for MEP items such as water lines, waste drain lines, electrical conduit, mechanical ducts, sprinkler lines, etc. to start with a supply source at the base or roof of the structure and extend vertically throughout, with horizontal runs splicing off the main vertical runs. However, as with differential movement between wood framing and brick veneer or masonry walls, the ducts/conduit/pipe materials used in MEP seldom shrink. Rather, depending on the temperature during installation, most have a tendency to increase slightly in length. The result is a potential situation where the wood-frame building has shrunk, vertical MEP lines have expanded up, and horizontal tees coming off the vertical lines and running through wood-frame partition walls have reduced in slope. See the images on this page for examples of this condition.

One approach that can significantly reduce the effects of wood shrinkage on MEP elements is to wait as long as possible to install vertical runs after completion of framing.

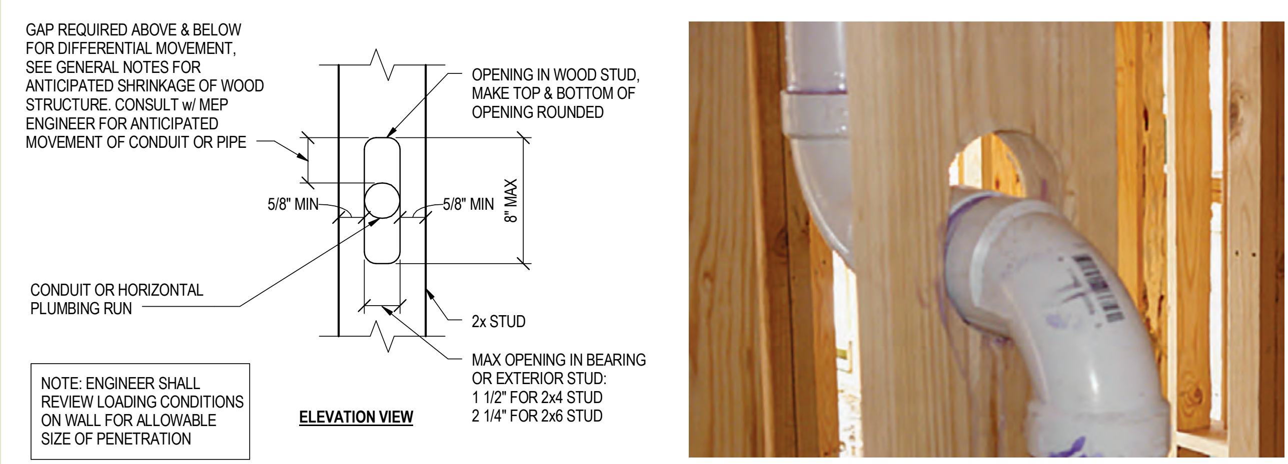
Plumbing vertical line with horizontal tees through wood stud partition
Photo: Armchair Builder

This allows the framing to come closer to its EMC and allows more dead loading of the structure (which helps close small gaps) prior to MEP installation.

Plumbing pipe failure due to lack of shrinkage accommodation in adjoining wood stud hole

Specifying the cumulative shrinkage that needs to be accounted for on each floor level in the contract documents or on the drawings will let the MEP subcontractors know to make appropriate accommodations in their components and/or connections. For MEP items running through stud walls, one method of addressing differential movement is to oversize the holes in studs where pipes/conduit run horizontally. Holes should be vertically slotted so their width is no more than necessary but their height allows up to the anticipated building shrinkage at each level without causing the pipe/conduit to come in contact with the top of the hole. The project's structural engineer should be consulted on allowable hole sizes, especially if the wall is load bearing. Figure 19 illustrates options for this solution.

FIGURE 19:
Example detail and photo showing the hole in a wood stud added to accommodate shrinkage around plumbing



Sources: (left) Schaefer; (right) Louisiana-Pacific Corporation

An alternative would be to install an expansion or slip joint in the vertical run of pipes/conduits/ducts. These connections permit vertical movement in the MEP items while allowing them to remain functional and avoid issues with wood building shrinkage around them. As the horizontal MEP items move down with the framing as it shrinks, this vertical movement is accommodated by the expansion/slip joint connection. The connections are located strategically at various positions in the vertical MEP runs, and sized to reflect the total anticipated accumulated wood shrinkage in the building. Examples of expansion/slip connections are shown below.

Photos (left to right): Copper pipe expansion joint (Metraflex), PVC expansion joint (IPEX USA LLC), PVC expansion joint (Fernco)

Structural Connections

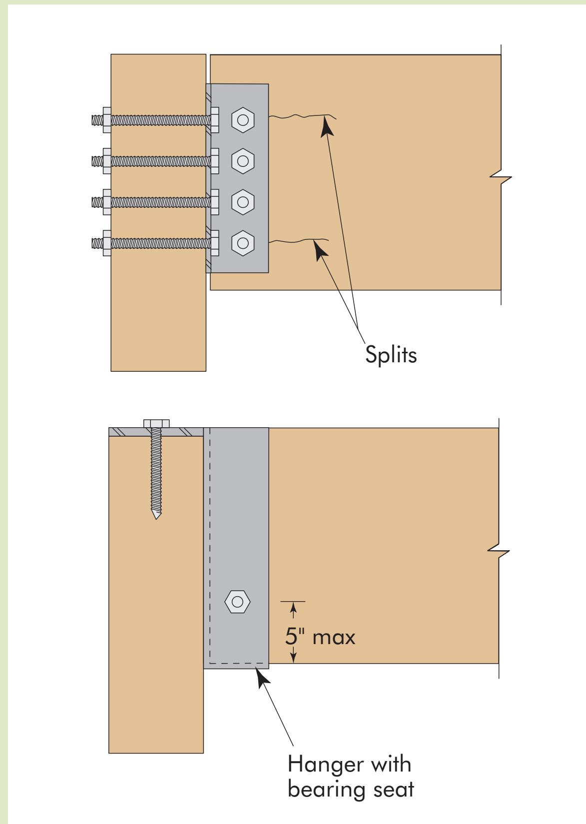
Shrinkage in multi-story wood-frame structures can impact structural framing members, especially connections. This section will address two different connection considerations: heavy timber members and light-frame members.

Beam Connections

Although not specific to multi-story buildings, shrinkage in connections of beams and heavy timber truss chords including solid sawn, glulam and SCL should be considered and detailed appropriately. As noted, shrinkage occurs in the cross-grain dimension of wood members. In large cross-sections such as solid sawn or glulam beams and columns, it is important to know how shrinkage will occur and detail the connection to avoid restraint of the shrinkage. Figure 20 illustrates the effects of a connection with larger diameter fasteners installed near both the top and bottom of a wood member. Horizontal shear splits/cracks can form along the member if the shrinkage is restrained between rows of fasteners. In order to avoid this, recommended details utilize fasteners grouped together only near the bottom of the connection or using only one row of fasteners along the grain of the member. For more information on recommended connection details, see APA's document T300, *Glulam Connection Details,* and the American Wood Council (AWC) publication WDC 5 – *Heavy Timber Construction.*

In addition to detailing to avoid shrinkage restraint at connections, Table 12.5.1F of AWC's 2015 National Design Specification® (NDS®) for Wood Construction specifies maximum allowable distances between outermost fasteners in glulam members.

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

Lateral and Uplift Connections

For light-frame, multi-story buildings, consideration should be given to shrinkage effects on uplift and overturning restraint systems. Connections such as shear wall end holdowns and uplift floor-to-floor straps rely on being installed tight and remaining in this condition in order to resist these overturning and uplift tension forces as soon as the loads are applied. However, as shrinkage occurs in wood-frame buildings, slack in these systems can be introduced, creating the potential for building movement prior to beginning tension restraint engagement. See the image below for an example of this condition. If issues such as this exist, reengagement of the tension systems is required, either through re-tightening the nuts on threaded rods (and periodically checking that they remain tight) or installation of new tension systems which can accommodate shrinkage as discussed below.

Gap between wood plate and tension-threaded rod without shrinkage compensation
Photo: Simpson Strong-Tie

There are several methods of detailing to avoid these potential issues. First, when using continuous threaded rod tie-down systems at the ends of shear walls or to resist uniform roof uplift, integrated shrinkage compensation or take-up devices can be used. Many hardware manufacturers produce variations of a similar concept—i.e., hardware incorporated with continuous threaded rods, which allows connections at each floor to move with a wood building as it shrinks while keeping the threaded rod fully engaged in tension at all times.

Threaded rod tie-down with shrinkage compensation devices
Photos: (left) Simpson Strong-Tie; (right) CLP Systems/Earthbound

For uniform roof uplift, utilizing floor-to-floor connections that have integral shrinkage take-up devices is one way to minimize issues with shrinkage. An example is shown below.

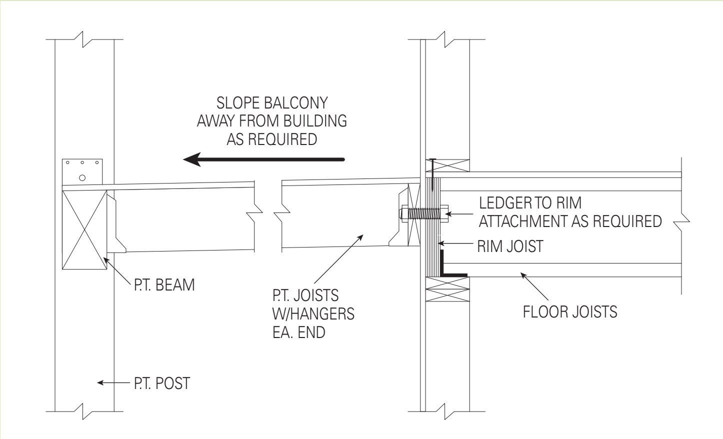
Floor-to-floor uplift connector with integral shrinkage take up device
Photo: Simpson Strong-Tie

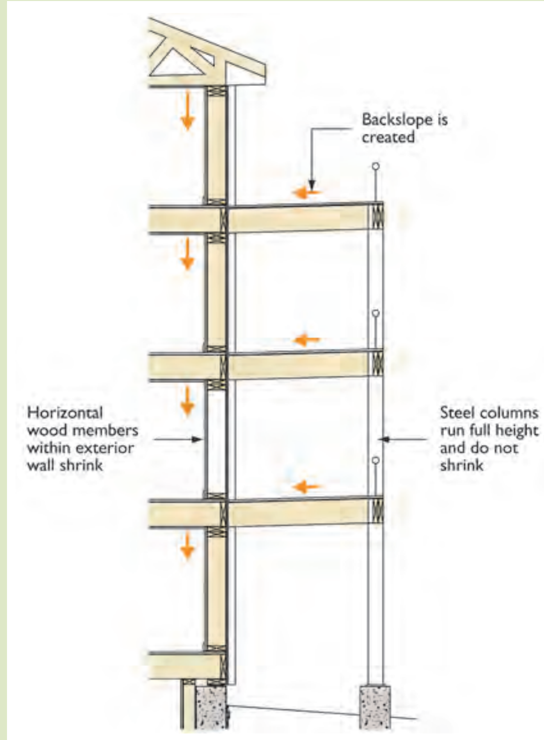
Balcony/Deck Support

Although cantilever balconies are common in mid-rise wood-frame construction, some balconies are supported on exterior columns. The potential for shrinkage must be addressed for exterior decks supported by wood-frame walls on the inner edge of the balcony and exterior walls/posts on the outer edge. When utilizing columns to support the outer edge of a balcony attached to a wood-frame building, the slope of the balcony should be taken into account. If the balcony is originally designed to slope slightly away from the building, the balcony could rotate back toward the building as shrinkage occurs in the wood framing but not the exterior balcony columns. This could result in less balcony slope than planned or, worst case, the balcony could end up with a negative slope draining water back toward the building. See Figure 21 for an example of this condition.

Solutions to this include supporting balconies on a row of columns just outboard of the exterior wall (same materials and support conditions as the columns at the balconies' outer edge), supporting all balcony edges with wood framing and ensuring that the balcony shrinkage zone at each level matches the building's, utilizing cantilever balconies, or accommodating shrinkage in the initial slope in the balconies such that they would still drain away from the building even if all anticipated building shrinkage occurs. If utilizing the option of a row of columns just outboard of the exterior wall (and potentially not attaching the balcony to the exterior wall), care should be taken to ensure that any differential elevation between the deck surface and adjacent interior floor surface complies with code requirements.

FIGURE 21:
Example balcony column support detail (left) and balcony slope issues due to lack of shrinkage accommodation (right)





Sources: (left) Multi-Story Wood-Frame Shrinkage Effects on Exterior Deck Drainage: A Case Study by Martin and Anderson, Wood Design Focus; (right) RDH Building Science Inc.

Conclusion

Shrinkage in multi-story wood-frame buildings is not a new phenomenon nor is it overly complex to address. It requires an awareness of how and why wood shrinks, close attention when selecting and specifying materials and details, proper material care on the jobsite, and installation that closely adheres to the construction drawings.

When addressing wood shrinkage, the entire design and construction team should be involved in the solution. In multi-story buildings, for example, some of the details used may differ from those traditionally seen by contractors and other design trades. Regular, on-site observations by the design team, owner's representative and third party inspectors to review shrinkage-accommodating details as installed, and to check items such as flashing gaps, sill elevation and use of appropriate shrinkage-compensating measures will help to ensure that performance matches design intent. In order to have successful building shrinkage performance, proper detailing must lead to proper installation.

Education may also be necessary for the building owner, contractor and subcontractors to understand the potential issues and how to avoid them. Once fully understood, accommodating shrinkage simply becomes another design criteria. For copies of the details in this paper, email the WoodWorks project support help desk at help@woodworks.org.

End Notes:

1. *Wood Handbook: Wood as an Engineering Material,* United States Department of Agriculture Forest Products Laboratory, 2010
2. American Softwood Lumber Standard PS 20-15
3. *Monitoring of Vertical Movement in a 5-Storey Wood Frame Building in Coastal British Columbia*, Jieying Wang and Chun Ni (2014 World Conference on Timber Engineering proceedings); *Impact of Moisture and Load on Vertical Movement of a Simulated Platform Frame Wood Structure*, Jieying Wang and Luke King, Journal of Testing and Evaluation; *Field Measurements of Moisture in Building Materials and Assemblies: Pitfalls and Error Assessment*, Donald M Onysko, Christopher Schumacher and Peter Garrahan.
4. *Multi-Story Wood-Frame Shrinkage Effects on Exterior Deck Drainage: A Case Study,* Wood Design Focus, Zeno Martin, P.E. and Eric Anderson, P.E., S.E.