



TECH NOTES

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Shrinkage Calculations for Multistory Wood Frame Construction

Lack of affordable housing is an important issue affecting all major industrialized cities. Multistory/multifamily wood frame construction offers one cost-effective solution. Wood frame construction has advantages over steel, masonry and concrete in speed of construction and material cost in buildings ranging from one to five stories in height.

How wood acclimates to its surrounding environment is an important design consideration. Wood, as a natural material, shrinks and swells with changes in moisture content. Accommodating for the effects of shrinkage of wood frame members is one of the key considerations in designing and building these structures. Proper design and construction contribute to the performance of multistory wood frame structures over time.

Moisture in Solid-Sawn Lumber

Standard moisture content designations are used to indicate the moisture content (MC) of lumber at time of manufacture. The designations are as follows:

S-GRN (Surfaced Green), HT S-GRN (Heat Treated Surfaced Green) – Over 19% MC

S-DRY (Surfaced Dry), KD (Kiln Dried), or KD HT (Kiln Dried and Heat Treated) – Maximum 19% MC

MC 15 or KD 15 – Maximum 15% MC



The moisture content designation is included in the lumber grade stamp (Figure 1).

Figure 1. A typical lumber grade stamp facsimile.

Shrinkage in Wood Products

Lumber products shrink as wood dries. Shrinkage begins once the MC of lumber drops below the Fiber Saturation Point (FSP), approximately 27-30% MC for most species. Shrinkage continues until wood reaches Equilibrium Moisture Content (EMC) of surrounding atmospheric conditions (average 8% to 12% MC for the interior of most structures across the U.S.)

The shrinkage effects must be considered for horizontal framing members (width or thickness) in wall and floor design. Wood is anisotropic, meaning the dimensional change in wood is unequal in different directions. In most softwoods, radial (across growth rings) shrinkage is approximately 4% and tangential (parallel to growth rings) is approximately 8%. Longitudinal shrinkage (parallel-to-grain) for vertical framing members is generally negligible and usually does not affect building performance (see Figure 2).

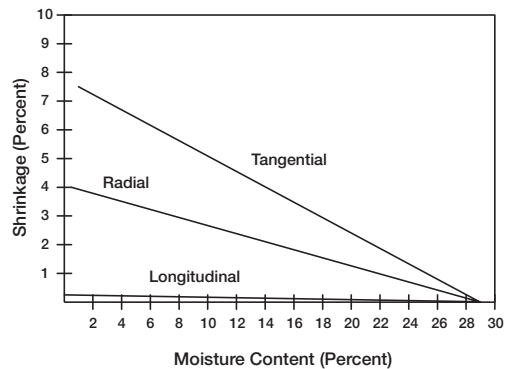


Figure 2. Average shrinkage properties

While both radial and tangential shrinkage coefficients have been determined for most commercial species, true vertical (growth rings perpendicular to wide face) or flat (growth rings

parallel to wide face) grain is rare for common lumber products. Lumber is often sold in mixed species groups and, unless specified, as mixed grain.

For Western softwood species, a shrinkage coefficient of 0.0020 per 1% change of moisture content is suggested for estimating wood shrinkage in multistory wood frame buildings. This coefficient represents the average of radial and tangential shrinkage. The coefficient is applicable for all Western softwood species except Western Cedars and Redwood. For Western Cedars, 0.0017 per 1% MC change is suggested.

The *American Softwood Lumber Standard*, PS 20, provides a general rule for calculating shrinkage in most softwood species. It states that for each four percentage points reduction in moisture content below the fiber saturation point, there is one percent corresponding shrinkage, a 0.0025 shrinkage coefficient. This 0.0025 coefficient is used for lumber agencies' reinspections of all softwood species (Note: Redwood and Western Red Cedar are assigned a coefficient of 0.00175).

Indoor and Outdoor EMC

Table 1 lists average outdoor and indoor EMC for selected U.S. locations. Tabulated values may be used in approximating EMC for shrinkage calculations. Outdoor exposure assumes lumber is off the ground and sheltered (covered) from rain and direct sunlight. Individual pieces may vary in EMC.

Shrinkage in Wood Buildings

The cumulative effect of wood shrinkage can be accommodated readily using normal construction practices in most one and two-story buildings, even when unseasoned lumber is used. Consideration for shrinkage is important for wood frame buildings more than three stories to avoid problems such as drywall cracks and stressed plumbing systems.

Code Requirements of Shrinkage Analysis for Multistory Wood Frame – The Uniform Building Code (UBC) and International Building Code (IBC) states that consideration shall be given to the possible effect of cross-grain dimensional changes considered vertically which may occur in lumber fabricated in a green condition (Figure 3). See 1997 UBC Section 2304.7 and 2003 IBC Section 2303.7.

Further, 1997 UBC Section 2308 Wall Framing and 2003 IBC Section 2304.3.3, states wood studs shall not support more than two floors and a roof, unless an analysis satisfactory to the building official shows that shrinkage of wood framing does not have adverse effects on the structure, plumbing, electrical or mechanical systems, or other equipment installed therein due to excessive shrinkage or differential movements caused by shrinkage.

Calculating Shrinkage of Wood Buildings – Shrinkage calculations are not complex. Designers often overestimate shrinkage making it difficult to detail for differential movements.

Table 1. Average Outdoor and Indoor EMC

Location	Average Outdoor EMC (%)	Average Indoor EMC (%)
Los Angeles, CA	10	9
San Diego, CA	12	10
Twentynine Palms, CA	6	6
San Francisco Bay Area	13	9
Sacramento Valley (CA)	11	8
N. Coast Red. (CA)	14	9
Sierra Nevada (CA)	11	7
San Joaquin Valley (CA)	11	8
Phoenix/Tucson, AZ	7	6
Flagstaff, AZ	10	7
Denver/Co.Springs, CO	10	8
Missoula, MT	13	7
Salt Lake City, UT	11	7
Boise, ID	11	7
Reno, NV	10	7
Las Vegas, NV	7	6
Portland/Salem, OR	14	8
Eugene, OR	15	8
Seattle/Tacoma, WA	14	8
Spokane, WA	13	8
Chicago, IL	13	8
Kansas City/St. Louis, MO	13	8
Dallas-Ft. Worth, TX	13	8
Austin, TX	13	8
Houston, TX	14	11

For EMC of additional outdoor locations, refer to:

- 1) Simpson, William T. 1998. *Equilibrium Moisture Content of Wood in Outdoor Locations in the United States and Worldwide. Res. Note FPL-RN-0268. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. <http://www.fpl.fs.fed.us/documnts/fplrn/fplrn268.pdf>*
- 2) Smith, Harvey H.; Ellwood, Eric L.; Erickson, Robert W. 1959. *Survey of the Moisture Content of Wood in use in California. No. 16. Berkeley, CA: University of California, Forest Products Laboratory.*
- 3) National Weather Service at <http://www.nws.noaa.gov>

Total shrinkage in conventional framed buildings can be calculated by summing the estimated shrinkage of horizontal lumber members in walls and floors, such as wall plates and floor joists.

Shrinkage of a softwood lumber member can be estimated using the following equation:

$$S = D \times M \times C$$

Where S = Shrinkage, inches
D = Dimension, inches
M = Change in moisture content, percent
C = Shrinkage coefficient, 0.0020 for Western softwood species (including Redwood) except 0.0017 for Western Red Cedar.

Shrinkage Example: A four-story building framed with Douglas Fir, S-DRY, 2x10 lumber floor joists and 2x6 wall plates, with an EMC of 10% in use.

Cumulative Size and Number of Horizontal Members Used: 3 – 2x10 floor joists, 12 – 2x6 sills and wall plates shown in *Figure 3*.

$$D = (3 \times 9.25") + (12 \times 1.5") = 45.75"$$

$$M = 19\% \text{ MC (S-DRY)} - 10\% \text{ EMC} = 9\% \text{ MC}$$

$$C = 0.0020$$

$$S = 0.0020 \times 9 \times 45.75" = 0.824" \text{ total shrinkage estimate}$$

from the first-story sill plate to the last top plate on the third-story wall.

The 19% MC (S-DRY) in the above calculation for M is conservative given the average MC for S-DRY lumber at the time of manufacture is around 15%.

If S-GRN lumber is used instead of S-DRY, the estimated shrinkage for all plates, sills and joists is 1.796 inches (0.0020 x 19 x 47.26).

Calculating longitudinal shrinkage of wall studs is generally neglected because it is relatively small. It can be calculated and added to the total shrinkage estimate above using the same procedures but using a shrinkage coefficient of 0.00005.

For the above example, assuming S-DRY, KD or KD HT lumber studs 92.25 inches in length at each story; additional shrinkage for all vertical studs (4 stories) is 0.166 inches (0.00005 x 9 x 4 x 92.25).

The total horizontal and vertical member shrinkage is 0.824" + 0.166" = 0.990".

Note: Design plumbing, mechanical and finishing for relative dimensional change, not total shrinkage. Relative dimensional change is the calculated shrinkage from point to point such as the ceiling-to-floor section between the first and second floors, etc. Also, a lower MC percentage should be used in point-to-point shrinkage calculations at time of plumbing, mechanical and finishing work, given lumber is likely to have dried and shrunk somewhat since the initial framing stage.

Table 2 lists average lumber shrinkage in inches of specified sizes for Western softwood species. For example, on average, the 6-inch "narrow face" of a S-GRN 6x10 timber shrinks 0.209 inch and the 10-inch "wide face" shrinks 0.361 inch from 29% MC to 10% MC. The 2-inch "narrow face" of a S-DRY 2x6 shrinks 0.027 inch and the 6-inch "wide face" shrinks 0.099 inch from 19% MC to 10% MC.

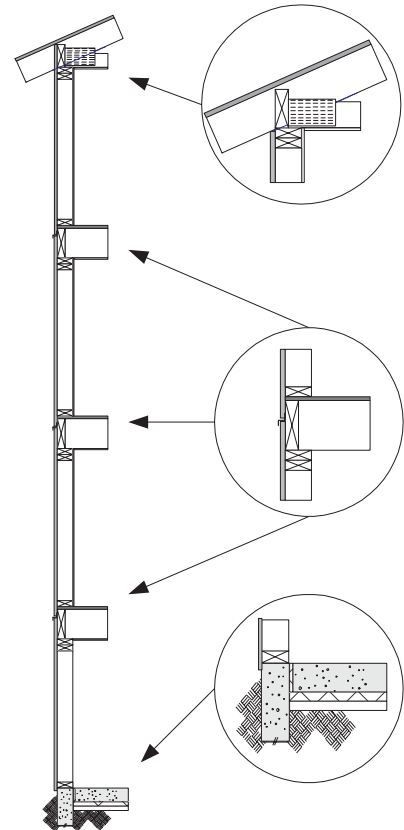


Figure 3. Shrinkage areas in Multistory Wood Frame

Dimension Lumber (2 to 4 inches thick, 2 inches and wider)

Unseasoned dressed (surfaced) lumber (S-GRN) is manufactured oversized so when it reaches 19% MC, it will be approximately the same size as the S-DRY dressed size. Dressed framing lumber greater than 2 inches thick is typically manufactured unseasoned and indicated as S-GRN on the grade stamp. Regional market preferences dictate availability of dry or unseasoned lumber. For more information on S-GRN lumber, refer to WWPAs publication *Unseasoned (GRN) Framing Lumber* online at <http://www.wwpa.org/pdf/a12.pdf>.

The most readily available seasoned 2-inch thick framing lumber is "S-DRY", "KD", or "KD HT" indicating a maximum 19% moisture content. Lumber labeled "MC 15" or "KD 15" has been dressed at a maximum MC of 15%. Because of limited availability, MC 15 and KD 15 lumber must be specially ordered for applications where maximum dimensional stability is desired – cost is likely to be higher.

Table 2. Estimated Shrinkage of solid sawn Western softwood species except Western Cedars and Redwood, to 10% EMC
[shrinkage coefficient 0.0020]

	Nominal Size	S-GRN Size	Shrinkage (from FSP)	S-DRY Size	Shrinkage (from 19% MC)
Thickness	2"	1.563"	0.059"	1.500"	0.027"
	3"	2.563"	0.097"	2.500"	0.045"
	4"	3.563"	0.135"	3.500"	0.063"
	6"*	5.500"	0.209"	----	----
Width	6"	5.625"	0.214"	5.500"	0.099"
	8"	7.500"	0.285"	7.250"	0.131"
	10"	9.500"	0.361"	9.250"	0.167"
	12"	11.500"	0.437"	11.250"	0.203"

*6" thickness S-GRN size is for unseasoned 6x timbers.

Heavy Timbers (5 inches and thicker)

Timbers are generally manufactured unseasoned and allowed to season in service. The moisture content designation may not be present on grade stamps for this reason.

Shrinkage Effects

Total shrinkage in multistory wood frame construction can be reduced using different construction details; such as placing floor joists in metal joist hangers bearing off beams or top plates instead of bearing on wall top plates. S-DRY lumber may be specified to minimize shrinkage. Another consideration is to balloon frame walls using dry plates.

Site Storage – An often-overlooked aspect in multistory wood frame construction is handling and storage of lumber on the project site. The steps taken by the engineer, architect, or designer to ensure the building is designed appropriately may be lost if the lumber is left exposed to the elements.

Storing unprotected lumber directly on the ground must be avoided. Instead, place lumber units on supports to keep units away from mud and standing water. Lumber that has increased MC from rain should be allowed to dry before attaching sheathing elements. For more storage information, refer to the WWPAs publication *Lumber Storage* online at <http://www.wwpa.org/pdf/tg5.pdf>.

Dimensional Stability of Building Materials

Lumber shrinks and swells due to changes in moisture content, but subsequent dimensional changes are minimal after lumber reaches EMC. Other building materials such as brick, steel and concrete continue to expand and contract with temperature changes while in place.

Accommodations must be made for connecting components that have different dimensional stability characteristics, such as wood framing combined with brick veneer, a steel framed atrium space, a masonry block elevator shaft, a steel stair tower, or even another wood-based system installed at a different moisture content. Design for these conditions may require framing wood members entirely independent of other building materials.

Differential movement can occur when joists are side-mounted to engineered wood beams, leaving the joists top edges below the supporting beams top edges. If not properly detailed, this could leave a bulge in the finish floor. The joists should be seated slightly above the beam top to accommodate shrinkage using face mounted hangers or ledger strips.

Heavy Timber Connections – Detailing connections to prevent problems due to wood shrinkage is most critical in large wood member connections such as heavy timber framing. Improperly designed connections can cause wood splitting. An example of proper connection is a beam to column detail (U-plate) shown in *Figure 4*.

The *Allowable Stress Design Manual for Engineered Wood Construction (ASD)*, published by the American Forest and Paper Association, contains details showing proper techniques for connection design and fabrication. *ASD Manual* information is available online at <http://www.awc.org>.

Finish Material – Exercise care in detailing large expanses of interior and exterior drywall, paneling and siding where cumulative effects of multistory dimensional change could cause finish surfaces to buckle. Examples are stairwells, shafts, vaulted ceilings areas, atriums and continuous vertical siding applications.

Expansion joints or slip-type architectural details (*Figure 5*) are often employed in these areas at each floor elevation. When detailing panel sheathing, the panels should not extend across the floor joists framing if the joists are sitting on top of the wall.

Metal holdowns and ties should be retightened before finishing materials are installed.

Brick Veneer – The Brick Institute of America has available a technical report on anchoring brick veneer in wood frame construction. The report provides designs and details addressing movement provisions. The report is available online at <http://www.bia.org>.

Doors and Windows – Windows should be installed into prepared openings in exterior walls when lumber is as close to the EMC as possible. Windows are usually independent from brick veneer or detailed to allow for up to one-half inch movement per floor. Further, a clear gap should be provided to allow for differential movement at the bottom window rail and the sill below.

Doors should be installed with a minimum 1/8" gap between the jamb and top of door. For all door rough openings, a gap should also be left above the jamb. The adjacent trimmer studs located to the right and left should support doors.

Electrical, Mechanical, and Plumbing – Using flexible joints for electrical, mechanical and plumbing work between floors may eliminate potential problems resulting from wood shrinkage. Such products include flexible pipe, conduit, couplings, elbows, and tees.

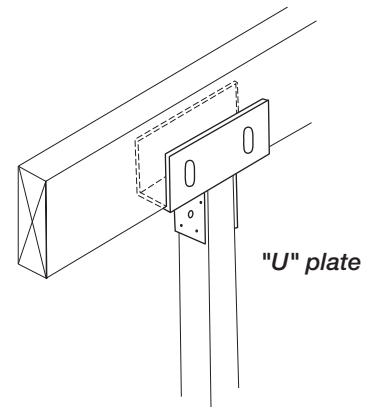


Figure 4. Typical beam to column connection detail

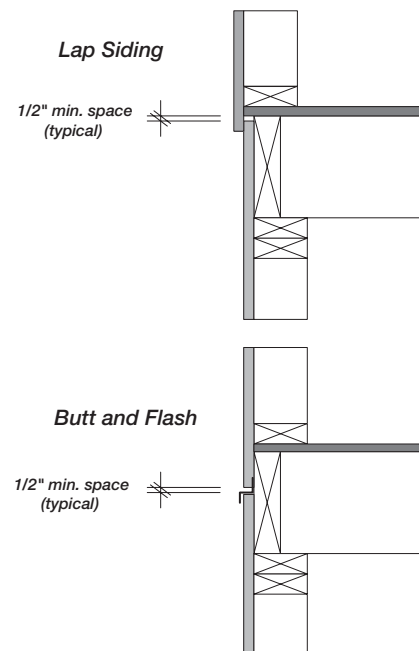


Figure 5. Common slip joint details for siding between floors