Wood Design Focus
Multistory Wood-Frame Structures
Shrinkage Considerations

Wood Shrinkage Basics and Construction Issues

Objective

To gain understanding of relationship between wood shrinkage and moisture content (MC) and show examples of how changes in MC can adversely affect wood framing and connections.

Rationale

Wood responds to moisture changes differently than other building materials. Design professionals need to be aware of wood-moisture relationships to avoid problems in the field.

Reference

- Wood Handbook - Wood as an Engineering Material. 2010. USDA Forest Products Laboratory (free download)
  www.fpl.fs.fed.us/products/publications/several_pubs.php?grouping_id=100&header_id=p&trending=yes

Fundamentals

Moisture content (MC) of wood is computed on a dry-weight basis as follows

$$MC = \frac{(\text{moist weight} - \text{ovendry weight})}{\text{ovendry weight}} * 100\% \quad = \quad \frac{H_2O \text{ weight}}{\text{dry wood weight}} * 100\%$$

A living tree can have MC > 100%. At 100%, a 1000-lb log would have 500 lb of moisture and 500 lb of dry wood. When MC is above fiber saturation (~30%), "free water" exists in cell cavities and changes in MC do not affect mechanical properties or dimensional size. As you dry the wood below fiber saturation, "chemically bound water" is removed, and mechanical properties increase and the wood shrinks. Figure 1 illustrates this concept.

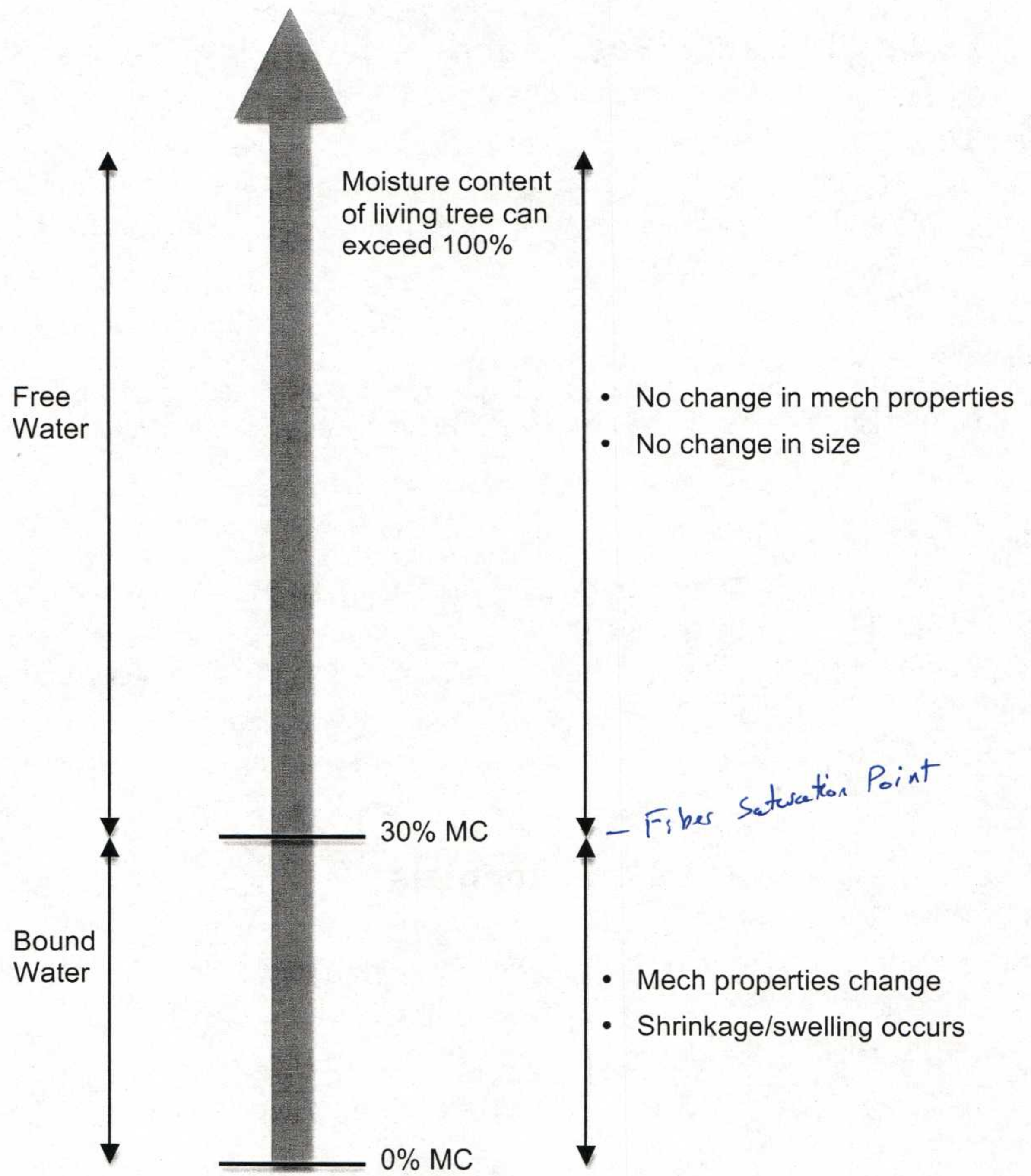


Figure 1. Moisture content ranges where size and mechanical properties change.

Wood is a hygroscopic material – meaning that it attracts moisture from its surrounding environment. The MC below fiber saturation is a function of temperature and relative humidity. Equilibrium moisture content (EMC) is defined as the MC at which wood is neither gaining nor losing moisture. Table 1 shows EMC for a range of temperature and relative humidity. It can take several weeks (or even months) for wood to reach EMC, depending on the size of the member and environmental conditions.

Table 1. Equilibrium moisture content of wood at stated dry-bulb temperature and relative humidity (Wood Handbook, Chapter 4).

Temp,	Relative Humidity (%)																		
(°F)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
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	13.6	14.9	16.5	18.5	21.0	24.3
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	12.4	13.5	14.9	16.5	18.5	21.0	24.4
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
60	1.3	2.5	3.6	4.6	5.4	6.3	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
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	18.0	20.5	23.9
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	11.8	12.9	14.2	15.7	17.7	20.2	23.6
90	1.2	2.4	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.6	11.5	12.6	13.9	15.4	17.4	19.9	23.3
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
110	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.5	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.5
120	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.8	10.7	11.7	12.9	14.4	16.2	18.6	22.0
130	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.3	7.9	8.7	9.5	10.3	11.3	12.5	14.0	15.8	18.2	21.5
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	12.2	13.6	15.4	17.7	21.0
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	13.2	14.9	17.2	20.5
160	0.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.5	7.1	7.8	8.5	9.3	10.3	11.4	12.7	14.4	16.7	19.9
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
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	10.6	11.8	13.5	15.7	18.8

Example

What is the EMC for wood that is exposed to prolonged periods of 70 °F and 70% RH?

Solution: EMC = 13.1% from Table 1.

Shrinkage Values from Green to Oven-Dry

Wood shrinks different amounts along its three principal axes shown in Figure 2. For this reason, wood can develop checks, splits and warp.

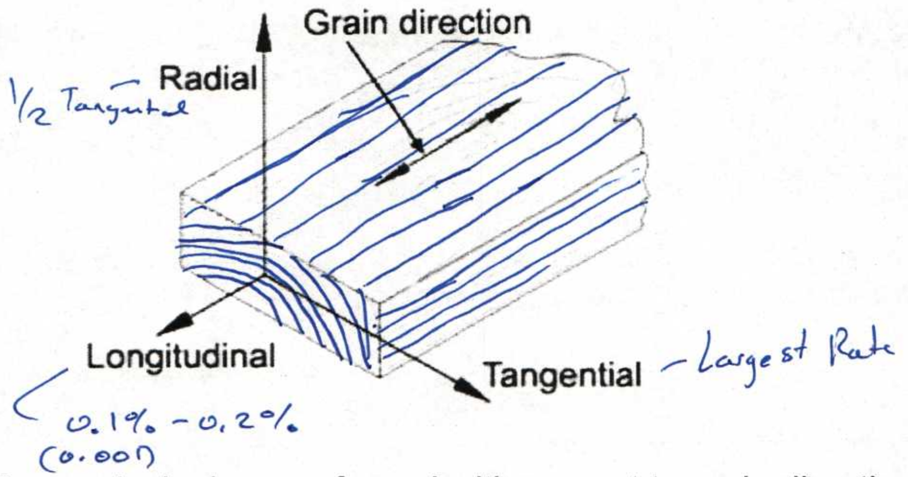


Figure 2. Three principal axes of wood with respect to grain direction and growth rings.

The following **radial and tangential** shrinkage values were excerpted from Table 4-3 in the Wood Handbook. Two common species for framing and two for interior woodwork are shown.

Species	Shrinkage (%) from green to ovendry moisture content	
	Radial	Tangential
Douglas-fir, Coast	4.8	7.6
Loblolly Pine	4.8	7.4
Oak, Northern red	4.0	8.6
Walnut, black	5.5	7.8

Longitudinal shrinkage (parallel-to-grain) is generally quite small – around 0.1% to 0.2% for most species, from green to oven dry conditions. However, *reaction wood* and *juvenile wood* can shrink 2% (10x more). Reaction wood and normal wood can occur in the same board, and usually results in excessive warping.

Reaction/Compression Cells (will warp wood)

- wafer thin Piece - can see thru Normal
- reaction cannot see thru

Minimise Juvenile — MSR Lumber or Dense (Higher Grade)

Shrinkage calculation – from green to MC<30%

The following equation is used to calculate shrinkage of wood from the green condition (fiber saturation) to a moisture content *MC* < 30%, where *S* is the total shrinkage from green to oven dry in decimal form.

$$\Delta\, dimension = \left[\frac{(30 - MC)}{30}\right] * S * (green\ dimension)$$

shrinkage % ratio or pcent

Example

Approximately how much transverse shrinkage will occur for a piece of 2x6 PPT Southern Pine lumber from 50%MC to 12%MC? Assume the initial width is 5-5/8 in, and a transverse shrinkage value of 7.5%.

Solution

7.5%

$$\Delta\, \text{dim}ension = \left[\frac{(30-12)}{30}\right] * 0.075 * 5.625 = 0.25\ in$$

Note that no shrinkage occurred from 50% MC to 30% since this was "free water" as shown in Figure 1.

4% Rule of Thumb for Transverse Shrinkage

Lumber shrinkage varies from piece to piece, and the surface of the lumber is usually not cut exactly along tangential or radial planes. As such, a rule of thumb used by some grading agencies for **transverse shrinkage is that a 4% change in MC = 1% change in size.** This is equivalent to assuming a 7.5% total shrinkage from 30% to oven dry condition.

Example

Approximately how much shrinkage will occur in a piece of framing lumber that arrived to the jobsite at 20% MC and dried to 8% MC in service?

Solution

(20 – 8)/4 = 3%

So if the lumber was 2x12, the expected shrinkage would be

11.25 in * 0.03 = 0.34 in

Shrinkage Variability

Wood shrinkage is influenced by a number of natural characteristics. The Wood Handbook reports a coefficient of variation of 15% for transverse shrinkage. Using the rule of thumb that the range of a random variable is ± 2 standard deviations, it follows that the range of shrinkage is ± 30%. So, the calculated shrinkage should be multiplied by 1.3 to estimate maximum transverse shrinkage possible.

Framing Examples

Example 1 – seasonal arching of trusses (due to longitudinal shrinkage)

One cause of seasonal arching of trusses is differential longitudinal shrinkage of the top and bottom chords. The problem is exacerbated if juvenile wood is present, as the longitudinal shrinkage can be 10x that of normal wood. For example, consider winter conditions in an attic that expose the top chord (TC) to 36°F and 80%RH, while the bottom chord (BC) is under loose-fill insulation at 65°F and 27%RH. Assume that approximately ½ of the BC and TC lumber is juvenile wood with longitudinal shrinkage of 2% (hence, we will assume an effective shrinkage value of 1%).

Solution

EMC for both chords is obtained from Table 1

TC: @ 36°F and 80%RH EMC = 16.5%

BC: @ 65°F and 27%RH EMC = 5.9%

$$\text{Shrinkage of BC relative to TC} = \left[\frac{(16.5-5.9)}{30}\right] * 0.01 * \left(32\,ft * 12\,in/ft\right) = \underline{1.3\ in}$$

The calculated shrinkage assumes unrestrained condition – not exactly the case in a MPC truss. The net effect in an actual truss is arching of the bottom chord.

Bonus question: Consider a truss chord in a hot attic during summer. Do we need to concern ourselves with thermal expansion?

Answer: The Wood Handbook gives a thermal expansion coefficient for wood, and it is very small. Thermal expansion is negligible and as the wood is heated, its EMC decreases, and the net effect is shrinkage – not thermal expansion.

Example 2 – columns (longitudinal shrinkage)

A timber column is 12 ft long when installed at 40% MC. Assume an average service environment of 70°F and 65% RH. Calculate how much change in the length is anticipated as the column nears equilibrium condition. Solve this problem under the assumptions of (1) mature wood and (2) juvenile wood.

Solution

At 70°F and 65% RH, the EMC = 12% [Table 1]

Assume longitudinal shrinkage of 0.2% for mature wood and 2% for juvenile wood.

1. For mature wood, Δ_{avg} = [(30 – 12)/30] * 0.002 * 144 in = 0.17 in
2. For juvenile wood, Δ_{avg} = 10 * 0.17 in = 1.7 in

Note that no shrinkage occurs as the column dries from 40% to 30%, since this is "free water" (see Figure 1).

Example 3 - Deck board (transverse shrinkage)

PPT Hem Fir deck boards, nominal size 2x6-in, are installed with no gaps between boards at a moisture content (db) of 38%. You should assume that the dimensions of the boards at installation are equal to the minimum dressed dimensions for green boards given in the NDS Supplement. What gaps would you expect after the boards reach an equilibrium moisture content of 8%?

Solution

Assume shrinkage of 7.5% from FSP (i.e. 30%) to oven dry.

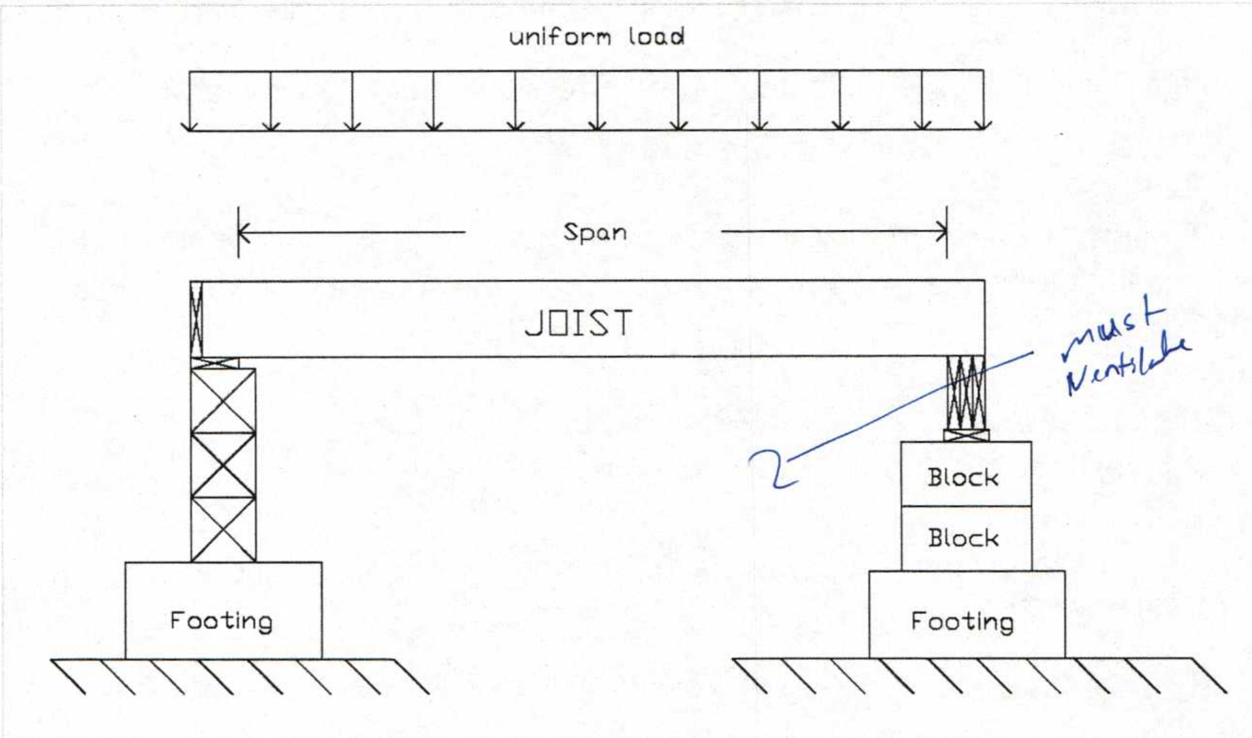
Note that no shrinkage from 38 to 30%, since free water.

Green dressed width = 5.625 in [Table 1A, NDS Supp]

Gap = [(30 – 8)/30] * 0.075 * 5.625 in = 0.31 in

Bonus question: Which way would you orient your deckboards – bark side up or down?

Example 4 – floor joist and girder (transverse shrinkage)



Problem: Don Bender's mother-in-law has a house with cracks that occur in the walls of the living room. The dry wall was repaired, but cracks kept recurring seasonally.

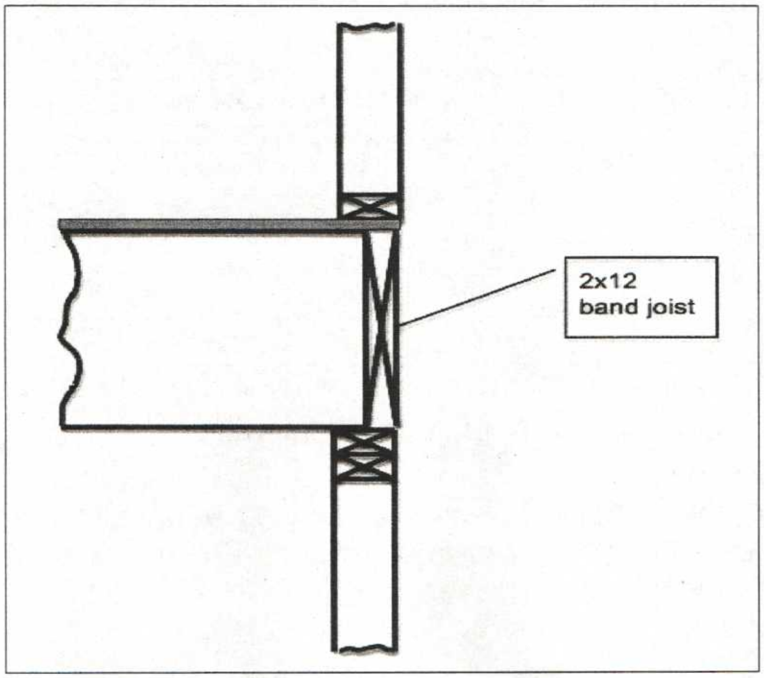
Solution: Conditions in the crawl space are estimated to range seasonally from 40°F and 90% RH (EMC = 21.0%) to 80°F and 50% RH (EMC = 9.1%). The floor joist and girders are 2x12 lumber.

Seasonal displacement = [(21.0 – 9.1)/30 * 0.075] * 2 * 11.25 = 0.67 in

Bonus question: How would propose to make the problem go away? (House fire and/or divorce are not acceptable answers.)

Example 5 – Band joist (transverse shrinkage)

Suppose you installed a 2x12 band joist at initial moisture content of 25% and it dried to a final MC of 10% after the house was finished. How much shrinkage would you expect in the band joist? Note that this problem can cause visible buckling of the siding.



Solution

Δ dimension = [(25 – 10) / 30] * 0.075 * 11.25 = 0.42 in

Note that this is the expected shrinkage. The maximum shrinkage could be as much as

Δ dimension = 1.3 * 0.42 in = 0.55 in

Connection Examples

Background

Table 10.3.3 in the NDS gives the wet service factor values, C_M, for connections. This table can be confusing to interpret, so we will highlight portions with explanations as follows.

Fastener Type	Moisture Content		C_M
	time of fabrication	in-service	
Lateral Loads			
Dowel-type Fasteners (nails, bolts, screws)	≤ 19%	≤ 19%	1.0
	> 19%	≤ 19%	0.4*
	any	> 19%	0.7

* C_M = 0.7 for dowel-type fasteners with diameter, D, less than ¼"

C_M = 1.0 for dowel-type fastener connections with:

1) one fastener only, or
2) two or more fasteners placed in a single row parallel to grain, or
3) fasteners placed in two or more rows parallel to grain to separate slice plates for each row.

First, we note that for design, lumber is considered "dry" if MC ≤ 19% and it is wet if MC > 19%.

Case 1: dry at time of fabrication and dry in-service

This case is straightforward and no moisture reduction is needed.

Case 3: any condition at time of fabrication and wet in-service

When the lumber is wet in-service, its dowel bearing strength is reduced and a 30% reduction is required for nail, bolt, and screw lateral capacities.

Case 2: wet at time of fabrication and dry in-service

This case requires careful interpretation of the footnote. Fasteners with diameter less than ¼" (e.g. nails) must use a value of C_M = 0.7 (i.e. a 30% reduction in lateral capacity). For larger diameter fasteners (e.g. bolts), there is no reduction for one fastener, or for two or more fasteners in a single row parallel-to-grain, or for rows of fasteners with separate splice plates for each row. The reason is that longitudinal shrinkage is relatively small.

So when does the $C_M = 0.4$ apply? When the lumber with bolted connection dries, it shrinks significantly in the *transverse* direction. For example, a 2x12 going from 30% to 10% MC would be expected to shrink

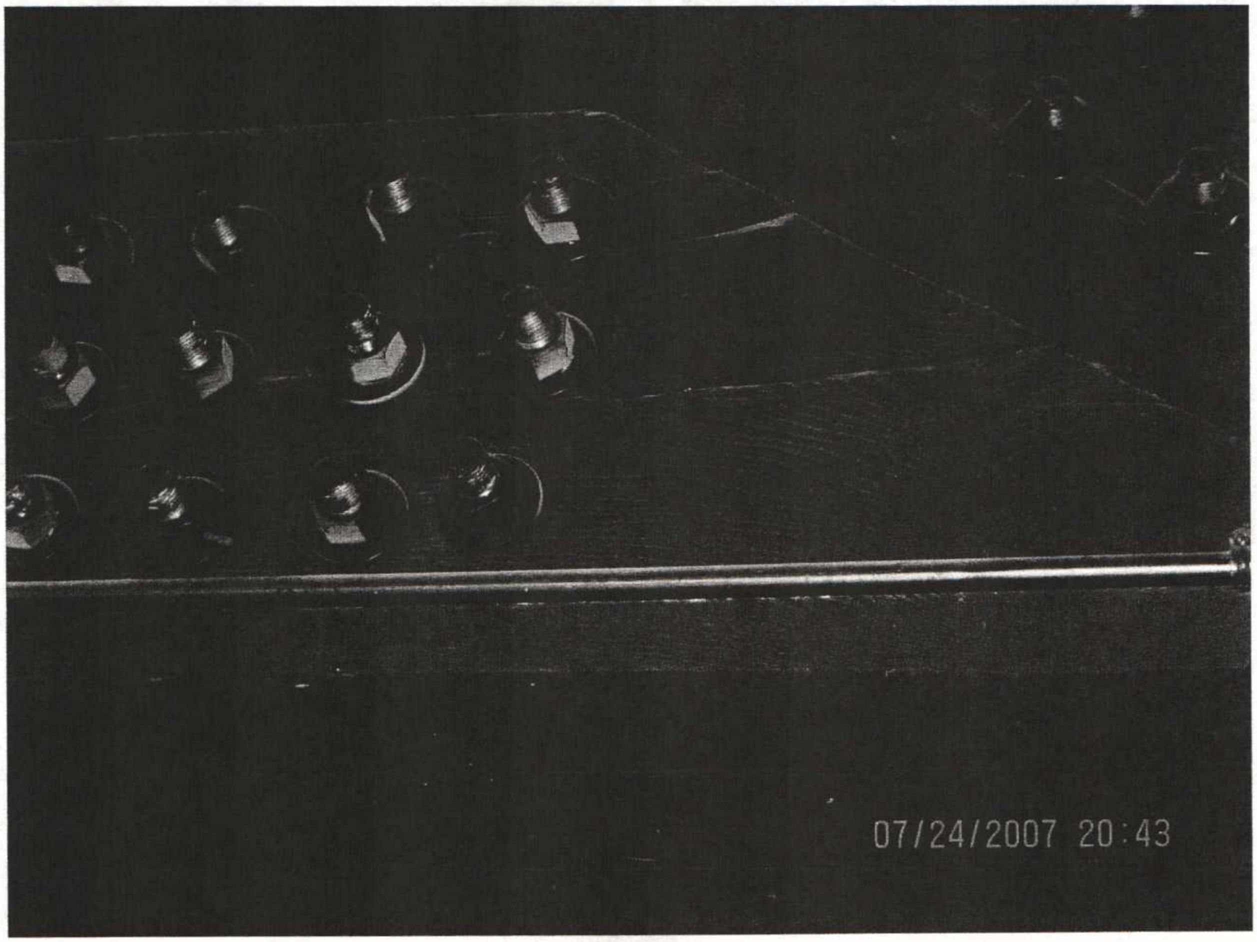
Shrinkage = [(30 – 10)/30 * 0.075] * 11.25 = <u>0.56 in</u>

Taking into account natural variability, the shrinkage could be as much as

Max shrinkage = 1.3 * 0.56 = 0.73 in

If the shrinkage is restrained, e.g. with a steel splice plate, the shrinkage can cause tension perpendicular-to-grain stresses that result in splitting. Once a splitting has occurred, the member and connection capacities are severely reduced.

In the photo below, the heel joints were fabricated with ¼-inch steel plates sandwiched between the lumber. When the truss lumber dried in-service, the lumber width decreased and the steel plates resisted the change in dimension of the lumber. The steel plates prevailed causing a split through the middle row of bolts.



Footnote 2 of NDS Table 11.5.1D restricts the spacing of outer rows of fasteners on a single splice plate to ≤ 5 in, as illustrated in NDS Figure 11H. The C_M = 0.4 situation would apply here.

Figure 11H Spacing Between Outer Rows of Bolts