

9 WOOD CONSTRUCTION

Nomenclature

A	area of a member	in ²
b	width of beam	inches
C_f	size factor	
d	depth of beam	inches
d'	depth of beam remaining at a notch	inches
E	modulus of elasticity	psi
f_b	actual value for extreme fiber in bending stress	psi
F_b	design value for extreme fiber in bending	psi
F_c	design value for compression parallel to grain	psi
F'_c	design value for compression parallel to grain, adjusted for l/d ratio	psi
$F_{c\perp}$	design value for compression perpendicular to grain	psi
f_t	actual unit stress in tension parallel to the grain	psi
F_t	design value for tension parallel to grain	psi
f_v	actual unit stress in horizontal shear	psi
F_v	design value for horizontal shear	psi
I	moment of inertia	in ⁴
K	largest slenderness ratio, l/d , at which intermediate column formula applies	
K_e	effective buckling length factor	
l	span of bending member or effective length of column	inches
L	span of bending member	feet
P	total concentrated load or total axial load	pounds
S	section modulus	in ³
V	vertical shear	pounds
w	uniform load per foot	plf
Δ	deflection	inches

1 PROPERTIES OF STRUCTURAL LUMBER

A. Sizes

Structural lumber is referred to by its nominal dimension in inches such as 2×4 or 2×10 . However, after surfacing at the mill and drying, its actual dimension is somewhat less.

Table 9.1 gives the actual dimensions for various nominal sizes of sawn lumber. Also shown in Table 9.1 are the actual areas, section modulus, and moment of inertia, which are all based on the actual size. The majority of structural lumber used is surfaced and dried to the actual sizes listed in Table 9.1, so these are the values that must be used in structural calculations.

B. Grading

Since a log yields lumber of varying quality, the individual sawn pieces must be categorized to allow selection of the quality that best suits the purpose. For structural lumber, the primary concern is the amount of stress that a particular grade of lumber of a species will carry. The load-carrying ability is affected by such things as size and number of knots, splits, and other defects, as well as the direction of grain and the specific gravity of the wood.

Grading of structural lumber is done under standard rules established by several different agencies certified by the American Lumber Standards Committee. The grading is done at the sawmill either by visual inspection or by machine. The resulting allowable stress values are published in tables referred to as design values for visually graded structural lumber and design values for machine-stress-rated structural lumber.

Visually graded lumber is divided into categories based on nominal size, so the same grade of lumber in a species may have different allowable stresses depending on

Table 9.1
Sectional Properties of Standard Dressed Lumber

nominal size	standard dressed size (inches) $b \times d$	area (in ²) A	moment of inertia (in ⁴) I	section modulus (in ³) S
2 × 3	1 1/2 × 2 1/2	3.750	1.953	1.563
2 × 4	1 1/2 × 3 1/2	5.250	5.359	3.063
2 × 6	1 1/2 × 5 1/2	8.250	20.797	7.563
2 × 8	1 1/2 × 7 1/4	10.875	47.635	13.141
2 × 10	1 1/2 × 9 1/4	13.875	98.932	21.391
2 × 12	1 1/2 × 11 1/4	16.875	177.979	31.641
4 × 4	3 1/2 × 3 1/2	12.250	12.505	7.146
4 × 6	3 1/2 × 5 1/2	19.250	48.526	17.646
4 × 8	3 1/2 × 7 1/4	25.375	111.148	30.661
4 × 10	3 1/2 × 9 1/4	32.375	230.840	49.911
4 × 12	3 1/2 × 11 1/4	39.375	415.283	73.828
4 × 14	3 1/2 × 13 1/4	46.375	678.475	102.411
6 × 6	5 1/2 × 5 1/2	30.250	76.255	27.729
6 × 8	5 1/2 × 7 1/2	41.250	193.359	51.563
6 × 10	5 1/2 × 9 1/2	52.250	392.963	82.729
6 × 12	5 1/2 × 11 1/2	63.250	697.068	121.229
6 × 14	5 1/2 × 12 1/2	74.250	1127.672	167.063
6 × 16	5 1/2 × 15 1/2	85.250	1706.776	220.229
8 × 8	7 1/2 × 7 1/2	56.250	263.672	70.313
8 × 10	7 1/2 × 9 1/2	71.250	535.859	112.813
8 × 12	7 1/2 × 11 1/2	86.250	950.547	165.313

which category it is in. This can be confusing, but is critical in selecting the correct allowable stress for a particular design condition. For example, one of the most common categories is 2 inches to 4 inches thick, 5 inches and wider. This includes wood members like 2 × 6s, 2 × 8s, and the like, but not 2 × 4s. 2 × 4 members are in two separate categories: 2 inches to 4 inches thick, 2 inches to 4 inches wide; and 2 inches to 4 inches thick, 4 inches wide. The first category is based on structural grades, and the second category is based on appearance grades.

There are also categories for beams and stringers, and posts and timbers. *Beams and stringers* are defined as members 5 inches and wider, having a depth more than 2 inches greater than the width. *Posts and timbers* are defined as members 5 inches by 5 inches and larger, with a depth not more than 2 inches greater than the width.

Machine-stress-rated lumber is based on grade designations, which depend on the allowable bending stress and modulus of elasticity of the wood.

C. Design Values

For visually graded lumber, allowable design values are based on the species of wood, the size category, the grade, and the direction of loading. Different values are required based on the direction of loading because wood is not an isotropic material. The tables give values for extreme fiber stress in bending, F_b ; tension parallel to the grain, F_t ; horizontal shear, F_v ; compression perpendicular to grain, $F_{c\perp}$; and compression parallel to grain, F_c . Table 9.2 shows a portion of a table of design values as published by the National Forest Products Association.

Table 9.2(a)
Design Values for Visually Graded Dimension Lumber

Species and commercial grade	Size classification	Design values in pounds per square inch (psi)						Grading Rules Agency	
		Bending F_b	Tension parallel to grain F_t	Shear parallel to grain F_v	Compression perpendicular to grain $F_{c\perp}$	Compression parallel to grain F_c	Modulus of Elasticity E		
DOUGLAS FIR-LARCH									
Select Structural	2"-4" thick	1450	1000	95	625	1700	1,900,000	WCLIB WWPA	
No. 1 & Btr		1150	775	95	625	1500	1,800,000		
No. 1	2" & wider	1000	675	95	625	1450	1,700,000		
No. 2		875	575	95	625	1300	1,600,000		
No. 3		500	325	95	625	750	1,400,000		
Stud		675	450	95	625	825	1,400,000		
Construction	2"-4" thick	1000	650	95	625	1600	1,500,000		
Standard	2"-4" wide	550	375	95	625	1350	1,400,000		
Utility		275	175	95	625	875	1,300,000		
DOUGLAS FIR-LARCH (NORTH)									
Select Structural	2"-4" thick	1300	800	95	625	1900	1,900,000	NLGA	
No. 1/No. 2	2" & wider	825	500	95	625	1350	1,600,000		
No. 3		475	300	95	625	775	1,400,000		
Stud		650	375	95	625	850	1,400,000		
Construction	2"-4" thick	950	575	95	625	1750	1,500,000		
Standard	2"-4" wide	525	325	95	625	1400	1,400,000		
Utility		250	150	95	625	925	1,300,000		
DOUGLAS FIR-SOUTH									
Select Structural	2"-4" thick	1300	875	90	520	1550	1,400,000		WWPA
No. 1		900	600	90	520	1400	1,300,000		
No. 2	2" & wider	825	525	90	520	1300	1,200,000		
No. 3		475	300	90	520	750	1,100,000		
Stud		650	425	90	520	825	1,100,000		
Construction	2"-4" thick	925	600	90	520	1550	1,200,000		
Standard	2"-4" wide	525	350	90	520	1300	1,100,000		
Utility		250	150	90	520	875	1,000,000		
EASTERN HEMLOCK-TAMARACK									
Select Structural	2"-4" thick	1250	575	85	555	1200	1,200,000	NELMA NSLB	
No. 1		775	350	85	555	1000	1,100,000		
No. 2	2" & wider	575	275	85	555	825	1,100,000		
No. 3		350	150	85	555	475	900,000		
Stud		450	200	85	555	525	900,000		
Construction	2"-4" thick	675	300	85	555	1050	1,000,000		
Standard	2"-4" wide	375	175	85	555	850	900,000		
Utility		175	75	85	555	550	800,000		
EASTERN SOFTWOODS									
Select Structural	2"-4" thick	1250	575	70	335	1200	1,200,000		NELMA NSLB
No. 1		775	350	70	335	1000	1,100,000		
No. 2	2" & wider	575	275	70	335	825	1,100,000		
No. 3		350	150	70	335	475	900,000		
Stud		450	200	70	335	525	900,000		
Construction	2"-4" thick	675	300	70	335	1050	1,000,000		
Standard	2"-4" wide	375	175	70	335	850	900,000		
Utility		175	75	70	335	550	800,000		

Courtesy, American Forest & Paper Association, Washington, D.C.

Table 9.2(b)
Adjustment Factors

Size Factor, C_F

Tabulated bending, tension, and compression parallel to grain design values for dimension lumber 2" to 4" thick shall be multiplied by the following size factors:

SIZE FACTORS, C_F

Grades	Width	F_b		F_t	F_c
		Thickness			
		2" & 3"	4"		
Select Structural, No. 1 & Btr. No. 1, No. 2 No. 3	2", 3" & 4"	1.5	1.5	1.5	1.15
	5"	1.4	1.4	1.4	1.1
	6"	1.3	1.3	1.3	1.1
	8"	1.2	1.3	1.2	1.05
	10"	1.1	1.2	1.1	1.0
	12"	1.0	1.1	1.0	1.0
Stud	14" & wider	0.9	1.0	0.9	0.9
	2", 3" & 4"	1.1	1.1	1.1	1.05
Construction & Standard	5" & 6"	1.0	1.0	1.0	1.0
	2", 3" & 4"	1.0	1.0	1.0	1.0
Utility	4"	1.0	1.0	1.0	1.0
	2" & 3"	0.4	-	0.4	0.6

Repetitive Member Factor, C_R

Bending design values, F_b , for dimension lumber 2" to 4" thick shall be multiplied by the repetitive member factor, $C_R = 1.15$, when such members are used as joists, truss chords, rafters, studs, planks, decking or similar members which are in contact or spaced not more than 24" on centers, are not less than 3 in number and are joined by floor, roof or other load distributing elements adequate to support the design load.

Flat Use Factor, C_{fu}

Bending design values adjusted by size factors are based on edgewise use (load applied to narrow face). When dimension lumber is used flatwise (load applied to wide face), the bending design value, F_b , shall also be multiplied by the following flat use factors:

FLAT USE FACTORS, C_{fu}		
Width	Thickness	
	2" & 3"	4"
2" & 3"	1.0	-
4"	1.1	1.0
5"	1.1	1.05
6"	1.15	1.05
8"	1.15	1.05
10" & wider	1.2	1.1

Wet Service Factor, C_M

When dimension lumber is used where moisture content will exceed 19% for an extended time period, design values shall be multiplied by the appropriate wet service factors from the following table:

WET SERVICE FACTORS, C_M					
F_b	F_t	F_v	$F_{c\perp}$	F_c	E
0.85*	1.0	0.97	0.67	0.8**	0.9

* when $(F_b)(C_F) \leq 1150$ psi, $C_M = 1.0$
 ** when $(F_c)(C_F) \leq 750$ psi, $C_M = 1.0$

NOTE

To facilitate the use of Table 4A, color coding has been employed to distinguish design values based on a 4" nominal depth (Construction, Standard and Utility grades) or a 6" nominal depth (Stud grade) from design values based on a 12" nominal depth (Select Structural, No.1 & Btr, No.1, No.2 and No.3 grades).

Courtesy, American Forest & Paper Association, Washington, D.C.

One additional variable for selecting the extreme fiber in bending stress is whether or not the member is being used alone or with other members such as a row of joists. In order to qualify for repetitive member use, there must be at least three members spaced not more than 24 inches apart, and there must be some method to distribute the load among them such as bridging or sheathing.

As mentioned in Chapter 8, the amount of stress a wood member can withstand is also dependent on the length of time the load acts on the member. Design values given in the tables are based on what is considered a normal duration of loading: ten years. However, for shorter duration of loading, the allowable unit stresses may be increased as follows.

- 15 percent for two months' duration, as for snow
- 25 percent for seven days' duration, as for roof loading
- 60 percent for wind or earthquake loading
- 100 percent for impact loads

D. Moisture Content

Moisture content is defined as the weight of water in wood as a fraction of the weight of oven-dry wood. Moisture content is an important variable because it affects the amount of shrinkage, weight, strength, and withdrawal resistance of nails.

Moisture exists in wood both in the individual cell cavities and bound chemically within cell walls. When the cell walls are completely saturated but no water exists in the cell cavities, the wood is said to have reached its *fiber saturation point*. This point averages about 30 percent moisture content in all woods. Above this point, the wood is dimensionally stable, but as the wood dries below this point it begins to shrink.

When wood is used for structural framing and other construction purposes, it tends to absorb or lose moisture in response to the temperature and humidity of the surrounding air. As it loses moisture it shrinks, and as it gains moisture it swells. Ideally, the moisture content of wood when it is installed should be the same as the prevailing humidity to which it will be exposed. However, this is seldom possible, so lumber needs to be dried—either air dried or kiln dried—to reduce the moisture content to acceptable levels.

To be considered dry lumber, moisture content cannot exceed 19 percent. To be grademarked *kiln dry*, the maximum moisture content permitted is 15 percent. Design values found in tables assume that the maximum moisture content will not exceed 19 percent. If it does, the allowable stresses must be decreased slightly.

Wood shrinks most in the direction perpendicular to the grain and very little parallel to the grain. Perpendicular to the grain wood shrinks most in the direction of the annual growth rings (tangentially) and about half as much across the rings (radially).

In developing wood details, an allowance must be made for the fact that wood will shrink and swell during use regardless of its initial moisture content. Of particular importance is the accumulated change in dimension of a series of wood members placed one on top of the next. The shrinkage of an individual member may not be significant, but the total shrinkage of several may result in problems such as sagging floors, cracked plaster, distortion of door openings, and nail pops in gypsum board walls.

2 WOOD BEAMS

The design of wood beams is a fairly simple procedure. First, the loads and stresses on the beam are determined as described in Chapter 4. This includes finding the support reactions, vertical shear forces, and bending moments. Then, the basic flexure formula is used to find the required section modulus needed to resist the bending moment. A beam size is then selected that has the required section modulus. Second, horizontal shear stresses are calculated and compared with the allowable horizontal shear for the species and grade of lumber being used. This is especially important because wood beams have a tendency to fail parallel to the grain where their strength is lowest. Finally, deflection is checked to see if it is within acceptable limits. This, too, is important because wood is not as stiff as steel or concrete. Even though a beam may be strong enough to resist bending moment, the deflection may be outside of tolerable limits.

A. Design for Bending

To design wood beams for bending, the basic flexure formula is used.

$$S = \frac{M}{F'_b} \quad 9.1$$

The basic allowable extreme fiber stress in bending, F_b , is found in Table 9.2(a) or similar tables in the building code or other referenced sources, and the section modulus is found in Table 9.1. This value must be modified for many factors, including those shown in Table 9.2(b). For sawn lumber under major axis bending, the following formula is used.

$$F'_b = F_b C_D C_M C_t C_L C_F C_i C_r \quad 9.2$$

The definitions of C_M , C_F , and C_r are given in Table 9.2(b). Values of C_D are used to include the duration of load. In any combination of loads the largest

value of C_D is used. This corresponds to the shortest load duration. The duration of load factors are as follows.

permanent duration, dead load = 0.90
 normal, ten-year duration, floor live load = 1.00
 two-month duration, snow load = 1.15
 seven-day duration, roof live load = 1.25
 ten-minute duration,
 wind or earthquake load = 1.60
 impact duration = 2.00

The other values are for special cases of high temperature, C_t ; laterally unbraced beams, C_L ; and incised members, C_i . For laterally braced beams under normal usage, these values, along with C_M , may all be taken as 1.0. The examples presented in this chapter will assume this is the case.

Example 9.1

A simply supported wood beam spans 12 feet and carries a combined dead and roof live load of 350 pounds per linear foot. If the beam is Douglas fir-larch, #2, what size beam should be used?

First, find the maximum bending moment. From Figure 4.7, the moment for a uniformly loaded beam is $wL^2/8$. The moment is

$$M = \frac{wL^2}{8} = \frac{(350)(12)^2}{8}$$

$$= 6300 \text{ ft-lbs}$$

Using Table 9.2(a), find the column labeled "bending." For Douglas fir-larch no. 2, the tabulated value of F_b is 875 psi. All appropriate adjustments must be made to this value. The load is due to dead and roof live load, so the value of C_D should be 1.25. Since the beam size is known, a value of C_F must be assumed. A reasonable assumption would be 1.1. The allowable bending stress is then found by multiplying the tabulated values by the appropriated factor, using Equation 9.2.

$$F'_b = C_D C_F F_b = (1.25)(1.1)(875 \text{ psi})$$

$$= 1203 \text{ psi}$$

The required section modulus is then found from the basic flexure formula, Equation 9.1.

$$S = \frac{M}{F'_b} = \frac{(6300)(12)}{1203}$$

$$= 62.84 \text{ in}^3$$

Remember to multiply the moment by a factor of 12 to convert foot-pounds to inch-pounds.

Looking in Table 9.1, the smallest beam that will provide this section modulus is a 4 × 12 with an S of 73.828 in³. Notice that a 6 × 10 would also provide

the required value (82.729), but this has more area and therefore costs more than the 4 × 12. In addition, if a 6-inch wide beam were used, a different value for F_b may have to be used in the beams and stringer category. The adjustment factors would also be different for a beam and stringer.

The assumed value for C_F of 1.1 is correct. This value is given in Table 9.2(b) for a #2 grade, 12 inches in width and 4 inches in thickness. The 4 × 12 is the most appropriate selection to support the load.

Example 9.2

What is the maximum moment-carrying capacity, in foot-pounds, of a 2 × 10 select structural Douglas fir-larch beam with applied dead and floor live load?

Rearranging Equation 9.1 and dividing by 12 to convert inch-pounds to foot-pounds gives

$$M = \frac{SF'_b}{12}$$

The allowable tabulated unit stress, F_b , from Table 9.2(a) is 1450 psi, and the section modulus (from Table 9.1) of a 2 × 10 is 21.391 in³. The load duration factor, C_D , for combined dead and floor live load is 1.0. The size factor C_F from Table 9.2(b) is 1.1.

$$F'_b = C_D C_F F_b = (1.00)(1.1)(1450 \text{ psi})$$

$$= 1595 \text{ psi}$$

$$M = \frac{SF'_b}{12} = \frac{(21.391)(1595)}{12}$$

$$= 2843 \text{ ft-lbs}$$

Sometimes, either the width or depth of a beam is established by some limiting factor (such as ceiling clearance), and the other dimension must be found. This is easy to calculate if you remember that the section modulus of a rectangular beam is

$$S = \frac{bd^2}{6} \quad 9.3$$

Example 9.3

A wood beam spanning 10 feet must be designed to support a concentrated load of 2900 pounds in the center of the span, but there is only enough room for a nominal 8-inch deep beam. If the beam can be dense select structural Douglas fir-larch with an allowable unit stress of 1900 psi, what beam width is necessary?

The moment of a beam with a concentrated load is $PL/4$ (from Figure 4.7). The moment is

$$M = \frac{PL}{4} = \frac{(2900)(10)(12)}{4}$$

$$= 87,000 \text{ inch-pounds}$$

The required modulus from Equation 9.1 is

$$\begin{aligned} S &= \frac{M}{F'_b} = \frac{87,000}{1900} \\ &= 45.79 \text{ in}^3 \end{aligned}$$

If there were no limitation on the depth of the beam, a 4×10 would work with a section modulus of 49.911. However, if the maximum depth is 7.5 inches (the actual depth of a nominal 8-inch beam and stringer), then the required width, from Equation 9.3, is

$$S = \frac{bd^2}{6}$$

Rearranging the formula gives

$$\begin{aligned} b &= \frac{6S}{d^2} = \frac{(6)(45.79)}{(7.5)^2} \\ &= 4.88 \text{ inches} \end{aligned}$$

A nominal 6-inch wide beam will work with an actual width of 5.50 inches.

Example 9.4

A Douglas fir-larch #1 beam supports a roof with a dead load of 100 pounds per linear foot and a snow load of 150 pounds per linear foot. If the beam must span 8 feet, what is the most economical size to use?

For the snow load, a load duration factor of 1.15 is multiplied by the tabulated allowable stress. However, when there are loads of different durations on wood members, each load combination should be checked. For the dead load, a load duration of 0.9 is used. From Figure 4.7, for a uniformly loaded beam, the moment due to dead loads is

$$\begin{aligned} M &= \frac{wL^2}{8} = \frac{(100)(8)^2(12)}{8} \\ &= 9600 \text{ in-lbs} \end{aligned}$$

The moment due to dead load and snow load is

$$\begin{aligned} M &= \frac{(250)(8)^2(12)}{8} \\ &= 24,000 \text{ in-lbs} \end{aligned}$$

Remember, the factor of 12 must be used to convert foot-pounds to inch-pounds.

Since the beam size is unknown, the size factor will be assumed to be 1.1. The tabulated bending stress from Table 9.2(a) for Douglas fir-larch #1 is 1000 psi. The required section modulus for dead load only is

$$\begin{aligned} S &= \frac{M}{F'_b} = \frac{M}{C_D C_F F_b} = \frac{9600}{(0.9)(1.1)(1000)} \\ &= 9.70 \text{ in}^3 \end{aligned}$$

The required section modulus for the combined load is

$$\begin{aligned} S &= \frac{24,000}{(1.15)(1.1)(1000)} \\ &= 18.97 \text{ in}^3 \end{aligned}$$

Use the greater of the calculated section moduli. You would need to use a 2×10 with a section modulus of 21.391 (from Table 9.1). The assumed value for C_F of 1.1 is correct. This value is given in Table 9.2(b) for a #1 grade, 10 inches wide and 2 inches thick. The 2×10 is the most appropriate selection to support the loads.

B. Design for Horizontal Shear

Because it is easy for wood to shear along the lines of the grain, actual horizontal shear must always be checked against the allowable unit shear stress, F_v . This is especially important for short spans with large loads. Frequently, a beam that is sufficient in size to resist bending stresses must be made larger to resist horizontal shear stresses.

Because horizontal shear failure will always occur before vertical shear failure, it is not necessary to check for vertical shear except for beams notched at their supports.

For rectangular beams, the maximum unit horizontal shear stress is

$$f_v = \frac{3V}{2bd} \quad 9.4$$

The basic allowable stress in shear, F_v , is found in Table 9.2(a), and the sizes are found in Table 9.1. This value must be modified for five factors, including those shown in Table 9.2(b). The following formula is used for allowable shear stress.

$$F'_v = F_v C_D C_M C_t C_i C_H \quad 9.5$$

The values of C_D , C_M , C_t , and C_i are found in a manner similar to that for finding the values applied to bending stress. Values of C_H are given in Table 9.2(b). This value should only be used if the architect or engineer will verify the extent of cracking in the wood member.

When calculating the vertical shear, V , the loads within a distance from the supports equal to the depth of the member may be neglected.

Example 9.5

Check the beam found in Example 9.1 for horizontal shear.

The load is 350 pounds per linear foot for 12 feet, or 4200 pounds total. The vertical shear at each reaction

is 2100 pounds. Subtract the load within a distance equal to the depth of the beam, 11 1/4 inches.

$$V = 2100 - \left(\frac{11.25}{12} \right) (350) = 1772 \text{ pounds}$$

The value of bd is the area, found in Table 9.1 to be 39.375 in².

The actual horizontal shear is found from Equation 9.4,

$$\begin{aligned} f_v &= \frac{3V}{2bd} = \frac{(3)(1772)}{(2)(39.375)} \\ &= 67.50 \text{ psi} \end{aligned}$$

From Table 9.2(a), the allowable tabulated horizontal shear, F_v , is 95 psi for Douglas fir-larch #2. This must be multiplied times the duration of load factor of 1.25. The allowable shear stress, F'_v , is 118.8 psi and is larger than the actual stress, so the beam is adequate to resist horizontal shear. If the actual value were greater than the allowable, a larger beam would be needed.

C. Design for Deflection

Since wood is not as stiff as steel or concrete, deflection is always a concern. Detrimental effects of deflection can include nail popping in gypsum ceilings, cracking of plaster, bouncy floors, and visible sagging. In many cases, a wood member can be selected that will satisfy bending requirements but will not satisfy deflection criteria. Therefore, the design of wood beams must always include a check for deflection.

The formulas for deflection are the same ones used for other materials and are outlined in Figure 4.7. The criteria for maximum deflection is given in the Uniform Building Code and requires that two different conditions of loading be checked. The first limits deflection due to live load only to $L/360$ of the span. The second limits deflection due to live load and dead load for unseasoned wood to $L/240$ of the span. In both cases, the units of deflection will be the same as the units used for the value of L .

The Uniform Building Code does allow a reduction by one-half of the dead load for the condition of the live load and dead load if seasoned wood is used. *Seasoned wood* is defined as wood with a moisture content of less than 16 percent at the time of installation and used under dry conditions. This is typically the case, but since wood will deflect under long-term use beyond its initial deflection, it is common practice to use the full value of dead load and live load when checking deflection against the $L/240$ criterion. This provides for the extra stiffness necessary to limit deflection under long-term loading.

The basic modulus of elasticity, E , is found in Table 9.2(a). This value must be modified for four factors,

including those shown in Table 9.2(b). The following formula is used for allowable modulus of elasticity.

$$E' = EC_M C_t C_i C_T \quad 9.6$$

The values of C_M , C_t , and C_i are found in a manner similar to that for finding the values applied to bending stress. Values of C_T only apply to small truss members in compression. All of these values are 1.0 under normal conditions.

Example 9.6

Using the same beam found in Example 9.1, check to see that its deflection is within allowable limits. Assume that of the total load of 350 pounds per foot, dead load is 150 pounds and live load is 200 pounds per foot.

From Figure 4.7, the deflection for a uniformly loaded beam is

$$\Delta = \frac{5wl^4}{384EI} \quad 9.7$$

The modulus of elasticity of Douglas fir-larch #2 is 1,600,000 psi as found in Table 9.2(a), and the moment of inertia of a 4 × 12 is 415.283 as found in Table 9.1.

In this case, it is important to keep units consistent in order for the answer to be in inches. Remember that in Equation 9.7, w is the load per unit length and l is the length. If l is in inches, the load must be in pounds per inch, not feet. For calculating the total dead and live load, 350 pounds per foot is 350/12 or 29.167 pounds per inch. The beam length of 12 feet must be converted to inches and then raised to the fourth power.

$$\begin{aligned} \Delta &= \frac{(5)(29.167)((12)(12))^4}{(384)(1,600,000)(415.283)} \\ &= 0.25 \text{ inches} \end{aligned}$$

Another way to arrive at the same answer is to remember that Equation 9.7 can also take the form

$$\Delta = \frac{5Wl^3}{384EI} \quad 9.8$$

W is the total uniformly distributed load on the beam. The length still needs to be converted to inches and then raised to the third power, so the calculation is

$$\begin{aligned} \Delta &= \frac{5Wl^3}{384EI} = \frac{(5)((350)(12))((12)(12))^3}{(384)(1,600,000)(415.283)} \\ &= 0.25 \text{ inches for dead and live load} \end{aligned}$$

For deflection of live load only,

$$\begin{aligned} \Delta &= \frac{5Wl^3}{384EI} = \frac{(5)((200)(12))((12)(12))^3}{(384)(1,600,000)(415.283)} \\ &= 0.14 \text{ inches} \end{aligned}$$

Next, determine the allowable deflection limits. For live load only,

$$\frac{L}{360} = \frac{(12)(12)}{360} = 0.40 \text{ inches}$$

This is more than the actual deflection under live load only of 0.14, so this is acceptable. For total load,

$$\frac{L}{240} = \frac{(12)(12)}{240} = 0.60 \text{ inches}$$

This is also more than the actual deflection under total load of 0.25 inches, so the 4 × 12 beam is acceptable for deflection requirements.

3 MISCELLANEOUS PROVISIONS

A. Notched Beams

Notching of beams should be avoided, but if it is done, the UBC states that notches in sawn lumber bending members cannot exceed one-sixth the depth of the member and cannot be located in the middle third of the span. When the notches are at the supports as shown in Figure 9.1, the depth cannot exceed one-fourth of the beam depth.

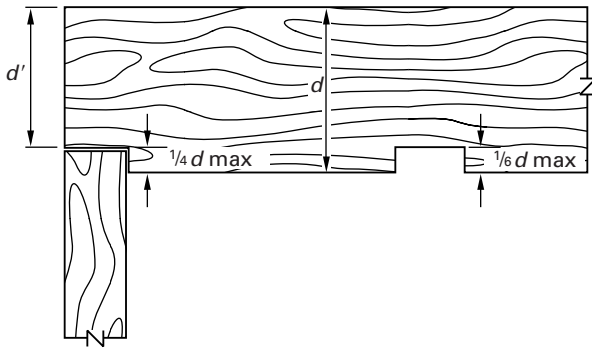


Figure 9.1 Notching of Beams

If beams are notched, the vertical shear cannot exceed the value determined by the formula

$$V = \left(\frac{2bd'F'_v}{3} \right) \left(\frac{d'}{d} \right) \quad 9.9$$

Example 9.7

If the beam in Example 9.1 is notched 2 inches, is it still an acceptable size?

The beam found in Example 9.1 is a 4 × 12, so its actual width is 3.5 inches and its actual depth is 11.25 inches. Subtracting 2 inches from the depth gives a d' value of 9.25 inches. From Example 9.5, the allowable horizontal

shear for Douglas fir-larch #2 is 118.8 psi. Applying Equation 9.9, the vertical shear is

$$\begin{aligned} V &= \left(\frac{2bd'F'_v}{3} \right) \left(\frac{d'}{d} \right) \\ &= \left(\frac{(2)(3.5)(9.25)(118.8)}{3} \right) \left(\frac{9.25}{11.25} \right) \\ &= 2108 \text{ pounds} \end{aligned}$$

From Example 9.5, the vertical shear at each reaction was found to be 2100 pounds, so this beam could be notched 2 inches without exceeding the allowable vertical shear limitation.

B. Size Factor

As the depth of a beam increases, there is a slight decrease in bending strength. The Uniform Building Code requires that the allowable unit stress in bending, F_b , be decreased by a size factor as determined by the formula

$$C_f = \left(\frac{12}{d} \right)^{\frac{1}{9}} \quad 9.10$$

This applies only to rectangular sawn bending members that are visually graded timber or visually graded southern pine dimension lumber exceeding 12 inches in depth. Design values for bending, tension, and compression parallel to grain for visually graded dimension lumber, excluding southern pine, 2 to 4 inches thick must be multiplied by size factors given at the beginning of Tables 4A, 4B, and 4E of NDS-91 of the *National Design Specification for Wood Construction*. The size factor does not affect the allowable strength to any great amount. C_f for a 14-inch deep beam, for example, is only 0.987, and for a 16-inch deep beam, it is 0.972.

C. Lateral Support

When a wood beam is loaded in bending, there is a tendency for it to buckle laterally. The UBC provides that a decrease in allowable bending strength be made if certain conditions are not met. For the vast majority of wood construction, this is not required if proper lateral support is provided. This amounts to providing continuous support at the compression edge, such as with sheathing or subflooring, and providing restraint against rotation at the ends of the members and at intervals with bridging. Most wood construction meets these conditions, so adjustments are not required.

D. Bearing

The load on a wood beam compresses the fibers where the weight is concentrated at the supports. To determine the required bearing area, the total reaction load is divided by the allowable compression perpendicular to grain, $F_{c\perp}$, found in Table 9.2. For joists, the UBC

states that there must be at least 1 1/2 inches bearing on wood or metal, and at least 3 inches bearing on masonry. Beams or girders supported on masonry must have at least 3 inches of bearing surface.

Example 9.8

What is the required bearing area on a masonry wall for the beam selected in Example 9.1?

The total reaction of the beam is

$$R = \frac{(350)(12)}{2} \\ = 2100 \text{ pounds}$$

The required bearing area is

$$A = \frac{2100}{625} \\ = 3.36 \text{ square inches}$$

Since the beam is 3 1/2 inches wide, the required length of bearing is 3.36/3.5, or 0.96 inches. However, since this is less than the code requirement of 3 inches, 3 inches must be used.

4 WOOD COLUMNS

As discussed in Chapter 4, columns have a tendency to buckle under a load, so even though a column may have enough cross-sectional area to resist the unit compressive forces, it may fail in buckling. For wood columns, the ratio of the column length to its width is just as important as it is for concrete and steel columns. However, for wood columns, the slenderness ratio is defined as the laterally unsupported length in inches divided by the least dimension of the column. This is a little different than the length divided by the radius of gyration as discussed in Chapter 4, but the same principles apply.

Wood columns can be solid members of rectangular, round, or other shapes, or spaced columns built up from two or more individual solid members separated by blocking. Since almost all wood columns are solid rectangular sections, the method of design in this section will be limited to these types.

As mentioned in Chapter 4, the load-carrying capacity of a wood column depends on the way the ends of the column are fixed. For design, the *effective length* must be determined. This is the total unsupported length multiplied by an effective buckling length factor, K_e . These factors for various end conditions are shown in Figure 9.2. Notice that this diagram is very similar to Figure 4.8, but the values are slightly different.

Because of the way most wood construction is detailed, columns are usually fixed in translation but free to rotate, so the K value is taken as 1, and the effective

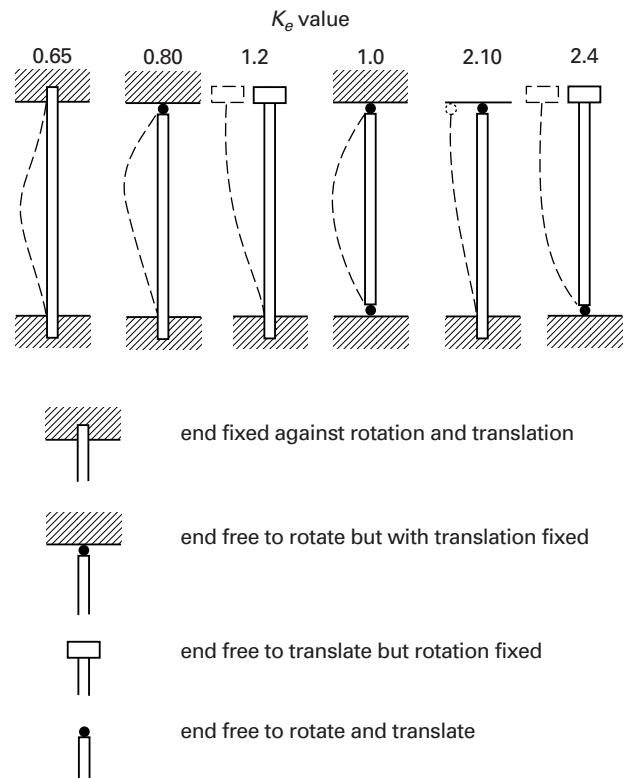


Figure 9.2 K_e Values for Wood Columns

length is taken as the actual unsupported length. For the purposes of this chapter, the letter l indicates the effective length of a column in inches.

The allowable unit stress in pounds per square inch of cross-sectional area of square or rectangular solid columns is determined according to a complex formula that considers the effective length, whether the wood is visually graded or machine graded, and whether the wood is sawn lumber, round timber piles, or glued-laminated timber. Because of the complexity of the formula, it is unlikely that the test will ask for specific values to be calculated.

5 JOISTS

Joists are a very common type of wood construction. They are small, closely spaced members used to support floor, ceiling, and roof loads, and are usually lumber nominally 2 inches wide by 6, 8, 10, and 12 inches deep, spaced 12, 16, or 24 inches on center. Of course, they are beams and can be designed using the methods described earlier in this section, but since they are used so frequently, their size and spacing is usually selected from tables. When they are designed as beams, the design value of F_b from Table 9.2(a) should be multiplied by the repetitive use factor, C_r , from Table 9.2(b). The design value is slightly larger for multiple member use than for single members.

Table 9.3
Allowable Spans for Floor Joists

DESIGN CRITERIA: Deflection—For 40 psf (1.92 kN/m ²) live load. Limited to span in inches (mm) divided by 360. Strength—Live load of 40 psf (1.92 kN/m ²) plus dead load of 20 psf (0.96 kN/m ²) determines the required bending design value.																		
Joist Size (in)	Spacing (in)	Modulus of Elasticity, <i>E</i> , in 1,000,000 psi																
		× 0.00689 for N/mm ²																
× 25.4 for mm		0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4
2 × 6	12.0	8-6	8-10	9-2	9-6	9-9	10-0	10-3	10-6	10-9	10-11	11-2	11-4	11-7	11-9	11-11	12-1	12-3
	16.0	7-9	8-0	8-4	8-7	8-10	9-1	9-4	9-6	9-9	9-11	10-2	10-4	10-6	10-8	10-10	11-0	11-2
	19.2	7-3	7-7	7-10	8-1	8-4	8-7	8-9	9-0	9-2	9-4	9-6	9-8	9-10	10-0	10-2	10-4	10-6
	24.0	6-9	7-0	7-3	7-6	7-9	7-11	8-2	8-4	8-6	8-8	8-10	9-0	9-2	9-4	9-6	9-7	9-9
2 × 8	12.0	11-3	11-8	12-1	12-6	12-10	13-2	13-6	13-10	14-2	14-5	14-8	15-0	15-3	15-6	15-9	15-11	16-2
	16.0	10-2	10-7	11-0	11-4	11-8	12-0	12-3	12-7	12-10	13-1	13-4	13-7	13-10	14-1	14-3	14-6	14-8
	19.2	9-7	10-0	10-4	10-8	11-0	11-3	11-7	11-10	12-1	12-4	12-7	12-10	13-0	13-3	13-5	13-8	13-10
	24.0	8-11	9-3	9-7	9-11	10-2	10-6	10-9	11-0	11-3	11-5	11-8	11-11	12-1	12-3	12-6	12-8	12-10
2 × 10	12.0	14-4	14-11	15-5	15-11	16-5	16-10	17-3	17-8	18-0	18-5	18-9	19-1	19-5	19-9	20-1	20-4	20-8
	16.0	13-0	13-6	14-0	14-6	14-11	15-3	15-8	16-0	16-5	16-9	17-0	17-4	17-8	17-11	18-3	18-6	18-9
	19.2	12-3	12-9	13-2	13-7	14-0	14-5	14-9	15-1	15-5	15-9	16-0	16-4	16-7	16-11	17-2	17-5	17-8
	24.0	8-11	11-10	12-3	12-8	13-0	13-4	13-8	14-0	14-4	14-7	14-11	15-2	15-5	15-8	15-11	16-2	16-5
2 × 12	12.0	17-5	18-1	18-9	19-4	19-11	20-6	21-0	21-6	21-11	22-5	22-10	23-3	23-7	24-0	24-5	24-9	25-1
	16.0	15-10	16-5	17-0	17-7	18-1	18-7	19-1	19-6	19-11	20-4	20-9	21-1	21-6	21-10	22-2	22-6	22-10
	19.2	14-11	15-6	16-0	16-7	17-0	17-6	17-11	18-4	18-9	19-2	19-6	19-10	20-2	20-6	20-10	21-2	21-6
	24.0	13-10	14-4	14-11	15-4	15-10	16-3	16-8	17-0	17-5	17-9	18-1	18-5	18-9	19-1	19-4	19-8	19-11
<i>F_b</i>	12.0	862	932	1000	1066	1129	1191	1251	1310	1368	1424	1480	1534	1587	1640	1692	1742	1793
	16.0	949	1026	1101	1173	1243	1311	1377	1442	1506	1568	1629	1688	1747	1805	1862	1918	1973
	19.2	1008	1090	1170	1246	1321	1393	1464	1533	1600	1666	1731	1794	1857	1918	1978	2038	2097
	24.0	1086	1174	1260	1343	1423	1501	1577	1651	1724	1795	1864	1933	2000	2066	2131	2195	2258

NOTE: The required bending design value, *F_b*, in pounds per square inch (× 0.00689 for N/mm²) is shown at the bottom of this table and is applicable to all lumber sizes shown. Spans are shown in feet-inches (1 foot = 304.8 mm, 1 inch = 25.4 mm) and are limited to 26 feet (7925 mm) and less.

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Table 9.3 shows one joist table from the Uniform Building Code. Similar tables are published by the National Forest Products Association, the Southern Forest Products Association, other trade groups, and reference sources. For a given joist size and spacing and a given modulus of elasticity, the table gives the maximum allowable span when the deflection is the limiting factor. Below the span is the required extreme fiber stress in bending. Most tables are established for typical floor and roof loads, so if you have unusual circumstances you need to calculate the required size and spacing using the methods of beam design.

To use the table, you can either begin with a known span and lumber species and find the required size and spacing of joists, or begin with the span and joist design and determine what design values are required to satisfy your requirements. Then you can specify a lumber species and grade that have the design values you need. The design values are found in Table 9.2.

Example 9.9

A roof must be designed to support a live load of 40 pounds per square foot and a dead load of 10 pounds per square foot. The joists will span 13 feet. If the most

readily available grade of wood joist is Douglas fir-larch #2, what size and spacing is required?

Since joists are being used, they fall in the size classification of 2 inches to 4 inches thick, 5 inches and wider. From Table 9.2(a), Douglas fir-larch #2 has a modulus of elasticity of 1,600,000 psi and an *F_b* value (875 psi) modified for repetitive member use (*C_r* = 1.15), load duration (*C_D* = 1.25), and size (*C_F* = 1.2) of 1509 psi.

Table 9.3 gives *E* in multiples of 1,000,000 psi, so look down the 1.6 column until you find a span of 13 feet or more. The first value to fit this requirement is 14'2", corresponding to a 2 × 8 inch joist 12 inches on center. Below the span is a value of 1368 psi for the minimum *F_b*. Since this is less than the actual value of 1509, this size and spacing will work.

6 GLUED-LAMINATED CONSTRUCTION

Glued-laminated wood members consist of a number of individual pieces of lumber glued together and finished under factory conditions for use as beams, columns, purlins, and other structural uses. Glued-laminated construction, or *glue-lam* as it is usually referred to, is used when larger wood members are required for heavy

loads or long spans, and simple sawn timber pieces are not available or cannot meet the strength requirements. Glue-lam construction is also used where unusual structural shapes are required and appearance is a consideration. In addition to being fabricated in simple rectangular shapes, glue-lam members can be formed into arches, tapered forms, and pitched shapes.

Glue-lam members are manufactured in standard sizes of width and depth. In most cases, 1 1/2-inch actual depth pieces are used, so the overall depth is some multiple of 1 1/2 depending on how many laminations are used. Three-quarter-inch thick pieces are used if a tight curve must be formed. Standard widths and depths are shown in Figure 9.3.

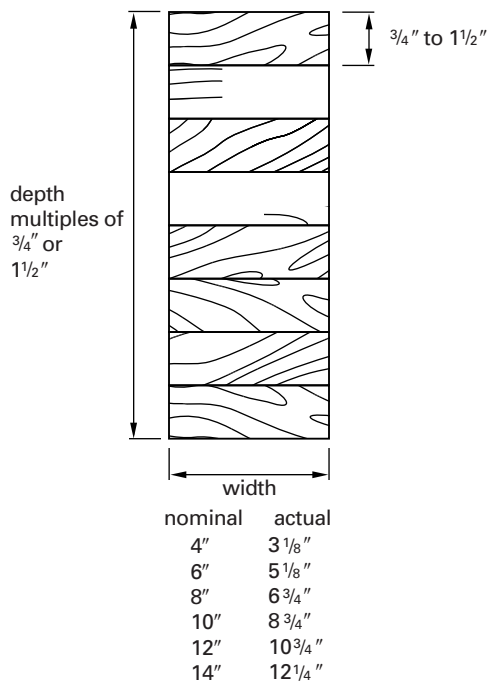


Figure 9.3 Glued Laminated Beam

Because individual pieces can be selected free from certain defects and seasoned to the proper moisture content, and the entire manufacturing process is conducted under carefully controlled conditions, the allowable stresses for glue-lam construction are higher than for solid, sawn lumber. Although glue-lam beams are usually loaded in the direction perpendicular to the laminations, they can be loaded in either direction to suit the requirements of the design. Tables of design values give allowable stresses about both axes.

For structural purposes, glue-lams are designated by size and a commonly used symbol that specifies its stress rating. For design purposes, glue-lams are available in three appearance grades: *industrial*, *architectural*, and *premium*. These do not affect the structural properties but only designate the final look and finishing of the member. Industrial is used where appearance is not a primary concern, while premium is used where the finest appearance is important. Architectural grade is used where appearance is a factor but the best grade is not required.

7 PLANKING

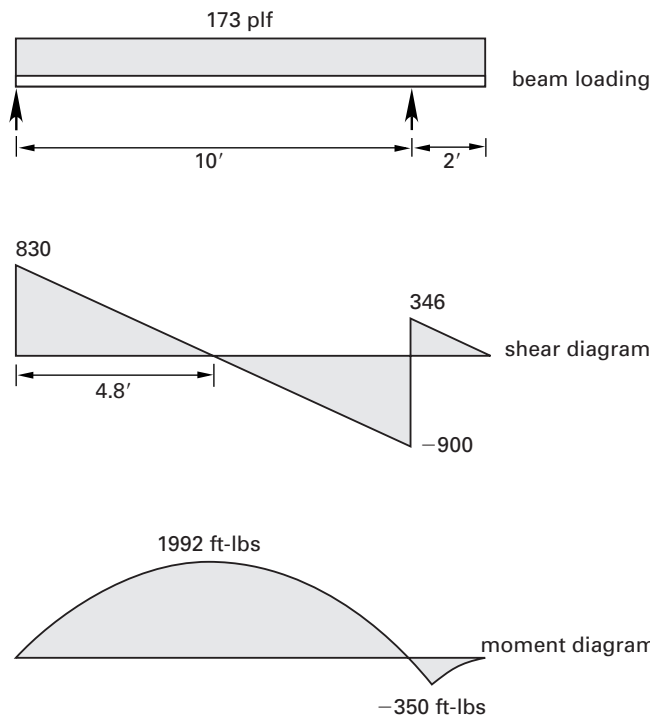
Wood planking, or *decking* as it is often called, is solid or laminated lumber laid on its face spanning between beams. Planking is available in nominal thicknesses of 2, 3, 4, and 5 inches with actual sizes varying with manufacturer and whether the piece is solid or laminated. All planking has some type of tongue-and-groove edging, so the pieces fit solidly together and load can be distributed among adjacent pieces.

The allowable span depends on the thickness of the planking and load to be supported, and ranges from 4 feet to 20 feet. Planking is often used in heavy timber construction with glued laminated beams and purlins. Planking has the advantages of easy installation, attractive appearance, and efficient use of material since the planking serves as floor structure, finish floor, and finish ceiling below. Its primary disadvantages are that there is no place to put additional insulation or conceal mechanical and electrical services.

SAMPLE QUESTIONS

1. Which of the following statements is correct?
 - A. Glue-laminated beams may shrink excessively once on the job site.
 - B. Selecting a premium appearance grade glue-lam allows an increase in allowable bending stress.
 - C. 3/4-inch laminations are used in glue-lam beams primarily when a tight curve must be formed.
 - D. A nominal 8-inch wide glue-lam is actually 7 1/2 inches wide.

2. An outdoor deck in a mountain region is supported on #2 redwood joists with an F_b of 925 psi and an F_v of 80 psi. The joists are cantilevered 2 feet as shown in the figures. If the snow load creates a uniform load on each joist of 173 pounds per foot, what size joist is required (neglecting the weight of the joist and considering both bending and horizontal shear)?



- A. 2 × 6
- B. 2 × 8
- C. 2 × 10
- D. 2 × 12

3. Which of the following is usually not checked when designing floor joists for heavy loads?

- A. vertical shear
- B. horizontal shear
- C. moment effects
- D. deflection

The answers to questions 4 through 6 can be found on the following key list. Select only one answer for each question.

- A0 appearance grade
- A1 buckling length factor
- A2 compression parallel to grain
- A3 compression perpendicular to grain
- A4 deflection cracking
- A5 extreme fiber in bending
- A6 fiber saturation point
- A7 lateral support
- A8 machine grading
- A9 modulus of elasticity
- B0 moisture content
- B1 size categories
- B2 slenderness ratio
- B3 vertical shear
- B4 visual grading

4. What must be used in designing bearing plates for girders?

5. What would be used to design a column with its lower end encased in concrete?

6. What is as important as wood species in selecting allowable stresses?

7. Which of the following affect the selection of a value for allowable tension parallel to the grain, before modification due to duration of loading?

- I. wood species
- II. size of member
- III. single or multiple member use
- IV. grade of lumber
- V. duration of loading

- A. I, II, and IV
- B. I, III, and IV
- C. II, IV, and V
- D. all of the above

8. A wood column is anchored solidly in concrete at its base and supports a rigid beam in such a way that the top of the column is free to rotate. If the actual length is 12 feet, what is the effective length?

- A. 7.8 feet
- B. 9.6 feet
- C. 12.0 feet
- D. 25.2 feet

9. The maximum bending moment on a 20-foot long beam is 8200 ft-lbs. If the beam is Douglas fir-larch dense #1 and lateral support is provided, what is the most economical size that should be used? (Neglect effects of deflection. Assume the allowable stress is to be 1800 psi for 4-inch wide beams and 1550 psi for 6-inch wide beams.)

- A. 4×10
- B. 4×12
- C. 6×8
- D. 6×10

10. Select the incorrect statement.

- A. Design values can be increased 60 percent for wind loading on wood structures.
- B. Structural lumber should be specified at an absolute maximum moisture content of 19 percent.
- C. Horizontal shear is almost always more critical than deflection or bending in short, heavily loaded beams.
- D. Beams can be notched a maximum of one-sixth of their depth at end supports.