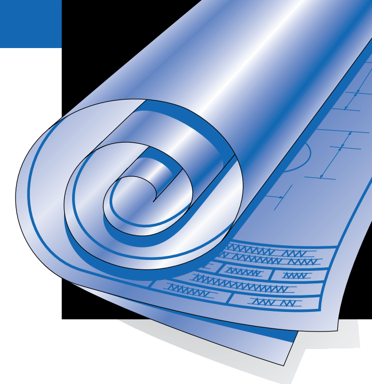


Calculating Fire Resistance Of Glulam Beams And Columns

Number EWS Y245

May 1998

Introduction

Glulam beams and columns provide architectural warmth and beauty along with structural strength and natural fire resistance. In the presence of fire, the outer portion of a glulam member becomes charred. This layer of charred wood then functions as an insulator, helping to protect the undamaged interior of the member from the heat. The rate of advancement of this insulating char layer into the remaining, undamaged portion of the member has been measured (approximately 0.025 inches (0.6 mm) per minute) and forms the theoretical basis of the equations used to predict fire endurance.[1] Tests on loaded beams and columns[2] have confirmed the validity of the equations in predicting their load-carrying ability under fire conditions and the method has been recognized by all three U.S. model building codes.

Design Methodology

Calculation of the ability of a glulam beam or column to resist fire for up to one hour is accepted in the 1997 Uniform Building Code (UBC), Volume 1, Section 703.3 and UBC Volume 3, Section 7.727, and in the 1997 Standard Building Code, Section 709.6.3. The method is also recognized in Section 6.1 of *Guidelines for Determining Fire Resistance Ratings of Building Elements*, published by Building Officials and Code Administrators International, Inc. (BOCA). The equations apply to members with fire on three or four sides.

1 Lie, T. T., 1977. A method for assessing the fire resistance of laminated timber beams and columns. Fire Research Section, Division of Building Research, National Research Council of Canada, Ottawa, Ont., Canada.

2 Fackler, J. P., 1961. Essais de résistance au feu. Centre Scintifique et Technique du Bâtiment, Cahier 415., et al.

Beams:

Fire on 3 sides $t = 2.54ZB\left[4 - \frac{B}{D}\right]$ ....(1)

Fire on 4 sides $t = 2.54ZB\left[4 - \frac{2B}{D}\right]$ ....(2)

Columns:

Fire on 3 sides $t = 2.54ZB\left[3 - \frac{B}{2D}\right]$ ....(3)

Fire on 4 sides $t = 2.54ZB\left[3 - \frac{B}{D}\right]$ ....(4)

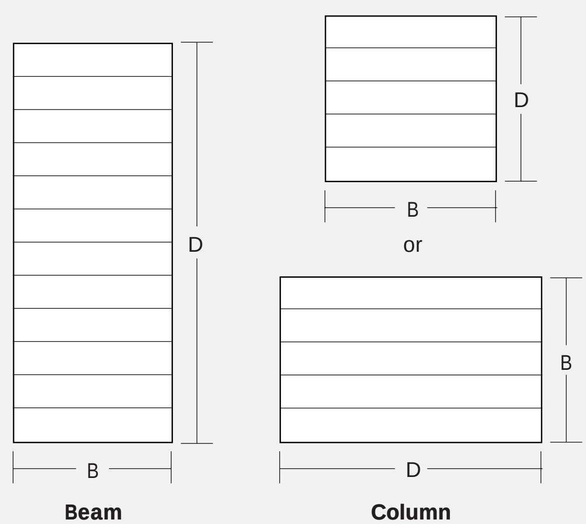
Where:

t = fire resistance in minutes

Z = partial load compensation factor (see Figure 3) which is a function of applied load to design capacity

FIGURE 1

DIMENSIONS FOR CALCULATION OF FIRE RESISTANCE
Where B is always the lead dimension.



ENGINEERED WOOD SYSTEMS APA EWS

B = the breadth or width of a beam or the smaller dimension of a column (in.) (see Figure 1)

D = the depth of a beam or the larger dimension of a column (in.) (see Figure 1)

These equations apply to glulams with a minimum nominal size of six inches by six inches or more before exposure to fire. Equations 1 and 3 are accurate only when the smallest dimension (B) is the side not exposed to the fire. When a beam or column is partially recessed into a wall, floor or ceiling, the full dimension of the member, including the portion of the column recessed into the wall, floor or ceiling may be used in the calculations to obtain the maximum calculated fire resistance. (The Standard Building Code requires the use of the full column dimension in calculating fire endurance.)

Equations 3 and 4 are slightly altered from the way they appear in the U.S. building codes. The dimensions B and D are reversed to maintain consistency and clarity of notation on glulam beams and columns (see Figure 1).

Tables 1a, 1b and 1c show the minimum dimensions of a glulam member that will provide 100% design capacity and one-hour fire protection. These tables have been generated using Equations 1-4.

Beams and columns with dimensions less than those shown in Tables 1a, 1b and 1c, but at least 6 inches by 6 inches nominal size, may meet the requirements for a one-hour fire resistance when the member is over-designed for the applied load. This principle is demonstrated in the design examples that follow.

Specifying A One-Hour Fire-Resistant Glulam

Tension laminations of glulam beams are always positioned as the outermost laminations of the beam subjected to maximum tension stresses, and in a fire, the outermost fibers in a wood member are the first to be damaged. For this reason, when a one-hour rating is required for a glulam beam, the designer should specify one additional tension lamination in place of a core lamination (see Figure 2) and the glulam should be marked “Fire-rated one-hour” by the manufacturer. For a balanced beam layup, an additional tension lamination should be added to both outer zones. An additional tension lamination is not required for columns and arches.

FIGURE 2

TYPICAL UNBALANCED GLULAM BEAM LAYUPS
FOR UNRATED AND ONE-HOUR FIRE RESISTANCE
One extra tension lamination added for one-hour resistance.

Unrated	One Hour
Outer Compression	Outer Compression
Inner Comp.	Inner Comp.
Inner Comp.	Inner Comp.
Core	Core
Core	Core
Core	Core
Core	Core
Core	Core
Core	Inner Tension
Inner Tension	Inner Tension
Inner Tension	Extra Outer Tension
Outer Tension	Outer Tension

Fasteners

Because metal fasteners conduct heat directly into the member, exposed fasteners must be given rated protection from fire that is equivalent to that expected of the member. For a one-hour rating, sufficient wood, gypsum wallboard or other material must be applied to protect the exposed portions of the fasteners for one hour. This may be 1-1/2 inches (38 mm) of wood, 5/8 inch (16 mm) Type X gypsum board or other approved material. Example details can be found in Figures 9-14.

Design Examples For One-Hour Fire Rating

Glulam Beam Example

Assume a simply supported roof beam is to span 30 feet, carry 240 lb/ft of total load (dead load plus snow load) and be used in a dry service condition. It is continuously supported along its compression side and will have three sides exposed to fire. A one-hour rating is required. The beam used will be a 24F-V4/DF (Douglas-fir) with the following allowable design stresses:

F_b = 2400 psi

E = 1.8 x 10^6 psi

F_v = 190 psi

TABLE 1a

Member Type	Beam									
Fire Exposure	Fire Three Sides					Fire Four Sides				
Beam Width (in.)	6-3/4	8-1/2	8-3/4	10-1/2	10-3/4	6-3/4	8-1/2	8-3/4	10-1/2	10-3/4
Minimum Depth (in.): 1-1/2" thick Laminations	13-1/2	–	7-1/2	–	6	27	–	13-1/2	–	12
Minimum Depth (in.): 1-3/8" thick Laminations	13-3/8	6-7/8	–	6-7/8	–	27-1/2	13-3/4	–	12-3/8	–

TABLE 1b

Member Type	Column							
Fire Exposure	Fire Three Sides*							
$K_e l/d$ Condition[(a)]	≤ 11				> 11			
Column Width (in.)	8-1/2	8-3/4	10-1/2	10-3/4	8-1/2	8-3/4	10-1/2	10-3/4
Minimum Depth (in.): 1-1/2" thick Laminations	–	9	–	7-1/2	–	15	–	10-1/2
Minimum Depth (in.): 1-3/8" thick Laminations	8-1/4	–	8-1/4	–	19-1/4	–	9-5/8	–

*Minimum dimensions are only valid when the unexposed side of the column is the smaller side.

(a) See Figure 8.

TABLE 1c

Member Type	Column							
Fire Exposure	Fire Four Sides							
$K_e l/d$ Condition[(a)]	≤ 11				> 11			
Column Width (in.)	8-1/2	8-3/4	10-1/2	10-3/4	8-1/2	8-3/4	10-1/2	10-3/4
Minimum Depth (in.): 1-1/2" thick Laminations	–	12	–	10-1/2	–	30	–	13-1/2
Minimum Depth (in.): 1-3/8" thick Laminations	12-3/8	–	9-5/8	–	38-1/2	–	13-3/4	–

(a) See Figure 8.

General Note for Tables 1a, 1b and 1c:
Glulam members having a net width of 8-1/2" or 10-1/2" are typically manufactured using 1-3/8" thick laminations. Glulam members having a net width of 8-3/4" or 10-3/4" are typically manufactured using 1-1/2" thick laminations.

What size glulam beam should be used? Use an initial estimate of the dead weight of the beam as 25 pounds per lineal foot (plf). Total design load = 240 + 25 = 265 plf.

From Table 3 of EWS Data File *Glued Laminated Beam Design Tables*, select a 5-1/8 x 13-1/2 beam with total capacity of 266 plf which is greater than 265 plf.

Determining the actual beam depth that will continue to carry the design load for one hour is aided by the use of Figure 4, *Beams – Fire 3 Sides*. From this graph, the range of depths that might be practical to use can by anywhere from approximately 12 to 32 inches. Obviously, this beam must be deeper than 13-1/2 inches as the beam in this example is stressed to approximately 100% of design capacity.

All of these 5-1/8-inch-wide beams will retain 50-60% of design after one hour. An initial estimate of a percentage that corresponds with a practical beam depth is 55%.

$$\text{Approximate } S_{Required} = \frac{142}{0.55} = 258 \text{ in.}^3$$

$$\text{Approximate } d_{Required} = \sqrt{\frac{6S}{b}} = \sqrt{\frac{6(258)}{5.125}} = 17.4 \text{ in.}$$

Try an 18-inch-deep beam with $S = 277 \text{ in.}^3$

Determine if this beam will have sufficient strength left after one hour of fire exposure to continue to carry the design load by determining the ratio of applied moment to design flexural capacity. Beam size will also have to be checked for shear and deflection.

Determine F_b'

$$\text{Volume factor} = C_v = \left(\frac{21}{L}\right)^{\frac{1}{10}} \left(\frac{12}{d}\right)^{\frac{1}{10}} \left(\frac{5.125}{b}\right)^{\frac{1}{10}}$$

$$C_v = \left(\frac{21}{30}\right)^{\frac{1}{10}} \left(\frac{12}{18}\right)^{\frac{1}{10}} \left(\frac{5.125}{5.125}\right)^{\frac{1}{10}} = 0.9266$$

$$F_b' = F_b C_D C_v = (2{,}400)(1.15)(0.9266) = 2{,}557 \text{ lb/in.}^2$$

Determine f_b

Calculate beam weight using 35 lb/ft^3

$$\text{Beam weight} = \frac{(5.125)(18)(12)}{12^3}(35) = 22.4 \text{ lb/ft}$$

$$M_{Applied} = w\frac{L^2}{8} = (240 + 22.4)\frac{30^2}{8} = 29{,}520 \text{ ft-lb}$$

$$= 354{,}240 \text{ in.-lb}$$

$$f_b = \frac{M}{S} = \frac{354{,}240}{277} = 1{,}279 \text{ lb/in.}^2$$

Check the ratio of applied moment to flexural capacity

$$\frac{f_b}{F_b'} = \frac{1{,}279}{2{,}557} = 0.500 < 55\% \Rightarrow \text{OK}$$

Check fire endurance:

From Figure 3, for a beam loaded to 50% of capacity, Z is approximately 1.3.

Using Equation 1:

$$t = 2.54(1.3)(5.125)\left[4 - \frac{5.125}{18.0}\right] = 62.9 \text{ minutes} > 60 \Rightarrow \text{OK}$$

This beam has a moment capacity that is significantly greater than is needed if the one-hour fire resistance is not a requirement. In some cases, a wider beam may be required to satisfy a beam depth limitation while still meeting the one-hour fire resistance requirement. For instance, any 6-3/4-inch-wide beam that is 13-1/2 inches deep, and has the extra tension lamination, will carry 100% of its design load after one hour of fire exposure on three sides. (Table 1a and Figure 4.)

The designer will also need to confirm that the design shear and deflection values for the trial beam size are less than 50% of these capacities.

When specifying the beam, advise the manufacturer to eliminate one core lamination and substitute one additional tension lamination (Figure 2) and mark the beam "Fire-rated one-hour."

Glulam Column Example

An existing building is to be remodeled with a change of occupancy requiring that the glulam columns meet a one-hour fire-resistance. The existing glulam column is 22 feet high, measures 8-3/4 inches wide by 10-1/2 inches deep and will remain dry in service. It supports a concentrated total floor load (DL + LL) of 50,000 lb. ($C_D = 1.0$) applied concentrically to the top of the column. The column is not subjected to any lateral loads. From the original specifications, the glulam is a Douglas-fir combination 5. Determine if the column is adequate to carry the imposed axial load for one hour with fire on four sides and how long it can be expected to carry the applied load? If it is not adequate, determine what size column is required?

To answer these questions, the total load capacity of the column must be determined along with the percentage of the total load capacity used by the applied load and the partial-load compensation factor, Z.

Determine Load Capacity

$d = 8.75$ in.

$A = 8.75(10.5) = 91.9 \text{ in.}^2$

$C_D = 1.0$ for DL plus floor LL

$E = E' = 2{,}000{,}000 \text{ lb/in.}^2$

$F_c = 2{,}400 \text{ lb/in.}^2$

$l = 22(12) = 264$ in.

$K_e = 1.0$ (see Figure 8) Column is assumed to be pinned at both ends.

$l_e = l\,K_e = 264(1.0) = 264$ in.

$$\frac{l_e}{d} = \frac{264}{8.75} = 30.17$$

$K_{cE} = 0.418$

$c = 0.9$

Where: E = tabulated modulus of elasticity (lb/in.^{2})

F_c = tabulated compression design value parallel to grain (lb/in.^{2})

A = area of cross section (in.^{2})

d = least dimension being evaluated for potential buckling (in.)

L = column length (ft.)

l = length of column (in.)

l_e = $l\,K_e$ = effective length of column (in.)

K_e = buckling length coefficient for compression members

c = coefficient that depends on member type (0.9 for glulam)

K_{cE} = coefficient that depends on the coefficient of variation of the member (0.418 for glulam)

F_c^* = tabulated compression design value multiplied by all applicable adjustment factors except C_p (lb/in.^{2})

$$F_{cE} = \frac{K_{cE}E'}{\left(\frac{l_e}{d}\right)^2} = \frac{0.418(2{,}000{,}000)}{30.17^2} = 918 \text{ lb/in.}^2$$

$$\frac{F_{cE}}{F_c^*} = \frac{918}{2{,}400} = 0.382$$

$$C_p = \frac{1 + \frac{F_{cE}}{F_c^*}}{2c} - \sqrt{\left[\frac{1 + \frac{F_{cE}}{F_c^*}}{2c}\right]^2 - \frac{\left(\frac{F_{cE}}{F_c^*}\right)}{c}}$$

$$= \frac{1 + 0.382}{2(0.9)} - \sqrt{\left[\frac{1 + 0.382}{2(0.9)}\right]^2 - \frac{0.382}{0.9}} = 0.362$$

$F_c' = F_c^* C_p$ = allowable compressive stress (lb/in.^{2})

$F_c' = 0.362(2{,}400) = 869$ psi

Axial load capacity = AF_c' = 91.9(869) = 79,861 lb > 50,000 ⇒ OK for design axial load

Check fire endurance based on ratio of applied load to design capacity

$$\frac{\textit{Applied Load}}{\textit{Design Capacity}} = \frac{50{,}000}{79{,}861} = 0.626 = 62.6\%$$

From Figure 7, for a column 8-3/4 inches wide and $l_e/d > 11$, 62.6% corresponds to about a 12-inch depth which is greater than the existing column's depth of 10-1/2 inches. The existing column will therefore not carry the applied load for one hour. To check, calculate the fire endurance.

From Figure 3, for a column with $l_e/d > 11$ and the load at 62.6% of capacity, Z is approximately 1.18.

Using equation 4:

B = 8.75 in.

D = 10.5 in.

$$t = 2.54ZB\left[3 - \frac{B}{D}\right] = 2.54(1.18)(8.75)\left[3 - \frac{8.75}{10.5}\right] =$$

57 minutes < 60 ⇒ NG

The existing column is inadequate to meet the one-hour fire-resistance requirement even though it is adequate to carry the applied load in occupancies not requiring a one-hour fire rating.

Determine column size necessary to carry the design load and *meet the one-hour requirement.*

Using Figure 7 as a guide, try a 10-3/4" x 10-1/2" glulam, Douglas-fir combination 5. Another trial option would be 8-3/4" x 13-1/2".

A = 10.75(10.5) = 112.875 in.^{2}

$l_e/d = 264/10.5 = 25.14$

$$F_{cE} = \frac{K_{cE}E'}{\left(\frac{l_e}{d}\right)^2} = \frac{0.418(2{,}000{,}000)}{25.14^2} = 1{,}323 \text{ lb/in.}^2$$

$F_c^* = 2{,}400$ lb/in.^{2}

$$\frac{F_{cE}}{F_c^*} = \frac{1{,}323}{2{,}400} = 0.5513$$

$$C_p = \frac{1 + \frac{F_{cE}}{F_c^*}}{2c} - \sqrt{\left[\frac{1 + \frac{F_{cE}}{F_c^*}}{2c}\right]^2 - \frac{\left(\frac{F_{cE}}{F_c^*}\right)}{c}}$$

$$= \frac{1 + 0.5513}{2(0.9)} - \sqrt{\left[\frac{1 + 0.5513}{2(0.9)}\right]^2 - \frac{0.5513}{0.9}} = 0.5010$$

$F_c' = 0.5010(2{,}400) = 1{,}202$ lb/in.^{2}

Axial load capacity = Af_c' = 112.875(1,202) = 135,676 lb ⇒ > 50,000 lbs.

Check the fire endurance

$$\frac{\textit{Applied Load}}{\textit{Maximum Capacity}} = \frac{50{,}000}{135{,}676} = 0.368 = 36.8\%$$

Z, from Figure 3, is 1.3.

Using equation 4:

B = 10.5 in.

D = 10.75 in.

$$t = 2.54ZB\left[3 - \frac{B}{D}\right] = 2.54(1.3)(10.5)\left[3 - \frac{10.5}{10.75}\right] =$$

70 minutes > 60 OK

Summary

As shown by the proceeding examples, glued laminated timber members can be designed to provide a one-hour fire rating when required. Tables 1a, 1b and 1c provide basic minimum dimensions for one-hour fire-rated glulam beams and columns when the applied load represents 100% of the member design capacity. Figures 4, 5, 6 and 7 provide estimated sizes of beams and columns that will satisfy a requirement for a one-hour fire rating when the member is loaded to less than 100% of capacity.

For additional information related to the design of glulams, contact *Engineered Wood Systems* at: P.O. Box 11700, Tacoma, Washington 98411-0700, Phone (253) 565-6600, Fax (253) 565-7265.

FIGURE 3

FACTOR Z AS A PERCENTAGE OF DESIGN CAPACITY

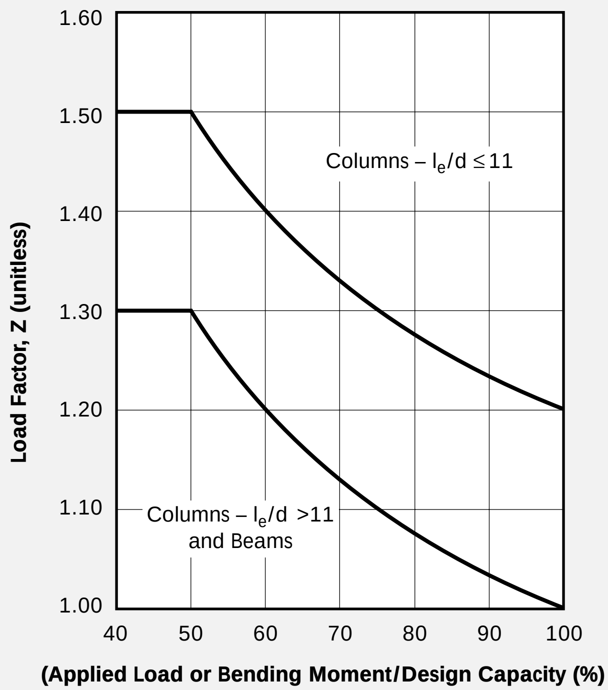
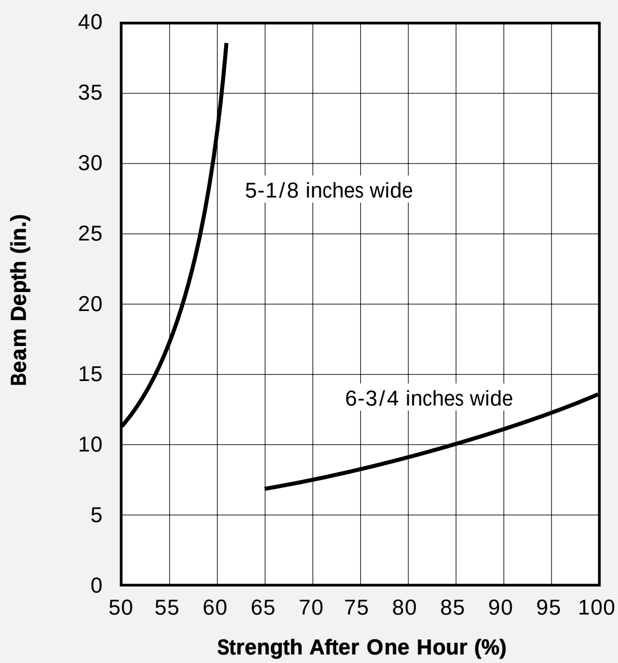


FIGURE 4

BEAMS – FIRE 3 SIDES



(Beams wider than 6-3/4" will generally carry 100% of capacity for 1 hour provided they are as deep as they are wide.)

FIGURE 5

BEAMS – FIRE 4 SIDES

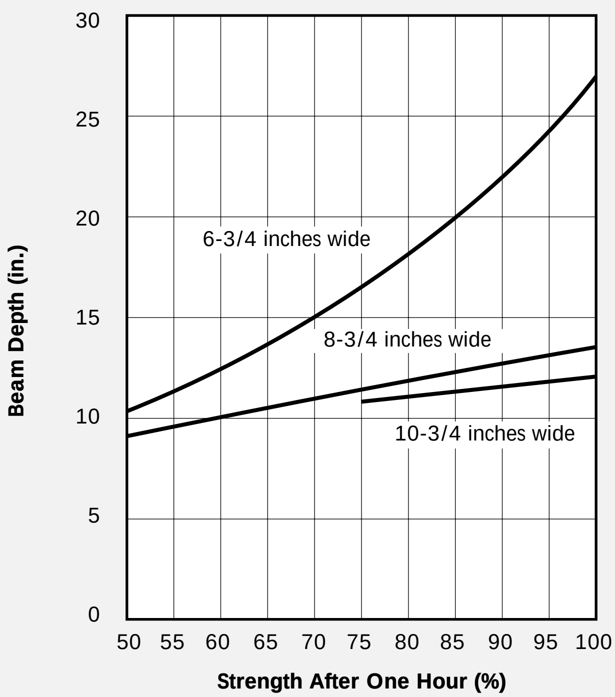


FIGURE 7

COLUMNS – FIRE 4 SIDES

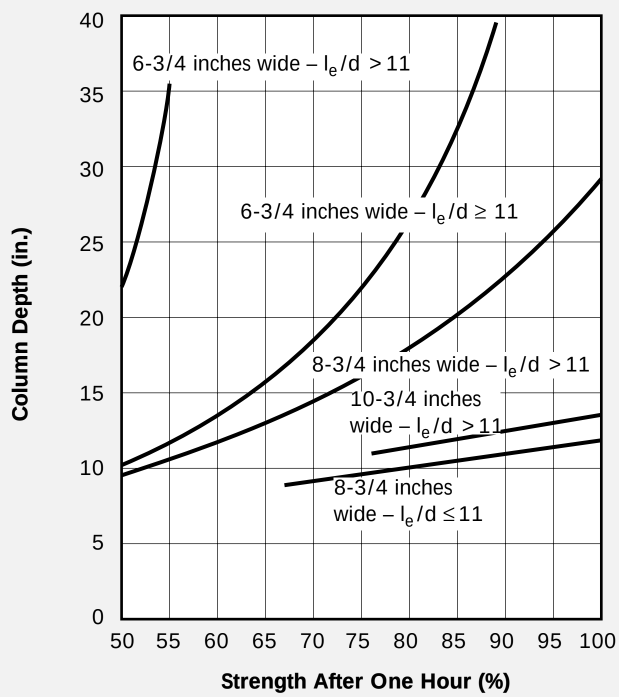


FIGURE 6

COLUMNS – FIRE 3 SIDES

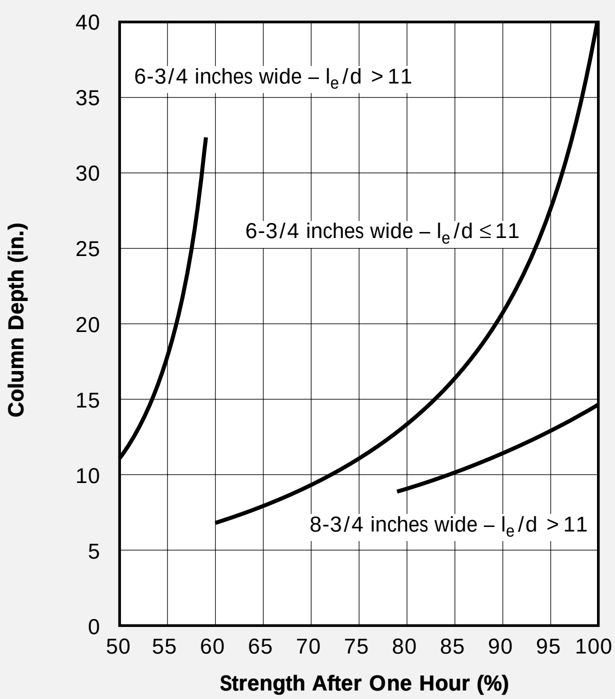
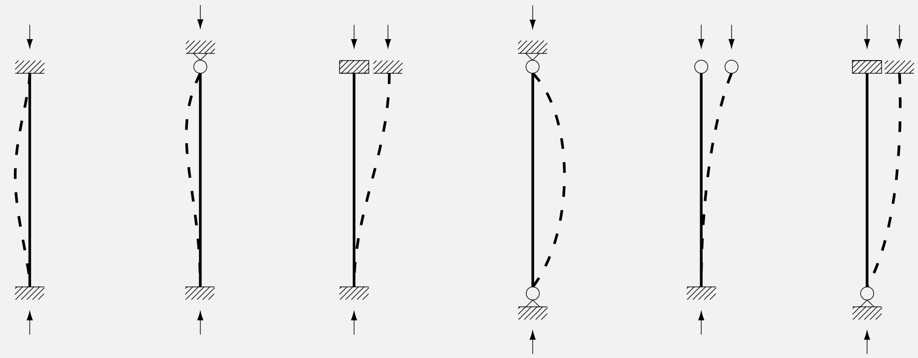


FIGURE 8

APPENDIX N, 1997 NDS – EFFECTIVE COLUMN LENGTH

Buckling modes



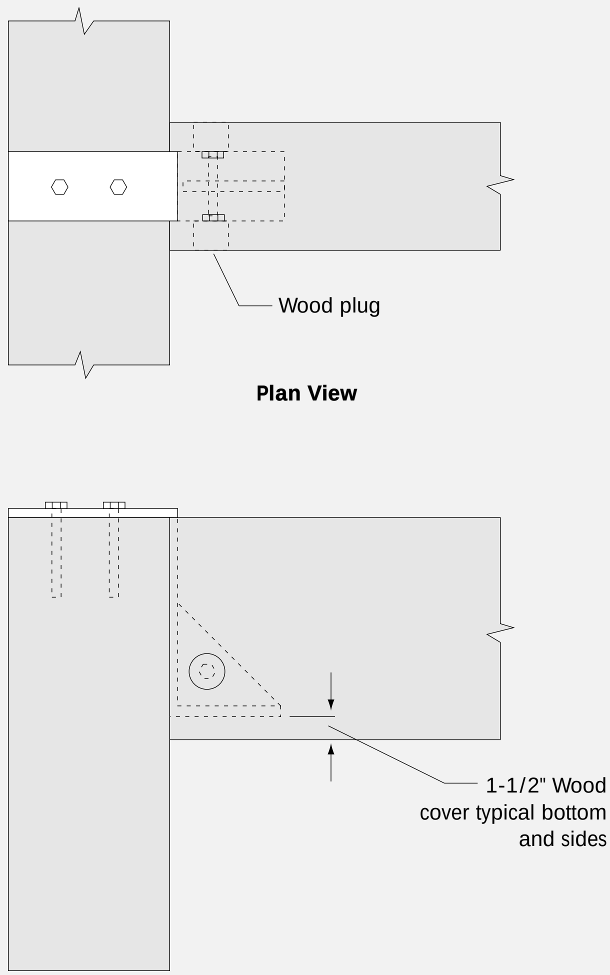
Theoretical K_e value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design K_e when ideal conditions approximated	0.65	0.8	1.2	1.0	2.1	2.4

End condition code

- Rotation fixed, translation fixed
- Rotation free, translation fixed
- Rotation fixed, translation free
- Rotation free, translation free

FIGURE 9

BEAM TO GIRDER – CONCEALED CONNECTION

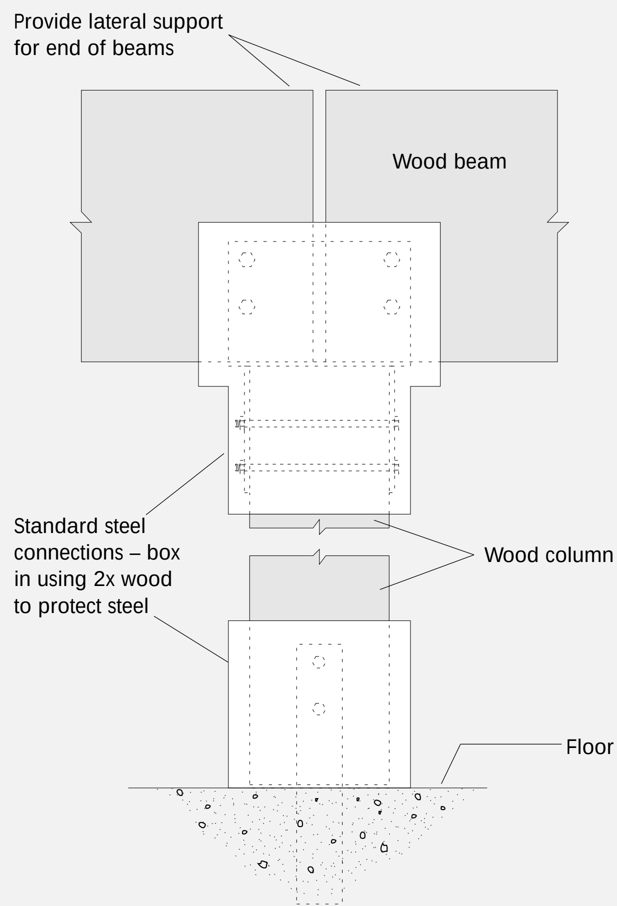


Plan View

Elevation

FIGURE 10

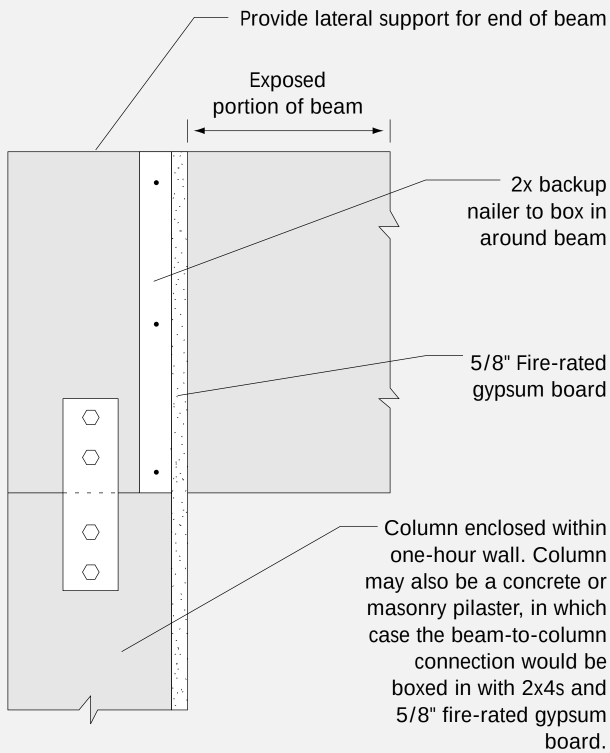
COLUMN CONNECTIONS – COVERED



Elevation

FIGURE 11

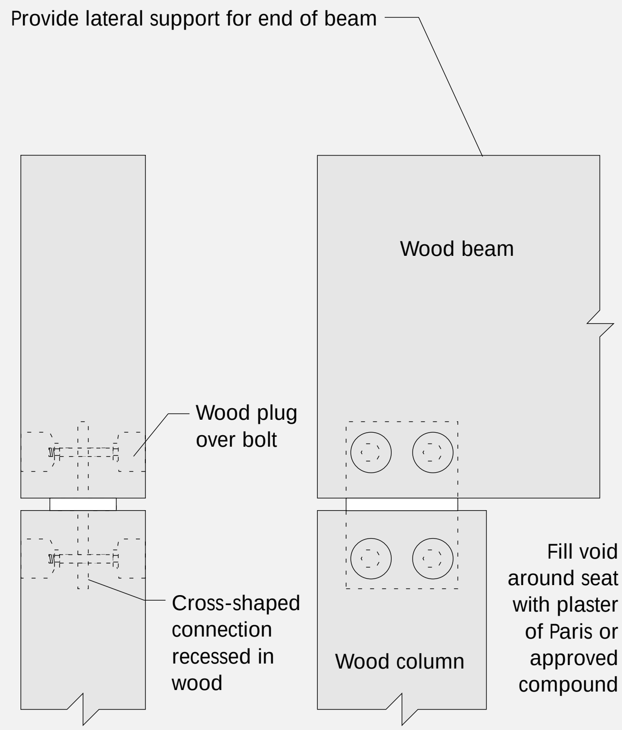
BEAM-TO-COLUMN CONNECTION
Connection not exposed to fire



Elevation

FIGURE 12

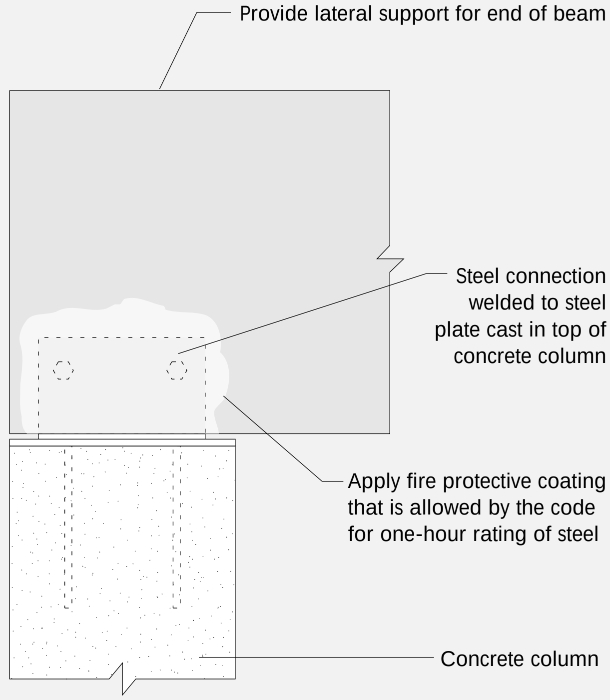
BEAM-TO-COLUMN CONNECTION
Connection exposed to fire where appearance is a factor



End View **Elevation**

FIGURE 13

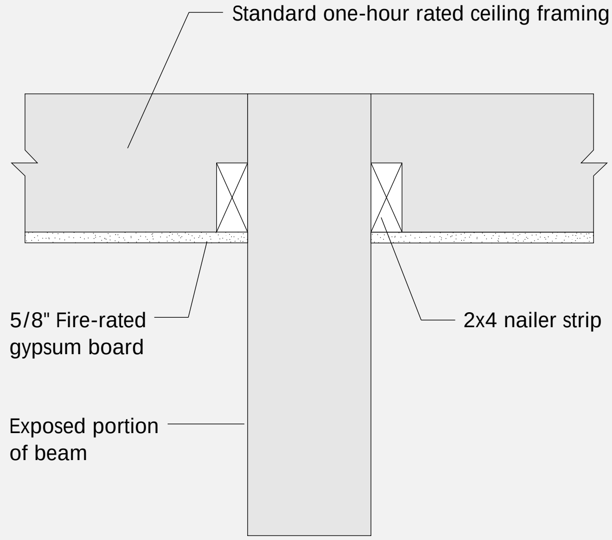
BEAM-TO-COLUMN CONNECTION
Connection exposed to fire where appearance is not a factor



Elevation

FIGURE 14

CEILING CONSTRUCTION



Section

We have field representatives in most major U.S. cities and in Canada who can help answer questions involving APA and *APA EWS* trademarked products. For additional assistance in specifying engineered wood products or systems, get in touch with your nearest APA regional office. Call or write:

WESTERN REGION
7011 So. 19th St. ▪ P.O. Box 11700
Tacoma, Washington 98411-0700
(253) 565-6600 ▪ Fax: (253) 565-7265

EASTERN REGION
2130 Barrett Park Drive, Suite 102
Kennesaw, Georgia 30144-3681
(770) 427-9371 ▪ Fax: (770) 423-1703

U.S. HEADQUARTERS AND
INTERNATIONAL MARKETING DIVISION
7011 So. 19th St. ▪ P.O. Box 11700
Tacoma, Washington 98411-0700
(253) 565-6600 ▪ Fax: (253) 565-7265
Internet Address: http://www.apawood.org

(Offices: Antwerp, Belgium; London, United Kingdom; Hamburg, Germany; Mexico City, Mexico; Tokyo, Japan.) For Caribbean/Latin America, contact headquarters in Tacoma.

The product use recommendations in this publication are based on the continuing programs of laboratory testing, product research, and comprehensive field experience of Engineered Wood Systems. However, because EWS has no control over quality of workmanship or the conditions under which engineered wood products are used, it cannot accept responsibility for product performance or designs as actually constructed. Because engineered wood product performance requirements vary geographically, consult your local architect, engineer or design professional to assure compliance with code, construction, and performance requirements.

Form No. EWS Y245/Issued May 1998/0100

ENGINEERED WOOD SYSTEMS
APA EWS