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TECHNICAL NOTE

Calculating Fire Resistance of Glulam Beams and Columns

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Introduction

Structural glued laminated timber (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 well documented (approximately 0.025 inches or 0.6 mm per minute) and forms the theoretical basis of the equations used to predict fire endurance. Full-scale fire tests on loaded beams and columns have confirmed the validity of the equations in predicting their load-carrying capability under fire conditions.

This document provides two analytical methods in calculating the fire resistance of glulam beams and columns. Both methods are based on a similar fire performance database and result in a comparable result, except that Method A is limited to a maximum fire resistance of two hours, while Method B is limited to a maximum fire resistance of one hour.

a. Chapter 16 of the National Design Specification for Wood Construction (NDS): This method is recognized in Section 722.1 of the 2021, 2018 and 2015 International Building Code (IBC).

b. Legacy Method (also known as T.T. Lie Method): This method is recognized in Section 722.6.3 of the 2012 IBC and 721.6.3 of the 2009 IBC.

Design Methodology

Method A. Chapter 16 of the NDS

Calculation of the fire resistance for glulam beams and columns for **up to two hours** is described in Chapter 16 of the NDS. The effective char depth can be estimated by using the following equations:

$$\alpha_{eff} = 1.2\beta_n t^{0.813} \qquad \text{Equation (1)}$$

Where:

α_{eff} = effective char depth (in.)

β_n = nominal char rate (in./hr.), linear char rate based on 1-hr exposure = 1.5 in./hr. for glulam

t = exposure time (hr.)

This equation applies for each exposed surface of glulam beams or columns. Effective char layer depths, α_{eff}, for each surface are summarized in Table 1, by using Equation (1).

TABLE 1

EFFECTIVE CHAR LAYER DEPTHS (β_n=1.5 INCHES/HOUR)

Required Fire Resistance (hr.)	Effective Char Layer Depth, α_{eff} (in.)
1-hour	1.8
1-1/2-hour	2.5
2-hour	3.2

To determine whether the selected glulam beam or column is qualified for a certain fire rating (e.g., 1 hr. or 2 hrs.), the induced stress calculated using reduced section properties shall not exceed the member strength. Section properties calculated using standard equations for area, section modulus and moment of inertia should be calculated using the reduced cross-sectional dimensions. The dimensions are reduced by the effective char depth, α_{eff}, for each surface exposed to fire. The average strength and capacity of glulam beams or columns exposed to fire can be estimated by multiplying the allowable design values by an adjustment factor, K, shown in Table 2. Detailed calculations are demonstrated in the design examples.

TABLE 2

ASD TO AVERAGE ULTIMATE STRENGTH ADJUSTMENT FACTOR

Member Capacity	K
Bending strength	2.85
Beam Buckling Strength	2.03
Tensile Strength	2.85
Compressive Strength	2.58
Column Buckling Strength	2.03

Method B. Legacy Method (T.T. Lie Method)

Calculation of the fire resistance of glulam beams and columns for **up to one hour** is described in Section 722.6.3 of the 2012 IBC and 721.6.3 of the 2009 IBC. The equations apply to members with fire on three or four sides.

Beams:

Fire on 3 sides $$t = 2.54ZB\left[4 - \frac{B}{D}\right]$$ Equation (2)

Fire on 4 sides $$t = 2.54ZB\left[4 - \frac{2B}{D}\right]$$ Equation (3)

Columns:

Fire on 3 sides $$t = 2.54ZB\left[3 - \frac{B}{2D}\right]$$ Equation (4)

Fire on 4 sides $$t = 2.54ZB\left[3 - \frac{B}{D}\right]$$ Equation (5)

Where:

t = fire resistance in minutes

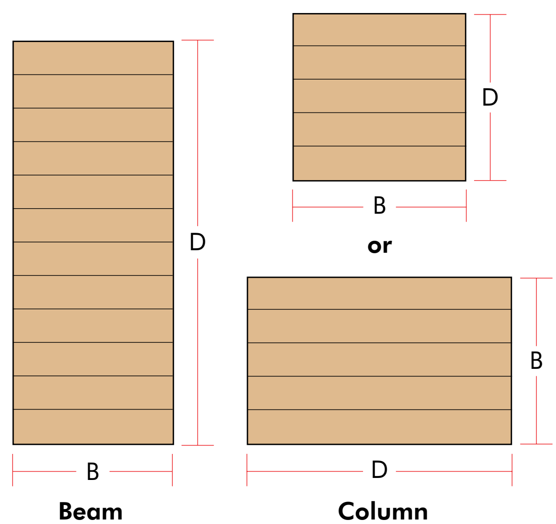
Z = partial load compensation factor (see Figure 2) which is a function of applied load to design capacity

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)

FIGURE 1

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



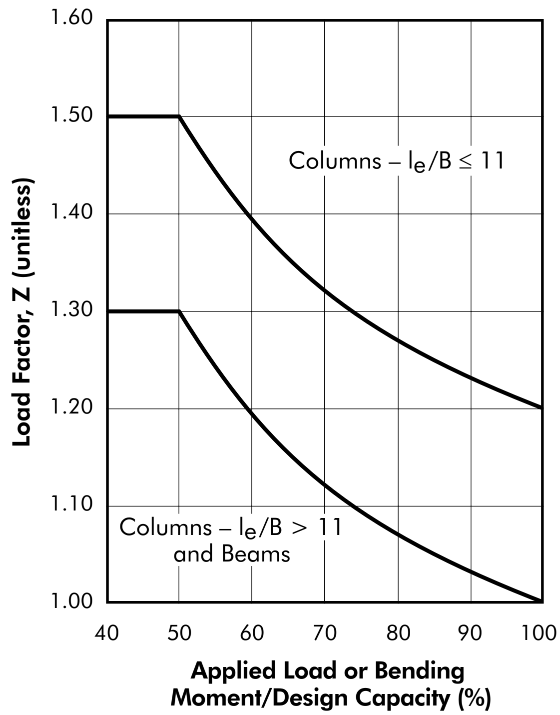
These equations apply to glulams with a minimum nominal size of six inches by six inches before exposure to fire. Equation 4 is accurate only when the smallest dimension (B) is the side not exposed to the fire. When a beam or column is partially recessed into a wall, floor or ceiling, the full dimension 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.

Equations 4 and 5 are slightly altered from the way they appear in the IBC. In the column equations, the dimensions B and D are reversed to maintain consistency and clarity of notation on glulam beams and columns (see Figure 1). B is assumed to be the narrowest dimension of the column (weak axis buckling).

Tables 3a, 3b and 3c 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 2–5.

FIGURE 2

FACTOR Z AS A PERCENTAGE OF DESIGN CAPACITY



Beams and columns with dimensions less than those shown in Tables 3a, 3b and 3c, but at least 6 inches by 6 inches nominal size, may meet the requirements for one-hour fire resistance when the member is over-designed for the applied load. This principle is demonstrated in the design examples that follow.

Figures 3 through 6 depict the required beam or column sizes for one-hour fire rating as a function of the percentage of the glulam strength after one-hour fire.

TABLE 3a

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 3b

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 7.

TABLE 3c

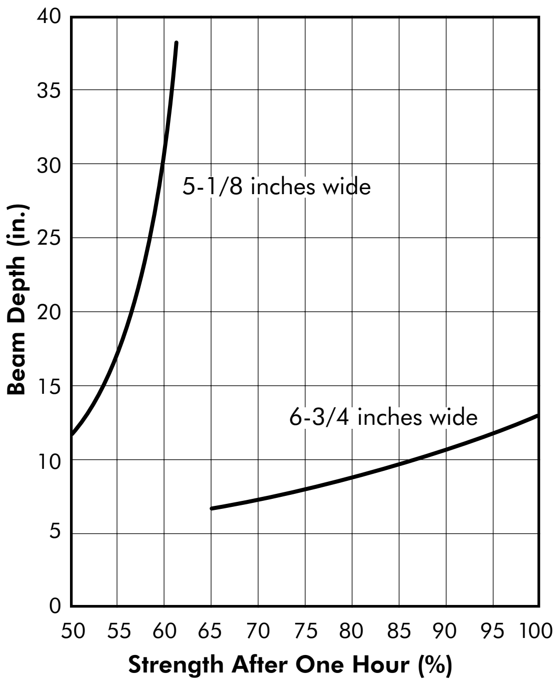
Member Type	Column							
Fire Exposure	**Fire Four Sides**							
$K_e l/d$ Condition[a]	**≤ 11**				**> 11**			
Column Width (in.)	**8-1/2**	**8-3/4**	**10-1/2**	**10-3/4**	**8-1/2**	**8-3/4**	**10-1/2**	**10-3/4**
Minimum Depth (in.): 1-1/2" thick Laminations	–	12	–	10-1/2	–	30	–	13-1/2
Minimum Depth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

a. See Figure 7.

General Note for Tables 3a, 3b and 3c:
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.

FIGURE 3

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 4

BEAMS – FIRE 4 SIDES

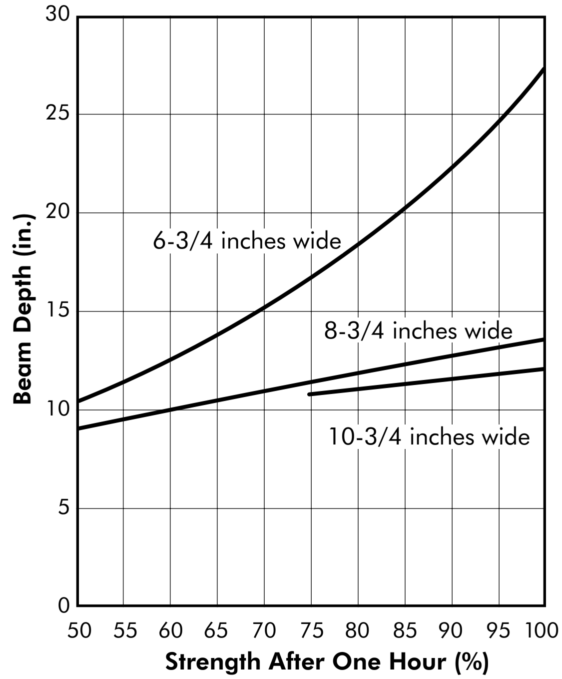


FIGURE 5

COLUMNS – FIRE 3 SIDES

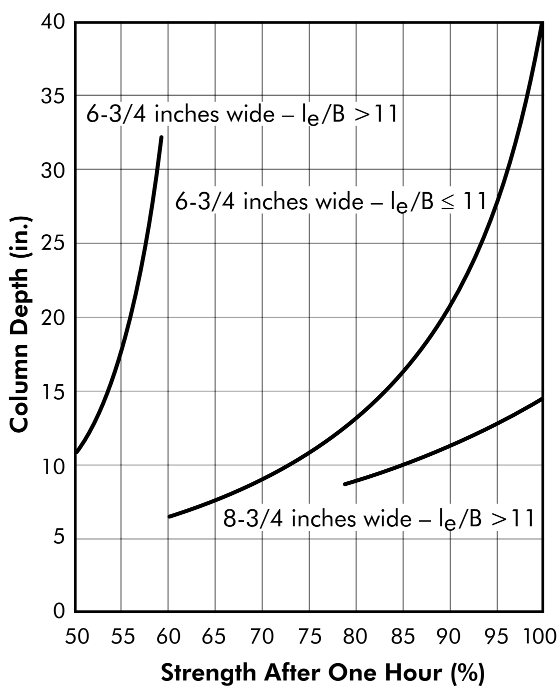


FIGURE 6

COLUMNS – FIRE 4 SIDES

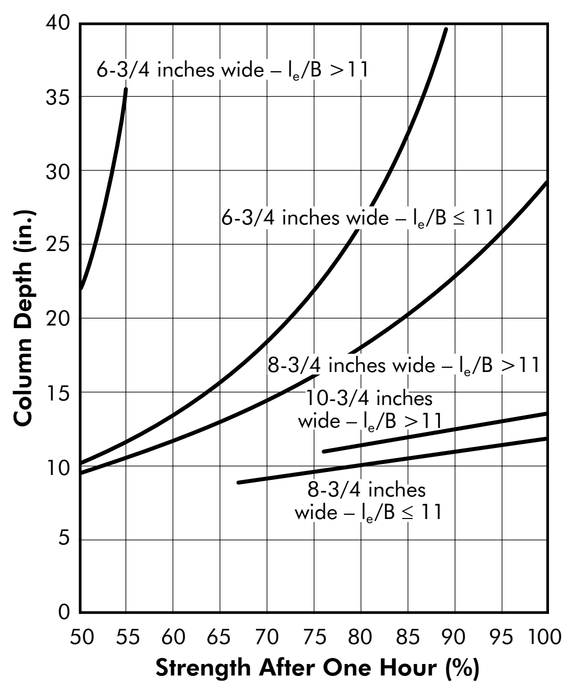
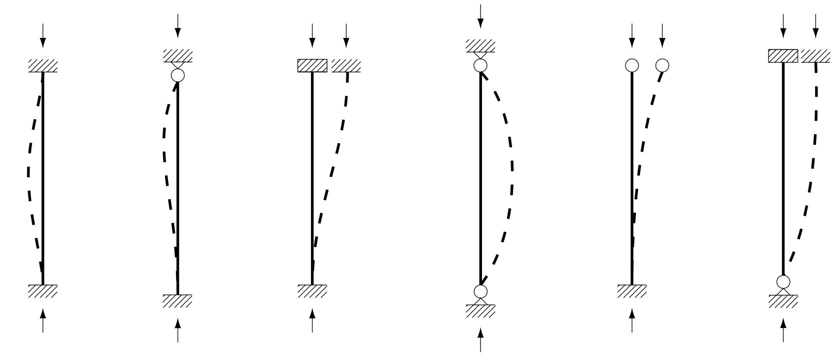


FIGURE 7

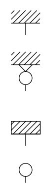
BUCKLING LENGTH COEFFICIENTS, K_e

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

Specifying a Fire-Rated 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 rating is required for a glulam beam, the designer should specify additional tension lamination(s) in place of a core lamination (see Figure 8) and the glulam should be marked "Fire-rated one-hour" or "Fire-rated 2 hours" by the manufacturer. For a balanced beam layup, additional tension lamination(s) should be added to both outer zones unless the top of the beam is not exposed to fire, in which case the additional tension lamination(s) is required only on the bottom of the beam. Additional tension lamination(s) are not required for columns and arches.

FIGURE 8

TYPICAL GLULAM BEAM LAYUPS FOR UNRATED AND FIRE-RATED GLULAM

TOP OF BEAM NOT EXPOSED TO FIRE

Unbalanced Layup			Balanced Layup		
Outer Compression	Outer Compression	Outer Compression	Outer Tension	Outer Tension	Outer Tension
Inner Compression	Inner Compression	Inner Compression	Inner Tension	Inner Tension	Inner Tension
Inner Compression	Inner Compression	Inner Compression	Inner Tension	Inner Tension	Inner Tension
Core	Core	Core	Core	Core	Core
Core	Core	Core	Core	Core	Core
Core	Core	Core	Core	Core	Core
Core	Core	Core	Core	Core	Core
Core	Core	Inner Tension	Core	Core	Inner Tension
Core	Inner Tension	Inner Tension	Core	Inner Tension	Inner Tension
Inner Tension	Inner Tension	Extra Outer Tension	Inner Tension	Inner Tension	Extra Outer Tension
Inner Tension	Extra Outer Tension	Extra Outer Tension	Inner Tension	Extra Outer Tension	Extra Outer Tension
Outer Tension	Outer Tension	Outer Tension	Outer Tension	Outer Tension	Outer Tension
Unrated	**One Hour**	**Two Hour**	**Unrated**	**One Hour**	**Two Hour**

TOP OF BEAM EXPOSED TO FIRE

Unbalanced Layup			Balanced Layup		
Outer Compression	Outer Compression	Outer Compression	Outer Tension	Outer Tension	Outer Tension
Inner Compression	Extra Outer Comp.	Extra Outer Comp.	Inner Tension	Extra Outer Tension	Extra Outer Tension
Inner Compression	Inner Compression	Extra Outer Comp.	Inner Tension	Inner Tension	Extra Outer Tension
Core	Inner Compression	Inner Compression	Core	Inner Tension	Inner Tension
Core	Core	Inner Compression	Core	Core	Inner Tension
Core	Core	Core	Core	Core	Core
Core	Core	Core	Core	Core	Core
Core	Core	Inner Tension	Core	Core	Inner Tension
Core	Inner Tension	Inner Tension	Core	Inner Tension	Inner Tension
Inner Tension	Inner Tension	Extra Outer Tension	Inner Tension	Inner Tension	Extra Outer Tension
Inner Tension	Extra Outer Tension	Extra Outer Tension	Inner Tension	Extra Outer Tension	Extra Outer Tension
Outer Tension	Outer Tension	Outer Tension	Outer Tension	Outer Tension	Outer Tension
Unrated	**One Hour**	**Two Hour**	**Unrated**	**One Hour**	**Two Hour**

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 or two-hour rating, sufficient wood, gypsum wallboard or other material must be applied to protect the exposed portions of the fasteners for one hour or two hours, respectively. This may be 1-1/2 inches (38 mm) of wood, 5/8-inch (16-mm) Type X gypsum board, other approved materials or a combination of the materials listed above. Example details can be found in Figures 9–14.

FIGURE 9

BEAM TO GIRDER – CONCEALED CONNECTION

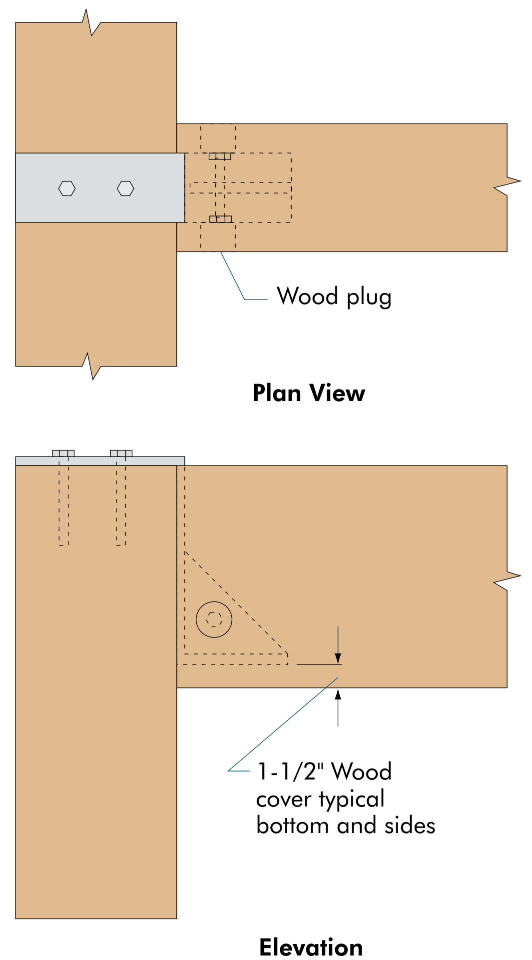


FIGURE 10

COLUMN CONNECTIONS – COVERED

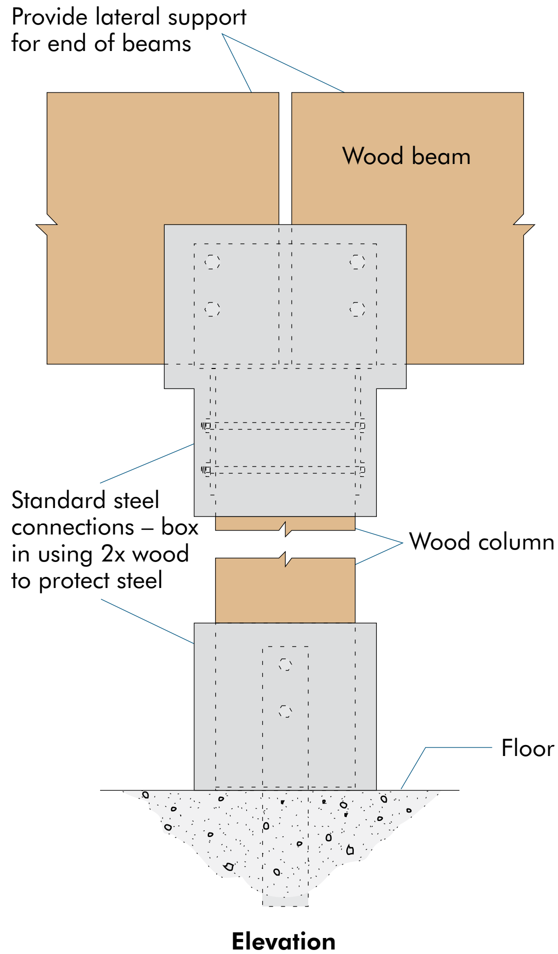


FIGURE 11

BEAM-TO-COLUMN CONNECTION
Connection not exposed to fire

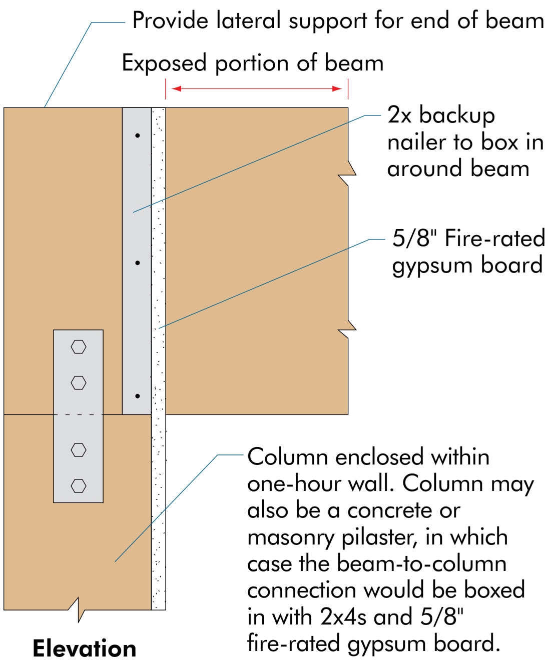


FIGURE 12

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

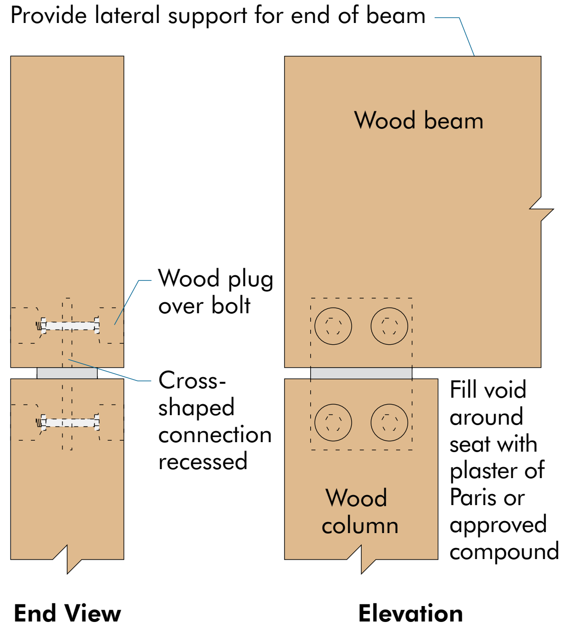


FIGURE 13

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

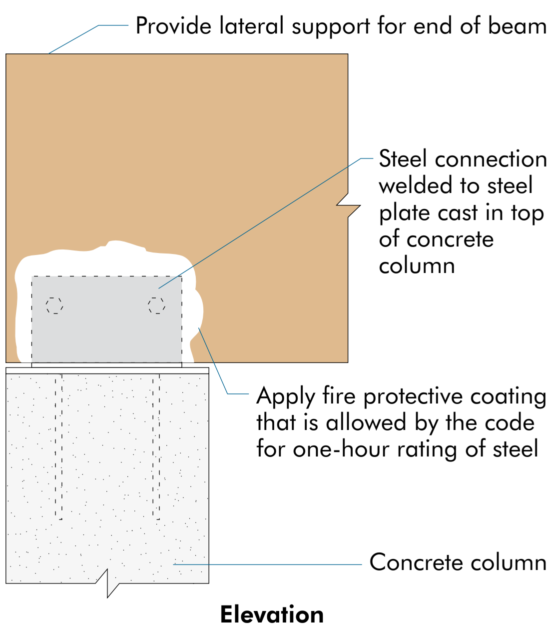
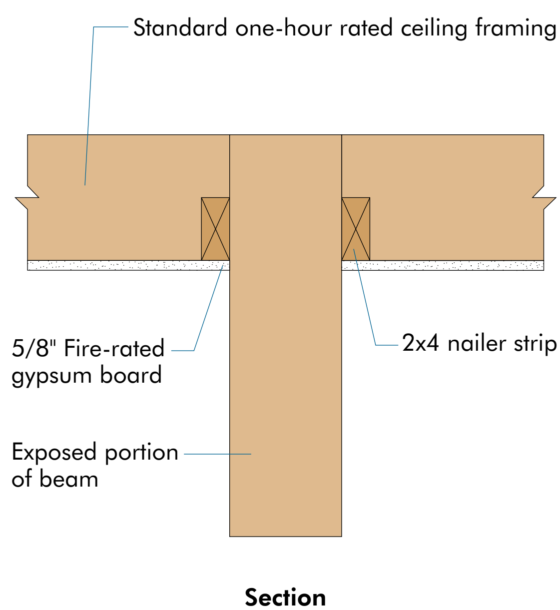


FIGURE 14

CEILING CONSTRUCTION



DESIGN EXAMPLE 1: Glulam Beam for One-Hour Fire Rate in Accordance with Method A (Chapter 16 of the NDS)

Assume a simply supported roof beam is to span 30 feet, carry 240 lbf/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 = 265 psi

What size glulam beam should be used?

Step 1:
From Table 3 of *APA Data File, Glued Laminated Beam Design Tables*, Form S475, select a 5-1/8-inch by 15-inch beam with total capacity of 266 plf which is greater than 240 plf (note that the tabulated capacity in APA Form S475 has considered the dead weight of the beam).

Step 2:
Determine the actual beam depth that will continue to carry the design load when exposed to a one-hour fire as follows:

Step 2a:
From Chapter 16 of the NDS

$\alpha_{eff}=1.2\beta_n t^{0.813}$

Where:

α_{eff} = effective char depth (in.)

β_n = nominal char rate (in./hr.), linear char rate based on 1-hr exposure = 1.5 in./hr. for glulam

t = exposure time (hr.)

Therefore, when t = 1 hr, α_{eff} = 1.8 in.

Step 2b:
The residual cross section after a one-hour fire exposure on three sides (top of the beam is protected from fire damage) can be calculated as:

$b_{residual}$ = 5.125 – (1.8 x 2) = 1.525 in.

$h_{residual}$ = 15 – 1.8 = 13.2 in.

$S_{residual}$ = 1.525 x 13.2^2/6 = 44.3 $in.^3$

Step 2c:
The residual moment capacity after a one-hour fire exposure on three sides can be calculated based on Table 16.2.2 of the NDS.

$M_{residual} = 2.85\ F_b'\ x\ S_{residual} = 2.85\ x\ 2{,}400\ x\ 0.9437\ x\ 44.3/12 = 23{,}821$ ft-lbf

Where:

F_b' = adjusted allowable bending stress, including beam volume effect factor, but not the load duration factor.

0.9437 = glulam beam volume effect factor (see Appendix A of APA Form S475)

Step 2d:
The applied moment due to the 240 lbf/ft of total load and the beam weight of 18.7 lbf/ft can be calculated as:

$$M_{applied} = \frac{\omega\ell^2}{8} = \frac{(240 + 18.7)\ x\ 30^2}{8} = 29{,}102 \text{ ft-lbf} > 23{,}821 \text{ ft-lbf} \Rightarrow \textbf{NG}$$

Step 2e:
Therefore, the beam size should be increased to accommodate the one-hour fire exposure. Select a 5-1/8-inch by 18-inch beam. From Table 3 of APA Form S475, the load carrying capacity of this beam is 470 plf which is greater than 240 plf.

Step 2f:
Repeat Steps 2b and 2c for one-hour fire exposure,

$b_{residual} = 5.125 – (1.8\ x\ 2) = 1.525$ in.

$h_{residual} = 18 – 1.8 = 16.2$ in.

$S_{residual} = 1.525\ x\ 16.2^2/6 = 66.7$ in.^{3}

$M_{residual} = 2.85\ F_b'\ x\ S_{residual} = 2.85\ x\ 2{,}400\ x\ 0.9266\ x\ 66.7/12 = 35{,}213$ ft-lbf

$$M_{applied} = \frac{\omega\ell^2}{8} = \frac{(240 + 22.4)\ x\ 30^2}{8} = 29{,}522 \text{ ft-lbf} < 35{,}213 \text{ ft-lbf} \Rightarrow \textbf{OK}$$

Therefore, <u>use a 5-1/8-inch by 18-inch 24F-V4 Douglas fir glulam beam.</u>

Alternative Solution in Accordance with Method B (Legacy Method)

From Table 3 of *APA Data File, Glued Laminated Beam Design Tables*, Form S475, select a 5-1/8 x 15 beam with total capacity of 266 plf, which is greater than 240 plf. (Note that the tabulated capacity in APA Form S475 has considered the dead weight of the beam.)

Determining the actual beam depth that will continue to carry the design load for one hour is aided by the use of Figure 3, *Beams – Fire 3 Sides*. From this graph, the range of depths that might be practical to use can be anywhere from approximately 12 to 30 inches. Obviously, this beam must be deeper than 15 inches as the beam in this example is stressed to approximately 90% of design capacity.

All of the 5-1/8-inch-wide beams in the depth range of 12 to 30 inches will retain 50–60% of design capacity after one hour. An initial estimate of a percentage that corresponds with this range of beam depths is 55%, which corresponds to a beam depth of 18 inches.

$$\text{Section modulus, } S = \frac{5.125(18)^2}{6} = 276.75 \text{ in.}^3$$

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'

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

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

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

Determine f_b

Calculate beam weight using 35 lbf/ft^3

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

$$M_{applied} = w\frac{L^2}{8} = (240 + 22.4)\frac{30^2}{8} = 29{,}520 \text{ ft-lbf} = 354{,}240 \text{ in.-lbf}$$

$$f'_b = \frac{M}{S} = \frac{354{,}240}{276.75} = 1{,}280 \text{ lbf/in.}^2$$

Check the ratio of applied moment to flexural capacity

$$\frac{f_b}{F_b'} = \frac{1,280}{2,557} = 0.50 < 55\% \Rightarrow \textbf{OK}$$

Check fire endurance:

From Figure 2, for a beam loaded to 50% of capacity, Z is approximately 1.3.

Using Equation 2:

$$t = 2.54(1.3)(5.125)\left[4 - \frac{5.125}{18}\right] = 62.9 \text{ minutes} > 60 \text{ minutes} \Rightarrow \textbf{OK;}$$

Therefore, use 5-1/8-inch x 18-inch 24F-V4 Douglas fir glulam beam.

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, a 6-3/4-inch-wide beam that is 13-1/2-inch deep, and has the extra tension lamination, will carry 100 percent of its design load after one hour of fire exposure on three sides. See Table 3a and Figure 3.

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

When specifying the beam, advise the manufacturer to eliminate one core lamination and substitute one additional tension lamination (Figure 8) and mark the beam “Fire-rated one-hour.”

DESIGN EXAMPLE 2:
Glulam Column for One-Hour Fire Rating in Accordance with Method A (Chapter 16 of the NDS)

An existing building is to be remodeled with a change of occupancy requiring that the glulam columns meet a one-hour fire-resistance requirement. The existing glulam column is 20-foot high, measures B = 8-3/4-inches wide by D = 10-1/2-inches deep and will remain dry in service. It supports a concentrated total floor load (DL + LL) of 50,000 lbf. (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 2 (see Table A2 of ANSI 117 or Table 5B of NDS Supplement).

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.

Step 1:
The 8-3/4-inch by 10-1/2-inch glulam column capacity can be calculated based on Section 3.7.1 of the NDS as 78,713 lbf > 50,000 lbf ⇒ **OK**

Step 2:
Determine the actual column size that will continue to carry the design load when exposed to a one-hour fire as follows:

Step 2a:
From Chapter 16 of NDS,

$\alpha_{eff}=1.2\beta_n t^{0.813}$

Where:

α_{eff} = effective char depth (in.)

β_n = nominal char rate (in./hr.), linear char rate based on 1-hr exposure = 1.5 in./hr. for glulam

t = exposure time (hr.)

Therefore, when t = 1 hr, α_{eff} = 1.8 in.

Step 2b:
The residual cross section after a one-hour fire exposure on four sides can be calculated as:

$b_{residual}$ = 8.75 – (1.8 x 2) = 5.15 in.

$h_{residual}$ = 10.5 – (1.8 x 2) = 6.90 in.

$A_{residual}$ = 5.15 x 6.90 = 35.54 in.^{2}

Step 2c:

The residual axial capacity after a one-hour fire exposure on four sides can be calculated based on Table 16.2.2 of the NDS.

$F_c' = 2.58 \times F_c \times C_p = 2.58 \times 1{,}950 \times 0.1273 = 640.4$ psi

$P_{residual} = F_c' \times A_{residual} = 640.4 \times 35.54 = 22{,}755$ lbf $< 50{,}000$ lbf $\Rightarrow$ **NG**

Where:

C_p = column stability factor, which can be calculated based on Section 3.7.1 of the NDS with the exception that the column buckling strength F_{cE} is determined using equation given in Table 16.2.2 of the NDS.

Step 2d:

Therefore, the column size would need to be increased to accommodate the one-hour fire exposure. Select 10-3/4 inches by 10-1/2 inches. The column capacity can be calculated based on Section 3.7.1 of the NDS as 130,939 lbf > 50,000 lbf $\Rightarrow$ **OK**

Step 2e:

Repeat Steps 2b and 2c for one-hour fire exposure,

$b_{residual} = 10.75 – (1.8 \times 2) = 7.15$ in.

$h_{residual} = 10.5 – (1.8 \times 2) = 6.90$ in.

$A_{residual} = 7.15 \times 6.90 = 49.34$ in.^{2}

$F_c' = 2.58 \times F_c \times C_p = 2.58 \times 1{,}950 \times 0.2253 = 1{,}133.3$ psi

$P_{residual} = F_c' \times A_{residual} = 1{,}133.3 \times 49.34 = 55{,}911$ lbf $> 50{,}000$ lbf $\Rightarrow$ **OK**

Therefore, a 10-3/4-inch by 10-1/2-inch Combination 2 Douglas fir glulam column is required to meet the one-hour fire rating.

Alternative Solution in Accordance with Method B (Legacy Method)

To address these issues, 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

B = 8.75 in.

D = 10.5 in.

A = B x D = 8.75(10.5) = 91.875 in.^{2}

C_D = 1.0 for DL plus floor LL

E = 1,600,000 lbf/in.^{2}

F_c = 1,950 lbf/in.^{2}

ℓ = 20(12) = 240 in.

K_e = 1.0 (see Figure 7) Column is assumed to be pinned at both ends.

$\ell_e = \ell K_e$ = 240(1.0) = 240 in.

$$\frac{\ell_e}{B} = \frac{240}{8.75} = 27.43$$

c = 0.9

Where:

- E = tabulated modulus of elasticity (lbf/in.^{2})
- E′ = adjusted modulus of elasticity (lbf/in.^{2})
- F_c = tabulated compression design value parallel to grain (lbf/in.^{2})
- A = area of cross section (in.^{2})
- B = least dimension being evaluated for potential buckling (in.)
- ℓ = length of column (in.)
- $\ell_e = \ell K_e$ = effective length of column (in.)
- K_e = buckling length coefficient for compression members
- c = coefficient that depends on member type (0.9 for glulam)

$$E'_{min.} = \frac{(E'[1 - 1.645\ COV_E]\ 1.05)}{1.66} = \frac{(1{,}600{,}000[1 - (1.645)(0.10)]\ 1.05)}{1.66} = 845{,}566\ \text{lbf/in}^2$$

Where:

COV_E = coefficient of variation in modulus of elasticity = 0.10 for glulam

1.05 = conversion factor to obtain true E (1.05 for glulam)

1.66 = factor of safety

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

$$F_{cE} = \frac{0.822\ E'_{min}}{\left(\frac{l_e}{B}\right)^2} = \frac{0.822(845{,}566)}{27.43^2} = 924\ \text{lbf/in.}^2$$

$$\frac{F_{cE}}{F_c^*} = \frac{924}{1{,}950} = 0.474$$

$$C_p = \frac{1+\frac{F_{cE}}{F_c^*}}{2c} - \sqrt{\left[\frac{1+\frac{F_{cE}}{F_c^*}}{2c}\right]^2 - \frac{\left(\frac{F_{cE}}{F_c^*}\right)}{c}} = \frac{1+0.474}{2(0.9)} - \sqrt{\left[\frac{1+0.474}{2(0.9)}\right]^2 - \frac{0.474}{0.9}} = 0.440$$

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

$F_c' = 1{,}950(0.440) = 857$ psi

Axial load capacity = $AF_c' = 91.875(857) = 78{,}737$ lbf > 50,000 lbf ⇒ **OK** for concentric axial load without fire endurance consideration

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

$$\frac{\text{Applied Load}}{\text{Design Capacity}} = \frac{50{,}000}{78{,}737} = 0.635 = 63.5\%$$

From Figure 6, for a column 8-3/4-inches wide and $l_e/B > 11$, 63.5% corresponds to about a 13-1/2-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 the full duration of the prescribed one-hour fire.

To check this conclusion, calculate the fire endurance

From Figure 2, for a column with $l_e/B > 11$ and the load at 63.5% of capacity, Z is approximately 1.16.

Using Equation 5:
B = 8.75 in.
D = 10.5 in.

$$t = 2.54ZB\left[3 - \frac{B}{D}\right] = 2.54(1.16)(8.75)\left[3 - \frac{8.75}{10.5}\right] = 56 \text{ minutes} < 60 \text{ minutes} \Rightarrow \textbf{NG}$$

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 6 as a guide, try a 10-3/4-inch x 10-1/2-inch glulam, Douglas fir Combination 2, assuming a depth of 10-1/2 inches is a design requirement.

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

Slenderness ratio = $l_e/B = 240/10.5 = 22.86$

$$F_{cE} = \frac{0.822\,E'_{min}}{\left(\frac{l_e}{B}\right)^2} = \frac{0.822(845{,}566)}{22.86^2} = 1{,}330 \text{ lbf/in.}^2$$

$F_c^* = 1{,}950 \text{ lbf/in.}^2$

$$\frac{F_{cE}}{F_c^*} = \frac{1{,}330}{1{,}950} = 0.682$$

$$C_p = \frac{1+\frac{F_{cE}}{F_c^*}}{2c} - \sqrt{\left[\frac{1+\frac{F_{cE}}{F_c^*}}{2c}\right]^2 - \frac{\left(\frac{F_{cE}}{F_c^*}\right)}{c}} = \frac{1 + 0.682}{2(0.9)} - \sqrt{\left[\frac{1 + 0.682}{2(0.9)}\right]^2 - \frac{0.682}{0.9}} = 0.595$$

$F_c' = 1{,}950(0.595) = 1{,}160 \text{ lbf/in.}^2$

Axial load capacity = $AF_c' = 112.875(1{,}160) = 130{,}939 \text{ lbf} > 50{,}000 \text{ lbf} \Rightarrow$ **OK**

Check the fire endurance

$$\frac{\text{Applied Load}}{\text{Maximum Capacity}} = \frac{50{,}000}{130{,}939} = 0.382 = 38.2\%$$

Z, from Figure 2, is 1.3.
Using Equation 5:
B = 10.5 in.
D = 10.75 in.

$$t = 2.54ZB\left[3 - \frac{B}{D}\right] = 2.54(1.30)(10.5)\left[3 - \frac{10.5}{10.75}\right] = 70 \text{ minutes} > 60 \text{ minutes} \Rightarrow \textbf{OK;}$$

Use 10-3/4-inch x 10-1/2-inch Combination 2 Douglas fir glulam column.

Summary

As shown by the preceding examples, glued laminated timber members can be designed in accordance with Method A or B to provide a one-hour or two-hour fire rating when required. Note that Tables 3a, 3b and 3c 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 3 through 6 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.

References

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. American Wood Council. 2018. National Design Specification for Wood Construction. Leesburg, VA.

Calculating Fire Resistance of Glulam Beams and Columns

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