Chapter 10 Design for Fire Safety

CIVE480 Timber Structures
2019

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10.1 General Information

1) Design requirements

- Based on Division B, Part 3, *Fire Protection, Occupant Safety and Accessibility*, of the *National Building Code of Canada (NBCC)*.

Fire protection objectives:

- Structural stability under fire conditions,
- Protection against fire spread, and
- Safe means of egress.

2) Fire protection systems

- Passive systems
  - Escape routes or "exits" → ensure a means of escaping a life-threatening situation
  - Fire compartments → ensure a safer environment during a fire for the building occupants

- Active systems
  - Fire alarm systems → provide detection, early warning
  - Automatic fire sprinklers → control/suppression of fire

3) Wood construction

<u>Permitted based on occupancy, building height and area</u>

Table 10.1b Examples of maximum building area permitted per floor

	Use	Building Height in Storeys	Number of Sides With Access & Sprinklering	Maximum Building Area Per Floor (m^2)
Major Occupancy Group **C**	**Residential** Apartments, hotels, motels	3	1, unsprinklered	600
			2, unsprinklered	750
			3, unsprinklered	900
			1, sprinklered	1800
		2	1, unsprinklered	900
			2, unsprinklered	1125
			3, unsprinklered	1350
			1, sprinklered	2700
		1	1, unsprinklered	1800
			2, unsprinklered	2250
			3, unsprinklered	2700
			1, sprinklered	5400

4) Fire-resistance ratings

- The time that a component will withstand heat and flames under standard test conditions.
- Many wood-frame assemblies meets the range: 0 to 2 hours.

Methods to determine the fire-resistance ratings

1. Standard fire-resistance test
2. Appendix D (*Fire Performance Ratin*gs) of the NBCC
3. Other methodologies (Annex B of the CSA O86)

10.2 Light Wood Frame Structures

1) Component additive method (CAM)

- NBCC Division B, appendix D-2.3. – Component Additive Method
- Adding the time assigned to the protective membrane (e.g. gypsum board) on the "fire side" to the time assigned to the structural framing members
- Used for assign a fire-resisting rating up to 1.5 hours

- For wall assemblies, rating is based on fire exposure on one side (interior partitions, use the lowest ratings of both sides)
- For floor or roof assemblies, rating is based on performance from fire exposure from below

1) Component additive method (CAM)

Tables 10.2a Time assigned for the contribution of protective membranes on the fire-exposed side of wood-frame walls

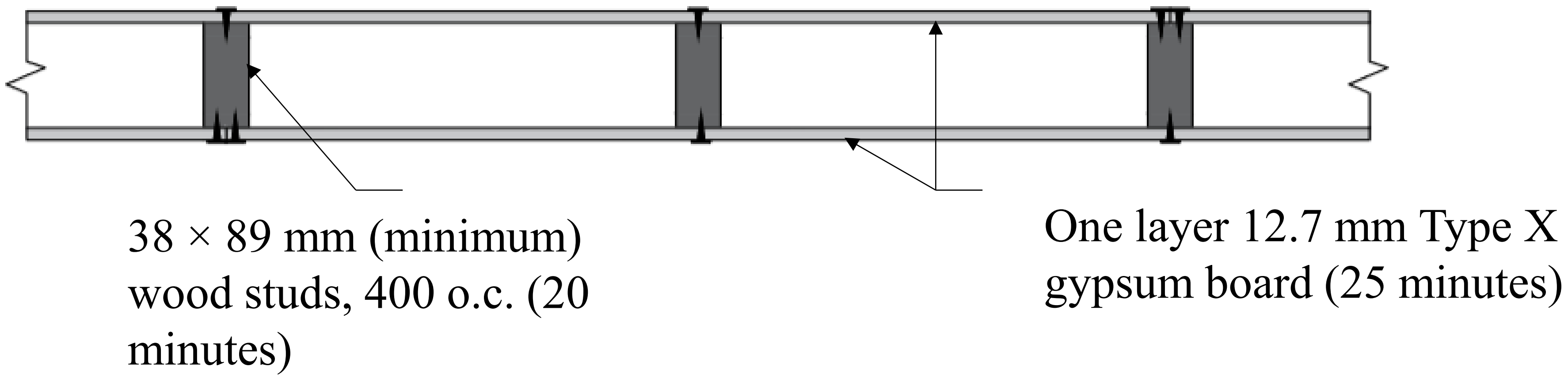
Description of Finish	Time, minutes	
	Loadbearing Walls	Non-loadbearing Walls
11.0 mm Douglas Fir plywood phenolic bonded	-	10
14.0 mm Douglas Fir plywood phenolic bonded	-	15
12.7 mm Type X gypsum wallboard	25	25
15.9 mm Type X gypsum wallboard	40	-
Double 12.7 mm Type X gypsum board	50	80

Tables 10.3 Time assigned for contribution of wood-frame members

Description of Frame	Time, minutes
Walls – wood studs spaced ≤ 400 mm o.c.	20
Walls – wood studs spaced ≤ 600 mm o.c.	15
Floors – wood joists, wood I-joists, and wood trusses spaced ≤ 600 mm o.c.	10
Roofs – wood joists spaced ≤ 400 mm o.c.	10
Roofs – metal-plate-connected wood trusses spaced ≤ 600 mm o.c.	5

Example 1: Using NBCC Division B, Appendix D-2.3 – Lightweight woodframe interior partitions

Determine the fire-resistance rating of an interior partition (i.e. interior non-loadbearing wall assembly) with 12.7 mm Type X gypsum board (GB) on both sides of wood studs spaced at 400 mm on center.

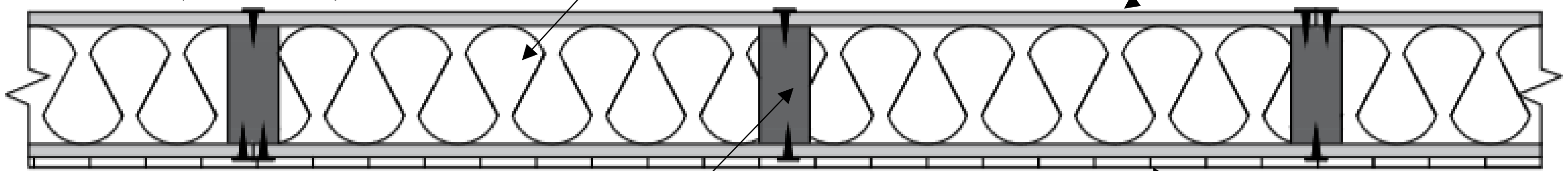


Example 1 – Solution

- Tables are located on Slide #9
- From Table 10.2a:
  - Time assigned to 12.7 mm Type X GB 25
- From Table 10.3:
  - Time assigned to wood studs at 400 mm o.c. 20
- **Fire-resistance rating of interior partition: 45 minutes**

Example 2: Using NBCC Division B, Appendix D-2.3 – Lightweight woodframe exterior wall assemblies

Determine the fire-resistance rating of a loadbearing wood stud exterior wall assembly with 12.7 mm Type X gypsum board (GB) on the interior side and plywood sheathing and wood shingle siding on the exterior with studs spaced at 400 mm on the center.



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Example 2: Solution

Table 10.5 Examples of time assigned for additional protection

Description of Additional Protection	**Time, minutes**
Add to the fire-resistance rating of wood stud walls, sheathed with gypsum board or lath and plaster, if the spaces between the studs are filled with preformed insulation of rock or slag fibres conforming to CAN/ULC-S702, *Mineral Fibre Thermal Insulation for Building*, and with a mass per unit area of not less than 1.22 kg/m^2 of wall surface	15
Add to the fire-resistance rating of non-loadbearing wood stud walls, sheathed with gypsum board or lath and plaster, if the spaces between the studs are filled with preformed insulation of glass fibres conforming to CAAN/ULC-S702, *Mineral Fibre Thermal Insulation for Building*, and with a mass per unit area of not less than 0.6 kg/m^2 of wall surface	5
Add to the fire-resistance rating of loadbearing wood stud walls sheathed with gypsum board if the spaces between the studs are filled with insulation of cellulose fibres conforming to CAN/ULC-S703, *Cellulose Fibre Insulation (CFI) for Buildings*, and having a density of not less than 50 kg/m^3	10

Example 2 – Solution

- From Table 10.2a:
  - Time assigned to 12.7 mm Type X GB 25
- From Table 10.5:
  - Time assigned to mineral fiber insulation 15
- From Table 10.3:
  - Time assigned to wood studs at 400 mm o.c. 20
- **Fire-resistance rating of exterior wall: 60 minutes**

10.3 Mass Timber

1) Mass timber

- Large-cross-sectioned solid-sawn beams and columns
- Glued laminated timber (glulam)
- Structural composite lumber (SCL)
- Built-up solid wood walls, floors and roofs
- Cross-laminated timber (CLT)

2) NBCC Division B, Appendix D-2.11 Method for Glulam Beams and Column

- Method of calculation (refer to D-2.11.2)

$$FRR = 0.1fB\left[4 - \frac{2B}{D}\right]$$ for beams exposed to fire on 4 sides

$$FRR = 0.1fB\left[4 - \frac{B}{D}\right]$$ for beams exposed to fire on 3 sides

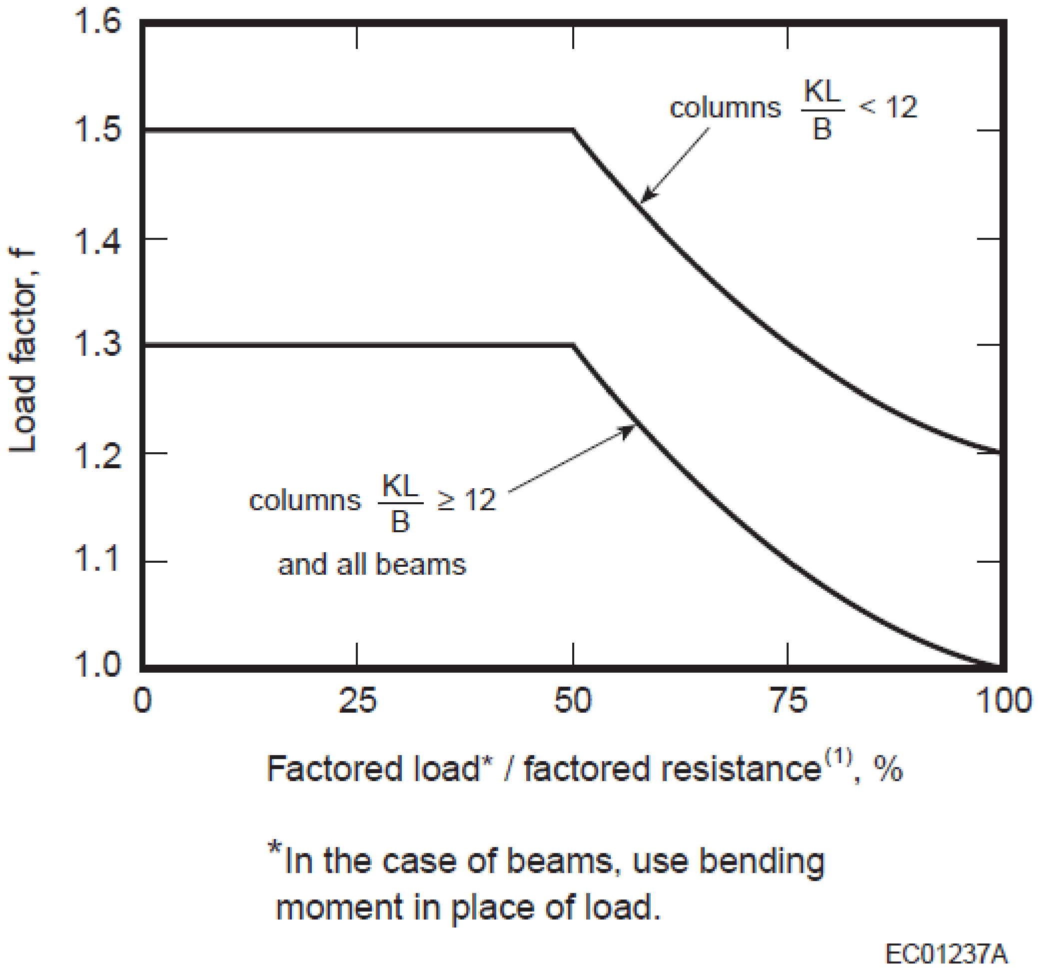
$$FRR = 0.1fB\left[3 - \frac{B}{D}\right]$$ for columns exposed to fire on 4 sides

$$FRR = 0.1fB\left[3 - \frac{B}{2D}\right]$$ for columns exposed to fire on 3 sides

where:

- FRR = fire resistance time in minutes
- f = the load factor shown in Figure 10.1 on next slide
- B = the full dimension of the smaller side of the beam or column in mm before exposure to the fire
- D = the full dimension of the larger side of the beam or column in mm before exposure to fire

Figure 10.1 Load factor for glulam fire-resistance calculations (NBCC 2015)



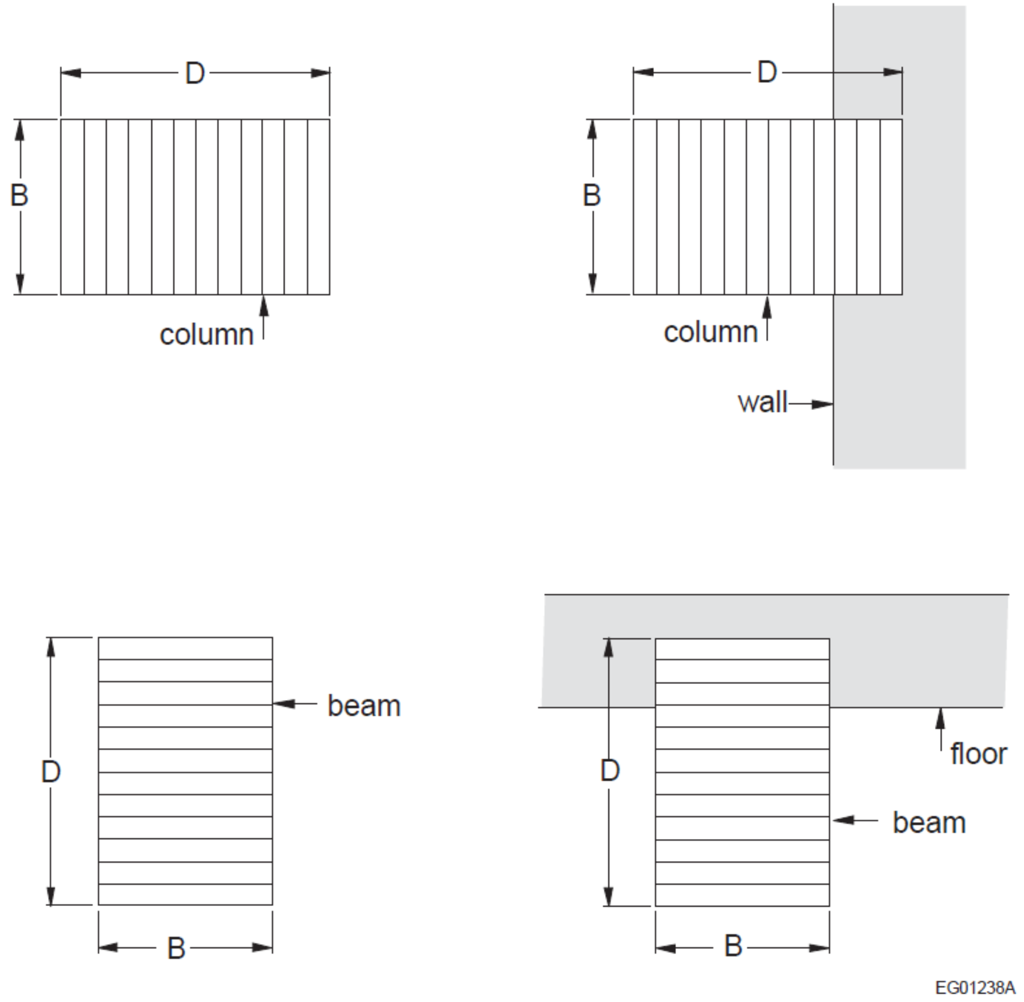


Figure 10.2 Full dimensions of glued-laminated beams and columns

k = the effective length factor obtained from CSA O86, "Engineering Design in Wood,"
L = the unsupported length of a column in millimetres.

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Example 3: Using NBC Division B, Appendix D-2.11 – Beams

- Determine the fire-resistance rating of a glulam beam exposed on 3 sides
- Dimensions are 175 × 380 mm
- Stressed to 80% of its factored bending moment resistance

Solution

- B = 175 mm
- D = 380 mm
- From Figure 10.1 (on previous slide), f = 1.075 for a beam designed to carry a factored load equal to 80% of factored bending moment

$$FRR = 0.1fB\left[4 - \frac{B}{D}\right] = 0.1(1.075)(175)\left[4 - \frac{175}{380}\right] = \mathbf{66.6\ minutes}$$

- Therefore, this beam could be used to support a floor assembly having a one-hour fire-resistance rating

3) CSA-O86 Annex B Method (Alternative)

- Reduced cross-section approach
- Adjustment factor for fire resistance, K_{fi} (refer to B.3.9 of Annex B)

Table B.3.9: Adjustment Factor for Fire Resistance, K_{fi}

Product	K_{fi}
Timber and plank decking	1.5
Glued-laminated timber	1.35
Structural composite lumber	1.25
Cross-laminated timber -V1-V2 stress grade -E1-E3 stress grade	 1.5 1.25

Note: adjustment factor for fire resistance, K_{fi}, converts specified strength to mean strength

4) Char Depth

- <u>Design charring rates</u>

Table B.4.2: Design Charring Rates for Wood and Wood-based Products, mm/min

	β_o	β_n
Timber and plank decking	0.65	0.80
Glued-laminated timber	0.65	0.70
Structural Composite Lumber	0.65	0.70
Cross-laminated timber	0.65	0.80

4) Char depth

- <u>One-dimensional char depth</u>

$$x_{c,o} = \beta_o t$$

where:

- β_o = one-dimensional charring rate, mm/min
- t = fire exposure duration, min

- <u>Notional char depth</u>

$$x_{c,n} = \beta_n t$$

where:

- β_n = notional charring rate, mm/min
- t = fire exposure duration, min

5) Zero-strength layer

- Zero-strength layer depth

$$x_t = \frac{7t}{20} \text{ (for } t < 20)$$

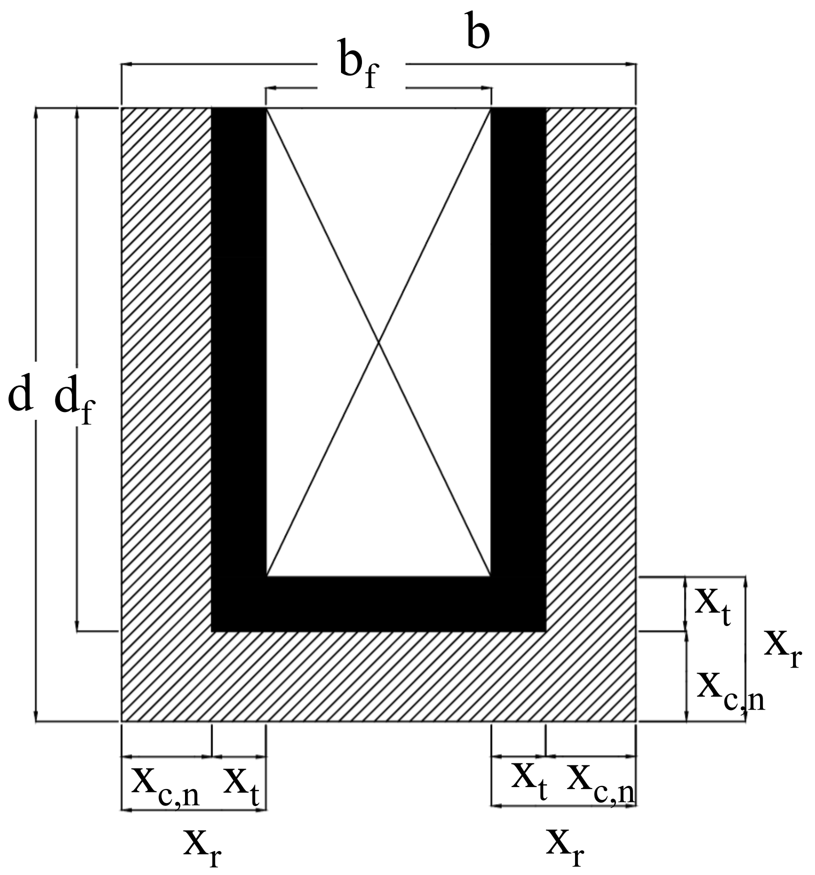
$$x_t = 7 \text{ (for } t \geq 20)$$

where:

- t = fire exposure duration, min

Example 4: Using CSA O96 Annex B Calculation Method – Beams

- The following example illustrates how a 1-hour fire-resistance rating may be verified for a glulam beam using the calculation method in Annex B of CSA O86, under the following conditions:
- Species and grade: D.Fir-L, 20f-E
- Beam dimensions: 215 × 456 mm
- Compressive edge assumed fully laterally supported by floor deck (K_L = 1.0)
- Tributary width of floor deck for beam is 4.0 m
- Beam span = 7.0 m
- Specified dead load = 2.0 kPa (includes partitions)
- Specified live load = 2.4 kPa (commercial use and occupancy)
- Exposed to fire on three sides (top side protected by floor deck)

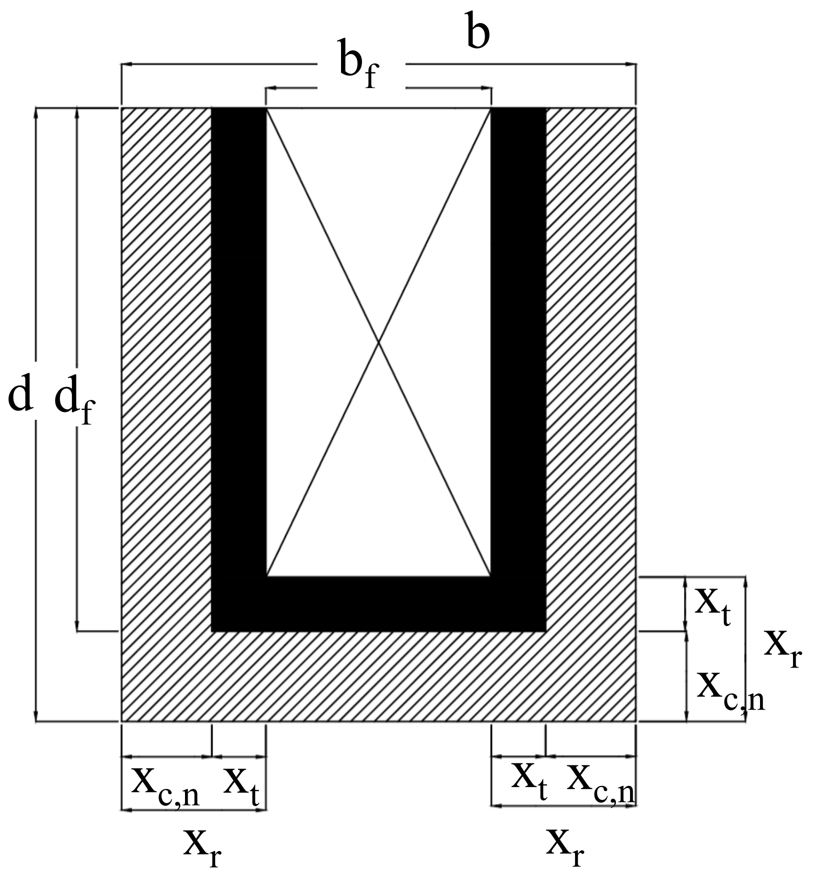


Example 4 – Solution

- Total specified load = 2.4 + 2.0 = 4.4 kPa
- Specified distributed load:
  - w = 4.4(4.0) = 17.6 kN/m
- Specified bending moment
  - $M = \frac{wL^2}{8} = \frac{(17.6)(7.0)^2}{8} = 108$ kNm

<u>Calculating the reduced cross-section dimensions based on notional charring rate:</u>

- Char depth after 60 minutes of standard fire exposure:
  - $x_{c,n} = \beta_n t = (0.7)(60) = 42$ mm
- Zero strength zone depth:
  - $x_t = 7$ mm
- Therefore, the resulting loss of cross-section on each side of exposure
  - $x_r = 42 + 7 = 49$ mm



Example 4 – Solution

- Based on the 3-sided fire exposure for the beam, the resulting dimensions for the width (b_f) and depth (d_f) after exposure are:
  - $b_f = b – [(x_r)(\text{number of side exposed})] = 215 – [(49)(2)] = 117$ mm
  - $d_f = d – [(x_r)(\text{number of side exposed})] = 456 – [(49)(1)] = 407$ mm
- Bending strength modified for 50th percentile value and short term loading:
  - $F_b = K_{fi} f_b(K_D K_H K_{Sb} K_T) = (1.35)(25.6)[(1.15)(1.0)(1.0)(1.0)] = 39.7$ MPa
- Section modulus calculated based on reduced cross-section:
  - $S_f = \frac{b_f d_f^2}{6} = \frac{(117)(407)^2}{6} = 3.23(10^6)$ MPa
- Size factor is based on original beam size:
  - $K_{Zbg} = \left(\frac{130}{b}\right)^{\frac{1}{10}} \left(\frac{610}{d}\right)^{\frac{1}{10}} \left(\frac{9100}{L}\right)^{\frac{1}{10}} < 1.3$
  - $K_{Zbg} = \left(\frac{130}{215}\right)^{\frac{1}{10}} \left(\frac{610}{456}\right)^{\frac{1}{10}} \left(\frac{9100}{7000}\right)^{\frac{1}{10}} = 1 < 1.3$

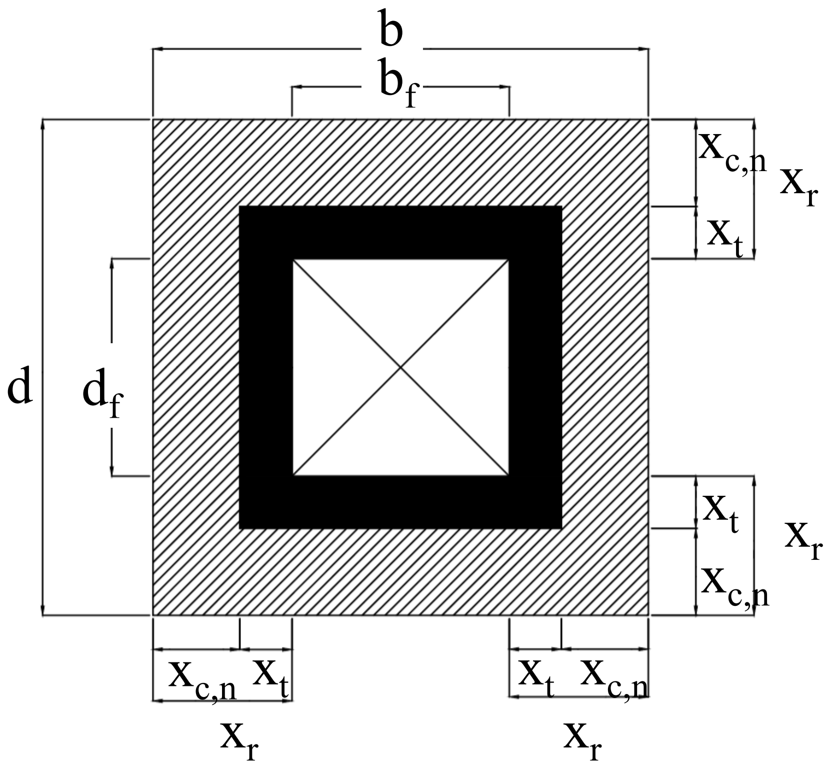
Example 4 – Solution

- Since $K_{Zbg} = K_L = 1.0$, calculation of bending moment resistance ofr reduced cross-section:
  - $M_r = \phi F_b S_f K_X K_{Zbg} = (1.0)(39.7)(3.23 \times 10^6)(1.0)(1.0) = 130$ kNm
- The moment resistance of the reduced cross-section after 1 hr of fire exposure is 130 kNm, which is greater than the specified-load-induced moment of 108 kNm

The structural fire resistance of the glulam beam is greater than 1 hr

Example 5: Using CSA O86 Annex B Calculation Method – Columns

- The following example illustrates how a 45-minute fire-resistance rating may be verified for a solid-sawn timber column using the calculation method in Annex B of CSA O86 under the following conditions:
- species and grade: D.Fir-L, No.1
- Column dimensions: 241 × 241 mm
- Column height is 3.5 m
- Specified dead load = 130 kN
- Specified live load = 150 kN
- Column is effectively pinned at both ends (K_e = 1.0)
- Exposed to fire on four sides

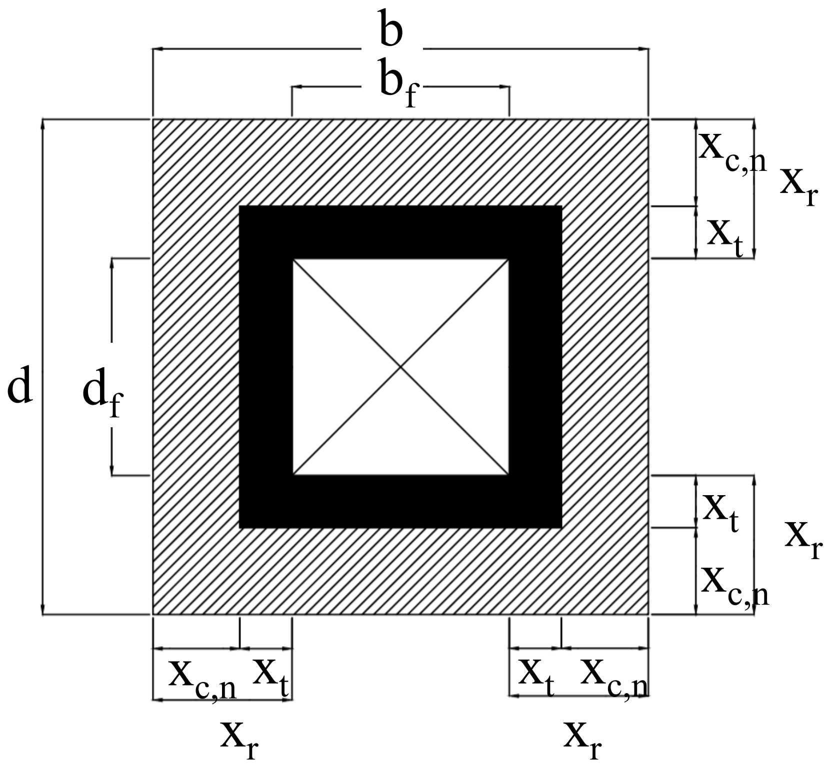


Example 5 – Solution

- Total specified load = 130 + 150 = 280 kN

<u>Calculating the reduced cross-section dimensions based on notional charring rate:</u>

- Char depth after 45 minutes of standard fire exposure:
  - $x_{c,n} = \beta_n t = (0.8)(45) = 36$ mm
- Zero strength zone depth: $x_t = 7$ mm
- Therefore, the resulting loss of cross-section on each side of exposure:
  - $x_r = 36 + 7 = 43$ mm
- Based on the 4-sided fire exposure for the column, the resulting dimensions for the width (b_f) and depth (d_f) after exposure are:
  - $b_f = b - [(x_f)(\text{number of sides exposed})] = 241 - [(43)(2)] = 155$ mm
  - $d_f = d - [(x_f)(\text{number of sides exposed})] = 241 - [(43)(2)] = 155$ mm



Example 5 – Solution

- Compressive strength parallel to grain modified for 50th percentile value and short term loading:
  - $F_c = K_{fi} f_c (K_D K_H K_{Sc} K_T) = 1.5(12.2)[(1.15)(1.0)(1.0)(1.0)] = 21.0$ MPa
- Slenderness ratio calculated based on reduced cross-section:
  - C_{cb} and $C_{cd} = \frac{effective\ length\ associated\ with\ width\ or\ depth}{member\ width\ or\ depth} = \frac{3500}{155} = 22.6$
- Size factor is based on original column size:
  - $K_{Zc} = 6.3(dL)^{-0.13} \leq 1.3$
  - K_{Zcb} and $K_{Zcd} = 6.3[(241)(3500)]^{-0.13} = 1.07$
- Calculation of slenderness factor:
  - K_{Cb} and $K_{Cd} = \left[1.0 + \frac{F_c K_{Zc} C_c^3}{35 E K_{SE} K_T}\right]^{-1} = \left[1.0 + \frac{(21.0)(1.07)(22.6)^3}{(35)(10500)(1.0)(1.0)}\right]^{-1} = 0.59$
- Note: for fire design, the E_{05} is replaced with mean value for E (as specified in B.6.4)

Example 5 – Solution

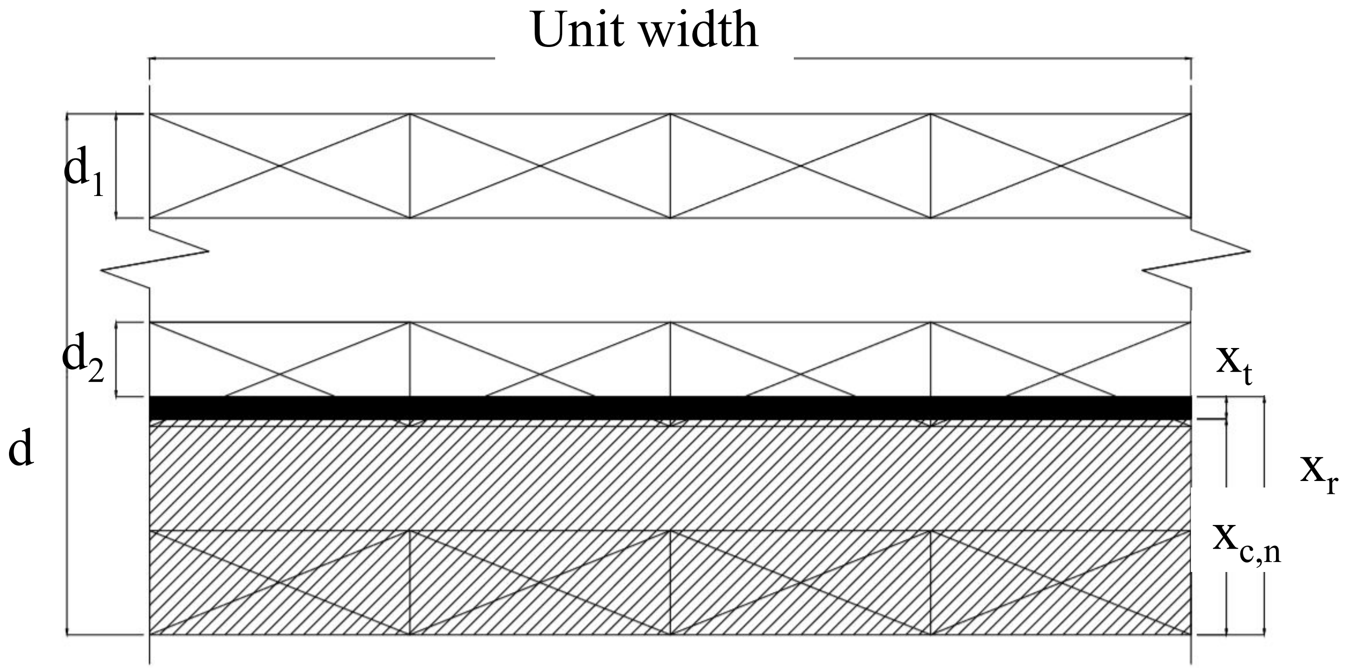
- Calculation of axial compressive resistance for reduced cross-section:
  - P_{rb} and $P_{rd} = \phi F_C A K_{Zc} K_C = 1.0(21.0)[(155)(155)](1.07)(0.59) = 319$ kN
- The axial resistance of the reduced cross-section after 45 minutes of fire exposure is 319 kN, which is greater than the total specified load of 280 kN

The structural fire resistance of the solid-sawn timber column is greater than 45 minutes

Example 6: CLT Floor and Roof Panels

- The following example illustrates how a 2-hour fire-resistance may be verified for a 5-ply CLT floor assembly using the calculation method in Annex B of CSA O96 under the following conditions:
- 5-ply CLT panels, 35 mm thick plies (175 mm total thickness)
- CLT Stress Grade – V2
- Bending strength f_b in the longitudinal plies is 11.8 MPa
- 1 Layer of 15.9 mm Type X gypsum board directly applied to underside of CLT panels
- Simply supported span of 4732 mm
- Specified dead load = 4.0 kPa (including self-weight)
- Specified live load = 4.27 kPa
- Note that floor and roof assemblies are rated for exposure to fire on the underside

Example 6 – Solution



Example 6 – Solution

- Total specified load = 4.0 + 4.27 = 8.27 kPa
- Specified bending moment:
  - $M = \frac{wL^2}{8} = \frac{(8.27)(4.732)^2}{8} = 23.1$ kNm/m of panel width
- 30 minutes of fire resistance is attributed to the 15.9 mm Type X gypsum layer
- The CLT panels must possess a 90-minute rating
- Calculating the reduced cross-section based on notional charring rate (assume char depth reaches first adhesive bond line in CLT panels)
- Char depth after 90 minutes:
  - $x_{c,n} = \beta_n t = (0.8)(90) = 72$ mm
- Check: Since the char depth surpasses the first adhesive bond line (i.e. 72 mm char depth > ply thickness of 35 mm), it is appropriate to use the char rate β_n from Table B.4.2

Example 6 – Solution

- Zero strength zone depth:
  - $x_t = 7$ mm
- Therefore, the resulting loss of cross-section on the bottom surface is:
  - $x_r = 72 + 7 = 79$ mm
- Since the longitudinal plies are all made up of the same material with the same modulus of elasticity, the neutral axis for the panels after 90 minutes of fire exposure can be calculated based on the remaining areas of the of those plies alone

$$\bar{y} = \frac{\sum_i \widetilde{y}_i d_i}{\sum_i \widetilde{y}_i d_i} = \frac{\left(\left(\frac{35}{2}\right)(35)+35+35+\frac{26}{2}\right)}{35+26} = 45.4 \text{ mm}$$

- Where:
- $\bar{y}$ = distance from the top of the panel surface to the neutral axis, mm
- $\widetilde{y}_i$ = distance from the top of the panel surface to the centroid of the area, mm
- d_i = thickness of ply, mm
- Therefore, the neutral axis is 45.4 mm from the top of the floor panel surface

Example 6 – Solution

- Moment of inertia (for 1 m wide section of panel):
  - $I = \sum_i \frac{bd_i}{12} + \sum_i bd_i z_i^2$

Where:

- I = moment of inertia, mm^4
- b = width of the ply (unit length), mm
- z_i = distance from the centroid of the ply to the neutral axis, mm
- $I = \frac{(1000)(35)^2}{12} + \frac{(1000)(26)^3}{12} + (1000)(35)\left(45.4 - \frac{35}{2}\right)^2 + (1000)(26)\left(35 + 35 + \frac{26}{2} - 45.4\right)^2$
- Section modulus (for a 1 m wide section):
  - Since only laminations that run parallel to the applied stress are included in design for fire resistance and these laminations have the same modulus of elasticity, the equation in Clause 8.4.3.1 can be simplified to:
  - $S_{eff} = \frac{I}{c}$

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Example 6 – Solution

where:

- S_{eff} = section modulus, mm^3
- c = distance from the extreme (bottom) tension fiber to the neutral axis, mm

- Note that the distance to the extreme tension "fiber" used for this calculation is to an extreme tension "fiber" in a longitudinal ply
  - $S_{eff} = \frac{69*10^6}{(35+35+26)-45.4} = 1.36 * 10^6$ mm^3
- Moment resistance of the CLT panel (as specified in Clause 8.4.3.1):
  - $M_{r,y} = \phi F_b S_{eff} K_{rb}$

  Where:

  - ϕ = 1.0 for fire design
  - $F_b = f_b(K_D K_H K_{Sb} K_T)K_{fi}$
  - $K_D = 1.15$
  - $K_H = 1.0$
  - $K_{rb} = 0.85$
  - $K_{Sb} = 1.0$
  - $K_T = 1.0$
  - $K_{fi} = 1.5$
  - $F_b = (11.8)[(1.15)(1.0)(1.0)(1.0)](1.5) = 20.4$ MPa
  - $M_{r,y} = (1.0)(20.4)(1.36 \times 10^6)(1.0)(0.85) = 23.6 \times 10^6$ Nmm/m
  - $M_{r,y}$ = 23.6 kNm/m of panel width

Example 6 – Solution

- The moment resistance after 90 min is 23.6 kNm/m, compared to the moment induced by the applied load of 23.1 kNm/m (i.e. $M_r > M$)

The CLT floor panels provide at least 90 minutes of structural fire resistance without gypsum protection, and the CLT floor assembly provides at least 2 hours of structural fire resistance with one layer 15.9 mm Type X gypsum board

This lecture is developed based on the Wood Design Manual [1], CSA O86-2014 [2] and National building code of Canada 2015 [3].

References

[1] Canadian Wood Council (CWC). 2017. *Wood design manual*. Ottawa, ON, Canada.

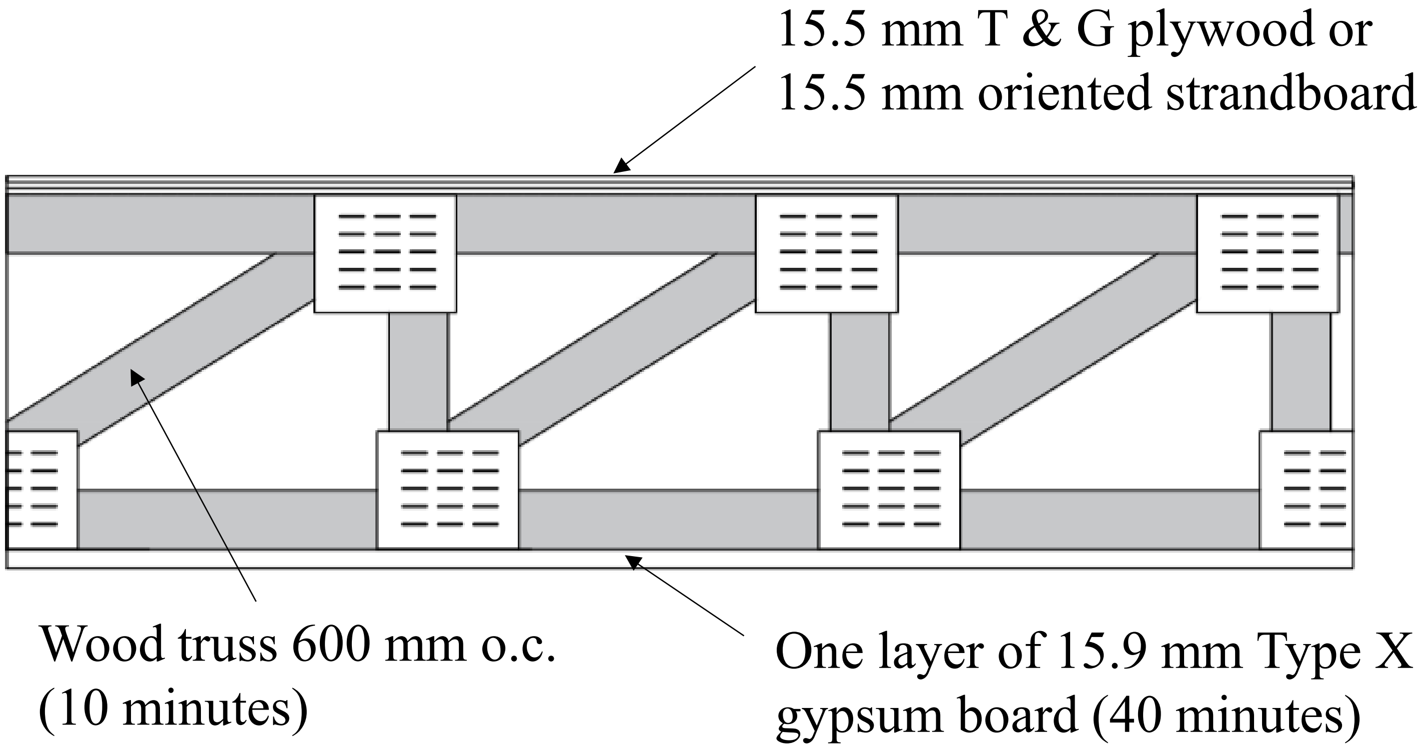
[2] Canadian Standards Association (CSA). 2017. *Engineering design in wood*. CSA O86-14, Toronto, ON, Canada.

[3] National Research Council (NRC). 2015. *National building code of Canada 2015*. Ottawa, ON, Canada.

Additional Examples

Example 7: Using NBC Division B, Appendix D-2.3. – Lightweight wood truss floor assemblies

- Determine the fire-resistance rating of the wood truss floor assembly
- Ceiling is 15.9 mm Type X gypsum board (GB) directly applied
- Trusses are spaced at 600 mm on center

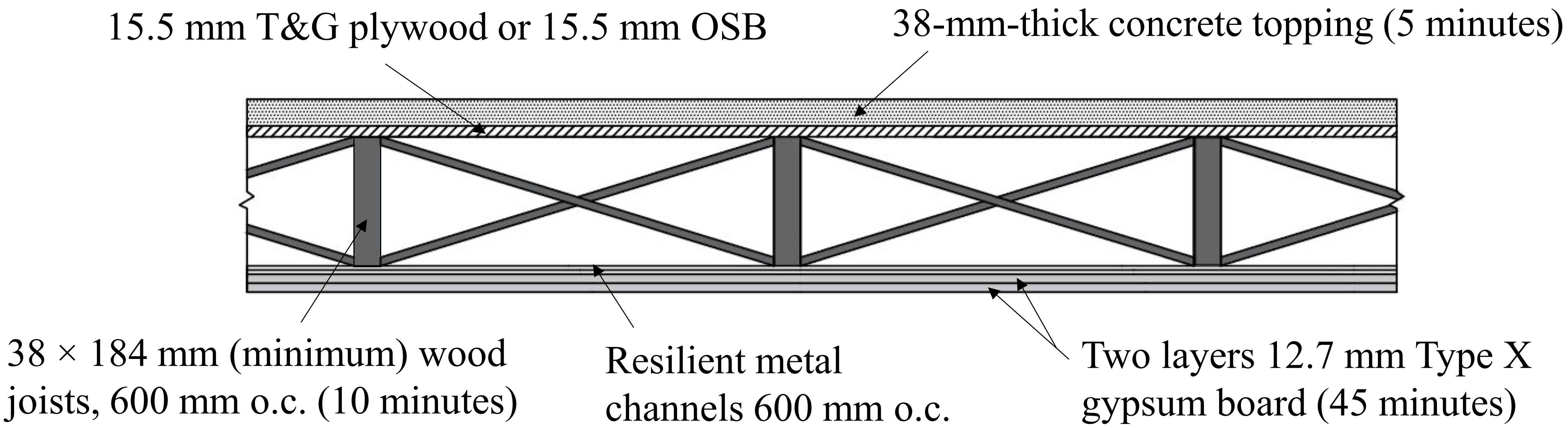


Example 7 – Solution

- Tables located on Slide #9
- From Table 10.2b [2]:
  - Time assigned to 15.9 mm Type X GB 40
- From Table 10.3:
  - Time assigned to wood trusses 10
- **Fire-resistance rating of wood truss floor assembly: 50 minutes**

Example 8: Using NBC Division B, Appendix D-2.3 – Lightweight wood joist floor assemblies

- Determine the fire-resistance rating of the wood joist floor assembly
- Ceiling is two layers of 12.7 mm Type X gypsum board attached with resilient metal channels spaced at 600 mm on center and joists spaced at 600 mm on center
- There is 38-mm-thick concrete topping the subfloor



Example 8 – Solution

- Tables located on Slides #9 and #13
- From Table 10.2b [2]:
  - Time assigned to two layers of 12.7 mm Type X GB 45
- From Table 10.3:
  - Time assigned to wood joist at 600 mm on center 10
- From Table 10.5:
  - Time assigned to concrete topping 5
- **Fire-resistance rating of wood joist floor assembly: 60 minutes**

Example 9: Using Selection Tables for Fire Resistance – Beams

- Design single-span floor beams for the following conditions:
- Beam spacing = 3.0 m
- Beam span = 6.0 m
- Specified dead load = 1.5 kPa (includes partitions and self-weight)
- Specified live load = 2.4 kPa (commercial use and occupancy)
- Exposed to fire on three sides (top side protected)
- 1-hour fire-resistance rating
- Dry service condition
- Untreated
- Use D.Fir-L No.1 sawn timber

Example 9 – Solution

- Tributary area = 3.0(6.0) = 18.0 m^2 < 20.0 m^2
- Therefore, no live load reduction is permitted by the NBC
- Total specified load = 1.5 + 2.4 = 3.90 kPa
- Specified distributed load:
  - w = 3.90(3.0) = 11.7 kN/m
- Specified bending moment:
  - $M = \frac{wL^2}{8} = \frac{(11.7)(6.0)^2}{8} = 52.7$ kNm
- Specified shear:
  - $V = \frac{wL}{2} = \frac{(11.7)(6.0)}{2} = 35.1$ kN
- From Beam Selection Tables for Fire Resistance of 60 min for sawn timber, try 241x394 mm:
  - M_r = 61.5 kNm > 52.7 kNm [Acceptable]
  - V_r = 68.9 kN > 35.1 kN [Acceptable]

Use 241×394 mm No.1 D.Fir-L

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Example 10: Using Selection Tables – Beams

- Design single-span floor beams for the following conditions:
- Beam spacing = 5.0 m
- Beam span = 7.5 m
- Specified dead load = 2.0 kPa (includes partitions and self-weight)
- Specified live load = 2.4 kPa (commercial use and occupancy)
- Exposed to fire on three sides (top side protected)
- 2-hour fire-resistance rating
- 1 layer of 15.9 mm Type X gypsum board directly applied to bottom and sides of beams
- Dry service condition
- Untreated
- Compression edge assumed fully laterally supported by floor system
- Use D.Fir-L 20f-E glulam

Example 10 – Solution

- Tributary area = 5.0(7.5) = 37.5 m^2 > 20.0 m^2
- Live load reduction factor (LLRF) $= 0.3 + \sqrt{9.8/37.5} = 0.81$
- Total specified load = 2.0 + 2.4(0.81) = 3.94 kPa
- Specified distributed load:
  - w = 3.94(5.0) = 19.7 kN/m
- Specified bending moment:
  - $M = \frac{wL^2}{8} = \frac{(19.7)(7.5)^2}{8} = 139$ kNm
- Specified shear:
  - $V = \frac{wL}{2} = \frac{(19.7)(7.5)}{2} = 73.9$ kN
- 30 minutes of fire-resistance is attributed to one layer of 15.9 mm Type X gypsum board fastened to the beam member, meaning the beam must possess a 90-minute fire-resistance rating

Example 10 – Solution

- From Beam Selection Tables for Fire Resistance of 90 min for glulam, try 215x608 mm:
  - $M'_r = 144$ kNm
  - M_r = lesser of $M'_r K_L$ or $M'_r K_{Zbg}$
  - $K_L = 1.0$ (compression edge laterally supported)
  - $K_{Zbg} = \left(\frac{130}{215}\right)^{\frac{1}{10}} \left(\frac{610}{608}\right)^{\frac{1}{10}} \left(\frac{9100}{7500}\right)^{\frac{1}{10}} = 0.97$ [Governs]
  - $M_r = 144(0.97) = 140$ kNm > 139 kNm [Acceptable]
- For beam volumes < 2 m³, W_r may be used to check beam shear capacity
- For beam volumes ≥ 2 m³, W_r must be used to check beam shear capacity
- Calculate W_r and compare to W_f to check shear resistance:
  - $W_f = wL = 19.7(7.5) = 148$ kN
  - $W_r L^{0.18} = 395$ kNm$^{0.18}$
  - $W_r = (W_r L^{0.18})(L^{0.18}) = 395 \times (7.5)^{-0.18} = 275$ kN > 148 kN [Acceptable]

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Use 215 × 608 mm 20f-E D.Fir-L glulam

Example 11: Using Selection Tables for Fire Resistance – Columns

- Design columns for the following conditions:
- Specified dead load = 2.0 kPa
- Specified live load = 2.4 kPa (residential use and occupancy)
- Tributary area = 25 m^2
- Unbraced length = 5 m
- Exposed to fire on four sides
- 1-hour fire-resistance rating
- Dry service condition
- Untreated
- Column effectively pinned at both ends ($K_e = 1.0$)
- No eccentricity considered
- Use No.1 D.Fir-L

Example 11 – Solution

- Tributary area = 25 m^2 > 20 m^2
- Live load reduction factor (LLRF) $= 0.3 + \sqrt{9.8/25} = 0.926$
- Total specified load:
  - P = 25(2.0 + 2.4(0.926)) = 106 kN
- From Column Selection Tables for Fire Resistance of 60 minutes for sawn timber, try 292x292 mm:
  - P_r = 318 kN > 106 kN [Acceptable]

Use 292 × 292 mm No.1 D.Fir-L

Example 12: Using Selection Tables for Fire Resistance – Columns

- Design columns for the following conditions:
- Specified dead load = 1.0 kPa
- Specified live load = 1.9 kPa
- Specified snow load = 2.0 kPa
- Tributary area = 25 m^2 (for both snow and live load)(residential use and occupancy
- Unbraced length = 5 m
- Exposed to fire on four sides
- 2-hour fire-resistance rating
- 2 layer of 15.9 mm Type X gypsum board directly applied to all four sides of column
- Wet service condition
- Treated with a preservative
- Column effectively pinned at both ends (K_e = 1.0)
- No eccentricity considered
- Use No.1 D.Fir-L

Example 12 – Solution

- Tributary area = 25 m^2 > 20 m^2
- Live load reduction factor (LLRF) $= 0.3 + \sqrt{9.8/25} = 0.926$
- Total specified load:
  - P = 25(1.0 + 1.9(0.926) + 2.0) = 119 kN
- 60 minutes of fire-resistance is attributed to two layers of 15.9 mm Type X gypsum board fastened to the beam member, meaning the beam must possess a 60-minute fire-resistance rating
- Since service conditions are wet, the Column Selection Tables cannot be used, however, they can be used to obtain a trial section
- Select 292×292 mm from the tables, as it is the smallest section with P_r > 119 kN

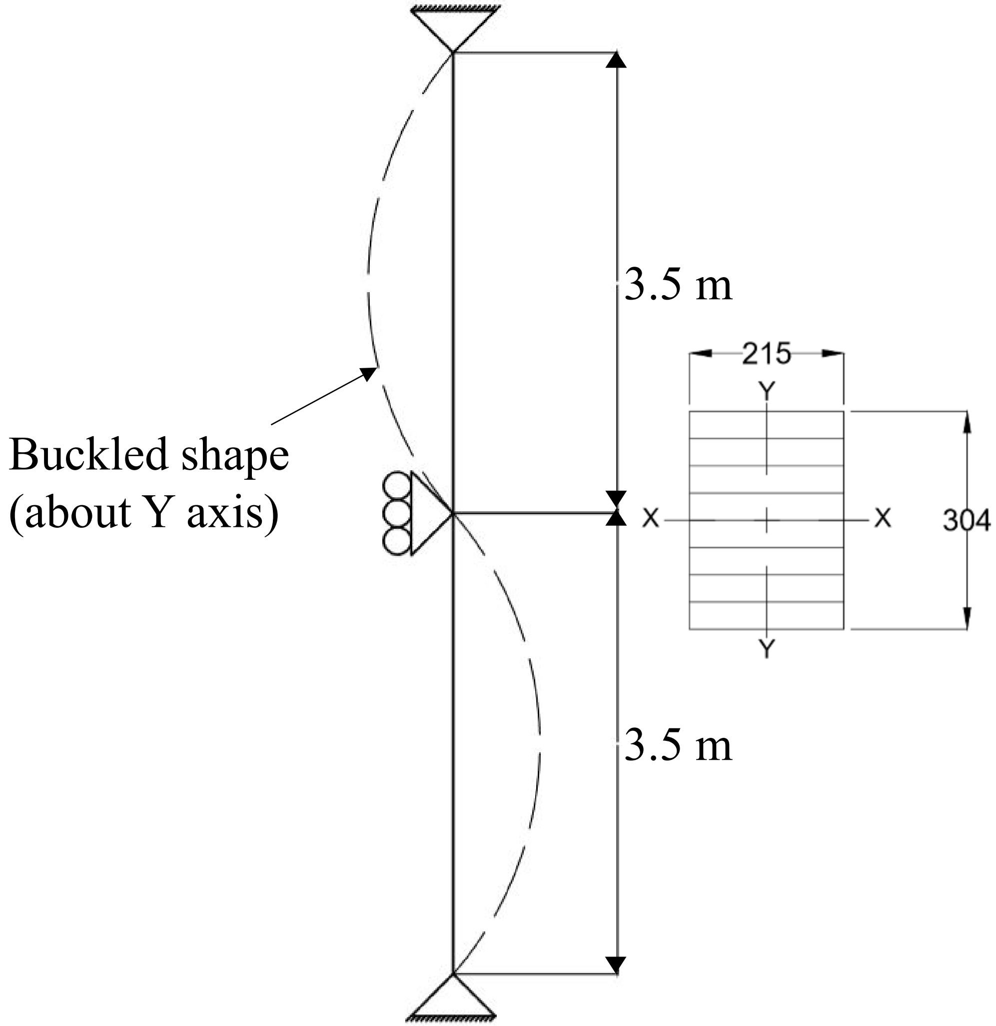
Example 12 – Solution

- Calculate P_r for wet service conditions:
  - P_r is the lesser of:
  - $P_{rd} = \phi F_C A K_{Zcd} K_{Cd}$ or $P_{rb} = \phi F_C A K_{Zcb} K_{Cb}$
- Where:
- $\phi F_C = 19.2$ MPa (from Table 10.7)
- Depth of member cross-sectional loss per side = 55 mm (from Table 10.11)
- $d_{eff} = 292 – 2(55) = 182$ mm
- $b_{eff} = 292 – 2(55) = 182$ mm
- $A = 182(182) = 33.1 \times 10^3$ mm^2
- K_{Zcd} and $K_{Zcb} = 6.3[292(5000)]^{-0.13} = 0.995$
- C_{cd} and C_{cb} $1.0(5000)/182 = 27.5$
- $F_c/E' = 52.1 \times 10^6$ (from Table 10.8)
- K_{Cd} and $K_{Cb} = [1 + (52.1 \times 10^{-6})(0.99)(27.5^3)]^{-1} = 0.482$
- P_{rd} and $P_{rb} = 19.2(33.1 \times 10^3)(0.995)(0.482) = 305$ kN [Acceptable]

Use 292×292 mm No.1 D.Fir-L column

Example 13: Using Selection Tables for Fire Resistance – Columns

- Is a 215 × 304 mm 12c-E Spruce-Pine glulam column adequate for the following conditions:
- Specified dead load = 1.5 kPa
- Specified snow load = 3.5 kPa (residential use and occupancy)
- Tributary area = 30 m^2
- Total length = 7 m
- 1-hour fire-resistance rating
- 1 layer of 12.7 mm Type X gypsum board directly applied to all four sides of column
- Dry service condition
- Untreated
- No eccentricity considered
- The column is effectively pinned at both ends and braced at mid-height



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Example 13 – Solution

- The column supports dead plus snow loads only; no live load reduction factor
- Total specified load:
  - $P = 30(1.5 + 3.5) = 150$ kN
- 15 minutes of fire-resistance is attributed to one layer of 12.7 mm Type X gypsum
- The beam must possess a 45-minute fire-resistance rating
- Slenderness ratio, C_c:
  - Effective depth of member cross-sectional loss per side = 38.5 mm (from Table 10.11)
  - $d_{eff} = 304 – 2(38.5) = 227$ mm
  - $b_{eff} = 215 – 2(38.5) = 138$ mm
  - $C_{cx} = K_eL_d/d_{eff} = 1.0(7000)/227 = 30.8$ [Governs]
  - $C_{cy} = K_eL_b/b_{eff} = 1.0(3500)/138 = 25.4$

Example 13 – Solution

- Buckling about X axis is the governing case
- Since the effective column length in the direction of buckling is equal to the total column length ($K_e L_d = L$), the Column Selection Tables may be used
- From Column Selection Tables for Fire Resistance:
  - $P_{rx} = 260$ kN > 150 kN [Acceptable]

The 215 × 304 mm 12c-E Spruce-Pine glulam section is adequate

Example 14: Using Selection Tables for Fire Resistance – Columns

- Is a 215 × 304 mm 12c-E Spruce-Pine glulam column adequate for the following conditions:
- Specified dead load = 1.5 kPa
- Specified snow load = 3.5 kPa (residential use and occupancy)
- Tributary area = 30 m^2
- Total length = 7 m
- 1-hour fire-resistance rating
- 1 layer of 12.7 mm Type X gypsum board directly applied to all sides of column
- Dry service condition
- Untreated
- No eccentricity considered
- The column is effectively pinned at both ends and braced at mid-height in all directions

Example 14 – Solution

- Effective column length about X and Y axis ($K_eL_{d,b}$ = 1.0(4.5) = 4.5 m) is not equal to total column length (L = 9.0 m)
- Therefore, Column Selection Tables cannot be used
- Total specified load:
  - P = 30(1.5 + 3.5) = 150 kN
- 12.7 mm Type X gypsum attributes 15 minutes of fire-resistance
- The beam must possess 45-minutes of fire-resistance

Example 14 – Solution

- Calculate P_r:
  - $P_r = \phi F_c A K_{Zcg} K_C$
  - Effective depth of member cross-sectional loss per side = 38.5 mm (from Table 10.11)
  - $d_{eff} = 304 – 2(38.5) = 227$ mm
  - $b_{eff} = 215 – 2(38.5) = 138$ mm
  - Effective A = 227(138) = 31.3 x 10^3 mm^2
  - $K_{Zcg} = 0.68[(0.215)(0.304)(9.0)]^{-0.13} = 0.729$
  - $F_c/E' = 115 \times 10^{-6}$ (from Table 10.10)
  - $C_{cx} = K_e L_d / d_{eff} = 1.0(4500)/227 = 19.8$
  - $C_{cy} = K_e L_b / b_{eff} = 1.0(4500)/138 = 32.6$ [Governs]
  - $K_C = [1 + (115 \times 10^{-6})(0.729)(32.6^3)]^{-1} = 0.256$
  - P_{rd} and $P_{rb} = 39.1(31.3 \times 10^3)(0.729)(0.256) = 228$ kN > 150 kN [Acceptable]

The 215 × 304 mm 12c-E Spruce-Pine glulam section is adequate

Example 15: Using Selection Tables for Fire Resistance – CLT floor and roof panels

- Design single-span CLT floor panels for the following conditions:
- Specified dead load = 1.5 kPa
- Specified live load = 2.4 kPa
- Panel span = 6 m
- Panel width (unit width) = 1 m
- 1-hour fire-resistance rating
- Dry service condition
- Untreated
- Use CLT Stress Grade V1, with 35 mm ply thickness for all plies

Example 15 – Solution

- Total specified load = 1.5 + 2.4 = 3.90 kPa
- Specified distributed load:
  - w = 3.90(1.0) = 3.9 kN/m
- Specified bending moment:
  - $M = \frac{wL^2}{8} = \frac{(3.9)(6.0)^2}{8} = 17.6 \text{ kNm}$
- From Solid Floor and Roof Panel Selection Tables, try 5-ply panels oriented in the major strength axis:
  - $M_{r,y}$ = 25.9 kNm > 17.6 kNm [Acceptable]

Use 5-ply V1 CLT floor panels oriented in the major strength axis

Example 16: Using Selection Tables for Fire Resistance – CLT floor and roof panels

- Design single-span floor CLT panel for the following conditions:
- Specified dead load = 2.0 kPa
- Specified live load = 2.4 kPa
- Panel span = 8 m
- Panel width (unit width) = 1 m
- 2-hour fire-resistance rating
- 1 layer of 15.9 mm Type X gypsum board applied directly to underside of CLT floor panels
- Dry service conditions
- Untreated
- Use CLT Stress Grade E2, with 35 mm ply thickness for all plies

Example 16 – Solution

- Total specified load = 2.0 + 2.4 = 4.40 kPa
- Specified distributed load:
  - w = 4.40(1.0) = 4.40 kN/m
- Specified bending moment:
  - $M = \frac{wL^2}{8} = \frac{(4.4)(8.0)^2}{8} = 35.2$ kNm
- 30 minutes of fire-resistance is attributed to the 15.9 mm Type X gypsum board
- CLT panels must possess a 90-minute fire-resistance rating
- From Solid Floor and Roof Panel Selection Tables, try 5-ply panels oriented in the major strength axis:
  - $M_{r,y}$ = 39.9 kNm > 35.2 kNm [Acceptable]

Use 5-ply E2 CLT floor panels oriented in the major strength axis