Fundamentals of Wood Design and Engineering

Wood Design

- Session 3
  - Introduction to Wood Engineering; Codes & Standards; Load combinations, weights of building materials and tributary area; Simple beam design: floor/roof joists, beams and girders.
- Session 4
  - Column design, stud walls, headers, posts.
- Session 5
  - Connection design, bolts, lag bolts, screws, nails.
- Session 6
  - Diaphragms and shearwalls, seismic issues; Options regarding composite panels

Codes and Standards

- Original Model Codes
  - Uniform Building Code (UBC) - International Conference of Building Officials (ICBO) - 1997
  - National Building Code (NBC) - Building Officials and Code Administrators International (BOCA) - 1999
  - Standard Building Code (SBC) - Southern Building Code Congress International (SBCCI) - 1997 and 1999

Codes and Standards

- Codes (continued)
  - One and Two Family Dwelling Code (OTFDC) - Council of American Building Officials (CABO) - 1995
  - International Building Code (IBC) - International Code Council (ICC) – 2000 and 2003
  - International Residential Code (IRC) - International Code Council (ICC) – 2000 and 2003
  - National Fire Protection Association (NFPA) – NFPA Building Code (NFPA 5000) - 2003
  - National Earthquake Hazard Reduction Program (NEHRP) - Federal Emergency Management Administration – 1994, 1997 and 2000

Codes and Standards

- Jurisdictions
  - National
    - NEHRP document, other FEMA publications
  - State
    - Two Versions
      - State buildings, Schools, Hospitals - Higher requirements
      - Minimum requirements for all jurisdictions in the state
  - Cities, Counties

Codes and Standards

- National Standards
  - National Design Specifications (NDS) - American Forest & Paper Association, American Wood Council – 1991, 1997 and 2001
    - Allowable Stress Design (ASD) of wood sawn and glued laminated members, diaphragms, shearwalls and connections.
  - Load and Resistance Factor Design (LRFD) - American Forest & Paper Association, American Wood Council – 1996
    - Load and Resistance Factor Design of wood members, diaphragms, shearwalls, connections.

Codes and Standards

- National Standards
  - ASCE-7 – American Society of Civil Engineers – 1998 and 2003
  - ACI-318 - American Concrete Institute (ACI) - 2002
  - ASD Specification for Structural Steel Buildings - American Institute for Steel Construction (AISC) - 1989
  - LRFD Specification for Structural Steel Buildings - American Institute for Steel Construction (AISC) – 1999/2000
  - ACI-530/ASCE-5/TMS-402 - American Concrete Institute (ACI), American Society of Civil Engineers (ASCE), The Masonry Society (TMS) - Masonry ASD - 2002

Codes and Standards

- Industry Associations
  - American Forest & Paper Association
  - American Wood Council
  - American Plywood Association
  - American Institute of Timber Construction
  - Grading Agencies
    - Western Wood Products Association (WWPA)
    - West Coast Lumber Inspection Bureau (WCLIB)
    - Others - see NDS

Allowable Stress Design

- Load Combinations - 1997 Uniform Building Code
  1. D
  2. D + L + (L_r or S)
  3. D + (W or E/1.4)
  4. 0.9D ± E/1.4
  5. D + 0.75[L + (L_r or S) + (W or E/1.4)]
  - Note:
    - Seismic force, E, is a strength level force in the 1997 UBC

Allowable Stress Design

- Load Combinations - 1997 Uniform Building Code - Alternate (1994 UBC Load Combinations)
  1. D + L + (L_r or S)
  2. D + L + (W or E/1.4)
  3. D + L + W + S/2
  4. D + L + S + W/2
  5. D + L + S + E/1.4
  - Notes:
    - a 1/3 allowable stress increase is permitted for Load Combinations 2 through 5 for the 1997 UBC Alternate ASD Load Combinations
    - Seismic force, E, is a strength level force in the 1997 UBC

Allowable Stress Design

- Load Combinations - 2003 International Building Code
  1. D
  2. D + L
  3. D + L + (L_r or S or R)
  4. D + (W or 0.7E) + L + (L_r or S or R)
  5. 0.6D + W
  6. 0.6D + 0.7E
  - Note:
    - Seismic force, E, is a strength level force in the 2000 IBC

Allowable Stress Design

- Load Combinations - 2003 International Building Code - Alternate
  1. D + L + (L_r or S or R)
  2. D + L + (ωW)
  3. D + L + ωW + S/2
  4. D + L + S + ωW/2
  5. D + L + S + E/1.4
  6. 0.9D + E/1.4
  - Notes:
    - a 1/3 allowable stress increase is permitted for Load Combinations 2 through 6 for the 2000 IBC Alternate ASD Load Combinations
    - Seismic force, E, is a strength level force in the 2000 IBC

Dead Loads

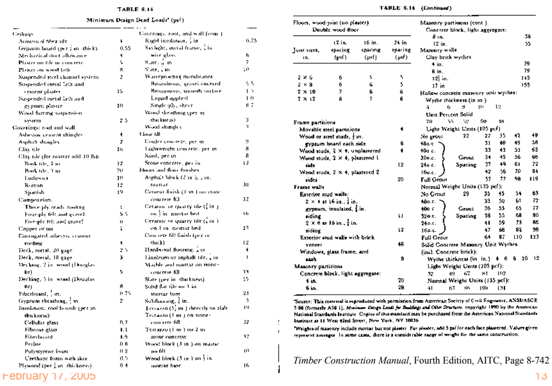


TABLE 8.14 Minimum Design Dead Loads (psf)

TABLE 8.14 (Continued)

Timber Construction Manual, Fourth Edition, AITC, Page 8-742

Dead Loads

- Floors

Floor Covering	2.0 psf
Plywood (Sheathing)	3.0 psf
Framing	4.0 psf
Ceiling	3.0 psf to 12.0 psf
Electrical & Mechanical	2.0 psf to 5.0 psf
Miscellaneous	1.0 psf
TOTAL	15.0 psf to 25.0 psf
Partitions	10.0 psf for residential
	20.0 psf for office

Dead Loads

- Roofs

Roofing	5 ply or singles	6.0 psf plus 3.0 psf for reroofing
	or Tile	12.0 psf
	or Shakes	3.0 psf
Plywood (Sheathing)		2.0 psf
Framing		3.0 psf
Ceiling		3.0 psf
Insulation		3.0 psf
Electrical & Mechanical		1.0 psf to 2.0 psf
Miscellaneous		1.0 psf
TOTAL		15.0 psf to 25.0 psf

Live Loads

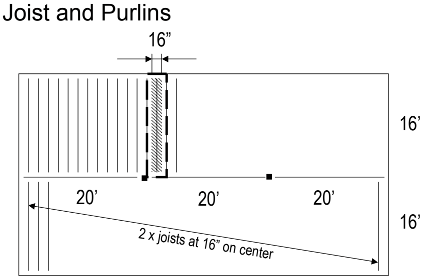
Residential	40 psf
Office/Schools	50 psf
Stairs/Corridors	100 psf
Storage	125 psf

Live Load Reduction

- Old UBC Method - Tributary Area
  - $R = r(A - 150)$
- ASCE 7 Method - Influence Area
  - $L = L_0\left(0.25 + \dfrac{15}{\sqrt{A_i}}\right)$

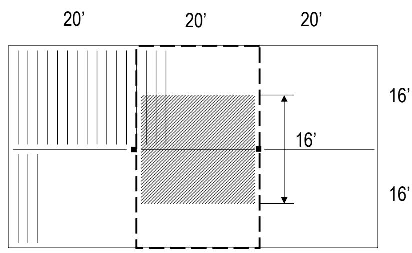
Tributary Area vs Influence Area

- Joist and Purlins



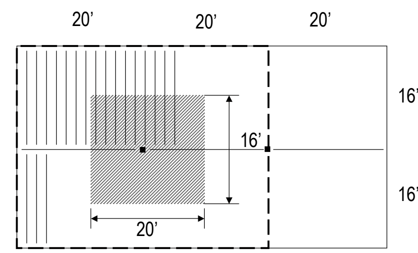
Tributary Area vs Influence Area

- Beams and Girders



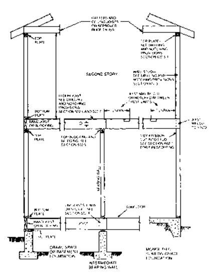
Tributary Area vs Influence Area

- Columns



Framing Methods

- Platform Framing
- Balloon Framing



CABO One and Two Family Dwelling Code, 1995 Edition, Page 67

Types of Wood Buildings

- Residential/Houses
  - Single Family
  - Two Family (Duplexes)
  - Townhouses
  - Apartments
- Commercial
  - Stores, offices
- Warehouse/Industrial
- Bridges
  - Vehicular
  - Pedestrian
- Miscellaneous
  - Play Structures
  - Gazebos
  - Decks

Why Use Wood?

- Economics
- Availability
- High Strength per Weight Ratio
- Simple Construction
- Light Weight
- Fire Resistant

Why Use Wood?

- Strength of Material per Unit Weight

	Reinforced Concrete	Steel	Wood
Strength / Weight	$\frac{4000\ psi}{150\ pcf} = 27$	$\frac{36{,}000\ psi}{490\ pcf} = 73$, $\frac{50{,}000\ psi}{490\ pcf} = 102$	$\frac{7500\ psi}{30\ pcf} = 250$
Wood / Other	9.4	3.4, (2.5)	1

Wood Products

- Remanufactured Lumber
  - Plywood
  - Glued Laminated Beams
  - Microlam
  - Laminated Decking
- Wood Chips and Fibers
  - OSB - Oriented Strand Board
  - Particle Board
- Pre-Engineered Products
  - I - Joists
  - Open Web Joists
  - Pre-Manufactured Trusses

Lumber Sizes

- Sawn Lumber
  - 2 x 4 — 2 x 14
  - 3 x 4 — 3 x 16
  - 4 x 4 — 4 x 16
  - 6 x 6 — 6 x 24
  - 8 x 8 — 8 x 24
  - 10 x 10 — 10 x 24
  - 12 x 12 — 12 x 24
  - 14 x 14 — 14 x 24
  - 16 x 16 — 16 x 24
  - 18 x 18 — 18 x 24
  - 20 x 20 — 20 x 24
  - 22 x 22 — 22 x 24
  - 24 x 24

Lumber Sizes

- Sawn Lumber
  - Dimension Lumber
    - 2 x 4 — 2 x 12
    - 3 x 4 — 3 x 16
    - 4 x 4 — 4 x 16
  - Beams & Stringers
    - 6 x 10 — 6 x 16
    - 8 x 12 — 8 x 16
  - Posts & Timbers
    - 6 x 6 — 6 x 8
    - 8 x 8 — 8 x 10
    - 10 x 10

Lumber Sizes

- Sawn Lumber - Standard Dressed Sizes
  - Dimension Lumber
    - Thickness
      - 2 x, 3 x, 4 x - nominal thickness minus 1/2”
    - Width
      - 2” through 6” - nominal width minus 1/2”
      - 8” and wider - nominal width minus 3/4”
  - Timbers
    - Thickness
      - 5 x and thicker - nominal thickness minus 1/2”
    - Width
      - 5” and wider - nominal width minus 1/2”

Lumber Sizes

- Glued Laminated Lumber
  - Western Species Beams
    - Widths
      - 3-1/8”, 5-1/8”, 6-3/4”, 8-3/4”, 10-3/4”, 12-1/4”
    - Laminations
      - 1-1/2”
  - Southern Pine Beams
    - Widths
      - 3”, 5”, 6-3/4”, 8-1/2”, 10-1/2”
    - Laminations
      - 1-3/8”

Connections

- Nails
  - Common
  - Box
  - Sinkers
- Bolts
- Staples
- Glue
- Sheet Metal Connectors
  - “Simpson Strong-Tie”
  - “KC Metals”

Grading of Lumber

- Knots
- Checks
- Shakes
- Splits
- Slope of Grain

Grading of Lumber

- Visual Grading
  - Dense Select Structural
  - Select Structural
  - Dense No. 1
  - No. 1 and Better
  - No. 1
  - No. 2
  - No. 3
  - Stud
  - Standard
  - Construction
  - Utility

Allowable Stresses

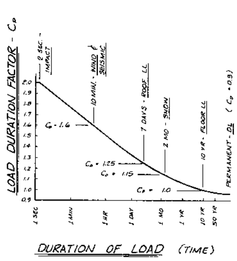
- Allowable Stresses (Allowable Design Values)
  - Tabulated Design Values x Adjustment Factors
    - $F_b' = F_b \, x \, C_D C_M C_t C_L C_F C_V C_{fu} C_i C_r C_c C_f$
    - $F_t' = F_t \, x \, C_D C_M C_t C_F C_i$
    - $F_v' = F_v \, x \, C_D C_M C_t C_i [C_H]$ (C_H no longer used)
    - $F_{c\perp}' = F_{c\perp} \, x \, C_M C_t C_i C_b$
    - $F_c' = F_c \, x \, C_D C_M C_F C_i C_P$
    - $E' = E \, x \, C_M C_t C_i C_T$
    - $F_g' = F_g \, x \, C_D C_t$ – Not listed in 2001 NDS

Allowable Stresses

- Allowable Stresses (Allowable Design Values)
  - Tabulated Design Values x Adjustment Factors
- Tabulated Design Values
  - Tables 4A
    - Visually Graded Dimension Lumber except Southern Pine
  - Table 4B
    - Visually Graded Southern Pine Dimension Lumber
  - Table 4C
    - Mechanically Graded Dimension Lumber

Allowable Stresses

- Bending Stress Adjustment Factors
  - Load Duration Factor, C_D



Design of Wood Structures, Breyer, Donald, Page 4.39

Allowable Stresses

- Bending Stress Adjustment Factors
  - Load Duration Factor, C_D
    - Use shortest duration load in combination

Dead Load	0.9
Floor Live Load	1.0
Snow Load	1.15
Roof Live Load	1.25
Wind or Seismic Force	1.6

Allowable Stresses

- Bending Stress Adjustment Factors
  - Wet Service Factor, C_M
    - C_M = 1.0 for moisture content less than or equal to 19 percent for sawn dimension lumber and timber.
    - C_M = 1.0 for moisture content less than or equal to 16 percent for glued laminated timber.
    - C_M = 0.85 for moisture content greater than 19 percent for sawn dimension lumber with a tabulated allowable bending stress times the size factor of more than 1150 psi. Otherwise, C_M = 1.00.
    - C_M = 1.0 for moisture content greater than 19 percent for sawn timber.
    - C_M = 0.80 for moisture content greater than 16 percent for glued laminated timber.

Allowable Stresses

- Bending Stress Adjustment Factors
  - Temperature Factor, C_t
    - Wet Service Condition
      - C_t = 1.0 for temperature less than or equal to 100 degrees Fahrenheit.
      - C_t = 0.7 for temperature greater than 100 and less than or equal to 125 degrees Fahrenheit.
      - C_t = 0.5 for temperature greater than 125 and less than or equal to 150 degrees Fahrenheit.
    - Dry Service Condition
      - C_t = 1.0 for temperature less than or equal to 100 degrees Fahrenheit.
      - C_t = 0.8 for temperature greater than 100 and less than or equal to 125 degrees Fahrenheit.
      - C_t = 0.7 for temperature greater than 125 and less than or equal to 150 degrees Fahrenheit.

Allowable Stresses

- Bending Stress Adjustment Factors
  - Beam Stability Factor, C_L
    - For beams which are laterally supported on their compression flange and braced to prevent buckling or have shapes which do not buckle under bending, C_L = 1.0.
    - For beams which do not meet the above criteria a stability factor is calculated depending on the unbraced length of the member.
      - See NDS Section 3.3.3, Equation 3.3-6

$$C_L = \frac{1+\left(F_{bE}/F_b^*\right)}{1.9} - \sqrt{\left[\frac{1+\left(F_{bE}/F_b^*\right)}{1.9}\right]^2 - \frac{F_{bE}/F_b^*}{0.95}}$$

Lateral Stability of Beams

Table 3.3.3 Effective Length, ℓ_e, for Bending Members

Cantilever[1]	when $\ell_u/d < 7$	when $\ell_u/d \geq 7$
Uniformly distributed load	$\ell_e = 1.33\ \ell_u$	$\ell_e = 0.90\ \ell_u + 3d$
Concentrated load at unsupported end	$\ell_e = 1.87\ \ell_u$	$\ell_e = 1.44\ \ell_u + 3d$
Single Span Beam[1,2]	when $\ell_u/d < 7$	when $\ell_u/d \geq 7$
Uniformly distributed load	$\ell_e = 2.06\ \ell_u$	$\ell_e = 1.63\ \ell_u + 3d$
Concentrated load at center with no intermediate lateral support	$\ell_e = 1.80\ \ell_u$	$\ell_e = 1.37\ \ell_u + 3d$
Concentrated load at center with lateral support at center	$\ell_e = 1.11\ \ell_u$	
Two equal concentrated loads at 1/3 points with lateral support at 1/3 points	$\ell_e = 1.68\ \ell_u$	
Three equal concentrated loads at 1/4 points with lateral support at 1/4 points	$\ell_e = 1.54\ \ell_u$	
Four equal concentrated loads at 1/5 points with lateral support at 1/5 points	$\ell_e = 1.68\ \ell_u$	
Five equal concentrated loads at 1/6 points with lateral support at 1/6 points	$\ell_e = 1.73\ \ell_u$	
Six equal concentrated loads at 1/7 points with lateral support at 1/7 points	$\ell_e = 1.78\ \ell_u$	
Seven or more equal concentrated loads, evenly spaced, with lateral support at points of load application	$\ell_e = 1.84\ \ell_u$	
Equal end moments	$\ell_e = 1.84\ \ell_u$	

1. For single span or cantilever bending members with loading conditions not specified in Table 3.3.3:
$\ell_e = 2.06\ \ell_u$ when $\ell_u/d < 7$
$\ell_e = 1.63\ \ell_u + 3d$ when $7 \leq \ell_u/d \leq 14.3$
$\ell_e = 1.84\ \ell_u$ when $\ell_u/d > 14.3$
2. Multiple span applications shall be based on table values or engineering analysis.

Allowable Stresses

- Bending Stress Adjustment Factors
  - Beam Stability Factor, C_L
    - $d/b < 2$; no lateral support required
    - $2 < d/b < 4$; the ends shall be held in position
    - $4 < d/b < 5$; the compression edge of the member shall be held in line for its entire length and ends at points of bearing shall be held in position
    - $5 < d/b < 6$; bridging, full depth blocking or cross bracing shall be installed at 8 feet o.c. maximum, the compression edge of the member shall be held in line for its entire length and ends at points of bearing shall be held in position
    - $6 < d/b < 7$; both edges of the member shall be held in line for their entire length and ends at points of bearing shall be held in position

Allowable Stresses

- Bending Stress Adjustment Factors
  - Size Factor, C_F
    - C_F for sawn dimension lumber, except Southern Pine, ranges from 0.9 to 1.5 depending on the width and thickness of the member.
    - C_F for Southern Pine sawn dimension lumber has been incorporated into the design value tables.
    - C_F for sawn timber loaded on the narrow face is calculated by the equation $C_F = (12/d)^{1/9}$ when the depth exceeds 12 inches.
    - C_F for sawn timber loaded on the wide face ranges between 0.74 and 1.00.
    - C_F does not apply to glued laminated timbers.

Allowable Stresses

- Bending Stress Adjustment Factors
  - Volume Factor, C_V
    - $C_V = (21/L)^{1/x}(12/d)^{1/x}(5.125/b)^{1/x}$
      - L = distance between points of zero moment
      - d = depth of member
      - b = width of member
      - x = 10 for all species except Southern Pine (SP = 20)
    - C_V does not apply to sawn dimension lumber and timber.
    - C_V for glued laminated lumber is calculated for each size member.
    - C_V does not apply simultaneously with the C_L factor. The lesser values is taken where both factors apply.

Allowable Stresses

- Bending Stress Adjustment Factors
  - Flat Use Factor, C_{fu}
    - C_{fu} for sawn dimension lumber ranges between 1.0 and 1.2.
    - C_{fu} for glued laminated timber ranges between 1.01 and 1.19.

Allowable Stresses

- Bending Stress Adjustment Factors
  - Incising Factor, C_i
    - Incisions parallel to grain to a maximum depth of 0.4 inches and a maximum length of 3/8 inches with a maximum density of 1,100 per square foot.
    - C_i = 0.80 for sawn dimension lumber and timber, when incisions have been made to increase penetration of pressure preservative treatment.
    - C_i was 0.85 in previous versions of the NDS.

Allowable Stresses

- Bending Stress Adjustment Factors
  - Repetitive Member Factor, C_r
    - C_r = 1.15 for sawn dimension lumber 2” to 4” thick, when the same members are repeated and spaced at less than or equal to 24 inches on center.

Allowable Stresses

- Bending Stress Adjustment Factors
  - Curvature Factor, C_c
    - C_c for glued laminated timber is calculated when the member is curved, such as in arched glued laminated timbers.

Allowable Stresses

- Bending Stress Adjustment Factors
  - Form Factor, C_f
    - C_f = 1.18 for round wood sections.
    - C_f = 1.414 for square wood sections loaded on the diagonal (diamond shaped wood section).

Allowable Stresses

- Shear Stress Adjustment Factors
  - The same as bending stress adjustment factors for the following:
    - Load Duration Factor, C_D
    - Temperature Factor, C_t

Allowable Stresses

- Shear Stress Adjustment Factors
  - Wet Service Factor, C_M
    - C_M = 1.0 for moisture content less than or equal to 19 percent for sawn dimension lumber and timber.
    - C_M = 1.0 for moisture content less than or equal to 16 percent for glued laminated timber.
    - C_M = 0.97 for moisture content greater than 19 percent for sawn dimension lumber.
    - C_M = 1.0 for moisture content greater than 19 percent for sawn timber.
    - C_M = 0.875 for moisture content greater than 16 percent for glued laminated timber.

Allowable Stresses

- Shear Stress Adjustment Factors
  - Incising Factor, C_i
    - C_i = 1.00 for sawn dimension lumber and timber, whether or not incisions have been made to increase penetration of pressure preservative treatment.

Allowable Stresses

- Shear Stress Adjustment Factors
  - Shear Stress Factor, C_H – Factor Eliminated in the 2001 NDS
    - C_H was based on the size of splits, checks and shakes on the face of a member.
    - The tabulated shear stress values were based on standard sizes of splits, checks and shakes.
    - If the sizes of splits, checks and shakes were less than assumed for the tabulated values, then the shear stress value may be increased.
    - The values for C_H ranged between 1.00 and 2.00.

Allowable Stresses

- Bearing Stress (Compression Perpendicular to Grain) Adjustment Factors
  - The same as bending stress adjustment factors for the following:
    - Temperature Factor, C_t

Allowable Stresses

- Bearing Stress (Compression Perpendicular to Grain) Adjustment Factors
  - Wet Service Factor, C_M
    - C_M = 1.0 for moisture content less than or equal to 19 percent for sawn dimension lumber and timber.
    - C_M = 1.0 for moisture content less than or equal to 16 percent for glued laminated timber.
    - C_M = 0.67 for moisture content greater than 19 percent for sawn dimension lumber.
    - C_M = 0.67 for moisture content greater than 19 percent for sawn timber.
    - C_M = 0.53 for moisture content greater than 16 percent for glued laminated timber.

Allowable Stresses

- Bearing Stress (Compression Perpendicular to Grain) Adjustment Factors
  - Incising Factor, C_i
    - C_i = 1.00 for sawn dimension lumber and timber, whether or not incisions have been made to increase penetration of pressure preservative treatment.

Allowable Stresses

- Bearing Stress (Compression Perpendicular to Grain) Adjustment Factors
  - Bearing Area Factor, C_b
    - $C_b = l_b + 0.375/l_b$ for bearing lengths less than 6 inches long and greater than 3 inches from the end of the member.
    - Supports in the middle of the span.
    - Ranges between 1.75 for 0.5 inch bearing length and 1.0 for 6 inch bearing length.

Allowable Stresses

- Modulus of Elasticity Adjustment Factors
  - Wet Service Factor, C_M
    - C_M = 1.0 for moisture content less than or equal to 19 percent for sawn dimension lumber and timber.
    - C_M = 1.0 for moisture content less than or equal to 16 percent for glued laminated timber.
    - C_M = 0.9 for moisture content greater than 19 percent for sawn dimension lumber.
    - C_M = 1.0 for moisture content greater than 19 percent for sawn timber.
    - C_M = 0.833 for moisture content greater than 16 percent for glued laminated timber.

Allowable Stresses

- Modulus of Elasticity Adjustment Factors
  - Temperature Factor, C_t
    - C_t = 1.0 for temperature less than or equal to 100 degrees Fahrenheit.
    - C_t = 0.9 for temperature greater than 100 and less than or equal to 125 degrees Fahrenheit.
    - C_t = 0.9 for temperature greater than 125 and less than or equal to 150 degrees Fahrenheit.

Allowable Stresses

- Modulus of Elasticity Adjustment Factors
  - Incising Factor, C_i
    - C_i = 0.95 for sawn dimension lumber and timber, when incisions have been made to increase penetration of pressure preservative treatment.

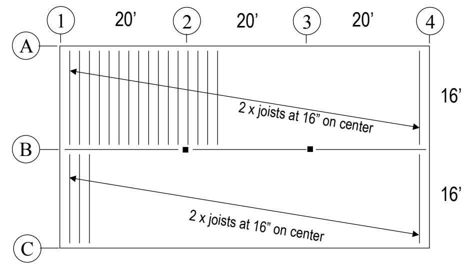
Allowable Stresses

- Modulus of Elasticity Adjustment Factors
  - Buckling Stiffness Factor, C_T
    - C_T is only used for 2” x 4” or smaller members in sawn lumber truss compression chords.

Governing Load Combination

- C_D can be used in determining the governing load combination
  - Divide the total combined load by the appropriate C_D factor.

Floor Joist Design

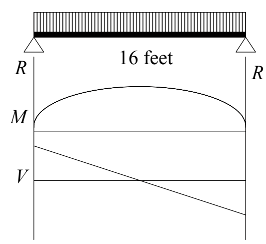


Floor Joist Design

$w_{\mathrm{DL,F}}$	=	15.0 psf
$w_{\mathrm{Partitions}}$	=	10.0 psf
w_{DL}	=	25.0 psf
w_{LL}	=	40.0 psf
w_{T}	=	65.0 psf

w_{T} = 65.0 psf (16”/12”/’) = 86.7 plf

Floor Joist Design



$$M = wl^2/8 = \frac{86.7 \text{ plf } (16 \text{ ft})^2\ 12''/'}{8}$$

M = 2,773 lb-ft = 33,280 lb-in

$$V = wl/2 = R = \frac{86.7 \text{ plf } (16 \text{ ft})}{2}$$

V = 693 lb

Floor Joist Design

- $F_b' = F_b \times C_D C_M C_t C_L C_F C_V C_{fu} C_i C_r C_c C_f$
  - F_b = 1000 psi - DFL No. 1 - NDS Table 4A
  - C_D = 1.0 long term loading
  - C_M = 1.0 used where the moisture content will not exceed 19 percent.
  - C_r = 1.15 repetitive members
  - C_L = 1.0 member is braced against compression flange buckling by blocking at supports and the plywood sheathing.
  - C_F = 1.0 - conservative for design unless a member is greater than 14 inches deep.
  - C_t, C_{fu}, C_i, C_f = 1.0
  - C_c and C_V are only for glued laminated timbers.

Floor Joist Design

- $F_v' = F_v \times C_D C_M C_t C_i$
  - F_v = 95 psi - DFL No. 1 - NDS Table 4A
  - C_D = 1.0 long term loading
  - C_M = 1.0 used where the moisture content will not exceed 19 percent.
  - C_t, C_i = 1.0

Floor Joist Design

- $F_{c\perp}' = F_{c\perp} \times C_M C_t C_i C_b$
  - $F_{c\perp}$ = 625 psi - DFL No. 1 - NDS Table 4A
  - C_M = 1.0 used where the moisture content will not exceed 19 percent.
  - C_t, C_i = 1.0
  - C_b = 1.0 the bearing is always at the end of the member.

Floor Joist Design

- $E' = E \times C_M C_t C_i C_T$
  - E = 1,700,000 psi - DFL No. 1 - NDS Table 4A
  - C_M = 1.0 used where the moisture content will not exceed 19 percent.
  - C_t, C_i = 1.0
  - C_T = 1.0 the member is not a truss chord.

Floor Joist Design

- Deflection
  - Minimum $L/240$ for Total Load
    - $L/240$ = 16 ft x 12"/' /240 = 0.80 in.
  - Minimum L/360 for Live Load
    - $L/360$ = 16 ft x 12"/' /360 = 0.53 in.
- Deflection = $\Delta = 5wL^4/(384EI)$
  - Therefore $I_{req} = 5wL^4/(384E\Delta)$

Floor Joist Design

- F'_b = 1000 psi x 1.15 = 1150 psi
- F'_v = 95 psi
- $F_{c\perp}$ = 625 psi
- E' = 1,700,000 psi

  Therefore
  - $S_{req} = M/F'_b$ = 33,280 lb-in/1150 psi = 28.9 in^3
  - $A_{req} = 3V/2F'_V$ = 3 x 693 lb/(2 x 95 psi) = 10.9 in^2
  - $I_{req} = 5wL^4/(384E\Delta) = \frac{5(86.7\text{ plf})(16')^4(1728\text{in}^3/\text{ft}^3)}{384(1,700,000\text{psi})(0.80\text{in})}$ = 94.0 in^4
- Try 2 x 12 DFL No. 1 - NDS Table 1B
  - A = 16.88 in^2, S = 31.64 in^3, I = 178.0 in^4

Floor Joist Design

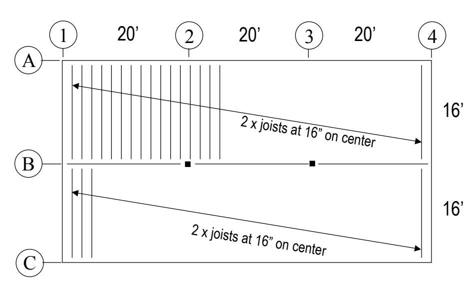
- Required Bearing

  R = 693 pounds

  Required Bearing Area = 693 lbs/625 psi
  = 1.1 in^2

  Required Bearing Length = 1.1 in^2 / 1.5 in (width)
  = 0.73 inches
- Use a standard joist hanger - bearing length = 1.5 in.

Floor Beam Design



Floor Beam Design

- Live Load Reduction
  - Tributary Area greater than 150 square feet
  - Roof
    - See table 16-C in the Uniform Building Code
  - Floor
    - R (reduction in percentage) = $r(A - 150)$
      - r = 0.08 for floors
    - $R \le 40\%$ for members supporting loads from one level only.
    - $R \le 60\%$ for members supporting loads from more than one level.
    - $R \le 23.1(1 + D/L)$

Floor Beam Design

- Live Load Reduction
  - Tributary Area = A = 16 feet x 20 feet = 320 sq ft
  - R = 0.08(320 sq ft - 150 sq ft) = 13.6%
  - $R \le 23.1(1 + D/L) = 23.1(1 + 24/40) = 37.0\%$ - OK
- Live Load = 40 psf x (1-13.6%) = 34.6 psf

Floor Beam Design

- Live Load Reduction (Influence Area Method)
  - Influence Area = A_i = 32 feet x 20 feet = 640 sq ft
  - $L = L_0\left(0.25 + \frac{15}{\sqrt{640}}\right) = 84.3\% \times L_o$
- Live Load = 40 psf x (84.3%) = 33.7 psf

Floor Beam Design

$w_{DL,F}$ = 15.0 psf

$w_{Partitions}$ = <u>10.0 psf</u>

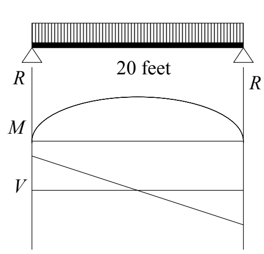
w_{DL} = 25.0 psf

w_{LL} = <u>34.6 psf</u>

w_T = 59.6 psf

w_T = 59.6 psf (16') = 953.6 plf

Floor Beam Design



$M = wl^2/8 = \frac{954 \text{ plf } (20 \text{ ft})^2\ 12''/'}{8}$

M = 47,680 lb-ft = 572,160 lb-in

$V = wl/2 = R = \frac{954 \text{ plf } (20 \text{ ft})}{2}$

V = 9,536 lb

Floor Beam Design

- $F_b' = F_b \times C_D C_M C_t C_L C_F C_V C_{fu} C_i C_r C_c C_f$
  - F_b = 2400 psi - 24F-V4 - NDS Table 5A
  - C_D = 1.0 long term loading
  - C_M = 1.0 used where the moisture content will not exceed 16 percent.
  - C_V assume equal to 1.0 for preliminary design.
  - C_L = 1.0 member is braced against compression flange buckling by joists.
  - C_t, C_{fu}, C_i, C_r, C_C, C_f = 1.0

Floor Beam Design

- $F_v' = F_v \times C_D C_M C_t C_i$
  - F_v = 190 psi - 24F-V4 - NDS Table 5A
  - C_D = 1.0 long term loading
  - C_M = 1.0 used where the moisture content will not exceed 16 percent.
  - C_t, C_i = 1.0

Floor Beam Design

- $F_{c\perp}' = F_{c\perp} \times C_M C_t C_i C_b$
  - $F_{c\perp}$ = 650 psi - 24F-V4 - NDS Table 5A
  - C_M = 1.0 used where the moisture content will not exceed 16 percent.
  - C_t, C_i = 1.0
  - C_b = 1.0 the bearing is always at the end of the member.

Floor Beam Design

- Floor Beam Design
  - $E' = E \times C_M C_t C_i C_T$
    - E = 1,800,000 psi - 24F-V4 - NDS Table 5A
    - C_M = 1.0 used where the moisture content will not exceed 16 percent.
    - C_t, C_i = 1.0
    - C_T = 1.0 the member is not a truss chord.

Floor Beam Design

- Deflection
  - Minimum $L/240$ for Total Load
    - $L/240$ = 20 ft x 12"/' /240 = 1.00 in.
  - Minimum $L/360$ for Live Load
    - $L/360$ = 20 ft x 12"/' /360 = 0.67 in.

Floor Beam Design

- F'_b = 2400 psi
- F'_v = 190 psi
- $F_{c\perp}$ = 650 psi
- E' = 1,800,000 psi

  Therefore
  - $S_{req} = M/F'_b$ = 572,160 lb-in/2400 psi = 238 in^3
  - $A_{req} = 3V/2F'_V$ = 3 x 9,536 lb/(2 x 190 psi) = 75.3 in^2
  - $I_{req} = 5wL^4/(384E\Delta) = \frac{5(953.6\text{ plf})(20')^4(1728\text{in}^3/\text{ft}^3)}{384(1{,}800{,}000\text{psi})(1.00\text{in})} = 1910\text{ in}^4$
- Try 5-1/8" x 18" G.L. - NDS Table 1C
  - A = 92.25 in^2, S = 276.8 in^3, I = 2491 in^4

Floor Beam Design

- Calculate C_V to verify beam size
  - $C_V = (21/L)^{1/x}(12/d)^{1/x}(5.125/b)^{1/x}$
    - L = distance between points of zero moment
    - d = depth of member
    - b = width of member
    - x = 10 for all species except Southern Pine (SP = 20)
  - $C_V = 1.0\,(21/20)^{1/10}(12/18)^{1/10}(5.125/5.125)^{1/10} = 0.97$

  - Therefore S_{req} = 572,160 lb-in/(2400 psi x 0.97) = 246 in^3 - OK

Floor Beam Design

- Required Bearing

  R = 9,536 lbs

  Required Bearing Area = 9,536 lbs/650 psi = 14.7 in^2

  Required Bearing Length = 14.7 in^2 / 5.125 in(width) = 2.9 inches
- Use a minimum 6 x 6 post with a heavy duty post cap - minimum bearing length = 5.5 in.

Notches in Beams

- Limitations
  - Notches are not allowed in the areas of highest bending stress.
  - Limited to the end thirds of the member and the following dimensions:
    - Notch Depth <= Beam Depth/6
    - Notch Length <= Beam Depth/3
  - The notch depth at the support may be up to the Beam Depth/4.

Notches in Beams

- Bending Stresses
  - Minimal to No effect
- Deflection
  - Minimal to No effect
- Shear Stresses
  - The shear stress is increased by the following equations:

Tension Side Notch

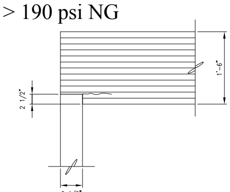
$$f_v = \left[\frac{3V}{2bd_n}\right]\left[\frac{d}{d_n}\right]$$

Compression Side Notch

$$f_v = \frac{3V}{2b\left[d - \left(\frac{d-d_n}{d_n}\right)e\right]}$$

Notches in Beams

- Check Floor Beam for 2.5 in notch in tension side at bearing of beam over support.
  - $f_v = \left[\frac{3V}{2bd_n}\right]\left[\frac{d}{d_n}\right] = \left[\frac{3 \times 9536\,\text{lbs}}{2 \times 5.125\,\text{in} \times 15.5\,\text{in}}\right]\left[\frac{18\,\text{in}}{15.5\,\text{in}}\right]$
  - f_v = 209 psi > 190 psi NG



Lateral Stability of Beams

- For beams which are not laterally supported the value of C_L must be calculated.

$$C_L = \frac{1+(F_{bE}/F_b^*)}{1.9} - \sqrt{\left[\frac{1+(F_{bE}/F_b^*)}{1.9}\right]^2 - \frac{F_{bE}/F_b^*}{0.95}}$$

Lateral Stability of Beams

- Beam Stability Factor, C_L

$$C_L = \frac{1+(F_{bE}/F_b^*)}{1.9} - \sqrt{\left[\frac{1+(F_{bE}/F_b^*)}{1.9}\right]^2 - \frac{F_{bE}/F_b^*}{0.95}}$$

F^*_b = Tabulated compression design value multiplied by all applicable adjustment factors except C_{fu}, C_V, C_L

$$F_{bE} = \frac{K_{bE}E'}{R_B^2}$$

$$R_B = \sqrt{\frac{l_e d}{b^2}}$$

K_{bE} = 0.745 - 1.225(COV_E)
0.439 for visually graded lumber
0.561 for machine evaluated lumber
0.610 for products with COV_E <= 0.11

Lateral Stability of Beams

Table 3.3.3 Effective Length, ℓ_e, for Bending Members

Cantilever[1]	when $\ell_u/d < 7$	when $\ell_u/d \ge 7$
Uniformly distributed load	$\ell_e = 1.33\ \ell_u$	$\ell_e = 0.90\ \ell_u + 3d$
Concentrated load at unsupported end	$\ell_e = 1.87\ \ell_u$	$\ell_e = 1.44\ \ell_u + 3d$
Single Span Beam[1,2]	when $\ell_u/d < 7$	when $\ell_u/d \ge 7$
Uniformly distributed load	$\ell_e = 2.06\ \ell_u$	$\ell_e = 1.63\ \ell_u + 3d$
Concentrated load at center with no intermediate lateral support	$\ell_e = 1.80\ \ell_u$	$\ell_e = 1.37\ \ell_u + 3d$
Concentrated load at center with lateral support at center	$\ell_e = 1.11\ \ell_u$	
Two equal concentrated loads at 1/3 points with lateral support at 1/3 points	$\ell_e = 1.68\ \ell_u$	
Three equal concentrated loads at 1/4 points with lateral support at 1/4 points	$\ell_e = 1.54\ \ell_u$	
Four equal concentrated loads at 1/5 points with lateral support at 1/5 points	$\ell_e = 1.68\ \ell_u$	
Five equal concentrated loads at 1/6 points with lateral support at 1/6 points	$\ell_e = 1.73\ \ell_u$	
Six equal concentrated loads at 1/7 points with lateral support at 1/7 points	$\ell_e = 1.78\ \ell_u$	
Seven or more equal concentrated loads, evenly spaced, with lateral support at points of load application	$\ell_e = 1.84\ \ell_u$	
Equal end moments	$\ell_e = 1.84\ \ell_u$	

1. For single span or cantilever bending members with loading conditions not specified in Table 3.3.3:
$\ell_e = 2.06\ \ell_u$ when $\ell_u/d < 7$
$\ell_e = 1.63\ \ell_u + 3d$ when $7 \le \ell_u/d \le 14.3$
$\ell_e = 1.84\ \ell_u$ when $\ell_u/d > 14.3$
2. Multiple span applications shall be based on table values or engineering analysis.

Lateral Stability of Beams

- Check Floor Beam Design for unbraced length of twenty feet.
  - $K_{bE} = 0.610$ (NDS 3.3.3)
  - $l_e = 1.37 l_u + 3d = 445$ in
  - $R_{bE} = \sqrt{\frac{l_e d}{b^2}} = \sqrt{\frac{445 \text{ in} \times 18 \text{ in}}{(5.125 \text{ in})^2}} = 17.5$
  - $F_{bE} = \frac{K_{be} E'}{R_B^2} = \frac{0.610 \times 1{,}600{,}000 \text{ psi}}{17.5^2} = 3{,}199 \text{ psi}$
  - $F_b^* = F_b \times C_D C_M C_t C_F C_{fu} C_i C_r C_c C_f = 2{,}400$ psi
- $C_L = \frac{1 + (F_{bE}/F_b^*)}{1.9} - \sqrt{\left[\frac{1 + (F_{bE}/F_b^*)}{1.9}\right]^2 - \frac{F_{bE}/F_b^*}{0.95}} =$
- $C_L = 0.90$

Lateral Stability of Beams

- $F_b' = F_b \times C_D C_M C_t C_L C_F C_V C_{fu} C_i C_r C_c C_f$
  - $F_b = 2400$ psi - 24F-V4 - NDS Table 5A
  - $C_D = 1.0$ long term loading
  - $C_M = 1.0$ used where the moisture content will not exceed 16%.
  - $C_V = 0.97$ - previously calculated
  - $C_L = 0.90$ - just calculated
  - $C_t, C_{fu}, C_i, C_r, C_C, C_f = 1.0$

  Therefore
- $F_b' = 2{,}095$ psi => $S_{req} = 273 \text{ in}^3 < S = 276.8 \text{ in}^3$ - OK

Homework

- Breyer Chapter 4
  - Use the UBC Basic Load Combinations for solving the following problems:
  - 4.28, 4.29, 4.30 (assume: seismic load, E, is at strength level), 4.31 (assume: lateral load is due to wind)
- Breyer Chapter 5
  - 5.12, 5.13, 5.14
- Breyer Chapter 6
  - 6.1, 6.5, 6.6, 6.8