Code Applications for Nail-laminated Timber and Cross-laminated Timber- MAT252-2

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Description

This presentation will focus on Nail-laminated Timber (NLT) and Cross-laminated Timber (CLT) wood structural framing members. NLT has been adopted in the IBC and utilized throughout the world for decades on a wide variety of buildings. CLT has been recently included in AWC’s National Design Specification (NDS) for Wood Construction 2015 and adopted in ICC’s 2015 International Building Code (IBC). CLT has been used for over a decade in Europe and has made its way to Australia and North America within the last 10 years. In addition to structural features, this presentation will provide information on fire protection of NLT and CLT.
Learning Objectives

1. Recognize code acceptance of nail-laminated timber and cross-laminated timber.
2. Understand structural design considerations for NLT and CLT.
3. Become acquainted with the unique fire resistive characteristics of nail-laminated timber and cross-laminated timber as it influences the use of wood in building construction.
4. Understand NDS Chapter 16 and how it can be used to design for up to 2-hours of fire-resistance.

Outline

- Overview & Building Code Allowances
- Nail-laminated Timber
- Cross-laminated Timber
- Fire
- Projects & Resources
Traditional Stick Framed Construction

Warner Drive – Culver City, CA

- Type V Construction
- Assembly & Business Occupancy


Architect: Profeta Royalty Architecture
Structural Engineer: Structural Focus
Completed: 2011
Warner Drive – Culver City, CA

- Nail-Laminated Timber – 2x12 vertical mechanically-connected w/nails
- NDS principles of mechanics

Architect: Profeta Royalty Architecture
Structural Engineer: Structural Focus
Completed: 2011

Bullitt Center – Seattle, WA

250 YEAR STRUCTURE
HEAVY TIMBER, CONCRETE & STEEL

Architect: Miller Hill Partnership
Structural Engineer: DCI Engineers
Photo Credit: Miller Hull Partnership
Bullitt Center – Seattle, WA

- Glulam beams and columns
- Nail-laminated timber floors

Architect: Miller Hill Partnership
Structural Engineer: DCI Engineers
Photo Credit: Miller Hull Partnership

Stadhaus, London, UK
The Story of Wood
– Wood Carbon Cycle

Climate Change: The Role of CO₂

2,400 sf home = 32 m³ structural wood = 29 metric tons CO₂ = 5.7 passenger annual emissions

Source: FP Innovations
Forte’, Melbourne

10 stories

CRADLE TO SITE SAVINGS OF CLT

- Scale: 10 floors, 23 apartments
- Build Period:
  - Start on site: February 2012
  - Begin CLT installation: June 2012
  - CLT structure complete: Aug 2012
  - Practical completion: December 2012
- Architect: Land Leaue
- CLT supplier: KLH

Forte will have positively affected the environment by:
- Storing (sequestering) 781 tonnes CO2 eq
- Equivalent to taking 345 cars off the road for a year
- Saving 7,7 GL of water
- Lowering water consumption (the supply of non-renewable water systems) by 73%

10 stories, 23 apartments

https://youtu.be/pHpthNiYqE
Building Code

Where is NLT Allowed in IBC 2015?

- **Type III** have noncombustible exteriors with interiors of any material.
- **Types IV & V** are generally combustible such as wood although V includes any material permitted.
Fire Tests

American Wood Council
ASTM E119 Fire Endurance Test
- 5-Ply CLT (approx. 7” thick)
- 5/8” Type X GWB each side
- Sought 2 hour rating
- RESULTS: 3 hours 6 minutes

[Images of test setup and results]

[Links to test reports and CLT fire test information]

Where is CLT Allowed in IBC 2015?

**Code modifications to Ch. 23 Wood**

2303.1.4 Structural glued **cross laminated timber**. Cross-laminated timbers shall be manufactured and identified as required in ANSI/APA PRG 320-2011.

CROSS-LAMINATED TIMBER. A prefabricated engineered wood product consisting of at least three layers of solid-sawn lumber or structural composite lumber where the adjacent layers are cross-oriented and bonded with structural adhesive to form a solid wood element.

**Code modifications to Ch. 35 Reference Standards**

ANSI/APA PRG 320-2011 Standard for Performance-Rated **Cross-Laminated Timber**

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Where is CLT Allowed in IBC 2015?

**Type IV Construction**

602.4 **Type IV.** Type IV construction (Heavy Timber, HT) is that type of construction in which the exterior walls are of noncombustible materials and the interior building elements are of solid or laminated wood without concealed spaces... **Cross laminated timber (CLT)** dimensions used in this section are actual dimensions.
Where is CLT allowed in IBC 2015?

**Type IV Construction – Exterior Walls**

602.4.2 *Cross-laminated timber* complying with Section 2303.1.4 shall be permitted within exterior wall assemblies with a 2-hour rating or less provided:
- Exterior surface of the *cross-laminated timber* is protected *fire retardant treated wood* sheathing complying with 2303.2 and not less than 15/32 inch thick;
  OR
- *gypsum board* not less than ½ inch thick;
  OR
- a noncombustible material.

Where is CLT allowed in IBC 2015?

**Type IV Construction – Floors**

602.4.6.2 CLT. *Cross laminated timber* shall be not less than 4 inches (102 mm) in thickness. It shall be continuous from support to support and mechanically fastened to one another. *Cross laminated timber* shall be permitted to be connected to walls without a shrinkage gap providing swelling or shrinking is considered in the design...
Where is CLT allowed in IBC 2015?

Type IV Construction – Roofs

602.4.7 Roofs. Roofs shall be without concealed spaces and wood roof decks shall be sawn or glued laminated…and of cross laminated timber…Cross laminated timber roofs shall be not less than 3 inch nominal in thickness and shall be continuous from support to support and mechanically fastened to one another.

Where is CLT allowed in IBC 2015?

Type IV Construction – Walls & Partitions

602.4.8.1 Interior walls and partitions. Interior walls and partitions shall be of solid wood construction formed by not less than two layers of 1-inch (25 mm) matched boards or laminated construction 4 inches (102 mm) thick, or of 1-hour fire-resistance-rated construction.

602.4.8.2 Exterior walls. All exterior walls shall be of one of the following:
1. Noncombustible materials; or
2. Not less than 6 inches in thickness and constructed of one of the following:
   2.1 Fire retardant treated wood in accordance with 2303.2 and complying with 602.4.1 or
  2.2. Cross laminated timber complying with 602.4.2.
Governing Codes for Wood Design

2015 IBC references in 2015 NDS

2015 NDS Chapter Reorganization

2012 NDS
- 1-3 General
- 4-9 Products
- 10-13 Connections
- 14 Shear Walls & Diaphragms
- 15 Special Loading
- 16 Fire

2015 NDS
- 1-3 General
- 4-10 Products + CLT
- 11-14 Connections
- Shear Walls & Diaphragms
- 15 Special Loading
- 16 Fire
2015 NDS

Product Chapters
• Ch. 4 Sawn Lumber
• Ch. 5 Structural Glued Laminated Timber
• Ch. 10 Cross-Laminated Timber

State of Oregon

Building Codes Division
Statewide Alternate Method January 15th

http://www.cbs.state.or.us/bcd/programs/structural/alt_methods/15-01_Cross_Laminated_Timber_SAM.pdf
State of Oregon

Technical Discussion:

A. Acceptance:
This ruling recognizes the code language of the 2015 International Building code and associated provisions that are reflected in the 2015 National Design Specification (NDS).

B. Fire Protection:
In terms of fire protection, CLT assemblies perform like heavy timber in that they char at a rate that is slow and predictable. CLT structures also tend not to have as many concealed spaces within floor and wall assemblies, which reduce the risk that a fire will spread.

As part of a project to produce a U.S. design manual for cross-laminated timber (CLT), AWC conducted a successful ASTM E119 fire endurance test on a CLT wall at NGC Testing Services in Buffalo, N.Y. A 5-ply CLT specimen (approximately 7 inches thick), was covered on each side with a single layer of 5/8" Type X gypsum wallboard. The wall was loaded to the maximum attainable load by the test equipment, although it remained significantly below the full design strength of the CLT. It was then exposed to a standard fire that reached over 1800 degrees Fahrenheit in the first 90 minutes of exposure. The wall functioned as a load bearing wall for over 180 minutes.

Type IV Construction

Outline

• Overview & Building Code Allowances
• **Nail-laminated Timber**
• Cross-laminated Timber
• Fire
• Projects & Resources

Resource: StructureCraft
What is Nail-Laminated Timber?

Nail-Laminated Timber

(g) Mechanically Laminated Floors and Decks. A laminated timber floor or deck built up of wood members set on edge, when meeting the following requirements, may be designed as a solid floor or roof deck of the same thickness, and continuous spans may be designed on the basis of the full cross section using the simple span moment coefficient.

Laminations shall be driven up and spiked closely together with a row of nails near each edge at spaced intervals and staggered vertically. Nail spacing in each row shall not exceed eighteen inches (18") for two-inch by eight-inch (2" x 8") nominal width and be proportional for other plank widths. Nail length shall be not less than two and one-half times the net thickness of each lamination.

A single span deck shall have all laminations full length.

A continuous deck of two spans shall have not more than every fourth lamination spliced within quarter points adjoining supports.

A continuous deck of more than two spans shall have not more than every third lamination spliced within quarter points adjoining supports.

Joints shall be closely butted over supports or staggered across the deck but within the adjoining quarter spans.

No lamination shall be spliced more than twice in any span.
Mechanically laminated decking shall comply with Sections 2304.8.3.1 through 2304.8.3.3.

Mechanically laminated decking consists of square-edged dimension lumber laminations set on edge and nailed to the adjacent pieces and to the supports.

The length of nails connecting laminations shall not be less than two and one-half times the net thickness of each lamination. Where decking supports are 48 inches (1219 mm) on center (o.c.) or less, side nails shall be installed not more than 30 inches (762 mm) o.c. alternating between top and bottom edges, and staggered one-third of the spacing in adjacent laminations. Where supports are spaced more than 48 inches (1219 mm) o.c., side nails shall be installed not more than 18 inches (457 mm) o.c. alternating between top and bottom edges and staggered one-third of the spacing in adjacent laminations. Two side nails shall be installed at each end of butt-jointed pieces.

Laminations shall be toenailed to supports with 20d or larger common nails. Where the supports are 48 inches (1219 mm) o.c. or less, alternate laminations shall be toenailed to alternate supports; where supports are spaced more than 48 inches (1219 mm) o.c., alternate laminations shall be toenailed to every support.

There shall be a minimum distance of 24 inches (610 mm) between end joints in adjacent courses. The pieces in the first and second courses shall bear on at least two supports with end joints in these two courses occurring on alternate supports. A maximum of seven intervening courses shall be permitted before this pattern is repeated.

Nail length: \( t_{\text{lamination}} \times 2.5 \)

Nail spacing:
- \( \leq 30" \) o.c.: 48" span
- \( \leq 18" \) o.c.: \( > 48" \) span

*nail placement alternates between top and bottom
Nail-Laminated Timber

General Contractor: EllisDon
Location: Richmond, British Columbia, Canada
Design Assist, Fabrication and Installation: StructureCraft
Completion: 2010

Resource: StructureCraft
Nail-Laminated Timber

Resource: StructureCraft

Nail-Laminated Timber

Resource: StructureCraft

General Contractor: Companion
Location: Surrey, British Columbia, Canada
Design Assist, Fabrication and Installation: StructureCraft
Completion: 2013
Nail-Laminated Timber

Resource: StructureCraft

Nail-Laminated Timber

Resource: StructureCraft
Outline

• Overview & Building Code Allowances
• Nail-Laminated Timber
• **Cross-laminated Timber**
• Fire
• Projects & Resources

Concept of Cross-Laminated Timber

Photos provided by FPInnovations
CLT Layup, Press and Glue

CNC Technology

Slide Courtesy of Structurlam
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CLT Design: 2015 NDS

2015
1. General Requirements for Building Design
2. Design Values for Structural Members
3. Design Provisions and Equations
4. Sawn Lumber
5. Structural Glued Laminated Timber
6. Round Timber Poles and Piles
7. Prefabricated Wood I-Joists
8. Structural Composite Lumber
9. Wood Structural Panels
10. Cross-laminated Timber
11. Mechanical Connections
12. Dowel-Type Fasteners
13. Split Ring and Shear Plate Connectors
14. Timber Rivets
15. Special Loading Conditions
16. Fire Design of Wood Members

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Chapter 10 – Cross-Laminated Timber

10. General

10.1.1 Application

10.1.2 Definition

Cross-Laminated Timber (CLT) – a prefabricated engineered wood product consisting of at least three layers of solid-sawn lumber or structural composite lumber where the adjacent layers are cross-oriented and bonded with structural adhesive to form a solid wood element.

10.1.3 Standard Dimensions

10.1.4 Specification

All required reference design values shall be specified.
Product Marking

Marks contain the following:

a) CLT grade qualified
b) CLT thickness or identification
c) Mill name or identification number
d) Approved agency name or logo
e) “ANSI/APA PRG 320”
f) Manufacturer’s designation
g) “Top” stamped on top face

Chapter 10 – Cross-Laminated Timber

1, 2, 3, 4 transverse layers

Single or multiple surface layers

Laminations: 5/8”-2” sawn lumber or SCL
Panel thickness: 20” max
In-Service MC: 16%

Graphics provided by FPInnovations
Chapter 10 – Cross-Laminated Timber

10.2 Reference Design Values

10.2.1 Reference Design Values

Reference design values for cross-laminated timber shall be obtained from the cross-laminated timber manufacturer’s literature or code evaluation report.

10.2.2 Design Section Properties

Reference design values shall be used with design section properties provided by the cross-laminated timber manufacturer based on the actual laptop used in the manufacturing process.

10.3 Adjustment of Reference Design Values

10.3.1 General

Reference design values: $F_{d}(S_{a})$, $F_{d}(A_{max})$, $F_{d}(A)$, $F_{d}(B/0.2Q_{n})$, $F_{d}(A_{max})$, $F_{d}(A)$, $E_{d}$, $E_{d}$, and $E_{d}$ provided in 10.2 shall be multiplied by the adjustment factors specified in Table 10.3.1 to determine adjusted design values: $F_{d}(S_{a})$, $F_{d}(A_{max})$, $F_{d}(A)$, $F_{d}(B/0.2Q_{n})$, $F_{d}(A_{max})$, $F_{d}(A)$, $E_{d}$, and $E_{d}$.

10.3.2 Load Duration Factor, $C_{0}$ (ASD only)

All reference design values except stiffness, $E_{d}$, $E_{d}$, $E_{d}$, rolling shear, $F_{d}(B/0.2Q_{n})$, and compensation perpendicular to grain, $F_{d}(A)$, shall be multiplied by load duration factors, $C_{0}$, as specified in 2.3.2.

Chapter 10 – Cross-Laminated Timber

| Table 10.3.1: Applicability of Adjustment Factors for Cross-Laminated Timber |
|-------------------------------------------------|----------|-----------|-----------|
| ASD only | ASD and LRFD | LRFD only |
| Load Duration Factor | High Severity Factor | Medium Severity Factor | Low Severity Factor | Column Stability Factor | Bearing Area Factor | Shear Factor | Axial Load Factor | |
| $F_{d}(S_{a})$ | $F_{d}(A_{max})$ | $F_{d}(A)$ | $F_{d}(B/0.2Q_{n})$ | $F_{d}(A)$ | $E_{d}$ | $E_{d}$ | $E_{d}$ | $E_{d}$ |
| $x$ | $C_{D}$ | $C_{M}$ | $C_{L}$ | $- | $2.70$ | $0.89$ |
| $F_{d}(A_{max})$ | $F_{d}(A)$ | $x$ | $C_{D}$ | $C_{M}$ | $C_{L}$ | $- | $2.70$ | $0.89$ |
| $F_{d}(B/0.2Q_{n})$ | $F_{d}(A)$ | $x$ | $C_{D}$ | $C_{M}$ | $C_{L}$ | $- | $2.70$ | $0.89$ |
| $F_{d}(A)$ | $x$ | $- | C_{D}$ | $C_{M}$ | $C_{L}$ | $- | $2.70$ | $0.89$ |
| $(E)_{d}$ | $(E)_{d}$ | $x$ | $C_{D}$ | $C_{M}$ | $C_{L}$ | $- | $2.70$ | $0.89$ |
| $(E)_{d}$ | $(E)_{d}$ | $x$ | $C_{D}$ | $C_{M}$ | $C_{L}$ | $- | $2.70$ | $0.89$ |

New
### TABLE 1
**REOUIRED CHARACTERISTIC TEST VALUES**, **E** FOR P3G 320 CLT

<table>
<thead>
<tr>
<th>CLT Grades</th>
<th>$f_{u0}$ (psi)</th>
<th>$E_{3}$ (10^3 psi)</th>
<th>$f_{w0}$ (ksi)</th>
<th>$f_{y0}$ (ksi)</th>
<th>$f_{x0}$ (ksi)</th>
<th>$f_{v0}$ (ksi)</th>
<th>$f_{w0}$ (ksi)</th>
<th>$f_{v0}$ (ksi)</th>
<th>$f_{x0}$ (ksi)</th>
<th>$f_{y0}$ (ksi)</th>
<th>$f_{z0}$ (ksi)</th>
<th>$f_{w0}$ (ksi)</th>
<th>$f_{v0}$ (ksi)</th>
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<td>1.7</td>
<td>2,885</td>
<td>3,420</td>
<td>425</td>
<td>140</td>
<td>1,050</td>
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<td>425</td>
<td>140</td>
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<td>E2</td>
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<td>1.5</td>
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<td>190</td>
<td>1,100</td>
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<td>735</td>
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<td>345</td>
<td>115</td>
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<td>E4</td>
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<td>2,885</td>
<td>3,420</td>
<td>550</td>
<td>180</td>
<td>1,205</td>
<td>1.4</td>
<td>550</td>
<td>180</td>
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<td>1.4</td>
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### TABLE A1
**ALLOWABLE DESIGN PROPERTIES**, **E** FOR P3G 320 CLT (FOR USE IN THE U.S.)

<table>
<thead>
<tr>
<th>CLT Grades</th>
<th>$f_{u0}$ (psi)</th>
<th>$E_{3}$ (10^3 psi)</th>
<th>$f_{w0}$ (ksi)</th>
<th>$f_{v0}$ (ksi)</th>
<th>$f_{x0}$ (ksi)</th>
<th>$F_{w0}$ (ksi)</th>
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<td>175</td>
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For SI, 1 psi = 6.894755 MPa.
(a) See Section 4 for symbols.
(b) Tabled values are allowable design values and not permitted to be increased for the lumber size adjustment factor in accordance with the NDS. The design values shall be used in conjunction with the section properties provided by the CLT manufacturer based on the actual layup used in manufacturing the CLT panel (see Table A2).
(c) Custom CLT grades that are not listed in this table shall be permitted in accordance with Section 7.0.1.
CLT Manufacturing Standard

CLT layups:

- E1: 1950 f-1.7E Spruce-pine-fi MSR lumber in all parallel layers and No. 3 Spruce-pine-fi lumber in all perpendicular layers
- E2: 1650 f-1.5E Douglas fir-Larch MSR lumber in all parallel layers and No. 3 Douglas fir-Larch lumber in all perpendicular layers
- E3: 1200 f-1.2E Eastern Softwoods, Northern Species, or Western Woods MSR lumber in all parallel layers and No. 3 Eastern Softwoods, Northern Species, or Western Woods lumber in all perpendicular layers
- E4: 1950 f-1.7E Southern pine MSR lumber in all parallel layers and No. 3 Southern pine lumber in all perpendicular layers
- V1: No. 2 Douglas fir-Larch lumber in all parallel layers and No. 3 Douglas fir-Larch lumber in all perpendicular layers
- V2: No. 1/No. 2 Spruce-pine-fi lumber in all parallel layers and No. 3 Spruce-pine-fi lumber in all perpendicular layers
- V3: No. 2 Southern pine lumber in all parallel layers and No. 3 Southern pine lumber in all perpendicular layers
Bending Members

No standardized design properties for in-plane loading
- contact the manufacturer

NDS – Chapter 12

Updated to include CLT Connections
Shake Table Tests on 7-story Building

- Conducted at E-Defense
- Building weight 270t
  - Self weight 120t
  - Added weight 150t
- Panel thickness
  - 140 mm (5.5”) floors 1 and 2
  - 125 mm (4.9”) floors 3 and 4
  - 85 mm (3.3”) top 3 floors
- Wall panels length 2.3 m (7.5’)

Seismic Design Options

- ASCE 7 Minimum Design Loads for Buildings and Other Structures
- Response Modification Coefficient, R
  - CLT not recognized system in ASCE 7 Table 12.2-1
  - Options
    - Performance-based design procedure per ASCE 7
    - Demonstrating equivalence to an existing ASCE 7 system
    - ASCE 7-10, FEMA P695, and FEMA P795
      Quantification of Building Seismic Performance Factors; Component Equivalency Methodology
- Research
  - NEES-CLT - John Van de Lindt
  - FPInnovations
Seismic Design Options

Outline

• Overview & Building Code Allowances
• Nail-Laminated Timber
• Cross-laminated Timber
• Fire
• Projects & Resources
Fire Performance Glulam vs. Steel

![Image of construction site]

Fire Performance of Wood vs. Steel

![Comparison chart showing Comparative Strength Loss of Wood versus Steel]

Results from test sponsored by National Forest Products Association at the Southwest Research Institute.

http://www.aitc-glulam.org/shopcart/Pdf/superior%20fire%20resistance.pdf
Chapter 16 – Calculated Resistance

- Fire resistance of exposed wood members may be calculated using the provisions of NDS Chapter 16

Chapter 16 – Fire (ASD)

- Fire resistance up to **two hours**
  - Columns
  - Beams
  - Tension Members
  - ASD only

- Products
  - Lumber
  - Glulam
  - SCL
  - Decking
  - CLT - NEW

**SECTION 722**
**CALCULATED FIRE RESISTANCE**

722.1 General. The provisions of this section contain procedures by which the fire resistance of specific materials or combinations of materials is established by calculations. These procedures apply only to the information contained in this section and shall not be otherwise used. The calculated fire resistance of concrete, concrete masonry and clay masonry assemblies shall be permitted in accordance with ACI 216.1/TMS 6216. The calculated fire resistance of steel assemblies shall be permitted in accordance with Section 9 of ASCE 29. The calculated fire resistance of exposed wood members and wood decking shall be permitted in accordance with Chapter 10 of ANSI/AF&PA National Design Specification for Wood Construction (NDS).
2015 NDS Methodology

- Chapter 16 – Fire Design of Wood Members
- Mechanics Based Model
- Supported by empirical data
- NLT, GLT & CLT

Chapter 16 – Fire (ASD)

Technical Report No. 10
- Background on NDS provisions
- Design examples
- CLT provisions
Nail-Laminated Timber

Calculated fire-resistance of NLT

Method for calculated fire-resistance of Timber Decks may be used for Nail-laminated timber (NLT)

NDS 16.2.5. Provisions for Timber Decks

- > 2” (actual) thick
- Planks span the distance between supporting beams
- Designed as an assembly of wood beams partially exposed on the sides and fully exposed on one face.
- Char rate on sides reduced to 33% of the effective char rate
- Calculation do not address thermal separation
- Typically would require one layer of Type X gypsum
4.4 Exposed Deck Example (Allowable Stress Design)

Decking spans $L = 6$ feet. A single layer of 3/4 inch sheathing is installed over the decking. The design loads are $q_{\text{live}} = 40$ psf and $q_{\text{dead}} = 10$ psf. Calculate the required decking depth for a one-hour fire resistance time using tongue-and-groove or butt-jointed timber decking.
TR-10 Deck Design Example

4.4.2 Butt-Jointed Decking

Assume a board width of 5.5 inches
Calculate deck load:
\[ w_{\text{load}} = B(q_{\text{dead}} + q_{\text{live}}) = (5.5 \text{ in} / 12 \text{ in/ft})(50 \text{ psf}) = 22.9 \text{ plf} \]
Calculate maximum induced moment on each member:
\[ M_{\text{max}} = w_{\text{load}} L^2 / 8 = (22.9)(62)/8 = 103 \text{ ft-lbs} \]
Select nominal 3x6 (2½” x 5½”) Hem-Fir butt-jointed Commercial decking with a tabulated repetitive member bending stress, \( F_{b(Cr)} = 1350 \text{ psi} \).

Calculate the section modulus of each member:
\[ S_s = bd^2/6 = (5.5)(2.5)^2/6 = 5.73 \text{ in}^3 \]

Fire Design of Exposed Wood Members

New

Cross-laminated Timber-Effective Char Depth

\[ a_{\text{char}} = 1.2 \left[ n_{\text{lam}} h_{\text{lam}} + \beta_n \left( t - (n_{\text{lam}} t_{\beta}) \right)^{0.813} \right] \]
\[ t_{\beta} = \left( \frac{h_{\text{lam}}}{\beta_n} \right)^{1.23} \]
\[ t_{\beta} = \text{time for char front to reach glued interface (hr.)} \]
\[ h_{\text{lam}} = \text{lamination thickness (in.)} \]
\[ n_{\text{lam}} = \frac{t}{t_{\beta}} \]
\[ n_{\text{lam}} = \text{number of laminations charred (rounded to lowest integer)} \]
\[ t = \text{exposure time (hr.)} \]

\[ \text{NDS} \]
Fire Design of Exposed Wood Members

CLT manufactured with laminations of equal thickness

<table>
<thead>
<tr>
<th>Required Fire Endurance (hr.)</th>
<th>Effective Char Depths, $a_{char}$ (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5/8</td>
</tr>
<tr>
<td>1-Hour</td>
<td>2.2</td>
</tr>
<tr>
<td>1 1/4-Hour</td>
<td>3.4</td>
</tr>
<tr>
<td>2-Hour</td>
<td>4.4</td>
</tr>
</tbody>
</table>

GLT and CLT Adhesives

CLT- ANSI/APA PRG 320-2011 references ANSI/AITC 405-2008
GLT- ANSI/AITC 405-2008 – references D7247
GLT and CLT Adhesives

CLT-ANSI/APA PRG 320-2012 references ANSI/APA 405-2008
GLT - ANSI/APA 405-2008 – references D7247

Calculated Fire Resistance?

- Chapter 16 NDS
  - Charring Rate and Char Depth
  - Modified char depth model
  - Step-wise approach
Fire Performance

Calculated Fire Resistance?

- Net section properties
TR-10 CLT Design Example

4.5 Exposed CLT Floor Example (Allowable Stress Design)
Simply-supported cross-laminated timber (CLT) floor spanning L=16 ft in the strong-axis direction. The design loads are \( q_{ext} = 80 \text{ psf} \) and \( q_{load} = 36 \text{ psf} \) including estimated self-weight of the CLT panel. Floor decking, nailed to the unexposed face of CLT panel, is spaced to restrict hot gases from venting through half-lap joints at edges of CLT panel sections. Calculate the required section dimensions for a one-hour fire resistance time.

4.6 Exposed CLT Wall Example (Allowable Stress Design)
Cross-laminated timber (CLT) wall with an unbraced height of \( L=120 \text{ inches} \) and loaded in compression in the strong-axis direction. The design loads are \( w_{ext} = 14,000 \text{ psf} \) and \( w_{load} = 6,150 \text{ psf} \) including estimated self-weight of the CLT panel. Walls above are supported on a CLT floor slab and aligned with a CLT wall below. Use of fire-rated caulkung of wall joints restricts hot gases from venting through half-lap joints at edges of CLT panel sections. Calculate the required section dimensions for a 2-hr fire resistance time from the CLT.

Calculate column load:

\[ P_{load} = P_{ext} = P_{max} = 6,150 \text{ psf} + 14,000 \text{ psf} = 20,150 \text{ lb/foot of width}. \]

From PRG 320, select a 7-ply CLT panel made from \( 1 \frac{1}{8} \text{ inch} \) x \( 3 \frac{1}{8} \text{ inch} \) lumber boards (CLT thickness of \( 9 \frac{1}{8} \text{ inches} \)). For CLT grade E1, tabulated properties are:

- Compressive stress, \( F_{c}\text{E1} = 1800 \text{ psi} \) (PRG 320 Annex A, Table A1)
- Bending moment, \( F_{b}\text{E1} = 18.375 \text{ lb-ft/ft of width} \) (PRG 320 Annex A, Table A2)
- Bending stiffness, \( F_{b}\text{E1} = 1.089 \times 10^6 \text{ lb-in/ft of width} \) (PRG 320 Annex A, Table A2)
- Shear stiffness, \( G_{s}\text{E1} = 1.4 \times 10^6 \text{ lb-ft/ft of width} \) (PRG 320 Annex A, Table A2)

Connections

Examples of connections seen in CLT platform construction

Source: U.S. CLT Handbook

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Connections

Examples of connections seen in CLT balloon construction

Source: U.S. CLT Handbook

Connections

Concealed metal plates

Source: U.S. CLT Handbook
Recent Demonstration Fire Tests

Heat Release Rate

[Graph showing heat release rate over time]
Recent Demonstration Fire Tests


Recent Demonstration Fire Tests

Room after 60 minutes

Room after drywall removed following the three-hour test
CLT Test

Outline

- Overview & Building Code Allowances
- Nail-Laminated Timber
- Cross-laminated Timber
- Fire
- Projects & Resources
Tsingtao Pearl Visitor Centre
Qingdao, China

Resource: StructureCraft

General Contractor: StructureCraft, SKF
Location: Qingdao, China
Design Build: StructureCraft
Completion: 2012
Tsingtao Pearl Visitor Centre
Qingdao, China

Resource: StructureCraft

Samuel Bridghouse Elementary School

Resource: StructureCraft

General Contractor: EllisDon
Location: Richmond, British Columbia, Canada
Design Assist, Fabrication and Installation: StructureCraft
Completion: 2010
Samuel Bridghouse Elementary School

Resource: StructureCraft

Design Team: Perkins + Will Canada, Fast + Epp
Photo Credit: Stephan Pasche

Samuel Bridghouse Elementary School

Resource: StructureCraft
Nail-Laminated Timber

Project: T3 Office Building (Timber Transit Technology)

Building Area: 220, sq. ft.
Location: Minneapolis, MN, United
Owner: Hines Group
General Contractor: Kraus Anderson Construction
Architect: Michael Green Architects / DLR Group
Engineer: MKA Engineering
Design Assist/Build: StructureCraft

Nail-Laminated Timber

MINNPOST

Into the wood: America's first modern tall timber building rises in Minneapolis

• 7 Stories (6-Stories Type IV + 1-Story Concrete Podium)
• 2 levels subterranean parking
• IBC 610 Special Provisions
• Heavy Timber framing, prefabricated floor panels 2x8 NLT
• Elevator Concrete Core
Condominiums, Chibougamau, Quebec

Architect: ACP Architecture

Project Description

Location: Chibougamau
Date on Site: 2015-10-15

Materials Volumes:
- CLT: 1150m³
- Glulam: 70m³
- St 그렇지: 2000 kg

Fabrication Time (Estimated): 3 weeks
Erection Time (Estimated): 7-8 weeks for the structure
Actual: 22 construction days (10 hours a day) - 5 men

Exterior Wall Build-Up

Source: Nordic Engineered Wood

Franklin Elementary School

46,200 sq. ft.  8 week assembly
Architect: MSES Architects, Fairmont, WV

Source: LignaTerra
Franklin Elementary School

Scheduled completion date: Winter 2015

Private Army Hotel
Redstone Arsenal Huntsville, AL

Four stories 58,000 sq ft
Architect: Lend Lease
Resources

- [www.awc.org](http://www.awc.org)
- Print versions
- PDF versions

Resources

- *Structure Magazine*
  - 2015 NDS
    - January 2015
  - 2015 SDPWS
    - July 2015

- [www.awc.org](http://www.awc.org)

What's Changed?
Resources

Technical Report No. 10

- [http://awc.org/codes-standards/publications/tr10](http://awc.org/codes-standards/publications/tr10)

Resources

CLT- ANSI/APA PRG 320-2011 references ANSI/AITC 405-2008
GLT- ANSI/AITC 405-2008 – references D7247
CLT Production

Mass Timber Manufacturers in the USA:
- Nordic Engineered Wood Products
- SmartLAM
- Structurlam Wood Products
- StructureCraft
- Cross Lam Timber Solutions
- KLH U.S.
- DR Johnson Lumber
- Stora Enso Wood Products

Questions?

- This concludes The American Institute of Architects Continuing Education Systems Course

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www.awc.org
Wood Design Workshop

http://cpe.forestry.oregonstate.edu/WoodDesign