Today’s Glulam: What Design and Building Professionals Need to Know for Code Conformance

Speaker’s Name
Title
American Wood Council

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Description

Glued-laminated timber is often used as a primary load carrying member of buildings. Often selected for aesthetic reasons or its unparalleled design flexibility, glulam also offers superior structural performance combined with long term durability. This seminar will focus on recent glulam innovations — such as the use of fiber reinforced polymers to increase strength and stiffness — as well as sustainability considerations related to product selection and endurance. Member, connection, and fire design as outlined in AWC’s National Design Specification (NDS) for Wood Construction will also be discussed.

Learning Objectives

• Be able to identify research and correctly specify glued-laminated timber appropriately on their projects.
• Become familiar with a number of technology advances and standards related to glued-laminated timber.
• Become familiar with key design considerations.
• Become acquainted with the unique fire resistive characteristics of glulam as it influences the use of wood in building construction.
• Understand the application of NDS Chapter 16 can be utilized to provide up to 2-hours of fire-resistance.
What is Glulam?

- Glulam = a structural composite of lumber and adhesives

Glulam = One of the Original Engineered Wood Composites

Lumber Laminations

Glue Lines

Natural Characteristics

End Joint
Inherent Advantages of Glulam

- High degree of engineering efficiency

![Engineering Efficiency Graph](chart.png)

**Relative Frequency**

**Material Property Value**

- Glulam (2400psi)
- MSR lumber (2000 psi)
- Visually graded lumber (1200psi)
Inherent Advantages of Glulam

- High degree of engineering
- Highly efficient use of wood resource

Resource Efficiency

[Diagram showing Glulam layup and Bending stress distribution with compression and tension directions]
Inherent Advantages of Glulam

- High degree of engineering efficiency
- Highly efficient use of wood resource
- Large dimensions

Large Sizes
Oceans Exhibit – Indianapolis Zoo

10-3/4” x 72”
115 ft. clear span

Church in Louisville, KY

12-1/4” x 84”
140 ft. clear span
Inherent Advantages of Glulam

- High degree of engineering efficiency
- Highly efficient use of wood resource
- Large dimensions
- Virtually unlimited versatility in shapes and spans

Flexibility of Shapes and Spans
Inherent Advantages of Glulam

- High degree of engineering efficiency
- Highly efficient use of wood resource
- Large dimensions
- Virtually unlimited versatility in shapes and spans
- Virtually unlimited versatility in shapes and spans
- Natural aesthetic appearance only possible with wood

Natural Aesthetics of Glulam
Natural Aesthetics of Glulam

- Product qualification and quality assurance requirements are specified
- Third-party inspection is required on an on-going basis
- All glulam must bear a grademark meeting ANSI A190.1 -2012
Glulam Manufacturing Process

- Material Preparation
- End Joint Bonding
- Pre-glue Layup
- Quality Verification
- Face Bonding and Curing
- Finish Marking Shipping

Manufacture of Glulam
Material Preparation

- Lumber grading and sorting
  - Visual
  - E-Rated
  - Moisture
  - Dimensional tolerances
- Adhesive selection and mixing

Lumber Grading in Mill

Checking visual grades

Verifying E-rating
Lumber Grading and Sorting

Visual Lumber Grades

<table>
<thead>
<tr>
<th>Grade</th>
<th>Maximum knot size</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>1/4 width</td>
</tr>
<tr>
<td>L2</td>
<td>1/3 width</td>
</tr>
<tr>
<td>L3</td>
<td>1/2 width</td>
</tr>
</tbody>
</table>
E-Rated Lumber Grades

- E-rated Lumber
- Lumber stiffness MOE
- Visual Characteristics

Lumber Species

- Traditional softwoods
  - Douglas Fir & Southern Pine
- Other softwoods
  - Spruce/-Pine/-Fir and Hem-Fir
- Naturally durable softwoods
  - Alaska Yellow Cedar
  - Port Orford Cedar
- Hardwoods
- Mixed species layups
Glulam Adhesives

- Adhesives used for glulam must meet:
- **ASTM D 2559 for Exterior-Use**

![ASTM D 2559 - 04](image)

Standard Specification for Adhesives for Structural Laminated Wood Products for Use Under Exterior (Wet Use) Exposure Conditions

- **ASTM D 7247 for heat durability**

![ASTM D 7247 - 07a](image)

Standard Test Method for Evaluating the Shear Strength of Adhesive Bonds in Laminated Wood Products at Elevated Temperatures

---

Structural End Joint

- **Horizontal Finger Joint**
- **Vertical Finger Joint**
- **Scarf Joint**
Structural End Joint

- Create final length required for each lamination depending on finished member size
- Generally only limited by the manufacturing space

Horizontal Finger Joint  
Vertical Finger Joint

End Joint Bonding

- **Adhesives**  
  - Phenol resorcinol  
  - Melamine  
  - Others
- **Joint configuration**  
  - Horizontal  
  - Vertical
- **Bonding**  
  - Integral gluing  
  - Stop and go radio frequency (RF)  
  - Continuous RF
Horizontal Finger Joint

Horizontal Finger Joint

Adhesive being applied
Finger Jointing Using RF Curing

In-line bending proof loader

Pre-Glue Layup

- Long length laminations positioned by grade
- All national and international glulam standards require positioning laminations by grade
- Lumber quality is a key to controlling glulam member performance
Glulam Lay-Ups

- Compression Zone
- Inner Zone
- Tension Zone

Unbalanced Beam

Unbalanced Layup

- Unequal capacity in positive and negative bending
- Primarily for use in simple beams or short cantilevers
- Requires 5% tension laminates on the bottom of the beam
Glulam Lay-Ups

Compression Zone

Inner Zone

Tension Zone

Unbalanced Beam

Cantilever or Continuous Span
Balanced Layup

- Equal capacity in both positive and negative bending
- Primarily for use in continuous beams or long cantilevers
- Requires 5% tension lamin on top and bottom of beam

Single-Grade Layup

- Same lumber grade and species used throughout
- Primarily for use in axially loaded members, such as columns and truss chords
Single-Grade Layup

Glulam truss chords and webs

Glulam columns

Pre-Glue Layup

Lumber is typically color coded by grade
Face Bonding

Clamping and Curing
Large Dimensions Are Possible

21” x 30” x 110’

Curved Shapes
Quality Assurance Verification

- Glue bond integrity
  - Shear strength
  - Durability/delamination
- End joint strength
  - Tension test required in U.S.
  - Bending test in some countries
- Finished dimensions & shape
- Appearance characteristics

Fabrication & Finishing
Fabrication and Finishing

- Appearance Options
- Framing (3-1/2”, 5-1/2”)
- Industrial
- Architectural
- Premium
- Rough Sawn
- Special

Factory or field applied stains and finishes
Fabrication and Finishing

Protection And Shipping

- Individual Wrap
- Bundle Wrap
- Load Wrap
- Special Edge Protection
- On-Site Container Loading
Basic Glulam Design Concepts

- Type of member / load application
- Determination of allowable design stresses / layup selection
- Structural analysis
- Stress modification factors
- Special design provisions
- Connection design /detailing
- Durability & fire

Member Type

- Column
- Truss member
- Simple span beam
- Cantilever span beam
Loading Orientations

- Typical use X-X major axis
- Y-Y major axis
- $F_{bx} \neq F_{by}$
- $F_{vx} \neq F_{vy}$
- $E_x \neq E_y$
- $F_{c,x} \neq F_{c,y}$
- $F_{bx}^+ \neq F_{bx}^-$

Importance of Axis Orientation

- Design Properties for 24F-V4 layup
- Major Axis (X-X) Minor Axis (Y-Y)
  - $F_b = 2,400$ psi (16.5 MPa) $F_b = 1,500$ psi (10.3 MPa)
  - $E = 1,800,000$ psi $E = 1,600,000$ psi
Basic Glulam Design Concepts

- Type of member / load application
- Determination of allowable design stresses / layup selection
- Structural analysis
- Stress modification factors
- Special design provisions
- Connection design / detailing

US Glulam Standards Design Values

- Design values are derived in accordance with:

  Designation: D 3737-12
  Standard Practice for Establishing Allowable Properties for Structural Glued Laminated Timber (Glulam)

  Designation: D 7341 – 06
  Standard Practice for Establishing Characteristic Values for Flexural Properties of Structural Glued Laminated Timber by Full-Scale Testing
ASTM D 3737

- Based on the growth characteristics of lumber (knots and slope of grain)
- Standardized analysis procedures

ASTM D 7341

- Based on full-scale glulam performance tests in combination with or without modeling
Full-Scale Glulam Beam Tests

- APA and the FPL combined have the largest full-scale glulam beam database in the world.

APA Glulam Code Report

- Includes APA computer program, Glulam Allowable Properties (GAP), which is based on ASTM D 3737.
- Permits the determination of values for new species and layups.
1. Sawn Lumber Grading Agencies
2. Species Combinations
3. Section Properties
4. Design Values
   a. Lumber and Timber
   b. Non-North American Sawn Lumber
   c. Structural Glued Laminated Timber
   d. MSR and MEL

NDS Stress Classes

- Stress Classes Combined for Simplicity

Table 5A Reference Design Values for Structural Glued Laminated Softwood Timber
(Members stressed primarily in bending) Tabulated design values are for normal load duration and dry service conditions. See NDS 5.3 for a comprehensive description of design value adjustment factors.)

<table>
<thead>
<tr>
<th>Stress Class</th>
<th>F_{y} (ksi)</th>
<th>F_{u} (ksi)</th>
<th>F_{L} (ksi)</th>
<th>E (ksi)</th>
<th>E_{f} (ksi)</th>
<th>F_{R} (ksi)</th>
<th>F_{y} (ksi)</th>
<th>F_{u} (ksi)</th>
<th>F_{L} (ksi)</th>
<th>F_{y} (ksi)</th>
<th>F_{u} (ksi)</th>
<th>F_{L} (ksi)</th>
<th>F_{y} (ksi)</th>
<th>F_{u} (ksi)</th>
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<th>F_{y} (ksi)</th>
<th>F_{u} (ksi)</th>
<th>F_{L} (ksi)</th>
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</thead>
<tbody>
<tr>
<td>BF-1.25</td>
<td>1900</td>
<td>2500</td>
<td>3100</td>
<td>1.3</td>
<td>350</td>
<td>500</td>
<td>500</td>
<td>100</td>
<td>1.1</td>
<td>500</td>
<td>700</td>
<td>1.1</td>
<td>350</td>
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<td>500</td>
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<tr>
<td>BF-1.5</td>
<td>2000</td>
<td>2600</td>
<td>3200</td>
<td>1.3</td>
<td>370</td>
<td>520</td>
<td>520</td>
<td>100</td>
<td>1.1</td>
<td>520</td>
<td>720</td>
<td>1.1</td>
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<tr>
<td>BF-1.75</td>
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<td>400</td>
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<td>120</td>
<td>1.2</td>
<td>570</td>
<td>770</td>
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<td>1.2</td>
<td>570</td>
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<td>BF-2.0</td>
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<td>3000</td>
<td>3600</td>
<td>1.8</td>
<td>420</td>
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<td>420</td>
<td>590</td>
<td>590</td>
<td>160</td>
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<td>590</td>
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<tr>
<td>BF-2.5</td>
<td>2600</td>
<td>3200</td>
<td>3800</td>
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<td>820</td>
<td>1.7</td>
<td>450</td>
<td>620</td>
<td>620</td>
<td>200</td>
<td>1.7</td>
<td>620</td>
</tr>
</tbody>
</table>
| BF-3.0       | 2800        | 3400        | 4000        | 2.5     | 480         | 650         | 650         | 240         | 1.8         | 650         | 850         | 1.8         | 480         | 650         | 650         | 240         | 1.8         | 650         | 850         | 0.90

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Glulam Standards / ICC Codes

- Glulam standards are referenced in the IBC and IRC

Allowable Bending Design Stress:

- 24F = 2,400 psi
- 30F = 3,000 psi

US Glulam Standards- Combination Symbols

- **24F- V4/DF**
  - Allowable Bending Design Stress: 24F = 2,400 psi
  - V = visually graded
  - E = mechanically graded
  - Assigned combination number
  - Wood species

- **30F-E2/SP**
Glulam Design Stresses

- The vast majority of glulams are rated at:
  - $F_b = 2,400$ psi  $E = 1.8 \times 10^6$ psi
  - Southern Pine
    - $F_b > 3,000$ psi  $E = 2.1 \times 10^6$ psi
  - LVL hybrid
    - $F_b = 3,000$ psi  $E = 2.1 \times 10^6$ psi
  - FRP beams
    - $F_b > 3,000$ psi  $E > 2.1 \times 10^6$ psi

Glulam with LVL Outer Laminations

- LVL Laminations
  - Full length with no finger joints required
  - Greater tensile strength compared to lumber
  - 30F-2.1E stress level achieved
FRP Reinforced Glulam

Thin layer of fiber reinforced polymer (FRP)

Behavior of FRP Reinforced Glulam

- Compression
- Tension

Lower grades adequate to resist compression forces
Very high grades needed to resist higher bending member tension forces
Reinforced concrete analogy
FRP Reinforced Glulam

Fiber Reinforced Polymer

Fiberglass Carbon Kevlar Other

Adaptable to glulam manufacturing process

Bending strengths of 30F, 32F, 34F or higher
FRP Reinforced Glulam

1/3 less wood than conventional glulam

Optimizing Strength with FRP
**Tension Reinforcement**

![Graph showing tension reinforcement](image)

- **3% GRP:** MOR = 9,465, DUCT = 3.1
- **1% GRP:** MOR = 7,229, DUCT = 1.7
- **CONTROL:** MOR = 4,013, DUCTL = 1

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**ICC-ES AC 280**

**ACCEPTANCE CRITERIA FOR FIBER-REINFORCED-POLYMER GLUED-LAMINATED TIMBER USING MECHANICS-BASED MODELS**

AC280

Approved February 2005

Effective March 1, 2005

**PREFACE**

Evaluation reports issued by ICC Evaluation Service, Inc. (ICC-ES) are based upon performance testing of the materials and systems. The Evaluation Report documents the compliance of a material or product to the referenced code, standard, or commentary. The Evaluation Report is intended to be used solely as a means of confirming that a material or product meets specified performance criteria. It is not intended to be a substitute for the International Building Code® (IBC®), the International Plumbing Code®, or any other applicable code.

The provisions of the Code are not intended to prohibit the installation of any material or provide any guidance on the installation of any material. The provisions of the Code are not intended to provide any enforcement guidance. The provisions of the Code are not intended to provide any enforcement authority. The provisions of the Code are not intended to provide any enforcement authority for any enforcement body. The provisions of the Code are not intended to provide any enforcement authority for any enforcement body. The provisions of the Code are not intended to provide any enforcement authority for any enforcement body. The provisions of the Code are not intended to provide any enforcement authority for any enforcement body. The provisions of the Code are not intended to provide any enforcement authority for any enforcement body. The provisions of the Code are not intended to provide any enforcement authority for any enforcement body.

Similar provisions are contained in the Uniform Codes, the National Codes, and the Standard Codes.
University of Maine - RELAM Computer Model

- Mechanics based computer model to determine the strength and stiffness properties of FRP reinforced glulam
- Uses lumber properties as model inputs
  - Tension strength
  - Compression strength
  - MOE
- Uses FRP properties as model inputs
APA Test Program

- FRP Test Program for APA code report
- Based on AC 280 and ASTM 7199
- Based on University of Maine "RELAM" computer model
- Uses lumber properties, FJ strength and FRP characteristics as inputs

Test Beam Failure Modes
### AASHTO FRP Reinforced Glulam - Stress Classes

<table>
<thead>
<tr>
<th>Stress Class</th>
<th>Fb *</th>
<th>MOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>30F-2.0E</td>
<td>3000</td>
<td>2,000,000</td>
</tr>
<tr>
<td>32F-2.1E</td>
<td>3200</td>
<td>2,100,000</td>
</tr>
<tr>
<td>34F-2.1E</td>
<td>3400</td>
<td>2,100,000</td>
</tr>
<tr>
<td>36F-2.2E</td>
<td>3600</td>
<td>2,200,000</td>
</tr>
</tbody>
</table>

* Volume Effect = 1.0 for all bending stresses

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### Western Washington University

- **Small Gym**: 10/3/4” x 57” x 78 ft.
- **Natatorium**: 10/3/4” x 64-1/2” x 91 ft.
Western Washington University

Main Gym
10-3/4” x 75” x 106 ft.

Cost savings for the FRP glulam beams was $22,000

Basic Glulam Design Concepts

- Type of member / load application
- Determination of allowable design stresses / layup selection
- Structural analysis
- Stress modification factors
- Special design provisions
- Connection design /detailing
- Durability & Fire
Glulam Design: 2012 NDS

2005
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. Mechanical Connections
11. Dowel-Type Fasteners
12. Split Ring and Shear Plate Connectors
13. Timber Rivets
14. Shear Walls and Diaphragms
15. Special Loading Conditions
16. Fire Design of Wood Members

Glulam Design: 2012 NDS

- Includes both Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD)
LFRD vs. ASD

- LRFD and ASD presentation formats are different
- Example equation for bending moment:
  Simple span beam with uniform load

**ASD**
- Applied stress $\leq$ Allowable stress
  $$f_b \leq f_b'$$
  $$M / S_x \leq F_b C_D$$

**LRFD**
- Factored Load $\leq$ Factored Resistance
  $$M_u \leq M_n'$$
  $$M_u \leq F_b K_f l f S_x$$

Basic Glulam Design Concepts

- Type of member / load application
- Determination of allowable design stresses / layup selection
- Structural analysis
- Stress modification factors
- Special design provisions
- Connection design /detailing
Adjustments for Basic Design Values

- ASD
- \( F'_b = F_b \cdot C_D \cdot C_M \cdot C_t \) (\( C_L \) or \( C_v \))
- \( F'_v = F_v \cdot C_D \cdot C_M \cdot C_t \)
- \( E' = E \cdot C_M \cdot C_t \)

- \( C_D \) = load duration factor
- \( C_M \) = wet-use factor (16% or greater)
- \( C_t \) = temperature factor
- \( C_L \) = beam stability factor
- \( C_v \) = volume effect factor

Take lesser of \( C_L \) or \( C_v \)

Volume Factor for Bending Strength

\[
C_v = \left( \frac{21}{L} \right)^{1/x} \left( \frac{12}{d} \right)^{1/x} \left( \frac{5.125}{b} \right)^{1/x} \leq 1.0
\]

- \( b \) = beam width (inches)
- \( d \) = beam depth (inches)
- \( L \) = beam length (ft)
- \( x = 10 \) for North American western species
- \( x = 20 \) for Southern pine
- \( x = 14 \) for hardwoods
Impact of $C_v$

8-3/4" x 72" x 110'
$C_v = 0.77$
$F_b' = 2400 \times 0.77 = 1850 \text{ psi}$

Basic Glulam Design Concepts

- Type of member / load application
- Determination of allowable design stresses / layup selection
- Structural analysis
- Stress modification factors
- Special design provisions
- Connection design /detailing
- Durability & Fire
Note the “TOP” Stamp – for Unbalanced Layup

Improper Installation
Unbalanced Layups - “Upside Down” Bending Stresses

• Based on full-size beam tests conducted at APA, the “upside down” bending stress is approximately 75% of the regular capacity

Glulam Camber

• Glulam can be manufactured to a camber to offset the dead load deflection
• Very important for long span members
Importance of Camber

Camber can be 1”- 12” or more depending on span and loads

Notching and Drilling

Notching should be avoided, especially on tension side of glulam
Glulam Lay-Ups

Balanced Lay up

- High Strength Outer Tension Lams
- Medium Grade Inner Compression Lam
- Lower Grade Inner Lams
- Medium Grade Inner Compression Lam
- High Strength Outer Tension Lams

Notching

Problem
Tension perpendicular to grain

Solution
Provide full end grain bearing
Possible Reinforcement for an End Notch

A REINFORCEMENT TECHNIQUE TO MINIMIZE CRACK PROPAGATION AT END BEARING NOTCHES

Notching and Drilling

Notching on compression side is generally less severe if beam has an unbalanced layup.
Glulam Lay-Ups

Unbalanced Lay up

- High Strength Outer Compression Lams
- Medium Grade Inner Compression Lam
- Lower Grade Inner Lams
- Medium Grade Inner Compression Lam
- High Strength Outer Tension Lams

Glulam Manufacturing - Engineered Layups

Simple Span – Unbalanced Layup
Cantilever or Continuous Span

Notching and Drilling

Tapered cut on compression side

(a) Square End Bearing

(b) Slope End Bearing
Notching and Drilling

Tapered cut on compression side

Effects of Vertical Holes

- Strength reduction
  \[ = 1.5 \times \text{hole diameter/beam width} \]

- Example:
  - 6-3/4” beam width
  - 1” diameter vertical hole
  - Reduction = \( (1.5 \times 1.0/6.75) \)
  - Reduction = 0.22
  - Beam has 78% of original strength
Permissible Horizontal Round Hole Locations for Glulam Beam under Uniform Loads (APA Form S560)

Zones where horizontal holes are permitted for passage of wires, conduit, etc.

Limits: max. size (1/10d, 1-1/2")
spacing 8 dia. of largest hole
no. holes = 1 every 5 feet

Basic Glulam Design Concepts

- Type of member / load application
- Determination of allowable design stresses / layup selection
- Structural analysis
- Stress modification factors
- Special design provisions
- Connection design /detailing
- Durability & Fire
Glulam Connections

Connection Design

- The NDS has design provisions
- Allowable = nominal x adjustment factors
- Adjustment factors account for a wide range of different end use applications
Basic Glulam Design Concepts - Summary

- Identify type of member and how load will be applied
- Determine allowable design stresses by selecting layup combination
- Apply stress modification factors
- Complete structural analysis (ASD or LRFD)
- Be aware of special design considerations
- Apply proper connection design and detailing practices

Basic Wood Connection Concepts

Wood and tension perpendicular to grain

- Initiators:
  - Hanging load
  - Large diameter fastener
  - Restraint by connector detail
Hanger to Beam

- Load suspended from lower half of beam
  - Tension perpendicular to grain
  - May cause splits

Hanger to Beam

- Load supported in upper half of beam
  - Extended plates puts wood in compression when loaded

Full wrap sling option

Compression
Local Stress in Fastener Group

- Closely spaced fasteners
- Brittle failure
- Lower capacity

- Wood failure mechanism needs to be considered in design (this is in addition to yield equations)

Local Stress in Fastener Group

- Properly spaced fasteners
- Increased ductility
- Higher capacity

- Spread out the fasteners!
Local Stresses in Fastener Groups

Appendix E NDS Expressions

**Net tension:**

\[ Z_{NT}^i = F_t A_{net}^i \]

**Row tear-out:**

\[ Z_{RTi}^i = n_i F_t t_s \min \]

\[ Z_{RT}^i = \sum_{i=1}^{n_{row}} Z_{RTi}^i \]

**Group tear-out:**

\[ Z_{GT}^i = \frac{Z_{RT\text{-top}}^i}{2} + \frac{Z_{RT\text{-bottom}}^i}{2} + F_t A_{group\text{-net}}^i \]
Basic Glulam Design Concepts - Summary

- Identify type of member and how load will be applied
- Determine allowable design stresses by selecting layup combination
- Apply stress modification factors
- Complete structural analysis (ASD or LRFD)
- Be aware of special design considerations
- Apply proper connection design and detailing practices

Basic Glulam Design Concepts

- Type of member / load application
- Determination of allowable design stresses / layup selection
- Structural analysis
- Stress modification factors
- Special design provisions
- Connection design /detailing
- Durability & Fire
Durability and Long Term Performance

- Proper design
  - Members
  - Connections
- Proper installation
- Proper adhesive selection
- Protection from moisture
- Maintenance

Glulam - One of the Original Glued Engineered Wood Composites

St. Gallen, Switzerland
Durability and Long Term Performance

- **Strategies for durable glulam construction**
- **Keep glulam dry**
  - Focus on design and construction details
  - Focus on moisture management
- **Use appropriate preservative treatments when exposed to the elements or**
- **Specify naturally durable and decay resistive wood species**
- **Numerous examples of glulam structures 50-100 years old worldwide**
Glulam Beams Stored at Distribution Yard

Proper handling

Proper storage

Glulam Beams Shipped to Job Site

Proper handling

Proper storage
Interior Applications - Durability Not Typically An Issue

Golf Course Bridge
Pedestrian Bridge - 105 ft. Span

Pedestrian Bridge – 120 ft. span
Glulam Arch Highway Bridge Suspended Deck - Colorado

Glulam Arch Highway Bridge Elevated Deck - Michigan
Short Span Glulam RR Girders

100 ft. Span Glulam - Railroad Girders
Glulam Electric Utility Structures

Tri-Level Highway Bridge - Keystone Wye - S.D.

Original installation 1968

1980

Over 40 years of exposure to the elements

2009
Preservative Treatment of Glulam

**U.S. Standards**

- **American Wood Preservers Standard (AWPA U1)**
  - UC1 Interior, dry Insects
  - UC2 Interior, wet Decay and insects
  - UC3 Exterior, above ground Decay and insects
  - UC4 Ground contact Decay and insects
  - UC5 Salt water Salt water organisms

- **American Association of State Highway and Transportation Officials (AASHTO)**
  - Above ground
  - Ground contact, fresh water
  - Ground contact, salt water

- U.S. building codes require treatment of exposed glulam
Preservative Treatment of Glulam

Incising used for difficult to treat species
No effect on glulam strength

Decay

- Decay fungi needs:
  - Moderate temperature (50° - 100°F)
  - Food (organic substances such as wood)
  - Air
  - Moisture (20% or above for prolonged periods)
  - Typically cannot control temperature and air
  - Need to control exposure to moisture and/or poison the food (glulam)
Preservative Treatment of Glulam

- APA - Preservative Treatment of Glued Laminated Timber
- EWS S580C


Many treatments available for glulam
Preservative Treatment of Glulam

- Applicable treatments are a function of species and whether treatment is before or after gluing

**TABLE 3**

<table>
<thead>
<tr>
<th>Treatment Type</th>
<th>Glulam Treated Prior to Gluing</th>
<th>Glulam Treated After Gluing</th>
<th>Southern Pine</th>
<th>Hardwoods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crescote</td>
<td>No²</td>
<td>Yes</td>
<td>No²</td>
<td>No</td>
</tr>
<tr>
<td>Oil-borne Penta</td>
<td>No³</td>
<td>Yes</td>
<td>No³</td>
<td>No</td>
</tr>
<tr>
<td>Copper Naphthenate</td>
<td>No²</td>
<td>Yes</td>
<td>No²</td>
<td>No</td>
</tr>
<tr>
<td>Cu-B-Q¹</td>
<td>No²</td>
<td>No²</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>CCA</td>
<td>No²</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>ACZA</td>
<td>No²</td>
<td>No²</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>ACC</td>
<td>No²</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>ACQ-C</td>
<td>No³</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

1. For above ground use only, AWPA Use Category UC1, UC2 and UC3B.
2. Although not recommended, AWPA Standard U1 permits this treatment.
3. Except when penta with hydrocarbon solvents is used.
4. Except when treating western hemlock and hem-fir.

**Preservative Treatment of Glulam**

**TABLE 5**

| Preservative Retentions (pcf): Glulam Members (Treated after gluing) |
|-----------------------------|-----------------------------|
| **USE CATEGORY**             | **Preservative System**     |
| **Species**                  | **Crescote**                |
| UC1, UC2, UC3B               | CR                           |
| Southern Pine               | 8.0                         |
| Coastal Douglas-fir          | 8.0                         |
| Western Hemlock, Hem-fir     | 8.0                         |
| Red Oak                     | 7.0                         |
| Red Maple, Yellow Poplar     | 8.0                         |
| UC4A                        |                             |
| Southern Pine               | 10.0                        |
| Coastal Douglas-fir          | 10.0                        |
| Western Hemlock, Hem-fir     | 10.0                        |
| Red Oak                     | 8.5                         |
| Red Maple, Yellow Poplar     | 10.0                        |
| UC4B, UC4C: See Table 7 (Glulam Poles). |  |

1. Not recommended by AWPA
2. Not recommended by the glulam industry, see Table 3.
Preservative Treatments

• Considerations for preservative treatments
  • Incising may be required for some hard to treat species
  • Fastener corrosion may occur with some waterborne arsenical treatments – use hot dipped galvanized or stainless steel connectors
  • Field cuts require field applied treatments
  • Structural properties not affected by approved treatments and processes

Naturally Durable Species

• Port Orford Cedar 22F-1.8E
• Alaska Yellow Cedar 20F-1.5E
• Western Red Cedar 16F-1.3E
• California Redwood 16F-1.1E
Van Norman Reservoir Cover

650,000 sq. ft.
15 acres

Alaska Yellow Cedar
Santa Monica, CA Reservoir Cover
Connection Serviceability Issues

- Temperature – not of major importance
- Humidity and moisture – major concerns
  - exposed end grain
  - contact with concrete or masonry
  - moisture entrapment
  - ambient conditions/dimensional changes

Effects of Moisture

- Issue: direct water ingress into the wood
- Water is absorbed most quickly through wood end grain
  No end caps or flashing used
Connection Serviceability

- **Issue: direct water ingress**
  - Re-direct the water flow around the connection
  - Use preservative treated glulam or durable species

Connection Serviceability

**End caps and flashing used**

Flashing Installation

- Nails or screws into discontinuous strip
- 1" min. w/ turned out ends
- ½" air space w/ insect screen
- Exposed sections of members to be preservative treated
- End cap protects end grain
- Open bottom or weep holes
Effects of Moisture

- End grain checking
- Is it of structural concern?

Examples of Checking

- Side checks
- Bottom glue line check
- End checks
Delamination and Checking?

- Checking is a natural phenomena associated with natural drying of the glulam
- Delamination is a deterioration of the glue bond when exposed to moisture
- The introduction of wet-use (durable) adhesives in the mid 1940’s virtually eliminated delamination in the U.S.
- This is assured by requiring adhesives to meet D2559 and by conducting daily quality control checks using a cyclic delamination test

Delamination? NO

Typically unbonded edges due to lack of bonding pressure and intimate contact during the manufacturing process
Checking

- Owner’s Guide to Understanding Checks in Glued Laminated Timber
- APA EWS F450

Checking Test Program

- Guidelines established for what size checks are OK without an engineering analysis
- Published in an Owners Guide to Checking
- One of APA’s most widely used publications
Checking

- AITC
- Technical Note 11
- Checking in Glued Laminated Timber

http://www.aitc-glulam.org/

Glulam to Masonry

Grout used at bearing  
No air space

Need 1/2” air gap between wood and masonry
Glulam to Masonry

- Prevent contact with masonry
- Use bearing plate under beam
- Maintain air gap at end

Note gap at end

Note steel bearing plate

Buried Column Base

- Floor slab poured over connection
  - Can cause decay due to moisture entrapment
  - Not recommended
Column to Base

**Problem**
- No weep holes in closed shoe
- Moisture entrapped
- Decay inevitable

**Column to Base**

- Bearing plate
  - Anchor bolts in bearing plate
  - Dapped column end

- Angle brackets
  - Anchor bolts in bracket
  - Loose bearing plate
Arch Base to Support

Glulam arches with closed shoe
No provision such as weep holes to allow moisture to drain

Arch Base to Support

Note flashing on top of glulam
Note open shoe allowing water to drain
Arch Base to Support

Sawn timber ¾"

Green → 8%

15-1/4"

Glulam ¼"

24"

12% → 8%
Glulam Beam End Bearing

- Problem is shrinkage that transfers load from bearing seat to bolts inducing tension perpendicular to grain stresses

Note: bolts high and low

Note: steel bearing seat

Cracks developing

Note bearing angle and slight gap at wood
Glulam Beam End Bearing

- Solution: allow shrinkage to occur without inducing tension perp stresses

Importance of Detailing
Importance of Detailing

Ends covered

Closed shoe
Importance of Detailing

Elevated bearing

Moisture staining

No bearing plate
Lessons Learned to Ensure Durable and Long Life Glulam Structures

- Keep glulam dry whenever possible
- Account for moisture effects
  - High moisture = mold, decay, insect attack
  - Protect from direct exposure to elements
  - Use preservative treatments
  - Use naturally durable species
- Design connections for long term performance
  - Allow for movement due to moisture changes
  - Design to avoid moisture entrapment
  - Avoid direct contact with masonry and concrete

Building Size Example I

- Assume an unprotected office building is desired – Group B

<table>
<thead>
<tr>
<th>GROUP</th>
<th>TYPE OF CONSTRUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TYPE I</td>
</tr>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>HGT (S)</td>
<td>HGT (feet)</td>
</tr>
<tr>
<td>B</td>
<td>S</td>
</tr>
</tbody>
</table>

- For Type IB 11 stories/UL sf is allowed
- For Type IIB 4 stories/23,000sf is allowed
- For Type IIIB 4 stories/19,000sf is allowed
- For Type IV 5 stories/36,000sf is allowed
- For Type VB 2 stories/9000sf is allowed

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### Fire Protection

<table>
<thead>
<tr>
<th>Stories</th>
<th>Building Type</th>
<th>III-A</th>
<th>IV-A</th>
<th>V-A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>III-A</td>
<td>111,625</td>
<td>121,125</td>
<td>87,875</td>
</tr>
<tr>
<td>2</td>
<td>IV-A</td>
<td>88,125</td>
<td>95,625</td>
<td>69,375</td>
</tr>
<tr>
<td>3</td>
<td>V-A</td>
<td>88,125</td>
<td>95,625</td>
<td>Not Permitted</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>88,125</td>
<td>95,625</td>
<td>Not Permitted</td>
</tr>
</tbody>
</table>

(a) Occupancy - Education  
(b) Based on 4 side frontage and sprinkler area increases in IBC  
(c) All square feet per floor

### Characteristics of Glulam in Fire

- Wood is an excellent heat insulator  
-Develops a char layer after fire exposure  
- Self-extinguishing after fire source removed  
- Retains significant residual strength after being exposed to fire
Glulam vs. Steel

Performance of Wood vs. Steel

http://www.aitc-glulam.org/shopcart/Pdf/superior_fire%20resistance.pdf
Glulam vs. Steel

Char rate = 1/40” per minute or 1-1/2” per hour

Fire Rating for Glulam

- Two accepted methods under US Building Codes
  - IBC Empirical Method
  - NDS Mechanics Based Model
IBC Methodology

- Empirical protocol
- Based on extensive testing in the U.S. and other countries using the ISO 834 fire test protocol
- Beams – 3 or 4 sides exposed
- Columns – 3 or 4 sides exposed

IBC Methodology for Beams

- Section IBC 722.6.3
- Beams exposed on 3 sides
  \[ t = 2.54Zb \left[ 4 - b/d \right] \]
- Beams exposed on 4 sides
  \[ t = 2.54Zb \left[ 4 - 2b/d \right] \]
  - \( b \) = beam width
  - \( d \) = beam depth
  - \( t \) = fire resistance in minutes
  - \( Z \) = load compensation factor
    \[ = \text{applied load} / \text{design capacity} \]
**IBC Methodology**

\[ K_e = \text{the effective length factor} \]
\[ L = \text{the unsupported length of columns} \]

**2012 NDS Methodology**

- Chapter 16 – Fire Design of Wood Members
- Mechanics Based Model
- Supported by empirical data
2012 NDS Methodology

• Determine reduced section properties of glulam after fire exposure using effective char layer
• Calculate induced bending stress with reduced section
• Determine the member strength based on tabulated stress x fire adjustment factor (2.85 for bending)
• \( F_b \times 2.85 \geq \) calculated induced stress

Table 16.2.2 Adjustment Factors for Fire Design

<table>
<thead>
<tr>
<th>Bending Strength</th>
<th>( F_b )</th>
<th>x</th>
<th>2.85</th>
<th>( C_T )</th>
<th>( C_V )</th>
<th>( C_{th} )</th>
<th>( C_L )</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>( F_t )</td>
<td>x</td>
<td>2.85</td>
<td>( C_T )</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Compression Strength</td>
<td>( F_c )</td>
<td>x</td>
<td>2.58</td>
<td>( C_T )</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>( C_p )</td>
</tr>
<tr>
<td>Beam Buckling Strength</td>
<td>( F_{be} )</td>
<td>x</td>
<td>2.03</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Column Buckling Strength</td>
<td>( F_{ce} )</td>
<td>x</td>
<td>2.03</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

• The strength factor brings the fire design to the average breaking strength of glulam
2012 NDS Methodology

\[
\beta_{\text{eff}} = \frac{1.2 \beta_n}{t^{0.187}}
\]

Where:
- \( \beta_{\text{eff}} \) = Effective char rate (in./hr), adjusted for exposure time, \( t \)
- \( \beta_n \) = Nominal char rate (1.5 in./hr)
- \( t \) = Exposure time (hr)

<table>
<thead>
<tr>
<th>( t )</th>
<th>( \beta_{\text{eff}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hr</td>
<td>1.8 in./hr (45.7 mm/hr)</td>
</tr>
<tr>
<td>1 ½ hr</td>
<td>1.67 in./hr (42.4 mm/hr)</td>
</tr>
<tr>
<td>2 hr</td>
<td>1.58 in./hr (40.1 mm/hr)</td>
</tr>
</tbody>
</table>
Fire Rated Glulam

**TABLE 4**
MINIMUM DEPTHS AT WHICH 6-3/4 IN. AND 8-3/4 IN. WIDE BEAMS CAN BE ADAPTED FOR ONE-HOUR FIRE RATINGS

<table>
<thead>
<tr>
<th>Beam Width (in.)</th>
<th>Depth 3 Sides Exposed (in.)</th>
<th>Depth 4 Sides Exposed (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-3/4</td>
<td>13-1/2</td>
<td>12</td>
</tr>
<tr>
<td>8-3/4</td>
<td>7-1/2</td>
<td>10-1/2</td>
</tr>
</tbody>
</table>

**TABLE 5**
MINIMUM DEPTHS AT WHICH 8-3/4 IN. AND 10-3/4 IN. COLUMN WIDTHS QUALIFY FOR ONE-HOUR RATING FOR GIVEN C/D

<table>
<thead>
<tr>
<th>C/D Criteria</th>
<th>Column Width (in.)</th>
<th>Depth 3 Sides Exposed (in.)</th>
<th>Depth 4 Sides Exposed (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/D &gt; 11</td>
<td>10-3/4</td>
<td>10-1/2</td>
<td>13-1/2</td>
</tr>
<tr>
<td>C/D = 11</td>
<td>8-3/4</td>
<td>7-1/2</td>
<td>12</td>
</tr>
<tr>
<td>C/D &lt; 10</td>
<td>10-3/4</td>
<td>7-1/2</td>
<td>10-1/2</td>
</tr>
</tbody>
</table>

Typical Glulam Beam Layup

- **24F-V4 Doug Fir (12 Lamination Example)**

  2 - L2 Dense Grade Outer Comp. Lams
  1 - L2 Grade Inner Comp. Lam
  6 - L3 Grade Core Lams
  1 - L2 Grade Inner Ten. Lam
  1 - L1 Grade Outer Tension Lams
  1 - 302-24 Outer Tension Lams

For 1-hour fire rated beam: substitute additional tension lam for core lam
Tension Lam Provisions

Fire Protection

- Where fire endurance is enquired, connectors and fasteners shall be protected from fire exposure
  - Wood
  - Fire-rated gypsum board
  - Coating
Connections

University of Oregon Football Stadium
Office Building in Portland, OR

Airport Terminal - Victoria, B.C.
Light Rail Transit Center - Vancouver, B.C.

Chicago Bears Football Practice Facility
Cathedral of Light

Cathedral of Light - Oakland, CA
Olympic Skating Oval - Richmond, B.C.

Glulam for Office Buildings

Microsoft Campus
Nike Pedestrian Bridge

Raleigh Durham Airport
Toronto Ontario Art Gallery

Metrotown Overpass - Vancouver, B.C.
Glulam Truss Bridge in Hiroshima Japan

Additional Glulam Information

- www.apawood.org
- www.aitc-glulam.org
- Handouts
Questions?

www.awc.org

info@awc.org