AMERICAN WOOD COUNCIL

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

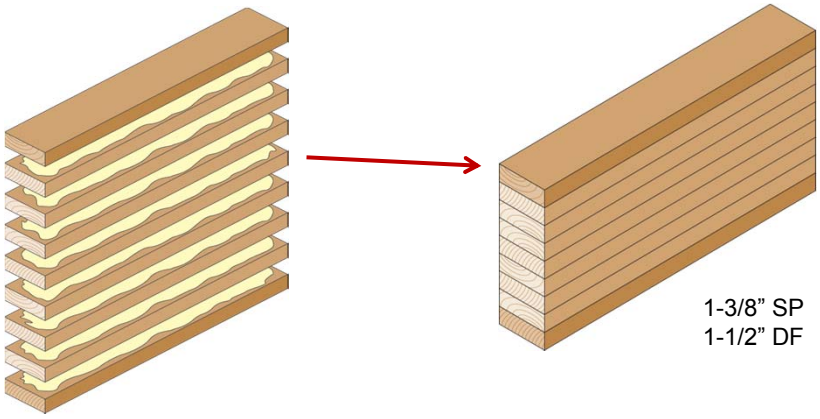
Glued-laminated timber is often used as a primary load carrying member of buildings. Often selected for aesthetic reasons or its unparalleled design flexibility, glulam also offers superior structural performance combined with long term durability. This seminar will focus on recent glulam innovations — 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

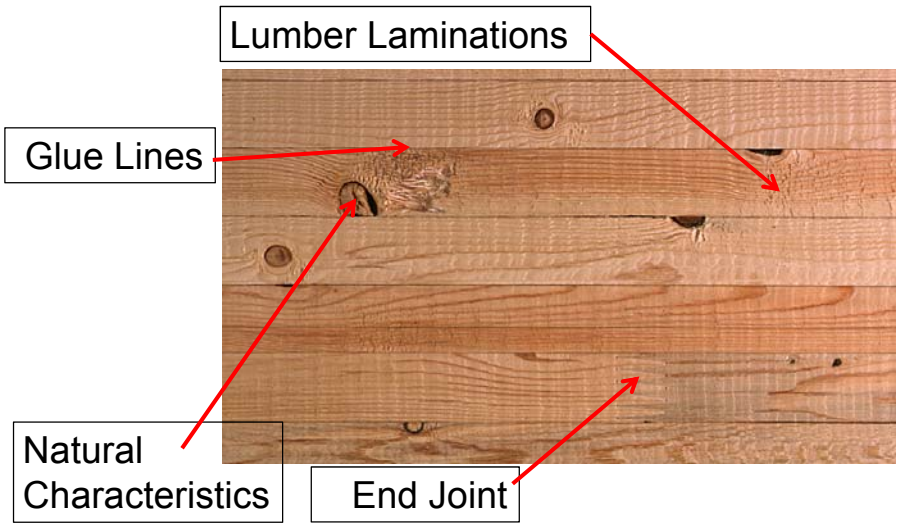
- Be able to identify research and correctly specify glued-laminated timber appropriately on their projects.
- Become familiar with a number of technology advances and standards related to glued-laminated timber.
- Become familiar with key design considerations.
- Become acquainted with the unique fire 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



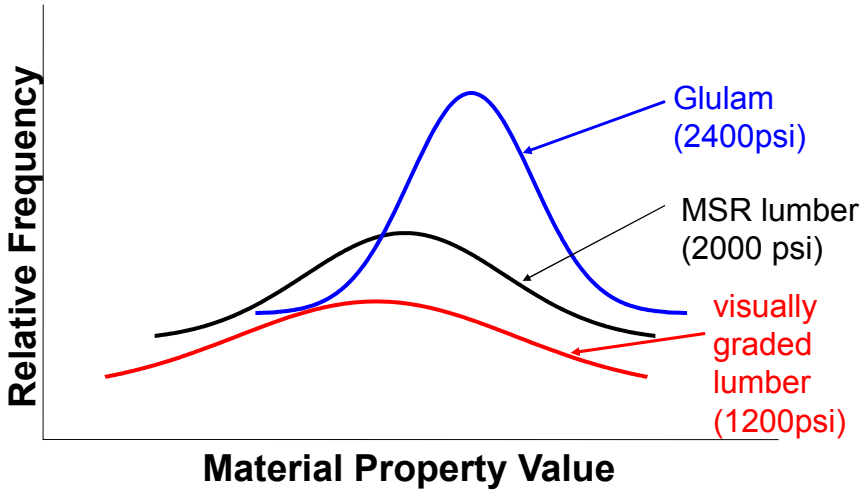
Glulam = One of the Original Engineered Wood Composites



Inherent Advantages of Glulam

- **High degree of engineering efficiency**

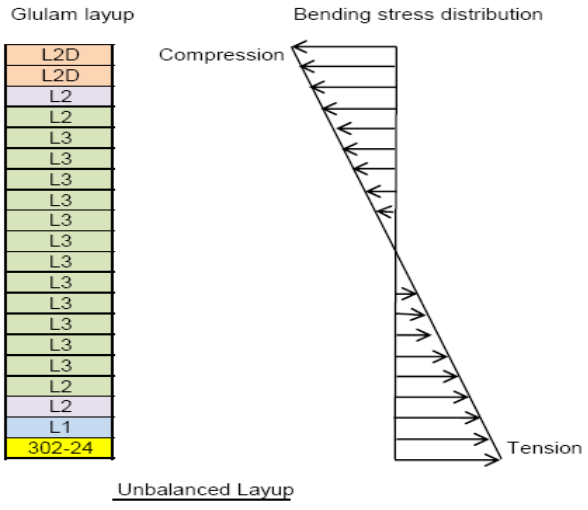
Engineering Efficiency



Inherent Advantages of Glulam

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

Resource Efficiency



Inherent Advantages of Glulam

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

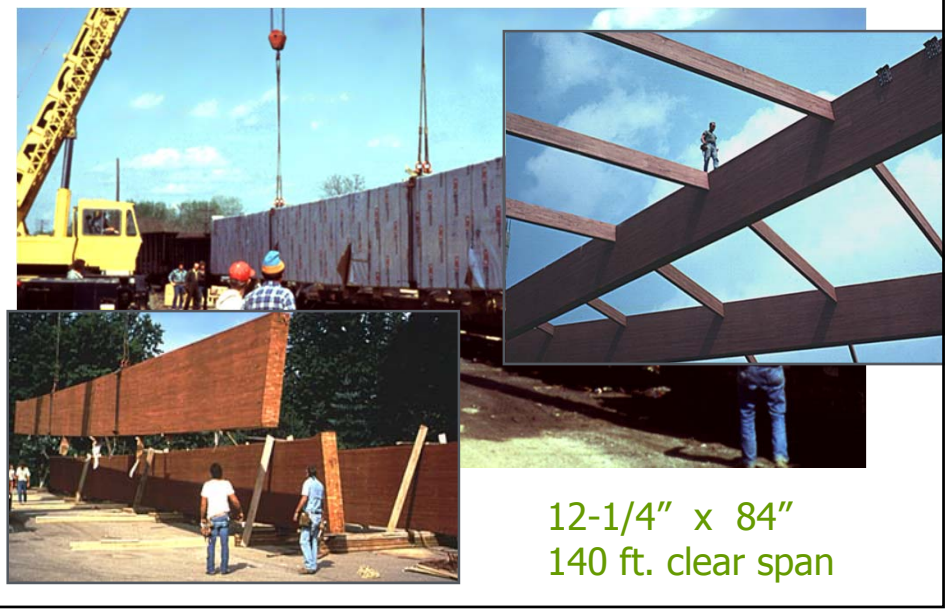
Large Sizes




Oceans Exhibit – Indianapolis Zoo

10-3/4″ x 72″
115 ft. clear span

Church in Louisville, KY

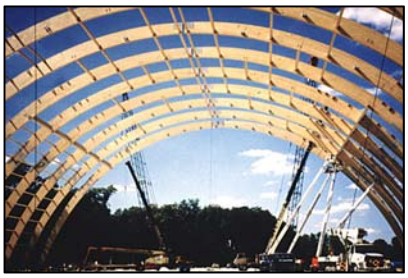


12-1/4″ x 84″
140 ft. clear span

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

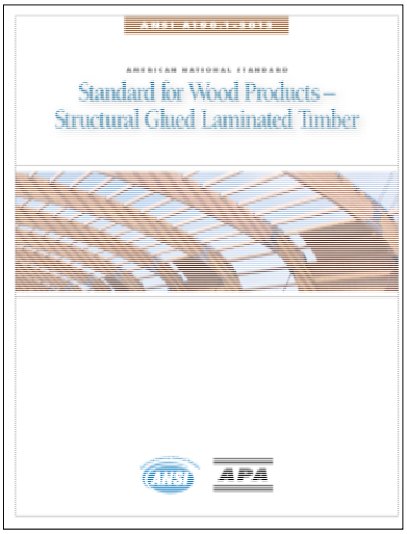
- **High degree of engineering efficiency**
- **Highly efficient use of wood resource**
- **Large dimensions**
- **Virtually unlimited versatility in shapes and spans**
- **Virtually unlimited versatility in shapes and spans**
- **Natural aesthetic appearance only possible with wood**

Natural Aesthetics of Glulam

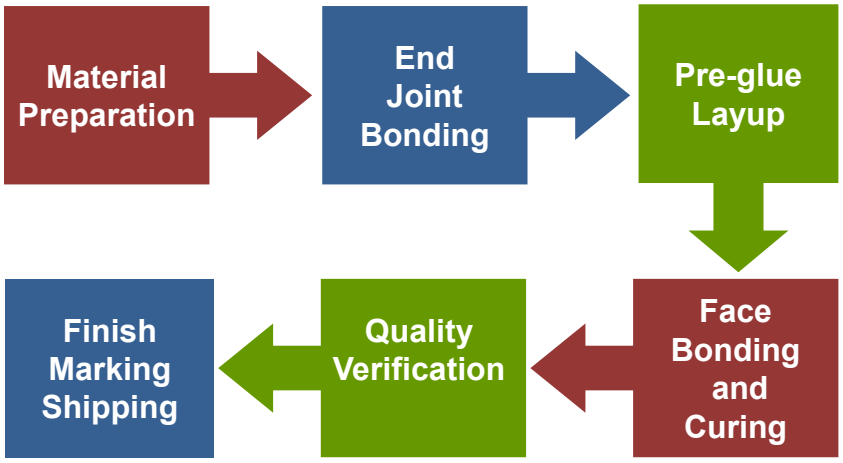
Natural Aesthetics of Glulam

Glulam Manufacturing Standard ANSI A190.1

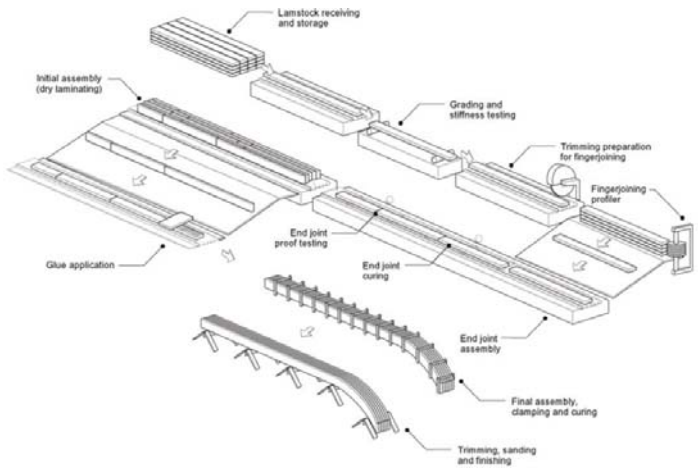
- **Product qualification and quality assurance requirements are specified**
- **Third-party inspection is required on an on-going basis**
- **All glulam must bear a grademark meeting ANSI A190.1 -2012**



Glulam Manufacturing Process



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

Grade	Maximum knot size
L1	1/4 width
L2	1/3 width
L3	1/2 width

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**

Designation: D 2559 – 04

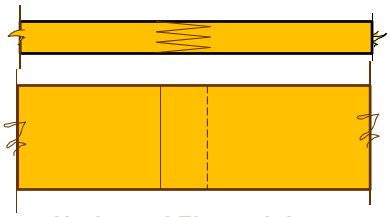
Standard Specification for
Adhesives for Structural Laminated Wood Products for Use Under Exterior (Wet Use) Exposure Conditions[1]

- **ASTM D 7247 for heat durability**

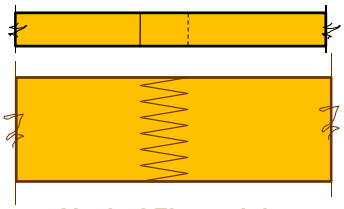
Designation: D 7247 – 07a[ε1]

Standard Test Method for
Evaluating the Shear Strength of Adhesive Bonds in Laminated Wood Products at Elevated Temperatures[1]

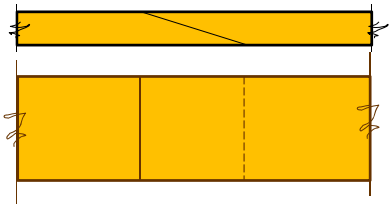
Structural End Joint



Horizontal Finger Joint



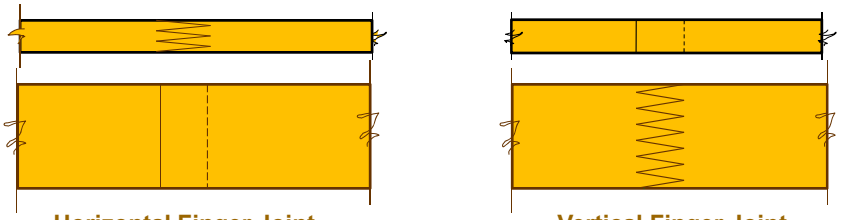
Vertical Finger Joint



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

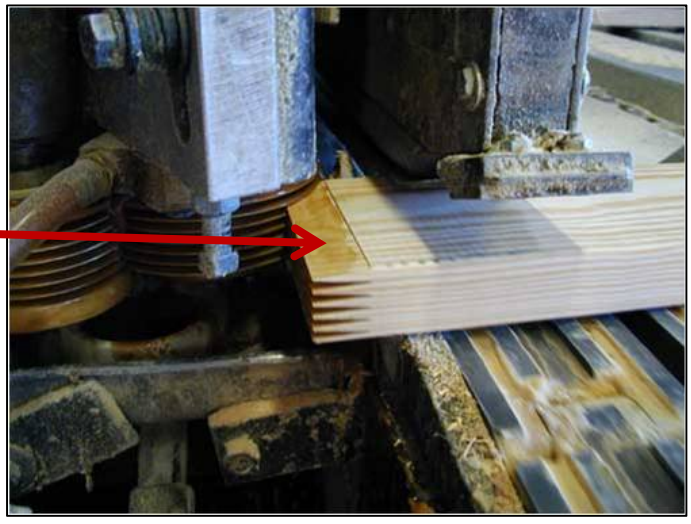
End Joint Bonding

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

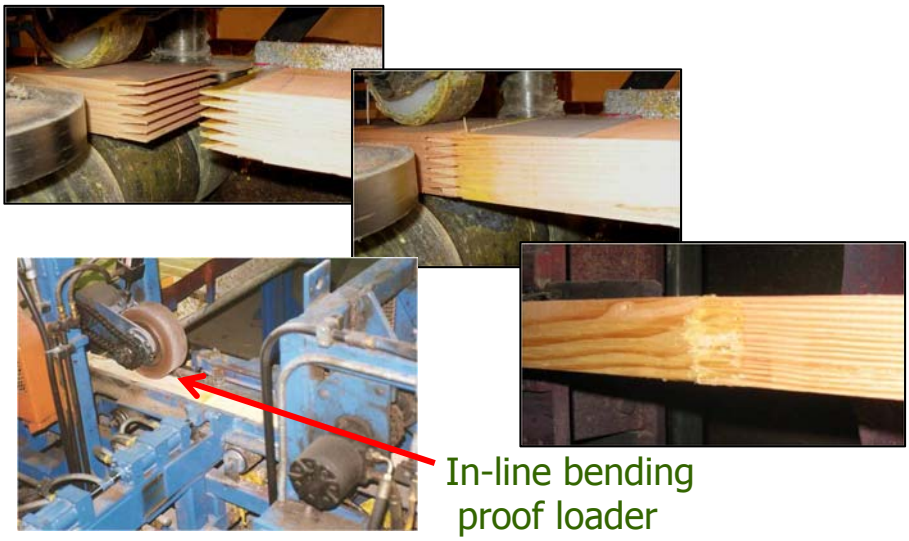
Horizontal Finger Joint

Horizontal Finger Joint

Adhesive being applied



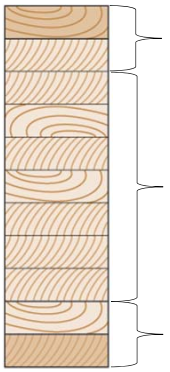
Finger Jointing Using RF Curing



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



Unbalanced Beam

Unbalanced Layup

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

L2D
L2D
L2
L2
L3
L3
L3
L3
L3
L3
L3
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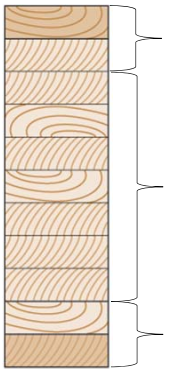
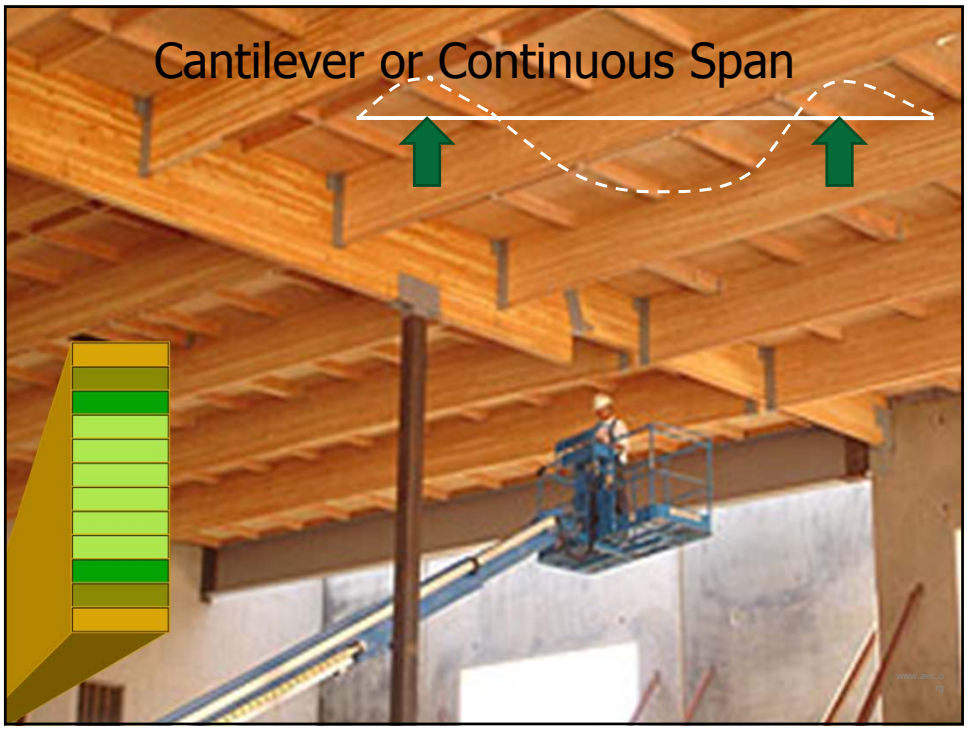
L3
L3
L3
L3
L2
L2
L1
302-24

Glulam Lay-Ups

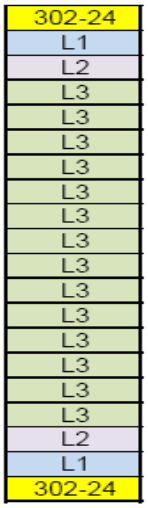


Unbalanced Beam



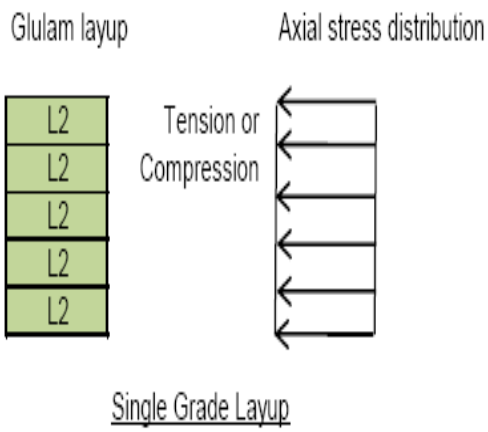
Balanced Layup

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



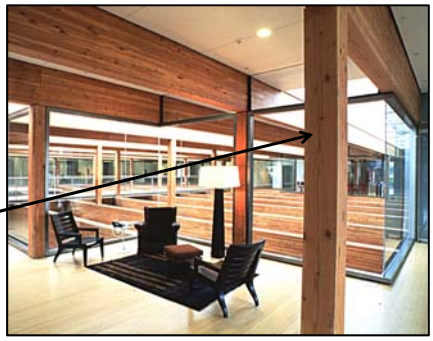
Single-Grade Layup

- 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

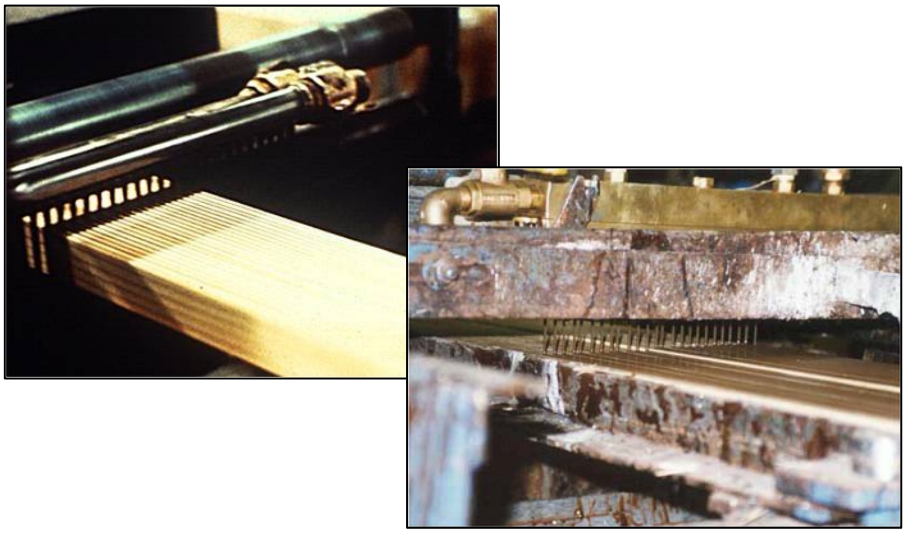


Glulam columns

Pre-Glue Layup

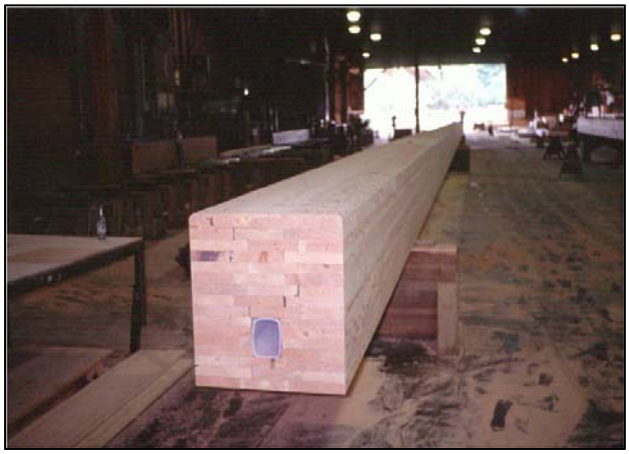
Lumber is typically color coded by grade

Face Bonding



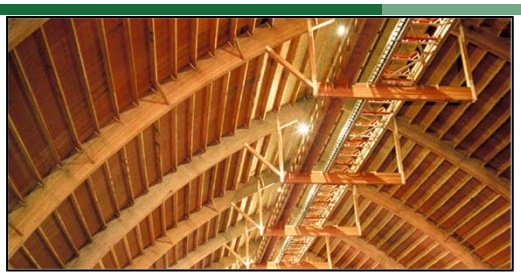
Clamping and Curing

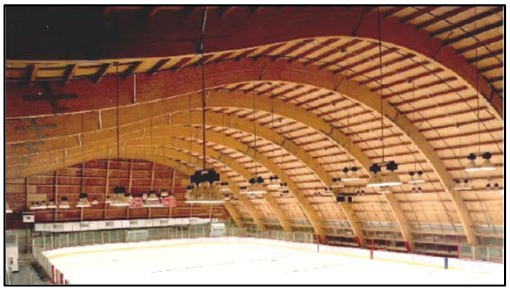
Large Dimensions Are Possible



21″ x 30″ x 110′

Curved Shapes

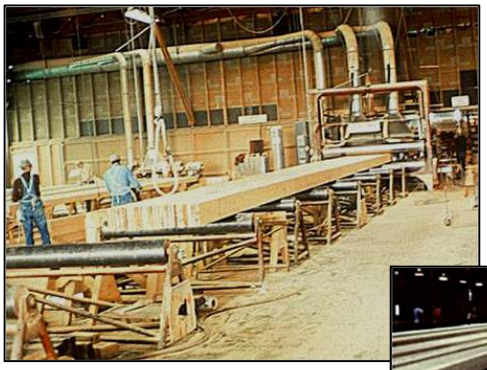




Quality Assurance Verification

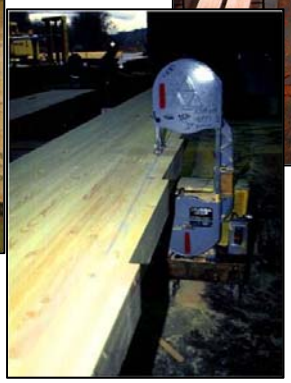
- **Glue bond integrity**
  - **Shear strength**
  - **Durability/delamination**
- **End joint strength**
  - **Tension test required in U.S.**
  - **Bending test in some countries**
- **Finished dimensions & shape**
- **Appearance characteristics**

Fabrication & Finishing



Fabrication and Finishing

Planing



Sawing

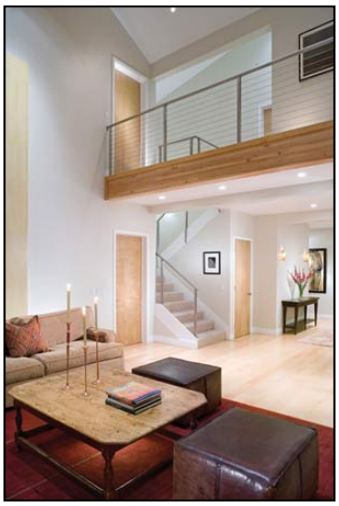
Patching

Fabrication and Finishing

Fabrication and Finishing

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

Fabrication and Finishing



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**

Protection & Storage

Trademarks

APA EWS

B IND EWS Y117

EWS 24F-1.8E DF

MILL 0000 ANSI/AITC A190.1-2007

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

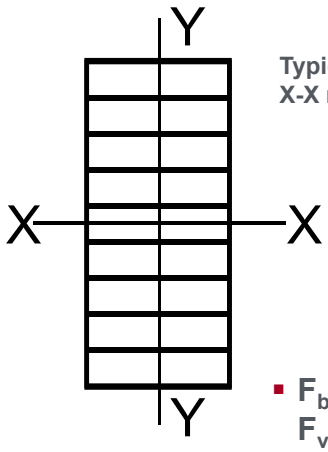
Column

Truss member

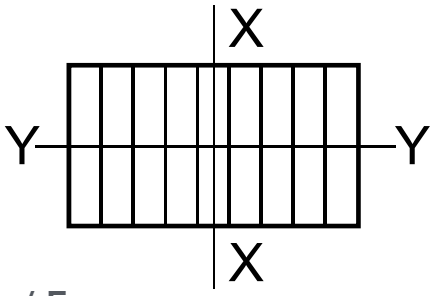
Simple span beam

Cantilever span beam

Loading Orientations



Typical use
X-X major axis



Y-Y major axis

- $F_{bx} \neq F_{by}$ $E_x \neq E_y$
  $F_{vx} \neq F_{vy}$ $F_{c\perp x} \neq F_{c\perp y}$
- $F_{bx}^{+} \neq F_{bx}^{-}$

Importance of Axis Orientation

- **Design Properties for 24F-V4 layup**

Major Axis (X-X)	Minor Axis (Y-Y)
Fb = 2,400 psi (16.5 MPa)	Fb = 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)[1]

Designation: D 7341 – 09

Standard Practice for
Establishing Characteristic Values for Flexural Properties of Structural Glued Laminated Timber by Full-Scale Testing[1]

ASTM D 3737

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

Designation: D 3737 – 08

Standard Practice for
Establishing Allowable Properties for Structural Glued Laminated Timber (Glulam)[1]

1. Scope

1.1 This practice covers the procedures for establishing allowable properties for structural glued laminated timber. Included are the allowable stresses for bending, tension and compression parallel to the grain, horizontal shear, compression perpendicular to the grain, and radial tension and compression in curved members. Also included are modulus of elasticity and modulus of rigidity.

1.2 This practice is limited to the calculation of allowable properties subject to the given procedures for the selection and arrangement of grades of lumber of the species considered.

1.3 Requirements for production, inspection and certification are not included, but in order to justify the allowable properties developed using procedures in this practice, manufacturers must conform to recognized manufacturing standards. Refer to ANSI/AITC A190.1 and CSA 0122.

1.4 The values stated in inch-pound units are to be regarded as standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 9 Terminology Relating to Wood and Wood-Based Products

D 198 Test Methods of Static Tests of Lumber in Structural Sizes

D 245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber

D 2395 Test Methods for Specific Gravity of Wood and Wood-Based Materials

D 2555 Practice for Establishing Clear Wood Strength Values

D 2915 Practice for Evaluating Allowable Properties for Grades of Structural Lumber

D 4761 Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material

D 5456 Specification for Evaluation of Structural Composite Lumber Products

D 6570 Practice for Assigning Allowable Properties for Mechanically Graded Lumber

E 105 Practice for Probability Sampling Of Materials

2.2 *Other Standards:*

ANSI/AITC A190.1 Structural Glued Laminated Timber[3]

ANSI/AF&PA/BS, National Design Specification for Wood Construction[4]

CSA 0122 Structural Glued Laminated Timber[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *alternative lumber*—laminated veneer lumber (LVL), laminated strand lumber (LSL), oriented strand lumber (OSL), or parallel strand lumber (PSL) meeting the requirements of Specification D 5456, or solid-sawn lumber that is produced according to Practice D 6570 and the grading rules of the applicable grading or inspection agency.

3.1.2 *E-rated lumber*—lumber graded for use in manufacturing structural glued laminated timber by nondestructive measurement of a modulus of elasticity (*E*) and by visual inspection in accordance with the grading rules of the applicable grading or inspection agency.

3.1.3 *glulam*—a term used to denote structural glued laminated timber, which is a product made from suitably selected and prepared pieces of wood bonded together with an adhesive either in a straight or curved form with the grain of all pieces essentially parallel to the longitudinal axis of the member.

ASTM D 7341

- Based on full-scale glulam performance tests in combination with or without modeling

Designation: D 7341 – 09

Standard Practice for
Establishing Characteristic Values for Flexural Properties of Structural Glued Laminated Timber by Full-Scale Testing[1]

1. Scope

1.1 This practice describes procedures for full scale testing of structural glued laminated timber (glulam) to determine or verify characteristic values used to calculate flexural design properties. Guidelines are given for: (*1*) testing individual structural glued laminated timber lay-ups (with no modeling), (*2*) testing individual glulam combinations (with limited modeling), and (*3*) validating models used to predict characteristic values.

1.2 This practice is limited to procedures for establishing flexural properties (Modulus of Rupture, MOR, and Modulus of Elasticity, MOE). Some of the principles for sampling and analysis presented may be applicable to other properties. However, other properties may require additional testing considerations that are beyond the scope of this practice.

1.3 This practice is not intended to supersede the provisions of Practice D 3737, but provides an alternative method for establishing characteristic values. Lay-up combinations developed in accordance with Practice D 3737 are not required to be governed by this standard.

NOTE 1—The models described by Practice D 3737 have been developed and modified based on more than 50 years of experience and many test programs. In some cases, however, it may be desirable to develop a new model based on other layup properties or using lumber materials or grades not covered by this standard.

1.4 Details of production, inspection, and certification are beyond the scope of this document. However, for test results to be representative of production, quality control systems shall be in place to ensure consistent quality. Manufacturing shall conform to recognized manufacturing standards such as ANSI/AITC A190.1 or CSA O122.

1.5 Adjustments to characteristic values to determine reference values for design shall be in accordance with Practice D 2915 for allowable stress design (ASD) or Specification D 5457 for load and resistance factor design (LRFD).

1.6 Adjustments to ASD reference values for end-use conditions intended for design purposes shall be performed in accordance with Practice D 3737. The same adjustment factors shall apply to LRFD reference values, except that the ASD *load duration* factor shall be replaced by an appropriate LRFD *time effect* factor as determined in accordance with recognized industry practice.

1.7 The values stated in inch-pound units are to be regarded as standard. No other units of measurement are included in this standard.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

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D 3737 Practice for Establishing Allowable Properties for Structural Glued Laminated Timber (Glulam)

D 4761 Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material

D 5456 Specification for Evaluation of Structural Composite Lumber Products

D 5457 Specification for Computing Reference Resistance of Wood-Based Materials and Structural Connections for Load and Resistance Factor Design

D 6815 Specification for Evaluation of Duration of Load and Creep Effects of Wood and Wood-Based Products

2.2 *Other Standards:*

AITC Test T119 Full Size End Joint Tension Test[3]

ANSI/AITC A190.1 American National Standard for Wood Products – Structural Glued Laminated Timber[3]

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

ESR Report™

ESR-1940

Reissued January 1, 2009

This report is subject to re-examination in one year.

ICC Evaluation Service, Inc.

www.icc-es.org

DIVISION: 06—WOOD AND PLASTICS

Section: 06251—Design Information

REPORT HOLDER:

APA—THE ENGINEERED WOOD ASSOCIATION

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EVALUATION SUBJECT:

GLUED-LAMINATED TIMBER COMBINATIONS AND THE GAP2006 COMPUTER PROGRAM

ADDITIONAL LISTEES:

ANTHONY FOREST PRODUCTS CO.

300 NORTH WASHINGTON

EL DORADO, ARKANSAS 71730

CALVERT COMPANY, INC.

210 V STREET

VANCOUVER, WASHINGTON 98661

CASCADE STRUCTURAL LAMINATORS, INC.

195 RISELIN ROAD

CHEHALIS, WASHINGTON 98532

ROSBORO, LLC

POST OFFICE BOX 20

SPRINGFIELD, OREGON 97477

STANDARD STRUCTURES INC.

3900 PRUITT AVENUE

WINDSOR, CALIFORNIA 95492

WESTERN STRUCTURES, INC.

1381 BAILEY HILL ROAD

EUGENE, OREGON 97402

1.0 EVALUATION SCOPE

Compliance with the following codes:

- 2006 International Building Code® (IBC)
- 2006 International Residential Code® (IRC)

Property evaluated:

Structural

2.0 USES

The GAP2006 computer program is utilized to determine design stresses for the specific layups of glued-laminated timbers listed in Tables 1 and 2 of this report.

Glued-laminated timbers manufactured to the glued-laminated timber combinations or single grade layups that have been developed using the GAP2006 program, and that are produced at the facilities listed in Table 3, are recognized as being in compliance with the design parameters indicated in Section 3.0 of this report.

3.0 DESCRIPTION

The GAP2006 computer program is based on the principles of ASTM D 3737. It is an alternative method for determining associated allowable design stresses for a given layup combination of glued-laminated timber. The GAP2006 computer program complies with the IBC and the IRC for allowable stress design. The design assumptions discussed in Sections 3.1 through 3.4 of this report are basic parameters utilized with the development of the allowable design stresses for the combinations listed in Table 1 or single grade layups listed in Table 2. See Section 5.4 for requirements applicable to these parameters.

3.1 Adhesive:

Face and end-joint bonding adhesives comply with ASTM D 2559 for exterior or wet use.

3.2 End Joints:

End joints comply with ANSI A190.1 and ASTM D 3737.

3.3 Lumber:

Lumber having a nominal thickness of 2 inches or less is glued-laminated into rectangular cross-sections complying with industry standards for depth, width, and appearance. Lumber that is E-rated or visually graded complies with rules of applicable approved lumber grading agencies and has identification of the grade and species on each piece for documentation. Quality control for E-rating and beam fabrication is conducted under the supervision of an approved third-party inspection agency. Grade specifications are included in rules of the applicable approved lumber grading agencies and follow industry classifications and nomenclature as provided in the applicable code.

3.4 Layup:

Beams are fabricated in accordance with ANSI A190.1 using the grade combinations noted in Table 1 or single grade layups noted in Table 2 of this report. Combinations are in accordance with ASTM D 3737 requirements. Reseen purlin

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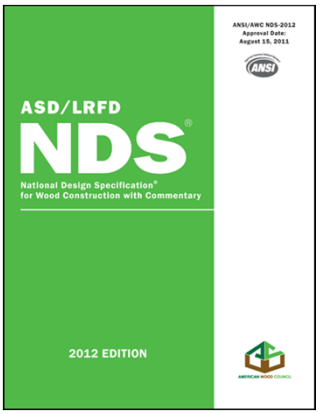
2012 NDS Supplement

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.)

Use with Table 5A Adjustment Factors

	Bending About X-X Axis Loaded Perpendicular to Wide Faces of Laminations						Bending About Y-Y Axis Loaded Parallel to Wide Faces of Laminations					Axially Loaded		Fasteners
	Bending		Compression Perpendicular to Grain	Shear Parallel to Grain	Modulus of Elasticity		Bending	Compression Perpendicular to Grain	Shear Parallel to Grain	Modulus of Elasticity		Tension Parallel to Grain	Compression Parallel to Grain	Specific Gravity for Fastener Design
	Bottom of Beam Stressed in Tension (Positive Bending)	Top of Beam Stressed in Tension (Negative Bending)			For Deflection Calculations	For Stability Calculations				For Deflection Calculations	For Stability Calculations			
Stress Class	F_{bx}^{+} (psi)	F_{bx}^{-} (psi) [1]	$F_{c\perp x}$ (psi)	F_{vx} (psi) [4]	E_x (10^6 psi)	$E_{x\,min}$ (10^6 psi)	F_{by} (psi)	$F_{c\perp y}$ (psi)	F_{vy} (psi) [4][5]	E_y (10^6 psi)	$E_{y\,min}$ (10^6 psi)	F_t (psi)	F_c (psi)	G
16F-1.3E	1600	925	315	195	1.3	0.69	800	315	170	1.1	0.58	675	925	0.41
20F-1.5E	2000	1100	425	195 [6]	1.5	0.79	800	315	170	1.2	0.63	725	925	0.41
24F-1.7E	2400	1450	500	210 [6]	1.7	0.90	1050	315	185	1.3	0.69	775	1000	0.42
24F-1.8E	2400	1450 [2]	650	265 [3]	1.8	0.95	1450	560	230 [3]	1.6	0.85	1100	1600	0.50 [10]
26F-1.9E [7]	2600	1950	650	265 [3]	1.9	1.00	1600	560	230 [3]	1.6	0.85	1150	1600	0.50 [10]
28F-2.1E SP [7]	2800	2300	805	300	2.1 [9]	1.11 [9]	1600	650	260	1.7	0.90	1250	1750	0.55
30F-2.1E SP [7][8]	3000	2400	805	300	2.1 [9]	1.11 [9]	1750	650	260	1.7	0.90	1250	1750	0.55

Glulam Standards / ICC Codes

- Glulam standards are referenced in the IBC and IRC

US Glulam Standards- Combination Symbols

- 24F- V4/DF

Allowable Bending Design Stress: 24F = 2,400 psi 30F = 3,000 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:**
- **Fb = 2,400 psi E = 1.8 x 106 psi**
- **Southern Pine**
  Fb > 3,000 psi E = 2.1 x106 psi
- **LVL hybrid**
- **Fb = 3,000 psi E = 2.1 x106 psi**
- **FRP beams**
- **Fb > 3,000 psi E > 2.1 x106 psi**

Glulam with LVL Outer Laminations

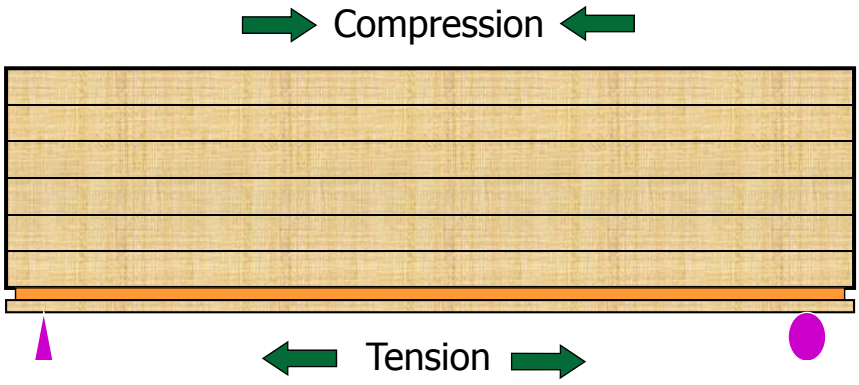
LVL Laminations

- 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



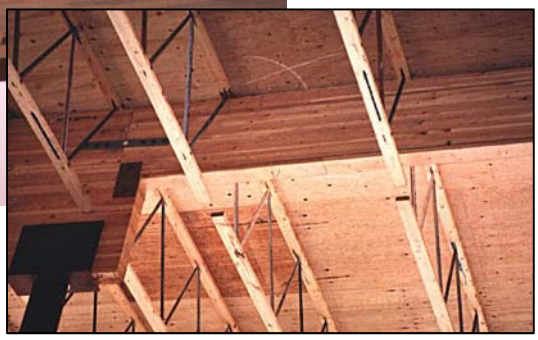
Lower grades adequate to resist compression forces
Very high grades needed to resist higher bending member tension forces
Reinforced concrete analogy

FRP Reinforced Glulam

Fiber Reinforced Polymer

FRP Reinforced Glulam

Adaptable to glulam manufacturing process



Bending strengths of 30F, 32F, 34F or higher

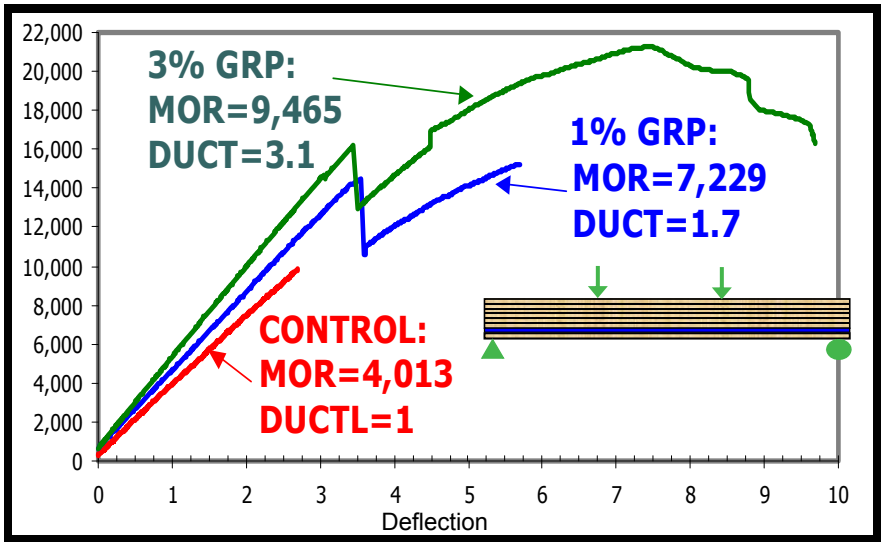
FRP Reinforced Glulam

1/3 less wood than conventional glulam

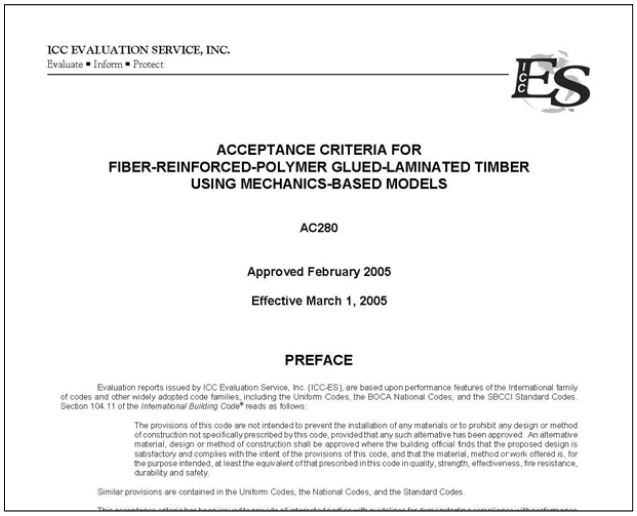
Optimizing Strength with FRP

FRP

Tension Reinforcement



ICC-ES AC 280



ICC EVALUATION SERVICE, INC.
Evaluate ▪ Inform ▪ Protect

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

AC280

Approved February 2005

Effective March 1, 2005

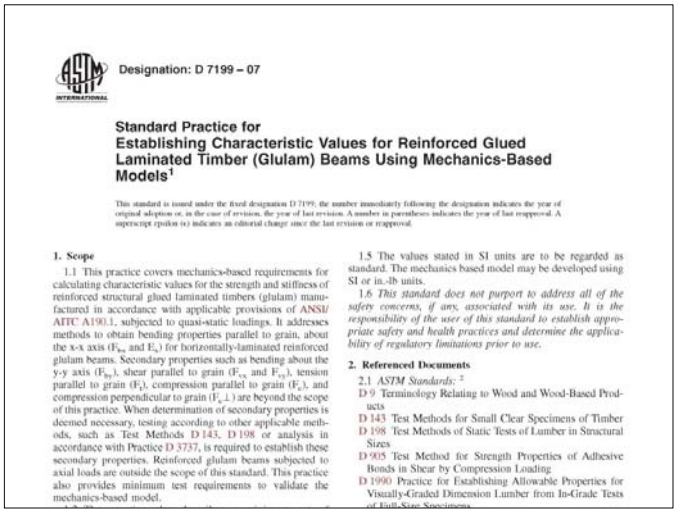
PREFACE

Evaluation reports issued by ICC Evaluation Service, Inc. (ICC-ES), are based upon performance features of the International family of codes and other widely adopted code families, including the Uniform Codes, the BOCA National Codes, and the SBCCI Standard Codes. Section 104.11 of the *International Building Code*® reads as follows:

The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

Similar provisions are contained in the Uniform Codes, the National Codes, and the Standard Codes.

ASTM D 7199



Designation: D 7199 – 07

Standard Practice for Establishing Characteristic Values for Reinforced Glued Laminated Timber (Glulam) Beams Using Mechanics-Based Models[1]

This standard is issued under the fixed designation D 7199; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers mechanics-based requirements for calculating characteristic values for the strength and stiffness of reinforced structural glued laminated timbers (glulam) manufactured in accordance with applicable provisions of ANSI/AITC A190.1, subjected to quasi-static loadings. It addresses methods to obtain bending properties parallel to grain, about the x-x axis (F_{bx} and E_x) for horizontally-laminated reinforced glulam beams. Secondary properties such as bending about the y-y axis (F_{by}), shear parallel to grain (F_{vx} and F_{vy}), tension parallel to grain (F_t), compression parallel to grain (F_c), and compression perpendicular to grain ($F_{c\perp}$) are beyond the scope of this practice. When determination of secondary properties is deemed necessary, testing according to other applicable methods, such as Test Methods D 143, D 198 or analysis in accordance with Practice D 3737, is required to establish these secondary properties. Reinforced glulam beams subjected to axial loads are outside the scope of this standard. This practice also provides minimum test requirements to validate the mechanics-based model.

1.5 The values stated in SI units are to be regarded as standard. The mechanics based model may be developed using SI or in.-lb units.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 9 Terminology Relating to Wood and Wood-Based Products

D 143 Test Methods for Small Clear Specimens of Timber

D 198 Test Methods of Static Tests of Lumber in Structural Sizes

D 905 Test Method for Strength Properties of Adhesive Bonds in Shear by Compression Loading

D 1990 Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens

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

Stress Class	Fb *	MOE
• 30F-2.0E	3000	2,000,000
• 32F-2.1E	3200	2,100,000
• 34F-2.1E	3400	2,100,000
• 36F-2.2E	3600	2,200,000

* Volume Effect = 1.0 for all bending stresses

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

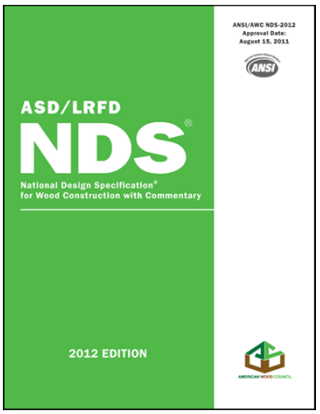
Basic Glulam Design Concepts

- **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 ≤ Allowable stress

$f_b \leq F_b'$

$M / S_x \leq F_b C_D$

LRFD

Factored Load ≤ 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**
- **$F_b' = F_b C_D C_M C_t (C_L \text{ or } C_V)$**
- **$F_v' = F_v C_D C_M C_t$**
- **$E' = E C_M C_t$**

  - **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 x .77 = 1850 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

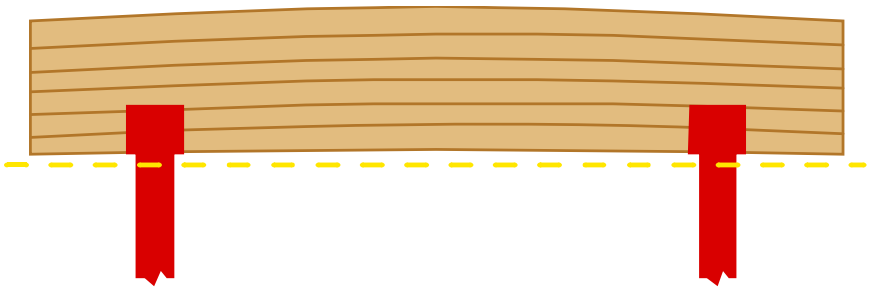
Improper Installation

Unbalanced Layups - "Upside Down" Bending Stresses

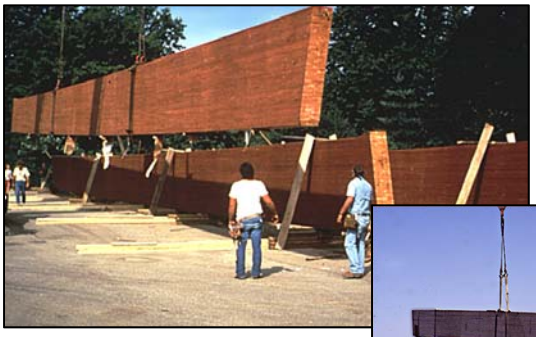
- **Based on full-size beam tests conducted at APA, the "upside down" bending stress is approximately 75% of the regular capacity**

Glulam Camber

- **Glulam can be manufactured to a camber to offset the dead load deflection**
- **Very important for long span members**



Importance of Camber

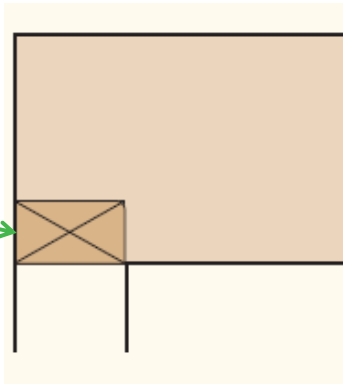


Camber can be 1”- 12” or more depending on span and loads

Notching and Drilling

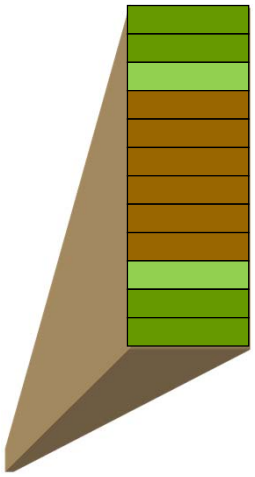
Notching

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

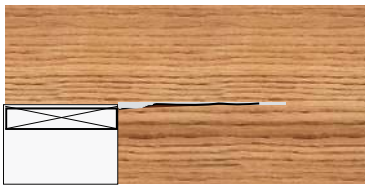
Medium Grade Inner Compression Lam

High Strength Outer Tension Lams

Notching

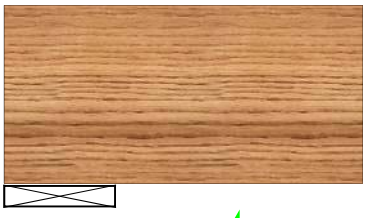
Problem

Tension perpendicular to grain



Solution

Provide full end grain bearing



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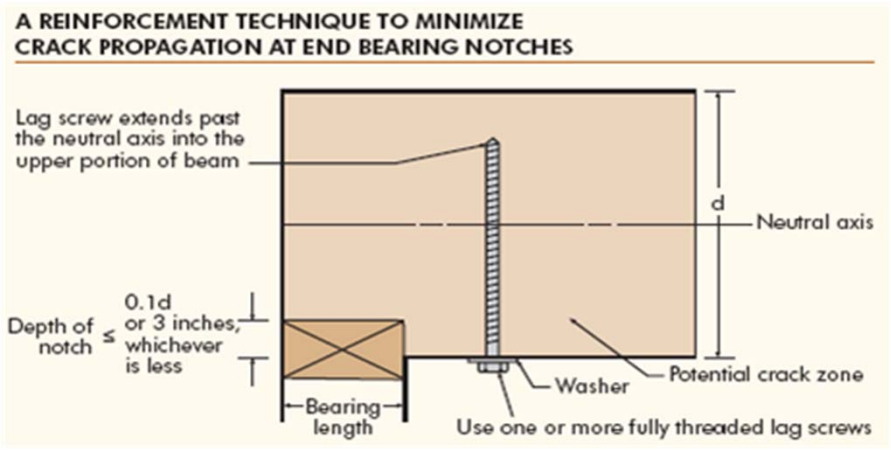
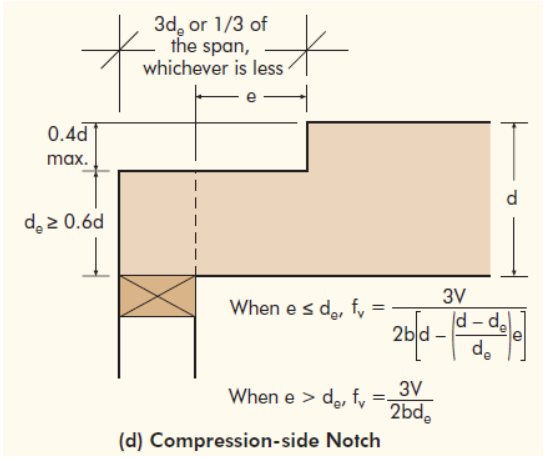
Possible Reinforcement for an End Notch



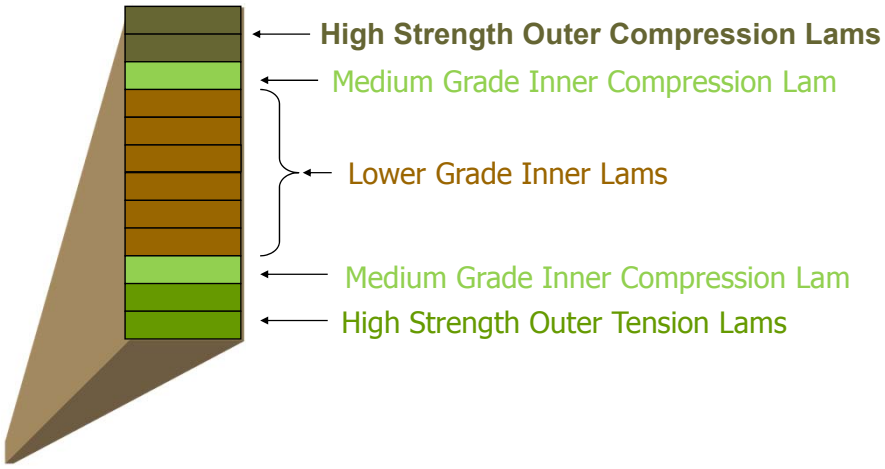
Notching and Drilling

Notching on compression side is generally less severe if beam has an unbalanced layup

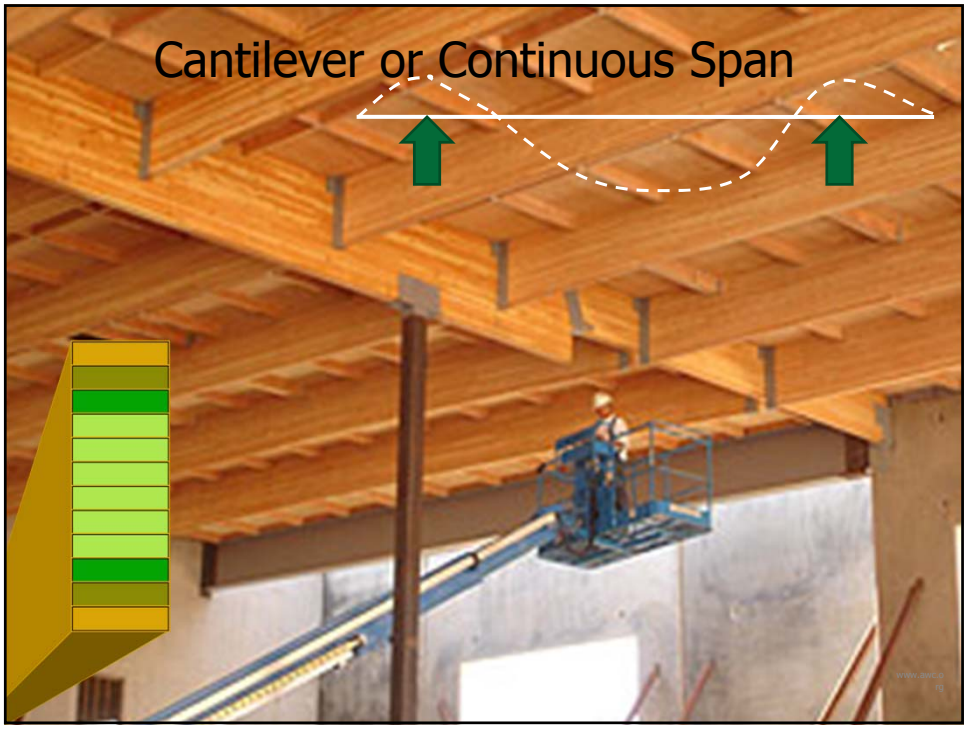


Glulam Lay-Ups

Unbalanced Lay up

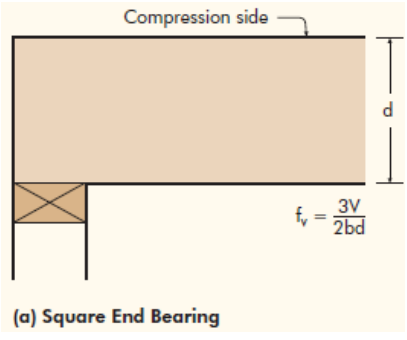


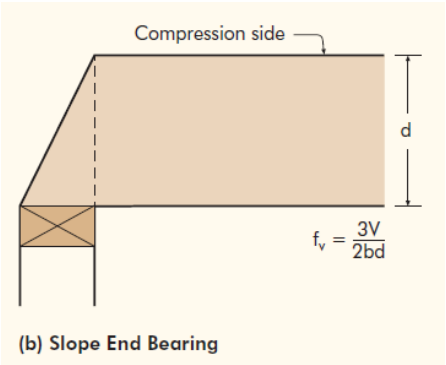
Glulam Manufacturing- Engineered Layups



Notching and Drilling

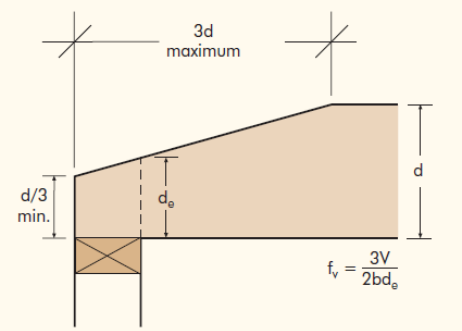
Tapered cut on compression side





Notching and Drilling

Tapered cut on compression side



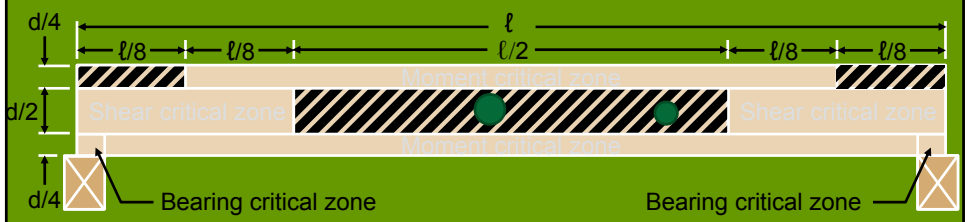
(c) Sloped End Cut for Roof Drainage

Effects of Vertical Holes

- Strength reduction
  = 1.5 x hole diameter/beam width

- Example:
- 6-3/4" beam width
- 1" diameter vertical hole
- Reduction = (1.5 x 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

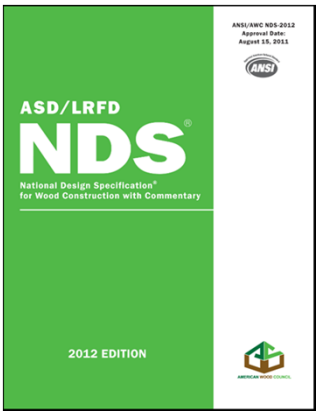
Basic Glulam Design Concepts

- **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**



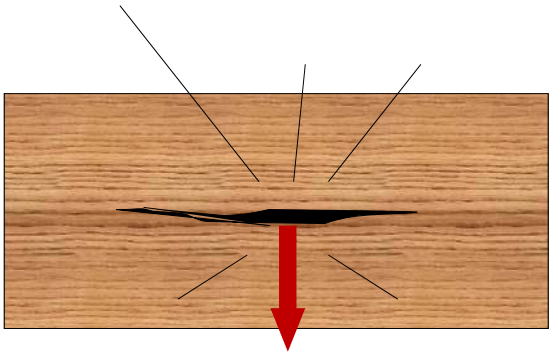
Basic Glulam Design Concepts - Summary

- **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**

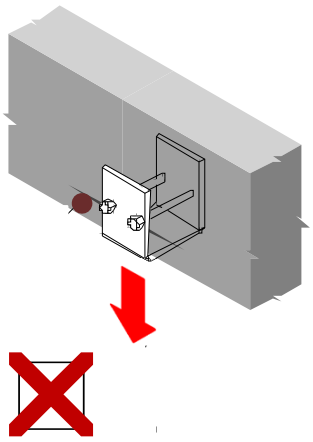
Basic Wood Connection Concepts

Wood and tension perpendicular to grain

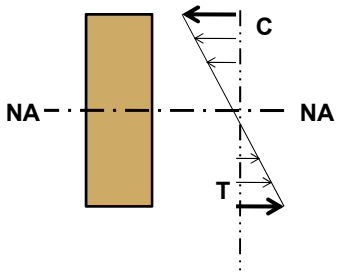
- Initiators:
  - Hanging load
  - Large diameter fastener
  - Restraint by connector detail



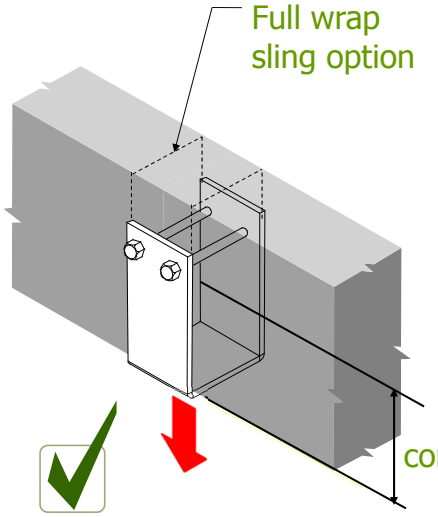
Hanger to Beam



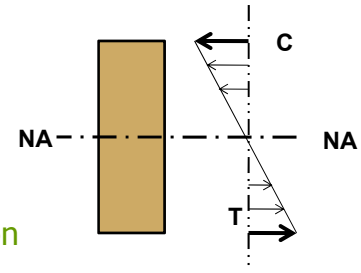
- **Load suspended from lower half of beam**
  - **Tension perpendicular to grain**
  - **May cause splits**



Hanger to Beam



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



Local Stress in Fastener Group

- Closely spaced fasteners
- Brittle failure
- Lower capacity

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

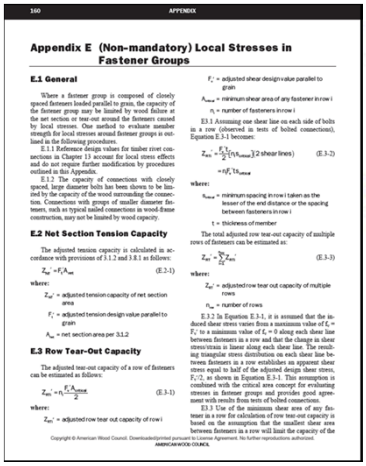
Local Stress in Fastener Group

- Properly spaced fasteners
- Increased ductility
- Higher capacity

- Spread out the fasteners!

Local Stresses in Fastener Groups

Appendix E NDS Expressions



Appendix E (Non-mandatory) Local Stresses in Fastener Groups

E.1 General

Where a fastener group is composed of closely spaced fasteners loaded parallel to grain, the capacity of the fastener group may be limited by wood failure at the net section or tear-out around the fasteners caused by local stresses. One method to evaluate member strength for local stresses around fastener groups is outlined in the following procedures.

E.1.1 Reference design values for timber rivet connections in Chapter 13 account for local stress effects and do not require further modification by procedures outlined in this Appendix.

E.1.2 The capacity of connections with closely spaced, large diameter bolts has been shown to be limited by the capacity of the wood surrounding the connection. Connections with groups of smaller diameter fasteners, such as typical nailed connections in wood-frame construction, may not be limited by wood capacity.

E.2 Net Section Tension Capacity

The adjusted tension capacity is calculated in accordance with provisions of 3.1.2 and 3.8.1 as follows:

$$Z'_{nt} = F'_t A_{nn} \qquad \text{(E.2-1)}$$

where:

Z'_{nt} = adjusted tension capacity of net section area

F'_t = adjusted tension design value parallel to grain

A_{nn} = net section area per 3.1.2

E.3 Row Tear-Out Capacity

The adjusted tear-out capacity of a row of fasteners can be estimated as follows:

$$Z'_{rt} = n_i \frac{F'_v A_{vmin}}{2} \qquad \text{(E.3-1)}$$

where:

Z'_{rt} = adjusted row tear out capacity of row i

F'_v = adjusted shear design value parallel to grain

A_{vmin} = minimum shear area of any fastener in row i

n_i = number of fasteners in row i

E.3.1 Assuming one shear line on each side of bolts in a row (observed in tests of bolted connections), Equation E.3-1 becomes:

$$Z'_{rt} = \frac{F'_v}{2}(t s_{min})(2 \text{ shear lines}) \qquad \text{(E.3-2)}$$

$$= n_i F'_v t s_{min}$$

where:

s_{min} = minimum spacing in row i taken as the lesser of the end distance or the spacing between fasteners in row i

t = thickness of member

The total adjusted row tear-out capacity of multiple rows of fasteners can be estimated as:

$$Z'_{RT} = \sum_{i=1}^{n_{row}} Z'_{rt_i} \qquad \text{(E.3-3)}$$

where:

Z'_{RT} = adjusted row tear out capacity of multiple rows

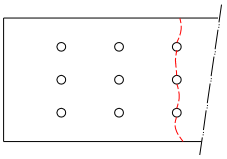
n_{row} = number of rows

E.3.2 In Equation E.3-1, it is assumed that the induced shear stress varies from a maximum value of $f_v = F'_v$ to a minimum value of $f_v = 0$ along each shear line between fasteners in a row and that the change in shear stress/strain is linear along each shear line. The resulting triangular stress distribution on each shear line between fasteners in a row establishes an apparent shear stress equal to half of the adjusted design shear stress, $F'_v/2$, as shown in Equation E.3-1. This assumption is combined with the critical area concept for evaluating stresses in fastener groups and provides good agreement with results from tests of bolted connections.

E.3.3 Use of the minimum shear area of any fastener in a row for calculation of row tear-out capacity is based on the assumption that the smaller shear area between fasteners in a row will limit the capacity of the

Net tension:

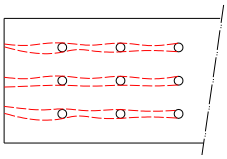
$$Z'_{NT} = F'_t A_{net}$$



Row tear-out:

$$Z'_{RT_i} = n_i F'_v t s_{min}$$

$$Z'_{RT} = \sum_{i=1}^{n_{row}} Z'_{RT_i}$$



Local Stresses in Fastener Groups

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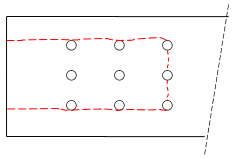
E.3.3 Use of the minimum shear area of any fastener in a row for calculation of row tear-out capacity is based on the assumption that the smaller shear area between fasteners in a row will limit the capacity of the

Group tear-out:



$$Z'_{GT} = \frac{Z'_{RT-top}}{2} + \frac{Z'_{RT-bottom}}{2} + F'_t A_{group-net}$$

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**

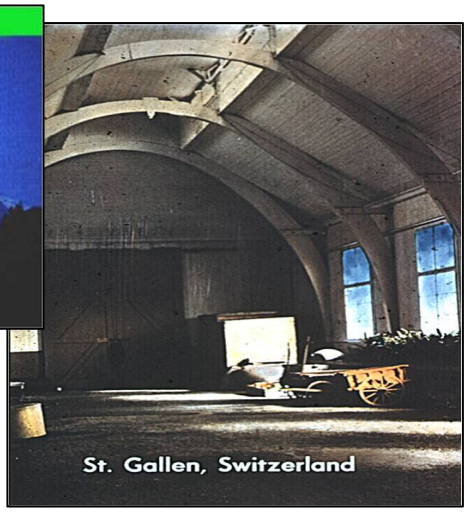
Basic Glulam Design Concepts

- **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



Original U.S. Glulam Structure
USDA Forest Products Laboratory

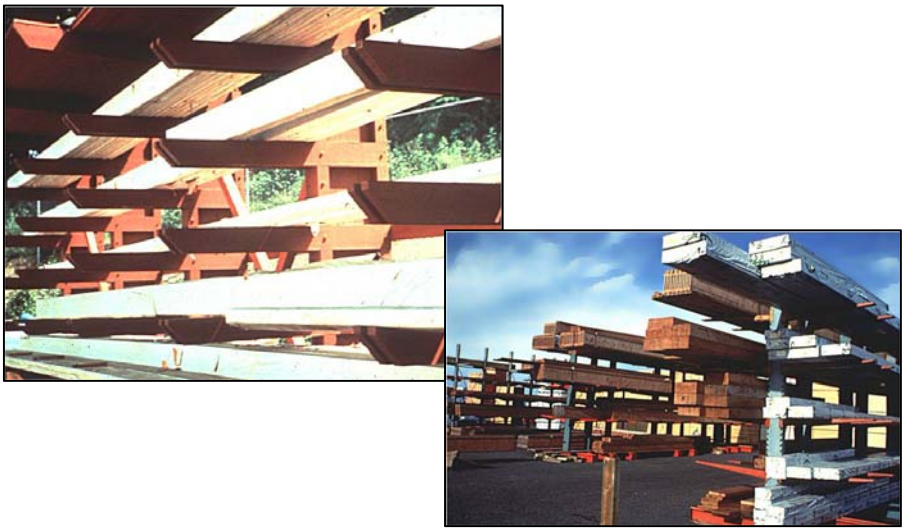
1934

2008

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



Glulam ~~Beams~~ Shipped to Job Site

Interior Applications - Durability Not Typically An Issue

Golf Course Bridge

Pedestrian Bridge - 105 ft. Span

Pedestrian Bridge – 120 ft. span

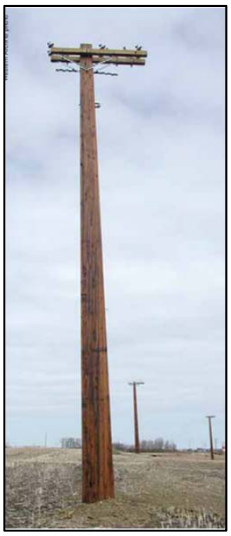
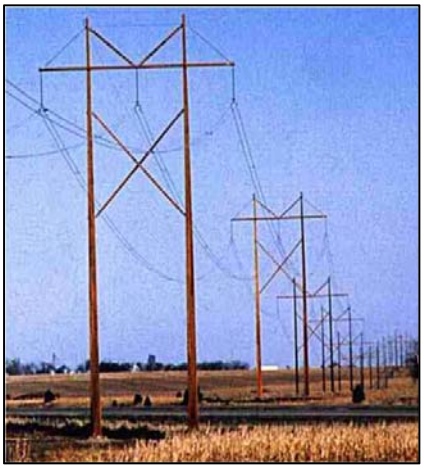
Glulam Arch Highway Bridge Suspended Deck - Colorado

Glulam Arch Highway Bridge Elevated Deck - Michigan

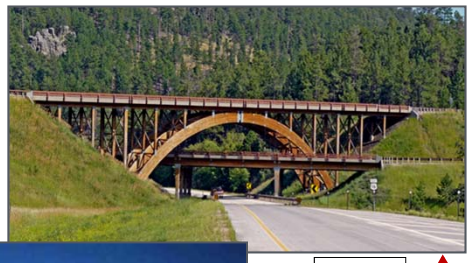
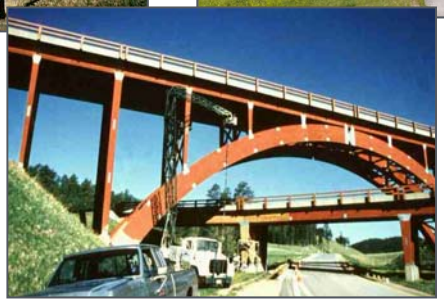
Short Span Glulam RR Girders

100 ft. Span Glulam - Railroad Girders

Glulam Electric Utility Structures


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

Original installation 1968

1980

2009

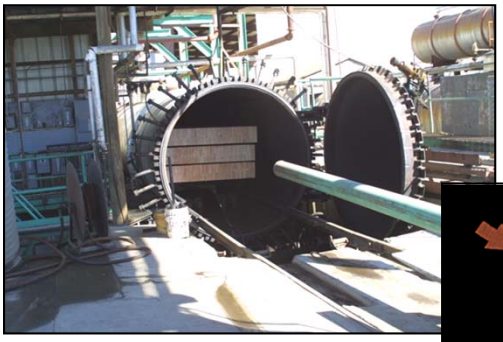
Over 40 years of exposure to the elements

Preservative Treatment of Glulam

U.S. Standards

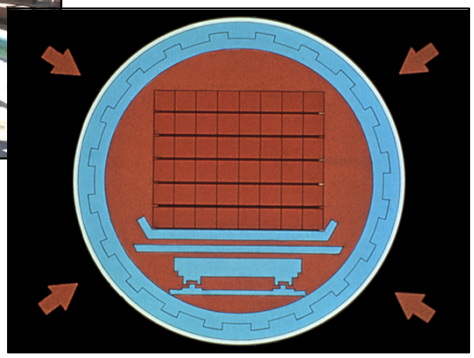
- **American Wood Preservers Standard (AWPA U1)**
  - UC1 Interior, dry — Insects
  - UC2 Interior, wet — Decay and insects
  - UC3 Exterior, above ground — Decay and insects
  - UC4 Ground contact — Decay and insects
  - UC5 Salt water — Salt water organisms
- **American Association of State Highway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

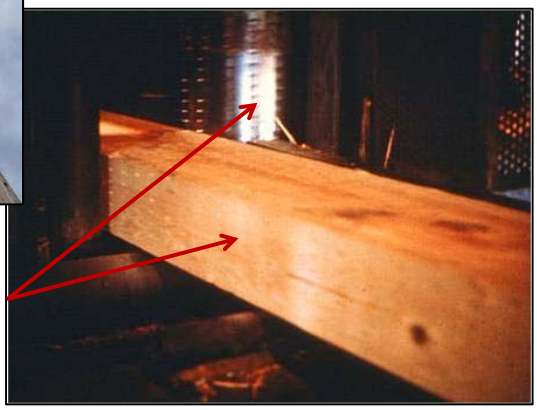


Untreated glulam in pressure cylinder ready for treatment

Preservative forced into wood cells under pressure



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

http://www.anthonyforest.com/pdfs/APA-Preservative-Treatment-of-Glued-Laminted-Timber.pdf

TECHNICAL NOTE

PRESERVATIVE TREATMENT OF GLUED LAMINATED TIMBER

INTRODUCTION

APPLICABLE STANDARDS

APA EWS

Preservative Treatment of Glulam

TABLE 2*

TREATMENT TYPE CHARACTERISTICS

	Creosote	Penta in Oils	Penta in Light Solvents	Copper Naphthenate	Oxine Copper (Cu-8-Q)	Waterborne Preservatives
Suitable Applications	Saltwater or fresh water applications, wood block floors, bridges, towers and ground contact.	Fresh water, above-ground uses, including docks, bridges, towers and beams.		Ground contact and above-ground uses. Should not be used in direct contact with water.	Above-ground use only.	Fresh water applications and ground contact. May be used indoors provided sawdust and construction debris are cleaned up and disposed by ordinary trash collection.
Appearance	Dark, oily odor.	Oily, may be blotchy, may have odor.	Varies from natural appearance of wood to some darkening of wood.	Light green coloration that may diminish during weathering.	Varies from natural appearance of wood to some darkening of wood.	Green to brown depending on chemicals used and exposure to light.
Paintability	Not paintable.	Not practical.	Can be finished with water repellent or oil-based semitransparent stain.	Can be stained or painted after thorough drying.	Can be finished with an oil based stain or paint.	Can be stained or painted when surface is dry and prepared in accordance with coating manufacturer's recommendations.
Comments	Should not be used in residential interiors. May be used in industrial interiors when two coats of effective sealer are applied.	May be used in residential, industrial or commercial interiors as laminated beams or building components that are in ground contact and where two coats of effective sealer are applied.		May develop greenish discoloration of light-colored finishes. Stain-blocking primer or second topcoat is recommended for finishing to minimize potential discoloration by the treatment. Check with supplier for use in high decay hazard applications.	Stain-blocking primer will help to minimize discoloration. May be used in residential interiors where frequent human contact will not occur.	May develop greenish discoloration of finish. Stain-blocking primer will help to minimize discoloration. Surfaces may have raised grain and extensive checking may occur.

Many treatments available for glulam

Preservative Treatment of Glulam

TABLE 3

RECOMMENDED PRESERVATIVE TREATMENTS FOR GLULAM

	Western Species		Southern Pine		Hardwoods	
Treatment Type	Glulam Treated Prior to Gluing	Glulam Treated After Gluing	Glulam Treated Prior to Gluing	Glulam Treated After Gluing	Glulam Treated Prior to Gluing	Glulam Treated After Gluing
Creosote	No[2]	Yes	No[2]	Yes	No	Yes
Oil-borne Penta	No[3]	Yes	No[3]	Yes	No	No
Copper Naphthenate	No[2]	Yes	No[2]	Yes	No	No
Cu-8-Q[1]	No[2]	No[4]	Yes	Yes	No	No
CCA	No[2]	No	Yes	No	No	No
ACZA	No[2]	No[2]	Yes	No	No	No
ACC	No	No	Yes	No	No	No
ACQ-C	No[2]	No	Yes	No	No	No

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.

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

Preservative Treatment of Glulam

TABLE 5

PRESERVATIVE RETENTIONS (pcf): GLULAM MEMBERS (Treated after gluing)

USE CATEGORY	Preservative System						
	Creosote			PCP-A			
Species	CR	CR-S	CR-PS	PCP-C	Cu-8-Q	CuN	ACZA
UC1, UC2, UC3B							
Southern Pine	8.0	8.0	8.0	0.3	0.02	0.4	—[1,2]
Coastal Douglas-fir	8.0	8.0	8.0	0.3	—[1,2]	0.4	0.3[2]
Western Hemlock, Hem-fir	8.0	8.0	8.0	0.3	0.02	0.4	—[1,2]
Red Oak	7.0	7.0	7.0	—[1,2]	—[1,2]	—[1,2]	—[1,2]
Red Maple, Yellow Poplar	8.0	8.0	8.0	—[1,2]	—[1,2]	—[1,2]	—[1,2]
UC4A							
Southern Pine	10.0	10.0	10.0	0.6	—[1]	0.06	—[1,2]
Coastal Douglas-fir	10.0	10.0	10.0	0.6	—[1,2]	0.06	0.6[2]
Western Hemlock, Hem-fir	10.0	10.0	10.0	0.6	—[1]	0.06	—[1,2]
Red Oak	8.5	8.5	8.5	—[1,2]	—[1,2]	—[1,2]	—[1,2]
Red Maple, Yellow Poplar	10.0	10.0	10.0	—[1,2]	—[1,2]	—[1,2]	—[1,2]
UC4B, UC4C: See Table 7 (Glulam Poles).							

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

Retention levels must be met

Preservative Treatments

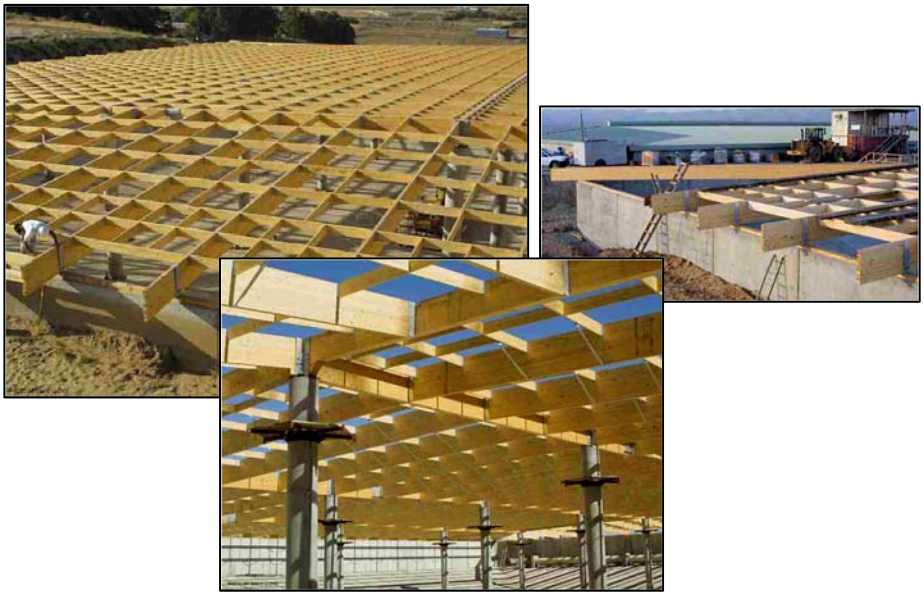
- **Considerations for preservative treatments**
  - **Incising may be required for some hard to treat species**
  - **Fastener corrosion may occur with some waterborne arsenical treatments – use hot dipped galvanized or stainless steel connectors**
  - **Field cuts require field applied treatments**
  - **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

Alaska Yellow Cedar
Santa Monica, CA Reservoir Cover



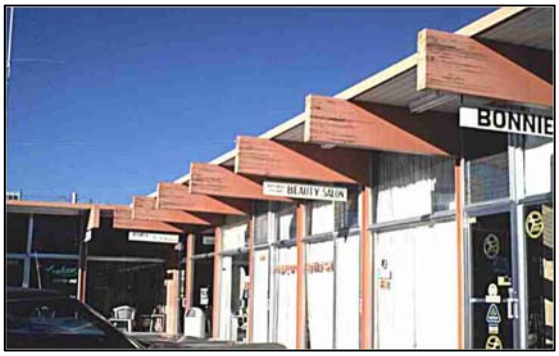
Connection Serviceability Issues

- **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



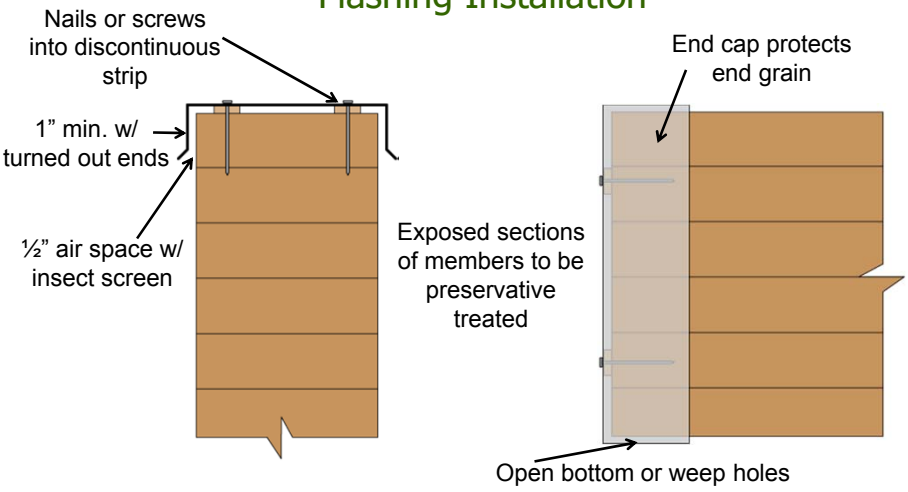
Connection Serviceability

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

End caps and flashing used

Connection Serviceability

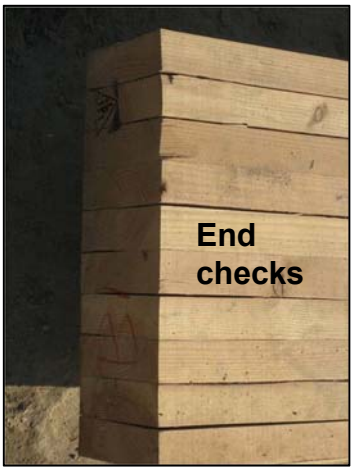
Flashing Installation



Effects of Moisture

- End grain checking
- Is it of structural concern?

Examples of Checking



Delamination and Checking?

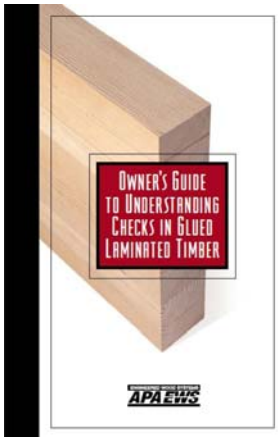
- **Checking is a natural phenomena associated with natural drying of the glulam**
- **Delamination is a deterioration of the glue bond when exposed to moisture**
- **The introduction of wet-use (durable) adhesives in the mid 1940's virtually eliminated delamination in the U.S.**
- **This is assured 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

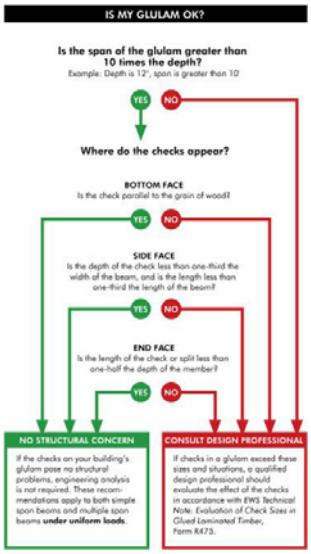
Checking

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



Checking Test Program

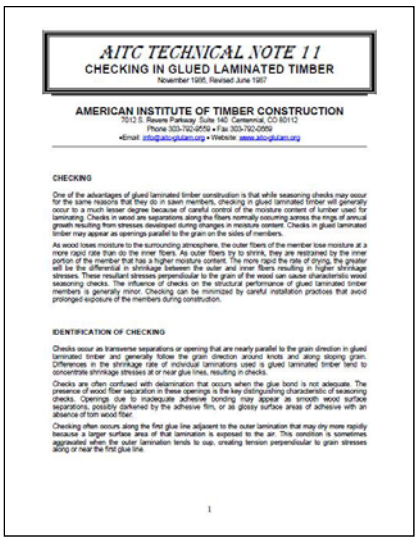
- **Guidelines established for what size checks are OK without an engineering analysis**
- **Published in an Owners Guide to Checking**
- **One of APA's most widely used publications**



Checking

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

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



AITC TECHNICAL NOTE 11
CHECKING IN GLUED LAMINATED TIMBER
November 1995, Revised June 1997

AMERICAN INSTITUTE OF TIMBER CONSTRUCTION
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CHECKING

One of the advantages of glued laminated timber construction is that while seasoning checks may occur for the same reasons that they do in sawn members, checking in glued laminated timber will generally occur to a much lesser degree because of careful control of the moisture content of lumber used for laminating. Checks in wood are separations along the fibers normally occurring across the rings of annual growth resulting from stresses developed during changes in moisture content. Checks in glued laminated timber may appear as openings parallel to the grain on the sides of members.

As wood loses moisture to the surrounding atmosphere, the outer fibers of the member lose moisture at a more rapid rate than do the inner fibers. As outer fibers try to shrink, they are restrained by the inner portion of the member that has a higher moisture content. The more rapid the rate of drying, the greater will be the differential in shrinkage between the outer and inner fibers resulting in higher shrinkage stresses. These resultant stresses perpendicular to the grain of the wood can cause characteristic wood seasoning checks. The influence of checks on the structural performance of glued laminated timber members is generally minor. Checking can be minimized by careful installation practices that avoid prolonged exposure of the members during construction.

IDENTIFICATION OF CHECKING

Checks occur as transverse separations or opening that are nearly parallel to the grain direction in glued laminated timber and generally follow the grain direction around knots and along sloping grain. Differences in the shrinkage rate of individual laminations used is glued laminated timber tend to concentrate shrinkage stresses at or near glue lines, resulting in checks.

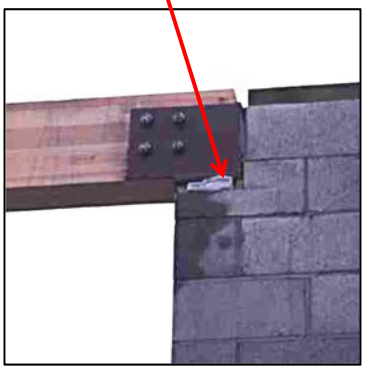
Checks are often confused with delamination that occurs when the glue bond is not adequate. The presence of wood fiber separation in these openings is the key distinguishing characteristic of seasoning checks. Openings due to inadequate adhesive bonding may appear as smooth wood surface separations, possibly darkened by the adhesive film, or as glossy surface areas of adhesive with an absence of torn wood fiber.

Checking often occurs along the first glue line adjacent to the outer lamination that may dry more rapidly because a larger surface area of that lamination is exposed to the air. This condition is sometimes aggravated when the outer lamination tends to sup, creating tension perpendicular to grain stresses along or near the first glue line.

1

Glulam to Masonry

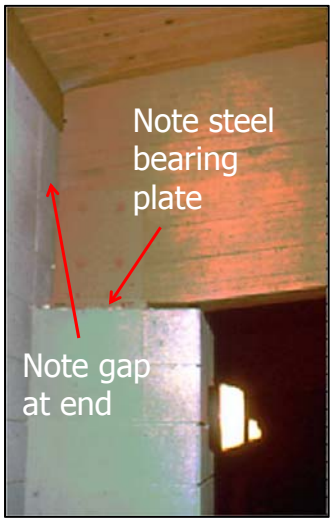
Grout used at bearing



No air space

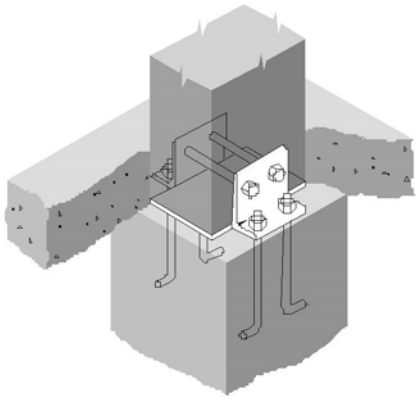
Need 1/2” air gap between wood and masonry

Glulam to Masonry



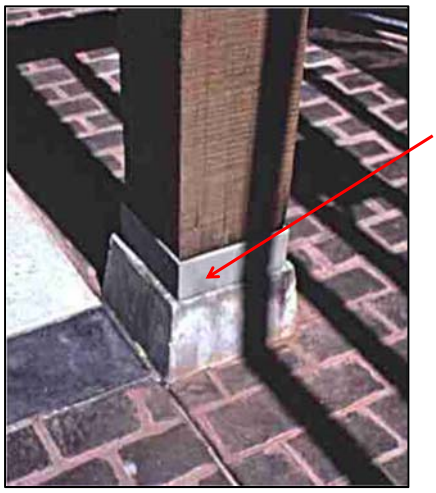
- **Prevent contact with masonry**
- **Use bearing plate under beam**
- **Maintain air gap at end**

Buried Column Base



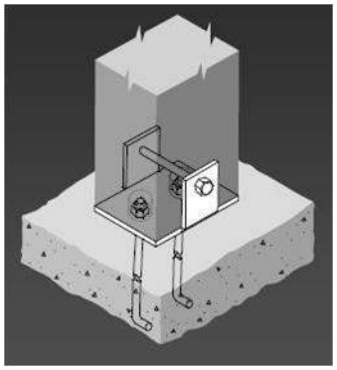
- **Floor slab poured over connection**
  - **Can cause decay due to moisture entrapment**
  - **Not recommended**

Column to Base

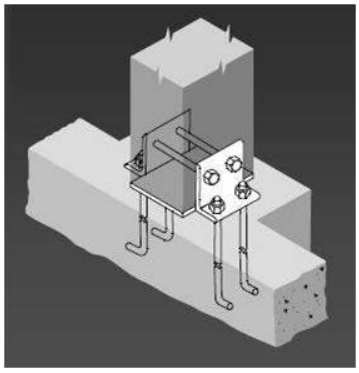


- **Problem**
  - **No weep holes in closed shoe**
  - **Moisture entrapped**
  - **Decay inevitable**

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

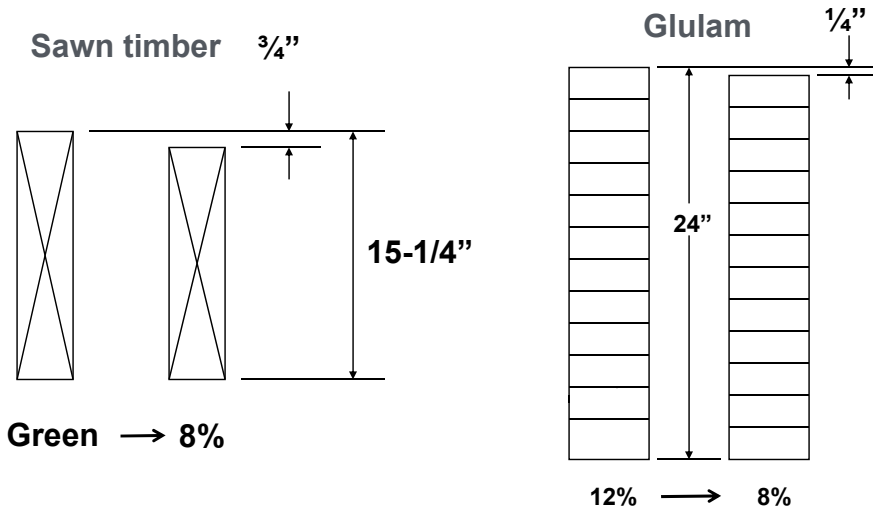
Arch Base to Support

Note flashing on top of glulam

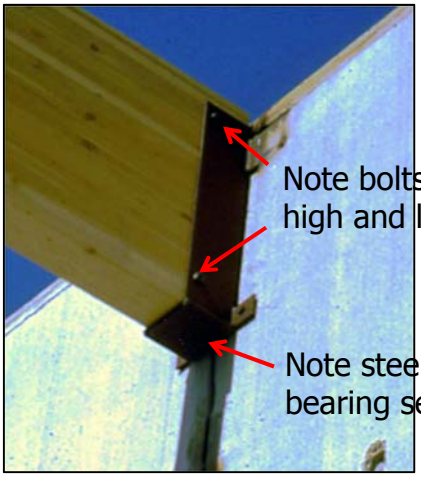
Note open shoe allowing water to drain

Arch Base to Support

Effects of Moisture Changes on Connections



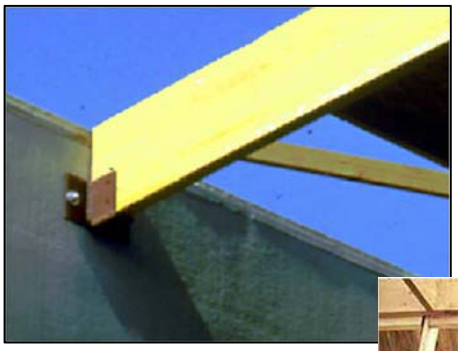
Glulam Beam End Bearing



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

Glulam Beam End Bearing

Glulam Beam End Bearing

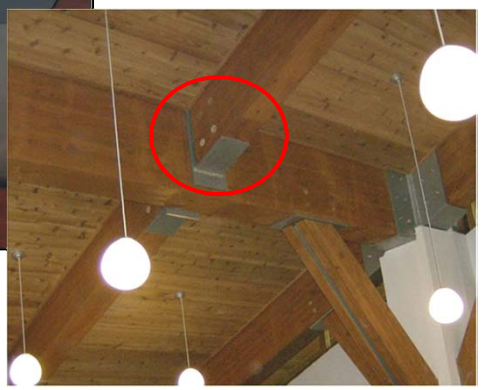


- **Solution: allow shrinkage to occur without inducing tension perp stresses**

Slotted holes

Importance of Detailing

?



Importance of Detailing

Importance of Detailing

Importance of Detailing

Elevated bearing

Importance of Detailing

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 503

		TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
GROUP	HGT (S) HGT (feet)	UL	160	65	55	65	55	65	50	40
B	S A									

- **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**

Fire Protection

Maximum Allowable Total Areas (ft^2)[(a)(b)(c)]			
Stories	Building Type		
	III-A	IV-A	V-A
1	111,625	121,125	87,875
2	88,125	95,625	69,375
3	88,125	95,625	Not Permitted
4	88,125	95,625	Not Permitted

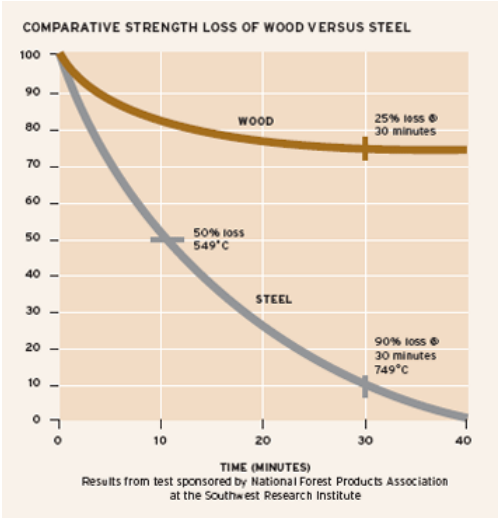
(a) Occupancy - Education
(b) Based on 4 side frontage and sprinkler area increases in IBC
(c) All square feet per floor

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%20fire%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**
    $t = 2.54Zb [4 – b/d]$
- **Beams exposed on 4 sides**
  $t = 2.54Zb [4 – 2b/d]$
  - **b = beam width**
  - **d = beam depth**
  - **t = fire resistance in minutes**
  - **Z = load compensation factor**
    = applied load / design capacity

IBC Methodology

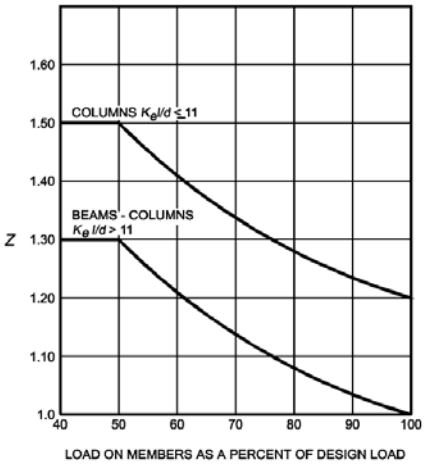
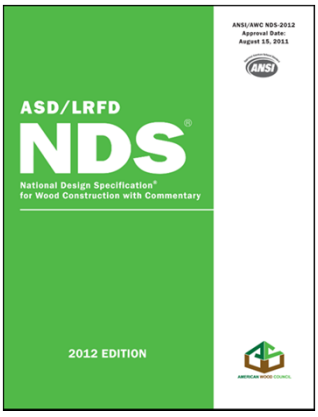


FIGURE 722.6.3(1)
LOAD FIGURE

K_e = the effective length factor
L = 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)**
- **Fb x 2.85 ≥ calculated induced stress**

2012 NDS Methodology

Table 16.2.2 Adjustment Factors for Fire Design

			ASD					
			Design Stress to Member Strength Factor	Size Factor [2]	Volume Factor [2]	Flat Use Factor [2]	Beam Stability Factor [3]	Column Stability Factor [3]
Bending Strength	F_b	x	2.85	C_F	C_V	C_{fu}	C_L	-
Tensile Strength	F_t	x	2.85	C_F	-	-	-	-
Compression Strength	F_c	x	2.58	C_F	-	-	-	C_P
Beam Buckling Strength	F_{bE}	x	2.03	-	-	-	-	-
Column Buckling Strength	F_{cE}	x	2.03	-	-	-	-	-

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

2012 NDS Methodology

$$\beta_{eff} = \frac{1.2\beta_n}{t^{0.187}}$$

Where:

b_{eff} = Effective char rate (in./hr), adjusted for exposure time, t

b_n = Nominal char rate (1.5 in./hr)

t = Exposure time (hr)

2012 NDS Methodology

t	b_{eff}
1 hr	1.8 in./hr (45.7 mm/hr)
1 ½ hr	1.67 in./hr (42.4 mm/hr)
2 hr	1.58 in./hr (40.1 mm/hr)

Fire Rated Glulam

TABLE 4

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

Beam Width (in.)	Depth 3 Sides Exposed (in.)	Depth 4 Sides Exposed (in.)
6-3/4	13-1/2	27
8-3/4	7-1/2	13-1/2

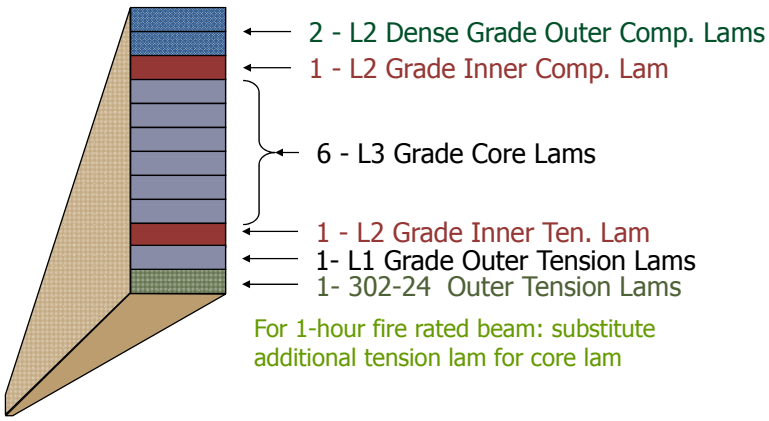
TABLE 5

MINIMUM DEPTHS AT WHICH 8-3/4" AND 10-3/4" COLUMN WIDTHS QUALIFY FOR ONE-HOUR RATING FOR GIVEN ℓ/D

ℓ/d Criteria	Column Width (in.)	Depth 3 Sides Exposed (in.)	Depth 4 Sides Exposed (in.)
$\ell/d > 11$	10-3/4	10-1/2	13-1/2
$\ell/d \leq 11$	8-3/4	7-1/2	12
	10-3/4	7-1/2	10-1/2

Typical Glulam Beam Layup

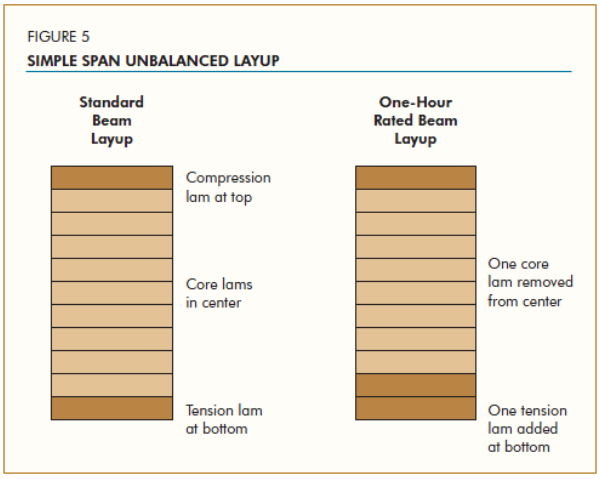
- **24F-V4 Doug Fir (12 Lamination Example)**



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

Tension Lam Provisions

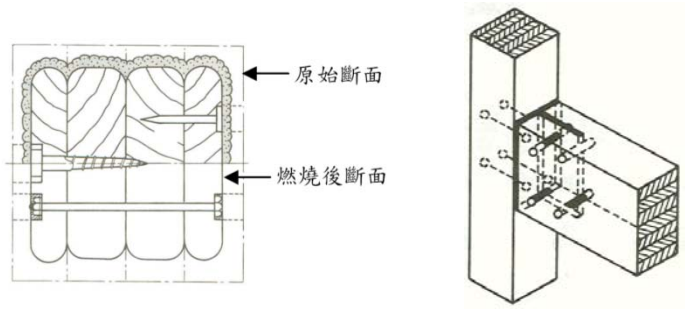
Fire Protection



Fire Rated Glulam

- **16.3 Wood Connections-**
  - **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

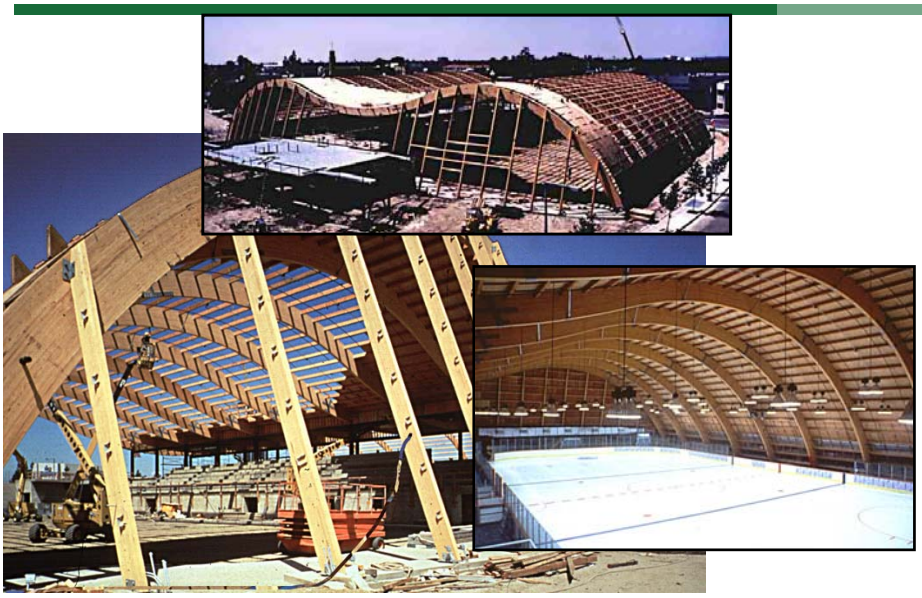
Office Building in Portland, OR

Airport Terminal - Victoria, B.C.

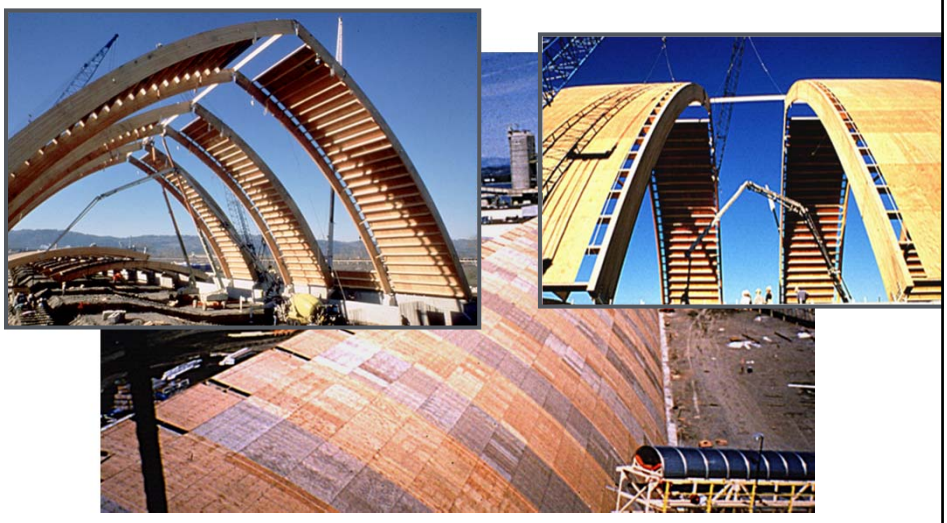
Light Rail Transit Center - Vancouver, B.C.

Chicago Bears Football Practice Facility

Twin Rink Ice Arena - Anaheim, CA.

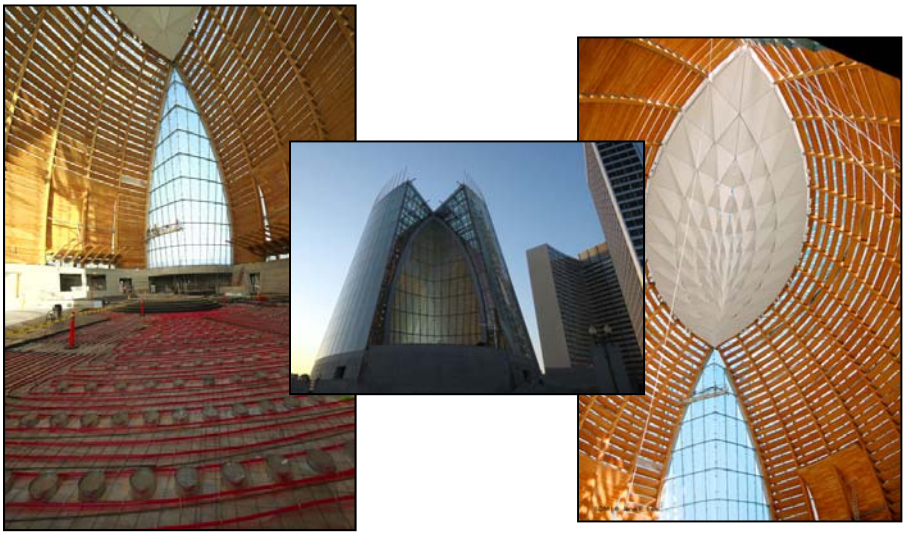


Chemical Storage Facility - Portland, OR

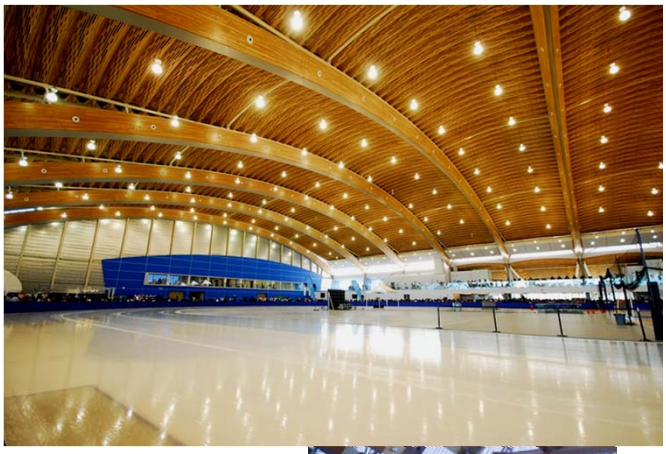


Cathedral of Light

Cathedral of Light - Oakland, CA



Olympic Skating Oval - Richmond, B.C.

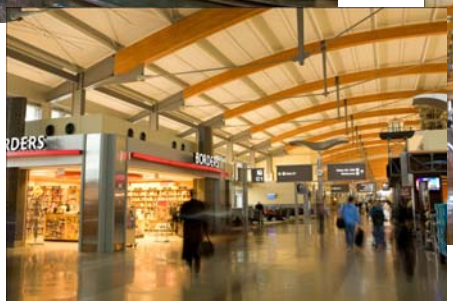


Glulam for Office Buildings

Microsoft Campus

Nike Pedestrian Bridge

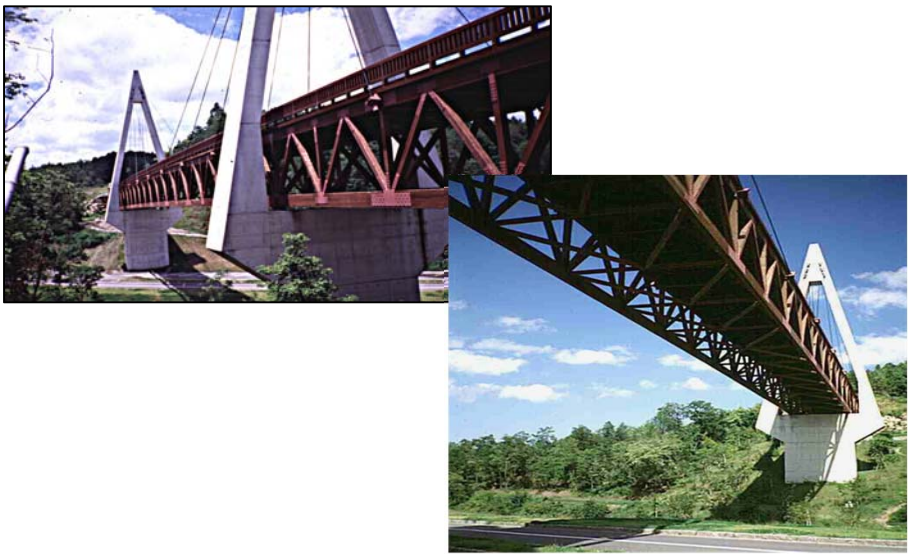
Raleigh Durham Airport



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