Designation: D7199 – 20

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 D7199; 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 describes procedures for establishing the characteristic values for reinforced structural glued-laminated timber (glulam) beams using mechanics-based models and validated by full-scale beam tests. Glulam beams shall be manufactured in accordance with applicable provisions of ANSI A190.1.

1.2 This practice also describes a minimum set of performance-based durability test requirements for reinforced glulam beams, as specified in Annex A1. Additional durability test requirements shall be considered in accordance with the specific end-use environment. Appendix X1 provides an example of a mechanics-based methodology that satisfies the requirements set forth in this practice.

1.3 This practice is limited to procedures for establishing flexural properties (modulus of rupture, MOR, and modulus of elasticity, MOE) about the x-x axis of horizontally-laminated reinforced glulam beams.

1.4 The establishment of secondary properties, such as bending about the y-y axis, shear parallel to grain, tension parallel to grain, compression parallel to grain, and compression perpendicular to grain, for the reinforced glulam beams are beyond the scope of this practice.

NOTE 1—When the establishment of secondary properties is deemed necessary, testing according to other applicable methods, such as Test Methods D143 and D198 or analysis in accordance with Practice D3737, may be considered.

1.5 Reinforced glulam beams subjected to axial loads are outside the scope of this practice.

1.6 Proper safety, serviceability, and adjustment factors including duration of load, to be used in design are outside the scope of this practice.

1.7 Evaluation of unbonded, prestressed, and shear reinforcement is outside the scope of this practice.

1.8 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard. The mechanics-based model shall be permitted to be developed using SI or inch-pound units.

1.9 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D9 Terminology Relating to Wood and Wood-Based Products

D143 Test Methods for Small Clear Specimens of Timber

D198 Test Methods of Static Tests of Lumber in Structural Sizes

D905 Test Method for Strength Properties of Adhesive Bonds in Shear by Compression Loading

D1990 Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens

D2559 Specification for Adhesives for Bonded Structural Wood Products for Use Under Exterior Exposure Conditions

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[1] This practice is under the jurisdiction of ASTM Committee D07 on Wood and is the direct responsibility of Subcommittee D07.02 on Lumber and Engineered Wood Products.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products

D3039/D3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials

D3410/D3410M Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading

D3737 Practice for Establishing Allowable Properties for Structural Glued Laminated Timber (Glulam)

D4761 Test Methods for Mechanical Properties of Lumber and Wood-Based Structural Materials

D5124 Practice for Testing and Use of a Random Number Generator in Lumber and Wood Products Simulation

2.2 *Other Standard:*

ANSI A190.1 Structural Glued Laminated Timber[3]

3. Terminology

3.1 *Definitions*—Standard definitions of wood terms are given in Terminology D9 and standard definitions of structural glued laminated timber terms are given in Practice D3737.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bonded reinforcement*—reinforcing material that is continuously attached to a glulam beam through adhesive bonding.

3.2.2 *bumper lamination*—wood lamination continuously bonded to the outer side of reinforcement.

3.2.3 *compressive reinforcement*—reinforcement placed on the compression side of a flexural member.

3.2.4 *conventional wood lamstock*—solid sawn wood laminations with a net thickness of 2 in. or less, graded either visually or through mechanical means, finger-jointed and face-bonded to form a glulam.

3.2.5 *development length*—length of the bond line along the axis of the beam required to develop the design tensile strength of the reinforcement.

3.2.6 *fiber-reinforced polymer (FRP)*—composite material consisting of at least two distinct components: reinforcing fibers and a binder matrix (a polymer).

3.2.6.1 *Discussion*—The reinforcing fibers may be either synthetic (for example, glass), metallic, or natural (for example, wood), and may be long and continuously-oriented, or short and randomly oriented. The binder matrix may be either thermoplastic (for example, polypropylene or nylon) or thermosetting (for example, epoxy or vinyl-ester).

3.2.7 *laminating effect*—apparent increase of lumber lamination tensile strength because it is bonded to adjacent laminations within a glulam beam.

3.2.7.1 *Discussion*—This apparent increase may be attributed to a redirection of stresses around knots and grain deviations through adjacent laminations.

3.2.8 *partial length reinforcement*—reinforcement that is terminated within the length of the glulam.

3.2.9 *reinforcement*—lamination or material that is not a conventional wood lamstock and having a mean longitudinal ultimate tensile and compressive strength greater than 20 ksi (138 MPa) and a mean tension and compression MOE greater than 3000 ksi (20.7 GPa).

3.2.9.1 *Discussion*—Examples of acceptable reinforcing materials include fiber-reinforced polymer (FRP) plates and bars, metallic plates and bars, FRP-reinforced laminated veneer lumber (LVL), and FRP-reinforced parallel strand lumber (PSL).

3.2.10 *tensile reinforcement*—reinforcement placed on the tension side of a flexural member.

3.3 *Symbols:*

Arm = moment arm, distance between compressive and tensile force couple applied to beam cross-section

b = beam width

C = total internal compressive force within the beam cross-section (see Fig. A2.2)

$CFRP$ = carbon fiber reinforced polymer

d = beam depth

E = long-span flatwise-bending modulus of elasticity for wood lamstock (Test Methods D4761; also see Fig. A2.1)

F_b = allowable bending stress parallel to grain

F_x = internal horizontal force on the beam cross-section (see Eq A2.2)

$GFRP$ = Glass fiber-reinforced polymer

LTL = lower tolerance limit with 75 % confidence

$M_{applied}$ = external moment applied to the beam cross-section

$M_{internal}$ = internal moment on the beam cross-section

MC = moisture content (%)

MOE = modulus of elasticity

MOR = modulus of rupture

$MOR_{5\,\%}$ = 5 % one-sided lower tolerance limit for modulus of rupture, including the volume factor

$MOR_{BL5\,\%}$ = 5 % one-sided lower tolerance limit for modulus of rupture corresponding to failure of the bumper lamination, including the volume factor

$m{*}E$ = downward slope of bilinear compression stress-strain curve for wood lamstock (see Fig. A2.1)

$N.A.$ = neutral axis

T = total internal tensile force within the beam cross-section (see Fig. A2.2)

UCS = ultimate compressive stress parallel to grain

UTS = ultimate tensile stress parallel to grain

Y = distance from extreme compression fiber to neutral axis (see Fig. A2.2)

y = distance from extreme compression fiber to point of interest on beam cross-section (see Fig. A2.2)

ε_c = strain at extreme compression fiber of beam cross-section (see Fig. A2.2)

ε_{cult} = compressive strain at lamstock failure (see Fig. A2.1)

ε_{cy} = compressive yield strain at lamstock UCS (see Fig. A2.1)

ε_{tult} = tensile strain at lamstock failure (see Fig. A2.1)

$\varepsilon(y)$ = strain distribution through beam depth (see Fig. A2.2)

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[3] Available from APA – The Engineered Wood Association, 7011 South 19th Street, Tacoma, WA 98466, http://www.apswood.org.

ρ = tensile reinforcement ratio (%); cross-sectional area of tensile reinforcement divided by cross-sectional area of beam between the center of gravity of tensile reinforcement and the extreme compression fiber

ρ' = compressive reinforcement ratio (%); cross-sectional area of compressive reinforcement divided by cross-sectional area of beam between the center of gravity of compressive reinforcement and the extreme tension fiber

σ(*y*) = stress distribution through beam depth (see Fig. A2.2)

4. Modeling Requirements

4.1 *General:*

4.1.1 *Purpose for Modeling*—Characteristic values for the flexural properties about the x-x axis of horizontally-laminated reinforced glulam beams shall be established through the use of an analytical model. The establishment of flexural properties using full-scale beam tests is outside the scope of this practice.

4.1.2 *Mechanics-Based Models*—Models used to develop new combinations and predict characteristic values shall be able to predict accurately these values for a broad range of combinations and validated by full-scale tests according to Section 5.

4.2 *Minimum Model Inputs*—Any numerical solution methodology shall be permitted for use, so long as it incorporates the nonlinearities in mechanical properties for wood and reinforcement as specified in A2.1 and satisfies the conditions of strain compatibility (A2.2), and equilibrium (A2.3). In addition, the mechanics-based analysis shall account for variability of mechanical properties, volume effects, finger-joint effects, laminating effects, and stress concentrations at termination of reinforcement in beams with partial length reinforcement.

NOTE 2—These analysis input requirements are described in detail in Annex A2.

4.3 *Minimum Model Analyses:*

4.3.1 *Bending Strength*—The model shall predict the lower 5 % tolerance limit (LTL) for modulus of rupture ($MOR_{5\ \%}$) for the reinforced layup being analyzed. The model-predicted bending strength characteristic values $MOR_{5\ \%}$ shall include the volume effect. Beam MOR shall be based on gross (full width and depth) cross-sectional properties.

4.3.2 *Bending Stiffness*—The model shall predict the mean modulus of elasticity (MOE) for the reinforced layup being analyzed. Beam MOE shall be based on gross (full width and depth) cross-sectional properties.

4.3.3 *Bumper Lamination*—If a bumper lamination is to be used, the characteristic bending strength value $MOR_{BL5\ \%}$ corresponding to bumper lamination failure shall also be calculated and reported. In addition, the beam stiffness properties before and after failure of the bumper lamination shall be calculated and reported.

NOTE 3—See Appendix X1 for example calculations.

NOTE 4—A bumper lamination, if used, will likely fail prior to reaching the ultimate capacity of the reinforced beam. In tests of GFRP-reinforced glulam with 1.1 % to 3.3 %, the bumper lam failure load was typically 10–20 % below the ultimate strength. This range will differ depending on the reinforcement type, reinforcement ratio, beam layup, and grade of the bumper lamination.

4.4 *Secondary Properties:*

4.4.1 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 ($F_{c\perp}$) shall be permitted to be determined following methods described in Practice D3737.

NOTE 5—Analysis has shown that with the level of FRP extreme fiber tensile reinforcement typically envisioned (up to 3 % GFRP or 1 % CFRP), the maximum shear stress at the reinforced beam neutral axis is very similar to that of an unreinforced rectangular section. In addition, under the same conditions, the shear stress at the FRP-wood interface is always significantly smaller than the shear stress at the reinforced beam neutral axis.

5. Model Validation Testing Requirements

5.1 *Test Method*—Tests for flexural strength and modulus of elasticity shall be conducted in accordance with Test Methods D198 or D4761. If Test Methods D4761 is used, the load rate shall be modified to be in accordance with Test Methods D198. Specimens shall be tested under dry-service conditions where the moisture content of the wood, excluding non-wood reinforcement, is 12 ± 3 %. The temperature of the test specimens shall not be less than 50°F (10°C) nor more than 90°F (32°C) at the time of the tests.

5.2 *Sampling Requirements*—Mechanics-based models which satisfy the requirements set forth in this standard shall be validated through physical testing as shown in Tables 1 and 2. The sample size shall be large enough to provide the standard error of the sample less than 10 % of the 5 % LTL of MOR, but not less than 10 beams for each size/reinforcement ratio. Six sample sets shall be tested using a primary wood species (Table 1) equating to a minimum of 60 beams, and two sample sets shall be tested for each additional wood species (Table 2) equating to a minimum of 20 beams.

6. Analysis and Applicability of Test Results

6.1 *Failure Modes*—Each failed specimen shall be inspected to determine the failure mode(s). The location and type (end joint, lumber, shear, tension, compression, etc.) of observed failures shall be documented and compared to the model. Lamination characteristics influencing failure shall be noted.

TABLE 1 Initial Qualification Using Primary Species: DF, SP, or SPF—Minimum Beam Test Matrix for Mechanics-Based Model Validation[A,B]

Beam Size	Number of Beam Tests		
	Min[C]	Typical[C]	Max[C]
5⅛ in. by 12 in. by 21 ft (130 mm by 305 mm by 6.40 m)	10	10	10
6¾ in. by 24 in. by 42 ft (171 mm by 610 mm by 12.8 m)	10	10	10

[A] All beams shall use the same layup, species, reinforcement type, and wood lam thickness.

[B] A larger set shall be required if the Standard Error is greater than 0.1 × 5 % LTL. See Practice D2915 for determining the minimum sample size.

[C] See Table 3. The model shall only be considered valid for ρ within the tested minimum and maximum.