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Design Requirements and Bending Properties for Mechanically Laminated Columns

American Society of Agricultural Engineers

STANDARD

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Developed by the ASAE Mechanically Laminated Post Design Subcommittee of the Structures Group; approved by the Structures and Environment Division Standards Committee; adopted by ASAE December 1996; approved as an American National Standard February 1997; reaffirmed by ANSI February 2003; reaffirmed by ASAE February 2003.

1 Purpose and scope

1.1 The purpose of this Engineering Practice is to establish guidelines for designing and calculating allowable bending properties of mechanically laminated columns used as structural members in wood construction.

1.2 The scope of this Engineering Practice is limited to mechanically laminated columns with three or four laminations that have the following characteristics:

1.2.1 The actual thickness of each lamination is between 38 and 51 mm (1.5 and 2.0 in.).

1.2.2 All laminations have the same depth (face width), d.

1.2.3 Faces of adjacent laminations are in contact.

1.2.4 The centroid of each lamination is located on the centroidal axis of the post (axis Y-Y in figure 1a), that is, no laminations are offset.

1.2.5 Concentrated loads are distributed to the individual laminations by a load distributing element.

1.2.6 All laminations are of the same grade and species of lumber.

1.2.7 There is no more than one end joint per lamination.

1.3 The provisions of this Engineering Practice do not apply to columns being designed for biaxial bending. The design requirements in clause 4, and allowable bending properties in clauses 5 and 6, are only for uniaxial bending about axis Y-Y (figure 1a). Spliced columns with butt joints shall have sufficient lateral support to prevent out-of-plane (lateral) movement or buckling, and/or delamination in the splice region.

1.4 This Engineering Practice does not preclude the use of column designs not meeting the criteria in clauses 1.2 and 1.3.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Engineering Practice. At the time of publication, the editions were valid. All standards are subject to revision, and parties to agreements based on this Engineering Practice are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Standards organizations maintain registers of currently valid standards.

AF&PA (1991), *National Design Specification (NDS) for Wood Construction*
ANSI/AITC A190.1, *Structural Glued Laminated Timber*
ANSI/TPI 1-1995, *National Design Standard for Metal Plate Connected Wood Truss Construction*
ASTM D 198-84, *Standard Methods of Static Testing of Timbers in Structural Sizes*
ASTM D 245-92, *Standard Methods for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber*
ASTM D 2915-86, *Methods for Evaluating Allowable Properties for Grades of Structural Lumber*
ASTM D 3737-89, *Standard Methods for Establishing Stresses for Structural Glued-Laminated Timber (Glulam)*
ASTM A153, *Specifications for Zinc Coating (Hot-Dip) on Iron and Steel Hardware*
ASTM B695, *Standard Specification for Coating of Zinc Mechanically Deposited on Iron and Steel*
AWPA C15-92, Wood for Commercial Residential Construction—Preservative Treatment by Pressure Processes
NIST PS20-94, *American Softwood Lumber Standard*

3 Definitions

3.1 mechanically laminated column: A structural assembly consisting of suitably selected wood laminations joined with nails, bolts, and/or other mechanical fasteners.

3.2 nail-laminated column: Used interchangeably with "mechanically laminated column" when nails are the only fastener used to join individual layers.

3.3 post: Solid-sawn or laminated members that provide lateral and vertical support for a building.

3.4 vertically laminated assembly: An assembly primarily designed to resist bending loads applied parallel to the planes of contact between individual layers (figure 1a). Virtually all mechanically laminated columns are designed as vertically laminated assemblies.

3.5 horizontally laminated assembly: An assembly primarily designed to resist bending loads applied normal to the planes of contact between individual layers (figure 1b). Mechanically laminated columns designed as horizontally laminated assemblies do not fall under the scope of this Engineering Practice.

3.6 unspliced column: A mechanically laminated column in which each layer is comprised of a single piece of dimension lumber.

3.7 spliced column: A mechanically laminated column that contains one or more end joints. End joints are generally simple butt joints; however, they may be reinforced. End joints may also be glued to form structural joints.

3.8 overall splice length, *L*: The distance between the two farthest removed (extreme outer) end joints in a column that contains one end joint in each layer (figure 2).

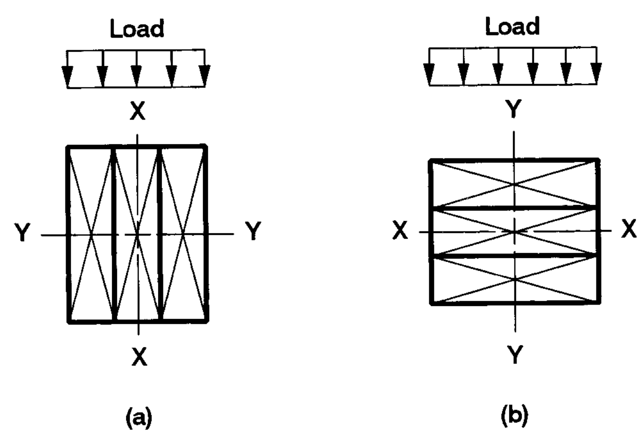

Figure 1 – (a) Vertically laminated, (b) horizontally laminated columns

3.9 joint spacing, *S:* The distance between end joints (figure 2). When end joints are equally spaced and there is only one end joint in each layer, *S* is equal to the overall splice length divided by $n - 1$, where *n* is the number of layers.

3.10 splice region: That portion of a column located between and within a distance of *L*/4 of the end joints. In a column with one end joint in each layer, the total length of the splice region is equal to 1.5*L* (figure 2).

3.11 unspliced region: Those portions of a column that fall outside of a splice region (figure 2).

3.12 joint arrangement: The relative location of end joints in a spliced column.

4 Material and manufacturing requirements

4.1 Lumber. Laminations (lumber) shall be identified by the grade mark of, or certificate of inspection issued by, a lumber grading or inspection bureau or agency recognized as being competent (see NIST PS20-94).

4.2 Preservative wood treatment. Any mechanically laminated column or portion thereof that is used where the in-service moisture content will exceed 19% shall be pressure preservative–treated with standard formulations in accordance with AWPA C15-92. Table 1 cites minimum preservative retentions that apply. When pressure preservative–treated laminations are required for soil embedment, all treated laminations shall extend a minimum of 400 mm (16 in.) above the exterior gradeline.

4.3 Restricted use of preservatives. The US Environmental Protection Agency has restricted, but not banned, the use of creosote, pentachlorophenol, and inorganic arsenicals, including CCA, ACA, and ACZA. The restrictions are variable. They may require only coating for a specific use, while in other cases they are prohibited. Generally, more restrictions occur where the environment is enclosed, and severe restrictions are imposed around feed and water. Refer to the Federal Register, January 10, 1986, Part III, or to Environmental Protection Consumer Information sheets for specific criteria and limitations.

4.4 Fasteners in treated lumber. Mechanical fasteners used above grade to join waterborne preservative–treated lumber, shall be of AISI type 304 or 316 stainless steel, silicon bronze, copper, hot-dipped galvanized (zinc-coated) steel nails conforming to the requirements of ASTM A153, or hot-tumbled galvanized steel nails conforming to the minimum requirements for Class 55 coatings in ASTM B695. Mechanical fasteners that are used below grade to assure compatibility of deformation between treated laminates shall be of AISI type 304 or 316 stainless steel.

4.5 Glued end joints. Glued end joints shall meet all requirements for structural end joints as specified in ANSI/AITC A190.1.

4.6 Metal plate connectors. Metal plate connectors shall meet all applicable requirements specified in ANSI/TPI 1.

5 Nail-laminated column design requirements

5.1 Joint arrangement. Joint arrangement is dependent on the number of layers, type of end joints, and presence (or absence) of butt-joint reinforcement. Recommended joint arrangements for three- and four-layer columns are shown in figure 3. To maximize bending strength of the splice region, use these joint arrangements in accordance with table 2.

Table 1 – Minimum retentions levels for structural wood columns

Preservative type	Minimum preservative retention, kg/m^3 (lb/ft^3)
Oil-Borne Preservatives	
Creosote, creosote solution, or creosote petroleum	192.2 (12.0)
Pentachlorophenol	9.61 (0.60)
Waterborne Preservatives	
Ammoniacal copper arsenate (ACA), ammoniacal copper zinc arsenate (ACZA), or chromated copper arsenate (CCA)	9.61 (0.60)

5.2 Overall splice length. Wood stresses and nail shear forces within the splice region increase rapidly as overall splice length is reduced. For applications where the splice region is located at a point of high column bending moment, the minimum overall splice lengths in table 3 are recommended. When the splice region is centered at a point of low column bending moment, overall splice lengths shorter than those in table 3 may be more practical.

5.3 Nail requirements. The number of nails required in a column is dependent on the amount of shear that must be transferred between layers (interlayer shear capacity). Nail location is controlled by spacing requirements which reduce the likelihood of splitting, yet ensure a good distribution of fasteners.

5.3.1 Interlayer shear capacity. Minimum required interlayer shear capacities are expressed on the basis of force per interface per unit length of column. There are two design levels. Level I values are listed in table 4 and apply to: (1) unspliced columns, (2) unspliced regions of spliced columns, and (3) spliced columns with glued end joints (see clause 4.5). Level II values apply to the splice region of all columns with simple butt joints. Use equation 1 to calculate level II values. This equation only applies to assemblies with overall splice lengths equal to or greater than the table 3 minimums.

$$ISC = F_{b,u} d (0.0024 + Ad/L^2 - MOE/B) \qquad (1)$$

where:

- ISC is minimum required interlayer shear capacity per interface per unit length of column, N/mm (lbf/in.);
- $F_{b,u}$ is allowable design bending stress for the unspliced region (see clause 6.1), MPa (lbf/in.^{2});
- d is column depth (lamination face width), mm (in.);
- L is overall splice length, mm (in.);
- MOE is wood modulus of elasticity, MPa (lbf/in.^{2});
- A is a constant = 43.3 mm (1.708 in.);
- B is a constant = 8,600,000 MPa (12.46×10^8 lbf/in.^{2}).

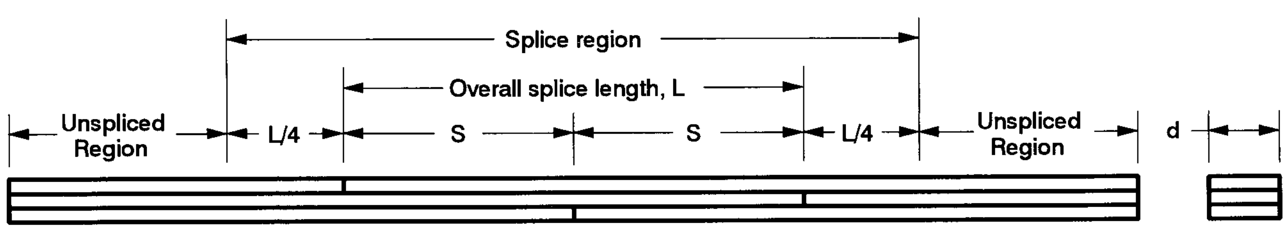

Figure 2 – Spliced column definitions

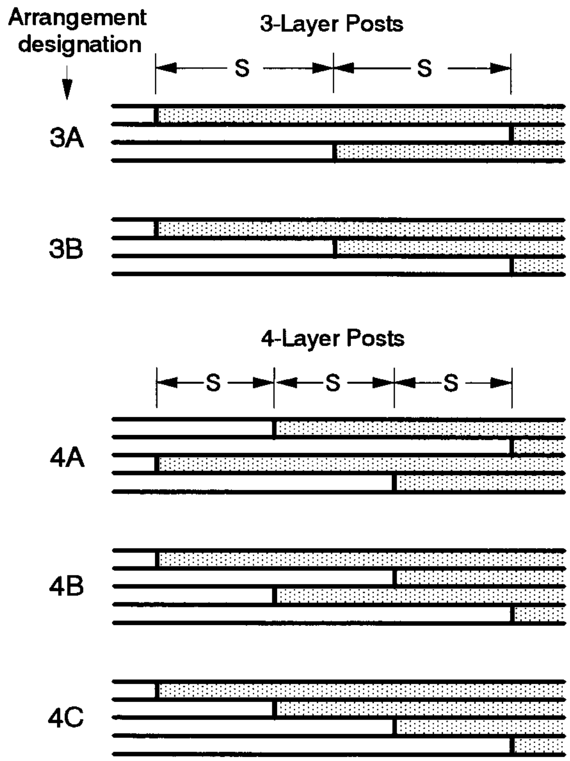

Figure 3 – Joint arrangements for three- and four-layer spliced columns

5.3.2 Nail density. The minimum number of nails required for lamination is obtained by dividing the minimum required interlayer shear capacity by the lateral design load of an individual fastener. The lateral design load for a fastener shall be calculated in accordance with AF & PA National Design Specification (NDS®) for Wood Construction, Part XII: Nails and Spikes.

5.3.3 Nail diameter. Nail diameter shall not exceed one-eighth the actual thickness of a lamination.

5.3.4 Nail location. To reduce the likelihood of wood splitting, the minimum nail spacings in table 5 shall be followed. To ensure a good distribution of nails, the following additional provisions shall be adhered to:

5.3.4.1 A minimum of two nail rows shall be provided.

5.3.4.2 One nail row shall be placed within 20 nail diameters of one edge and another nail row within 20 nail diameters of the other edge. The spacing (pitch) between nails in each of these two rows shall not exceed 0.45 m (18 in.).

Table 2 – Recommended joint arrangements

Number of layers	Joint type	Outside butt joint reinforcement[1)]	Recommended joint arrangements[2)]
	Butt joints	no	3A
3	Butt joints	yes	3A, 3B
	Glued end joints[3)]	NA	3A, 3B
	Butt joints	no	4B, 4C
4	Butt joints	yes	4A
	Glued end joints[3)]	NA	4A, 4B, 4C

[1)]See clause 5.4.
[2)]See figure 3.
[3)]See paragraph 4.5.

Table 3 – Recommended minimum overall splice lengths

Actual face width of laminations, mm (in.)	Minimum overall splice length, m (in.)	
	Glued end joints[1)]	Butt joints
140 (5.5)	0.61 (24)	1.22 (48)
184 (7.25)	0.91 (36)	1.52 (60)
235 (9.25)	0.91 (36)	1.83 (72)
286 (11.25)	1.22 (48)	2.44 (96)

[1)]See clause 4.5.

5.3.4.3 At least half of the nail rows shall have a fastener within 20 nail diameters of each side of each butt joint. All nail rows shall have a fastener within 35 nail diameters of each side of each butt joint.

5.4 Butt-joint reinforcement. The strength and stiffness of columns with simple butt joints can be improved by reinforcing joints in the outside laminations with metal plate connectors. To apply the bending strength modification factor in table 8, each outside joint shall be reinforced with one metal plate connector (MPC). The MPC shall be centered on the joint and meet the following requirements:

5.4.1 Width shall be no less than 90% of the actual face width of the laminations;

5.4.2 Length shall be no less than 1.5 times the MPC width;

5.4.3 Thickness shall be no less than 0.91 mm (0.036 in., 20 gage) for columns with depths of 140 and 184 mm (5.5 and 7.25 in.), and no less than 1.47 mm (0.058 in., 16 gage) for columns with depths of 235 and 286 mm (9.25 and 11.25 in.);

5.4.4 The allowable design value in tension, V_t, for the MPC must meet the following criteria

$$V_t \geqslant 0.22 F_{b,u} t d^2 / w^2 \qquad (2)$$

where:

- V_t is allowable MPC design value in tension (allowable load per unit of plate width), N/mm (lbf/in.);
- $F_{b,u}$ is design bending stress for the unspliced region of the column, MPa (lbf/in.^{2}), from clause 6.1;
- t is thickness of an individual lamination, mm (in.);
- d is column depth (lamination face width), mm (in.);
- w is plate width, mm (in.).

Table 4 – Minimum required interlayer shear capacities—Level I[1)]

Actual face width of laminations, mm (in.)	Minimum required interlayer shear capacity per interface per unit length of column, N/mm (lbf/in.)
140 (5.5)	2.1 (12)
184 (7.25)	2.6 (15)
235 (9.25)	3.3 (19)
286 (11.25)	4.2 (24)

[1)]For unspliced columns, unspliced regions of columns with butt joints, and spliced columns with glued end joints.

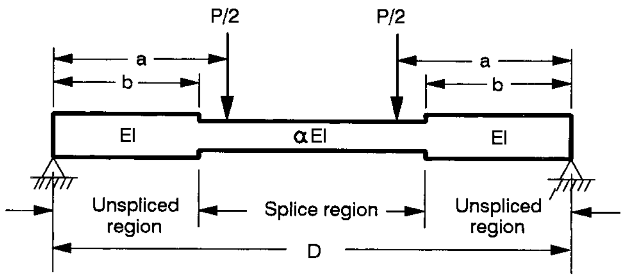

Figure 4 – Model of a spliced assembly under a two-point loading; reduced flexural stiffness in the splice region

Table 5 – Minimum nail spacings

	Nail diameters
Edge distance	10
End distance	15
Spacing (pitch) between fasteners in a row	20
Spacing (gage) between rows of fasteners	
- in-line	10
- staggered	5

6 Design bending stress

6.1 Unspliced columns. The design bending stress of a mechanically laminated column without end joints shall be calculated according to AF&PA National Design Specification (NDS®) for Wood Construction. All provisions of the NDS® shall apply with the exception that the appropriate repetitive member factor, C_r, from table 6 can be used for any unspliced mechanically laminated column with an interlayer shear capacity that meets or exceeds the values in table 4. Table 7a contains allowable bending stresses for selected visually graded softwood species. The values in table 7a have been adjusted by the appropriate repetitive member factor and the appropriate NDS® size factor, C_F. Table 7b contains similarly adjusted, allowable bending stresses for machine stress rated lumber. Bending stress values in tables 7a and 7b shall be further adjusted to account for stability (clause 6.1), load duration, wet use, temperature, and in certain cases, special preservative and fire treatments. Wet-use factors shall be applied where the moisture content in service will exceed 19% for an extended period of time. The wet use factor shall be applied when calculating the allowable bending stress at the groundline of an embedded column.

6.1.1 Beam stability factor. To adjust for stability, the NDS® beam stability factor, C_L, is used. The beam stability factor is a function of the slenderness ratio, R_B, which in turn is a function of dimensions d and b, and the effective span length of the bending member, L_e. For mechanically laminated columns, b shall be equated to 60% of the actual column thickness, and d to the actual face width of a lamination. The effective span length, L_e, is a function of the unsupported length, L_u. The unsupported length shall be set equal to the on-center spacing of bracing that keeps the assembly from buckling laterally.

6.2 Spliced columns with glued end joints. Design bending stresses for unspliced columns (clause 6.1, tables 7a and 7b) are applicable to spliced columns with glued end joints when:

— The glued end joints conform to the requirements of clause 4.5;

— Interlayer shear capacity meets or exceeds the table 4 values.

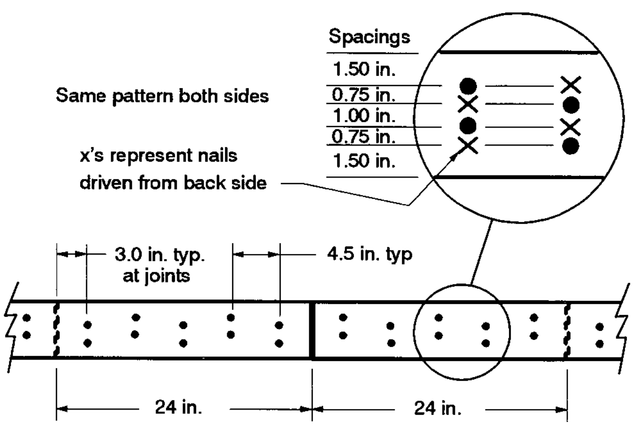

Figure 5 – Example nail pattern for a three-layer spliced column fabricated using 10 d common wire nails. Only a portion of the splice region is shown. The same nail pattern is used on both sides of the column

6.3 Spliced columns with simple butt joints. The strength and stiffness of a mechanically laminated column are reduced within the vicinity of simple butt joints. For design purposes, spliced columns shall be segmented into spliced and unspliced regions as defined in clauses 3.10 and 3.11. The design bending stress of the unspliced regions shall be calculated in accordance with clause 6.1. The design bending strength of the splice region shall be obtained by multiplying the design bending strength of the unspliced regions of the column by an appropriate bending strength modification factor. Bending strength modification factors are determined by test according to clause 6.4. For nail-laminated columns that meet all requirements of clause 5, the bending strength modification factors in table 8 can be used.

6.4 Testing laminated columns. Tests used to determine the bending strength and stiffness of the splice region of a column shall be conducted in accordance with ASTM D198 and ASTM D2915. A two-point loading shall be used with all end joints in spliced columns located between the load points (i.e., in the constant moment region). Fabricate specimens according to clause 6.4.1. Determine the bending strength modification factor in accordance with clause 6.4.2.

6.4.1 Specimen fabrication. An equal number of spliced and unspliced columns (five minimum) shall be tested. The spliced and unspliced columns shall be identical in size and fabricated from the same batch of lumber. Lumber shall be allocated to the spliced and unspliced column groups such that the distribution of wood modulus of elasticity (MOE) values is similar for both groups. The latter can be accomplished by sorting lumber by MOE (in either ascending or descending order) and assigning every other piece to the same group.

6.4.2 Bending strength modification factor. To calculate the bending strength modification factor, divide the mean ultimate bending moment for the spliced columns by the mean ultimate bending moment for the unspliced columns, and then multiply the resulting value by the appropriate adjustment factor from table 9. If a sufficient number of columns have been tested (e.g., 25 of each type), a more accurate estimate of the bending strength modification factor can be obtained by dividing the 5% exclusion value of ultimate bending moment for the spliced columns by the 5% exclusion value of ultimate bending moment for the unspliced columns.

Table 6 – Repetitive member factors[1)]

	Number of laminations	
	3	4
Visually graded	1.35	1.40
Mechanically graded	1.25	1.30

[1)]For mechanically laminated dimension lumber assemblies with minimum interlayer shear capacity as specified in table 4.

Table 7 – a. Design values for visually graded dimension lumber used in unspliced mechanically laminated columns[1)]

		Extreme fiber in bending stress[c], Mpa (lbf/in.^{2})								
		Actual width of individual layers, mm (in.)								
		140 (5.5)		184 (7.25)		235(9.25)		286(11.25)		
		Number of laminations:								
Species[2)]	Grade	3	4	3	4	3	4	3	4	Modulus of Elasticity, GPa($\times 10^6$ lbs/in.^{2})
DFL	Sel Str	17.5 (2540)	18.2 (2640)	16.2(2350)	16.8(2440)	14.8(2150)	15.4(2230)	13.5(1960)	14.0(2030)	13.1(1.9)
DFL	No. 1 & Better	13.9 (2020)	14.4 (2090)	12.8(1860)	13.3(1930)	11.8(1710)	12.2(1770)	10.7(1550)	11.1(1610)	12.4(1.8)
DFL	No. 1	12.1 (1760)	12.5 (1820)	11.2(1620)	11.6(1680)	10.2(1490)	10.6(1540)	9.3(1350)	9.7(1400)	11.7(1.7)
DFL	No. 2	10.6 (1540)	11.0 (1590)	9.8(1420)	10.1(1470)	9.0(1300)	9.3(1350)	8.1(1180)	8.4(1230)	11.0(1.6)
HF	Sel Str	16.9 (2460)	17.6 (2550)	15.6(2270)	16.2(2350)	14.3(2080)	14.9(2160)	13.0(1890)	13.5(1960)	11.0(1.6)
HF	No. 1 & Better	12.7 (1840)	13.2 (1910)	11.7(1700)	12.2(1760)	10.8(1560)	11.1(1620)	9.8(1420)	10.1(1470)	10.3(1.5)
HF	No. 1	11.5 (1670)	11.9 (1730)	10.6(1540)	11.0(1600)	9.7(1410)	10.1(1460)	8.8(1280)	9.2(1330)	10.3(1.5)
HF	No. 2	10.3 (1490)	10.7 (1550)	9.5(1380)	9.8(1430)	8.7(1260)	9.0(1310)	7.9(1150)	8.2(1190)	9.0(1.3)
SP	Dense Sel Str	25.1 (3650)	26.1 (3780)	22.8(3310)	23.6(3430)	20.0(2900)	20.8(3010)	19.1(2770)	19.8(2870)	13.1(1.9)
SP	Sel Str	23.7 (3440)	24.6 (3570)	21.4(3110)	22.2(3220)	19.1(2770)	19.8(2870)	17.7(2570)	18.3(2660)	12.4(1.8)
SP	Non-Dense SS	21.9 (3170)	22.7 (3290)	19.5(2840)	20.3(2940)	17.2(2500)	17.9(2590)	16.3(2360)	16.9(2450)	11.7(1.7)
SP	No. 1 Dense	16.3 (2360)	16.9 (2450)	15.4(2230)	15.9(2310)	13.5(1960)	14.0(2030)	12.6(1820)	13.0(1890)	12.4(1.8)
SP	No. 1	15.4 (2230)	15.9 (2310)	14.0(2030)	14.5(2100)	12.1(1760)	12.5(1820)	11.6(1690)	12.1(1750)	11.7(1.7)
SP	Non-Dense No. 1	14.0 (2030)	14.5 (2100)	12.6(1820)	13.0(1890)	11.2(1620)	11.6(1680)	10.7(1550)	11.1(1610)	11.0(1.6)
SP	No. 2 Dense	13.5 (1960)	14.0 (2030)	13.0(1890)	13.5(1960)	11.2(1620)	11.6(1680)	10.7(1550)	11.1(1610)	11.7(1.7)
SP	No. 2	11.6 (1690)	12.1 (1750)	11.2(1620)	11.6(1680)	9.8(1420)	10.1(1470)	9.1(1320)	9.4(1370)	11.0(1.6)
SP	Non-Dense No. 2	10.7 (1550)	11.1 (1610)	10.2(1490)	10.6(1540)	8.8(1280)	9.2(1330)	8.4(1220)	8.7(1260)	9.6(1.4)

[1)]For dry columns under normal load duration.
[2)]*DFL*, Douglas FirLarch; *HF*, HemFir; *SP*, Southern Pine.
[3)]Size and repetitive member factor applied. For other applicable modification factors see NDS table 2.3.1 (AF&PA, 1991).

7 Bending stiffness

7.1 Unspliced columns. The MOE of an unspliced column is equal to the average MOE of the individual laminations.

7.2 Spliced columns with glued end joints. The MOE of spliced columns with glued end joints is equal to the average MOE of the individual laminations.

7.3 Spliced columns with butt joints. The stiffness of a mechanically laminated column is reduced within the vicinity of simple butt joints. For structural analysis purposes, spliced columns can be segmented into spliced and unspliced regions as defined in clauses 3.10 and 3.11, respectively. The MOE of the unspliced regions is equal to the average MOE of the individual laminations. An ''effective'' MOE for the spliced

Table 7 – b. Design values for machine stress rated dimension lumber used in unspliced mechanically laminated columns[1)]

	Extreme fiber in bending stress[2)] Mpa (lbf/in.^{2})			Extreme fiber in bending stress[2)], Mpa (lbf/in.^{2})	
	Number of laminations			Number of laminations	
Grade	3	4	Grade	3	4
900f-1.0E	7.79(1130)	8.07(1170)	1950f-1.5E	16.8 (2440)	17.5 (2540)
900f-1.2E	7.79(1130)	8.07(1170)	1950f-1.7E	16.8 (2440)	17.5 (2540)
1200f-1.2E	10.3 (1500)	10.8 (1560)	2100f-1.8E	18.1 (2630)	18.8 (2730)
1200f-1.5E	10.3 (1500)	10.8 (1560)	2250f-1.6E	19.4 (2810)	20.2 (2930)
1350f-1.3E	11.6 (1690)	12.1 (1760)	2250f-1.9E	19.4 (2810)	20.2 (2930)
1350f-1.8E	11.6 (1690)	12.1 (1760)	2400f-1.7E	20.7 (3000)	21.5 (3120)
1450f-1.3E	12.5 (1810)	13.0 (1890)	2400f-2.0E	20.7 (3000)	21.5 (3120)
1500f-1.3E	13.0 (1880)	13.4 (1950)	2550f-2.1E	22.0 (3190)	22.9 (3320)
1500f-1.4E	13.0 (1880)	13.4 (1950)	2700f-2.2E	23.3 (3380)	24.2 (3510)
1500f-1.8E	13.0 (1880)	13.4 (1950)	2850f-2.3E	24.5 (3560)	25.6 (3710)
1650f-1.4E	14.2 (2060)	14.8 (2150)	3000f-2.4E	25.9 (3750)	26.9 (3900)
1650f-1.5E	14.2 (2060)	14.8 (2150)	3150f-2.5E	27.2 (3940)	28.3 (4100)
1800f-1.6E	15.5 (2250)	16.1 (2340)	3300f-2.6E	28.5 (4130)	29.6 (4290)
1800f-2.1E	15.5 (2250)	16.1 (2340)			

[1)]For dry columns under normal load duration.
[2)]Repetitive member factor applied. For other applicable modification factors see NDS table 2.3.1 (AF&PA, 1991).

Table 8 – Bending strength modification factors for nail-laminated columns[1)]

Joint description	Bending strength modification factor
Unreinforced butt joints	0.42
Each outside butt joint reinforced with one MPC	0.55

[1)]Factors apply only to nail-laminated columns that meet all requirements in clause 5. Recommended joint arrangements and minimum overall splice lengths in tables 2 and 3 shall be used.

region is obtained by multiplying the MOE of the unspliced regions of the column by a bending stiffness modification factor.

7.3.1 Bending stiffness modification factors. The bending stiffness modification factor for any spliced column can be determined from tests conducted in accordance with clause 6.4. Use the equations in table 10 to obtain stiffness modification factors from the test data. For spliced nail-laminated columns without butt-joint reinforcement that meet the requirements of clause 5, equation 3 can be used to calculate the bending stiffness modification factor.

$$\alpha = 0.887 - 1.329[d^3 MOE t/(L^5 K\rho)]^{0.25} \quad (3)$$

where:

- α is bending stiffness modification factor;
- d is face width of laminations, mm (in.);
- t is thickness of an individual lamination, mm (in.);
- L is overall splice length, mm (in.);
- K is stiffness of an individual nail joint (i.e., shear force divided by interlayer slip), N/mm (lbf/in.);
- ρ is average nail density in the splice region (nails per unit contact area), 1/mm^2 (1/in.^{2});
- MOE is wood modulus of elasticity, MPa (lbf/in.^{2}).

Table 9 – Adjustment factors for mean strength ratio[1)]

n[2)]	Spliced columns with outside butt-joint reinforcement only	All other spliced columns
5	0.88	0.77
10	0.92	0.80
15	0.93	0.81
20	0.935	0.815
25	0.94	0.82

[1)]Multiply adjustment factor by ratio of mean strengths of spliced and unspliced columns to obtain the bending strength modification factor.

[2)]n is the number of spliced (or unspliced) columns tested.

8 Commentary

8.1 Purpose and scope

8.1.1 The suitability of a column for use in a post-frame building is generally dependent on its bending properties. Bending properties for a mechanically laminated column vary significantly depending upon orientation and whether or not it contains butt joints.

8.1.2 Although this Engineering Practice does not address axial column strength, all columns must be designed to resist axial loads acting alone and in combination with bending loads. Section 15.3 of the 1991 NDS contains special provisions for calculating the design compressive strength of mechanically laminated columns.

8.1.3 The scope of this Engineering Practice is limited to three- and four-layer columns because they represent the vast majority of columns used, and are the only mechanically laminated assemblies that have been extensively tested and modeled to date. The scope of this Engineering Practice is limited to uniaxial bending about axis Y-Y (figure 1a) because: (1) mechanically laminated columns are generally substantially weaker when bent about axis X-X, and (2) calculating biaxial bending stresses in mechanically laminated assemblies is a complex function of boundary conditions, the stiffness of individual laminations, and the stiffness of interlayer connections.

8.2 Definitions

Table 10 – Equations for calculating bending stiffness modification factors from test data[1)]

Location of load point	Location of deflection measurement: Load point	Location of deflection measurement: Midspan
$b \geq a$	$\alpha = \dfrac{D-2b}{4EI\Delta_l/(a^2P)+4a/3-2b}$	$\alpha = \dfrac{D^2/4-b^2}{4EI\Delta_m/(aP)+a^2/3-b^2}$
$b \leq a$	$\alpha = \dfrac{3a^2D-4a^3-2b^3}{12EI\Delta_l/P-2b^3}$	$\alpha = \dfrac{3aD^2/8-b^3-a^3/2}{6EI\Delta_m/P-b^3}$

where:

- α is bending stiffness modification factor
- D is distance between supports
- a is distance between support and load point
- b is distance from support to spliced region. Equal to $(D - 1.5L)/2$
- Δ_l is load point deflection for spliced column
- Δ_m is midspan deflection for spliced column
- P is total applied load (sum of both point loads)
- EI is effective flexural rigidity of the unspliced column. Equal to the product of wood modulus of elasticity and moment of inertia
- L is overall splice length

[1)]See figure 4 for graphical depiction of equation variables.

8.2.1 Splice region. Defining a splice region is very important for columns with simple butt joints. In such assemblies, the splice region is required to have more interlayer connectors and is assigned bending strength and stiffness values that are lower than those for unspliced regions of the column. The decision to terminate the splice region at a distance of *L*/4 from the ''extreme outer'' end joints (resulting in a splice region length of 1.5 times the overall splice length, *L*) was based on finite element analyses of three- and four-layer columns. These analyses showed that nail shear forces fall off rapidly as the distance from the extreme outer joints increases. At a distance *L*/4 from the extreme outer joints, the nail shear forces have dropped to level where they are at or below the average shear force of the nails located between the two extreme outer end joints.

8.3 Material and manufacturing requirements

8.3.1 Fasteners in treated lumber. Clause 4.5 was based on Section 2.4.1 of *The Permanent Wood Foundation System—Design, Fabrication and Installation Manual* (AF&PA, 1992). The requirements in this document are based on the results of a 17-year Forest Products Laboratory study (Baker, 1992).

8.3.2 Glued end joints. In glued-laminated assemblies, lumber may be end-jointed to form any length of lamination as long as the end joints meet the requirements of ANSI/AITC A190.1. Glued end joints that meet ANSI/AITC A190.1 are classified as structural end joints. Lumber grading agencies such as the Western Wood Products Association and Southern Pine Inspection Bureau certify and stamp structural end-jointed lumber. Grade marks identifying such lumber contain the words *Certified Glued Joints*.

8.4 Nail-laminated column design requirements

8.4.1 Most mechanically laminated columns used in construction are nail laminated. When a nail-laminated column contains simple butt joints, the bending strength and stiffness of the column is controlled by the overall splice length, nail location and density, and presence (or absence) of butt-joint reinforcement. Clause 5 of this Engineering Practice contains design requirements for these nail-laminated column variables. When these design requirements are followed (i.e., recommended minimum splice lengths, joint arrangements, and nail capacities are used), the bending strength and stiffness of the spliced columns can be calculated according to procedures outlined in clauses 6 and 7. In other words, there is no need to conduct laboratory tests to determine bending properties of spliced nail-laminated columns.

8.4.2 Joint arrangement. The recommended joint arrangements (table 2) and minimum overall splice lengths (table 3) were selected after extensive finite element analysis (FEA) and laboratory testing. The ability of FEA to accurately predict the behavior of columns has been demonstrated in four major studies (Bohnhoff et al., 1989; Bohnhoff et al., 1991; Bohnhoff et al., 1993; Williams et al., 1996). Columns featuring joint arrangements 3A, 4A, and 4B have been laboratory tested, while columns with joint arrangements 3B and 4C have not.

8.4.3 Overall splice length. Minimum overall splice length is primarily controlled by nail forces in columns that are 140 and 184 mm (5.5 and 7.25 in.) deep, and by wood shear stresses in columns fabricated from 235 and 286 mm (9.25 and 11.25 in.) wide lumber. When overall splice lengths less than those in table 3 are used for 140 and 184 mm deep columns, the number of nail fasteners required within the splice region to maintain strength becomes excessive and minimum nail spacings are difficult to maintain.

8.4.3.1 The minimum splice lengths listed in table 3 for mechanically laminated columns with glued end joints are half as long as those specified for columns with simple butt joints. This decrease in required splice length reflects the fact that interlayer shear transfer is considerably less in mechanically laminated assemblies with glued end joints than it is in columns with simple butt joints. It is important to note that the effect of overall splice length on the strength of mechanically laminated columns with glued end joints has not been investigated, this despite the fact that such assemblies are commonly used in post-frame buildings. To this end, the minimum splice lengths listed in table 3 for columns with glued end joints are felt to be slightly conservative. Based on a brief review of literature, it would appear that the spacing of end joints in vertically glued-laminated assemblies has also not been studied. ANSI/AITC A190.1, which contains end joint spacing requirements for all Glulam assemblies, states that concentration of end joints should be avoided and requires a minimum 152 mm (6 in.) spacing between joints in adjacent layers.

8.4.3.2 Recommended minimum overall splice lengths increase as the face width of the laminations increase because column bending strength increases as lamination width increases. Unless the minimum overall splice length is increased along with lamination face width, the strength gain associated with the increased width will be compromised by a lower bending strength in the splice region.

8.4.4 Interlayer shear capacity. Level II values (equation 1) are based on an EISS (effective interlayer shear stress) equation developed by Bohnhoff (1996) after extensive computer modeling. The EISS equation predicts the average interlayer shear stress in the 25% most highly loaded nails within the splice region when the average slip of these nails is 0.38 mm (0.015 in.). Equation 1 yields values that are two-thirds of those obtained from the EISS equation. The two-thirds factor was applied because designs with this lower shear capacity did not experience nail-related failures when laboratory tested. Care should be taken not to over-specify shear capacity since over-nailing can negatively influence column strength.

8.4.4.1 Nail location. The minimum nail spacings in table 5 are based on a study of actual column failures. These minimums are more conservative than those published in the 1991 NDS® Commentary (AF&PA, 1993). In addition to the minimum nail spacings, clause 5.3.4 also contains provisions to ensure a good distribution of nails. These provisions were based in part on the requirements given for mechanically laminated built-up columns in clause 15.3.3 of the 1991 NDS®.

8.4.5 Butt-joint reinforcement. The specifications in clause 5.4 are based on tests conducted by Bohnhoff et al. (1991) and Williams et al. (1994). Equation 2 ensures that the ratio of MPC bending capacity to lamination bending capacity is consistent with that for column designs used to establish the 0.55 factor in table 8.

8.5 Design bending stress

8.5.1 Repetitive member factors. The repetitive member factors in table 6 are based on test results from four major studies (Bonnickson and Suddarth, 1966; Bohnhoff et al., 1991; Williams et al., 1994; Chiou, 1995).

8.5.2 Slenderness ratio. The slenderness ratio required for calculation of the beam stability factor is based on a width, *b*, that is equal to 60% of the actual width of the column. The 60% factor is equal to the column stability coefficient, K_f, used in the NDS® to calculate allowable compressive stresses for nail-laminated columns.

8.5.3 Bending strength modification factors. The table 8 values are based on tests conducted by Bohnhoff et al. (1991) and Williams et al. (1994) on columns with minimum overall splice lengths.

8.5.4 Testing laminated columns. When the bending strength modification factors in table 8 do not apply, a series of laboratory tests must be conducted. Both spliced columns and unspliced columns are tested and the bending strength modification factor is calculated from the test results using procedures outlined in clause 6.4.2. In the past, it was common practice to determine the design bending strength of a new spliced column design by testing a series of the columns and then dividing the 5% exclusion value of ultimate bending moment by a factor of 2.1. The drawbacks of this method were that (1) the reduction in strength due to splicing could not be calculated (since unspliced columns had not been tested), and (2) the resulting design value applies only to columns fabricated from the same batch of lumber as that used to fabricate the test specimens (lumber strength and stiffness can vary significantly from batch to batch, even through both batches may be of the same grade and species). Both of these shortcomings are avoided with the outlined procedure.

8.5.5 Adjustment factor for mean strength ratio. The adjustment factors in table 9 account for the number of assemblies tested and for the difference between mean column strength and the 5% exclusion value of column strength. The factors were developed assuming: (1) normal distributions of bending strength for all column types, (2) a ratio of 1.50 between the bending strength COV for spliced columns (without outside butt-joint reinforcement) and the bending strength COV of unspliced columns, (3) a ratio of 1.00 between the bending strength COV for spliced columns with outside butt-joint reinforcement and the bending strength COV of unspliced columns. Under these conditions, the values in table 9 provide a one-sided lower 90% confidence bound on the bending strength modification factor. Because of the assumptions made in the development of the table 9 adjustment factors, use of the table 9 factors will generally produce a conservative bending strength modification factor. For this reason, it is recommended that at least 25 spliced and 25 unspliced columns be tested, and 5% exclusion values of bending strength be used (instead of mean strengths and table 9 values) to determine the bending strength modification factor.

8.6 Bending stiffness

8.6.1 Unspliced columns. When the layers of an unspliced column are forced (by a load-distributing element) to have the same displaced geometry, there is little, if any, slip between the individual layers. When there is little or no slip between individual layers, and each layer has (1) the same moment of inertia, and (2) a centroid located on the centroidal axis Y-Y (figure 1), then the MOE of the column is equal to the average MOE of the layers.

8.6.2 Spliced columns with glued end joints. The criteria for unspliced columns also applies to spliced columns with glued end joints because at a glued end joint the members forming the joint have the same rotation and vertical displacement.

8.6.3 Spliced columns with butt joints. To be accurately represented in a plane-frame structural analog, a column with butt joints must be divided into elements. To be consistent with the rest of this Engineering Practice, spliced columns are segmented into spliced and unspliced regions as defined in clauses 3.10 and 3.11, respectively.

8.6.4 Bending stiffness modification factors. The equations in table 10 apply only to columns tested under a symmetric two-point loading. They were derived using the conjugate beam method. Use of these equations requires a good estimate of the effective rigidity of the unspliced section, EI, which is the product of wood modulus of elasticity and moment of inertia. For the stiffness modification factor to be meaningful, EI must be determined by a laboratory test of lumber representative of that used to fabricate the spliced assemblies (either individual pieces or unspliced assemblies can be tested).

8.6.4.1 Equation 3 is from Bohnhoff (1996) and requires an estimate of individual nail-joint stiffness, K, which is the slope of the relationship between nail shear force and interlayer slip. For common wire nails, the secant stiffness corresponding to an interlayer slip of 0.38 mm (0.015 in.) can be approximated as:

$$K = CG^{1.25}D^{1.5} \qquad (4)$$

where:

K is interlayer stiffness, N/mm (lbf/in.);
G is specific gravity based on oven-dry weight and volume;
D is nail diameter, mm (in.);
C = 415.3 (for K in N/mm and D in mm);
= 303600 (for K in lbf/in and D in in.)

Annex A
(informative)
Bibliography

The following documents are cited as reference sources used in the development of this Engineering Practice:

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Annex B
(informative)
Spliced nail-laminated column design example

Problem: Design a three-layer spliced nail-laminated column. Use nominal 2- by 6-in. No. 2 southern pine lumber and 10d common wire nails. End joints will not be glued or reinforced.
Solution:

Step 1—Allowable Bending Stresses

a. Allowable bending stress in dry unspliced regions, $F_{b,u}$, for normal load duration (table 7a) = 1690 lbf/in.^{2}
b. Allowable bending stress in dry splice region, $F_{b,s}$, for normal load duration = 1690 lbf/in.$^2 \times 0.42 =$ 710 lbf/in.^{2} [The 0.42 value is the bending strength modification factor from table 8. To use this value, all minimum design recommendations in clause 4 must be followed.]

c. *MOE* in dry unspliced regions (table 7a) = 1.6×10^6 lbf/in.^{2}

Step 2—Recommended Splice Arrangement & Overall Splice Length

a. For a three-layer assembly with unreinforced butt joints, splice arrangement 3A is recommended (table 2)
b. Recommended minimum overall splice length, L, for a nominally 6-in.-deep assembly (table 3) = 4 feet

Step 3—Required Interlayer Shear Capacity

a. Unspliced regions (level I value from table 4) = 12 lbf/in.
b. Splice regions (Equation 1 with: $F_{b,u}$ = 1690 lbf/in.^{2}; d = 5.5 in.; L = 48 in.; and MOE = 1,600,000 lbf/in.^{2}) = 48.3 lbf/in.

Step 4—Lateral Design Load for a Nail Joint

a. For a 10d common wire nail in southern pine (1991 NDS) = 114 lbf. This value was calculated using a fastener diameter of 0.148 in., fastener yield strength of 100,000 lbf/in.^{2}, and penetration depth factor of 0.84.

Step 5—Minimum Required Number of Nails

a. Nails required (per interface) for a 48 in. section of the splice region = (48 in.)(48.3 lbf/in.)/(114 lbf/nail) = 20 nails
b. Nails required (per interface) for a 12 in. section of the splice region = (12 in.)(48.3 lbf/in.)/(114 lbf/nail) = 5 nails
c. Nails required in unspliced regions = (12 lbf/in.)/(114 lbf/nail) = 0.105 nails/in. = 1 nail every 9.5 in.

Step 6—Minimum spacings based on 0.148-in. nail diameter

a. Edge distance=1.48 in.
b. End distance=2.22 in.
c. Spacing (pitch) between fasteners in a row = 2.96 in.
d. Spacing (gage) between rows of fasteners—in-line = 1.48 in.
e. Spacing (gage) between rows of fasteners—staggered = 0.74 in.

Step 7—Nail Layout

a. A nail pattern that meets the proceeding requirements is shown in figure 5.