# 7

# SOLID-SAWN AND LAMINATED POSTS

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Posts are the main structural elements in the post-frame wall. All loads applied to a structure are eventually channeled through the posts to ground level. Although posts may be bolted to the top of a concrete frost wall or floating slab foundation, they are generally embedded in the soil. When embedded, the posts and bearing structure transfer load to the soil and thereby function as the foundation for the building.

Posts fall into two main categories: solid-sawn and laminated. Solid-sawn posts can be purchased as either dressed, rough-sawn, or full-sawn timber. Timber which is dressed (i.e., planed) on all four sides is referred to as S4S timber (surfaced four sides). Rough-sawn timber has not been dressed to obtain smooth surfaces. The actual cross-sectional dimensions of rough-sawn timber are approximately 1/8 in. larger than the standard S4S sizes. Full-sawn timber is similar to rough sawn in that it has a rough surface. However, the actual dimensions of full-sawn timber should be the same as the nominal dimensions.

The term "laminated post" applies to any column assembly consisting of two or more layers of dimension lumber that have been joined together. Today, laminated posts comprise the majority of the posts used in engineered post-frame buildings. Laminated posts can behave quite differently depending upon the method used to join the individual layers, the continuity of the individual layers, and the direction of the applied load. For this reason, laminated posts are categorized according to the following definitions.

***Mechanically Laminated Post*** is an assembly in which the individual layers are mechanically fastened together. Typical mechanical fasteners include: nails, screws, bolts, and/or shear transfer plates (a shear transfer plate is best described as a metal plate connector with teeth on both sides).

***Structural Glued-Laminated Timber Post*** or Glulam Timber Post is an assembly in which the individual layers are joined together with a structural adhesive.

***Nail-Laminated Post*** is used interchangeably with mechanically laminated post if nails are the only fastener used to join the individual layers together.

***Vertically Laminated Post*** is an assembly primarily designed to resist loads applied parallel to the planes of contact between the individual layers. Almost all mechanically laminated posts are vertically laminated.

***Horizontally Laminamd Post*** is an assembly primarily designed to resist loads applied normal to the interlayer planes. Most glulam beams are horizontally laminated. The difference between horizontal and vertical lamination is shown in figure 7.1.

***Unspliced Post*** is a laminated assembly in which each layer is comprised of a single piece of dimension lumber. In other words, there are no end joints (butt, scarf, finger, or otherwise) present in the assembly.

***Spliced Post*** is a laminated assembly in which at least one of the layers is comprised of two or more pieces of lumber (i.e., contains at least one end joint). End joints in glued laminated assemblies are typically glued finger joints. End joints in mechanically laminated assemblies are generally simple butt joints which are either left plain or are reinforced with steel sheets, nail plates, metal plate connectors, etc.

Every laminated post falls into at least three of the preceding categories. For example, a post could be a horizontally glued-laminated assembly without end joints.

## POST-TYPE SELECTION CONSIDERATIONS

There are advantages and disadvantages to using a particular post type. In the following section, factors to consider when selecting a post are reviewed.

### COSTS

Proper cost comparison of posts requires that material, fabrication, storage, handling/transportation, and erection costs be considered. The total material cost associated with a laminated post is generally less than that of a similarly sized solid-sawn post, even when the cost of fasteners and reinforcing are included. This is because laminated posts are pieced together from smaller, shofter, less expensive dimension lumber. As the length of a laminated post increases, the material cost per foot of post stays relatively constant. Solid-sawn posts become increasingly more expensive (on a per foot basis) in lengths over 16 ft (4.9 m). Additional savings in material costs, specifically in wood

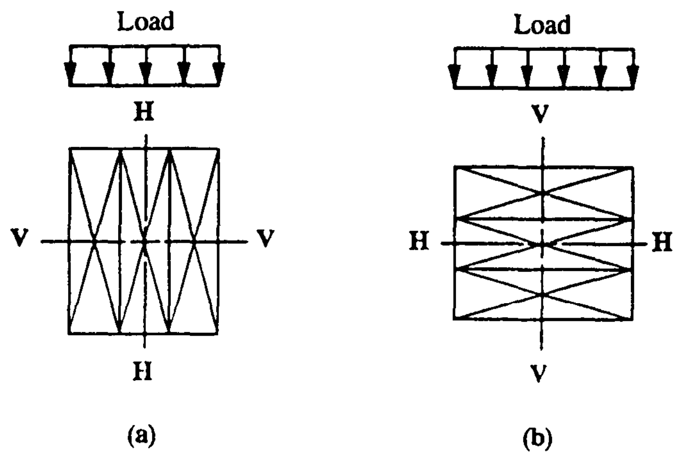



**Figure 7.1–(a) Vertically laminated, (b) horizontally laminated posts.**

preservative, may be realized if spliced posts are used when only one end of the posts are treated.

Whether or not it is feasible to use laminated posts is largely dependent on the labor and equipment costs associated with post fabrication. Glulam post assembly involves planing operations to (1) prepare surfaces for gluing, and (2) remove excess glue. Equipment for clamping layers together is essential in glulam post fabrication and is often used in the fabrication of mechanically laminated posts. If metal plate connectors are used for reinforcing, equipment with the capacity to embed the plates is also required. The initial cost of equipment is highly dependent on the degree to which the assembly process will be automated. Machines specifically built to manufacture nail-laminated posts are in use.

Costs associated with storage, handling/transportation, and erection influence post selection to a lesser degree. Maintaining a large inventory of solid-sawn posts in a variety of lengths adds to overhead costs. Builders who predominately use laminated posts are able to reduce their inventory of solid-sawn posts.

## MATERIAL REQUIREMENTS

Since allowable design values are needed by the design engineer(s), only lumber with tabulated allowable design stresses (i.e., stress-rated lumber) can be used in engineered applications. Design values for stress-graded lumber are published in the National Design Specification (NDS) for Wood Construction (NFPA, 1991)[26].

Any part of a post which is in contact with the soil or used in an application where the moisture content of the wood will exceed 20% must be pressure-treated with a wood preservative. ASAE Engineering Practice 388.2 (ASAE, 1989)[9] requires that for embedded laminated posts, the shortest treated lamination extend a minimum of 16 in. (0.40 m) above the exterior grade iine.

Minimum preservative retentions for solid-sawn and nail-laminated posts are also given in ASAE EP388.2.

Special fasteners are generally required for special environments. For below-grade use and regions that will be in wet-use condition, stainless-steel fasteners (types 304 and 316) are recommended. In above-grade areas where lumber is treated with water-borne preservatives, hot-dipped galvanized steel (1 oz. zinc/$ft^2$), silicon bronze, copper, or stainless steel types 304 and 316 fasteners should be used[10].

### Design and Constitution Options

Many design and construction options are available when laminated posts are used in a structure. Probably the greatest advantage of splicing and laminating lumber is that continuous members of any length can be built. This has enabled the construction of buildings requiring sidewall posts upward of 30 ft and endwall posts of even greater length.

Laminated posts can also be designed to “better” fit with trusses. For example, in a three-layer post, the heel of a truss can be sandwiched between the outside layers (figure 7.2). This is accomplished by leaving a portion of the center layer out until after post erection. Once the post has been set in place, the length of the missing center piece can be accurately determined. The piece, which functions only as blocking, should not be more than 1 to 2 ft in length. Gaps are reduced by setting the truss on the center block before the block is fastened in place. The advantages of sandwiching the truss in the center layer are (1) weak-axis bending moments in the posts due to eccentrically applied axial loads are reduced, and (2) fasteners used to attach the truss to the post are placed in double shear.

Another option with mechanically laminated posts is that they can be fabricated at the job site. In applications where spliced posts are being embedded, the lower (treated) portion of the post can be fabricated and set in place before the top half is assembled. This has two advantages. First, it is much easier to set only the lower part of the post. Second, the length of the top portion of each post can be adjusted prior to fabrication to account for differing elevations of the embedded portions. This procedure eliminates the need for additional adjustments for truss attachment after the top of the post has been erected (e.g., blocking as described in the previous paragraph is eliminated).

In using laminated posts, there is a need for quality control during fabrication. Inconsistencies in the placement of fasteners in mechanically laminated posts, or poor surface preparation and glued joins in glued-laminated assemblies, can substantially reduce the strength of the posts. Quality control may become an even greater problem when fabrication is done at the job site.

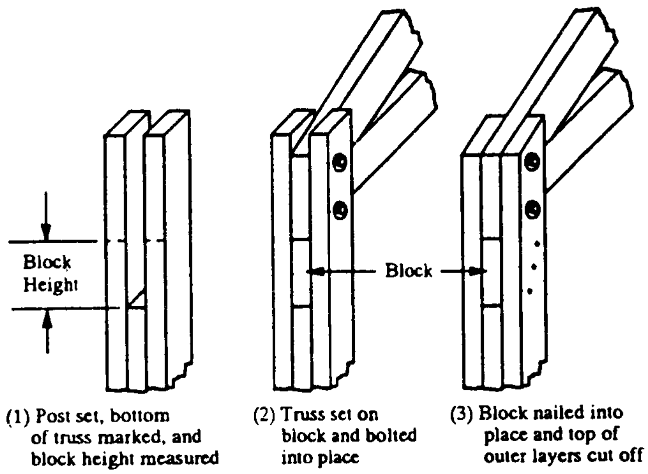



**Figure 7.2–Placement of a truss between the outer layers of a three-layer assembly.**

### DESIGN PROPERTIES

For design purposes, posts are placed in the following four categories:

1. Solid-sawn
2. Glued-laminated
3. Unspliced mechanically laminated
4. Spliced mechanically laminated

Strength and stiffness properties for the first three post types (solid-sawn, glued-laminated, and unspliced mechanically laminated posts) can be calculated using equations and data tabulated in the NDS (NFPA, 1991)[26]. The NDS does not cover spliced mechanically laminated posts. Properties for these posts can only be obtained by testing a representative sample of specimens. Such testing can be costly, and once a particular post design has been tested, modifications to the design will require that it be retested.

### STRENGTH

The relative strength of laminated posts is very dependent on the type of lamination, the presence (or absence) of end joints or splices, and the type and direction of applied loads.

Glued-laminated and mechanically laminated posts can behave quite differently under load. In the analysis of glued-laminated posts, it is assumed that there is complete composite action, that is, there is no slip between layers when the post is loaded. In this respect, glued-laminated posts behave similarly to solid-sawn posts. Mechanically laminated posts differ from glued-laminated posts in that there can be considerable slip between the layers.

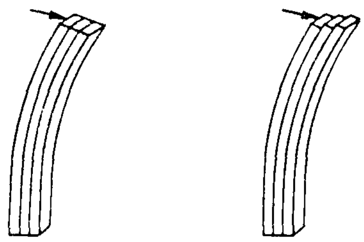



**Figure 7.3–(a) Interlayer rigidity of a horizontally glued laminated post, (b) interlayer slip of a horizontally mechanically laminated post.**

The amount of interlayer slip in a mechanically laminated post is dependent on the direction of applied loads and on the presence or absence of end joints. When a mechanically laminated post does not contain joints and is subject only to bending about axis V-V (figure 7.1a), there is negligible slip between layers. If the same unspliced post is subject to bending about axis H-H (figure 7.1b), there can be considerable slip between layers (figure 7.3b). In some mechanically laminated posts, this slip can be so large that for all practical purposes, the individual layers act independently to resist the applied loads. For this reason, mechanically laminated posts are orientated and designed to resist the highest bending moments in bending about axis V-V (figure 7.1a). When this is done, the posts are classified as vertically laminated assemblies. Because mechanically laminated posts are generally much weaker in bending about axis H-H than in bending about axis V-V, it is generally more efficient to use solid-sawn or glued-laminated posts where loads exist which will induce equally high bending moments about both post axes.

The addition of end joints to a mechanically laminated post will increase interlayer slip and reduce the strength of the post in bending about axis V-V at the location of the joints (figure 7.4a). If nail fasteners are used and the post is bent about axis H-H, delamination of the post can occur if it is not held together in the joint region (figure 7.4b). In post-frame buildings, lateral bracing (i.e., girts) helps prevent such delamination.

If a solid-sawn, a glued-laminated, an unspliced mechanically laminated, and a spliced mechanically laminated post of equal size were each fabricated using material from the same log and then compared on the basis of bending strength about their strongest axis, the rating (from strongest to weakest) would be:

1. Glued-laminated
2. Unspliced mechanically laminated
3. Solid-sawn
4. Spliced mechanically laminated

If the same four posts were compared on the basis of bending about their weak axis, the rating (from strongest to weakest) would be:

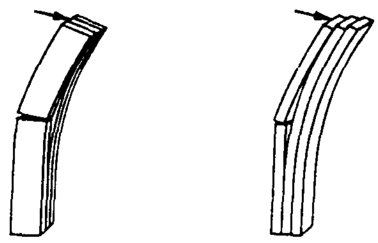



**Figure 7.4--(a) Interlayer slipin the joint region of a vertically mechanically-laminated post, (b) delamination in the joint region of a horizontally nail-laminated post.**

1. Glued-laminated
2. Solid-sawn
3. Unspliced mechanically laminated
4. Spliced mechanically laminated

The main advantage that glued-laminated posts have over solid-sawn posts is that they have more uniform strength and stiffness properties. This is because laminating spreads out natural and seasoning defects and, consequently, they are not concentrated in a particular area to the extent that they are in solid-sawn posts. This characteristic translates into greater reliability and therefore higher design stresses are justified for glued-laminated posts.

## SOLID-SAWN POSTS

The NDS[26] contains design values for solid-sawn posts that have been graded by an approved agency in accordance with U. S. Department of Commerce Voluntary Standard PS 20-70 (i.e., the American Softwood Lumber Standard)[29]. Design values appearing in the NDS are based on the provisions of ASTM Designation D245[5], "Methods for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber".

Table 7.1 gives design stresses for selected species and grades of solid-sawn posts. The values in table 7.1 have been adjusted for conditions where the moisture content of the wood will exceed 19% for extended periods of time. The latter is applicable for any portion of a post which is embedded in the soil.

## STRUCTURAL GLUED-LAMINATED TIMBER POSTS

Because individual laminations are rigidly bonded together, glulam posts behave much like solid-sawn posts, and can be designed to efficiently resist

**Table 7.1. Design stress for selected species and grades of sawn posts***

| Species and Grade | Bending $F_b$ | Tension Parallel to Grain $F_t$ | Shear Parallel to Grain $F_v$ | Compression Perpendicular to Grain $F_{c\perp}$ | Compression Parallel to Grain $F_c$ | Modulus of Elasticity E |
|---|---|---|---|---|---|---|
| | Design Values in Pounds per Square Inch (psi) | | | | | |
| Douglas Fir-Larch | | | | | | |
| Sel Str | 1500 | 1000 | 85 | 420 | 1045 | 1,600,000 |
| No. 1 | 1200 | 825 | 85 | 420 | 910 | 1,600,000 |
| No. 2 | 750 | 475 | 85 | 420 | 430 | 1,300,000 |
| Northern Pine | | | | | | |
| Sel Str | 1150 | 800 | 65 | 290 | 820 | 1,300,000 |
| No. 1 | 950 | 650 | 65 | 290 | 730 | 1,300,000 |
| No. 2 | 500 | 375 | 65 | 290 | 340 | 1,000,000 |
| Ponderosa Pine | | | | | | |
| Sel Str | 1000 | 675 | 65 | 360 | 730 | 1,100,000 |
| No. 1 | 825 | 550 | 65 | 360 | 635 | 1,100,000 |
| No. 2 | 475 | 325 | 65 | 360 | 295 | 900,000 |
| Southern Pine | | | | | | |
| Sel Str | 1500 | 1000 | 110 | 375 | 950 | 1,500,000 |
| No. 1 | 1350 | 875 | 110 | 375 | 825 | 1,500,000 |
| No. 2 | 850 | 550 | 100 | 375 | 525 | 1,200,000 |

* From the National Design Specifications (NDS) for wood under wet-use conditions[26]. Values are for lumber in the size category "Posts and Timbers". Southern Pine lumber values are from Supplement No. 1 to SPIB 1991 Standard Grading Rules for Southern Pine Lumber.

biaxial bending loads. Although a glulam member may be subject to bending about both axes, it is classified according to its orientation with respect to the larger bending moment(s). Smaller glulams that are more square in shape are typically designed as vertically laminated components; that is, they are designed to resist the largest bending moments in bending about axis V-V (this would include posts commonly used in post-frame buildings). Large, deep glulams are generally horizontally laminated because (1) higher grade lumber is more effectively used by simply placing it farther from the neutral axis (figure 7.5), and (2) the fabrication of vertically laminated assemblies of appreciable depth requires wider, more expensive pieces of lumber (in horizontal lamination, the pieces are only required to be as wide as the assembly). It is also worth noting that horizontal lamination, unlike vertical lamination, facilitates the fabrication of curved members.

Design values for glulam assemblies are published by the American Institute of Timber Construction in AITC 117, and also appear in the NDS[26] and the Uniform Building Code[24]. AITC 117, which is entitled, "Standard Specifications for Structural Glued Laminated Timber of Softwood Species" is divided into a manufacturing section[3] and a design section[2]. The manufacturing

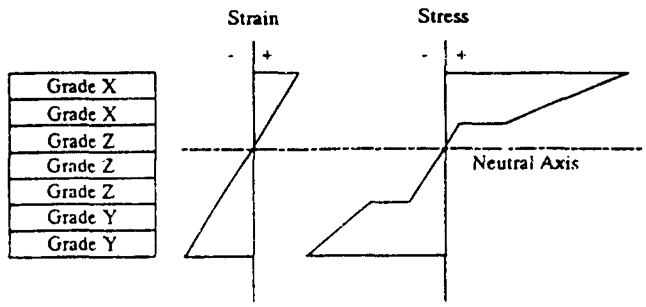



**Figure 7.5–Strain and corresponding stresses in horizontally glued laminated assembly manufactured from differential lumber grades.**

section specifies the lay-up of the grades and species of lumber for each assembly designation. The design section gives allowable properties for each of the assembly designations, as well as equations and constants for adjusting tabulated stresses for load duration, size, curvature and condition of use.

Design values for glued-laminated assemblies are based on clear wood design stresses and are established using procedures outlined in ASTM D 3737[8] "Establishing Stresses for Structural Glued Laminated Timber". Under the provisions of ASTM D 3737, individual lamination thickness cannot exceed 2 in. (51 mm) and lumber used in glulams must be specifically graded as required for the laminating combinations. Dimension lumber graded as Structural Joist and Plank and Structural Light Framing is allowed under conditions specified in the manufacturing section of AITC 117[3].

Actual fabrication of glulams must conform to ANSI/AITC A190.1 "Structural Glued Laminated Timber". This standard covers minimum requirements for the production of laminated timber, including sizes and tolerances, adhesive types, end-joint assembly, and laminating. It also covers inspection and test procedures, the quality control system for the laminator, the functions of a qualified inspection and testing agency, marking and identification. Inspection and test procedures which must be conducted to meet the requirements of ANSI/AITC Al90.1 include: (a) qualification tests to prove the capability of the manufacturing facility to meet the requirements of the standard, (b) a check of daily production including production line tests, physical tests and visual inspection, and (c) certification by a qualified inspection and testing agency upon completion of all requirements.

Lumber may be end-jointed to form any length of lamination as long as the end joint meets the requirements specified in ANSI/AITC Al 90.1. End joints which meet ANSI/AITC A190.1 requirements are classified as structural end joints. Finger joints comprise the vast majority of the structural end joints, followed by scarf joints in a distance second. If well manufactured, scarf joints can achieve up to 90% of the strength of clear wood[23]. If poorly manufactured, they may have virtually no strength.

**Table 7.2. Design values for vertically glued laminated assemblies from AITC 117**

| | | | | Extreme Fiber in Bending (psi) | | | | Tension Parallel to Grain (psi) | Compression Parallel to Grain (psi) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Bending About V-V Axis | | | Bending about H-H Axis | | | |
| AITC Combination Symbol | Species* | Lumber Grade | MOE (million psi) | 2 Lams | 3 Lams | 4 or More Lams | 2 lams to 15 in. Deep | 2 or More Lams | 2 or 3 Lams | 4 or More Lams |
| 13 | DFL | Dense Sel Str | 2.0 | 1950 | 2300 | 2400 | 2200 | 1600 | 1950 | 2300 |
| 12 | DFL | Sel Str | 1.8 | 1650 | 1950 | 2100 | 1900 | 1400 | 1650 | 1950 |
| 11 | DFL | No. 1 Dense | 2.0 | 1750 | 2100 | 2300 | 2100 | 1500 | 1700 | 2300 |
| 10 | DFL | No. 1 | 1.8 | 1500 | 1750 | 1950 | 1750 | 1300 | 1450 | 1950 |
| 9 | DFL | No. 2 Dense | 1.8 | 1500 | 1800 | 1850 | 1600 | 1150 | 1350 | 1800 |
| 8 | DFL | No. 2 | 1.6 | 1300 | 1550 | 1600 | 1350 | 1000 | 1150 | 1550 |
| 21 | HF | Sel Str | 1.6 | 1400 | 1650 | 1750 | 1500 | 1100 | 1350 | 1450 |
| 20 | HF | No. 1 | 1.6 | 1250 | 1500 | 1550 | 1350 | 975 | 1250 | 1450 |
| 19 | HF | No. 2 | 1.4 | 1100 | 1300 | 1350 | 1150 | 850 | 975 | 1300 |
| 52 | SP | Dense Sel Str | 1.9 | 1950 | 2300 | 2400 | 2100 | 1500 | 1850 | 2200 |
| 51 | SP | Sel Str | 1.7 | 1650 | 1950 | 2100 | 1750 | 1300 | 1600 | 1900 |
| 50 | SP | No. 1 Dense | 1.9 | 1750 | 2100 | 2100† | 1800† | 1550 | 1700 | 2300 |
| 49 | SP | No. 1 | 1.7 | 1500 | 1750 | 1850† | 1550† | 1350 | 1450 | 2100 |
| 48 | SP | No. 2 Dense | 1.7 | 1500 | 1800 | 1850† | 1600† | 1400 | 1350 | 2200 |
| 47 | SP | No. 2 | 1.4 | 1300 | 1550 | 1600† | 1350† | 1200 | 1150 | 1900 |
| Wet Service Factors ($C_M$‡) | | | 0.833 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.73 | 0.73 |

* DFL = Douglas Fir-Larch, HF = Hem-Fir, SP = Southern Pine
† Values reflect the removal of the more restrictive slope-of-grain requirements.
‡ The tabulated values are applicable when in-service moisture content is less than 16%. To obtain wet-use values, multiply tabulated values by factors shown.

## Design Properties

Design properties for glued-laminated assemblies appear in two separate tables[2,24,26]. Table 1 in AITC 1172 contains values for assemblies principally stressed about axis H-H (i.e., horizontally laminated assemblies), and table 2 in AITC 1172 contains values for assemblies principally stressed about axis V-V (i.e., vertically laminated assemblies). Although table 2 in AITC 117 also contains design values for bending about axis H-H, the lumber combinations in table 1 of AITC 117 are designed to more efficiently resist bending about axis H-H.

Design stresses for 15 different vertically glued-laminated assemblies from table 2 of AITC 117 are given in table 7.2. The values in table 7.2 are for normal load duration and dry conditions of use. For in-service moisture contents greater than 16%, multiply the values in the table by the wet-use factors at the bottom of the table. In addition to load duration and wet-service factors, design stresses must be adjusted by temperature factors when the member will experience sustained exposure at temperatures between 100 and 150° F (38 and 65°C)[26]. Glulam bending stresses must also be adjusted by the curvature factor, $C_c$, if the beam is curved, and by the lesser of (a) the beam stability factor, $C_L$, or (b) the volume factor, $C_v$, which is given in table 7.3[26]. Compression

**Table 7.3. Glulam volume adjustment factor ($C_V$)**

$C_V = K_L\ (21/L)^{1/x}\ (12/d)^{1/x}\ (5.125/b)^{1/x} \leq 1.0$

in which b = width (breadth) of bending member (in.)
d = depth of bending member (in.)
L = length of bending member between points of zero moment (ft)
x = 20 for Southern Pine
x = 10 for all other species
$K_L$ = loading condition coefficient described below

| Loading Condition | $K_L$ |
|---|---|
| Single span beam | |
| Concentrated load at midspan | 1.09 |
| Uniformly distributed load | 1.00 |
| Third point loading | 0.96 |
| Continuous beam or cantilever | |
| All loading conditions | 1.00 |

parallel-to-grain stresses must also be adjusted by the column stability factor, $C_P$.

Three glulam post designs which are currently being manufactured and marketed for use in post-frame buildings are shown in figure 7.6. Samples of these posts were tested in compression and also in bending about axis V-V (figure 7.1a) by researched at the Pennsylvania State University[35,36]. For each of the three posts designs, the allowable bending stress value (calculated according to ASTM 2915 procedures) was found to exceed the allowable AITC 117 value.

## UNSPLICED MECHANICALLY LAMINATED POSTS

Unspliced mechanically laminated posts **are** popular because they are relatively inexpensive and easy to assemble, and unlike spliced mechanically laminated posts, they can be designed using data tabulated in the NDS (NFPA, 1991)[26].

### DESIGN PROPERTIES

**Design Bending Strength about Axis V-V.** When bent about axis V-V (figure 7.1a), unspliced mechanically laminated posts behave much like glued-laminated and solid-sawn posts. The reason for this is that the rigidity of mechanical fasteners has little influence on an unspliced post subject to bending about axis V-V. In theory, if (a) the flexural stiffness of each layer in a laminated post without splices is the same, and (b) the post is bent around axis V-V such that all layers are forced to have the same deflected shape, then there is no transfer of force(s) between layers. Since in practice, the flexural stiffness of a piece of lumber varies somewhat along its length, and the individual layers

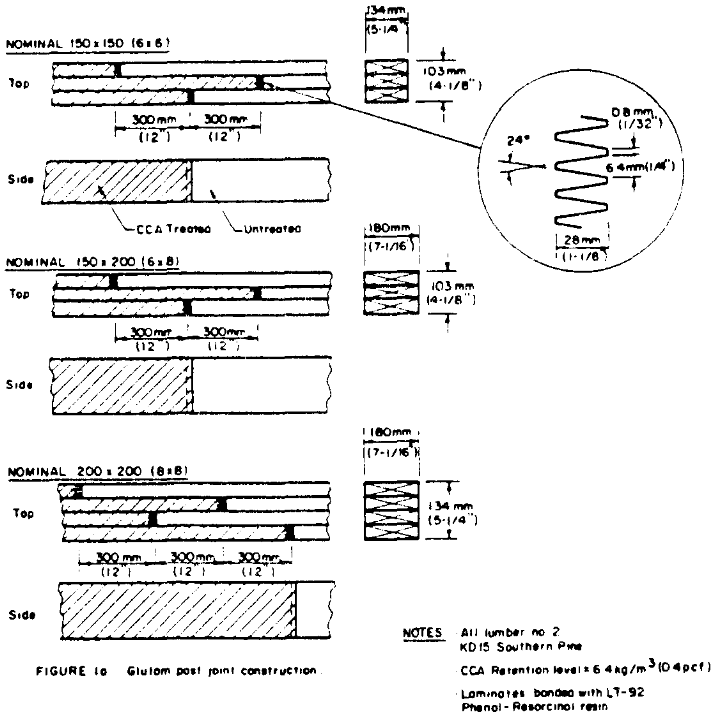



**Figure 7.6–Glued-laminated posts tested by Wright et al.[36] in compression and in bending about axis V-V.**

of a piece of lumber varies somewhat along its length, and the individual layers of a post are not always forced to have the same deflections, there will always be some transfer of force between layers.

When art unspliced mechanically laminated post has three or more layers, all of the same size, lumber grade and species. the tabulated bending stress about axis V-V is generally obtained by multiplying the tabulated bending design value for the lumber by the repetitive member factor, $C_r$, of 1.15. Tabulated bending design values, which are listed in the NDS (NFPA, 1991)[26], are established according to ASTM Standard D 245[5] "EstablishiIlg Stnsctural Grades and Related Allowable Properties for Visually Graded Lumber". ASTM D 245 allows for the use of the 1.15 repetitive member factor anytime "three or more load-carrying members such as joists, rafters, studs, or decking are contiguous or are spaced not more than 24 in. (610 mm) in frame construction and are joined by transverse floor, roof, or other load distributing elements".

Based on tests, the repetitive member factor of 1.15 would appear to be conservative for unspliced posts. Results from two separate studies showed a 46%[17] and a 28%[15] increase in design bending stress when single members were nail-laminated into three-layer unspliced assemblies. These results are similar to results reported by Sexsmith[28] on 6, 12, and 18-ply specimens held

**Table 7.4. Design values for unspliced mechanically laminated posts with three or more layers***

| | | Extreme Fiber in Bending Stress† (psi) | | | | | | Modulus of Elasticity (× $10^6$ psi) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Nominal Size of Individual Layers | | | | | | | |
| | | 2 × 6 in. | | 2 × 8 in. | | 2 × 10 in. | | | |
| | | Moisture Content in Use‡ | | | | | | | |
| Species§ | Grade | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet |
| DFL | Sel Str | 2170 | 1840 | 2000 | 1700 | 1835 | 1560 | 1.9 | 1.71 |
| DFL | No. 1 & Better | 1720 | 1460 | 1590 | 1350 | 1455 | 1235 | 1.8 | 1.62 |
| DFL | No. 1 | 1495 | 1270 | 1380 | 1170 | 1265 | 1265 | 1.7 | 1.53 |
| DFL | No. 2 | 1310 | 1310 | 1210 | 1210 | 1110 | 1110 | 1.6 | 1.44 |
| HF | Sel Str | 2090 | 1780 | 1930 | 1640 | 1770 | 1505 | 1.6 | 1.44 |
| HF | No. 1 & Better | 1570 | 1335 | 1450 | 1230 | 1330 | 1130 | 1.5 | 1.35 |
| HF | No. 1 | 1420 | 1200 | 1310 | 1310 | 1200 | 1200 | 1.5 | 1.35 |
| HF | No. 2 | 1270 | 1270 | 1170 | 1170 | 1075 | 1075 | 1.3 | 1.17 |
| SP | Dense Sel Str | 3105 | 2640 | 2820 | 2395 | 2470 | 2100 | 1.9 | 1.71 |
| SP | Sel Str | 2930 | 2490 | 2645 | 2250 | 2360 | 2000 | 1.8 | 1.62 |
| SP | Non-Dense Sel Str | 2700 | 2300 | 2415 | 2050 | 2130 | 1810 | 1.7 | 1.53 |
| SP | No. 1 Dense | 2010 | 1710 | 1900 | 1610 | 1670 | 1420 | 1.8 | 1.62 |
| SP | No. 1 | 1900 | 1610 | 1725 | 1465 | 1495 | 1270 | 1.7 | 1.53 |
| SP | Non-Dense No. 1 | 1725 | 1465 | 1550 | 1320 | 1380 | 1170 | 1.6 | 1.44 |
| SP | No. 2 Dense | 1670 | 1420 | 1610 | 1370 | 1380 | 1170 | 1.7 | 1.53 |
| SP | No. 2 | 1440 | 1220 | 1380 | 1170 | 1210 | 1025 | 1.6 | 1.44 |
| SP | Non-Dense No. 2 | 1320 | 1320 | 1265 | 1265 | 1090 | 1090 | 1.4 | 1.26 |

* For lumber surfaced dry or surfaced green under normal load duration.

† Size and repetitive member factors applied. For other applicable modification factors s‹ NDS Table 2.3.1 [26].

‡ Wet values apply when dimension lumber is used where moisture content will exceed 19% for an extended time period.

§ DFL – Douglas Fir-Larch, HF – Hem-Fir, SP – Southern Pine.

together with a transverse stressing technique, and results reported by Wolfe and Moody[34] for assemblies that were glued.

Table 7.4 contains allowable bending stresses for unspliced mechanically-laminated posts with three or more layers. Table values reflect incorporation of size, wet service, and repetitive member factors. “Wet” values should be used when post moisture content will exceed 19% for an extended period of time. The reduction for high moisture content conditions is generally required because a mechanically laminated post, regardless of its size, does not fall under the classification of “lumber 5 in. (127 mm) and thicker”. Wet values where obtained by multiplying the “dry” values by a wet service factor, $C_{M,}$, of 0.85 except when the product of the single member bending stress, $F_b$ and the size factor, $C_F$ was less than 1,150 psi (7930 kPa) , in which case CM was set equal to 1.0026.

Before the allowable stresses in table 7.4 can be used, they must be further adjusted to account for stability, load duration, and other conditions.[26] To adjust for stability, the beam stability factor, $C_L$, is used. This 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 an unspliced mechanically laminated post, d is the actual depth of an individual layer, and b may be conservatively taken as the actual thickness of an individual layer. The width b should not be equated to the overall width of the post n × b, where n is the number of layers. Such an assignment would be unconservative since the individual layers, because of interlayer slip, do not act together like a solid-sawn or glued-laminated post in resisting out-of-plane buckling (i.e., bending about axis H-H). The effective span length, $l_e$ is a function of the unsupported length, $l_U$, which is generally taken as the on-center spacing of the lateral bracing (i.e., girts).

**Design Bending Strength about Axis H-H.** Where loads that induce bending about axis H-H (figure 7.1b) exist in addition to those that induce bending about axis V-V, the design stress for bending about the weak axis must also be determined.

When an unspliced mechanically laminated post has three or more layers, all of the same size, lumber grade and species, the allowable bending stress about axis H-H is generally obtained by multiplying the tabulated single member design value for the lumber by the 1.15 repetitive member factor and by a flat use factor, $C_{fu}$. For lumber that is 2 in. (51 mm) thick, $C_{fu}$ is equal to: 1.1 for pieces 4 in. (102 mm) wide, 1.15 for pieces 6 in. and 8 in. (152 and 203 mm) wide, and 1.20 for pieces 10 in. (254 mm) and wider[26]. The tabulated allowable stress must be further adjusted to account for load duration and other conditions; however, since the depth of a piece of dimension lumber laid flatwise does not exceed its breath, the tabulated allowable stress need not be further adjusted to account for stability.

The allowable bending capacity about axis H-H is calculated by multiplying the adjusted allowable bending stress by (a) the “flatwise” section modulus of an individual layer, and (b) the number of layers. This calculation is conservative in that individual layers are assumed to act independently in resisting the applied bending loads.

**Design Compressive Strength.** The allowable compressive stress for an individual layer is calculated by treating the layer as a simple solid column. Two allowable compressive stresses must generally be calculated for each layer, one for buckling about axis V-V and one for buckling about axis H-H (buckling about the minor axis cannot be assumed if the effective column length, $l_e$, is less for buckling about the minor axis). The lesser of the two values is multiplied by the net cross-sectional area of the layer to obtain the allowable load for the layer. Allowable “layer” loads are summed to obtain the maximum allowable compressive load for the post.

As with bending about axis H-H, the preceding calculation conservatively assumes that the layers act independently to resist buckling about axis H-H. In

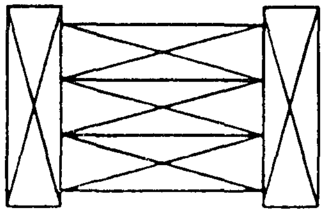


**Figure 7.7–Cover plates used to increase the bending capacity of a laminated post about axis H-H.**

reality, there is a certain amount of composite action between layers. Contained in section 15.3 of the latest NDS (1991) are design procedures for "nailed built-up columns" and "bolted built-up columns" that take into account partial composite action. These new design procedures can only be used when specific connection requirements, as outlined in the NDS, are met. Results of tests conducted on built-up columns are available from other sources [18,25,27].

Cover plates are often added to an unspliced mechanically-laminated post (figure 7.7) when instability about the H-H axis limits the design compressive strength. The allowable compressive strength for posts with cover plates is determined by first calculating the column capacity of a solid column equal in size to the "built-up" post (i.e., the post with the cover plates installed). This value is then reduced by the appropriate adjustment factor from table 7.5 to arrive at the allowable compressive strength for the built-up post[19]. The values in table 7.5, which are a function of the slenderness ratio of the solid column, are only applicable when the cover plates are well nailed or bolted.

**Bending Stiffness about Axis V-V.** When bent about axis V-V, unspliced posts are assumed to have no slip between the individual layers, a valid assumption when the layers are forced (by a load-distributing element) to have the same displaced geometry. When there is no slip between individual layers, and each layer has (a) the same moment of inertia and (b) a centroid located on centroidal axis V-V, then the flexural rigidity (modulus of elasticity × moment of inertia) of the post is equal to the average modulus of elasticity of the layers multiplied by the total moment of inertia of the post.

**Bending Stiffness about Axis H-H.** The stiffness in bending about axis H-H is highly dependent on the lateral load-slip (i.e., stiffness) properties and the location of the nail fasteners. High and low bounds on stiffness can be calculated by assuming that (a) there is no slip between layers (complete composite action), and (b) there is no connection between the layers (no composite action). Computer programs specifically written for the analysis of horizontally, mechanically laminated assemblies are available and can be used if a more accurate estimate of stiffness is desired[11].

### NAIL LOCATION

To reduce or minimize the splitting of wood, nail spacing and the distance between a nail and the end or edge of a member must be controlled. Although

Table 7.5. Adjustment factors for built-up columns with cover plates[19]

| Slenderness Ratio (L/d) of Equivalent Solid Column | Ratio of Built-Up Column Strength to Equivalent Solid Column Strength |
|---|---|
| 6 | 82 |
| 10 | 77 |
| 14 | 71 |
| 18 | 65 |
| 22 | 74 |
| 26 | 82 |

diameter and wood grain orientation. In special cases, they may also be dependent on wood species.

Hoyle and Woeste[22] proposed the following minimum nail spacings when no pre-drilled holes are used:

| | |
|---|---|
| End distance | 20 nail diameters |
| Edge distance | 5 nail diameters* |
| Perpendicular-to-grain spacing | 10 nail diameters |
| Parallel-to-grain spacing | 20 nail diameters |

(*With the exception of the edge distance value, Hoyle and Woeste's minimum nail spacings are recommended for nail-laminated assemblies. Because of high fiber stresses on member edges it is recommended that the minimum edge distance be increased to 10 nail diameters for nail-laminated assemblies.)

One additional note with respect to nails is that lumber design stresses from the NDS do not need to be adjusted downward to account for the presence of the fasteners.

## Spliced Mechanically Laminated Posts

Posts are spliced for two primary reason: (a) to obtain long posts from shorter, less expensive lumber, and (b) to save on wood preservative and corrosion resistant fasteners and hardware. The disadvantage of splicing is that it reduces post strength in the vicinity of the joints, and complicates post analysis and design procedures. The magnitude of the strength reduction is primarily dependent on the type of end joint(s), the relative location of the joints, and the type and relative location of the mechanical fasteners. To compensate for strength reductions, joint areas are often reinforced.

The majority of the spliced posts fabricated today are nail-laminated. Although bolts, screws, and shear transfer plates (metal plate connectors with teeth on both sides) have been used to fabricate spliced mechanically-laminated posts, design information for the assemblies is not in the public domain, consequently, they are not covered in detail here.

The type of end joints used inspliced posts can significantly affect post strength. The vast majority of spliced mechanically laminated posts feature

The type of end joints used inspliced posts can significantly affect post strength. The vast majority of spliced mechanically laminated posts feature simple butt joints, which even when glued, are assumed to transfer no bending or tensile load. Structurally-glued finger joints, which can transfer substantial load, are seldom used in mechanically laminated posts. Because structurally glued end joints are a stronger alternative to butt joints, mechanically laminated posts with structurally glued end joints are covered at the end of this section.

### ANALYSIS METHODS

To quantify the properties of various vertically mechanically-laminated post designs a finite element method of analysis for the assemblies was developed by Bohnhoff et al.[22]. This method, which is embodied in a computer program entitled FEAST, contains five basic modeling elements: a conventional plane-frame element for modeling lumber, a frame-to-frame connector element for modeling a fastener joining two layers, a gap element for modeling butt joints, and a plate and a frame-to-plate element which are used to model metal plate connectors and shear transfer plates. It is important to note that FEAST is a research tool that is not user-friendly or marketed for routine structural analysis.

### DESIGN PROPERTIES

**Design Bending Strength about Axis V-V.** Because of the complex redistribution of forces in end joint areas, the bending strength about axis V-V of a spliced mechanically laminated post is currently determined by a laboratory test of a representative sample of actual assemblies. The procedure generally followed to obtain allowable design properties from laboratory tests is ASTM D 2915[6] "Evaluating Allowable Properties for Grades of Structural Lumber". A 2-point load, applied in accordance with ASTM D 198[4] is commonly used to establish the ultimate bending strength of each post. To arrive at an allowable bending strength for design, the fifth percentile of the distribution of the ultimate bending strength for all assemblies tested is divided by 2.1. The 2.1 is from ASTM D 245[5] and is the product of a load duration factor of 1.6 and a traditional safety factor of 1.3[22]. The load duration factor is used to adjust the strength determined in a test with an approximate duration of 5 min to that expected under a load with a duration of 10 yr.

Table 7.6 contains the results of flexural tests for 11 three-layer, spliced nail-laminated post designs. Corresponding nailing patterns are shown in figure 7.8. The three-layer nail-laminated assembly is probably the most commonly used spliced mechanically-laminated post. In cases where the post will be embedded in the soil, the three members making up the lower portion of the post are preservative treated. The three butt joints are normally staggered and spaced either 18 or 24 in. (457 or 610 mm) apart for an overall splice length of 3 or 4 ft (914 or 1220 mm), respectively. The type and amount of butt joint reinforcing and the type and location of nails vary from builder to builder.

**Table 7.6. Bending strength of three-layer vertically nail-laminated assemblies with staggered butt joints***

| Source | Design | No. Tested | Lumber Type§ | Size∥ | Nail Specifications | | | Butt Joint Reinforcement | Overall Splice Length [ft (m)] | Ultimate Midspan Bending Moment† | | Allowable Design Bending Moment‡ [ft-k (kN-m)] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Shank Type | Driving Method | No.# | | | Mean [ft-k (kN-m)] | C.V. (%) | |
| DeBonis [20] | 1 | 20 | No.2D SP | 12d | Common | Hand | 48 | None | 4 (1.22) | 6.15 (8.34) | 33.1 | 1.63** (2.21) |
| Winistorfer [30] | 2 | 5 | No.2 HF | 20d | Ring | Hand | 16 | None | 2 (0.61) | 2.83 (3.84) | 20.6 | †† |
| | 3 | 5 | No.2 HF | 20d | Ring | Hand | 16 | None | 4 (1.22) | 5.64 (7.65) | 11.5 | †† |
| | 4 | 5 | No.2 HF | 20d | Ring | Hand | 16 | ‡‡ | 2 (061) | 5.04 (6.83) | 10.2 | †† |
| | 5 | 5 | No.2 HF | 20d | Ring | Hand | 16 | ‡‡ | 4 (1.22) | 6.61 (8.96) | 12.5 | †† |
| Woeste [32] | 6 | 25 | No.1D SP | A | Threaded | Gun | 48 | §§ | 4 (1.22) | 9.58 (13.0) | 11.0 | 3.71∥∥ (5.03) |
| Woeste [33] | 7 | 20 | No.1D SP | B | Threaded | Gun | 48 | ## | 4 (1.22) | 10.90 (14.8) | 8.3 | 4.43∥∥ (6.01) |
| Bohnhoff [15] | 8 | 28 | No.1D SP | C | Spiral | Machine | 16 | None | 4 (1.22) | 8.75 (11.9) | 18.1 | 2.92*** (3.96) |
| | 9 | 28 | No.1D SP | D | Threaded | Gun | 16 | None | 4 (1.22) | 9.06 (12.3) | 18.7 | 2.91∥∥ (3.95) |
| | 10 | 28 | No.1D SP | C | Spiral | Machine | 16 | ††† | 4 (1.22) | 9.84 (13.4) | 13.7 | 3.52∥∥ (4.77) |
| | 11 | 28 | No.1D SP | D | Threaded | Gun | 16 | ††† | 4 (1.22) | 10.47 (14.2) | 12.9 | 3.82∥∥ (5.20) |

* Nominal 2 × 6 in. (standard 38 × 140 mm) lumber used in all assemblies. All assemblies loaded to failure in bending under a two-point loading.
† Moment between load points at maximum applied load. C.V. is coefficient of variation.
‡ Five percent exclusion limit for ultimate midspan bending moment divided by 2.1.
§ SP is Southern Pine, KD15. HF is Hem-Fir, surface dry.
∥ Nail dimensions: 12d common, 0.14 × 3.3 in. (3.8 × 83 mm); 20d ring-shank, 0.18 × 4.0 in. (4.5 × 102 mm). Other nail sizes were as follows: A, 0.12 × 3 in. (3 × 76 mm); B, 0.12 × 3 in. (3 × 76 mm); C, 0.19 × 4.5 in. (4.8 × 114 mm); D, 0.145 × 4 in. (3.7 × 102 mm).
\# Number of nails in center four feet of assembly.
** Based on lognormal distribution.
†† Sample size not large enough to obtain a good 5% exclusion limit.
‡‡ One 5 × 10 in. × 19 gauge (127 × 254 × 1.2 mm) nail plate per outside joint.
§§ One 5 × 24 in. × 20 gauge (127 × 610 × 0.9 mm) AISI 1010 steel sheet per joint.
∥∥ Based on three parameter Weibull distribution.
\## One 5.1 × 10.8 in. × 18 gauge (130 × 275 × 1.2 mm) metal plate connector per outside joint.
*** Based on normal distribution.
††† One 5.25 × 8.75 in. × 18 gauge (133 × 222 × 1.2 mm) metal plate connector per outside joint.

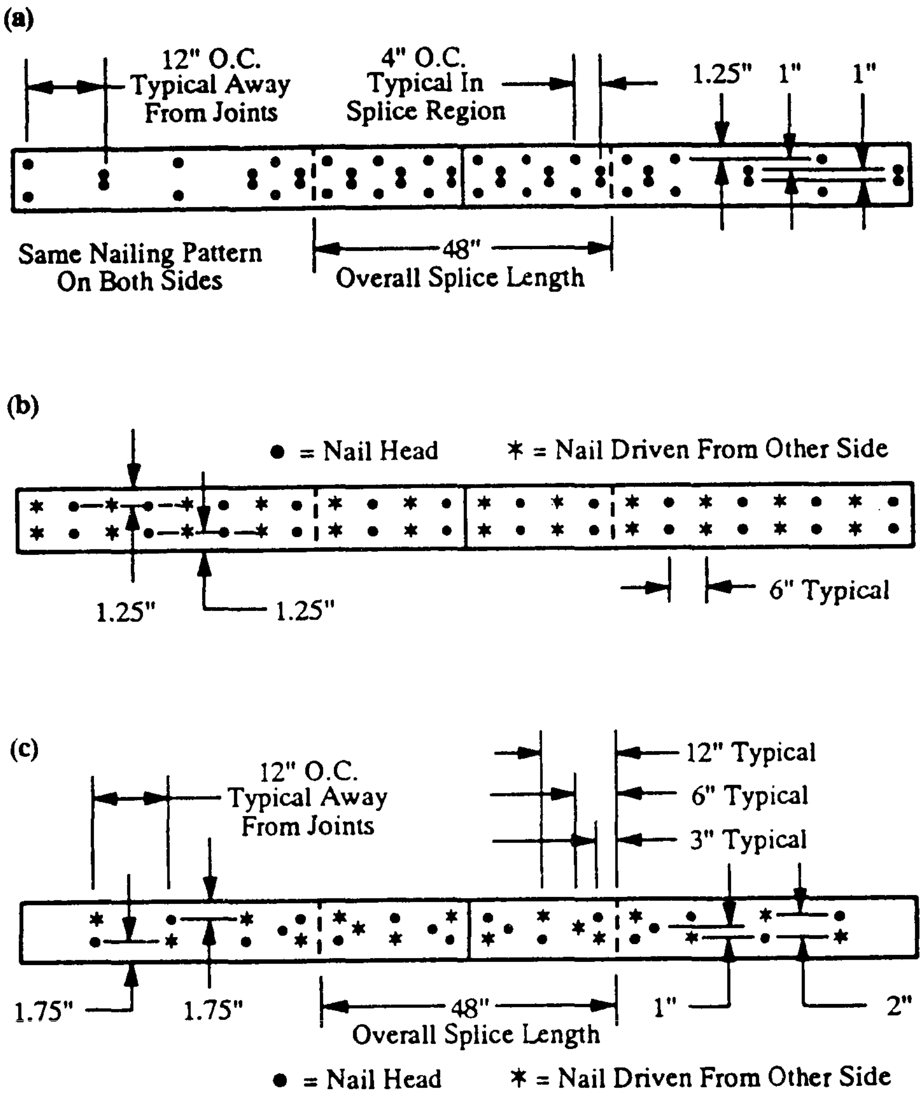



**Figure 7.8–Nailing patterns for three-layer, nail-laminated posts with staggered butt joints. Nailing patterns used by (a) Woeste[32] (similar to pattern used by DeBonis et al.[20] and Woeste et al.[33]), (b) Winistorfer et al.[30] (not recommended for use), and (c) Bohnhoff et al.[15].**

To avoid confusion with respect to the strength of spliced posts, the allowable design bending strength values for the posts have been expressed as moment values and not as stress values. Spliced posts are complex structural systems and are not homogeneous, rectangular members. Engineers who assign allowable bending stresses to spliced mechanically laminated assemblies must assume some effective moment of inertia or section modulus. Some engineers use the actual outside dimensions of the post to calculate the section properties. This results in a bending stress that is an average of the bending stresses of the

**Table 7.7. Bending strength modification factors for four types of spliced posts (from Bohnhoff and Moody[14])***

| Nail Driving Method | Butt Joint Reinforcement | Bending Strength Modification Factor† |
|---|---|---|
| Machine | No | 0.425 |
| Gun | No | 0.424 |
| Machine | Yes | 0.512 |
| Gun | Yes | 0.558 |

* See designs 8 to 11 in table 7.6 for post designs.

† Calculated by dividing design bending moment value by the calculated design value for an unspliced post assuming a three-parameter Weibull distribution.

individual layers. Such an average value. although useful for comparisons and design, does not indicate the actual level of stress-in the individual layers.

Because different procedures are used to arrive at the allowable bending moment values for spliced and unspliced mechanically laminated posts, it is possible to find a design value for a spliced post with butt joint reinforcement that is greater than that calculated for an unspliced post fabricated using the same size, grade, and species of lumber. This leads to confusion because the engineer is led to conclude that the spliced region of the post is stronger than the unspliced region. In spliced nail-laminated posts, this is seldom, if ever, true because of the relatively light reinforcing used in the assemblies. The bottom line is that if the same test procedure used to determine the allowable bending moment for spliced posts was used for unspliced posts, the allowable bending stress for that sample of unspliced posts would, in most instances, be higher than that based on published allowable stress values [15,17].

**Proposed Method for Calculating Design Bending Strength about Axis V-V.** As previously mentioned, allowable design values for spliced posts are determined by actually fabricating and testing a number of specimens. Since this is a costIy and time-consuming process, a procedure has been proposed whereby allowable values for spliced posts are calculated by multiplying the design values for unspliced posts by strength modification factors[14]. Before such a procedure cart be implemented, (a) the "conservativeness" of the design values for unspliced posts must be investigated, and (b) considerably more testing or analysis is needed to establish strength reduction factors.

A strength modification factor would be determined by dividing the design strength of a spliced post by the design strength of an unspliced post. To establish such strength modification factors, spliced and unspliced posts must be evaluated under the same conditions. This includes using randomly selected lumber from the same lot to fabricate both post types. Without such a procedure, variability in strength caused by lumber characteristics (such as species and grade) cannot be differentiated from differences in strength caused by splicing.

Only recently has an experiment comparing spliced and unspliced post been conducted [15]. Both spliced and unspliced assemblies were fabricated from the same lot of lumber. Bending strength modification factors calculated on the basis of these data are listed in table 7.7.

The bending strength modification factors listed in table 7.7 demonstrate the significant reduction in strength associated with splicing. The design bending strength of three-layer spliced posts without butt joint reinforcement was found to be 40% to 45% of the design strength of the three-layer unspliced assemblies. One belief is that since two of the three layers are continuous at each joint, the post should have a design bending strength that is approximately two-thirds of that for an unspliced post. The problem with this assumption is that the following three factors are not taken into account: (a) the bending moments in the two continuous layers adjacent to a joint can be substantially different because of the redistribution of forces in the vicinity of the joint: (b) fastener shear forces are much higher in spliced posts and precipitate failures in the posts that are not common to unspliced posts; and (c) design strengths are highly dependent on the variability in strength of individual specimens, and such variability is generally higher for spliced posts than it is for unspliced posts.

Another reason that bending strength modification factors are lower than typically perceived is because test results for spliced posts are not compared to test results for unspliced posts, but instead, are often compared to NDS allowable design values for unspliced posts. The latter comparison is misleading since the design bending strength for an unspliced post based on NDS can be considerably lower than that based on actual test results. In one study, the NDS allowable bending moment for an unspliced post was found to be only 59% of the value determined from test [15]. This large difference can be attributed to two factors: (a) the conservativeness of the NDS repetitive member factor of 1.15; and (b) the fact that NDS values are applicable to ail lumber from a broad range of sources, and therefore are often conservative for specific groups of lumber.

Before bending strength modification factors can be used to assign design values to various types of spliced posts, additional testing and modeling will be necessary. This is because bending strength modification factors are dependent on such design variables as overall splice length, number of layers, grade and species of wood, lumber size, nail size and density, nail joint stiffness, and type and location of butt joint reinforcement. Although several studies involving spliced nail-laminated posts have been conducted, their usefulness is limited because individual pieces of lumber and unspliced posts were not also evaluated. Lumber is variable, even within the same grade and species. If the strength and stiffness of individual pieces of lumber are not known, it is very difficult to determine where the batch or lot of lumber ranks with respect to others batches and lots of the same grade. Without design values for unspliced posts, strength modification factors cannot be calculated and dissimilar spliced post designs can not be compared.

**Design Bending Strength about Axis H-H.** The design bending strength about axis H-H can be determined in the same manner as used to determine the bending strength about axis V-V. It should be noted that spliced nail-laminated

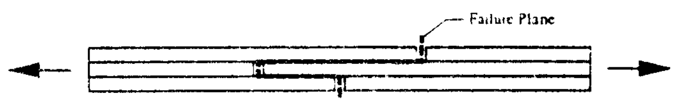



**Figure 7.9–Failure plane for spliced, mechanically laminated posts loaded in tension.**

posts are designed into walls such that they are not subjected to any appreciable bending about axis H-H. For this reason few, if any, spliced posts have been tested in bending about axis H-H. When spliced, nail-laminated posts are not located within a wall and/or are not laterally supported. loads applied normal to the interlayer plane tend to cause delamination of the assembly in the joint area (figure 7.4b).

**Design Tensile Strength.** In tension tests conducted on six different spliced, mechanically laminated post designs at the USDA Forest Products Laboratory [16], all posts failed as shown in figure 7.9: that is, the strength of each post was dictated by the force required to separate the three wood members on one end of the post from the three on the other end. In other words, post tensile strength was limited by the strength of the mechanical fasteners and not by the tensile strength of the No. 1 Dense KD Southern Pine lumber used to fabricate the posts. The same study demonstrated that splicing substantially reduces post stength, but that a good percentage of the strength lost by splicing could be recovered with proper use of butt joint reinforcement. Without butt joint reinforcement, the design tensile strengths of two of the unreinforced spliced designs involved in the study were shown to be less than 15% of the design strength of an unspliced post fabricated using the same grade and species of wood [16].

Assuming that all unreinforced nail-laminated posts will fail as shown in figure 7.9, the design tensile strength of the posts can be calculated by multiplying the NDS design value for a nail in single shear by the number of active nail shear planes. The number of active nail shear planes is equal to the number of nail shear planes located along the failure plane shown in figure 7.9.

**Design Compressive Strength.** Allowable compressive stresses for spliced posts are generally calculated by treating the assemblies as solid-sawn posts. The assumption that a spliced post in compression behaves like a solid column is justifiable when (a) butt joint gaps are narrow and thus closed under relatively low compressive loads, and (b) post buckling is prevented.

**Combined Bending and Axial Compression.** The combination of bending moments and axial compressive forces generally controls the design of posts in post-frame buildings. In cases of combined flexure and axial compression, use of the NDS[26] combined load equation (i.e., the interaction fommla) for single members can be justified when: (a) stresses due to flexure are higher than those due to compression, and (b) allowable flexural stresses are based on laboratory tests of spliced posts, and (c) butt joint gaps are closed by relatively low compressive loads. The reasoning behind this statement is that flexutal failures in spliced posts are almost always tension related; that is, the

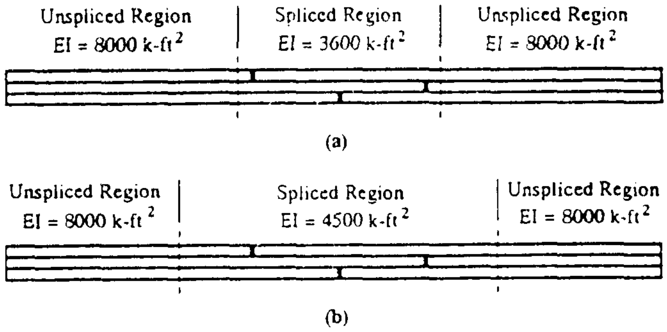



**Figure 7.10–Effect of selection of spliced region length on effective flexural ridigity.**

majority of the failures are either wood splits that run through nails located in the tension zone, or fractures of the tension strands of the metal connecting plates used to reinforce butt joints. The addition of an axial compressive force to a spliced post already under a bending load will not only decrease forces in the tension regions, but will increase the amount of load transferred across the butt joints. The latter works to equalize the distribution of load among the individual layers. Although not substantiated by test, it is quite likely that the addition of a small compressive force may actually increase the bending capacity of a spliced post, much like the addition of a small compressive load to a reinforced concrete member increases the bending capacity of the concrete member.

In cases of combined flexure and axial compression, where stresses due to axial compression are higher than those due to bending, use of the NDS interaction formula for single members would appear suspect in all cases except those where butt joint gaps are closed under relatively low load and the post buckling is prevented.

**Bending Stiffness about Axis V-V.** The bending stiffness of a homogeneous member is commonly defined as EI/L where E is the modulus of elasticity, I the moment of inertia and L the length of the member. The product of E and I is generally referred to as the flexural rigidity of the member.

The flexural rigidity of a spliced nail-laminated post, unlike that of homogeneous members, varies along the length of the post. Consequently, to be accurately represented in a plane-frame structural analog, each post must be divided into elements. Exactly where to section a spliced post and what flexural rigidity to assign each section are functions of several design variables. To standardize the procedure for accomplishing these two tasks, Bohnhoff and Moody[14] proposed a method by which spliced posts are sectioned into elements with and without joints. Sections without joints will be treated like unspliced nail-laminated assemblies and assigned flexural rigidities accordingly. The stiffness of each section containing a splice or splices will be obtained by

**Table 7.8. Equations for calculation stiffness modification factors using notation from figure 7.11**

| Location of Load Point | Location of Deflection Measurement: Load Point | Location of Deflection Measurement: Midspan |
|---|---|---|
| b > a | $\alpha = \dfrac{L - 2b}{4EI\Delta_l/(a^2P) + 4a/3 - 2b}$ | $\alpha = \dfrac{L^2/4 - b^2}{4EI\Delta_m/(aP) + a^2/3 - b^2}$ |
| b < a | $\alpha = \dfrac{3a^2L - 4a^3 - 2b^3}{12EI\Delta_l/P - 2b^3}$ | $\alpha = \dfrac{3aL^2/8 - b^3 - a^3/2}{6EI\Delta_m/P - b^3}$ |

where

- $\alpha$ = stiffness modification factor
- $L$ = distance between supports
- $a$ = distance between support and load point
- $b$ = distance from support to change in assembly stiffness
- $\Delta_l$ = load point deflection
- $\Delta_m$ = midspan deflection
- $P$ = total applied load (sum of both point loads)
- $EI$ = effective flexural rigidty of the unspliced section

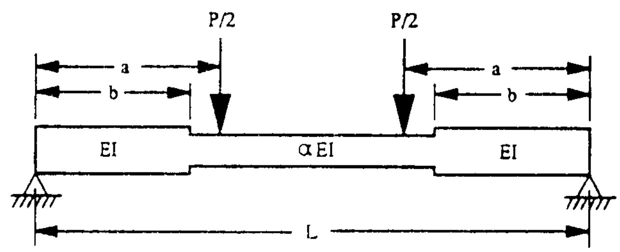



**Figure 7.11–Model of a spliced assembly under a two-point loading; reduced flexural ridigity in the spliced region.**

multiplying the flexural rigidity of the unspliced section or sections by a stiffness modification factor.

By definition, the stiffness modification factor is the ratio of the "effective" flexural rigidity of the spliced section in question to the flexural rigidity of the adjacent unspliced section or sections. The effective flexural rigidity for the section containing joints is highly dependent upon the stiffness of the mechanical fasteners used to construct the post, and can be determined with the aid of a special computer program [13] or can be calculated using load-deflection data from laboratory tests.

The effective flexural rigidity assigned to a section with joints depends on how the length of the section is defined. Figure 7.10 shows the same laminated post, sectioned at two different locations. In figure 7.10a, the sections without joints (outside sections) have a flexural rigidity twice that of the section with

**Table 7.9. Properties for modeling the spliced regions of three-layer nail-laminated posts fabricated with staggered butt joints***

| | | Properties for Modeling† | |
|---|---|---|---|
| Overall Splice Length [ft (m)] | Outside Butt Joint Reinforcement | Length of Spliced Section [ft (m)] | Stiffness Modification Factor‡ |
| 2 (0.61) | no | 6 (1.83) | 0.37 |
| 2 (0.61) | yes | 6 (1.83) | 0.68 |
| 4 (1.22) | no | 8 (2.44) | 0.59 |
| 4 (1.22) | yes | 8 (2.44) | 0.74 |

* Posts made from nominal 2 × 6 in. (actual 38 × 140 mm) lumber.

† Multiply by the flexural rigidity of the unspliced sections to obtain the effective flexural rigidity (EI) of the spliced region.

‡ See designs 2 to 5 and 8 to 11 in table 7.6 for post designs. Because the data are based on a limited number of tests, the value should be used with caution.

joints (middle section). As the length of the middle section is expanded to include more of the "stiffer" outer regions (figure 7. 10b), its effective flexural rigidity increases.

Figure 7.11 and the equations in table 7.8 can be used to obtain stiffness modification factors from laboratory test data. The equations only apply to posts 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 flexural rigidity of the unspliced section, EL 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).

The equations in table 7.8 were used to obtain the factors in table 7.9. A value for b was selected that made the length of the spliced region equal to the overall splice length plus 4 ft (1.22 m). In other words, the spliced section included those portions of the post within 2 ft (0.61 m) of the leftmost and rightmost joints. The values in table 7.9 were based on a limited number of assembly tests and are included to demonstrate the approach only. The magnitude of these factors is highly dependent on nail type and location.

### SPLICED NAIL-LAMINATED POST DESIGN

**Layout of Butt Joints.** Splices in nail-laminated posts are almost always simple butt joints. Since butt joints do not transfer tensile force, they will reduce the strength of the assembly when they are used. By properly locating butt joints with respect to each other, this loss of strength can be minimized.

When laying out butt joints, two factors must be considered. First, and probably most important, is the distance between the joints. Second is the arrangement of the joints.

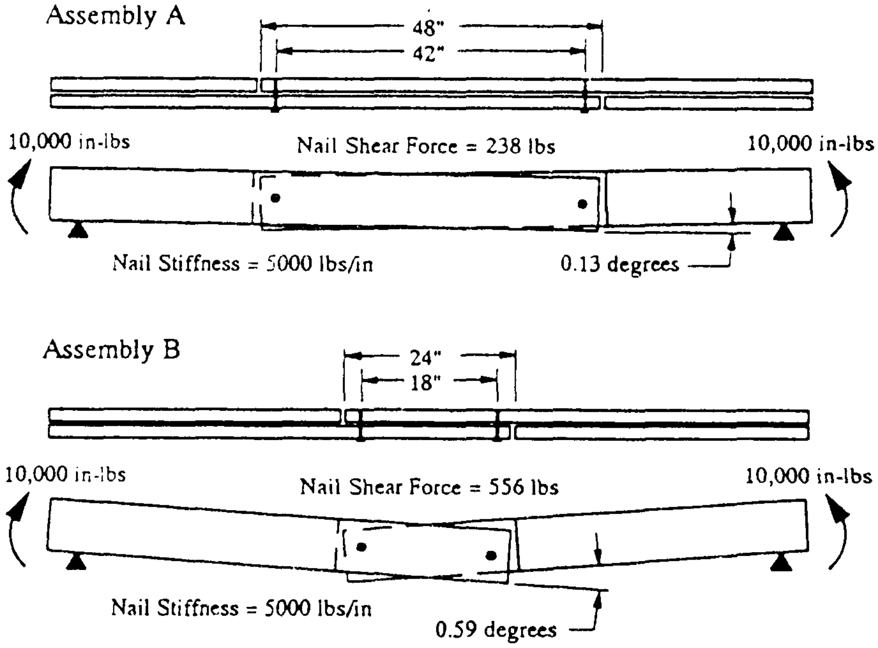



**Figure 7.12–Influence of splice length on nail shear force and stiffness of a two-layer assembly.**

The influence of joint spacing on bending strength and stiffness is demonstrated with the two-layer assemblies in figure 7.12. In assembly A, a 4 ft (1.22 m) lap of the longer members is created when the joints are spaced 4 ft (1.22 m) apart. This long lap allows for a nail spacing of 42 in. (1.07 m) In assembly B, the lap length is 2 ft (0.61 m) and the distance between the nails is only 18 in. (0.46 m). When a bending moment of 10,000 in.-lb (1.13 kN-m) is applied to the assemblies in figure 12, the nail shear forces in assemblies A and B are 238 lb and 556 lb (1.06 and 2.47 kN), respectively. If all nail joints are assumed to have a shear stiffness of 5,000 lb-in., (0.565 kN-m) the rotation (due to just nail slip) between the members in assembly A would be 0.13 and the rotation between the members in assembly B would be 0.59°. This example illustrates one very important principle: longer lap lengths facilitate greater nail spacings which result in lower nail forces and stiffer assemblies.

When a post is comprised of three or more layers, the arrangement of joints becomes a design variable. For three layer posts there are two possible joint patterns or arrangements: the step and the stagger. Both are shown in figure 7.13. Almost all three-layer posts fabricated today feature the staggered arrangement of joints. Although the reason for this practice is not entirely clear, two possible explanations are: (1) it is easier to field connect the upper and lower parts of a post when joints are staggered; and (2) the unreinforced stagger has a tensile strength greater than the unreinforced step. The latter statement is based on the fact that more nail shear planes are involved in the tensile failure

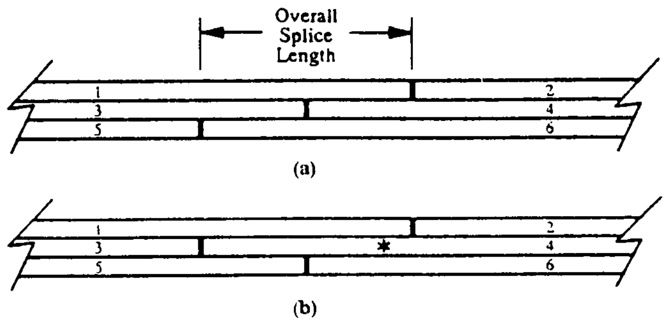



**Figure 7.13–Arrangement of joints in spliced nail-laminated posts: (a) step pattern, (b) commonly used stagger pattern, * point of high stress.**

of a post with staggered joints (figure 7.9) than are involved in the failure of a post with a stepped arrangement of joints. Preliminary modeling of both joint arrangements indicates that unreinforced posts with the step pattern are equally as strong in bending as unreinforced posts with staggered joints.

Because of its popularity in the field, the three-layer post with staggered joints has been the center of most research. Laboratory tests and computer modeling[12] has shown unreinforced posts have an inherent weakness in that the longest member in the center layer (member 4 in figure 7.13b) is almost always the most highly stressed member. This can be attributed to two factors. First, because of its location, member 4 is the major load distributing element in the post and therefore experiences high loads regardless of its individual stiffness. If the joints are not reinforced, all forces in members 2 and 6 must be transferred through member 4 to reach members 1, 3, and 5. Second, the lap between members 4 and 1 is twice as long as any other lap in the post. Consequently, these two members make up a very stiff component in the assembly and attract much of the load. For this reason, member 1 (figure 7.13b) is usually the second highest stress member in the post.

Laboratory testing and computer modeling of three-layer posts with staggered butt joints have also shown the significant influence of overall splice length on the bending strength of posts when the butt joints are not reinforced. As shown in table 7.6, Winistorfer[30] found that the mean ultimate bending strength of posts with 4 ft (1.22 m) overall splices lengths and no butt joint reinforcement was twice that of similar posts with splice lengths of 2 ft (0.61 m). There are two reasons for this behavior. First, as previously stated, longer laps facilitate greater nail spacings, which result in lower nail forces. Second, wherever a joint occurs in one layer, the other two layers must resist all the applied bending moment. Unfortunately, the other two layers do not share this load equally. The shorter the overall splice length, the more disproportionate the distribution of load between the two layers because less force is redistributed in posts with shorter overall splice lengths. To fully realize how disproportionate these loads can be, consider the point marked by the

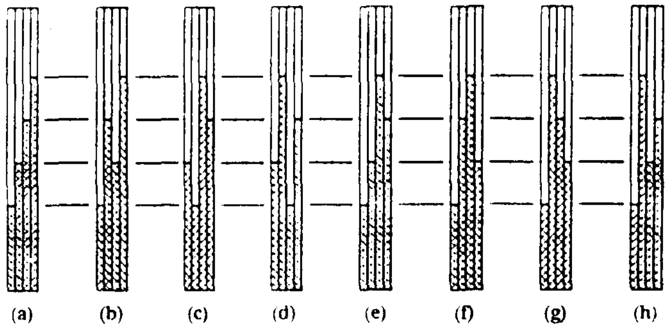



**Figure 7.14–Arrangement of joints in four-layer assemblies, fixed spacing of end joints.**

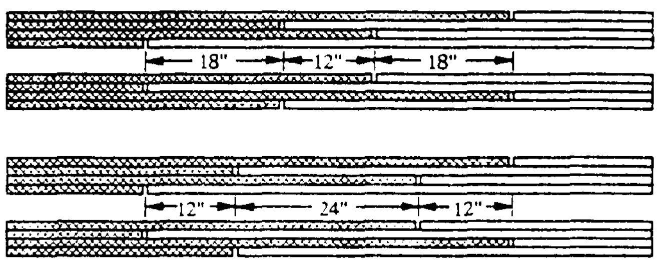



**Figure 7.15–Arrangement of joint in four-layer assemblies, spacing of end joints not fixed.**

asterisk on member 4 in figure 7.13b. At this point in an assembly with a 2 ft (0.61 m) overall splice length and no butt joint reinforcement, member 4 resists an average 87% of the total bending moment applied to the post. This average value drops to 73%, 62%, and 54% when the overall splice length is increased to 3,4, and 6 ft (0.91, 1.22, and 1.85 m), respectively [12].

Four layer posts are often used in buildings where cave heights are relatively high and/or lateral forces are higher than normal. In going from three to four layers the number of possible joint configurations increases substantially. Figure 7.14 contains the eight patterns possible for a four-layer post, given a fixed spacing of joints. Variations on two of the designs are shown in figure 7.15. Because of the lack of research involving four-layer posts, it is not known how assembly strength and stiffness are affected by variations in joint arrangement, overall length, and reinforcement.

**Butt Joint Reinforcement.** The main objective when designing butt joint reinforcement is to obtain a significant increase in bending strength without substantially increasing the cost of the assembly. Because of this, the cost of adding Reinforcement must always be considered along with the relative increase in post strength. Reinforcing in most laminated posts consist of 16 to 24 gauge: steel sheets, nail plates, or metal plate connectors. This type of joint reinforcing would be considered “light”. Heavier reinforcement is generally not cost effective.

The shorter the overall splice length, the more effective the butt ***joint*** reinforcement (table 7.6). When Winistorfer[30] added nail plates to the outside butt joints of posts with 2 ft (0.61 m) overall splice lengths, the mean ultimate bending strength of the assemblies increased 78%. When the same plates were added to the outside butt joints of posts with 4 ft (1.22 m) overall splice lengths, the mean ultimate bending strength increased only 17%. This difference is simply due to the fact that reinforcement does more to equalize nail forces and wood stresses in posts with shorter overall splice lengths because they are initially more unequal or unbalanced.

For three-layer posts with a staggered arrangement of joints, it is recommended that only the outside butt joints (and not the middle butt joint) be reinforced [12]. This recommendation is based on the recognition that the longest member in the center layer is typically the most highly stressed and interlayer slip is typically highest at the outside butt joints. By reinforcing only the outside joints, less load is channeled into the center layer and stresses in the center layer are reduced. Reinforcing the joints also reduces interlayer slip at the joints, thus lowering nail forces in the vicinity of the joints. In research on three-layer laminated posts with 4 ft (1.22 m) overall splice lengths, outside butt joint reinforcement was found to increase mean ultimate bending strength approximately 14% [15]. More importantly, the reinforcement was found to increase the allowable design bending strength 20 to 30%. The reason for the larger difference in allowable design strength was that the ultimate bending strength values for the reinforced posts were less variable than were the values for the unreinforced posts.

**Nail Selection and Placement.** In nail-laminated post design proper fastener selection and placement is critical. Assembly strength can be substantially reduced: (1) if the diameter of the nails is too large (thus splitting the members), (2) if the nails are not stiff enough, (3) if too few nails or too many nails are used, and/or (4) if the nails are located too close to the edges and ends of individual layers.

Research on three-layer posts fabricated from 2 × 6 in. lumber has indicated that nail shank diameter should probably not exceed 0.190 in. (4.8 mm) When nails larger than this are used, nailing induced cracks and stress concentrations can lead to premature assembly failure. At the same time, nail joint connections should have adequate shear stiffness to ensure a minimal amount of composite action between lumber layers. For this reason, it has been recommended that nails to be used in laminated assemblies meet minimum stiffness requirements and that the Morgan Impact Bend-Angle Nail Tester (MIBANT) be used for nail testing (ASTM F680[7] covers impact bend testing of nails)[31]. Because of the importance of nail joint stiffness, nails with shank diameters near 0.120 in. (3.0 mm) should be checked for stiffness before they are used in an assembly.

As previously mentioned, a minimum distance of 20 nail diameters is recommended between nails that are aligned along the wood grain, and between any nails and the end of the wood member. A minimum distance of 10 nail diameters is recommended as a perpendicular-to-grain nail spacing, and as a minimum distance between any nail and the edges of the wood member. The nailing pattern in figure 7.8c, which was based on these recommendations, can be used for nails with diameters no greater than 0.190 in. (4.8 mm). For nails with diameters in the 0.120 to 0.135 in. (3.0 to 3.5 mm) range, the denser nailing pattern in figure 7.8a is suggested. The pattern shown in figure 7.8b is not recommended for use. The combination of having nails spaced too close along the grain and too close to member edges led to a number of nail related failures during tests of this post design[30].

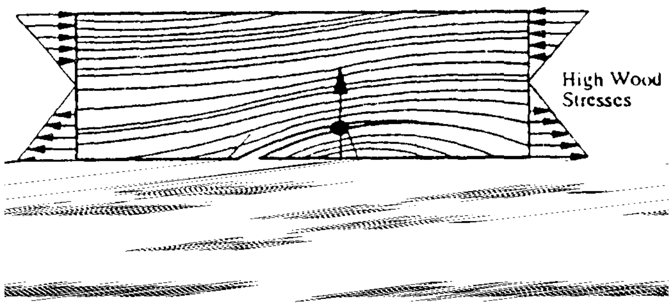
With respect to nail density, using fewer nails than shown in figures 7.8a and 7.8c is not recommended. At the same time, substantially increasing nail density without simultaneously reducing nail size, can adversely affect post strength. An increase in nail density of more than 50% of that shown in figures 7.8a and 7.8c is not recommended unless nails smaller in diameter (than previously recommended) are used. Note that because of reduced nail forces, nails located away from the splice region can be spaced farther apart.

The length of a nail can significantly affect the total number of nails required per post. If long enough, a nail in a three-layer post will provide an adequate connection at both interlayer planes thereby cutting in half the total number of nails required for the post. To provide an adequate connection at all intedayer planes: (1) all nails should penetrate at least half-way through the last layer and (2) adjacent nails should be driven in from opposite sides of the post (figure 7.8c). When nails fully penetrate all layers, they can all be driven in from the same side of the post.

Before selecting a gun-driven nail, it should be established that the gun will completely drive the nail through the lumber. Some guns designed to drive long nails cannot completely drive them into dense lumber (e.g., dense Southern Pine). This would not be a major practical problem except that gun-driven nails tend to be thinner and much more ductile than hand-driven nails. Consequently, it is difficult to finish driving a substantially under-driven, gun-driven nail without bending it. Thus, adequate penetration may not be obtained.

**Lumber Selection.** The strength of vertically laminated posts is more sensitive to lumber quality when nails are used instead of glue to fasten layers together. This is because nails, when located in an area where there is a natural defect in the lumber, have a tendency to accentuate the defect. The effect of lumber quality on the strength of nail-laminated posts is evident when the mean ultimate strengths for designs 1 through 5 in table 7.6 (those fabricated using No. 2 grade lumber) are compared with those for designs 6 through 11 (those fabricated with lumber graded No. 1 or better).

Figure 7.16 shows the most common type of failure in tests of nail-laminated posts fabricated from low grade lumber, that is, a cross grain failure or parallel-to-grain split on the tension side of the lumber which runs through




one or more nails. This type of failure, while it may appear to start at the edge of the lumber, actually starts at the nail. It is typically the propagation of a very small nailing induced crack. This crack is extended by (1) stress concentrations caused by nailing, (2) high nail shear forces, and (3) components of wood bending stress which act perpendicular to the grain of the wood. The percentage of failures of the type shown in figure 7.16 can be decreased by (1) using lumber with a lower slope of grain (i.e., by using higher grade lumber), (2) using smaller diameter nails, or (3) moving nails farther away from the edge of the lumber and into an area of lower wood bending stress. Nails should be moved away from the lumber edges because nail shear forces act in a direction that is, if not perpendicular to lumber edges, within a few degrees of being perpendicular to the edges. When nail forces act in this direction, wood near the nails is loaded in tension perpendicular-to-grain (a direction in which wood is relatively weak). Introducing high perpendicular-to-grain wood stresses near the edge of the lumber where high stresses due to bending already exist, increases the chance of wood splitting.

## MECHANICALLY LAMINATED POSTS WITH STRUCTURALLY GLUED END JOINTS

Little is known about the strength and stiffness of vertically mechanically laminated assemblies with structurally glued end joints since researchers are first starting to test the assemblies. The reason for including these posts in the discussion is because they would appear to be the ideal assemblies for post-frame construction - combining the low cost of mechanical lamination with the strength afforded by the continuity of the individual layers.

When the continuity of the individual layers in vertically laminated posts can be maintained with well-manufactured adhesive-bonded end joints, the rigidity of the interlayer connections is less important. To this end, when structurally glued end joints are used, mechanical lamination can replace glue lamination without sacrificing strength. This practice would not only save the expense of gluing, but would also save the strength loss, cost, and labor associated with a planing operation.

Since the design values for glued-laminated posts without joints can be used for glued-laminated posts with joints, it would seem logical that the design values for unspliced mechanically laminated posts could be applied to spliced mechanically laminated posts provide the joints satisfy the requirements of ANSI/AITC A190.1[1]. Given that the values for unspliced mechanically-laminated posts are somewhat conservative, applying them to spliced mechanically laminated posts with structurally glued joints would seem reasonable in situations where structural end joints have only a minimal influence on strength (such as when low grade material is being laminated). At the same time, one should realize that end jointing and laminating lumber with vastly different stiffness properties increases the magnitude of the forces transferred between layers. In this respect, mechanically laminated posts without joints and those with glued joints can behave differently.

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