9.9—WOOD DECKS AND DECK SYSTEMS

9.9.1—Scope

This Article shall apply to the design of wood decks supported by beams, stringers, or floorbeams or used as a deck system.

C9.9.1

This Article applies to wood decks and deck systems that are currently being designed and built in the United States and that have demonstrated acceptable performance. The supporting components may be metal, concrete, or wood.

9.9.2—General

The provisions of Section 8 shall apply.

Materials used in wood decks and their preservative treatment shall meet the requirements of Sections 2, 5, 6, and 8.

The nominal thickness of plank decks shall not be less than 4.0 in. for roadways and 2.0 in. for sidewalks. The nominal thickness of wood decks other than plank decks shall not be less than 6.0 in.

C9.9.2

In laminated decks, large deviations in the thickness or extensive warping of the laminations may be detrimental regarding both strength and long-term performance. Although rough or full sawn material can be more economical than planed, the variations in dimensions can be quite large. If appropriate dimensional tolerances are not likely to be obtained, dressing of the components should be recommended.

9.9.3—Design Requirements

9.9.3.1—Load Distribution

Force effects may be determined by using one of the following methods:

- The approximate method specified in Article 4.6.2.1,
- Orthotropic plate theory, or
- Equivalent grid model.

If the spacing of the supporting components is less than either 36.0 in. or 6.0 times the nominal depth of the deck, the deck system, including the supporting components, shall be modeled as an orthotropic plate or an equivalent grid.

In stress-laminated decks satisfying the butt stagger requirements specified in Article 9.9.5.3, rigidity may be determined without deduction for the butt joints.

C9.9.3.1

In wood decks with closely spaced supporting components, the assumption of infinitely rigid supports upon which approximate methods of analysis are based is not valid. Two-dimensional methods of analysis are, therefore, recommended to obtain force effects with reasonable accuracy.

9.9.3.2—Shear Design

Shear effects may be neglected in the design of stress-laminated decks. In longitudinal decks, maximum shear shall be computed in accordance with the provisions of Article 8.7.

In transverse decks, maximum shear shall be computed at a distance from the support equal to the depth of the deck.

C9.9.3.2

Shear problems in laminated wood decks are rare, as the inherent load sharing benefits of the multiple-member system are believed to be quite significant. The probability of simultaneous occurrence of potentially weak shear zones in adjacent laminates is low. Therefore, a multiple-member shear failure, which would be necessary to propagate shear splits in any one lamination, would be difficult to achieve.

For both longitudinal and transverse decks, the tire footprint shall be located adjacent to, and on the span side of, the point of the span where maximum force effect is sought.

With little test data available, no changes to the shear design for spike-laminated decks are being introduced.

9.9.3.3—Deformation

At the service limit state, wood decks shall satisfy the requirements specified in Article 2.5.2.6.

9.9.3.4—Thermal Expansion

The coefficient of thermal expansion of wood parallel to its fibers shall be taken as 0.000002 per °F.

Thermal effects may be neglected in plank decks and spike-laminated decks.

For stress-laminated and glued laminated panel decks made continuous over more than 400 ft, relative movements due to thermal expansion with respect to substructures and abutments shall be investigated.

C9.9.3.4

Generally, thermal expansion has not presented problems in wood deck systems. Except for the stress-laminated deck and tightly placed glued laminated panels, most wood decks inherently contain gaps at the butt joints that can absorb thermal movements.

9.9.3.5—Wearing Surfaces

Wood decks shall be provided with a wearing surface conforming to the provisions of Article 9.9.8.

C9.9.3.5

Experience has shown that unprotected wood deck surfaces are vulnerable to wear and abrasion, and they may become slippery when wet.

9.9.3.6—Skewed Decks

Where the skew of the deck is less than 25 degrees, transverse laminations may be placed on the skew angle. Otherwise, the transverse laminations shall be placed normal to the supporting components, and the free ends of the laminations at the ends of the deck shall be supported by a diagonal beam or other suitable means.

C9.9.3.6

With transverse decks, placement of the laminations on the skew is the easiest and most practical method for small skew angles, and cutting the ends of the laminations on the skew provides a continuous straight edge.

In longitudinal decks, except for stress-laminated wood, any skew angle can generally be accommodated by offsetting each adjacent lamination on the skew.

9.9.4—Glued Laminated Decks

9.9.4.1—General

Glued laminated timber panel decks shall consist of a series of panels, prefabricated with water-resistant adhesives, that are tightly abutted along their edges.

Transverse deck panels shall be continuous across the bridge width.

If the span in the primary direction exceeds 8.0 ft, the panels shall be interconnected with stiffener beams as specified in Article 9.9.4.3.

C9.9.4.1

In glued laminated decks built to date, transverse deck panels have been 3.0 to 6.0 ft wide, and longitudinal deck panels have been 3.5 to 4.5 ft wide. The design provisions are considered applicable only to the range of panel sizes given herein.

These design provisions are based upon development work carried out at the USDA Forest Products Laboratory in the late 1970s.

This form of deck is appropriate only for roads having low to medium volumes of commercial vehicles.

9.9.4.2—Deck Tie-Downs

Where panels are attached to wood supports, the tie-downs shall consist of metal brackets that are bolted through the deck and attached to the sides of the supporting component. Lag screws or deformed shank spikes may be used to tie panels down to wood support.

Where panels are attached to steel beams, they shall be tied down with metal clips that extend over the beam flange and that are bolted through the deck.

C9.9.4.2

The methods of tie-down specified herein are based upon current practices that have proven to be adequate. Use of other methods require approval by Owner.

9.9.4.3—Interconnected Decks

9.9.4.3.1—Panels Parallel to Traffic

Interconnection of panels shall be made with transverse stiffener beams attached to the underside of the deck. The distance between stiffener beams shall not exceed 8.0 ft, and the rigidity, *EI*, of each stiffener beam shall not be less than 80,000 kip-in.^{2}. The beams shall be attached to each deck panel near the panel edges and at intervals not exceeding 15.0 in.

C9.9.4.3.1

Although the transverse stiffener beam ensures interpanel shear transfer of loads, some relative deflection will take place. Under frequent heavy loads, this relative deflection will cause reflective cracking of bituminous wearing surfaces.

9.9.4.3.2—Panels Perpendicular to Traffic

Interconnection of panels may be made with mechanical fasteners, splines, dowels, or stiffener beams. Where used, the stiffener beams should be continuous over the full length of the span and should be secured through the deck within 6.0 in. of the edges of each panel and as required between edges.

When panels are interconnected with stiffener beams, the beams shall be placed longitudinally along the centerspan of each deck span. Provisions of Article 9.9.4.3.1 shall apply for the design of the stiffener beams.

The live load bending moment per unit width shall be determined in accordance with the provisions of Article 4.6.2.1.3.

C9.9.4.3.2

The doweling of the deck system is intended to prevent relative displacement of the glued laminated deck panels. A design procedure for dowels can be found in Ritter (1990). With proper prefabrication and construction, this doweled system has proven to be effective in preventing relative displacement between panels. However, in practice, problems with hole alignment and the necessity for field modifications may reduce their efficiency.

Using one longitudinal stiffener beam in each space between girders has proven to be both a practical and effective method of reducing relative displacements between transverse panels.

9.9.4.4—Noninterconnected Decks

Decks not interconnected at their edges shall only be employed on secondary rural roads. No transfer of force effects at the panel edges shall be assumed in the analysis.

C9.9.4.4

The noninterconnected panel deck will likely cause reflective cracking in the wearing surface at the butt joints, even under relatively low levels of loading. It is appropriate only for roads having low volumes of commercial vehicles in order to avoid the extensive maintenance that the wearing surface may require.

9.9.5—Stress-Laminated Decks

9.9.5.1—General

Stress-laminated decks shall consist of a series of wood laminations that are placed edgewise and post-

C9.9.5.1

The majority of decks of this type include laminations which are 2.0 to 3.0 in. in thickness.

tensioned together, normal to the direction of the lamination.

Stress-laminated decks shall not be used where the skew exceeds 45 degrees.

The contract documents shall require that the material be subjected to expansion baths to remove excess oils.

The increased load distribution and load sharing qualities of this deck, coupled with its improved durability under the effects of repeated heavy vehicles, make it the best choice among the several wood decks for high-volume road application (Csagoly and Taylor, 1979; Sexsmith et al., 1979).

The structural performance of these decks relies on friction, due to transverse prestress, between the surfaces of the laminations to transfer force effects. Unlike spiked or bolted connections in wood, the friction-based performance of stress-laminated decks does not deteriorate with time under the action of repeated heavy loads.

Experience seems to indicate that the use of waterborne preservatives can negatively affect the performance of stress-laminated decks. Wood treated with waterborne preservatives responds rapidly to the short-term changes in moisture conditions to which bridges are subjected frequently in most areas of North America. The attendant dimensional changes in the wood can result in substantial changes in the prestressing forces. Wood treated with oil-borne preservatives does not respond so readily to short-term changes in moisture conditions.

The preservative treatment for wood to be used in stress-laminated decks should be kept to the minimum specified in the standards given in Article 8.4.3. Excessive oils in the wood may be expelled after the deck is stressed and can contribute to higher prestress losses over a short period after construction.

9.9.5.2—Nailing

Each lamination shall be specified to be fastened to the preceding one by common or spiral nails at intervals not exceeding 4.0 ft. The nails shall be driven alternately near the top and bottom edges of the laminations. One nail shall be located near both the top and bottom at butt joints. The nails should be of sufficient length to pass through two laminations.

C9.9.5.2

Nailing is only a temporary construction convenience in stress-laminated decks, and it should be kept as close to minimum requirements as possible. Excessive nailing may inhibit the build-up of elastic strains during transverse stressing, which could subsequently contribute to decreasing its effectiveness.

9.9.5.3—Staggered Butt Joints

Where butt joints are used, not more than one butt joint shall occur in any four adjacent laminations within a 4.0 ft distance, as shown in Figure 9.9.5.3-1.

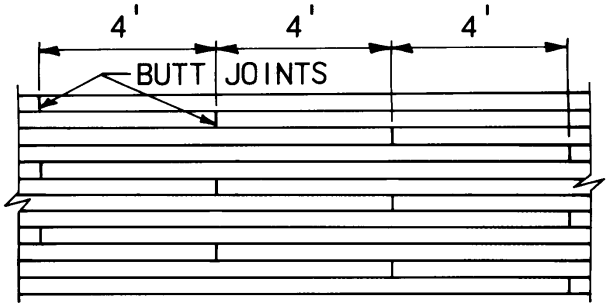

Figure 9.9.5.3-1—Minimum Spacing of Lines of Butt Joints

C9.9.5.3

Butt joint requirements are extreme values and are intended to allow for lamination lengths that are less than the deck length. Uniformly reducing or eliminating the occurrence of butt joints, distributing butt joints, or both will improve performance.

The implication of this provision is that laminations shorter than 16.0 ft cannot be used. If laminations longer than 16.0 ft are used, the spacing of butt joints is one-quarter of the length.

9.9.5.4—Holes in Laminations

The diameter of holes in laminations for the prestressing unit shall not be greater than 20 percent of the lamination depth. Spacing of the holes along the laminations shall be neither less than 15.0 times the hole diameter nor less than 2.5 times the depth of the laminate.

Only drilled holes shall be permitted.

C9.9.5.4

These empirical limitations are intended to minimize the negative effects of hole size and spacing on the performance of the deck.

Punched holes can seriously affect the performance of the laminates by breaking the wood fibers in the vicinity of the holes.

9.9.5.5—Deck Tie-Downs

Decks shall be tied down at every support, and the spacing of the tie-downs along each support shall not exceed 3.0 ft. Each tie-down shall consist of a minimum of two 0.75-in. diameter bolts for decks up to and including 12.0 in. deep and two 1.0-in. diameter bolts for decks more than 12.0 in. deep.

C9.9.5.5

The stress-laminated deck requires a more effective tie-down than toe-nailing or drift pins. It has a tendency to develop curvature perpendicular to the laminates when transversely stressed. Tie-downs using bolts or lag screws ensure proper contact of the deck with the supporting members.

9.9.5.6—Stressing

9.9.5.6.1—Prestressing System

New stressed wood decks shall be designed using internal prestressing. External prestressing may be used to rehabilitate existing nail-laminated decks and shall utilize continuous steel bulkheads.

In stress-laminated decks with skew angles less than 25 degrees, stressing bars may be parallel to the skew. For skew angles between 25 degrees and 45 degrees, the bars should be placed perpendicular to the laminations, and in the end zones, the transverse prestressing bars should be fanned in plan as shown in Figure 9.9.5.6.1-1 or arranged in a step pattern as shown in Figure 9.9.5.6.1-2.

Dimensional changes in the deck due to prestressing shall be considered in the design.

Anchorage hardware for the prestressing rods should be arranged in one of the three ways shown in Figure 9.9.5.6.1-3.

C9.9.5.6.1

External and internal prestressing systems are shown in Figure 9.9.5.6.1-3. The internal system provides better protection to the prestressing element and lessens restriction to the application of wearing surfaces.

Generally, it is not necessary to secure timber decks to the supports until all the transverse stressing has been completed. There is the potential for extensive deformation when a deck is stressed over a very long length due to unintentional eccentricity of prestressing. It is recommended that restraints during stressing be provided when the width of the deck, perpendicular to the laminations, exceeds 50.0 times the depth of the deck for longitudinal decks and 40.0 times the depth of the deck for transverse decks. These restraints should not inhibit the lateral movement of the deck over its width during the stressing procedure.

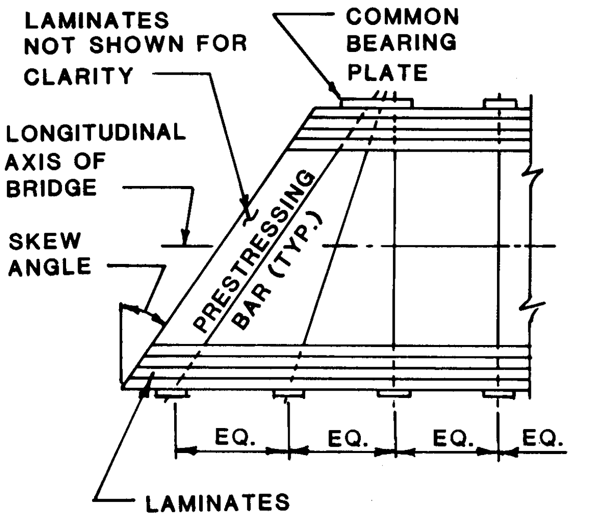

Figure 9.9.5.6.1-1—Fanned Layout of Prestressing Bars in End Zones of Skewed Decks—Illustrative Only

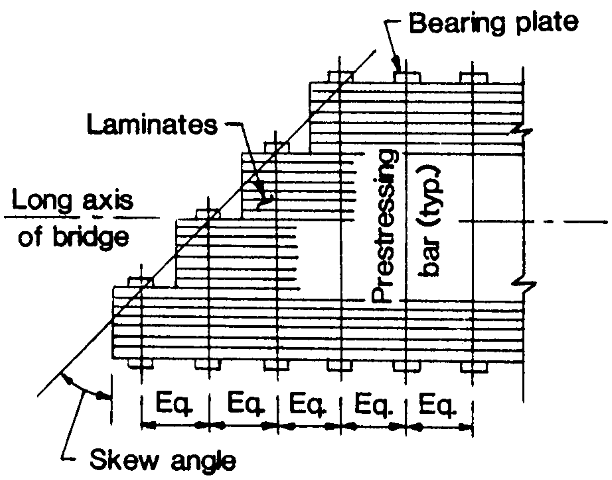

Figure 9.9.5.6.1-2—Staggered Layout of Prestressing Bars in End Zones of Skewed Decks—Illustrative Only

Potential concentration of bearing stresses and sliding of the common bearing plate should be considered in conjunction with the fanned arrangement of prestressing elements shown in Figure 9.9.5.6.1-1.

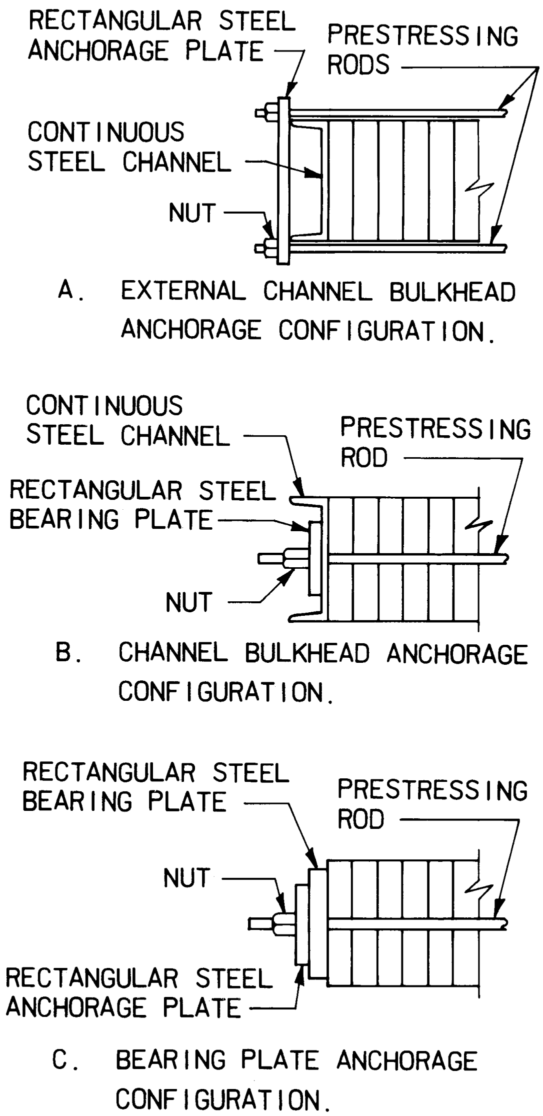

Figure 9.9.5.6.1-3—Types of Prestressing Configurations

The isolated steel bearing plates should be used only on hardwood decks, or, where a minimum of two hardwood laminations are provided, on the outside edges of the deck.

Continuous steel bulkheads or hardwood laminations are required because they improve field performance. Isolated steel bearing plates on softwood decks have caused crushing of the wood, substantially increased stress losses and resulted in poor aesthetics.

9.9.5.6.2—Prestressing Materials

Prestressing materials shall comply with the provisions of Article 5.4.

C9.9.5.6.2

All prestressed wood decks built to date have utilized high-strength bars as the stressing elements. Theoretically, any prestressing system that can be adequately protected against corrosion is acceptable.

9.9.5.6.3—Design Requirements

The steel–wood ratio, R_{sw}, shall satisfy:

$$R_{sw} = \frac{A_s}{sh} \leq 0.0016 \qquad (9.9.5.6.3\text{-}1)$$

where:

s = spacing of the prestressing elements (in.)
h = depth of deck (in.)
A_s = area of steel bar or strand (in.^{2})

The prestressing force per prestressing element (kip) shall be determined as:

$$P_{pt} = 0.1hs \qquad (9.9.5.6.3\text{-}2)$$

The effective bearing area, A_B, on the wood directly under the anchorage bulkhead due to prestress shall be determined by considering the relative stiffness of the wood deck and the steel bulkhead. The bulkhead shall satisfy:

$$P_{BU} = \phi F A_B \geq P_{pt} \qquad (9.9.5.6.3\text{-}3)$$

where:

P_{BU} = factored compressive resistance of the wood under the bulkhead (kip)
ϕ = resistance factor for compression perpendicular to grain as specified in Article 8.5.2.2
F = as specified in Table 9.9.5.6.3-1

Table 9.9.5.6.3-1—*F* Values for Prestressed Wood Decks

Species	F (ksi)
Douglas Fir–Larch	0.425
Hemlock Fir	0.275
Spruce–Pine–Fir	0.275
Eastern Softwoods	0.225
Mixed Southern Pine	0.375
Southern Pine	0.375
Spruce–Pine–Fir (South)	0.225
Northern Red Oak	0.600
Red Maple	0.400
Red Oak	0.550
Yellow Poplar	0.275

C9.9.5.6.3

The limitation on the steel–wood area ratio is intended to decrease prestress losses due to relaxation caused by wood and steel creep as well as deck dimensional changes due to variations in wood moisture content. Prestress losses are very sensitive to this ratio, and most existing structures have values less than 0.0016. A small area ratio of 0.0012 to 0.0014, coupled with an initial moisture content of less than 19 percent and proper preservative treatment, will ensure the highest long-term prestress levels in the deck.

The average compressive design stress represents the uniform pressure that is achieved away from the anchorage bulkhead. Limitation on compressive stress at maximum prestress minimizes permanent deformation in the wood. Increasing the initial compressive stress beyond these levels does not significantly increase the final compressive stress after all losses have occurred.

Eq. 9.9.5.6.3-2 is based on a uniform compressive stress of 0.1 ksi between the laminations due to prestressing. For structural analysis, a net compressive stress of 0.04 ksi, after losses, may be assumed.

Relaxation of the prestressing system is time-dependent, and the extensive research work, along with the experience obtained on the numerous field structures, have shown that it is necessary to restress the system after the initial stressing to offset long-term relaxation effects. The optimum stressing sequence is as follows:

- Stress to full design level at time of construction,
- Restress to full design level not less than one week after the initial stressing, and
- Restress to full design level not less than four weeks after the second stressing.

After the first restressing, increasing the time period to the second restressing improves long-term stress retention. Subsequent restressings will further decrease the effects of long-term creep losses and improve stress retention.

9.9.5.6.4—Corrosion Protection

Elements of the prestressing system shall be protected by encapsulation and/or surface coatings. The protective tubing shall be capable of adjusting at least ten percent of its length during stressing without damage.

C9.9.5.6.4

Elements of a suitable protection system are shown in Figure C9.9.5.6.4-1.

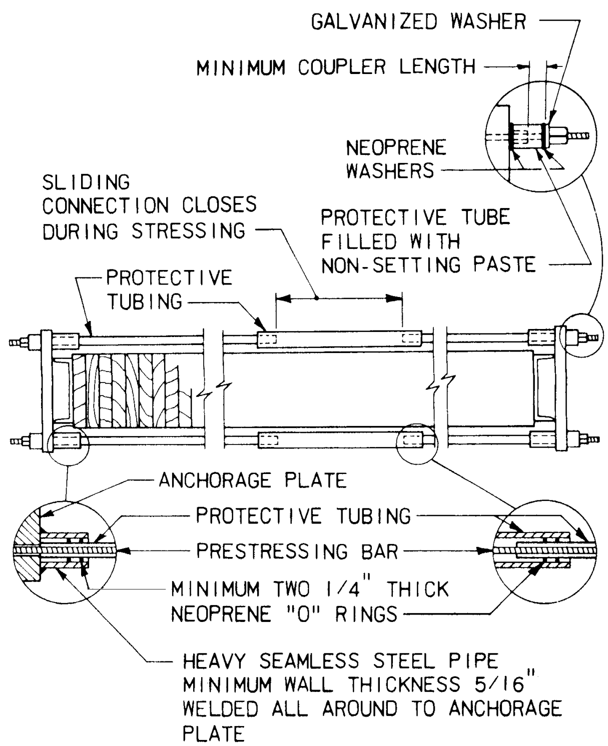

Figure C9.9.5.6.4-1—Elements of Corrosion Protection

9.9.5.6.5—Railings

Railings shall not be attached directly either to any prestressing element or to bulkhead systems. The deck shall not be penetrated within 6.0 in. of a prestressing element.

C9.9.5.6.5

Curb and railing attachment directly to any component of the stressing system increases the risk of failure in the event of vehicle impact.

9.9.6—Spike-Laminated Decks

9.9.6.1—General

Spike-laminated decks shall consist of a series of lumber laminations that are placed edgewise between supports and spiked together on their wide face with deformed spikes of sufficient length to fully penetrate four laminations. The spikes shall be placed in lead holes that are bored through pairs of laminations at each end and at intervals not greater than 12.0 in. in an alternating pattern near the top and bottom of the laminations, as shown in Figure 9.9.6.1-1.

Laminations shall not be butt spliced within their unsupported length.

C9.9.6.1

The use of spike-laminated decks should be limited to secondary roads with low truck volumes, i.e., *ADTT* significantly less than 100 trucks per day.

The majority of decks of this type have used laminations of 3.0 to 4.0 in. in thickness. The laminates are either assembled on site or are prefabricated into panels in preparation for such assembly.

The specified design details for lamination arrangement and spiking are based upon current practice. It is important that the spike lead holes provide a tight fit to ensure proper load transfer between laminations and to minimize mechanical movements.

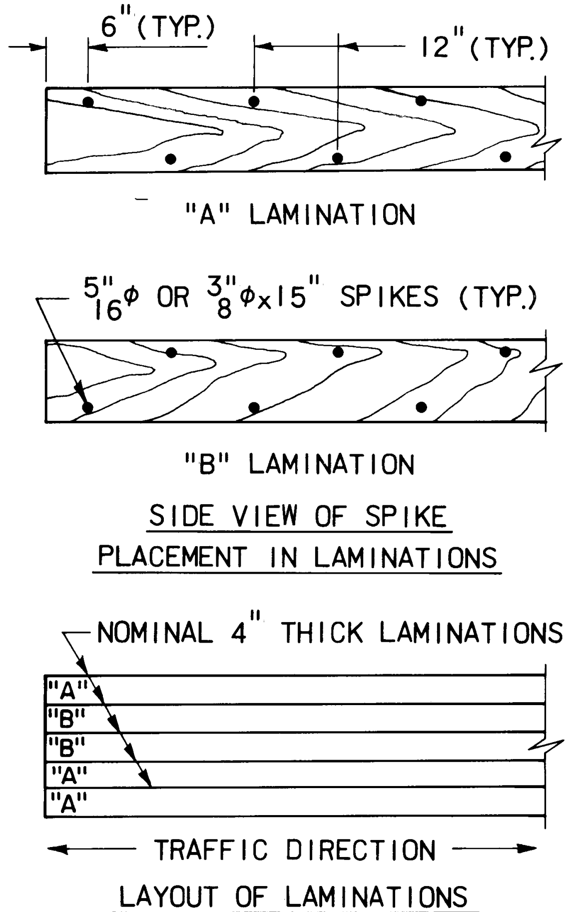

Figure 9.9.6.1-1—Spike Layout for Spike-Laminated Decks

9.9.6.2—Deck Tie-Downs

Deck tie-downs shall be as specified in Article 9.9.4.2.

9.9.6.3—Panel Decks

The distribution widths for interconnected spike-laminated panels may be assumed to be the same as those for continuous decks, as specified in Section 4.

The panels may be interconnected with mechanical fasteners, splines, dowels, or stiffener beams to transfer shear between the panels. If stiffener beams are used, the provisions of Article 9.9.4.3 shall apply.

C9.9.6.3

The use of noninterconnected decks should be limited to secondary and rural roads.

It is important to provide an effective interconnection between panels to ensure proper load transfer. Stiffener beams, comparable to those specified for glued laminated timber panels, are recommended. Use of an adequate stiffener beam enables the spike-laminated deck to approach the serviceability of glue-laminated panel construction.

With time, the deck may begin to delaminate in the vicinity of the edge-to-edge panel joints. The load distribution provisions given for the noninterconnected panels are intended for use in the evaluation of existing noninterconnected panel decks and interconnected panel decks in which the interconnection is no longer effective.