

Recommended Construction Practices for Stress-Laminated Wood Bridge Decks

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Abstract

Since their introduction in the late 1980s, more than 400 stress-laminated wood deck bridges have been built in the United States. Although there are guide specifications for the design of these bridges, little information exists on proper construction practices. Most bridges have been built by local governments with widespread geographical distribution. Therefore, little opportunity exists for local jurisdictions and contractors to gain experience in stress-laminated construction. As a result, there is confusion regarding proper construction methodology, and practices that adversely affect bridge performance continue to perpetuate as new structures are built. This paper summarizes recommended construction practices for stress-laminated lumber bridge decks, including bridge materials, assembly, and bar tensioning.

Keywords: Bridge, construction, stress-laminated, timber, wood

Introduction

Stress-laminated wood bridge decks consist of a series of lumber laminations that are stressed together with high strength steel bars to form an orthotropic wood plate. The concept of stress laminating was first developed in Ontario, Canada, in 1976 as a means of rehabilitating existing nail-laminated decks (Taylor and others 1983). Introduction into the United States came in the mid-1980s with the construction of several demonstration bridges. Since that time, stress-laminated wood bridges have become a relatively popular option for secondary road applications, and more than 400 bridges have been built in the United States.

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Most of these bridges have been designed in accordance with the *Guide Specifications for the Design of Stress-Laminated Wood Decks* published by the American Association of State Highway and Transportation Officials (AASHTO) in 1991 (AASHTO 1991). This specification provides recommended design criteria and procedures for stress-laminated bridges, but offers little in the way of construction or maintenance guidelines.

The popularity of stress-laminated bridges in the United States is primarily a result of the Timber Bridge Initiative (TBI) that was passed by the U.S. Congress in 1988. The objective of this legislation was to improve the utilization of wood by further developing and extending the use of wood bridges. Responsibility for administration of the TBI was delegated to the USDA Forest Service and included a demonstration bridge program managed by the Timber Bridge Information Resource Center (TBIRC) in Morgantown, West Virginia, and a research program at the Forest Products Laboratory (FPL) (USDA 1996). Under the demonstration bridge program, emphasis is focused on innovative bridge designs and the use of underutilized hardwood and secondary softwood species. As a result, many bridges in the demonstration program have been stress-laminated designs. To evaluate field performance and develop recommendations for more efficient design and construction, FPL initiated a national wood bridge monitoring program in which selected bridges are monitored for 2-5 years. To date, more than 40 stress-laminated wood bridges have been monitored.

Like all engineered structures, the performance and longevity of stress-laminated wood bridges depends on proper construction. In general, stress-laminated bridges have performed well in the United States, although there are several areas where performance could be improved (Ritter and others 1995). Most stress-laminated bridges have been built by local gov-

ernments with little experience in wood bridge construction. Given the widespread geographical distribution of the bridges, there has been little opportunity for local jurisdictions and contractors to gain experience in stress-laminated construction. As a result, there is confusion on proper construction methodology, and practices that adversely affect bridge performance continue to perpetuate as new structures are built.

The following summarizes recommended construction practices for stress-laminated lumber bridge decks. The information presented is based on FPL experience in monitoring the field performance of several stress-laminated bridges and includes recommendations for bridge materials and fabrication, assembly, and bar tensioning.

Materials and Fabrication

The success, performance, and longevity of any bridge begins with the materials. The first step to ensure proper materials and fabrication is the preparation of accurate and complete plans and specifications. However, the best plans and specifications do not ensure that the materials delivered to the job site will be in compliance with stated requirements. Thus, on-site inspection at the fabrication facility and construction site is necessary to verify that the materials provided are in compliance with those specified and purchased.

General guidelines for wood bridge plans and specifications are given in *Timber Bridges: Design, Construction, Inspection and Maintenance* (Ritter 1990). The following summarizes areas of particular emphasis for stress-laminated lumber decks.

- Lumber must be stress graded and grade stamped or otherwise certified by an approved grading rules agency. Laminations should also be straight and free of distortion because warp, sweep, or cupping make construction and bar insertion difficult and may result in lamination breakage when the bridge is stressed.
- All wood components should be accurately cut, drilled, and otherwise fabricated prior to pressure treatment with preservatives. Holes in the laminations for stressing bars should be approximately twice that of the bar diameter, but not greater than 20% of the lamination depth. The wide face of the lumber laminations must be surfaced on a minimum of one side to ensure uniform lamination thickness. Variations in lamination thickness may cause

changes in the deck width and prevent full contact and load distribution between adjacent laminations.

- All wood must be pressure treated with wood preservatives in accordance with the applicable specifications for highway use applications. Preservative retention should meet, but not substantially exceed, specification requirements. Excess preservative retention or improper treating procedures can result in preservative dripping after the structure is installed.
- Moisture content of the Laminations at the time of construction should be as close as possible to the expected equilibrium moisture content for the site. In most applications, a maximum moisture content of 19% is recommended. Lumber that is dry will result in better deck performance, because shrinkage and associated bar force loss will be minimized. If lumber is placed at a high moisture content, it will eventually dry and shrink, which will result in bar force loss. Most performance problems associated with stress-laminated decks have resulted from high lamination moisture content.
- Stressing bars must be of sufficient length to allow bridge assembly and stress laminating. In most cases, a bar length equal to the out-to-out bridge width plus 600 mm (2 ft) is sufficient.
- Stressing bars must be protected from corrosion based on the corrosion potential for the site. If galvanizing is used, nuts must be reamed or oversized to compensate for the galvanizing. In areas where the corrosion potential is high or when waterborne preservatives are used, encasing the bars in plastic tubing is recommended (discussed later in this paper).
- Field cutting, drilling, and damage to treated wood members must be minimized. When unavoidable, breaks in the preservative treatment envelope must be field treated with wood preservative in accordance with applicable specifications.

Bridge Assembly

Stress-laminated bridges may be assembled and stressed on the abutments, adjacent to the bridge site, or at a fabrication facility. Assembly guidelines for these three options follow.

Assembly on the Abutments

Bridge assembly on the abutments can be completed using individual laminations or preassembled panels. If all laminations are full length, they are placed directly on the abutments. If laminations are butt-jointed, it is advisable to place temporary scaffolding between abutments to support laminations prior to stress laminating (Fig. 1). When laminations are placed individually, the first four to eight laminations are placed at the deck edge location and are nailed together so they stand unsupported. The remaining laminations are then placed using wooden dowels to align holes. When holes are aligned, nails may be used to hold the laminations in place, or the stressing bars may be inserted and pushed through the holes as laminations are added. As bars are placed, it is important that they are supported on the free end and are not allowed to bend excessively. Excessive bending can damage the bar or the galvanized coating.

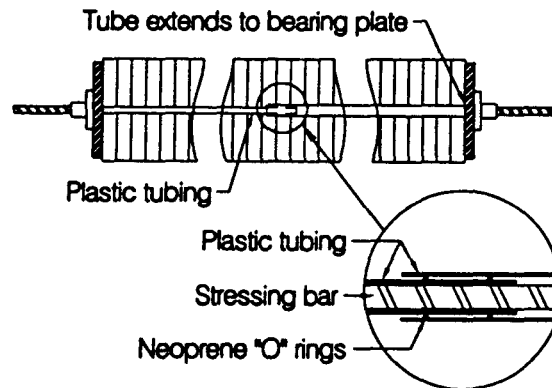
To use the panel method of bridge assembly, panels 0.6 to 1.2 m (2 to 4 ft) wide are preassembled by nailing laminations together or banding laminations with metal bands. In both cases, the holes must be aligned so that stressing bars can be easily inserted. If banding is used, corner guards must be provided to prevent damage to the wood when the bands are tightened. After assembly, the panels are lifted onto the abutments and the bars are inserted and tensioned. When lifting panels, full support across the bottom of the panels is required so that individual laminations do not move relative to one another.

If bars are difficult to insert through the laminations and gently striking the bar aids assembly, place a wood block over the end of the bar to protect the steel. Do not hammer directly on the end of the bar. This will cause the steel to "mushroom" and the nut cannot be properly threaded. Also, be careful not to bend or otherwise damage the bar. If bars cannot be inserted without excessive hammering, shift the laminations as necessary until the holes align properly. If this is not adequate, lamination holes must be redrilled and field treated with a preservative.

One method that works well for aiding in bar insertion and corrosion protection is to insert plastic tubing through the laminations as the bridge is being assembled (Fig. 2). The tubing is inexpensive and easy to handle in the field. After all laminations are placed, the bars are easily inserted through the plastic tubing. The o-ring joint provides a collapsible connection, allowing the tubing length to adjust as the bridge width



Figure 1—Construction of a stress-laminated deck by placing single laminations with butt joints on scaffolding supports.



Neoprene "O" rings provide collapsible connection to facilitate movement during bar tensioning.

Fill plastic tube with grease after bar placement.

Figure 2—Details of the plastic tubing insert to aid bar placement and corrosion protection.

compresses as a result of bar tensioning. To provide additional corrosion protection, the tubes can be filled with grease after bar placement.

Assembly Adjacent to the Site

Stress-laminated bridges may be completely assembled adjacent to the site and lifted into place with a crane (Fig. 3). To accomplish this, a level work site is necessary and wood blocking or other full-width support is needed at the bridge ends to serve as temporary abutments. Laminations may be placed on the supports individually or in panels, as previously described. After assembly, the bars must be fully tensioned

(discussed later) before the bridge is lifted. When lifting the assembled bridge, use full-width spreader beams under the bridge or lifting eyes through the bridge. Do not lift the bridge by the stressing bars because this can cause the bars to bend or laminations to slip.

Assembly at a Fabrication Facility

Stress-laminated bridge decks can also be completely assembled and stress laminated at a fabrication facility. This is accomplished by stress laminating two or more panels that are joined together at the bridge site. After placing the panels on the abutments, the force in alternate opposing bars is released and the interior plates and nuts are removed (Ritter 1990). The released bars are then inserted into couplers in the opposing panel, and the bars are tensioned (Fig. 4). When this method is used, it is important that only the bar without the interior bearing plate be tensioned. Otherwise only one panel will be stressed. Experience has shown that this may be confusing when the bars are tensioned. Therefore, this method of assembly should only be used if careful attention is paid to bar placement and tensioning, and complete field notes are maintained for future bar tensioning.

Bar Tensioning

The prestressing system is perhaps the most important part of a stress-laminated bridge because it holds the bridge together and develops the necessary friction for load transfer between the laminations. Thus, it is important that the bars be properly tensioned and a sufficient level of uniform, compressive prestress be maintained. In the United States, bar tensioning is typically accomplished using a single hydraulic jack. The following recommendations for equipment, procedures, tensioning sequence, and checking bar force are based on single jack usage.

Tensioning Equipment

Stress-laminated bridges are stressed together with a hydraulic jack that applies tension to the prestressing bar by pulling the bar away from the steel anchor plate. After bar tension is applied, the nut is tightened and the tension remains in the bar when jack pressure is released. The typical equipment for bar tensioning consists of a hydraulic hollow-core jack, pump, hose and gauge, steel tensioning chair, backplate, and backnut (Fig. 5). The following should be considered regarding equipment:

- The capacity of the jack must be sufficient to provide the design tension force. Jacks are available in

numerous capacities and must be capable of developing the required bar force.

- The hydraulic pump may be hand operated or electric. Hand-operated pumps are less expensive but are slower than electric pumps. Electric pumps require an on-site power source.
- The scale of the hydraulic gauge attached to the pump may be calibrated in units of hydraulic pressure or jack force. It is generally easier to work with units of force. If the gauge is calibrated for hydraulic pressure, a table that converts pressure to the jack force must be provided.

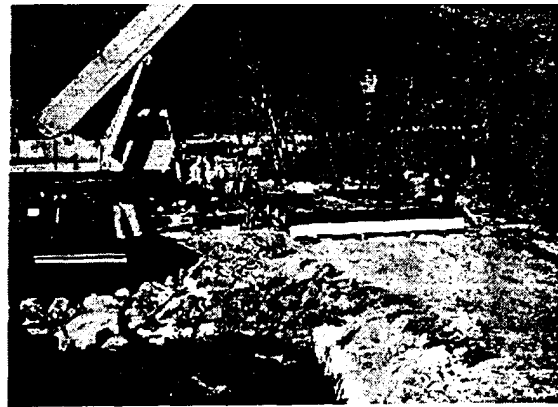


Figure 3—Stress-laminated deck assembled adjacent to the site and lifted into place with a crane.

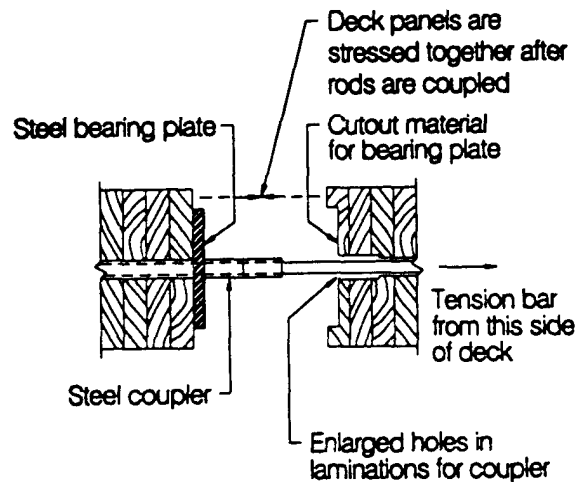


Figure 4—Detail of couplers for joining stress-laminated panels assembled at a fabrication facility.

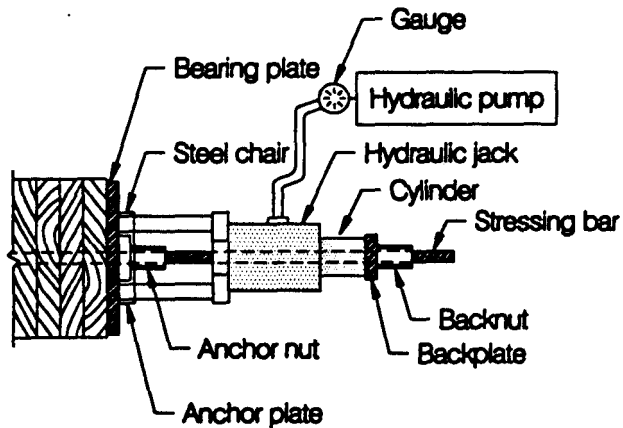


Figure 5—Typical equipment for bar tensioning.

- The stressing chair is usually fabricated locally. An example of a typical welded-steel stressing chair is shown in Fig. 6. It is important that the base of the chair be large enough to fit over the bar anchor plate, but remain on the bearing plate. The chair must not bear directly on the lumber laminations. The height of the chair should be two to three times the length of the bar nut plus the anchor plate thickness.
- The backplate should completely cover the cylinder of the hydraulic jack and is generally the same size as the bar anchor plate.
- Extra backnuts should be kept on-hand during bar tensioning. After repeated tensioning, the backnuts may tend to bind and should be replaced.

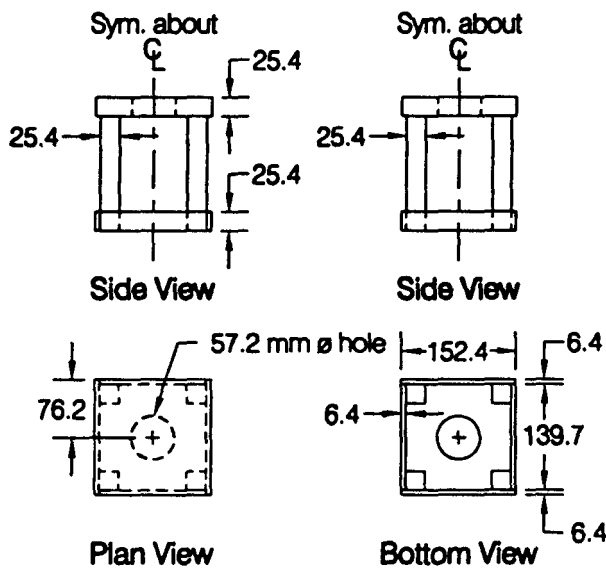
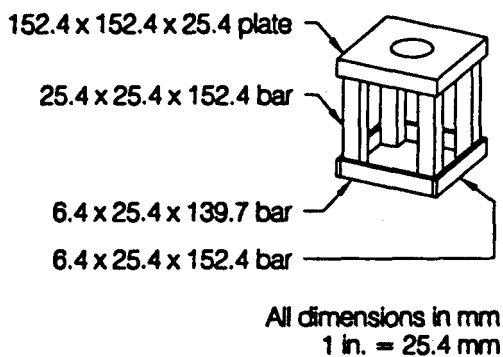


Figure 6—Typical details of a welded-steel stressing chair.

To tension the bars properly, there must be sufficient bar length beyond the nut on which to place the tensioning equipment. It is generally beneficial to select one bridge edge and place all bar extension on that edge. On the opposite edge, bars should extend approximately 25 mm (1 in.) beyond the nut. If there is insufficient bar length for the tensioning equipment, a temporary coupler and bar extension can be used (Fig. 7). If this is necessary, it is critical that each bar be threaded fully into half the coupler length. Failure to do so may result in coupler breakage. It is also important to verify that the holes in the hydraulic jack and stressing chair are large enough to fit over the coupler.

Bar Tensioning Procedures

To tension bars in a stress-laminated bridge, the stressing equipment must be placed on the bar extension along the bridge edge. The equipment is heavy, and proper steps must be taken to ensure worker

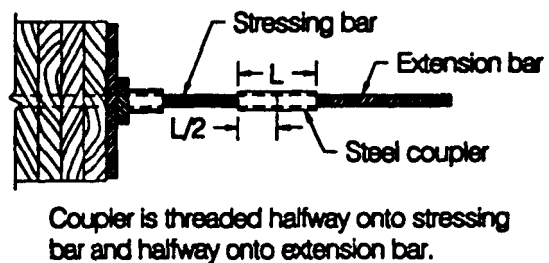


Figure 7—Coupler and extension bar for tensioning bars that are too short for jack and chair placement.

safety. If the bridge is near the ground, the equipment cart be lifted onto the bars from beneath the bridge. For higher bridges, ladders or scaffolding should be used and worker safety lines provided when necessary. The following steps outline the recommended procedures for bar tensioning.

1. Place the chair and jack on the bar. Position the jack so that the cylinder extends away from the bridge. Placing the cylinder against the chair may cause the chair to bend.
2. Place the backplate and backnut on the bar. Provide a small gap of approximately 6 mm (0.25 in.) between the backplate and the jack to prevent binding when hydraulic pressure is released.
3. Apply hydraulic pressure to the jack until the gauge indicates the required reading. It is common to apply 5%-10% greater force to compensate for lock-off loss when the nut is tightened. Ensure that the proper gauge scale is used. Most gauges have several scales for different jacks.
4. Tighten the bar nut snug against the bridge anchor plate using an open-end wrench. As the nut is tightened, the gauge pressure on the hydraulic pump will decrease slightly. On occasion, the nut may blind slightly on the bar. If this occurs, tap the nut gently along the bar axis towards the bridge to loosen the threads.
5. Release the pump hydraulic pressure slowly and remove the tensioning equipment. If the backnut binds, tap it gently along the bar axis towards the bridge.

During all bar tensioning procedures, it is important that personnel not stand in line with or beneath the bar or place hands or other body parts on or near the tensioning equipment. At the high bar force during tensioning, a broken bar will exit at great force and speed and can cause serious injury or death. It is also important not to lift the jack by the hydraulic hose as this may damage the hose and cause future rupture under high oil pressure. To aid in handling, a rope securely tied to the jack may be beneficial.

Tensioning Sequence

For a stress-laminated bridge to function properly, all bars must be tensioned uniformly to the design force. To minimize bar force loss caused by stress relaxation in the wood laminations, bar tensioning should be completed three times during the construction process: at the time of bridge erection, approximately 1 week after the first tensioning, and 6-8 weeks after the second tensioning. As the bars are tensioned, the laminations compress and the bridge deck narrows. When using a single hydraulic jack, tensioning one bar compresses the bridge and causes the force in adjacent bars to decrease. This effect is most pronounced when the bridge is initially tensioned and decreases as the force in all bars becomes equal. To compensate for this effect, bars must be sequentially tensioned several times to equalize force. This is generally accomplished by tensioning the first bar on one end of the bridge and sequentially tensioning each successive bar along the bridge length. The process is repeated several times until all bars are fully tensioned to the design level. ”

When initially tensioning bars with a single jack, it is important that the tension be applied gradually to prevent distortion along the bridge edges. If bars are initially tensioned to the full design level, the bridge edges may become distorted. For best results, the following procedure is recommended for the first tensioning.

1. Starting at one end of the bridge, sequentially tension each bar to approximately 25% of the design level. During this process, a stringline may be used to ensure that the edges of the bridge remain straight.
2. Following the same procedure, tension each bar to approximately 50% of the design level. The force level may be varied slightly to ensure that edges of the bridge remain straight.
3. Starting at one end again, sequentially tension each bar to the full design level. Again, the force level may be varied slightly to ensure that edges of the bridge remain straight.
4. Return to the first bar, and repeat step 3.
5. Check the force in several bars using the procedures described in the “Checking Bar Force” section. If the force is 10% or more below the design level, retension the bar. Generally, the preceding steps

are sufficient to achieve uniform bar tension. However, in some cases, it may be necessary to repeat step 3 one or two times.

After the initial tensioning, the bars must be retensioned a second and third time in accordance with the tensioning sequence previously discussed. At the conclusion of each bar tensioning, the force level should be checked to verify that all bars are at the design level. When the last two tensionings are completed, the bar force should stabilize and should not drop below 40% of the design level. However, the decrease in bar force depends on many factors and should be checked periodically after construction. It is recommended that the bar force be checked on an annual basis for the first 2 years after construction and at 1- to 3-year intervals thereafter. This typically requires little time or equipment and will ensure that the bridge performs properly over the design life.

Checking Bar Force

The force in tensioning bars can be checked quickly with the same equipment used for tensioning. The two methods, nut turn and gauge, provide acceptable estimates of bar force. The nut turn method is applicable to both the manual and electric pumps, and the gauge method is applicable only to hand-operated hydraulic pumps.

Nut Turn Method

To determine the bar force using the nut turn method, a wrench is placed on the bar nut adjacent to the anchor plate and force is slowly applied to the hydraulic jack. During the application of jack force, the wrench is pushed in the direction to loosen the nut. The gauge reading at the point where the nut just begins to turn represents the approximate force in the bar. In some cases, the nut may bind on the bar and may not turn when the bar force is applied. In this case, jack the bar until the nut is pulled away from the plate and turn the nut slightly in both directions to loosen the binding. After turning the nut, be sure to return it to the original position prior to releasing the jack force. After this is accomplished, the procedure to check bar force can be completed with the free-turning nut.

Gauge Method

When the hydraulic jack applies tension to a bar, the gauge needle moves relatively quickly as the load is initially applied. This is because only the short bar length between the anchor nut and the backnut is being tensioned. As the force increases, and tension is applied over the full bar length, the jack becomes more

difficult to pump and gauge needle movement is slower. When the bar force is overcome and the jack begins to apply force to the entire bar, there is a slight pause in the gauge needle rise. This occurs at approximately the point where the force in the jack equals the force in the bar. To check bar force, slowly pump the hydraulic jack and watch the movement of the gauge needle. When the needle stops moving momentarily, note the gauge reading. This reading represents the approximate bar force. Using this method to check bar force requires a "feel" for the release point when the jack force equals the bar force and should be practiced prior to determining the bar force.

Additional Considerations

As the bars in a stress-laminated bridge are tensioned, the laminations compress and the width of the bridge narrows slightly. This is most pronounced when the bars are initially tensioned and the amount decreases with subsequent retensioning. To avoid potential problems as the width of the bridge compresses, it is advisable to delay substructure attachment and curb and rail placement until after the second bar tensioning. It is also advisable to wait until after the second or third bar tensioning to apply the asphalt wearing surface.

After the bars in a bridge have been tensioned, it is important that sufficient bar length remain along one edge to allow for future bar force verification and retensioning. If a coupler and extension bar will be used for future tensioning, bars may be cut short, but a minimum of 250 mm (10 in.) of bar should remain beyond the nut. When no coupler and extension bar will be used for future tensioning, the bar length beyond the nut should be 450 to 600 mm (18 to 24 in.), depending on the bar length required for the tensioning equipment.

Concluding Remarks

Stress-laminated wood bridges provide good performance and longevity if properly constructed and maintained. The construction recommendations given in this paper are based on field experience and have been proven in past bridge construction. As more bridges of this type are constructed and experience by bridge owners and contractors is expanded, it is likely that new and/or modified construction methods will be developed. Through a combination of proper design, construction, and maintenance, it is expected that the use of stress-laminated wood bridges will continue to grow to meet the infrastructure needs of secondary road systems in the United States.

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