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PORTABLE TIMBER BRIDGE DESIGNS FOR TEMPORARY FOREST ROADS

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SUMMARY: Efforts to reduce the environmental impacts from forest operations point to the need for improved stream crossing technology on temporary forest roads and skid trails. New designs of timber bridges appear to be cost-effective alternatives for portable stream crossing structures. Bridge design criteria and example designs for portable, longitudinal glued-laminated and stress-laminated timber bridges are discussed in this paper.

KEYWORDS: forest roads, glued-laminated timber, stream crossings, stress-laminated timber, timber bridges

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PORTABLE TIMBER BRIDGE DESIGNS FOR TEMPORARY FOREST ROADS

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ABSTRACT

Efforts to reduce the environmental impacts from forest operations point to the need for improved stream crossing technology on temporary forest roads and skid trails. New designs of timber bridges appear to be cost-effective alternatives for portable stream crossing structures. Bridge design criteria and example designs for portable, longitudinal glued-laminated and stress-laminated timber bridges are discussed in this paper.

INTRODUCTION

Increasing concerns over environmental impacts from forest operations such as timber harvesting are leading to many new recommendations for forest practices. Most of these recommendations, which are called Best Management Practices (BMP's), are intended to reduce the potential for water pollution. Several studies in various states have shown that timber harvesting and the associated road construction are major contributors to nonpoint source pollution of forest streams. Harper (1979) listed several parameters related to nonpoint source pollution from silvicultural activities and indicated that reducing sediment in the stream should have one of the highest priorities for research. Rothwell (1983) and Swift (1985), in separate studies on forest roads and skid trails, found that stream crossings were the most frequent sources of erosion and sediment introduction into the stream. Therefore, there is a need to develop improved methods of stream crossings for forest roads and skid trails.

Fords and corrugated-metal or concrete culverts have been used as stream crossing structures on logging roads for many years. Using fords results in a continuous introduction of sediment into the stream as machines drive across the stream. While culverts alleviate this problem, there appear to be considerable sediment loads introduced into the stream during the excavation and fill work that accompanies culvert installation. Results reported by Swift (1985) showed that the cumulative amount of soil placed in a stream at the road-stream crossing during the construction period was over ten times greater than during the logging

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operations. In addition, culverts often clog with debris and may be washed out during heavy runoff periods, thereby introducing additional sediment into the stream. Often, the roads or trails are not permanent and the stream crossing structure is removed after logging operations or other activities are complete. Removal of a culvert also appears to introduce heavy sediment loads into the stream

In addition to fords and culverts, many possibilities exist for the development and use of portable bridge designs. With the recent activity of the USDA Forest Service Timber Bridge Initiative, state-of-the art timber bridge technology has been widely publicized for use on highway bridges. However, much of the current technology is well suited to the development of relatively portable timber bridge designs for use on logging roads and skid trails. These types of bridges can be cost-effective, portable, and reusable stream crossing structures that will reduce the amount of sediment introduced into streams at the stream crossing. Many of the advantages of timber bridges, which include using locally available materials, having long service lives, being relatively lightweight, being easy to fabricate, and being able to be prefabricated, make them ideal for temporary stream crossings. The objectives of this paper are to: 1) review background information on portable bridges for forest roads and skid trails; 2) discuss design criteria for portable bridges; and 3) discuss two example designs of portable timber bridges. One design is a longitudinal glued-laminated (glulam) deck bridge that is being used in research at Auburn University. The other bridge is a longitudinal stress-laminated deck designed by engineers in the USDA Forest Service.

BACKGROUND

Environmental Concerns

The Federal Water Pollution Control Act of 1972, the Clean Water Act of 1977, and the Water Quality Act of 1987 were adopted by Congress as a means of improving the nation's water quality. Although initial efforts were focused on point sources of pollution discharge, emphasis has now shifted to nonpoint source pollution. As stated earlier, forest roads are one of the major sources of nonpoint source pollution from forest operations. In addition, stream crossings are the most frequent source of sediment that is introduced into the stream. To control the various sources of these pollutants, the U.S. Environmental Protection Agency (EPA) adopted the concept of Best Management Practices (BMP's). EPA defined a BMP as a practice or combination of practices that are the most effective, practicable means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals. These BMP's are determined by a state or other areawide planning agency after problem assessment, appropriate public participation, and examination of alternative practices under local conditions. Although BMP's were originally voluntary guidelines, they have become mandatory practices in several states.

Some states are beginning to recommend the use of temporary or portable bridges as alternatives to fords or culverts. The rationale behind this recommendation is that the additional soil disturbance during installation and removal of a culvert or the use of a ford introduces excessive sediment into the stream. Indeed, Swift (1985) presented data that showed that most sedimentation from stream crossings occurs during the construction phase. This concern over sedimentation is of even greater importance when guidelines dictate that culverts or bridges be removed from intermittent-use or temporary roads after they are closed. In the case of a culvert, its removal may add a significant amount of sediment to the stream. In fact, these environmental concerns are the reason that many loggers will develop their timber harvesting plans so that they will not have to cross streams. However, this can be very costly due to the additional road building costs, which may range from $500 to $3,000 per mile of bare earth road in the southeastern states. Also, the additional road construction adds to the erosion and sedimentation problem. In some cases, landowners have stated that they have not even attempted to harvest small tracts of merchantable timber because the cost of the timber did not offset installing a culvert or permanent bridge and there was no other way to access the tract.

The installation and removal of a portable bridge, however, may involve little or no disturbance of the stream banks, resulting in very little additional sedimentation of the stream. Also, in the situations where additional roads would have been required or the timber would not have been harvested, the purchase price of a portable bridge could be offset by reducing road building costs, reducing transportation costs due to shorter haul distances, and increased income from harvesting and selling the timber. Portable bridges for spans up to 40 ft. appear to be feasible for most temporary stream crossings in timber harvesting operations, especially in the southern states.

Temporary Stream Crossing Structures

Steel Structures

Interest in portable stream crossing structures is currently very high due to these environmental issues. Mason (1990) gave an extensive description of many types of portable or prefabricated stream crossings that have been used in logging operations. Her discussion included pipe fascine systems, railroad flatcars, modular steel girder bridges with steel or timber decks, bridges made of steel truss panels (similar to the military's Bailey bridges), hinged steel bridges, and trailer- or armored military vehicle-launched bridges. These steel bridges were designed for spans ranging from 20 ft. up to 250 ft. Although the railroad flatcars and some of the perfabricated steel girder bridges have been used in logging operations, most of these bridges require heavy construction equipment for installation and removal due to their weight. Also, since they are prefabricated, their size may make transporting them to the site difficult. In addition, even though the military's Bailey bridge is lighter and can be assembled and installed with hand labor, this type of bridge does not appear to be feasible for logging operations with limited personnel available for bridge erection activities.

One commercial portable steel bridge design, however, can be moved with logging equipment and has been successfully used in logging operations. Bridges of this type, which are manufactured by the Pennsylvania company ADM Welding and Fabrication[2], are constructed of steel stringers with a timber deck. One of the smaller designs is 11.5 ft. wide and 26 ft. long and can be constructed to support either skidder or truck traffic. Skidders are vehicles that pull logs from the woods to the log deck or landing where they are loaded onto trucks. Other bridges of this type have been constructed for spans up to 55 ft. These bridges have a unique hinged design that allows them to be folded in half, thus allowing them to meet the legal width limit for highway transport. According to Mason (1990), they do not meet all of the requirements specified by the American Association of State Highway and Transportation Officials (AASHTO), mainly deflection criteria. Bridges classified for skidder and truck loads are advertised with capacities of 15 tons and 40 tons, respectively. The estimated initial costs for the skidder and truck bridges of this size are approximately $9,400 and $12,000, respectively. These estimates do not include shipping costs which could be quite high to the southern or western states since the skidder bridge weighs approximately 5.5 tons while the truck bridge weighs approximately 7 tons.

Other "homemade" steel bridge designs are used occasionally by loggers. One example of this is a design that is used by some loggers in Alabama. It is a welded steel panel consisting of two 26-ft.-long, 10-in.-deep steel channels spaced approximately 5 ft. apart and connected by 8-in.-deep steel channels spaced 2 ft. apart along the length of the panel. A 3/8-in.-thick plate steel deck is welded on the top of the steel framework. Two of these panels are placed across the stream for skidder traffic to drive across. The panels are pulled to the site with the skidder. If the skidder is equipped with a grapple, the grapple may be used to grasp one end of the panel and pick it up; then the skidder may back the panel into place across the stream. This type of design is popular due to its simplicity. However, these designs may not be safe for some vehicle loads, and the gap between the panels will allow trees or logs being skidded to drop into the stream when crossing it.

Concrete Structures

Alt (1991) discussed the use of a portable prestressed concrete bridge for logging operations. This bridge is currently being used by a forest products company in Florida for log truck traffic. It is constructed with 3 reinforced concrete slabs 4 ft. wide, 15 in. deep, and

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[2] Mention of commercial products or company names does not imply recommendation or endorsement by ASAE, Auburn University, or the USDA Forest Service over others not mentioned.

35 ft. long. The installed cost of the bridge was approximately $11,500 (or $27/ft^2). However, its total weight was approximately 78,000 lbs. Although this bridge was very cost effective, its relatively high weight required the use of heavy construction equipment for installation and removal. Therefore, this bridge is probably not suitable as a portable bridge for most loggers.

Timber Structures

Mason (1990) also discussed several timber bridge designs including log stringer bridges, modular timber truss bridges, and longitudinal glued-laminated or stress-laminated bridges. Although the log stringer bridge has been used successfully for many years, the recent advances in timber bridge technology include several designs that should be easily adapted for use as portable bridges. Another "non-engineered" type of portable bridge was described by Bihun (1991). This timber bridge design is 12 ft. long and 12 ft. wide. It consists of 5 nominal 8x10 in. mechanically-laminated stringers that are 12 ft. long. The stringers are fabricated by bolting together 4 nominal 2x10's. Twelve-ft.-long 2x10 planks are laid flatwise on top of the stringers (perpendicular to the stringers) and 3x12 longitudinal runners are placed on top of the planks. This design has been constructed with unseasoned Eastern hemlock lumber and has been used to carry skidder traffic across small streams in Vermont. Although Bihun (1991) stated that the bridge had been field tested, this design probably has a limited range of vehicle loads that it can safely carry. Other loggers have also used timber dragline mats to carry skidder traffic over relatively short spans.

Design procedures for modern timber bridges can be found in the manual by Ritter (1990). Probably the most promising designs for spans up to 35 ft. consist of longitudinal glued-laminated (glulam) or stress-laminated decks that are placed across the stream. These longitudinal deck designs are relatively simple to construct, somewhat lightweight, and have comparatively thin cross sections. They can be prefabricated into large sections that can be quickly and easily installed at the stream crossing site. These bridges can be installed with typical forestry equipment, such as hydraulic knuckleboom loaders or skidders, without the need for heavy construction equipment. Also, it may be possible to install these bridges without operating the equipment in the stream and with a minimum of soil movement around the structure. This reduction in site disturbance should lead to a reduced sediment load on the stream.

Hassler et al. (1990) discussed the design, fabrication, and testing of a portable longitudinal stress-laminated deck bridge for truck traffic on logging roads. Their bridge was constructed of untreated, green, mixed hardwoods. It was 16 ft. wide, 40 ft. long, 10 in. deep, and was fabricated in two 8-ft.-wide modules. They estimated that the cost of the bridge was approximately $7,000 excluding transportation costs to the site. It was installed to assist in timber harvesting activities in the West Virginia University Forest. They placed the bridge directly on the existing stream banks without constructing abutments. They recommended that at least 5 ft. of bridge/ground contact be allowed on both sides of the stream. The bridge was installed with a typical hydraulic knuckleboom loader and a skidder. The bridge performed satisfactorily under load tests. They also measured water quality before, during, and after the installation of the bridge. Results of these tests indicated that no significant changes in water conductivity, pH, or turbidity occurred as a result of the bridge installation.

DESIGN CRITERIA FOR PORTABLE TIMBER BRIDGES

General Considerations

There are several general design characteristics that a portable timber bridge should have to be a viable alternative for a temporary stream crossing structure. Two of the most important considerations are the ease with which the bridge can be assembled and the ease with which the bridge can be installed, removed, and transported.

As with most engineering projects, simplicity of the timber bridge design is of critical importance to the adoption and use of portable timber bridge technology. Many loggers or other forest workers will not adopt a design that requires extensive time and labor to fabricate and erect. Also, the more complex the assembly requirements, the more likely that errors in fabrication will occur or that instructions will simply be ignored and shortcuts taken. The hinged portable steel bridge and the individual steel panels require little in the way of user fabrication or assembly and are very appealing to loggers. Any connectors or railing systems that need to be installed on a bridge should be prefabricated as part of the bridge system. Also, they should allow the bridge to be moved without the need to completely disassemble the bridge, so that installation time will be saved at the next site. Any time taken away from logging or other forest work is usually considered unproductive time, so bridge designs that minimize fabrication time will be adopted more quickly.

The ease with which the bridge can be installed, removed, and transported determines the portability of the bridge. The concrete bridge discussed earlier may be a very cost-effective design, but if it requires special trucks or cranes to move the deck panels, few companies will adopt the design. Ideally, a portable bridge should be able to be installed and removed with typical forestry equipment, such as hydraulic knuckleboom loaders, forwarders, or skidders (cable or grapple). Most knuckleboom loaders on the market today are capable of lifting at least 7000 pounds with a reach of 25 ft. Obviously, the capacity of the loader decreases as the reach increases. Therefore, most knuckleboom loaders could probably lift sections or components of a bridge into place over the stream if the individual components or sections weighed less than 7000 pounds and if the stream was about 30 ft. wide. In some cases, the road to the stream crossing may not be in a condition suitable for moving a knuckleboom loader to the edge of the streambank. Therefore, the use of forwarders or skidders may be necessary.

Forwarders are vehicles that are equipped with smaller knuckleboom loaders and racks in which to carry wood. Forwarder payloads may be up to approximately 25,000 pounds. Although knuckleboom loaders are mounted on forwarders, they are smaller and therefore may not be able to lift payloads as large as the dedicated log loaders. However, their ability to carry bridge components in their racks may make them useful in installing smaller types of bridges. The skidder also may be used to drag bridge sections or components to the stream crossing. The weight of bridge section or components should be no more than approximately 10,000 pounds for many skidders to successfully transport them to the site. The maximum payload will depend on skidder or forwarder size. Regardless of the equipment used to lift or drag the bridge into place, provisions should be made to attach wire ropes, nylon straps, or chains to the bridge components so that they can be lifted without damaging the wood. The most convenient methods to transport portable timber bridges would be to use truck and trailer combinations that most loggers own. Therefore, it is important to design the bridge so that it can be broken down into sections for transport on logging trucks. Also, it may be possible to temporarily place the entire bridge or bridge sections on wheels and tow it to the site. However, this may be difficult to do on roads or skid trails that are still under construction.

Design Procedures

In addition to the publication by Ritter (1990), design procedures for timber bridges can be found in the AASHTO Standard Specifications for Highway Bridges (AASHTO, 1990, 1991). Little previous research has been conducted on appropriate design procedures for portable timber bridges on temporary forest roads. Knab et al. (1977) studied military theater of operations glulam bridges with design lives of 2 to 5 years. They concluded that using civilian design procedures, which are generally based on design lives of 50 to 75 years with relatively high levels of reliability, could result in unnecessarily conservative and uneconomical designs for the limited performance needs of theater of operations bridges. Using results from reliability analyses, they developed new design procedures and modification factors for allowable stresses that would result in adequate levels of structural safety for glulam stringer bridges. They concluded that a modification factor could be used that would result in increases for allowable stresses for bending, shear, and compression (both parallel- and perpendicular-to-grain) for these temporary military bridges. They did not, however, recommend changes in modulus of elasticity over those found in design data published by the American Institute of Timber Construction (AITC, 1987).

Other work by GangaRao and Zeliña (1988) examined the design specifications for low volume civilian roads. They also concluded that many bridges on low volume roads designed according to the same specifications as urban highway bridges were overly conservative and uneconomical. They defined low volume roads as those with maximum two-directional average daily traffic flow of 200 vehicles. The corresponding maximum two-directional average daily truck traffic would be approximately 30 trucks per day. They suggested that allowable stresses for steel and concrete structures might be increased for these types of roads. Also, they suggested that deflection limits might be relaxed for steel bridges. They did not recommend changing the deflection criteria for low-volume concrete or timber bridges; however, they were basing their discussion on timber bridge deflections of L/400 to L/300.

These research results of Knab et al. (1977) and GangaRao and Zelina (1988) indicate that the use of all AASHTO design recommendations for portable timber bridges for temporary forest roads may result in overly conservative designs. One item that the designer may consider is the appropriate value of the load duration factor for a portable timber bridge. In many cases, the design life of such a bridge may only be 5 to 10 years. Therefore, it may be possible to increase the load duration factor from the value of 1.0 which is used for bridges with design lives of 50 years or more. However, additional research is needed in this area before suggesting other changes in design procedures or increases in allowable stresses.

Load Criteria

Design requirements for highway bridge loads are given in the AASHTO Standard Specifications for Highway Bridges (AASHTO, 1991). The designer of a portable bridge should determine if these loads or other special loads and load combinations are appropriate for their situation. In addition to considering all dead loads, various live loads should be considered. For portable timber bridges that will carry truck traffic, the designer should probably use one of the AASHTO standard vehicle loads. The AASHTO HS20-44 (HS20) truck loading or lane loading should be sufficient for most log truck traffic on these types of portable timber bridges. The USDA Forest Service uses several additional standard vehicle overloads, such as the U80 or U102 truck (Ritter, 1990). Again, the designer should determine if the use of these special overloads is warranted for their application.

If the portable bridge is to be used only on skid trails and will only carry forestry equipment such as skidders, forwarders, feller-bunchers, or harvesters, alternate loading configurations may be used for design vehicle loads. Table 1 contains a list of various types and sizes of forestry equipment with approximate vehicle weights and wheelbases. This table also shows results of calculations to determine the approximate maximum bending moments and shear forces for a bridge with a span of 30 ft. These design loads vary depending on the assumptions used for distribution of the vehicle weight. If the bridge was to be subjected to only these types of ~~loads,~~ values such as those listed in Table 1 may be used for design purposes. Since these values are all less than that for the HS20 truck load, using the HS20 loads for design of a skidder bridge, for example, may be overly conservative. However, it may be difficult to insure that the bridge is not used for truck traffic at some point during its life. Therefore, the use of the HS20 load configuration may be the safest assumption for most cases, even though it may result in uneconomical bridge designs for some forestry equipment traffic.

Deflection Criteria

Ritter (1990) provided a good discussion of timber bridge deflection criteria. Deflection in bridge members is important for serviceability, performance, and aesthetics. In general, excessive deflections cause fasteners to loosen and wear surfaces, such as asphalt or concrete, to crack. Also, bridges that sag below a level plane can give the public a perception of structural inadequacy. Excessive deflections from moving vehicle loads also produce vertical movement and vibration that may annoy motorists. Since most portable bridges will not need an asphalt or concrete wear surface, concerns over deflection should not be as great as in highway bridges. However, the users' perception of the bridge may be a concern to the designer. Ritter (1990) noted that others have used deflection criteria ranging from L/200 to L/1200. He recommended a maximum deflection of L/360 for short-term loads and a maximum deflection criteria of L/240 for the combination of applied loads and dead load. It may be possible to relax these deflection criteria slightly in the case of a portable bridge. However, it may be more appropriate for the engineer to consider the relationship between the bridge span and the predicted deflection of the bridge in absolute terms instead of just using a criterion like L/240. For example, for a bridge with a 25 ft. span, L/360, L/300, L/240, and L/180 would be 0.83 in., 1 in., 1.25 in., and 1.67 in., respectively. In the case of some portable bridges, the designer may make the judgement that a deflection of 1.67 in. would not be excessive for the given bridge configuration, vehicle loads, and daily traffic for which it was designed.

EXAMPLE BRIDGE DESIGNS

Longitudinal Glued-Laminated Deck

Longitudinal glued-laminated deck bridges are composed of vertically-glued-laminated assemblies that are placed side by side across the stream. They are practical for clear spans up to 35 ft. The panels are typically fabricated in 48-in. widths and depths up to 10.5 in. for southern pine or 10.75 in. for western species. The panels can be interconnected with steel dowels or fasteners, but they are more commonly designed with transverse stiffener beams below the deck. These stiffener beams, which are usually bolted to the panels, help distribute wheel loads among the panels. The primary advantage to this type of bridge design is that it can be prefabricated in a few sections before shipping to the bridge site. All necessary cuts and holes can be made before preservative treatment.

Research is currently underway at Auburn University to document water quality impacts from different types of stream crossing structures on temporary forest roads and skid trails. A portable timber bridge consisting of longitudinal glulam deck panels has been designed and fabricated for use in this study. This bridge is 16 ft. wide, 30 ft. long, and uses 4 southern pine glued-laminated panels 4 ft. wide and 10.5 in. deep. It will be installed on a mud sill, with the bridge extending approximately 2 to 5 ft. on either side of the stream banks, thereby leaving an effective span of approximately 20 to 25 ft. Sketches of the bridge are shown in Figures 1 through 3. More detailed plans are available from the authors.

This bridge is designed for HS20 loadings with relaxed restrictions on deflection since the bridge will be installed on dirt or gravel roads. All components in this design are southern pine. Southern pine glulam combinations No. 48 (AITC, 1987) and higher will meet strength requirements for the deck panels assuming an effective span of 25 ft. If combination No. 48 deck panels are used with an effective span of 25 ft., the design live load deflection should be approximately L/230. Thirty-ft.-long glulam curb rails on glulam curb risers are also bolted to the outside deck panels. Sixteen-ft.-long glulam stiffener beams are bolted on the lower side of the deck. The glulam curb rails and risers are 16F-V5 beams 5 in. deep by 8.5 in. wide and the stiffener beams are 16F-V5 glulam beams 5 in. wide by 5.5 in. deep. These glulam combinations are balanced layups, i.e., neither side of the beam is designated as the tension or compression side, thereby reducing the possibility of installing the beam incorrectly. The deck panels may be installed directly on the stream banks with no other abutments necessary. If desired, a glulam bearing pad or sill may be placed under each end of the bridge. The current design specifies a southern pine combination No. 46 glulam beam that is 3 in. deep, 15.125 in. wide, and 16 ft. long. Other larger sills may be required depending on the site conditions. All glulam components were precut and predrilled and were treated with creosote to retentions of 12 lb/ft^3.

Galvanized A36 steel angles (8 in. by 6 in. by 0.5 in thick by 14 ft. long) are attached to each end of the bridge to prevent wear on the ends of the deck panels due to vehicle traffic. These wear plates are attached with lag screws. The stiffener beams, bearing pads, and steel angles all provide additional continuity to the bridge system. An additional plank or steel plate wear surface should be installed on the bridge deck. Galvanized steel tie-down brackets are also provided at each of the four bridge corners to prevent bridge movement from longitudinal vehicle loads and from lateral and buoyancy forces due to flooding. Wire rope will be used to connect the steel brackets to nearby trees or deadmen. All bolts are ASTM A307 and are galvanized. Bolts that connect the curb rails to the deck are 7/8 in. diameter while all other bolts and lag screws are 3/4 in. diameter.

The delivered cost of this bridge will be approximately $16,500 (or about $41/ft^2 using an effective span of 25 ft. and a width of 16 ft.). This 16-ft.-wide bridge is being used for research purposes and does not necessarily reflect the most economical width or length. A typical bridge used for log truck traffic would probably only need to be approximately 12 ft. wide and would therefore cost even less than the current bridge. Fabrication of this bridge has just been completed, but it has not been installed yet. Before the bridge is moved to the bridge site, the curb rails can be installed to minimize the amount of erection time at the site. The bridge can be transported to the site on a typical log trailer or equipment trailer. Each of the panels weighs approximately 5,500 pounds and should therefore be easily lifted with most knuckleboom loaders. Many types of articulated, rubber-tired front-end loaders should also be able to lift the panels. If necessary, the panels can be maneuvered into place using a grapple or cable skidder. Also, if the knuckleboom loader cannot be used at the stream crossing site, a skidder can be used to pull the panels to the stream crossing. A skidder also can be used to set the panels in place by securing a block and tackle on the opposite side of the stream and winching the panels across the stream. Installation or removal of this bridge can be accomplished in less than one day.

Longitudinal Stress-Laminated Deck

The concept of stress-laminating wood bridge decks began in Canada and has now been used in the construction of many permanent bridges in the U.S. In this system, vertical laminations of dimension lumber are stressed together with high strength steel rods. The rods squeeze the laminations together so that the stressed deck acts as a solid wood plate. The second portable timber design discussed here was designed by engineers in Region 8 of the USDA Forest Service and uses a longitudinal stress-laminated deck for its superstructure. The Forest Service also has a need for low-cost/low impact bridges for temporary stream crossings. In many cases, it is not economically feasible to construct and maintain permanent bridges for timber sales or other forest management activities in the National Forest System. To meet this need, engineers in Region 8 of the Forest Service have designed this portable stress-laminated bridge. This bridge is designed for HS20 loadings and is intended for use on temporary logging roads. Sketches of the bridge are shown in Figures 4 through 6.

The bridge consists of two separate stress-laminated panels 4.5 ft. wide. The panels are constructed with nominal 2x10 lumber for spans ranging from 16 ft. to 24 ft. Nominal 2x12 lumber is used for spans up to 32 ft. Each panel is stressed separately and then placed adjacent to the other panel with a 2 ft. space between panels. The overall width of the complete bridge is 11 ft. Solid sawn 6x6 curb rails run the length of the bridge. A unique design is used for a drop-in 3x12 filler panel in the space between the two deck panels. This filler panel primarily covers the gap between the two panels, but it also provides additional continuity between the deck panels. At each end of the bridge, the deck panels are placed on top of a 14-ft.-long solid sawn 12x12 sill, which sits directly on the stream bank. A minimum of 5 ft. is recommended between the edge of the sill and the edge of the stream. All timber components should be treated with creosote or pentachlorophenol in accordance with AWPA specification C14. All bolts and lag screws are galvanized steel. The 5/8-in.-diameter stress rods are spaced 2 ft. apart along the length of the bridge and should be stressed to a tension force of 30,500 pounds.

The delivered cost of a 32-ft.-long bridge of this design should be approximately \$14,000 (or \$40/ft^2). Each half of the bridge can be constructed off-site and installed and removed with typical forestry equipment. One 32-ft.-long panel constructed with nominal 2x12 lumber should weigh approximately 6,500 pounds and therefore should be able to be lifted and installed by a knuckleboom loader. Other types of front-end loaders should also be able to handle panels of this size. As with the glulam bridge discussed earlier, installation or removal can be accomplished in one day or less. With minor modifications, this bridge could also be used as a temporary trail bridge.

DISCUSSION

Current Research

Fabrication of the longitudinal glulam deck bridge is complete and it is scheduled for installation in early 1993. This bridge will be studied over the next two years as part of a project that is documenting stream bank disturbances and the resulting water pollution from these types of portable bridge installations. This project will also document the costs associated with this type of portable timber bridge. The longitudinal stress-laminated bridge designed by the Forest Service has not been constructed yet. However, the annual program of work for the USDA Forest Service Southern Region calls for installation of at least three such bridges during Fiscal Year 1993. Both bridge designs will be monitored to document how well they withstand the loads from logging trucks and other forestry equipment. In addition, since damage to the bridge components is expected during installation, removal, and transport, particular attention will be focused on design features which can improve the longevity of these bridges.

Design Procedures

Since little research has been conducted on portable timber bridge designs for temporary forest roads, additional research is needed on design procedures and design criteria. The work by Knab et al. (1977) indicates that if the design life of a portable bridge is on the order of 5 to 10 years instead of the 50 years for a typical highway bridge, it is possible that some of our design procedures may need to be modified for portable bridges. This would include examining values for load duration factor and allowable stress values as well as load and deflection criteria. Such modifications may lead to portable bridge designs that are lighter weight and more cost effective. However, until further research can be completed in this area, using current design recommendations by AASHTO (1991) and Ritter (1990) is still the safest approach for timber bridge design.

Additional work is also needed to examine alternatives to other design practices. Stress-laminated designs that utilize laminated veneer lumber for bridge components are also attractive options for portable bridges. Many other design problems need to be explored. One example is in the use of stiffener beams for the glulam deck bridge. Alternatives to the stiffener beams that would allow quicker assembly or reduce the need to work under the bridge deck to attach the stiffener beams would make the system more attractive to the logger or road construction crew. Also, the use of only two longitudinal glulam panels in a manner similar to that used in the stress-laminated deck design is a possibility that needs additional study.

Cost Effectiveness

Detailed lifecycle cost information is needed to determine the economic feasibility of this concept. However, only initial cost data are available at this time. The portable hinged steel bridge designed for truck traffic, which was discussed earlier, has an estimated cost of \$13,000 (or \$43/ft^2 for a bridge that is 11.5 ft. wide and 26 ft. long) when shipped to states in the southern U.S. The two portable timber bridges discussed here have estimated costs of \$ 16,500 (or \$41/ft^2 for the glulam bridge that is 16 ft. wide with an effective span of 25 ft.) and \$ 14,000 (or \$40/ft^2 for the stress-laminated bridge that is 11 ft. wide with a span of 32 ft.). The glulam bridge would probably cost approximately \$13,000 if its width were reduced to 12 ft. Although the concrete bridge had a very low installed cost, its extreme weight prohibits it from being used effectively as a portable bridge. In cases where loggers build additional roads to prevent crossing streams, they would only have to build an additional 26 miles of road to equal the cost of purchasing a \$13,000 portable bridge (using road construction costs of \$500 per mile). This estimate does not account for the additional losses in productivity due to increased travel times when detouring around the stream crossing. Therefore, many loggers could probably pay for the investment in a portable bridge very quickly. In some cases, landowners have stated that they may not even harvest small tracts of merchantable timber because the cost of the timber does not offset installing a culvert or permanent bridge and there was no other way to access the tract. In these instances, the purchase price of a portable bridge could also be offset quickly by the loss in revenues due to not harvesting and selling the timber. Therefore, these portable bridge designs appear to be cost-effective stream crossing options for temporary forest roads. In addition, the cost of timber bridges is competitive with that of steel structures.

SUMMARY AND CONCLUSIONS

New recommendations for forest practices are the result of pressure on the forest products industry to reduce environmental impacts from forest operations. One primary area of concern is improving water quality in forest streams. Construction of roads and the associated stream crossings during timber harvesting operations are one of the leading causes of nonpoint source pollution of forest streams. Although fords and culverts have been used for many years, they may introduce large sediment loads into forest streams during construction and use. In addition, many such roads are not permanent, and the stream crossings are removed after logging or site preparation operations have ceased. Therefore, there appears to be potential to develop and use portable timber bridge designs for these temporary forest roads. In fact, some states are recommending the use of portable bridges for temporary stream crossing structures.

Although much of the new technology in timber bridges is well suited to timber bridge designs, little research has applied this technology to portable bridges for forest roads. Many of the advantages of timber bridges, which include being relatively lightweight, being easy to fabricate, and being able to be prefabricated, make them ideal for temporary stream crossings.

Previous research on glulam military bridges and on bridges for low volume roads indicates that although using the AASHTO design procedures for portable timber bridges is safe and conservative, it may result in overly conservative and uneconomical designs. This is because portable bridges may be designed for service lives of 5 to 10 years with low volumes of traffic while permanent highway bridges are designed for service lives of 50 years or more with heavier traffic volumes. In addition, since portable bridges probably won't use concrete or asphalt wear surfaces, deflection may not be as critical in their design as it is in permanent bridges. More research is needed on design procedures and load and deflection criteria for portable timber bridges. In general, using HS20 truck loads will result in conservative portable bridge designs for log truck and forest equipment traffic. The designer should use his or her own judgement in determining an acceptable deflection criterion for these bridges.

Two types of portable timber bridge designs were presented: a longitudinal glulam deck and a stress-laminated timber deck. Both bridges are designed for HS20 truck loads with a relaxed deflection criterion. Each of the designs can be prefabricated before transporting to the jobsite and uses wood that has been pressure treated with creosote or pentachlorophenol. Also, both bridges are designed to minimize site preparation and substructure construction. Each design requires only a sill or bearing pad for the bridge substructure and calls for placing the bridge deck directly on the surface of the streambank. Both designs can be easily installed with a minimum of personnel at the stream crossing site.

The first design consists of 4 longitudinal glulam deck panels 4 ft. wide, 30 ft. long, and 10.5 in. deep. Glulam curb rails are attached to the sides of the bridge deck and glulam stiffener beams help distribute loads among the panels. The second design consists of two longitudinal stress-laminated deck panels 4.5 ft. wide. The panels should be constructed with nominal 2x10 lumber for spans from 16 to 24 ft., and with nominal 2x12 lumber for spans up to 32 ft. Since the glulam and stress-laminated panels each weigh approximately 5,500 pounds and 6,500 pounds, respectively, both designs can be installed and removed with knuckleboom log loaders or log skidders. Also, each bridge design can be transported on a typical log truck and trailer. Further research is underway to document the performance and longevity of these bridge designs. Additional research on bridges designed specifically for forestry equipment loads is also needed.

Cost comparisons between the portable timber bridge designs discussed here and commercial portable steel bridges show that the timber bridges may be cost effective solutions for portable stream crossings. The estimated costs for the glulam and stress-laminated bridges are approximately \$41/ft^2 and 40/ft^2, respectively, while the portable steel bridge may cost approximately \$43/ft^2 when shipped to the southern states. Additional research is needed to fully document the lifecycle costs and structural performance of these various designs of portable timber bridges. However, it appears that with modern timber bridge technology, portable timber bridges for temporary forest roads and skid trails are economical stream crossing structures.

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Table 1. Example design moments and shear forces for a 30-ft.-span bridge based on various types of forest harvesting equipment. The truck loads for AASHTO H20 and HS20 are also shown.

Vehicle Type	Overall Wheelbase (ft)	Approximate Loaded Total Weight (lb)	Maximum Moment for the Vehicle (in. lb)	Maximum Shear (lb)
John Deere 770B Motor Grader	19.6	33,450	157,825	25,251
John Deere 450E Crawler Tractor	6.8	15,350	102,233	13,361
Caterpillar D5H Track Skidder	9.0	42,405	270,332	36,044
Caterpillar 528 Grapple Skidder	10.7	27,000	151,470	22,680
John Deere 540D Cable Skidder	9.6	21,700	127,555	18,580
John Deere 748E Grapple Skidder	12.1	34,500	181,448	28,246
Tree Farmer C6D Forwarder	17.3	38,390	126,262	27,476
AASHTO H20-44	variable	40,000	246,620	36,260
AASHTO HS20-44	variable	72,000	282,140	49,600

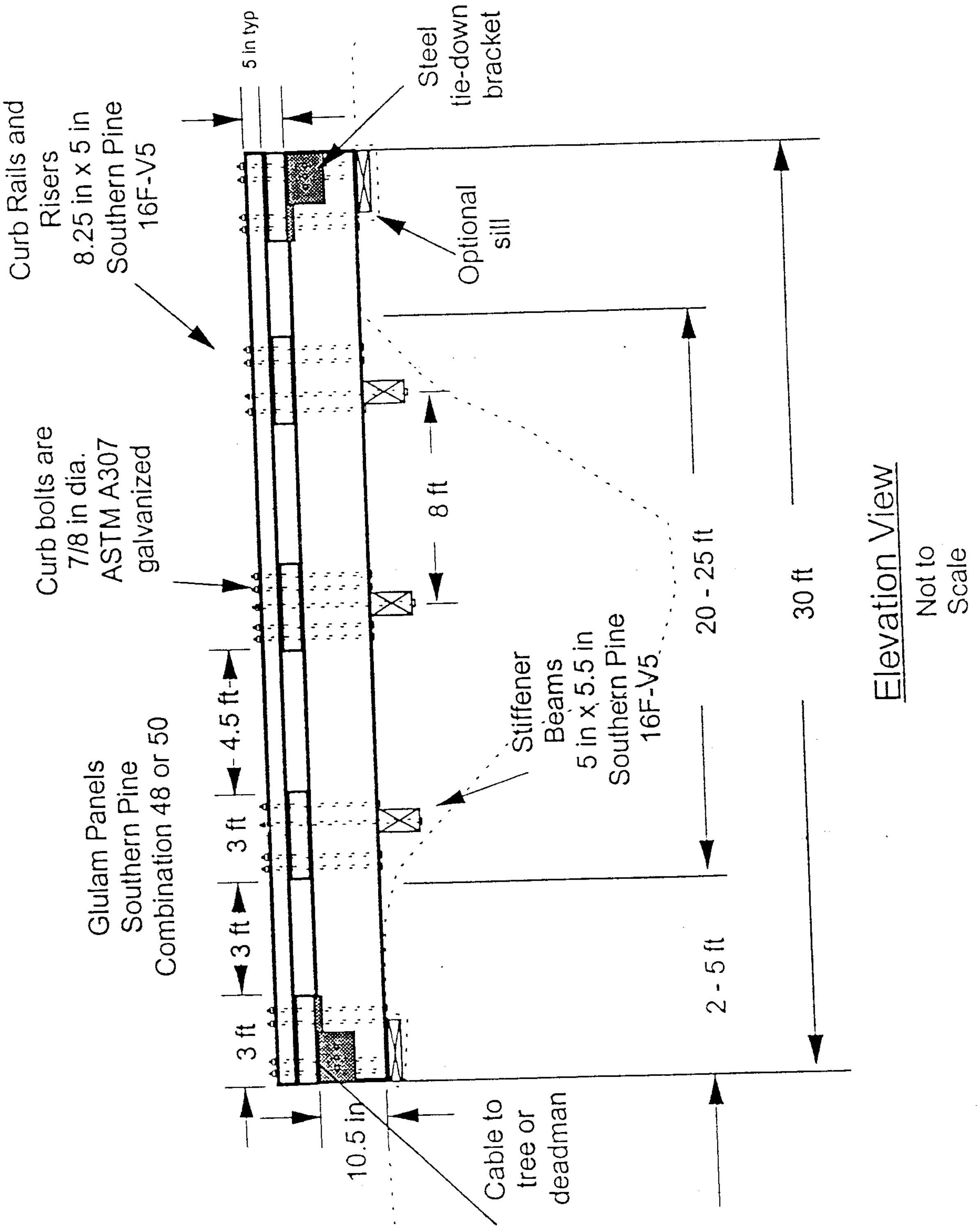

Figure 1. Elevation view of the longitudinal glued-laminated (glulam) bridge design.

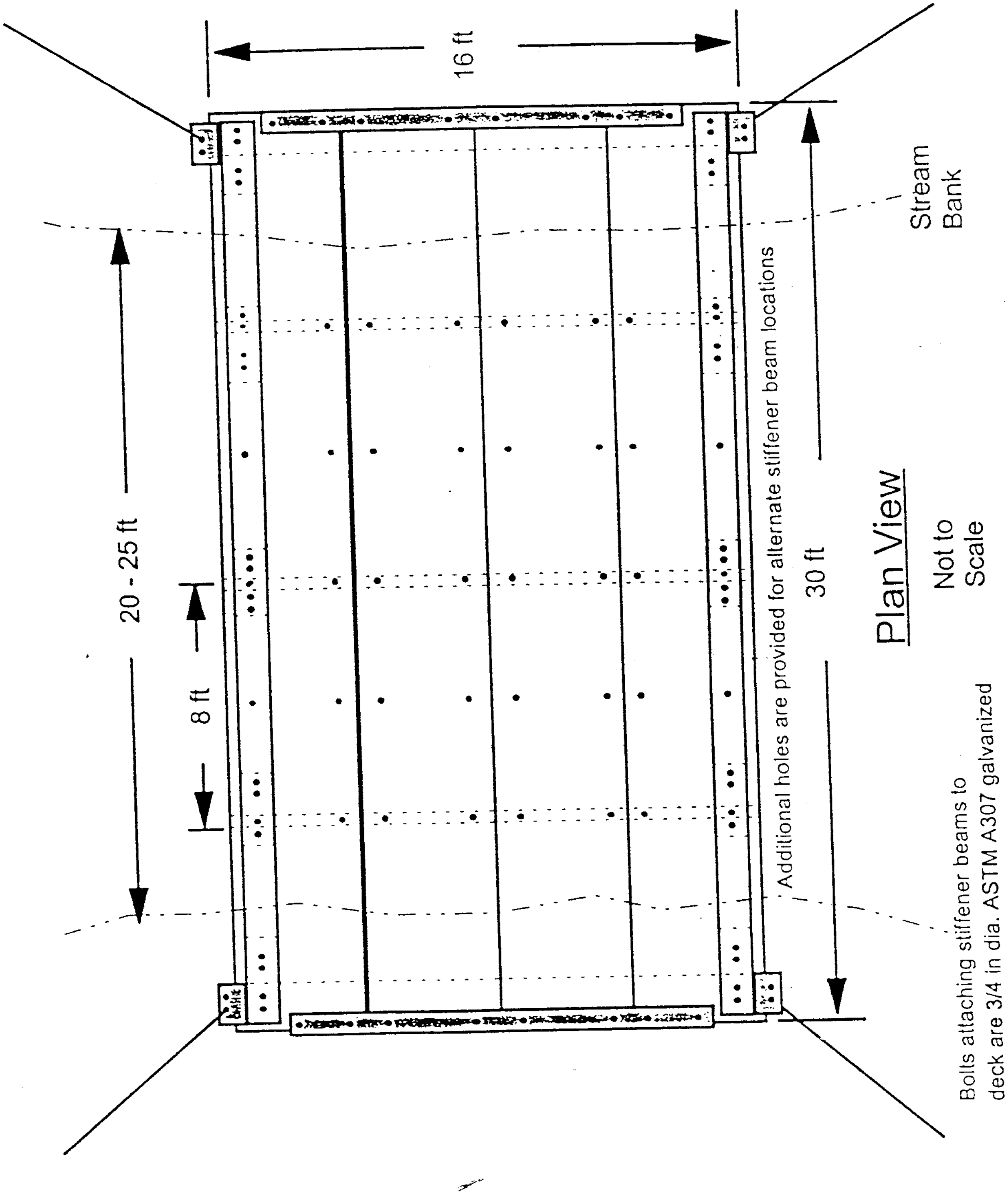

Figure 2. Plan view of the longitudinal glulam deck bridge.

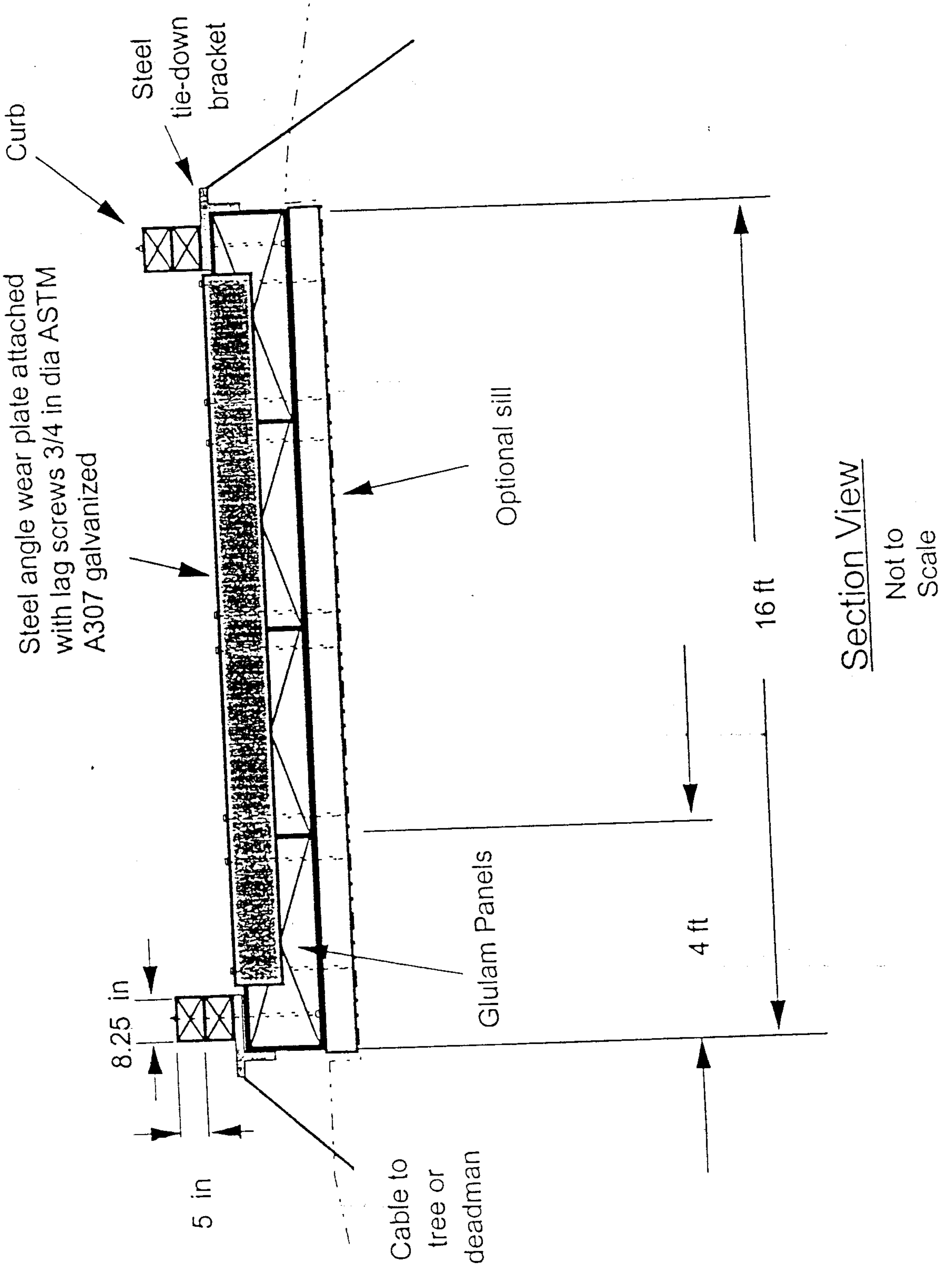

Figure 3. Section view of the longitudinal glulam deck bridge.

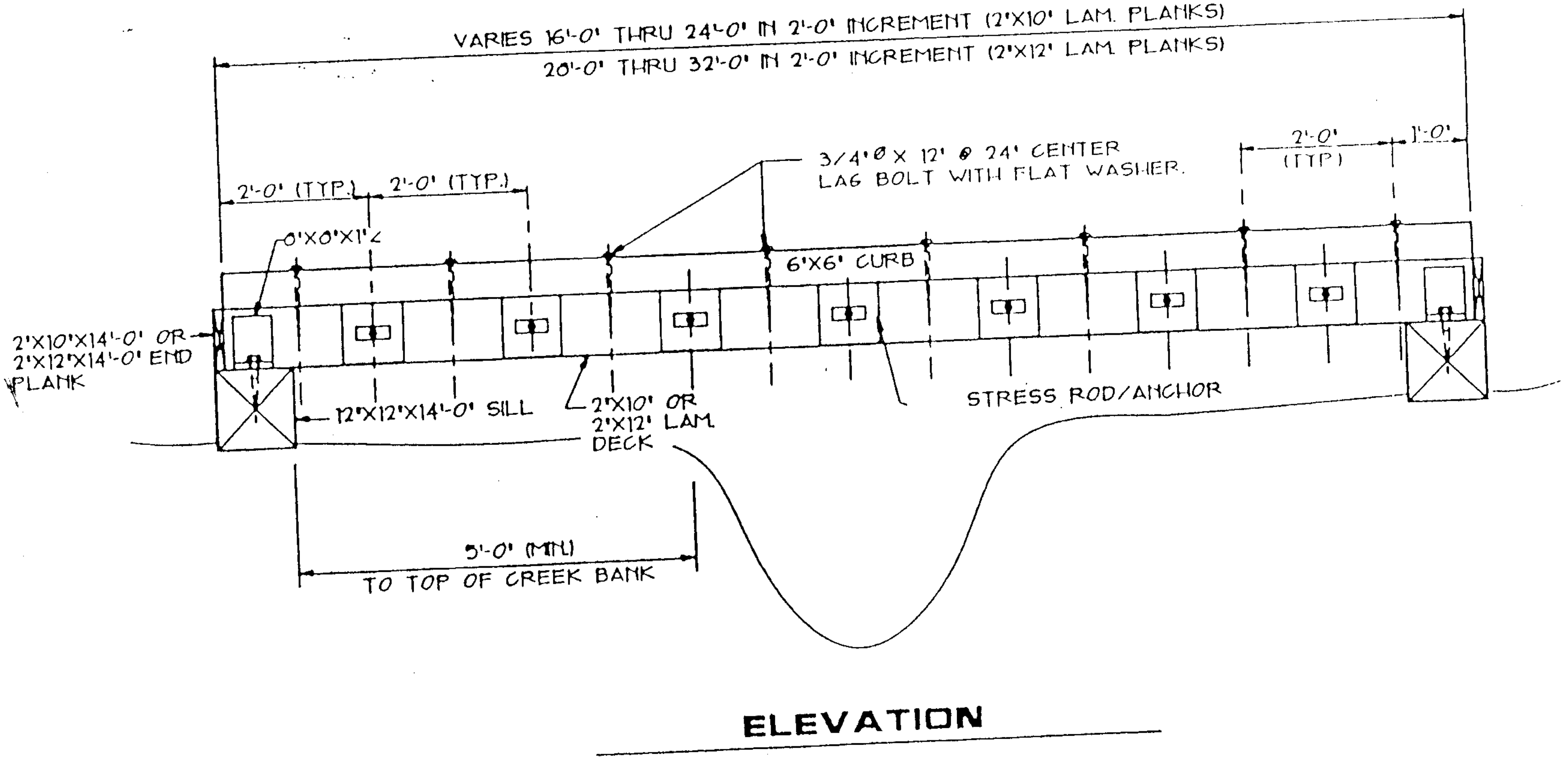

Figure 4. Elevation view of the longitudinal stress-laminated timber deck bridge.

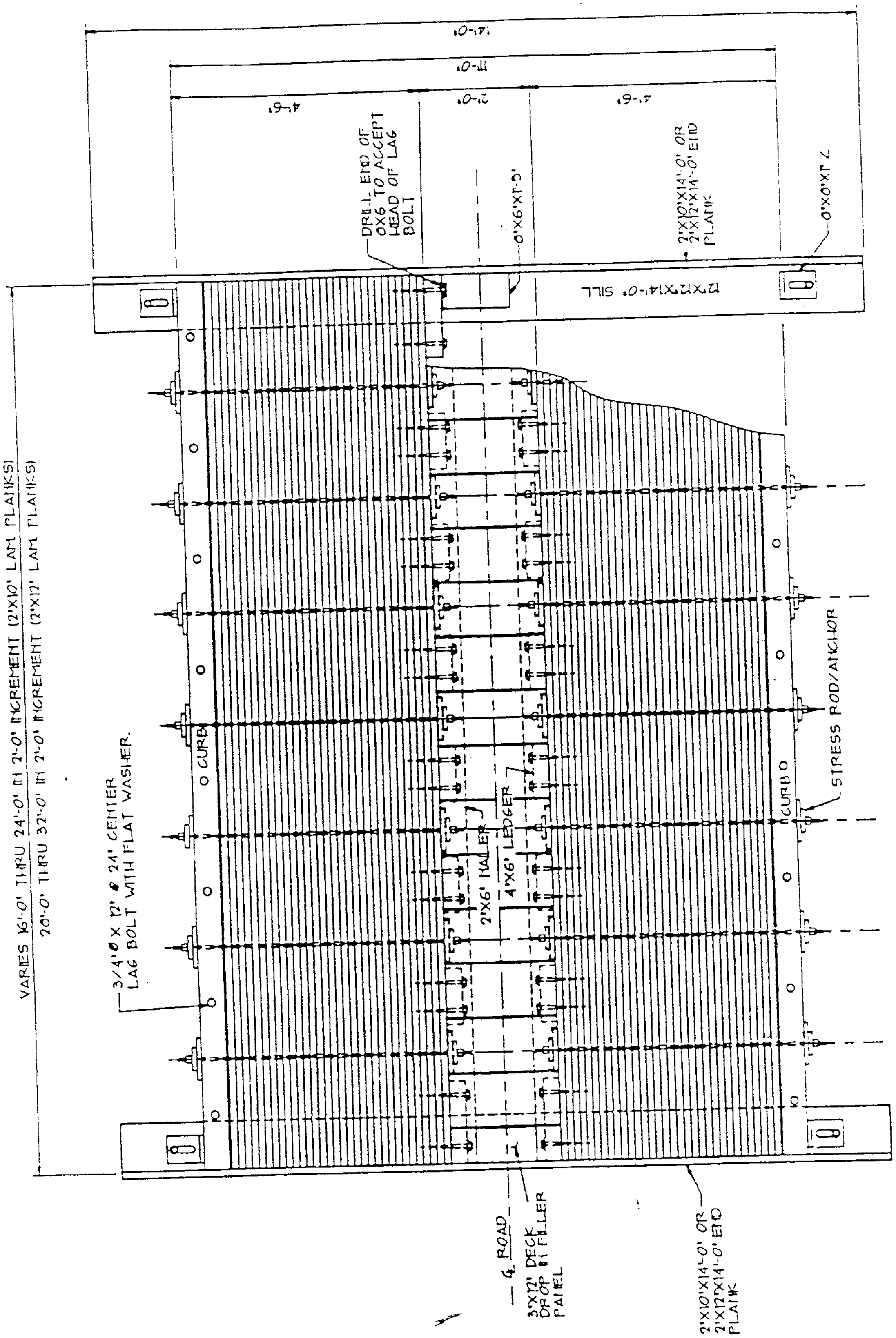

Figure 5. Plan view of the longitudinal stress-laminated timber deck bridge.

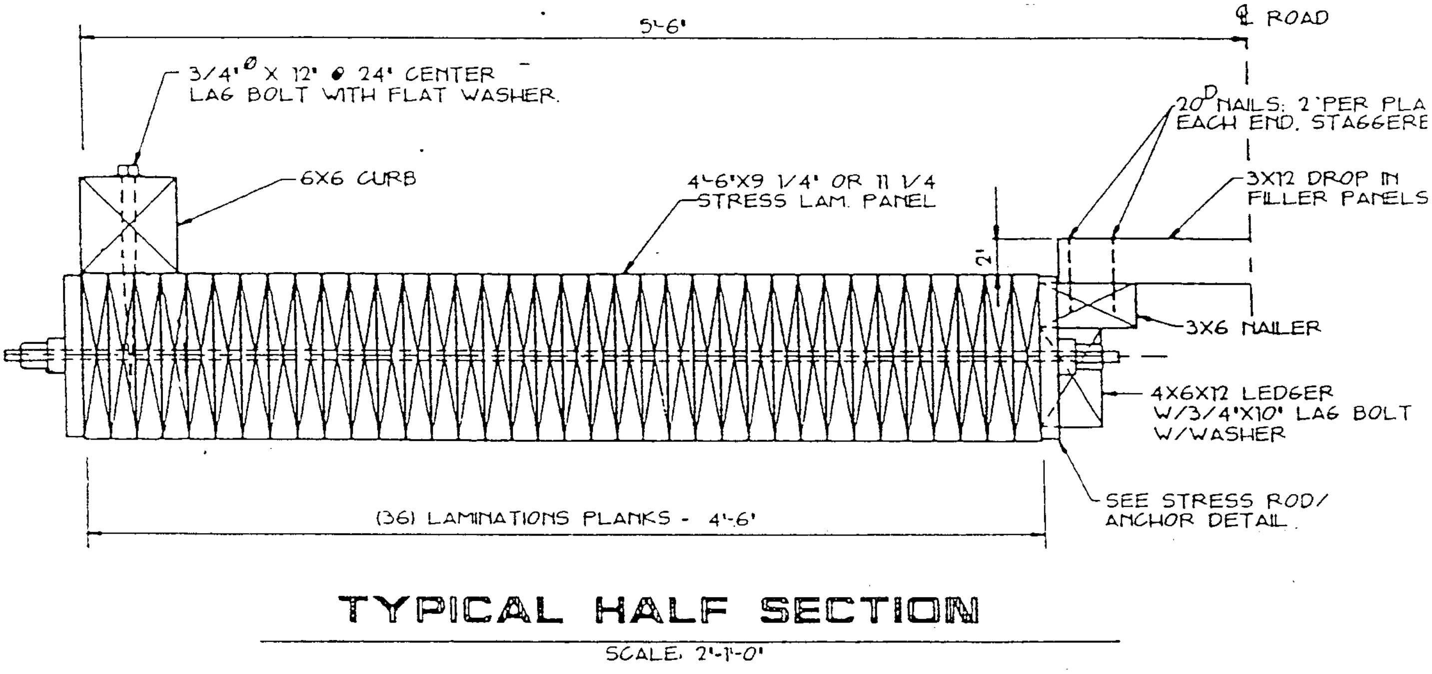

Figure 6. Section view of the longitudinal stress-laminated timber deck bridge.